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Performance Analysis of Underwater Communication System

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***Abstract*—Underwater communication has become a crucial information transmission technology, wide applied in remote control in the offshore oil business, pollution monitoring in environmental systems, collection of scientific information recorded at ocean-bottom stations, disaster detection and early warning, national security and defence(underwater surveillance), moreover as for the invention of recent natural resources .Thus, analysis of underwater wireless communication techniques plays a most significant role in additional exploring oceans and different aquatic environments. Many research challenges within the acoustics domain, specifically achieving high throughput and frequency utilization efficiencies whereas adapting to restricted spectrum and slow acoustic propagation rate. Modulation and decoding schemes for reliable high-data rate transmission whereas overcoming the time-varying and severely attenuated acoustic signal channel. spectrum and power-efficiency optimizations for improving underwater wireless communication performance with limited bandwidth and computing/power resources.**

***Index Terms*— Underwater Acoustic, Orthogonal Frequency Division Multiplexing, Doppler effect, Multicarrier modulation.**

I. INTRODUCTION

In recent years, underwater communication has become an active research area as there is still a big gap between the communication technology for terrestrial and underwater application Researchers and scientists have continually put a massive effort exploring the underwater world. The advancement in underwater technology helps human to understand better about a place that has totally different environment in terms of its nature, creatures, composition and physics. The growing research for underwater application has drawn interests of many sectors and industries around the world; government- based or private sector. Among the sectors that benefited much from the advancement of this technology are military, oil and gas industries, fisheries, underwater instrumentation companies, research agency etc. Works such as seismic monitoring, underwater robot operation, underwater surveillance and detection, sea exploration, ocean mapping and research data collection are also getting easier due to this advancement. The main carriers of underwater communication RF electromagnetic waves, optical waves and acoustic waves. By some analysis work it's determined that RF waves are affected with high attenuation in water. These may be used just for short ranges of up to ten to fifteen meters. Optical waves are most rapidly scattered really typically seen in water.

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therefore there is many advantages in using the acoustic waves for the underwater communication over long distance links. These Underwater communication is additionally being affected with noise, variable propagation delay, path loss. This UW communication works for any rage of systems with its variable frequencies based on the type of the system. Usually this operates for low bit rates based on their range. UW communication links may be divided into some classes like long, very long, medium, short and very short. The corresponding bandwidth is additionally mentioned in the table below.

TABLE I. DIFFERENT TYPES OF UW-A LINKS WITH ITS RANGE AND BANDWIDTH

Types	Range [km]	Bandwidth[kHz]
Short	0.1	> 100
Very short	0.1-1	20-60
Medium	1-15	10
Long	15-100	2-6
Very long	1000	< 1

A. Characteristics of signal carrier

In underwater world, there are 3 types of carrier wave that are most commonly used in wireless communication.

Electromagnetic wave
Using electromagnetic wave, the communication can be established at higher frequency and bandwidth. The limitation is due to high absorption/attenuation that has significant effect on the transmitted signal. Big antenna also needed for this type of communication, thus affects the design complexity and cost.

Optical wave
Optical wave also offers high data rate transmission. Nevertheless, the signal is rapidly absorbed in water and suffers from scattering effect. This will affect the data transmission accuracy.

Acoustic wave
Acoustic is the most preferred signal used as carrier by many application, owing to its low absorption characteristic for underwater communication. Even though the data transmission is slower compared to other carrier signal, the low absorption characteristic enables the carrier to travel at longer range as less absorption faced by the carrier.

Environment/Propagation Medium
Unlike the communication in terrestrial application, for underwater wave propagation, the challenges are quite different. Water itself has become the main source for the signal interference. The type of water (freshwater/sea water), depth pressure, dissolved impurities, water composition and temperature affect the sound propagation. Common terrestrial phenomena like scattering, reflection, refraction also occurs underwater communication.

Sources of Problems
As for terrestrial application, the underwater wireless communication is not a straight forward process. When considering the underwater communication process, the primary concern that researchers always consider are the channel model(underwater), attenuation, transmission distance, power consumption, SNR ratio, bit error, symbol interference, error coding, modulation strategies, instrumentation and underwater interferences. Dealing with interferences for underwater research is a complex task due to dynamic nature of water. Interferences are mainly caused by three major factors:

II. CHARACTERISTICS OF UNDERWATER COMMUNICATION ACOUSTIC

Bandwidth : the bandwidth of this system ranging about 10 km is only few kHz,it depends on transmission loss, ambient noise.
Multipath: With in the limited bandwidth ,the signal is subjected to multi path propagation through under water channel.Due to this multi path causes inter symbol interference ISI which restricts the data throughputs and degrades the system performance
Noise: Acoustic noise for the underwater communication channel can be of natural or it might be manmade. The noise during the UW-A channel is caused mainly due to the machine parts like pumps, gears or power

plants. If not due to machinery noise it may be due to the biological activities like tides, waves wind or rain. The noise sources can be expressed through some formulas, and that provides densities of source to the frequency F [kHz]. The noise may be generated for any kind of underwater acoustic communication. Here each of the noise generated will have different range of frequencies. The shallow water will be generating a noise which is not predictable easily. But the deep water noise can be predicted easily compared to shallow water. Based on these factors the signal to noise ratio can be predicted based on the transmission loss (TL) and the noise power density.

Because all of the above mentioned limitations of the underwater channel the selection of the type of modulation and error correction techniques has to be carefully analysed. One very promising solution for the Underwater Communication Channel is the use of Orthogonal Frequency Division Multiplexing, OFDM is very efficient when the noise is spread across the bandwidth. OFDM transmit several carriers instead of a single modulated carrier, so it is referred as a Multicarrier Modulation, carrier with better SNR are allocated with higher data rate, and so lower data rate will be used in carriers with smaller SNR values. In OFDM systems give more spectral efficiency and perform robustly in Multipath Fading Channels

This paper is organized as follows: Section II describes the factor affecting the UWC performance.Section III describes the modulation techniques in UWC.Section IV describes the Coding techniques used in UWC.Section V describes the work done by the authors on underwater communication and the performance of their work. Finally concluded the paper in section VI.

III. Modulation Techniques In Uwc

There are many techniques to reach the better Underwater Communication. OFDM is an attractive technique beginning used in UWA communication with three main advantages:

Good performance against multipath interference.

Ability to combat the frequency selective fading.

The high frequency band efficiency.

There is the challenge for the selection of modulation techniques and the correction techniques due to the channel characteristics. S.-J.Hwang et.al in their work explained how to increases the symbol interval by reducing ISI by making use of available bandwidth and multicarrier modulation is used to overcome the long delays[1]. Prasanth kumar and Preetham kumar, proposed DCT based OFDM for UWC to achieve constant envelope transmissision for less ISI for AWGN channel. PARP was also proposed by preprocessing techniques in MCM to achieve constant envelope. The bandwidth require is ½ and they described that the Multi-Carrier Modulation(MCM) have become popular in UWA channel for two reasons. First, a signal can be processed in a receiver without the increase of noise or interference caused by linear equalization of a single carrier signal ;second, the long symbol period used in MCM ensures greater immunity to impulse noise and fast fades [12].

Prasanth kumar and Preetham kumar described the orthogonal feature of conventional OFDM and can achieved by inverting DCT(IDCT)-DCT structure for underwater communication,which reduces implementation are a and increases computational speed, as only real calculations,is required. This system provides higher peak-to-average power ratio(PAPR)reduction and achieves better noise immunity and hence a better bit error rate (BER) performance than standard OFDM, while maintaining a low implementation cost[13]. They implemented the “DCT Based OFDM for Underwater Acoustic Communication,” because the bandwidth required for DCT is half of that required for DFT when both systems have same number of subcarriers which will be matched with underwater channel limited band- width. It has also been shown that the speed of calculation of orthogonal components is increased threefolds while the implementation size reduces to half as compared to fast FFT based design Further more, it is known that the DCT basis have excellent spectral compaction and energy concentration properties which in turn lead to improved performance with suitable channel estimation.

Filter bank multicarrier(FBMC) systems can be optimized for robust performance in the doubly dispersive UWA channels.OFDM multicarrier losses bandwidth efficiency of the transmission due to the allocation of 20% of each OFDM symbol to its cyclic prefix. This is equivalent of saying the cyclic prefix length is one quarter of the length of each fast FFT block in the OFDM system. Moreover, since the length of CP should be at least equal to the duration of the channel impulse response, and the latter is usually very long in UWA channels, very long symbols is used in the OFDM systems for UWA communications[14].UWA communication method using a class of FBMC systems was proposed. This class of FBMC systems was designed to be robust against dispersions in time and frequency domain.When the Filter bank multicarrier technique is compared with OFDM, it clearly shows that there is a wide gap between the performance of FBMC and OFDM for underwater communication in saving bandwidth. For the Single-user communications case OFDM offers a lower complexity. FBMC offers reasonable bandwidth efficiency and still more research is needed to improve the performance.

OFDM has a number of desirable features, including low complexity of implementation and mature technologies that keep it as the dominant technology for single-user(point-to-point)underwater communications. FBMC is an elegant meThod scope with that by taking a filtering approach to underwater multicarrier communication[15].Yuri Labrador et.al analyzed the use of 8PSK and 16QAM Modulation Techniques along with Turbo Codes in the underwater acoustic channel. Turbo Codes have been used successfully to correct errors especially with higher order digital modulations. The inter symbol interference (ISI) can be suppressed by using channel equalization techniques and decision feedback equalizers (DFE) can track the varying channel response and give high throughput values if the channel varies slowly, if the channel is varying much faster it is necessary and they concluded that Coherent modulations had lower performance for long transmissions by using ISI compensation with DFE, but these filtering algorithms are not easy to implement and do not performed well in real time links.

Shen Xiao Hong proposed the developing algorithms based on the analysis of characteristics of UWA channel, that can self-adapting select the best technique for time varying UWA channel,then the dynamic modulation and bandwidth optimization for high-rate UWA communication are deduced[16]. Modulation and detection techniques used for UWA communication include phase coherent (PSK and QAM) and noncoherent (FSK) techniques. The choice of modulation mode is based on the UWA channel parameters, such as multipath and the Doppler spread, as well as the SNR. The spread factor of the UWA channel determines whether phase coherent communications are possible. If the channel varies too rapidly, noncoherent signaling is chosen. The choice of modulation is determined by the operator. MFSK was seen as intrinsically robust for the time and frequency spreading of long range UWA channel. OFDM has been used in UWA communication at short or medium range. Adaptive UWA communication system combines MFSK and OFDM effectively, which dynamic selects modulation schema and optimizes bandwidth based on UWA communication estimation. This method has obvious advantages: being realized by DFT based filter banks as OFDM, good performance and the high frequency band efficiency in time varying fading UWA channel. Based on the results of simulation and experiments in a lake, it is shown that the adaptive UWA communication system is more efficient for high rate UWA communication not only at short range, but also at medium and long range.

Andreja Radosevic et.al explored the design aspects of adaptive modulation based on orthogonal frequency division multiplexing (OFDM) for underwater acoustic (UWA) communications, and study its performance using real-time at-sea experiments[16]. Their design criterion is to maximize the system throughput under a target average bit error rate (BER). They consider two different schemes based on the level of adaptivity. In the first scheme, only the modulation levels are adjusted while the power is allocated uniformly across the subcarriers, whereas in the second scheme, both the modulation levels and the power are adjusted adaptively. For both schemes linearly predict the channel one travel time ahead so as to improve the performance in the presence of a long propagation delay. The system design assumes a feedback link from the receiver that is exploited in two forms. one that conveys the modulation alphabet and quantized power levels to be used for each subcarrier, and the other that conveys a quantized estimate of the sparse channel impulse response. The second approach requires significantly fewer feedback bits for the same system throughput. The effectiveness of the proposed adaptive schemes is demonstrated using computer simulations, real channel measurements recorded in shallow water and they show that the adaptive modulation scheme provides significant throughput improvements as compared to conventional, nonadaptive modulation at the same power and target BER. This work concluded that adaptive modulation methods may be viable for reliable, high-rate UWA communications.

N.R. Krishnamoorthi et.al described the different codec and modulation and demodulation used in the UAC and the results of each work is highlighted [18]. BER may be improved by choosing strong signal strength by choosing a slow and robust modulation scheme and by applying channel coding schemes.The BER also enables other features such as the power and bandwidth survey of underwater modulation scheme shows that higher order modulation schemes (e.g. 64 QAM, etc) are able to carry higher data rates but are not as robust in the presence of noise. But it is also observed that Lower order modulation formats (e.g. BPSK, QPSK, etc.) offer lower data rates but are more robust. They have discussed the existing three different codec (algebraic, trellis and iterative) technique and advantage of basic digital modulation (PSK, QPSK, FSK) used in UAC communication.They conclude that we may have to go for an optimum value which will give better results.

IV. CODING TECHNIQUES IN UWC

For underwater communication, digital communication systems are used to perform accurately and reliably in the presence of noise and interference. Among many possible ways to achieve this goal, forward error correction coding is the most effective and economical. The fast Temporal variations, long multipath delay spreads, and severe frequency-dependent attenuation so underwater acoustic communication channels are extremely complex that impedes underwater acoustic data transmission. To alleviate this problem, channel coding is in dispensable in UWA communication system to increase the reliability was described by X.Xiaomei et.al [4].N.Nasri, proposed the efficient encoding and decoding methods for underwater communication. In their work, they explained Forward Error Correction(FEC) , which is a type of error correction which improves simple error detection schemes by enabling the receiver to correct errors once they are detected. This reduces the need for retransmissions and energy consumption [4] .The major drawback of the concatenation code is that the decoder is unable to decode correctly in the presence of a burst of erroneous bits. Hence, an interleaver can be designed to introduce a dependency between the bits input. In order to minimize the error rate two evolved coding scheme.
M.D.Haque,S. et.al ,illustrated the Performance Evaluation of a Wireless Orthogonal Frequency Division Multiplexing System under Various Concatenated FEC Channel-Coding Schemes. The power of error correcting codes increases with the channel coding length constraint and approaching the Shannon limit with a large number of length constraints. But in return the complexity of the decoder
also increases with length constraint[5]. For these reasons, it is desirable to construct long codes and minimize the complexity of the decoder.M.Chitre,S.et.al was motivated that the concatenation of codes is a cheap solution for multicarrier modulation in underwater acoustic communication[6].

V. COMPARITIVE ANALYSIS OF UNDERWATER COMMUNICATION SYSTEMS

Sl No	Authors	Title	Proposed Work	Performance
1	N.NASRI, A. KACHOURI and M. SAMET (2008)	Design Considerations For Wireless Underwater Communication Transceiver	Design of transceiver using simulink software to achieve high throughputs over band-limited underwater acoustic channels using modulation and coding techniques	Achieved BER of 10-1 using different encoding techniques and found QPSK with CRC coding followed by 2 convolutional encoder- is better compared to other encoding techniques. Simulated the optimal frequency for maximum SNR at fixed distance efficient underwater communication.
2	Shen Xiaohong, Wang Haiyan, Zhang Yuzhi and Zhao Ruiqin(2012) www.intechopen.com	Adaptive Technique for Underwater Acoustic Communication (2012)	Adaptive modulation and power management over UWA channel was investigated . Performance of the dynamic adaptive system of UWC was conducted in a lake.	Combination of MFSK and OFDM reduces the BER of 10-4 for the distance ranging from 5-25 km, with data rate of 3400bps which intern optimizes BW. Concluded that BW raises at the price of increasing SNR at the same BER.
3	Yuri Labrador, MasoumehKarimi,Deng Pan, and Jerry Miller International Journal of Computer Science and Network Security, VOL.9 No.7, July 2009	Modulation and Error Correction in the Underwater Acoustic Communication Channel	Proposed the of 8PSK and 16QAM Modulation Techniques along with Turbo Codes in the underwater acoustic channel.	Coherent modulations had lower performance for long transmissions. BER of 8PSK is better than 16QAM.
4	N.R. Krishnamoorthi & Dr.CD.Suriyakala (2011) International Conference on Advances in Recent Technologies in Communication and Computing	"comparative study of error control coding in underwater acoustic channel"	Proposed FEControlling codes to reduce the Retransmission and energy consumption.BER enables the features of BW & power.	TCM – high spectrum efficiency,high bit rate, low BER. Comparision of BER for different type of Modem in AWGN and Acoustic channel. Performance of RS,Convolutional and Turbo codes was analysed and concluded that performance of Turbo codes are better than the RS, CC w.r.t. BER Drawback: decoder was unable to decode

				correctly in the presence of a burst of erroneous bits-
5	NASRI Nejah, A.Laurent & SAMET M(2012) 7th International Multi-Conference on Systems, Signals and Devices	EFFICIENT ENCODING AND DECODING SCHEMES FOR WIRELESS UNDERWATER COMMUNICATION SYSTEMS	To minimize the error rate we have proposed two evolved coding scheme: Reed-Solomon (RS) encoder followed by an interleaver and a convolutional encoder. 2.second coding system is formed by a CRC encoder to detect compound errors and to profit from its simple implementation.	The 2 schemes are suitable for PSK modulation only for short distance . Combining PSK and OFDM techniques we can reduce still more BER.
6	Prashant Kumar and Preetham kumar - International Conference on Communications 2013: IEEE ICC'13	Performance Evaluation of Modified OFDM for Underwater Communications	BER and PAPR performances of the different variants of modified OFDM have been evaluated over underwater acoustic channel using Monte Carlo simulation in MATLAB.	Error floor For WHSOFDM is observed at BER of 4e-4 whereas for both DFT-SOFDM and DCT-SOFDM the error floor is observed at about 8e-5. CI-SOFDM achieves a BER of 2e-6 at 20 dB SNR. Due to the hostile behavior of UW channel it is extremely difficult to achieve a SNR value of even 15 dB at the receiver. Thus it is seen that CI-SOFDM seems to be better solution for UWA communication compared to other variants of spread.
7	Yanbo Wu, Min Zhu, Weiqing Zhu, Zeping Xing, Lijun Xu and Bo Yang(2013)	Nonbinary LDPC Code for Noncoherent Underwater Acoustic Communication and Its Experiment Results	Concatenated code based on nonbinary LDPC code and constant weight code is proposed in noncoherent communication and iteratively decoded in probability domain	proposed concatenated code has a 3 dB SNR benefit than non-iterative concatenated code. Underwater communication experiments were carried out in both deep ocean (vertical communication, 5 km) and shallow lake (horizontal communication, near 3 km, delay spread larger than 50 ms), signal frequency band was 6~10 kHz, and data transmission rate was 357 bps. It is shown that the proposed scheme can correctly transmit in both experiments with a signal noise ratio of 2 dB. The performance of proposed algorithm was verified by experiment.
8	Zhang Lan Xu Xiaomei Sun Haixin Chen Yougan(2009)	Performance analysis of IRA codes for underwater acoustic OFDM communication system	IRA code for underwater acoustic OFDM communication system is proposed.	Simulation results show that the system performances can be noticeably improved by the proposed channel coding scheme. The BER performance of IRA codes will get improved with the increase of the code length and the iteration of BP-decoding to a certain degree, and then tends to stable. The permissible BER range for an underwater acoustic communication system is from 10-3 to 10-5, so about-1000-bit IRA codes with about 5 to 8 iterations are suitable to meet the basic requirement of the UWA communication system. The sea trial results show that the BER of the system has decreased by an order of magnitude via the IRA coding scheme, some of BERs even are equal to zero, which confirm the proposed

VI. CONCLUSION

In this paper describes the recent advances in the underwater acoustic communication. The article also describes about the key factors of UW-A propagation which is necessary to know the efficiency of the underwater communication. The main objective of the article is to encourage the research work for the development of the modulation techniques and the coding techniques for the underwater communication. As a part of future work we are planning to obtain the maximum performance of underwater communication by adapting the different modulation techniques and the coding techniques, thereby we can increase the transmission range.

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