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Experimental Evaluation of Gateway Based Interdomain Routing Scheme for DTN

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EXPERIMENTAL EVALUATION OF GATEWAY BASED INTERDOMAIN ROUTING SCHEME FOR DTN

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ABSTRACT

EXPERIMENTAL EVALUATION OF GATEWAY BASED INTERDOMAIN ROUTING SCHEME FOR DTN

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Many routing protocols have been designed for mobile ad hoc networks. However, those existing solutions assume an end-to-end path established from a source to a destination. Some ad hoc network scenarios are characterized by intermittent connectivity and frequent topology changes. Therefore, disruption tolerant network (DTN) technologies are proposed to cope with these scenarios. Many routing protocols have been proposed for DTNs used for delivering messages within the same administrative domain. However, in real life scenarios, multiple groups may desire to communicate with one another. Thus, interdomain routing protocols need to be designed to deliver interdomain traffic.

In this thesis, we describe how we design experiments using the ORBIT testbed to evaluate the Gateway Based Interdomain Routing (GBIR) protocol. We also study the message delivery performance of GBIR in a large scale network by emulating node mobility using traces generated by the reference point group mobility (RPGM) model generator. Specifically,

we study how message sizes and the choice of intradomain routing scheme affects the end-to-end message delivery latency as well as the successful delivery ratio. In addition, we study the impact of node speed on the delivery performance. Our evaluations show that GBIR achieves high delivery ratio and low end-to-end delivery latency for the interdomain traffic. Smaller E2E delivery latency is observed when nodes move faster (but not to the extent of causing too much link disruptions). In addition, smaller intradomain delay is observed when a domain runs the PROPHET scheme rather than the RAPID scheme.

Chapter1

Introduction

Nowadays, small computing devices with wireless interfaces are involved in most aspects of people's daily life, e.g. PDAs, smart phones and portable game stations etc. These devices can form Mobile Ad Hoc networks (MANETs) and communicate with one another via the help of intermediate nodes [10]. The reason why MANETs draw more and more attention is that MANETs enable effective communications in infrastructureless networking scenarios including military operations, emergency operations for disaster recovery [1], and vehicular networks etc. Many MANETs routing protocols such as DSDV, OLSR and ADOV, etc, have been designed. However, these schemes cannot perform well in some challenging network scenarios where nodes have intermittent connectivity [10] and suffer frequent dynamic network topology changing. In these challenging environments, popular ad hoc routing protocols fail to establish routes because these ad hoc routing protocols try to establish an end-to-end route first before data can be forwarded[2] but such a route may not exist. Therefore, disruption tolerant network (DTN) technologies are proposed. Disruption tolerant networks (DTNs) allow nodes to store packets when there is no route to the destination and thus enable communications in networks with intermittent connectivity where end to end paths do not exist. By using the Bundle Protocol defined in [RFC4583], messages are turned into bundles and these bundles are routed in a store-and-forward manner between participating nodes until the bundles arrive at their destinations. Each node in DTN is assigned an Endpoint Identifier (EID). For the past few years, many routing protocols have been proposed for DTNs e.g. Probabilistic Routing Protocol using History of Encounters and Transitivity (PROPHET) [3] and Resource Allocation Protocol for Intentional DTN (RAPID) [4]. These DTN routing protocols mostly are used for delivering messages within the same administrative domain.

However, in real life, multiple groups or organizations may desire to communicate with one another but they may want to use their own intradomain routing protocols. Thus, interdomain routing protocols need to be designed such that interdomain messages can be delivered from one domain to another. For an instance, in a disaster recovery scenario, police force may need to coordinate with fire fighters and medical crews by sharing information and communicating with each other regardless of the particular networking protocols that each group uses. The existing Border Gateway Protocol (BGP) is the inter-domain routing protocol being used in the Internet. However, BGP is not applicable to MANETs and DTNs because BGP has been designed for a static Internet. Therefore, new inter-domain routing schemes should be designed to cope with new challenges that exist in MANETs and DTNs e.g. dynamic topology changes, lack of connectivity and etc. Some interdomain ad hoc routing protocols for MANETs have been designed, e.g., Geo-based Inter-domain Routing Protocol (GIDR) [5] and Cluster-based Inter-domain Routing Protocol (CIDR) [6]. A Gateway Based Inter-domain Routing Protocol (GBIR) [7] has been designed for DTNs. A prototype of the GBIR protocol has been developed but no one has done any evaluation of this protocol in a real testbed with many nodes.

In this thesis, we describe how we design experiments using the ORBIT testbed [8] to evaluate the GBIR protocol. We also present the measurement results we obtained in our experiment. Specifically, to evaluate the performance of GBIR in a large scale network, we set up an experiment network that consists of 16 nodes in ORBIT [8]. These 16 nodes present five domains with 3 or 4 nodes in each domain. We let three domains run PROPHET as their intradomain routing protocols while the other two run RAPID. We further developed scripts to emulate node movements in each domain. Using a UDP traffic generator we developed, we evaluated the delivery ratio and end-to-end message delivery latency of the GBIR protocol when messages of different sizes are sent. We also evaluate the impact of node speed on the delivery ratio and message delivery latency.

The rest of the thesis is organized in the following way. The background is briefly reviewed in Chapter 2. Detail description of Gateway Based Inter-domain Routing Protocol (GBIR) is presented in Chapter 3. Mobility models are presented in Chapter 4 Experimental setup and evaluation results are presented in Chapter 5. Last but not least, our concluding remarks are provided in Chapter 6.

Chapter 2

BACKGROUND

Here, we provide a brief overview of some of the existing intra-domain and inter-domain routing protocols that have been proposed in the literature for MANETs or DTNs.

2.1 Routing Protocols of Intermittently Connected Networks

In DTNs, there is no guarantee that a fully routing path between source and destination exists at any time, resulting in the failure of many popular intra-domain routing protocols designed for MANETS in DTNs. Thus, new intra-domain routing protocols need to be designed for DTNs, e.g., Spray and Wait [11], PROPHET [3], RAPID[4], Message Ferrying Scheme [12]. In general, these DTN routing protocols can be categorized into three categories:

- Ferry-based forwarding schemes, e.g. Message Ferrying scheme: special nodes called ferries are deployed to deliver messages between nodes that are partitioned. Ferry routes are carefully designed to meet certain delivery performance.
- Multihop forwarding schemes, e.g., PROPHET: Contact history information is used to determine the next hop node to pass a message.
- Two hop forwarding schemes, e.g., Spray and Wait: Intermediate nodes that receive messages from any source will have to store them and can only wait till

they meet the destinations before transferring these stored messages. Sometimes, redundant coded copies are used to improve the delivery performance.

In this thesis, we choose two protocols that have been deployed in real DTNs, namely PROPHET [3], and RAPID [4]. PROPHET was deployed in the Saami Network Connectivity (SNC) project in Sweden [23] while RAPID is deployed in a vehicular ad hoc network in the town of Amherst, Massachusetts [13].

2.1.1 PROPHET

The protocol operates on the assumption that human mobility is non-random, i.e. nodes in a network move in a predictable fashion rather than move randomly. If a node has reached a point several times, it is most likely that it will visit that location again. The PROPHET protocol assumes that knowledge of the history of previous encounters is a good indicator of future encounters. Based on this assumption, Anders Lindgren et al. [3] designed a probabilistic metric called delivery predictability, $\boldsymbol{P}_{(a,\ b)} \in [0,\ 1]$. This metric represents the chances of successfully delivering messages from every source node **a** to each known destination **b** and the metric value is updated using information about past encounter histories.

Specifically, this delivery predictability is calculated in the following ways:

Every node periodically sends a beacon to neighbor nodes about the existence of itself. A node a that can hear another node b's beacon will update the delivery predictability P(a,b) using Eq. 1 where $\boldsymbol{P}_{init} \in [0, 1]$ is an initialization constant.

$$\boldsymbol{P}_{(a,\, b)} = \boldsymbol{P}_{(a,\, b)old} + (1 - \boldsymbol{P}_{(a,\, b)old}) \times \boldsymbol{P}_{init} \tag{1}$$

The delivery predictability to non-neighbor nodes can be updated if neighbor nodes have a history of encounters with these non-neighbor nodes. This is called the transitive property. Let us assume that node **a** and node **b** are neighbors, and that node **b** has the information of encounters with node **c**. The delivery predictability of node **a** to node **c** is calculated using Eq. 2, where $\beta \in [0, 1]$ is a scaling constant that decides the transitivity impact.

$$\boldsymbol{P}_{(a,\, c)} = \boldsymbol{P}_{(a,\, c)old} + (1 - \boldsymbol{P}_{(a,\, c)old}) \times \boldsymbol{P}_{(a,\, b)} \times \boldsymbol{P}_{(b,\, c)} \times \beta \tag{2}$$

When a neighboring node moves out of connectivity, its delivery predictability is being reduced using Eq. 3, where $\gamma \in [0, 1]$ is the aging constant, and κ is the number of times its beacons are missed.

$$\boldsymbol{P}_{(a,\, b)} = \boldsymbol{P}_{(a,\, b)old} \times \gamma^{k} \tag{3}$$

The forwarding strategy is always to pick a neighboring node with the highest delivery predictability to the destination as the next hop. This protocol assumes that the bandwidth is unlimited and messages can be delivered in each encounter. However, this scenario is uncommon and if the duration of connectivity is unable to guarantee the fully transmission of all stored messages, PROPHET cannot perform well in this situation. Thus, the RAPID is proposed to provide better delivery performance in scenarios where the contact duration during node encounters may be short or the communication bandwidth when nodes meet varies.

2.1.2 RAPID

Although RAPID also makes use of historical information like PROPHET, the system model that RAPID designers assume is more realistic, i.e. they assume limited storage for in-transit data, finite bandwidth and short-lived connectivity.

RAPID provides rules on how to replicate packets to another encountered node such that a specified routing metric is optimized under the limited bandwidth assumption. A utility function is used to assign a utility value, U_i to every packet i, which is based on the performance metric being optimized. U_i is defined as the expected contribution of packet i to this metric. RAPID defines three metrics:

- Average delay
- Percentage of Packets that missed the deadlines
- Maximum delay

For an instance, let us assume that our objective is to optimize the average delay. The utility function defined for average delay is U_i = - $D(i)$, basically the negative of the average delay. Since the packet's expected delay is its contribution to the performance metric, the protocol replicates the packet that results in the greatest decrease in delay in a greedy manner. If network resources are sufficient to support flooding, then RAPID will replicate all packets. In a nutshell, RAPID achieves high delivery ratios and good latency performance, but still at the expense of excessive network resource usage.

2.2 Interdomain Routing Protocols of Ad hoc Networks

With the increasing popularity of using ad hoc networks, facilitating interoperations among multiple MANETs is becoming more and more important. Some inter-domain routing protocols for MANETs have been designed [1], [5], [6]. These approaches focus on identifying the challenges in real mobile ad hoc networks which never exist in static Internet scenario and come up with solutions to deal with these issues, e.g. dynamic node discovery, dynamic domain split/merge, frequent network topology changes due to mobility, etc. Any proposed solution needs to be scalable. In [6], the authors propose using clustering technique to generate clusters as domains. In each domain, a Cluster Head (CH) will be elected and acts as local DNS for the rest of nodes in its own domain and also for neighboring CHs. Thus, the routing mechanism is separated into two stages: (1) using local routing algorithm for local delivery; (2) routing inter-domain packets via cluster head advertised routes. In [5], the only difference with [6] is its routing algorithm. The authors assuming all nodes are equipped with GPS and know their geographic locations. The protocol uses Geo-DFR (Greedy Forwarding + Direction Forwarding) as its core routing scheme. First, it uses Greedy Forwarding to forward packets to the node which is the closest to the destination. In case of a failure of forwarding to the closest node due to a "hole", like a big mountain, the second forwarding feature will be applied. Direction Forwarding will route the packets to the "most promising" node along the advertised direction.

Although these approaches provide good delivery performance in some scenarios, they do not perform well in other situations, such as vehicular area networks and sensor network for whale monitoring [3]. The degradation in performance is due to frequent changes of gateway nodes in former scenario and sparsely distributed nodes over a large area in the latter scenario. Thus, in Disruption Tolerant Networks, these inter-domain protocols for MANETs are not able to achieve good performance. In order to address these new challenges in DTNs, new inter-domain protocol named Gateway Based Inter-domain Routing Protocol (GBIR) is proposed in [7]. The detail description of GBIR will be introduced in Chapter 3.

Other DTN routing schemes focus on addressing routing data among different groups or clusters are proposed, e.g. [14] [15].

In [14], Harra et al design a routing scheme for mobile nodes that self organized themselves into different clusters/regions. Within each region, there is an end-to-end path between any two nodes. In order to achieve inter-regional routing, this proactive approach introduces some extra nodes (messengers) which move around the networks actively for creating chances to re-connect disconnected regions or nodes. The authors describe two messenger ownership schemes: regional messengers and independent messengers, and three scheduling strategies for message delivery type: periodic, storage-based and on-demand. To realize this, messengers know the location of regions from updates provided by a GPS enabled node in each region. However, it only considered a one-hop delivery system where messengers visit one destination during each trip.

In [15], Chuah et al's work uses message ferries, i.e., nodes that store, carry and forward packets in a DTN. They address the disconnection problem in DTNs by allocating buffers in ferry nodes and other nodes in a max-min-fair fashion. They also incorporate this buffer allocation technique in their route design and present buffer efficient routing scheme (BERS) that achieves better session throughput and lower latency.

Chapter 3

INTERDOMAIN ROUTING SCHEME IN DTN

In this section, we first describe the system model we assume, and then present detail descriptions of how Gateway Based Inter-domain Routing scheme works.

3.1 System Model

We consider disruption tolerant networks where the nodes are mobile and end-to-end paths may not exist between any two nodes in the network. Each node is assigned to a group or domain administratively and will not change its group membership. A group may be a disaster rescue team or a military platoon. Security design is important for such scenarios but is considered to be out of the scope of this thesis.

The nodes within each group move as a group and each group moves independently from one another based on the Random Group Mobility Model (RPGM). When the nodes move as a group, each node is located within certain distance from a group center. We further assume that there is one node in each group that will act as the clusterhead. Each node has GPS device and hence can determine its location at any time. Each node periodically broadcasts a beacon that includes its end point identifier and its location. The end point identifier is structured in such a manner that each node can easily tell from its neighbor's beacon whether that neighbor belongs to its own group or not. For example, a node may have an EID that says “dtn://platoon5.battlionB.navy.us/sgt1234” while its neighbor may have an EID that says “dtn://platoon3.battalionB.navy.us/sgt2345”. The first node will realize that the other node belongs to the same battalion but not the same platoon. For security reason, such beacons can be encrypted with a group key and hence only group members or members from another friendly group with whom this group shares the key can decrypt the beacons. In this thesis, we assume all nodes are friendly and hence they can interpret all the information included in the beacons. In addition, we assume that the nodes are cooperative which means that they are willing to deliver interdomain traffic for other groups. All nodes are assumed to have a 802.11 radio that is used for beacon transmission and message delivery. The 802.11 radio uses default transmission parameters, e.g. it has a 250m transmission range.

3.2 Gateway Based Interdomain Routing (GBIR) Scheme

There are two stages in GBIR scheme, namely (1) gateway registration, deregistration, and (2) data delivery. Figure 1 and Figure 2 respectively illustrate the above two stages.

3.2.1 Gateway registration and deregistration

Each node broadcasts a beacon periodically. When one node moves into the overlapping area with other domains or it hears beacons of nodes from other domains, it will forward a gateway registration request message to its cluster-head (here, cluster-head is hard configured and known by the rest of nodes in the same domain). This step is shown in step (1) in Figure 1. This gateway registration request message contains information about the endpoint identifier of the potential gateway candidate, and the external domain that this candidate can hear.

After receiving the message, the cluster-head will send a gateway registration response message (as shown in step (2) in Figure 1) to that gateway candidate. The response message will indicate whether or not the gateway registration request is successful. There may be several nodes that can hear the same external domain, and in this case, cluster-head needs to assign one node to be the gateway for that external domain from all those candidates or limit the number of nodes that will act as gateway nodes for that external domain.

In the scenario of losing connectivity with any node in an external domain i.e. missing three beacons in a row), then a gateway node responsible for that external domain will send a deregistration message to inform its clusterhead (CH) of this change.

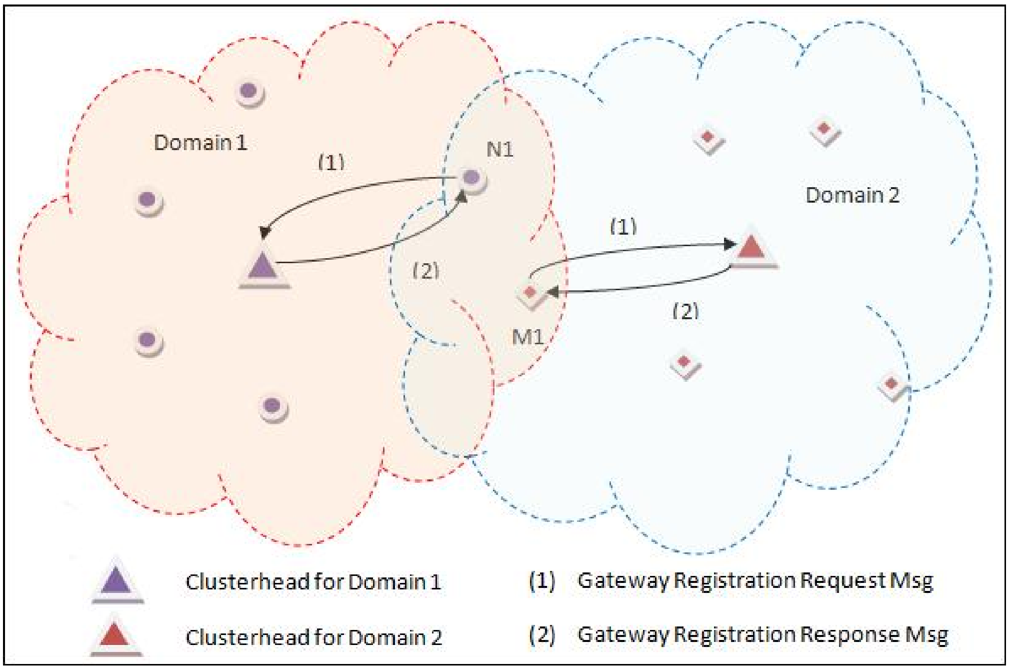

Figure 1: Gateway Registration of GBIR

3.2.2 Data Delivery

The delivery of data traffic happens in two steps: (a) for intra-domain data delivery, data is forwarded using the local intradomain routing protocol; (b) for inter-domain routing, a much more complicated procedure is performed. We illustrate how interdomain routing is performed in Figure 2.

When a node has data to send to another domain, it first checks if it is the gateway node for the destination domain. If so, this node can forward data directly to node that it can hear in the destined domain. Otherwise, it will send a gateway query request message (as shown in step (3) in Figure 2) to its cluster-head to query the gateway information. Upon receiving the query request message, the cluster-head replies with the information of gateway nodes that can reach the destination domain to the querying node in step (4).

After obtaining the gateway node information, the querying node will forward the interdomain data using its intra-domain routing protocol to that chosen gateway node. The inter-domain routing path is shown in step (5).

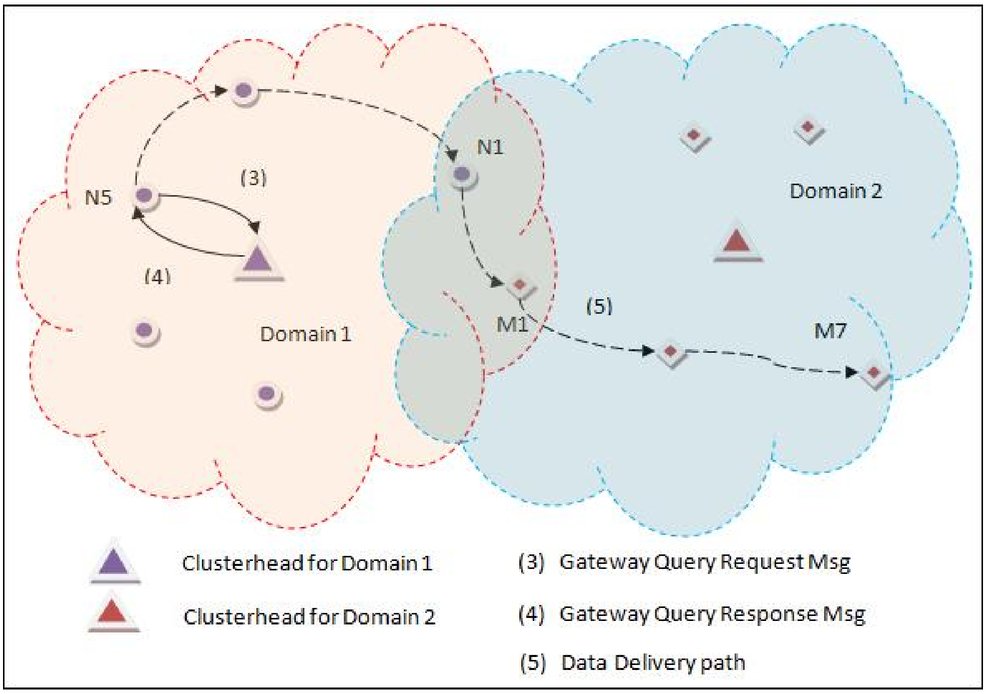

Figure 2: Interdomain traffic routing of GBIR

3.2.3 More Complex Scenarios

The above discussion only describes how interdomain traffic is delivered across two domains. In Figure 3, we describe how GBIR works with more than 2 domains. In Figure 3, we assume that some nodes in Domain 1 can hear nodes from Domain 2 but not any node from Domain 3. Similarly, some nodes in Domain 3 can hear nodes from Domain 2 but not Domain 1. Some nodes in Domain 2 can hear nodes from Domain 1 while other nodes in Domain 2 can hear nodes from Domain 3. To enable forwarding of interdomain traffic from Domain 1 to Domain 3, each cluster head should maintain a list of gateway nodes (referred to as the gateway list) and the foreign domains that these gateway nodes can reach. Whenever the cluster head (CH) receives any gateway registration request from a new gateway candidate node, the CH will make sure that there is no other node (or fewer than the maximum allowable gateways for an external domain) that is serving that external domain. If the CH approves that gateway registration request, then the CH not only sends a positive gateway registration response to that requesting gateway candidate node, the CH will also update the gateway list. Furthermore, the CH will send a control message to all gateway nodes to inform them of this new addition. To minimize the control overhead, the CH may only send incremental updates of all new gateway nodes periodically rather than using event-trigger approach. The downside of this periodic approach is there is some delay in getting the latest gateway nodes information.

In Figure 3, we show that Domain 1 and Domain 3 are running Prophet scheme as their intradomain routing protocol while Domain 2 is running RAPID as its intradomain routing protocol. We further show that node n3 from Domain 1 can hear node m1 from Domain 2 while node m3 from Domain 2 can hear node w1 from Domain 3. Thus, node n3 will serve as a gateway node for Domain 1 to reach both domain 2 & 3. Node m1 will serve as the gateway for Domain 2 to reach Domain 1 but node m3 will serve as the gateway node for Domain 2 to reach Domain 3. Node w1 will serve as the gateway node for Domain 3 to reach both domains 1 & 2.

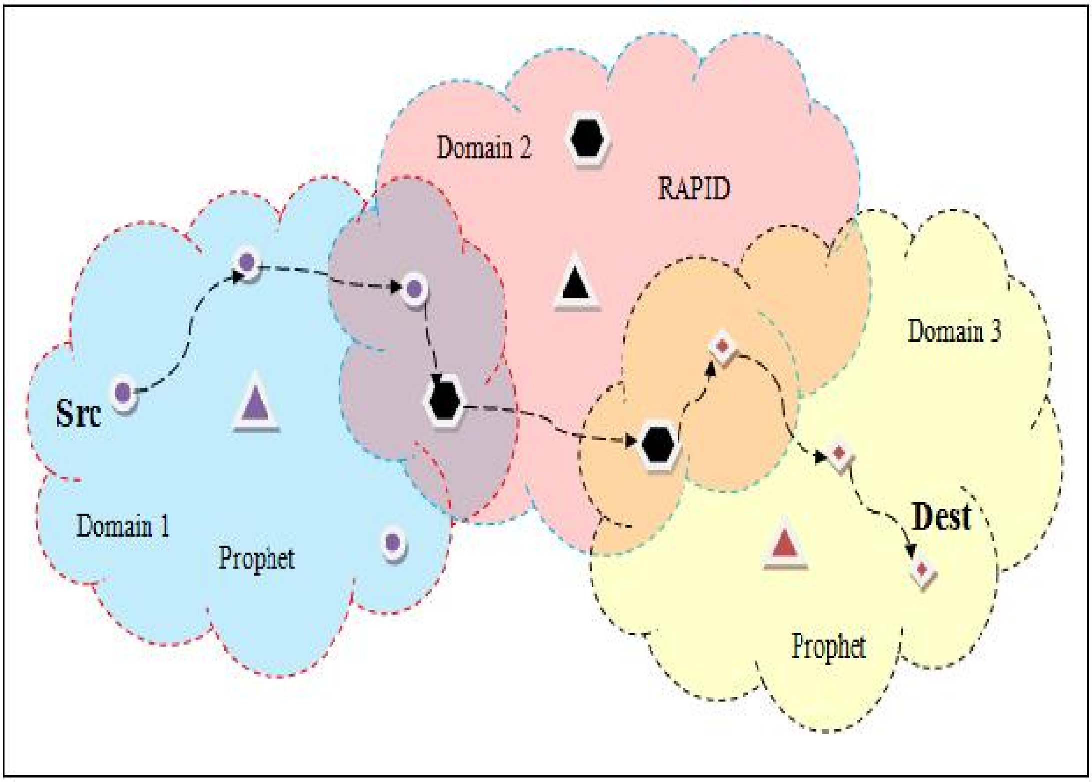

Figure 3: More Complex Interdomain Routing Scenario

Chapter 4

MOBILITY MODELS

In real life scenarios, the nodes move around. Thus, to properly evaluate both intradomain or interdomain routing protocols, we need to consider how nodes move. When wireless network protocols are designed, the performance analysis in the presence of node mobility is critically important because some protocols may not work well in the presence of node mobility. Thus, in this section, we describe several mobility models proposed in the literature.

In general, the mobility models can be classified according to different kinds of dependencies and restrictions [9].

- Random based: no dependencies or restrictions applied in the mobility model, e.g., the well-known Random Waypoint model (RWP) [16].
- Temporal dependencies: the actual movements of nodes are affected by the past. E.g. modeling in [18].
- Spatial dependencies: the movement of a node is influenced by the nodes around it, e.g. group mobility model such as the RPGM model [17].
- Geographic restrictions: the area where nodes are restricted to move in and out. The model is surveyed at [19] [20].

- ❖ Hybrid mobility model: a combination of all the above categories. In [22], the authors proposed to create hybrid mobility models by mixing the Random Waypoint and the Manhattan model.

4.1 Random Walk Mobility Model

The random walk mobility model is a random based mobility model for mobile communication systems. The mobility model is designed to describe the movement pattern of mobile users, and how their location, velocity and acceleration change over time. When a mobile node begins to move, it chooses its speed and direction from some predefined ranges. Then, it moves along that direction. After moving for a constant time or constant distance, the node changes its speed and direction and continues along this new path. The random walk mobility model is widely used, marked as memory less mobility pattern which means it retains no knowledge of past locations and speed values. This feature generates unrealistic movements compared to some real life scenarios which may have predictable stops or unpredictable stops. Another similar model that has been proposed is the random waypoint mobility model which includes some pause time at each turning point.

4.2 Random Waypoint Model

The random waypoint mobility model, which was originally proposed for studying the performance of MANETs, is simple and most widely used by researchers. In this model, a mobile node moves in an area along a zigzag path. Once the node reaches its destination location, it stays at that location for a certain period of time (referred to as the pause time) before it chooses its next destination location. After the pause time has elapsed, the node chooses the next destination randomly in the area and then moves toward that destination at a constant speed, which is drawn independently from a given speed distribution (0, V_{max}) where V_{max} is the maximum speed of a node and is a parameter that can be set to reflect the degree of mobility. As soon as the node arrives at the destination, it stays there for the pause time before the process is repeated again.

4.3 Reference Point Group Mobility Model (RPGM)

The reference point group mobility model represents the random motion of a group of mobile nodes as well as the random motion of each individual mobile node within the group. In RPGM [10], each group has a logical center whose motion defines the entire group's motion behavior, including location, speed and direction etc. The moving path of the center determines the trajectory of the group and nodes within the same group are usually randomly distributed within the group area. Each node within a group moves independently. It will choose a speed and direction that is derived by some slight deviations from the values chosen by its group's logical center. The velocity of each member is characterized as follows:

(i)|Vmember(t)|=|Vleader(t)|+random()*SDR*max_speed,

(ii) θmember(t)=θleader(t)+random()*ADR*max_angle.

where SDR is the speed deviation ratio, and ADR is the angle deviation ratio.

With appropriate selection of predefined paths for logical center and other parameters, the RPGM can be used to emulate various mobility scenarios including the following:

(a). In-place mobility model: battlefield communication is the best representative of this model, where an entire area is divided into several adjacent regions with each group travels only within each region.

(b). Overlapping mobility model: multiple groups with different tasks travel on the same area in an overlapping manner, e.g. disaster recovery scenario.

(c). Conventional mobility model: this model captures conference attendees. Different groups of attendees may be located in different rooms listening to authors' presentations while other groups of attendees may move from one room to another.

The first two, random waypoint mobility model and random waypoint mobility model, are often used in the past by researchers when they want to study and compare the performance of different intra-domain routing protocols in MANETs. The reference point group mobility model, is introduced when the researchers intend to evaluate the impact of group mobility on the performance of MANET routing protocols. This group mobility model is especially useful for evaluating the performance of interdomain routing protocols. The group mobility model allows us to represent having different groups of nodes moving within a certain geographical area and hence one group may have some overlapping area with another group at different time instants. Some nodes within one domain may hear one external domain while other nodes within the same domain may hear another external domain.

In this thesis, we use the mobility generator [21] to generate the group mobility trace. We assume that there are eight groups of nodes with each group having 20 nodes. The average group moving speed is 2.5 m/s and the average node speed is also 2.5m/s. The SDR and ADR are set to 0.1. Once the mobility trace is generated, we randomly select 5 groups and then select 3 to 4 nodes in each selected group. We extract the mobility traces of each of the 16 selected nodes and use these traces for our experiment.

Chapter 5

PERFORMANCE EVALUATION

In this section, we first describe the GBIR implementation used in our experiment. Next, we describe the testbed we used for our experimental evaluation of GBIR. Then, we describe our experimental design and present our experimental results.

5.1 GBIR Implementation

In the GBIR prototype [7] that we used, the following assumptions are made. Such assumptions are common for inter-domain routing [1].

- The node IDs are unique throughout the entire network and are pre-assigned. In DTN, each node has an Endpoint Identifier (EID) and periodically broadcasts beacons including its own EID. In GBIR, the EID of one node looks like: dtn://private1.navy.mil.dtn. It means this node is a member that belongs to the navy.
- The domain IDs are also unique across the whole network. In GBIR, the domain ID is the last three parts of each node's EID, e.g. navy.mil.dtn represents the domain for navy.

In the first stage of GBIR, namely gateway registration and deregistration (as discussed in chapter 3), when a node hears from another node that belongs to a different domain, it sends a gateway registration request to its cluster head. Upon receiving the request message, the cluster head will reply with a gateway registration response to decide whether or not this candidate is eligible to be the gateway for the external domain. When the clusterhead grants a gateaway candidate node's request to become a gateway, this clusterhead will multicast a gateway list update mssage to all the current gateways in its domain so that all of the internal gateway nodes can update their beacons with updated information of all external domains that can be reached by these gateway nodes. For example, in Figure 4, M1 in domain 1 can hear from N1 in domain 2. Assume M1 is given the permission to act as a gateway for domain 2; M1 will also receive the information about other foreign domains that N1 can reach, e.g. domain 3 and domain 4. Then M1 will report this event to its cluster head, and act as gateway to domain 3 and domain 4 after receiving the permission from cluster head. Now, by sending gateway query messages to their cluster head, other nodes in domain 1 can know that via M1 they can deliver data to domain 2, domain 3 and domain4.

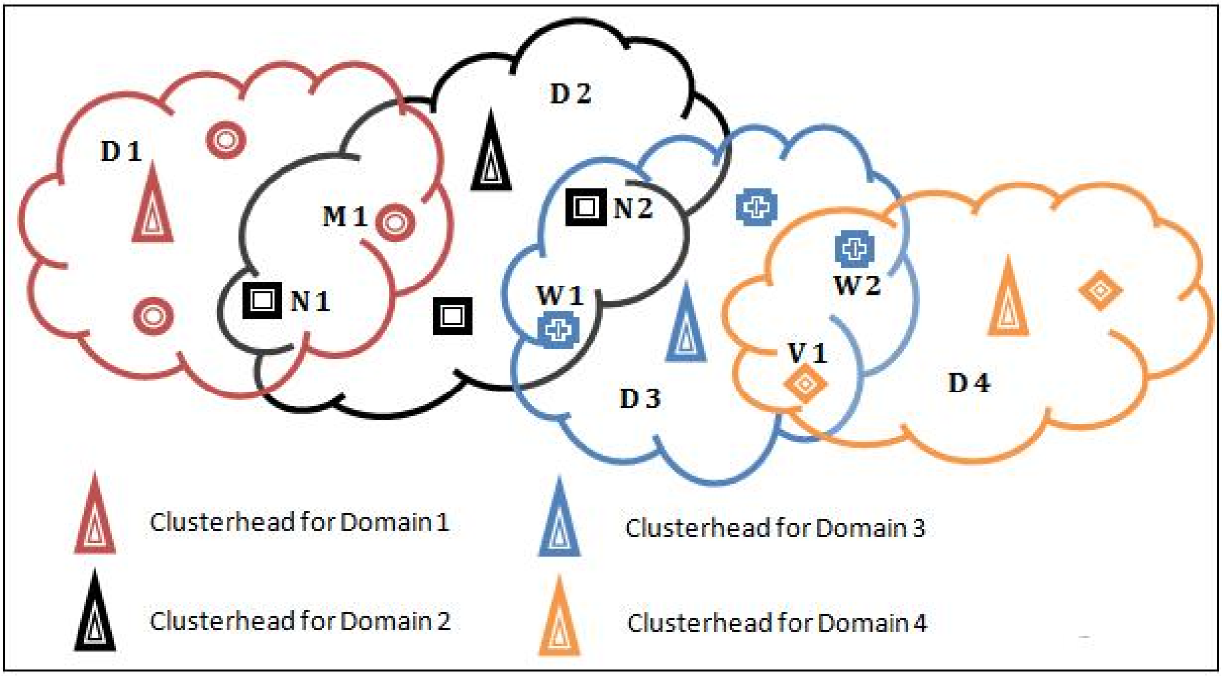

Figure 4: More detail about GBIR in complex inter-domain routing scenario

In the second stage, when a node desires to send inter-domain traffic to a destination in a foreign domain, it queries its cluster head for the information of the internal gateway node responsible for that foreign domain. After getting the information from its clusterhead, the node will insert a temporary bundle header to all inter-domain traffic that it sends. The source of the temporary header is its own EID while the destination of the temporary header is the EID of that gateway node that can reach that particular foreign domain (the gateway information is obtained from its clusterhead). For example, in Figure 3, if one node in domain 1 wants to send inter-domain traffic to W2 in domain 3, then this node will insert a temporary bundle header with destination of M1's EID. Once M1 receives the traffic, it removes the temporary header, search through the inter-domain routing entries to determine the external gateway node in other domain that can reach domain 3. In this case, N1 will be the next hop to forward the traffic. M1 will insert a new temporary header with destination of N1's EID. After N1 receives the traffic, it will remove the temporary header and check the domain of the original destination. After noticing that its own domain is an intermediate domain, N1 consults the inter-domain route entries and determines that N2 is the internal gateway it should forward the inter-domain traffic to. Then, N1 will add a temporary header with N2's EID as its destination, and forward the traffic using the underlying intra-domain routing protocol. When W1 receives the traffic and finds out that its own domain is the destination domain of the traffic, then W1 will not insert any new temporary bundle header but merely forward the traffic to the final destination, which is W2.

5.2 Network Topology Setup & Node Mobility

In this experiment, the chosen mobility model is the reference point group mobility model (RPGM). Cluster head in each domain acts as its logical center while individual nodes within same domain are usually randomly distributed within the domain area.

From the generated RPGM trace, we select 3 to 4 nodes from each domain that have better connectivity with its cluster head. Because in GBIR scheme, either at the stage of gateway registration and deregistration, or when non-gateway nodes want to forward inter-domain traffic, there should be a valid route between that node and its cluster head, no matter how many hops this particular route has using the underlying intra-domain routing protocol. For example, at the moment of hearing from other domains' beacons, the node needs a valid route to its cluster head to perform gateway registration request. Similarly, the cluster head needs a valid route back to the node so that its gateway registration response message can be delivered.

The topology we used in our experiments consists of five domains and each domain has three to four nodes, with one of them acts as a cluster head. The topology is shown in Figure 5. We let D1, D3 and D4 run PROPHET as their intradomain routing protocols while the other two run RAPID. In order to make our network environment looks like DTN with nodes that have intermittent connectivity, the gateway nodes in each domain are carefully chosen from the RPGM trace. These gateway nodes can only hear one another during certain time period.

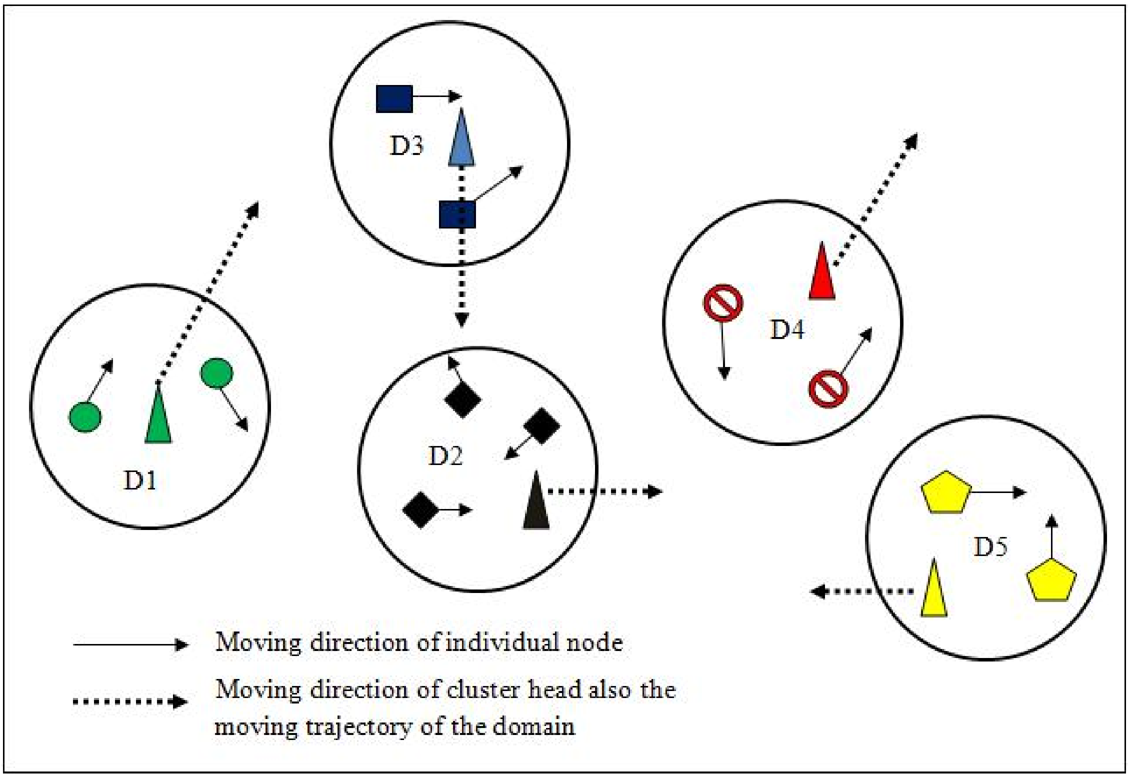

Figure 5: Mobility pattern and Topology setup

5.3 ORBIT Experimental Setup

To evaluate the GBIR in an actual wireless environment, we conduct our experiment using the ORBIT wireless testbed [8]. The ORBIT testbed consists of machines where each machine has 1 GHz VIA Nehemiah processor, 64KB cache, 512MB RAM, and supports two types of network adapters (Intel Pro-wireless 2915-based 802.11 a/b/g and Atheros AR5212-based 802.11 a/b/g). Nodes on the ORBIT testbed are placed a meter apart from one another in a grid and they use radios that transmit with 1dB transmit power.

To setup the network topology (as shown in Figure 4), 16 testbed nodes are utilized for our experiment. Four of five domains contain three nodes, and one domain contains four nodes. Each ORBIT machine executes an instance of GBIR process, and within the same domain, nodes are running the same underlying intra-domain routing protocol.

To emulate mobility, each node will receive the neighborhood information at certain time interval from the console node. Upon receiving this information, each node will utilize iptables to filter out traffic from non-neighboring nodes and hence communication links only exist among valid neighboring nodes. Each node only receives beacons from its designated neighbors.

5.4 Experimental evaluation

5.4.1 Experimental Setup

We first generated mobility traces using the RPGM generator. These traces contain printouts of locations of each node every 100sec. We have three traces where nodes move with an average speed of 2.5m/s, 5 m/s and 10 m/s respectively. From the traces, we observe the mobility patterns of the nodes and select three or four nodes from each domain that allow us to have the longest end-to-end path across the three domain hops in the five domain topology that we deployed (as shown in Fig 5). For example, D1 can reach D5 via intermediate domains D2 and D4. Thus, we select 3 nodes from Group 1 to represent nodes in Domain D1, three nodes from Group 2 to represent nodes in Domain 2 etc. We then develop scripts that allow us to read the locations of these selected nodes at predefined times and then use IPfilter tool to turn on/off the links between any selected nodes depending on their distances apart. Furthermore, we develop test scripts that allow us to send DTN packets of different packet sizes.

Overall, we evaluate the performance of the GBIR protocol in three scenarios: one where the interdomain traffic only traverses (a) one domain hop, (b) two domains hop, and (c) three domains hop. We select D1 to be the source domain that generates interdomain traffic with a packet size of 512 B, 1 KB and 2.3KB respectively. For each experiment, we first let the traffic generator generate some DTN packets during warm up periods. Then, we let the traffic generator generate 20 messages and record, the total number of interdomain messages that were received at the destination node out of these 20 messages. We also measure the observed message delivery latency for all delivered messages. We repeat each experiment three times.

For each experiment, we also measure the delivery performance of intradomain routing schemes used in our experiments. In each domain, it takes two hops from the source node to a gateway or destination node.

5.4.2 Experimental Results

Table I and Table II show the average delivery latency of intradomain traffic within the domain that is running Prophet or RAPID. We use these values as references while we evaluate the performance of GBIR in forwarding the interdomain traffic that traverses from one domain hop to three domain hops.

Table I

Delivery latency within single domain running Prophet

Packet size	Delivery latency (ms)
512 B	49
1 KB	56
2.3 KB	72

Table II

Delivery latency within single domain running RAPID

Packet size	Delivery latency (ms)
512 B	233
1 KB	249
2.3 KB	296

In Figures 6 to 8, we plot the average message latency of interdomain traffic for the three scenarios, namely those that traverses one to three domain hops. For single domain hop, we choose one node in D1 as the source and another node in the same domain as the destination. For two domains hop scenario, the destination domain we can choose is D3 and D4, since both of them run Prophet. From three domains hop scenario, the route is from D1 to D5, passing through D2 and D4. All interdomain traffic is generated at an interval of 10 seconds, and the node's moving speed is 2.5 m/s. From the plots, we see that the delivery latency is affected by both packet size and intradomain routing scheme. Small packets will have smaller delivery latency. Obviously, it takes shorter time to send smaller packet size using the same wireless transmission bandwidth. As the interdomain traffic traverses through more hops, the message delivery latency also increases. With any intradomain DTN routing scheme, a store-and-forward approach is taken. Nodes will receive a DTN packet, store it and decide which node to forward to next until the packet finally arrives at its gateway or destination node. We can see from Tables I & II that it takes shorter time to route using PROPHET compared to RAPID. As explained earlier, RAPID protocol relies on past history to decide if replicate copies of a packet will be made and this process repeats itself until a copy reaches the destination node. RAPID does not seem to be able to collect sufficient history information to optimize its routing metric. However, PROPHET takes faster time to build the appropriate delivery predictabilities. Thus, the average intradomain delay using RAPID is much higher than that for PROPHET.

From the plots, we also can see the delivery latency of D2 and D4 while acting as intermediate domains, is slightly larger than that observed when these 2 domains are acting as the destination domains. This is because as an intermediate domain, our GBIR scheme will perform the process of querying the clusterhead for the next internal gateway node that can reach destination domain, and inserting temporary bundle header with the new destination being set to the EID of this new internal gateway node. Thus, longer processing delay is incurred.

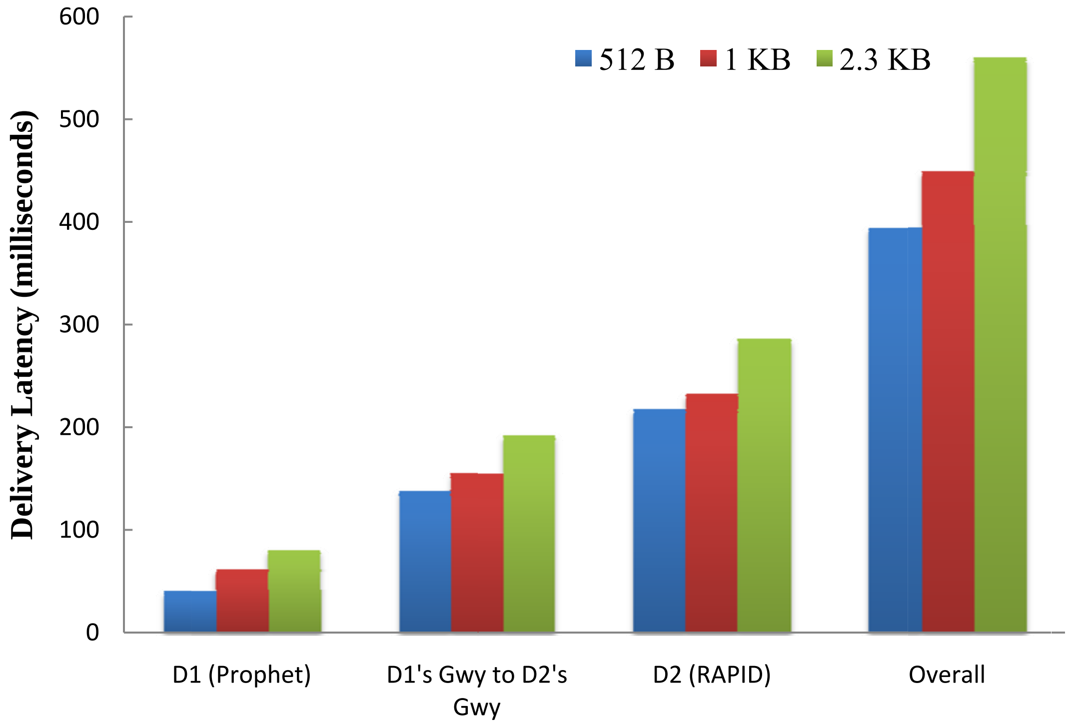

Figure 6: Delivery Latency of One domain hop

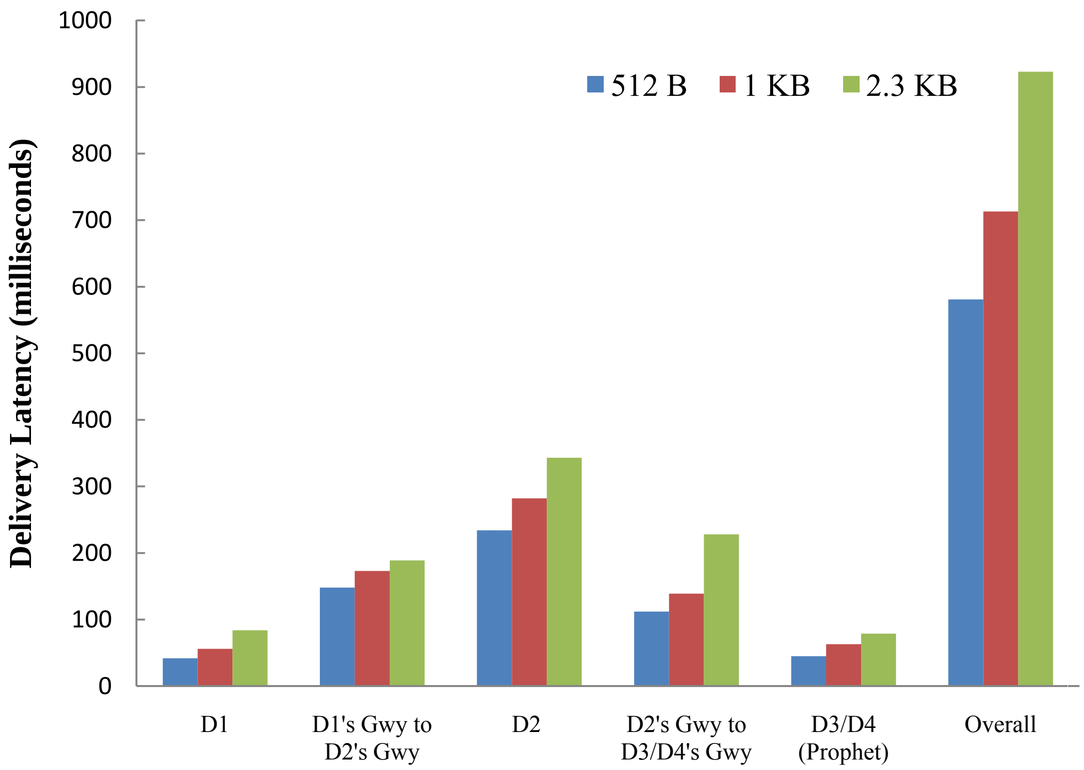

Figure 7: Delivery Latency of Two domains hop

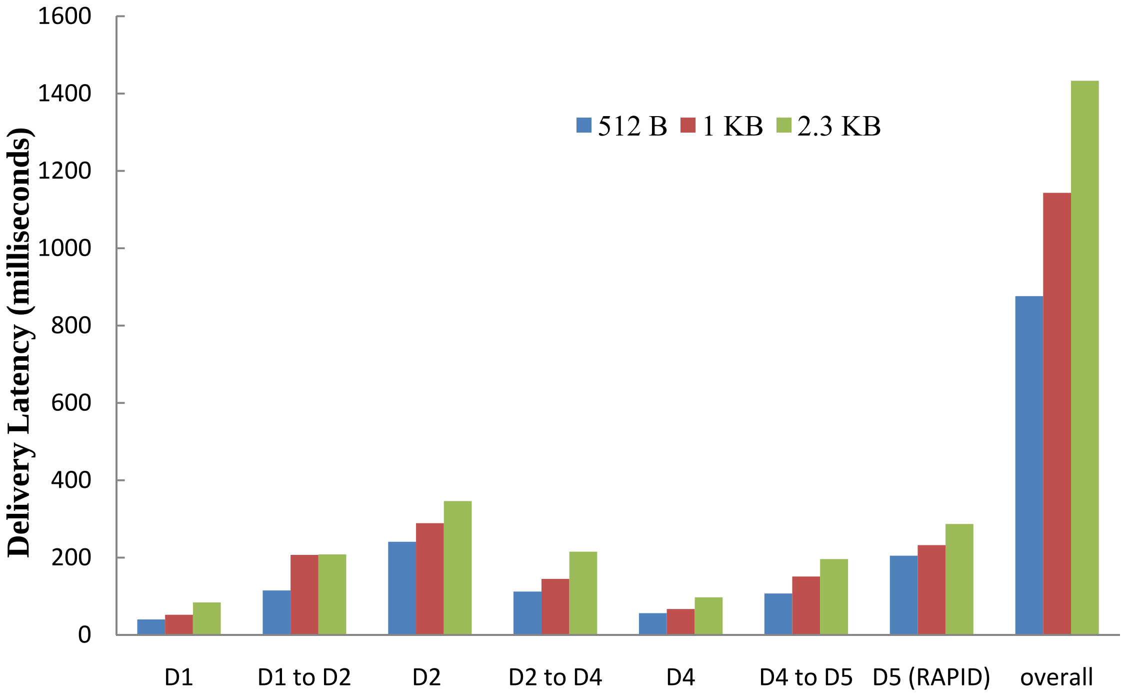

Figure 8: Delivery Latency of Three domains hop

We also evaluate the impact of node speed on the message delivery latency and delivery ratio. We plot in Figures 9-17 the delivery performance of our GBIR scheme for scenarios with one-domain to three-domain hops when node speed changes. Our results show that the average end-to-end delivery latency reduces as the nodes move faster. However, such reduction does not happen forever since as the node speed continues to increase, there will be frequent path changes, resulting in an increasing overhead in building paths within each domain. These plots show that the most important factor in the reduced message delivery latency lies with the rapid reduction in the intradomain delay in domains running RAPID. As nodes move faster, frequent encounters of nodes happen and such encounters allow RAPID to generate useful histories for its routing metric and hence quicker routing decisions can take place.

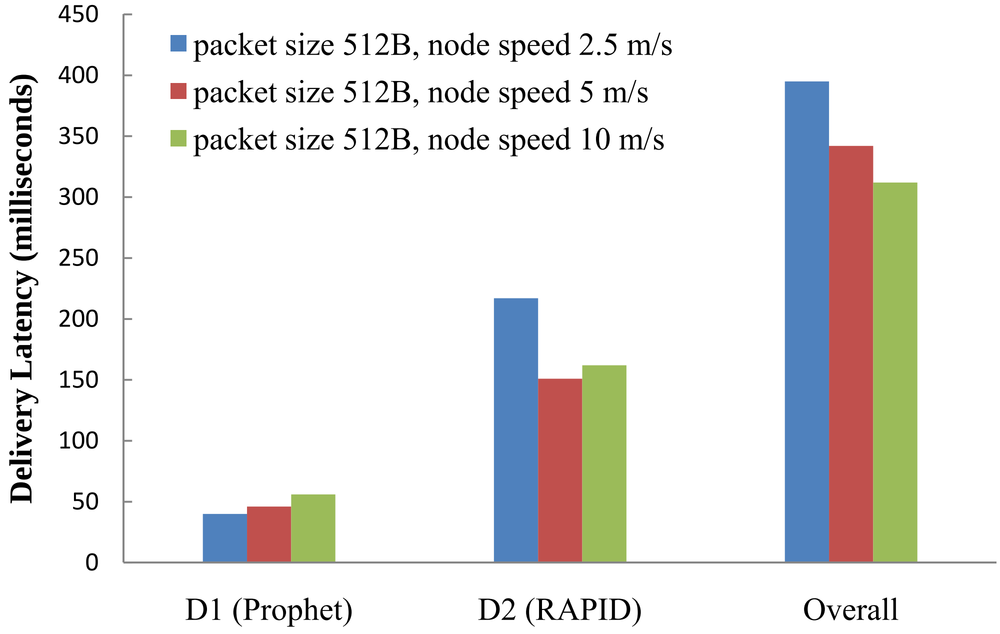

Figure 9: Delivery Latency of One domain hop for 512 B with different node speed

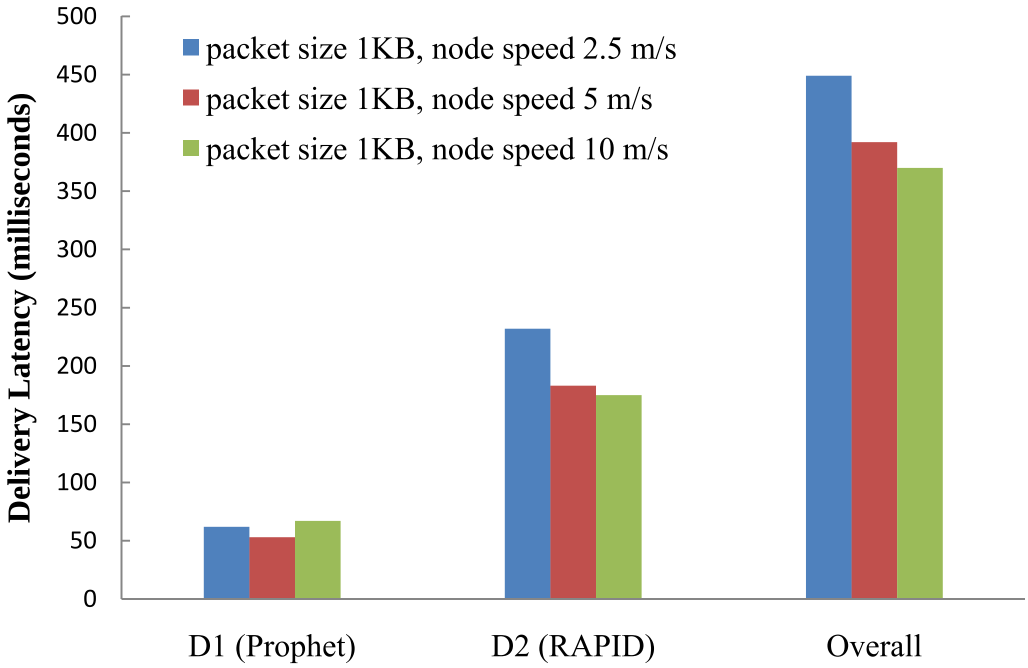

Figure 10: Delivery Latency of One domain hop for 1 KB with different node speed

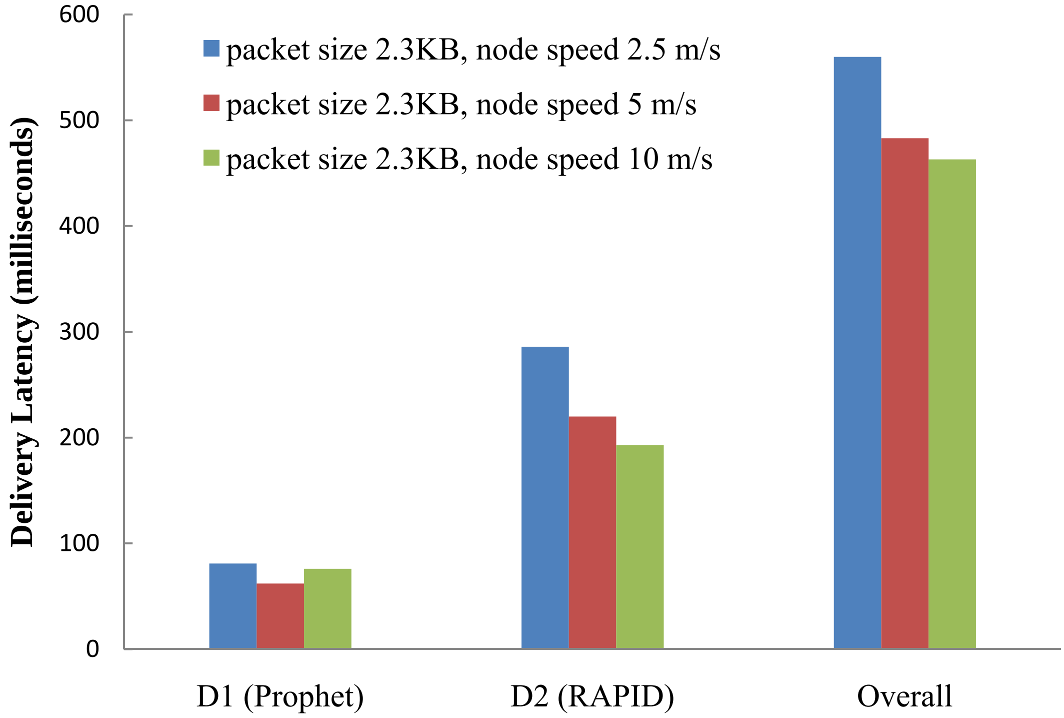

Figure 11: Delivery Latency of One domain hop for 2.3 KB with different node speed

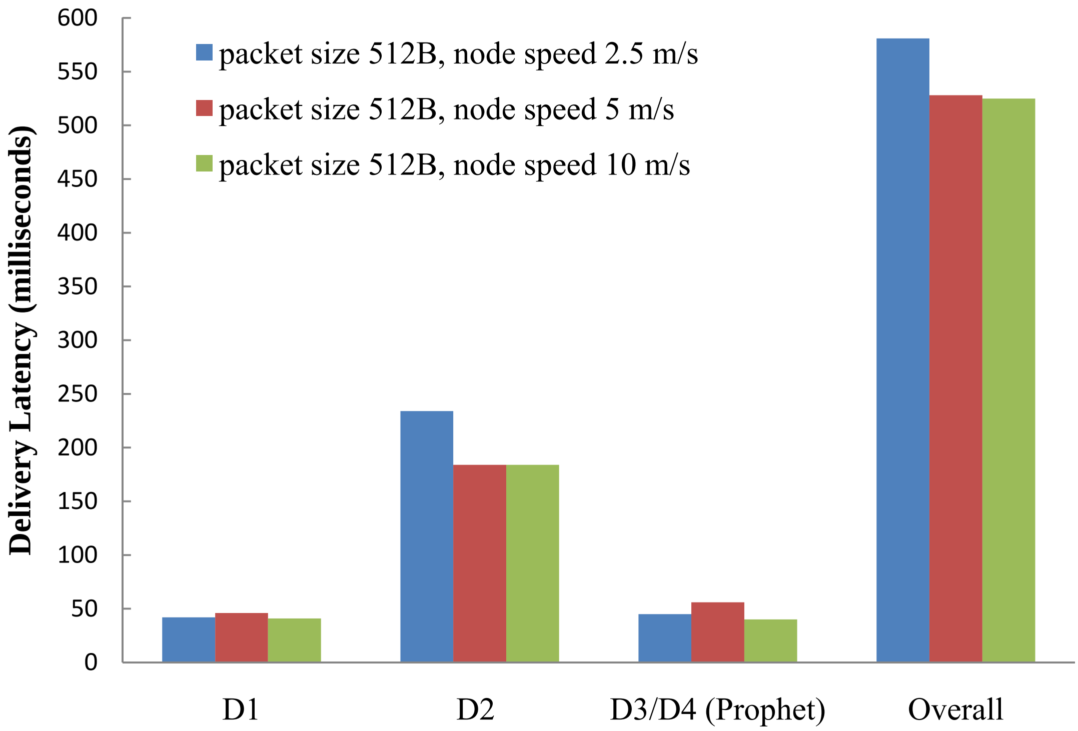

Figure 12: Delivery Latency of Two domains hop for 512B with different node speed

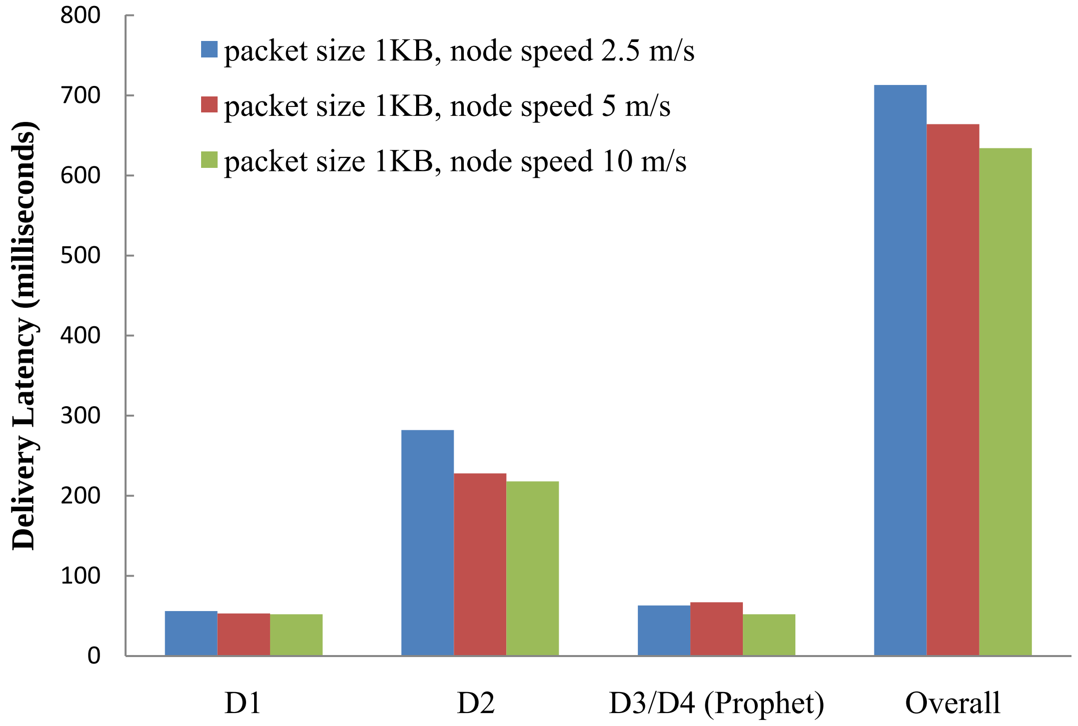

Figure 13: Delivery Latency of Two domains hop for 1KB with different node speed

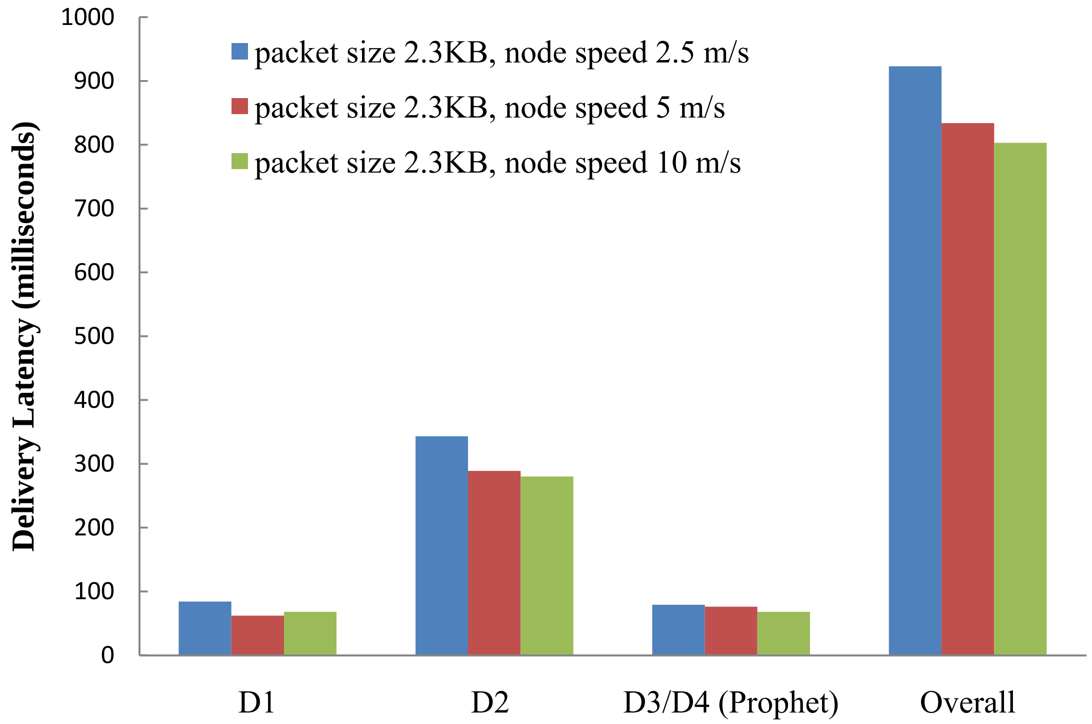

Figure 14: Delivery Latency of Two domains hop for 2.3KB with different node speed

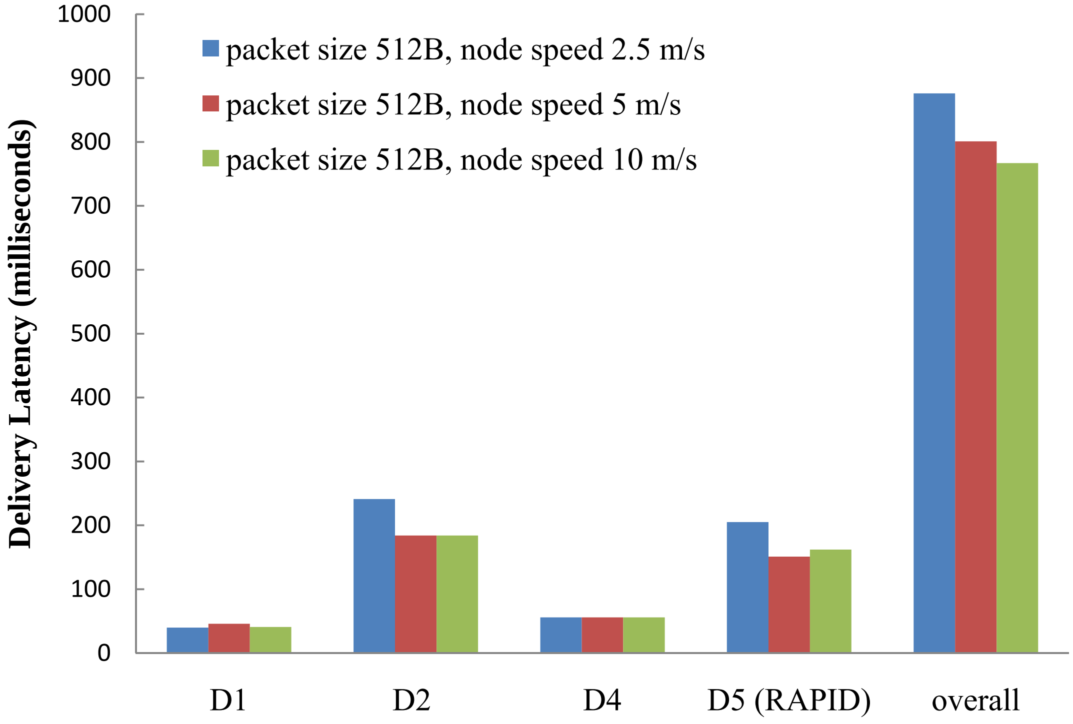

Figure 15: Delivery Latency of Three domains hop for 512B with different node speed

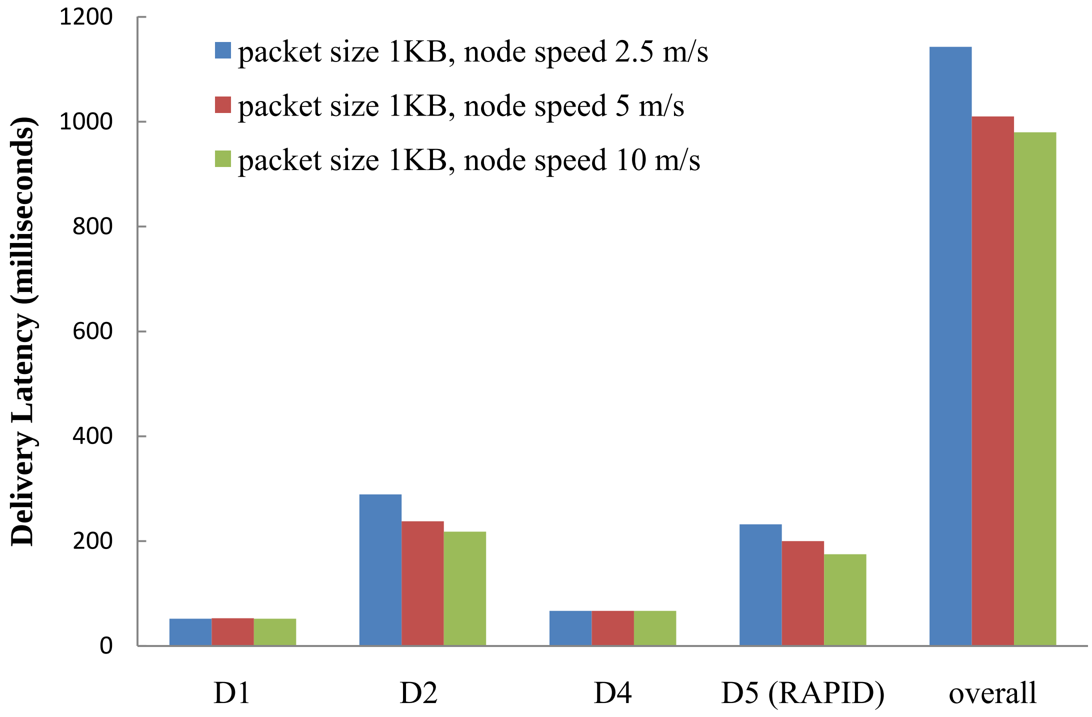

Figure 16: Delivery Latency of Three domains hop for 1KB with different node speed

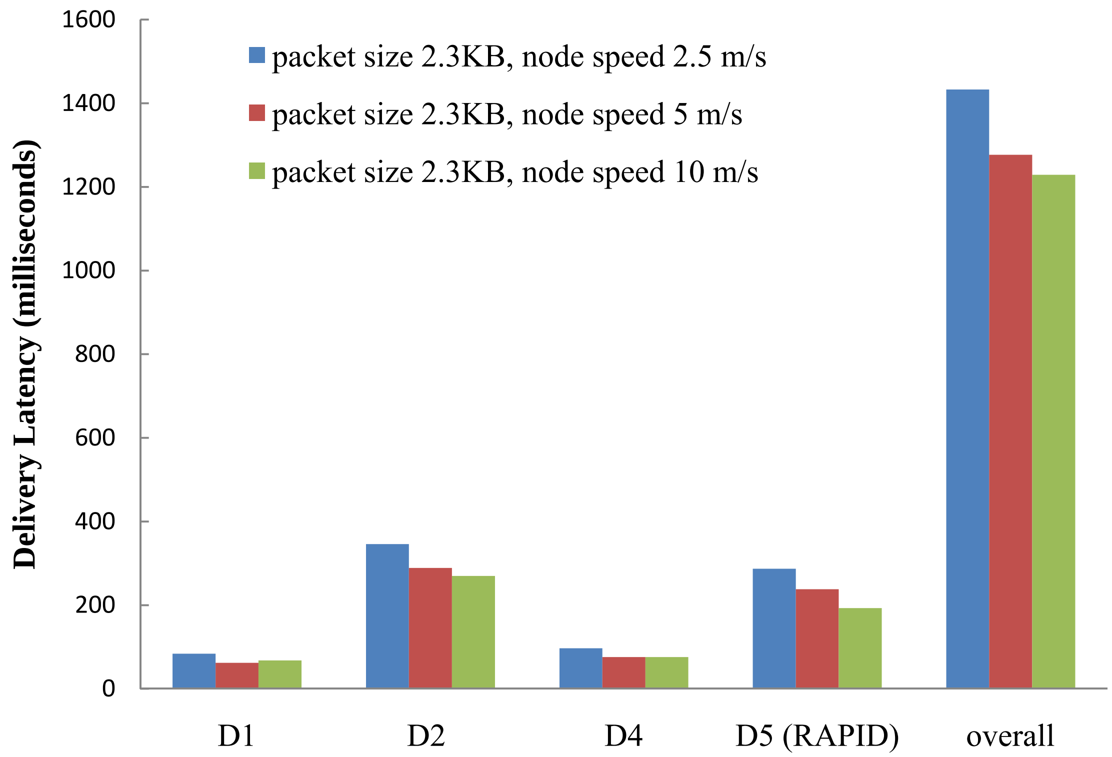

Figure 17: Delivery Latency of Three domains hop for 2.3KB with different node speed

Figures 18 to 20 show the impact of node speed on the delivery ratio. We send the interdomain traffic from D1 to D5, and check each gateway node in the domains to see how many packets are received by these gateways. Since the nodes we selected in each domain always have good connectivity, the intradomain delivery ratio is almost 100%. The packets are dropped by the frequent path changes among domains. When the nodes move faster and faster, the duration of connected links between gateway nodes is reduced. Thus, sometimes, the duration is sufficient to deliver all stored small packets but not sufficient to deliver all stored large packets. Thus, the delivery ratio for smaller packets will be higher as node speed increases.

In our topology, D4 & D5 have the worst connectivity situation with low frequency of node encounters and short link duration between gateways of these two domains. Thus, in Figure 20, the delivery ratio is much lower than other two scenarios.

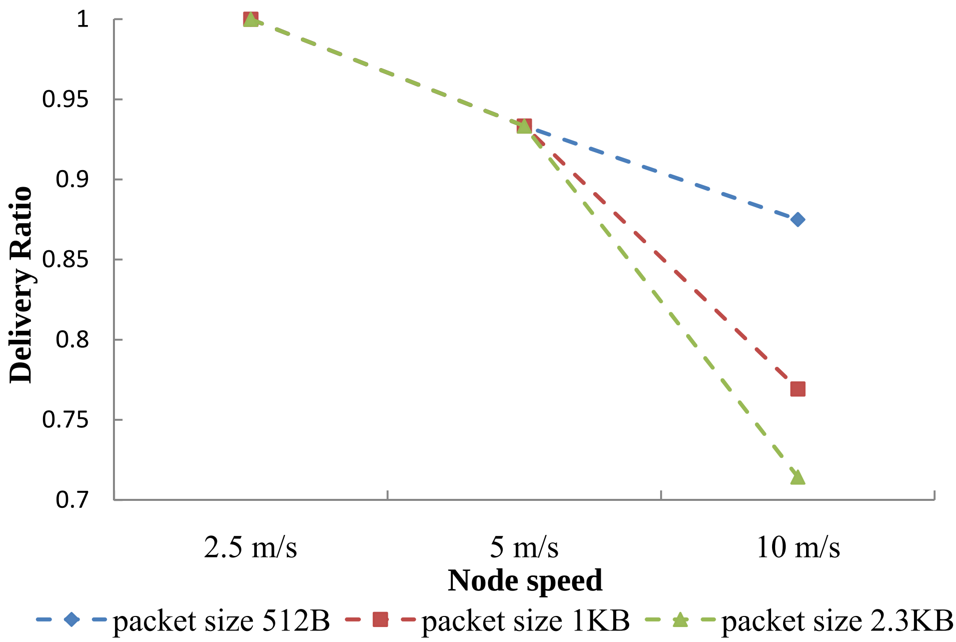

Figure 18: Delivery Ratio of one domain hop vs Node *speed*

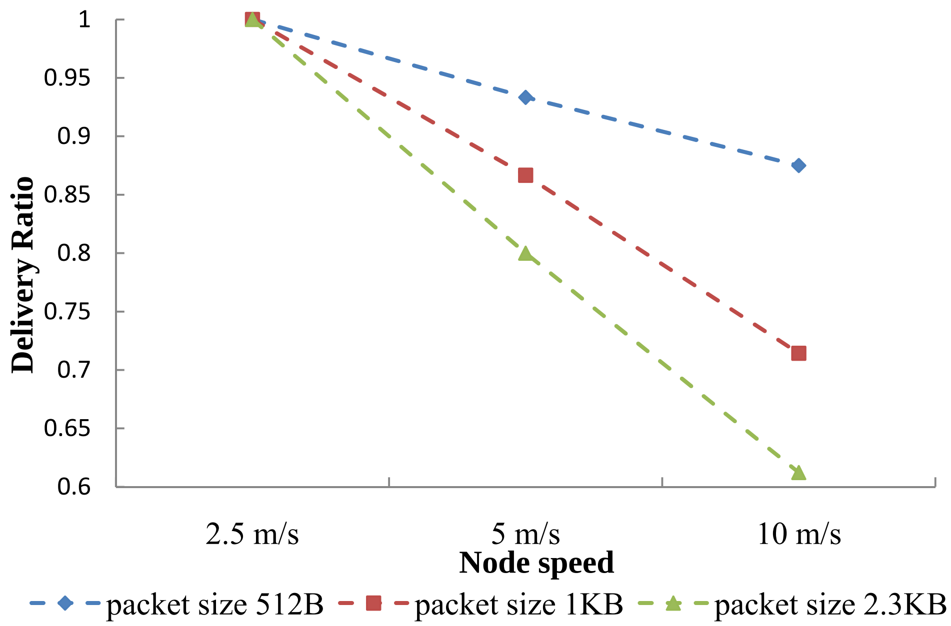

Figure 19: Delivery Ratio of two domains hop vs Node speed

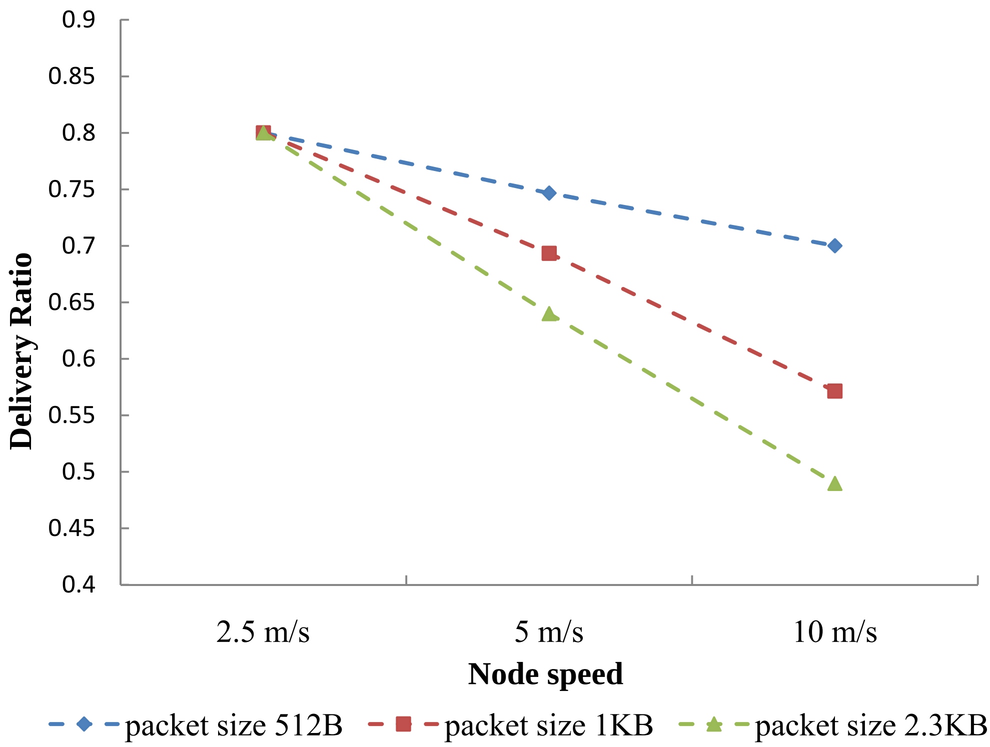

Figure 20: Delivery Ratio of three domains hop vs Node speed

Figure 21 shows a GUI that we developed, that is used to show how many packets that the destination node has received and can verify whether or not received packet is what the source node sends originally.

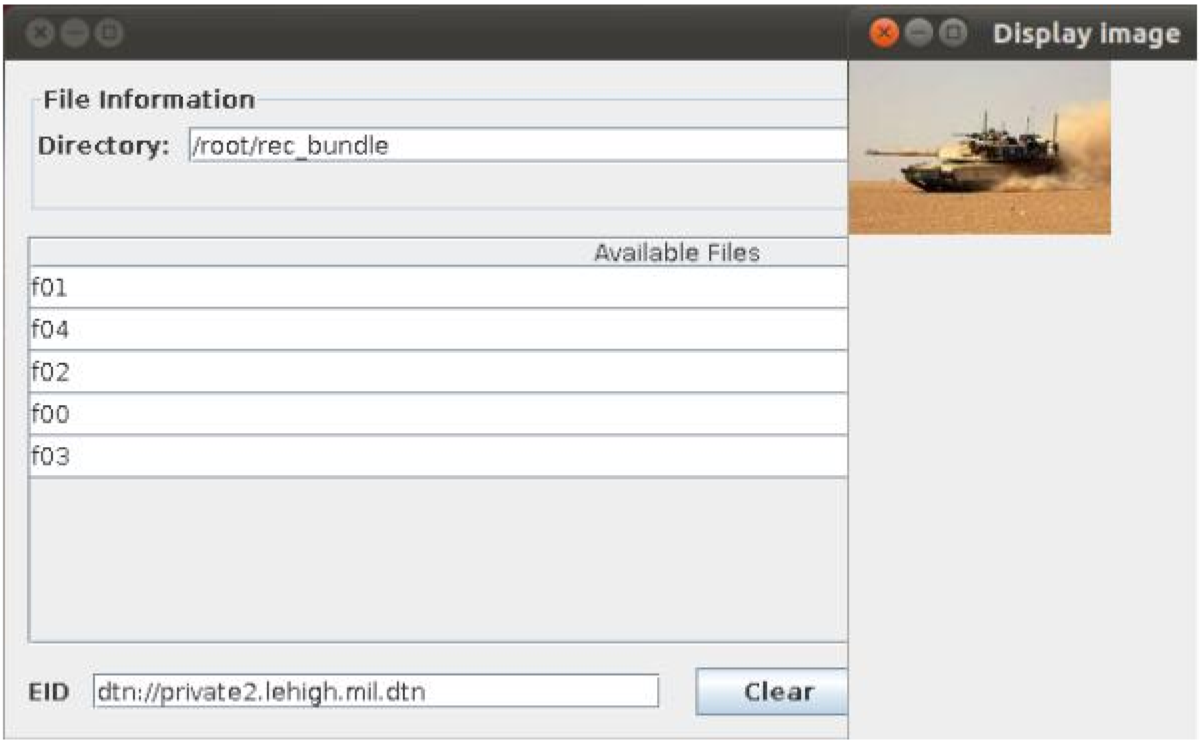

Figure 21 : GUI that displays received images and files

All the results we have presented indicate that our gateway based interdomain routing scheme achieves high delivery ratio and low end-to-end delivery latency for the interdomain traffic when the connectivity between domains is in good condition. It also shows that the end-to-end delivery latency is highly dependent on the choice of each domain's intradomain routing scheme. Our results show that the intradomain routing scheme for PROPHET is shorter than that for RAPID when the node movements are such that they do not allow RAPID to build the appropriate values for its routing metric.

Chapter 6

CONCLUSION

In this thesis, we have presented a gateway-based interdomain routing (GBIR) protocol for DTN. Via experimental evaluations, we have demonstrated the delivery performance of GBIR together with two intradomain routing protocols, namely PROPHET and RAPID. Specifically, we deployed a network topology with five domains in the ORBIT testbed. Furthermore, we create dynamic topological changes by turning the links between nodes on/off based on the distance between nodes at certain time instants using mobility traces that were generated via the RPGM generator. In addition, we also developed test scripts to generate interdomain DTN messages so that we can evaluate the delivery performance of the GBIR scheme.

Our evaluation showed that PROPHET produces smaller average intradomain delay than RAPID. It also shows that GBIR does not add too much extra processing delay to the end-to-end (E2E) message delivery latency. In general, larger messages result in longer E2E delivery latency. Faster node movements that do not result in too much link breakage often result in faster E2E message delivery latency.

Even though our experimental evaluations show some evidence of the usefulness of the GBIR scheme, we hope that in the near future, some students can actually conduct larger scale simulation experiments with multiple domains that run different intradomain routing protocols to evaluate the delivery performance of the GBIR scheme in large scale networks. We also hope that one can use the real traces collected in DieselNet to do more experimental evaluations since such real traces provide information on the changing in the available bandwidth when two nodes are in contact with each other.

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Vita

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