Modeling and Simulation of Acoustic Link Using Mackenize Propagation Speed Equation

Christhu Raj M. R., Rajeev Sukumaran

Abstract—Underwater acoustic networks have attracted great attention in the last few years because of its numerous applications. High data rate can be achieved by efficiently modeling the physical layer in the network protocol stack. In Acoustic medium, propagation speed of the acoustic waves is dependent on many parameters such as temperature, salinity, density, and depth. Acoustic propagation speed cannot be modeled using standard empirical formulas such as Urick and Thorp descriptions. In this paper, we have modeled the acoustic channel using real time data of temperature, salinity, and speed of Bay of Bengal (Indian Coastal Region). We have modeled the acoustic channel by using Mackenzie speed equation and real time data obtained from National Institute of Oceanography and Technology. It is found that acoustic propagation speed varies between 1503 m/s to 1544 m/s as temperature and depth differs. The simulation results show that temperature, salinity, depth plays major role in acoustic propagation and data rate increases with appropriate data sets substituted in the simulated model.

Keywords—Underwater Acoustics, Mackenzie Speed Equation, Temperature, Salinity.

I. INTRODUCTION

UNDERWATER SENSOR NETWORKS (UWSN) play an important role in the development of aquaculture, marine monitoring, pollution monitoring, military applications, offshore exploration, monitoring of flora and fauna and natural disasters like cyclones, tsunamis [1]. To construct such potential applications, terrestrial sensor network features and its parameters are not applicable for underwater acoustics sensor networks. UWSN exhibits several organizational and architectural challenges with respect to terrestrial sensor networks mainly due to its transmission medium characteristics and acoustics signals employed to transmit data [2]. Underwater acoustic channel differs from terrestrial wireless radio channels in many ways; for instance, the propagation speed of acoustic wave is at least five orders of magnitude lower than that of wireless radio channels. Only when we have a complete understanding of acoustic channel characteristics, it is possible to design a proper acoustic transmission system that can match the real-time marine environment. While designing the underwater communication environment the following problems like limited bandwidth, extended multipath, refractive properties of the medium, fading [3] needs to be addressed. In any wireless communication, designing an efficient and reliable communication channel is not an easy task. It is worth mentioning the same, as according to author's literature work, lot of research work in routing and MAC Protocols in UWSN are based on the characteristics of underwater acoustic channel [4]. Sound Field Model mainly includes the normal wave model, radiation model, fast sound field model, and the parabolic equation model [5]. The models of underwater acoustic channel mainly contain the deep vertical channel model and the shallow-water multi-path channel model. While the shallow-water multipath channel model can be divided into multi-path model based on ray theory, random time varying filter channel model and random statistical channel model [6]-[8]. Researchers simulate the underwater acoustic channel by establishing suitable mathematical models and then study the various properties using software simulation. Furthermore, the usable bandwidth of an underwater sound channel is typically a few kHz at large distances. In this research work, we have modeled the physical channel of underwater acoustics communication layer, as this layer serves as the foundation for the remaining layers and protocols in the ISO/OSI model [9]. We have considered the underwater physical layer channel parameters such as propagation speed, propagation loss, background noise, transmission loss, received power; propagation delay also needs to be considered. The existing work in literatures, model the acoustic propagation speed as 1500 m/s. This refers to empirical relation of the speed of sound. However, the speed of sound in water differs from the speed of sound in air medium; similarly acoustic wave propagation speed differs from sea to sea and from ocean to ocean. The bathymetry data shows that sound velocity in Pacific Ocean is around 1450 to 1485 m/s and in Atlantic Ocean, it varies from 1450 to 1500 m/s and in the Indian Ocean, Arabian Sea, and Bay of Bengal, it varies between 1490 to 1540 m/s. Therefore, the velocity of sound variation depends on parameters like temperature, salinity, depth, and pressure. In existing models, propagation speed is set to 1500 m/s whereas [10] proposed the nine-parameter equation to calculate the propagation of sound in water based on the parameters mentioned such as temperature, density, salinity, and depth. However, this work went unnoticed as researchers modeled the acoustic channel using the approximate speed velocity as 1500 m/s. In this work, we have modeled the acoustic link using Mackenzie propagation speed equation. Parameters such as temperature, density are obtained from real-time data in Bay of Bengal provided by National Institute of Ocean and Technology, India and Bathymetric data of Oceans for simulation purposes.

Christhu Raj is an External Research Scholar at the Centre for Research, Anna University, Chennai, India (e-mail: mrchristhuraj@gmail.com).

Rajeev Sukumaran is with the Teaching Learning Centre, Indian Institute of Technology Madras, Chennai, India (e-mail: rajeev@ieee.org).

World Academy of Science, Engineering and Technology
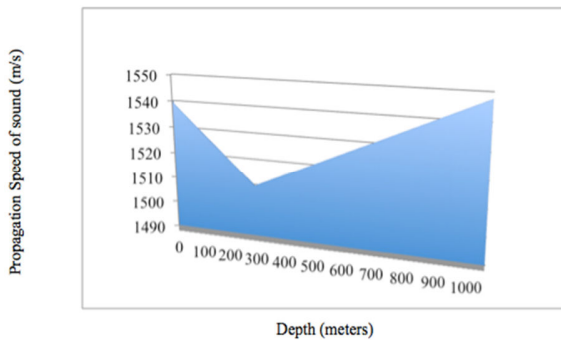International Journal of Computer and Information Engineering
Vol:9, No:10, 2015

Fig. 1 Propagation speed vs. Depth

In this paper, we have modeled the acoustic link using Mackenzie equation and real time data like depth, temperature and salinity. Propagation speed values changes with respect to depth and temperature. Therefore, we have modeled acoustic propagation with the real time values obtained from Bathymetry data. The results show acoustic propagation speed plays vitals role in the transmission of data.

The rest of this article is as follows, Section II shows the existing physical channel modeling, and Section III explains the parameter metrics needed for modeling an acoustic channel using standard equations followed by its simulations using industrial popular network simulator OPNET. Section V shows the result analysis and discussions followed by conclusions and future work.

II. EXISTING MODELS FOR ACOUSTIC COMMUNICATION

Designing an efficient and reliable communication channel is a major challenge in any wireless communication. Several work in literature models the underwater acoustic link taking into account of environment parameters such as salinity, temperature, depth, environmental noise, etc. The first implemented model was by [11]. In this model, the authors proposed a simple physical acoustic model based on the fundamentals of underwater physics. This model has failed to address the important parameters such as sensor's node density and depth. AUVNet Sim [12] model simulates the underwater acoustic channel by considering few underwater environment parameters, but the Physical Layer of the network is simple and it considers only the Thorp equation [13] in the channel. To implement a reliable and efficient model, the acoustic parameters must be taken into consideration and moreover the Throp formula addresses only the seawater absorption. Therefore, there will be significant difference in simulation results obtained in comparison with real-time marine network deployments. Xie and Gibson model [14] based on Monterrey Miami Parabolic Equation (MMPE) calculates the propagation and evolution of sound pressure produced by an acoustic source in an underwater scenario. MMPE suits well for small networks, but scalability is a major concern in this communication model and MMPE is not applicable for larger communication networks. Harris model [15], [16] was implemented by considering the node parameters like node density, propagation loss and

transmission loss, but the results obtained were not accurate since node depth, mobility and environmental conditions were never taken into consideration for modeling the acoustic channel. URICK and THROP Formula [13] were based on the theory of sound propagation i.e., Molecular Movement in an elastic substance propagates to adjacent particles [17]. The empirical formula defined by Throp is that the sound intensity decreases through the path between a given transmitter and the receiver and the absorption factor were dependent on the sound frequency [18]. The above models of URICK and Throp never considered the node density, depth, and environmental parameters. Bell Hop Ray Tracing [19] requires the solution of ray equations to determine the ray coordinates of the acoustic signal propagation. This tool is integrated with empirical formulas from world databases that measure Sound Speed Profile, bathymetry, and floor sediment such as General Bathymetric Chart of the Oceans (GEBCO) and National Oceanic and Atmospheric Administration. Bellhop model provides an accurate calculation of the acoustic propagation model, but propagation delays and signal attenuation values being computationally infeasible to support more complex model in UWSN Simulation. Most of these works never considered many important parameters in the acoustic wireless underwater communication. Few of those parameters are listed as follows; (1) the depth of the nodes, which is an essential factor for calculating the transmission loss; (2) the movement of the nodes that happens due to the continuous movement of the seawater. Adding mobility to the nodes has an increase of the computational time in calculating the list of reachable nodes all the time of the communication; (3) the environmental conditions (4). According to the author literature, there are few works that models the acoustic propagation speed using [10], [20]-[23] methods. The underwater network is a highly dynamic environment as many features can have an effect on it, like underwater biology (whales, fish banks, etc.), the changing climate of the surface, the sea tides, ship and human activity [24], [25]. Therefore, despite all the previous works, there is still a need to seek a complete model to simulate and define more realistic scenarios for underwater data communications

III. PERFORMANCE METRICS FOR MODELING UNDERWATER ACOUSTIC COMMUNICATION

In this section, we present the performance metrics used in modeling underwater acoustic channel. The propagation of acoustic communication will change in salinity, temperature, and the pressure. As per the Bathymetric data and the data from National Institute of Oceanography and Technology, India's acoustic propagation speed will range from 1503 to 1544 m/s in the Bay of Bengal Ocean. Fig. 1 explains the propagation speed in water with respect to depth.

A. Propagation Speed

Propagation speed or velocity is considered to be the critical parameter in the acoustic link modeling. As mentioned earlier, propagation speed of acoustic waves differs from sea to sea and from ocean to ocean and it is necessary to set the

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:9, No:10, 2015

appropriate value in the acoustic channel to obtain efficient simulation results. Acoustic Propagation speed can be calculated using the following model proposed by Mackenzie [10];

$$
\begin{aligned}
c = {}& 1448.96 + 4.591T - 5.304 * 10^{-2}T^2 + 2.374 * 10^{-4}T^3 \\
& + 1.340(S - 35) + 1.630 * 10^{-2}D + 1.675 \\
& * 10^{-7}D^2 - 1.025 * 10^{-2}T(S - 35) - 7.139 \\
& * 10^{-13}TD^3
\end{aligned}
\tag{1}
$$

where, T= Temperature in Celsius (2 to 30); S=Salinity parts per thousand (25 to 40 PPM); D=Depth of Sea in meters (0 to 800 m).

B. Transmission Loss

Acoustic Transmission Loss (ATL) is reduction of sound intensity from the transmitter to the receiver. There are many underwater acoustic signal-modeling techniques [26] used for modeling Underwater Communication. The acoustic signals used for underwater communication are subjected to fading due to a) Spreading and b) Attenuation. Transmission loss can be measured based on empirical expressions as

$$
ATL = cr * 10 \log r + \alpha r * 10^{-3}
\tag{2}
$$

where $cr = 1$ for spherical spreading loss, $cr = 2$ for cylindrical spreading loss in deep water. However, since sound energy is not perfectly contained by reflection (reflection coefficients less than 1) and refraction, the true spreading is often somewhere between the predictions given by $cr = 1$ and $cr = 2$. Thus, a practical spreading equation which represents an intermediate spreading condition between spherical and cylindrical spreading that is $cr = 1.5$. r is the range in meters α is the attenuation factor given as

$$
\alpha = \frac{0.11f^2}{1 + f^2} + \frac{44f^2}{4100 + f^2} + 2.75 * 10^{-4}f^2 + 0.003
\tag{3}
$$

where $\alpha(f)$ is given in dB/km, f is the center frequency of the transmitted signal in kHz.

C. Propagation Loss

The Monterrey Miami Parabolic equation model [24] provides a better framework to predict and calculate the underwater acoustic propagation loss using a parabolic equation. This model replicates the Helmholtz wave equation [25] and is based on Fourier analysis. By implementing a dynamic propagation loss calculation, this model proves that small changes in the acoustic parameters such as node distance, depth can result in wide differences in the acoustic propagation loss. The acoustic propagation loss formula for MMPE model is as

$$
PL(t) = m(f, s, d_A, d_B) + w(t) + e()
\tag{4}
$$

PL(t): Propagation loss in transmitting from node A to B; m(): Propagation loss without random and periodic components; obtained from regression using MMPE; f: Frequency of transmitted acoustic signals in (kHz); d_A: Sender's depth (in meters); d_B: Receiver's depth (in meters); s: Euclidean

Distance between A and B nodes (in meters); w(t): Periodic function to approximate signal loss due to wave movement; e(): Signal loss due to random noise or error.

The function m() represents the propagation loss provided in the MMPE Model. The equation to calculate m() function

$$
= \log\left(\left|\frac{\left(\frac{s}{0.914}\right)^{A0}(d_A)^{A9}s^{A7}((d_A - d_b)^2)^{A10}}{(s * d_B)^{10A5}}\right|\right) +
$$
$$
\left(f^2\left(\frac{A1}{1 + f^2} + \frac{40}{4100 + f^2} + 0.00275\right) + 0.003\right) * \left(\frac{s}{914}\right) + A6 * d_B + A8 * s
$$

The w() function approximates the signal loss due to the acoustic wave movements. The common waves have hundreds of meters of wavelength and have an effect up to 50meters of depth. For calculating the effects of the wave, we have considered the equation

$$
w(t) = h(l_w, d_b, t, h_w, T_w)E(t, T_w)
\tag{5}
$$

where: h(): Scale factor function; l_w: Ocean wavelength (meters); d_B: Depth of the receiver node (meters); h_w: Wave height (meters); T_w: Wave period (Seconds); E(): Function of wave effects in nodes.

$$
h(l_w, d_b, t, h_w, T_w) = \frac{\left(h_w\left(1 - \left(\frac{2d_B}{l_w}\right)\right)\right)}{0.5} * \left|\sin\left(\frac{2\pi(\bmod T_w)}{T_w}\right)\right|
\tag{6}
$$

The e() function represents a random term to explain the background noise. The number of sound sources is large and undetermined. This random noise follows a Gaussian distribution and is modeled to have a maximum of 20 dB at the furthest distance. This function is calculated as

$$
e() = 20\left(\frac{s}{s_{max}}\right)R_N
\tag{7}
$$

where: e(): Random noise function; s: Distance between the sender and receiver (in meters); s_{max}: Maximum distance (transmission range in meters); R_N: Random number from a Gaussian distribution centered in 0 and with variance 1.

D. Propagation Delay

Mobility plays an important role in the underwater sensor nodes. Nodes deployed underwater cannot be in static position as factors like strong currents, winds, waves makes it tough to deploy. So while calculating the propagation delay for mobile nodes, the following formula needs to be addressed

$$
T_P = (d_{start}/\bar{c} + d_{end}/\bar{c})/2
\tag{8}
$$

where d_{start} = Distance between transmitter and receiver at the beginning of the simulation (meters); d_{end} = Distance between transmitter and receiver at the end of the simulation (meters); $\bar{c}$= Velocity of Sound, from Mackenzie (1).

E. Background Noise

The noise includes environmental noises, the emission receiver noise, discrete ship noise, and disturbance noise. The size of environmental noise is directly affects Signal-to-Noise

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:9, No:10, 2015

(SNR) of the receiver and largely determines the transmitting power. Ocean Ambient noise is complex and changeable and it is described using Wenz Model. However, Thermal Noise of the Wenz model does not simulate the thermal noise generated by transmitting and receiving equipment.

$$N_{Shipping} = 40 + 20*(D - 0.5) + 26\ln(f) - 60\ln(f + 0.03)$$
$$N_{Wind} = 50 + 7.5w^{0.5} + 20\ln(f) - 40\ln(f + 0.4)$$
$$N_{Thermal} = (rx_{temp} + bkg_{temp}) * rx_{bw} * BOLTZMANN$$
$$rx\_temp = (rx_{noisefig} - 1.0) * 290.0$$
$$N_{Turbulence} = 17 - 30\ln(f)$$

The total Noise is calculated as

$$N_{All} = N_{Turbulence} + N_{Shipping} + N_{Wind} + N_{Thermal} + e() \qquad (9)$$

N_Turbulence: Turbulent Noise; N_Wind: Surface Noise; f: Center Frequency of the transmitted Signal (in kHz); w: Is the Ocean Surface Wind Speed (in m/s); D: Is the Shipping Density values ranges between 0 to 1; rx_temp: Device temperature; bkg_temp: Background Temperature; rx_bw: Receiver Bandwidth; BOLTZMANN: Boltzmann Constant; rx_noisefig: Noise Figure; e(): Random noise function calculated from MMPE Model.

F. Received Power and Signal-to-Noise Stage

The received power signals obey the exponential distribution, as for all arriving packets, whether valid or invalid, the average power level of the received signal is computed by the sonar equation which takes account of the transmitted power, the path loss and receiver and transmitted antenna gains. The final receiver power is calculated as:

$$p = SL - TL + TS + DI \qquad (10)$$

SL = Source Level , TL = Transmission loss, TS = Transducer gain, DI = Receiving Transducer Gain (Values 0-1)

At this point, the power difference between $\overline{p_z}$ and p, is

caused by time varying multipath and Doppler Effect and Signal to Noise stage is expressed as

$$SNR = \rho / N(f)B \qquad (11)$$

ρ is the Received Power, $N(f)$ is single noise power spectral density. B is the system bandwidth.

G. Bit Error Stage Model

Acoustic Bit error rate, BER is a key parameter that is used in assessing systems that transmit digital data from one location to another.

IV. MODELING ACOUSTIC CHANNEL

We have modeled the acoustic channel using well-known popular industrial software OPNET. The fourteen Stage Transceiver Pipeline used by the Simulation Kernel (SK) to evaluate the characteristics of wireless communication, with the first 6 pipeline stages implemented in the transmitter node and remaining 8 in the receiver node. To implement an efficient acoustic link model, an accurate underwater channel model need to be implemented in the transmitter node and receiver node.

A. Propagation Speed

Propagation speed is calculated using the Mackenzie [10] nine parameters speed propagation mentioned in (1). Propagation delay is the sixth stage in the radio transmitter stage in OPNET and it is mentioned as propdel model. The default propagation delay model for radio links, dra_propdel calculates delay based on the distance separating the transmitter and receiver, and the propagation velocity of radio waves. We need to replace the propagation velocity of radio waves with propagation velocity of acoustic waves 1503-1540 m/s. Therefore; the following modifications should be done in this stage.

TABLE I
UWA_PROPDEL.PS.C

```
#include "opnet.h"
#include "math.h"
#define T 18
#define S 27
#define D 4500
uwa_propdel_mt(OP_SIM_CONTEXT_ARG_OPT_COMMA Packet * pkptr) {
/*Mackenzie equation for Propagation speed */
double PROP_VELOCITY=(1448.96+4.591T)-(5.304*pow
(10,-2)*T*T)+2.374*pow(10,4)*T*T*T+1.340(S-35)+1.630*
pow(10,-2)*D+1.675*pow(10,-7)*D*D-1.025*pow(10,-2)T
(S-35)-7.139*pow(10,-13)*T*D*D*D;
double start_prop_delay, end_prop_delay;
double start_prop_distance, end_prop_distance;
FIN_MT (uwa_propdel (pkptr));
start_prop_distance = op_td_get_dbl (pkptr, OPC_TDA_RA_
START_DIST);
/* Getting distance between transmitter and receiver. */
end_prop_distance = op_td_get_dbl (pkptr, OPC_TDA_RA_
END_DIST);
/* Computing propagation delay to start of reception. */
start_prop_delay = start_prop_distance / PROP_VELOCITY;
/* Propagation delays in Packet transmission data attributes. */
op_td_set_dbl (pkptr, OPC_TDA_RA_START_PROPDEL,
start_prop_delay);
op_td_set_dbl (pkptr, OPC_TDA_RA_END_PROPDEL,
end_prop_delay);
FOUT }
```

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:9, No:10, 2015

B. Transmission Loss

Transmission Loss is implemented in the receiver node of the model. For all arriving packets, whether valid or invalid, the average power level of the received signal is computed by (2). This computation is a link budget, which takes into account of transmitter power, the path loss and receiver and transmitter antenna gains. The transmission loss for underwater channel is defined as the accumulated decrease in acoustic intensity when an acoustic pressure wave propagates outwards from a source. Transmission loss can be implemented in the sixth stage of the transmitter node. The attenuation factor for shallow water is calculated by (3).

TABLE II
UWA POWER.PS.C

```
#include "opnet.h"
#include "math.h"
/* Coding for Calculating Speed of Sound */
uwa_power_mt(OP_SIM_CONTEXT_ARG_OPT_COMMA    Packet
*pkptr) {
double a, b;
FIN_MT (uwa_,power(pkptr));
a=pow(tx_center_freq,2);
b=0.1*a/(1+a)+40*a/(4100+a)+0.000275*a+0.003;
path_loss=path_loss+n*10*log(prop_distance)+b*prop_d
istance*0.001;
FOUT }
```

C. Propagation Loss

Propagation loss mainly describes the loss in the medium of the wireless channel. In our case it is acoustic medium. During the process of transmitting the acoustic signal from the acoustic source to the acoustic receiver, the signal energy is prone to the propagation loss, which influences the signal-to-noise ratio in the receiver side. When the sound wave frequencies are above 1kHz, seawater acoustic absorption is the main factor causing acoustic wave attenuation and is proportional to the square of the wave frequency. After integrating a large number of measure results, the propagation loss for acoustic transmitting medium is given by Monterrey-Miami Parabolic Equation (MMPE Model) in (4)-(7). This model exactly simulates the propagation loss in acoustic medium. Since the proposed model considers appropriate underwater acoustic parameters such as temperature, density, depth, salinity it results in more efficient outcomes.

D. Propagation Delay

Concerning the mobility of the acoustic node, the pipeline mechanism calculates two delays namely, the delay to start of reception and the delay to the end of reception. In addition to the transmission delay, the propagation delay is another delay when there is acoustic packet transmission through the acoustic wireless channel. In the acoustic wireless simulation, considering the movement of the acoustic station, the distance between the transmitter and receiver could be changing all the time. Therefore, there is a need for a calculation in relation to the delays, namely, the start of the propagation delay and the end of the propagation delay and calculated using (8).

TABLE III
UWA POWER.PS.C

```
/* Compute the m() function Propagation Loss based
on MMPE Model */
#include "opnet.h"
#include "math.h"
double        propLoss(double       frequency,double
Sourcedepth, double Distance,
double receiverdepth, double waveP,double waveH) {
double pLoss, wavePL, plr;
FIN(propLoss(frequency,Sourcedepth,Distance,receive
rdepth,waveP,waveH));
pLoss=
getPloss(frequency,Sourcedepth,Distance,receiverdep
th);
wavePL=
getWavePL(waveLenght,op_sim_time(),waveP,waveH,rece
iverdepth );
plW = addWavePL(pLoss,wavePL);
plr = getRandompl(Distance);
FRET (plW+plr); }
```

TABLE IV
UWA PROPDELAY.PS.C

```
#include "opnet.h"
#include "math.h"
#define T  18
#define S  27
#define D  1800
uwa_propdel_mt(OP_SIM_CONTEXT_ARG_OPT_COMMA  Packet
* pkptr) {
/*Implementation   of   Mackenzie   equation   for
Propagation speed */
doublePROP_VELOCITY=(1448.96+4.591T)-
(5.304*pow(10,-
2)*T*T)+2.374*pow(10,4)*T*T*T+1.340(S-
35)+1.630*pow(10,-2)*D+1.675*pow(10,-7)*D*D
-1.025*pow(10,-2)T(S-35)-7.139*pow(10,-
13)*T*D*D*D;
double     start_prop_delay,     end_prop_delay,
total_prop_delay;
double start_prop_distance, end_prop_distance;
FIN_MT (uwa_propdel (pkptr));
start_prop_distance   =   op_td_get_dbl   (pkptr,
OPC_TDA_RA_START_DIST);
/* Get the end distance between transmitter and
receiver. */
end_prop_distance    =    op_td_get_dbl    (pkptr,
OPC_TDA_RA_END_DIST);
/* Compute propagation delay to start of
reception. */
start_prop_delay   =   start_prop_distance   /
PROP_VELOCITY;
/* Compute propagation delay to end of reception.
*/
end_prop_delay     =     end_prop_distance     /
PROP_VELOCITY;
/* Place both propagation delays in packet
transmission data attributes. */
total_prop_delay=(start_prop_delay+end_prop_delay)
/2;
op_td_set_dbl  (pkptr,  OPC_TDA_RA_START_PROPDEL,
start_prop_delay);
op_td_set_dbl  (pkptr,   OPC_TDA_RA_END_PROPDEL,
end_prop_delay);
op_td_set_db1(pkptr,OPC_TDA_RA_TOTAL_PROPDEL,total
_prop_delay);
FOUT }
```

E. Background Noise

Acoustic signals are corrupted because of fading and noise. The overall noise in the underwater acoustic channel

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:9, No:10, 2015

communication system includes the environmental noises, emission of receiver noise, discrete ship noise, ambient noise, and turbulence noise. The noise directly affects the Signal-to-Noise Ratio of the received signal in the receiver stage. Ocean and sea ambient noise is more complex and it changes with respect to time and sea area. Wenz model is suitable for describing the noise in the underwater communication; however, it failed to address the thermal noise and doesn't simulate the thermal noise generated by transmitter and receiver equipment. So considering the parameters like ambient noise, turbulence, and shipping can simulate the background noise, waves, thermal noise, the overall power spectral density on the ambient noise given by (9).

TABLE V
Uwa_Bcknoise.ps.c

```
#include "opnet.h"
#include<math.h>
#define BOLTZMANN   1.379E-23
#define BKG_TEMP   290.0
#define AMB_NOISE_LEVEL 1.0E-26
void uwa_bkgnoise_mmp(OP_SIM_CONTEXT_ARG_
OPT_COMMA Pacet *pkpts){
/* Calculating mmpe_e function*/
double      s=      op_td_get_dbl      (pkptr,
OPC_TDA_RA_TX_DIST);
double s_max= op_td_get_dbl (pkptr, OPC_TDA_RA_RX_
TRANG);
double mmpe_e= 20 *(s/smax)*0.5;
void uwa_bkgnoise_mt (OP_SIM_CONTEXT_ARG_OPT_
COMMA Packet * pkptr) {
double rx_noisefig, rx_temp, rx_bw;
double bkg_temp, bkg_noise, amb_noise;
double n1_t,n1_w,n1_s,n1_th,s=0.6,w=10;
double tx_base_freq,tx_bandwidth,tx_center_freq,f;
/* Noise   sources   other   than   transmission
interference. */
FIN_MT (uwa_bkgnoise (pkptr));
/* Get receiver noise figure. */
rx_noisefig = op_td_get_dbl (pkptr, OPC_TDA_RA_RX_
NOISEFIG);
/* Calculate effective receiver temperature. */
rx_temp = (rx_noisefig - 1.0) * 290.0;
/* Set the effective background temperature. */
bkg_temp = BKG_TEMP;
/* Get receiver channel bandwidth (in Hz). */
rx_bw = op_td_get_dbl (pkptr, OPC_TDA_RA_RX_BW);
bkg_noise  =  (rx_temp + bkg_temp)  *  rx_bw  *
BOLTZMANN;
tx_base_freq      =      op_td_get_dbl      (pkptr,
OPC_TDA_RA_TX_
FREQ)
tx_bandwidth      =      op_td_get_dbl      (pkptr,
OPC_TDA_RA_TX_
BW);
tx_center_freq = tx_base_freq + (tx_bandwidth /
2.0);
f=tx_center_freq;
n1_t=pow(10,(17-30*log(f))*0.1);
n1_s=pow(10,(40+20*(s-0.5)+26*log(f)-
60*log(f+0.03))*0.1);
n1_w=pow(10,(50+7.5*pow(w,0.5)+20*log(f)-
40*log(f+0.4))*0.1);
n1_th=pow(10,(-15+20*log(f))*0.1);
bkg_noise=bkg_noise+n1_t+n1_s+n1_w+n1_th+mmpe_e;
/* Calculate in-band ambient noise. */
amb_noise = rx_bw * AMB_NOISE_LEVEL;
op_td_set_dbl      (pkptr,      OPC_TDA_RA_BKGNOISE,
(amb_noise + bkg_noise));FOUT }
```

F. Received Power

This stage calculates the receiver antenna gain and receiver power by using the value of the reference frequency and the bandwidth obtained by overlapping acoustic bandwidth and by obtaining the location of the transmitter and receiver and calculates the distance value. The final receive power value is based on the free space path loss model.

TABLE VI
Uwa_Power.ps.c

```
/* Code Snippet for Received Power*/
#include "opnet.h"
#include "math.h"
rx_base_freq = op_td_get_dbl (pkptr, OPC_TDA_RA_RX_
FREQ);
rx_bandwidth = op_td_get_dbl (pkptr,OPC_TDA_RA_RX
_BW);
if (rx_base_freq > tx_base_freq)
band_min = rx_base_freq;
else band_min = tx_base_freq;
if (rx_base_freq + rx_bandwidth > tx_base_freq +
tx_bandwidth)
band_max = tx_base_freq + tx_bandwidth;
else band_max = rx_base_freq + rx_bandwidth;
in_band_tx_power = tx_power * (band_max - band_min)
/ tx_bandwidth;
tx_ant_gain=pow(10.0,
op_td_get_dbl(pkptr,OPC_TDA_RA_TX_GAIN)/ 10.0);
rx_ant_gain=pow(10.0,op_td_get_dbl(pkptr,OPC_TDA_RA_
RX_GAIN)/10.0);
/* Calculate received power level. */
rcvd_power=   in_band_tx_power   *   tx_ant_gain   *
path_loss * rx_ant_gain;
op_td_set_dbl      (pkptr,      OPC_TDA_RA_RCVD_POWER,
rcvd_power);
FOUT   }
```

TABLE VII
Uwa_Ber.ps.c

```
#include "opnet.h"
void ura_ber_mt (OP_SIM_CONTEXT_ARG_OPT_
COMMA Packet * pkptr) {
double ber, snr, proc_gain, eff_snr;
Vartype modulation_table;
/*Calculating average bit error rate affecting given
packet. */
FIN_MT (dra_ber (pkptr));
snr = op_td_get_dbl (pkptr, OPC_TDA_RA_SNR);
modulation_table = op_td_get_ptr (pkptr, OPC_TDA_RA_
RX_MOD);
proc_gain = op_td_get_dbl (pkptr, OPC_TDA_RA_PROC
_GAIN);
eff_snr = snr + proc_gain;
ber = op_tbl_mod_ber (modulation_table, eff_snr);
op_td_set_dbl (pkptr, OPC_TDA_RA_BER, ber); FOUT }
```

The receiver power stage is the crucial aspect of the acoustic channel modulation as the received power reveals about the correctness and validates acoustic channel that has been modeled. This computation is a link budget, which takes into account the initial transmitted power, the path loss, and receiver and transmitter antenna gains. It can be calculated by using (10).

G. Bit Error Rate and Signal to Noise Ratio

The next stage is calculating the signal-to-noise ratio for the acoustic packets. Acoustic signal modeling must consider appropriate mathematical modeling tools [27]. This is because,

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:9, No:10, 2015

BER and SNR can be eliminated, if modeling is done using appropriate modeling tools. The value of the SNR directly reflects the received power, background noise and interference noise. The SNR of the value is calculated individually in various periods. Finally after calculating the values in different period these are added together to provide the SNR value. The effective SNR can be calculated using (11). Bit error rates are computed the based on the modulation curve or modulation attribute could be set to different values and the modulation attribute is related to the channel model.

V. Model Implementation and Result Analysis

This section will provide the model implementation and result analysis. As mentioned in the existing work, there are few acoustic model available that addresses the node parameters issues like density, mobility, depth, and node scalability. In our work, we have modeled the acoustic link by considering the above parameters and using accurate speed of acoustic waves obtained from real time data.

TABLE VIII
SIMULATION PARAMETERS

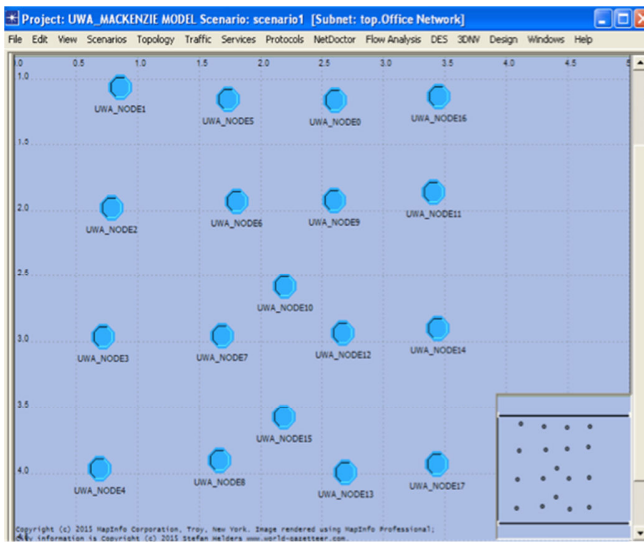| Parameters	Values
Channel Bandwidth	40 kHz
Carrier Frequency	20 kHz
Node Count	18
Temperature	18 0c
Salinity	27
Depth	4500 m
Density	50 m

Fig. 2 Network topology

A. Propagation Delay Stage

In this stage, the dra_propdel radio transceiver is modified with the acoustic parameters model. The default propagation velocity is replaced with acoustic propagation velocity using Mackenize equation. The necessary functional block code added in this stage is explained in Table I. This replaces the propagation velocity of light waves with the propagation velocity of acoustic waves. In order to implement the mobility in the nodes, trajectory needs to be set for each node. Trajectory will set the path for the nodes to traverse and propagation delay is implemented in this stage using the coding mentioned in Table IV. Source snippets in Table I and IV are implemented in this stage to calculate the propagation speed and propagation delay in our simulation model.

B. Receiver Power Stage

This receiver power stage is the eight stage of the acoustic transceivers and this stage computes the average power level of the received signal. This stage becomes important as the transmission loss is implemented in this stage. Apart from the acoustic transmission loss from Table II, propagation loss based on MMPE model from Table III is being implemented to compute the loss models. The final received power is calculated based on the Table VI coding. This computation takes into the account of the initial transmission power, the path loss, and receiver, transmitter antenna gains. The acoustic transmission loss for the underwater acoustic channel can be defined as the accumulated decrease in acoustic intensity, when an acoustic pressure wave propagates outwards from the source.

C. Background Noise Stage

The overall noise in the acoustic transmission involves turbulence noise, ambient noise, shipping noise, wave noise and thermal noise. The total power spectral density can be implemented in this channel by using the coding from Table V. This computes the overall noise generated in the acoustic transmission. The network topology for simulation model is shown in Fig 2.

D. Signal to Noise Ratio

In this stage, the value of the signal-to-noise ratio for the given packet is calculated. The received SNR is calculated in Table VII. This value is affected by the received power and the sum of the background noise and interference noise. In a whole packet reception process, there might be many packets arriving at the same time.
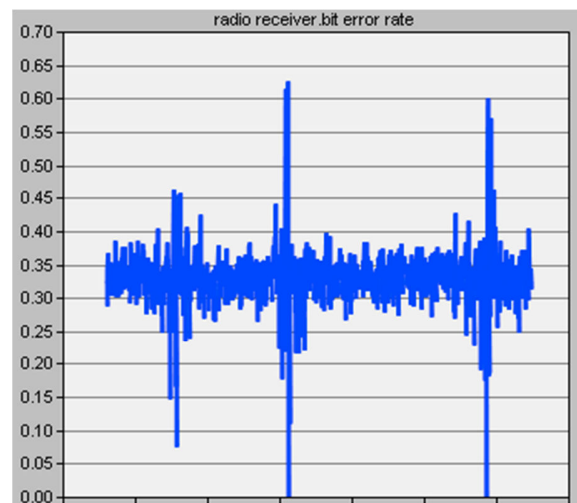

Fig. 3 Bit error rate in acoustic receiver

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:9, No:10, 2015

Because of new interference, the signal to noise ratio should be evaluated again and again. Therefore, the SNR value is calculated separately in different periods. These are then added together to provide the final SNR.

E. Bit Error Rate (BER)

In this stage, BER is calculated based on modulation curve. According to the BER value, the error bits are put into the packet randomly. The specific calculation method is to calculate the bit errors probability and then compare this with a random number from 0 to 1. If it is bigger than the random number, this bit is an error bit. Fig. 3 shows the BER calculated in the receiver level. Fig. 4 shows the acoustic link model transmission loss as a function of distance between the nodes in various frequencies. From this graph it is clear that, the transmission loss increases as distance between nodes increases. We have modeled the acoustic link with different frequencies. This proves that propagation speed (Mackenzie) in water and distance (depth) plays vital role in carrying the information. Fig. 5 explains shows, when the transmitted power and carrier frequency are fixed, the SNR and BER decrease with distance increases and it also fluctuates with time.
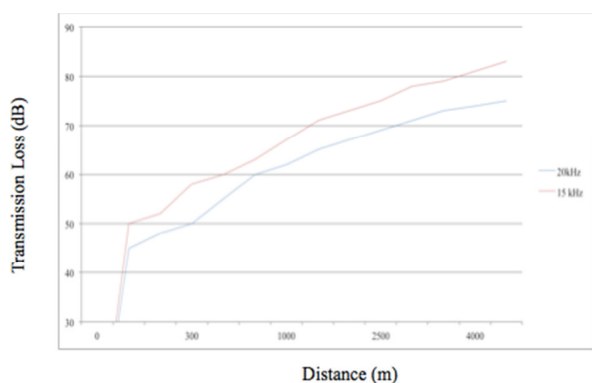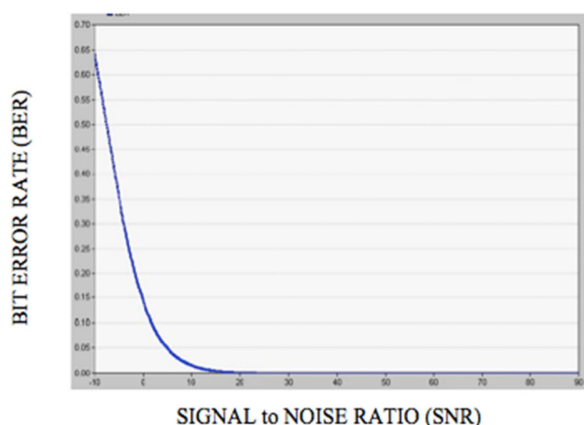

Fig. 4 Transmission loss vs distance

Fig. 5 BER vs SNR

It is noted clearly that the significant time-varying effect of underwater acoustic channel is modeled and average SNR obtained from the simulation decreases with distance. Even though there is complexity of underwater acoustics channel, delay is calculated in appropriated manner. This shows that the sound velocity is stable, when we compute using proper mathematical equation (Mackenzie equation) rather than assuming the propagation speed as 1500 m/s.

VI. CONCLUSION AND FUTURE

In this research paper, we have studied, designed and implemented underwater acoustic communication model with accurate speed equation model. The model serves best for upper layer protocols, as we have modeled the acoustic link propagation with corresponding to real time data like temperature, salinity and depth. This model is based on the characteristics of underwater acoustic channel. In-order to define an appropriate acoustic channel modeling slight changes in propagation model is needed and this will significantly affect the final results obtained in our simulation model. Since propagation speed differs in different geographic regions, there is need to model the propagation speed with real time data obtained. As future work, we will consider improving the model with various propagation speed equations like Del Grosso model, Chen and Millero Model, Coppens Model and Medwin Model

REFERENCES

[1] Jesus Llor M, P. Malumbres,"Underwater Wireless Sensor Networks: How Acoustic Propagation Models Impact on the Performance of Higher-level Protocols?", *Sensors* Vol. 12, No. 2, pp. 1312-1335, 2012
[2] Akyildiz. F, Pompili. D, Melodia T, "State of the Art in Protocol Research for Underwater Acoustic Sensor Network". *Proceedings of the ACM International Workshop on Underwater Networks (WuWNet)*, pp.7-16, 2006
[3] Christhu Raj, Rajeev Sukumaran ,"Modeling UWSN Simulators- A Taxonomy", *International Journal of Computer, Electrical, Automation, Control and Information Engineering, World Academy of Science, Engineering and Technology,* Vol. 9, No. 2, pp. 585-592, 2015.
[4] Weigang Bai, Haiyan Wang and Ruiqin Zhao, "Modeling Underwater Time-Varying Acoustic Channel using OPNET", *Applied Mechanics and Materials*, Vol.263-266, pp. 1178-1183,2013
[5] James Gadze "On Optimal Slot Allocation for Reservation TDMA MAC Protocols in Shadow Fading Environment Wireless Communication Systems" *ISWCS,* Norway 2007
[6] Salvador Climent, Antonio Sanchez, Juan Vicente Capella, Nirvana Meratnia, Juna Jose Serrano, "Underwater Acoustic Sensor Networks: Advances and Future Trends in Physical, MAC, and Routing Layers", *Sensors,* Vol. 14, No.1, pp. 795-853, 2014
[7] Chengsheng Pan, Liangchen Jia, Ruiyan Cai, Yuanming Ding "Modeling and Simulation of Channel for Underwater Communication Network", *International Journal of Innovative Computing, Information and Control* Vol. 8 No. 3(B), pp. 2149-2156, 2014
[8] T. Niu, R. Yang, F. Liu "Research on Simulation and modeling about underwater acoustic communication channel", *Silicon Valley,* No. 9, pp. 103-105, 2009.
[9] Christhu Raj, Rajeev Sukumaran, "Stochastic Network Calculus for Rician Fading in Underwater Wireless Networks", *Applied Mathematics and Information Sciences,* Vol. 10, No. 4, pp 1-10, 2016.
[10] Kenneth V. Mackenzie, "Nine –term equation for Sound speed in the oceans", *The Journal of the Acoustical Society of America,* Vol. 70, No. 3, Sept 1981, pp. 807-812
[11] Sozer, Ethem M,. Stojanovic, Milica Proakis, John.G, "Design and Simulation of an Underwater Acoustic Local Area Network", *IEEE Ocean Engineering,* Vol. 25, No. 1, pp 72-83, 2000.
[12] Jornet, J.M. AUVNetSim: A Simulator for Underwater Acoustic http://sourceforge.net/projects/auvnetsim/ (accessed on 12 December 2011).
[13] R.J Urick, "Principles of Underwater Sound", *3rd ed New York:*

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:9, No:10, 2015

McGraw-Hill, 1983

[14] Xie G, Gibson J, "Incorporating Realistic Acoustic Propagation Models in Simulation of Underwater Acoustic Networks: A Statistical Approach", *Proceedings of MTS/IEEE Oceans Conference.* pp. 18-21, 20066

[15] Harris III, Albert F. , "Modeling the Underwater Acoustic Channel in N2", *NSTOOLS,* OCT 22, 2007

[16] B. Sun, E. Cheng, X. Ou, "Research and Simulation on shallow water acoustic channels", *Wireless Communication Technology*, No. 3, pp. 11-15, 2006

[17] B. A. Tan, M. Motani, M. Chitre, S. S. Quek, "Multinational Communication based on adaptive equalization in very shallow water acoustic channels", *Proc of Acoustics* pp. 515-522, 2006.

[18] H. Wang, J. Jiang, X. Shen, J. Bai, "Modifying SNR-Independent velocity estimation method to make it suitable for SNR estimation in shallow water acoustic communication", *Journal of North-western Polytechnical University*, Vol. 27, No. 3, pp.368-374, 2009.

[19] L. Berkhovskikh, Y. Lysanov "Fundamentals of Ocean Acoustic", *Springer* 1982.

[20] Herman Medwin, "A Simple equation for realistic parameters", *The Journal of the Acoustical Society of America*, Vol. 59, No. 8, Dec 1975, pp. 1318-1319

[21] Chen-Tung Chen and Frank J. Millero, "Speed of Sound in seawater at high pressure", *The Journal of the Acoustical Society of America,* Vol. 62, No. 5, Nov 1975, pp. 1129-1135.

[22] V. A Del Grosso, "New equation for the speed of sound in natural waters (with Comparsion to other equations*)", The Journal of the Acoustical Society of America*, Vol. 56, No. 4, Dec 1974, pp. 1084-1091

[23] Wayne D. Wilson, "Equation for the speed of sound in sea water", *The Journal of the Acoustical Society of America*, Vol. 32, No. 10, Oct 1980, pp. 1357.

[24] Smith, Kevin B. "Convergence, Stability and Variability of Shallow Water Acoustic Predictions Using a Split-Step Fourier Parabolic Equation Model." *Special Issue of Proceedings of the Shallow Water Acoustic Modeling (SWAM'99)* Workshop 1999.

[25] Tikhonov, A. N; Samarskii, A. "A Equations of Mathematical Physics", *Dover Publ.*, New York, 1990.

[26] Christhu Raj M R, Rajeev Sukumaran, "Modeling UWSN-Simulators", *International Journal of Computer, Electrical, Automation, Control and Information Engineering, World Academy of Science, Engineering and Technology* Vol: 9, No: 2, pp. 585-592, 2015.

[27] Christhu Raj M R, Rajeev Sukumaran, "Stochastic Network Calculus for Rician Fading in Underwater Wireless Communication Networks", *Applied Mathematics and Information Sciences,* Vol 10(4), pp 1-10, July 2016.

Christhuraj is an active researcher in constructing Stochastic Network Models for Underwater Wireless Communication Networks. He received his Masters degree in Network and Internet Engineering. He is currently pursuing his Ph.D. at the Center for Research, Anna University, Chennai, India.

Professor Rajeev Sukumaran is an Engineering Epistemologist and Learning Researcher. He received his Ph.D in Computer Science & Engineering and is a Senior Member of IEEE. Currently he is with the Teaching Learning Centre at IIT Madras, Chennai, India.