Frontiers in Computing and Intelligent Systems
ISSN: 2832-6024 | Vol. 2, No. 3, 2022

A review of routing algorithms for underwater wireless sensor networks

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Abstract: With the rise of the upsurge of exploiting marine resources and the rapid development of the research of terrestrial wireless sensor networks, the research of underwater wireless sensor networks (UWSNs,) has become a new research hotspot. In UWSNs, routing protocol plays a very important role as one of the important components. This paper introduces several classical routing algorithms from the following categories: location, sector, reinforcement learning, and intelligent optimization algorithms. Finally, the paper also summarizes and prospects the research direction of underwater wireless sensor network routing algorithms.

Keywords: Underwater wireless sensor network; Routing algorithm.

1. Introduction

The widest part of the world is the ocean, which occupies two-thirds of the Earth's surface area. The oceans are not only rich in natural resources, but also play a role in regulating the climate and producing oxygen. However, due to the limitations of the ocean's complex environment, human beings have exploited the ocean to a far lesser extent than the land. In recent years, with the continuous depletion of land resources, the contradiction of more people and less land has become increasingly prominent, so the development of marine resources, the expansion of marine industries, and the development of the marine economy has become a matter of urgency. As a key technology for the smooth realization of the development and utilization of marine resources, underwater wireless sensor network (UWSN) has also attracted extensive attention from researchers [2-3]. In addition to resource detection, UWSN also plays a vital role in military applications, environmental monitoring, disaster warning and oceanographic research.

UWSN contains popular research topics such as network node deployment and networking, localization, and routing protocols. Among them, routing protocols are a remarkable part of the UWSN system and have a highly research value and significance. Unlike terrestrial routing protocols, the special underwater environment brings many challenges to routing protocols. The main problems at this stage are manifested in the limited energy of nodes, the difficulty of localization and the changing topology. According to the above difficulties, many targeted routing protocols are proposed, and this paper will classify the existing UWSN routing protocols, and then analyze and summarize the merits and drawbacks of each category of representative routing protocols.

2. Classification of underwater wireless sensor routing protocols

Depending on the transmission medium, UWSN can be classified into underwater radio frequency, acoustic and optical communication. Radio frequency waves have shortcomings such as severe attenuation and small coverage range, which cannot meet most application scenarios. Since acoustic waves are relatively less affected by attenuation in water, the transmission distance can extend up to tens of miles away. At present, underwater wireless acoustic network (UWAN) has become the most widely used and technically complete underwater communication technology, so the routing protocols about UWAN are the most numerous and diverse. However, the bandwidth of acoustic communication is very limited to bear the huge amount of information transmission, so human beings look at new transmission mediums. Compared with the first two transmission methods, optical wave is more affected by the environment, but it becomes the most promising underwater wireless communication technology in the future because it has the advantages of large capacity, strong anti-interference ability and high transmission rate . In recent years, scholars have also used acoustic-optical hybrid channel, taking the advantages of their respective channels to design a combined routing protocol.

Underwater nodes can only rely on battery power supply, so there are challenges such as limited energy and charging difficulties. Therefore, scholars have designed energy-efficient routing algorithms from the perspective of reducing energy consumption and extending network life. Because it is difficult for underwater nodes to obtain 3D location information and the equipment is expensive, some academics have designed depth-based routing protocols. This protocol only needs to obtain node depth information, which can be completed by a cheap depth sensor. The movement of water flow will lead to the movement of nodes. In order to improve the adaptability of the network, a routing based on reinforcement learning (RL) is proposed. Although RL performs well, it is time-consuming, so a routing protocol based on an intelligent optimization algorithm is proposed. In addition, there are also routing based on optical characteristics of sectors are proposed.

In summary, routing protocols can be broadly classified into two categories based on transmission media and characteristics, of which the specific divisions are shown in Figure 1.

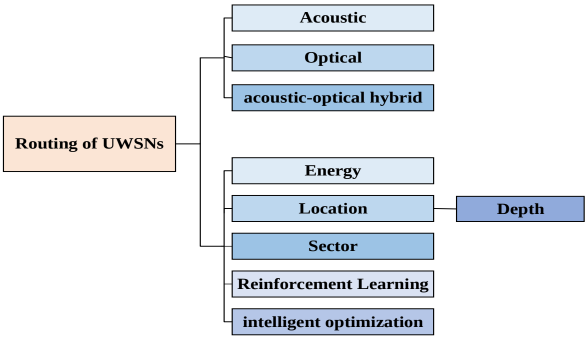

Figure 1. Routing protocol classification for UWSN

3. Analysis of routing algorithms for various types of UWSN

Since many routing protocols take this aspect of energy into account, it is not analyzed separately here. The following will analyze and compare classical routing algorithms in four categories: location, reinforcement learning, intelligent optimization algorithms, and sector.

3.1. Location-based routing protocols

In, P. Xie et al. proposed a vector-based forwarding (VBF) protocol for UAWN using geographic information. In VBF, an adaptation pipeline is established between the sink node and the source node, and only the nodes inside the pipeline have the ability to forward packets. And the current node's position is calculated from its previous hop by arriving at the packet. In, the first depth-based (DBR) algorithm is proposed, which determines the candidate set by calculating the depth difference between nodes and then selects the nodes for forwarding by holding time. Thus, nodes with lower depth are often used, which can cause early death of these nodes. To overcome this drawback, the authors in proposed the EEDBR protocol that considers the residual energy to improve the network lifetime. However, since EEDBR does not take into account the gaps in sparse networks, it has a low delivery rate. The Weighted Depth and Forwarding Area Division DBR (WDFAD-DBR) routing protocol is proposed in to mitigate the drawbacks of EEDBR.WDFAD-DBR solves the gap problem by considering the depth difference of two-hop nodes and reduces the energy consumption by designing forwarding area and neighbor node prediction.

3.2. Sector-based routing protocols

Alghamdi et al. proposed two routing protocols in reference, namely, the sector-based (DS) distributed routing protocol and the swept and sector-based (DSS) distributed routing protocol. Both (routing algorithms) are inspired by the sector coverage area of a light source.DS selects the candidate node with the highest weight within the sector determined by the current node as the forwarding node each time, which solves the problem of large end-to-end delays (solves the problem of large end-to-end delays). DSS improves on DS by expanding the sector through narrow beam scanning, which overcomes the problem of poor reliability in sparse environments. The sector-based opportunistic routing protocol (SectOR) for UOWC is studied in reference. Sector has some similarities with DS, except that SectOR uses DP (distance progress) and EDP (expected distance progress) metrics to evaluate the suitability of candidate sets (CSs) and to prioritize the members of CSs.

3.3. Rl-based routing protocols

QELAR was an adaptive and energy-efficient routing protocol for UAWC based on Q-learning. It calculated the reward function through the residual energy of nodes and energy distribution among a group of nodes in order to make the energy of the nodes more evenly distributed and prolong the lifetime of networks. The proposed routing protocol MARL in was based on multi-agent RL, which can adapt well to dynamic environments and prolong network life. MARL adopted the method of Q-learning and considered link quality and the residual energy of nodes into the design of the reward function. The authors in improved on MARL by proposing a new algorithm DMARL. It presented two optimization measures, including position-based Q-value initialization and variant learning rate, which can help to shorten the training time.

3.4. Routing protocols based on intelligent optimization algorithms

In , a routing protocol named EECRP based on genetic algorithms that view sensor nodes as genes and routing paths as chromosomes was proposed. Besides, EECRP also combined clustering and data fusion techniques with some improvements, such as an optimized cluster head selection scheme and improved crossover operator and mutation operator, which improved the transmission efficiency of the route and reduced energy consumption. Anitha et al. designed a novel routing protocol that combined three techniques, reinforcement learning, extreme learning machines, and firefly algorithms, to improve the packet-delivery ratio and throughput of routings. It improved on the reward function formula in Q-learning, where the reward function was no longer determined by a single element but by the signal strength, distance, depth, and residual energy between nodes.

4. Conclusion

This paper introduces and investigates the current routing algorithms for underwater wireless sensor networks, and classifies UWSNs routing protocols from two aspects of transmission media and characteristics. The working principle, advantages and disadvantages of different types of routing algorithms are further introduced. Although many achievements have been made in the research of routing algorithms for underwater wireless sensor networks, computer simulation experiments are still the main method at present. In practical applications, there will be various factors that affect the experimental results, such as water temperature, salinity, pressure, etc., as well as the communication protocol of underwater nodes, time synchronization and other issues, which need to be verified by more experimental data. This paper provides a reference for the subsequent research of UWSNs technology.

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