

Performance Comparison of Two Interdomain Routing Schemes for Disruption Tolerant Networks

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Abstract— Much research work has been done to design routing protocols for mobile ad hoc networks. However, existing solutions assume an end-to-end path exists from a source to a destination. Some ad hoc network scenarios are characterized by frequent partitions and intermittent connectivity. Hence, new routing schemes for such networks have emerged in the past two years. These disruption tolerant network (DTN) routing schemes assume a flat architecture. However, in real life scenarios, nodes may be from different administrative domains and hence form different clusters. Thus, other means need to be provided to deliver interdomain traffic. When nodes from different domains can potentially hear one another, one can use a gateway approach. Otherwise, message ferries can be used to deliver messages between partitioned nodes. In this paper, we compare the performance of these two types of interdomain routing schemes. Our evaluations show that the message ferry-based approach performs better than the gateway approach.

Keywords: interdomain routing; disruption tolerant networks; ferry route design

I. INTRODUCTION

Wireless adhoc networks are networks that can be formed dynamically by mobile hosts without any preinstalled infrastructure. Much work has been done in the past to design flat routing schemes for adhoc networks [1],[2]. The flat adhoc routing scheme is proven to have poor scalability [3]. Hence, hierarchical routing solutions have been recently proposed. For example, in [4], the authors propose a two level hierarchical adhoc network where some “backbone” nodes are assumed to have an additional powerful radio to establish long range wireless links among themselves, thus forming a mobile backbone. The backbone nodes are also moving and hence they form yet another adhoc network. The local subnets can run one routing protocol while the mobile backbone runs another routing protocol.

There are very few papers that address interdomain routing problems for the communication between various adhoc groups from different administrative domains and possibly with different network configurations. In [5], we designed and compared three gateway-based interdomain routing schemes for mobile ad hoc networks. In [5], we still

assume that an end-to-end path between a source and a destination from different domains exists. However, there are some real-life scenarios e.g. battlefields, disaster relief efforts where we may have clusters of nodes that are far away from one another and hence an end-to-end path may not exist either within each cluster of nodes or between clusters.

Recently, a new network architecture [6] called the Disruption Tolerant Network (DTN) has been proposed to allow partitioned nodes or clusters of nodes to communicate with one another. Recent research interests in this area include network architecture design [6],[7], and different routing algorithms for DTNs [8][9][10],[11],[12]. Most of the routing schemes designed are delivering intradomain traffic. In some scenarios e.g. battlefields, disaster relief efforts etc, there may be clusters of nodes that form different ad hoc networks that cannot communicate with one another. Hence, new interdomain routing schemes need to be designed to allow different clusters to communicate with one another.

In this paper, we propose two interdomain routing schemes for DTNs, namely (a) the gateway-based interdomain routing (GBIR) scheme, and (b) the ferry-based interdomain routing (FBIR) scheme. GBIR scheme is more useful for scenarios where nodes from different administrative domains may occupy overlapping geographical area while FBIR may be more useful for scenarios where clusters of nodes do not meet and are far away from one another. However, we are interested in knowing whether FBIR will perform better than GBIR in scenarios where the geographical area occupied by different clusters overlap partially.

The remainder of this paper is organized as follows. We provide a brief review of related work in Section II. In Section III, we present two interdomain routing schemes in detail. In Section IV, we describe our simulation setup and present our simulation results. We conclude in Section V with some discussions on future work.

II. RELATED WORK

A. Routing in Intermittently Connected Networks

Several routing schemes have been proposed for DTNs [10],[11],[12],[13],[14]. These different schemes can be grouped into three categories. The first category [9] uses special nodes called ferries to deliver messages between partitioned networks. Ferry routes have significant effect on the data delivery performance, hence they need to be designed efficiently. The second category [11],[12] uses multihop routing approach where contact history information is used to determine the next hop node to pass a message. For example, in [12], a probabilistic metric called delivery predictability is used to determine if a node needs to pass any stored messages to a new contact that it comes across. The third category [13],[14] uses a two-hop routing approach where the intermediate nodes that receive messages from any source have to store the messages until they can deliver the messages when they come into contact with the destinations of the messages. Sometimes, erasure-coding is used to encode and divide the message into multiple blocks and these different blocks are sent to different relays to increase the chances of a destination receiving a particular message since the destination only needs to receive a certain fraction of the encoded blocks to reconstruct the original message.

B. Hierarchical and Interdomain adhoc network routing

Most of the existing routing researches for adhoc networks only deal with scenarios where the nodes belong to the same administrative group. A real interdomain routing problem studied so far is the communications between adhoc networks and the wired Internet [15],[16]. These approaches assume that the nodes wait for a certain period of time for route replies. If no route reply is heard, then the sending node assumes that the destination node is in the wired Internet and proceeds to use Mobile-IP like protocol to register with a foreign agent that can access the wired Internet so that its packets can be delivered to the desired destination outside the adhoc network. Our paper [5] is the first that addresses the interdomain routing schemes for communications between different adhoc groups. In [5], we design and compare three interdomain routing schemes. These schemes are gateway-based schemes where the nodes from one group that can hear nodes from another group will compete to become the gateway for forwarding interdomain route requests. Since the nodes move and hence the gateway nodes may change frequently, these schemes will not perform well especially when the

nodes become sparsely distributed over a large area. Thus, in this paper, we design a new gateway-based interdomain routing scheme that has better performance than the schemes described in [5]. In addition, we also design a ferry-based interdomain routing scheme. In [8], the authors also propose using message ferries to deliver inter-region messages. Our work differs from theirs in that we use the waiting time as the triggering condition for ferry to move to foreign group and we allow ferry to visit multiple groups before returning. In addition, we evaluate the impact of intradomain routing protocols on the end-to-end delivery delay of interdomain traffic.

III. INTERDOMAIN ROUTING SCHEMES

In this section, we describe the two interdomain routing schemes we consider.

A. Gateway-Based Interdomain Routing (GBIR) Scheme

Figure 1 illustrates how GBIR works. There are three components in GBIR, namely (a) leader selection and transfer, (b) gateway registration, deregistration, and transfer, and (c) data delivery.

1) Leader Selection and Transfer

All nodes which are within one hop away from the center of the subnetwork area are considered leader candidates. At the bootstrap stage, every leader candidate backoffs a random time before sending a message to claim its leadership. The node that sends the claim first will be selected as the leader. If more than one leader succeeds almost the same time, the one closest to the subnetwork center will be selected.

When a leader moves out of the one hop area from the center, it checks all its neighbors and chooses the one which is closest to the subnet center to take over its leadership.

2) Gateway registration, deregistration and transfer

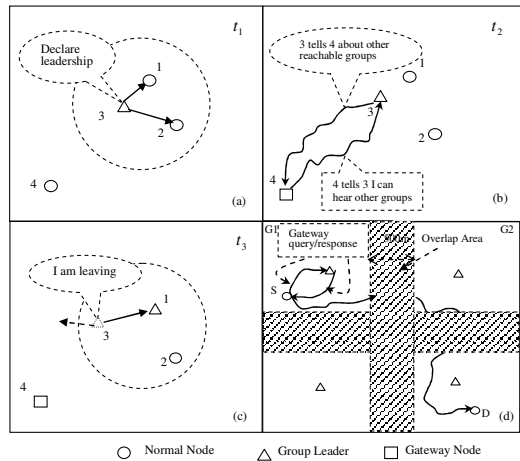
Each node broadcasts a beacon periodically when it enters into the overlapping area. Any node that hears messages from other groups forwards a gateway registration message to the leader of its own subnetwork. Since the leader of the subnet is always within the single-hop area from the subnet center, geographical routing will be used to forward registration message. Thus, even if the gateway does not know the identity of its current leader, it can still register successfully with its leader. The registration message contains gateway location information.

When a registered gateway cannot hear from other groups, it sends a de-registration message to its

leader. When a gateway node moves away from the overlapping area, it finds a neighbor from its subnet that is currently in the overlapping area to take over.

3) Data Delivery

When a node has data to send to another group, it queries its leader for the gateway information. The leader only provides information on a rough location of the gateway. When a query node gets a response from the leader, it uses the underlying multihop routing or geographical forwarding scheme to deliver the data packets to the gateway.



Gateway based inter-group routing: (a) Leader Election (b) Gateway Registration (c) Leadership Transfer (d) Data delivery

Fig. 1: Gateway-Based Interdomain Routing Scheme

B. Ferry-Based Interdomain Routing (FBIR) Scheme

In FBIR, we assume that each group has one ferry which is responsible for delivering intergroup messages from this particular group to all other groups. We further assume that each group member knows the identifier of its own group’s ferry.

A ferry can be in either of two possible states: (i) local i.e. being with its own group, and (ii) roaming i.e. the ferry is visiting other groups. When a ferry crosses over to a neighboring territory, it broadcasts a service announcement message periodically to discover nodes from other groups. A ferry also periodically checks the packets that are stored in its buffer to see if

- a) there are packets which have been queued more than w seconds,
- b) the buffer occupation has exceeded 99%,

If either of these conditions happens, then the ferry will start to move towards the destination group of the oldest message among those queued messages. If the second condition is the triggering condition, then the ferry will visit the destination group with the highest

number of queued messages. If both conditions are triggered, then the ferry will consider condition (b) to be more important than condition (a) and act accordingly.

We assume that the ferry knows the approximate location of the destination group. When the ferry approaches the border of the destination group, it issues hello messages periodically to look for nodes from the destination group. Once such a node is discovered, the ferry transfers messages destined to this destination group to this newly discovered node. If there are messages destined to other groups in the ferry’s buffers, then the ferry will move to other groups. Otherwise, the ferry stays in the visiting group to collect messages destined to the ferry’s own group. The ferry continues the data collection until one of the above two conditions triggers the ferry to move back to its own group.

Each node within a group delivers an intergroup message either to the local ferry or a destination group’s ferry that is currently visiting. Figure 2 illustrates how the ferry-based interdomain routing scheme operates.

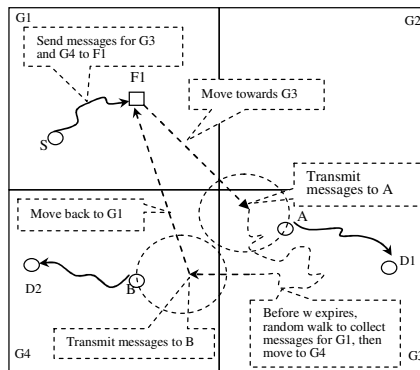


Fig. 2: Ferry-Based Interdomain Routing Scheme

IV. PERFORMANCE EVALUATION

A. Simulation Setup

In order to compare the two interdomain routing schemes, we implement these two schemes in ns-2 [18]. We also implement two intradomain routing protocols, namely (a) an enhanced DSR-like multihop routing scheme designed for DTNs [19] and a two-hop routing protocol described in [13]. The performance metrics we used in our evaluation are: (1) *Delivery Ratio*, which is the successfully received number of interdomain messages divided by the total number of interdomain messages sent. (2) *Average Delivery Latency* which is defined as the average end-to-end delay incurred by interdomain messages, and (3) *Transmission Efficiency* is the total number of received

interdomain messages over the number of transmissions used to deliver these interdomain messages.

In our simulation, we use a network scenario with four groups of nodes. Each group has 20 nodes which are constrained to move within a geographical area of 1400x1400m² (shown in Figure 2). All the nodes communicate using a transmission range of 250 m and a bandwidth of 2 Mbps. Since the transmission range is 250m, there is an overlapping area where different groups of nodes may potentially hear one another. The nodes move according to the random waypoint model. Unless otherwise stated, we set the pause time to be 10 seconds, and the maximum node speed to be 5 m/s. There is only one ferry in each group and the ferry speed is set to 15 m/s unless otherwise stated. The ferry buffer size is set to 600 messages.

The sources and destinations of the intradomain flows are randomly selected among the nodes from a group. For interdomain flows, we use a random group communications pattern where each group has one intergroup flow to each of the other three groups. We randomly select the source or destination of each interdomain flow from the selected groups. Thus, there are 12 intergroup flows in each scenario. Each flow generates CBR traffic with a packet size of 512 bytes. The traffic generation rate for each flow is varied from 0.2 msgs/sec to 2 msgs/sec. We run each simulation for 10,000 seconds with a warming up period of 1000 seconds and the reported simulation results are based on the average of 5 runs.

B. Comparison of different interdomain routing schemes with random traffic model.

In our first set of experiments, we compare the performance of the gateway-based and ferry-based interdomain routing schemes. We use the random group communication pattern for the intergroup traffic scenario with 0, 4 or 8 intragroup flows. All four groups use the enhanced multihop scheme as the intradomain routing scheme. We vary the traffic generation rate of each flow (both intergroup and intragroup flow) from 0.2 pkt/sec to 2 pkts/sec.

Figures 3 to 5 show the delivery ratio, the average delay and the transmission efficiency for the scenario where all groups use multihop routing scheme as the intradomain routing scheme (refers to as Scenario 1). From the plots, we see that the ferry-based interdomain routing scheme gives higher delivery ratio and smaller delivery latency for the interdomain traffic. The improvement in delivery ratio with the FBIR scheme grows larger with increasing traffic load. This is because the GBIR scheme uses paths with more hops and hence suffers from more frequent path changes and

hence more packets are dropped with increasing traffic load during path changes. The average packet delivery latency with the FBIR scheme is also better than that achieved using the GBIR scheme. The average packet delay using the FBIR scheme is 50% of that achieved using the GBIR scheme when each flow generates 0.25pkts/sec, and the delay achieved by the FBIR scheme is only 33% of that achieved using the GBIR scheme with each flow generates 2 pkts/sec.

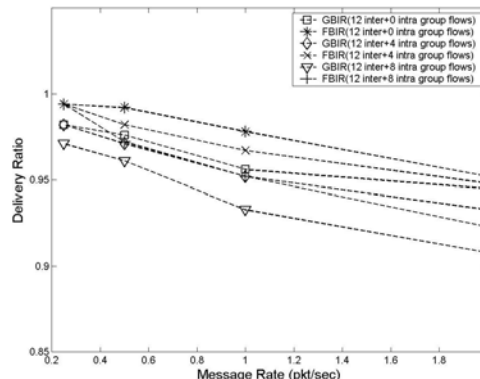


Figure 3: Delivery Ratio vs Message Rate (Scenario 1).

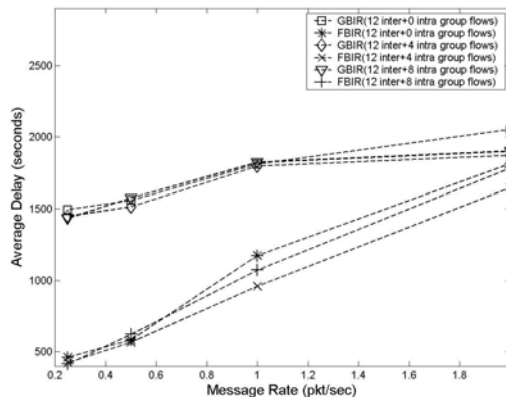


Figure 4: Average Delay vs Message Rate (Scenario 1)

C. Impact of different intradomain routing schemes

Using the random group communication traffic pattern, we investigate on the impact of different intradomain routing schemes on the performance of the interdomain traffic delivery. We use two more scenarios, namely having (a) all four groups use two-hop relay scheme as their intradomain routing schemes (Scenario 2), (b) two groups use the enhanced multihop routing scheme and two groups use the two-hop relay scheme as their intradomain routing schemes (Scenario 3). Figures 6-8 plot the delivery ratio, the average delay and the transmission efficiency with all four groups using two-hop relay scheme as the intradomain routing scheme. Figures 9-11 plot the

delivery ratio, the average delay and the transmission efficiency with two groups using the enhanced multihop scheme and two groups using the two-hop relay scheme as the intradomain routing scheme.

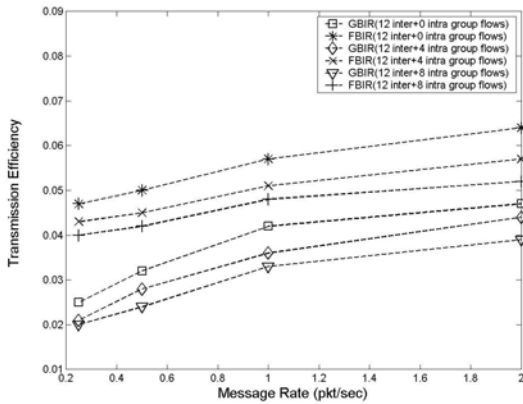


Figure 5: Transmission Efficiency vs Message Rate (Scenario 1)

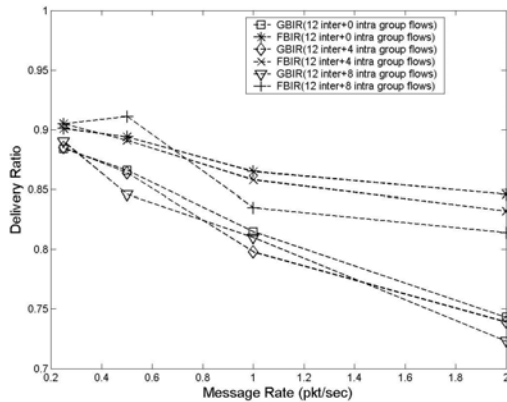


Figure 6: Delivery Ratio vs Message Rate (Scenario 2)

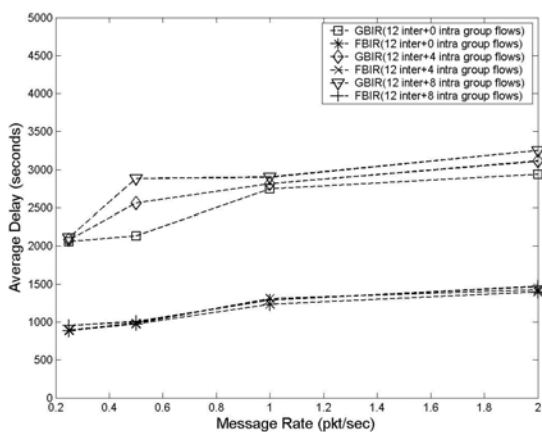


Figure 7: Average Delay vs Message Rate (Scenario 2)

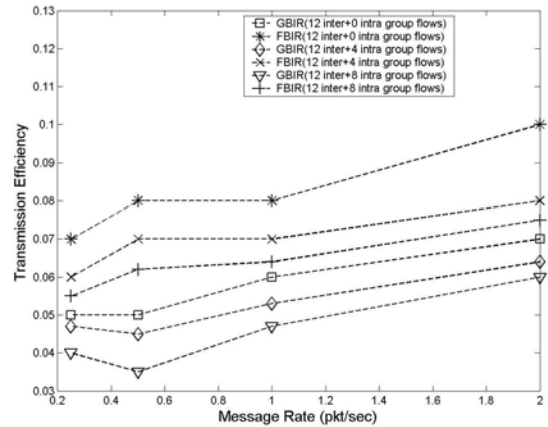


Figure 8: Transmission Efficiency vs Message Rate (Scenario 2).

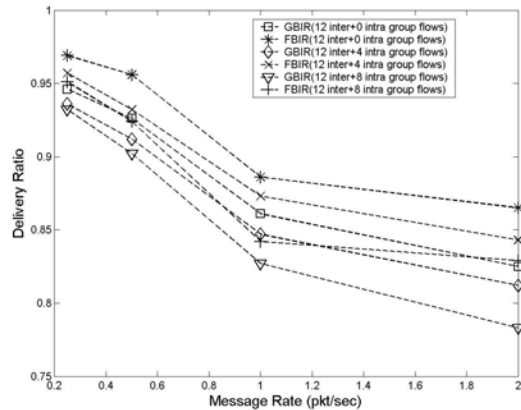


Figure 9: Delivery Ratio vs Message Rate (Scenario 3)

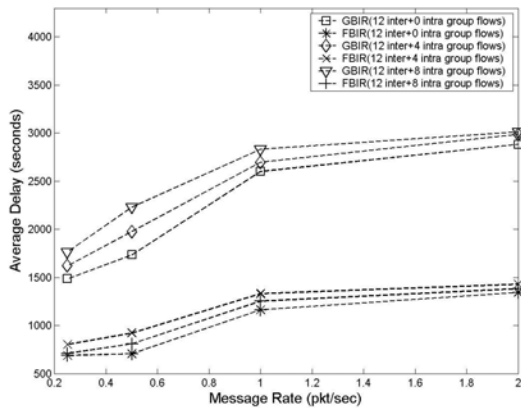


Figure 10: Average Delay vs Message Rate (Scenario 3)

The results indicate that the interdomain traffic delivery performance is better when all groups use the enhanced multihop scheme as the intradomain routing scheme. The interdomain traffic delivery performance

with all groups using the two-hop relay scheme is the worst. The performance achieved with two groups using the enhanced multihop and two groups using the two-hop relay scheme is intermediate between the best and the worst case. The number of intradomain flows affects the end-to-end delivery performance of interdomain flows more when the intradomain approach is a multihop approach and also when the interdomain approach is the gateway-based approach.

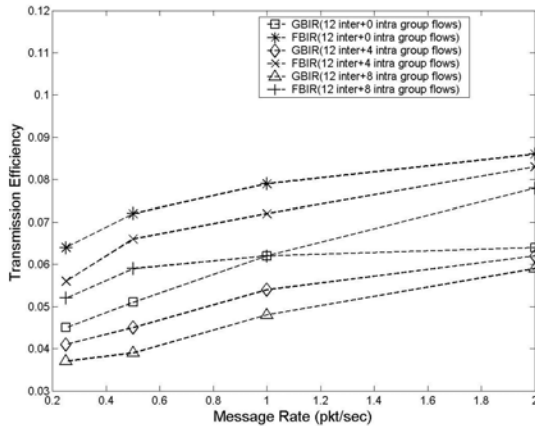


Figure 11: Transmission Efficiency vs Message Rate (Scenario 3)

All the results indicate that the ferry-based interdomain routing scheme achieves higher delivery ratio and smaller average end-to-end delivery latency for the interdomain traffic irrespective of the intradomain routing scheme used by each group.

V. CONCLUSION

In this paper, we have presented two interdomain routing schemes for disruption tolerant networks, namely the gateway-based, and the ferry-based interdomain routing scheme. Our simulation studies show that the ferry-based scheme achieves higher delivery ratio and lower average end-to-end delay for the interdomain traffic. In addition, we also study the impact of running different intradomain routing schemes on the delivery performance of intergroup traffic. Our studies show that the delivery performance of intergroup traffic is the best when all groups use the enhanced multihop routing scheme as their intradomain routing protocol and the worst when all groups use the two-hop relay scheme as the intradomain routing protocol. The achieved intergroup delivery performance is intermediate between the best and the worst case when two groups use the enhanced multihop scheme and two groups use the two-hop relay scheme as their intradomain routing scheme.

There are several interesting issues we intend to explore further e.g. we wish to investigate the impact of

mobility models, traffic patterns, and the number of ferries on the delivery performance of the interdomain traffic.

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