Research of Channel Capacity of Acoustic Communication Network for Oceanographic Applications

R.S Deepak Ram, Vijayalakshmi.P, Venkataraman Padmaja, T. Jaya, V. Rajendran

Abstract: In comparison with terrestrial wireless network, underwater communication network for any oceanographic applications have only a few tens of communication nodes. Researchers recently discussed elaborately on network parameters like SNR, throughput, Power optimization etc. However, the variation in finding the optimal frequencies and related bandwidth and its channel capacity with different modelling technique needs specific attention. From the detailed analysis, the optimization of system model also depends on location & distance. Therefore, the research aims to realize a research model in line with the above challenges. Summary relieves that results are very encouraging for any underwater acoustic applications.

Index Terms: Channel capacity, UWACN, SNR, Attenuation Noise.

I. INTRODUCTION

In many well-known technologies it has been discussed that underwater communication acoustic network consists of few tens of communication nodes for any oceanographic applications [1]. It is also clear that acoustic communication network only feasible and its improvements on SNR, BW efficiency and its power optimization are discussed quite well in many references. However, depends on the underwater location, optimization of operation frequency, its related BW and channel capacity need to be studied.

This paper proposes to examine in detail on the similar lines with different modeling techniques. In section 2, channel modeling, noise effects, SNR and the related theory is discussed, and the method to obtain optimal frequency. Section 3 discusses the simulation software Aquasim tool. Section 4 explains the results. Section 5 conclusion.

II. CHARACTERIZATION OF CHANNEL

The channel characteristics are analyzed usingdifferent channel parameters as given below. The first parameter to be considered is propagation loss. The addition of absorption losses and the spreading loss gives total transmission loss. This is given by equation

TL = TL spreading + TL absorption

Spreading loss occurs when the transmitted signal travels outwards from the source. The two-spreading losses are the spherical loss and the cylindrical loss.

Values of k is given
k=2; Spherical
k=1; Cylindrical and
k=1.5; for practical applications

Attenuation caused due to acoustic energy being absorbed in underwater which is converted to heat is called absorption loss. This process if frequency dependent. At higher frequencies the absorption is more[2, 3].

Combining the two equations we get total transmission loss equation. It is written as

$$\boldsymbol{10logA(l,f) = k.10logl + l.10log\alpha}$$

These absorption coefficients (α) are based on the signal and environmental characteristics of propagation models.

The first propagation model considered is Thorp Model [4] which considers only the signal frequency with depths of about 1000m and temperature 4°C.

The equation for finding α is given as

$$\boldsymbol{10log\alpha = \frac{0.1f^2}{1+f^2} + \frac{40f^2}{4100+f^2} + 2.75 \times 10E-4.f^2 + 0.003}$$

The second propagation model considered is the Ainslie and McColm model. This model was proposed in 1998 and it based on the Fisher-Simmons model which was proposed in 1977. This model proposed extra relaxations and simplifications. In this model the acidity of sea water is taken into consideration and is dependent on depth and not pressure and thus can be used in a variety of applications and give more accurate results [5].

This equation for the model is given

$$\boldsymbol{\alpha = \frac{0.106f1f^2}{f1^2+f^2}e^{\frac{pH-8}{0.56}} + 0.52\left(1+\frac{T}{43}\right)\left(\frac{S}{35}\right)\frac{f2f^2}{f2^2+f^2}e^{\frac{-D}{6}} + 4.9 \times 10-4x^2e^{-(\frac{T}{27}+\frac{D}{17})}}$$

Equations for f1 and f2 are given as:

$$f1 = 0.78\sqrt{\frac{S}{35}}\,e^{\frac{T}{26}}$$

$$f2 = 42e^{\frac{T}{17}}$$

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R. S Deepak Ram, Research Scholar, Dept. of ECE, VISTAS, Pallavaram, Chennai, Tamilnadu, India.(Email: deepakramrs@gmail.com)

Vijayalakshmi. P, Asst. professor, Dept. of ECE, Vels Institute of Science, Technology & Advanced Studies (VISTAS), Pallavaram, Chennai, Tamilnadu, India.(Email: viji.se@velsuniv.ac.in)

Venkataraman Padmaja, Research Scholar, Sathyabama Institute of Science and Technology, Chennai, Tamilnadu, India.(Email: ktananya@gmail.com)

Dr. T. Jaya, Asst. professor, Dept. of ECE, Vels Institute of Science, Technology & Advanced Studies (VISTAS), Pallavaram, Chennai, Tamilnadu, India.(Email: Jaya.se@velsuniv.ac.in)

Dr. V. Rajendran, Professor and Director of Department of Electronics and Communication Engineering, VISTAS, Chennai, Tamil Nadu, India. (Email: drvrajen@gmail.com).

Apart from attenuation and spreading loss there are other parameters that affect the transmission. One major contributor is the ambient noise. Ambient noise consists of up to four different components. Each of these components has effect at different frequencies.

Table 1: Frequency Values for Different Noise types

Noise Type	Frequency range
Turbulence noise	<10 Hz
Shipping	10 Hz-100Hz
Wind driven noise	100Hz-100kHz
Thermal noise	>100kHz

The p.s.d of all the above noise can be represented in equations. Also, the total noise p.s.d is obtained by adding them. The p.s.d is gaussian and continuous in nature.

Equations are given as

Turbulence

$$\mathbf{10\log Nt(f) = 17 - 30logf}$$

Shipping

$$\mathbf{10logNs(f) = 40 + 20(s - 0.5) + 26logf - 60\log(f + 0.03)}$$

Wind

$$\mathbf{10logNw(f) = 50 + 7.5w^{\frac{1}{2}} + 20logf - 40\log(f + 0.4)}$$

Thermal

$$\mathbf{10logNth = -15 + 20logf}$$

Total PSD is given as

$$\mathbf{N(f) = Nt(f) + Ns(f) + Nw(f) + Nth(f)}$$

Using both the transmission loss along with the noise we can characterize the channel. To characterize the communication channel, we need to analyze parameters like SNR, optimal frequency, and capacity. [6]

Signal-to-Noise-ratio:

As we know the signal attenuation A (l, f) and the noise p.s.d N(f) the SNR at the receiver side can be obtained from the below given equation.

$$\mathbf{10logSNR(l,f) = 10logPtx - 10logA(l,f) - 10logN(f)}$$

Optimal Frequencies:

The attenuation-noise product is the frequency dependent portion of the SNR. SNR is inversely proportional to the attenuation -noise product. For every distance l, t an optimal frequency at which the narrow band SNR will be minimum exists.

The equation for optimal frequency is given as

$$-(10logA(l,f) + 10logN(f))$$

Bandwidth is given as the difference in the AN factor value at a f0 (l) and the AN value at the f(l).

The transmission bandwidth is given as

$$B(l) = fmax(l) - fmin(l)$$

Where

fmax(l) is ANf0(l)-AN(f)≤3 and

fmin(l)is ANf0(l)-AN(f)≤ 3.

Capacity:

Based on channel capacity we can design the network which leads to topological changes, protocols, access schemes to maximize the throughput. Channel capacity as per Shannon theorem is given by

$$C = Blog(1 + \frac{S}{N})$$

III. CONFIGURATION OF SIMULATION SETUP

The communication network was simulated using Aquasim. Aquasim is based on the NS2 simulator and the CMU packages of Aquasim are parallel and independent of Ns2. [7]

The network is an adhoc network with 10 nodes. Out of theses 10 nodes 4 nodes are fixed nodes, 3 nodes are mobile nodes along with 1 AUV, 1ROV and 1 mine crawler.

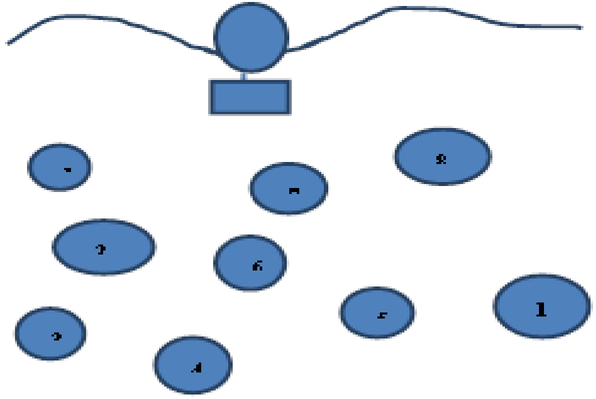

Fig. 1. Underwater Acoustic network configuration

Fig.1 describes the nodes configuration of the proposed system design. The nodes 3, 4, 5 and 6 are the fixed nodes, and the nodes 1, 7 and 9 are the moving nodes and 2 is AUV, 8 is described as ROV and 10 is shown as mining crawler. For the simulation values of salinity, water depth, temperature, pH etc. have been assigned. Long and medium range distances are simulated. The optimal frequency values were obtained. Different propagation models are simulated using Aquasim channel modeling [8].

IV. RESULTS AND DISCUSSIONS

For validation of the implemented models many simulations have been performed. It is essential to validate the parameters like noise, AN optimal frequency, bandwidth, and capacity. Noise calculations are important and to study parameters like bandwidth, capacity, and SNR. Calculations are based on the optimal frequency as at this frequency the best-case performance occurs. The noise is not directly dependent on transmission but is dependent upon the frequency used for transmission as this will help to determine if the optimal frequency used is accurate or not.

Fig. 2 discusses the variation in ambient noise as each model accounts different environmental parameters. The SNR is an important value as it helps to decide the position the nodes in the network such that high network efficiency is maintained. It also helps in determining if the whether the arriving signal has enough strength to be accepted or discarded.

The SNR is related closely to the AN factor, one of deciding factor which helps to obtain the optimal frequency, bandwidth, and capacity. The AN factor depends on distance and frequency and hence it gives better method of predicting the SNR behavior as SNR values depend on the transmission power. The AN factor curve is matching to that of SNR curve. The AN factor is chosen as the bench mark to validate the SNR in turn to be able to predict the bandwidth and capacity.

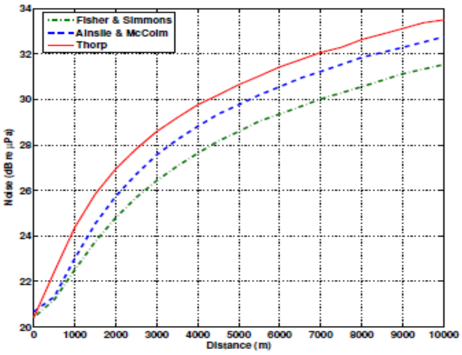

Fig. 2. Model analysis with Ambient noise condition

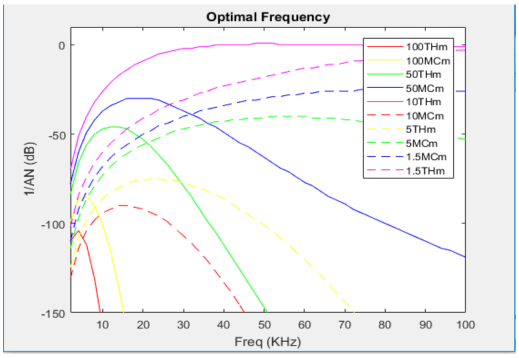

Fig. 3. AN factor graphs for Thorp and Ainslie & McColm model at different distances

Fig. 3 discusses that both the models follow similar patterns of the curves and from figures we understand that larger distances have smaller bandwidths and smaller distances have larger bandwidths. It is obvious that optimal frequency exponentially decreases with distance. Thus, both optimal frequency and bandwidth are determined based on how far the two communicating nodes are placed. [9]. The simulation analysis of the models Throp & Mclom is shown in figure 4 where it shows the frequency changes with respect to the distance.

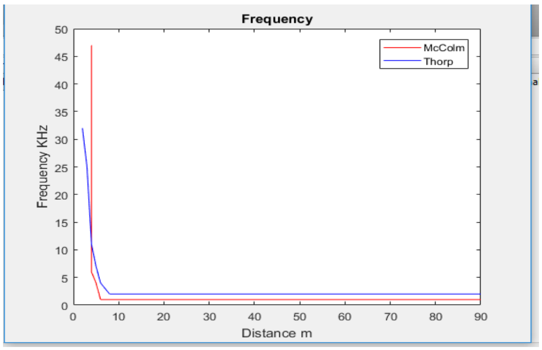

Fig. 4. Optimal Frequency vs distance

Table 2: Optimal Frequency Values for Different Ranges

Range (Km)	Optimal Frequency (KHz)	
	McColm	Thorp
1-100	47	32

The optimal range of frequencies for McColm and Throp is given in Table 2. Channel capacity and distance are reciprocals to each other also channel capacity is a function of bandwidth. The relation between capacity and bandwidth is so strongly that the curves for both parameters will look identical. From fig 5 it is obvious that both bandwidth and capacity have identical curves.

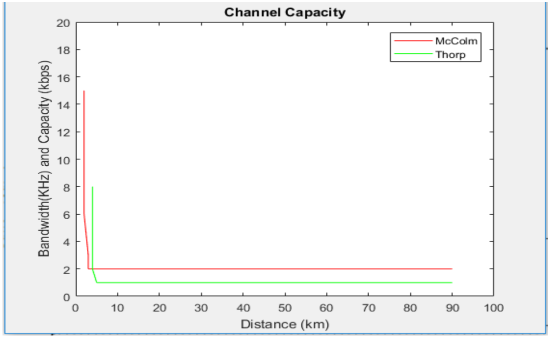

Fig. 5. Bandwidth and Capacity

As long and medium range distances are simulated**,** the typical bandwidthvalues for different underwater channels is based on distance [10, 11]. For distances between 10-1000Km the bandwidth is between 5KHz to less than1KHz, distances between 0.1 to 10Km is between 10-50KHz and for distances less than 0.1km the bandwidth is greater than 100KHz

As the simulation was carried out for long and medium range the bandwidth and capacity are close in the given range.

Table 3: Simulated bandwidth value

	Range(Km)	Bandwidth(KHz) & Capacity (Kbps)	
		McColm	Thorp
Long	10-100	2	1
Medium	1-10	15	8

V. CONCLUSION

Conclusion from the paper is that, for modelling an efficient communication channel, an optimal frequency exists at a transmission distance where the loses are minimum. It is also seen that both capacity and bandwidth have identical curves and as distance increases the bandwidth decreases and in turn the capacity decreases. Thus, it can be deduced that shorter distance has larger bandwidth hence more capacity.

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