Routing with Bridging Nodes for Drifting Mobility

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ABSTRACT

Drifting with oceanic current forces is an unique mobility pattern for the underwater sensor networks. The different current velocities at the different depth levels and the periodic velocities can impact the three dimensional network deployment greatly over time. One outcome of such impact is the disruption to the network connectivity. In this paper, a routing protocol that utilizes the bridging nodes is introduced to tackle the connectivity problem. The protocol bears features that explore the unique mobility pattern and geological structure to suppress transmission overhead and improve energy efficiency.

1. INTRODUCTION

One unique type of delay tolerant networks in underwater sensor networks (UWDTN) can form largely due to the drifting of deployed sensors with the oceanic current forces [1]. The oceanic current driven mobility can be very different depending on the water body in question, e.g., shallow water with tidal current and deep water current with gyre. In addition, the current mobility can be different at different levels of depthes. Models of ideal one-layer current and multi-layer currents are introduced where vertical velocity is balanced by floating devices [2]. While a few land-based DTN routing protocols have been evaluated for different types of UWDTN, a single copy DTN routing protocol PASR has been proposed that takes the unique features of oceanic currents and the 3D underwater sensor network deployment into the protocol design [1]. The protocol uses prediction based on the current model and the geographic direction of the sink. However, as discovered in a few papers, periodicity in oceanic current forces can be weak, and time-slotted topology graph can be hard to achieve in reality.

In this paper, we introduce a routing protocol, Routing with Bridging Nodes (RBN), for the semi-UWDTN with less dependency on mobility prediction and time synchronization. The protocol identifies the bridging nodes when two disconnected sensor groups moving closer, and uses these nodes for selecting a routing path from one group to the other in order to reach the sink. The RBN protocol bears features that address the bandwidth and energy usage, with a goal for bandwidth efficiency and energy efficiency to count for the extreme shortage of these resources. The detail of the protocol and the analysis of the protocol are introduced in Section 2. And the future work is outlined in Section 3.

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2. RBN PROTOCOL

The paper follows the 3D layered underwater sensor network architecture shown in Fig. 1. At each level, sensors drift according to the same horizontal velocity model. But different levels drift with different horizontal motion parameters. The sensors in two adjacent levels can communicate when they are initial deployed. Each layer is sparse and could be partitioned when they move. The acoustic channels are symmetric. During initialization, each node is loaded with all the needed IDs and the levels they associated with.

2.1 Routing Principle with Bridging Nodes

We use an undirected graph to represent the underwater sensor networks, where nodes are the sensors and the edges are the communication links between the sensors. Thus, the semi-UWDTN is not a connected graph through its lifetime of deployment. Rather, there are time durations when the network renders itself as several connected components (islands) of sensors while they drift with the currents.

Suppose there are two disconnected sensor groups. When two sensors, each belongs to the different groups, are in transmission range of each other, they will exchange the list about their directly connected neighbors along with any known connections to those neighbors (define the list as neighbor list). Thus, they can construct a connected sub-graph $G'(V', E')$ where V' is the vertex set that includes the two nodes and all the nodes in each's neighbor list, and E' is an undirected edge set which represents this newly formed bridge link and the known connections among those nodes. Up on having this graph G', the two nodes are able to compute the cut vertices of G' by using depth first search (DFS). We call a cut vertex found in G' a bridging node. Fig. 1 demonstrates links that are current present (in solid lines), and links to come soon in dashed lines. When nodes C and D join, they find themselves a bridging node. When nodes at level-3 want to send a message to the sink, the message will go through one (or more) bridging nodes. Here, computing the cut vertices only uses a local sub-graph. The bridging nodes remain until the sub-graph G' is partitioned. New bridging nodes can emerge due to mobility.

In the protocol, when a sensor has a message for the sink, it will check if the sink is in the sub-graph it belongs to. If so, it will deliver the message to the sink directly using an existing routing protocol. Otherwise, it will buffer a copy of the message and forward the message to all the available bridging nodes. Those bridging nodes will then attempt to deliver the message in the same manner as the source node.

When two sensors A and B meet each other, say, when node B receives a hello message from node A, it will look in its neighbor table to determine if A is a new neighbor. If this is the case, node B obtains A's neighbor list, and node A shall do so. Node B will construct a local sub-graph and

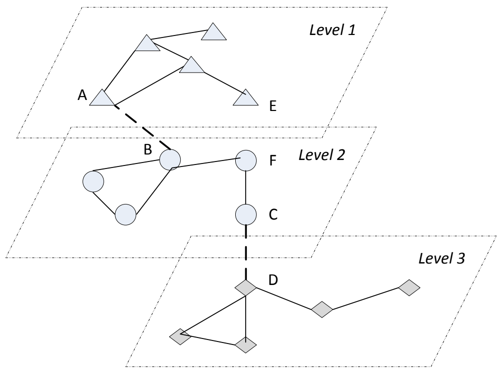

Figure 1: Routing with Bridging Nodes in 3D network

compute the bridging nodes of this local graph. If node A is a bridging node, node B will forward all current messages it carries to node A. Node A then becomes a carrier of those messages and vice versa. If neither node is a bridging node, the messages will be forwarded from B to the newly learned or calculated bridging nodes via node A. If none of these cases applies, both nodes will not send any messages. When either A or B discovers that the sink is within the newly formed subgraph, it will search its buffer and deliver the messages to the sink.

2.2 Protocol Features

The detailed protocol design considers several important issues. The first issue is the 3D network scenario. It is expected that the messages are sent to the sink on the surface. The sensors can be loaded with the index of their levels, or they can use a positioning technique to obtain their locations. With these information, the sensors can choose a bridging node that is closer to the surface, or, at the same level. For RBN to work, the index of the level is sufficient.

The second issue is to exploit the semi-periodic features of the velocity of the oceanic currents. Such features can guide the adaptation of the time interval in determining staled bridging nodes. A good estimation can result in reduced number of message transmissions caused by the change of the bridging nodes, which, reduces bandwidth and energy consumption. In the extreme best case, the protocol can reveal itself as a single-copy protocol.

The third issue relates to the correctness of the protocol when dealing with intermittent links and the dynamic network topology bearing temporal properties. The protocol uses the best-practices in routing, including time stamps, unique IDs, secondary buffer, and thresholds for tolerance over changes.

The fourth issue is the memory usage and message size. Because the membership of the network is known at setup, each node can be assigned to a fixed location in a vector. Some routing related fields can be expressed by a single bit, e.g., the adjacent matrix, the list of the message sources, etc. A time stamp using a real clock will need many bits. But if time synchronization is used among the sensors, a logical clock, which requires less bits, can be used for the time stamp instead of a real clock.

2.3 Protocol Analysis

The RBN protocol design has followed a few common practices. Its performance has to consider three issues, namely, routing overhead, latency and energy consumption, in the targeted environment. In underwater sensor networks, the typical transmission range is 5km; the bandwidth is 5kbps; and the propagation delay is 1.5km/s. Thus, transmitting a message size of 1Kbytes will take 1.6s. On the other hand, the passive mobility following the current velocity will be about 1km/hr. On average, two mobile sensors moving in opposite direction can have a link duration of more than 90 minutes.

Routing overhead relates to the use of hello messages or piggybacking topological information in data packets. With the bandwidth limitation of the underwater acoustic channel, would such usage be realistic? The above calculations suggest that although the transmission delay and propagation delay all seem extreme (compared to the wired/wireless Internet application experiences), the much larger coverage and the much slower velocity (than a typical land-based MANET or DTN) leave plenty of time for message exchanges. If the goodput of the reliable MAC protocols can reach 30%, the entire connection time of 90 minutes can transmit 8.1Mb data. Take for example an underwater sensor network with 50 nodes, a sampling rate of once per 5 minutes of size 1kbytes. The total data is 7.2Mbits in 90 minutes. The transmitted topology information from each node uses one bit for its 2-hop neighbors, that will give total 45K bits. The sum is around 7.2Mbits and it is within the capacity of the channel.

As for network latency, it has been reported that real-time oceanic applications operate at a (slower) time domain that is not matched by real time Internet applications. The latency incurred by the long propagation delay and transmission delay is less a concern.

However, the energy consumption is a critical issue due to the difficulties in recharging the underwater sensors. The proposed protocol reduces the transmission overhead due to the use of bridging nodes and also the additional methods to suppress transmissions compared to other similar DTN routing protocols. But it is still a multiple-copy protocol. Compared to a single-copy protocol, more transmissions will be used in transmitting the copies by different bridging nodes.

3. FUTURE WORK

We will evaluate the RBN protocol with comparisons to the similar protocols. Our evaluation criteria include message delivery rate, link overhead, energy consumption, delay and number of hops. The protocol will be evaluated against different drifting mobility parameters for the 3D network scenario.

4. REFERENCES

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