Virtual Void-Based Marine Organism Protection Routing Protocol for Underwater WSNs

Hao Su\textsuperscript{1}, Yujie Qian\textsuperscript{2} and Yuan Zhang\textsuperscript{3}

\textsuperscript{1} College of Internet of Things Engineering, HoHai University, 200 Jinling North Road, Changzhou, China
\textsuperscript{2} HoHai University, Changzhou, 200 Jinling North Road, China
\textsuperscript{3} College of Internet of Things Engineering, HoHai University, 200 Jinling North Road, Changzhou, China

E-mail: 20141923@hhu.edu.cn

Abstract. With the progress and development of the Internet of Underwater Things, underwater wireless sensor networks (UWSNs) have been showed as a promising technology to monitor and explore the oceans. Different from terrestrial WSNs, UWSNs adopts acoustic signals instead of radio frequencies for wireless communication. However, marine mammals’ frequencies are heavily overlapped with the frequencies used by UWSNs, where the noise of underwater acoustic networks (UAN) made by human may interfere with or even harm marine organism. In order to protect these marine organism, it is very necessary and urgent to develop an environment-friendly UAN and cognitive acoustic (CA) is considered as a promising technique. Based on this, aiming at not only protecting marine mammals, but also attaining optimal network performance, in this paper, we propose a virtual void -based marine organism protection routing (VMOPR) protocol for UWSNs, which is a location-based flow transmission scheme. Simulation results show that the performance of the scheme is better than the corresponding EEIAR and VBF protocol in terms of packet delivery ratio, throughput and energy efficiency when taking marine mammals into account.

1. Introduction
Oceans cover more than 2/3 of this planet’s surface, and numerous resources underneath. For decades, there has been a growing interest in monitoring aqueous environments. The corresponding UWSNs has a wide range of application, such as oceanographic data collection, pollution detection, underwater resource exploration, offshore infrastructure protection and target tracking [1], [2]. Acoustic communication is the only feasible method for underwater wireless communication in UWSNs [3]. The unique features of underwater acoustic communication bring many challenges such as temporary path loss, high noise, multipath fading, high communication energy cost and so on [4].

In addition to communication quality problems, it is worth noticing that the deployed area of UWSNs may be the same area where some marine creature appears. Due to the marine mammals’ frequencies are heavily overlapped with the frequencies used by UWSNs [5,6], the noise of UWSNs made by human will have harmful impact on those marine creatures. Therefore, designing an environment friendly routing protocol with high network performance to protect marine organism is necessary.
In this paper, we propose a virtual void region-based marine organism protection routing (VMOPR) protocol for UWSNs that avoids interference with marine mammals’ acoustic systems. VMOPR utilizes the location information of nodes and marine creatures to select the path. In order to effectively avoid channel interference. VMOPR adopts OFDM sub-channels at the MAC layer. Aiming at maximizing the throughput and improving the packet delivery ratio, flow routing is used [7]. In order to avoid interference with the marine mammals’ acoustic system, the virtual void -based methodology is used in the proposed scheme, which means that the nodes around marine life will be set to idle state to avoid the interferences. And the nodes that may have impact on marine mammals’ acoustic system will maintain the idle state until the marine life moves away.

The rest of the paper is organized as follows. In section 2, we introduce the network model of VMOPR. We describe the VMOPR with multiple constraints in section 3 and the simulation in section 4 is analyzed. Finally, section 5 concludes the paper and state our future works.

2. Network model
As shown in Figure. 1, we consider an UWSNs consisting of a sonobuoy, also named sink node, a group of forward nodes, a group of source nodes and several marine creatures. The sink node is fixed in the middle of the water surface, source nodes are anchored to the ocean bottom for underwater resource exploration, target tracking, or oceanography data collection. The forwarding nodes are randomly deployed in the water in the water. We assume that each sensor node knows its location and the location of marine mammals can be obtained by existing location techniques.

---

![Network architecture of UWSN](image)

Figure 1: Network architecture of UWSN
3. Virtual void-based marine organism protection routing protocol

In this section, a virtual void-based marine organism protection routing (VMOPR) protocol for UWSNs is elaborated. The available spectrum is divided into $M$ OFDM sub-channels. In order to protect marine mammals, we define the safe distance $D_s$ between marine life and sensor nodes, which indicates that marine organism will not be influenced by UWSNs acoustic signal from this distance. Based on these notations, the strategy of interference avoidance, selecting path and flow routing transmission is presented.

3.1. Strategy of selecting path

In order to protect marine mammals, we use the state $l_{i,j}$ to denote whether the node $i$ links with node $j$:

$$l_{i,j} = \begin{cases} 1, & \text{if } j \text{ is a link} \\ 0, & \text{otherwise} \end{cases}$$ (1)

And the value of $l_{i,j}$ is a binary value. We use $C_i$ to denote whether the node is in the biological interference range:

$$C_i = \begin{cases} 1, & d_{im} \leq r \\ 0, & \text{otherwise} \end{cases}$$ (2)

Where $d_{im}$ is the distance between node $i$ and the nearest marine mammal, $R$ being the communication range of the sensor node as shown in Figure 2. If $C_i = 1$, it means that there are marine creatures around node $i$ and node $i$ is in the biological interference range, conversely $C_i = 0$. The nodes with $C_i = 1$ will not participate in forwarding and enter an idle state. With this strategy, the acoustic communication of UWSNs will not interfere with the marine creature. And the nodes of the idle state make the area centered the marine life a virtual void-region, which will not return to normal working state until the marine mammals swim away.

Figure 2: Virtual void node diagram
3.2. Route discovery and establishment
When the source node $S$ have collecting data to transmit, it will initiate a route discovery through flooding. Firstly, it broadcasts a route request packet (REP) to all its neighbors, and each node with $C_i = 0$ receiving REP forwards REP to its neighbors. By analogy, multiple REPs will finally reach the destination –sink node. And sink node will choose the route that has the least hop count to be used as the data transfer path and enhance the selected path by replying route response packet (RRP). When the source node $S$ receives the RRP, the data transfer path is established and enhanced.

3.3. Flow routing transmission
Aiming to maximize end-to-end throughput, VMPOR adopts flow routing. In flow routing, for each forward node, the total incoming data should be equal to the total outgoing data. Thus we have:

$$
\sum_{i \neq \text{source}} \{i, j \in \text{path}\} f_{ij} = \sum_{k \neq \text{sink}} \{j, k \in \text{path}\} f_{jk}
$$

(3)

Where $f_{ij}$ denotes the flow arranged on the link from node $i$ to node $j$ and $f_{ij}$ denotes the flow arranged on the link from node $j$ to node $k$. In this constraint, node $i$, node $j$ and node $k$ present forwarding nodes in the selected path to sink node.

Then, for the source node, the total incoming data should be zero. Hence, the second constraint can be denoted as:

$$
\sum_{\{s,j\} \in \text{path}} f_{js} = 0
$$

(4)

On the contrary, the total outgoing data of sink node should be zero.

$$
\sum_{\{j,d\} \in \text{path}} f_{dj} = 0
$$

(5)

Since the forwarding nodes need to transmit upon receiving the data in flow routing, the VMPOR adopts OFDM at the MAC layer. The whole available spectrum can be divided into $M$ OFDM sub-channels. One sub-channel is used as control packet delivery, and the other $M-1$ sub-channels are used as data transferring. In order to avoid collisions, each forwarder needs to utilizes two different sub-channels to transmit and receive data, respectively.

Table 1: The value of parameters.

| Parameter                  | Value                        |
|----------------------------|------------------------------|
| Network Size               | $4500m \times 4500m \times 2000m$ |
| Receive Power              | $0.756w$                     |
| Forward Power              | $2w$                         |
| Carrier Frequency          | $10kHz - 40kHz$             |
| Packet Size                | $160bytes$                  |
| Number of Nodes            | $54 - 162$                  |
| Data Generation Rate       | $0.16kbps - 0.96kbps$        |
| Safe Range                 | $1000m$                      |
| Initial Energy             | $100J$                       |
| Transmission Rate          | $10kbps$                     |
4. Performance evaluation

In this section, we compare our proposed protocol VMOPR with EEIAR (Energy Efficient Interference-aware Routing) [8] and VBF (Vector based Forwarding Protocol) [9] through extensive simulations on Matlab. Firstly, we simply explain the implementation of MAC protocol, and then we discuss the simulation results.
4.1. Implementation of MAC protocol

Because there is no standard protocol at the MAC layer, we adopt the simple MAC protocol based on CSMA in VBF and EEIAR. In this MAC protocol, the forward node senses the channel before forwarding data packets, if the channel is busy, it will utilize a back-off algorithm to wait until the channel is free [9]. Since VMOPR is a flow routing protocol, we implement a MAC protocol based on OFDM. To implement this MAC protocol, we divide the frequency into M sub-channels. What’s more, there is no RTS/CTS and ACK in both MAC protocols.

4.2. Simulation setup

In our simulation, all nodes are deployed in the space of 4500m × 4500m × 2000m. In order to make the distribution of nodes more reasonable, the region is divided into 27 sub-regions with size of 1500m × 1500m × 667m. The number of source node is 9 and the number of forward nodes range from 27 to 162. We assume that the mobility of all sensor nodes can be ignored. The number of marine creature group is 2 and they can appear in the region randomly. Besides, the value of parameters are shown in Table 1.

First, we evaluate three protocols with number of forwarding nodes ranging from 54 to 162, and we want to know how they perform in terms of packet delivery rate, throughput, and energy consumption as the network density varies.

Figure. 3a shows the compassion results of the packet delivery rate among these three protocols. It can be seen from Figure. 3a that, as the forwarders increase, the packet delivery rate for all protocols improve in the overall trend. The performance of VMOPR with regarding to the packet delivery rate is better than two other protocols, because both VBF and EEIAR use vector forwarding to find the next hop, while VMOPR carries out the route discovery to find the most suitable path in the whole network through flooding. However, when the number of forwarding nodes exceeds 140, the he packet delivery rate almost reaches saturation for all protocols due to the packet loss caused by the channel conflict.

Figure. 3b shows the results concerning the throughput. VMOPR has a large advantage over VBF and EEIAR in the performance of throughput because of the use of flow routing methodology. Based on this, VMOPR can simultaneously transmit upon receiving the data.

Figure. 4a shows the results concerning the average energy consumption per received packet. We can notice that these three protocols have little difference for low network density. However, as the number of forwarding nodes increases, the energy consumption of VMOPR has a very small rise, and the counterpart of VBF and EEIAR increases greatly. This happens because that the higher the network density, the more the forwarding nodes in the path involved in forwarding a packet successfully with VBF and EEIAR. Since VMOPR adopts a route discovery and establishment on demand method, it is almost unaffected by network density when the network model and transmission radius are constant.

Next, these three protocols are evaluated with the data packet generation rate ranging from 0.16kbps to 0.96kbps. Figure. 4b shows the results of the packet delivery ratio. As shown in the plot, the performance of VMOPR is the best, compared with the other two protocol. It is because VMOPR will transmit the data packet successfully if there exists a path from source node to the sink. It happens more channel conflicts when more data packets need to be transmitted in VBF and EEIAR.

The comparison of throughput is shown in Figure. 5a. The throughput of our proposed scheme has proportional growth and outperforms other two protocols because it uses flow routing to maximize throughput.

Figure. 5b shows the results concerning the average energy consumption. As we set the number of forward nodes to 81, the ranking of energy consumption is consistent with Figure. 4a where the number of nodes is 81. As expected, the energy consumption performances of all protocols are basically stable.
5. Conclusion
This paper has presented a virtual void-based marine organism protection routing (VMOPR) protocol—an environmental friendly routing protocol for UWSNs. We create a virtual void region by setting the nodes interfering with marine creature to idle state which can only sense information during route discovery, and as a result these nodes will not be involved in route establishment ultimately. Therefore marine mammals’ acoustic systems will not be interfered by the acoustic communication of UWSNs. Aiming to achieve high packet delivery ratio and end-to-end throughput, the data transfer is done based on flow routing method. The experimental simulation results show that the proposed VMOPR scheme can not only effectively avoid man-made noise causing fatal impact on marine mammals, but also have higher packet delivery ratio and end-to-end throughput compared with EEIAR and VBF protocol. Further study will take the environmental noise and the link capacity into consideration.

Acknowledgments
The work is supported by National Natural Science Foundation of China (No.11604077 and No.61601169).

References
[1] J.-H. Cui, J. Kong, M. Gerla, and S. Zhou, “The challenges of building mobile underwater wireless networks for aquatic applications,” IEEE Netw., vol. 20, no. 3, pp. 12–18, May 2006.
[2] I. F. Akyildiz, D. Pompili, and T. Melodia, “Underwater acoustic sensor networks: research challenges,” Ad Hoc Networks, vol. 3, no. 3, pp. 257–279, 2005.
[3] E. M. Sozer, M. Stojanovic, and J. G. Proakis, “Underwater acoustic networks,” IEEE J. Ocean. Eng., vol. 25, no. 1, pp. 72–83, Jan. 2000.
[4] M. Stojanovic and J. Preisig, “Underwater acoustic communication channels: Propagation models and statistical characterization,” IEEE Commun. Mag., vol. 47, no. 1, pp. 84–89, 2009.
[5] W. Yonggang, T. Jiasheng, P. Yue, and H. Li, “Underwater communication goes cognitive,” in Proc. OCEANS, Quebec City, QC, Canada, Sep. 2008, pp. 1–4.
[6] Y. Luo, L. Pu, M. Zuba, Z. Peng, and J.-H. Cui, “Challenges and opportunities of underwater cognitive acoustic networks,” IEEE Trans. Emerg. Topics Comput., vol. 2, no. 2, pp. 198–211, Jun. 2014.
[7] H. Y. Thomas and S. Yi, “Variable bit rate flow routing in wireless sensor networks,” IEEE Transactions on Wireless Communications, v 6, n 6, pp. 2140-2148, June 2007.
[8] K. Anwar, J. Nadeem, A. Ilham, A.-M. Hossain, R.-A. Ur, B. Naem, Z. Muhammad and M. Hasan, “An Energy Efficient Interference-aware Routing Protocol for Underwater WSNs” in KSII transactions on internet and information systems Vol. 11, NO. 10, Oct. 2017, pp. 4844-4863.
[9] X. Peng, C. Jun-Hong and L. Li, “VBF: Vector-Based Forwarding Protocol for Underwater Sensor Networks,” in uconn cse Technical Report: UbiNet-TR05-03, Feb.2006, pp. 1-20. [15] A. O. Bicen, A. B. Sahin, and O. B. Akan, “Spectrum-aware underwater networks: Cognitive acoustic communications,” IEEE Veh. Technol. Mag., vol. 7, no. 2, pp. 34–40, Jun. 2012.