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Research Article

Modelling and Simulation on Acoustic Channel of Underwater Sensor Networks

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The reliability of the modelling system mainly depends on the simulation of underwater acoustic channel characteristics. The reliability of simulator is improved because of the use of Bellhop in NS-Miracle. World Ocean Simulation System (WOSS) can retrieve the data of marine environment by accessing the database of seabed depth, sound speed profile and seabed sediment, and transmit them to Bellhop simulator automatically, so that the model is closer to the actual underwater acoustic transmission channel than not using WOSS. In order to verify the reliability of NS2/NS-Miracle simulation system with WOSS, a centralized underwater sensor network with five nodes is simulated on the integrated simulation system. The characteristic empirical model, Bellhop Ray-Tracing model, and WOSS combined with Bellhop model are, respectively, adopted to simulate underwater acoustic channel. The results of three types of simulation, such as average throughput, average delay, and packet error rate, and simulation time are very close under the same condition. It proves that the accuracy of integrated simulation system is as excellent as that of NS-Miracle. However, WOSS can automatically acquire the actual sea environment parameters and provide them to the simulator, which can improve the authenticity of the simulation system. Furthermore, three MAC protocols, Aloha-CS, CSMA/CA, and DACAP, are simulated on the integrated simulation system under the same condition including ocean environment, network topology, and parameters. The results show that the performance of CSMA/CA is greater than the other protocols in such networks. It also proves that the integrated simulation system can accurately simulate the relevant characteristics of the MAC protocol.

1. Introduction

Internet of Underwater Things (IoUT) [1–3] has a wide range of application prospects in civilian and military fields. As a key technology of IoUT, underwater sensor networks (UWSNs) have attracted widespread attention from academia and industry. In recent years, the underwater sensor network has been no stranger to the people. It has been widely used in industrial, civil, and military fields [4–7] and has a very impressive application scenario [8]. Using this technology, human beings can perform marine environmental monitoring, marine resource management, underwater reconnaissance and multipoint detection, and dispatching and commanding of cluster management [9, 10]. However, the underwater environment is complex and unstable, with high delay, dynamic variation of delay, multipath effect, Doppler effect, and severe attenuation [11]. These factors make the research of underwater acoustic sensor network far behind the land wireless sensor network technology. Therefore, studying the underwater acoustic sensor network and promoting the advancement of technology in this field is of great significance to the development of the country and human beings.

The underwater sensor network adopts the underwater acoustic communication method. The actual network construction requires a large amount of equipment support, which requires a long establishment period and a large amount of human and financial resources consumption [12]. Therefore, it is very difficult and impractical to establish an underwater sensor network entity for scientific

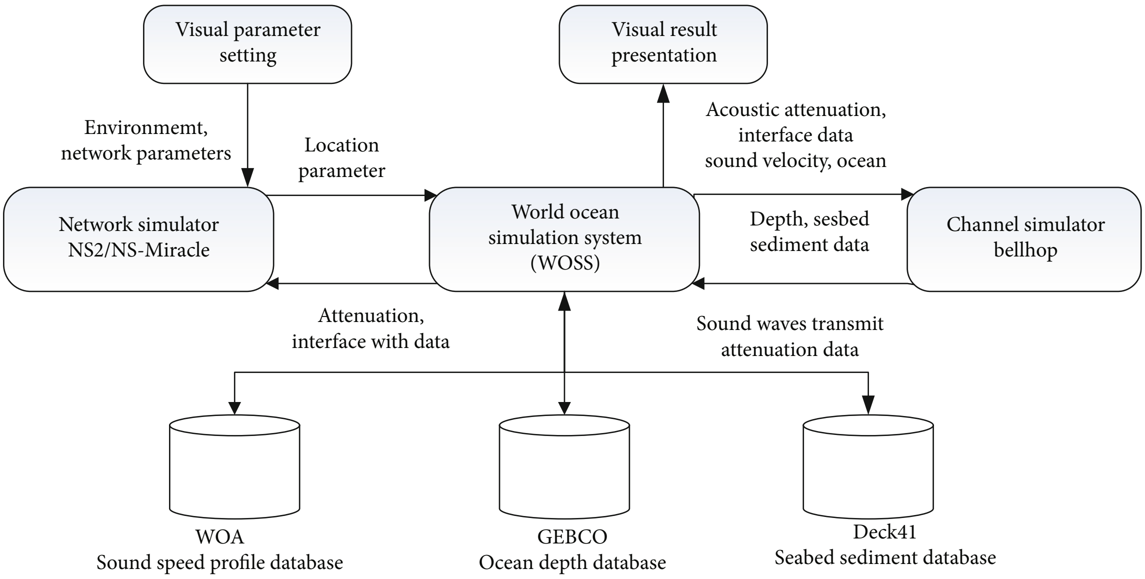

Figure 1: Data flow diagram of WOSS in simulation platform.

research under conditions that are not mature. It is a reasonable and effective way to verify the feasibility of the underwater sensor network model and protocol by using computer technology simulation.

Most of the current simulation systems are based on mathematical modelling, which greatly simplifies the real environment. There is still no widely recognized simulation system of underwater acoustic sensor networks [13]. Thomase [14] proposed a modular simulation software with a visual platform. Users can set the underwater acoustic parameters in the platform, and the operation is convenient. However, the software does not consider the impact of seawater temperature, depth, salinity, and other factors in channel modelling. The same is true for the Aqua-Sim [15] software, which do not take into account some seawater factors when establishing the underwater acoustic channel model. To improve the realism of computer simulations, Harris and Zorzi [16] added the marine environmental noise model to the channel model of the NS-Miracle [17] simulation software.

The common feature of the above simulation platforms is that they did not consider the differences between underwater environments in different sea areas (such as sea temperature, salinity, depth, and seabed sediments). These parameters can affect underwater acoustic propagation. In order to improve the accuracy of the computer simulation of underwater acoustic channel, WOSS [18] was introduced into the simulation software (NS2/NS-Miracle). Compared with other literatures, the main contribution of this paper is to simulate and analyze UWSNs by integrating NS2, NS-MIRACLE, WOSS, and Bellhop. The integrated simulator makes the simulation channel of underwater wireless sensor networks closer to the real ocean environment than original channel simulation.

In this paper, the first section introduces the simulation work of the underwater sensor network. The environment model of the simulation platform and WOSS is represented in the second section. The third section describes the underwater acoustic channel modelling of the simulation platform, mainly including the Ray-Tracing model, empirical model, and noise model. The fourth section tests the channel model. The MAC protocol of the underwater sensor network is simulated and analyzed by using the simulation platform in the fifth section. The sixth section summarizes the whole paper.

2. Environmental Modelling of Simulation Platform

WOSS is an open source multithreaded framework, which provides a series of APIs that automatically deliver environmental data to the channel simulator. The aim is to improve the reliability of underwater sensor network simulation through modelling of more realistic underwater environment [19]. We provide the visualization platform in order that users can set network topology parameter and location information (latitude, longitude, and depth). WOSS obtains the marine environment data of the region according to the location information and provides the data to Bellhop simulator.

In order to retrieve the required environmental data, WOSS provides a free-to-use marine database interface for the network simulator and Bellhop [20–22] as shown in Figure 1. User inputs the simulation parameters through the visual interface, after NS-Miracle gets the simulation data, and transmits the location data to WOSS. WOSS retrieves the regional environmental data through accessing the environment parameters database according to its location data and transmit them to the Bellhop channel simulator. After simulation processing, the simulation results are transmitted to NS-Miracle, which finally presents the simulation results to the user in the form of a diagram through the visual platform.

There are three major databases in WOSS. They are the WOA (World Ocean Atlas) sound speed profile database,

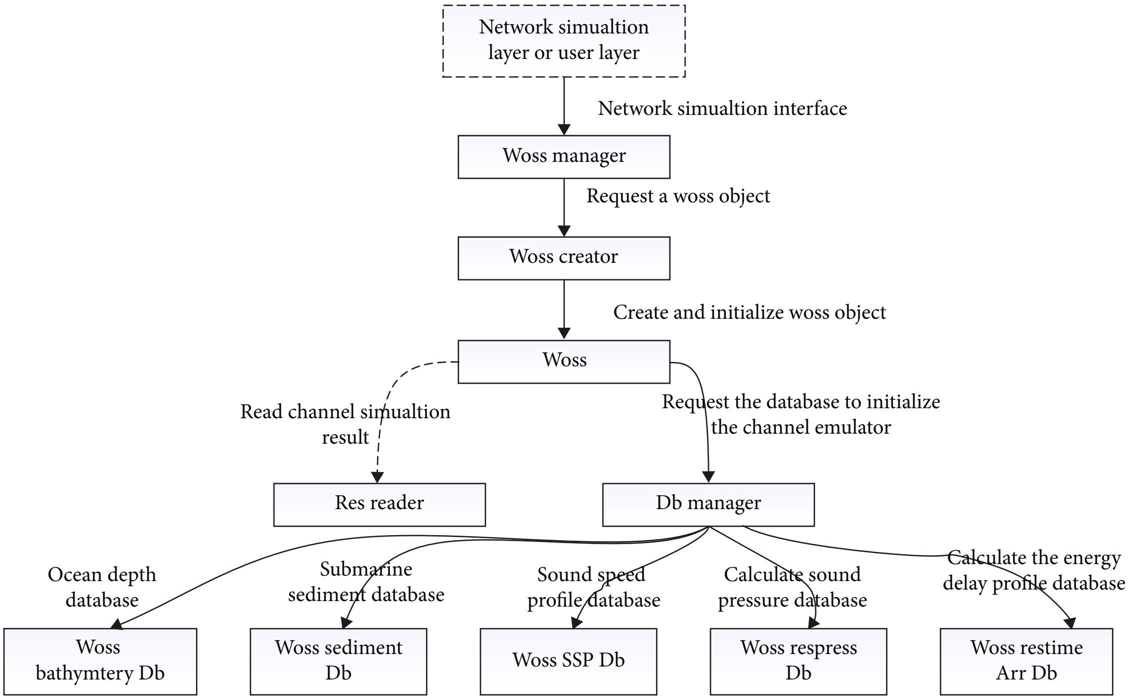

FIGURE 2: WOSS system block diagram.

the GEBCO ocean depth database, and the DECK41 ocean sediment database. WOSS obtains the location information (latitude, longitude, and depth) of the node through the visual simulation platform, then uses this information to inquire the database, and calculates the sound speed profile through WOA. The WOA database collects environmental data of the oceans around the world, including salinity and temperature sampling data. The seawater depth data of the network is extracted and transmitted to Bellhop by accessing the GEBCO grid database interface. WOSS obtains seabed sediment data by accessing the Deck41 database, which is taken into account when Bellhop calculates the loss and attenuation. The accuracy of model is improved because the more precise environment data is obtained by WOSS.

The WOSS interfaces are mainly divided into three categories, which, respectively, implement communication connections with network simulator, channel simulator, and environment databases. The first category is the base class library, which contains 11 classes, which implement the underwater network node geographic coordinates, time calculation, random number generator, sound speed profile calculation, ocean depth data, seabed sediment data definition, etc. The second category is the interface class library of the database, which is used to create and initialize the database, which to achieve data access and extraction of the database. The third category is the interface class library of the channel simulator, which is used to create and initialize WOSS objects. The library automatically integrates with the channel simulator and provides simulation result reading and output interfaces.

The framework of WOSS is shown in Figure 2. It can be seen from the figure that the user layer of the network emulator is responsible for passing the ocean geolocation parameters to the WossManager. The WossManager is responsible for requesting a WOSS object from the WossCreator. After the WossCreator receives the request, it will create and initialize a WOSS object. WOSS object calls the database interface of environment parameters. The WOSS object can also call ResReader and WossResReader to read the results of the channel simulator.

3. Underwater Acoustic Channel Modelling of Simulation Platform

3.1. Bellhop Ray-Tracing Model. Bellhop Ray-Tracing model (called Bellhop model) [23, 24] is a static underwater acoustic propagation model and is the most common acoustic propagation model in the field of underwater acoustics. Its description of radio acoustics is similar to geometric optics. It has absolute advantages in computational efficiency in high frequency and complex environments. The results can be visually displayed through physical images, which is more helpful for people to understand.

Bellhop is a Ray-Tracing model software for predicting the sound pressure field of the marine environment, proposed by Porter and Bucher [25]. Bellhop calculates the sound field in horizontal nonuniform environment by Gaussian beam tracking method, calculates the sound ray propagation process based on the known sound field environment description file and sound speed gradient file, and can be applied to the calculation of sound field in 3D environment [26, 27].

Ray-Tracing model calculates the propagation loss based on ray theory. It is an assumption that the solution of wave equation $\nabla^2\mu + k^2\mu = 0$ is in the form of the product of amplitude function $A = A(x, y, z)$ and phase function $P = P(x, y, z)$, namely,

$$\mu(x, y, z) = A(x, y, z)e^{jP(x,y,z)}, \quad (1)$$

where ∇ is a Hamiltonian, k is the wave number, and μ is the amplitude. After the Eq. (1) is brought into the wave equation, two independent equations are obtained after solving:

$$\frac{1}{A}\nabla 2A - [\nabla P]^2 + k^2 = 0, \quad (2)$$

$$2[\nabla A \cdot \nabla P] + A\nabla^2 P = 0, \quad (3)$$

where Eq. (2) determines the geometry of the sound ray; Eq. (3) determines the transmission equation of the amplitude of the sound wave. Using geometric acoustic approximation and $1/A\nabla^2 A < <k^2$, Eq. (2) is simplified:

$$[\nabla P]^2 = k^2. \quad (4)$$

Equation (4) is called the eikonal equation, and the wave front is obtained by a set of planes of equal phase defined by eikonal equation. If the defined soundtrack is $x(s)$, then $dx/ds = 1/k\nabla P$. In the cylindrical coordinate system (r, z), the auxiliary variables $\xi(s)$ and $\zeta(s)$ are introduced, and the trajectory equation of the sound ray is obtained [28]:

$$\frac{dr}{ds} = c\varsigma(s)\frac{d\xi}{d\zeta} = -\frac{1}{c^2}\frac{dc}{dr}, \quad (5)$$

$$\frac{dz}{ds} = c\zeta(s)\frac{d\zeta}{ds} = -\frac{1}{c^2}\frac{dc}{dz}, \quad (6)$$

where $(r(s), z(s))$ is the ray trajectory, $(\xi(s), \zeta(s))$ is the tangent vector of the ray, s is the arc length of the ray, and c is the speed of sound. In the case of setting an initial amount of an angle and a certain angular increment, a plurality of rays can be emitted to cover a certain range, and the ray trajectory can be obtained by solving Eq. (5) for the initial angle value.

3.2. Empirical Model. The underwater sensor network communicates in the form of underwater acoustic communication, but the underwater environment (natural factors, geographical factors, and random factors) is complex and variable. These factors cause the acoustic signal to delay and attenuate during propagation. Due to the extremely complex factors affecting underwater acoustic signals, complete theoretical calculation is impractical, and only a large number of measured data can be used to establish a recognized empirical model [29].

3.2.1. Sound Speed Model. Sound speed is the main factor in generating communication delays. According to the Mackenzie sound speed empirical formula, the ocean temperature and salinity data were brought into the WOSS database and were used to calculate the sound speed profile, and the minimum value of the surface sound speed and the axial depth of the sound speed channel are obtained. The Mackenzie sound speed experience formula is as follows:

$$\begin{aligned} c(S, T, Z) = {} & 1448.96 + 4.951T - 5.304 \times 10^{-12}T^2 + 2.374 \\ & \times 10^{-4}T^3 + 1.340(S - 35) + 1.630 \times 10^{-2}Z \\ & + 1.675 \times 10^{-7}Z^2 - 1.025 \times 10^{-2}T(S - 35) \\ & - 7.139 \times 10^{-13}TZ^3. \end{aligned} \quad (7)$$

In Eq. (7), S is salinity, T is temperature, and Z is depth. In addition, the main factors of acoustic attenuation loss in underwater acoustic communication include path loss, shadowing, and fading.

3.2.2. Path Loss Model. Path loss is caused by radiation diffusion of transmitting power and propagation characteristics of channel. In this paper, the path loss is based on the large-scale propagation model, as shown as follows:

$$\Pr(d) = \frac{PtGtGr\lambda^2}{(4\pi)^2 d^2 L}, \quad (8)$$

where $\Pr(d)$ is the received power, Pt is the received power, Gt is the transmitter antenna gain, Gr is the receiver antenna gain, d is the distance from the transmitter to the receiver, L is the system loss factor, and λ is the wavelength.

3.2.3. Shadowing. Shadowing is caused by obstacles between the transmitter and the receiver. The logarithmic normal shadow model is adopted in this paper, that is, the decibels emitted and received follow normal distribution. Assuming that the ratio of transmitted power and received power is $\psi = Pt/\Pr$, $\psi_{dB} = 10\log_{10}\psi$, the probability density function of ψ_{dB} is shown in the following equation:

$$P(\psi_{dB}) = \frac{1}{\sqrt{2\pi}\sigma_{\psi_{dB}}}\exp\left\{-\frac{\left(\psi_{dB} - \mu_{\psi_{dB}}\right)^2}{2\sigma^2_{\psi_{dB}}}\right\}, \quad (9)$$

where $\mu_{\psi_{dB}}$ is the mean of ψ_{dB}, and $\sigma_{\psi_{dB}}$ is the standard deviation of ψ_{dB}.

3.2.4. Fading. Fading refers to the attenuation caused by multipath propagation in the mobile propagation environment. The Jakes attenuation model is used in the paper. Assuming that the transmitted signal is vertically polarized and there are N transmission paths between the transmitter and the receiver, the receiver signal can be expressed as

$$R_Z(t) = E\sum_{n=1}^{N} c_n \cos(\omega_m t \cos\alpha_n + \omega_n + \phi_n). \quad (10)$$

In Eq. (10), α_n and ϕ_n are independent uniform distributions on $[-\pi, \pi]$, E is the amplitude of the cosine wave, c_n is the attenuation of the nth path, α_n is the angle of arrival of the nth path, and ϕ_n is the path through n after the

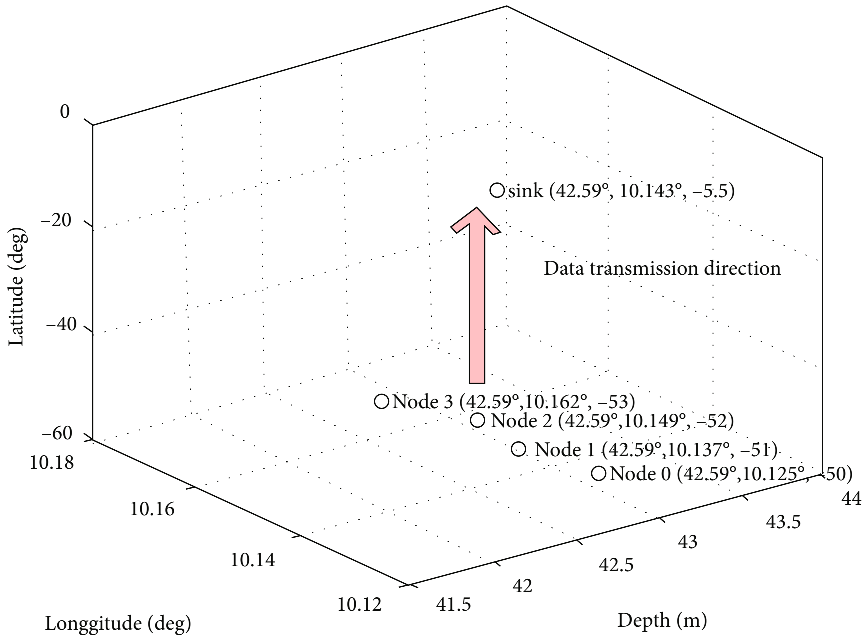

Figure 3: Network topology diagram.

additional phase shift, ω_m is the maximum value in the Doppler frequency domain ω_n, and the additional phase shifts of the different paths are independent of each other and are random variables uniformly distributed on $\phi_n[0, 2\pi]$.

3.3. Noise Model. Environmental noise in seawater refers to noise other than the noise of transducer itself, and all noise sources of that can be determined. The most important environmental noise in the ocean is ocean turbulence, ships, wind waves, and thermal noise [30]. An empirical formula for the power spectral density of these four noise sources is given below, in dB re μPa/Hz [31].

$$\begin{aligned}
&10 \lg N_t(f) = 17 - 30 \lg f, \\
&10 \lg N_s(f) = 40 + 20(s - 0.5) + 26 \lg f - 60 \lg (f + 0.03), \\
&10 \lg N_w(f) = 50 + 7.5w^{0.5} + 20 \lg f - 40 \lg (f + 0.4), \\
&10 \lg N_{th}(f) = -15 + 20 \lg f.
\end{aligned} \tag{11}$$

The total noise power spectral density $N(f)$ is the sum of the four. The relationship between $N(f)$ and the noise level NL is as shown in Eq. (12) [32], where B is the bandwidth in kHz, and l is the distance between nodes.

$$\begin{aligned}
NL &= 10 \lg (1000B) + N(f), \\
B &= 14.39\left(\frac{l}{1000}\right)^{0.55}.
\end{aligned} \tag{12}$$

4. Channel Model Test

In order to test whether the integrated simulation platform can operate correctly after the introduction of WOSS and Bellhop and simulate the transmission of underwater sound waves as realistically as possible, the paper selected a centralized network with five nodes, its network topology is shown in Figure 3, and the MAC protocol uses the Additive Link On-line Haw Aii (Aloha) protocol [33]. Based on the visual simulation platform, three sets of simulation experiments were carried out, and empirical model of underwater acoustic channel was adopted in the first experimental set. The second set of experiments used ∗.env type input files to provide environmental parameters for the Bellhop simulator. The third set of experiments indexed the environment parameter database according to node geolocation to obtain parameters and pass to Bellhop by WOSS. The calculation results of Bellhop were transmitted to the network simulator.

The parameters used in the three sets of experiments were identical, as shown in Table 1. All the nodes in the network are arranged at 42.59 degrees north latitude, and the longitude is 10.125 degrees to 10.162 degrees east longitude. The latitude and depth distance between adjacent nodes are, respectively, 0.01 degrees and 1 meter. The sink is located at the 10.143 degrees east longitude and 5.5 meters underwater.

The comparison of the data of the three sets of simulation results is shown in Table 2. The comparison results show that the three sets of simulation results are relatively close. The average throughput and average delay of the two sets of experiments using Bellhop channel simulation model are very close, while the average throughput and delay obtained by the first set of simulations using the empirical models are the slightly larger than the latter. The average packet error rate of the three is very close. This indicates that the integrated simulation platform introduced by WOSS and Bellhop can correctly simulate the propagation characteristics of underwater acoustic channel. Since WOSS can retrieve the global ocean data information and provide it to the Bellhop channel simulator, the simulation performance

Table 1: Three sets of simulation experimental parameters.

Parameter	Value	Parameter	Value
Number of nodes	5	Frequency	11.5 kHz
Packet length	512 byte	Bandwidth	5 kHz
Simulation time	1.0×10^5 s	Receive node maximum bit rate	4800 bps
Transmitting the maximum sound source level	190 dB	Bit rate/node	51.2 bps
Transmitter transducer opening angle	90°	Receiving transducer opening angle	90°
Maximum emission distance	10 km		

Table 2: Comparison of three sets of simulation results.

Parameter	Average throughput (bps)	Average normalized throughput	Average delay (s)	Average packet error rate	Simulation time consuming (s)
Group 1	46.653	0.911	2.326	0.063	2
Group 2	47.478	0.927	1.522	0.066	70
Group 3	47.52	0.928	1.524	0.061	223

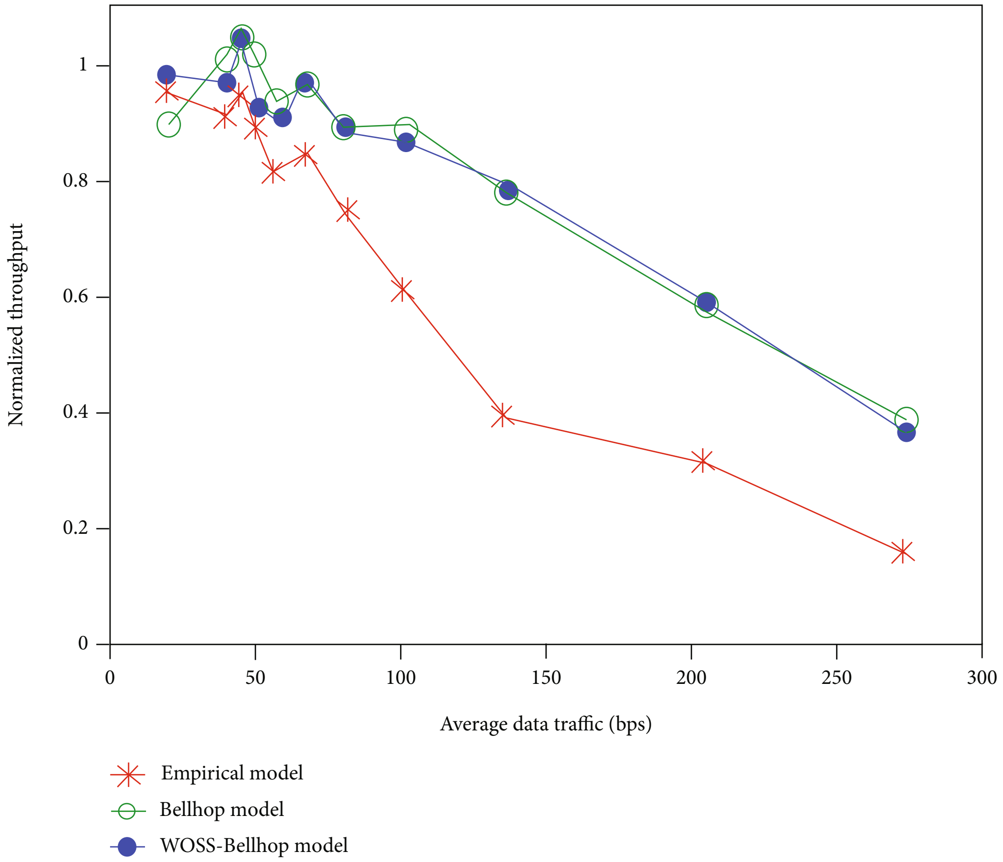

Figure 4: Normalized throughput for three models.

is close to that of the actual underwater network. In addition, WOSS can automatically retrieve the environmental parameters needed for simulation with only the geographic location (longitude, latitude, and depth), this simplifies the simulation. However, compared with the simulation time-consuming, the latter two sets spend a relatively long simulation time, especially the third group, which indicates that Bellhop and WOSS will seriously reduce the simulation efficiency.

The influence of the empirical model, the Bellhop model, and WOSS combined with Bellhop model on the MAC protocol was discussed. The simulation results of the ALOHA-CS protocol (the protocol is detailed in Section 6) are shown in Figures 4–6 when three channel models are used. The

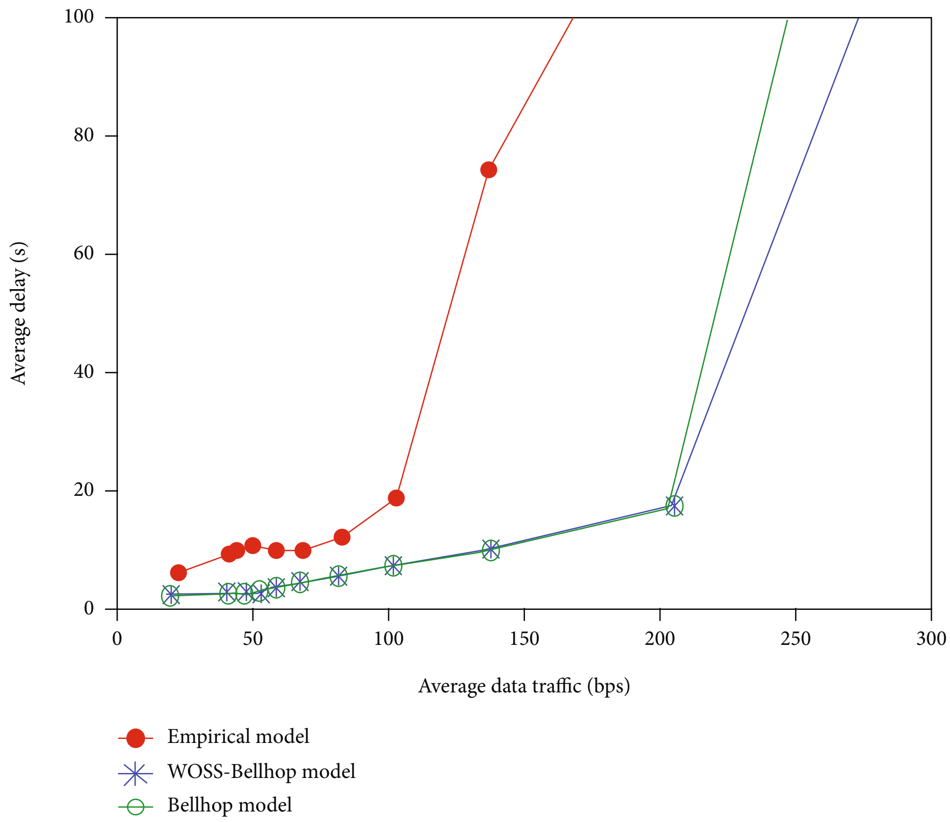

Figure 5: Average delay for three models.

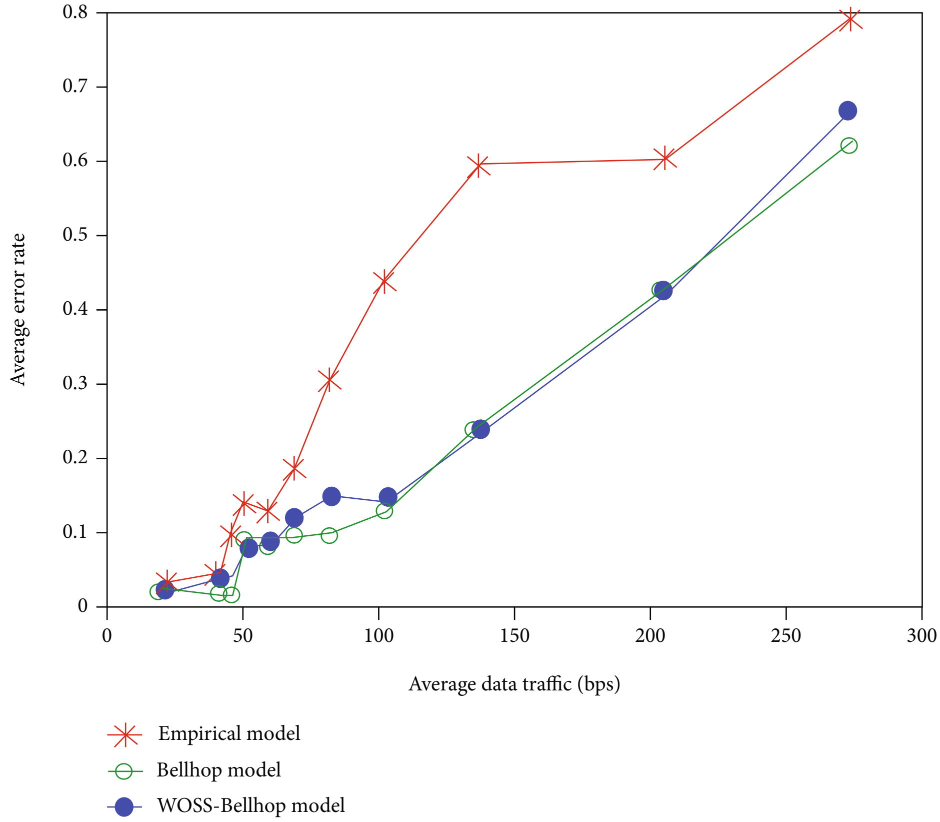

Figure 6: Average error rate for three models.

network topology as shown Figure 3, and other experimental parameters are the same as in Table 1.

The simulation experiment sets the packet sending period of each node is sampled from 15 seconds to 200 seconds, a total of samples is eleven, the samples of packet sending period in experiment are shown in Table 3. The simulation platform tracks the transmission data between each transmitting node and the sink node during the network running process. The average throughput, delay, and packet error rate of each simulation experiment are calculated. The normalized throughput is the ratio of the number of bits correctly arriving at the receiver per second divided by the data traffic because this is the maximum rate at which information can reach the receiver. In order to compare the performance of each protocol, the average throughput is done as normalized as shown as follows

$$\tau_n = \frac{\tau t}{8L_p}, \tag{13}$$

where τ_n is the normalized throughput, τ is the network average throughput, t is the packet-issuing period, and L_p is the packet length in bytes.

The average normalized throughput of the three models obtained by simulation is shown in Figure 4. It can be seen from the figure that the throughput of the three models gradually decreases with the increase of the data traffic. The average normalized throughput of Bellhop model and WOSS combined with Bellhop model is very close, and the average normalized throughput is always higher than that of empirical model when the data traffic of protocol is between 30 bps and 270 bps.

Figure 5 shows the simulation results of the impact of the data traffic on network packet delay. It can be seen from the figure that as the increase of the data traffic, the delay of the three models increases gradually. When the data traffic is between 30 bps and 211 bps, the average delay of Bellhop model and WOSS combined with Bellhop model increase steadily, when the data traffic higher than 211 bps that the two models increase rapidly, but it is always lower than that of empirical model.

The network average packet error rate simulation results using three models are shown in Figure 6. The average packet error rate of the three models is gradually increasing, and when the data traffic is between 40 bps and 270 bps, the packet error rate of the Bellhop model and WOSS combined with Bellhop model is always lower than of the empirical model.

The simulation results of three models show that, as the Bellhop model and the WOSS combined with Bellhop model take into account the complex characteristics of real-time ocean channels, the simulation results are more realistic compared with the empirical model. At the same time, WOSS combined with Bellhop model only obtains the marine environment data of the region according to the location information (latitude, longitude, and depth) and provides the data to Bellhop simulator, which makes the operation more convenient.

Table 3: Experimental grouping list.

Average delivery period second (seconds)	Total
15, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200	11 groups × 10 times

5. MAC Protocol Simulation of UWSNs

The ALOHA-CS protocol [34] is an improved version of the ALOHA protocol. The ALOHA-CS protocol adds the channel monitoring function. When data is transmitted, the node monitors the channel. If there is packet transmission, it waits for a randomly distributed time and monitors the channel again and finally performs the next retransmission. When the number of retransmissions reaches the maximum, it abandons the transmission. The carrier sense multiple access with collision avoid (CSMA/CA) protocol [35] is a multiple access method in wireless networks for sensing and avoiding the collisions. The CSMA/CA protocol adds an RTS-CTS (Request To Send-Clear To Send) handshake mechanism to the CSMA protocol, which solves the problems of hidden terminals and exposed terminals. The Distance Aware Collision Avoidance Protocol (DACAP) protocol [36] uses the RTS-CTS handshake for reserving the channel for packet transmission and saves broadcast energy by avoiding collisions.

In order to further test whether the extended simulation software is available, the paper uses the integrated system to simulate the Aloha-CS protocol, the CSMA/CA protocol, and the DACAP protocol in a five-node centralized topology (see Figure 3). In the test, the network data generation method is a fixed bit rate, and BPSK modulation and demodulation is adopted. The geographic location of the nodes and other experimental parameters is the same as that of the previous section. The simulation experiments are divided into three groups, and three MAC protocols are simulated by the same parameters.

The average normalized throughput of the three protocols obtained by simulation is shown in Figure 7. It can be seen that the throughput of the Aloha-CS and DACAP protocols gradually decreases with the increase of the packet delivery rate, and the throughput of Aloha-CS protocol is always higher than that of DACAP protocol when the average data traffic is between 80 bps and 270 bps. The reason is that Aloha-CS and DACAP protocols implement collision avoidance mechanisms through channel listening and avoidance time. The channel listening and handshake mechanisms consume a certain amount of time and increase the network load, so the throughput declined when the average data traffic increased. The DACAP handshake and warning packet mechanism are more complex than Aloha-CS, so the throughput performance is even worse. For CSMA/CA protocol, after the transmitting node received confirmation message of the receiving node, the data packets will be transmitted according to whether the network is blocked or not. This mechanism makes the impact of increasing the average data traffic on throughput weakly when the bandwidth is large enough. Therefore, Figure 7 shows that the average data traffic has little effect on the throughput of the network using the CSMA/CA MAC protocol.

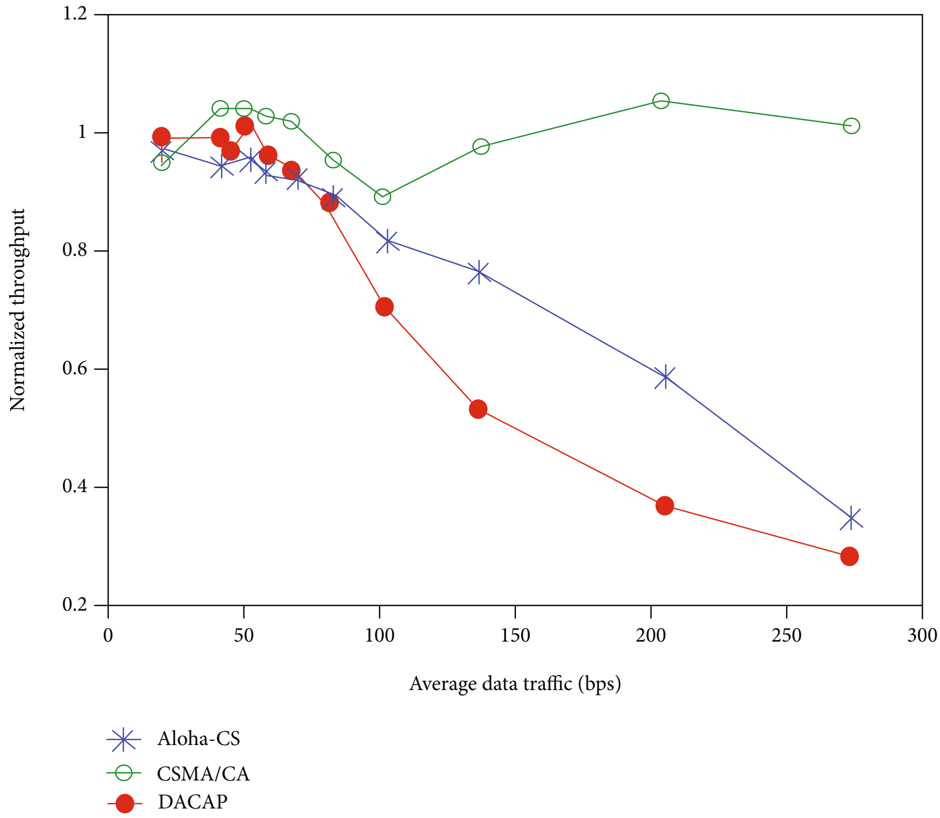

Figure 7: Normalized throughput for three MAC protocols.

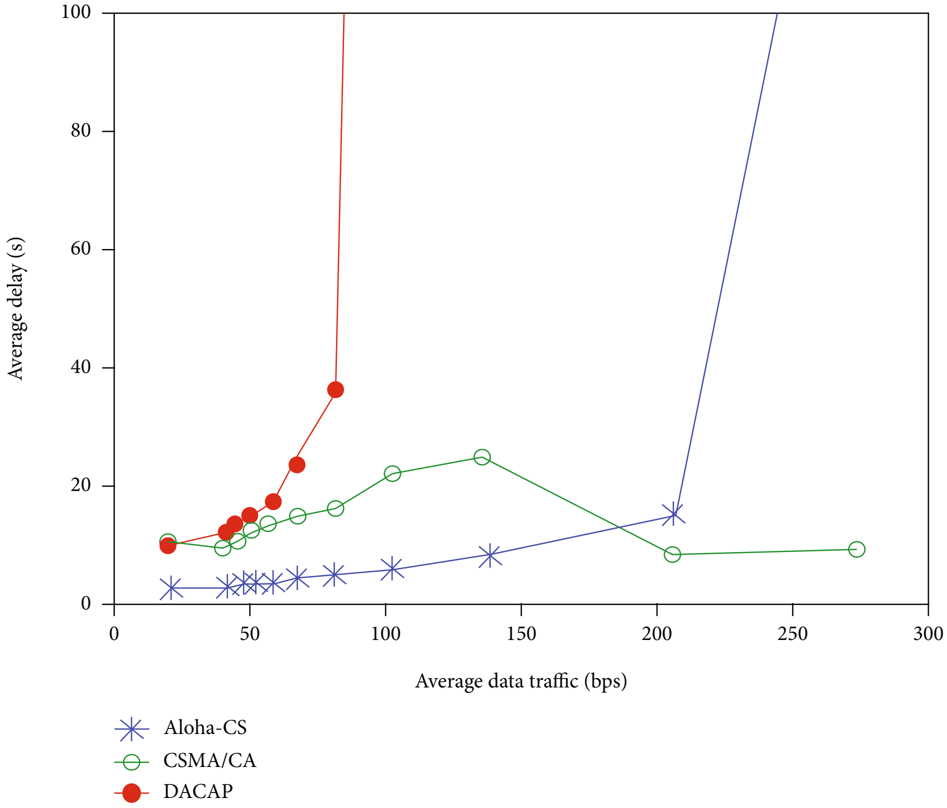

Figure 8: Average delay for three MAC protocols.

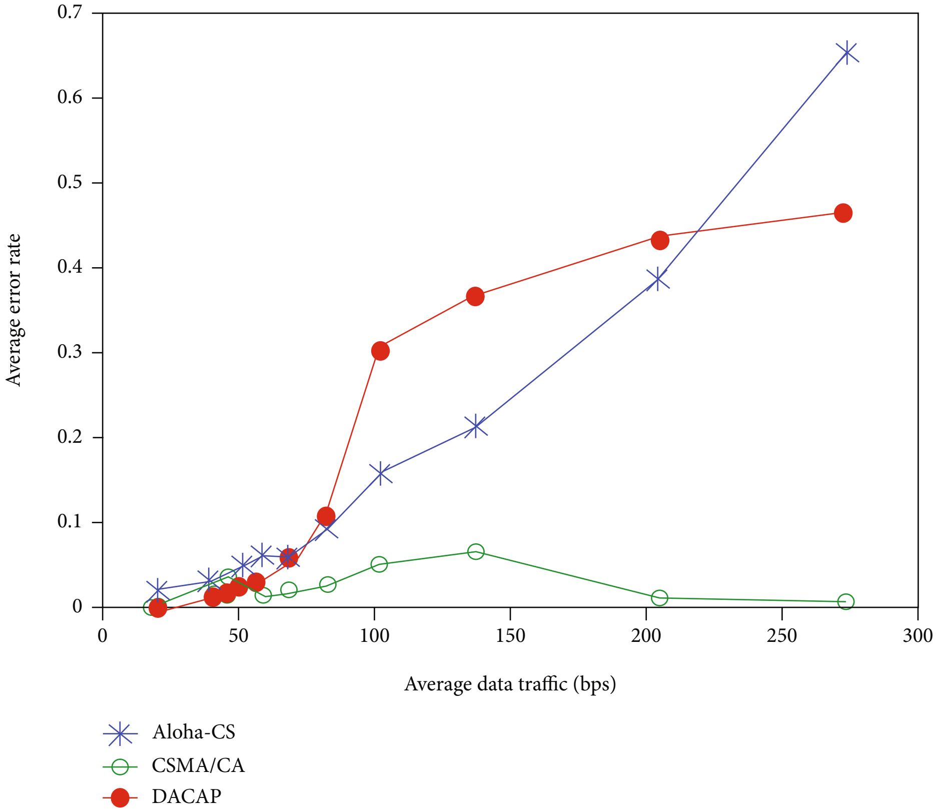

Figure 9: Average error rate of three MAC protocols.

Figure 8 shows the simulation results of the impact of the average data traffic on the network delay. It can be seen from the figure that as the average data traffic increases, the delay of the Aloha-CS and DACAP protocols increases gradually. When the average data traffic reached 100 bps, the delay of the DACAP protocol has reached 700 seconds, which indicates that the protocol is not working properly. So the DACAP protocol is not applicable to underwater networks with the average data traffic higher than 100 bps. When the average data traffic is 270 bps, the delay of the Aloha-CS protocol reaches 160 seconds. It indicated the network basically did not work. Therefore, the Aloha-CS protocol is not applicable to UWSNs with the average data traffic higher than 200 bps. Delay and average throughput of both protocols are affected by the collision avoidance mechanism. The delay of CSMA/CA protocol increases firstly with the increase of the average data traffic. When the average data traffic is greater than 150 bps, the average delay decreases slightly.

The network average packet error rate using three MAC protocols is shown in Figure 9. When the average data traffic is less than 30 bps, the average packet error rate of the Aloha-CS and DACAP protocols is almost zero. The packet error rate of both tends to increase with the increase of the average data traffic. The packet error rate of the CSMA/CA protocol is always less than 0.1 in the whole process. It shows very good performance.

The simulation results of three MAC protocols show that, as a result of DACAP strongly avoid collision mechanism, the packet error rate is almost zero during the average data traffic is very low. However, because its performance is limited by the handshake mechanisms, its performance declined seriously, even unable to work with the average data traffic increasing. This protocol achieves a very high success rate at the expense of lower throughput. For the Aloha-CS and CSMA/CA protocols, the performance of the CSMA/CA protocol is higher obviously than that of the Aloha-CS protocol. Therefore, it is concluded that CSMA/CA is more suitable for the underwater sensor network with centralized topology than the other two protocols.

6. Conclusion

The NS2/NS-Miracle simulation system extended by WOSS and Bellhop can simulate correctly the propagation characteristics of underwater acoustic channel. Since WOSS can retrieve the global marine data and provide it to Bellhop, the network modelling is closer to the actual communication situation of underwater network, so as to the reliability of the integrated simulation system improve.

The characteristic empirical model, Bellhop Ray-Tracing model, and WOSS combined with Bellhop model were, respectively, adopted to simulate underwater acoustic channel in order to verify the reliability of the integrated system. The simulation results of three models are very close. It proves that the accuracy of integrated simulation system is as excellent as that of NS-Miracle. In addition, the characteristics of three MAC protocols of Aloha-CS, CSMA/CA, and DACAP in the integrated simulation system show that the integrated simulation system can more accurately simulate the MAC protocol in the real underwater network.

The network topology of this paper is currently limited to the subnet with a small number of nodes. In the future work, further simulation experiments and analysis will be carried out for a wide range of node transmission. It is necessary to investigate the related works about IoUT thoroughly and add the Autonomous Underwater Vehicle (AUV) to analyze the influence of mobile nodes on network topology and protocol performance.

Data Availability

The experimental data used to support the findings of this study are included within the supplementary information file(s) (available here).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

The paper uses WOSS and NS2/NS-MIRACLE to simulate the water of the ALOHA-CS protocol, CSMA/CA protocol, and DACAP protocol in a five-node centralized topology. *(Supplementary Materials)*

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