VAPR: Void Aware Pressure Routing Protocol

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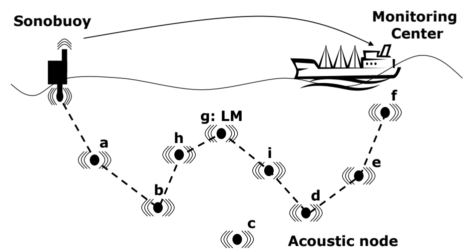
I. Problem Description

Underwater acoustic sensor networks (UW-ASNs) have lately been suggested as a potent means of supporting aquatic applications ranging from environmental monitoring to intrusion detection. A bevy of mobile sensor nodes each equipped with a variety of sensors and a low bandwidth acoustic modem (e.g. Drogues [1]) can be deployed the region of interest to form an *ad-hoc* network. The sensor network forms what is known as a SEA Swarm (Sensor Equipped Aquatic Swarm), where each individual node is capable of moving with the underwater jet streams and currents. The swarm is escorted by sonobuoys at the sea surface which are equipped with both acoustic and radio modems (Wi-Fi or satellite) and GPS. In this architecture, each sensor monitors local underwater activities and reports time-critical data to any one of the sonobuoys using acoustic multi-hopping; then the data are delivered to a monitoring center using radio communications. The main focus of this paper is to design an efficient anycast routing protocol from a mobile sensor to any one of the sonobuoys on the sea level. However, this is challenging because geographic greedy routing causes a data packet to be dispatched to a node which is not the destination, but closer to the destination than all of its neighbors. This node is known as a *local maxima* node. In such situations, it becomes necessary to recover from this dead end path by routing around the perimeter of the region (a *void*).

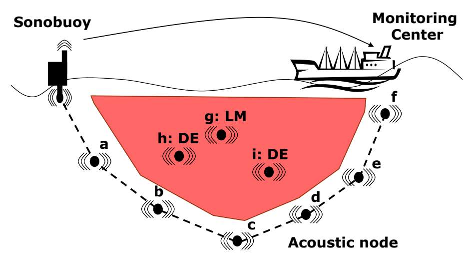
II. Void Aware Pressure Routing Protocol

In order to remedy this problem, we propose the Void Aware Pressure Routing (VAPR) protocol. VAPR takes advantage of what is already inherently a natural part of geographic routing to provide clues on the routing direction for data packets with minimal overhead to navigate around the voids. To illustrate problem of existing geographic greedy routing protocols, looking at Fig. 1(a), a node, c, which has a packet to send to a sonobuoy on the sea surface using a greedy algorithm is inclined to forward the data packet towards node g, which is a local maxima node, denoted as LM. Once the data packet is received at g, there does not exist any path which can allow the packet to be forwarded onward to another node which is closer to the final destination than g itself. Node g must then perform a route recovery process to backtrack the data packet around the void above it using either flooding or randomization techniques.

Instead, VAPR exploits opportunistic beacon packet receptions to circumvent void areas and efficiently progress towards the destination when choosing forwarding nodes. Fig. 1(b) shows our proposed routing goal. In this scenario, a node, c, which has a packet to send to a sonobuoy can avoid forwarding to the local maxima node, g, and the dead end nodes, h and i, which can only forward to the local maxima node g using greedy forwarding. By avoiding these nodes, a recovery scenario can be averted.



(a) Blind greedy routing



(b) VAPR protocol

Fig. 1. Conceptual greedy routing by avoiding *dead end* nodes

The key to achieving this within VAPR lies in utilizing the beaconing mechanism inherent in geographic routing. Beraldi *et al.* suggested the use of utilizing routing meta-information to provide *hints* for nodes to dynamically discover a routing path to the destination on-the-fly [2]. Our protocol follows this direction by embedding small amounts of trace routing data in each beaconing packet to inform neighboring nodes about the broadcasting node's status as a local maxima or dead end node. This routing meta-information forms the basis for providing cues to nodes on its surrounding neighbors. Given this information, nodes can locally make routing decisions to best avoid routing to nodes which may lead to a void in the network. Since information is embedded in the beaconing mechanism, it can be (reactively) propagated downwards repetitively throughout the network to isolate the void regions and the clusters of (dead end) nodes in which to avoid routing to.

Similar to most geographical routing protocols, a periodic beaconing mechanism is used to inform neighboring nodes of a node's presence and the former's one-hop connectivity in VAPR. It is during this exchange which nodes inform their neighbors of its depth. Based on this information, each node can determine whether or not it is a local maximum by examining the depths of neighboring nodes and comparing with its own depth. In addition to just broadcasting the depth

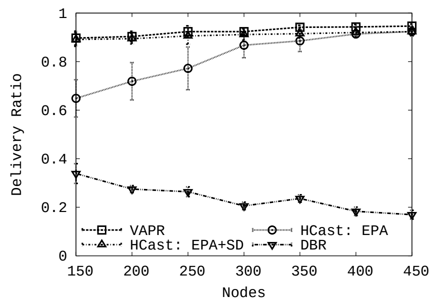


Fig. 2. Packet delivery ratio

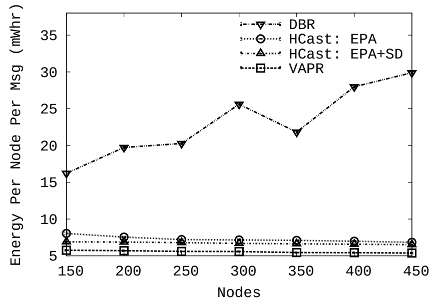


Fig. 3. Energy consumption per node to deliver each packet

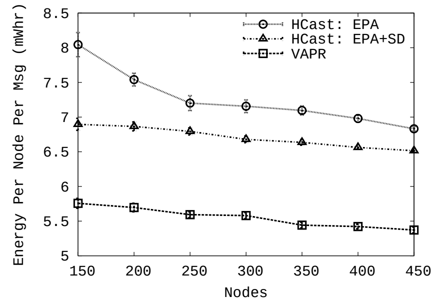


Fig. 4. Closer look at energy consumption per node to deliver each packet

information, the *hint* of whether the neighboring node is also a local maximum can be distributed in the beacon to give a clue as to whether or not to prune a particular node from a potential forwarding path calculation as it leads to a dead end (either from above or below) which it must then recover from.

Each node is expected to keep a minimal amount of local state information pertaining to its one-hop neighbors. The only relevant information which must be stored by a node for each neighbor is defined by a $5-tuple$ of ($node_{ID}$, $depth$, ψ_{hint}, ϕ_{bound}, $t_{expiration}$) where $node_{ID}$ identifies the neighboring node, $depth$ indicates that node's depth from the sea surface, ψ_{hint} is a single bit indicator of dead end node, ϕ_{bound} specifies whether the node is bound from above, below, or both, and $t_{expiration}$ is an expiration time for the entry. Only single hop neighbor information is required to be stored, henceforth, broadcasted beacons only need to include information about the broadcasting node itself. Given this, the size of average beacons can be greatly reduced. Moreover, each received beacon is set with an expiration timer and can be refreshed with the periodic beacons to keep storage manageable.

III. Evaluation

We have evaluated our proposed routing algorithm against two recent UW-ASN routing protocols: DBR [3] and HydroCast [4]. *Recall* that DBR floods the network, greedily forwarding the packet towards the sea surface using a linear back-off timer proportional to the distance to the destination. This ensures that the nodes closest to the broadcasting node will wait for the nodes closer to the destination that have received the packet to broadcast first. Overhearing the broadcast of the packet by a node closer to the destination serves as an acknowledgement that the packet was forwarded towards the sea surface, and suppressing node transmissions of the packet by nodes which are closer to the source, providing an opportunistic forwarding flavor. HydroCast uses a similar linear back-off timer; however, HydroCast does not flood the network. Instead it calculates an optimal forwarding set based on EPA and directs the packet to be routed in a general direction relying on opportunistic packet receptions. If the packet is routed to a void, a hop limited ring search is used to flood a discovery packet along the 2D surface of the convex hull around the void to search for a path around the vacuum before recommencing opportunistic greedy routing. We evaluate HydroCast both with and without this recovery process.

In Fig. 2 we examine the packet delivery ratio of VAPR in comparison between DBR and HydroCast with and without recovery. HydroCast with 2D surface flooding for recovery is denoted as HCast: EPA+SD. We see a general trend amongst VAPR and both HydroCast flavors of a positive correlation with node density. This is not however the case with DBR. Surprisingly, the packet delivery ratio of DBR actually dropped as node density increased, in fact, DBR performed the worst. It appears that the opportunistic flavor of DBR's implicit acknowledgements were not enough to suppress redundant packet transmissions by the physical layer, thereby causing congestion in the acoustic channel leading to excessive packet collisions so that very few packets made it to the sink nodes. Fig 3 indicates the average engery used to deliver a single packet. In this worst case scenario, DBR uses nearly 600% more energy to deliver a single packet than any of the others. This is primarily due to the inability of DBR to successfully suppress all of the packet broadcasts, thereby congesting the acoustic channel. An enlarged version of Fig. 3 is provided as Fig. 4 to distinguish between VAPR and the HydroCast variants. It shows that on average, VAPR can deliver a packet more efficiently in terms of energy than either of HydroCast's variants which require larger beaconing packets and potentially extra broadcasting for route recovery.

IV. Conclusion

In this paper we have proposed the VAPR protocol, a greedy forwarding algorithm, which can achieve better efficiency by exploiting opportunistic packet receptions and by utilizing the inherent beaconing mechanisms of geographic routing to avoid routing into vacuous regions where there is a need to flood the network or use random walks to recover from a dead end path. Extensive simulation results have verified that VAPR provides not only reliable delivery performance but also a high level of energy efficiency as another critical factor of routing protocols for UW-ASNs.

References

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