

The Seamless Connection between Underwater and Terrestrial Communication for 6G

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Abstract— Underwater communication was chiefly employed in military affairs and underwater exploration in the early days. In recent years, thanks to the progressive advancement of communication networks, many protocols have already been developed for underwater communication. However, due to technological factors, underwater communication is still looking for a seamless link to terrestrial communication. This paper proposes a novel frame format to improve the frame head of underwater communication, and presents a corresponding operation process of underwater nodes with the hope that the data link layer of the OSI 7-layer model provides the Media Access Control (MAC) protocol to the corresponding underwater network. This proposed method can be provided as a standard solution to create a seamless connection between underwater and terrestrial communication.

Keywords— Underwater communication, 6G, Gateway for underwater communication.

I. INTRODUCTION

To enable the space-air-ground integrated network for the emerging 6G networks, many countries have initiated the research on quantum communication technology to improve communication performance. However, the standardisation of quantum communication is still in its infancy. Compared with the OSI 7-layer network architecture, quantum communication does not have its specific data transmission method in the physical layer.

Since various Media Access Control (MAC) protocols have been designed for underwater environment and characteristics of sounds have been fully studied in the classical physics, this paper proposes an underwater communication gateway to enable the seamless connection between underwater communication and terrestrial communication. Based on Wireless Ad Hoc Network (WANET) and ALOHA, we modify the Ethernet frame format widely used in terrestrial communication, improve the drawbacks of using the Ethernet frame format or the IEEE802.11 frame format in underwater communication, and present a novel frame format for underwater communication.

The proposed gateway for underwater communication can translate the frame format of terrestrial communication and sends the results to designated underwater nodes. In addition,

by introducing the idea of backbone network and last mile network, this paper classifies underwater nodes to increase communication network reliability but reduce network deployment cost.

II. METHOD

To propose a new frame head format for underwater communication, we first modify the Ethernet frame format to match the properties of underwater communication and satisfy its transmission requirements. To put the protocol into practice, this paper also gives the interaction details between frames and nodes so that nodes and frame format can be compatible and collaborative with each other.

Because the underwater transmission of signals is far slower than the propagation of EM waves in terrestrial communication, the Ethernet frame format cannot be directly adopted. For this reason, in light of the existing frame format of terrestrial communication and the features of underwater environment, this paper improves the frame header so that underwater and terrestrial communication protocols can be compatible and interfaced to suit the requirements of the space-air-ground integrated 6G network.

Figure 1 compares our proposed underwater communication frame format with the Ethernet frame format and marks the differences, including:

- **Group Number:** This column is used to tag the group number of the frame. The details about groups of frames will be given below.
- **Next-Hop Node MAC Address:** MAC address of the next-hop node.
- **Previous-Hop Node MAC Address:** MAC address of the previous-hop node.

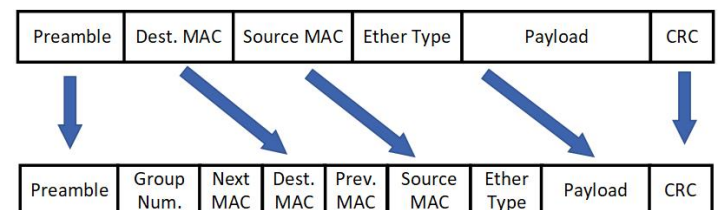


Figure 1. Frame Format Comparison between our proposed method with the Ethernet

The Group Number is used to tag the group number of devices. In our design, this column requires 4 bits, numbered from 00 to 15, among which 01 is allocated to the sink node gateway, 02 is allocated to the bridge nodes and 03-15 are allocated to the normal nodes. Next, we will introduce the use of bridge nodes and normal nodes, and how the two types of nodes process the frames while receiving.

Compared with replacing or recharging the node batteries in terrestrial communication, the power supply to underwater communication nodes is rather difficult. Therefore, one of the major concerns in underwater communication is the power supply and power consumption. To deal with the problem, the proposed method classifies the nodes into different types according to their uses and properties. By designating certain nodes to take responsibility for forwarding traffic, the proposed method can extend the battery life and make a charge last longer so as to help improve the overall network reliability. According to our design, each normal node will stop listening to frames while receiving signals that do not belong to its group, in order to save energy required to analyze the frames once receiving.

● Sink Node Gateway– Group 01:

The sink node gateway needs to exchange frames with other communication protocols and is responsible for managing all nodes' communications in the region, making it very busy and consuming a lot of power. Therefore, in our design, the sink node gateway is built on the water surface and is equipped with power supply models like cables or solar panels to provide unlimited power supply. Since the sink node gateway has limitless power sources, it is not especially designed in power-saving design and will always continue to listen to frames.

◆ Bridge Node – Group 02:

Bridge nodes need to transfer the frames captured. So, bridge nodes will be built under the water surface and work as nodes in the underwater network. Since bridge nodes are responsible for transferring frames, they need high energy storage capacity to bridge the connections.

◆ Normal Node –Group 03-15:

In our design, normal nodes do not transfer frames and therefore consume less power. However, underwater nodes perform different tasks, resulting in different transmission frequencies. An underwater environment monitoring system includes different functional sensors to measure underwater noises, temperature, salinity and so on. Since different sensors have different properties, the required times for transmission are also different. For example, while detecting the changes of sounds, sound monitoring nodes irregularly report the status of sounds to the network, but underwater temperature and salinity sensor may need to report salinity changes every half an hour. Traditionally, while encountering frames bound for sound sensors or from sound sensors, the temperature and salinity sensors need to receive the frames first. Once finding itself not the destination of the frames, the temperature and salinity sensors abandon the frames, leading

to unnecessary power consumption. If energy consumption can be reduced, the temperature and salinity sensors will not require such large capacity power storage so as to reduce the manufacturing cost of building a node and extend the lifetime of underwater nodes.

Let us use Fig. 2 as an example and see how the system operates when a frame is transmitted from external network to N1. First, the frame enters the sink node gateway from an external network and the frame is translated into the format for underwater communication. The sink node gateway is its starting point in underwater network. When the frame is transmitted to B2, its group number is changed to 2. Because the group number of the sink node gateway and green normal nodes near B2 is 3, they stop receiving the frame and go in idle status, instead of wasting power in analyzing the frame. If a routing protocol can build a routing table for all bridge nodes and the sink node gateway, including the information of all network nodes, the bridge nodes B2, B3 and B4 in group 2 all have the detailed routing table of the underwater network and the routing table can bind normal nodes and bridge nodes together. When receiving frames from other bridge nodes, each bridge node can search for the destination address to modify the next-hop node MAC address of the header.

For example, while being transmitted from B3 to B4, the frame's destination MAC address is always the MAC address of N1. From the routing table, B3 knows that N1 has been bound with B3 and the next-hop MAC address of the frame is therefore changed to B3. After B3 receives the frame, B3 confirms its destination MAC address and changes the next-hop MAC address to N1 to send the frame. Moreover, when the frame is broadcasted from B3 to B4, B2 receives the frame also and B2 will use the frame to detect if the transmission is completed. After B2 sends out the frame, B2 starts the timer and temporarily saves data. If the frame from B3 is successfully received by B4 within the time counting range, the timer between B2 and B3 is stopped and the data temporarily saved is eliminated. If the frame from B3 to B4 is not detected within the time counting range, the transmission fails. Then, the system reads the temporary data and sends the frame again until it is successfully delivered.

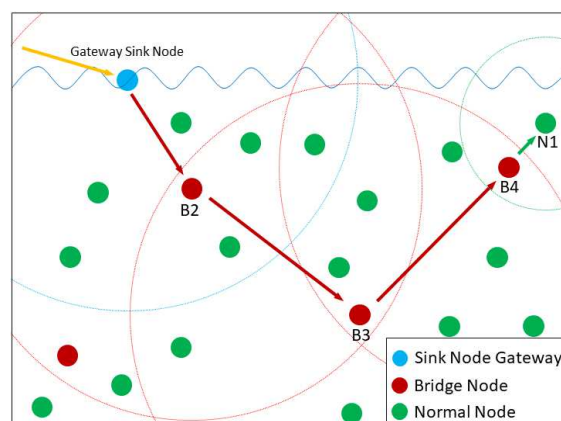


Figure 2. Node placement and Routing path of the frame

III. EXPERIMENT DESIGN AND SIMULATION RESULTS

A. Experiment Design

This paper runs a simulation for underwater transmission and places fixed nodes in the simulated underwater environment. In the experimental group, each group of nodes has the following characteristics:

- Sink Node Gateway: has unlimited source of power and analyses every frame.
- Bridge Node: With high capacity power storage, bridge nodes receive and analyze the frames according to the properties of bridge nodes.
- Normal Node: With less capacity power storage, normal nodes receive and analyse the frames according to the properties of normal nodes.

In the control group, the frame receive procedure is conventional: nodes receive the frames and consume all energy to transfer. Nodes are not divided into groups.

- Sink Node Gateway: has unlimited source of power and analyses all frames.
- Bridge Node: With high capacity power storage, bridge nodes analyse all frames.
- Normal Node: with less capacity power storage, normal nodes analyses all frames.

This experiment ignores the power consumption of other systems but nodes in the experimental group need to consume corresponding energy for decision making in addition to fundamental power consumption. Because of different elements in different systems, the power consumption in analysing the same data amount will be different. Therefore, this paper takes consumption counts as unit of measurement.

B. Simulation Result

A simulated environment is created to analyze the performance of MAC frame and protocols. Figure 3 shows the placement of nodes in the simulated environment and compares node power consumption. Table 1 and 2 display the result of ten times of simulations, in which T1, the node in red square, is set as the destination node.

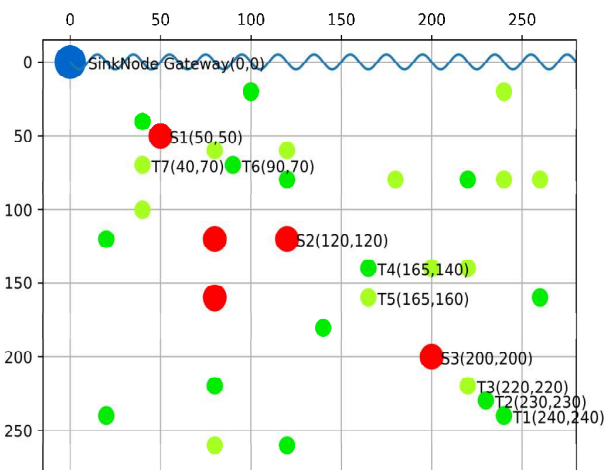


Figure 3. Node placement in the simulated environment

Table 1 and 2 show that the proposed new frame format can effectively reduce the power consumption of the nodes. For example, the bridge node S1 is very close to the sink node gateway and therefore receives lots of frames, including those that are destined for S1 and those that are destined for other nodes. In the conventional method, such frames must be abandoned or fully analyzed before being transferred, increasing the power consumption of the bridge nodes. By using our proposed method, S1 obviously saves a lot of energy. As far as normal nodes are concerned, normal nodes that are divided into groups effectively reduces power consumption. Take T7 as an example. T7 is close to the network center where many frames pass by. In the conventional method, T7 is not designated as the receiving node but consumes lots of power. By using our proposed method, nodes can detect and immediately ignore those packets that are bound for other destinations, extending the lifetime of normal nodes in the network.

IV. CONCLUSIONS

This paper proposes a solution to improve the frame format header and modify the frame format so that the MAC protocol can be more suitable for underwater communication. By introducing the idea of backbone network and classifying the nodes, energy of the nodes can be efficiently utilized. Thus, the novel method allows underwater and terrestrial communication protocols to be compatible and interfaced and provides a solution for 6G to connect underwater and terrestrial communication.

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TABLE 1. RESULTS OF 10 TIMES OF SIMULATION BY USING THE NOVEL FRAME FORMAT

Node	S1	S2	S3	T1	T2	T3	T4	T5	T6	T7
Group	2	2	2	3	3	4	3	4	3	4
Type	Bridge	Bridge	Bridge	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Initial Power	1M	1M	1M	100K	100K	100K	100K	100K	100K	100K
Residual Power	988180	988250	985730	38730	97800	99340	99240	99760	98800	99640

TABLE 2. RESULTS OF 10 TIMES OF SIMULATION BY USING THE CONVENTIONAL FRAME FORMAT

Node	S1	S2	S3	T1	T2	T3	T4	T5	T6	T7
Group	2	2	2	3	3	4	3	4	3	4
Type	Bridge	Bridge	Bridge	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Initial Power	1M	1M	1M	100K	100K	100K	100K	100K	100K	100K
Residual Power	588196	885856	911604	98360	95736	92620	88356	86716	51784	27676