Connectivity-based Routing Protocol for Underwater Wireless Sensor Networks

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***Abstract*— We propose a connectivity-based routing protocol (named CRP) for underwater wireless sensor networks (UWSNs). CRP considers the reliability issue due to high error rate in UWSNs. Hence, during forwarding, a node with the highest connectivity to the sink is selected as a next forwarding node. Using the NS-2 simulator, CRP is compared against a localization-free routing protocol in UWSNs (i.e. H2-DAB). Simulation results prove that CRP shows increased performance improvements over H2-DAB.**

***Keywords*— underwater wireless sensor networks, routing.**

I. INTRODUCTION

Underwater Wireless Sensor Networks (UWSNs) support various applications including underwater monitoring, disaster prevention, tactical surveillance etc. In UWSNs, acoustic signals are used as a physical medium for UWSNs, since the radio and optical signals have absorption and scattering problem, respectively. Radio signals propagate long distances only at extra low frequencies that require large antennas and high transmission power. Optical signals require high precision in pointing narrow laser beam, which is very hard to achieve in harsh underwater environment. Therefore, acoustic signals are considered the most suitable physical medium for underwater communications.

However, using acoustic signals imposes other challenges on UWSNs i.e. large propagation delay (i.e. 1500m/sec), high error rate, and low bandwidth (i.e. <100 kHz). Furthermore, the underwater sensor nodes contain limited energy. Due to the above-mentioned challenges, designing communication protocol for UWSNs is a challenging task [1]. Specifically, the routing protocol is of great importance since the routing protocol selects forwarding nodes between source and sink. The routing protocol should select a next forwarding node that increases the packet delivery probability towards the sink, consequently, increasing the reliability. Since the UWSNs have high error rate, the selection of a reliable next forwarding node is highly significant.

In this article, we therefore propose a routing protocol named CRP (connectivity-based routing protocol), addressing the above-mentioned issues and selects the most reliable next forwarding node towards sink. In CRP, the forwarding nodes between the source and sink pair are selected based on their connectivity to sink. Connectivity is defined as the number of neighboring nodes closer to sink from a forwarding node. The node having higher connectivity to sink is selected as a next forwarding node among its neighbors. Hence, selecting the node having higher connectivity increases the packet's delivery probability towards the sink, improving the data delivery ratio.

II. RELATED WORK

In [1], VBF (vector based forwarding) protocol was proposed. In VBF, it is assumed that the sensor nodes know their location information. A vector starting from the source towards the destination is computed. The sensor nodes residing around the computed vector forward the packet towards the sink. HHVBF [2] is a successor of VBF, HHVBF also assumes localization and employs a vector based forwarding. However, in HHVBF, the vector is computed at each hop starting from each sender/forwarder towards the sink. DBR [3] (depth based routing) is a well-known localization-free routing protocol proposed for UWSNs. DBR uses the depth of sensor nodes as a routing metric. The sensor nodes having lower depths are utilized for forwarding the data packets. H2-DAB [4] (hop-by-hop dynamic addressing based routing protocol) is another localization-free routing protocol proposed for UWSNs. In H2-DAB, each sensor node is assigned an ID called HopID based on hop count from the sink. During forwarding, the sensor nodes having smaller HopIDs are selected as forwarders.

III. PROPOSED ROUTING PROTOCOL

In this section, we present our proposed routing protocol, CRP, in detail. We assume a common architecture of UWSNs where the sinks are positioned at the water surface and the sensor nodes are deployed underwater. The sensor nodes are deployed at different depths underwater from the top to the bottom of the deployment region. CRP works in two phases i.e. connectivity index assignment phase and data forwarding phase.

A. Connectivity Index (level) Assignment Phase

During this phase, each sensor node is assigned a connectivity index/level. The process is as follows. Each sink broadcasts a Hello packet. Upon receiving the Hello packet, the sensor nodes are assigned a connectivity index and a hop count value (i.e. 1). Then, the receiving nodes rebroadcast the Hello packet including their connectivity index and their hop count towards the sink. Hence, other sensor nodes receive the Hello packet along with the sensor nodes which have been already assigned a conectivity index. Therefore, some sensor nodes receive the Hello packet again from their neighboring nodes. Upon receiving the Hello packet from the neighboring nodes, the connectivity index of a node increases. However, it is important to note that the connectivity index increases when a node receives a Hello packet from a distinct neighboring node with either same or less number of hop count towards sink. Through this way, each node is assigned a connectivity index.

Furthermore, each node keeps a record of the neighboring nodes from which the Hello packets are received. The record contains the ID, connectivity index and hop count of the neighboring node.

B. Data Forwarding Phase

During this phase, the data packets are forwarded from the source to sink. Each node selects a forwarding node that has the highest connectivity index among its neighbors having smaller hop counts. The ID of the selected next forwarding node is included in the data packet. Upon overhearing the data packet, each node compares its ID with the ID included in the data packet. The node whose ID matches forwards the data packet without any delay, while all other nodes hold that packet. The holding time is based on the connectivity index, i.e. the node having higher connectivity index has a short holding time compared to the node having low connectivity index. The holding time is computed using Equation 1.

$$\text{Holding time} = 1 - CI / CI_{max} \quad (1)$$

, where CI is the connectivity index and CI_{max} is a system paramter i.e. the maximum connectivity index. Upon overhearing the same data packet from a high priority node (i.e. the node having highest connectivity index), the nodes holding the data packet drop that packet.

The selection of a node with a higher connectivity level has a high probability of packet delivery towards the sink. To support this statement, we take into account the delivery probability model used in [5] as follows.

$$P(d, m) = (1 - P_e(d))^m \quad (2)$$

, where P_e is the packet error rate, d is the distance between nodes, and m is the packet size. Suppose, all links have the same packet error rate regardless of distance and the packet size is fixed, as the number of receiving nodes (i.e. connectivity index/level) increases, the delivery probability also increases.

$$P = 1 - (1 - P_e)^n \quad (3)$$

, where n is the connectivity level. Suppose the packet error rate is 50% on all links and the connectivity level is 3. In case of connectivity index based routing, $P = 1 - (1 - 0.5)^3 = 0.875 * 100 = 87.5\%$, and in case of a single node (traditional routing), $P = 1 - (1 - 0.5)^1 = 0.5 * 100 = 50\%$. Hence, selecting a node with higher connectivity increases the delivery probability.

IV. Performance Evaluation

We evaluated the performance of CRP using NS-2 simulator against H2-DAB. Simulations were performed with a different number of sensor nodes (16, 25, 36, 49 and 100) in grid topologies. A transmission range of 200m was set for each sensor node. A single sink and a source node were selected in each topology. The source node generated a data packet every 15 seconds. The data packet size was fixed to 64 bytes.

As shown in Figure 1, CRP dominates H2-DAB in all topologies in terms of delivery ratio. In H2-DAB, only a single node is selected as a forwarder. In case the selected forwarder does not receive the packet due to packet error, the packet is lost. In contrast, CRP employs a connectivity-based selection of forwarding nodes where more than one nodes receive the data packet. Hence, in case one node misses the data packet, other nodes can forward the packet, which increases the reliability/delivery ratio. Figure 2 shows the end-to-end delay of H2-DAB and CRP. The inquiry request/reply packets used in H2-DAB result in long end-to-end delay. Hence, the delay in H2-DAB is longer than CRP. In contrast, in CRP, the highest priority node (i.e. having the highest connectivity index) forwards the data packet as soon as it receives the packet. Therefore, CRP has a short end-to-end delay.

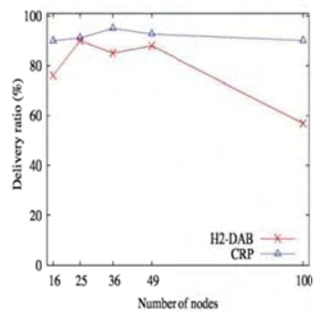

Figure 1. Delivery ratio

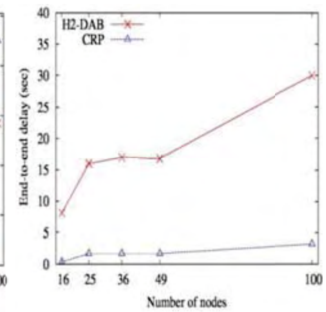

Figure 2. End-to-end delay

V. Conclusion

We proposed a connectivity-based routing protocol (named CRP) for UWSNs. CRP works in two phases: connectivity index assignment and data forwarding phases. In the former, each node is assigned a connectivity index based on its connectivity towards the sink. In the data forwarding phase, each sender selects its next forwarding nodes based on the assigned connectivity index. From the simulations, we observed that CRP improves the delivery ratio up to 36% against H2-DAB. Furthermore, the end-to-end delay of CRP is up to 90% smaller than H2-DAB.

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