Received January 16, 2019, accepted February 18, 2019, date of publication February 25, 2019, date of current version May 10, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2901375

Research on Underwater Wireless Sensor Network and MAC Protocol and Location Algorithm

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This work was supported by the National Natural Science Foundation of China under Grant 61701295, Grant 61803254, and Grant 61703270.

ABSTRACT In recent years, underwater wireless sensor networks (UWSNs) have received extensive attention due to their application in the development of marine resources. The underwater acoustic channel has a long delay, low bandwidth, and highly dynamic changes in the underwater environment so that the existing technologies and protocols in the traditional wireless sensor network cannot be directly applied to underwater. This paper studies the medium access control (MAC) protocol and positioning technology of UWSNs and introduces the typical underwater line sensor network MAC protocol. Aiming at the problem of spatial fairness caused by the propagation characteristics of the underwater acoustic channel and the triple terminal problem caused by the long propagation delay in UWSNs, and effectively implementing the multi-channel mechanism, an underwater multi-channel based on a single transceiver is proposed, which is SFM-MAC. The existing underwater positioning algorithms are divided into two categories, centralized positioning algorithm and distributed positioning algorithm, and each type of algorithm is briefly explained. In this paper, the Markov chain is used to construct the reservation model of the control channel, and the theoretical analysis of multi-channel throughput is given. The theoretical throughput of the multi-channel MAC protocol under the condition of reserved collision is obtained. Finally, this paper verifies the actual performance of SFM-MAC through simulation experiments.

INDEX TERMS Underwater wireless sensor networks, MAC protocol, localization algorithm, fairness, hidden terminal.

I. INTRODUCTION

In recent years, around the development of marine technology, international organizations have launched many large-scale marine research program [1]. In many fields of light and seawater technology, Underwater Wireless Sensor Networks (UWSN) has been monitored in recent years for water pollution monitoring, underwater resource exploration, marine agrometeorological data collection, earthquake, tsunami disaster prevention, and defense security. Applications such as these are receiving increasing attention [2], [3]. The research on underwater sensor networks abroad started relatively early. The United States Woods Hole Oceanographic Institution (WHOI) proposed the concept of The Acoustic Local Area Network in 1994. It consists of a number of subsea nodes that communicate with the surface buoy nodes via acoustic signals, while the buoy nodes communicate with the coast base stations via radio waves. In 2000, the Global Real-Time Ocean Observation Program (ARGO) was launched [4]. China 2002 became an important member of the Argo program and has placed 161 Argo profile buoys in the Indian Ocean and Pacific Ocean. From 2007 to 2010, more than 300 scientists from 14 European countries participated in the European Undersea Observation Network (ESONET) program, etc.

The underwater environment is a transmission medium that is distinct from the traditional terrestrial environment and is one of the most complex environments faced by researchers

The associate editor coordinating the review of this manuscript and approving it for publication was Muhammad Imran.

to date [5]. Since electromagnetic waves propagate rapidly in the air (3 × 108 m/s), the propagation delay is small, and has a wide bandwidth, therefore, electromagnetic waves are used for data transmission in the conventional terrestrial wireless communication. However, in the underwater environment, the attenuation of electromagnetic waves is very large, the propagation distance is very short, and long-distance communication cannot be realized, so it is not suitable as a carrier for underwater communication; while the light wave is less attenuated, it faces the problem of color dispersion, and at the same time Laser beams are also required to be precisely aligned, which is obviously not suitable for use in underwater environments [6]. However, the sound can propagate in a longitudinal wave in an underwater environment, the attenuation speed is much slower, and it can transmit a long distance, which is an ideal underwater communication carrier. Therefore, underwater acoustic communication is the most effective means to solve underwater communication. However, due to the small speed of sound propagation, long propagation delays, limited bandwidth, and frequency fading are caused [7], [8]. The particularity of the underwater acoustic channel makes it impossible for some mature technologies or solutions in traditional terrestrial wireless sensor networks to be directly applied to underwater environments.

This paper first expounds the background and development status of wireless sensor networks, and introduces the network characteristics of underwater sensors. Then the sweet potato underwater wireless sensor MAC protocol and positioning algorithm are introduced, and the centralized positioning algorithm and distributed positioning are introduced. The algorithm is introduced and discussed separately. The characteristics of the MAC protocol are merged. A hybrid multi-channel MAC protocol is proposed, and its performance is simulated and analyzed. The validity of the proposed protocol is proved.

II. UNDERWATER WIRELESS SENSOR NETWORK

A. NETWORK CHARACTERISTICS OF UNDERWATER WIRELESS SENSOR NETWORKS

The characteristics of underwater wireless sensor networks are mainly reflected in:

1) LARGE SCALE

In an underwater environment, a large number of underwater sensor nodes are typically deployed to obtain specific information. On the one hand, it is to obtain information in a wider area, on the one hand, to achieve a larger spatial perspective and signal-to-noise ratio, and to reduce communication blind spots.

2) SELF-ORGANIZING

In underwater wireless sensor networks, sensor nodes are usually randomly deployed in the monitoring waters. A single sensor node cannot know its location information and the neighbor relationship between nodes in advance. This requires nodes to have strong self-organization ability. According to the topology control and network protocol, an underwater network that facilitates storing and forwarding data is spontaneously formed.

3) DYNAMIC

The topology of underwater wireless sensor networks often changes. For example, the addition of new nodes leads to changes in topology; sensor nodes fail due to energy exhaustion or environmental factors; changes in the marine environment cause communication links to be unstable. This requires underwater wireless sensor networks to adapt to this dynamic change.

4) RELIABILITY

Nodes of underwater it is very meaningful to study the underwater infinite sensor network protocol wireless sensor networks are susceptible to dirt or corrosion in harsh underwater environments. Sensor nodes are often randomly deployed in designated areas by specific equipment, which requires sensor nodes to adapt to various harsh environments. Therefore, the underwater sensor node needs to be characterized by being difficult to damage and having high reliability.

B. UNDERWATER WIRELESS SENSOR NETWORK ARCHITECTURE

The sensor network architecture is divided into static two-dimensional and three-dimensional underwater sensing networks.

Static two-dimensional underwater sensor network. Mainly used for submarine monitoring, consisting of sensor nodes anchored to the seabed [9].

In the two-dimensional underwater network reference architecture, the sensor nodes are anchored at the bottom of the ocean [10]–[12]. The underwater sensor node communicates via a wireless acoustic link using one or more underwater gateways. The underwater gateway is responsible for data relay from the submarine network to the sea level. To achieve this goal, two transceivers for acoustic signals are provided, namely vertical transceivers and horizontal transceivers. The horizontal transceiver is used for communication between the underwater gateway and the sensor node, and the vertical transceiver is used for data transmission with the sea level base station.

Static 3D underwater sensor network [13]. It mainly includes sensor nodes anchored on the seabed, its depth can be controlled, and can generally be used to monitor marine phenomena such as marine life, water flow, pollution, etc.

In a three-dimensional underwater network, the sensor device is anchored at the bottom of the ocean, as shown in Figure 1. Each sensor is anchored to the sea floor and is equipped with a buoy that can be inflated by a pump that allows the sensor to reach the surface of the ocean [14].

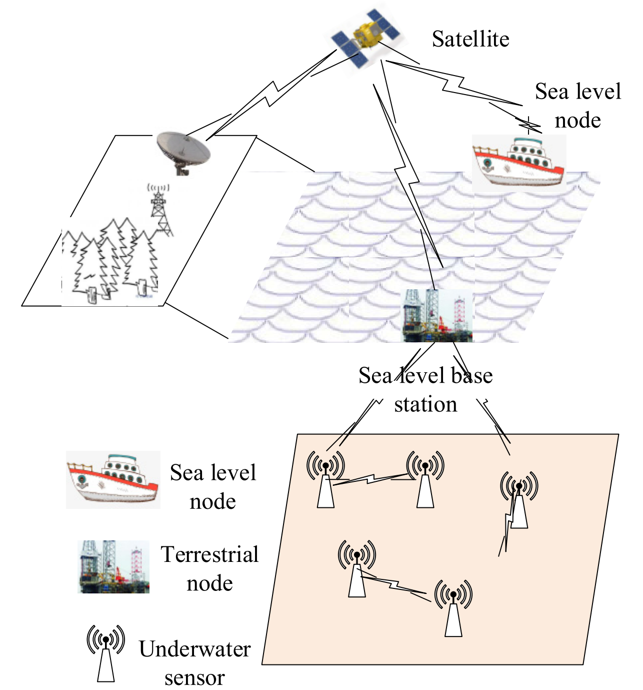

FIGURE 1. Static three-dimensional underwater sensor network structure.

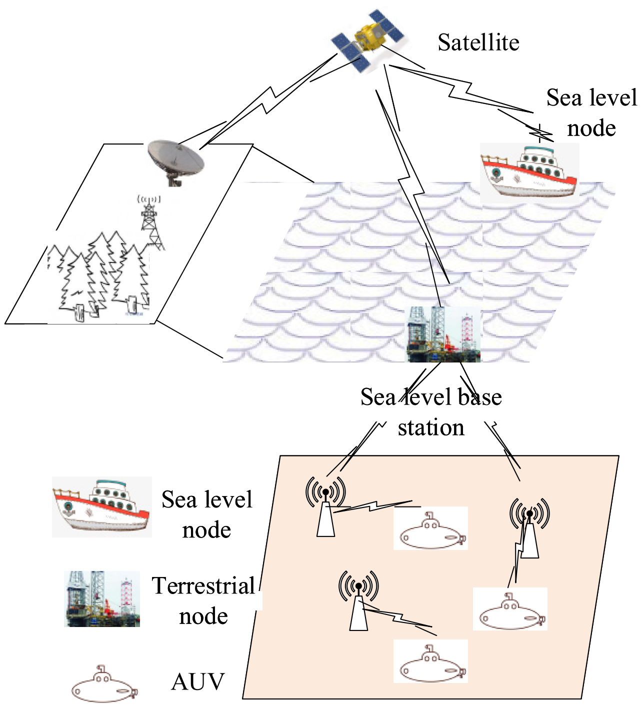

FIGURE 2. Three-dimensional autonomous underwater robot c network structure.

The depth of the sensor can be adjusted by adjusting the length of the wire.

In addition, there is an innovative three-dimensional autonomous underwater robot network. It consists of fixed sensor nodes and Autonomous Underwater Vehicles (AUVs), [15] and its structure is shown in Figure 2.

III. LOCALIZATION ALGORITHM OF WIRELESS SENSOR NETWORK MAC PROTOCOL

A. MAC PROTOCOL

In wireless sensor networks, the medium access control (MAC) is responsible for allocating wireless communication resources to nodes and determining how channels are used [16].

Since the underwater acoustic channel is limited by resources such as bandwidth and rate, the research of MAC protocol is very important. At present, the design idea of the MAC protocol for underwater wireless sensor networks is mainly to overcome the adverse effects of long propagation delay [17]–[19]. These MAC protocols can be mainly classified into competitive and non-competitive. The latter is limited by factors such as synchronization and bandwidth, and has not become the mainstream of the underwater MAC protocol. The former can be divided into a random multiple access class and a channel reservation based protocol. The structure of the random multiple access protocol is simple and convenient to implement, but it is not conducive to the use in the burst data scenario; the MAC protocol based on the channel reservation mechanism, although the collision avoidance mechanism is relatively complicated and has a large network delay [20]. However, there is a very outstanding throughput performance in the burst data network scenario.

The underwater MAC protocol can be roughly divided into two categories: one is a non-competitive MAC protocol, such as frequency division multiple access (FDMA) [21], time division multiple access (TDMA) [22], code division multiple access (CDMA). One type is based on the competition-based MAC protocol, such as ALOHA, Carrier Sense Multiple Access (CSMA). Code Division Multiple Access (CDMA) technology can be used in the scheduling-based MAC protocol. The advantages of each technology are shown in Table 1.

B. UNDERWATER WIRELESS SENSOR NETWORK LOCALIZATION ALGORITHM

The existing underwater positioning technologies can be divided into two categories, a centralized positioning algorithm and a distributed positioning algorithm. Underwater sensor network structure can be roughly divided into three types, fixed network, mobile network and hybrid network. In a fixed network, all nodes have fixed locations; in a mobile network, all nodes move, or actively move, or passively move; in a hybrid network, fixed nodes coexist with mobile nodes. The positioning techniques in these three underwater networks are discussed separately below.

1) FIXED NETWORK

The fixed network is shown in Figure 3. It is a positioning method based on hyperbolic detection and error estimation and correction using normal distribution. As shown in Figure 3, when an unknown node detects an event, it will send it to the anchor node. A1, A2 can use the time difference of arrival of this event to draw the hyperbola H12 of the

TABLE 1. **Comparison of advantages and disadvantages of MAC protocol.**

Comparison of advantages and disadvantages of MAC protocol	Typical protocol	Advantageous	Disadvantageous
Non-competitive agreement	FDMA	High channel multiplexing rate, allowing for more multiplexing channels and convenient branching	Need more bandwidth
	TDMA	Each channel can be used effectively by many users	Need precise synchronization information, the number of carrier channels that can be achieved is limited
	CDMA	Good anti-interference, anti-multipath fading, high frequency utilization	Need to assign pseudo-random code and have near-far problems
Competitive agreement	CSMA	Better performance in small-scale, high-density, busty data scenarios	Greater energy consumption
	ALOHA	Suitable for low density networks	Suitable for low density networks

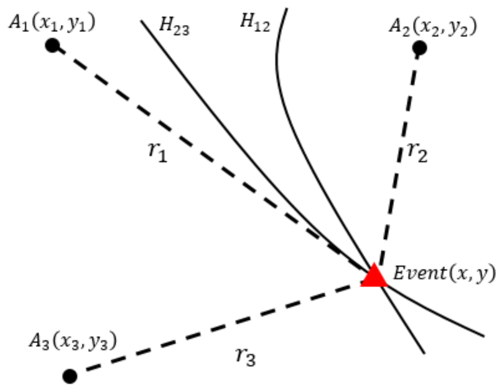

FIGURE 3. **Hyperbolic positioning algorithm.**

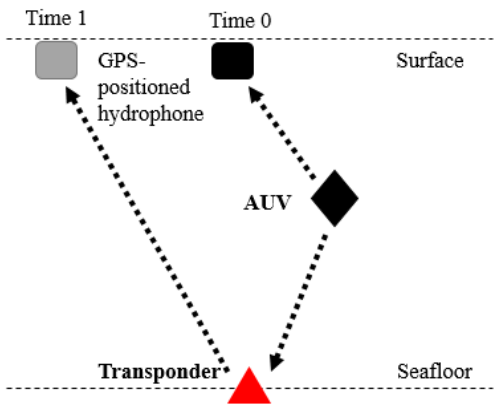

FIGURE 4. **AUV absolute positioning algorithm.**

unknown node. Similarly, using the anchor nodes A2, A3, another curve H23 is obtained, and the intersection of the two curves is the estimated position of the unknown node. The advantage of this algorithm is that the measurement error is small, the precision is high, and more unknown nodes can be located. The disadvantage is that it needs to send a remote signal (about 1km), the energy consumption increases, and the anchor node is fixed at the corner, which is not conducive to extending to the three-dimensional mobile network.

2) MOBILE NETWORK

As the node moves, the distance estimate will be outdated or invalid, and the underwater sound communication speed is lower, the delay is longer, and the time required for underwater exploration and positioning will increase, and the possibility of obsolescence or invalidity will increase. The Underwater Autonomous Vehicle (AUV) provides researchers with a new form of exploration for the ocean. And these all require accurate location information of the AUV. The researchers proposed an absolute positioning algorithm based on AUV. In the algorithm, as shown in Figure 4, the AUV is bound to a pressure sensor, which can measure its depth, and the AUV sends an interrogation signal at a certain frequency. This signal can reach the water surface directly at Time0, or can be forwarded through the transponder on the seabed. After that, it reaches the water surface at Time1, and uses this time difference of arrival and the depth to locate the AUV. The disadvantage of this positioning algorithm is that the positioning range is limited, and because the AUV and the ship will move, the arrival time difference is not accurate enough, and the positioning will be inaccurate.

3) HYBRID NETWORK

The ASL algorithm is extended to a three-dimensional underwater network, and DET (Detachable Elevator Transceivers) can be used to broadcast its GPS coordinates with different power signals while falling. The unknown node collects the DET coordinates and their respective minimum powers and sends them to the sink, which calculates the approximate area of the unknown node. The disadvantage of this algorithm is that the positioning accuracy is low, and because the DET propagates signals of different powers, the power consumption and communication overhead increase. Moreover, the speed of DET drop and the time interval for sending messages can have a significant impact on the positioning time.

IV. FUSION POSITIONING UNDERWATER MULTI-CHANNEL MAC PROTOCOL

Studies have shown that in terrestrial wireless networks, MAC protocols that utilize multiple channels for data transmission can greatly improve network throughput, mitigate channel access delays, and reduce energy consumption. In the underwater sensor network, the researchers analyzed the underwater MAC protocol based on multi-channel ALOHA and multi-channel RTS/CTS, in which there is a common control channel dedicated to sending and receiving control messages, and each node continues Listen to the channel. Research indicates that in an underwater environment, multi-channel mechanisms can achieve higher throughput and energy utilization than single-channel mechanisms. The throughput increases significantly as the number of data channels increases, and the average power consumption decreases monotonically. In addition, as the number of data channels increases, the impact of long propagation delays can be mitigated to some extent, the system will approach the ideal zero propagation delay, and higher throughput and energy utilization can be achieved.

A. TRIPLE HIDDEN TERMINAL PROBLEM OF UNDERWATER MULTI-CHANNEL MAC PROTOCOL

The triple hidden terminal problem of the underwater multi-channel MAC protocol is as follows:

1) MULTI-HOP HIDDEN TERMINAL

In an underwater network, not all nodes are within the communication range of the sending node. When a node has data to send, nodes outside its communication range will not be aware that other nodes are sending data, which may cause conflicts at the receiving end. As shown in figure. 5, both Node B and Node C are within the communication range of Node A, but Node B and C do not perceive each other. Therefore, the packet sent by Node B and the packet sent by Node C may occur at Node A. collision.

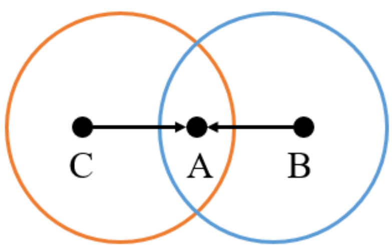

FIGURE 5. Multi-hop hidden terminal.

2) MULTI-CHANNEL HIDDEN TERMINAL

If the node has only one transceiver, it can only work on one sub channel at the same time, for example, it only works on the control channel, or only works on the data channel, but it cannot work on several different channels at the same time. Lead to multi-channel hidden terminal problems. As shown in FIG. 6, when node A and node B perform handshake on the control channel, node C and node D communicate on a certain data channel (assumed to be data channel 2). Therefore, nodes C and D cannot hear which data channel is selected by nodes A and B (assuming that data channel 1 is selected). Then, when node C needs to send data to node D, it will initiate a handshake process on the control channel again. Since node D does not know that data channel 1 has been occupied by nodes A and B at this time, node D may select data channel 1, and thus may cause a collision.

3) LONG DELAY HIDDEN TERMINAL

The long propagation delay characteristic of the underwater acoustic channel introduces another hidden terminal problem - long delay hidden terminal problem. As shown in Figure 7, initially, all nodes listen to the control channel. Node A and Node B initiate a handshake process on the control channel and select Data Channel 1 for communication. Node C and Node D make reservations on the control channel later. If node D selects the data sub channel it wants to use and sends CTS to node C, node C's CTS arrives at node D. Then, before node D does not know the data channel selected by node B, then D is likely to also the data channel 1 is selected for communication, and when the data is transmitted, a collision is caused on the channel 1.

B. SPACE FAIR MULTI-INFORMATION CHANNEL MAC PROTOCOL

It is assumed that there are N+2 channels in the network, and each channel has the same bandwidth, one of which serves as a positioning channel, the other serves as a control channel, and the remaining N serve as data channels. Each node listens to the control channel when there is no data transmission, but periodically switches to the positioning channel to update the positioning information. Each node has only one transceiver that can be dynamically switched to a different channel. The communication range of each node is r, and the propagation speed of the acoustic signal is v.

The E-UPS positioning algorithm is used to perform three-dimensional positioning on the nodes. As shown in Figure 8, A is the main anchor node, A sends a beacon signal, B also starts transmitting the beacon signal after receiving the signal of A, C receives the signal of A and B and then starts transmitting the beacon signal, D receives A, After the signals of B and C, the beacon signal is started to be transmitted. After receiving all the beacon signals of A, B, C, and D, the S node can calculate the time difference of arrival, then convert the time difference into a distance difference, and then perform positioning according to the trilateral positioning method. At the same time, the E-UPS designs an overflow time for the longest waiting time of the anchor node information. Due to the complex acoustic channel environment, if the signal is

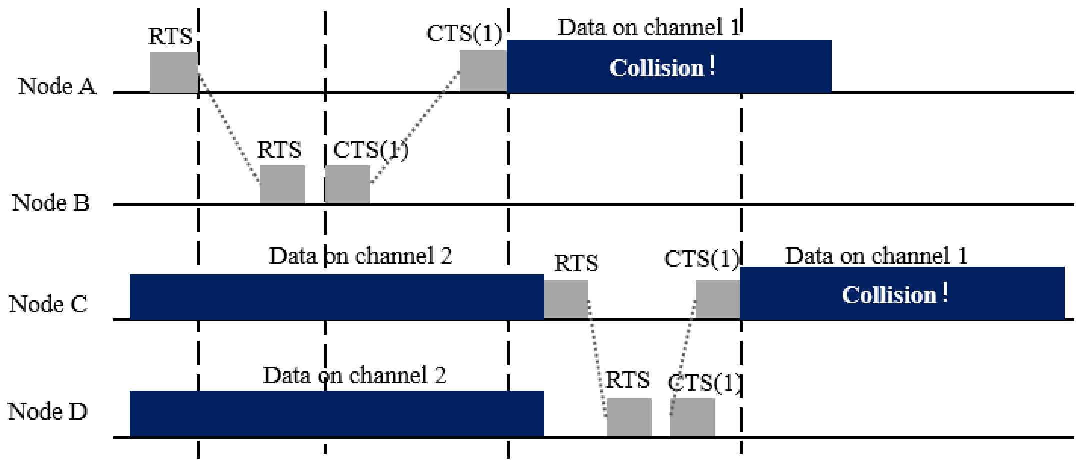

FIGURE 6. Multi-channel hidden terminal.

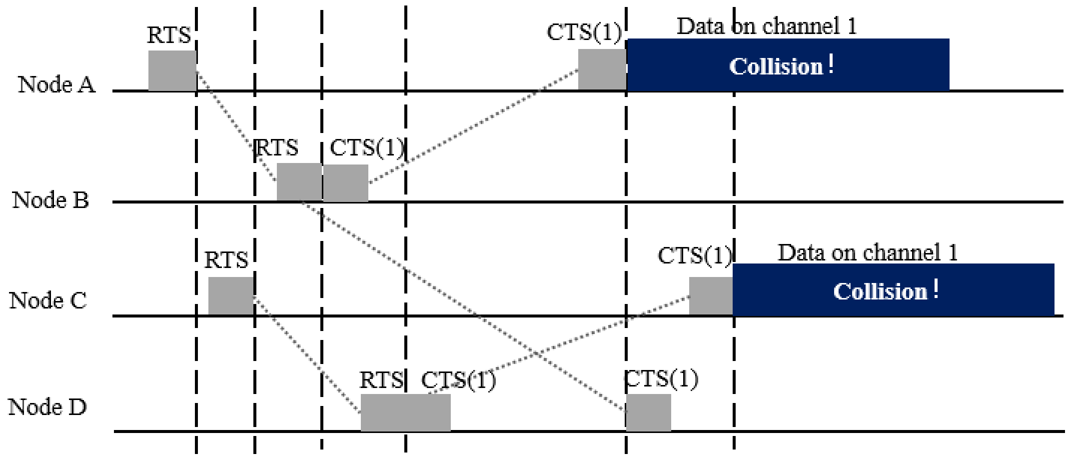

FIGURE 7. Long delay hidden terminal.

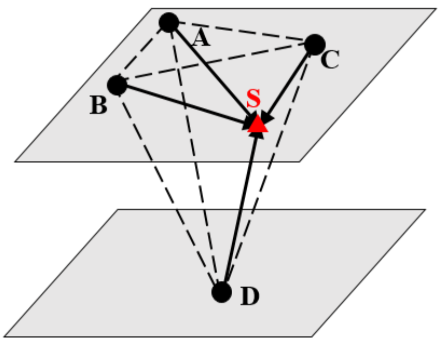

FIGURE 8. E-UPS positioning method.

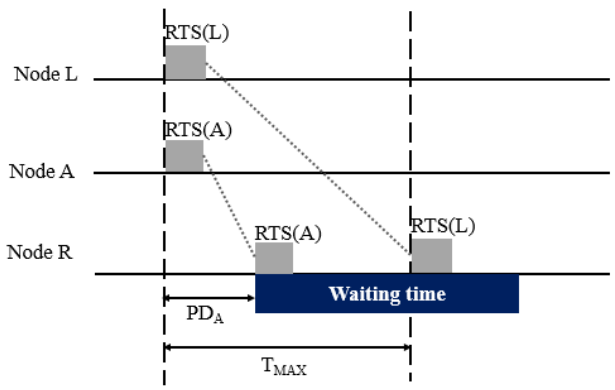

FIGURE 9. Calculate minimum wait time considering fairness issues.

lost during the transmission process, the node waits for the timeout period and then restarts the positioning process.

Through the RTS/CA/CL/CTS handshake phase, SFM-MAC can alleviate triple hidden terminal problems and achieve spatial fairness. And the entire process does not require time synchronization, and the equipment requirements are low.

As shown in Figure 9, the RTS packet sent by the A node first arrives at the receiving node R, and the node R needs to wait for a period of time, so that all RTS packets that may be sent before the RTS (A) can reach R during this time. Node L is the node on the communication boundary of R.

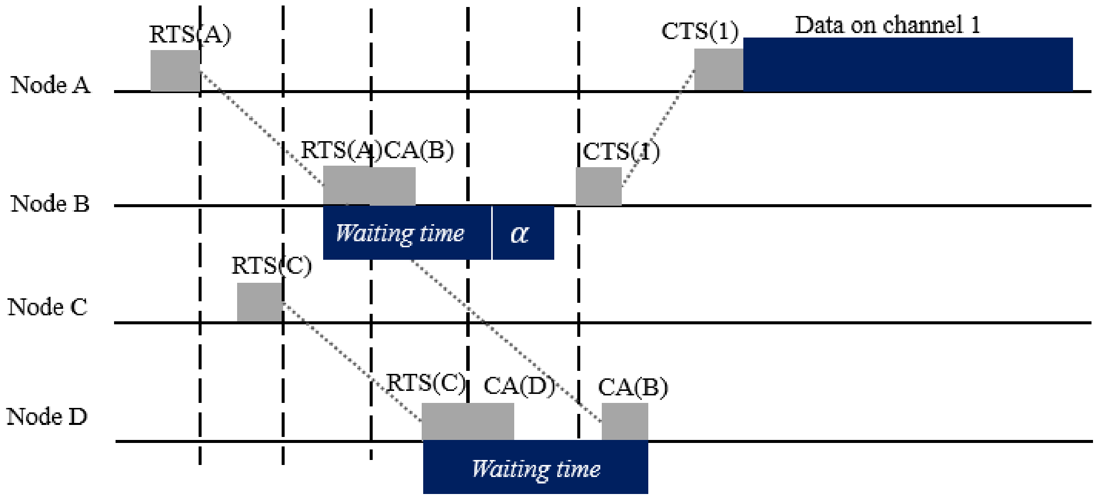

FIGURE 10. Consider extending the hidden terminal to calculate the minimum wait time.

Considering the issue of fairness, the minimum waiting time should be:

$$WT = T_{MAX} - PD_A \tag{1}$$

Considering that during this waiting time, the node should be able to receive all potential channel usage claims, as shown in Figure 10. Channel reservation and data transmission are performed between node A and node B, and channel reservation and data transmission are performed between node C and node D. When the nodes A and B are the same as the channels reserved by the nodes C and D, the data channels will collide.

Considering the time difference measurement error, the minimum waiting time after correction is:

$$W = T_{MAX} + f(\lambda_1, \lambda_2, \lambda_3) \tag{2}$$

In the synchronization problem, since the E-UPS positioning algorithm is based on the time difference of arrival (TDoA), one of the advantages is that no time synchronization is required. No need to consider this issue.

V. PROTOCOL PERFORMANCE AND SIMULATION EXPERIMENT

A. TWO-DIMENSIONAL MARKOV CHAIN

Based on the multi-channel scheme, it is possible that a plurality of nodes simultaneously transmit an RTS, and a collision occurs on the control channel. This paper improves the two-dimensional Markov chain model to include the frozen state during the back off process, as shown in Figure 11.

In this Markov chain model, m represents the maximum number of times a node performs back off, and also indicates the maximum number of retransmissions. m' represents the maximum number of changes in the process from the initial contention window value W0 to the maximum contention window value Wm'. Once CW reaches the maximum contention window value Wm', CW will remain unchanged until it is reset to the initial contention window value, thus:

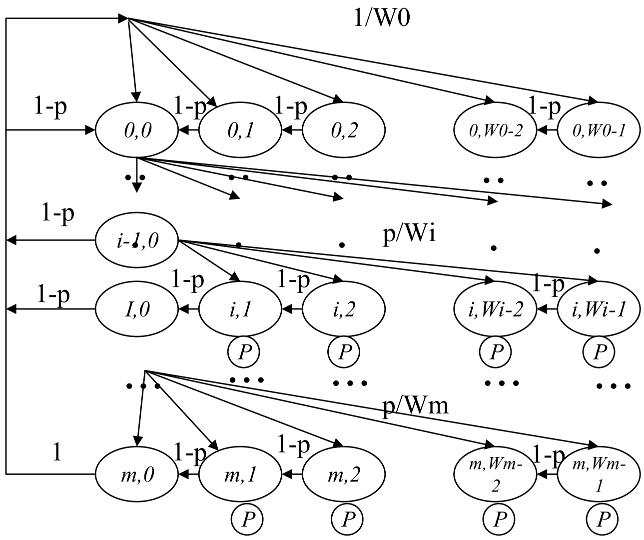

FIGURE 11. Makov chain model for controlling sub channel back off mechanism.

$$\begin{cases} W_i = 2^i W_0 & i < m' \\ W_i = 2^{m'} W_0 & i > m' \end{cases} \tag{3}$$

The one-step transfer probability formula of the Markov chain model is as follows:

$$\begin{cases} P\{i,k|i,k\} = p \\ \qquad k \in (0, W_i - 1] \quad i \in [0, m] \\ P\{i,k-1|i,k\} = 1-p \\ \qquad k \in (0, W_i - 2] \quad i \in [0, m]\, P\{0,k|i,0\} \\ \qquad\qquad = (1-p)/W_0 \\ \qquad k \in (0, W_0 - 1] \quad i \in [0, m-1] \\ P\{i,k|i-1,0\} = p/W_i \\ \qquad k \in (0, W_i - 1] \quad i \in [1, m] \\ P\{0,k|m,0\} = 1/W_0 \\ \qquad k \in (0, W_0 - 1] \end{cases} \tag{4}$$

According to the transition probability and global equilibrium equation of the Markov chain, there is

$$b_{i,k} = \begin{cases} \frac{1}{1-p} \times \frac{b_{i-1,0} \times p}{W_i} \\ \frac{1}{1-p} \times \left[\frac{b_{i-1,0} \times p}{W_i} + b_{i,k+1}(1-p) \right] \end{cases} \quad (5)$$

Based on the conversion probability, the formula can be reduced to:

$$b_{i,k} = \begin{cases} \frac{1}{1-p} \times \frac{1}{W_i} \times p^i \times b_{0,0} \\ \frac{1}{1-p} \times \frac{W_i - k}{W_i} \times p^i \times b_{0,0} \end{cases} \quad (6)$$

The sum of all steady-state probabilities in the Markov chain is 1, which can be solved in (7) and (8), as shown at the bottom of this page.

UWSIFS is the shortest frame interval under water, PD is the underwater average transmission delay, and T_{switch} is the time for channel switching.

$$T_S = RTS + UWSIFS + PD + CA + UWSIFS + WT + T_{witch} + CL + T_{switch} + CTS + UWSIFS \quad (9)$$

The throughput can be calculated from this.

B. SIMULATION ENVIRONMENT

Currently, simulation through virtual environments to verify the correctness of network protocols and performance testing of network protocols is the most widely used method. NS (Network Simulator) is one of the most popular network simulation software's, and has been widely used in network analysis by universities and research institutes. NS is supported by DARRA (US Department of Defense Advanced Research Projects Agency), LBL (Lawrence Berkeley National Laboratory, USA), Xerox PARC (Xerox Palo Alto Research Center), UCB (University of California, Berkeley), and USC/l51 (USA) The Network Simulator of the VINT (Virtual Internet Testbed) project jointly participated in the School of Information Science of the Ministry of Commerce.

The NS-2 uses two programming languages, the OTcl scripting language and the C++ programming language. The choice of these two languages is due to the fact that the simulator has two things to do. On the one hand, a programming language is required to implement and simulate a specific protocol, while efficiently processing bytes, headers, etc., and using appropriate algorithms for manipulation of large data sets. In order to achieve this task, the speed of the internal modules of the program is very important, and the time to simulate the environment, the time to find and fix bugs, and the time to recompile and run are not very important. In this case, the C++ language is very suitable. On the other hand, in many network research work, the specific parameters of the environment and the setting of network components need to be able to quickly develop and simulate the required network environment in a short time, and can be easily modified, discovered and repaired. The bug. This makes the time of the network environment layout very important, because the parameter information can be configured and the simulation environment can be established only once. The Tcl scripting language with object-oriented features can fully meet this requirement. The overall architecture of NS2 is shown in Figure 12.

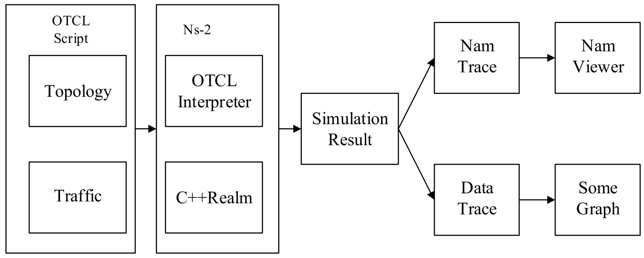

FIGURE 12. The overall architecture of the NS-2.

C. SIMULATION RESULTS

In this section, we use the Fairness Index (FI) used in previous work to measure the fairness of transmission.

Assuming that there are n nodes competing for transmission data, and the order of transmission is represented by s_i, r_i indicates the order of the received reservation control packet RTS, then the delay xi of the competing node can be expressed as:

$$x_i = r_i - s_i + n \quad (10)$$

The result of the fairness index FI is between 0 and 1. If the FI is closer to 1, the fairness is higher.

$$FI = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n \times \left(\sum_{i=1}^{n} x_i^2\right)} \quad (11)$$

Suppose there are n sending nodes and one receiving node. In the ideal channel, the packet loss rate is ignored, and the

$$b_{0,0} = \begin{cases} \frac{2(1-p)^2(1-2p)}{W_0\left(1-(2p)^{m+1}\right)(1-p)+\left(1-p^{m+1}\right)(1-2p)} \\ \frac{2(1-p)^2(1-2p)}{W_0\left(1-(2p)^{m+1}\right)(1-p)+\left(1-p^{m+1}\right)(1-2p)+W_0 2^{m'} p^{m'+1}(1-2p)\left(1-p^{m-m'}\right)} \end{cases} \quad (7)$$

$$S = \frac{P_{tr} P q E[P]}{(1-P_{tr})\sigma + P_{tr}(1-P_S) T_C + P_{tr} P_S q T_S + P_{tr} P_S (1-q) T_S'} N' \quad (8)$$

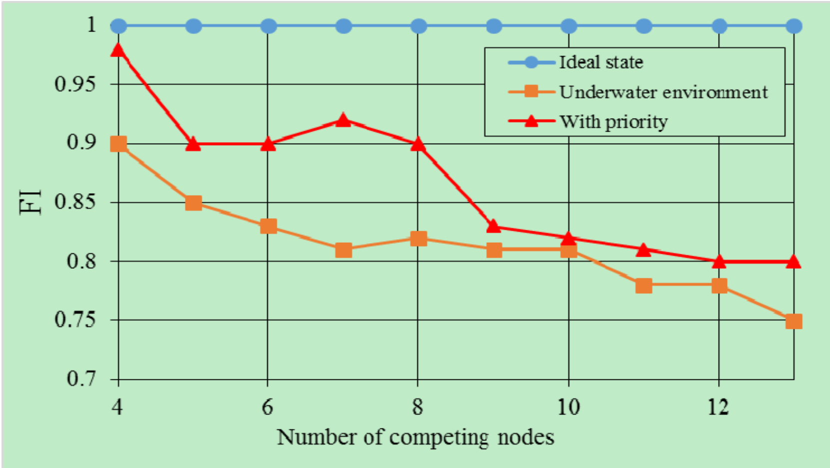

FIGURE 13. Fairness index.

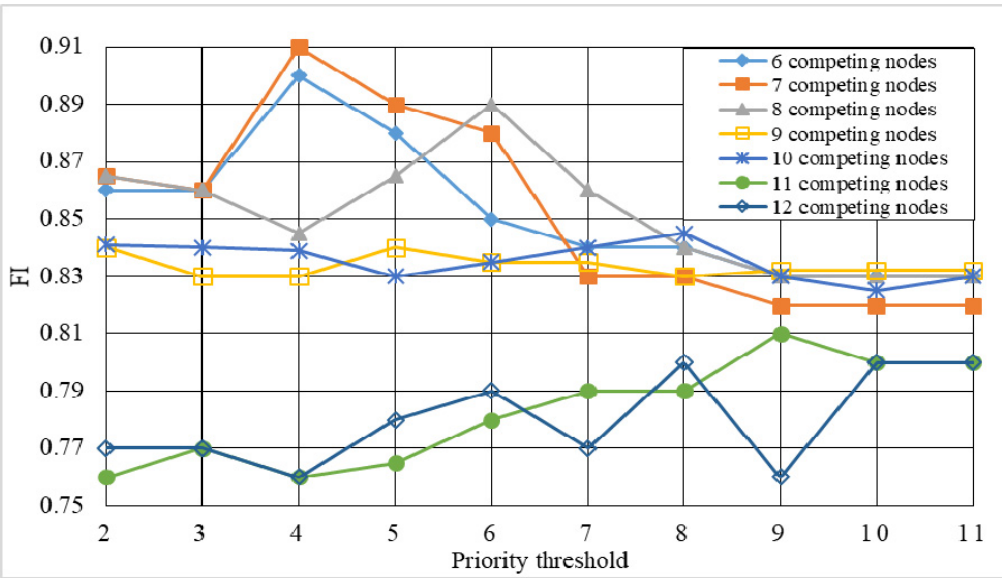

FIGURE 14. The effect of different competition times threshold on the FI index.

RTS message transmission is always successful. The acoustic signal travels at a speed of 1500 m/s. The receiving node is in the middle, and the transmitting nodes are randomly distributed in a circle with a radius of 500m. This ensures that each transmitting node can communicate with the receiving node within the maximum transmission range of the underwater acoustic modem. Each node sends an RTS message at a constant rate of one packet/second. The length of the data packet is 300 bytes, and each node sends 1000 data packets. The simulation time is 1000 s, and the simulations are n = 4, 5..., respectively. 13 situation.

The change in the fairness index is shown in Figure 13.

Ideally, the first RTS packet sent first arrives at the receiving node. At this time, the fairness index FI is 1, as shown in FIG. Due to the particularity of the underwater acoustic channel, the long propagation delay causes the first transmitted RTS packet to arrive at the receiving node, so that the fairness index FI is no longer 1, which becomes unfair. By setting different competition times thresholds and dividing transmission priorities, the fairness index FI can be improved. Although the FI decreases as the number of competing nodes increases, fairness is higher relative to the mechanism without any improvement.

The fairness results under different competition time's threshold are shown in Figure 14:

The fairness performance of multiple competing nodes is simulated and analyzed by setting different competition thresholds to prioritize. As shown in Figure 14, the situation of 6 ∼ 13 nodes is simulated separately. For example, when there are 7 competing nodes, the maximum fairness can be achieved when the threshold is set to 5 times (the number of times of competition); when there are 8 competing nodes, the maximum fairness can be achieved when the threshold is set to 6 times. For different numbers of competing nodes, there is a corresponding optimal number of competitions to achieve maximum fairness.

In order to effectively solve the triple terminal problem and achieve fairness, the SFM-MAC protocol extends the handshake process between packets, which may result in increased packet delay. However, due to the low sound signal rate, the underwater wireless sensor network itself is a network with long delay characteristics, and the underwater network is mostly limited by energy and bandwidth. For some delay-insensitive applications, packet delay is sometimes not particularly important. That is, SFM-MAC sacrifices latency for improved throughput, energy efficiency, and fairness.

VI. CONCLUSION

In underwater wireless sensor networks, sound waves have lower attenuation and better propagation characteristics in underwater environments. However, due to the low speed of sound propagation, there is a problem of long propagation delay. The particularity of the underwater acoustic channel makes it impossible for some technologies and solutions that have been matured in terrestrial wireless networks to be directly applied to underwater networks. This paper studies the MAC protocol and location algorithm of wireless sensor networks. This paper introduces the typical underwater MAC protocol, and analyzes the centralized positioning algorithm and distributed positioning algorithm in detail for the existing underwater positioning algorithm.

An underwater multi-channel MAC protocol with fusion positioning is proposed. The fairness problem and triple hidden terminal problem of underwater multi-channel MAC protocol design are analyzed. Based on a single transceiver and underwater positioning information, an underwater multi-channel MAC protocol is designed. By delaying the transmission of CTS packets for a period of time, the fairness problem is alleviated; by listening to the channel usage statement sent by other nodes and monitoring the usage of the data sub channel, the correct channel selection and utilization information is obtained, and the triple hidden terminal problem is solved. The back-off mechanism of the control sub channel is analyzed by the discrete Markov chain model, and the network throughput calculation expression is given based on this. Finally, the performance analysis and simulation of the proposed protocol are carried out. The results show that the handshake mechanism proposed in this paper can effectively improve the fairness index and effectively improve the throughput of the network.

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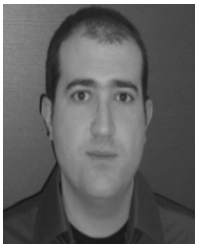

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