# Energy-based Performance Evaluation of Various Routing Protocols in Infrastructure-less Opportunistic Networks

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## Abstract

Opportunistic Networks (Oppnets) provide the communication facilities in the network scenarios where the end-to-end path between the source and the destination never exists or may last only for an unpredictable and very short period of time. The disconnections and re-connections between the nodes are very common in Oppnets. Therefore, routing in these types of networks is a very challenging task and it is different from that in Mobile Ad hoc Networks (MANETs), which assumes a complete path from the source to the destination before the delivery of a message. As the nodes does all the computations for next hop selection in infrastructure-less Oppnets, a lot of battery power gets consumed which reduces the network lifetime. Thus a proper energy efficient routing protocol should be selected for message passing in these types of networks. In this paper, we have simulated, investigated and compared the performance of various already existing routing protocols for infrastructure-less Oppnets in terms of energy consumption. These protocols have been compared with each other by using various performance evaluating factors like average residual energy, number of nodes that become dead after the simulation run of the protocol.

**Keywords**: Opportunistic networks (Oppnets), Opportunistic routing, The ONE (Opportunistic Network) simulator.

## 1 Introduction

Opportunistic networks [13] has emerged as one of the most recent and interesting evolutions of the mobile ad-hoc networks (MANETs) paradigm. Thus they have all the challenges and issues faced by MANETs along with some new challenges of their own. In MANETs, the nodes which want to communicate remain connected with each other through a common inter-network. This requirement of connected path is rarely possible in the pervasive network scenarios. In such type of environments, mobile

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devices carried by users are partially connected to the network, as users may turn them off to save energy, nodes may move out of the radio range of other nodes due to their high mobility. Thus, traditional MANET routing protocols such as AODV [17], DSR [10] and internet routing protocols such as TCP/IP will fail to work in Oppnets. These protocols are based on the concept of establishing a complete path between the source and the destination before the delivery of the message which is not possible in case of Oppnets.

Oppnets can have both fixed nodes as well as mobile nodes like pedestrian users and vehicles, but generally they are mobile in nature. The nodes can communicate with each other via all types of communication media like bluetooth [2], WiFi[1], and other communication-based technologies and point of access towards the fixed Internet or a satellite. Initially, an Oppnet may start working with a single node [13] called the Seed Oppnet and then can grow into an expanded Oppnet by employing several foreign helper nodes which contribute in the routing and forwarding of the messages. Such type of Oppnet is useful in the events of emergency preparedness and response activities. Other types of Oppnets include pocket-switched networks, battlefield networks, Socio-Aware Community Networks, transportation networks, autonomic networks, just to name a few.

Routing of messages in Oppnets is based on the contact opportunity between the nodes that arises due to their mobility, Store-Carry-and-Forward technique and the local forwarding between the nodes [5, 6]. Message can be forwarded to the intermediate neighboring nodes, which help in delivering it to the destination node. Due to the sparse nature of Oppnets, it is possible that the intermediate nodes do not encounter other nodes frequently or consistently [8]. It may also happen that there might not be some suitable intermediate node which can be selected as next hop to take the message closer to the destination or to the destination itself. In such type of situations, the message will be directly delivered to the destination whenever a direct contact arises with it. Thus, intermediate nodes may have to store the packets for a long period of time in their buffers when there is no forwarding opportunity towards the destination. The aforementioned Store-Carry-and-Forward method is a very good technique to increase the probability of successful message delivery to the destination in Oppnets. The messages may also suffer longer delays as they are buffered in the network, waiting for a path to be available towards the destination [8]. This is the reason why Oppnets are considered as the subclass of Delay Tolerant Networks (DTNs) [7, 21]. The nodes must have enough buffer space to store all the messages for an unpredictable period of time in order to avoid the dropping of packets until the next contact occurs.

Routing and forwarding is a very challenging task in Oppnets due to the uncertain mobility and intermittent behavior of the nodes. Most of the research work in Oppnets has been done in the area of routing and forwarding. As finding routes towards the desired destination in such network is the most compelling task [16]. Thus, there is always a need to design a new routing protocol for Oppnets that is energy efficient and consumes less power of nodes in forwarding of the message. It should also try to maximize the successful data delivery rate and minimize the transmission delay to the destination. The routing protocols used in Oppnets can be classified into two categories – infrastructure based protocols and infrastructure-less protocols [16]. In this paper, the main focus will be on the infrastructure-less protocols. Also, we have only considered the energy-based performance evaluation of the protocols with the help of certain metrics such as Average residual energy and the number of dead nodes in the network. The performance of these protocols based on other metrics such as number of messages delivered, delivery probability, average hop count, average delay, average buffer occupancy can be referred from [6].

The remainder of this paper is organized as follows. Section 2 presents the background and related work that are important for the understanding of Oppnets. In Section 3, we describe the simulation setup and various assumptions used to simulate the chosen six different routing protocols of Oppnets. Section 4 is devoted to the simulation results, where the above-mentioned six routing protocols are compared in depth. Finally, Section 5 concludes our work and provides some insights on the future work.

## 2 BACKGROUND AND RELATED WORK

In this Section, an overview of the significant concepts on routing protocols for Infrastructure-less Oppnets, namely First Contact [9], Direct Delivery [18], Epidemic [20], Spray and wait [19], PRoPHET [14], MaxProp [3], is presented along with their relative advantages and disadvantages.

### 2.1 First Contact

This Protocol [9] is the simplest of all the routing protocols available in Oppnets. In this, the source node and the intermediate nodes forward the message randomly to a neighboring node which they encounter first. Thus, any node which comes first in the radio range of the source node will be given the message irrespective of the fact that it may not be a good forwarder towards the destination. It does not require any calculation to be done at the node in order to determine the next best hop towards the destination. If two or more nodes come in contact with the sender node at the same time, then the source can send the message to any of them randomly. The message is forwarded along a path chosen randomly among all the first available contacts. If no path is available, the message waits for a path to become available and is then assigned to the first available contact. The local copy of the message is removed in this method after a successful transfer from one node to another node. Thus, only a single copy of the message flows in the network, which leads to the lesser resource consumption and low congestion in the network. As it is a single copy scheme, if any intermediate node carrying the message fails then the message will be lost. It also suffers from the problem of path loops. Path loops occurs when frequent contacts exist between the same node pair that stay in contact with each other for a long time, resulting in the exchange of the same message again and again between them. The delivery ratio is poor as the next hop is chosen randomly without considering the ability of the node to carry the message near to the destination. The forwarding along the selected path may not make any progress towards the destination which also increases the message delivery delay.

### 2.2 Direct Delivery

In this routing method [18], the message is not forwarded to the neighboring nodes. The source node does not pass the message to the intermediate nodes, but keeps it with itself until it comes in direct contact of the destination node. On encountering the destination node, the message is directly given to it. This scheme is very simple and easy to deploy. It also utilizes minimum bandwidth and network resources for message transfer since each message is transmitted at most once only to the destination node. On the other hand, this technique may have long delays for message delivery as the source may meet the destination after a very long time. Moreover, the delivery delay is unbounded in case the source never meets the destination. It may also happen that there may not be a direct contact available between the source and the destination, but a path between them exists through the intermediate nodes which can be utilized for the message passing. If the source node fails then the message will be lost as there is only one message copy available in the network. The delivery probability is poor and it is not an optimal approach in situations where high delivery probability is required.

### 2.3 Epidemic

The Epidemic routing [20] protocol uses the concept of complete flooding for message transfer in Oppnets. Each node maintains two buffers. The first buffer is used for storing the messages generated by the node itself, and the second one is used for the messages received from other nodes. Each message has a unique message ID associated with it. Each node also maintains a list of the message IDs of all the messages that it is carrying in its buffer, and whose delivery is pending in the form of a Summary

Vector. When two nodes meet with each other, they exchange their Summary Vectors. By comparing these Summary Vectors, the two nodes exchange all those messages which they do not have in common. After the completion of message exchange, multiple copies of the same message flows in the network and all nodes have the same messages in their buffers. In this way, all messages are spread in the network to all the nodes including the destination in an epidemic (like disease) manner. Due to a large number of redundant messages in the network, this protocol has significant demand on both bandwidth and buffer capacity. Even though a message is received at the destination, some nodes still continue passing on the same message which waste the resources. The simulation results obtained in this work show that this protocol has high message delivery ratio, low delay if sufficient resources are available.

## 2.4 Spray and Wait

The Spray and Wait protocol [19] provides an improvement over the Epidemic routing protocol by controlling the level of flooding. It has two phases: the Spray phase and the Wait phase. In Spray Phase, every message originating at the source node is passed to L distinct relays in the network i.e. L 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. Thus, it is a hybrid technique of the Epidemic and the Direct delivery protocol. The performance of this protocol depends on the value of L. The smaller value of L makes it similar to the Direct delivery protocol and a larger value of L makes it similar to the Epidemic protocol. The simulation results obtained in this work show that this protocol has less number of transmissions and less delivery delay as compared to the Epidemic Routing.

## 2.5 PRoPHET

In PRoPHET (Probabilistic Routing Protocol using History of Encounters and Transitivity) [14], each node before sending a message, calculates a probabilistic metric called Delivery Predictability for each known destination. 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. When two nodes meet, they exchange their Delivery Predictability with each other. Two nodes have higher value of Delivery Predictability to each other if they are often encountered. A node will forward the message to another node only if it has a higher value of Delivery Predictability to the destination node. If a pair of nodes does not find each other for a considerable period of time, they may not be the good forwarders of the message to each other. Thus, their Delivery Predictability value must decrease with time. The delivery predictability has a transitive property based on the observation that if node A frequently encounters node B and node B encounters node C then node B is a good forwarder for node A's messages to node C. Thus, their Delivery Predictability value should be updated accordingly. The simulation results obtained in this work show that PRoPHET has lesser number of message exchanges, lesser communication overhead, lesser delay, and higher message deliver rate than the Epidemic routing protocol.

## 2.6 MaxProp

This Protocol [3] does not assume any prior knowledge about the network connectivity and uses the local information, mobility of nodes to select the next best-hop for message delivery. It was designed for vehicle-based disruption-tolerant networks. It forwards the message to any node in the network having maximum probability of delivering the message towards the destination. It is based on the prioritizing the schedule of the packets sent to other nodes, and the schedule of the packets to be deleted from the buffer.

MaxProp is divided into three parts namely Estimating delivery likelihood, Complementary mechanisms, and Managing buffers. In the first part, an optimal delivery path is found by constructing a directed graph of nodes connected by edges towards the destination. A variation of Dijkstra's algorithm [9] is used to determine the shortest path out of those given paths at any given point of time. The second part describes the priority order in which the different type of messages (such as routing information, acknowledgments, and actual message) are exchanged between two nodes when they discover each other. In the third part, an acknowledgment scheme for delivered messages is used that helps in flushing the redundant messages from the network when the buffer space is almost full. The buffer management scheme defined in this work leads to a lowered rate of packet dropping.

### 2.7 Adaptive Fuzzy Spray and Wait

This protocol [15] has been proposed as an improvement over the popular spray based routing schemes. It smartly integrates the overheads and buffer management policies into an adaptive protocol that includes local network parameters estimation. The protocol has a clear distinction between forwarding and dissemination strategies. While forwarding it attempts to deliver only one copy to the best node amongst the neighbors. In dissemination it attempts to deliver message by diffusing it through the entire network. In this protocol, the node on encountering other nodes divides the values of L by 2 and updates it in the message before passing it. The node passes all the copies to the nodes it encounters except the last copy which is passed on as direct transmission. The messages in the buffer are sorted by a priority decided by a Fuzzy decision making function. When the buffer is full, the messages are dropped according to the priority level i.e. the oldest first.

## 3 SIMULATION SETUP

In this work, we have done the simulation and energy-based performance evaluation of only six already existing routing protocols of Oppnets namely First Contact, Direct Delivery, Epidemic, Spray and wait, PRoPHET, MaxProp using the ONE simulator [11]. There are five different types of mobility models namely Random Waypoint [4], Map based movement [12], Shortest path map based movement [12], Map route movement [12] and External movement [12] are present in the ONE simulator. The summary data of simulation runs is stored in form of reports. The EnergyLevelReport available in ONE has been used to take the energy related results for all the protocols in this work.

In the simulations, all nodes are assumed to be mobile in nature, e.g. modern mobile phones or similar devices. The nodes communicate with each other using bluetooth at 2Mbit/sec data rate with 10m of radio range. The simulation area is taken as 4500m x 3400m. The total number of nodes present in the simulation area are divided into four different groups. Group 1 nodes are pedestrians which move at speeds of 0.5-1.5 m/s with pause times of 0-120 sec. Group 2 nodes are cyclists which move at the speeds of 1.5-5 m/s with pause times of 0-120 sec. Group 3 nodes are cars which move at a speed of 5-10 m/s with pause times of 10-30 sec. Group 4 nodes are trams which move at the speeds of 7-13 m/s with pause time of 10-30 sec. Groups 1 and Group 2 nodes have up to 5MB of free buffer space while Group 3 and Group 4 nodes have 50MB of free space for storing and forwarding the messages. Nodes generate one new message on average after every 25 to 35 seconds. The message size varies between 500KB to 1MB and the message lifetime is set to 300 minutes. Each simulation was run for 43200 second for all six different protocols.

The Following energy settings have been used for all group nodes.

Table 1: Energy settings table.

| | |
|---|---|
| Group.initialEnergy | 5000 *units* |
| Group.scanEnergy | 0.1 *units* |
| Group.transmitEnergy | 0.2 *units* |
| Group.scanResponseEnergy | 0.1 *units* |
| Group.baseEnergy | 0.01 *units* |

The initialEnergy is the energy of nodes before the start of the simulation. The scanEnergy is the energy usage per scanning i.e. amount of energy consumed in device discovery. The scanResponseEnergy is the energy usage per scanning response i.e. amount of energy consumed in device discovery response. The transmitEnergy is energy usage per second while sending i.e. the amount of energy consumed in sending the message from one node to another node. The baseEnergy is the amount of energy consumed when the node is not performing any transmission and is idle.

We chose the shortest path map based movement model for the simulation of the protocols. In this movement model, the nodes move on a path defined in the form of maps, and choose the shortest path from the source to destination. We obtained the results for the average residual energy, number of dead nodes present in the network for the different values of number of nodes, message size, node speeds, and the message generation interval. The results are taken for all six protocols of Oppnets. These parameters are used to compare the performance of the above mentioned six protocols. The following setting and configurations are used while varying the aforementioned fields:

a) *Varying the number of nodes:* We increased the number of nodes from 40− > 80− > 120− > 160− > 200 during the simulation. The message generation interval i.e. the time after which a new message gets generated is fixed between 25sec and 35sec. The message size is set between 0.5MB and 1MB, and all nodes move according to their respective group speeds.

b) *Varying the message Size:* We varied the message size from 0.0-0.5MB− > 0.5-1.0MB− > 1.0-1.5MB− > 1.5-2.0MB− > 2.0-2.50MB. The total number of nodes is kept fixed at 120. The message generation interval is fixed between 25sec and 35sec and all nodes move according to their respective group speeds.

c) *Varying the message generation interval:* We varied the message generation interval from 0-10sec− > 10-20sec− > 20-30sec− > 30-40sec− > 40-50sec. The total number of nodes is kept fixed at 120. The message size is set between 0.5MB and 1MB, and all nodes move according to their respective group speeds.

d) *Varying the speed of nodes:* We varied the speed of all group nodes from 0-2.5m/s− > 2.5-5m/s− > 5-7.5m/s− > 7.5-10m/s− > 10-12.5m/s. The total number of nodes is kept fixed at 120. The message size is set between 0.5MB and 1MB and the message generation interval is fixed between 25sec and 35sec.

We use the following performance metrics in our comparison:

a) *Average residual energy:* It is the average of the nodes energy left after the completion of the simulation.

b) *Number of dead nodes:* It is the count of the number of nodes whose residual energy becomes almost zero i.e. below 50 units after the completion of the simulation.

# 4 SIMULATION RESULTS

The results obtained in this work are depicted in Figures 1 to 8. It can be observed from these figures that the number of nodes, message size, message generation interval, and the node's speed impact the performance of the routing protocols of Oppnets.

## 4.1 Varying the number of nodes

From Figure 1, it is clear that as the number of nodes increases, the average residual energy of nodes decreases. This is due to the fact that the increases in number of nodes increases the number of messages delivered which results in more number of transmits and scans of nodes. The rate of decrease is higher in the cases of Epidemic, MaxProp, PRoPHET and First Contact routing protocol as compared to the Spray & Wait and Direct Delivery protocols. The Direct Delivery protocol has the highest average residual energy among all the protocols. This is due to the fact that in Direct Delivery, the source node keeps the copy of the message in its buffer until it encounters the destination. Thus, a small number of scans and transmits with other nodes take place which results in low energy consumption. In Figure 2, it can be observed that as the number of nodes increases, the number of dead nodes present in the network also increases. The rate of increase is higher in the cases of MaxProp, Epidemic, PRoPHET and First Contact routing protocol. MaxProp has the highest number of dead nodes while no dead nodes are found in case of Direct Delivery protocol. In Spray & Wait protocol only some nodes become dead when the total number of nodes in simulation are increased to 200.

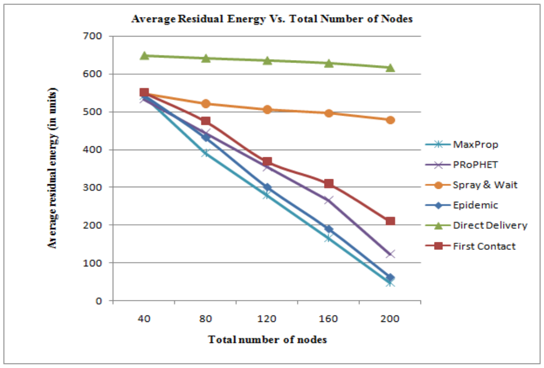

Figure 1: Average residual energy vs. Total number of nodes

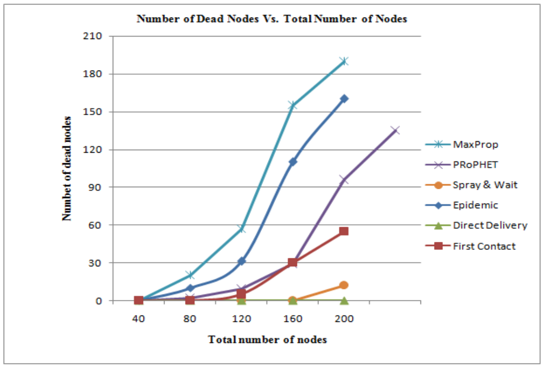

Figure 2: Number of dead nodes vs. Total number of nodes

### 4.2 Varying the message size

From Figure 3, it can be seen that as the message size increases, the average residual energy of nodes decreases. This is due to the fact that with the increase in message size more number of packets gets transmitted which consumes more energy of the participating nodes. The rate of decrease is more in the cases of Spray & Wait, First Contact and MaxProp protocol as compared to the other routing protocols. The Direct Delivery protocol has the highest, while the Epidemic routing protocol has the lowest average residual energy among all the protocols. In Figure 4, it can be observed that as the message size increases, the number of dead nodes also increases. The rate of increase is higher in the cases of MaxProp, Epidemic, and First Contact routing protocol. MaxProp has the highest number of dead nodes while Direct Delivery has zero number of dead nodes. All other protocols number of dead nodes are in between MaxProp and Direct Delivery protocol.

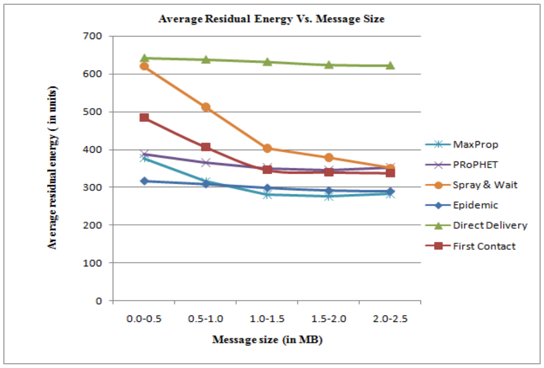

Figure 3: Average residual energy vs. Message size

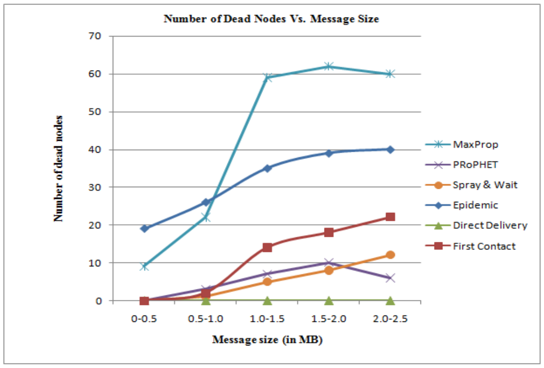

Figure 4: Number of dead nodes vs. Message size

### 4.3 Varying the message generation interval

In Figure 5, it is observed that the value of average residual 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 the nodes, and hence less energy gets consumed. The rate of increase is highest for the Spray & Wait and lowest for the Epidemic protocol. The value of residual energy is maximal when Direct Delivery protocol is used and minimal when MaxProp protocol is used. Any other protocols performance is in between these two protocols. Figure 6 shows that the number of dead nodes decreases with increase in the message generation interval. This is due to the fact that with a decrease in the number of message generation, lesser energy is consumed and more nodes will be active in the network. The numbers of dead nodes are maximum in case of MaxProp and zero in case of Direct Delivery and First Contact protocol.

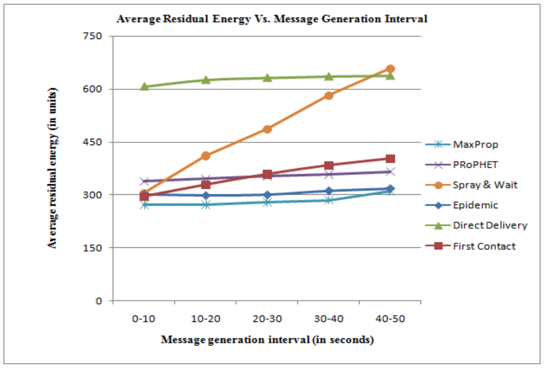

Figure 5: Average residual energy vs. Message generation interval

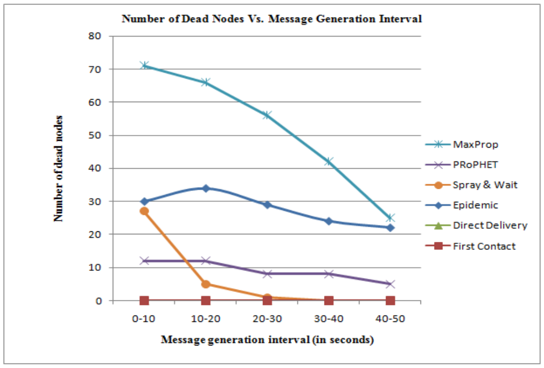

Figure 6: Number of dead nodes vs. Message generation interval

## 4.4 Varying the speed of nodes

In Figure 7, it is observed that as the speed of nodes increases the average residual energy decreases. This is justified by the fact that with the increase in speed of nodes the number of contacts between the nodes per unit time also increases. This results in more number of scans and message transfers between the nodes and hence more energy gets consumed. The rate of decrease is more in cases of Spray & Wait, First Contact and PRoPHET as compared to the Epidemic, MaxProp and Direct Delivery routing protocol. In Figure 8, it can be seen that the number of dead nodes present in the network increases with increase in node speed. The rate of increase is higher in cases of MaxProp and Epidemic protocol as compared to the other routing protocols. The numbers of dead nodes are zero when First Contact and Direct Delivery protocols are used for routing and forwarding of messages in the network.

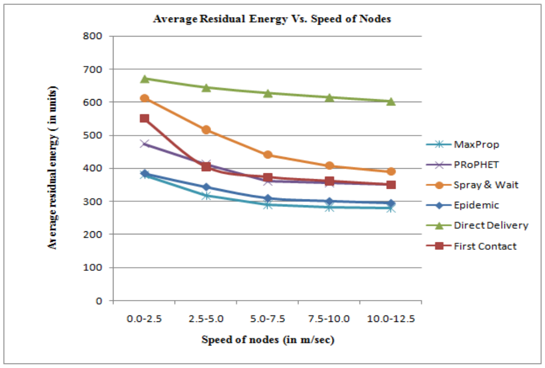

Figure 7: Average residual energy vs. Speed of nodes

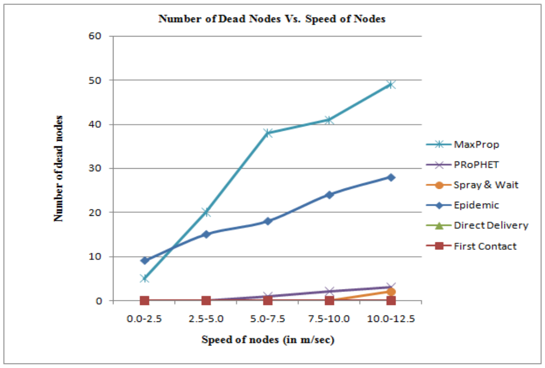

Figure 8: Number of dead nodes vs. Speed of nodes

# 5 CONCLUSION AND FUTURE WORK

In this work, we have investigated and simulated the performance of six existing routing protocols of Oppnets in terms of energy consumption and the number of dead nodes in the network over the 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 residual 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 average residual energy is maximal for the Direct Delivery protocol and minimal for the MaxProp protocol, (3) The number of dead nodes decreases with increase in the message generation interval and increases with increase in number of nodes, message size, and the speed of nodes (4) The number of dead nodes are maximum when MaxProp is used and zero when Direct Delivery protocol is used. In our future work, we plan to develop new energy efficient routing protocols for Oppnets, and compare their performance in terms of energy consumed against the six routing protocols studied in this paper. Also, the performance of Spray and Wait with different values of L will be considered in the future work.

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