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An Efficient Way Of Communication Between Underwater Sensor Networks Using GEDAR Protocol

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Abstract— Underwater wireless sensor networks (UWSNs) plays an important role in monitoring and exploring the oceans instead of traditional underwater wireline instruments. In spite of that, data gathering of UWSNs is still severely limited because of the acoustic channel communication characteristics. One way to improve the data collection in UWSNs is through the design of routing protocols, by considering the unique characteristics of the underwater acoustic communication and the highly dynamic network topology. In this paper, we propose the GEographic and opportunistic routing with Depth Adjustment-based topology control for communication Recovery over void regions (GEDAR) routing protocol for UWSNs. GEDAR is an anycast, geographic and opportunistic routing protocol that routes data packets from sensor nodes to multiple sonobuoys (sinks) at the sea's surface. When the node is in a communication void region, GEDAR switches to the recovery mode procedure which is based on topology control through the depth adjustment of the void nodes, instead of the traditional approaches using control messages to discover and maintain routing paths along void regions. Simulation results show that GEDAR significantly improves the network performance when compared with the baseline solutions, even in hard and difficult mobile scenarios of very sparse and very dense networks and for high network traffic loads.

Keywords— Geographic and opportunistic routing; communication void region; underwater sensor networks; sonobuoy; depth adjustment.

I. INTRODUCTION

Underwater sensor nodes are deemed to enable applications for oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications. Multiple Unmanned or Autonomous Underwater Vehicles (UUVs, AUVs), equipped with underwater sensors, will also find application in exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. To make these applications viable, there is a need to enable underwater communications among underwater devices. Underwater sensor nodes and vehicles must possess self-configuration capabilities, i.e., they must be able to coordinate their operation by exchanging configuration, location and movement information, and to relay monitored data to an onshore station.

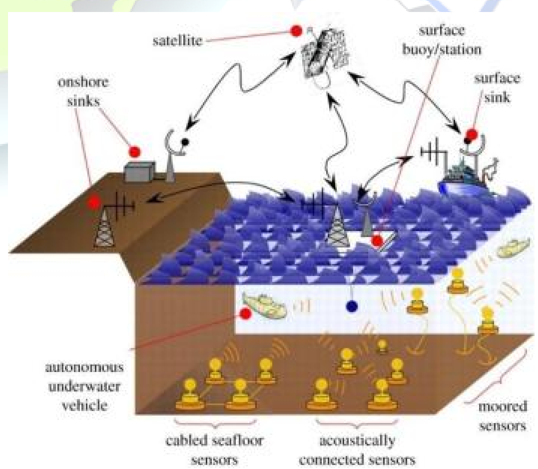

Figure 1 Underwater Sensor Network

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The main disadvantage in Underwater sensor network is communication over void region.

Communication Void Region

The communication void region problem occurs whenever the current forwarder node does not have a neighbor node closest to the destination than itself, i.e., the current forwarder node is the closest one to the destination. The node located in a communication void region is called void node. Whenever a packet gets stuck in a void node, the routing protocol should attempt to route the packet using some recovery method or it should be discarded.

Void Node Recovery Using Depth Adjustment Method

The communication void region problem can be eliminated by using GEDAR protocol. GEDAR utilizes the location information of the neighbor nodes and some known sonobuoys to select a next-hop forwarder set of neighbors to continue forwarding the packet towards the destination. To avoid unnecessary transmissions, low priority nodes suppress their transmissions whenever they detect that the same packet was sent by a high priority node. The most important aspect of the GEDAR is its novel void node recovery methodology. Instead of the traditional message based void node recovery procedure, we propose a void node recovery depth adjustment based topology control algorithm. The idea is to move void nodes to new depths to resume the geographic routing whenever it is possible.

II. RELATED WORKS

In this section we will see the brief description of previously proposed acoustic protocols.

In [1] they have proposed a novel routing protocol, called vector-based forwarding (VBF), to provide robust, scalable and energy efficient routing. VBF is essentially a position- based routing approach: nodes close to the “vector" from the source to the destination will forward the message. In this way, only a small fraction of the nodes are involved in routing. VBF also adopts a localized and distributed self-adaptation algorithm which allows nodes to weigh the benefit of forwarding packets and thus reduce energy consumption by discarding the low benefit packets.

In [2] the authors provides us a scalable and an efficient routing services for underwater sensor networks (UWSNs), which is very challenging due to the unique characteristics of UWSNs. Firstly, UWSNs often employ acoustic channels for communications because radio signals do not work well in water. Compared with radio-frequency channels, acoustic channels feature much lower bandwidths and several orders of magnitudes longer propagation delays. Secondly, UWSNs usually have very dynamic topology as sensors move passively with water currents. Some routing protocols have been proposed to address the challenging problem in UWSNs. However, most of them assume that the full-dimensional location information of all sensor nodes in a network is known in prior through a localization process, which is yet another challenging issue to be solved in UWSNs. In this paper, they propose a depth-based routing (DBR) protocol. DBR does not require full-dimensional location information of sensor nodes. Instead, it needs only local depth information, which can be easily obtained with an inexpensive depth sensor that can be equipped in every underwater sensor node.

In [3] they have proposed Vector Based Void Avoidance (VBVA) routing protocol, which extends the VBF routing protocol by including a communication void region recovery mode. Data packets are routed using the same strategy as VBF. During the void node recovery phase, VBVA attempts to route the packet along the boundary of the communication void region by either shifting the forwarding vector or by means of a back-pressure method when the communication void region is convex. In the vector shifting mechanism, the void node asks its neighbors to change the current routing vector. After, the node keeps listening to the channel to check if a neighboring node forwarding the packet is using the new routing vector. If a node is a final node (void node), that is, even with the vector shifting the packet cannot be forwarded, the back-pressure mechanism is used. In the back-pressure mechanism, the packet is routed back in the direction moving away from the destinations. This is performed until the packet reaches a node which can do vector shifting to forward the packet towards the destination.

Hydrocast also employs the opportunistic routing paradigm in which the next-hop node priority is given according to the trade-off between the progress of the packet towards the surface and the link cost of reaching the neighbor node. To cope with redundant transmissions, the authors proposed a greedy heuristic to determine a cluster of next-hop forwarders without hidden terminal problems. When a node determines that it is in a communication void region, it performs a search for a node whose depth is lower than its depth by

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means of controlled flooding and explicitly maintains a path to the node. This method [4] discussed about a method, Optimality results are presented for an end-to-end inference approach to correct(i.e., diagnose and repair) probabilistic network faults at minimum expected cost.

In [5] they have proposed Void-aware pressure routing (VAPR), which uses the depth information of the nodes to forward data packets towards the sea surface. VAPR is a geographic and opportunistic routing protocol where a next-hop forwarder set to continue the packet forwarding is determined from the greedy pressure strategy. In VAPR, each node is aware of the void nodes from the sonobuoy's reachability information disseminated in the network via periodic beaconing. Each node uses that information to build a directional (upwards or downwards) path towards some surface sonobuoy. The next-hop forwarding set is selected according to the neighbor forwarding direction, that is, those directions in which there is a match of the forwarding direction with the current forwarder (upward or downward).

In [6] they proposed a way to observe and explore the lakes, rivers, seas, and oceans. However, due to characteristics of the acoustic medium, efficient protocols for delivering data must exist. In this work, we propose a novel geographic routing protocol for underwater sensor networks, that adjusts the depth of the nodes in order to organize the network topology for improving the network connectivity and forward data where the greedy geographic routing fail. The proposed protocol is the first geographic routing protocol that considers the sensor node vertical movement ability to move it for topology control purpose. The simulation results show that, with the topology organization, the fraction of disconnected nodes is drastically reduced and consequently the delivered data rate is maximized. It achieve more than 90% of data delivered even in hard and difficult scenarios of very sparse or very dense networks.

III. PROPOSED SCHEME

GEDAR is an anycast, geographic and opportunistic protocol that tries to deliver a packet from a source node to some sonobuoys. During the course, GEDAR uses the greedy forwarding strategy to advance the packet, at each hop, towards the surface sonobuoys. A recovery mode procedure based on the depth adjustment of the void node is used to route data packet when it get stuck at a void node.

The proposed routing protocol employs the greedy forwarding strategy by means of the position information of the current forwarder node, its neighbors, and the known sonobuoys, to determine the qualified neighbors to continue

known and used next-hop forwarder selection strategy, GEDAR considers the anycast nature of underwater routing when multiple surface sonobuoys are used as sink nodes. We consider that, as in, each sonobuoy at the sea surface is equipped with a global positioning system (GPS) and uses periodic beaconing to disseminate its location information to the underwater sensor nodes. We assume that each underwater sensor node knows its location. The location of the neighbors is known through periodic beaconing. Moreover, the localization problem in underwater networks continues to attract research efforts due to the importance of nodes localization to tag the collected data, track underwater nodes and targets, and to group nodes coordinated motion. Furthermore, GEDAR is opportunistic routing aiming to mitigate the effects of the acoustic channel. Thus, a subset of the neighbor nodes is determined to continue forwarding the packet towards some surface sonobuoy (next-hop forwarder set).

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ENHANCED BEACONING

Periodic beaconing plays an important role in GEDAR. It is through periodic beaconing that each node obtains the location information of its neighbors and reachable sonobuoys. Unlike the solutions in Depth-Controlled Routing protocol, where each node can be informed beforehand concerning the location of all sonobuoys, we need an efficient beaconing algorithm that keeps the size of the periodic beacon messages short as possible.

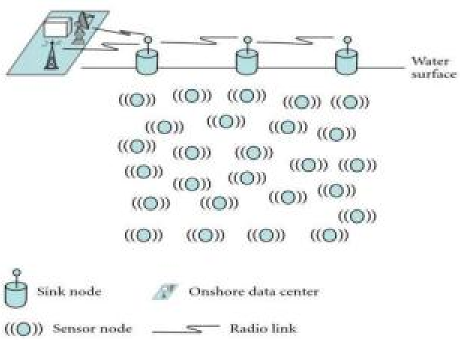

Figure 2. SEA Swarm Architecture

In the beacon messages, each sonobuoy embeds a sequence number, its unique ID, and its X, Y location. We assume that each sonobuoy at the surface is equipped with GPS and can determine its location. The sequence number of the beacon message does not need to be synchronized among all sonobuoys. It is used together with the ID to identify the most recent beacon of each sonobuoy. The depth information of sonobuoys is omitted from the beacon message since the sonobuoys are deployed on the surface and vertical

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movement is negligible with respect to the horizontal movement.

Similarly, each sensor node embeds a sequence number, its unique ID and X, Y, and Z position information. Moreover, the beacon message of each sensor node is augmented with the information of its known sonobuoys from its set $S_i(t)$. Each node includes the sequence number, ID, and the X, Y location of the its known sonobuoys. The goal is for the neighboring nodes to have the location information of the all reachable sonobuoys. GPS cannot be used by underwater sensor nodes to determine their locations given that the high frequency signal is rapidly absorbed and cannot reach nodes even localized at several meters below the surface. Thus, each sensor node knows its location through localization services. Localization services incur additional costs in the network.

NEIGHBOR CANDIDATE SET SELECTION

Whenever a sensor node has a packet to send, it should determine which neighbors are qualified to be the next-hop forwarder. GEDAR uses the greedy forwarding strategy to determine the set of neighbors able to continue the forwarding towards respective sonobuoys. The basic idea of the greedy forwarding strategy is, in each hop, to advance the packet towards some surface sonobuoy. The neighbor candidate set is determined as follows. Let n_i be a node that has a packet to deliver, let its set of neighbors be $N_i(t)$ and the set of known sonobuoys $S_i(t)$ at time t. We use the packet advancement (ADV) metric to determine the neighbors able to forward the packet towards some destination. The packet advancement is defined as the distance between the source node S and the destination node D minus the distance between the neighbor X and D.

Thus, the neighbors candidate set in GEDAR is given as:

$$C_i = \{ n_k \in N_i(t) : \exists s_v \in S_i(t) \mid D(n_i, s_i^*) - D(n_k, s_v) > 0\}$$

Where $D(n_i, s_j)$ is the Euclidean distance between the nodes a and b and, $s_i^* \in S_i(t)$ is closest sonobuoy of n_i as :

$$s_i^* = \operatorname{argmin}_{s_j \in S_{i(t)}} \{ D(n_i, s_j) \}.$$

NEXT-HOP FORWARDER SET SELECTION

GEDAR uses opportunistic routing to deal with underwater acoustic channel characteristics. In traditional multihop routing paradigm, only one neighbor is selected to act as a next-hop forwarder. If the link to this neighbor is not performing well, a packet may be lost even though other neighbor may have overheard it. In opportunistic routing, taking advantage of the shared transmission medium, each packet is broadcast to a forwarding set composed of several neighbors. The packet will be retransmitted only if none of the neighbors in the set receive it. For each transmission, a next-hop forwarder set F is determined. The next-hop forwarder set is composed of the most suitable nodes from the next-hop candidate set C_i so that all selected nodes must hear the transmission of each other aiming to avoid the hidden terminal problem.

RECOVERY MODE

Void node recovery procedure is used when the node fails to forward data packets using the greedy forwarding strategy. During the transmissions, each node locally determines if it is in a communication void region by examining its neighborhood. If the node is in a communication void region, that is, if it does not have any neighbor leading to a positive progress towards some surface sonobuoy, it announces its condition to the neighborhood and waits the location information of two hop nodes in order to decide which new depth it should move into and the greedy forwarding strategy can then be resumed. After, the void node determines a new depth based on two-hop connectivity such that it can resume the greedy forwarding.

The Figure 3 shows underwater sensor nodes, such as the *a*, *b*, *c*, *d*, and *e* nodes, that should deliver collected data to sonobuoys at sea surface through multihop underwater acoustic communication. In this example, the node *c* has data packet to be sent. It discovers that it is in a communication void region and then it starts the void node recovery algorithm. At this moment, nodes *b* and *d* uses node *c* as the next-hop forwarder.

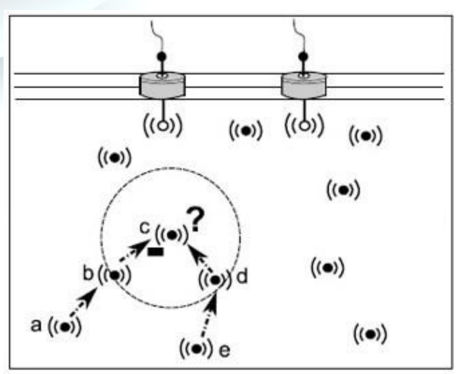


Figure 3. Example of recovery mode procedure at *c*

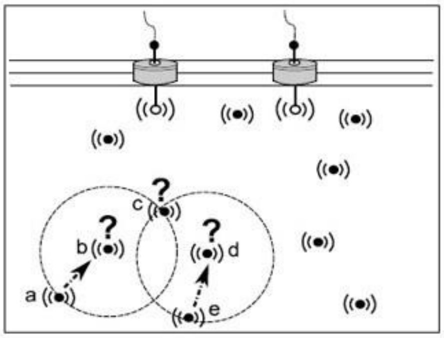


Figure 4. Nodes *b* and *d* start the recovery procedure after receiving a *c*'s void_node_announcement_message

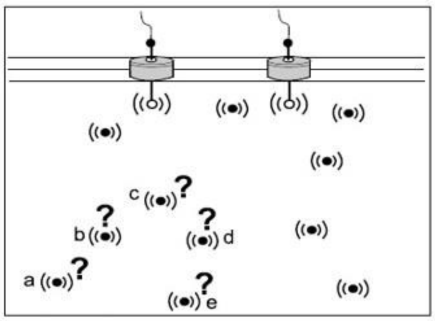


Figure 5. Scenario after the recovery mode procedure at nodes *a*, *b*, *c*, *d* and *e*. All generated data packet from these nodes will be discarded

During the void node recovery, node *c* sends *a* void_node_announcement_ message to its 5 uclidean nodes (see Fig. 3). After receiving that control packet, nodes *b* and *d* remove *c* from its 5 uclidean table and determine whether they can continue forwarding the packet, using the greedy geographic and opportunistic strategy, through other 5 uclidean nodes. In this scenario, as they cannot, *b* and *d* start the recovery mode procedure (see Fig. 4). The same procedure is performed by nodes *a* and *e*. At the end, none of them can continue the recovery void node procedure as they have not received any replay of a void_node_announcement_message. Thus, all generated packets from these nodes will be discarded as they do not have a next-hop forwarder candidate, as shown Fig. 5.

IV. SIMULATION RESULTS

In this section we will see the simulation results of the proposed GEDAR protocol with 40 nodes.

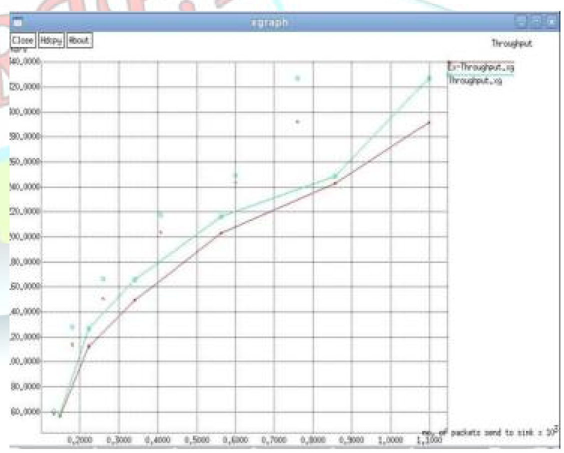
Number of Nodes	40
Area Size	1200*900*1000
Number of Packets Sent	1100
Average Packets per Node	28
Energy Consumed by the Network	9 J

Figure 6. Throughput

Figure 6 shows the throughput of the network. From this it is clearly evident that, as the data rate increases number of packets sent to the sink is also getting increased in the proposed GEDAR than the existing protocol.

Figure 7. Packet Delivery Ratio

Figure 7 shows the packet delivery ratio of the network. Initially the packet delivery ratio is dropping, but after 200 packets have been transmitted the packet delivery ratio is increasing and also the proposed protocol shows a significant increase.



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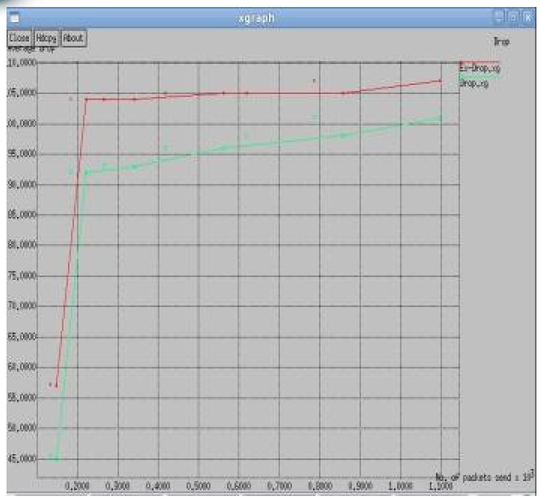

Figure 8. Packet Drop

Figure 8 shows the packet drop in the network. It is clear that, packet drop in the proposed protocol is comparatively less than the existing GEDAR protocol.

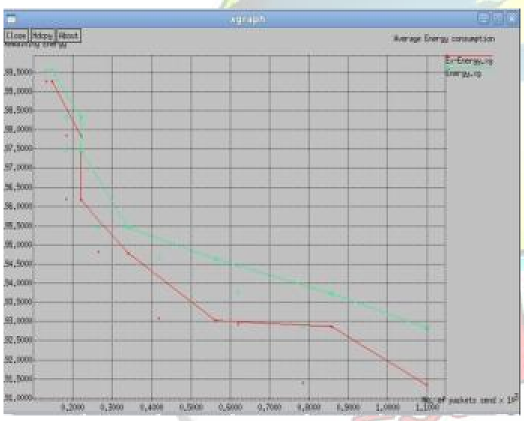

Figure 9. Average Energy Consumption

Figure 9 shows the average energy consumed by the network. Here it is clear that, the proposed GEDAR protocol consumes very less energy than the existing protocol.

V. CONCLUSION

In this paper, we have proposed and evaluated the GEDAR routing protocol to improve the data routing in underwater sensor networks. GEDAR is a simple and scalable geographic routing protocol that uses the position information of the nodes and takes advantage of the broadcast communication medium to greedily and opportunistically forward data packets towards the sea surface sonobuoys. Furthermore, GEDAR provides a novel depth adjustment based topology control mechanism used to move void nodes to new depths to overcome the communication void regions. Our simulation results showed that geographic routing protocols based on the position or location of the nodes are more efficient than the existing protocols. Moreover, opportunistic routing proved crucial for the performance of the network besides the number of transmissions required to deliver the packet. The use of node depth adjustment to cope with communication void regions improved significantly the network performance.

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