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Modelling of Underwater Acoustic Channel Properties

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Abstract:* The interest in the field of underwater communication is growing for the last three decades because it finds very diverse applications in the area of scientific exploration, attack protection, commercial exploitation, oceanography, military applications etc. Since 70% of the earth surface is covered with water, this area remains largely unexplored. For effective and efficient exploration one of solution is establishing communication system underwater environment. Underwater Wireless Sensor Networks is the enabling technology for this task. Sensor nodes perform different operations such as collection of data, storing data and relaying data to the required stations. In this paper underwater channel modeling, pathloss and other transmission parameters are discussed. Due to high development and deployment cost coupled with complexity of underwater channel, we first develop the simulation model using appropriate simulator.

***Keywords:* Underwater acoustic networks, pathloss, spreading, attenuation, Thorp's model, Fisher and Simmons model, Francois and Garrison model, salinity, temperature, Depth.**

I. INTRODUCTION

Underwater acoustic sensor networks hasbeen the area of intense research by networking, communications and signal processing communities for the past few years [1]. To meet the networking challenges the various protocols are being developed which work at different layers of protocol stack.

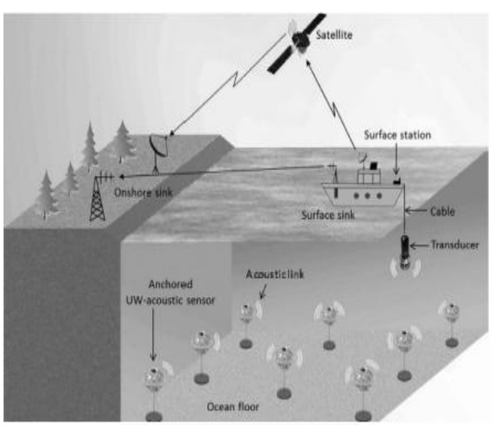

Fig 1. Underwater Acoustic Sensor Network [1]

In case of traditional underwater system such as oceanography data collection , it uses individual equipments that are disconnected and sense the data and send it to onshore stations by means of cable.

This traditional system when replaced with sensor nodes and acoustic links looks as shown below

In the above shown figure the sensor nodes may be fixed to the sea bed or they can have mobility.The sensors communicate among each other using acoustic signal.The data collected from each nodes is relayed to the stations present on the water surface.These stations further trasmit the data to the main stations available at the onshore.The communication between surface and onshore stations can take place using WiFi or WiMAX standards.

Various challenges for deployment of wireless sensor networks underwater are listed below

- The bandwidth underwater is strictly limited.
- The propagation delay is more when compared to radio frequency.
- The battery utilization is limited, since replacement or recharging of batteries is expensive or not feasible.

To address these challenges theProtocols are to be developed at Network, MAC and Physical Layer.

II. DIFFERENCES WITH TERRESTRIAL NETWORKS

The main differences between terrestrial and underwater sensor networks are[2]

- Deployment: While terrestrial sensor networks are densely deployed, in underwater, the deployment is deemed to be more sparse, due to the cost involved and to the challenges associated to the deployment itself.
- Communication: In underwater communication Electro Magnetic (EM) waves cannot travel over a long distance. Underwater feature are large latency and low bandwidth, because of this behavior terrestrial protocols may not be appropriate for underwater networking.
- Cost: While terrestrial sensor nodes are expected to become increasingly inexpensive, underwater sensors

are expensive devices. This is especially due to the more complex underwater transceivers and to the hardware protection needed in the extreme underwater environment.

- Power: The power needed for acoustic underwater communications is higher than in terrestrial radio communications due to higher distances and to more complex signal processing at the receivers to compensate for the impairments of the channel.
- Memory: While terrestrial sensor nodes have very limited storage capacity, uw-sensors may need to be able to do some data caching as the underwater channel may be intermittent.

III. CHANNEL MODELLING

The behaviour of the underwater channel is observed by modelling it accurately by appropriate parameters.

Loss:

The energy of acoustic signal propagating in water is absorbed that is the energy is transformed into heat and the other part is lost is due to scattering of sound by inhomogeneties[3].

A. Physical Layer:

Sensor devices used underwater should work for long durations may be for months or years, because of difficulty in replacing batteries. That is the power consumed by the devices must be the least.

To achieve this efficient physical layer protocols are used. This enables the devices to be active only when required and go to sleep mode when inactive which saves the power[5].One of the proposed protocol is IEEE 802.15.4 standard,which is for low rate Wireless Personal Area Netwrok or WPAN.

B. Pathloss:

One of the factor which decides the effective transmission of signal and data received at receiver is transmission loss or pathloss.

Pathloss in general terms is the degradation or reduction in the signal energy due to various effects such as attenuation ,Doppler spread, channel impairments, different kinds of noise,multipath effects etc.In channel modeling, the attenuations due to the frequency absorption, ambient noises and loss due to the wave scatterings at the surface and bottom for deferent grazing angles and bottom types are considered. Also Ray theory is the basis of the mathematical model of multipath effects.

The pahtloss basically constitutes spreading of acoustic signal and attenuation of signal

Pathloss = Geometric Spreading + Attenuation

Pathloss = k. log (d) + a(f) * d

Here k is spread factor , a(f) is attenuation as function of frequency and d is distance between two nodes.

1) Spreading

It refers to spreading of sound energy. It is the geometry of propagation of acosutic signal. There are two kinds

Spherical :In this type the sound signal spreads as if signal propagating out of sphere.The spread factor k value is 2

Cylindrical: The signal spreading is in particular direction , specifically in horizontal direction.Spread factor k value is 1. [6]

For practical spreading the k value is 1.5

Spread	Spherical	Practical	Cylindrical
k	2	1.5	1

2) Attenuation

The pathloss depends not only on the distance between transmitter and receiver but also on frequency and various other parameters. The signal frequency determines the absorption loss which occurs because of the transfer of acoustic energy into heat.

Other parameters include such as temperature of water , depth of nodes, salinity of water i.e the salt content in water and pH which indicates the acidity of water.

The following are the attenuation models considered

i) Thorp's Model

This model is purely function of frequency of acoustic signal only. It is suited for generally low frequencies of the order of 10 to less than 100 kHz .The empirical formula is given below

$$A(f) = \frac{1.0936(0.1 * f^2)}{(1 + f^2)} + \frac{40f^2}{(4100 + f^2)}$$

A(f) is attenuation in dB/Km.

f is frequency in kHz

ii) Fisher and Simmons Model

This attenuation model not only considers frequency but also takes into account temperature ,depth ,salinity and pH to accurately determine the attenuation.

The condition that salinity must be 35 and pH must be 8 must be satisfied only then this model is valid otherwise it is not applicable.

The expression for calculation of attenuation using this model is shown below

$$\alpha = \left(\frac{A_1P_1*(f_1*f^2)}{(f_1^2+f^2)} + \frac{A_2P_2*(f_2*f^2)}{(f_2^2+f^2)} + A_3P_3f^2\right)*8686[4]$$

The term 8686 is used to convert it to dB/km.

Where a is attenuation in dB/km and

$$A_1 = 1.03*10^{-8} + 2.36*10^{-10}*T - 5.22*10^{-12}*T^2$$

$$A_2 = 5.62*10^{-8} + 7.52*10^{-10}*T$$

$$A_3 = [55.9 - 2.37*T + 4.77*10^{-2}*T^2 - 3.48*10^{-4}*T^3]*10^{-15}$$

$$F_1 = 1.32*10^3(T+273.1)*e^{-\frac{1700}{(T+273.1)}}$$

$$F_2 = 1.55*10^7(T+273.1)*e^{-\frac{3052}{(T+273.1)}}$$

$P_1 = 1$

$$P_2 = 1 - 10.3*10^{-4}*P + 3.7*10^{-7}*P^2$$

$$P_3 = 1 - 3.84*10^{-4}*P + 7.57*10^{-8}*P^2$$

A_1, A_2, A_3, F_1, F_2 are temperature dependent and P_2, P_3 are pressure dependent. Pressure is in atmospheres, T is temperature in ^{o}C and frequency in Hz

iii)Francois and Garrison Model

In addition to frequency, temperature depth, salinity and pH are considered here in this model

The empirical formula is as shown

$$\alpha = \left(\frac{A_1P_1*(f_1*f^2)}{(f_1^2+f^2)} + \frac{A_2P_2*(f_2*f^2)}{(f_2^2+f^2)} + A_3P_3f^2\right)$$

α is attenuation in dB/Km. f is frequency in kHz.

The first term $\frac{A_1P_1*(f_1*f^2)}{(f_1^2+f^2)}$ gives the absorption due to boric acid.

Boric acid absorption

$A_1 = \left(\frac{8.86}{c}\right)*(10^{(0.78*p^H-5)})$,

$P_1 = 1$, c is speed of sound, k=237+T

$$f_1 = 2.8*\left(\frac{S}{35}\right)^{0.5}*10^{(4-\left(\frac{1245}{(273+T)}\right))}$$

S is salinity

The second term $\frac{A_2P_2*(f_2*f^2)}{(f_2^2+f^2)}$ gives contribution to absorption due to magnesium sulphate.

$$A_2 = 21.44*\left(\frac{S}{c}\right)*(1+0.025T)$$

$$P_2 = 1 - (1.37*10^{-4}*D) + (6.2*10^{-9}*D^2)$$

$$F_2 = \frac{8.17*10^{\left(8-\left(\frac{1990}{273+T}\right)\right)}}{1+0.0018*(S-35)}$$

The third term $A_3P_3f^2$ is absorption due to pure water.

$A_3 = 4.937*10^{-4} - (2.59*10^{-5}*T) + 9.11*10^{-7}*T^2 - (1.50*10^{-8}*T^3)$ for T≤20^{o}C

$A_3 = 3.964*10^{-4} - (1.146*10^{-5}*T) + 1.45*10^{-7}*T^2 - (6.50*10^{-10}*T^3)$ for T>20^{o}C

The range of validity of the above model is different for different range of frequencies as shown below.

For frequencies of 10- 500 kHz, where absorption due to magnesium sulphate dominates, the limits of reliability are

-2 < T < 22^{o}C, temperature

30 < S <35 , salinity

0 < D < 3.5 km depth

At frequencies greater than 500 kHz, the absorption due to pure water exceeds that of the magnesium sulphate, hence the limits are given by

0 < T < 30^{o}C temperature

0 < S < 40 ppt salinity

0 < D < 10 km depth

3) Sound Speed Profile

Attenuation depends on Speed of sound, it is function of Temperature, Salinity and depth.

The sound speed profile is a fundamental set of oceanographic parameters that determines the behavior of sound propagation in the ocean.[8]

$$C = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.01T)(S-35) + 0.016Z$$

Where,

C= Speed of sound (in meters/seconds)

T= Temperature (in ^{o}C)

S=Salinity (in parts per thousand)

Z=Depth (in meters)

i) Temperature

The temperature of the water in the oceans ranges between 0 ◦C to 6 ◦C. The water that is present at depth and at the poles is cold. It gets warmer towards the surface and towards equator.

ii) Depth

The average depth of the ocean is 3 Km to 4km and the speed of sound varies highly with respect to depth.

iii) Salinity

Salinity is the ratio of the weight of dissolved salts to total weight of water. The ratio is usually expressed as parts per thousand (ppt). Almost 75% of seawater has a salinity ranging between 34-35 ppt. The average salinity in the oceans is 34.7 ppt, i.e., on an average there is 34.7 g of salt in every kilo gram of seawater[7].

IV. CONCLUSION

In this paper an overview of state of art in the underwater sensor networks is been presented. The objective of this paper is to look into developing acoustic model using IEEE 802.15.4 protocol at physical layer and modeling pathloss at propagation layer. The channel modeling is done considering three different attenuation models which consider not just the transmission frequency but also temperature, depth, salinity and acidity to more accurately determine attenuation. The attenuation models considered also work for higher range of frequencies.

V. FUTURE WORK SCOPE

The future work of this paper can be include effects of attenuation on multipath propagation and Doppler shift. Different modulation schemes for the physical layer protocol such as OFDM, multicarrier modulation etc can be incorporated to get the higher data rates as future work.

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