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Exploiting Social Relations for Efficient Routing in Delay Tolerant Network Environment

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Abstract— DTN is subclass of mobile ad hoc network (MANET) where instantaneous end-to-end connectivity is not available in source and destination nodes. Nodes in DTN are sparsely distributed. Frequent disconnections along with limited resources make routing in DTN more challenging. This paper proposes two routing protocols. One is Buddy Router with Time Window, which exploits social relations to maximize delivery probability. Another variant presented is Buddy Router with Replication, where controlled replication approach is used, along with social metric for message forwarding. Detailed formulation of proposed work, along with comparative analysis, based on simulations is presented. The paper also presents impact of buffer size variation and TTL variation on routing performance of different routing protocols.

Keywords— Delay Tolerant Network (DTN), Routing, Opportunistic Routing and Pocket Switched Networks (PSN)

I. INTRODUCTION

Delay Tolerant Networks or Disruption Tolerant Networks (DTN) are the networks which can be categorised as a subclass of Mobile Ad hoc Networks (MANET), where continuous connectivity from sender and receiver is not present at one point of time. Number of terminologies in the literature, such as Intermittently Connected Mobile Ad hoc Networks (ICMANET), Opportunistic Networks, challenged networks or extreme networks has referred for DTN. These networks are often deployed in challenged environments with limited resources at mobile devices. In MANET, any routing algorithm holds one basic assumption that, there is an end-to-end connectivity in between the source and destination prior to actual communication, which is not true in case of DTN. The connectivity in DTN is intermittent, time varying and no guarantee about instantaneous end-to-end (complete) connectivity between source and destination node. Therefore, no MANET routing algorithm will work in DTN environment. Therefore, to alleviate this problem DTN uses store-carry-forward mechanism to deliver messages from source and destination. DTN became an active area of research from last decade after the landmark paper by Kevin Fall [1]. Research communities growing interest can be witnessed by number review and survey articles.[3][4][5][6][7][8].

DTN implemented successfully in number of application scenarios such as military applications, wild life tracking [6], providing internet access to remote areas [23], vehicular ad hoc network [9] and sensor networks. The concept of DTN is very much helpful for connecting devices and regions, which underserved by current network technologies [1]. Increased penetration of smart phones led the emergence of new form of communication called as Pocket Switched Networks (PSN) or Mobile Social Networks (MSN). Here human carried nodes will opportunistically communicate with each other using Wi-Fi / Bluetooth or any other interfaces. The key issue here is to design an efficient message routing algorithm in these environments. Uncertainty of mobility of the nodes and lack of central information for scheduling makes it more challenging. To tackle this issue, routing decision has to be carried out by the devices (mobile) and the message has to be forwarded towards the destination on hop-by-hop basis. These forwarding decisions typically influenced by the goal to achieve increased delivery ratio by reducing number of replicas of the message, with minimum latency time.

Routing algorithms [4][5][7] uses opportunistic contact information to predict about future encounter. Opportunistic contact information changes constantly, so social based metrics will be useful in these situations [7, 8]. Measurement of accurate connections strength in between the nodes is an important aspect, which can be simplified by constructing social graph through contact graphs. Here we propose the extension to our existing [25] work, which based on the use of the "Buddy" metric. Basic intuition behind the proposed algorithm is to select the relay node among the neighbours, which is having greater social value towards the destination, and it will be the good candidate for message forwarding. In this paper, we proposed new modified approaches called Buddy Router with Time Window and Buddy Router with replication. These are novel DTN routing schemes, where routing decision, carried out using heuristic information collected locally by every node. We introduced the forwarding strategy using metric called “Buddy” metric. We simulated the performance of proposed algorithms using ONE (Opportunistic Network Environment) simulator. Rest of the paper structured as follows. In Section II related literature is discussed, in Section III the Buddy metric concept and proposed protocol has been introduced and discussed. In Section IV, a simulation results presented along with discussion and in Section V provides concluding remarks.

II. RELATED WORK

In [3] authors presented comprehensive survey on developments and challenges in DTN research. Papers [4][5] and [6] formulated DTN routing problem and classified different routing algorithms by using different taxonomies. Thorough examination of different routing strategies used such as replication, forwarding and coding are presented. This study is helpful to create proper understanding of routing algorithm as well as application scenarios where it can be used. Authors [7][8] have reviewed/discussed another domain of routing, i.e. social based routing, where social relations are used to determine connection strength between the nodes, to make message forwarding. In [10] authors presented Epidemic algorithm which is flooding based in nature. Whenever two codes are in contact with each other, they exchange messages. This way messages will be replicated through number of hops and reach to the destination.

PROPHET [11] uses delivery predictability, which is maintained by every node, for other nodes it encountered with, to make routing decisions. Nodes which meet frequently with each other have the higher delivery predictability. It has the aging counter which decreases the delivery predictability when nodes do not encounter with each other for a while. Packet forwarding occurs only when, delivery predictability of neighbouring node is higher than that of node itself.

Spray and Wait [14] aims to reduce packet replication that happen in Epidemic routing. It works in two phases, spray phase and wait phase. It achieves better delivery ratio than singly copy schemes such as direct delivery.

Few articles [18][19][20] have also discussed use of social based metrics for DTN routing in different scenarios.

III. METHODOLOGY

Emergence of new generation mobile smart phones prepared the ground for new means for communication. It led to the new category in DTN called as Mobile Social Networks (MSNs) or Pocket Switched Networks (PSN). Where human carried mobile devices act as network devices. These devices are able to exchange the data with each other when they are within the proximity of each other. Here routing decisions can be relied on the knowledge that node has accumulated, while it is carried out by the human. It is believed, that we human are social animals and we meet or interact with other members with same nature. Therefore, it is possible that these social relationships between the nodes can exploited to make effective routing decisions in MSN/PSN.

In literature, DTN routing [10], [11], [14] has been carried out, which uses several matrices, such as contact frequency, average contact time etc. The contact frequency denote the number of times these two nodes have a contact with each other over a period of time and the contact time denotes contact duration of these encounters. However, these metrics are having their own limitations. They do not reflect the correct representation of forwarding opportunities arising from history of encounters and none of these protocols used composite metric; rather they have done routing based on single parameter.

We can have a very valid assumption in number of scenarios, that old contacts may not have much forecasting power as in case of more recent once. So its valid hypothesis, that instead of having single criteria based metric, multi criteria based routing can accurately measure the forwarding capacity between the two nodes. So three important parameters, which can affect routing decision are; frequency of contact, aggregate contact duration and recency of the contact. This hypothesis is more accurate in MSN/PSN scenarios, where people tend to meet each other regularly and there will be more chances of two persons meet again if they met very recently.

Novelty of our work i.e. Buddy Router lies with its use of multi parameter composite metric for efficient routing, which is based on number of past encounters, aggregate contact duration and recency of encounter.

System Model

We consider PSN, where transmission will take place whenever two nodes come within the transmission range of each other using its wireless interfaces. Such type of DTN can be modeled using a graph $G = (V, E)$ where vertex set V denote mobile nodes and undirected edge set E denote pair wise connections. Each mobile node i,, maintain a local social graph $G = (V_i^t.E_i^t)$ where $G_i^t = (V_i^t, E_i^t)$ ($V_i^t \in V$ *and* $E_i^t \in E$) over time t. In addition, neighbor set of i is denoted as $N_i^t \in V_{i.}^{\ t}$. Based on earlier observations, we proposed a new composite metric called as buddy metric[25]. Buddy metric reflects the connection strength in between two nodes and it can measure potential transmission capabilities in between them. Buddy metric calculates connection strength using three different parameters that is contact frequency, aggregate contact duration and recency of latest contact. As explained in previous section contact frequency is nothing but number of times two nodes encounter with each other over a period of time *T*. Aggregate contact duration is the total amount of time two nodes are within the communication range of each other over a period of time T. Last parameter recency reflects how recently the other node was in contact. Recency parameter assumes that the chances to meet, in near future are high, with a node who met very recently.

Every node maintains a routing table with $N-1$ entries for the network size of *N* nodes. This table consists of entry for each node in the network with which it has met with. This table consists of fields such as contact frequency, Contact Recency and aggregate contact duration. An encounter happens between two nodes whenever these nodes are one-hop neighbors. Encounters detected by overhearing hello packets or by using link layer mechanisms. Major advantage of Buddy Router protocol variants is that it does not require collecting global information and they are distributed in nature. Every Node calculates buddy social metric value for every other node it encountered using following formula

$$BM_{(i,j)} = w_f{*}F(c) + w_r{*}1/R(c) + w_d{*}D(c) \qquad \text{(I)}$$

Where $BM(i, j)$ is buddy metric value between the node i and j. Terms $F(c)$ and $D(c)$ indicate contact frequency and aggregate contact duration respectively. The contact duration between two nodes is defined as the time elapsed between, when the two nodes come within communication range of each other and when they go out of the communication range of each other. The term $R(c)$ denotes how recently contact happened in between node i and j. Network features may change depending on the application scenarios so three tuning parameters are proposed. Where wf is the weight for contact frequency, wd is the weight for contact duration and wr is the weight for contact recency. These weights can be adjusted depending on the network scenarios and

$$0 \le wf \le 1,\ 0 \le wr \le 1 and 0 \le wd \le 1 \qquad \text{(II)}$$

and

$$wf + wd + wr = 1 \qquad \text{(III)}$$

We can set high weight to the contact frequency where mobile nodes frequently encounter with each other but for very short period. If mobile nodes have very high contact duration but if they have very limited contact frequency then we can assign more weight to contact duration. Recency parameter will assign more importance to fresh contact rather than old one, as there may be more chances of meeting with one another. Aggregate contact duration in between nodes i and j over period of time *t* is calculated as

$$D(C)_{i,j} = \sum_{i=0}^{f} t_{i,} \qquad \text{(IV)}$$

Based on this buddy metric value distributed routing strategy Buddy Router with time window and Buddy Router with replication has been implemented.

One of the motivations behind BuddyRouter with Time Window is that, normally people movement's exhibits high degree of repetitions. They visit regular places and make regular contacts for their day-to-day activities. e.g. they stay at their home at night, in day time they go to office, at evening they visit community places and in night they again come back to their home. In addition, in between, these people commute as well. They may have regular contact with different people in different time slots. So considering the above fact, we can divide time of a day into different time slots of size 4, 6, 10 hours etc. So by maintaining this historical contacts in different time windows we can better

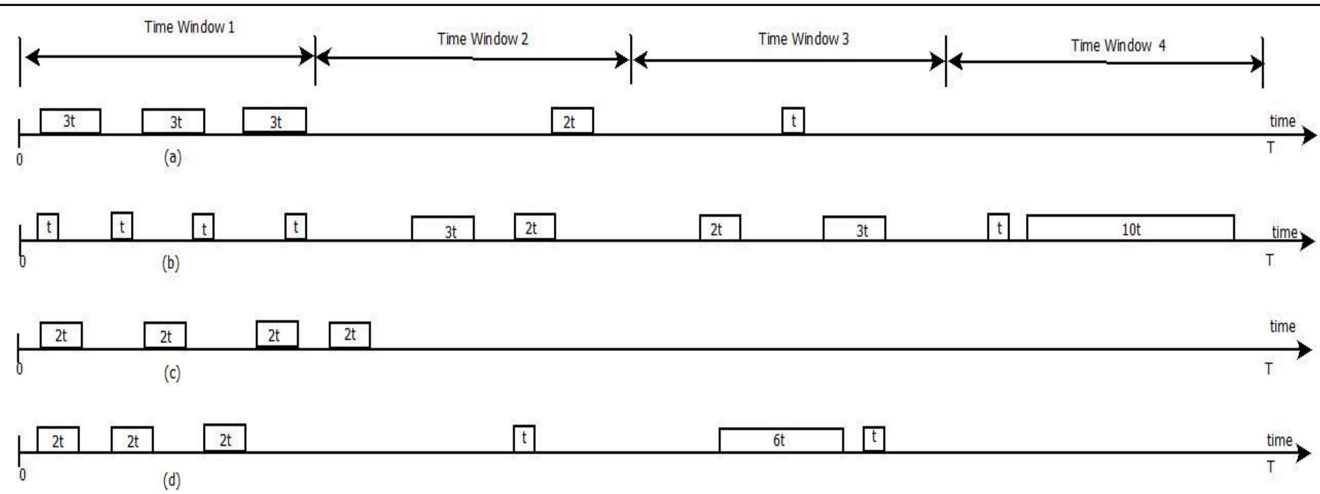

Figure 1: Scenarios with Time Windows

predict the future contacts, which can be used to make better forwarding decision in case of PSN scenario. This better explained in Figure 1. Figure 1 shows contact traces of four nodes with same destination node *D* for one daytime and more or less this pattern may be repeat for other working days in a week. The total daytime divided into 4 time slots. These slots may be variable and not necessarily be fixed in size. In case Figure 1(a) node is having regular contact with the destination *D* in time window 1 but it is not having any contact in time window 4. Regular contact means it is having better encounter frequency along with contact duration. In case of Figure 1(b), node is having contact with the destination in each time window. In case of Figure 1(c), it is having contact history in time window 1 and 2 only and in case of Figure 1(d) we can notice frequent encounters in time window 1 and 3 only.

Algorithm 1: Buddy Router with Time Window

- START
  - Every node maintains a routing table with n-1 rows. Where n is the number of nodes in the network. Divide the total daytime (24 Hours) in to four slots (time windows) depending on the application environment.
  - Based on current time, each node will make an entry into the routing table, for each node it encountered with. The routing table consists of fields such as Contact Frequency, Contact Recency and aggregate Contact Duration within the corresponding time window.
  - Whenever any node has to make forwarding decision, forwarder node calculates buddy social metric value for every other node it encountered, within a current time window using equation I
  - Neighbour node exchanges routing information with each other when requested.
  - If message destination is within the transmission range of forwarder then message is sent directly to the destination itself else
    - Forwarder node selects the node from its neighbours, which is having more buddy metric value for message destination in current time window.
    - If no neighbour holds the better buddy metric value for destination than forwarder, then it will keep the message with itself.
  - Forward the message to the selected node.
- END

Now consider a situation where all these nodes are in the neighbour list of node *X* and it has to make forwarding decision for its message *M* that is destined for destination node *D*. It is very much appropriate to consider the time window in which message forwarding has to be carried out along with other parameters such as encounter frequency, contact duration and recency. Suppose node *X* has to forward a message in time window 1 then node *X* has to choose node Figure 1 (a) as it is having greater aggregate contact duration along with frequency than any other within this time period. If node *X* has to make routing decision in time window 4 then node in Figure 1(b) is right forwarder as it is the only node, which is having contact with the destination *D* in this time window.

Considering above situation we proposed variation in BuddyRouter [25] protocol called as Buddy Router with Time Window (BuddyRouter_TW) where total daytime period of 24Hrs is divided into different time slots. These time windows may be decided based on morning exercise in the parks, office-working time, evening time where people may visit some community places and night, which they spend, with closed ones in the home. Details of Buddy Router with Time Windows are given in algorithm 1.

BuddyRouter and BuddyRouter_TW are single copy protocols. To improve delivery ratio, we proposed multi copy variations of BuddyRouter protocols, namely BuddyRouterBinary and BuddyRouter_Rep. In BuddyRouterBinary version, forwarder node will send a message copy to, two relay nodes, having greater buddy metric value than itself for the destination. These nodes are the best buddy value for the message destination, amongst the neighbour nodes. Ultimately, delivery performance is expected to be improved with increased overheads.

Algorithm 2: Buddy Router with Replication

- START
  - Every node maintains a routing table with n-1 rows. Where n is the number of nodes in the network.
  - This table consists of entry for each node it encountered with and consists of fields such as Contact Frequency, Contact Recency and aggregate Contact Duration.
  - Every Node calculates buddy social metric value for every other node it encountered using equation I
  - Neighbour node exchanges routing information with each other when requested.
  - If message destination is within the transmission range of forwarder then message is sent directly to the destination itself else
    - Forwarder node selects all those nodes from its neighbours, which are having more buddy metric value for message destination, than itself.
    - If no neighbour holds the better buddy metric value for destination than forwarder, then forwarder will keep the message with itself.
  - Forward the message replicas to all the selected nodes.
- END

BuddyRouter_Rep, which is replication-based version of original BuddyRouter. Here forwarder sends the copy of message to all neighbouring nodes that are having greater buddy metric value for the destination, than itself. Here number of replicas of message being forwarded are created and forwarded to relay nodes from neighbours. It is not blindly flooding the messages as in case of Epidemic, rather it is doing it more systematically using algorithm 2. As its replication based strategy, delivery overheads are expected to increase, but it is acceptable as delivery ratio is also increased. Another overhead in this algorithm is that it requires neighbour node list in sorted order based on buddy index for particular destination and it has to be done at the time of each message forwarding decision. The detailed algorithm for BuddyRouter with replication listed in algorithm 2.

IV. EXPERIMENTAL WORK

In this section, we present simulation results with proposed Buddy Router schemes. We also compare these results with already existing DTN routing strategies. We have divided simulated routing protocols into two categories; single copy vs. multicopy protocols. Single copy protocols that we considered for simulation are Direct Delivery, First Contact, BuddyRouter[25] and proposed protocols i.e. Buddy Router with binary, Buddy Router with Time Window and Buddy Router with Replication. Multicopy protocols that we considered for benchmarking are Epidemic [10], PROPHET [11], and Spray and Wait [14]. Before proceeding for the numerical results, we present herewith-brief overview of the performance metrics used for evaluation of routing schemes.

A. Metrics for Routing Performance

- Message Delivery Ratio: This metric measures ratio of number of messages delivered to the final destination to the number of messages generated. This is also referred as Delivery Probability and its value ranges from 0 to 1.
- Overhead Ratio: Overhead ratio is nothing but number of copies or replicas created for each delivered message. This is an assessment of bandwidth efficiency. Overhead ratio is expected to be comparatively smaller for good routing strategy.
- Latency Average: This metric reflects average message delay; from message creation to its delivery to final destination. Lesser the value of Latency Average better is the routing strategy.
- Hop Count Average: Average number of hops in between source and destination node is exhibited by Hop Count Average.
- Buffer Time Average: This is the average time for the message stayed in the buffer at each node.

We used Opportunistic Network Simulator (ONE) [21], We conducted two different sets of experiments for the evaluation of proposed strategies. For the initial experiment, we used synthetic data sets and for the second experiment, we evaluated impact of buffer size variation and TTL variation. We evaluated the performance of BuddyRouter (BUDDY), BuddyRouterBinary, BuddyRouter_TW and BuddyRouter_Rep. We compared these performances along with Direct Delivery, First Contact, Spray and Wait, PRoPHET and Epidemic.

For the first set, we created a scenario using Helsinki city map and using working day movement model [21]. We considered scenario consisting of 1000 nodes with 17 groups. It consists of offices, meeting spots and homes in the city. We considered Bluetooth interface with transmission range of 10 meters. We simulated the scenario for 700 k seconds. Table 1 presents the simulation parameters.
For the second set of experiments, we evaluated the routing strategies using real data set. We used data set obtained from

experiments conducted by University of Cambridge at the 2005 at IEEE Infocomm conference [22]. This dataset captured the contacts established between various mobile nodes due to the movement of node carriers. For the simulation purpose, we generated message traffic of 35 messages per destination. Table 2 presents the simulation carried out using this data set.

In both scenarios, we have given equal weightages for all three parameters. That is these weightages are 0.33 for frequency, 0.33 for contact duration and 0.33 for recency.

Table 1: Simulation parameters for Helsinki scenario using Working Day Movement model

S.N.	Parameter	Value
1	No. of Nodes	1000
2	Buffer Size	100 MB
3	Transmit Range	10 Meter
4	Time to Live	1433 Minute
5	Message Size	500K -1MB
6	Transmit Speed	100 KBps
7	Speed	0.8 to 1.4 m/sec for Mobile Nodes carried by Humans and 7 to 10 m/s for bus and tram
8	Movement Model	WDM with Helsinki map with world size of 10000*8000 meters
9	Total Simulation Time	700 K sec with warm up period of 43000 sec

Table 2: Simulation parameters for scenarios using Cambridge experiment real data set

S.N.	Parameter	Value
1	No. of Groups /Nodes	2 groups comprising of 35 nodes
2	Buffer Size	1/2/5/10/20/50/100/200/500MB
3	Transmit Range	10 Meters
4	Time to Live	360/720/1440/2880/4320 Minutes
5	Transmit Speed	2 Mbps
6	Speed	0.8 to 1.4 m/s
7	Message Size	500 kB to 1 MB
8	Movement Model	External data set
9	Total Simulation Time	1036800 seconds

V. Results and Discussion

A. Results and discussions have been presented herewith for WDM scenario.

Table 1 shows the parameters used for simulations using working day movement model (WDM) with synthetic data set [21], where 1000 nodes were divided in 17 groups. This group consists of buses, pedestrians and cars. This model is based on Helsinki map with movement model world size of 10000meter * 8000 meter [21]. Figure 2 shows the performance of several single copy and multi copy protocols over above data set. Our simulation result shows that both BuddyRouter_TW and BuddyRouter_Rep outperforms all other single copy forwarding algorithms (Direct Delivery, First Contact, BuddyRouter) in terms of message delivery. As shown in Figure 2 it BuddyRouter_Rep exhibits 26 percent higher delivery ratio than direct delivery, 28 percent higher than First Contact. It gives 3 percent higher delivery probability than Spray and Wait and 4 percent improvement than PROPHET as well, which are one of the well-known multi copy protocols. It gives marginal improvement over Epidemic routing protocol as well.

BuddyRouter_TW collects more amount of information while making routing decision, to improve its message delivery performance as reflected in Figure 3.

Collecting the additional information does not incur a huge overhead in BuddyRouter variants. It is higher than single copy protocols but it is equal or very less than in case of multi copy protocols. It can be seen from Figure 3, both Epidemic (100 times) and PROPHET (30 times) incurs much higher overheads than BuddyRouter_Rep. The overhead ratio of Spray and Wait and BuddyRouter_Rep is almost equal.

Hop count average reflects how many average number of hops traversed for successful message delivery. Figure 4 reflects that all BuddyRouter variants are doing much better than any other routing protocols except Direct Delivery. This is because it makes routing decision based on heuristics and makes it more systematically than others make. BuddyRouter_Rep exhibits 40 percent less than its closest counterpart that is spray and waits does. Average delay or latency average of delivered packets in case of BuddyRouter_Rep is less than PRoPHET by 8 percent and 16 percent less than Epidemic as shown in Figure 5 at the same time it is inferior to Spray and Wait by 14 percent.

Buffer time average of PRoPHET and Epidemic is superior to all BuddyRouter variants as shown in Figure 6. However, BuddyRouter_TW and BuddyRouter_Rep exhibits better buffer time average than spray and wait in our simulation environments.

B. Results and discussions have been presented herewith for TTL and Buffer size variation.

We also study the impact of changing the Time To Live (TTL) value and buffer capacity on the performance of different routing protocols along with proposed. We investigated the performance of BubbleRap [17], which is one of the well-known routing protocol based on social metric. We conducted two sets of experiments with Cambridge real data set [22]. As shown in Figure 7, increase in buffer capacity also increases the delivery probability. This is due to reduction in number of dropped packets due to buffer overflow. Increasing the buffer capacity creates more space to store more packets for the storage, which in turn propagates large number of packets through network. It can be seen in Figure 7 Epidemic protocol is doing better in case of large buffer sizes, but better results are exhibited by BuddyRouter_Rep. It outperforms Spray and Wait and BubbleRap.

Having studied the impact of variation in buffer space on performance of routing protocols, we also studied the routing performance by varying the TTL value for the messages. By increasing TTL, it gives more lifetime to the messages. Obviously, it increases the delivery ratio of protocols but up to certain point. It gives constant result and starts declining, due to buffer overflow. BuddyRouter_Rep gives much better performance than any other protocols including BubbleRap and Spray and Wait. The performance of Epidemic starts declining with larger TTL because of number of message replicas created and therefore it leads to buffer overflows.

VI. CONCLUSION and Future Scope

In this paper, we focused on number of routing algorithms for Delay Tolerant Networks and proposed novel routing strategy called BuddyRouter_TW along with BuddyRouter_Rep. BuddyRouter_TW is multi parameter routing strategy which takes routing decision based on three parameters i.e. frequency of encounters in between nodes, aggregate contact duration and recency parameter. BuddyRouter_TW is single copy based forwarding mechanism, which is more suited in scenarios such as Pocket Switched Networks. We presented three variants of BuddyRouter. We simulated BuddyRouterBinary, BuddyRouter_TW and BuddyRouter_Rep, which all are multi copy protocols. We simulated these proposed algorithms with different scenarios. We compared these results with well-known DTN routing protocols. The simulation results shows that BuddyRouter_ Rep is 3% higher in terms of message delivery than spray and wait and 4 % higher than PROPHET. It also incurs reduced overheads with its counterpart We studied the impact of changing the buffer capacity and TTL value of messages in participating nodes for different routing protocols. Simulation results shows, BuddyRouter_Rep is providing better results than its counterpart that spray and wait and BubbleRap. The problems related to network security, congestion control and trust management may be the part of further research.

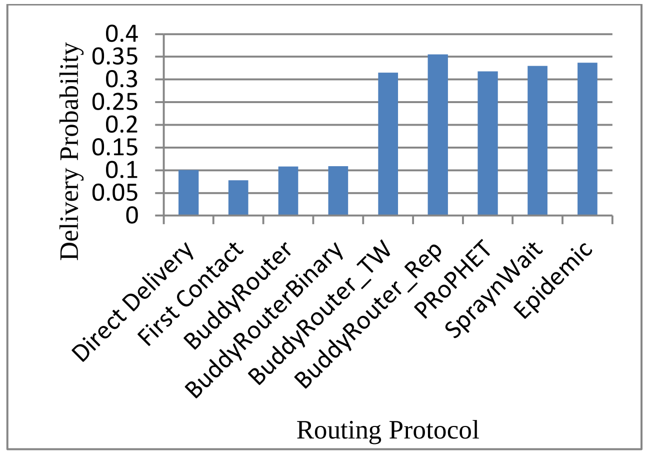

Figure 2: Performance of Routing Protocols for Message Delivery Probability

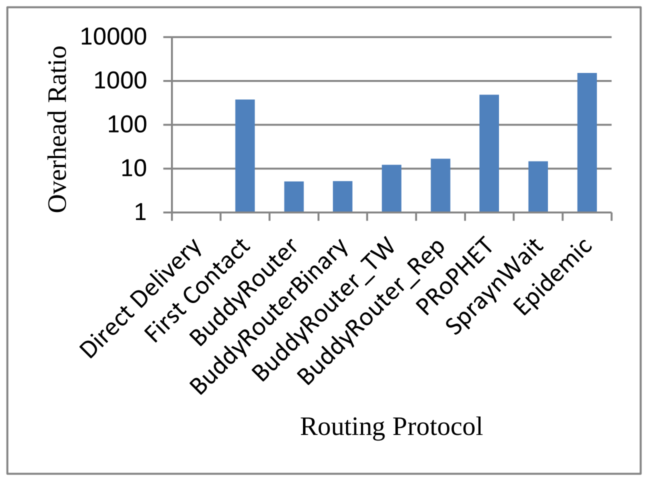

Figure 3: Performance of Routing Protocols for Overhead Ratio

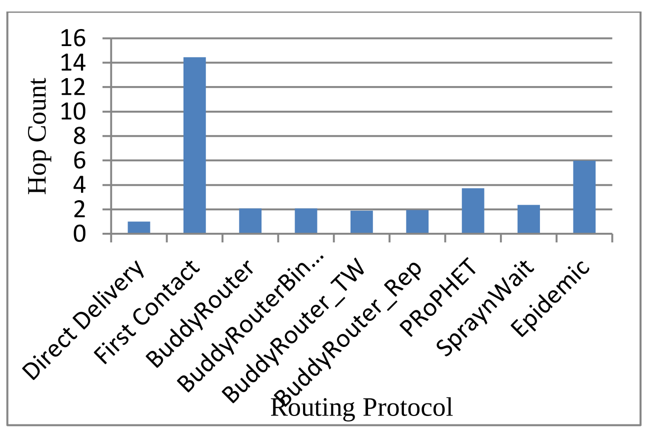

Figure 4 : Performance of Routing Protocols for Hop Count Average

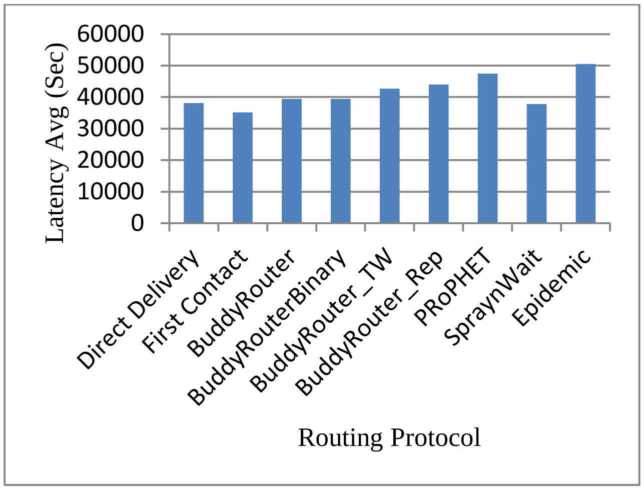

Figure 5: Performance of Routing Protocols for Latency Average

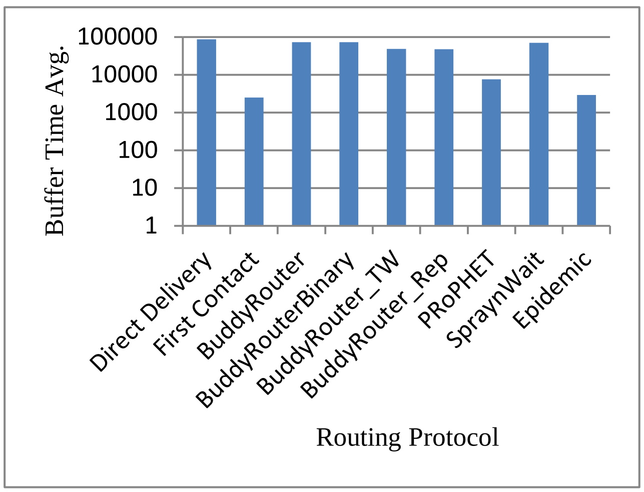

Figure 6: Performance of Routing Protocols for Buffer Time Average

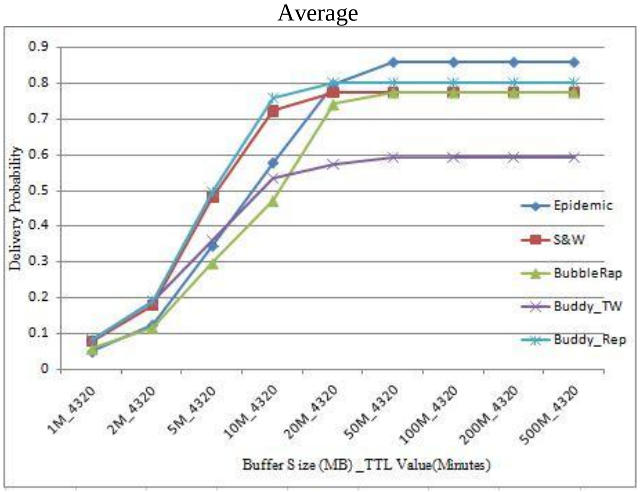

Figure 7: Impact of Buffer Variation on Delivery Performance

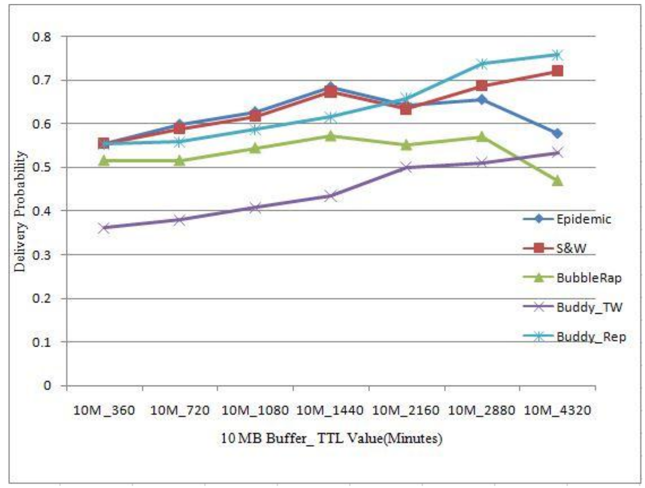

Figure 8: Impact of TTL Variation on Delivery Performance

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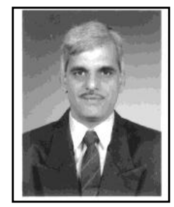

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