Akif BAHÇEBAŞI

PERFORMANCE ANALYSIS OF UNDERWATER COMMUNICATION ...

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PERFORMANCE ANALYSIS OF UNDERWATER COMMUNICATION WITH DIFFERENT MODULATION TECHNIQUES

A THESIS
SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
AND THE GRADUATE SCHOOL OF NATURAL SCIENCES OF ABDULLAH GUL UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE
MASTER'S

By
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ABDULLAH GÜL
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ABSTRACT

PERFORMANCE ANALYSIS OF UNDERWATER COMMUNICATION WITH DIFFERENT MODULATION TECHNIQUES

There is an increasing interest in using Underwater Acoustic Sensor Networks (UASNs) for various oceanographic applications, such as pollution monitoring, seismic monitoring, environmental data collection, offshore exploration, and tactical surveillance. As well as underwater sensor nodes, unmanned underwater vehicles are used in some application scenarios of UASNs such as exploration of underwater resources and data gathering in collaboration-requiring missions. UASNs rely on acoustic communications; however, the underwater acoustic channel is highly variable and its link quality depends on environmental factors and the locations of the communicating nodes. Therefore, ensuring reliable communication in UASNs is quite difficult. Moreover, path losses and retransmissions lead to the wastage of energy resources and reduce the network lifetime. In this study, we used well-known underwater modulation schemes to analyse and simulate various underwater scenarios with different depth, distance and BER values in order to make a fair comparison between the modulation schemes and find the optimal transmission power. As proven in our simulation study 32-PSK and 16-QAM techniques achieved the minimum energy consumption rates. Therefore network designers can prolong the underwater network lifetime using 32-PSK and 16-QAM modulation techniques.

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Keywords: Underwater Sensor Networks, Modulation Techniques, Performance Analysis

ÖZET

FARKLI MODÜLASYON TEKNİKLERİ İLE SU ALTI İLETİŞİMDE PERFORMANS ANALİZİ

Sualtı Kablosuz Algılayıcı Ağlarının özellikle veri toplama, sınır güvenliği, kirlilik izleme, sahil araştırma ve taktiksel takip gibi bir çok oşinografi uygulaması son yıllarda pek çok araştırmacının ilgisini çekmeye başlamıştır. Pek çok su altı uygulamasında, su altı sensor düğümlerinin yanında, insansız su altı araçları da su altı kaynaklarının keşfi ve veri toplama gibi işbirliği gerektiren görevlerde yaygın olarak kullanılmaktadır. Su altı ağlarda kurulan bağlantı akustik iletişime dayanmasına rağmen, akustik kanal özellikleri çok ani değişiklikler gösterir ki, bu nedenle kurulan bağlantı kalitesinde, çevresel faktörler ve düğümlerin konumları önemli rol oynar. Bu sebeple su altı ağlarda güvenilir bir iletişimin kurulması oldukça zordur. Bütün bunlardan başka, sinyal kayıpları ve yeniden iletimler enerji kaynaklarının gereksiz sarfiyatına dolaysıyla ağ ömrünün kısalmasına neden olur. Bu tez çalışmasında su altı akustik ağlarda en çok bilinen modülasyon teknikleri kullanılarak farklı derinlik, mesafe ve Bit hata oranına sahip su altı ortamları analiz edilmiştir. Sonuç olarak veri iletimi için gerekli minimum enerji miktarı bulunmuş ve modülasyon teknikleri uygun şekilde kıyaslanmıştır. Simülasyon çalışmalarımızda kanıtlandığı üzere 32-PSK ve 16-QAM teknikleri minimum (optimum) enerji tüketim oranlarına ulaşmıştır. Bundan dolayı ağ tasarımcıları 32-PSK ve 16-QAM modülasyon tekniklerini kullanarak su altı ağların ömrünü artırabilirler.

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Chapter 1

Introduction

There has been a remarkable progress in underwater acoustic communications for over 30 years. This progress has been carried out in different fields, such as Error Control Coding, Underwater Channel Physics, Channel Simulations, Networked Systems and Alternative Modulation Strategies [1].

There are three options for underwater communications system each having various advantages and disadvantages. These are electromagnetic waves (RF), optic waves and acoustic waves. According to empirical results, optical waves encounter scattering problems, which make it unsuitable for underwater communication, whereas radio waves have other problems, such as propagation problem and path loss. In detail, RF waves can propagate to long distances in underwater only at quite low frequencies (30-300 Hz.), which need high transmission power and large antennas. Consequently, these two options (radio, optic) are not appropriate for underwater communications at least for now. Transmission loss, which increases with frequency and distance, large transmission delay, serious Doppler and multi-path effects are the general characteristics of UWA (Underwater Acoustic) channel, when it is compared to electromagnetic wave channel. These features affect the efficiency of the communication significantly in underwater acoustic networks; therefore channel capacity is limited seriously [2]. Indeed, the performance of underwater acoustic communication is not a matter of telecommunication, even if the applied techniques look similar. In detail, the distance restricts viable bandwidth because transmission data loss rises up, as the range distance gets longer.

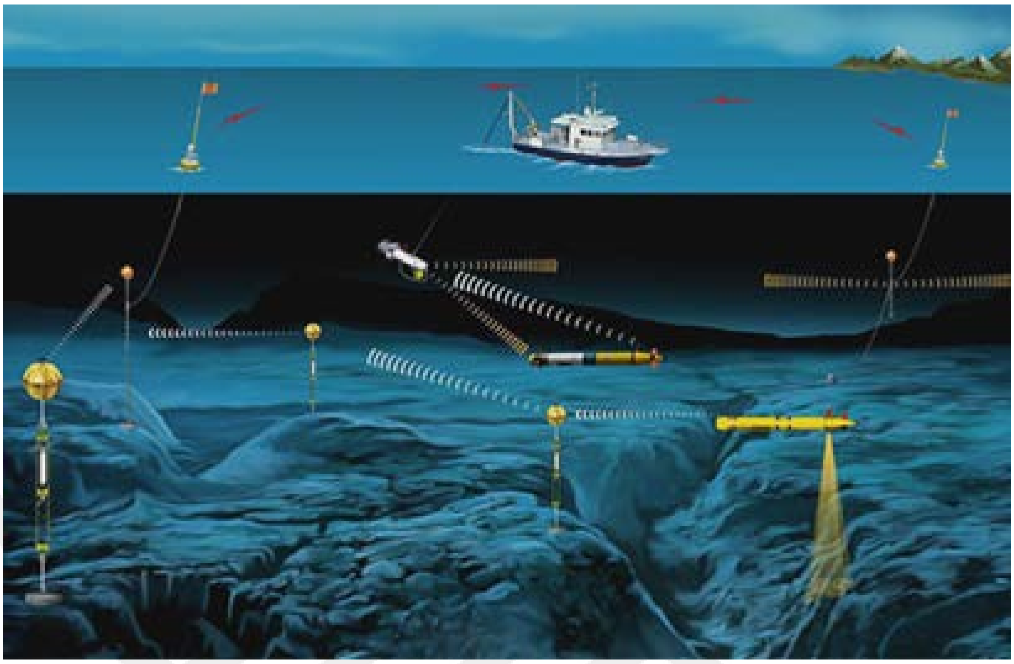

Figure 1.1 Underwater Wireless Sensor Networks (UWSN) [46].

Figure 1.1 and 1.2 illustrates the general view of underwater wireless sensor networks (UWSNs). In UWSNs, selecting the correct modulation scheme is one of the critical key techniques to provide a robust communication to improve the utilization ratio of bandwidth [2]. The bandwidth utilization could be described as “to use available bandwidth wisely to reach specific goals”. There are two types of bandwidth utilization; multiplexing and spreading.

The primary objective of the study in [3] is to address how to integrate channel models that have already been deployed in other network types into ongoing underwater acoustic networks. In the article, an approach called decision directed noise estimation is explained in detail to reduce the pulsed interference as much as possible. In other words, the proposed technique extracts the effect of inter-carrier interference, which is a challenging problem for conventional pulse blanking method. The study in [4] focuses on channel estimation and equalization for underwater acoustic systems.

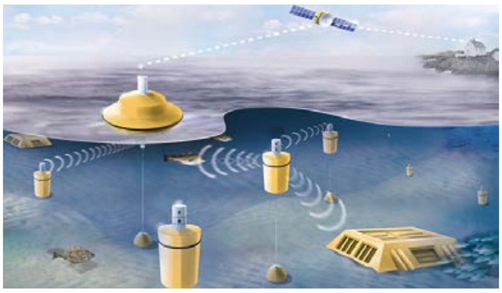 

Figure 1.2 Test beds for UWSN [47].

In this thesis, an overview of underwater wireless sensor networks, specifically modulation techniques applicable for underwater wireless networks, will be explained followed by their application areas, cons and pros, challenges and constraints of the systems that have been employed so far. In chapter 1.1, the modulation techniques for underwater acoustic communication are given in detail. In chapter 1.3, communication system and channel model are revealed, specifically focusing on the reason behind why it is important to use correct modulation scheme. Further discussions will be reckoned for the recent development aimed at improving the modulation technique that has been deployed until recently. In chapter 2.1, the essential characteristics of UWSN channels were studied and are briefly explained. Following this chapter, the factors influencing the communication performance, such as small and large-scale fading, transmission loss, path loss, large propagation delay, Doppler, multipath effect, absorption coefficient and the relations between range and SNR, frequency and SNR together with their formulas and explanations are given briefly. Chapter 3 includes the design aspects of underwater environment, such as channel estimation methods regarding underwater acoustic communication. Chapter 4 gives the details of methodology used during simulations and the results of the simulations, which we have obtained via using different modulation schemes namely, BPSK, 8-PSK, 16-PSK, 32-PSK and 16-Qam, are given in detail. Lastly, Chapter 5 contains the conclusion regarding our study and research.

1.1 Modulation Techniques For Underwater Wireless Acoustic (UWA) Communication

The process is called as modulation when a carrier wave, which has more power comparatively, carries the message or signal in terms of ones and zeros. There are 3 essential methods of modulation: frequency, amplitude and phase shift keying. It is necessary to reach higher order of modulation in order to encode more bits per symbol. The widely used modulation types in underwater acoustic communication are PSK, QAM and FSK as given in paper [2]. CSK, QPSK, OFDM are also other common modulation types deployed for underwater acoustic communication. DSSS is one of the most common modulation schemes in use nowadays. In this modulation scheme, the total information to be sent is divided into small pieces and a frequency channel is allocated to each piece so that a much higher frequency is obtained rather than having higher data rates. The ultimate objective of DSSS is to resist signal interference and to recover the data during transmission. Another interesting and popular modulation type is QPSK, which enables to transmit 2 bits per symbol. In other words a QPSK symbol represents 2 bits instead of 1 bit contrary to other modulation types; therefore, QPSK is advantageous in terms of energy efficiency.

QAM is also another alternative and significant modulation type especially used to reach higher throughputs. However, it is generally inconvenient unless the conditions of communication channel are really good. In other words, better SNR values are required to overwhelm difficulties like interference problems and to keep a constant bit error ratio (BER). It is necessary to keep in mind that QAM is a combination of PSK and ASK where both amplitude and phase of the signal are changed.

An advanced modem can change its reconfigurable parameters, such as modulation scheme and depth and distance to be able to transmit more data in packets over varying communication channel as the author described in paper

[5]. The main duty of an improved modem is the competence of changing the features based on some parameters like SNR and SNIR. Many of these values rely on current and future circumstances of the acoustic channel. Therefore, channel estimation plays a critical role on the efficiency of any improved modem. Consequently, there are some significant channel state information values that have to be measured or predicted through Doppler shift, channel path gains and SNR [5]. Figure 1.1.1 shows underwater sensors modules in real network platforms.

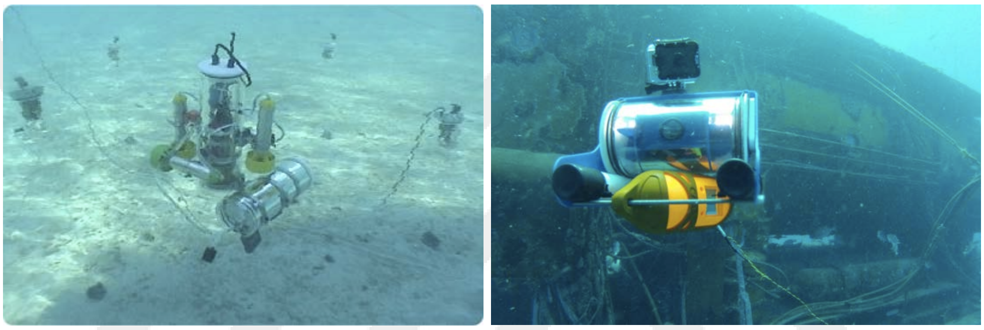

Figure 1.1.1 Underwater Sensors for UWSN [48].

In the article [7], the authors propose to merge time-sharing together in collaboration with hierarchical modulation to show how this different version of modulation scheme can enhance the available rate. According to the paper, the authors present a method that is called as a hierarchical 16-PSK to improve the efficiency of the online monitoring standards. They also evaluate multiple strategies for grouping the receivers in pairs to utilize hierarchical modulation in the paper. Finally, they prove in a real environment that DVB-S2 modulation scheme can provide approximately more than 10% gain on throughput when compared to the best time-sharing strategy. Despite all these technological novelties on UWSN communication, video multicast or real time monitoring of underwater environment does not seem so possible at least for now, since it requires really high amount of data stream transmission.

The paper [8] presents a joint Slot-allocation and MCS-selection scheme in multi-base station system model. The authors first declare the problem as how to maximize the total system utility, then an intra-session MCS assignment technique based upon a greedy algorithm, which can also be applicable to other multi-session scenarios, is verified.

1.2 Communication System And Channel Model

As it was explained at the introduction part, three alternatives; electromagnetic waves (RF), optic waves and acoustic waves, have already been deployed at underwater communication system so far by various researchers working on this area. However, the most respectable results have been obtained only with the help of acoustic system, which requires basically a hydrophone to produce sound waves, sonar to listen to these waves and a processor to convert the received waves into meaningful data. Acoustic communication is the most promising way for UWSN communication since optical waves encounter scattering and attenuation problems while radio waves have other problems such as propagation delay and path loss. In paper [3], the author not only summarized a series of highly cited surveys related to UWSN communication written by some of the prestigious researchers but also gave place to comprehensive literature reviews of UWSN communication, recent trends multicarrier communication, and alternative modulation strategies.

	Acoustic Wave	**RF**
Propagation Speed	$1.5*10^3$ m/s	$3*10^8$ m/s
Transmission Range	10 km on 10kHz	120 cm on 430 MHz
Bandwidth	Few kHz	More than MHz
Rate	0.02kbps	250kbps

Table 1.2.1 Acoustic Wave vs. Electromagnetic Wave.

The comparison between Acoustic and RF waves related to some parameters of underwater is given in the Table 1.2.1. In paper [9], the authors reveal some difficulties related to UWSN communication channel; it is explicitly given in the paper that in Underwater Wireless Sensor Networks (UWSNs), spatial reuse index remains too low when compared to RF networks because spreading loss of acoustic signals is relatively higher than electromagnetic waves. This problem causes generally lower network throughput in UWSNs. They claim that their protocol increases the spatial reuse index efficiency just by adjusting the dynamic transmission power. The authors of [10] analyze underwater environment to use it for some significant applications with the aim of military, industrial and scientific purposes as well as to preserve and take the advantage of natural underwater resources. To achieve these goals, the most crucial issue is the reliability and energy efficiency at the design of underwater acoustic networks. Plenty of drafts have been implemented in order to enhance the energy efficiency and reliability of these networks so far. Nevertheless, most of them have become ineffective due to unrealistic assumptions or ignored attenuation of noise as well as disregarded uniformly distribution of noise in underwater surroundings. Since the location information of the nodes plays a critical role on node tracking, data tagging, routing and localizing the sensor nodes for UWSNs has to be taken into account for an efficient and reliable network construction. A high number of techniques regarding localization have been proposed recently due to its significant importance for UWA networks. In the paper [11], these localization techniques have been discussed and investigated in order to broaden the literature related to underwater communication. The paper [12] is an outstanding article discussing this active research topic and having a survey on recent techniques related to localization issue. ARQ is a error control protocol, which detects errors during data transmission. When the receiver detects an error in a packet, it automatically requests the transmitter to resend the packet. The authors propose a novel scheme to advance the efficiency of ARQ over UWSN links in their paper.

Their proposal is based on a selective repeat ARQ policy; more in detail, a time division duplex link is established between transmitter and receiver in order to prevail or at least to leverage large propagation delays of underwater sound. In [13], the authors propose an approach to decrease Doppler effect in UWSN. So they assume that there is a common Doppler effect on all propagation paths of communication channel. As a result, a solution to this problem consisting 2 steps is suggested in the paper. . In paper [14], the researchers suggest a novel scheme called as optimal redundancy allocation over variable conditions of underwater links to provide the spectral efficiency and reliability of the connection. Based on their proposal, it is possible to design a real time algorithm to able to allocate the redundancy in point-to-point links without any extra control messages.

However, it is suggested in the article that it is necessary to do an extensive research on some definitions like rate, channel complexity, range and etc. in order to develop an improved underwater modem. Figure 1.3.1 demonstrates samples of these modems. The researchers propose a novel architecture of traditional TCP/IP protocol for UWA communication in the paper [16] to ensure efficient interoperability for commercial underwater modems. The proposed architecture is located on adaptation layer, which is between the data link and the network layer. Hence, the purpose of this layer is to perform header compression and data fragmentation different than other layers to guarantee energy efficiency.

The authors of [17] discuss and focus on a novel modulation system, which allows multiple synchronous users to transmit data packets simultaneously. The unique part of their work is that allocating a single path for each user cause a major diversity of Doppler scales, whereas the authors of [18] focus on the key aspects of underwater communication and deal with the general challenges of UWA communication, which enlighten most of the researchers working on this area. The authors deal with implementing a hardware platform in [19] to optimize the energy efficiency with low costs. The proposed platform consists of reconfigurable hardware as microcontrollers, digital signal processors, sensors and other parts. In addition to hardware, they implement an algorithm (Matching Pursuits for channel estimation) to be used in acoustic modems as well.

They try to broaden the field of underwater communication by applying current terrestrial systems into the underwater environment to lead low cost and high performance mobile devices to be useful for UWA communication in the paper [20]. The authors of article [21] deal with designing an improved modem, which can change its parameter based on the estimation of underwater channel. As well as introducing the proposed modem, they hold in the paper a set of test results in order provide the benefits of their modem design. In the paper [22], the differences between underwater acoustic and RF networks are discussed by the authors to address various problems related to network topology, MAC protocols, routing protocols, energy consumption and signal propagation. The researchers of the paper pay attention to the noise attenuation and suggest a novel mechanism to increase energy efficiency and reliability in UANs. In this context, they propose a novel scheme, which allocates the underwater communication space, as tree-based multi-paths.

Another challenging problem of underwater sensor networks is the design of receivers, which is explicitly revealed in [23]. The authors of the article bring to light to this matter and propound a novel receiver design with user or path Doppler scaling distortions. The scenario is prompted by the framework where deployed transmitter, receiver pairs may come across with considerably dissimilar Doppler distortions just as single user scenarios.

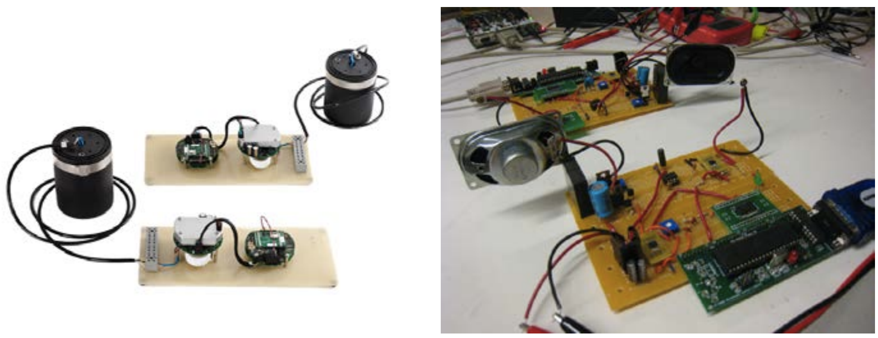

Figure 1.3.1 Underwater re-configurable modems [49].

The paper [23] contains a comprehensive study on cognitive underwater multiple-access communications so that they propose a configurable receiver and implement a radio, which is software-defined and provides a real-time monitoring of underwater environment. The authors propose a novel modulation scheme in the paper [24] in order to maximize the system throughput under a target BER values. Their proposal is based two different modulation techniques in order mitigate the long propagation delays due to underwater communication channel characteristics. The challenges of designing a scalable underwater mobile is briefly explained in [25] and concluded as the challenge can be formulated and solved by interdisciplinary efforts.

In the paper [26] the authors deal with general problems and prospects of today's world UWA communication as well as giving the details, cons and pros, about adopting different communication carriers such as optical, acoustic and radio. In the paper [27] a novel platform is proposed for UWSN in order to facilitate long term monitoring of coral reefs and fisheries. They also introduce an integrated TinyOs stack for node-to-node communication in the paper within the presentation of their proposal. Mari Carmen Domingo presents feasible solutions for several challenges of underwater communication and she tries to simplify some existing channel models in her paper [28]. Beside, giving a brief review of the related literature, the paper includes fundamentals and research challenges of today's world underwater acoustic communication. In the paper the author analyzes underwater environment with its all aspects such as absorption coefficient, multipath fading, shadow zones, depth, water salinity and temperature, turbulences, shipping activities, operating frequency etc. She carried out set simulations and simulation results following their mathematical modeling are explicitly presented in the paper to highlight the main issues related to UWA communication. The authors of [29] proposed a channel allocation scheme, which allows users to communicate over long distances. As a result, it is proved via experimental field studies that cognitive channelization is a robust and powerful technique for spectrum utilization and the authors of the paper concludes with a novel modulation scheme as the most promising alternative for future UWA communication systems. In the paper [30], a mathematical model is presented for UWA communication and compares it with existing models by Felemban. The author investigates number of hops, optimal node placement, the tradeoffs among energy consumptions as well as end-to-end delays of UWSN's throughout the paper. The paper concludes with determining the optimal number of hops for an energy efficient underwater communication.

The authors of [31] discuss the latest trends related to underwater communication and try to find out a feasible method to apply the multicarrier communication systems for UWA networks with respect to theoretical models and simulation studies whereas the authors of [32] do their experiments on real environments: water-tanks and swimming pools. In the article they mostly focus on shallow water and short-range communication systems; introduce a novel function called as probability density function, which estimates channel conditions based an impulse response.

In the paper [33], a scalable network design is studied to find a solution for the most challenging problem of underwater networks: energy efficiency. To maximize the energy efficiency they demonstrate in the paper a proposal: optimal knowledge range for geographical routing. The writers deal with general underwater networking systems and benefits, challenges and problems related to the literature in [34]. The paper [35] contains general aspects of modulation schemes as QPSK and QAM: how to achieve higher throughputs and better spectral efficiencies via using these schemes. The authors also give the details about obtaining a high SNR value to overcome fading and interference problem.

We have already mentioned that underwater sensor networks have many application areas ranging from military surveillance to pollution monitoring and data gathering for scientific purposes; the paper [36] deals with a reconfigurable UWA modem for providing a flexible modem, which can ideally change its parameters and be modified for testing different alternative networking algorithms. Since the channel capacity is significantly low in UWA channels, it is quite hard to transmit high amount of data through UWA communication, in [37] an efficient method for image transmission is presented with its all its features. Moreover the authors propose an image compression algorithm for a low cost networking. A high number of various modulation schemes have been proposed for underwater communication during the last decade. A benchmark shell, which enables testing different modulation schemes at different channel conditions and frequencies, is introduced in paper [38].

Unmanned vehicles and autonomous devices are used in underwater applications commonly; on this context the authors of [39] carried out a set of tests with these devices at 2 different environments: at the bottom and at the surface of water in order distinguish their challenges from each other for a robust UWA communication. We have explained underwater acoustic communication as the most promising technology for future trends. In paper [40], a high frequency and high data rate hydro acoustic modem is presented for enabling higher data transmission in an open water environment.

Since the inflexible and expensive underwater modems can't change its algorithms or parameters, software-defined modems can provide the researchers flexibility to use different modulation schemes and protocols for UWA communication. The motivation of [41] is encouraging research efforts by holding a low cost and mobile system, which is integrated with smart phone or tablet. They perform a set of real experiments on real environments with a spread spectrum acoustic modem and share their results in their paper. The authors try to overcome Doppler spread and multipath propagation in [42] and implement a software-defined radio on a chip for this purpose. In order to achieve their goals, a novel algorithm together with a novel modulation scheme is proposed in the paper. The limited bandwidth and low signal propagation of underwater medium are the main drawbacks of underwater communication; the paper [43] includes a remarkable research and model design to overwhelm these drawbacks. They authors focus on implementing a novel transmission system and receiver design, in order to accomplish reliable and energy efficient communication. The paper [44] holds a brief survey on current research challenges of underwater communication as well as localization algorithms and deployment techniques. The authors also give a comprehensive analyze and comparison of localization techniques based on their cons and pros in the paper.

The researchers of [45] claim, that most of well-known modulation schemes are not suitable for a confidential underwater communication. Hence they propose a novel chaotic modulation scheme to improve the security of the communication. The paper concludes with verification of their proposal based on real experiment results.

Chapter 2

2.1 Characteristics of Underwater Wireless Acoustic (UWA) Channel

Underwater acoustic channel has some challenging difficulties characteristically such as serious multi-path effect, Doppler effect, large propagation delay, transmission loss, limited bandwidth and etc. These obstacles influence UWA communication performance seriously and constraint the channel capacity for a robust and efficient communication. Indeed, the performance of underwater acoustic communication is not a matter of telecommunication even if the applied techniques look similar. Beside all these challenges, transmissions loss increases with the ascending distance and frequency. Actually these characteristics of acoustic channel show a great diversity based on the location of the deployed network. Sound propagation is generally influenced by homogeneities of water column and scattering from rough surfaces while there are more challenging problems to cope with at the ocean water (rough seas) such as wind, turbulences, channel variations, surface fluxes, internal waves and so on. In this chapter, the general characteristics of underwater acoustic channel will be briefly analyzed and the formulations of such terms affecting the acoustic communication as large and small scale fading, absorption coefficient of water medium, path loss, transmission loss, propagation delay variance, Doppler and multipath effect will be given in detail. Consequently the chapter ends up with the correlation between SNR and Frequency for underwater acoustic communication.

This chapter consists of a comprehensive analysis of general characteristics of underwater acoustic channel to perceive the differentiations among modulations schemes while data transmissions over fast varying UWA channel. Afterwards, the main differences among modulation schemes together with bandwidth optimization for a reliable and energy efficient UWA communication will be concluded. The results obtained via simulations will be explicitly demonstrated at the 4th chapter. Figure 2.1.1 shows general architecture of underwater sensor networks together with its surface and onshore peripherals.

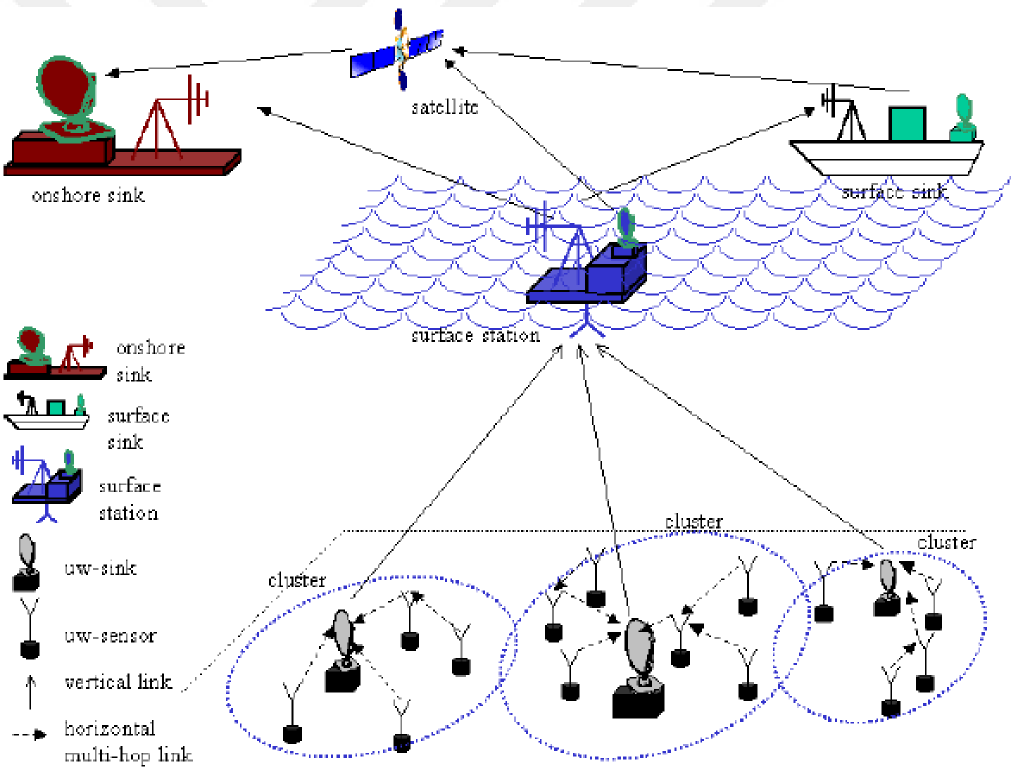

Figure 2.1.1 Architecture of 2D Underwater Sensor Networks [50].

There are many factors influencing the intensity of the sound reducing the acoustic power on its propagation way to the destination. These factors can be ranked as the bending of acoustic ray, the scattering due to non-uniformity of ocean, absorption coefficient of seawater and wave-front expansion during propagation. All these effects of water will cause small scale or large scale fading on acoustic waves. Fading depends on many arguments such as frequency, location of nodes, distance and so on. All these mentioned channel dynamics of the water cause many challenging problems to cope with. Most of these problems can be ranked as follows:

- **Attenuation**: A term that refers to any decrease on the power of the signal. Generally occurs during signal transmission over long distances.
- **Transmission loss:** It is not possible to transmit whole power of the signal from source to destination. This partly lost of the power is called as transmission loss.
- **Path loss**: Changes on received signals as phase difference due to propagation over long distances is generally known as Path loss.
- **Large propagation delay:** The duration that is required for a signal from transmitter to receiver is called as propagation delay. If it is larger than estimated than it is called as large propagation delay.
- **Doppler effect:** If the source of a sound or receiver is moving thereby frequency of the sound can be perceived by receiver different than its original and this effect is named as Doppler effect.
- **Multi-path effect:** This effect generally occurs if a single signal travels to destination from different paths, they will probably reach to destination at different instances thus an interference of received signals may happen. This event is called as multi-path effect.
- **Absorption coefficient:** The water medium itself absorbs some part of travelling acoustic wave naturally. This absorption ratio is known as absorption coefficient. Figure 4.1.1.1 shows how the absorption

coefficient of water affects the frequency of acoustic signals in different depths of underwater.

- **Large-scale fading:** Attenuation of signal due to propagating over long distances or diffraction from objects on its direction is generally called as large-scale fading. In underwater channels it is generally caused by propagation of acoustic waves itself or acoustic ray convergence. The fading is composed of 2 main elements: absorption and transmission loss. Convergence fading can be described as when the energy of sound strong at a location whereas it is weak at another location.
- **Small-scale fading:** Generally known as rapid amplitude fluctuations of received signal. In UWA communication small scale fading is generally caused due to Doppler spread and multipath spread. Physical characteristics of the ocean create interference of multipath signals. This type interference is called as Multipath fading which is highly depended on the location of the receiver and transmitter. As a conclusion of the analysis above it could be extracted that small scale fading changes as a function of time and distance, whereas large-scale fading changes as a function of distance and frequency.

2.1.1 Relationship between bandwidth and frequency/ range in UWA channel

The SNR of receiver can be calculated as given in paper [2], when only the large-scale fading is taken into account, based on the passive sonar function:

$$SNR = SL - TL - NL - 10logB \tag{1}$$

Where, transmission loss is TL, sound source level is SL in terms of decibel (dB), bandwidth is symbolized by B and noise spectrum level by NL. We need to note that if the SNR and transmitting power of transmitter are fairly defined, the bandwidth of the system will be the function of frequency and distance.

2.1.2 Relationship between BER and SNR in UWA Communication

In UWA communication the most commonly used modulation types are FSK, PSK and QAM. Although having many drawbacks, acoustic communication is preferred instead of optical and RF communication since the attenuation ratio of acoustic signals is much less than the other 2 signal types.

The available bandwidth is highly depended on communication range of the network in underwater communications. For instance: the bandwidth can reach up to values around 10kHz for ranges below 100m whereas the bandwidth is restricted to a 10 kHz for ranges between (1-10km). When the communication range gets longer (10-100km), the available bandwidth diminishes of only a few kHz. Available bandwidth ranges for underwater acoustic propagation are listed in Table 2.1.2.1

	Range[km]	**Bandwidth[kHz]**
Very Long	1000	<1
Long	10-100	2-5
Medium	1-10	≈10
Short	0.1-1	20-50
Very Short	<0.1	>100

Table 2.1.2.1 Available bandwidth of underwater acoustic propagation for different ranges In UWA Channels.

All these challenges mentioned above are generally caused by bad channel conditions and restrict underwater communication quite a lot. As a consequence it is highly important to use correct parameters before starting the communication. Selection of the parameters such as depth, distance and BER plays a critical role to overcome most of these challenges. Chapter 4 includes the results of our analysis related the performances of different modulation types, such as BPSK, 8-PSK, 16-PSK, 32-PSK, 16-QAM.

Chapter 3

3.1 Design Aspects of Underwater Communication System

We consider the underwater environment where there are nodes as transmitter and receiver and the communication system is set to single hop during the simulations. We have constant parameters and changing parameters related to the circumstances of water such as depth, distance and BER. We have computed the results for 5 different modulation schemes namely BPSK, 8-PSK, 16-PSK, 32-PSK and 16-QAM. The basic mechanism of our system depends on a pilot signal to check/detect channel characteristics sent to the receiver from transmitter, and it is processed by receiver in order to estimate instant characteristics of acoustic channel and the receiver sends a feedback to transmitter to let it select one of the modulation schemes as well as a suitable bandwidth based on this estimation to start transmitting information. The estimation of the channel by receiver is computed based on the parameters such as received SNR, time elapsed and estimated/calculated power gain. The details of the estimation process have been briefly explained in the previous parts of the thesis. Beside all these computational and mathematical modeling of estimations, the efficiency of modulation schemes in terms of transmission power, has been studied and demonstrated in the result chapter of our study.

It is highly significant to use correct modulation scheme while transmission from source to target node in underwater environment. Because fading channels obstruct us to achieve a reliable and efficient communication due to the problem of lost packets and the necessity of persistent retransmissions. Besides these difficulties, rapid changes of underwater channel conditions make it compulsory to use the correct modulation scheme for underwater acoustic communication. However, the complexity of such models has to be simplified to make them available for communications systems and networks as given in paper [27]. Unless these challenges are handled correctly, the communication system will not be able to cope with signal degradation, thereby the quality of service will not be guaranteed. Bandwidth optimization and selecting the most convenient modulation scheme are the most powerful techniques in order to overcome these effects and guarantee quality of service obligations.

3.2 Channel Estimation

Channel estimation is one of the most compulsory tasks for underwater communication due to fast varying channel conditions. Some researchers suggest doing the estimation with some pilot signals, which measure channel frequency response, whereas others suggest doing it by producing a stable reference signal. However, the mentality of both suggestions is based on the same reason to predict the channel conditions whether it is the correct/best time to start communication. As it is expressed in the paper [4], the process of channel estimation relies on estimation of Doppler scaling factors from the synchronization preamble right after obtaining the reference signal. As the second step of the estimation process, the Path coefficients could be predicted via using obtained signal. Thereafter, Doppler factors are not required anymore since it is assumed that the channel coefficients show adequate stability for the prediction of a few seconds in the future.

In order to compute the estimations correctly, we have to know the factors affecting the acoustic communication. More in detail, the increase of salinity, pressure and temperature let the sound speed rises up. In addition to this, we have taken into consideration other factors such as noise, multipath propagation, high delay and delay variance, Doppler spread, depth, distance and frequency.

It is important and necessary to keep in mind that total response time of the communication is directly related to the speed between underwater sink nodes and the surface station. In [19] the authors propose a novel modulation scheme for underwater acoustic communication systems integrated with an algorithm for frequency selective channel estimation. Their proposal is based on achieving multiple-input and multiple-output. It is stated out in the paper that the proposed algorithm can be one of the most efficient alternatives for undetermined sparse channels in UWSNs with its low complexity. In the paper [24], a remarkable method for SNR estimation is proposed which achieves the estimation by directly received signals.

In the article [25] the authors also deal with channel estimation and try to find a convenient solution for this challenging problem. The proposed a novel modulation scheme, which is quite considerable technique in the infrequent underwater acoustic channels. Their approach is based on channel impulse response to enhance the efficiency of channel estimation. The novelty of their algorithm is that initially from source to destination all sparse channel taps together with their locations are predicted by using matching pursuit approach. As a result, they have come up with a remarkable solution for channel estimation problem in UWSNs.

Chapter 4

4.1 Simulation Results and Discussions

We have simulated underwater environment using the parameters of Ham.[Node] commercial modem specifications, as given in [51] which is demonstrated in the table 4.1.1 below.

Parameter	Values
K	1,5
Noise bandwidth (Bn)	1KHz
Wind speed(w)	0 m/s
Shipping activity factor (s)	0.5
Water Acidity (pH)	8
Water salinity (S)	35 ppt
Date rate (R)	2 Kpbs
Temperature (T)	15 C^0
R_{max}	30 km
BER	10^{-7},10^{-6}, 10^{-3},10^{-1}
Depth	100, 300, 500, 1000 (m)
Distance	100, 300, 500, 1000 (m)
Frequency	0-200 KHz

Table 4.1.1 Parameter values used our simulations

We have carried out a set of simulations in order to find the optimal (minimum) transmission power of an underwater network having various specifications. The table 4.1.1 shows the parameter values those we have used during our simulation studies. The figure 4.1.1 demonstrates the block diagram of our simulation process with its input and output parameters. We have used variables such as BER, depth and distance as inputs and found out the optimal transmission power as output.

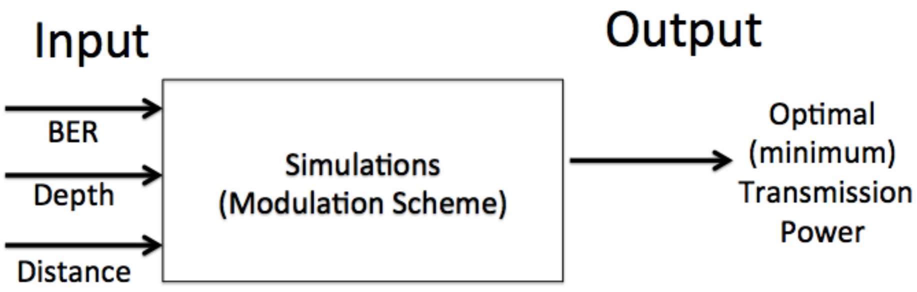

Figure 4.1.1 Block Diagram of our Simulation Process.

We have used Ainslie and McColm models to find the absorption coefficient values for various depths and distances of underwater. Figure 4.1.2 shows the 3d graph of absorption coefficient for depth between 0-1000 m. and frequencies between 0-300 KHz. The absorption coefficient increases suddenly with the increase of frequency and therefore limits the use of higher frequencies for underwater communication. Beside all these, it is necessary to keep in mind that absorption coefficient shows an opposite characteristics with depth and decreases with increase of depth.

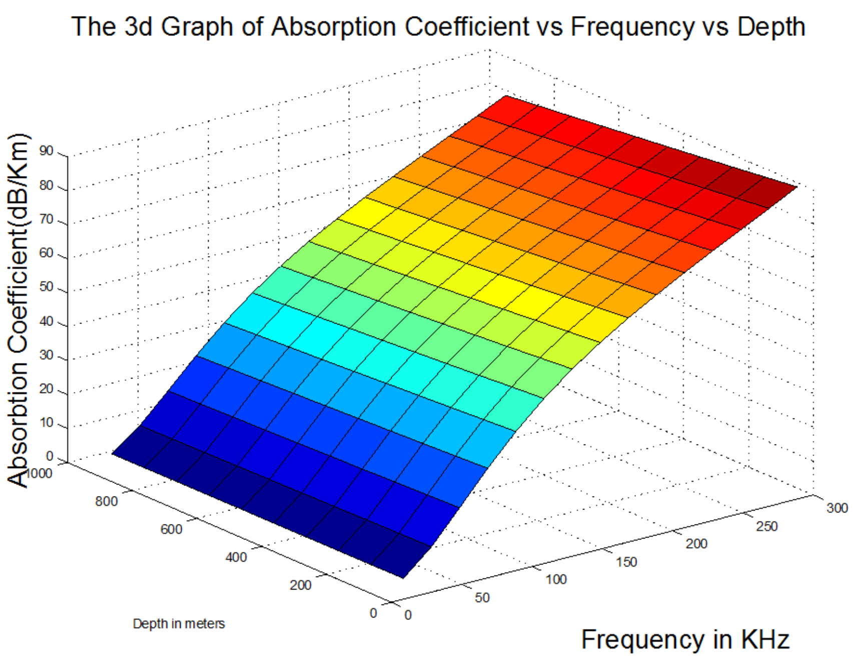

Figure 4.1.2 Absorption coefficient vs. frequency vs. depth.

Ainslie and McColm present the formulation of absorption coefficient as follows:

$$\alpha(\mathrm{f}) = y1\,\frac{\mathrm{f1}.f^2}{\mathrm{f1}+f^2} + y2\,\frac{\mathrm{f2}.f^2}{\mathrm{f2}+f^2} + y3\,\mathrm{f}^2 \qquad (2)$$

where,

$$f1 = 0.78\left(\frac{S}{35}\right)^{1/2} e^{\frac{T}{26}}$$

$$f2 = 42\,e^{\frac{T}{17}}$$

$$\mathrm{Y1} = 0.106e^{\frac{Ph-8}{0.56}}$$

$$\mathrm{Y2} = 0.52(1+\frac{T}{43})(\frac{S}{35})e^{\frac{-d}{6}}$$

$$\mathrm{Y3} = 0.00049e^{-(\frac{T}{27}+\frac{d}{17})}$$

Where, S is the water salinity, T stands for the temperature in C^0, d is the depth in m , pH is water acidity and the default values of pH and S are 8 and 35, respectively.

A(d, f) is known as path loss in acoustic communication and caused by 2 phenomena: absorption due to water medium and energy spreading . Attenuation of the propagating signals mainly depends on the distance of the established link. It is necessary to keep in mind that high frequency signals are more fragile to absorbtion loss due to convertion of the acoustic energy into the heat. The A(d, f) path loss can be found as a function of transmission distance d and frequency f as follows [28] :

$$\mathrm{A(d,f)} = \mathrm{K}\log(\mathrm{d}) + \alpha(\mathrm{f})\,d\,10^{-3} \qquad (3)$$

Where, $\alpha(\mathrm{f})$ is absorbtion coefficient of the water medium as given in the expression (2) and K is the spreading factor caused by energy spreading. Commonly used values for K is 10 for cylindrical spreading, 20 for spherical spreading, and 15 for practical spreading. Attenuation is an important parameter in communication systems, which determines the signal strength as a function of frequency.

Consequently, absorption coefficient triggers the increase of transmission loss with the increase of communication frequency. However the effect of distance at low frequencies on transmission loss is very limited since absorption loss doesn't effect the transmission at low frequencies that much. Lastly, it should be also noted as the depth of water increases, the transmission loss decreases due to lower absorption loss in deeper water.

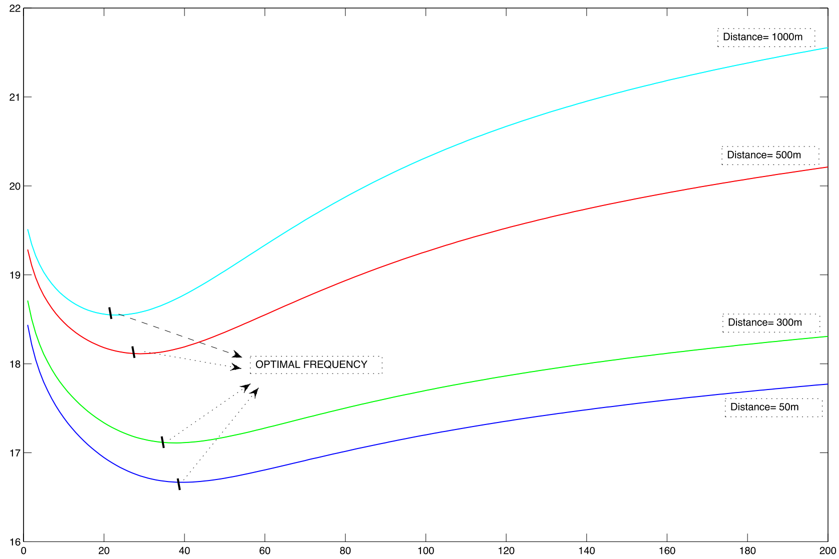

Figure 4.1.3 A (d, f) + N (f) product as a part of the passive sonar equation.

Figure 4.1.3 shows AN A (d, f) + N (f) product for distances of 50 m, 100 m, 500 m, and 1 km at depth of 100m and BER of 10^{-9}. It indicates a part of path loss model for 4 different distances.

Ambient noise reaches its minimum values due to water's own characteristics more or less around frequencies of 20-40 KHz. As we can abstract from the descriptions above acoustic signals can best propagate only at low frequencies (15-40 KHz.) and available bandwidth is quite narrow which is around 5 KHz.

Sonar systems can be divided into 2 groups as active and passive. The sound is produced in an active sonar system and listened for echos of the produced sound. On the contrary a passive sonar system listens the sounds emitted by other sources. Hence, passive sonar equations can be used to differentiate among the sound emitted by the transmitter and the background noise interfering the sound signal carrying the data packets. The passive sonar equation will be given before graphs related to optimal transmission power. In addition to this the power spectral density of ambient noise in dB can be described as:

$$N\ (f) = N_t(f) + N_s(f) + N_{th}(f) + N_w\ (f) \qquad (4)$$

Where, N_t is the noise by turbulences, N_s is surface-shipping activities, N_{th} is thermal noise and N_w breaking waves (by wind) and can be obtained by using these formulations:

$$10\log\ (Nt\ (f) = 17 + 30\log\ (f) \qquad (5)$$

$$10\log\ (N_s\ (f)) = 40 + 20(S - 0,\ 5) + 26\log\ (f) - 60\log(f + 0.03) \qquad (6)$$

$$10\log\ (N_{th}\ (f)) = -\ 15 + 20\log\ (f) \qquad (7)$$

$$10\log\ (N_w\ (f)) = 50 + 7{,}5w^{1/2} + 20\log\ (f) - 40\log(f + 0.4) \qquad (8)$$

The path loss A (d, f) in acoustic communication mainly caused by 2 reasons: geometric and energy spreading of acoustic waves and highly depends on the range of the transmission. The change of path loss (A (d, f) + N (f)) of acoustic signal with transmission frequency f in KHz. was given figure 4.1.3 and has been explained in detail so far.

It should be noted that related to equation (4), the effect of acoustic spectrum and thermal noise is quite dominant, whereas shipping activities and surface turbulence have a little effect on the ambient noise calculation. Shipping activities are represented N_s (f) which occurs on the surface of water, obtains values ranging between 0 and 1. As a consequence, various components influence the noise at different frequencies. Average transmitted SNR value as a function of frequency and distance can be found via given expression (16).

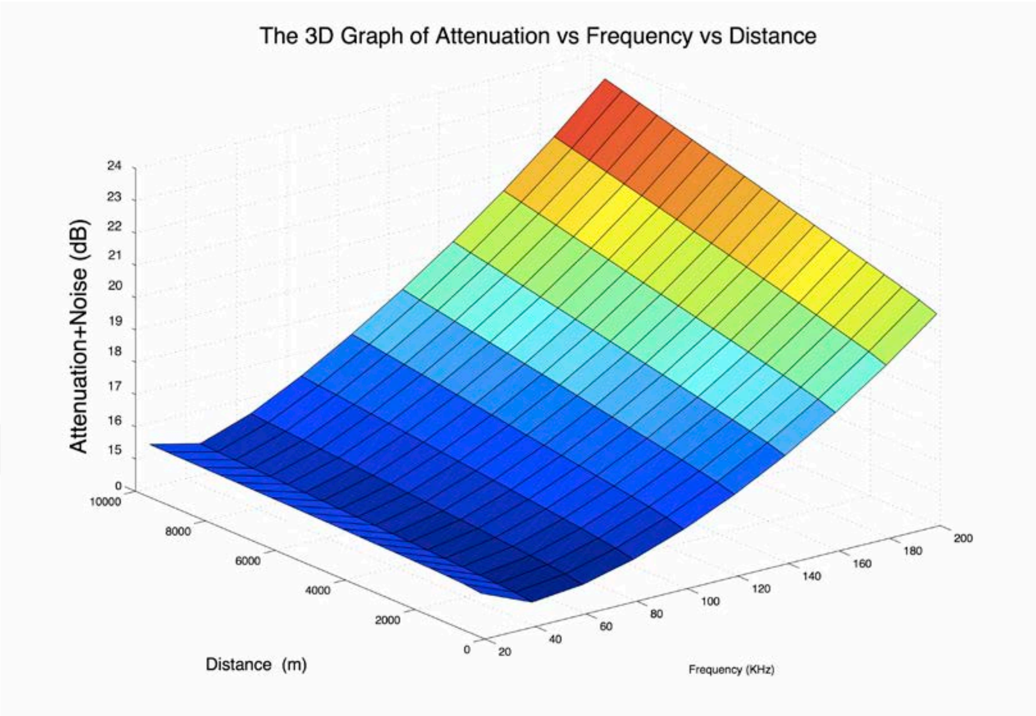

Figure 4.1.4 AN Sum (A (d, f) + N (f)) vs. distance (m.) vs. frequency (KHz.)

Figure 4.1.4 Illustrates 3d graph of AN sum in dB vs. distance in meters vs. frequency in KHz. Attenuation increase is directly related to Distance between source and sink together with the frequency of signal of the link established. Increase of distance effects signal quality negatively and attenuation of the signal rises up. On the Other hand since the optimal frequency is always around 40 KHz, AN product starts increasing after 40 KHz level of frequency. The computations of the graph have been obtained based on Ainslie and McCollum formulations, which we have given as equation (3). As we can abstract from the figure, AN factor may goes up to 20 dB in case of frequencies around 200 KHz. and distance of 10 km. Consequently, higher attenuation of the acoustic signal leads to higher transmission loss thus quality of communication deteriorates. Consequently, it is necessary to point out that coefficients of attenuation are used in order to quantify total attenuation in dB/m during the communication and linearly dependent on the frequency of the acoustic signals.

The transmission loss of acoustic waves can be defined as the total decrease on the intensity of the propagated signal. Transmission loss is mainly caused by absorption of the water. However, there are other factors influencing the loss as scattering and geometrical spreading. The transmission loss is increased at some certain frequencies due to water medium's own characteristic by ionic relaxation of dissolved salts. Beside absorption effect, it is necessary to keep in mind that the loss of the total energy of acoustic waves increases since acoustic signals do not propagate to one direction which is called as geometrical spreading. Lastly, scattering of the acoustic signals occurs when it encounters with bubbles, rocks and other underwater bodies.

We need to state out that the increase of distance raises up the total transmission loss, which might be up to 70-75 decibels Hence the transmission loss might range from 30 to 80 dB at distances ranging from 0 - 7 km. Another interesting issue is that the total loss of transmission power is lower at lower frequencies when compared to higher frequency signals.

We are going to explain the details about the relationship between SNR and BER values furthermore. We have briefly stated out the relationship between SNR and frequency and bandwidth in the second Chapter. SNR can also be described as the reduction in the intensity or in the amplitude of a signal.

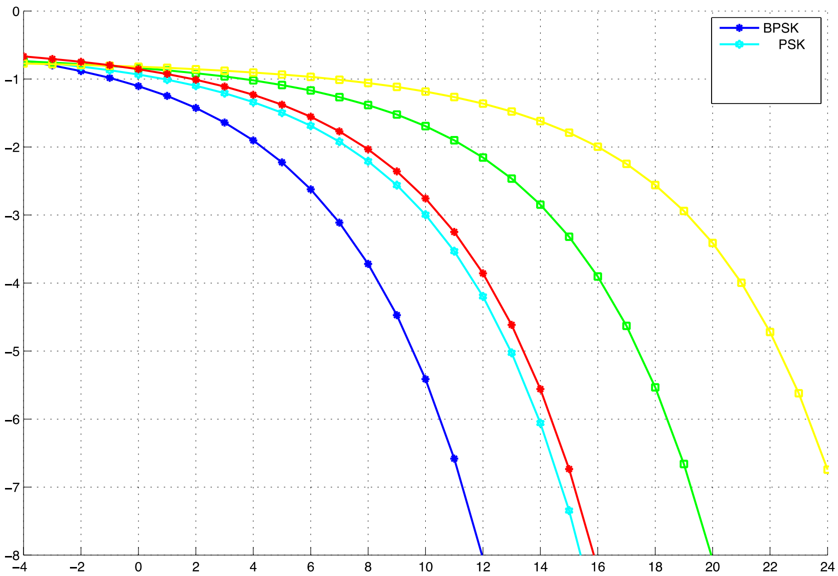

Figure 4.1.5 Probability of BER vs. E_b / N_o of Various Modulation Schemes

Figure 4.1.5 shows the probability of BER values in log scale (Given that SNR per bit Ratio – E_b/N_0) for various modulations schemes. It indicates linear modulation schemes that we have used during our simulations such as BPSK, 8-PSK, 16-PSK, 32-PSK and 16-QAM. Actually BER is the main indicator, which shows the health (quality) of communication system. During transmission some of the bits may not be transmitted correctly. It is important to know the ratio of the bits transmitted incorrectly in order predict the percentage of corrupted data. A signal can be called as good signal when target BER is lower than 10^{-10}.

The formulations of probability of BER of various schemes mentioned above, energy per bit to noise power spectral density ratio that we use during our simulations is given in this chapter. BER (Bit error rate) for different modulation schemes can be computed as follows:

$$P_b{}^{16QAM} = \frac{3}{2k} erfc(\sqrt{\frac{k}{10}\frac{E_b}{N_0}} \qquad (9)$$

$$P_b{}^{BPSK} = \frac{1}{2}\, erfc\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{10}$$

$$P_b{}^{M-PSK} = \frac{1}{k}\, 2Q\left(\sqrt{2\gamma_s}\, sin\frac{\pi}{M}\right) \tag{11}$$

Where M=8,16 and 32, k is $\log_2$M, $\gamma_s = \frac{E_s}{N_0}$ and $\frac{E_b}{N_0}$ is the energy per bit to noise power spectral density ratio and can be calculated as:
E_s=Energy per bit,
E_b=Energy per symbol,
N_0=Noise Power Spectral density (W/Hz.)

$$\frac{E_b}{N_o} = SNR\frac{B_n}{R} \tag{12}$$

Where B_n is the noise bandwidth in Hz, R is the data rate in kbps and SNR is as follows:

$$SNR=10^{SNR(d,f)/10} \tag{13}$$

Where P_b represents probability of bit error rate and expressions of BER values for different modulations schemes were given above. Table 4.1.2 shows the SNR values for certain BER values that we have computed using the equations (12) and (13) assuming that B_n as 1 KHz. and R as 2 Kbps.

BER	SNR
10^{-1}	4.8919
10^{-3}	13.532
10^{-6}	17.4120
10^{-7}	18.1147

Table 4.1.2 BER vs. SNR

We have obtained the following 5 graphs related energy consumption of the network based on BER equations which was given as formulas (9), (10) and (11).

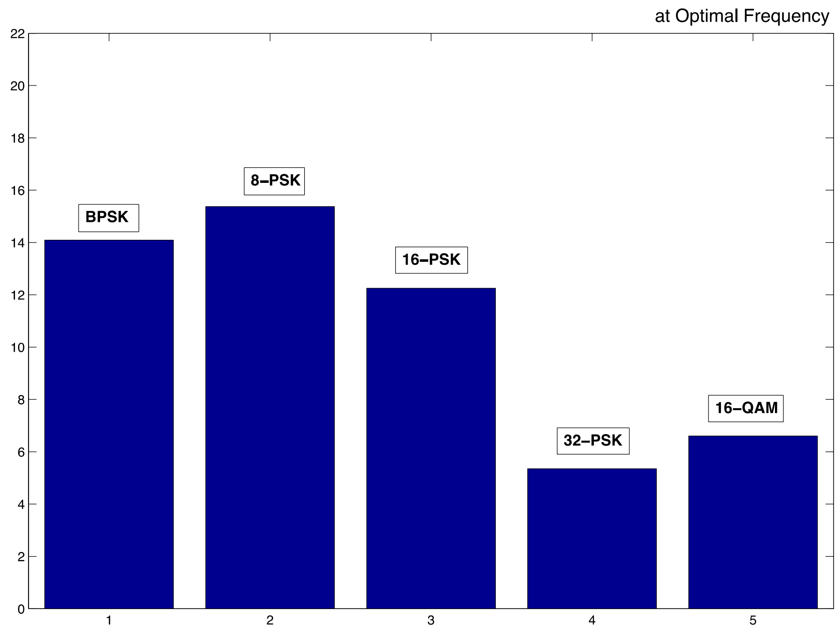

Figure 4.1.6 Transmission Power of the Network for Single Hop 100 (m).

It can be observed from the Figure 4.1.6 indicates energy consumption of the network when sending a single packet at depth of 100 m, distance of 100 m and having BER of 10^{-3}. It can be observed that the energy consumption differs based on the selected modulation scheme. The network consumes highest amount of energy when 8-PSK is used. On the contrary the optimal (minimum) energy consumption is obtained when 32–PSK is selected as modulation scheme. These graph is obtained where, Depth = 100m, Distance=100m, BER= 10^{-3}

In order to compute optimal transmission power we have used passive sonar equation, which is placed in literature in many forms, but we have used following formula in order to find sound source level of the received signal strength, which is a function of distance and frequency as given in [30] by Felemban:

$$SL(d, f) = A(d, f) + N(f) + SNR - DI \quad (14)$$

Where, DI stands for directivity index and since we assume it as ommi-directional directivity, DI is set to 0. In addition to this, the ratio of the intensity of emitted signal to some predefined reference intensity can be found as follows:

$$SL(d, f) = 10 \log (I_t / I_0) \quad (15)$$

Where, the reference intensity is represented by I_0 and has a value of $0.67*10^{-18}$ and the intensity of the emitted signal It in terms of Watts/m, depends on the transmission power (P_{tx}) can be obtained using the following expression:

$$SNR(d, f) = \frac{P_{tx}}{A(d, f)N(f)\Delta f'} \quad (16)$$

where, P_{tx} is the transmit power and N(f) is the noise power spectral density (assumed constant in a narrow band Δf around f). It is clear in the equation that $[A(d, f) + N(f)]^{-1}$ product mainly depends on the frequency of transmitted signal as given in paper [29] by Zorzi. We should keep in mind that A (d, f) increases with frequency while N (f) decreases at least up to certain point (f=40 KHz.).

We have obtained signal level of the emitted sound from the source by setting all necessary values to equation (14), and received transmission power by receiver P_{tx} was found using the expressions (15) and (16). Consequently, there is an optimal frequency, which brings forth the minimum A (d, f)+N (f) product, which results with minimum path loss.

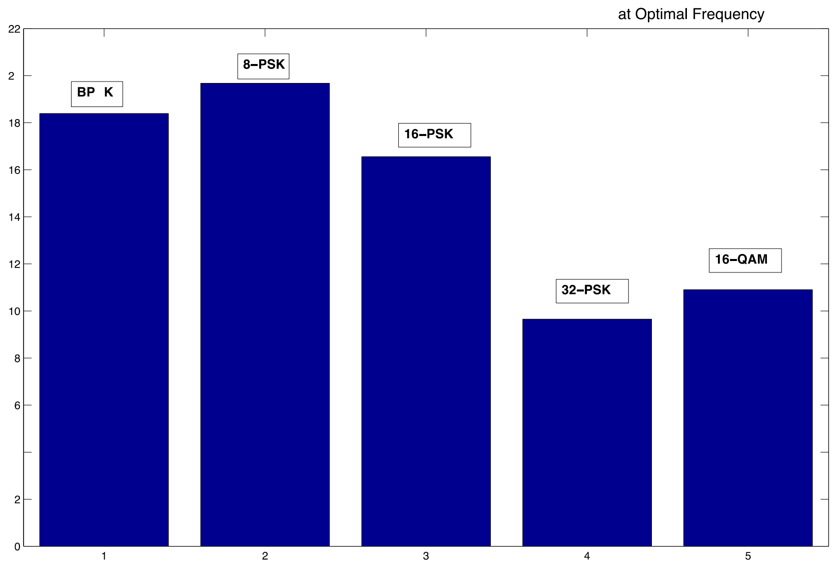

Figure 4.1.7 Transmission Power of the Network For Single Hop 1000 (m).

Figure 4.1.7 Depicts that the total transmission power of the network that increases when the distance between sender and receiver rises up to 1000 m from 100 m. Note that, all parameters were kept constant in order to see the effect of distance on the energy consumption of the network. We have computed transmission power (P_{tx}) through the equations (14), (15) and (16) belonging to various modulation schemes. These P_{tx} values are obtained where, Depth=100m, Distance=1000m, BER= 10^{-3}.

We have used the equations (14), (15) and (16) in order to compute the minimum transmission power with different modulation schemes in Figures 4.1.8, 4.1.9, and 4.1.10.

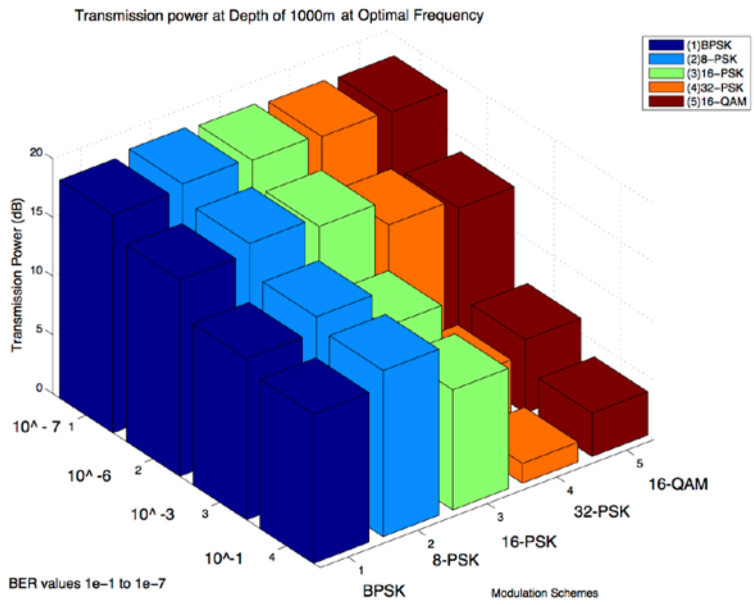

Figure 4.1.8 Transmission Power of the Network for Various Modulation Schemes

Figure 4.1.8 shows the energy consumption (transmission power) of UASN. Transmission power increases as target BER values decrease from 10^{-1} to 10^{-7}. It is barely seen that modulation schemes show more or less similar performance when BER is selected, as 10^{-7}. Hence there is no difference which modulation scheme is selected when target BER is selected as 10^{-7}. On the other hand 32-PSK and 16-QAM outperform all other schemes when BER is selected as 10^{-3} or 10^{-1}. We have taken the parameter values as follows: Depth=1000m, Distance=1000m and BER= 10^{-7},10^{-5}, 10^{-3} and 10^{-1}. As a conclusion it is clear that the increase of bit error rate causes lower transmission power, thus the total energy consumption of the network will decrease down as a consequence.

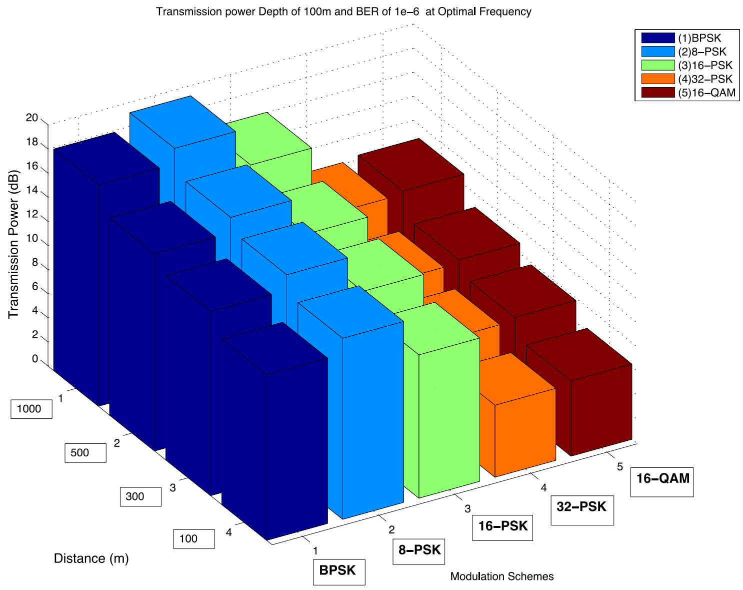

Figure 4.1.9 Transmission Power of the Network for Various Distances

Figure 4.1.9 depicts performances of the modulation schemes in terms of transmission power in (dB) for different distances (1000m, 500m, 300m, 100m). It can be observed from the figure that the transmission power (P_{tx}) decreases linearly as the distance between sender and receiver decreases. 32-PSK and 16-QAM showed the best performances at all the distances when compared to other schemes. In order obtained the figure 4.1.9 we have taken the parameter values as follows: Depth=100m, BER=10^{-6} and Distance=1000m, 500m, 300m, 100m

As a conclusion it is clear that the increase of distance causes higher transmission power hence the total energy consumption of the network will increase naturally.

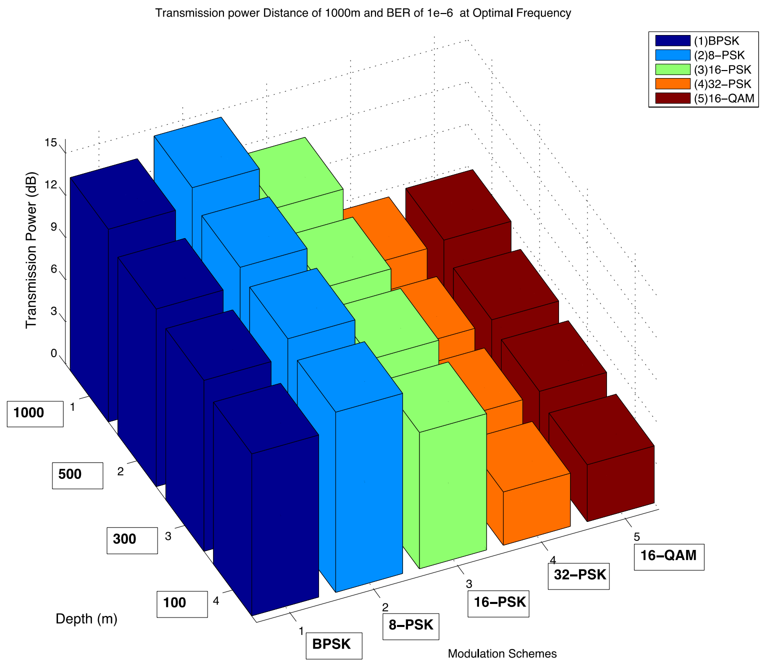

Figure 4.1.10 Transmission Power of the Network for Various Depths

Figure 4.1.10 indicates the transmission power (P_{tx}) of the network when sending a single packet for different depths (1000m, 500m, 300m, and 100m) at distance of 1000 m. The BER is set to 10^{-6}. We can understand from the figure that transmission power does not change as the depth of the network changes. It is clear that 32-PSK and 16-QAM outperform other modulation schemes at all depths. In order obtained the figure 4.1.10 we have taken the parameter values as follows: Distance=1000m, BER=10^{-6} and Depth=1000m, 500m, 300m, 100m

Consequently, there is not remarkable increase or decrease of transmission power with the increase of depth unlike the previous simulation results related to distance (fig.4.1.9).

Chapter 5

Conclusions

In Underwater networks it is not possible to recharge or change the batteries of units without recovery, which leads to really high costs. Hence, one of the most crucial challenging aspects of UWA is the energy limitation. Therefore, retransmissions and path losses may lead to huge amount of waste of energy. In this sense, the specifications of the deployed network play a critical role to prevent these problems and to prolong the lifetime of network as much as possible. Hence, we have analyzed and simulated various underwater circumstances; different depth, distance and BER values with different modulation schemes in order to find optimal (minimum) transmission power. In this thesis, our ultimate goal is to investigating the energy efficiency of underwater acoustic sensor networks (UASNs) by conducting performances analysis of different modulation schemes. According to simulation results, 32-PSK and 16-QAM techniques achieved the minimum energy consumption. Therefore, using these modulation schemes may prolong our limited energy sources according to our simulation results. Consequently, it is aimed to contribute the related literature and encourage future research efforts for advanced underwater communication systems to be a reference source for various underwater applications.

BIBLIOGRAPHY

[1] D. B. Kilfoyle and a B. Baggeroer, “The state of the art in underwater acoustic telemetry,” *Oceanic Engineering, IEEE Journal of*, vol. 25, no. 1, pp. 4–27, 2000.

[2] S. Xiaohong, W. Haiyan, Z. Yuzhi, and Z. Ruiqin, “Adaptive Technique for Underwater Acoustic Communication.”, *Underwater Acoustics*, pp. 9–17, 2012.

[3] M. Raja, A. P. Vinod, and A. S. Madhukumar, “DME interference mitigation for LDACS1 based on decision-directed noise estimation,” *ICNS 2015 - Innovation in Operations, Implementation Benefits and Integration of the CNS Infrastructure, Conference Proceedings*, pp. L41–L410, 2015.

[4] H. Senol, E. Panayirci, M. Erdogan, and M. Uysal, “Channel estimation in underwater cooperative OFDM system with amplify-and-forward relaying,” *GLOBECOM - IEEE Global Telecommunications Conference*, pp. 3725–3730, 2012.

[5] A. S. Rao, M. S. Rao, S. K. Rao, and A. M. Prasad, “Design aspects of signal waveform for underwater acoustic communication system,” *Ocean Electronics (SYMPOL), 2013*, pp. 1–7, 2013.

[6] H. Meric, J. Lacan, F. Arnal, G. Lesthievent, and M. L. Boucheret, “Combining adaptive coding and modulation with hierarchical modulation in satcom systems,” *IEEE Transactions on Broadcasting*, vol. 59, no. 4, pp. 627–637, 2013.

[7] J. Li, Z. Bao, C. Zhang, and Q. Li, “Scalable video multicast with joint resource allocation and Adaptive Modulation and Coding over multiple base station networks,” *ICNSC 2015 - 2015 IEEE 12th International Conference on Networking, Sensing and Control*, pp. 134–139, 2015.

[8] P. Casari and M. Zorzi, “Protocol design issues in underwater acoustic networks,” *Computer Communications*, vol. 34, no. 17, pp. 2013–2025, 2011.

[9] Y. Su, Y. Zhu, H. Mo, J.-H. Cui, and Z. Jin, “A joint power control and rate adaptation MAC protocol for underwater sensor networks,” Ad Hoc Networks, vol. 26, pp. 36–49, 2015.

[10] J. Xu, K. Li, and G. Min, “Multi-path division transmission for improving reliability and energy efficiency in underwater acoustic networks”, Procedia Computer Science, vol. 4, pp. 86–95, 2011.

[11] M. Erol-Kantarci, H. T. Mouftah, and S. Oktug, “Localization techniques for underwater acoustic sensor networks,” *IEEE Communications Magazine*, vol. 48, no. 12, pp. 152–158, 2010.

[12] S. Azad, P. Casari, F. Guerra, and M. Zorzi, “On ARQ strategies over random access protocols in underwater acoustic networks,” *OCEANS 2011 IEEE - Spain*, 2011.

[13] K. Tu, T. M. Duman, M. Stojanovic, and J. G. Proakis, “Multiple-resampling receiver design for OFDM over doppler-distorted underwater acoustic channels,” *IEEE Journal of Oceanic Engineering*, vol. 38, no. 2, pp. 333–346, 2013.

[14] B. Tomasi, D. Munaretto, J. C. Preisig, and M. Zorzi, “Realtime Redundancy Allocation for Time-Varying Underwater Acoustic Channels.”

[15] B. Benson et al., “Energy Benefits of Reconfigurable Hardware for Use in Underwater Sensor Nets,” IEEE Int’l. Parallel Distribution. Processing, pp. 1–7, May 2009.

[16] Y. Sun, “The Internet Underwater : An IP-compatible Protocol Stack for Commercial Undersea Modems,” in *WUWNet*, pp. 0–7, 2013.

[17] C. Gabriel, M.-A. Khalighi, S. Bourennane, P. Leon, and V. Rigaud, “Investigation of suitable modulation techniques for underwater wireless optical communication,” *2012 International Workshop on Optical Wireless Communications (IWOW)*, pp. 1–3, 2012.

[18] I. F. Akyildiz, D. Pompili, and T. Melodia, “Challenges for efficient communication in underwater acoustic sensor networks,” *ACM SIGBED Review*, vol. 1, no. 2, pp. 3–8, 2004.

[19] S. Kim, “Angle-domain frequency-selective sparse channel estimation for underwater MIMO-OFDM systems,” *IEEE Communications Letters*, vol. 16, no. 5, pp. 685–687, 2012.

[20] J. Heidemann, M. Stojanovic, and M. Zorzi, “Underwater sensor networks: applications, advances and challenges.,” *Philosophical transactions of the Royal Society. Series A, Mathematical, physical, and engineering sciences*, vol. 370, no. 1958, pp. 158–75, 2012.

[21] L. Wu et al., “Designing an adaptive acoustic modem for underwater sensor networks,” IEEE Embedded Systems Letters, vol. 4, no. 1, pp. 1–4, 2012.

[22] S. Climent, A. Sanchez, J. V. Capella, N. Meratnia, and J. J. Serrano, “Underwater acoustic wireless sensor networks: advances and future trends in physical, MAC and routing layers.,” *Sensors (Basel, Switzerland)*, vol. 14, no. 1, pp. 795–833, 2014.

[23] Z. E. A. Ismaili, W. Ajib, O. A. Yeste-Ojeda, and R. Landry, “Implementation of adaptive modulation for A/G communication system using ZeptoSDR,” 2015 IEEE/AIAA 34th Digital Avionics Systems Conference (DASC), p. 2C5-1-2C5-10, 2015.

[24] A. Radosevic, R. Ahmed, T. M. Duman, J. G. Proakis, and M. Stojanovic, “Adaptive OFDM modulation for underwater acoustic communications: Design considerations and experimental results,” *IEEE Journal of Oceanic Engineering*, vol. 39, no. 2, pp. 357–370, 2014.

[25] J. H. Cui, J. Kong, M. Gerla, and S. Zhou, “The challenges of building scalable mobile underwater wireless sensor networks for aquatic applications,” *IEEE Network*, vol. 20, no. 3, pp. 12–18, 2006.

[26] L. Liu, S. Zhou, and J. Cui, “Prospects and Problems of Wireless Communication for Underwater Sensor Networks,” *Wireless Communications and Mobile Computing*, vol. 8, pp. 977–994, 2008.

[27] I. Vasilescu, K. Kotay, D. Rus, M. Dunbabin, and P. I. Corke, “Data collection, storage, and retrieval with an underwater sensor network,” *2005 International conference on Embedded networked sensor systems (SenSys ’05)*, p. 154, 2005.

[28] M. C. Domingo, “Overview of channel models for underwater wireless communication networks,” Physical Communication, vol. 1, no. 3, pp. 163–182, 2008.

[29] N. Baldo, P. Casari, and M. Zorzi, “Cognitive Spectrum Access for Underwater Acoustic Communications,” ICC Workshops - 2008 IEEE International Conference on Communications Workshops, pp. 518–523, 2008.

[30] M. Felemban and E. Felemban, “Energy-delay tradeoffs for Underwater Acoustic Sensor Networks,” 2013 First International Black Sea Conference on Communications and Networking (BlackSeaCom), pp. 45–49, 2013.

[31] P. Kumar, Vinay Kumar Trivedi, and P. Kumar, “Recent Trends in Underwater Acoustic Communications,” Marine Technology Society Journal, vol. 47, no. 5, pp. 45–50, 2013.

[32] H. Kulhandjian and T. Melodia, “Modeling Underwater Acoustic Channels in Short-Range Shallow Water Environments,” Proceedings of the International Conference on Underwater Networks Systems - WUWNET ’14, pp. 1–5, 2014.

[33] T. Melodia, D. Pompili, and I. F. Akyildiz, “Optimal local topology knowledge for energy efficient geographical routing in sensor networks,” 23rd Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM), no. Id, pp. 1705–1716, 2004.

[34] M. C. Domingo, “An overview of the internet of underwater things,” Journal of Network and Computer Applications, vol. 35, no. 6, pp. 1879–1890, 2012.

[35] R. F. Masood, “Adaptive Modulation (QPSK, QAM),” pp. 1–4, 2013.

[36] M. Aydinlik, A. T. Ozdemir, and M. Stajanovic, “A physical layer implementation on reconfigurable underwater acoustic modem,” Oceans 2008, pp. 8–11, 2008.

[37] A. M. Atallah, H. S. Ali, and M. I. Abdallah, “Image Transmission,” pp. 169–172, 2016.

[38] K. Pelekanakis and A. B. Baggeroer, “Peer-Reviewed Technical Communication for Underwater Acoustic Communications,” vol. 36, no. 4, pp. 502–513, 2011.

[39] B. Binnerts, K. Blom, and S. Giodini, “Analysis of underwater acoustic propagation in a harbour environment and its effect on communication,” 2017.

[40] R. M. Dunbar and C. R. Benson, “Acoustic Modem Testing,” pp. 3–7, 2017.

[41] B. Sherlock, J. A. Neasham, and C. C. Tsimenidis, “Implementation of a Spread-Spectrum Acoustic Modem on an Android Mobile Device,” 2017.

[42] L. M. Wolff, S. Badri-hoeher, and S. Noack, “Bitwise Ranging through Underwater Acoustic Communication with Frequency Hopped FSK Utilizing the Goertzel Algorithm,” no. 4, pp. 0–5, 2017.

[43] K. N. J. George and V. K. Jayasree, “An Intensity Modulation Transmission System for under Water Channel Modeling and Communication,” Procedia Technology, vol. 24, pp. 834–841, 2016.

[44] G. Tuna and V. C. Gungor, “A survey on deployment techniques, localization algorithms, and research challenges for underwater acoustic sensor networks,” International Journal of Communication Systems, no. February, pp. 1–21, 2017.

[45] X. Shu, H. Wang, X. Yang, and J. Wang, “Chaotic modulations and performance analysis for digital underwater acoustic communications,” Applied Acoustics, vol. 105, pp. 200–208, 2016.

Web sources:

[46] Underwater Sensor Networks (UWSN), http://www.http://ais.unist.ac.kr (05.05.2017)

[47] Test Beds For UWSN, http://wsnlab.org/reviewing-underwater-wireless-sensor-networks-features/ (05.05.2017)

[48] http://publications.csail.mit.edu/abstracts/abstracts07/vasilescu1/vasilescu1.html (06.05.2017), Underwater Sensors for UWSN,

[49] https://people.ece.cornell.edu/land/courses/ece4760/FinalProjects/s2010/gjm76_asr96/gjm76_asr96/index.html (08.05.2017) Underwater Re-Configurable Modems,

[50] Architecture of 2D Underwater Sensor Networks, http://www.rfwireless-world.com/Tutorials/underwater-wireless-communication-and-networks.html (10.06.2017)

[51] http://www.develogic.de/wp-content/uploads/2011/04/HAM-NODE-klein.pdf (10.25.2017)