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# On the Performance of Underwater Mobile Acoustic Sensor Networks:Work in Progress

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***Abstract*—In this paper several computer simulations and pool experiments have been carried out to verify and demonstrate underwater communication between moving acoustic sensor nodes over different distances achieving optimum mutual information. We have developed GUI software “SAM-control” that generates *m*-sequences of 1023 length, handles their transmission and communications between sensor nodes. In addition, it performs numerical calculations of the probability of error, entropy of message signal, information loss, bit error rate, cross correlation, and mutual information. Simulation study of the underwater acoustic channel model is also presented. Our work shows that the use of mobile acoustic sensors in underwater communication system is able to provide a reliable wireless link with low probability of error (<0.003) for different sensor velocities. In addition, it is achieved comparable results in terms of the performance based on information theory aspects.**

**Keywords—** ***mutual information, channel capacity, maximum rate of information, underwater sensor communication, acoustic channel, collaborative network channel, parallel network channel.***

## I. INTRODUCTION

In any underwater acoustic communication system, it is of practical importance to consider environmental effects when we consider the performance measure of signal processing function [1]. After the wide development in wireless digital communication for the underwater environment, it is important to improve the performance of existing system, such as data rate, channel capacity, information loss, probability of error, etc. Underwater Wireless Communication (UWC) imposes many constraints that affect the design of wireless network like path loss, transmission distance, energy absorption by water, long propagation delays, channel dispersion, Doppler effects, and interference.

In this paper, we analyzed an underwater wireless network using mobile sensors and compared its performance to the underwater wireless network with fixed nodes proposed in [3]. Moreover, we developed a GUI software “SAM Control” which we used to control the miniature acoustic modem and to process our data. The anticipated network system setup developed in [3] will focus on:

1. Entropy of transmitted and received message signal, where we use the PN-sequence as transmitted and received signals, which will be a binary sequence due to PPM modulation used by default in acoustic modem set.
2. Channel noise for underwater communication transmission medium, which receives an input X and produces an output Y. If the channel is noiseless, the output will be equal to input. However, in general the transmission medium is noisy and an input is converted to Y with probability $P_{Y|X}(y|x)$[10].

$$x_1x_2x_3 \dots\dots.x_n \dashrightarrow [noisy\ channel\colon P_{Y|X}(y|x)] \dashrightarrow y_1y_2y_3 \dots\dots.y_n$$

3. Analyzing the probability of error between mobile and fixed sensor nodes in terms of number of bits loss to the total number of bits sent. Information loss is calculated given conditional entropy of input and output data.

$$L(X \longrightarrow Y) = H(X|Y) \quad \text{where}$$

$$H(X|Y) = \sum_{y} P_Y(y)\left[-\sum_{x} P_{X|Y}(x|y)\log\left(P_{X|Y}(x|y)\right)\right]$$

4. Evaluate the maximum number of messages that can be transmitted almost error free, which will give the mutual information between *X* and *Y*. The connection between mutual information and number of message is related to the capacity of underwater channel.

The mutual information *I(X; Y)* is the relative entropy between the joint distribution and the product distribution.

$$I(X;Y) = \sum_{x}\sum_{y} p(x,y)\log\frac{p(x,y)}{p(x)p(y)}$$

For our experimental approach, we used information theoretic tools such as: entropy, conditional entropy, mutual information, probability mass function and joint probability mass function of both input and output data. Our approach is to investigate an underwater distributed mobile sensor network and analyze how the communication of transmitting sensor message signal is correlated to receiving mobile sensors. We approximate the optimum placement and location of sensor network in underwater to reduce transmission loss, and thus increase the rate of data transmission with lower probability of error [3]. At first, we investigate the noise itself in communication channel, distance between transmitter and receiver, multipath and geometric spreading of sound energy.

The rest of the paper is organized as follows: In Section II, we discuss the related work, in Section III, we introduce the underwater acoustic channel model, in Section IV, we introduce our experimental system model setup for using mobile acoustic sensors and present our developed software GUI (SAM-Control) features. In Section V, we give the numerical and simulation results for the both network models mobile and static sensor nodes. Our conclusions will be summarized in the last section.

## II.RELATED WORK

In [3] the authors analyze the mutual information of sensor networks in an underwater wireless acoustic network by placing the acoustic sensor nodes at different location in order to achieve optimum mutual information. The performance of acoustic sensor nodes are observed and analyzed by placing fixed sensors in a collaborative and parallel channel network system, as shown in Fig. 1 and Fig.2:

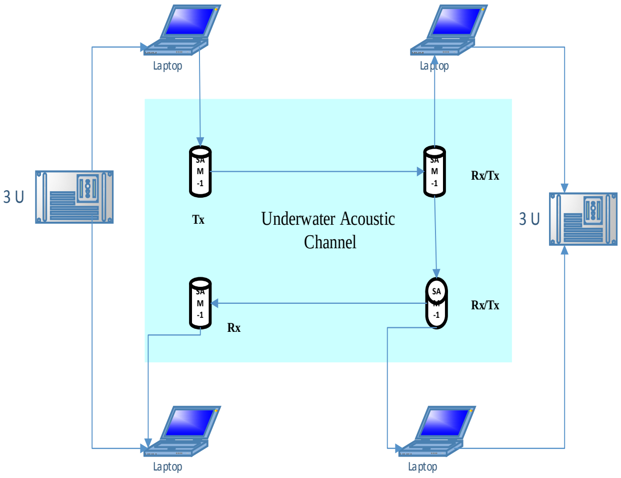


Figure 1: Cascaded underwater wireless sensor network

In the cascaded sensor network model, data is transmitted from sensor 1 and received in sensor 2. Then, sensor 2 transmits the received data to sensor 3. The same process was repeated to send data from sensor 3 to sensor 4. The output at sensor 4 was compared with input data at sensor 3, and then mutual information, bit error rate, probability error, and information loss were calculated at each communication channel. The results of these calculations are shown in Table 1.

Table 1: Numerical results for the Cascaded System

| S.N | Case study | *I(X:Y)* | BER | Information loss *H(X\|Y)* |
|---|---|---|---|---|
| 1 | $Tx_1$ and $Rx_1$ | 1 | 0.0081 | 0 |
| 2 | $Tx_2$ and $Rx_2$ | 1 | 0.0078 | 0 |
| 3 | $Tx_3$ and $Rx_3$ | 1 | 0.0082 | 0 |
| 5 | $Tx_1$ and $Rx_4$ | 0.9054 | 0.1853 | 0.0824 |

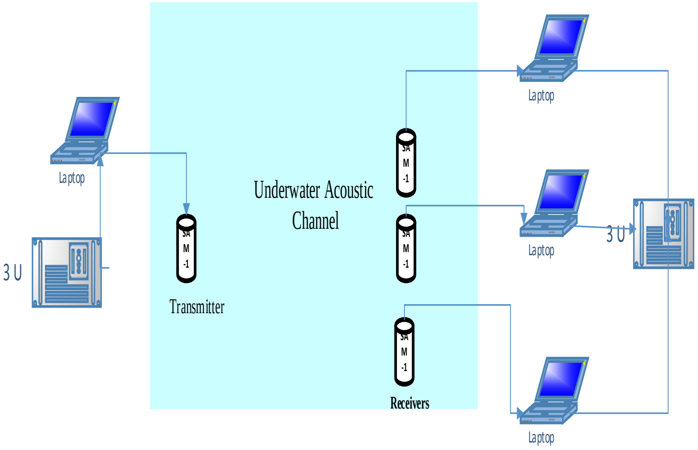


Figure 2: Parallel underwater wireless sensor network

The authors concluded that forming a cascaded system network with multiple sensor nodes at different distance will reduce the propagation loss, information loss, multipath fading, etc., which resulted in the improvement of the communication system.

## III. UNDERWATER ACOUSTIC CHANNEL MODEL

In this section, a simulation study of underwater acoustic propagation loss (TL) and ambient noise will be conducted.

### A. Signal Attenuation

Acoustic path loss depends on the signal frequency and the distance between transmitter and receiver. This dependence is a consequence of absorption loss (i.e. transfer of acoustic energy into heat) [7]. In addition, the signal experiences a spreading loss, which increases with distance. Spreading loss refers to the energy distributed over an increasingly larger area due to the regular weakening of a sound signal as it spreads outwards from the source [4]. In Fig. 4, we displayed the overall transmission loss that occurs in underwater acoustic channel over a transmission distance of meters at a signal frequency f (kHz):

$$TL = k.10logl + l.10log\, a(f) \tag{1}$$

In the above relation k is a spreading factor: k = 2 for spherical spreading, k = 1 for cylindrical spreading, and k = 1.5 for the so-called practical spreading, and $10log\ a(f)$ is the absorption coefficient using Thorp's formula for frequencies above 3 KHz represented in Fig.3

$$10loga(f) = 0.11\frac{f^2}{1+f^2} + 44\frac{f^2}{4100+f^2} + 2.75f^2\ 10^{-4} + 0.003 \qquad (2)$$

while for lower frequencies the following formula may be used: $10loga(f) = 0.002 + 0.11\frac{f^2}{1+f^2} + 0.011f^2$ (3)

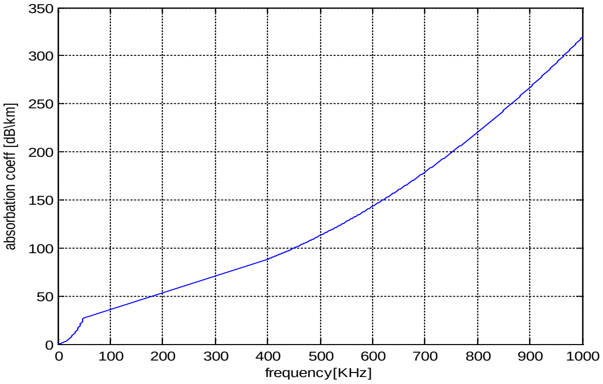


Figure 3: Absorption Coefficient

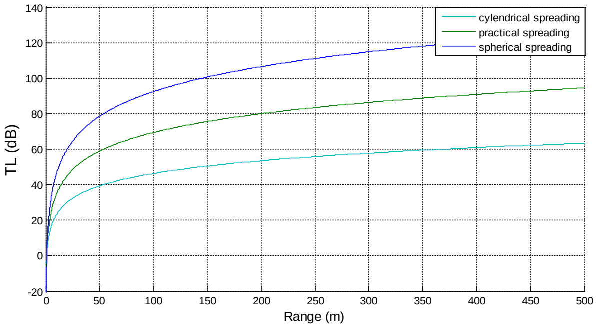


Figure 4: Overall transmission loss (f = 50KHz).

## B. Noise

The ambient Noise in ocean can be represented as Gaussian, as well as having a continuous power spectrum density (psd). It consists of four causes (outlined below), where each has a dominating influence in different portions of the frequency spectrum [2].

- Turbulence noise influences only where f < 10Hz
  $10log\ N_t(f) = 17 - 30log\ (f)$
- Shipping noise is dominant only where 10 < f < 100 Hz, and has defined a shipping activity factor of s ranges from 0 to 1 for low high respectively.
  $10log\ N_s(f) = 40 + 20\ (f - 0.5) + 26log(f) - 60log(f + 0.03)$
- Wave noise caused by wind and rain is a major factor in the frequency region of 100Hz - 100 kHz where wind speed given by m/s.
  $10log\ N_w(f) = 50 + 7.5w\text{^}(1/2) + 20log(f) - 40log\ (f + 0.4)$
- Thermal noise start effect where f >100 KHz
  $10log\ N_s(f) = 40 + 20log(f)$ .

For PSD of the noise of an acoustic channel we use the same approximation as given in [2].

$10logN_0(f) = N_1 - \eta\log(f)$

The positive constant $N_1$ = 50 dB re µ pa [19] and η = 18 dB/decade [2]

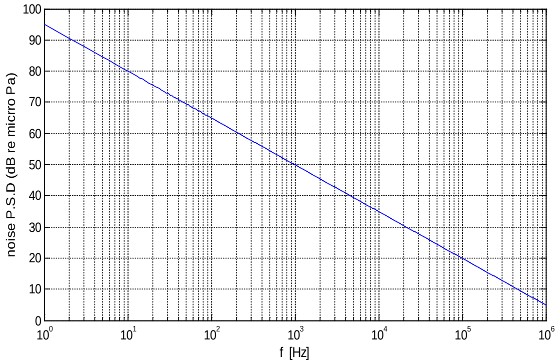


Figure 5: Power spectral density of the ambient noise using the approximation equation in [9].

# IV. Methods

The following section describes the equipment used, developed software (SAM Control), and the experimental procedures.

## *A. Equipment*

The experimental model is comprised of two portable computers equipped with MATLAB software, signal processing toolbox, a communication toolbox, a pair of SAM-1 acoustic transducers provided by Desert Star Systems, a hydrophone to measure sound underwater, and an acoustic speaker to generate noise. The data was transferred using a pair of acoustic modems and was processed by our developed software "SAM-control" in MATLAB. Figure 7, illustrates our prototype environment where the transmitter and moving sensors are connected to the computer via a serial port. The sensors were positioned in a way that they could float and move freely.

The modems can operate in the range of 250 meters. The transmitting power of sensors depends on the voltage supply (ranging from 183dB at 8V to 189dB at 16V).The modems were configurable to a specific data rate. However, increase in data rate decreased the range of transmission. Therefore, we configured the sensors to operate in 5 bits per second. Details of the hardware are shown in the Table 2.

TABLE 2: Specification of the modem

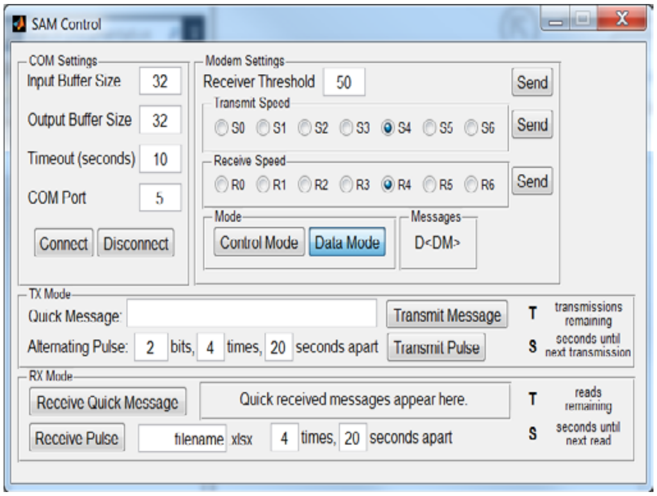
| Specification | Description |
|---|---|
| Serial port | 4800 baud, 8 data bits, no parity, one stop bit |
| Operating temperature | 0-70° C |
| Operating frequency for single channel receiver | 33.8 KHz |
| Operating frequency of modem | 33 KHz-42KHz |
| Modulation | Pulse Position Modulation |

### B. *Program*

SAM Control is a GUI program that is written for these experiments. The program is written in MATLAB, which reads and writes data to the serial buffer of the modem. SAM Control greatly streamlines the data collection and data analysis process by automating commonly used functions of the modem.

Multiple instances of the program can be run so that one computer can control multiple modems simultaneously. Its main features:

- COM settings: Configure the COM port settings that are connected to the modem.
- Modem Settings: These sets of control are used to configure the sensor communication parameters, such as receiver threshold, transmission speed (data rate) and receive speed.
- TX Mode: mainly responsible of generating the transmitting data which are the m-sequences of 1023 length so to be send through the sensor.
- RX Mode: managing all operations need to be done by the receiver, including reading the received data and storing it in a desired file type, so it can be ready for performing our analysis and evaluation on the data.



Input Buffer Size 32

Output Buffer Size 32

Timeout (seconds) 10

COM Port 5

Receiver Threshold 50

Transmit Speed: ○ S0 ○ S1 ○ S2 ○ S3 ● S4 ○ S5 ○ S6

Receive Speed: ○ R0 ○ R1 ○ R2 ○ R3 ● R4 ○ R5 ○ R6

Messages: D<DM>

Quick Message:

T transmissions remaining

Alternating Pulse: 2 bits, 4 times, 20 seconds apart

S seconds until next transmission

Quick received messages appear here.

T reads remaining

filename .xlsx 4 times, 20 seconds apart

S seconds until next read

Figure 6: SAM Control GUI

### C. *Procedure*

Our work is an extension of the analysis given in [3] on the performance of UWSN, using fixed acoustic sensor nodes. In our experimental model, we used mobile acoustic sensor node in a point to point communication system to accomplish same work.

During our experiment, we configured the sensors for serial communication, generated PN-sequence of the code length of 1024 by choosing the 10th order polynomial. We chose 10th order polynomial so that we could get the sequence with period length of 1023bits.

We transmitted baseband m-sequences of length 1023. Initially, we were not able to receive 1023 bits because of 32 bytes buffer memory of the sensors used. The buffer memory size was only 32 bytes and each bit sent via serial port was codded as 8 bits. As a result, we were only able to send maximum of 30 bits plus 2 bytes handshaking at a time from the m-sequences of length 1023. Therefore, practically the length of the sequence could be considered 30 for one transmission.

The receiver has been moving while receiving the transmitted data in both vertical and horizontal directions, the maximum distances reached between the two sensor nodes is 15m, as we limited it by the size of the indoor pool, where the experiments took place.

We have done the transmission of the data several times over different distances with different velocities. All the experimental observations and result we obtained for probability of error, BER, mutual information, entropy estimation is displayed in numerical results in Section V.

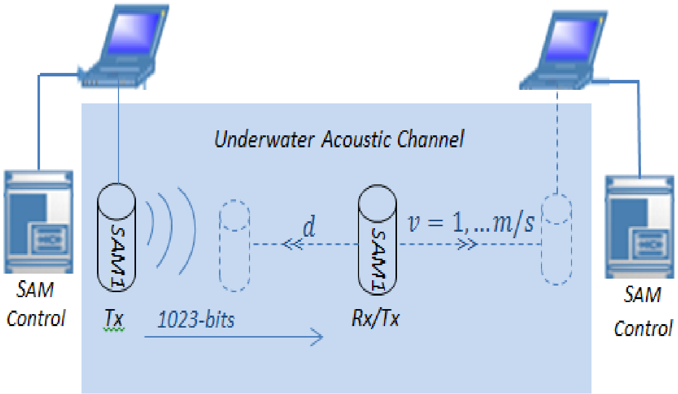


Figure 7: Underwater Mobile Acoustic Sensor Network

## V. EXPERIMENTAL RESULTS AND CONCLUSIONS

First, we obtained the experimental result for wireless mobile sensor network in an underwater acoustic communication.

In table 3, the bit loss and bit error were computed in an underwater channel sending 1023 bits of 1’s and 0’s alternately for a couple of times for different velocities of the moving sensor over 15m maximum distance apart between the sensors.

Table 3: Bit loss test for mobile sensor nodes of maximum distances = 15m.

| Sensor Velocity | No. of bits transmitted | Received no. of bits | Bit loss | Bit error rate |
|---|---|---|---|---|
| 1 Knot | 1023 | 1018 | 5 | 0.004 |
| 2 knots | 1023 | 1018 | 5 | 0.004 |
| 3 knots | 1023 | 1015 | 8 | 0.007 |

Table 4: Bit loss test for mobile sensor nodes moving in vertical direction.

| Sensor Velocity | No. of bits transmitted | Received no. of bits | Bit loss | Bit error rate |
|---|---|---|---|---|
| 1 Knot | 1023 | 1018 | 5 | 0.004 |
| 2 knots | 1023 | 1018 | 5 | 0.004 |
| 3 knots | 1023 | 1015 | 8 | 0.007 |

In the table below, we show the information theoretic aspects, we use to evaluate the performance of our point to point communication system model using mobile sensors nodes moving with velocities = 1 knot, 2knots, 3knots.

Table 5: Performance results of using mobile sensor nodes

| V | Data length | Bits received | P (E) | $I(X;Y)$ | Information loss $H(X\|Y)$ |
|---|---|---|---|---|---|
| $v1$ | 1023 | 1023 | 0.004 | 1.00 | 0.0 |
| $v2$ | 1023 | 1023 | 0.004 | 1.00 | 0.00 |
| $v3$ | 1023 | 1023 | 0.007 | 1.00 | 0.00 |

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X and Y are the transmitter and receiver nodes respectively in our communication system. As shown in Table 4, we achieve maximum mutual information (I(X, Y) = 1), since we have received same sequence length of the transmitted data, However, there is a small probability of error in reconstructing the transmitted bits. In conclusion, after estimating a simulation study of the UAC model, we used the information theory aspects tools to compare the performance of our UWSN model using mobile sensor nodes to the UWSN model that the author proposed [3].

We observed remarkable results in terms of the performance based on probability of error, mutual information and loss of information. The result of this work indicates that the use of few mobile sensors in UWSN can accomplish the same work as a larger group of static networks and achieve comparable results with low probability of error $\approx 0.001$.

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