A Comprehensive Comparison of some Popular Routing Protocols in Delay Tolerant Networks

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Abstract: Following the conception of Delay Tolerant Networks for interplanetary communication in the year 2003, there has been considerable amount of research in this field, which has been modified to work in terrestrial networks. As such new researchers feel overwhelmed when they start research in this field. This paper tries to simplify the domain of routing protocols in DTN and makes it helpful to new researchers. This paper surveys some popular routing protocols in Delay Tolerant Network and presents a comprehensive comparison between them for easy perusal by new researchers in this field. The simulation has been done using the widely accepted ONE simulator.

1. Introduction

Vinton Cerf is a pioneer in the field of computers and networking and a name to reckon with. The idea for a Delay Tolerant Network can also be contributed to him and his team of researchers. This came around while conceptualizing the InterPlaNetary (IPN) Internet project [1]. The project’s aim was to establish an efficient means of communication between planets and satellites keeping in mind their enormous difference in distance as well as unavailability of message routers (usually satellites) at all times. Hence the concept (and a need) for a new network emerged wherein messages would be passed around the network based on scheduled contacts (as satellite contact periods are usually fixed). On further research, it was seen that not only interplanetary but many new networks in Earth too needed something more than what was provided by the TCP/IP. The TCP/IP works on some assumptions that are:

1. Cannot work with long link delay.
2. Necessity of existence of end-to-end routing paths.
3. Works with data packets having low time-to-live.
4. Lack of large memory at intermediate nodes.

Abiding by these strict prerequisites is not feasible for some new networks like:

1. Terrestrial civilian networks connecting mobile wireless devices, including personal communicators, intelligent highways, and remote Earth outposts.
3. Outer-space networks, such as the InterPlaNetary (IPN) Internet project.
4. Sensor Networks both on land and in water.
5. War torn or Disaster struck areas like a place hit by some natural calamity whose connection with the outside world has disrupted resulting into a network partition.

These above networks on the other hand are characterised by:

1. intermittent connectivity.
2. power limitations.
3. network partitions.
4. long and variable delays.
5. arbitrarily long periods of link disconnection.
6. high error rates and large bidirectional data-rate asymmetries.

The answer to all these is the Delay Tolerant Network (DTN) [1, 2]. A DTN is a network of regional networks. It is an overlay on top of regional networks, including the Internet. DTNs support interoperability of regional networks by handling enormous propagation delays between and within regional networks, and by translating between regional network communication characteristics. In providing these functions, DTNs accommodate the mobility and limited power of evolving wireless communication devices and cover up for their inconveniences. To accommodate these features onto the existing TCP/IP layer, DTN adds the Bundle layer, which most importantly does persistent storage. It is an additional layer on top of the transport layer where the ‘delay is tolerated’. Actually it is the layer in between the application layer and heterogeneous region specific lower layers that will act as a bridge between incompatible networks [3].
A DTN is a family of various networks challenged in some way or the other. Hence each network has a different priority on what is more important for itself. For almost all kinds of DTN, message delivery in severe situations is the goal and thus delivery of a message is of utmost importance. As the name suggests, delay should be “tolerated” as network connections are sparse and random. A packet is considered successfully delivered if it is received by the destination within a certain time called TTL (Time To Live) since its generation at the source. Generally messages in DTN have inherently higher TTL value keeping into consideration the significant amount of time a particular message has to wait in intermediary buffers before reaching its final destination. In such scenarios message replication seems the solution, but we need to keep in mind the various network limitations of DTN like energy, cost and low bandwidth. More replication means increasing all these factors and hence pure replication would not give a desirable result here. Thus we need to work on mechanisms that can provide a network with a balanced solution without testing its limitations too severely.

2. Comprehensive Theoretical Comparison

A considerable amount of work has been done on the routing aspect of DTNs. Even then routing remains a big problem for systems working in DTN as not all schemes suit every kind of DTN application. In fact finding an optimal routing algorithm for DTN in the general case has been proved to be an NP hard problem [4]. The key is to find a protocol that suits a given network’s requirements. Let us discuss some popular and widely known existing DTN routing protocols.

Routing protocols in DTN can be broadly classified into two groups on the nature of their strategy chosen to forward a message. This strategy itself can be either replication based (which relies on more number of copies to increase the chances of a message being delivered) or knowledge based (which uses network information to route data). Based on these strategies the classification are namely, flooding based and forwarding based routing. In flooding based protocols, a node makes numerous copies (or replicas) of a single message in an attempt to increase the chance of it being delivered. One such popular routing protocol (and also one of the earliest protocol for routing in DTN) is the Epidemic routing. Epidemic routing [5] simply replicates messages from one node to another as and when a connection is established between them. In this way the chances of message delivery increases but a lot of network resources (like bandwidth, buffer storage, energy and cost) are wasted in return. An improvement on this protocol is the Credit Based strategies [6, 7], which assign a credit value to every node, connected on their time of connection and gives them the power to replicate based on that credit. These strategies greatly reduce number of replicas. Another protocol in this family is the Spray & Wait [8]. Spray & Wait is composed of two phases. The first phase is known as the Spray phase in which the source of the message sprays one copy to L (predefined) distinct nodes. After a node receives the copy it enters the wait phase (the second phase) where it holds the message until it meets its destination directly. Spray & Wait has a variant known as Binary Spray & Wait [8] in which a node that has n > 1 message copies (source or relay), and encounters another node B (with no copies), hands over to B ceil[n/2] copies and keeps floor[n/2] copies for itself; when it is left with only one copy, it switches to direct transmission. Spray and focus [9] has the same 1st phase as Spray and Wait [8]. In its 2nd phase a node forwards the message based on an utility criteria. MaxProp [10] maintains an ordered-queue based on the destination of each message, ordered by the estimated likelihood of a future transitive path to that destination. PRoPHET [11] too uses previous performance records of nodes and routes data based on its findings. Incentive aware routing [12] uses the pairwise tit-for-tat (TFT) mechanism for routing. The Optimal Probabilistic Forwarding Protocol [13], uses an optimal probabilistic forwarding metric derived by modeling each forwarding as an optimal stopping rule problem. The performance of these methods may deteriorate when the network behaves differently from what they had anticipated.

The best method to combat increase in network cost due to numerous replication of messages is the forwarding based routing mechanism of forwarding a single copy of a message through the network [14]. This belongs to the family of forwarding based protocols. In this approach a node will pass the message it has to only one of the nodes it connects to according to some metric acquired on observing the network. One such algorithm is the Store and Forward on First Contact, which routes the message to the first node it connects to [15]. Here chances of reaching the destination decreases but since no replications are done; replication cost evanesces thereby decreasing the total cost of the network. Keeping in mind the rarity of any node-to-node connection it is very evident that although this algorithm incurs the minimum cost among all algorithms, it is very dubitable that it will be able to deliver many messages. Another variant of this single copy strategy is the Direct Delivery protocol [16], which forwards a message only to its destination node directly when it comes in contact with it. This algorithm can be defined as degenerative cases of both Flooding based as well as
Table 1. Behavioral Characteristics of Some Popular DTN Routing Protocols

<table>
<thead>
<tr>
<th>Routing Protocols</th>
<th>Flooding Family</th>
<th>Forwarding Family</th>
<th>Utilisation of Network Knowledge</th>
<th>Upperbound on Message Replica</th>
<th>Upperbound on No. of Hops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epidemic Router</td>
<td>✔</td>
<td></td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Spray &amp; Wait Router</td>
<td>✔</td>
<td></td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Binary Spray &amp; Wait Router</td>
<td>✔</td>
<td></td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>MaxProp Router</td>
<td>✔</td>
<td></td>
<td>YES (Based on current connectivity)</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>PRoPHET Router</td>
<td>✔</td>
<td></td>
<td>YES (Based on past connectivity)</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>First Contact Router</td>
<td>✔</td>
<td>✔</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>Direct Delivery Router</td>
<td>✔</td>
<td>✔</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>

Forwarding based schemes. It has the least overhead of all but suffers greatly in delivery and delay performances due to obvious reasons.

There are many more protocols belonging to this family of forwarding based algorithms where the messages are forwarded instead of replicating them perhaps using some information about the network or where routing completely takes place according to some opportunistic or probabilistic metric [17, 18, 19, 20]. Some of them are Two hop relay [21], Utility based routing [22], Mobispace [23] and Seek and Focus [24].

There are further protocols in this division, which uses past network performance information (also referred to as network oracles) as a means to develop an efficient routing strategy. Practical routing [25] uses observed information about the network for calculating minimum estimated expected delay (MEED) for routing.

Conditional shortest path routing [26] routes messages with the help of a metric called conditional intermeeting time based on the observations about human mobility traces. These techniques mainly thrive on network oracles such as future contact arrival time, last encounter time etc and as a result fail to utilize the opportunity presented by the present network configuration.

3. Tabular Comparison of some Popular Protocols

Table 1 gives a comprehensive behavioural comparison of some of the most popular routing protocols in DTN.

4. Comparison Through Simulation

Any analysis is incomplete and unsatisfying without results from extensive and precise simulation to back our theories and assumptions. For simulation we have used the widely accepted and established simulator-the Opportunistic Network Environment (ONE) simulator [27, 28], which has been specifically designed for simulating the behaviour of a Delay Tolerant Network. Here any event recording is done after a time step of 0:1s. A new message is created every 25 to 35 seconds with message sizes varying between 500kB and 1MB. The simulation world size is 4500 X 3400meters. The movement model that we have chosen for all hosts (except for Trams that use their own predetermined route using the MapRouteMovement file) in our simulation is the Shortest Path Map-Based Movement (SPMBM) model. Each group has a different route and stops between ten to thirty seconds at certain locations on the map. Further details of the simulation parameters taken into consideration are discussed in Table 2.

The simulations were done in a laptop with 4 GB of RAM running the Windows 10 operating system. The version of the ONE simulator used was 1.4.1.
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Node Type</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pedestrian</td>
<td>Cars</td>
<td>Trams</td>
<td></td>
</tr>
<tr>
<td>No. of Nodes</td>
<td>80</td>
<td>40</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>0.5 to 1.5 m/s</td>
<td>2.7 to 13.9 m/s</td>
<td>7 to 10 m/s</td>
<td></td>
</tr>
<tr>
<td>Buffer Size</td>
<td>5 MB</td>
<td>5 MB</td>
<td>50 MB</td>
<td></td>
</tr>
<tr>
<td>Message Time To Live</td>
<td>300 minutes</td>
<td>300 minutes</td>
<td>300 minutes</td>
<td></td>
</tr>
</tbody>
</table>

### 4.1 Results and Findings

From the plots of Figure 1 to 4 we can clearly see for ourselves how the different protocols have fared with respect to varying units of time for simulation. Let us discuss them in details.

### 4.2 Delivery Probability

Delivery Probability is the fraction of generated messages that are correctly delivered to the final destination within given time period.

We see from Figure 1 that the delivery probability of MaxProp is highest among all routing protocols and increases with respect to simulation time. In case of Spray and Wait, Epidemic, PRoPHET and First Contact the delivery probability is low and also increases with increasing of simulation time, whereas in the case of Direct Delivery, initially the delivery probability is low but with increasing simulation time the delivery probability increases and eventually surpasses that of First Contact and PRoPHET.

### 4.3 Overhead Ratio

The overhead ratio shows the amount of network resources needed to deliver a packet to its destination. It defines how many redundant packets are relayed to deliver one packet. It simply reflects the cost of transmission in a network, and is defined as follows:

\[
\text{Overhead ratio} = \frac{(R-D)}{D}
\]

where \( R \) is the number of messages forwarded by relay nodes, and \( D \) is the number of messages delivered to their destination.

The plot of Figure 2 shows that Epidemic as already predicted in the theoretical analysis, due to hunger of resources has the highest overhead ratio among all routing protocols. This shows that it needs high amounts of network resource to deliver packet to the destination. First contact, MaxProp and PRoPHET also have high overhead ratio but less than Epidemic routing. On the other hand Spray and Wait has low overhead ratio which means it requires less network resources and in Direct Delivery case overhead ratio is zero because it uses only a single copy and zero hop i.e. it selects the direct path between source and destination.

### 4.4 Average Latency

It is defined as the average value of the delays for each successful delivered packet.

The average latency of Epidemic routing is higher than Spray and wait and less than PRoPHET for all simulation periods. Epidemic routing has higher average latency than First Contact, Direct Delivery, MaxProp routing when running for smaller simulation time but lesser latency when the simulation time increases. For Direct Delivery the average latency increases with respect to simulation time and has usually the highest latency among all.

### 4.5 Average Hop Count

The Average Hop Count is defined as the average number of hops or more precisely the number of nodes, which a message has to pass from the source to reach the destination node. It helps in understanding how messages, along a path, must pass from the source to the destination or how the network resources have been used. Direct Delivery obviously has the least hop count average because it selects the direct path between the source and destination. Second to that come Spray and Wait, MaxProp and PRoPHET who have considerably less hop count average. Epidemic has higher hop count average than Spray and Wait, MaxProp and PRoPHET but less than First contact routing, which has the highest hop count average.

### 5. Conclusion

The Delay Tolerant Networks have made quite a stir in the field of networking. As such many budding researchers are taking interest in it. As it has been a decade since its inception quite a lot of work has happened in this field. This paper presents a comprehensive study of some of the most popular routing protocols in DTN. This would provide a new researcher in DTN an easy and quick guide to the routing protocols in DTN that might otherwise be a bit daunting and confusing for a rookie to grasp. This paper accordingly compared the protocols not only theoretically but also provided tables and
simulation results to make it even clearer for the reader to assess. And from all the analysis and

**Figure 1.** Simulation Results for Message Delivery Probability

**Figure 2.** Simulation Results for Overhead Ratio

comparison one judgment can be passed that no protocol can be universally declared as the optimum solution for all situations thus reinstating the fact that routing in DTNs is an NP complete problem.

### 6. References


[9] Konstantinos Psounis Thrasyvoulos Spyropoulos and Cauligi S. Raghavendra, Spray and focus: Efficient mobility-assisted...

![Figure 3](image-url)

**Figure 3. Simulation Results for Average Message Latency**

![Figure 4](image-url)

**Figure 4. Simulation Results for Average Hop Count**


