Evaluation of Dynamic DTN Routing Protocols in Space Environment

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***Abstract*—As the number of space elements increases, routing becomes an issue of great interest. The majority of routing schemes that have been proposed till now employ a fairly static design and only recently more sophisticated protocols have been introduced. In this study, we evaluate some of the most prominent routing protocols for Delay-Tolerant Networks, Epidemic, PRoPHET and Contact Graph Routing, in space environment. Using COMNET Lab's DTN testbed, we show that for increasing delay, Contact Graph Routing significantly outperforms the other two routing schemes.**

***Index Terms*—DTN, testbed, routing, DTN2, ION, Epidemic, PRoPHET, Contact Graph Routing.**

I. Introduction

Delay Tolerant Networking (DTN) [1][2] composes an emerging network architecture that facilitates data transfers in challenged networks, characterized by intermittent connectivity, high loss rates and long propagation delays. In this context, DTN is the key technology to support future space communications, since the constant movement of space elements together with the variable delay and loss rate values, render the existing networking technologies inefficient. While various aspects of Space communications, like transport protocols, have attracted extended research interest, only little progress has been made as far as routing is concerned.

Routing in Delay Tolerant Networks becomes a matter of utmost importance as the number of Space elements constantly increases. The total duration of opportunistic contacts is considerable, alternative paths exist, and a multihop architecture becomes a viable solution. These network characteristics, along with the challenged environment, pose restrictions to the development of reliable and efficient routing protocols.

In this study, we investigate the performance of some of the most prominent routing solutions when long delays and high error rates are present. Epidemic Routing [3] and Probabilistic Routing Protocol using History of Encounters and Transitivity (PRoPHET) [4] are evaluated in the DTN2 Bundle Protocol implementation [5], while Contact Graph Routing (CGR) [6] performance is evaluated using ION platform [7]. The results show that PRoPHET is only efficient for RTT delay values less than 1 sec, in contrast to CGR that works well for long propagation delays and, also, achieves better performance. Epidemic Routing achieves a relatively good performance, although lower than CGR, in the expense of extensive network load.

II. Protocol Description

Early routing schemes for DTN technology were completely static and even a simple communication anomaly could lead to time-consuming manual reconfiguration. The first form of replication-based routing is epidemic, where transmitted data is continuously replicated until all nodes receive a copy. In particular, when a node receives a new packet, it first checks whether it is the final destination of the packet, and if not, it multicasts the received packet to every other node it shares a link with. If buffer requirements do not pose a restriction and a path towards the receiver is to become available any time in the future, Epidemic Routing will utilize it for the successful delivery of the data.

Dynamic routing has only recently been developed as a solution to DTN; PRoPHET and CGR are two of the most remarkable routing solutions. PRoPHET utilizes each node's knowledge of previous encounters, while CGR exploits a priori knowledge of future contacts. In particular:

A) *PRoPHET*

PRoPHET incorporates the novel idea of utilizing knowledge of previous encounters between any two nodes, in order to select the best path towards the receiver. This is achieved by calculating a delivery predictability for each node based on three basic parts:

- Encounters: Any pair of nodes that encounters each other frequently has greater probability for a successful message delivery.
- Aging: If two nodes have not encountered each other for a long time period, an aging factor is used to lower the delivery probability.
- Transitivity: When a node N2 encounters frequently nodes N1 and N3, which however do not encounter each other frequently, it can be used as a relay node for the communication between N1 and N3.

Depending on the topology of the network, three distinct parameters, one for each of the aforementioned parts, are configured for the calculation of the delivery predictability. Another important parameter that affects PRoPHET performance is HelloTimer, which defines the frequency that a node informs its neighbours of its existence. The lower the value of HelloTimer is, the faster a node is discovered after a link outage.

B) *Contact Graph Routing*

CGR is a dynamic routing protocol which takes advantage of the fact that contact information between any nodes in space communications is predetermined. In particular, all nodes utilize knowledge of both their current state and all scheduled future communication contacts and, thus, compute successful routes. Moreover, CGR includes mechanisms to react to any communication anomaly that may occur. Computation of all possible routes is either:

- Static, when a direct route to the receiver has been specifically defined as input to CGR
- Dynamic, if no static route exists and a hop-by-hop dynamic route to the destination has to be computed and, finally,
- Default, when a bundle is transmitted to the receiver only through a predefined gateway.

Prior to data transmission, certain parameters need to be defined. First of all, the duration of the contacts, as well as the bandwidth of the links, between active nodes have to be specified. Other parameters that need to be declared are the expiration time of the bundles, any flags for the transmission of critical data, the approximate distance between any communicating nodes etc.

III. Analysis and comparison of routing protocols

Each of the proposed routing protocols for Space communications carries unique characteristics, depending on the applied architecture. These attributes affect significantly the performance and the efficiency of the protocols.

Epidemic routing is a fundamental routing technique, in which all nodes continuously replicate messages to newly discovered contacts that do not already possess a copy of the message. In this context, all messages generated by a source node are delivered to all nodes in the network and, eventually, the receiver. One of the advantages of epidemic routing is the simplicity of its philosophy; no special configuration is required. If a path towards the receiver exists, then epidemic routing guarantees that all messages will be successfully delivered, without spending any time for communication purposes prior to each transmission. However, epidemic routing has the main drawback of wasting valuable network resources, especially in space communications where resources are scarce. The constant flow of data packets in the network will inevitably lead to buffer overflow and loss of data.

The Probabilistic Routing Protocol using History of Encounters and Transitivity (ProPHET) utilizes an algorithm that attempts to exploit the non-randomness of real-world encounters by maintaining a set of probabilities for successful delivery to known destinations (delivery predictabilities) and replicating messages during opportunistic encounters only if the node that does not have the message, appears to be a better chance of delivering it. PRoPHET is a completely autonomous routing protocol since no management is required; available links between nodes are dynamically discovered and previous knowledge is used for planning future transmissions. Moreover, opportunistic contacts are utilized too, in contrast to Contact Graph Routing where all contacts need to be predefined. An important drawback of PRoPHET routing, however, is its inability to support priorities and, as a result, to provide any form of Quality of Service. In this context, all data packets are handled equally and no special treatment can be applied to urgent data. Most important, PRoPHET routing consumes considerable amount of both energy and time for message exchange prior to each transmission. Practically, applying a completely autonomous routing protocol, like PRoPHET, in Space poses a significant risk for space agencies.

Contact Graph Routing is a dynamic routing system that computes routes through a time-varying topology composed of scheduled, bounded communication contacts in a Delay Tolerant Network. CGR is an energy saving protocol, given that all contacts between nodes are predefined and no exchange of connectivity information takes place during the transmission. A basic form of Quality of Service is provided in CGR, since critical bundles can be handled in exception; urgent data is transmitted similarly to epidemic routing, making sure that it is successfully delivered. In terms of applicability, CGR composes a natural evolution of current static routing in space environment, as it utilizes all predetermined connections without being a completely autonomous and, therefore, possibly unstable solution. The main drawback of Contact Graph Routing is the need to schedule all active connections prior to transmission; in this context, opportunistic contacts cannot be exploited. Another characteristic of CGR, which composes both an asset and a limitation, is the use of Licklider Transmission Protocol as a convergence layer. LTP may provide reliable data transmission, however its mechanisms have not been extensively evaluated yet.

	Epidemic Routing	PRoPHET Routing	Contact Graph Routing
Energy-Efficient	No	No	Yes
Autonomous	Yes	Yes	No
Contacts Exploited	All	All	Scheduled Only
QoS	No	No	Yes

Fig. 1. Characteristics of Epidemic, PRoPHET and Contact Graph Routing

The above figure summarizes the characteristics of the aforementioned routing protocols as far as energy consumption, autonomy, contact exploitation and Quality of Service are concerned. As noticed, Epidemic and PRoPHET routing may be automonous and able to exploit both scheduled and opportunistic contacts, however none of them is energy-efficient or provides Qos, like Contact Graph Routing.

IV. Evaluation

We evaluated three different delay-tolerant routing schemes, namely Epidemic, PRoPHET and Contact Graph Routing, using COMNET Lab's space-oriented DTN testbed. Epidemic and PRoPHET Routing are incorporated in DTN2 implementation, while CGR is part of the ION platform.

In the first set of our experiments, we emulated some fundamental scenarios of space communications, i.e. a sensor in Space transmitting temperature measurements to Earth. We set bandwidth between any two connected nodes to be 10Mbps, packet size 10KB and interval between two packet transmissions equal to 5sec. For each network configuration, we calculated the results by averaging the output of 50 emulation runs.

In the first experiment, we used a topology of 4 nodes to compare Epidemic, PRoPHET and Contact Graph Routing under increasing RTT values, using Task Completion Time as a metric. The topology of the experiment consists of one sender, one receiver and two intermediate nodes, as shown in Figure 2 below. The intermediate nodes provide two alternative routing paths, only one of them connected to the endpoints at any given time. The sender transmits 100 packets of 10 KB each to the receiver with a time interval of 5 seconds between two consecutive transmissions.

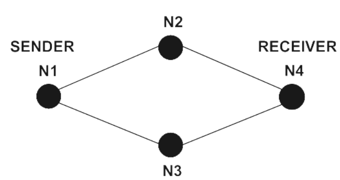

Fig. 2. 2-hop, alternate path topology

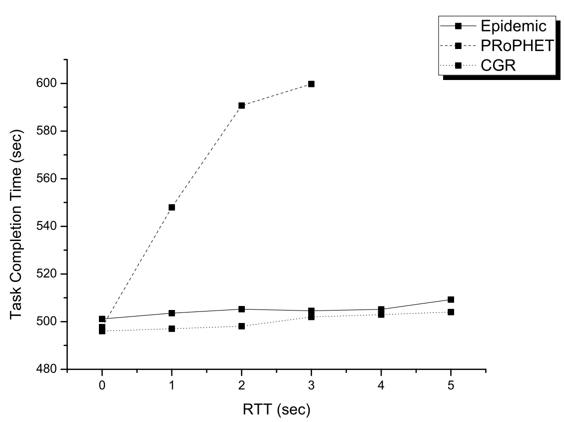

Fig. 3. Round-Trip Time impact on Task Completion Time

Figure 3 demonstrates the Task Completion Time of each protocol in relation to Round Trip Time. As depicted in this figure, CGR outperforms both PRoPHET and Epidemic routing as RTT values increase; for almost zero second delay we observe that the performance of all three protocols is almost identical, whereas for RTT values greater than 1 sec PRoPHET's performance degrades in contrast to the relatively stable performance of both CGR and Epidemic routing. CGR, however, achieves better performance by utilizing predetermined information on each node's position and movement.

In order to investigate PRoPHET's poor performance, we utilized a simpler single-hop topology (Figure 4). In this scenario, the sender transmits 50 data packets throughout the duration of the emulation. Our aim is to highlight PRoPHET's inability to quickly dispatch data packets, even when a path towards the receiver exists.

Fig. 4. Single-hop topology

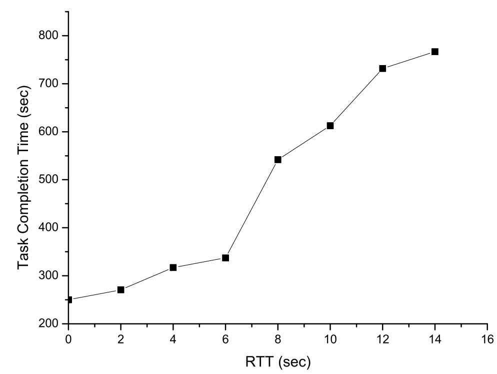

Fig. 5. Task Completion Time for varying RTT

Figure 5 shows the Task Completion Time of PRoPHET routing with various RTT values. The results show that as RTT values increase, there is a significant increase in the Task Completion Time. In this context, it is understood that although PRoPHET is advertised as a suitable routing protocol for DTN, in fact it does not perform well in space environment, where transmission delay is in the order of seconds or even minutes. The reason behind this, is PRoPHET's need to exchange routing information before each application data transmission, resulting to waste of valuable time resources.

In our next set of experiments, we emulated the transfer of a large file over a topology of 4 nodes (Figure 2), using Epidemic, PRoPHET and CGR as a routing protocol. The sender transmits a file of a variable size (starting from 1 MB and up to 20 MB) and each time we measure Task Completion Time. The link characteristics remain the same as in the previous set of experiments.

As one can easily notice in Figure 6, CGR outperforms both Epidemic and PRoPHET Routing, although with a minor

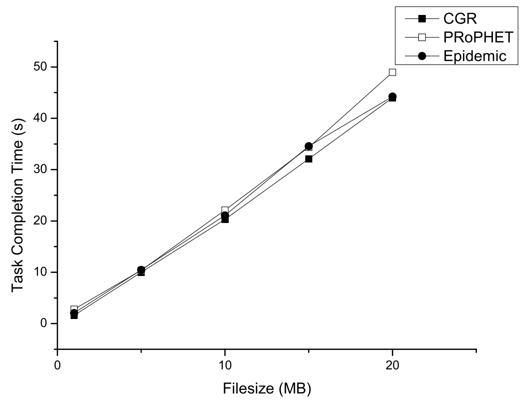

Fig. 6. Task Completion Time for varying Filesize

variation. This can be attributed to the fact that CGR is the most "static" protocol among all three, in the sense that CGR knows a priopri the available contacts and links and does not spend any time for active link discovery. Even Epidemic routing results to a lower Task Completion Time, in comparison to PRoPHET, as each node quickly multicasts all the packets it receives.

In order to evaluate the impact of Hello Timer in PRoPHET's performance, we repeated the first experiment (Figure 2), this time applying a 2 second delay at every available link and setting the value of Hello Timer equal to 1000, 5000 and 10000 respectively.

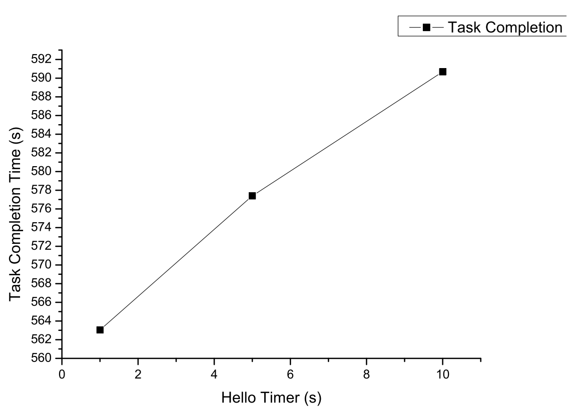

Fig. 7. Task Completion Time for varying Hello Timer values

As it can be observed in Figure 7, Hello Timer plays a crucial role in PRoPHET's performance, as bigger Hello Timer values lead to larger Task Completion Time and, thus, lower performance. This can be explained by the fact that only after the expiration of Hello Timer and the subsequent exchange of control information, can a node transmit data bundles.

In the last experiment we tried to assess the effect of the number of intermediate nodes between the sender and the transmitter in the Task Completion Time in PRoPHET Routing. To measure this, we used a topology with a varying number of intermediate nodes (Figure 8) over which we transmitted a file of variable size.

Fig. 8. Single-hop topology

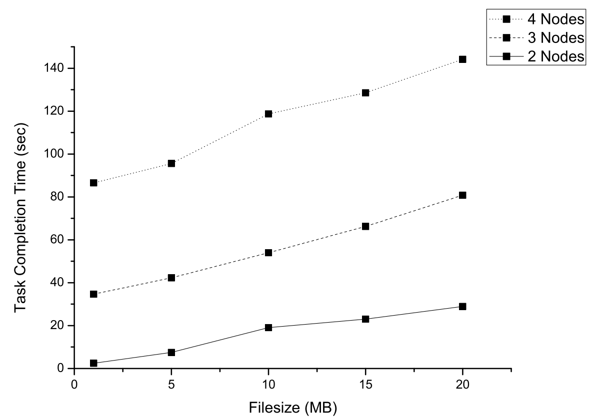

Fig. 9. Task Completion Time for varying number of intermediate nodes

As depicted in Figure 9, there is an almost linear increase in Task Completion Time with the insertion of more nodes between the sending and the receiving node. This means that as the number of intermediate nodes increases, the amount of information that needs to be exchanged prior to transmission is increased too, and as a result the performance of PRoPHET degrades.

V. Conclusions

In this paper, we study the performance of Epidemic Routing and two sophisticated routing protocols for Delay-Tolerant Networks, namely PRoPHET and CGR, in space environment. PRoPHET exploits knowledge of previous encounters each node has, while CGR's functionality is based on a priori knowledge of future contacts. Using our emulation platform, we show that CGR achieves considerably better performance than Epidemic and PRoPHET Routing when delay is in the order of seconds. We also observe that PRoPHET does not perform well even for short delay values, neither for small, nor for large filesizes. This can be explained by PRoPHET's mechanism that exchanges routing information prior to each data transmission.

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