Performance Analysis of Delay Tolerant Network Routing Protocols in Different Mobility Environments

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Abstract — Performance of routing protocols for mobile ad hoc network is affected by mobility environments of mobile nodes. In this paper, we perform analysis of different Delay Tolerant Routing protocols in different mobility environments. Delay Tolerant Network (DTN) is a mobile ad hoc network in which every node does not have wireless connection with other nodes all the time i.e. there is no path from one node to other nodes and data delivery path cannot be calculated before sending data. Traditional ad hoc routing protocols cannot be used in DTN. Basically in DTN routing, a node stores message and when it encounters another node it forwards a copy of the message to the node which repeats the same process until the destination node is encountered and the message is delivered or the message life is expired. Nodes in DTN are resource constrained, i.e. they have less energy (battery operated) and have less memory to buffer messages. It is important to utilize the resources efficiently in DTN. In this paper, we perform analysis of three important DTN routing protocols to investigate their resource utilization, especially energy consumption under three different mobility environments. Furthermore, we also compare their message delivery probability and message overhead ratio. We extensively simulate different protocols under different mobility environments by changing number of nodes, message size and message generation interval. We have found that some protocols perform almost the same in all mobility environments and some do not.

Keywords - Delay Tolerant Network, energy aware routings, mobility models

I. INTRODUCTION

Mobile ad hoc networks are wireless networks that are formed by mobile nodes. However, the network may partition into many islands due to unpredictability of node movements, less number of nodes in a certain geographic area or communication range of nodes. In order to overcome this problem, the concept of Delay Tolerant Network (DTN) [1], sometimes known as “network of regional networks” has been used. A node in DTN essentially stores message and forwards it to next node when the connection is available. The process is continued until the message is delivered to the destination node or the life of the message expires. There are many routing protocols proposed for DTN. The major ones are Epidemic [6], PRoPHET [7, 8] and Spray-and-Wait [9]. However these routing protocols are designed for nodes without any energy constraint such as vehicles.

Due to proliferation of mobile devices such as smartphones and tablet PCs which are constraint with energy supply, many energy efficient DTN protocols have been proposed [12]. As far as we know, previously proposed energy efficient DTN routing protocols assume a certain node movement model such as Random Walk model, Random Waypoint model, or Shortest Path Map-based model etc. In wireless communication devices, most of the energy is consumed while transmitting data. Different movement models will cause a node to have different number of encounters with other nodes thus each node will have different number of data transmissions causing different amount of energy consumption.

In this paper, we analyze different node movement models in different DTN routing protocols in terms of energy consumption. We particularly investigate Random Walk movement model [10], Random Waypoint movement model and Shortest Path Map-based movement model in each of the well know DTN routing protocols; particularly Epidemic, PRoPHET and Spray-and-Wait. Our main contribution of the paper is how a movement environment can impact the energy consumption and performance of DTN routing protocols.

The paper is organized as follows. In section II, we briefly describe the most related works. In section III, we describe the DTN routing protocols that we are analyzing in this paper. In section IV, we explain the movement models that are frequently used in simulation. In section V, we perform the simulation and present the results. Finally, in section VI, we conclude our paper.

II. RELATED WORK

In [2], authors present performance comparison of Epidemic, Spray-and-Wait, PRoPHET, MaxProp and Bubble Rap DTN routing protocols with respect to energy consumption. However they use only one movement model and do not explain what will happen with other movement models. In [3], authors perform the same analysis as in [2] and also using the same protocols also. They use the Shortest
Path Map-based movement model only. In [4], [5] and many other energy efficient DTN routing protocols, they concentrate on energy efficiency of routing protocols. They do not consider the impact of movement models in energy consumption and performance of DTN routing protocols.

Unlike above mentioned works which use only one mobility environment, here we use different mobility environments to compare performance of different DTN routing protocols. Furthermore, we also investigate how they perform when number of nodes, message size and message generation intervals are changed. By doing so, we believe that our performance comparison of DTN routing protocol is more exhaustive compared to previous works.

III. DTN ROUTING PROTOCOLS

In this paper, we consider Epidemic, PRoPHET and Spray-and-Wait DTN routing protocols and we briefly describe them below.

A. Epidemic Routing Protocol

Epidemic routing protocol [6] is one of the first routing protocols that was proposed for DTN. That may be one reason why it is simple and easy to implement. In Epidemic routing protocol, a node forwards a copy of a message to all nodes it encounters, thus the name Epidemic. A node will not receive the message if it has the message already in its buffer. Eventually all nodes will have the same message. The protocol provides the optimum delivery time however the consumption of nodes resources such as memory and network resources such as bandwidth are inefficient. So in order to improve the efficient use of resources and delivery probability the following two protocols were proposed.

B. PRoPHET Routing Protocol

In order to improve the delivery probability of messages and reduce the network and node resources, Lindgren et al. proposed PRoPHET routing protocol [7, 8]. The basic idea of PRoPHET is that a mobile node does not move randomly, instead it has repeated movement patterns, i.e. it tends to pass through some locations more often than others and more likely meet the nodes it has met in the past again. Therefore if a node X encounters a node Y frequently, node Y has higher delivery probability for messages of node X. So when node X encounters node Y and some other nodes which it has not met before it will forward messages to Y instead of other nodes. Unlike Epidemic routing protocol, in PRoPHET routing protocol, a node forwards messages only to some higher delivery probability nodes, not all nodes it encounters thus saves resources.

C. Spray-and-Wait Routing Protocol

Spray-and-Wait routing protocol controls the spreading of messages in the network. Unlike PRoPHET routing but like Epidemic routing, it has no previous knowledge of encountering nodes and simply forwards multiple copies of messages to nodes it encounters. The main difference with Epidemic routing is that it spreads only L copies of message. The protocol has two phases: (i) Spray phase: a source node spreads a limited number of copies (L) of message to nodes which it encounters. (ii) Wait phase: after spreading of all copies of the message is done and the destination node is not encountered by the source node, each node with the copy of the message in the spread phase, tries to deliver its own copy to the destination node via direct transmission. In order to improve the performance of the algorithm, authors have proposed binary Spray-and-Wait protocol. In this protocol, a source node prepares L copies of message and transmits half of it to a node it encounters first. The source node and other nodes which have copies of the message, transmit half of the message to nodes they encounter and do not have the message. The process is repeated until only one copy of the message is left. When only one copy is left, nodes with the copy of the message will try to deliver it to destination node via direct transmission. Here, we use binary Spray-and-Wait protocol with L = 6.

IV. MOVEMENT MODELS

We briefly describe movement models we consider in this paper as shown below.

A. Random Walk Movement Model

A random walk is a succession of random steps taken from a point to other points. The term random walk was first introduced by Karl Pearson in 1905 [10]. The Random Walk model was developed to mimic the unpredictable movement of things in nature such as movement of molecules in liquid and so on. In Random Walk mobility model, a mobile node moves from its current location to a new location by randomly choosing a direction and speed to travel with. Both speed and direction are chosen from pre-defined ranges. This model is used in simulation when area is considered as a field such as festival area, battle field, grasslands and so on.

B. Random Waypoint Movement Model

Random Waypoint movement model is similar to Random Walk model except that there is pause time between changes in direction and speed. A mobile node begins by staying in one location for a certain period of time (pause time). Once the time expires, the node chooses a random destination in the simulation area and a speed that is uniformly distributed between minimum speed and maximum speed and moves to the destination. Upon arrival to the new destination it pauses for a specified time period and starts the same process again. This model is used in similar situation as in Random Walk model.

C. Shortest Path Map-Based Movement Model

In this model, a map of a road or a footpath/trail is used. Every mobile node has knowledge of the map. A node chooses its destination in the map and calculates the shortest path to reach the destination and moves along the calculated path. Once it reaches its destination it chooses another destination in the map and calculates the shortest path to the destination and moves along the path to reach the destination. This model is used in vehicular movement and walking in cities and so on.
V. SIMULATION SETUP AND RESULTS

We used well known DTN protocol simulator called “Opportunistic Network Environment (ONE)” [11]. The simulator is written in Java. However, the simulation script has to be written in plain text.

A. Simulation Parameters

In simulation, we assume that all nodes are mobile in nature such as smartphones or tablet PCs and their speed is same as the human walking speed. For Random Walk and Random Waypoint movement models, we use the simulation area as shown in Table I whereas for Shortest Path Map-based movement model we use the Helsinki downtown area map that comes with the simulator. First we simulate by changing number of nodes, then by changing message size and finally by changing message generation interval. The following Table I shows the simulation settings and Table II shows the node energy. We assume that nodes do not recharge their batteries during simulation.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Area</td>
<td>4500m x 3400m</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>100–600</td>
</tr>
<tr>
<td>Interface</td>
<td>WiFi</td>
</tr>
<tr>
<td>Interface Data Rate</td>
<td>2Mbps</td>
</tr>
<tr>
<td>Radio Range</td>
<td>100m</td>
</tr>
<tr>
<td>Movement Speed</td>
<td>0.5 ~ 1.5 m/s</td>
</tr>
<tr>
<td>Buffer Size</td>
<td>50MB</td>
</tr>
<tr>
<td>Message Size</td>
<td>500KB ~ 1MB</td>
</tr>
<tr>
<td>Message Generation Interval</td>
<td>25s ~ 35s</td>
</tr>
<tr>
<td>Message TTL</td>
<td>300 minutes (5 hours)</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>43200 sec (12 hours)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values (units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Energy</td>
<td>4800</td>
</tr>
<tr>
<td>Scan Energy</td>
<td>0.06</td>
</tr>
<tr>
<td>Scan Response Energy</td>
<td>0.08</td>
</tr>
<tr>
<td>Transmit Energy</td>
<td>0.08</td>
</tr>
<tr>
<td>Base Energy</td>
<td>0.07</td>
</tr>
</tbody>
</table>

All nodes have the same initial energy. Scan energy represents the energy for scanning (discovering) devices/neighbors. Scan response energy represents the energy consumed while responding neighbors/devices on discovery. Transmit energy is energy used sending messages. Its value is set same as the scan response energy (consumed in transmitting the response message). Base energy is the energy consumed while the node is idle (i.e. not scanning, scan responding and transmitting). Simulation was performed for 12 hours.

B. Results for Varying Number of Nodes

We changed the number of nodes from 100 to 600. We check the average remaining energy of nodes in each DTN routing protocol under different movement models. Similarly, we check message delivery probability and overhead ratio for each protocol under different movement models. Furthermore, we check how a routing protocol performs in different movement models. In following figures, E-RW represents Epidemic under Random Walk model, E-RWP represents Epidemic under Random Waypoint model, E-ShortPath represents Epidemic under Shortest Path Map-based model. Similarly, P-RW, P-RWP, P-ShortPath, S-RW, S-RWP and S-ShortPath represent PRoPHET and Spray-and-Wait under Random Walk, Random Waypoint and Shortest Path Map-based models.

1) Average Remaining Energy

Higher remaining energy a node has better it is because it will live longer and can transfer message for longer time. When the energy level of a node is zero it is a dead node and it cannot perform any activities. As shown in Fig. 1, Fig. 2 and Fig. 3, average remaining energy of nodes in Spray-and-Wait protocol is the highest in all movement models whereas it is the lowest in Epidemic protocol. We can see from figures that the average remaining energy of nodes in Epidemic and PRoPHET decreases as the number of nodes increases because there will be increase in number of transmission of message whereas it remains almost the same in Spray-and-Wait protocol because the number of transmission of message is limited by size of L. As shown in Fig.4, the average remaining energy of nodes for each protocol is the highest in Random Walk model and the lowest in Shortest Path Map-based model.
2) Delivery Probability

Delivery probability is defined as the number of messages delivered divided by number of messages created. This is of course higher the better and is affected by nodes energy, i.e. if nodes die, delivery ratio will effectively decrease. As shown in Fig. 5, PRoPHET performs better in Random Walk model whereas Spray-and-Wait performs better both in Random Waypoint and Shortest Path Map-based models which are shown in Fig. 6 and Fig. 7 respectively. As shown in Fig. 8, all the protocols perform worse in Random Walk model. PRoPHET performs better in Random Waypoint model whereas Spray-and-Wait performs better in Shortest Path Map-based model. Epidemic performs almost the same in both Random Waypoint and Shortest Path Map-based models. Delivery probability increases in Epidemic and PRoPHET as the number of nodes increases whereas it remains almost the same in other models.
3) Overhead Ratio

This is an assessment of bandwidth efficiency. It is interpreted as the number of created copies per delivered messages, i.e. number of replicas necessary to perform a successful delivery. Higher the value means higher number of copies of messages were created and not a better result. As shown in Fig. 9, Fig. 10 and Fig. 11, Spray-and-Wait protocol has the lowest overhead ratio because it does not make copies after L becomes 1. Since in our simulation we set the initial value of L as 6 the overhead ratio is less. For Epidemic and PRoPHET the overhead ratio increases as the number of nodes increases. As shown in Fig. 12, overhead ratio is low for Epidemic and PRoPHET in Random Walk model whereas it is high for Spray-and-Wait protocol.

C. Results for Varying Message Size

We vary the message size from 100KB–500KB, 500KB–1MB, ..., 2MB–2.5MB as shown in figures below and simulated using 200 nodes. Other parameters were same as the Table I. As in section B, we check the average remaining energy, delivery probability and overhead ratio of each protocol under different mobility models.

1) Average Remaining Energy

For each movement model, the average remaining energy of nodes in different protocol is almost the same as the size of message increases though there is drop when the message size is changed from 100KB–500KB to 500KB–1MB for some protocols (Figs. 13–15). For each protocol average remaining energy of nodes is the highest in Random Walk model and the lowest in Shortest Path Map-based model (Fig. 16).
2) Delivery Probability

In all mobility models, for Epidemic and PRoPHET protocols delivery probability decreases as the size of the message increases (Figs. 17–19). This is because message will be dropped when the buffer is full causing decrease in delivery probability. For Spray-and-Wait protocol it remains the same as it is determined by size L. Each protocol performs worst in Random Walk model (Fig. 20). Epidemic and PRoPHET performs slightly better in Radom Waypoint model.
3) Overhead Ratio

Overhead ratio decreases as the size of the message increases in all models and all protocols except in Random Walk model. This is because when message size increases the buffer will be full soon and message will be dropped before the message can be copied and transferred to other nodes (Figs. 21–24). In Random Walk especially in Epidemic, messages are spread faster as nodes meet other nodes earlier before they are dropped thus overhead ratio is higher.

![Figure 21. Random Walk](image1)

![Figure 22. Random Waypoint](image2)

![Figure 23. Shortest Path Map-based](image3)

Figure 24. Overhead Ratio in Different Mobility Environments

D. Results for Varying Message Generation Interval

We change the message generation interval from 5–15, 15–25, ..., 45–55 (sec.) as shown figures below for 200 nodes simulation and left other parameters same as in Table I. As in previous sections, we check the average remaining energy, delivery probability and overhead ratio of each protocol under different mobility models.

1) Average Remaining Energy

As the message generation interval increases average remaining energy of nodes in all protocols and in all mobility models also increases though very slightly, i.e. less energy consumption in nodes (Figs. 25–28). When message generation interval is high, less number of message will be generated and there will be less number of transmission and thus remaining energy of nodes will be higher.

![Figure 25. Random Walk](image4)
2) Delivery Probability
As we can see from Figs. 29–32, except Spray-and-Wait protocol, other two protocols have higher delivery probability as the message generation interval increases. This is because less number of message will be generated and buffer overflow (message drop) will be less frequent making delivery probability higher. As explained before, for Spray-and-Wait protocol it is almost the same in all message generation interval because message generation is restricted by L. All protocols’ delivery probability is less in Random Walk model than other two models.
3) Overhead Ratio

As shown in figures below (Figs. 33~36), overhead ratio increases as message generation interval increases. This is because less message will be dropped as a result of buffer overflow and there is more chances that message will be copied and transferred to other nodes.

VI. CONCLUSIONS

In this paper, we analysed different DTN routing protocols in different mobility environments. We found that there is no single mobility environment suitable for all DTN routing protocols. Depending upon which resource of nodes one wants to save or which performance of a routing protocol one wants to improve, selection of a routing protocol and a mobility model may be different for different cases.

From our analysis, we found that if saving energy of nodes is important, Spray-and-Wait protocol consumes less energy in all mobility environments. However, one should note that it depends upon the size of L. Next one is PRoPHET which consumes less energy in all mobility models. For any particular protocol Random Walk model consumes less energy.

If a user’s concern is to use a protocol with improved delivery probability then Epidemic or PRoPHET can be chosen as they give almost the same result in all mobility environments. However, if one chooses a particular routing protocol and wants to choose a mobility model to improve delivery probability, then Random Walk model should be avoided as it performs worst. Other two models perform almost the same.

If overhead ratio is the main concern one can choose Spray-and-Wait protocol because it performs better in all mobility models. However, one should note that it depends upon the size L. PRoPHET has lower or almost the same overhead ratio in all models compare to Epidemic, so it may be the best choice for all mobility environments. However, if a protocol is chosen and which mobility model gives the best result is a concern, then for Epidemic and PRoPHET Random Walk gives the best result. For Spray-and-Wait either Random Waypoint or Shortest Path Map-based can be chosen.

Our contribution in this work is that, we showed different DTN routing protocols perform differently in different mobility environments and choosing a particular protocol for particular mobility environment is very important. Investigation of DTN protocols in this paper with other mobility environments as well as other routing protocols
under different varying parameters such as buffer size is desirable in future.

REFERENCES