Poster: Improving Delay-Tolerant Network Performance Using Forward Routing Information

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I. INTRODUCTION

The development of delay-tolerant networks (DTNs) has attracted significant attention in the recent years. The concept started with the idea of interplanetary internet and later the DTN Research Group (DTNRG) took up the work concerning the architectural and protocol design principles for the DTNs.

A DTN can be regarded as a group of highly disconnected networks/regions where the communication environment may be far from ideal with high error rates, large delays and sporadic connectivity with the outside world. One approach to transfer data between these disconnected regions is by using mobile message ferries [2, 3], which travel in pre-defined paths between regions. To reduce the latency multiple ferries can be incorporated in the same route and to different nodes in the same region. Each ferry has a fixed data storage buffer which can be loaded/unloaded at regional gateways when the ferries stop for some time. However, the performance of ferries will be poor if the disconnected network regions have no information about the ferries' schedule and capacity, because the traffic demand pattern is dynamic and unpredictable. The main motivation of our work, therefore, is to improve the DTN performance via the provision of appropriate information to the disconnected network regions.

In our approach we assume that there are multiple ferries operating on fixed paths, as shown in Fig. 1. The ferries are competing for profits, so each of them has a scheme to dynamically reserve the space in the buffers according to the recent traffic demand patterns for each region *i* on the ferry's path. This is similar to Ali et al. [4] where they discuss various resource allocation techniques for improving the QoS in MANETs. But our approach is different in that we have a system of fixed network regions and fixed ferry routes.

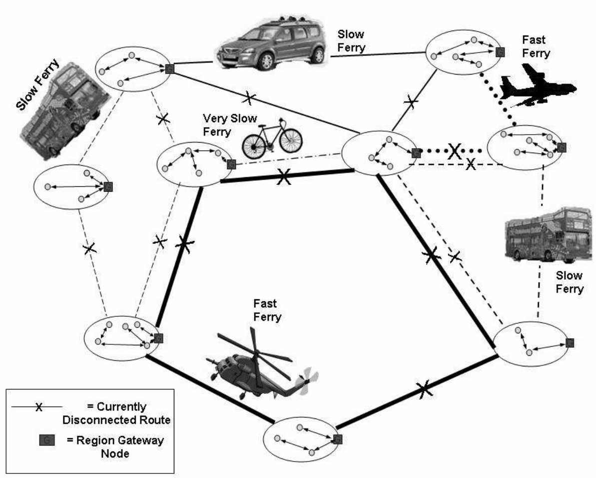

Fig. 1: A simple DTN with different types of message ferries in fixed routes between disconnected network regions. A link with X represents that there is currently no ferry on that link to transfer data.

Regional gateways present at each network region store the messages from the nodes in the form of a priority queue with message priority. For accommodating the mismatched network delays among the regions, Fall et al. [1] propose node-to-node custody transfers using store and forward methods at intermediate gateways. However, although custody transfer provides higher reliability, it is not designed to fulfill QoS requirements such as cost and time constraints.

In this work we seek to improve the performance of DTNs from two aspects. First, we propose to let the ferries inform the regional gateways *forward routing information* about their schedule and buffer allocation for the next few rounds. Second, we propose to let regional gateways apply a modified multi-dimensional Dijkstra's shortest path algorithm to the received forward routing information to calculate the path with the shortest multi-dimensional Euclidean distance from source to destination which satisfies multiple QoS requirements of the data (determined by cost and time constraints of the data packets). Thus, the gateways make reasoned decisions after learning about the various routes from source to destination.

Each gateway decides about which ferry to forward its data based on the cost and the time constraints for the data packets, which depend on various variables like message size, ferry wait time at each region, data transfer cost per kilobyte for the data's priority, ferry moving latency between source and destination, message wait time for next ferry, etc. Each of these variables represents a dimension in the Euclidean distance between the source and the destination, and can be normalized according to the bias of the region (for example, some regions emphasize more on latency, but other regions emphasize more on cost).

Using these (normalized) variables, regional gateways calculate the optimal route of data packets from source to destination utilizing the multi-dimensional Dijkstra's algorithm. This decides the sequence of ferries and regions through which the data packets travel.

II. OUR APPROACH

Assumptions:

We assume a set of disconnected network regions with fixed gateways and a system of message ferries to transfer data between the network regions. Inside each network region the nodes can route their data to the gateway, to be sent to other regions. There exist different types of ferries, namely fast, medium and slow; each type of ferry has different cost. We assume that the route of each ferry is fixed but the ferry's schedule and buffer allocation policy is dynamic. All the gateway nodes are informed about the ferry's schedule and buffer allocation policy for the next few rounds and can estimate when the ferry arrives. It is assumed that a ferry can store as much data as pre-allocated buffer space permits.

Problem Formulation:

Let S = {1, 2, 3…. n} denote the different network regions. The following notation is used in the subsequent discussion. Let *msize* be the message size, *cost*(*f, p*) be the function that gives the cost of sending one unit of message with priority p using ferry f, and *dist*(*i, j, f*) be the distance between region i and region j on the route of ferry f. Then the total cost associated with sending data of priority p from gateway of region i to gateway of region j using ferry f is given by

$$C_{ij} = msize * cost(f, p) * dist(i, j, f)$$

Let *wait*(*f*) be the function that exploits the forward routing information provided by the ferries to calculate the wait time at source gateway before the data is transferred from gateway to ferry f. So, *wait*(*f*) occurs only at the source gateway. Also, let *stop*(*f*) be the maximum time a ferry stops at a gateway for message uploading/downloading, *hops*(*i, j, f*) be the number of hops between region i and region j on the route of ferry f, and *speed*(*f*) be the minimum speed of ferry f. Then, the total time taken by the message to travel from gateway i to gateway j is bounded by:

$$T_{ij} = wait(f) + stop(f) * hops(i, j, f) + dist(i, j, f) / speed(f)$$

We define a Quality function (Q) to incorporate the above cost and time constraints, whose magnitude is given by:

$$\|Q\| = \sqrt{Q(C)^2 + Q(T)^2}$$

where $Q(C)$ is the change in quality based on cost of transfer and $Q(T)$ is the change in quality based time of transfer. Let α and β be the weights assigned to the cost and time functions for normalization purposes (the values of α and β are dependent on the bias of each network region). Then,

$$Q(C) = \alpha * C_{ij} \text{, and}$$

$$Q(T) = \beta * (1 / T_{ij})$$

The above equation states that one has to pay more for the data to be delivered faster. If the desired transfer time is less, then the cost increases which is reflected by an increase in value of Q.

The goal is to determine the best path from source i to destination j by finding the ferry whose Q value is minimal. Therefore, it is a modified form of Dijkstra's algorithm using multiple parameters.

To calculate *wait*(*f*) we propose a modified TCP Round Trip Time (RTT) estimation method. In this let T_{cur} be the current time when the ferry arrives. T_{avg} is the estimation time when the ferry arrives. Let a_1 be a constant representing the gain for T_{avg} estimation time and the value of a_1 lies between 0 and 1. Also, let a_2 be a constant representing the gain for deviation from the estimated value (Dev), with value greater than 1, chosen such that there is an acceptably small probability that the round-trip time for the ferry will exceed the normal value. Constants a_1 *and* a_2 control how rapidly the TCP - Smoothened RTT (TCP-SRTT) adapts to changes.

$$Error = T_{cur} - T_{avg}$$

$$T_{avg} = T_{avg} + a_1 * Error$$

Deviation from the estimated value (Dev) is given by

$$Dev = Dev + a_2 * (ABS(Error) - Dev)$$

So the expected time, T_{exp} is approximately given by:

$$T_{exp} = T_{avg} + 4 * Dev$$

Then, *wait*(*f*) is given by, $wait(f) = T_{exp} - T_{cur}$

Later we will consider the case where the ferry has finite amount of buffer. Here a finite amount of the buffer is allocated for each gateway, so we want to consider the procedure of preempting/uploading the messages at each gateway so as to utilize the complete buffer space intelligently.

III. Evaluation

We will conduct in-lab simulations and field experiments to evaluate the performance of the developed algorithms. For in-lab simulations we will implement delay-tolerant network components that are compatible with SSFNet simulator. For field measurements, we will deploy several prototype ad-hoc networks on the corners of our campus, and install mobile routers on USC campus shuttle nextbus system to simulate the ferry nodes. We will also use personal vehicle to simulate a slow ferry node. We will model traffic demand pattern under different scenarios and validate the developed algorithms under the various traffic demand patterns.

In the simulations and experiments we will evaluate the Quality function in different network configurations for various paths, which helps us determine the appropriate values for α and β involved in Q. We will also evaluate the effect of the deviations in the ferry arrival time on the Q factor for the routed messages. Moreover, we will investigate how often the ferries should update their schedule and buffer allocation policy to achieve the best performance.

In the future work, we plan to design and evaluate sophisticated buffer allocation schemes for preempting and relaying the data between multiple gateways and multiple ferries. For more information please refer to our website at http://www.cse.sc.edu/~chaturv2/Projects/DTN/main.html

IV. References

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