

# Poster Abstract: Adaptive Routing in Underwater Delay/Disruption Tolerant Networks

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## I. INTRODUCTION

Underwater sensor network has attracted significant attention recently [1] [2]. On the one hand, it enables a wide range of aquatic applications. On the other hand, harsh underwater environments pose grand challenges to underwater communication and networking. Firstly, acoustic channels have high error probability, long propagation delay and limited bandwidth. Secondly, underwater sensor nodes are usually mobile with water currents. Furthermore, compared with terrestrial sensors, underwater sensors are usually much bigger, more energy-consuming and more expensive. Thus it is very costly to deploy dense underwater sensors in a large area.

Due to node mobility and sparse deployment, an underwater sensor network often becomes an Intermittently Connected Network (ICN), that is, there may not be an available persistent route between a source and a destination. This kind of network is referred to as Delay/Disruption Tolerant Network (DTN). Traditional routing protocols are not practical for such scenarios since packets will be dropped when no routes are available. Therefore, new routing protocols are required for efficient message delivery in such networks.

A large number of routing protocols have been proposed for DTN. One extreme is epidemic routing [3], which is a flooding scheme. Without network constraints, such as contention, buffer, battery and bandwidth, epidemic routing can always maximize the delivery rate, or minimize the average delay. However, flooding based epidemic routing will consume too much energy which is precious in underwater sensor networks. Another extreme is single copy forwarding [4], which aims to achieve the best tradeoff between message delivery delay and energy efficiency. Many other protocols such as [5] [6] and [7] are between these two extremes. They are based on either flooding or gossip. They utilize some statistic profiles to route packets to the destination using multiple copies as well as some control mechanisms. All these protocols treat packets equally and aim at optimizing a single objective, e.g., minimum average delay or maximum delivery rate or efficient energy consumption.

In this paper, according to the special constraints of underwater delay/disruption tolerant networks, we propose an adaptive routing protocol for efficient routing. We assign packets different emergency levels and define several routing states. Afterwards, we adaptively choose appropriate routing state to satisfy different application requirements by utilizing

an information vector (see Section II). The objective of our protocol is to **achieve a good tradeoff among delivery ratio, average delay and energy consumption**. Our contributions are two folds. First, we propose an efficient routing protocol for underwater delay/disruption tolerant networks with special constraints. Second, we treat packets as application-oriented to adaptively choose appropriate routing states and achieve a good performance tradeoff.

## II. PROTOCOL DESCRIPTION

We consider the application of pollution monitoring. Underwater sensors are randomly deployed in an interested underwater area and periodically report the quality of the water detected to a data sink at the surface. The sink can be a boat, buoy or other vehicle equipped with radio to communicate with the on-shore control center. The data packets collected by sensors can be classified into different emergency levels: if the quality of the water is good or it only changes in a reasonable interval, the corresponding packets are treated as ordinary data with the lowest priority, which only require delivery to the sink with an acceptable delay and as little energy consumption as possible; if some pollution event is detected, then an emergent data packet is generated with the highest priority, which is required to be delivered to the sink with minimum delay for quick reaction. Otherwise, packets will be generated with an intermediate priority depending on the quality of the water, which require moderate delay and energy consumption.

Our adaptive routing protocol assigns different amount of redundancy to packets with different priorities. More specifically, our protocol covers a routing spectrum with one extreme as 4-replica epidemic routing for packets with the highest priority, and the other extreme as single-copy routing for packets with the lowest priority. Between these two extremes, it includes two additional routing states with different amount of redundancy.

We consider a 3D underwater sensor network with medium node density. Sensor nodes are deployed at different depths using buoyancy control, and they can only move in the horizontal 2D plane, only fluctuating in the vertical direction. In this way, sensors at the same depth form a layer. Further, we assume all sensors know their 3D positions through a certain localization service.

Based on a certain localization service, the 3D position vector is used for routing, i.e., the basic routing decision is

geo-based. We define the information vector as the combination of **emergency level, age (packet generation time), spatial-temporal density (density in a certain period of history) and battery level**, then jointly map this information vector into a priority value, which is used to decide which routing state the packet falls in. The emergency level and packet generation time are associated with the packet, while the density and energy level are associated with the current node. The priority for a packet keeps changing during relays according to packet properties and network conditions.

In the following, we briefly describe how to use the information vector to calculate the priority value and then decide the routing state.

The priority value is in the range of  $[0, 100]$  (this range can be changed when the values of the various components of the information vector change accordingly). We evenly divide the range into 4 intervals  $[0, 25]$ ,  $[26, 50]$ ,  $[51, 75]$  and  $[76, 100]$ , corresponding to 4 routing states of single-copy, 2-copy, 3-copy and 4-copy forwarding schemes respectively.

Each component in the information vector is in the same range as that of the priority level. More specifically, let  $E, A, D, B$  denote respectively the values for the emergency level, age of the packet, spatial-temporal density and battery level of the current node. Then the priority  $P$  is calculated as

$$P = \alpha_1 E + \alpha_2 A + \alpha_3 D + \alpha_4 B, \quad (1)$$

where

$$\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1. \quad (2)$$

The priority is calculated whenever a node is ready to forward packets. Except for that the emergency level is fixed for each packet, all other three components change along time and relays. Weights  $\alpha_i, 1 \leq i \leq 4, \alpha_i \geq 0$  are chosen depending on the application objective, e.g., if we want to clearly differentiate emergency levels, we would give a higher weight to  $\alpha_1$ ; if we want to minimize the delay, we would give a higher weight to  $\alpha_2$ .

### III. PERFORMANCE EVALUATION

In this section, we present some preliminary results.

We deploy 5 layers of sensors. Each layer is a square area of  $1km \times 1km$  and contains 15 sensor nodes. All nodes only move horizontally in their plane, and randomly choose a speed up to  $2m/s$  every  $0.2s$  until reach the boundary, then they are bounded back. The transmission range of a sensor is  $100m$ . The depth between two consecutive layers is  $60m$ . One sink is anchored at the middle of the surface layer. All packets are randomly generated from the lowest layer every  $1s$ , with a random emergency level between 1 and 4. Each node has a limited buffer for 20 packets and battery for delivering 40 packets. Because of the bandwidth constraint, we assume each node can successfully send 2 packets per second (considering long propagation delay and high loss probability). Epidemic ACK and contention detection MAC broadcast are also enabled. We run 100 rounds with 200 packets each round to get the average.

	Delivery ratio	# of transmissions	Delay
Epidemic	0.9359	23.5976	6000.02
Adaptive	0.9497	19.7667	3752.48
Single-copy	0.5974	18.5156	5122

TABLE I  
COMPARISON OF DIFFERENT ROUTING PROTOCOLS

Table I compares the delivery ratio, number of transmissions (measuring energy consumption) and delay for different routing protocols. We observe that adaptive routing outperforms others with the highest delivery ratio, lowest delay and acceptable energy consumption. Compared with single-copy routing, adaptive routing achieves much higher delivery ratio and much lower delay with similar energy consumption. This is because multiple copies always help to find a better route in underwater DTNs, while it is hard for single-copy routing protocol to find a good single route, and inappropriate route can waste energy. Compared with epidemic routing, adaptive routing achieves much lower delay and energy consumption with similar delivery ratio. This is because, in severe underwater scenarios, epidemic routing consumes too much energy and buffer space, causing many node failures due to battery drainage, which adversely affect its performance. Adaptive routing saves energy from low emergency level packets while provides low delay for high emergency level packets. It appropriately reassigns resources to different packets according to the application requirements and achieves a good performance tradeoff.

### IV. CONCLUSION AND FUTURE WORK

From the preliminary results, we can observe that adaptive routing is suitable for underwater environments and achieves a good tradeoff among delivery ratio, delay and energy consumption. We are continuing this work to explore more sophisticated routing mechanisms (such as controlling forwarding areas for packets with different priorities), and more algorithms to control the number of copies in the network.

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