Design considerations for wireless underwater communication transceiver

Conference Paper · December 2008

DOI: 10.1109/ICSCS.2008.4746954 · Source: IEEE Xplore

4 authors:

Nasri Nejah
National Engineering School of Sfax

Abdennaceur Kachouri
University of Sfax

Laurent Andrieux
Université Toulouse II - Jean Jaurès

Mounir Samet
University of Sfax

Design Considerations For Wireless Underwater Communication Transceiver

Nejah NASRI
LETI-ENIS, B.P.868-3018- SFAX-TUNISIA
nasrinejah@yahoo.fr

Abdennaceur KACHOURI
LETI-ENIS, B.P.868-3018- SFAX-TUNISIA
Abdennaceur.Kachouri@enis.rnu.tn

Laurent ANDRIEUX
LATTIS-IUT Blagnac
TOULOUSE – France
andrieux@iut-blagnac.fr

Mounir SAMET
LETI-ENIS, B.P.868-3018-SFAX-TUNISIA
mounir.samet@enis.rnu.tn

***Abstract*— Evolutionary processes have shaped acoustic communication behaviours of remarkable complexity, for thus many researches have led to the development of innovative receiver structures for robust underwater acoustic communication. As underwater channel model, attenuation, transmission distance, low power consumption, highly Signal to Noise Ratio, Bit Error Ratio, inter-symbol interference, error coding and alternative modulation strategies, are of primary concern in the whole study and in particularly the proposition of the transceiver structure and his design. The values of these parameters above - mentioned are crucial to improve the wireless underwater communication. In addition, the battery powered Network nodes limit the life time of the proposed transceiver. This paper aims to survey the existing and the reliability of this transceiver and its applicability to underwater communication based on these simulations parameters values that are evaluated and presented.**

***Index Terms*— Acoustics, Underwater communication, channel model, Wireless, Transceiver.**

I. INTRODUCTION

The ocean is a dynamic and complex environment. Water movements are never-ceasing, and conditions are always changing with the time of day and weather, it is generally very difficult to predict [1]. Acoustic signals travelling through it are distorted by a variety of factors; the major contributors are absorption, refraction and reflection (reverberation). Through these three factors, the signals picked up by receivers are duplicated forms of the original, of varying levels of strength and distorted by a certain degree of spreading or compression. In order to overcome these problems and limitations, advanced signal processing is very important and required to make optimum use of the transmission capabilities. Signal processing in the time, frequency and spatial domains is therefore an important part of modern marine acoustics. The area of marine acoustics is in rapid development, driven by increasing demands for improved system reliability and performance, and by new possibilities and solutions continuously made available as consequences of advances in electronics and computer technology. Large delays between transactions can reduce the throughput of the system considerably if it is not taken into account. Also, since the ocean bottom instruments are battery-powered, power efficiency is a desirable characteristic for underwater networks [2] [3]. Special attention should be given to these facts when designing an underwater transceiver.

To overcome these difficulties, in this paper we aim to purpose a new architecture of underwater transceivers based on the use of phase modulation techniques and signaling encoding methods which provide a feasible means for a more efficient use of the underwater acoustic channel bandwidth. In fact, the values of the transmission loss, transmission distance and power consumption, are optimized to improve the wireless underwater communication and his transceiver performance.

II. CHARACTERISTICS OF UNDERWATER WIRELESS COMMUNICATION

In this section, we examine technical differences between underwater and terrestrial wireless communication; we present the optimal parameters to minimize energy consumption in underwater wireless communication.

A. *Differences between Terrestrial and Underwater wireless communication*

Compared to radio channel, the available bandwidth of the underwater acoustic channel is very limited and dramatically dependent on both range and frequency, the propagation speed in the UW-A channel is five orders of magnitude lower .This speed can vary depending on pressure, water composition, and temperature[7]. Also huge propagation delay, floating node mobility, and limited acoustic link capacity, are significantly different from ground-based wireless sensor networks [8].The main differences between terrestrial and underwater networks can be outlined as follows:

TABLE I. DIFFERENCES BETWEEN TERRESTRIAL AND UNDERWATER WIRELESS COMMUNICATION

	Underwater	Terrestrial
Wave type	acoustic	electromagnetic
Velocity	$1500ms^{-1}$	$3.10\text{-}8ms^{-1}$
Time of propagation	low	important
Spatial correlation		
Spreading of sensors		
Bandwidth	0-400KHz	20KHz-300GHz
Required power	important	low
Recuperation cost		
Capacity of sensor storage	important(complex signal processing)	important(multimedia Application)
Receiver	Complex	Less complex
Numeric modulation type	M-PSK; M-FSK	M-QAM; M-PSK; M-FSK…
Transducer	piezoelectric	electromagnetic

This comparative study explains that wireless underwater communication is a challenging task. Most commonly used methods, which are well established for digital communication in air, do not work in water.

B. Choosing the best carrier frequency

The energy consumption in underwater acoustic networks is different from those in terrestrial radio-based networks. In fact in mobile underwater networks with high propulsion energy costs; minimizing network communication energy is always an important concern. To cope this constraint there are two solutions: the first is energetic based on the finding of optimal frequency for underwater communication, the second solution is formal based on the choice of MAC protocols essentially these of routing.

The marine environment is complex and homogeneous environment, for thus it's difficult to find a mathematical model who accounts the majority of the underwater channel physics parameters.

The transmission loss TL (d, f) [dB] that a narrowband acoustic signal centered at frequency f [KHz] experiences along a distance d [m] is described in equation (1) [4] which is divided in two sub equations that represent geometric transmission losses result of diffraction and diffusion effects, and non geometric transmission losses due to a chemical phenomenal essentially absorption and phenomenal of structural relaxation [5] [6] (equation (2)):

$$TL(dB) = a.d + 20\log(d) \qquad (1)$$

Where:

a (f): is the absorption coefficient expressed as:

$$a(f)_{(dB/m)} = f^2\left(2{,}692\,10^{-13} + \frac{7{,}858\,10^{-2}}{f^2 + 1{,}226\,10^{0}} + \frac{1{,}481\,10^{-4}}{f^2 + 1{,}522\,10^{6}}\right) + 0.001 \qquad (2)$$

As taking account of the transmission losses TL (d,f) and the P.S.D[1] N(f), the SNR[2](x, f,) can be given by [6]:

$$SNR(d, f) = \frac{P/TL(d, f)}{N(f)\ \Delta(f)} \qquad (3)$$

Where:

Δf is the receiver noise bandwidth.

P received power.

N(f) represents the ambient noise which is the result of turbulence, activity of ships, waves, and thermal noise.

The following formulas present the PSD of these four noise sources respectively in dB according to the frequency in KHz:

$$10\log(N_t(f)) = 17 - 30\log(f) \qquad (4)$$

$$10\log(N_s(f)) = 40 - 20(s - 0.5) + 26\log(f) - 60\log(f + 0.03) \qquad (5)$$

$$10\log(N_w(f)) = 50 + 7.5\,w^{1/2} + 20\log(f) - 40\log(f + 0.4) \qquad (6)$$

$$10\log(N_a(f)) = -15 + 20\log(f) \qquad (7)$$

Where:

S represents the activity of ships that varies between 0 and 1.

W represents the speed of wind in m/s.

The total P.S.D noise will be the sum of the four source of ambient noise:

$$N(f) = N_t(f) + N_s(f) + N_w(f) + N_a(f) \qquad (8)$$

The TL(d, f) × N(f) product, determines the frequency dependent part of the SNR. The factor 1/TL (d, f) N (f) is illustrated in Fig.2. For each transmission distance d, there clearly exists an optimal frequency (f) for which the maximal narrow-band SNR is obtained.

This survey permit to determine optimal parameters for better underwater communication.

C. Simulation results and comments

According to fig.1, it is well known that the frequency-dependency of the acoustic path loss imposes a bandwidth limitation on an underwater communication system; such that a greater bandwidth is available for a shorter transmission distance and the path loss (attenuation) variation is directly proportional to the distance between the two communicating nodes (Emitter/Receiver) and frequency of emitted signal.

The path loss difference for various frequencies is significant:

- For a low frequencies (from 1 KHz to 20 KHz), the path loss is less than 50 dB distance varying from 1Km to 5Km and do not exceed 100dB for a distance of 10Km.
- For a high frequencies (more than 20 KHz), for a distance of 10 Km, the path loss achieve 200dB at f=50 KHz and more than 400dB at f=100 KHz. For thus, we limit to low frequencies.

[1] Power Spectral Density

[2] Signal Noise Ratio

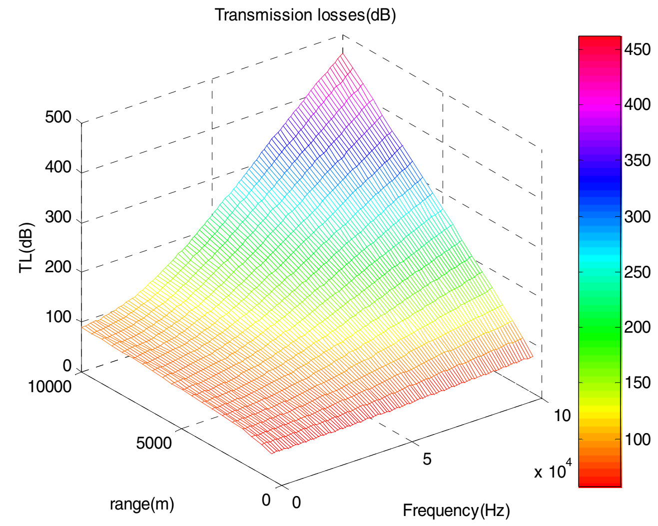

Fig.1. Attenuation vs distance

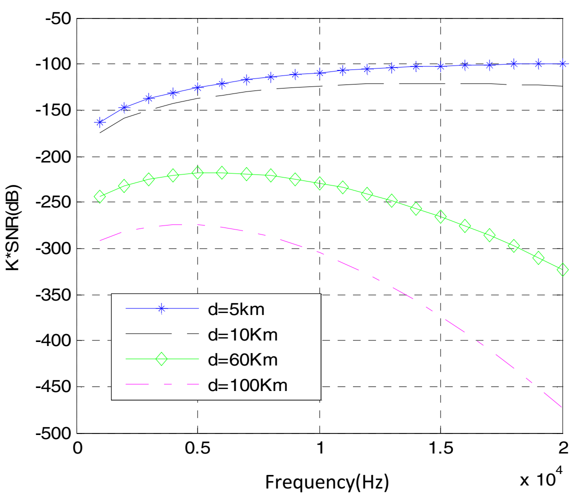

Fig.2. Frequency-dependent part of SNR,1/TL (d, f).N(f)

According to fig.2 we can determine optimal frequency for maximum SNR at fixed distance, these simulations are in accordance with stojanivc result[6].Table.1 resumes the optimal frequency and distances needed for efficient underwater communication.

TABLE II. AVAILABLE BANDWIDTH FOR DIFFERENT RANGES IN UWA CHANNELS

	Range[Km]	Bandwidth[KHz]
Very long	20≥	≤10
Long	5-20	5-10
Medium	1-5	≈20
short	0.1-1	20-50
Very Short	≤0.1	≥100

III. WIRELESS TRANSCEIVER FOR UNDERWATER COMMUNICATION

A. *Related work*

A different approach in the design of transceiver has been investigated in order to achieve high throughputs over band-limited underwater acoustic channels especially modulation and coding techniques [9].
With the goals of increasing the band width efficiency of an underwater acoustic communication system, many research focus on the PSK (Phase Shift Keying) modulation, which are a viable way of achieving high speed data transmission [9] [10].
The power of forward error correcting FEC codes increases with the number of concatenated codes which provides a very straightforward means of achieving a long and complex code out of much shorter component codes, which can be decoded much more easily by using an interleaver between the inner and the outer encoder[11] .

B. *Transceiver structure*

Considering all the design considerations above-mentioned and in accordance with the simulation parameters results that can be used as initial values for this wireless communication, our proposed underwater communication transceiver is shown in fig.3.

The proposed system will have:

- A two concatenated convolutionnel encoders in order to obtain a long constraint length which produces more powerful codes to improve the performance of under water communication

- An interleaver, to protect the transmission against burst errors. These errors overwrite a lot of bits in a row, so a typical error correction scheme that expects errors to be more uniformly distributed can be overwhelmed. Interleaving is used to help stop this from happening.

- A HADAMARD coding to achieve high underwater bandwidth efficiency and high signal security.

- A QPSK modulation mapper, to achieve higher bit-per-symbol and to profit on the less attenuation of phase in underwater communication.

- A CRC the cyclic redundancy check, is a technique for detecting errors in digital data.

An important concern regarding wireless transceiver for the underwater communication is its requirement of a transducer at the transmitter side. This transducer allow to transform electrical waves into sound waves and inversely. It is directly connected to an AWGN channel (added noise to the useful signal), multi-path Rayleigh fading channel and modelled aquatic channel.

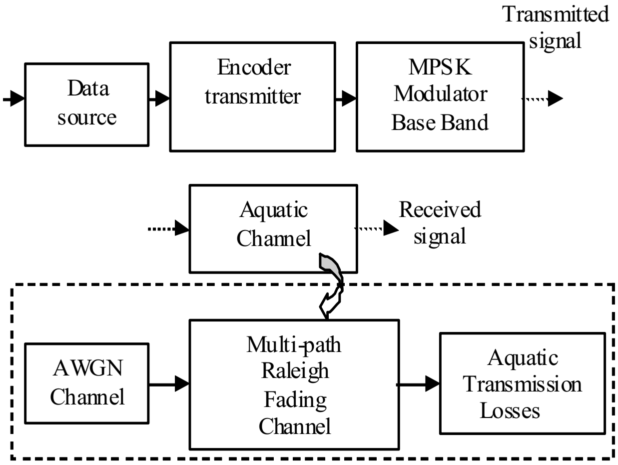

Fig.3. Wireless transceiver for the underwater communication

The data encoding as illustrated in figure 4 which's composed with general CRC generator (Cyclic Redundancy Check) concatenated Convolutionnels encoder, interleaver and HADAMARD code generator.

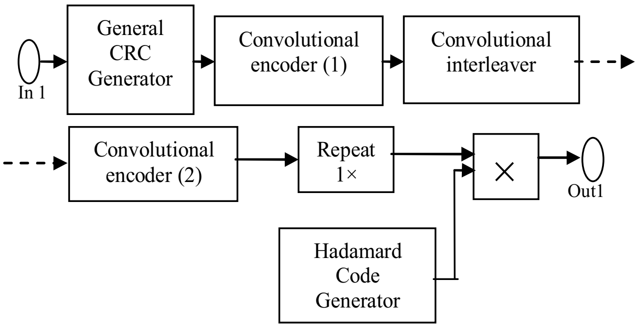

Fig.4. Encoder for wireless underwater transceiver

SIMULINK model of underwater path loss is shown in fig. 5.

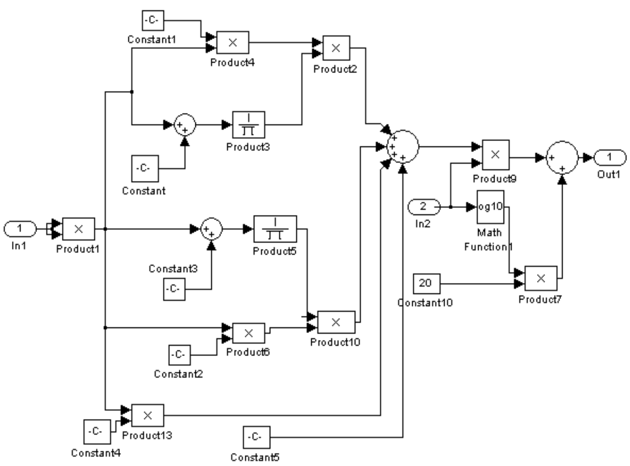

Fig.5. Underwater Acoustic signal Path loss modelled under simulink

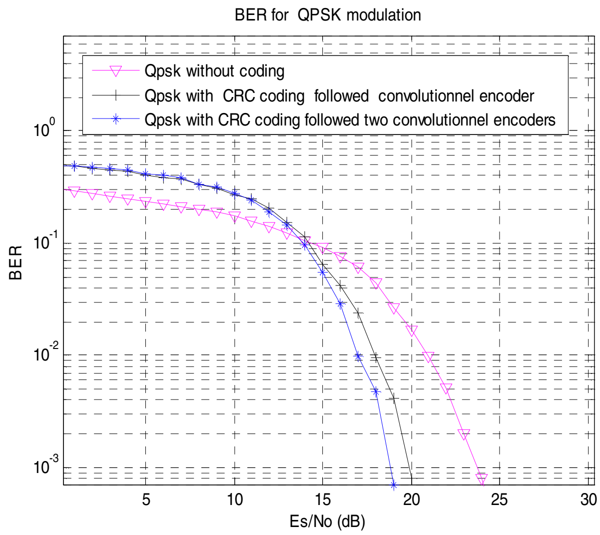

Fig.6. Bit error rate for QPSK modulation

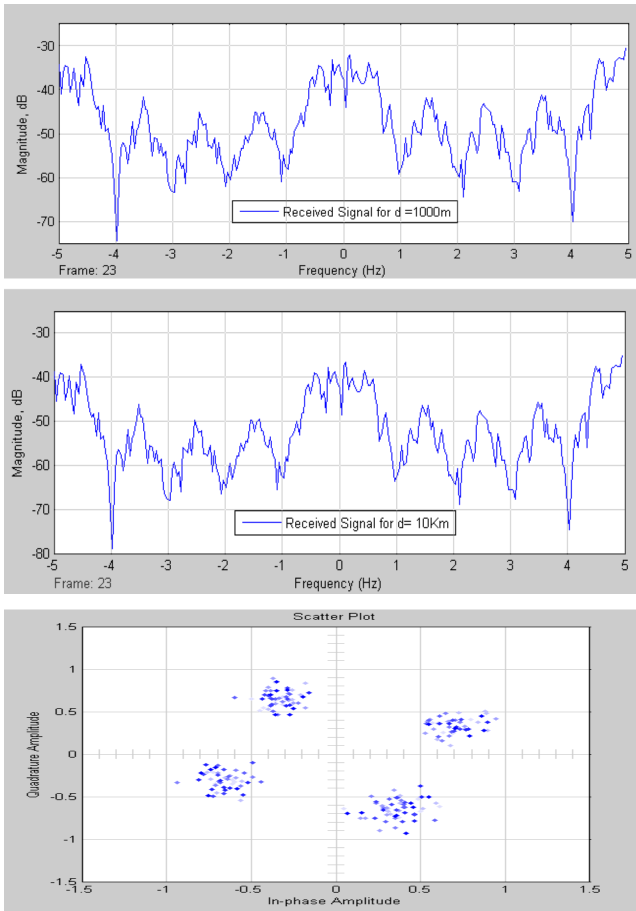

Fig.7. Received Signal for different transmission distance and Constellation scope for QPSK modulation

Fig.6 illustrates the importance of concatenated code used to decrease the bit error rate. The HADAMARD coding provides a significant decrease in the BER for increasing the level of the SNR; in a way, we decrease the value of the added noise to the useful signal and we increase the multi-path Rayleigh Fading channel, seeing that, the underwater channel is represented with AWGN channel and multi-path Rayleigh Fading channel.

Fig.7 shows the received signal, through the underwater channel, and constellation scope for QPSK modulation after aquatic channel block with the multi-path and the noise effects: instead of to have condensed points, we have a scatter of points. The recognizable rotation of the QPSK constellation is due to the multi-path spreading leads to ISI (Inter Symbol Interference), where subsequent transmitted symbols can over lap in time at the receiver's position. . This response represents a party of the transmission data, arrives along a clearly defined way different of all the others. In this work we have used SIMULINK software, because it's well adapted to modeling and simulating the path loss equation in underwater channel. Also this work is an amelioration of study realized by Bouzoualegh [9] in which he proposes underwater transceivers based on convolutionnel encoder and phase modulation. Figure 6 present the advantages of proposed transceivers in term of bit error rate. The table below resumes the effect of aquatic environment on the power of received signal.

TABLE III. MAGNITUDE OF RECEIVED SIGNAL (DB) VS. FREQUENCY AND DISTANCE

Maximal magnitude of received signal (dB)		**Frequency of emitted signal (KHz)**		
		10	20	30
Distances (m)	100	-6	-7	-11
	1000	-30	-33	-35
	5000	-48	-60	-78
	10000	-75	-96	-118

IV. CONCLUSION

This paper provided a comprehensive study of wireless transceiver for underwater communication. Our contribution consists in the determination of the important parameters to get better the wireless underwater communication. Calling in of sum advanced (characteristics) for underwater communication: PSK modulation performs well in dispersive channels as aquatics channels. When combined with HADAMARD code eliminates inter symbol interference and overcame fading by using concatenated forward error correction coding.

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