Void Aware Routing Protocols in Underwater Wireless Sensor Networks: Variants and challenges

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Abstract: Recently, Underwater Wireless Sensor Network (UWSN) become a wide range technology for gathering important events from underwater world. UWSNs is consisting of underwater sensors with limited energy and using acoustic link as a communication medium. Routing methods is the major part that need to be designed in order to transmit the data with minimum cost such as high delivery rate and low energy consumption. Communication void is one of the major perspectives that effects the delivery ratio and energy consumption in the whole network. Therefore, this issue attracts researchers to follow up and design techniques that helps in improving the overall performance of the networks. This article reviews and compares different void aware algorithms proposed for UWSNs. We analyze and discuss representative routing protocols, and discover the requirements considered by the different routing algorithms, as well as limitations and the design requirements under different operations. Finally, we highlight some important future perspectives for UWSNs belonging to routing protocols.

1. Introduction
Nowadays, underwater wireless sensor networks (UWSNs) attracts the researchers to employ UWSNs’ various application such as offshore exploration, ocean monitoring, controlling monitoring marine, wildlife studies, and underwater mineral extraction [1-5]. Basically, underwater wireless sensor nodes detect events from the low level of water and transmit the sensed data to one of the sink nodes that scattered at the water surface, which moved to the data center. In routing, each node selects a set of sensor nodes to forward the data to is next-hop from bottom to top by broadcasting the data. One of the candidate nodes have been elected as a best forwarder taking into account different criteria and priority. Criteria is some chosen metrics helps in selecting the forwarding nodes. Priority is calculated based on some different metrics and location of sensor. The sensor with the highest priority will be elected to forward the data packets [6,7]. the sender node can select its best neighbor by measuring the cost for all of its neighbors while the receiver nodes can also decide the next forwarder nodes in some algorithms. Then, the best selected sensor forwards the data packets and rest neighbors will discard it.

Routing is the main challenge in such networks. The most of research, which conducted on UWSNs, focus on both of physical and MAC layers. However, fewer works introduced in the network layer, which shows that’s the research of this part it still in its early phases [8,9]. The procedure of design and implement a routing algorithms for UWSNs faces serious difficulties that can’t be ignored because of
the harsh environment of underwater such as low bandwidth, high error rate, energy limitation, and the long propagation delay [10-12]. Therefore, this paper studies these challenges to examine the proficiency of routing in UWSNs.

Communication void is the major problem happens during the routing process. This problem has been occurred if the sensor node reaches some empty area and did not found any other sensor to receive the data from it. UWSNs composed of two types of topologies that are sparse and dynamic. These topologies have direct impact on delivery rate and network lifetime due to the less attention of designing a communication void technique. Besides, the use of low efficient void aware mechanisms effects in consumption of the energy. In terrestrial wireless sensor networks, void aware techniques cannot be employed in underwater due to the harsh environment of UWSNs.

In this paper, a comprehensive review of routing algorithms used in UWSNs is selected. We review the main issues of void aware algorithms and its effect on routing protocols in UWSNs. We examine each algorithm deeply, highlighting its pros and cons. We compare and summarize the explained algorithms. Lastly, we accomplish the paper by highlighting main future directions that helps in scheming algorithms in UWSNs.

2. Void Aware
As mentioned, communication void happens in the empty area. This issue attracts the researches to introduce an effective void avoidance algorithm that determine the void sensors and escape these nodes in the process of forwarding data packets. Next subsections discussed void aware algorithms in detail.

One of enhancement of VBF that use the same concepts of HH-VBF regarding the process of choosing the forwarder sensor which did not consider any energy-efficient and reliable metrics [13]. The major difference between VBVA, HH-VBF and VBF that is VBVA, to deal with communication void, offers two 3-D flooding technique that is vector-shift and back-pressure.

Authors in [14] design a location-assisted scalable routing technique based on cross-layer approach, called Focused Beam Routing (FBR). This protocol employs cone from sender node to sink and then choose the forwarder sensor based on the highest weight that calculated based on distance from sender node towards the sink. Instead, FBR can work with communication void by increasing the power level to send the packets until reach maximum power level. If still did not find nodes, it uses shifting cones.

An Efficient Directional Flooding-Based Routing protocol (DFR) is a location based protocol tackled the problem of VBF and HH-VBF regarding throughput [15]. The architecture of this algorithm as follows, both of source node and sinks are located in around side of the transmission area. likewise, the regular sensors are distributed at the lowest level of the water. Additionally, this algorithm employed with dynamic method to forward the data packet. Moreover, as shown in figure 1, this algorithm utilizes calculation of the link quality between sensors to elect the forwarder sensor with two angles called current and reference angle. This algorithm offered two procedures to deal with communication void. The first method modification the dynamic zone’s size. The second method is finding the detour-path.

Fig. 1: Packet forwarding in DFR [15]
Authors develop an effective pressure-routing protocol for secure networks of underwater sensors in [16]. To this end the authors suggested hydraulic pressure routing protocol (HydroCast). This algorithm discusses the major problems (energy and bandwidth) that affect the water current. HydroCast is categorized into two separate modes: greedy routing, and void handling. Greedy mode has the duty of selecting the forwarder sensor. For this reason, each receiving sensor measures the link quality metric called Expected Packet Advance (EPA). next, the sensors have been listed according to their depth information i.e. the priority heads to the shallower and then to the shortest hold time. The sensors attempt to overhear the packet by using a two-hop clustering strategy. This approach is an improvement variation of the method used in DBR. At the other side, mode of void handling addresses the issue of communication void. To the above purpose, if the data packets enter a void node (Local Maximum) a path from the void node to the lower depth node is discovered. Figure 2 demonstrated the process in detail. The void handling methodology used in this algorithm needs complete position information to find the shallower sensor that imposes high overhead network with high energy consumption.

Fig. 2: Void handling in HydroCast [16]

Authors in [17] conduct experiment to improve energy-efficiency and tackle the problem of communication void. Thus, a routing protocol based on pressure-beacon called Void-Aware Pressure Routing Protocol (VAPR) was introduced. VAPR is split into two major components, the enhanced beaconing and the opportunistic forwarding of directional data. During the first phase, each sonobuoy transmitted periodic beacon messages from the surface of the water to the low depth of the water. The forwarder nodes were chosen in the second part using both directions which were established in the previous phase i.e. the sensor with minimum hop distance towards the sink. On the other hand, the node was singed way DOWN in order to deal with contact void problem and the next forwarding sensor were chosen in void handling nodes among less depth neighbours. Whereas the node was singing in direction UP and the next forwarding nodes were chosen in greedy mode between high depth neighbours as shown in Figure 3. The nodes attempt to overhear the packet of data by using a two-hop clustering method. This method is a variant of the improved method used in HydroCast. The key drawback of VAPR is that the position of nodes should be changed in the enhanced beacon phase in a short period of time due to dynamic topology in the UWSNs, which cause network overhead and increases the total consumed energy.
Authors in [18] studied the effects to enhance energy efficiency by introducing such courier nodes to their network architecture named adaptive mobility of courier sensors in UWSN’s threshold optimized DBR (AMCTD) protocol. AMCTD is composed of three stages. The first two stages are responsible for choosing the next forwarding sensors, while the third stage is for the problem of void communication. During the first step, each sensor uses its residual energy and depth to measure the weight. Next, a hello packet was created and exchanged among neighbours. So, every sensor has details regarding its neighbors and stores this data in the table of next nodes for selection. In addition, Courier Nodes continue moving vertically. The node must test its table of next selection nodes in the second step (data forwarding process). If the courier node has been identified in the table, it will forward the data packet directly to the courier node and then return acknowledgement to prevent repeated forwarding of packets. Otherwise, the sensors in the table will be ordered by their weight value and the data will be transmitted to those sensors. If the number of dead nodes reaches 2 per cent in the last step, the void communication problem has been expanded. The weight was then adjusted based on distance, instead of residual energy. Furthermore, if the number of missing nodes expanded and the size decreased further, the flow of couriers and the threshold of depth would be adjusted to enhance the reliability of the network. AMCTD’s key drawback, however, is: First, courier nodes are so costly that the network cost rises. Secondly, courier motion is not efficient for handling the problem of communication void and drastically reduces routing efficiency. Last, the use of threshold depth decreases the efficiency of choosing the next hop sensor with specific density and shortest range of paths.

3. Analysis and Discussion

Opportunistic routing is one of the most important routing strategies in UWSNs as described earlier because of its unique characteristics and harshness in the underwater area. We studied the most important routing algorithms in UWSNs in this paper in terms of communication void during selecting the next forwarding nodes. The current state-of-the-art algorithms are listed in Table 1. A comparison between different routing algorithms within UWSNs is oversimplified in this table. The importance of each content is described in the paragraphs below.

**Selected metrics:** the key metrics used in the current algorithms that employ various metrics to identify the process of next node selection.

**Forwarding node’s selection:** the purpose of this study is to discuss the key problems in UWSNs concerning the strategy of choosing the forwarding sensor. So, this section illustrates the key strategies of choosing the next hop algorithms for each algorithm.

**The best candidate:** This section highlights how each algorithm chooses the candidates’ best sensor.

| Protocol | Selected metrics | Forwarding nodes’ selection | The best neighbor candidate |
|----------|------------------|-----------------------------|-----------------------------|
| VBVA [13] | Calculation of distance | Neighbors inside each individual pipeline | The minimum distance to the sink |
Calculation of distance
Neighbors inside cone
The minimum distance to the sink

Calculation of distance along with link quality estimator (ETX)
Neighbors inside selected zone on the basis of reference and angle
The best link quality (ETX) and minimum distance to the sink

link quality calculation (EPA), depth
Lower depth sensors along with link quality
the best link quality with lower depth

Packet sequence ID, node’s direction, hop-count, depth
Lower depth sensors along with hop-count
the minimum hop-count with lower depth

residual energy, depth
Lower depth sensors along with threshold and residual energy
The highest weight with lower depth

Table 2 provides a complete protocol performance metrics which provides a summarization of the key behaviors of all the above listed algorithms. This summary is focused on different factors that have been employed in determining the next forwarding sensors, namely void aware, link quality, reliability, residual energy, multi-hop, and short path.

Choosing the next forwarding sensors and finding the best sensor to transmit the data packets is a main issue in routing algorithms that directly affect total routing efficiency such as network lifetime, packet delivery rate, and energy consumption. VBVA and FBR use only distance parameters as shown in Table 1 above, while DFR use distance criteria together with the quality of the link. HydroCast, on the other hand, employs link quality (EPA) and depth to identify the next forwarding sensor. VAPR uses hop-count towards destination for choosing the best forwarder Eventually, AMCTD determines a weight based on residual energy and depth for all neighbors, in order to choose the best possible candidate by choosing the maximum weight. Selecting the right forwarder sensor affects the overall efficiency of the network and avoids the low efficient nodes from transmitting the data. Nonetheless, current opportunistic depth-based protocols in UWSNs suffer from the selection algorithm of weak forwarding nodes. Therefore, developing a multi-metric void aware selection algorithm for forwarding nodes, which chooses energy-efficient routing to avoid the empty area, reduce energy consumption, reduce network overhead and guarantee reception rate, is crucial.

4. Future Work
Forwarding selection of nodes in UWSNs is a main challenge due to the use of acoustic waves as a medium of communication which consumes high energy. It is therefore important to implement an energy-efficient selection algorithm for forwarding nodes, which improve the delivery ratio, reduce energy consumption, and improve the network lifetime. In addition, route selection must be carefully developed to reduce the number of involved nodes in the forwarding phase which aims to reduce overhead on the network.
In military application, security problems become one of the main issues in UWSNs. However, this study did not take this issue into account. This study can be extended by designing a secure scheme to deal with security problem.

Congestion is another major concern because of the restricted bandwidth available. This problem wasn't discussed in this review, though. This research can therefore be improved by designing and developing congestion control mechanisms to reduce packet loss in systems that are suffering from this issue, such as event-driven data reporting models [19].

Another major problem in choosing next forwarding nodes is communication void. However, current techniques of void avoidance in terrestrial networks cannot be employed in underwater areas. In addition, the current void handling algorithms in UWSNs seek to identify a recovery route that consumes high energy. Hence, designing an efficient void avoidance algorithm that locally identifies the void sensors and avoids those sensors in the process of data forwarding is important.

5. Conclusion
Communication void is one of the most important problems that must be taken into account in routing protocols. This problem encourages scientists to develop an efficient routing algorithm. We have reviewed the most relevant and descriptive algorithms in the literature in detail in this paper. We also thoroughly addressed each routing algorithm, outlining its strengths and drawbacks. We compared and summed the routing algorithms discussed in various functionalities and efficiency metrics. Finally, we also discussed some essential future directions which need to be further investigated to establish an effective forwarding mechanism for UWSNs.

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