Improving Efficiency of a Flooding-based Routing Protocol for Underwater Networks

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ABSTRACT

Routing protocols based on limited flooding can be used reliably in small scale underwater networks for fleets of autonomous underwater vehicles (AUVs). Scalability issues inherent in flooding are addressed by COFSNET+ [3], a framework protocol that controls which nodes will retransmit a packet during its delivery. COFSNET+ does not specify a method for the selection of nodes; this paper proposes such a method, based on the past contribution of nodes in delivering packets to their destinations. A simulator study shows that the proposed method not only reduces the total number of nodes that retransmit a packet, but also that it can adapt to overcome packet loss conditions in the network. For scenarios where loss is negligible, the method converges on the equivalent of the shortest path. In case of higher packet loss rates, end-to-end robustness is achieved by allowing more nodes to retransmit each packet.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network Protocols—*Routing protocols*

General Terms

Algorithms, Design, Performance, Reliability

Keywords

Underwater networks, ad hoc routing, flooding

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1. INTRODUCTION

Networking in an underwater environment poses challenges that are not commonly encountered in radio frequency (RF) surface networks. Underwater networks suffer from frequent packet delivery errors and disconnections; long latency and high cost of transmission make protocol coordination difficult. These challenges have a significant impact on the design of routing protocols, and it is likely that optimal solutions will be quite different from those in the RF domain. In this paper we continue our study of a non-traditional approach: routing based on limited flooding. Flooding is rightfully considered inefficient in traditional RF networks, and – with the exception of several specialized protocols – is rarely used. Our previous work has shown benefits of flooding protocols for small underwater networks consistent in size with current AUV deployment scenarios [2]. This paper attempts to address scalability of a flooding based protocol to make it suitable for medium sized networks without sacrificing its main benefit: robustness.

2. PREVIOUS WORK

Multihop routing in underwater networks has been studied by several groups [1, 11, 12]. Carlson et al. proposed a location-aware source routing (LASR) [5] protocol and compared the performance with RF-domain ad hoc protocol DSR [8] and limited flooding. While their results show superiority of LASR in most cases, they also indicate that limited flooding is competitive at times of volatility in the network.

The work presented here is motivated by our experience – from design to field testing – of two ad hoc underwater routing protocols in the context of the Solar-powered AUV platform [7]: AUSNET [4] and COFSNET (Controlled Flooding for Small Networks) [2, 6, 10]. Both protocols are tailored versions of existing ad hoc routing protocols; AUSNET is a combination of DSR [8] and prediction-based routing, while COFSNET is based on limited flooding – a packet is retransmitted once by every node that hears it. Although COFSNET requires more transmissions than other routing methods, there are significant benefits to this approach: no exchange of control messages, no sensitivity to topology changes (e.g. mobility), and lowest possible end-to-end la-

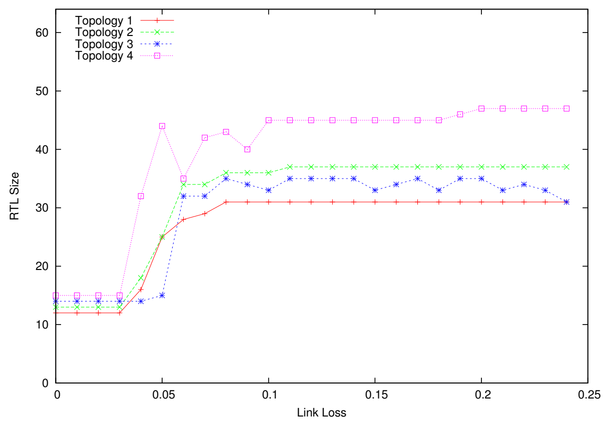

Figure 1: RTL size for varying link losses.

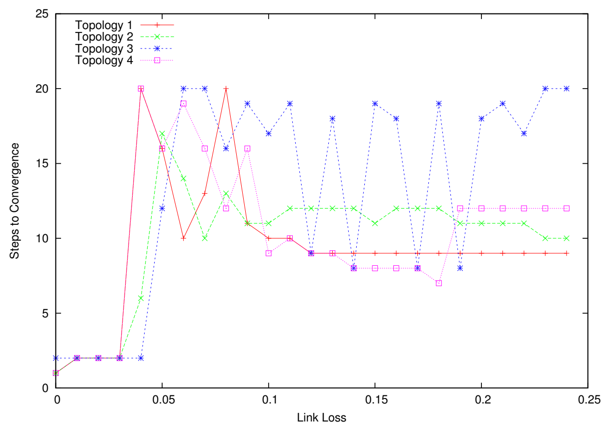

Figure 2: Cycles required to stabilize the RTL.

tency. Furthermore, the multiplicity of packet transmissions can compensate for the unreliability of nodes or the severity of acoustic conditions.

COFSNET+ [3] is an extension to the COFSNET protocol, which aims to maintain its benefits while reducing the overall number of packet retransmissions. This is accomplished through the use of a *Retransmission List* (RTL), part of the protocol header, which specifies the nodes that may retransmit the packet. Because the overall cost of transmission is directly proportional to the size of the RTL, the benefits of reducing it can be significant.

COFSNET+ does not specify a method for determining the contents of the RTL; one such method is proposed in this paper and evaluated using a simulator. The eventual outcome of this work will be a working implementation of COFSNET+ on the SAUV platform.

3. APPROACH AND METHODOLOGY

The method of RTL creation is a repeated cycle of *list discovery* and *list update*. In list discovery, information about the paths taken by packets from source to destination is recorded in the protocol header, as described in [3]. In list update, this information is conveyed back to the source. The approach outlined in this paper focuses only on list discovery; list update is implemented by returning data omnisciently from the destination to source, and a more practical mechanism will be developed in future work.

In the first list discovery, there is no path information; the RTL contains every node in the network, equivalent to full flooding. The destination may receive several copies of the packet, each taking a different route through the network.

Each node (excluding the source and destination nodes) is rated with a usefulness index $U_{i,j}$, $0 \leq U_{i,j} \leq 1$, for the node i for the j^{th} list discovery. Initially, the usefulness index of each node is set to 1, and for subsequent cycles is calculated from its number of retransmissions relative to the maximum retransmissions:

$$\left.\begin{aligned} U_{i,0} &= 1 \\ U_{i,j} &= \alpha U_{i,j-1} + (1-\alpha)\frac{r_{i,j-1}}{R_{j-1}} \end{aligned}\right| \forall i \in N$$

where N is the set of all nodes, α is the exponential smoothing factor, $r_{i,j}$ is the number of retransmissions done by node i in cycle j, and $R_j = \max_{\forall i \in N}[r_{i,j}]$. Note that α controls the balance between resistance to random fluctuations in path loss and sensitivity to topology changes such as those caused by mobility.

A node i is included in the j^{th} RTL if $U_{i,j}$ is greater than the threshold T_j. The value of threshold T_j is calculated based on mean of indices $\mu[U_{i,j}]$, increment factor γ and decrement factor δ as:

$$T_0 = 0$$
$$T_j = \frac{\mu[U_{i,j}] + \gamma s}{\delta^f}$$

where s and f indicate the number of successes or failures of the given RTL, dependent on the observed loss rates L:

$$s = \sum_{k=1}^{j} 1\{L_k < L_{target} - \varepsilon\}$$
$$f = \sum_{k=1}^{j} 1\{L_k > L_{target} + \varepsilon\}$$

where L_{target} and ε indicate a range of "acceptable loss" for the network and L_k is the observed packet loss in cycle k. $1\{.\}$ is a function that returns 1 if the condition is satisfied and 0 otherwise.

4. EXPERIMENT SETUP

Performance of the proposed method was evaluated in simulated networks of 64 nodes. The nodes occupied a virtual area of 8000 × 8000 meters, divided equally into 64 squares each containing one randomly placed node [9] with a maximum transmission range of 1200 meters. Although this method does not guarantee a fully-connected network in every case, it typically produces networks with multiple paths between nodes. Four different fully-connected and static topologies were generated (Topology 1 – 4) and used throughout the simulation experiments.

The simulator [3] does not consider collisions in the MAC layer, and was configured to initiate the packet transmissions at an interval greater than the time required for packet delivery. The probability of packet delivery to an in-range node is a simulation parameter; it is independent of internode distance.

In each simulation, a total of 2000 packets – 20 list discoveries of 100 packets each – were sent from the node in the bottom left corner to the node in the top right corner, with $L_{target} = 0.15$, $\varepsilon = 0.05$, $\delta = 2$, $\gamma = \frac{1}{16}$, and $\alpha = \frac{1}{2}$.

5. SIMULATION RESULTS

5.1 RTL Convergence and Robustness

The results show that the methodology described in Section 3 will generate RTLs that, in most cases, exhibit stable convergence to a single size (Figure 1, Figure 4) in a relatively small number of steps (Figure 2). Under some combinations of topology and link loss (e.g. Topology 3), the RTL size appears to be metastable. The exact cause of this behavior is currently being investigated.

COFSNET+ degrades gracefully under lossy conditions through its redundancy (Figure 5). It is important to note that when loss is negligible, the RTL converges to the optimal value: the nodes that form the shortest path. Even under the highest link loss rates, the RTL size is significantly less than the total number of nodes; "dead ends" between source and destination are not included (Figure 3), establishing a limit on worst-case performance.

5.2 Path Discovery

Figure 3 shows the paths through the network that are possible under three separate RTLs – representing a low, moderate, and high link loss simulation run – overlaid on the node locations in each of the four topologies. These paths illustrate the reaction of COFSNET+ to link loss as it attempts to minimize the path loss over the entire route. More circuitous paths are allowed only when cumulative link losses would inhibit the use of shorter paths.

6. CONCLUSIONS AND FUTURE WORK

COFSNET+ significantly reduces COFSNET's overall transmission cost, without sacrificing its end-to-end robustness. This paper proposes a method for building RTLs through the observation of normal network traffic, by iteratively learning the extent to which nodes aid the delivery of a packet; no probes or coordination messages are necessary. The tradeoff between robustness and cost is controlled by the "acceptable loss" used in the calculation of the RTL, and the aggressiveness of convergence may also be adjusted to match the characteristics of the environment and node mobility. The simulations verify the functionality of the proposed method, producing shortest-path routes under negligible loss and maintaining the robustness of a flooding-based protocol under lossy conditions.

In order to bring about a practical implementation of COFSNET+ on the SAUV platform, further research is necessary. Performance under non-uniform link loss – including asymmetric links, a more realistic propagation model, and MAC layer collisions – must be verified. An analysis of the operation of the list discovery/list update cycle for dynamic network topologies must be conducted, and optimal values for the parameters of the methods must be determined. Finally, a practical and efficient method for delivering list updates must be developed and verified.

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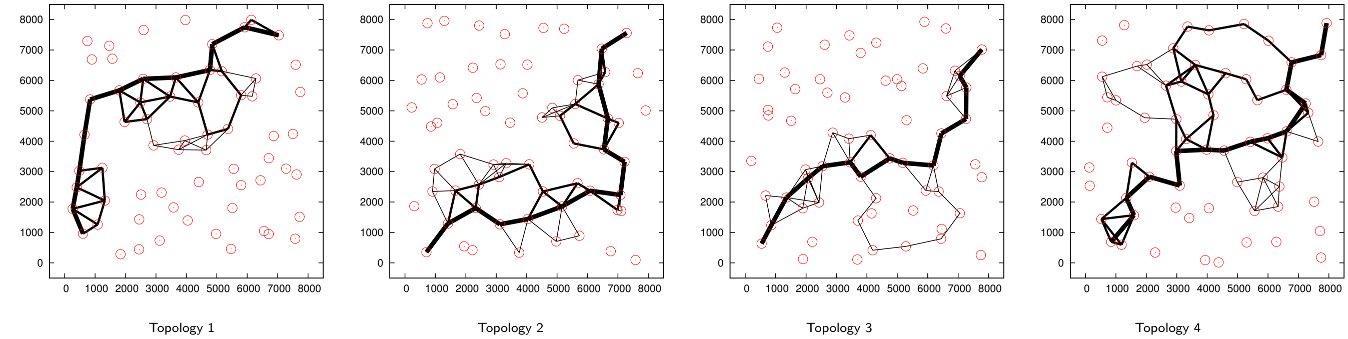

Figure 3: Connections representing the possible paths of packets for RTLs in 3 cases of link loss. The thickest lines represent the RTL under 0% link loss, (shortest path), while the thinnest represent the RTL under 24% link loss.

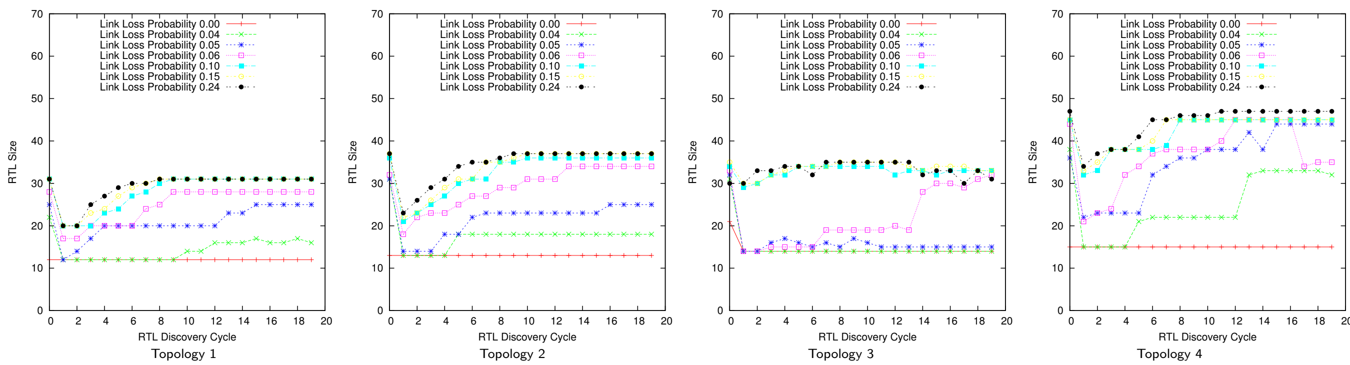

Figure 4: The convergence of RTL length over list discovery cycles.

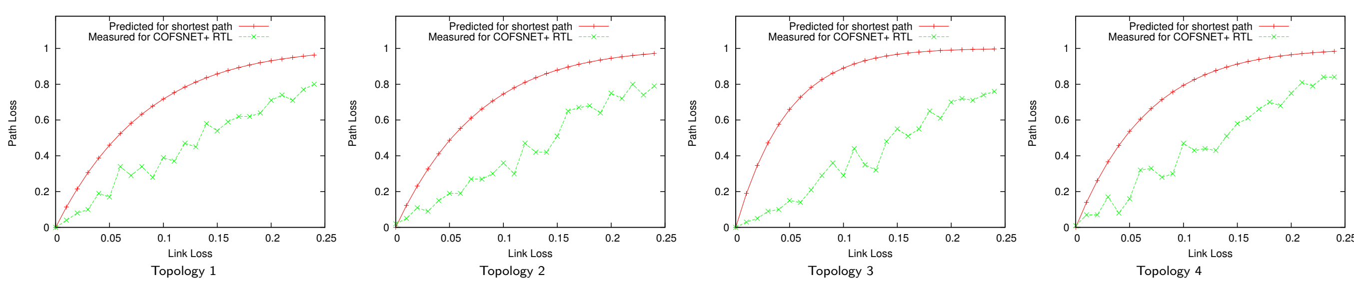

Figure 5: Predicted path loss for shortest-path routing ($L = 1 - (1 - P)^m$ where P is the link loss probability and m is the length of the shortest path) and measured path loss for the simulation of COFSNET+, as a function of link loss.