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Underwater wireless communication routing protocol

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Abstract: Due to the abundance of water resources in the human environment, experts began to study the application of water resources more and more, and underwater wireless communication (UWC) was immediately proposed for research. In order to improve and optimize these performance indicators, the routing protocols proposed in recent years are discussed, classified according to the specific problems they focus on solving, and divided into three categories: cooperative routing protocols, opportunistic routing protocols, and machine learning-based routing protocols, which respectively elaborate their advantages and disadvantages and contribute to future design and development.

Keywords: UWC, routing protocol, performance.

1. Introduction

The earth's surface covers about 140 million square miles of water, accounting for almost 70% of the earth's surface area. Underwater has become a huge available resource. Scientists are paying more and more attention to using wireless network technology to detect and monitor the underwater environment. It is necessary to establish an underwater network to connect and communicate with the land. In the field of communication, wireless communication technology is widely used. It has various advantages such as wide range, no wiring, low cost, and convenient networking. It is suitable for use in underwater environments to better overcome the harsh underwater communication conditions. Therefore, underwater wireless communication has become a new direction of research for many years and has made great progress. Underwater wireless communication usually uses carriers such as sound, light and radio frequency for information transmission, each of which has its own advantages and disadvantages, As shown in Table I.

TABLE I: Comparison of underwater wireless communication systems

Parameters	RF	Acoustic	Optical
Transmission Distance	100 m	Upto 20 Km	10-30 m
Attenuation	Frequency and conductivity dependent	Distance and frequency dependent	Distance
Speed	2.255×10^8 m/s	1500 m/s	2.255×10^8 m/s
Transmit power	Hundreds of Watts	Few tens of Watts	Few Watts
Cost	High	High	Low
Data rate	Upto 100 Mbps	In Kbps	Upto Gbps
Antenna size	0.5 m	0.1 m	0.1 m
Latency	Moderate	High	Low

To select the appropriate communication method according to the corresponding needs and network size, and there are also network architectures that mix multiple carriers for information transmission to adapt to complex changes, At the same time, there are many problems underwater, such as low visibility, difficult sensor replacement, marine life mobility and unpredictable disasters. Therefore, the routing design of underwater wireless communication is crucial in maintaining communication reliability and improving network performance, This paper mainly describes various performances of underwater wireless communication, summarizes the corresponding routing protocols to optimize them according to these performance classifications, and analyzes the design of these routing protocols.

2. Performance of Underwater Wireless Communication

In UWSN, sensor nodes collect data for disaster detection, resource protection, and marine military activities, etc., so it is crucial to build a safe and reliable underwater network. However, UWSN has more challenges and problems than terrestrial wireless sensor network (TWSN), such as: high noise and interference, node energy limitation and dynamic network environment, etc, Therefore, UWSN pays more attention to the following performance to improve network efficiency.

2.1 End-to-end Dalay

End-to-end latency refers to the minimum time (including propagation delay, propagation delay, hold time, compute delay, and queuing delay) required to successfully receive a packet from the source node to the destination node, which is expressed as：

$$Delay = \frac{\sum_{i=1}^{N}(T_{arrival} - T_{send})}{\mathrm{N}} \qquad (1)$$

where N is expressed as the total number of packets from the source node to the destination node, $T_{arrival}$ represents the time when the packet arrives at the destination node, and T_{send} represents the time when the source node sends the packet.

2.2 Packet Delivery Rates.

The packet delivery rate is defined as the ratio of the number of packets successfully transmitted to the destination node to the packets generated by the source node, where duplicate packets are not included, which can be calculated as：

$$PDR = \frac{\sum N_{success}}{\sum N_{send}} \tag{2}$$

where $N_{success}$ expressed the number of packets as successfully transmitted ,N_{send} represents the generated packets.

2.3 Average Energy Consumption

Energy consumption is the sum of the energy consumed by sensor nodes when sending, receiving, and idle (eavesdropping on packet messages), and the average energy consumption is the energy consumed by each sensor node on average in the network. It counts as：

$$E_{Avg.} = \frac{E_{total}}{\mathrm{N}} \tag{3}$$

$$E_{total} = \sum_{i=1}^{N} E_{tran} + E_{rec} + E_{idl} \tag{4}$$

where N is the number of sensor nodes,E_{tran}expressed as the energy consumption of the sending packet, E_{rec} expressed as the energy consumed by the receiving packet, and E_{idl} expressed as the energy consumption when the node is idle.

2.4 Average Network Lifetime

The network lifetime is a time when the network's first node drains its energy completely. NLT can be formulated as:

$$NLT_{Avg.} = \frac{\sum_{i=1}^{N}(ST_i - FT_i)}{\mathrm{N}} \tag{5}$$

Where ST_i and FT_i shows the time at which simulation starts in n^{th} simulation and the time when the first node of the network has utilized its energy completely in n^{th} simulation respectively.

Routing protocols should be designed so that end-to-end latency and energy consumption are smaller, and PDR is greater, so that nodes are fully utilized and die slowly, maximizing the speed, stability, and network life of data transmission overall.

3. Cooperative routing protocol

The underwater environment is more complex, affected by turbulence and the mobility of marine life, etc., underwater sensors are usually not fixed to a certain point but within a certain range of movement, which leads to the possibility of a broken communication link, resulting in messages can not accurately reach the destination, so important data is lost. Therefore, Meulen in the concept of cooperative routing was first proposed, in addition to the direct link from the sending node to the receiving node, there are one or more sensor nodes that can be used to forward messages from the sending node to the receiving node, in which they act as relay nodes. Cooperative nodes increase the reliability of communication, reduce packet loss due to sensor node movement in the form of standby transmission, improve packet delivery rate and network throughput, provide more possibilities in terms of routing protocols, and also have shortcomings such as excessive node energy loss and excessive network overhead.

3.1 Channel-Aware Cooperative Routing in Underwater Acoustic Sensor Network

In, Sensor nodes sense data from the environment, choose routing relay (RR) and cooperative relay (CR) independently of their neighbors, and forward the data to the destination using specific policies. Data transfer is performed from source to destination in a multi-hop fashion using CR and is described in four phases: neighbor table update, RTS/CTS message exchange, trunk segment, and packet transmission. The main advantage of this protocol is that it improves reliability at the receiver and the successful reception of packets, and the disadvantage is that the end-to-end latency increases with the use of RTS/CTS control packets. Figure 1 shows the entire process of this protocol.

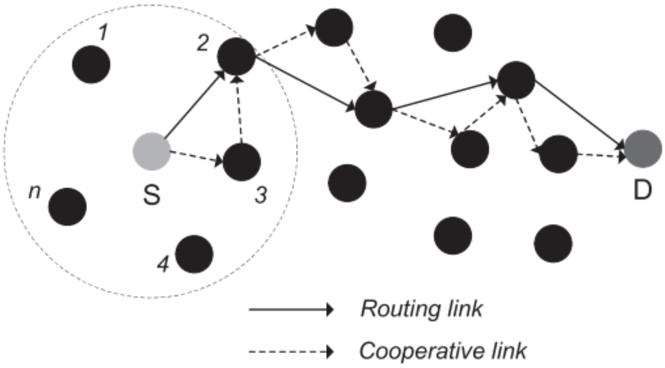

Fig.1 the process of the protocol

3.2 Link and stability-aware adaptive cooperative routing with restricted packets transmission and void-avoidance for underwater acoustic wireless sensor networks

In, First of all, the SRRPV protocol is proposed, the network is initialized as a cube, and the control packet is broadcast from the sink, so as to complete the hop count measurement, the neighbor node shares its important information with the broadcast node, and each node generates the corresponding route table and broadcasts. Using this information to check if the node has a three-hop forwarding node available, Figure 2 shows that the nodes form three connections, so they will be transmitted on this path.

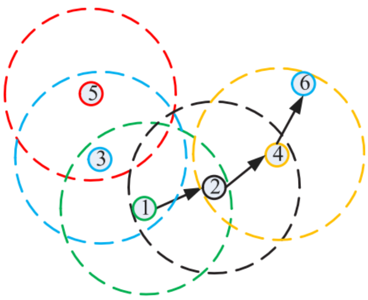

Fig.2 Schematic diagram of a three-hop connection

The LS-ACRPV protocol is a complement to SRRPV, which calculates the probability of successful packet delivery before the information is routed. If the calculated probability exceeds a certain threshold, the packet is routed. Otherwise, multiple packets on multiple links on the destination will be merged together through adaptive co-routing, thereby improving the service quality and reliability of packet transmission to the destination, and when multiple three-hop connection routes exceed the threshold, the one with the highest successful delivery rate is selected. The disadvantage of the protocol is that it increases the energy consumption.

4. Opportunistic routing protocol

Opportunistic routing strategy proposed by researchers at MIT, it makes full use of the broadcast characteristics of wireless networks for data propagation, the source node broadcasts data to a group of relay nodes instead of a relay node, this group of relay nodes is called a candidate node set, and then the best node can be selected from this candidate node set as a forwarding node, and the nodes in the candidate node set can also be set forwarding priority, and the rest of the nodes eavesdrop on the forwarding message and lose the packet, which makes the packet loss rate greatly reduced.

4.1 Coding-Aware Opportunistic Routing for Sparse Underwater Wireless Sensor Networks

In, a code-aware opportunistic routing method (CORS) for sparse UWSN is proposed. In CORS, we use topology information to adaptively extend the candidate set, on the basis of which we develop a forwarding of an opportunistic coding strategy to join inter-stream network encoding and opportunistic forwarding in CORS. In addition, we designed a sliding window-based coding algorithm that provides efficient coding gain with low coding overhead. During the encoding process, whenever a packet is received, the base station attempts to decode new information with buffered packets using a sliding window-based decoding algorithm. In addition, to mitigate interference between control packets and packets, CORS utilizes a backtracking strategy to wait for forwarded outgoing packets, a sliding window-based decoding algorithm to reduce decoding overhead. Figure 3 shows the opportunistic encoding policy used for routing.

4.2 Opportunistic Routing for Opto-Acoustic Internet of Underwater Things

In, The protocol consists of three main components: candidate filtering, candidate node selection, and candidate node coordination. The candidate node set consisting of the CS of the region selected by the smallest divergence angle starts, gradually increasing the angle in the search range, and recording the angle when a new node enters to form a new candidate node set. The metrics are divided into local and global, the local is DP or EDP or residual energy or delay, the local is based on its estimated number of transmissions, according to different indicators to select the best node to select the best CS and set the priority forwarding to the node. Nodes need to reply to the ACK to determine link quality, and setting the wait time can be considered for priority order of sending or completing multiple communication links. Increased reliability of the link, considering the directionality of optical transmission, faster and more secure data transmission, the disadvantage is that it may not be possible to find suitable candidate nodes in sparse networks, Figure 4 shows the candidate set screening and selection.

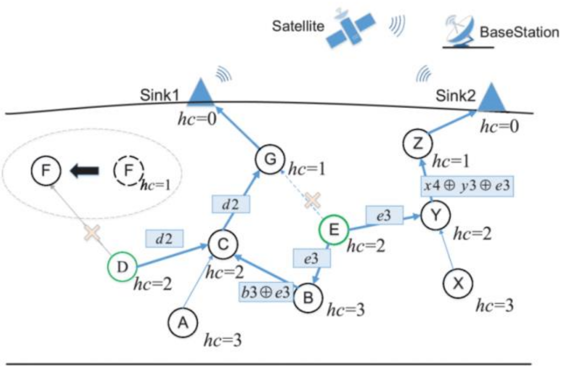

Fig.3 Candidate set expansion and opportunistic coding strategy.

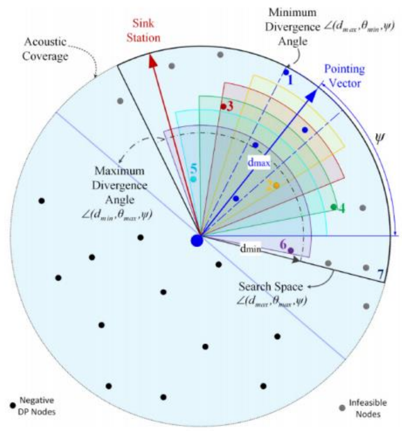

Fig. 4 Illustration of candidate filtering and selection.

5. Machine learning-based routing protocols

Path planning is a major field of machine learning applications, according to one or some optimization criteria (such as the shortest walking path, the shortest walking time, etc), find the optimal path from the starting state to the target state in the network, through machine learning can avoid the local optimal, find the global optimal performance of the path for data transmission.

5.1 Anypath Routing Protocol Design via Q-Learning for Underwater Sensor Networks

In, The next hop is calculated using the Q-learning algorithm, the reward function considers the depth information and the residual energy information, and the priority drop sequence table is established according to the Q value, and the forwarding node is selected according to the priority list. At the same time, a time-holding mechanism is designed, the packet retention time increases with the decrease in priority (the first priority hold time is 0), and when the node overhears the packet during the hold time, it drops the packet. Finally, a multipath suppression scheme is proposed, which designs a threshold Pth according to the actual application scenario, and when the PDR > Pth, shorten the length of the priority list to improve energy efficiency, otherwise increase the length of the priority list to improve the transfer rate. This protocol is relatively flexible, with the option to improve energy efficiency or delivery rates, with the disadvantage that Q tables occupy memory and updates increase end-to-end latency and energy consumption.

5.2 Deep Reinforcement Learning Based MAC Protocol for Underwater Acoustic Networks

In, A new deep reinforcement learning (DRL) technology, called DR-DQN, is proposed, which is suitable for environments with long latency by integrating long propagation delays. According to the DR-DQN algorithm, the DR-DLMA routing protocol is designed, which can be applied to the dynamically changing environment to maximize network throughput, and at the same time proposes a flexible neural network (DNN) training mechanism, only when the performance changes, the DNN is retrained, minimizing energy consumption and training DNN time, the disadvantage of the protocol is that training DNN generates cost consumption. This article is the first application of the deep Q-network algorithm to UWSN, and Figure 5 shows the protocol process.

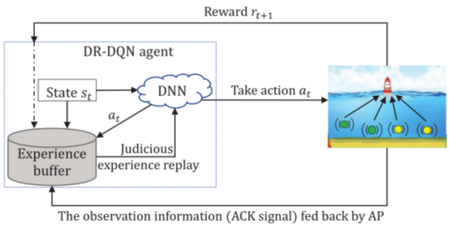

Fig.5 Delayed-reward deep Q-network for the UWAN communication.

6. Conclusion

This paper considers the end-to-end latency, packet delivery rate, energy consumption and network life multiple performance in UWC, divides the recently existing routing protocols into three categories, and also discusses their advantages and disadvantages, but does not discuss the rest of the more performance and algorithms in detail, in the future work, more underwater wireless sensor network routing protocol papers will be collected, from multiple perspectives to analyze the problems that need to be solved, combined with the actual situation to make reasonable suggestions, so that the protocol can be applied to the actual underwater environment faster.

References

[1] M. Jouhari, K. Ibrahimi, H. Tembine, and J. Ben-Othman, "Underwater wireless sensor networks: A survey on enabling technologies, localization protocols, and internet of underwater things," IEEE Access, vol. 7,pp. 96879–96899, 2019.

[2] M. Jouhari, K. Ibrahimi, H. Tembine and J. Ben-Othman, "Underwater Wireless Sensor Networks: A Survey on Enabling Technologies, Localization Protocols, and Internet of Underwater Things," in IEEE Access, vol. 7, pp.96879-96899,2019.

[3] K. M. Awan, P. A. Shah, K. Iqbal, S. Gillani, W. Ahmad, and Y. Nam,"Underwater wireless sensor networks: A review of recent issues and challenges," Wireless Commun. Mobile Comput., vol. 2019, pp. 1–20,Jan. 2019.

[4] H. Khan, S. A. Hassan and H. Jung, "On Underwater Wireless Sensor Networks Routing Protocols: A Review," in IEEE Sensors Journal, vol. 20, no. 18, pp. 10371-10386, 15 Sept.15, 2020.

[5] T. Hu and Y. Fei, "MURAO: A multi-level routing protocol for acoustic-optical hybrid underwater wireless sensor networks," 2012 9th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON), 2012, pp. 218-226.

[6] J. Luo, Y. Chen, M. Wu and Y. Yang, "A Survey of Routing Protocols for Underwater Wireless Sensor Networks," in IEEE Communications Surveys & Tutorials, vol. 23, no. 1, pp. 137-160, Firstquarter 2021.

[7] D. Niculescu, "Communication paradigms for sensor networks," IEEE Commun. Mag., vol. 43, no. 3, pp. 116–122, Mar. 2005.

[8] M. Xu, G. Liu, and H. Wu, "An energy-efficient routing algorithm for underwater wireless sensor networks inspired by ultrasonic frogs," Int.J. Distrib. Sens. Netw., vol. 10, pp. 1–12, Feb. 2014.

[9] F. Al Salti, N. Alzeidi, and B. R. Arafeh, "EMGGR: An energy-efficient multipath grid-based geographic routing protocol for underwater wireless sensor networks," Wireless Netw., vol. 23, no. 4, pp. 1301–1314,2017.

[10]S. Karim et al., "GCORP: Geographic and Cooperative Opportunistic Routing Protocol for Underwater Sensor Networks," in IEEE Access, vol. 9, pp. 27650-27667, 2021.

[11]V. Khajuria and M. Kaur, "Underwater wireless sensor network: Architecture, applications and challenges," in Proc. 2nd Int. Conf. Trends

[12]Electron. Informat. (ICOEI), May 2018, pp. 939–944.

[13]E. C. Van Der Meulen, "Three-terminal communication channels," Adv.Appl. Probab., vol. 3, no. 1, pp. 120–154, 1971.

[14]H. Tran-Dang and D. -S. Kim, "Channel-aware cooperative routing in underwater acoustic sensor networks," in Journal of Communications and Networks, vol. 21, no. 1, pp. 33-44, Feb. 2019.

[15]H. Tran-Dang and D. -S. Kim, "Channel-aware cooperative routing in underwater acoustic sensor networks," in Journal of Communications and Networks, vol. 21, no. 1, pp. 33-44, Feb. 2019.

[16]D. Zhao, G. Lun and R. Xue, "Coding-Aware Opportunistic Routing for Sparse Underwater

Wireless Sensor Networks," in IEEE Access, vol. 9, pp. 50170-50187, 2021.
[17]A. Celik, N. Saeed, B. Shihada, T. Y. Al-Naffouri and M. -S. Alouini, "Opportunistic Routing for Opto-Acoustic Internet of Underwater Things," in IEEE Internet of Things Journal, vol. 9, no. 3, pp. 2165-2179, 1 Feb.1, 2022.
[18]Y. Zhou, T. Cao and W. Xiang, "Anypath Routing Protocol Design via Q-Learning for Underwater Sensor Networks," in IEEE Internet of Things Journal, vol. 8, no. 10, pp. 8173-8190, 15 May15, 2021.
[19]X. Ye, Y. Yu and L. Fu, "Deep Reinforcement Learning Based MAC Protocol for Underwater Acoustic Networks," in IEEE Transactions on Mobile Computing, vol. 21, no. 5, pp. 1625-1638, 1 May 2022.