Underwater Optical Wireless Networking Based on Multiple Transmission-hops

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Abstract: In recent years, the demand for underwater wireless communication is increasing day by day, and marine exploration is carried out continuously. Underwater wireless communication is mainly used in military, industrial and scientific research fields. It plays an important role in the fields of marine environment detection, oil control, oceanographic research and tactical monitoring. Wired or optical fiber technology is usually used to achieve high data rate and reliable communication. However, in the deep sea, these optical fibers or cables face many challenges, such as maintenance problems, physical damage and vulnerability. In some places, it is very difficult to install cables or optical fibers. In this case, people are very interested in wireless communication technology. At present, underwater wireless communication technology mainly includes acoustic signal, RF signal and optical signal. However, with the increase of application requirements, underwater acoustic communication and electromagnetic wave communication have many limitations, which can not meet our needs, and optical fiber and cable can not be installed in a large area. Therefore, the research on underwater wireless optical communication is very useful. On the other hand, underwater optical communication (uowc) has the advantages of high bandwidth, low delay and enhanced security . However, light pulses propagating in seawater will be damaged by adverse channels, including absorption and scattering. It is also susceptible to many noise sources on the receiver side, such as sunlight, turbulence, thermal noise and dark wireless current noise. Using sufficiently dense network deployment, long-distance broadband communication can be realized, in which information can be transmitted through a series of relays. Therefore, in practical applications, it is necessary to describe end-to-end (E2E) paths and develop effective routing mechanisms. This paper studies the routing of underwater wireless sensor networks. This paper summarizes several existing main routing methods, and studies and analyzes their practical significance.

Keywords: Underwater optical wireless communication, Multi-hop, Routing.

1. Introduction

October 2019, The Ministry of natural resources and the national development and Reform Commission jointly organized the preparation of China's marine economic development report 2019 [1, 2], the article mentioned that China's total marine economy reached 8.3 trillion yuan in 2018, accounting for more than 9% of GDP, maintaining a basically stable proportion in the development of the national economy. Generally speaking, China's marine economy is gradually changing from high-speed development to high-quality development. China's Marine related science and technology will achieve more rapid development in the fields of green and safe technology under the guidance of the national innovation strategy and the strategy of revitalizing the sea through science and technology. In the process of promoting the transformation and upgrading of marine economy, some key technologies, core technologies and common technologies have also made greater breakthroughs and innovations [2].

The total area of the ocean accounts for about 71% of the total surface area of the earth, and contains extremely rich but untapped resources. With the continuous growth of social population and the gradual deterioration of the environment, the land natural resources are drying up day by day. How to reasonably and effectively develop, utilize and protect marine resources has gradually become the scientific and technological development plan and important strategic deployment of various coastal countries. Underwater communication is an indispensable part of all kinds of underwater operations in the process of exploring and developing marine resources. With the development of ocean exploration technology, the research on underwater communication system has extremely broad application prospects and great scientific research significance, so as to provide information for marine environment monitoring, seabed salvage, tsunami early warning Underwater investigation and other underwater operations provide effective technical support for communication networking. The methods of underwater communication technology are mainly divided into wired communication and wireless communication technology: wired communication can realize the stable transmission of underwater communication signals through optical cables and cables, but laying cables underwater requires high cost and difficult maintenance. In addition, the preset fixed lines will limit the scope of underwater operation; Wireless communication mainly uses electromagnetic wave, acoustic wave and light wave as the carrier for communication. Compared with wired communication, it has the advantages of high flexibility and low cost [1].

Marine resources are extremely rich, but they still need to be developed, and communication is an indispensable link for all kinds of underwater operations. In recent years, underwater wireless optical communication technology has attracted more and more researchers' attention because of its advantages of low energy consumption, high bandwidth and strong anti-interference. However, the current research on underwater optical wireless communication (UOWC) technology is usually oriented to the physical layer and rarely involves the network layer. Routing protocol is very important to solve the network layer problem in underwater wireless optical communication system. Compared with traditional land routing protocols, special waterway conditions (such as absorption, scattering, ocean turbulence, etc.) and the high directivity of underwater optical communication nodes bring new challenges. In addition to modifying the process of route discovery and route maintenance, selecting appropriate route metrics can also effectively improve the routing protocol, so as to improve the performance of underwater network.

2. Properties of Underwater Wireless Communication

The existing underwater wireless communication mainly adopts acoustic wave, electromagnetic wave, light wave and other media. Among them, underwater acoustic communication is the most widely used and the technology is the most mature, but it has many limitations in application. Compared with the strong attenuation characteristics of electromagnetic waves in seawater, the attenuation of sound waves propagating in water can be said to be much smaller. At low frequency, the transmission range of underwater acoustic communication can reach more than ten kilometers. Even for transmission above 30Hz, it can have a reliable transmission distance of 1-2km, as shown in Figure 1. Therefore, underwater wireless acoustic communication is widely used in commercial, scientific and military fields. However, due to the inherent limitations of omni-directional propagation, remote communication, low achievable rate and high delay, the underwater acoustic communication system is still unable to provide high-quality communication services, which is not enough to meet many underwater applications, and it is difficult to be used for real-time operation. Because underwater acoustic communication technology mainly relies on low-frequency sound waves, the bandwidth is generally below 50KHz due to the influence of various underwater factors [4].

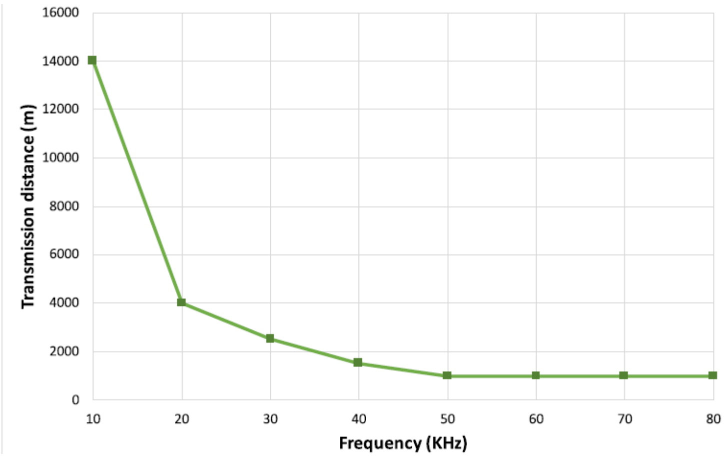

Figure 1. Data rate versus transmission range of published experimental work on underwater acoustic systems

In view of the significant shortcomings of underwater acoustic system and low-frequency electromagnetic wave system in low bandwidth and low data rate, many scholars have proposed another method to use light wave to provide low delay and high-speed underwater wireless optical communication (uwoc) in a limited communication range, because when light wave propagates underwater, Different wavelengths show unique characteristics [5]. Among various underwater transmission systems, high-speed link is very ideal. Uowc is a promising technology to realize high-speed underwater wireless communication system. At the same time, uowc has some other advantages. For example, the frequency of light wave is much higher than that of electromagnetic wave and acoustic wave. The lowest frequency can reach 10 ^ 13Hz and the highest frequency can reach 10 ^ 17hz. Therefore, it has large communication bandwidth, strong information carrying capacity and high communication capacity. In addition, it is not easily affected by the changes of seawater temperature and salinity, and has strong anti-interference ability. Light has strong directionality and is often carried out in a point-to-point way. Compared with omni-directional communication, eavesdropping becomes much more difficult, which undoubtedly enhances the security and confidentiality in the process of information transmission. Underwater wireless optical communication transceiver can adopt low-cost, energy-saving and small-size laser or photodiode. Therefore, underwater optical communication has high research value. It has the advantages of low cost, simple equipment, strong anti-interference ability and wide application. It can solve many problems in the field of underwater communication. However, light waves in water will have problems such as refraction, scattering and absorption. This will greatly reduce the transmission distance of UOWC. According to the existing research results, the actual transmission range is limited, usually less than 100m, as shown in Figure 2. Underwater wireless sensor network (UOWN) can extend the communication range of UOWC, so researchers need to study the application of multi hop routing technology in UOWN to extend the communication range of UOWC, as shown in Figure 3.

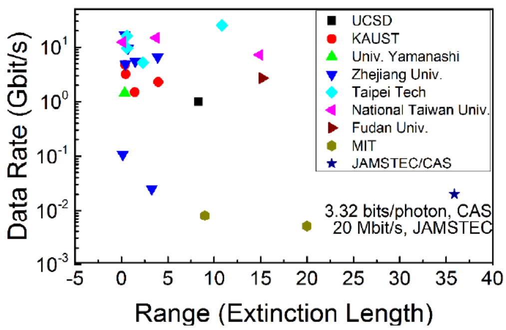

Figure 2. Simultaneous interpreting of transmission rate and transmission distance

In the following article, we mainly introduce several mainstream multi hop routing methods at home and abroad. At the same time, it should be expanded to summarize and guide future research.

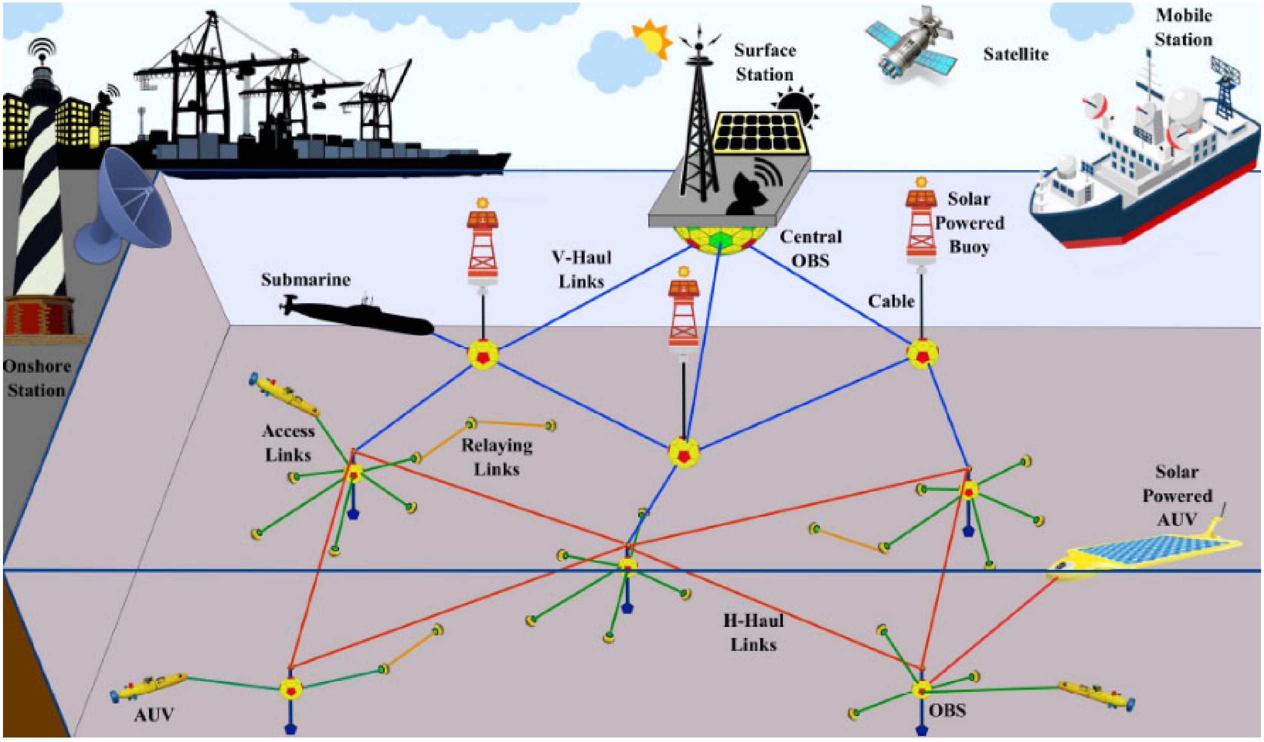

Figure 3. The model of underwater wireless sensor network UOWN

3. Underwater Optical Wireless Routing Algorithm

UOWN needs to design an efficient and reliable routing protocol, which considers the channel parameters of light propagation in underwater media. Generally speaking, there are few routing strategies developed for UOWN, which can be roughly divided into centralized and distributed from the perspective of computing operation.

3.1. Centralized Routing Protocols

The two models have their own advantages and disadvantages. Centralized routing protocol centralizes the calculation and allocation of routing strategy to the central node to improve the software and hardware performance of the node, which can provide better end-to-end performance. However, this requires a global network view, such as the location information of nodes, but also increases the complexity and energy consumption.

A centralized routing scheme for UOWN is proposed in reference [6], which considers the propagation characteristics of light beams under water. [6] The routing protocol proposed in assumes that the perfect pat mechanism and node location information are available. Our work is extended in [7] for location uncertainty to capture the negative impact of pointing mismatch on end-to-end performance of multi hop UOWC In order to achieve reliable and reliable links, we consider adaptive beamwidth and derive the divergence angle in the absence and presence of Pat mechanism. We also provide end-to-end performance analysis of DF and AF relays to obtain data rate, bit error rate, transmission power and amplifier gain. The proposed shortest path based routing protocol is customized to optimize specific performance indicators (data rate, power consumption, bit error rate), while ensuring the constraints on other routing protocols

3.2. Centralized Routing Protocols

Although the centralized routing protocol provides better end-to-end performance, it requires a global network view, resulting in high communication overhead and energy consumption of the whole network [8]. Therefore, many people have developed a distributed omnidirectional routing protocol, which provides lower complexity at the cost of relatively high end-to-end bit error rate and delay compared with the centralized solution [8]. The advantage of distributed routing is that it does not need to know the information of all nodes, the complexity can be reduced, and it can meet the pointing requirements more flexibly. Similarly, the optical routing protocol (lipar) is introduced in [7], which considers the distance beam width trade-off and provides better end-to-end performance without pointing mismatch.

Due to the advantages of distributed routing, this paper mainly discusses the existing distributed routing strategies.

1. Routing protocol based on distributed sector (DS)

This route calculates the weight of the inner edge of its transmission radius through the node, and selects the next node among the candidate nodes through the weight. Then repeat forwarding and selection on each node, and finally forward the information from the source node to the target node, as shown in Figure 4.

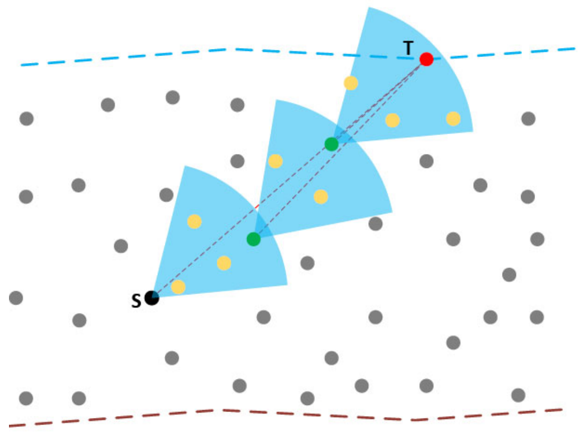

Figure 4. Network model of routing protocol based on distributed sector (DS)

2. Distributed Sweeping-and-Sector-based (DSS) routing protocol

This algorithm is based on the improvement of the previous algorithm. When the light wave is transmitted, the light wave transmission distance can be extended by adjusting the beam width under the same power. Therefore, this algorithm transmits in a shorter range with a wider beam through the transceiver, and transmits in a longer distance with a narrower beam, and then expands the transmission coverage of the node through scanning, as shown in Fig. 5.

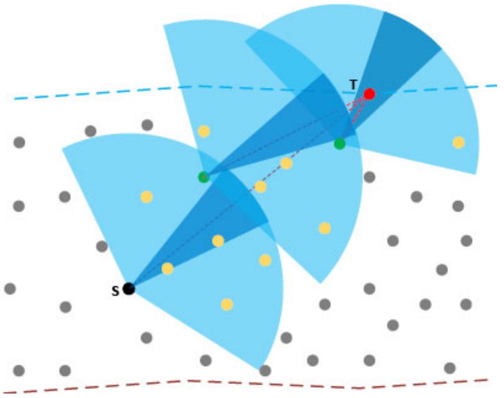

Figure 5. Network model of routing protocol based on DSS

3. Sector-Based Opportunistic routing protocol

This strategy can select multiple routes. When the optimal route is not available, you can select the standby route for signal transmission, which helps to improve the reliability of transmission. But at the same time, it will lose part of the energy consumption and improve the delay, as shown in Figure 6.

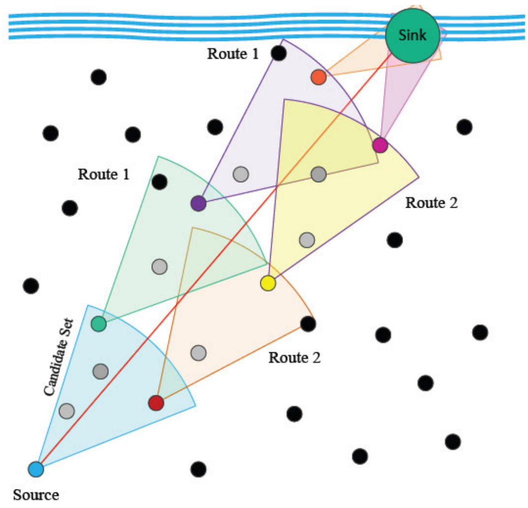

Figure 6. Network model of Sector-Based Opportunistic routing protocol

Because there are few existing underwater wireless optical communication routes, researchers need to continue to study. Due to the relatively mature technology of underwater acoustic communication, there are many routing solutions. This paper summarizes some routing strategies based on underwater acoustic communication. These strategies are potential UOWC routing protocols

4. Location based routing

In the location-based routing strategy, the location information of underwater sensors is used to find the best route from the source node to the destination node. In location-based routing, each node should know its own location, target area and neighbor location. Forward data according to location information. This routing method needs to know its location, target area and neighbor location. GPS or underwater local positioning system is required. However, GPS can not work in the underwater environment, and the bad underwater environment will lead to positioning error. Typical location-based routing mechanisms mainly include vector based routing and focused beam based routing. The network model is shown in Figure 7 and 8.

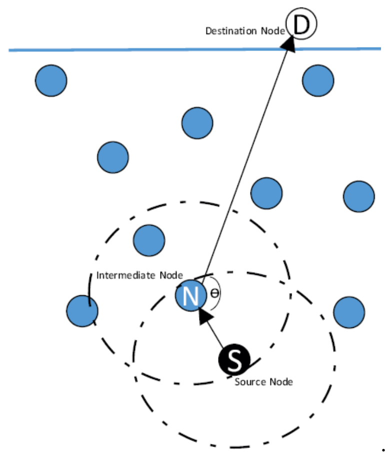

Figure 7. Network model of vector based routing

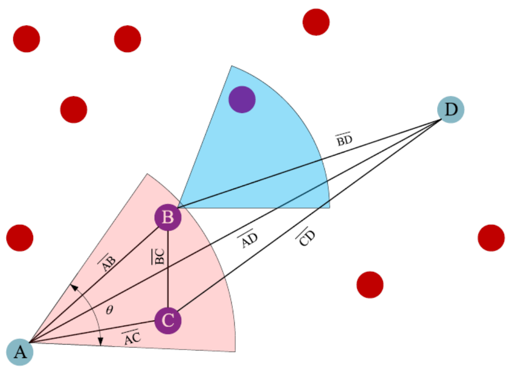

Figure 8. Network model of focused beam based routing

5. Source based routing

[8] introduces a simple and energy-saving source based routing protocol. The protocol in [204] selects the route with the least transmission delay from the source node to the receiver node. Once a route is defined, the node on the route can also transmit data to the sink node. The average end-to-end delay, average energy consumption and packet delivery rate of the protocol proposed in [8] are better than other traditional routing protocols. Another source based routing protocol suitable for small UAWC networks is proposed in [9], in which each node only shares information with its single hop neighbor nodes and finds the minimum cost path from source to destination.

6. Hop-by-hop routing

In hop-by-hop routing, the intermediate node (or relay node) selects the next hop by itself. Hop by hop routing provides flexibility and scalability for the network, but routing may not always be optimal. [10] a channel aware hop by hop routing protocol is introduced, in which the relay node considers the acoustic velocity at different depths to reduce the end-to-end transmission delay. The network model is shown in Figure 9.

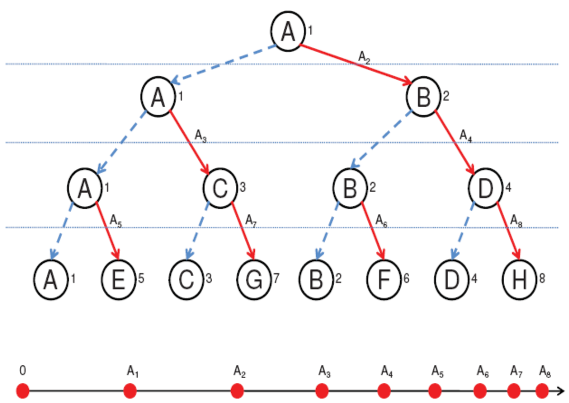

Figure 9. Network model of Hop-by-hop routing

7. Cross layer routing

The cross layer routing protocol considers the available information from different layers, and provides solutions to many network problems such as scheduling, defining routing strategy and power control. The cross layer routing protocol can also select the next hop for transmission by considering the transmission delay, the distance to the receiver, channel conditions and the buffer size of candidate nodes. The cross layer strategy improves the overall performance of the network and minimizes the energy consumption of the network. [11] The cross layer protocol of 3D underwater environment is studied. The protocol effectively uses the channel and sets the optimal packet size for transmission. A multipath power control routing protocol is proposed in [12, 13], which combines multipath routing with the power control of the sink node. The network model is shown in Figure 9.

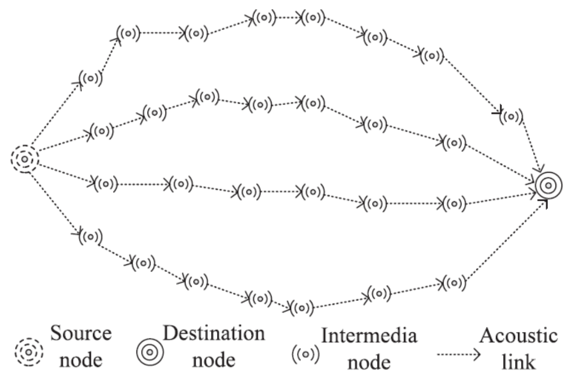

Figure 10. Network model of cross layer routing protocol

8. Clustered routing

Clustering routing is mainly by dividing sensor network nodes into clusters in some way. Each cluster selects a cluster head, and the cluster head collects the information of other ordinary nodes in each cluster. After the cluster head collects the processing information, it forwards it to the next hop node or sink node. The biggest advantage of clustering routing is that it can save the energy information of non-cluster head nodes to a great extent. Thus, the lifetime of the whole network can be prolonged. The cluster head acts as a gateway for communication between clusters and receiver nodes. [219] introduces a location-based routing protocol, which divides the network into multiple clusters, and the data from the nodes is collected by the cluster head. The cluster head acts as a gateway for communication between clusters and receiver nodes. [219] introduces a location-based routing protocol, which divides the network into multiple clusters, and the data from the nodes is collected by the cluster head. The network model is shown in Figure 10.

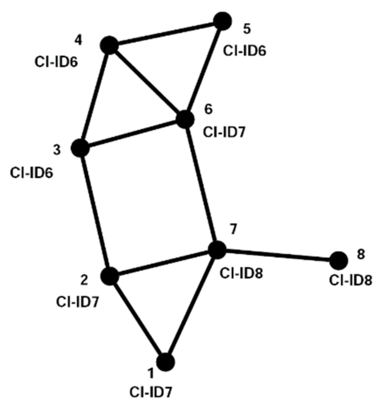

Figure 10. Network model of clustering routing protocol

4. Result

Underwater wireless optical sensor networks have many advantages over underwater acoustic networks. Such as fast transmission rate, large bandwidth, low cost, low delay and so on. But its transmission environment is a little more harsh. And underwater acoustic network technology is relatively mature, while underwater wireless network routing strategies are still few. We can combine some characteristics of visible light and propose more routing solutions for underwater wireless optical networks according to the Enlightenment of underwater acoustic networks. Even in some large networks, due to the influence of terrain factors and node energy factors, we can combine the two communication modes.

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