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Underwater Acoustic Sensor Network: Modeling and Estimation

Dr. G. G. Sarate
Lecturer (Sr. Grade) Department of EN
Govt. Poly, Amravati, Maharastra, India

Ms. Jyotsna W. Chavhan
Research Scholar/Department of EN
BDCoE, Sewagram, Wardha, Maharashtra

***Abstract*— In this paper, the Underwater Acoustic Sensor Network, design approach, modeling and estimation is presented, since the underwater wireless communication is a rapidly growing area of research and engineering. For designing the underwater sensor network, underwater channel is required for efficient communication. The acoustic channel used for propagating the underwater data from transmitter to receiver, in place of RF signal because RF signal attenuates under the water and Optical signal can be used only for long distance communication. Therefore; the acoustic signals are used for data transmission. This channel is having formidable challenges like slow transmission of data, prescribed bandwidth, varying transmission delay and many more, which gives multipath fading and Doppler Effect. In this paper, we present the estimation and modeling of efficient underwater acoustic channel for data communication. The channel is modeled based on designed algorithm for noise interference, transmission losses, multipath fading effect, Doppler Effect, transmission delay and bandwidth limitation. Acoustic signal scattered and propagates very slow under the water, due to which data may get scattered and lost. These issues are solved using OFDM approach. Here, we design the acoustic channel is particularly modeled based on Gaussian distribution, where the delay varies with time rapidly. The Orthogonal Frequency Division Multiplexing technique, which is used to overcome the problem of scattering by using the method called maximum entropy modeling method. In this method, the delay between transmitting signal and received signal has been calculated referred as Doppler Spread. It also calculates the bit transmitted rate and bit error rate by diving the channel in to sub-channels using OFDM. Because acoustic signal when travel under the water it get scattered in almost all direction due to which fading problem increases also it increases the issues of Doppler spread, Doppler shift, Doppler delay, etc.**

The proposed system is designed and tested for shallow water using two tested nodes. The low cost sensor nodes are designed which can continuously read the data like temperature, pressure and salinity below the water and it can then be transmitted to the receiver which is also kept under the water. The receiver receives the data and displays it on Laptop continuously. This process demonstrates the vertical and horizontal communication. The system is tested for all atmospheric condition under different environment. In this work, the system design and its simulation results are shown.

Index terms: Underwater Acoustic Sensor Network, Underwater Acoustic Channel (UW-A), Gaussian distribution, Orthogonal Frequency Division Multiplexing, Maximum Entropy method, Doppler Effect, Multipath Fading Effect.

I. INTRODUCTION

A. Underwater Acoustic Sensor Network

One third of the earth is covered by water. The underwater communication is necessary for various applications such as monitoring, surveillance, scheduling, underwater environment control, commercial exploitation, scientific exploration, attack protection and prevention etc. The self-organizing network of Underwater Acoustic Sensor Network (UWASNs) supports these applications [1]. It uses acoustic communications, since radio does not work well in underwater environments due to low bandwidth, large latency and high error rate; underwater acoustic channels bring much defiance to the protocol design. The recent development of underwater network systems moves one next step forward with respect to existing small-scale Underwater Acoustic Networks (UANs). UANs are associations of nodes that collect data using remote telemetry or assuming point-to-point communications. This under water acoustic network differs from the underwater sensor networks in scalability, self-organization and localization [7].

In this research paper, Underwater Acoustic Sensor Networks (UWASN) is designed to monitor the underwater data continuously with the help of sensors. The proposed system is designed and tested for shallow water condition using two tested nodes. The low cost sensor nodes are designed which can continuously read the data like temperature, pressure and salinity below the water and it can then be transmitted to the receiver which is also kept under the water, then the received data is transmitted to the base station (Laptop), which is kept above the water or nearby sea costal region which actually continuously monitor the received data. This process demonstrates the vertical and horizontal communication link. Here, the underwater Acoustic channel is model using maximum entropy modeling technique which calculates the Doppler spread is 0.5 - 2 Hz only. Here, the acoustic channel satisfy the smart antenna approach by using IEEE standard 802.15.4, which gives the data transmission rate up to 250 Kbps at 2.4 GHz carrier frequency for at least 2m vertical link and approximately 10 m horizontal link, by keeping the depth of water up to 1.5m for the bandwidth of 2.4 GHz.

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II. BLOCK DIAGRAM OF THE SYSTEM

In Figure 1, the microcontroller 89C52 is used to read the analog data using ADC 8090 chip interfaced with it. The sensors like temperature sensor LM 35, pressure sensor and salinity sensor are interfaced with the microcontroller 89C52 through ADC 8090 chip. The underwater data like temperature, pressure and salinity is read by the microcontroller continuously using these sensors. This data is then communicated to microcontroller, it processes the data and sends to the USART port (max232), which wirelessly transmits it to the underwater receiver using transmitting smart antenna chip CC2500. The transmitter transmits this data to the receiver which is also kept under the water wirelessly.

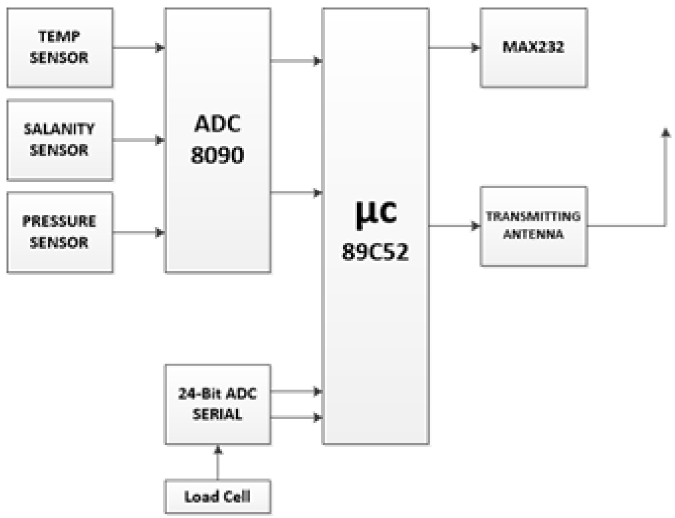


Figure 1. Block diagram of Underwater Transmitter

In Figure 2, the wireless data from the underwater transmitter is received through the receiving antenna. This data is then communicated to USART of underwater receiver. Microcontroller, which then wirelessly transmits, using Zigbee/Xbee S1 module to the base station (Laptop) and the laptop displays the data at the terminal used. The function of the underwater receiver is to just receive the data and wirelessly transmit it to the base station. The received antenna is a smart antenna which received the data with the frequency of 2.4 GHz at the speed of 250Kbps. Initially, we made wired connection between underwater receiver node and to the base station; later on we convert that into the complete wireless solution.

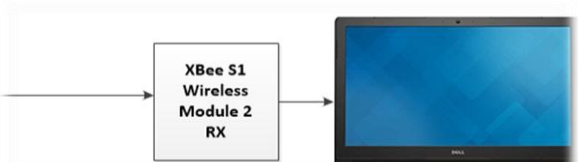
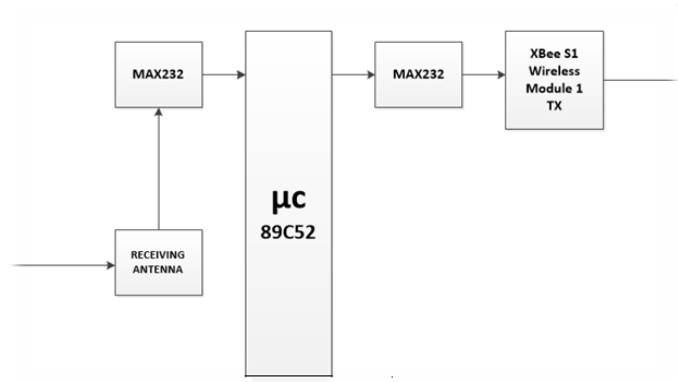


Figure 3. Wireless Receiver at Base Station (Laptop)

In the figure 3 shown above, the Zig-bee/X-Bee S1 module is connected to the base station (Laptop).

The X-Bee module wirelessly receives the data from the underwater receiver. The USB to serial adaptor is used to convert the USART data to the TTL logic. The base station continuously reads the serial data and displays it on the terminal.

Figure 2. Block diagram of Underwater Receiver



III. ACOUSTIC CHANNEL MODELING

The underwater sensor nodes are created for data transmission. These nodes are kept under the water, which read the temperature, pressure and salinity continuously and ready to transmit it to the underwater receiver. When the data get transmitting, it need an effective underwater channel for efficient data transmission for the an acoustic channel is used and modeled using Gaussian Distribution method and Maximum Entropy algorithm. Since, the acoustic channel creates various issues like transmission loss, includes noise, multi-path fading, Doppler Effects and propagation delay. These issues determine the temporary and spatially varying signal of the acoustic channel based on both the factors like bandwidth and frequency. Thus, this factor creates the refracting effect while reading the underwater data of temperature, pressure and salinity based on the sound speed rather than the light speed. The sound speed is less than the light speed which is within the range of 1450 to 1540 m/s [3]. Thus, these factors are solved in this research paper, which gives significant values of bit error rate, data transmission rate, transmission delay, noise factor, etc.

A. Propagation Delay:

As per the research, the temperature and pressure is almost constant near the surface of water, temperature decreases while pressure increases with depth of water. After certain level of depth the temperature reaches a constant level of 4^0 C, and from there the speed of sound increases with depth [4]. Here equation 1.1 shows the calculation of speed of sound in water.

$$c1 = 1449 + 4.6t + 0.055t^2 + 0.003t^3 + (1.39 - 0.012t)(s - 35) + 0.017d \text{........................(1.1)}$$

Where t is temperature in degree Celsius, s is the Salinity where as d is the Depth of water in meters. The propagation delay can then be calculated as

$$\tau = \frac{l}{c1} \qquad (1.2)$$

Where τ is time in seconds and *l* is distance in meters.

B. Transmission Loss:

The distinguishing property of acoustic channels is that the path loss depends on the signal frequency. This is a direct consequence of absorption, i.e. the transfer of acoustic energy to heat. Transmission loss is mainly caused by two phenomena: *spreading loss* and *attenuation loss*. Transmission loss for a signal of frequency f [kHz] over a transmission distance d [m] can be expressed in [dB] as:

$$10\log T_L(d,f) = k.10\log(d) + d.\alpha(f) + A..........(1.3)$$

Where k is the *spreading factor*, which describes the geometry of propagation, α(f) [dB/m] is the *absorption coefficient* and A [dB] is the so-called *transmission anomaly* which accounts for factors other than absorption including multipath propagation, refraction, diffraction and scattering. The transmission loss with varying frequency and distance for shallow and deep water UW-A channels. The shallow water UW-A channel has higher values of attenuation than the deep water. In UW-A channel, while transmission loss increases with distance and frequency. Path loss in the ocean can be categorized into these two losses. Attenuation loss includes losses incurred due to absorption, leakage out of ducts, scattering, and diffraction. In the low frequency range (100 Hz - 3 kHz) the absorption coefficient can be calculated as:

$$\alpha = \frac{0.011 f^2}{10+f^2} + \frac{44 f^2}{410000+f^2} + 2.75x10^{-4} f^2 + 0.003x10^{-3}$$

Where f is frequency in kHz and α is the absorption coefficient. The absorption coefficient increases rapidly with frequency. The absorption coefficient based on above equation is calculated using MATLAB and its plot is shown in Figure 4.

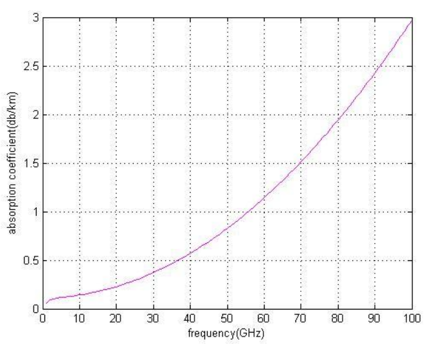


Figure 4: Absorption Coefficient

C. Noise:

Noise in an acoustic channel consists of ambient noise and site specific noise. The ambient noise in the ocean can be modeled using four sources: turbulence, shipping, waves, and thermal noise. Gaussian statistics and a continuous power spectral density describe the major sources or ambient noise. The following empirical formula gives the power Spectrum Density of the four noise components in a function of frequency in kHz [3]: Turbulence noise influences only the very low frequency region, f < 10 Hz. Noise caused by distant shipping is dominant in the frequency region 10 Hz - 100 kHz, and it is modeled through the shipping activity factor s, whose value ranges between 0 and 1 for low and high activity, respectively [3]. Surface motion, caused by wind-driven waves (w is the wind speed in m/s) is the major factor contributing to the noise in the frequency region 100 Hz - 100 kHz (which is the operating region used by the majority of acoustic systems). Thermal noise becomes dominant for f > 100 kHz. The overall power spectral density of the noise is given by equation no. 1.4

$$N(f) = N_t(f) + N_s(f) + N_w(f) + N_{th}(f).......(1.4)$$

Thermal noise becomes dominant for f > 100 kHz. The overall power spectral density of the noise is given by. Here in this shallow water proposed system, the Noise is almost negligible while transmitting the data, because the transmission range is considered to be very small i.e. in terms of meter. The horizontal link is established up to 2m and vertical link is maximum of 100m. ; Therefore the Noise generation rate is very small or negligible.

D. Multipath:

Multipath is caused by the presence of multiple paths that sound waves can take to travel from the transmitter to the receiver. Multipath is created underwater by two different effects: sound reflection at the surface, bottom, and any objects, and refraction of sound. The latter is caused by the spatial variation of the speed of sound. The impulse response of the acoustic channel depends on the nature of the channel and its reflection and refraction properties, which in turn determines the number of propagation paths that contribute significant energy components at the receiver. Each path of an acoustic channel can be assumed to act like a low pass filter, and hence the overall impulse response can be written as

$$h(t) = \sum_p h_p(t - Z_p)$$

Where hp(t) refers to the time varying path gain and _ (p) refers to the path delay of the p(th) path. The delay spread of the channel depends on the longest path delay, which is typically on the order of tens or even hundreds of milliseconds.

E. Doppler Effect:

Non-negligible Doppler shift/spread is another factor that distinguishes an acoustic channel from the radio channel. The magnitude of the Doppler effect (a shift) is measured by the ratio a = v/c where v is the relative velocity between transmitter and receiver, c is the speed of sound, and a is called the relative Doppler shift. Since the speed of sound is very low when compared to electromagnetic waves, the distortion due to Doppler can be quite severe for acoustic signals. Even when there is no intentional movement, the transducers tend to drift with waves and tides with a non-negligible velocity. There is always some amount of movement present in the system and this has to be considered while designing a communication system. The Doppler Effect can have a significant impact on multicarrier signals.

Simulated BER with 1/2-rate convolution coding, QPSK modulation and single transmit and receive antennas is shown in Figure 6.6. The scheme corresponds to mode 1

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coding in the IEEE 802.15.4 standard. The curves indicate that the estimation error starts to become critical for Doppler spread around 0.5 - 2 Hz (corresponding to normalized Doppler spread around 0.05 and 0.1) and delay spread around 1 ms (corresponding to normalized delay spread in the order of 0.01). To obtain BERs in the order of 10-5 and delay spread should be lower than shown in the figures5.

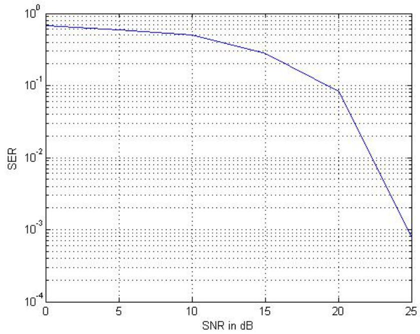

Figure 5: Simulated BER with 1/2-rate convolution coding

IV. CHANNEL ESTIMATION

This is the very popular 2.4GHz X-Bee module from Digi. These modules take the 802.15.4 protocol stack (the basis for Zig-bee) and wrap it into a simple to use serial command set. These modules allow a very reliable and simple communication between microcontrollers, computers, systems, really anything with a serial port! Point to point and multi-point networks are supported.

The X-Bee and X-Bee-PRO RF Modules were engineered to meet IEEE 802.15.4 standards and support the unique needs of low-cost, low-power wireless sensor networks. The modules require minimal power and provide reliable delivery of data between devices. The modules operate within the ISM 2.4 GHz frequency band and are pin-for-pin compatible with each other.

The series 1 802.15.4 1mW with wire antenna. It's good for point-to-point, multipoint and convertible to a mesh network point. We suggest this module for those starting out as it is the easiest to get going: if there are two X-Bees in the same area they will automatically 'sync' and pass serial data back and forth without any additional work or configuration. What we like about the Series 1 modules is that they are so easy to get set up. If you have two in range, they will automatically form a serial link with no configuration, so you can send TTL serial data back and forth. You can also configure the baud-rate, as well as sleep modes, power modes and tons more stuff using the Digi X-Bee tool. The pins on an X-Bee are 2mm spacing, not 0.1" so they will not fit into a breadboard. For that reason, they work best in our X-Bee adapter module kit (which has a 250mA 3.3V regulator) or with the USB X-Bee adapter.

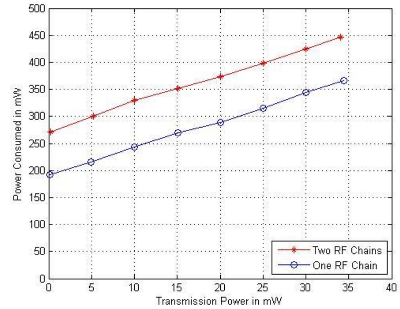

Figure 6: Simulation results of Transmission Power with Power Consumption

V. SIMULATION RESULTS

In this paper, we presented algorithms for estimating the standard deviation of some AWGN when observations derive from signals less present than absent in this background. According to experimental results, this algorithm is very promising. An application of two sensor nodes have been designed and tested on free air environment and under acoustic /aquatic environment for transmitting the data from transmitter to receiver. Using this MC-ESE algorithm, the efficient energy consumption is calculated and its simulating results are shown using MATLAB coding results as per the table given in Table 1.

Existing Algorithm		**Proposed Algorithm**	
Distance Travels by Nodes (m)	**Energy Consumption (J)**	**Distance Travels by Nodes (m)**	**Energy Consumption (J)**
20	0.15	10-20	0.2962
40	0.35	21-30	0.3471
78	0.39	31-45	0.275
100	0.72	**46-100**	**0.3459**

The energy efficiency can also be calculated using Greedy algorithm; these algorithms rely on the connectivity matrix. In short, a logical matrix where true represents a connection and the connections are determined by the distance between nodes and the range of the active modem. When a node receives a radio message it will use the connectivity matrix to determine it's furthest connected neighbor, the performance of the model implementing this algorithm is summarized in Table 2.

Therefore it is very much clear from the table shown above that, as the number of nodes increases, the power consumption to that much number of nodes reduces up to certain extended depends upon the distance between the transmitting and receiving nodes. Here we have simulated this results using Greedy algorithm, where the nodes distance is kept within the range of 10m to 100m and its power consumption is ranging from 0.2962J to 0.3459J. as shown in

Parameters	**Number of Nodes**			
	25	**50**	**75**	**100**
Avg. Distance (m)	90.0642	89.235	68.9515	57.6881
Avg. Depth (m)	25	25	25	25
Avg. Energy (J)	0.4050	0.2007	0.2232	0.2052
Avg. Time (ms)	0.22	0.31	0.28	0.38

the table 2. These results are achieved using the algorithm 2 of Greedy Furthest Acoustic.

VI. CONCLUSION

Research on underwater communications and the use of Underwater Sensor Networks is becoming a very hot topic because of the appearance of new marine/oceanographic applications. As a consequence, other available underwater acoustic technology can support mostly point-to-point, low-data-rate, delay-tolerant applications. Some of the shown experimental results for point-to-point acoustic modems use signaling schemes that can achieve data rates lower than 20 kbit/s with a link distance of 1 km over horizontal links. Whereas in the proposed system, where Communications is based on RF signal transmission offers great benefits such as, increase of the data rate of the link to transmit more information.

The underwater acoustic communication channel is model using Maximum Entropy modeling technique for Acoustic channel simulation with its root mean square. Doppler spread is 0.5 to 2 Hz. The Acoustic communication channel satisfy smart antenna approach by using IEEE standard 802.15.4 which gives the data transmission rate up to 250 Kbps at 2.4 GHZ carrier frequency for at least 2m vertical communication link and approximately 2m horizontal link by keeping the depth of water up to 1m, Since shallow water acoustic communication is consider. For this, the bandwidth was kept up to 2.4 GHz. The system can generate the maximum signal-to-noise ratio (SNR) is up to 1.477 dB and its Signal-Error-Rate (SER) is calculated as -14.9513 dB.

As the signal gets scattered in to the water, therefore orthogonal frequency division multiplexing technique is implemented, which divide the carriers into equivalent sub-carriers. Here 16 to 64 sub-carriers at the frequency of 3.6 MHz and each sub-carrier are made to process 256 bits per sub-channel; therefore, maximum 4096 bps to 16384 bps can be actually transmitted with the help of each sub-carrier. Based on this concept, the system is simulated for 25 numbers of nodes. For simulating this network the maximum energy required is 0.4094 Joules.

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Authors Profile

Dr. G. G. Sarate was born in 1967 in Akola, Maharashtra, India. He received his BE Electronics, ME Electronics degrees from Amravati University in the years 1990 and 1998 respectively. He has completed his Ph.D. in Optical Fiber Devices in 2006. He has 25 years of teaching experience. He is Pd.D. supervisor in Nagpur and Amravati University. He has to his credit more than 65 publications in International, National Journals and Conference proceedings in which 20 are at International Journals, **Three papers in IEEE International Journal and One in Spinger International Journal.** His **Four patents** are submitted to India Patent Authority & **Three** of it published in Journal. He is recipients of **Best Teacher Award** in 2006, by ISTE New Delhi. He is felicitated **National Award** for Promising Engineering Teacher 2010 by ISTE New Delhi. **Adarsh Sikshak Purskar** i.e Best Teacher Award of Govt. of Maharashtra 2010-11 for his creditable & outstanding work in Technical Education for last 20 years. He is Fellow of IETE and presently working as Executive member at IETE Amravati Center. He is Life Member of Optical Society of India Kolkata and Life Member of ISTE. **He has been associated with various committees of Directorate of Technical Education Mumbai, MS.** He has published Book on “Audio & Video” Engineering in 2008 for Engg Students. He has attended and chair technical sessions and worked as Programme Committee Member in many National and International Conferences.

His areas of interest are Fiber optics, Mobile Comm. Engineering, Biomedical Electronics, Microwave Engineering and Communication Engineering.

Ms. Jyotsna Chavhan received her B.E. degree in Electronics Engineering from Nagpur University in the year of 2000 and M.Tech degree in VLSI Technology from Ramdeobaba College of Engineering, Nagpur, MS, India in the year of 2007. Currently pursuing her PhD from RTMNU, Nagpur. She has submitted 11 research papers in National and International Journal and Conference Proceedings. Two Research papers are published in IEEE Explorer. She is having 13 years of teaching experience. Her areas of interest are Communication Network, C++ Programming and Data Structure, Microwave Engineering, Microprocessor and Microcontroller.