Poster Abstract: Void Avoidance in Mobile Underwater Sensor Networks

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I. INTRODUCTION

Underwater sensor networks have received growing interests recently [1], [3], [2]. Among many challenging issues in the area, routing is one of the fundamental networking problem to address, In the literature, a couple of geo-routing protocols, such as VBF [5] and HH-VBF [4], have been proposed for mobile underwater sensor networks. These protocols usually rely on the geographical information and exploit greedy policies to optimize the selection of nodes in the next hop. However, the greedy policies are not always feasible. For example, a node can not forward data further when none of its neighbors is qualified for the next hop according to the greedy policy. This phenomenon is refereed to as a "routing void". To make routing possible in such case, some measures should be taken to "avoid" the routing voids. In mobile underwater sensor networks, many network characteristics make this void avoidance problem very challenging. First of all, the voids in our targeted networks are three-dimensional. Secondly, the mobility of most nodes causes the voids in the forwarding path volatile. Sometimes the voids are concave, and sometimes the voids could be convex. Thirdly, the voids themselves might be mobile. For example, when a ship passes an underwater sensor network, the communication around the ship will be interrupted, thus generating a mobile void.

In this paper, we propose a void avoidance protocol, called **vector-based void avoidance (VBVA)**, to address the void problem in mobile underwater sensor networks. In VBVA, all the forwarding paths are represented by vectors, called forwarding vectors. The pipe centered at each vector is called forwarding pipe. All the nodes in the forwarding pipe are qualified for forwarding packets. When there is a void in the forwarding pipe, two methods: *vector-shift* and *back-pressure* are used to handle the void. The vector-shift method enables VBVA to route the packets along the boundary of the void to the target, while the back-pressure method allows VBVA to retreat the packet from the end paths. By simulations, we show that VBVA can effectively address 3-dimensional voids, voids in the mobile networks as well as mobile voids.

II. VECTOR-BASED VOID AVOIDANCE PROTOCOL

In this section, we describe our Vector-Based Void Avoidance (VBVA) protocol. We first review the key ideas in VBVA, then we describe an advanced algorithm adopted in VBVA.

A. Overview of The Protocol

In VBVA, each node can overhear the transmission of its neighbors due to the broadcast nature of acoustic communication in underwater sensor networks. Each packet in VBVA carries the position information of the start point and target point of the forwarding vector.

VBVA detects the presence of voids on demand. A node is defined as a *void node* for a packet if all the advances (along the forwarding vector) of its neighbors is less than its own advance. A void node is essentially the edge node surrounding a void in the forwarding direction. It can not forward the packet any further in the direction of the forwarding vector.

VBVA handles void problem by two mechanisms, vector-shift and back-pressure. When a node finds itself being a void node, the node broadcasts a vector-shift request to all its neighbors. All the nodes in the current forwarding pipe just ignore this request. However, the nodes outside the forwarding pipe will forward the packet with new forwarding vectors from themselves to the target.

A node is defined as an *end node* if the node does not have next hop even the vector is shifted. When a node determines that it is an end node, this node broadcasts the data packet marked as back-pressure. Upon receiving the back-pressure packet, a node checks the transmission status of the packet. If the node has shifted the forwarding vector before, then the node broadcasts the back-pressure packet. Otherwise, the node shifts the forwarding vector of this packet and forwards it.

Thus, VBVA first avoids voids by the vector-shift method, if it fails, VBVA routes the packet in the opposite direction to the target and forwards the packets to the target again after several hops of retreat.

The vector-shift method generates new forwarding paths in the network and consumes more energy on routing. In order to reduce energy consumption, VBVA also adopts an adaption algorithm, called self-center adaption algorithm, which enables each node in VBVA to weigh the benefit to shift the forwarding vector, thus reduces the number of forwarding vectors in the networks.

B. Self-Center Adaption Algorithm

When a node receives a request to shift the forwarding vector, the node delays to shift the forwarding vector for some time period proportional to its self-center factor, denoted as β. If after the time period, the node does not overhear the transmission of vector-shift packet, the node will shift the vector and forward the packet. Otherwise, the node quits

its vector-shift process. We define the self-center factor as follows,

$$\beta = \frac{(R - D)}{R} + \frac{R - R \times cos\theta}{R} \quad (1)$$

where R is the maximum transmission range and D is the distance between the node and the vector from the forwarder to the target, θ is the angle between vector from forwarder to the target and the vector from the forwarder to the node. Basically, self-center factor, β, is used to evaluate the position of the node. If the node is closer to the target and farther from the forwarder, then the self-center factor of the node is smaller.

III. Performance Evaluation

In this section, we evaluate the performance of VBVA using simulations. Due to space limit, we only show the results for one metric, *success rate*, which is defined as the ratio of the number of packets successfully received by the sink to the number of packets generated by the source.

A. The Capability of Avoiding Voids

In this simulation setting, the source is fixed at location $(900, 900, 500)$ near one corner of the field at the floor, while the sink is at location $(100, 100, 0)$ near the opposite corner at the surface. Besides the source and sink, all other nodes are mobile in the X-Y plane at the speed of $0{-}3m/s$. We compare the success rate of flooding and VBVA as shown in Fig. 1. Intuitively, flooding is the most powerful and naive method

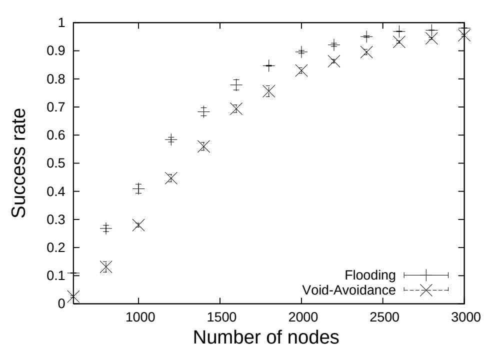

Fig. 1. The comparison of success rate: flooding and VBVA

to avoid voids in the networks. The success rate of flooding roughly is the upper bound for the routing protocols. From the Fig. 1, we can see that the success rate of VBVA is very close to the upper bound. VBVA is almost as robust against voids in the forwading path as flooding. On the other hand, VBVA consumes less energy compared with flooding. We do not present the simulation results on energy consumption here due to the space limit.

B. The Capability of Handling Mobile Voids

In this simulation setting, the target is fixed at location $(500, 0, 250)$ and the the source is fixed at location $(500, 1000, 250)$. In order to make sure there exist a path from the source to the target, we divided the whole space into small cube $(50m \times 50m \times 50m)$. A sensor node is randomly deployed in each cubic to guarantee that the there exists a path from the source to the target. We generate a sphere with the radius of 120 meters. The sphere moves back and forth along the straight line from the source to the target. All the nodes in the sphere are blacked out, i.e., they can not receive or transmit any packets. The simulation result is shown in Fig. 2.

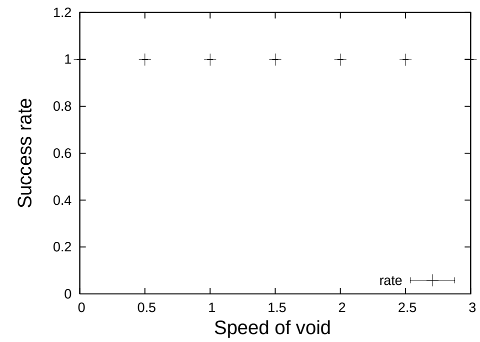

Fig. 2. The success rate under mobile void

From Fig. 2, we can see that the VBVA can get almost 100% success rate under various mobility of the void.

IV. CONCLUSIONS

The void problem in mobile underwater sensor networks is characterized as three dimensional, volatile, and mobile, as poses great challenges for geographic routing protocols.

In this paper, we propose a void avoidance protocol, called vector-based void avoidance (VBVA) to address the void problem in mobile underwater sensor networks. VBVA is the first protocol to address three-dimensional and mobile voids. VBVA adopts two mechanisms, vector-shift and back-pressure to bypass a void in the forwarding path. The vector-shift method attempts to bypass the void around its boundary by changing the forwarding vector of the data packet. The back-pressure mechanism enables the packet to be retreated from an end direction. VBVA detects a void only when needed and handles the void on demand. It is very robust against mobile nodes and mobile voids. Furthermore, VBVA adopts the self-center adaption algorithm to enable the node to weigh the gain to shift the forwarding vector to reduce the energy consumption.

We evaluate the performance of the VBVA under various network scenarios. The simulation results show that VBVA can handle the voids in mobile networks and mobile voids effectively and efficiently.

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