A Routing Void Handling Protocol Based on Autonomous Underwater Vehicle for Underwater Acoustic Sensor Networks

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Abstract. In underwater acoustic sensor networks (UASNs), efficient packet transmission is essential for monitoring new marine technologies. However, the uneven distribution of nodes and inappropriate selection of forwarding nodes lead to routing voids in adjacent nodes. Aiming at the problem, we propose a routing void handling protocol (RVHP) based on Autonomous Underwater Vehicle (AUV) for UASNs. RVHP effectively detects and avoids void nodes and trap nodes through a void avoidance mechanism, and then uses an AUV-assisted network repair mechanism to timely deal with failure routing in the communication area. AUV adopts a greedily path-finding strategy to visit void nodes, and realizes the void repair of UASNs. Simulation results show that RVHP can effectively improve the packet transmission rate and energy utilization rate.

Keywords: Underwater acoustic sensor network (UASN) · Routing void · Autonomous underwater vehicle (AUV) · Network repair

1 Introduction

With the decrease of land resources, people pay more and more attention to the development of underwater resources [1]. Underwater acoustic sensor network (UASNs) has widely applied in military defense, underwater environment monitoring, disaster prevention and other fields [2–4]. Compared with traditional sensor networks, UASNs communicate through underwater acoustic channels, node deployment is relatively sparse, and battery charging is difficult and expensive [5, 6]. In a harsh underwater environment, UASNs are facing many challenges such as narrow available bandwidth, high deployment cost, and limited energy [7], which lead to large transmission delay, high communication error rate and low network reliability. In addition, the uneven distribution of nodes and improper selection of forwarding nodes, which make it impossible for nodes to find neighbor nodes within the communication range of

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nodes, the nodes continue to forward packets, result in routing voids and packet forwarding failures [8]. Therefore, it is very important to find a solution to the routing void problem to improve the communication efficiency of a UASN. The existing routing void processing approaches mainly include decision strategies based on bypassing a void area, power control and mobile assistance [9].

The strategy of bypassing void areas is commonly used in underwater routing void handling protocols. This strategy discovers and maintains another path from an ordinary node to another ordinary nodes, the path can forward packet greedily. However, due to forwarding packets to more nodes, more packet transmission delay is caused. In void-aware pressure routing (VAPR) [10], packets are routed along directional paths to surface sonar buoys. The directional path is determined by a beacon message broadcast by a sonar buoy, which contains a sequence number, a hop number and depth information. When a node receives a beacon message, VAPR updates its forwarding direction based on the depth position of the sender, and detects void nodes through periodic beacons. When routing void occurs in the network, VAPR bypasses the routing void by saving the information of neighbor nodes with a maximum of two hops, and packets are only forwarded up or down according to the directed path, which leads to high network overhead. In vector-based forwarding (VBF) [11], packets are transmitted along virtual “routing pipe”. Due to the influence of node density in the pipe, redundant transmission or serious loss of packets is caused. In hop-by-hop vector-based forwarding (HH-VBF) [12], each hop uses different virtual “routing pipes” to transmit packets to sink, which solves the problem of no nodes in a virtual “routing pipe” in a VBF sparse network scenario. Hydraulic pressure based anycast routing (Hydrocast) [13] solves a void by local lower depth recovery. Each local maximum node maintains a recovery routing with a depth lower. When the recovery path is long, the process of finding and maintaining the path makes network expensive.

The void handling protocol based on power control can seek a neighbor node that can continue to forward packets by increasing the communication range of a void node. However, the increase of transmission power leads to the increase of network cost, and the expansion of a void area leads to the conflict of the packet. In adaptive power-controlled routing protocol (APCR) [14], the nodes are deployed in a hierarchical structure, and packets are forwarded to the nearest layer node of the sink until they are transmitted to the sink. The nodes adopt adaptive power control to improve power and ensure network connectivity when the network is sparse. The channel-aware routing protocol proposed in [15] uses power control and link quality in data forwarding, and uses hop information to successfully avoid void areas.

In mobile-based routing protocol for solving the void problem, void nodes are moved to a new location, and the greedy forwarding of nodes is restored, however, the disadvantage is that the energy cost of the mobile void node is high. In the multi-modal communication using the depth adjustment protocol (MMC) [16], according to the size of data transmission, a node decides whether to surface for communication based on network energy consumption and data delay. The depth controlled routing (DCR) [17] utilizes node mobility to reduce the number of void nodes in a UASN by moving nodes. The Geographic and opportunistic routing protocol with the depth adjustment protocol (GEDAR) [18] is based on the topological control of depth adjustment in geographical and opportunistic routing. In GEDAR, a packet is forwarded to the destination node through a greedily opportunity mechanism, and a void node is moved to a new depth position through the depth adjustment of the node so that the node can quickly restore the greedy forwarding.

The above protocols only introduce routing strategies for void nodes, ignoring trap nodes that lead to void nodes in UASNs. A trap node can forward packets to other nodes, but forwarding packets will eventually cause nodes to fall into a void. If trap and void nodes are found before routing and are avoided during packet forwarding, the efficiency of packet transmission can be improved. To this end, we propose a routing void handling protocol (RVHP) based on autonomous underwater vehicle (AUV) for a UASN. RVHP actively detects and effectively avoids void nodes and trap nodes by passive participation. Each ordinary node detects a void node by setting a failure time, and then identifies a trap node by means of controlling packet backward drive so that RVHP finds a void region locally without any increasing overhead. In view of the sudden routing failure of any node within its the communication range, RVHP directly collects data from the failed node by deploying a mobile node AUV. In order to reduce the packet loss, AUV uses a greedy path-finding strategy to access void nodes to adapt the dynamic of the network. Then the AUV sends packets to a sonar buoy through an acoustic channel to repair void in the network. Simulation results show that RVHP not only guarantees an efficient and stable data transmission rate, but also reduces the network energy consumption, and prolongs the network lifecycle.

The remainder of the paper is organized as follows. Section 2 introduces the system model considered in this work. Section 3 describes the design of RVHP. Section 5 evaluates the performance of RVHP. Section 6 concludes the paper.

2 System Model

2.1 Network Model

We consider a UWSN model with different types of network nodes in the network, mainly including ordinary nodes trap nodes, void nodes, AUVs and sonar buoys, as shown in Fig. 1.

In this network model, the ordinary nodes are distributed in the ocean. By sensing and collecting underwater information, each ordinary node sends its monitoring data to the next-hop forwarding node or sonar buoy. The sonar buoys are deployed on the surface as the destinations, which are mainly responsible for underwater and land communication. Data are collected from ordinary nodes through the acoustic link, and the wireless links are used to transmit data to the monitoring center for analysis [19]. An AUV dives into the water by itself, collects sensing data directly from void nodes, and transmits packets to sonar buoys through the acoustic channel, thus minimizing the energy consumption and prolonging the network lifecycle. The main characteristics of these nodes are as follows:

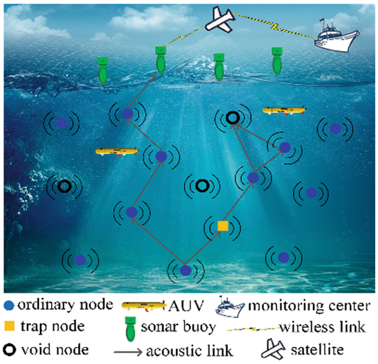

Fig. 1. Network model.

(1) Ordinary nodes are distributed in a discrete, three-dimensional and random manner in the underwater area, and they are responsible for collecting data.
(2) Void nodes are located in a routing void area. The packets lose in this area, ordinary nodes retransmit packets so that the communication efficiency of the acoustic link decreases.
(3) Trap nodes refer to the nodes through which packets can be forwarded to other nodes, but forwarding packets to these nodes will cause these nodes to fall into a void.
(4) AUVs are randomly deployed in underwater areas with unlimited energy [20, 21].

2.2 Underwater Acoustic Channel Model

RVHP adopts the attenuation model of an underwater acoustic signal [22, 23] to estimate the packet transmission rate $\mathrm{p}(d, m)$ of transmitted m bits by any pair of nodes with a distance of d. Thus, the attenuation factor without obstacles is

$$\mathrm{A}(d,f) = d^k a(f)^d \tag{1}$$

where f is the signal frequency, k is the diffusion factor (cylinder is 1, practical is 1.5, sphere is 2), and k takes 1.5 in the simulation experiment. The absorption coefficient $\alpha(f)$ is

$$\alpha(f) = \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2} + 2.75 \times 10^{-4} f^2 + 0.003 \tag{2}$$

The average SNR of distance d is

$$\tau(d) = \frac{E_b/A(d,f)}{N_0} = \frac{E_b}{N_0 d^k \alpha(f)^d} \tag{3}$$

where E_b and N_0 are constants, respectively, representing the average energy consumption per unit bit and noise power density.

We use Rayleigh fading to model small scale fading, where SNR has the following probability distribution:

$$p_d(X) = \int_0^\infty \frac{1}{\tau(d)} e^{-\frac{X}{\tau(d)}} \tag{4}$$

The probability of error can be evaluated as

$$p_e(d) = \int_0^\infty p_e(X) p_d(X) dX \tag{5}$$

This protocol adopts a BPSK modulation mode. The bit error probability of distance d is

$$p_e(d) = \frac{1}{2}\left(1 - \sqrt{\frac{\tau(d)}{1+\tau(d)}}\right) \tag{6}$$

Therefore, the packet transmission rate $\mathrm{p}(d, m)$ of any pair of nodes with distance d transmitting m bits is

$$\mathrm{p}(d, m) = (1 - p_e(d))^m \tag{7}$$

2.3 Energy Consumption Minimization Model

Since high energy consumption affects the communication performance, RVHP adopts a mathematical model based on linear programming to reduce the energy consumption of each ordinary node [24], i.e.,

$$\mathrm{Min} \sum\nolimits_{r=1}^{r_{max}} E_{consumption}(r), \forall r \in r_{max} \tag{8}$$

where the constraint condition is

$$E_{trans}, E_{rec} \le E_{init} \tag{9}$$

$$E_{forw} \le E_{forw}^{max} \tag{10}$$

$$T_{range} \le T_{rmax} \tag{11}$$

E_{trans} and E_{rec} are, respectively, the energy consumption when sending and receiving a packet, E_{forw} is the energy consumption of a forwarding node, T_{range} is the communication range of a node.

The total energy consumption of a node during transmission and reception is given by

$$\sum\nolimits_{r=1}^{r_{max}} E_{consumption}(r) = E_{trans} + E_{rec}, \forall r \in r_{max} \tag{12}$$

where

$$E_{trans} = P_{trans}\left(\frac{P_{size}}{p(d,m)}\right) \tag{13}$$

$$E_{rec} = P_{rec}\left(\frac{P_{size}}{p(d,m)}\right) \tag{14}$$

P_{trans} and P_{rec} are the power consumption when transmitting and receiving a packet, respectively, and P_{size} is the size of a packet.

3 Design of RVHP

3.1 Void Avoidance Mechanism

RVHP actively detects void node and trap node by passive participation, and uses the preventive mechanism to effectively avoid void area, excluding void node and trap node from the candidate set of packets forwarding, which makes RVHP ensure efficient and stable data transmission rate, and reduce network energy consumption.

1. **Void Node**

RVHP uses a time-based strategy to detect void nodes. Before routing starts, each node sets a void detection timer and waits for a neighboring node with lower depth to transmit a packet. If a node receives the packet within the failure time, the node resets its void detection timer. Otherwise, the node broadcasts a control packet to neighboring nodes, and declares itself as a void node. As shown in Fig. 2, node g and i are void nodes after detection.

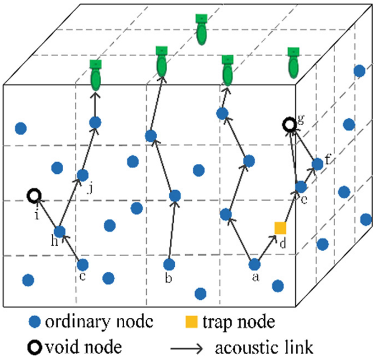

Fig. 2. Schematic diagram of a void avoidance mechanism.

The failure time T_{ω}^{φ} of the void detection timer consists of three parts [25]: (1) Packet transmission time $T_h(p)$; (2) The delay difference between the first node and the second node, and the sum $\sum_{k=1}^{\varphi} D(n_k, n_{k+1})/v$ of the delay difference between the $\varphi - 1$ and the φ node; (3) Packet processing time T_{proc}. Thus, the failure time T_{ω}^{φ} is given by

$$T_{\omega}^{\varphi} = T_h(p) + \sum\nolimits_{k=1}^{\varphi} \frac{D(n_k, n_{k+1})}{v} + \varphi \cdot T_{proc} \tag{15}$$

The packet transmission time $T_h(p)$ is given by

$$T_h(p) = \frac{R_c - D}{v} \tag{16}$$

where R_c is the communication range, D is the distance between a transmitter and a receiver, and v is the propagation speed of an underwater acoustic signal.

2. **Trap Node**

After RVHP detects the void nodes in the routing path, it will identify trap nodes using the backward-driven strategy and a control packet. After a node receives the packet, it will update its neighbor table, and check other neighbor nodes whose depth is lower than itself. If the node is a single neighbor in the neighborhood, it is be a trap node.

Similarly, after a node receives a packet from a trap node, the node will first update the state of the trap node in the neighbor table, and confirm own state. If the neighbor does not contain a lower-depth node other than the trap node, that node is also a trap node. This process stops when all trap nodes on the routing path are detected. As shown in Fig. 2, node *d* is identified as a trap node. Therefore, void nodes and trap nodes at different locations can be detected in the local identification network without any additional overhead.

3.2 Network Repair Mechanism

Due to the water flow, energy consumption of nodes, and high error rate of the propagation channel, a routing failure suddenly appears in the communication range of an ordinary node, resulting in a routing void, which makes a node unable to forward packets to sonar buoys. An AUV can effectively solve the problem. An AUV can dive into the water by itself, directly collect data from the void node, and transmit packets to a sonar buoy through the acoustic channel.

As shown in Fig. 3, during the packet forwarding, if an ordinary node finds itself in a void in a received neighbor message, the node will broadcast a void packet to an AUV through a single hop acoustic communication. The void packet includes the location coordinates L of a node, the size P_{size} of a packet, the attenuation type A, and the degree of emergency T. Meanwhile, all neighbor nodes broadcast the received void packet until it is received by the nearest AUV. When the AUV receives the packet, it will move to the position of the void node, and then transmit the packet directly to a sonar buoy.

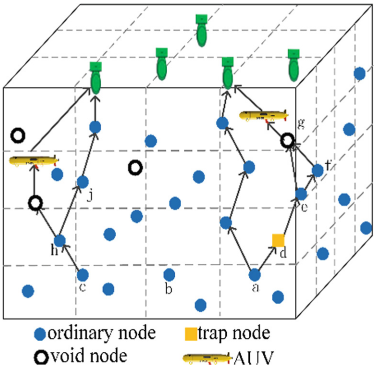

Fig. 3. Schematic diagram of a network repair mechanism.

In a sparse network, an AUV may receive multiple void packets in a certain period. In order to reduce the packets loss, an AUV uses the greedily pathfinding strategy to access void nodes to adapt to the dynamic of the network. At each decision point, the next void node to be visited by the AUV will be the largest node to transmit packets. If visiting another void node makes an AUV transmit larger packets, the AUV will change its path before reaching the void node.

RVHP decides the routing paths R_{AUV} based on the size P_{size} of packets sent to an AUV by a void node, and the effective transmission time t_{trans} of an AUV is given by

$$R_{AUV} = \frac{P_{size}}{t_{trans}} \tag{17}$$

When an AUV receives a void packet from node i and k, RVHP determines the first void node to visit by comparing the size R_{AUV}. If the value R_{AUV} of void node i is larger, the AUV first visit the void node.

In addition, while an AUV greedily visits the void node with the largest value R_{AUV}, it should also consider the attenuation type A and emergency degree T of packets transmitted by different void nodes. If the exponential attenuation of the packets monitored by node i is smaller, and node k is larger, the two nodes have the same R_{AUV} and T. Then the AUV will first collect the monitoring data of node k, in order to avoid a packet loss, and maximize the transmission of packets to sonar buoys.

4 Complexity Analysis

In terms of complexity, this paper mainly analyzes the computational complexity and communication complexity of RVHP in the routing decision-making process [26].

Assume that l_{ij} represents the link length from node i to node j, and d_{i1} represents the current shortest distance estimation from node i to a given destination node, which is stored in node i. Thus, the routing decision process can be briefly described as follows:

$$d_{i1}^{(0)} = \begin{cases} \infty, & i \neq 1; \\ 0, & i = 1 \end{cases} \tag{18}$$

$$d_{i1}^{(k+1)} = \begin{cases} \min\left[l_{ij} + d_{j1}^{(k)}\right], & j \in N(i), i \neq 1; \\ 0, & i = 1 \end{cases} \tag{19}$$

where $N(i)$ represents the current neighbor set of node i, and k represents the number of iterations. T_1 and T_2 represent the computational complexity and communication complexity, respectively,

$$T_1 = \mathrm{O}(\bar{d}\bar{n}_h) \tag{20}$$

$$T_2 = \mathrm{O}(\bar{n}_h) \tag{21}$$

where the $\bar{d}$ is the maximum node degree, n is the maximum number of nodes, $\bar{n}_h$ is the biggest hop number, and $1 \leq \bar{n}_h \leq n - 1$. Therefore, the computational and communication time complexity of the RVHP routing decision process should be $\mathrm{O}(\bar{d}n)$ and $\mathrm{O}(n)$.

5 Performance Analysis

We evaluate the performance of the proposed RVHP using NS-3. For this purpose, we compare RVHP with VAPR and GEDAR in terms of average end-to-end delay, packet transmission rate and average energy consumption. The parameters used in the simulation experimental are given in Table 1.

Table 1. Parameters.

Parameters	Values
Area size of three-dimensional water	1000 m * 1000 m * 1000 m
Number of ordinary nodes	800
Initial energy of a node	100 J
Acoustic signal frequency	25 kHz
Energy consumption of transmitting data	$80*10^{-8}$J/bit
Energy consumption of receiving data	$5*10^{-8}$J/bit
Number of AUVs	2
Packet size	50 Byte
AUV moving speed	2 kn
Simulation running time	2000 s
Number of simulations	50

5.1 Average End-to-End Delay

Figure 4 shows the average end-to-end delay with the three routing protocols as the number of nodes increases. It is seen that VAPR and GEDAR have a higher delay than RVHP. This is because when the nodes are located in the communication void area, VAPR adopts a void recovery mode, which increases the node hops, and GEDAR leads to a high network delay because the node is in a queued waiting state during the void repair. In contract, when the number of nodes increases, the delay of PVHP decreases, and its performance becomes better than those of VAPR and GEDAR. By avoiding local voids and repairing AUV in time, the number of conflicts and retransmission is significantly reduced, thus the network delay being reduced.

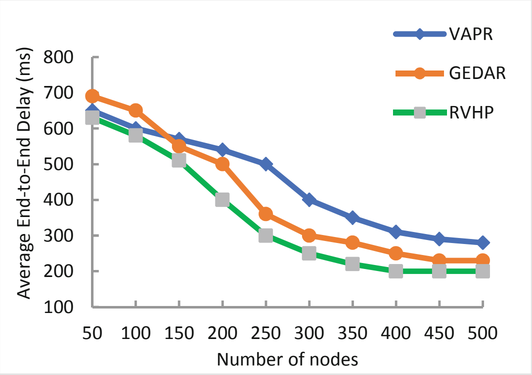

Fig. 4. Average end-to-end delay.

5.2 Packet Transmission Rate

Figure 5 shows the packet transmission rate with the three routing protocols, respectively.

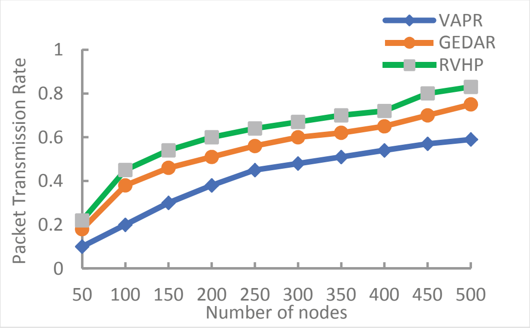

Fig. 5. Packet transmission rate.

It is seen that with the number of nodes increasing, the packet transmission rate increases as well. On the other hand, RVHP has a larger packet transmission rate than both VAPR and GEDAR. This is because RVHP effectively avoids void areas in the routing path by means of local discovery and maintenance. When a routing failure suddenly occurs in the communication area, a node does not discard a packet, but adopts the AUV-assisted network repair mechanism to deal with the routing void. An AUV uses the greedily path-finding strategy to access void nodes to adapt to the dynamic of the network. At each decision point, the next void node to be visited by an AUV is the largest node to transmit packets, which improves the probability for an ordinary node to successfully transmit a packet.

5.3 Average Energy Consumption

Figure 6 shows the average energy consumption with the three protocols, respectively. It is seen that the number of nodes is small, RVHP has a high energy consumption because an alternative path in RVHP may increase the routing length, leading to the increase of energy consumption. With the number of nodes increasing, the energy consumption for a node to send packets decreases. Compared with VAPR and GEDAR, RVHP can successfully transmit more packets when the number of nodes is large. When packets fall into void nodes, RVHP can directly collect and detect data through an AUV, which significantly reduces the energy consumption of a node.

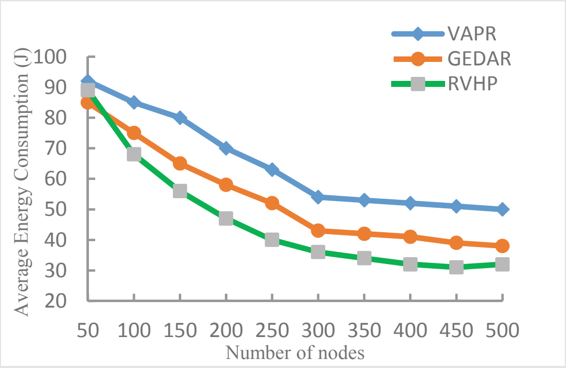

Fig. 6. Average energy consumption.

6 Conclusion

Routing void is one of the most challenging problems in underwater routing. To solve the problem, we proposed a routing void handling protocol (RVHP) based on AUV for a UASN. RVHP actively detects void nodes and trap nodes through the void avoidance mechanism, and effectively avoids a void area in routing path. When an ordinary node suddenly appears routing void in the communication range, RVHP directly collects data from the void node through the AUV-assisted network repair mechanism to realize the void handling of in the network, AUV uses the greedily path-finding strategy to a visit void node, and then sends a packet to a sonar buoy through the acoustic channel to realize void repair of the network. Simulation results show that RVHP can effectively solve the routing void problem, reduce the energy consumption in the network, and improve the packet transmission rate. In the future work, we will consider the link characteristics of a water environment in underwater routing, and effectively prolong the network lifecycle by reducing the communication void area.

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References

1. Khan, A., Javaid, N., Latif, G., Karim, O.A., Hayat, F., Khan, Z.A.: Void hole and collision avoidance in geographic and opportunistic routing in underwater wireless sensor networks. In: Barolli, L., Xhafa, F., Javaid, N., Spaho, E., Kolici, V. (eds.) Advances in Internet, Data & Web Technologies. EIDWT 2018. Lecture Notes on Data Engineering and Communications Technologies, vol. 17, pp. 225–236. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-75928-9_20
2. Luo, Y., Pu, L., Zhao, Y., Cui, J.H.: Harness interference for performance improvement in underwater sensor networks. IEEE Syst. J. **99**, 1–12 (2017)
3. Javaid, N., et al.: Delay-sensitive routing schemes for underwater acoustic sensor networks. Int. J. Distrib. Sens. Net. **11**(3), 532676 (2015)
4. Coutinho, R.W.: Topology Control and Opportunistic Routing in Underwater Acoustic Sensor Networks. Doctoral dissertation. Université d'Ottawa/University of Ottawa (2017)
5. Coutinho, R.W., Boukerche, A., Vieira, L.F., Loureiro, A.A.: Geographic and opportunistic routing for underwater sensor networks. IEEE Trans. Comput. **65**(2), 548–561 (2015)
6. Akbar, M., Javaid, N., Khan, A., Imran, M., Shoaib, M., Vasilakos, A.: Efficient data gathering in 3D linear underwater wireless sensor networks using sink mobility. Sensors **16**(3), 404 (2016)
7. Stojanovic, M., Preisig, J.: Underwater acoustic communication channels: propagation models and statistical characterization. IEEE Commun. Mag. **47**(1), 84–89 (2009)
8. Coutinho, R.W., Boukerche, A., Vieira, L.F., Loureiro, A.A.: Design guidelines for opportunistic routing in underwater networks. IEEE Commun. Mag. **54**(2), 40–48 (2016)
9. Coutinho, R.W., Boukerche, A., Vieira, L.F., Loureiro, A.A.: Performance modeling and analysis of void-handling methodologies in underwater wireless sensor networks. Comput. Netw. **126**, 1–14 (2017)
10. Noh, Y., Lee, U., Wang, P., Choi, B.S.C., Gerla, M.: VAPR: void-aware pressure routing for underwater sensor networks. IEEE Trans. Mobile Comput. **12**(5), 895–908 (2012)
11. Xie, P., Cui, J.H., Lao, L.: VBF: vector-based forwarding protocol for underwater sensor networks. In: Boavida, F., Plagemann, T., Stiller, B., Westphal, C., Monteiro, E. (eds.) NETWORKING 2006. Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks; Mobile and Wireless Communications Systems. NETWORKING 2006. LNCS, vol. 3976, pp. 1216–1221. Springer, Heidelberg (2006). https://doi.org/10.1007/11753810_111

12. Nicolaou, N., See, A., Xie, P., Cui, J.H., Maggiorini, D.: Improving the robustness of location-based routing for underwater sensor networks. In: Oceans 2007-Europe, 18–21 June 2007
13. Noh, Y., et al.: Hydrocast: pressure routing for underwater sensor networks. IEEE Trans. Veh. Technol. **65**(1), 333–347 (2015)
14. Al-Bzoor, M., Zhu, Y., Liu, J., Reda, A., Cui, J.H., Rajasekaran, S.: Adaptive power controlled routing for underwater sensor networks. In: Wang, X., Zheng, R., Jing, T., Xing, K. (eds.) Wireless Algorithms, Systems, and Applications. WASA 2012. LNCS, vol. 7405, pp. 549–560. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-642-31869-6_48
15. Basagni, S., Petrioli, C., Petroccia, R., Spaccini, D.: CARP: a channel-aware routing protocol for underwater acoustic wireless networks. Ad Hoc Netw. **34**, 92–104 (2015)
16. O'Rourke, M., Basha, E., Detweiler, C.: Multi-modal communications in underwater sensor networks using depth adjustment. In: Proceedings of the Seventh ACM International Conference on Underwater Networks and Systems, p. 31. ACM (2012)
17. Coutinho, R.W., Vieira, L.F., Loureiro, A.A.: DCR: depth-Controlled routing protocol for underwater sensor networks. In: 2013 IEEE Symposium on Computers and Communications, ISCC, pp. 453–458. IEEE (2013)
18. Coutinho, R.W., Boukerche, A., Vieira, L.F., Loureiro, A.A.: GEDAR: geographic and opportunistic routing protocol with depth adjustment for mobile underwater sensor networks. In: 2014 IEEE International Conference on Communications, ICC, pp. 251–256. IEEE (2014)
19. Latif, G., Javaid, N., Sher, A., Khan, M., Hameed, T., Abbas, W.: An efficient routing algorithm for void hole avoidance in underwater wireless sensor networks. In: 2018 IEEE 32nd International Conference on Advanced Information Networking and Applications, AINA, pp. 305–310. IEEE (2018)
20. Gong, Z., Li, C., Jiang, F.: AUV-aided joint localization and time synchronization for underwater acoustic sensor networks. IEEE Sig. Process. Lett. **25**(4), 477–481 (2018)
21. Su, R., Zhang, D., Li, C., Gong, Z., Venkatesan, R., Jiang, F.: Localization and data collection in AUV-aided underwater sensor networks: challenges and opportunities. IEEE Network (2019)
22. Brekhovskikh, L.M., Lysanov, Y.P., Beyer, R.T.: Fundamentals of ocean acoustics. Acoust. Soc. Am. J. **90**, 3382–3383 (1991)
23. Stojanovic, M.: On the relationship between capacity and distance in an underwater acoustic communication channel. ACM SIGMOBILE Mobile Comput. Commun. Rev. **11**(4), 34–43 (2007)
24. Khan, A., Javaid, N., Latif, G., Jatta, L., Fatima, A., Khan, W.: Cluster based and adaptive power controlled routing protocol for underwater wireless sensor networks. In: 2018 21st Saudi Computer Society National Computer Conference, NCC, pp. 1–6. IEEE (2018)
25. Darehshoorzadeh, A., Boukerche, A.: Underwater sensor networks: a new challenge for opportunistic routing protocols. IEEE Commun. Mag. **53**(11), 98–107 (2015)
26. Li, L.Y.: The routing protocol for dynamic and large computer network. Chin. J. Comput. **02**, 137–144 (1998)