Channel Model Simulation for Underwater Acoustic Sensor Networks Using OPNET

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***Abstract*-Underwater acoustic sensor networks (UWA-SNs) have attracted great attentions owing to their important underwater applications for military and commercial purposes The practical deployment and design of UWA-SNs face some special challenges, one of which is the accurate channel model for simulation. This paper provides details of the implementation of a channel model simulation using OPNET, with respect to Propagation-Delay-Stage, Receiver-Power-Stage and Background -Noise-Stage, and designs a simple project of two nodes with different distances to validate its accuracy that simulation results have shown.**

***Index Terms*—underwater acoustic sensor networks, channel model, OPNET**

I. INTRODUCTION

In the last two decades, underwater acoustic sensor networks (UWA-SNs) have attracted great attentions owing to their important underwater applications for military and commercial purposes [1]. Underwater acoustic communications are unlike radio communications, where data are transmitted via electromagnetic waves. In contrast, acoustic waves are used in underwater channels, so communications in an underwater acoustic environment must overcome the combination of extreme conditions such as limited bandwidth, extended multipath, refractive properties of the medium, severe fading and large Doppler shifts that adversely impact throughput, latency, and capacity [2-4].

The practical deployment and design of UWA-SNs face some special challenges, one of which is the accurate channel model for simulation. Ref. [5] presents an improved channel model based on NS-2 which allows the generation of a customized model built for a specific location. Ref. [6] presents the design of channel model for UWA-SNs in NS-2 and shows that the models predict the channel conditions accurately by comparing them to previously published predictions of channel state. In [7] the modeling of the underwater acoustic channel of UWA-SNs based on Optimal Network Engineering Tools (OPNET) is presented and the P-Aloha protocol is also modeled; results show that the performance of the protocol is improved by setting the optimal propagation delay parameter. The contribution of this paper is to implement with OPNET an efficient simulation-friendly model in which the underwater channel is modeled accurately, and design a simple project with two nodes to validate its accuracy.

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The rest of the paper is organized as follows. Section II gives a general introduction to the wireless modeling and simulation in OPNET's Modeler Wireless Suite. Section III provides details of the implementation of the channel model simulation using OPNET, with respect to Propagation-Delay-Stage, Receiver-Power -Stage and Background-Noise-Stage. The verification of the model and simulation results are described in section IV and some concluding remarks are shown in section V.

II. CHANNEL MODELING IN OPNET

OPNET is the industry's leading environment for network modeling and simulation, which provides powerful simulation capability for the study of network architectures and protocols. The Wireless functionality of OPNET provides a special 14-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 and the rest 8 in the receiver (in Fig. 1).

From Fig. 1 we can see that several of the pipeline stages

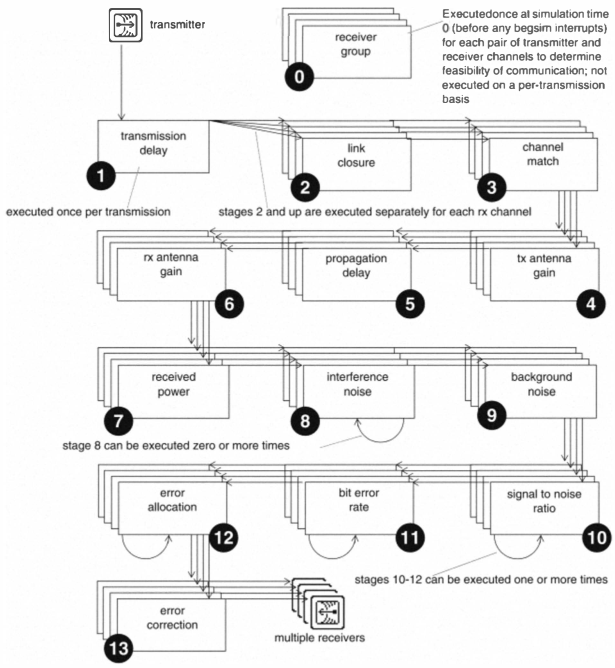


Figure 1. 14-stage Transceiver Pipeline in OPNET

might be executed multiple times for each receiver, due to interactions with multiple concurrent transmissions from other sources. As radio links do not exist as physical objects, the pipeline stages used to support a particular radio transmission must be associated with the radio transmitter and radio receiver that form the link. Meanwhile, the SK sets aside a number of Transmission Data Attributes (TDA) to provide pipeline stages with access to a minimum standard set of values, and to support communication between itself and the pipeline stages as well as between the stages and each other. TDA itself is used as a vehicle for conveying information back to the SK as well as to subsequent pipeline stages [8].

For UWA communication, however, it is not the case to some extent for the characteristics of acoustic propagation through the underwater environment, where there is significant frequency dependent attenuation and a relatively slow speed of propagation. So some of the 14 pipeline stages have to be customized in order to implement an accurate UWA channel simulation model. Pipeline stage source code files usually have the suffix .ps.c, so when modifying custom pipeline stage, we have to modify the .ps.c files and then compile to .ps.o files which are the object code files that can only be recognized by Modeler.

III. Channel Model Implementation

To implement an accurate UWA channel model, the following stages have to be modified:

- Propagation Delay (stage 5)
- Receiver Power (stage 7)
- Background Noise (stage 9)

A. Propagation Delay

The propagation delay stage is the sixth stage of the radio transceiver pipeline, and is specified by the "propdel model" attribute of the radio transmitter. 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.

The speed of sound v for underwater can be calculated according to the empirical formula as

$$v = 1450 + 4.21T - 0.037T^2 + 1.14(S-35) + 0.175P \quad (1)$$

where T, S and P respectively represent the temperature, salinity, and depth (or the pressure). For simplicity, we replace the propagation velocity of radio waves with a normal speed of sound as 1500 m/s (see TABLE I line 2), and rename the model as uwa_propdel. The uwa_propdel obtains the distances separating the transmitter from the receiver at both the start and end of transmission, which are provided by the SK in the OPC_TDA_RA_START_DIST and OPC_TDA_RA_END_DIST transmission data attributes. Both required results can be obtained by dividing these distances by the propagation velocity of the radio signal which is represented by the locally defined symbolic constant PROP_VELOCITY, as shown in TABLE I.

TABLE I
PROPAGATION DELAY MODEL FOR UWA TRANSCEIVER PIPELINE

	uwa_propdel.ps.c
1	`#include "opnet.h"   ….`
2	`#define  PROP_VELOCITY   1500`
3	`uwa_propdel_mt (OP_SIM_CONTEXT_ARG_OPT_COMMA Packet * pkptr)`
4	`{`
5	`double   start_prop_delay, end_prop_delay;`
6	`double   start_prop_distance, end_prop_distance;`
7	`FIN_MT (uwa_propdel (pkptr));`
8	`start_prop_distance = op_td_get_dbl (pkptr, OPC_TDA_RA_START_DIST);`
9	`end_prop_distance = op_td_get_dbl (pkptr, OPC_TDA_RA_END_DIST);`
10	`start_prop_delay = start_prop_distance / PROP_VELOCITY;`
11	`end_prop_delay = end_prop_distance / PROP_VELOCITY;`
12	`op_td_set_dbl (pkptr, OPC_TDA_RA_START_PROPDEL, start_prop_delay);`
13	`op_td_set_dbl (pkptr, OPC_TDA_RA_END_PROPDEL, end_prop_delay);`
14	`FOUT`
15	`}`

B. Receiver Power

The receiver power stage is the eighth stage of the radio transceiver pipeline, and is specified by the "power model" attribute of the radio receiver. For all arriving packets, whether valid or invalid, the average power level of the received signal is computed in the remainder of the *dra_power()* function. This computation is a link budget which takes into account the initial transmitted power, the path loss, and receiver and transmitter antenna gains.

The sonar parameter transmission loss TL for UWA channel is defined as the accumulated decrease in acoustic intensity when an acoustic pressure wave propagates outwards from a source. The path loss in UWA channels, which have to be added to the average power level, can be expressed as [9]

$$TL = n \cdot 10 \log r + \alpha r \times 10^{-3} \quad (2)$$

where r is the range expressed in meters, α represents the absorption coefficient with the unit dB/km and n is the spreading loss factor (n = 1 means the transmission loss is caused by cylindrical spreading in shallow water and n=2 is by spherical spreading in deep water).

The total absorption coefficient in dB/km is derived in [10, 11]. At frequencies above a few hundred Hz, the absorption coefficient can be calculated using Thorp's expression as [12]

$$\alpha = \frac{0.1f^2}{1+f^2} + \frac{40f^2}{4100+f^2} + 2.75\times10^{-4} f^2 + 0.003 \quad (3)$$

where f is the signal frequency in kHz. The implementation of TL is shown in TABLE II.

TABLE II
RECEIVER POWER FOR UWA TRANSCEIVER PIPELINE

uwa_power.ps.c

```
#include "opnet.h"    ….
#define   C    1500
uwa_power_mt (OP_SIM_CONTEXT_ARG_OPT_COMMA Packet * pkptr)
{
    double    f2, α ;
    FIN_MT (uwa_power (pkptr));
    f2 = pow(tx_center_freq, 2);
    α = 0.1 * f2 / (1 + f2) + 40 * f2 / (4100 + f2) + 0.000275 * f2 + 0.003;
    path_loss = path_loss + n * 10 * log(prop_distance)+α * prop_distance * 0.001;
    ……     FOUT
}
```

C. Background Noise

The background noise stage is the tenth stage of the radio transceiver pipeline, and is specified by the "bkgnoise model" attribute of the radio receiver. It is a simple model accounting for a constant ambient noise level, a constant source of background noise, and a constant thermal noise at the receiver.

For UWA channel, four basic sources model the ambient noise NL, turbulence, shipping, waves and thermal noise, have to be considered except for what is ranged over radio process. The overall power spectral density on the ambient noise is given by [13]

$$NL(f) = NL_t(f) + NL_s(f) + NL_w(f) + NL_{th}(f) \quad (4)$$

where $NL_t(f)$, $NL_s(f)$, $NL_w(f)$ and $NL_{th}(f)$ represent the ambient noise caused by turbulence, shipping, waves and thermal noise, respectively. They are described by the following equations.

$$\begin{cases} 10\log NL_t(f) = 17 - 30\log f \\ 10\log NL_s(f) = 40 + 20(s-0.5) + 26\log f - 60\log(f+0.03) \\ 10\log NL_w(f) = 50 + 7.5w^{1/2} + 20\log f - 40\log(f+0.4) \\ 10\log NL_{th}(f) = -15 + 20\log f \end{cases} \quad (5)$$

where s is the shipping activity factor, and its value ranges between 0 and 1 for low and high activity, respectively; w is the wind speed in m/s. The implementation of background noise is shown in TABLE III.

TABLE III
BACKGROUND NOISE MODEL FOR UWA TRANSCEIVER PIPELINE

uwa_bkgnoise.ps.c

```
#include "opnet.h"    ….
uwa_bkgnoise_mt (OP_SIM_CONTEXT_ARG_OPT_COMMA Packet * pkptr)
{
    double    nl_t, nl_s, nl_w, nl_th, s, w ;
    FIN_MT (uwa_bkgnoise (pkptr));
    f = tx_center_freq;
    nl_t = pow(10,(17 – 30 * log(f)) * 0.1);
    nl_s = pow(10,(40 + 20 * (s – 0.5) + 26 * log (f) – 60 * log(f + 0.03)) * 0.1);
    nl_w = pow(10,(50 + 7.5 * pow(w, 0.5) + 20 * log(f) – 40 * log(f + 0.4)) * 0.1);
    nl_th = pow(10,(-15 + 20 * log(f)) * 0.1);
    bkg_noise = bkg_noise + nl_t + nl_s + nl_w + nl_th;
    op_td_set_dbl (pkptr, OPC_TDA_RA_BKGNOISE, (amb_noise + bkg_noise));
    FOUT
}
```

IV. MODEL VERIFICATION

To verify the UWA channel model, we create a simple project containing two sensor nodes, one of which is a source node to send messages and the other is a sink node to receive the messages. With the distance between the two nodes changing, we will check how the attenuation and receiver power changes.

Fig. 2 (a) (b) show the transmitting and receiving node model, respectively. The transmitter node model consists of a packet generator module, a radio transmitter module, and an antenna module. The receiver node consists of an antenna module, a radio receiver module and a sink processor module.

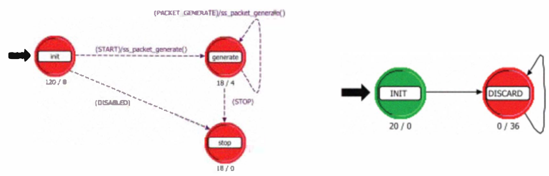
At the transmitter side, the packet generator generates 1024-bit packets that arrive at the mean rate of 1.0 packets/second with a constant interarrival time. After they are generated, packets move through a packet stream to the radio transmitter module, which transmits the packets on a channel at 1024 bits/second using the full channel bandwidth. The packets then pass from the transmitter through another packet stream to the antenna module of transmitting node model to that of receiving node model at the receiver side, and then to the radio receiver module and finally to the sink processor module.

Fig. 3 (a) (b) show the transmitting and receiving process model, respectively, which is the default process model of the packet generator module and the sink processor module.

Fig. 4 shows the transmission loss (expressed in dB relative to that of 1 meter) as a function of distance between nodes for different frequencies, which is a part of the simulation results.

(a) Transmitting node (b) Receiving node

Figure 2. Node Model



(a) Transmitting process (b) Receiving process

Figure 3. Process Model

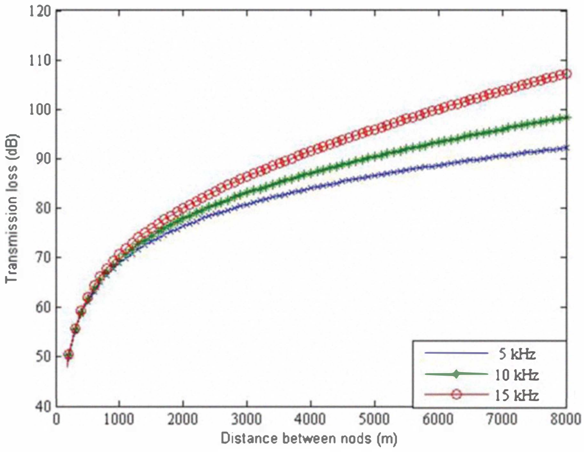


Figure 4. Transmit power as function of distance between nodes

We can see that the transmission loss goes up as the distance between nodes and frequencies rise, which is consistent with the theoretical calculation very well and therefore validates the accuracy of the proposed channel model for UWA-SNs.

V. Conclusion And Future Work

As a widely used network simulation tool, OPNET has several major deficiencies from wireless communication that need to be addressed for UWA communication simulation. It is necessary to modify several Transceiver Pipeline stages. In this paper, we first introduce the wireless modeling in OPNET's Modeler Wireless Suite, and then provide details and codes of the implementation of the channel model simulation, customizing several Transceiver Pipeline stages, specifically Propagation-Delay-Stage, Receiver-Power-Stage and Background-Noise-Stage. Elementary simulation results validate its accuracy and complex simulation scenery is our next step.

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