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Energy Consumption Analysis of Delay Tolerant Network Routing Protocols

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Abstract

In a resource constrained network such as Delay Tolerant Networks (DTN), efficient utilization of resources such as energy is important for optimum network performance. However, due to nodes mobility, frequency of encounters and message transmission, most of node's energy in this type of network is continuously depleted. A node's energy in DTN plays an important role in the success of delivering messages. The lower the energy a node has, the lower its chance to deliver messages across the network. Thus, a proper energy-efficient routing protocol should be selected for message transmission for DTN applications. This issue leads us to investigate on the energy consumption of nodes in DTN. We simulated and compared several existing routing protocols and assessed them in terms of average remaining energy and number of dead nodes. Our results show that significant characteristics of these routing protocols contribute to either consuming low or high energy in delivering messages under certain network settings.

Keywords: *Delay Tolerant Network, Energy efficient routing protocols*

1. Introduction

Energy consumption is a major factor in the performance and deployment of modern computational and communication systems [1]. In these days smartphones are quickly becoming the main computing and communication platform. These are equipped with communication capabilities (i.e. Bluetooth and Wi-Fi), which enables them to carry messages especially in Delay Tolerant Networks (DTNs) [2]. In this network, the amount of energy of a node is considered as an important factor in sending and receiving messages. However, most modern smartphones are powered by lithium-ion batteries and thus store limited energy and plenty of attempts have been done to increase the amount of energy that could extend the lifetime of a battery [3].

In DTN, for most cases, hardware resources might be highly constrained and it is important to take into account the remaining energy of a node while determining whether to exchange data during an encounter [4]. However, only few researches have addressed this problem. To investigate on the energy expenditure, we carry out an energy-based performance evaluation of several DTN protocols using metrics such as Nodes Average Remaining Energy and the Number of Unavailable Nodes in the network to find out which of these routing protocols are having minimal consumed energy under certain network settings.

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The remainder of the paper is organized as follows: Section 2 briefly discusses about DTN; Section 3 shows the experiment setup, scenario settings and evaluation metrics, Section 4 depicts the result of the simulation and finally, Section 5 concludes the paper.

2. Delay Tolerant Network

Delay Tolerant Networks (DTN) are a class of networks that lack continuous connectivity between nodes due to limited wireless radio coverage, widely scattered mobile nodes, constrained energy resources, high levels of interference or due to some other similar channel impairment [5]. Most of these DTN routing protocols belong to one of these three categories:

A. Message-ferry-based

In message-ferry-based methods, systems usually employ extra mobile nodes as ferries for message delivery. The trajectory of these ferries is controlled to improve delivery performance with store-and-carry message forwarding mechanism.

B. Opportunity-based

In opportunity-based schemes, nodes forward messages randomly hop by hop with the expectation of eventual delivery, but with no guarantees. Generally, messages are exchanged only when two nodes meet at the same place, and multiple copies of the same message are flooded in the network to increase the chance of delivery.

C. Prediction-based

In prediction-based schemes, routing protocols make relay selection by estimating metrics relative to successful delivery, such as delivery probability or expected delay based on a history of observations.

Table 1. Characteristics of DTN Categories

Characteristics	Message Ferry-based	Opportunity-based	Prediction-based
Forwarding method	Reactive/Proactive	Flooding	Proactive
Node Types	Heterogeneous	Homogeneous	Homogeneous
Mobility	Controlled	Random	Semi-random
Delay	Highest	Lowest	Moderate
Message Duplication	Upon ferry encounter	Every node encounter	Neighbors that meet criteria
Energy Consumption	Lowest	Highest	Moderate
Retain Encounter Information	Partially	No	Yes
Use of location Information	Yes	No	No
Complexity	Moderate	Simple	Highest

3. Experiment Setup

Opportunistic Network Environment (ONE) was used for the simulation. ONE is a Java-based simulation environment that combines movement modeling, routing simulation, visualization and reporting in one program [6]. We choose two routing protocols each from opportunity based and probability based due to their energy consumption nature presented in Table 1. The following routing protocols are the subject of the evaluation:

A. Epidemic Routing

An opportunity-based routing protocol that enables two nodes to exchange all messages currently carried upon encounter. Wherein, at the end of the encounter both nodes will possess the same set of messages. As this process continues, every node will be able to send information to every other node. The packets are basically flood-ed through the network much like the spread of a virus in epidemiology [1, 5].

B. Spray and Wait

An opportunity-based routing protocol and made as an improvement of the Epidemic routing protocol by controlling the level of message flooding. It has two phases: the Spray phase and the Wait phase [5]. In Spray Phase, every message originating at the source node is passed to a distinct relays in the network i.e. a number of copies of the message are spread over the network by the source node. In the Wait phase, if the destination was not found in the spray phase, each relay node having a copy of the message performs the direct transmission of the message to the destination itself.

C. PRoPHET

A prediction-based routing protocol where each node calculates a probabilistic metric called Delivery Predictability for each known destination before sending a message [7]. This metric indicates the probability of successful delivery of a message from the source node to the destination node. The Delivery Predictability is calculated on the basis of history of encounters between the nodes or the history of their visits to certain locations.

D. MaxProp

A prediction-based routing protocol that does not make use of any prior knowledge about the network. It uses the local information, mobility of nodes to select the next best-hop for message delivery. It is mostly designed for vehicle-based DTN [3]. It forwards the message to any node in the network having maximum probability of delivering the message towards the destination.

3.1. Simulation Parameters

In the simulations, all nodes are assumed to be mobile in nature, *e.g.*, modern mobile phones or similar devices. Table 2 and 3 shows the common group settings for the simulation environment and energy settings, respectively.

Table 2. Simulation Settings

Parameters	Value
Simulation Area	4500m x 3400m
Interface	Bluetooth
Interface data rate	2Mbps
Radio range	10m
Number of groups	3
Simulation time	12h (43200 sec)

Table 3. Nodes Energy Settings

Parameter	Value (units)
Initial_Energy	5000
Scan_Energy	0.1
Transmit_Energy	0.2
Scan_Response_Energy	0.1
Base_Energy	0.01

Initial_Energy is the energy of nodes before the start of the simulation while Scan_Energy represents the energy usage per scanning i.e. amount of energy con-sumed in device discovery. Scan_Response_Energy is the energy usage per scanning response i.e. amount of energy consumed in device discovery response. The Trans-mit_Energy is energy usage per second while sending i.e. the amount of energy con-sumed in sending the message. Lastly, Base_Energy stands for the amount of energy consumed when a node is idle [6].

Three groups of nodes are used in our simulation; pedestrians, cyclist and vehicles with different movement speed and wait time, meanwhile it chooses the shortest path map based movement model where nodes move on a path defined in the form of maps, and then selects the shortest path from the source to destination. And we use available Helsinki map and trace file in the simulator.

3.2. Metrics

We focused on nodes energy consumption and its effect on the network. Thus, the following metrics described in Table 4 is use to evaluate the routing protocols.

Table 4. Performance Metric for Evaluation

Metric	Description
Nodes Average Remaining Energy	It is the average of the nodes energy left after the completion of the simulation time.
Number of Unavailable Nodes	It is the number of nodes whose energy reaches almost zero

4. Results

The results obtained in simulations are depicted in Figures 1 to 8. It can be observed from these figures that the number of nodes, message size, message generation inter-val, and the node’s speed have a significant impact on the energy consumption and performance of the routing protocols of DTN.

From Figure 1, it is clear that as the number of nodes is increased, the average re-maining energy of nodes is decreased. Increasing in the number of nodes also in-creases the number of messages delivered which results in more number of transmits and scans of nodes. The Spray & Wait has the highest average remaining energy among all the protocols. This is due to the fact that in Spray & Wait, other nodes will just have to wait and deliver the message after the source node has not found the destination as address in [8]. Thus, a small number of scans and transmits with other nodes take place which results in low energy consumption while only giving energy strain to the source node. In Figure 2, it is observed that as the number of node is increased, the number of dead nodes present in the network also increased.

From Figure 3, with the increase in message size more number of packets transmitted is getting higher which consumes more energy of the participating nodes. Figure 4 shows that the number of dead nodes increased according to the increase in message size. MaxProp has the highest number of unavailable nodes.

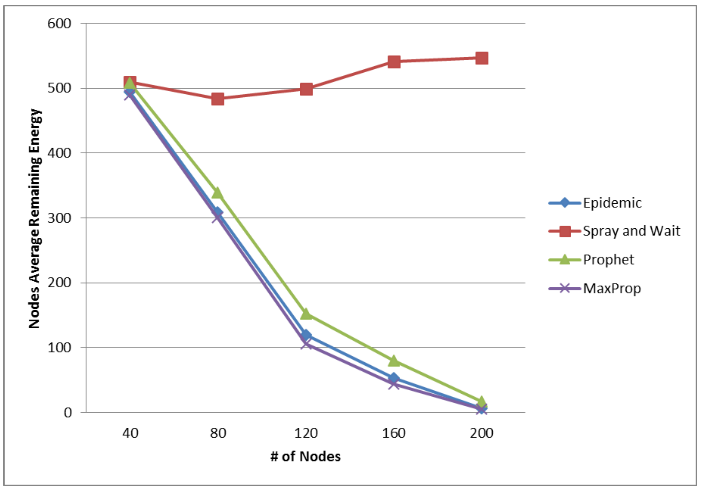

Figure 1. Nodes Average Remaining Energy vs. number of Nodes

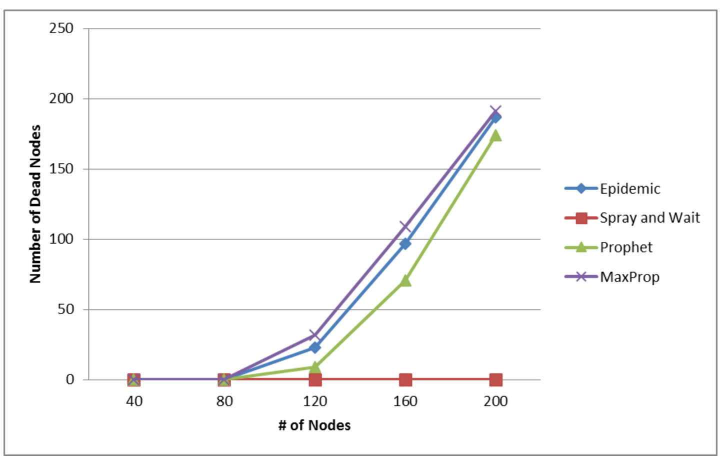

Figure 2. Number of Dead Nodes vs. number of Nodes

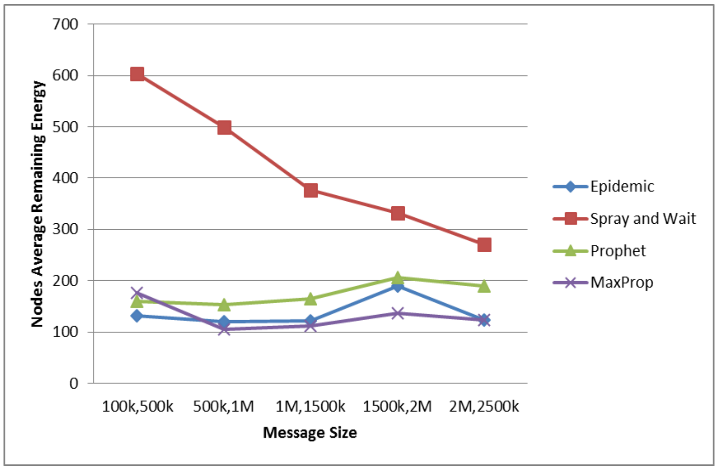

Figure 3. Nodes Average Remaining Energy vs. Message Size

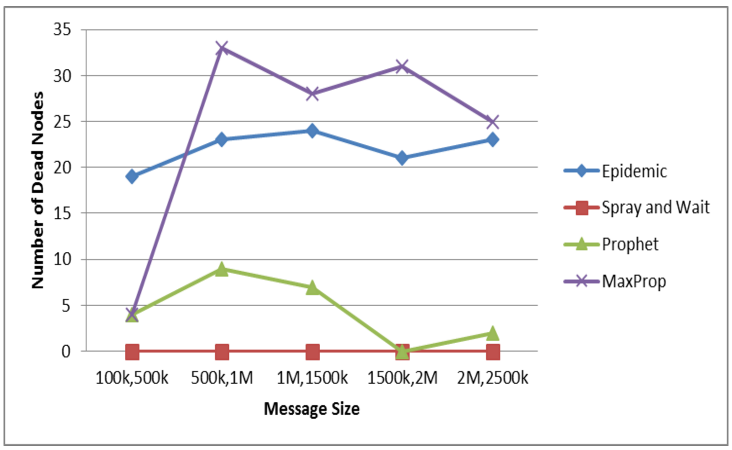

Figure 4. Number of Dead Nodes vs. Message Size

In Figure 5, it is observed that the value of average remaining energy increases with an increase in the message generation interval. This is justified by the fact that with increase in the message generation interval the total number of messages flowing in the network decreases. This result in a lesser number of scans and lesser number of messages transferred between nodes; hence, less energy gets consumed. The rate of increase is highest for Spray & Wait and lowest for the Epidemic protocol. The value of remaining energy is maximal when Spray and Wait protocol is used and minimal when MaxProp protocol is used. Figure 6 shows that the number of dead nodes de-creases with increase in message generation interval. With a decrease in the number of message generation, lesser energy is consumed and more nodes are active in the network. The numbers of unavailable nodes are high in case of MaxProp.

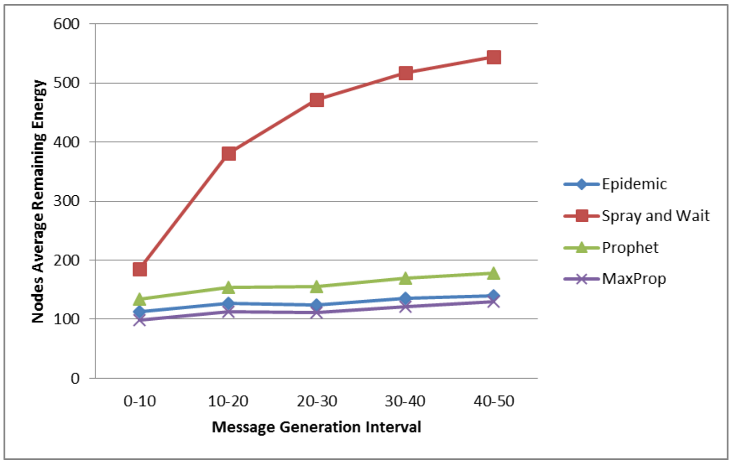

Figure 5. Nodes Average Remaining Energy vs. Message Generation Interval

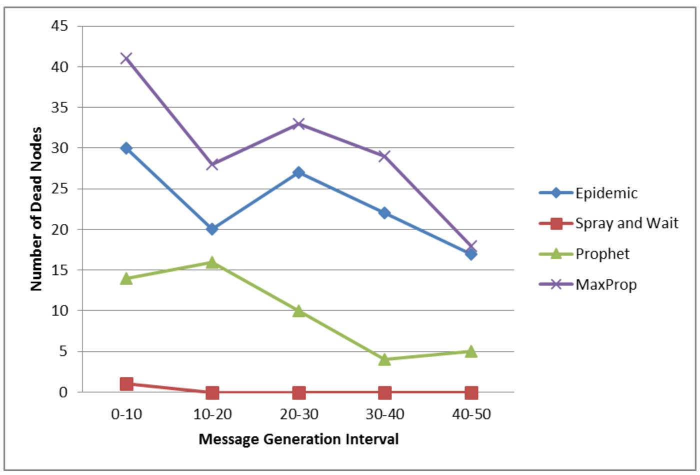

Figure 6. Number of Dead Nodes vs. Message Generation Interval

In Figure 7, it is observed that as the speed of nodes increases the nodes average re-maining energy is in decrease. With the increase in speed of nodes the number of contacts between the nodes per unit of time also increases. This results in more num-ber of scans and message transfers between the nodes and more energy gets con-sumed. The rate of decrease is more in Spray & Wait and PRoPHET. Finally, in Figure 8, it is shown that the number of dead nodes present in the network increases with increase in node's speed.

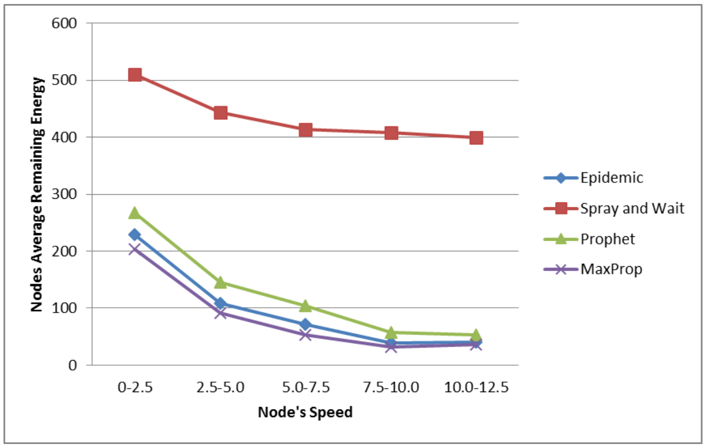

Figure 7. Nodes Average Remaining Energy as Node speed is Increased

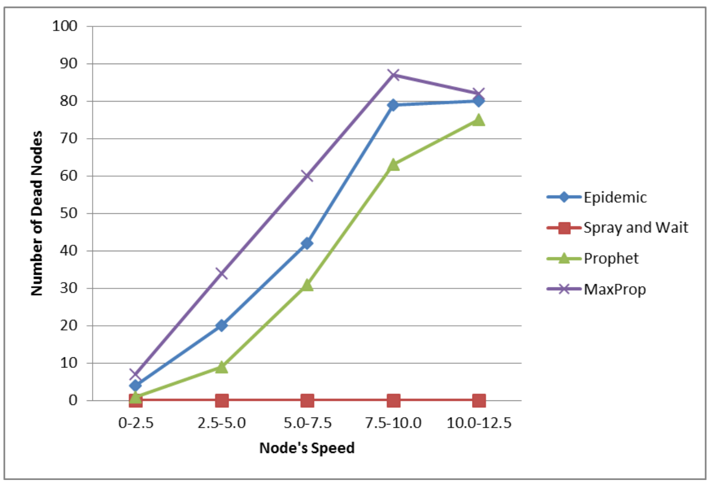

Figure 8. Number of Dead Nodes as Node's Speed is increased

5. Conclusion and Future Work

In this work, we have investigated and simulated the performance of four existing routing protocols in DTN in terms of energy consumption and evaluated them based on number of unavailable nodes in the network using shortest path map based mobility model. It has been observed that the varying number of nodes, message size, message generation interval, and the node’s speed affects the performance of the routing protocols. From the simulation results, we observed that: (1) The average remaining energy increases with increase in the message generation interval and decreases with increase in number of nodes, message size, and the speed of nodes, (2) The number of unavailable nodes decreases with increase in the message generation interval and increases with increase in number of nodes, message size, and the speed of nodes. In our future work, we aim to develop new energy efficient routing protocols for DTN based on the results acquired on this paper. We seek to incorporate the effects of the parameters from the scenarios used in this paper to create an energy-aware routing protocol that considers the available energy, the number of nodes, and speed and compare its performance with the existing routing protocols.

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