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Energy Consumption and Performance of Delay Tolerant Network Routing Protocols under Different Mobility Models

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***Abstract* — 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 the 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. There are various routing protocols designed to use resources efficiently. In this paper, we perform analysis of three important DTN routing protocols to see their resource utilization specially energy consumption under three different mobility models. Furthermore, we also compare their message delivery probability and message overhead ratio.**

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 is partitioned to 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 Networks (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 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 Forward [9]. However these routing protocols were designed for nodes without any energy constraint such as vehicles. However, 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 have different number of encounters with other nodes thus different number of data transmission and thus different level of energy consumption of mobile nodes.

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 model 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.

III. DTN ROUTING PROTOCOLS

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

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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. Nodes which receive the message repeats the same process. (ii) Wait phase: after spreading of all copies of the message is done and the destination is not encountered by a node with the copy of the message in the spread phase, the node carrying the copy of the message tries to deliver its own copy to the destination via direct transmission. In order to improve the performance of the algorithm authors proposed binary spray and wait scheme. In this scheme, a source node spreads L copies of message to nodes it encounters. The nodes that receive copies of the message spread half of it (L/2 copies, i.e. L/2 nodes) to nodes they encounter which then spread half of it and so on until only one copy 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.

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

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. The following Table I shows the simulation settings and Table II shows the nodes energy. We assume that nodes do not recharge their batteries during simulation.

TABLE I. SIMULATION SETTINGS

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

TABLE II. NODE ENERGY PARAMETERS

Parameters	Value (units)
Initial Energy	4800
Scan Energy	0.06
Scan Response Energy	0.08
Transmit Energy	0.08
Base Energy	0.07

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 for 100, 200,…,, 600 nodes respectively.

B. Results

We check the average remaining energy of nodes in each DTN routing protocols 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.

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 Spread-and-wait protocol is the highest in all movement models whereas it is the lowest in Epidemic protocol. As shown in Fig.4, Fig. 5, and Fig. 6, 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.

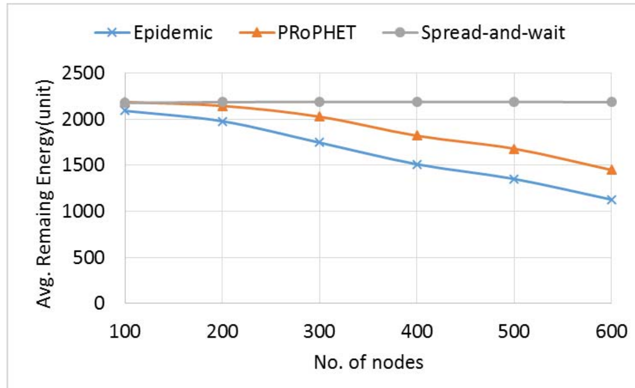

Figure 1. Random Walk

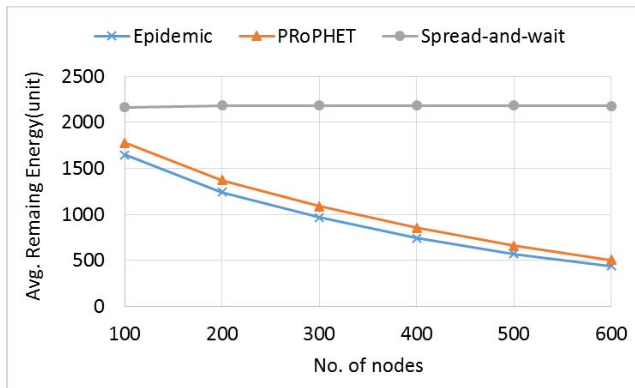

Figure 2. Random Waypoint

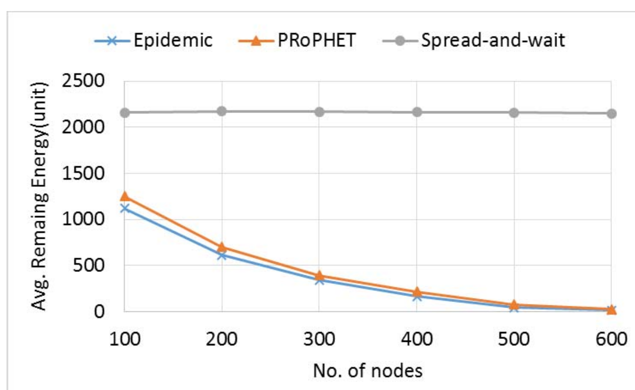

Figure 3. Shortest Path Map-based

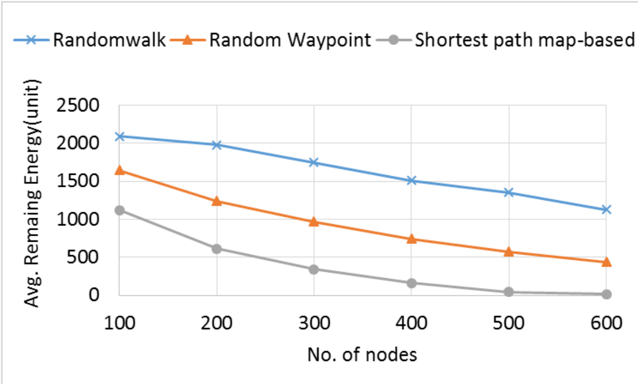

Figure 4. Epidemic

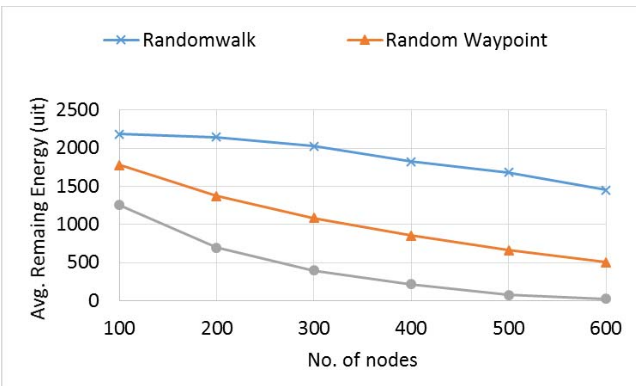

Figure 5. PRoPHET

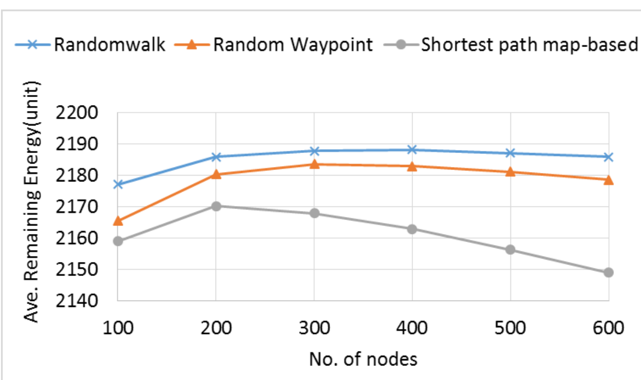

Figure 6. Spray-and-wait

2) *Delivery Probability*

Delivery probability is defined as the number of messages delivered divided by number of message 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. 7, PRoPHET performs better in Random Walk model whereas Spray-and-wait performs better both in Random Waypoint and Shortest Path Map-based models which is shown in Fig. 8 and Fig. 9 respectively. As shown in Fig. 10, Fig. 11 and Fig. 12, 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.

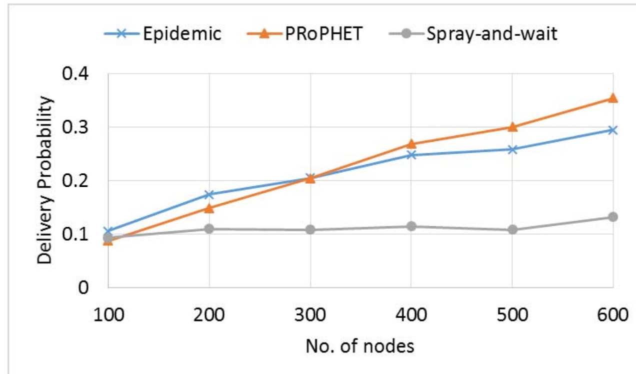

Figure 7. Random Walk

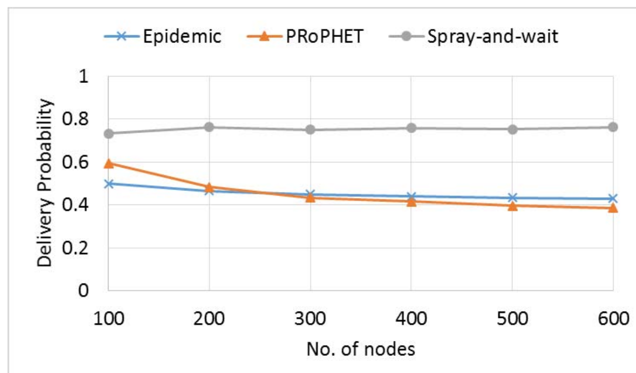

Figure 8. Random Waypoint

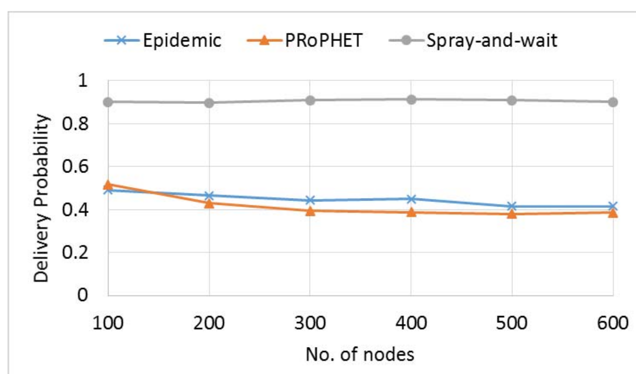

Figure 9. Shortest Path Map-based

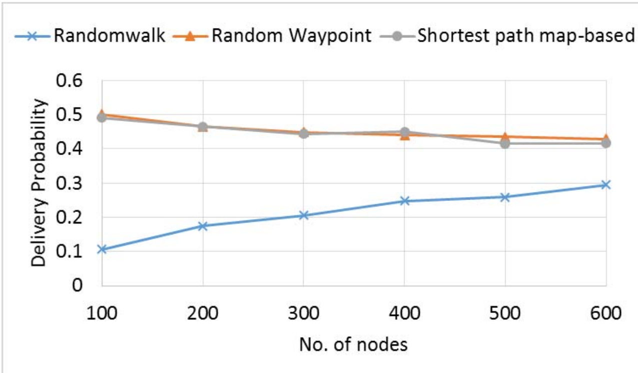

Figure 10. Epidemic

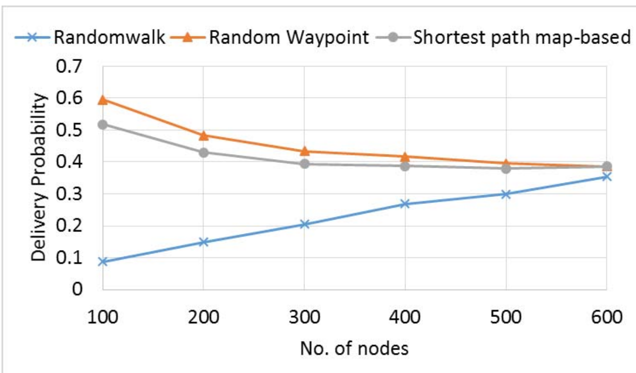

Figure 11. PRoPHET

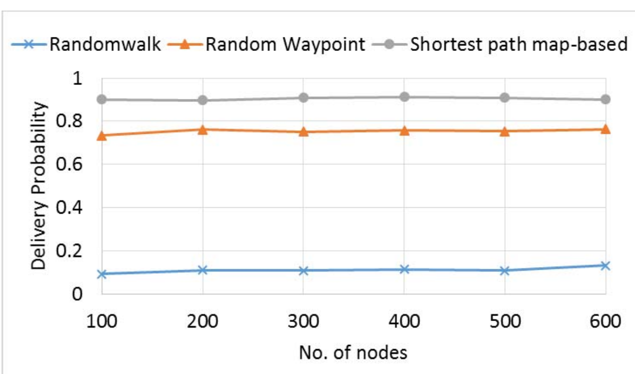

Figure 12. Spray-and-wait

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. 13, Fig. 14 and Fig. 15, 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. 16, and Fig. 17, overhead ratio is low for Epidemic and PRoPHET in Random Walk model whereas it is high for Spray-and-wait protocol which is shown in Fig. 18.

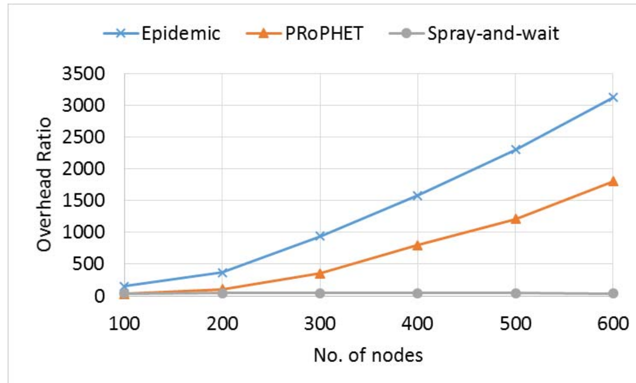

Figure 13. Random Walk

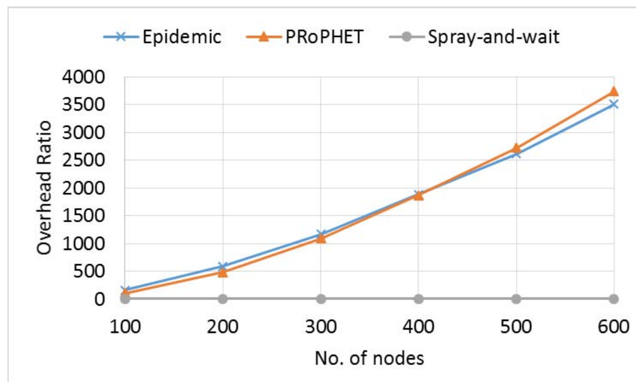

Figure 14. Random Waypoint

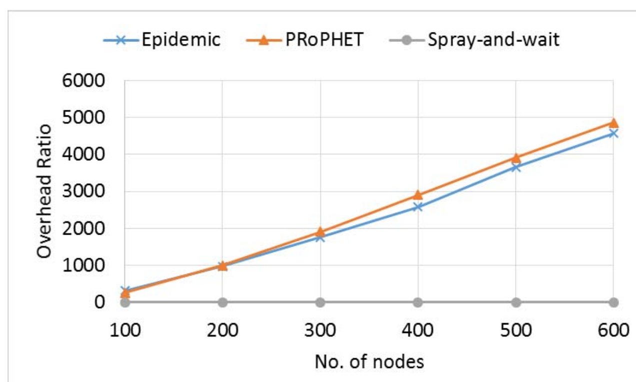

Figure 15. Shortest Path Map-based

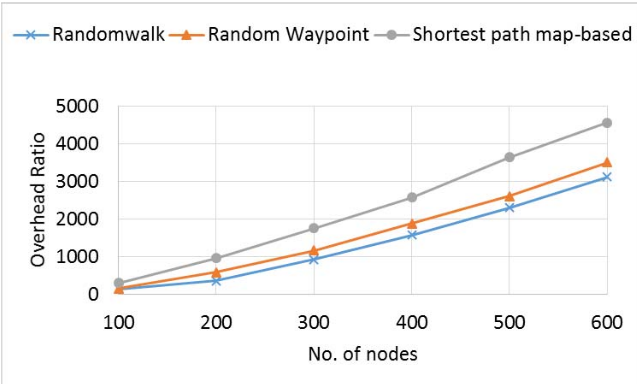

Figure 16. Epidemic

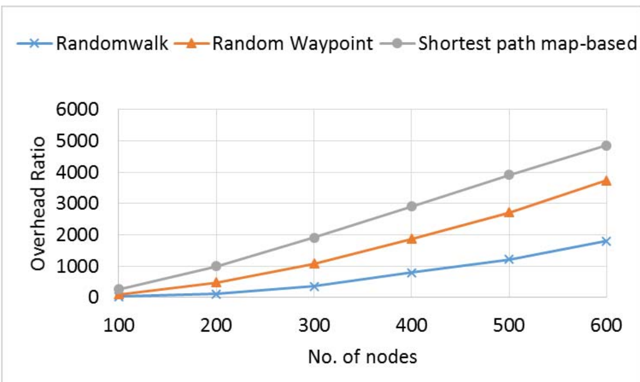

Figure 17. PRoPHET

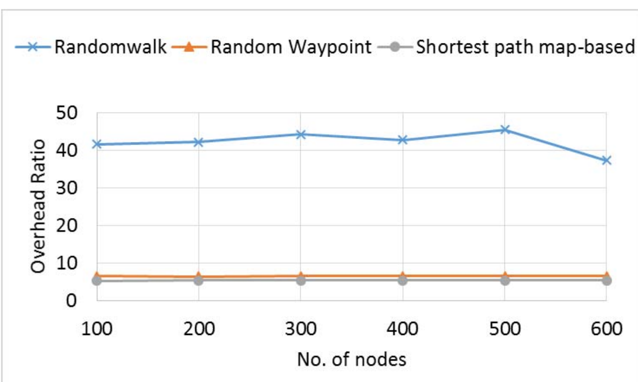

Figure 18. Spray-and-wait

VI. CONCLUSIONS

In this paper, we analysed different DTN routing protocols in different movement models. We found that there is no single movement model suitable for all DTN routing protocols. Epidemic and PRoPHET perform better in Random Walk model for energy consumption and overhead ratio while perform better in Random Waypoint for delivery probability. However, Spray-and-wait performs better in Random Walk model for energy consumption and performs better in Shortest Path Map-based model for both delivery probability and overhead ratio. In this paper, we simulated only for 12 hours. We need to simulate for longer period of time to see how many nodes will run out of battery in different routing protocols and movement models. Furthermore, we need to find how the movement models will affect the performance of routing protocols in different message size, buffer size, message generation interval and so on. We leave them as our future works.

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