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MODELING AND SIMULATION OF CHANNEL FOR UNDERWATER COMMUNICATION NETWORK

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Abstract. *According to the characteristics of underwater acoustic channel, Thorp experience formula is adopted in order to simulate seawater absorption properties, on the basis of which, the path loss is solved by means of simulation. A Wenz model is also improved so as to approach the noise model of underwater acoustic channel better. Furthermore, OPNET platform built-in propagation delay stage, a receiver power stage, background noise stage are improved in order to fit underwater acoustic channel, and then basically realize an approximate simulation of the real channel. Mobile network model is designed and simulated with the simulative underwater acoustic channel added, and then the network performance influence of underwater acoustic channel characteristics is analyzed.*
Keywords: Underwater communication network, Underwater acoustic channel, Wenz model

1. Introduction.

Underwater communication networks are the important means to achieve marine monitoring, data acquisition and strategic communications, but its performance is degraded by the characteristics of underwater acoustic channel. Only when we have a full understanding of the underwater acoustic channel characteristics, can we gradually make the underwater acoustic transmission system to match with the real marine environment, so as to achieve better performance [1,2].

At present, the researches for wireless underwater acoustic (WU-A) channel mostly focus on establishing mathematical model of the underwater acoustic channel. Sound field model, mainly includes the normal wave model, radiation model, fast sound field model, parabolic equation model and etc [3,4]. 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 multi-path channel model can be divided into multi-path model based on ray theory, random time-varying filter channel model and random statistical channel model [5-7].

Researchers simulate the underwater acoustic channel through establishing mathematical models, and further study the various properties of the acoustic channel by using MATLAB software simulation; however, these mathematical models can only be applied to point-to-point communication, not suitable for simulating the underwater acoustic communication network [8]. Furthermore, in respect of underwater acoustic network channel simulation based on the OPNET, although some researchers have simply applied Thorp empirical formula and Wenz noise model, the simulations are only for fixed networks, having not applied to mobile networks [1,9]. Therefore, for the result of simulating the underwater acoustic channel characteristics better, this article uses the improved Wenz noise model and introduces Rayleigh channel for simulating signal fading caused by multi-path effect of underwater acoustic channel [10]. Finally, the performance of underwater mobile network is simulated based on OPENT.

2. Characteristics of Underwater Acoustic Channel.

Seawater is very complex and variable, and its absorption of sound energy as well as the energy loss of expansion during the propagation causes the signal fading. The refraction on the top and bottom of sea interface and refraction of the different sound velocity gradient result in severe multi-path propagation. Seawater's random heterogeneity and various noise sources cause acoustic signal distortion.

2.1. Propagation loss.

During the process of transmitting sound signal from acoustic source to the reception, the signal energy is one of the important factors that influence signal-to-noise ratio of receiver losses. The absorption loss of sound energy is the main part of the attenuation loss, and the absorptions are usually seawater medium absorption and interface medium (such as the benthal) absorption [11].

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 empirical formula of the seawater absorption coefficient of sound waves, which is proposed by Thorp, etc., is expressed as [12]:

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

where $\alpha(f)$ is given in dB/km, f is the center frequency of the transmitted signal, in units of kHz. In order to assure that the receiver which is x away can receive the input power level of P_0, the transmitter power should be $P_0A(x)$. Here, $A(x)$ is the attenuation factor and its formula is as follows [13]:

$$A(x) = x^k a^x, \tag{2}$$

where, k is the power expansion factor, and represents sound waves expansion in the form of cylindrical wave when its value is 1; k takes 1.5 when it represents that sound waves expand in the form of actual expansion. a, which is obtained from the absorption coefficient $\alpha(f)$ and based on frequency, is a coefficient. And its formula is as follows:

$$a = 10^{\frac{\alpha(f)}{10}}. \tag{3}$$

2.2. Noise.

The overall noises of underwater acoustic communication system include environmental noise, the emission receiver noise, discrete ship noise, disturbance noise, and so on. The size of environmental noise directly affects Signal-to-Noise Ratio (SNR) of the receiver, and largely determines the transmitting power.

Ocean ambient noise is complex and changeable, and it is related to sea area, weather conditions and the frequency, which could be described by Wenz model. However, thermal noise of the Wenz model does not simulate the thermal noise generated by transmitting and receiving equipment perfectly. Therefore, the thermal noise model refers to radio model and is defined as:

$$\begin{aligned}
&N_{Turbulence} = 17 - 30\ln(f)\\
&N_{Shipping} = 40 + 20 * (D - 0.5) + 26\ln(f) - 60\ln(f + 0.03)\\
&N_{Wind} = 50 + 7.5w^{0.5} + 20\ln(f) - 40\ln(f + 0.4)
\end{aligned} \tag{4}$$

where, $N_{Turbulence}$, $N_{Shipping}$ and N_{Wind} respectively represent turbulent noise, shipping noise and surface noise. f is the center frequency of the transmitted signal, in units of kHz; w is the ocean surface wind speed, in units of m/s; D is the shipping density. The sum of the noises above is:

$$N = 10^{\frac{N_{Turbulence}}{10}} + 10^{\frac{N_{Shipping}}{10}} + 10^{\frac{N_{Wind}}{10}}. \tag{5}$$

Thermal noise is expressed as follows:

$$\begin{aligned} N_{Thermal} &= (rx\_temp + bkg\_temp) * rx\_bw * BOLTZMANN \\ rx\_temp &= (rx\_noisefig - 1.0) * 290.0 \end{aligned} \tag{6}$$

where, rx_temp is the device temperature; bkg_temp is the background temperature; rx_bw is the receiver bandwidth; $BOLTZMANN$ is the Boltzmann constant; $rx\_noisefig$ is noise figure property values of the receiver. The total noise is expressed as follows:

$$N_{all} = N + N_{Thermal}. \tag{7}$$

2.3. **Multi-path effect.** In water, propagation speed of sound wave is slow (acoustic propagation speed 1500m/s). Heterogeneity of seawater, reflection of the sea bottom and surface of the underwater sound propagation channels, as well as the existence of various reflectors and scatterers in seawater result in the phenomenon of multi-path of underwater acoustic channel. Intersymbol interference caused by expansion multi-path is the fundamental obstacle of data transfer (especially high-speed data transfer). However, signal decline and inter-symbol interference caused by multi-path effect can be described by Rayleigh fading channel [14,15]. And the model of Rayleigh fading channel is described as

$$r(t) = a(t)s(t) + n(t) \tag{8}$$

where $r(t)$ represents the signal of receiving, $s(t)$ is the modulated signal, $a(t)$ is a signal envelope whose distributing obeys the Rayleigh distributing, $n(t)$ is an additive white Gaussian noise (AWNG).

3. Simulation of Underwater Communication Network.

3.1. **Model design of underwater acoustic channel based on OPNET.** Wireless communication channel simulation, which is OPNET platform built-in, adopts 14 end-to-end pipeline stage (Pipeline Stage) to simulate the transmission of data frames in the channel as truly as possible, and provides a default model for each pipeline stage [16]. However, OPNET pipeline stage model just simulates the air wireless channel, and is not suitable for the underwater acoustic channel. Therefore, we need to improve existing models to fit the underwater acoustic channel.

In this paper, the modified stages include propagation delay stage, the receiver power stage and the background noise stage. In order to simulate the SNR fluctuation caused by multi-path effects, the increase of bit error rate, the increase of packet loss ratio and link failures, we introduce the Rayleigh channel and do some simulations by using Modulation Curve tool which comes from software OPNET.

3.2. **Simulation of underwater network.** Simulation is a 4 nodes to specify the path underwater acoustic channel of acoustic stage pipeline network. The range of Network is set as 10km $*$ 10km, generally, the speed of wind is set as 10m/s, and the waters shipping density is set as 0.6. The network includes a source node (node 0), a destination node (node 2) and two relay nodes (node 1, node 3). The depth and locomotion speed of the nodes are set as: node 2 (underwater 100m, 30km/h), node 1 (underwater 50m, 11km/h), node 3 (underwater 60m, 11km/h), node 0 (in the surface, 10m/h). According to the scene of network, considering Table 1, for all nodes, the bandwidth is 10kHz and the fundamental frequency is set as from 10kHz to 20kHz. For node 0, node 3 and node

1, all their transmit power is set as 100W. Nodes adopt directional antenna model and the antenna gain is set as 10dB. QPSK modulation is used and background temperature *bkg_temp* is set as 290 (the seawater normal temperature).

Table 1. A available bandwidth for different ranges in UW-A channel [17]

	Range (km)	Bandwidth (kHz)
Very long	1000	< 1
Long	10-100	2-5
Medium	1-10	≈ 10
Short	0.1-1	20-50
Very short	< 0.1	> 100

Network topology is shown as Figure 1. In this network, nodes move in a three-dimensional space in different depths at different speeds in different directions, and communicate with each other during moving.

Communication performances obtained from simulation, such as the received power, BER, SNR, end to end delay, are separately shown in Figure 2 to Figure 5.

From the analysis of simulation results, it appears that: In Figure 2, at the beginning of the simulation, the received power is low while the distance between nodes is far away and the path attenuation is high. With the continual locomotion of nodes, the node distance shortens and path attenuation becomes lower, as a result, the received power increases.

In Figure 3, at the beginning, the bit error rate of node 3 is higher due to large distance and large path loss, and it causes higher error rate, with the mobile nodes becoming resting ones, bit error rate tends to 0.0003. Initially, node 1 does not receive the forwarded packets of node 3, so the bit error rate is 0. Over time, bit error rate increases, and finally, the bit error rate fluctuates at 0.0035. As node 1 and node 3 move at a comparative speed, i.e., the transmitter and receiver move almost all the time. Therefore, for node 1, which is the receiver of the network, when the network is stable, its bit error rate is the highest; Node 2 moves so fast and the simulation time is so long that node 2 will soon stop moving and the bit error rate is very low, close to 0.

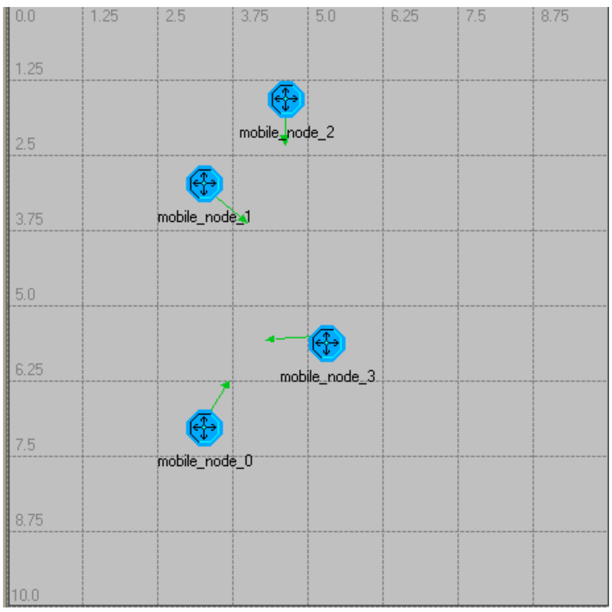

Figure 1. Network topology

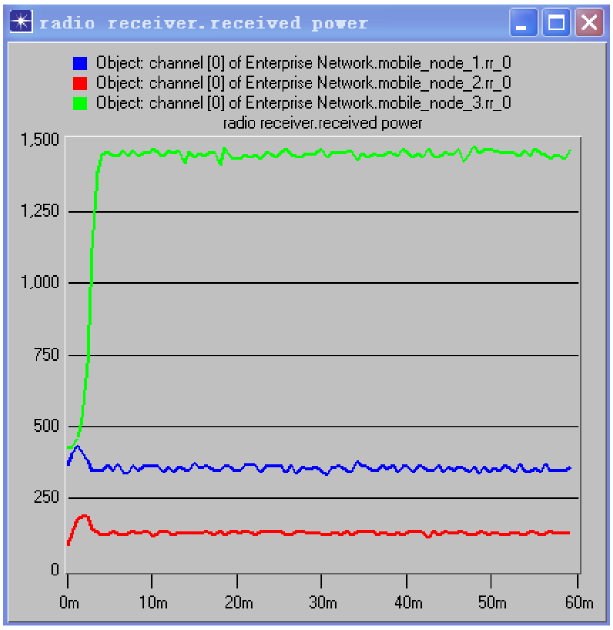

FIGURE 2. The received power curve of node l, node 2 and node 3

In Figure 4, because noise mainly relates to frequency and the fundamental frequency of node 3 is maximum while that of node 2 is minimum, the noise of node 3 is maximum while that of node 2 is minimum. When the network is stable, the receiving power of node 3 is larger than node 1, node 2, because node 3 is close to the transmitter node 0 and the power of path loss is small. With the analysis, it is concluded that the signal to noise of node1 is minimum while that of node 2 is maximum.

In Figure 5, the propagation speed of underwater acoustic channel is low, which is only about 1500m/s, so the total network delay is up to 8s, and finally the delay stabilizes at about 6s when nodes do not move any more.

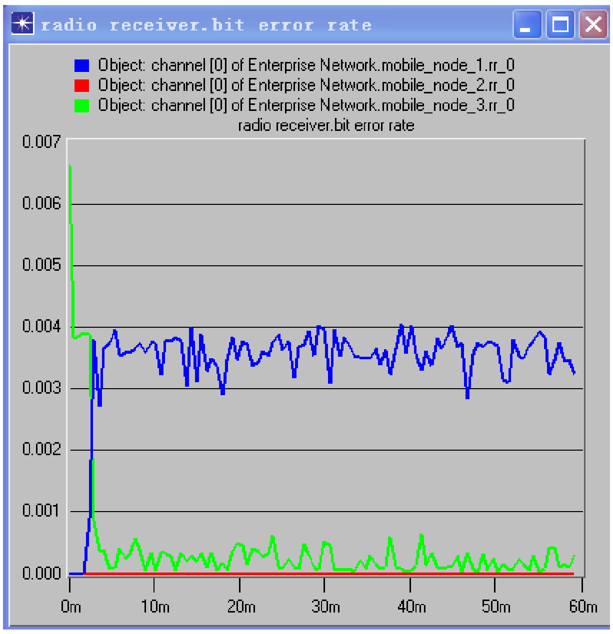

FIGURE 3. The BER curve of node 1, node 2 and node 3

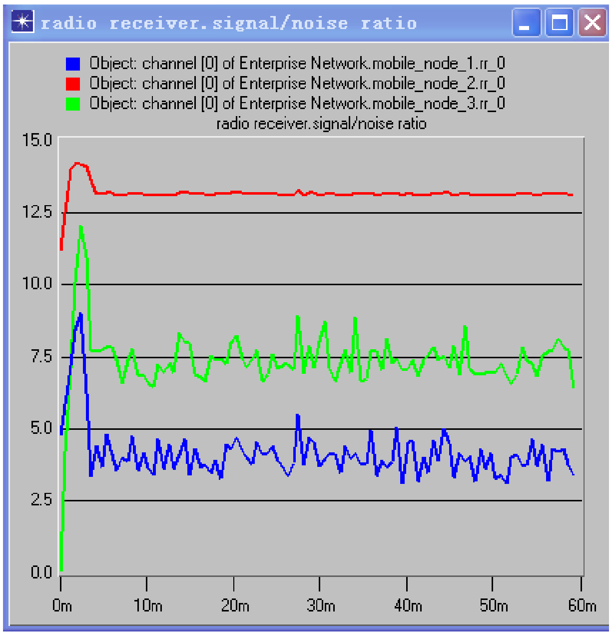

Figure 4. The SNR curve of node 1, node 2 and node 3

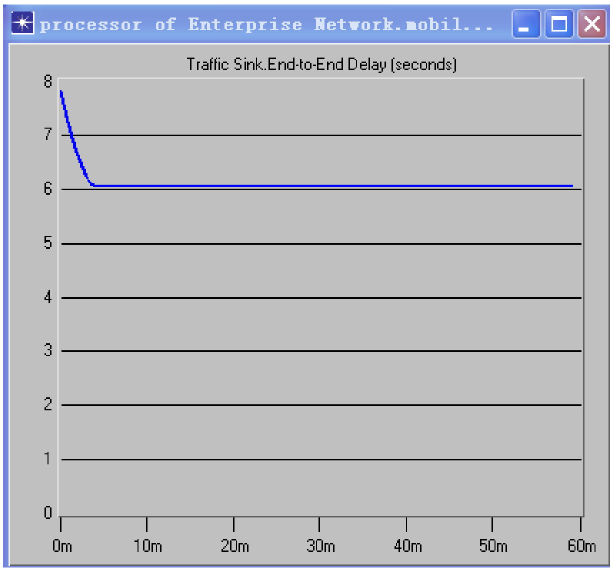

Figure 5. The network total delay

With other conditions fixedness, simulations are done respectively with the way of modulation changed into QPSK under Gaussian channel and rayleigh_qpsk1 under Rayleigh channel. And the contrastive simulation results are shown in Figure 6 and Figure 7.

For node 2, which is the receiving node, Figure 6 and Figure 7 separately show curves of its BER and the received power. It is shown from Figure 6 that, under Rayleigh channel, BER of node 2 is very high, the magnitude of which reaches to 10^{-3} while that is very low and almost close to 0 under Gaussian channel. Then this indirectly reflects that multi-path effect causes inter symbol interference. Looking at the curve of the received power in Figure 7, the received power under rayleigh_qpsk1 suddenly reduces and could only reach half of the received power under QPSK. Apparently, it is the result of signal fading caused by multi-path effect. Through the simulation, it proved again that the effect of multi-path in underwater acoustic channel cannot be neglected.

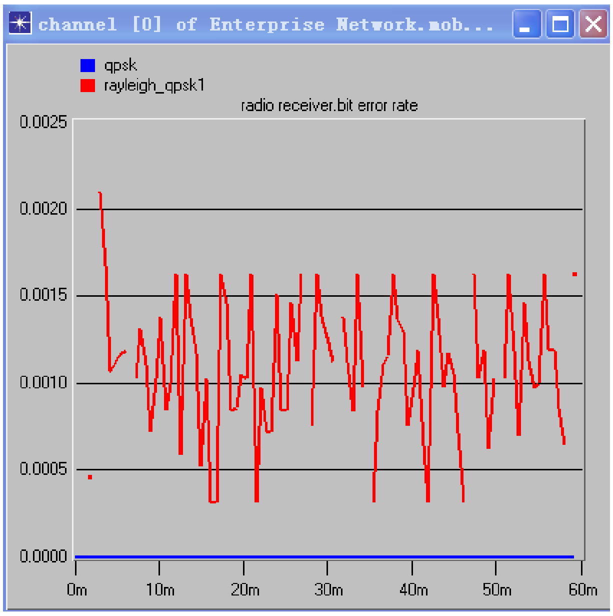

FIGURE 6. The BER curve of node 2

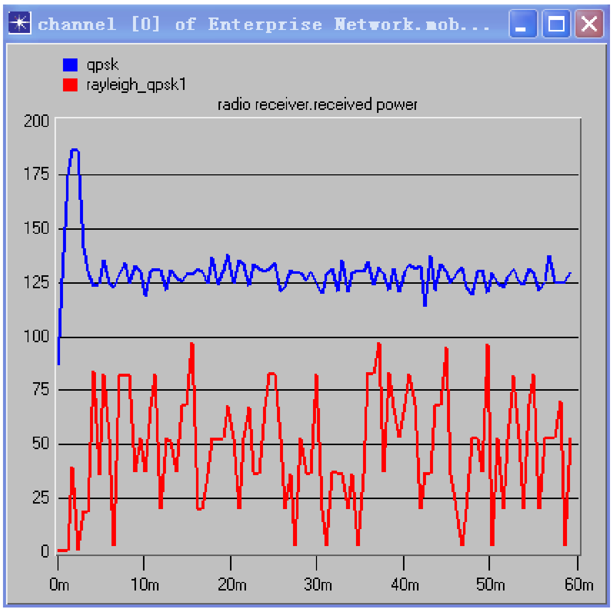

FIGURE 7. The received power curve of node 2

4. **Conclusion.** In this paper, we design an underwater acoustic channel model according to the characteristics of underwater acoustic channel. Model design does modifications mainly aiming at the three pipeline stages of the OPNET platform wireless communication channel, such as propagation delay, and achieves a better underwater acoustic channel environment analog by introducing the Rayleigh channel into OPNET to simulate multipath effects. Finally, a network model is designed and simulated with the underwater acoustic channel combined, and then the network performance influence caused by underwater acoustic channel characteristics is analyzed.

The performance indicators of the underwater acoustic mobile network are all obtained by simulation, including received power, error bit rate, signal to noise ratio and end-to-end delay, which can provide reference for the modeling and simulation of the acoustic mobile networks and lay the foundation for research of the underwater acoustic mobile network routing protocol and MAC protocol.

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