Evaluation of Spray Based Routing Approaches in Delay Tolerant Networks

Sweta Jain, and Meenu Chawla

Abstract— **Delay Tolerant Networks (DTN) are mobile ad-hoc networks in which connections are often disruptive or discontinuous. Data forwarding using an appropriate routing strategy is a highly confronting issue in such networks. The traditional ad-hoc routing protocols which require end-to-end connectivity fail to function here due to frequent occurrences of network partitions. Spray and Wait (SaW) routing algorithm is a popular controlled replication based DTN protocol which provides a better delivery performance balancing the average delay and overhead ratio. An empirical analysis of various spray based approaches that have been proposed for DTN has been performed in this paper to compare and evaluate the basic Spray and Wait algorithms (Source Spray and Wait and Binary Spray and Wait) with some of its major improvements (Spray and Focus, Average Delivery Probability Binary Spray and Wait and Composite methods to improve Spray and Wait). The main aim of this comparative study is to verify the effect of utility metrics in spray based routing protocols over simple spray based approaches. The ONE simulator has been used to provide a simulation environment to evaluate these algorithms and generate results. The performance metrics used are delivery ratio (DR), overhead ratio (OR) and average latency (ALat). The simulation results show that in terms of delivery ratio and average latency, Composite methods to improve Spray and Wait which incorporates delivery predictability metric in the wait phase and also acknowledgements to delete already delivered messages from a node's buffer, outperforms all the other variants compared.**

Index Terms— **delay tolerant, spray and wait.**

I. INTRODUCTION

THE wireless and mobile technologies have become so ubiquitous in the present world that it has started to transform way of life of people ranging from different aspects of the society. In the context of growing popularity for wireless technology, Mobile Ad Hoc Networks (MANET) have gained its own place in terms of its capability for providing improved communication in many areas like tactical fields, sensor networks, disaster recovery, and home networking. MANET as defined is a self configuring network of mobile devices communicating via wireless links [1]. The operation of a MANET does not rely on any fixed infrastructure. However, even MANETs may fail to provide data communication in extreme network conditions where network density is sparse and network partitions are quite frequent and long. DTNs may be used to enable data delivery even in the absence of end-to-end connectivity between communicating nodes which is the basic requirement in MANETs.

The inherent characteristics of a DTN include extremely long delays ranging up to days, frequent disconnections and opportunistic connections [2]. The DTN architecture introduces a bundle layer between application layer and transport layer [2], where bundles are arbitrary size messages consisting of multiple application packets which are forwarded in store-carry and forward manner. Each node has a buffer. Whenever a node comes in another nodes transmission range, it is termed as an '*encounter opportunity*' in DTN. During an encounter opportunity nodes exchange messages with each other that they don't possess. The messages that a node gets from the other during a contact opportunity are stored in its buffer and later forwarded to another node during the next encounter opportunity. The main goal of any routing protocol in a DTN is to provide a better delivery ratio with low overhead and small delay that is tolerable.

DTN routing protocols have been mainly classified as forwarding based or replication based depending on the number of copies of message spread by them in the network. Forwarding based routing protocols also known as single copy routing protocols maintain only one copy of the message in the network. Popular examples of single-copy routing are Direct Delivery, First Contact routing [5]. Replication based routing protocols spread multiple copies of the message in the network to increase the probability of delivery of messages. Although forwarding based routing protocols may have lower overheads and higher delays while replication based routing strategies may lead to lower delays and higher overheads. Among the different routing protocols that have been proposed for DTNs, some use the approach of blind flooding [3] whereas some others use the information regarding history of encounters or other utility functions [4,7, 9, and 11]. The first approach may ensure a high delivery rate with high communication overhead but the latter suffers from high delay due to extra computations.

Replication based routing protocols may be further classified as controlled replication based routing protocols which limit the number of copies of a message that may be created in the network. One of the most popular and basic controlled replication based routing protocol is spray and wait based routing protocol [6]. The spray based routing protocols try to achieve high delivery rate at the same time reducing the

Manuscript received May 21, 2014; revised October 10, 2014; revised December 02, 2014

Sweta Jain is working with Department of Computer Science and Engg. at MAulana Azad National Institute of Technology, Bhopal, India since 2004. (email:shweta_j82@yahoo.co.in).

Meenu Chawla is working with Department of Computer Science and Engg. at MAulana Azad National Institute of Technology, Bhopal, India since 1991. (e-mail: chawlam@manit.ac.in).

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overhead, by controlling the replication of messages throughout the network. This paper discusses about some of the major *spray based* approaches proposed in literature. An initial study of these algorithms has been presented in one of our previous works [14]. The current work discusses about the basic Spray and Wait algorithm [6] and compares it with all the new variants that have been proposed in the past literature [8, 10, and 12]. The main aim of this comparative study is to verify the effectiveness of use of utility metrics in spray based routing protocols over simple spray based approaches. To confirm their effectiveness, an extensive simulation study of these routing protocols has been conducted in different network environments. All the spray and wait based variants have been compared under two movement models namely map based movement model and random waypoint movement model to evaluate which of these works efficiently in each environment. Different network scenarios have been generated by changing the mobility model, the number of nodes and the buffer size of nodes in the network.

The rest of the paper is organized as follows. Section II presents the related works. Section III explains the various spray based routing protocols, their advantages and disadvantages. Section IV gives details of the simulation environment used for performance evaluation, and result analysis. Conclusions and future work are discussed in section V.

II. Spray and Wait Based Routing Protocols

Most of the routing protocols proposed in DTN are either flooding based or controlled replication based. *Spray based* routing protocols try to control the number of replicas of a message thereby reducing the overhead ratio but at the same time maintaining the delivery ratio. The different variants of Spray and Wait routing protocol are mentioned as follows.

A. Spray And Wait

The spray based approach was first introduced in [6] named *Spray and Wait.* The basic goal of this routing protocol was to use fewer transmissions to deliver a message to the destination, thereby trying to reduce the routing overhead of flood based routing protocols like Epidemic[3], MaxProP[4], ProPhet[7] which although result in high delivery ratio but at the increased cost of routing overhead. In Spray and Wait, the algorithm works in two phases:

Spray phase: The source node, which generates the message initially, spreads 'L' number of copies of the message to the first 'L' distinct encountered nodes (relays).

Wait phase: If the message does not reach the destination node in the spray phase, then each of the nodes carrying the message copy performs direct transmission. In direct transmission, messages are forwarded only to their destination, no relays are involved.

Two variations of Spray and Wait were introduced in [6] namely the Source Spray and Wait (SSaW) and Binary Spray and Wait (BSaW). SSaW is similar to basic Spray and Wait, where only source node sprays the L copies of the message. BSaW differs in the spray phase from SSaW; here when any node A with n>1 copies of the message, meets another node B with no copies of the same message, B receives $\lfloor n/2 \rfloor$ copies of the message and A keeps $\lceil n/2 \rceil$ copies for itself. When a node contains only one copy of the message, then it switches to direct transmission. It has been shown in [6] that when all the nodes follow IID (Identical Independent Distributed movement) manner, BSaW routing gives optimal results i.e. it has the minimum expected delay as compared to SSaW.

Spray and Wait tries to combine the advantages of both epidemic routing and direct transmission. It first sprays a limited number of copies of the message in the network. This is similar to epidemic except that the number of copies is bounded. This has an added advantage that it prevents the wastage of energy, bandwidth and storage and contention encountered in Epidemic routing. After spreading the copies the protocol then switches to direct transmission thereby reducing the overhead ratio.

B. Spray And Focus

Spray and Wait shows good performance when the nodes are homogeneous and the mobility is random. But in an environment with slow mobility, BSaW struggles to give a good performance [8] as it denies forwarding of the message copy to a relay node which may have better chances of meeting the destination in the wait phase.

In Spray and Focus (SnF) [8], the '*wait*' phase is replaced by the '*focus*' phase where a relay node with single copy of the message implements a *utility based single-copy forwarding* scheme instead of direct transmission. Each node i in the network maintains a timer $\tau_i(j)$ for every other node j. The timers are updated for each encounter. A source node creates a message with L number of copies and '*sprays*' them to L encountered relay nodes. When a node A carrying a message copy with destination D encounters any other node B without the same message then: (i) if there are n>1 message copies carried by node A, then it simply performs as in BSaW, otherwise (ii) if n=1, then it performs *Utility* based *forwarding* with last encounter times as the utility function, i.e. the message is forwarded from A to B only if

$$U_B(D) > U_A(D) + U_{th}(utility\ threshold) \quad (1)$$

This simply means that if the time of last encounter of node B with destination node D is greater than that of node A with D by a particular *utility threshold* U_{th}., then node A transfers the message to node B. The value of U_{th} is varied between 10 and 90 across the simulations for a good performance.

Since homogeneous nodes are a rare case in real scenarios, the intelligent forwarding technique of Spray and Focus provides better performance in such scenarios.

C. Average Delivery Probability Binary Spray and Wait (ADPBSW)

The delivery predictability in the ProPHET routing does not consider the long time delivery performance of the network, rather it tries to capture the current network scenario. Due to the inconsistent behavior of the delivery probabilities, routing jitter also occurs. An approach of using average delivery predictabilities was introduced in Advanced ProPHET [9]. The ADPBSW [10] utilizes the improved average delivery predictability metric of Advanced ProPHET in the wait phase of Spray and Wait routing protocol.

When node i encounters node j for the first time their delivery predictabilities are updated as in ProPHET. The average delivery predictability between the current encounter and the previous ones are retrieved in order to find the average predictabilities $P_{avg}(i, D)$ which denotes the average probability of node i to meet node D [9]. When a node i carrying a message with destination D encounters another node j without this message, then (i) if node i has n>1 message copies, it performs *Binary Spraying* (ii) else if node i is left with only one copy of the message, then this message copy is forwarded to j if and only if

$$P_{avg}(j, D) > P_{avg}(i, D) \qquad (2)$$

As the delivery predictabilities of the previous encounter and the last meeting time interval has to be stored in each node and synchronized, this proves to be an additional overhead for network with large number of nodes.

D. Composite Methods to Improve Spray and Wait (CMSnW)

Composite Methods to improve Spray and Wait (CMSnW) [12] is an approach similar to Spray and Focus. Additionally, it uses acknowledgements (ACKs) to delete those messages from the buffer which are known to be delivered to their respective destinations. The utility function used in the wait phase for message forwarding is based upon '*delivery predictability*' metric defined in the ProPHET routing protocol [4]. The ProPHET routing protocol is based on the History of Encounters of nodes. In most of the real scenarios, it is observed that nodes that have met frequently in the past have possibility of meeting again. When nodes meet, they exchange the list of messages ids that have been delivered and delete those messages from their buffers to save the buffer space.

Every node i in the network has a delivery predictability $P_{(i,j)} \in [0,1]$ for every other node j which indicates the meeting probability of i and j. The delivery predictabilities are updated as in [4]. When a node i carrying one of the messages whose destination is D encounters another node j without this message, forwarding is done based on the number of copies of a message, n, currently carried by node i (i) if n>1 message copies are carried by node i then it performs *Binary Spraying*; else (ii) if only single (n=1) message copy is left with node i, then the message copy is forwarded to j if and only if $P_{(j,D)} > P_{(i,D)}$.

III. Experimental Study

This section presents a simulation based study of the various routing protocols that have been reviewed in the previous section. These protocols are compared and analyzed through various simulations run in the ONE (Opportunistic Network Environment) [13] simulator with the intention to answer some basis questions:

- The main aim of all routing protocols in DTNs is to achieve high delivery ratio. Hence, we try to find out which routing protocol can provide better delivery ratio in the context of various environments where node movement can be either random or map based.
- Even though DTNs are supposed to tolerate considerable delays, it is desirable that routing protocol should be able to reduce the delay while delivering the messages.
- The number of relay nodes encountered to forward a message also influences the performance of a DTN routing protocol. If a message needs more relays to reach the destination, it is not desirable, as larger the number of relays used, higher is the resource consumption.

A. Performance Metrics

The performance metrics that have been used for performance evaluation and comparison are: Delivery Ratio (DR), Average Latency (ALat) and Overhead Ratio (OR). Here DR and ALat are meant to evaluate the effectiveness of the routing protocol in terms of delivery and OR gives a measure of the resource consumption/friendliness of the protocol. Higher OR means that the routing protocol is less resource friendly while higher DR and smaller ALat indicates the effectiveness of the protocol in terms of its ability to deliver more messages. These metrics are described in detail below:

- *Delivery Ratio (DR):* It is defined as ratio of total number of messages delivered (N_{delv}) to the total number of messages created (N_{creat}) as given in eq. (3). This metric is also known as *Delivery Probability (DP).*

$$DR = \frac{N_{delv}}{N_{creat}} \qquad (3)$$

- *Average Latency (ALat):* It is defined as the average time required by a message to get delivered. It is given in equation (9).

$$ALat = Average(\forall_{delivered}(T_{delv} - T_{creat})) \qquad (4)$$

where,
  - T_{delv} – time of message delivery,
  - T_{creat}– time of message creation,
  - *Delivered* – list of messages that are delivered.

- *Overhead Ratio (OR):* It is defined as the ratio of the total number of messages relayed (N_{rel}) to the total number of messages delivered (N_{delv}) as given in equation (10).

$$OR = \frac{N_{rel}}{N_{delv}} \qquad (5)$$

B. Simulation Setup

For comparing and evaluating the performance of various Spray and Wait based routing protocols that have been reviewed in this paper, the ONE (Opportunistic Network Environment) simulator [13] has been used. ONE is a powerful discrete event simulator especially designed for delay tolerant networks, which is capable of generating different node movements using various well known mobility models. It is also capable of routing messages between different types of nodes using various DTN routing protocols. Source Spray and Wait and Binary Spray and Wait routing protocols are available in the ONE simulator as is being used for the current simulation. The other three routing protocols namely SnF, CMSnW, and ADPBSW have been implemented in the ONE for the current comparative study according to their respective algorithms.

The aim of the simulations is to compare and evaluate the impact of network size, the impact of movement pattern of nodes and the buffer capacity of nodes on the performance of these routing algorithms. A number of different scenarios have been generated for evaluating each of these conditions.

TABLE I
SIMULATION ENVIRONMENT FOR MAP BASED MOVEMENT MODEL

Parameters	Values
Mobility Model	Map Based Movement Model
Simulation time	12 hours
Simulation area	4500 × 3400 m
Number of Group of nodes	3 (Pedestrians, Cars, Trams)
Number of Pedestrians	60% (total number of nodes)
Number of Cars	28% (total number of nodes)
Number of Trams	12% (total number of nodes)
Transmission Speed	250 KBps (for all groups)
Transmission Range	10m(Pedestrians), 20m(Cars, Trams)
Buffer size	10M(Pedestrians), 20M(Cars), 100M(Trams)
Node Speed	Pedestrians=[0.5,1.5]m/s Cars=[2.7,13.9]m/s Trams = [7,10] m/s
Message Size	500KB-1MB
Message generation interval	25-35 s
Message TTL	300 minutes
Value of L	6

IV. Result Analysis

TABLE II
SIMULATION ENVIRONMENT FOR RANDOM WAYPOINT MODEL

Parameters	Values
Mobility Model	Random Way Point
Simulation time	12 hours
Simulation area	4500 × 3400 m
No: of Group of nodes	1
Transmission Speed	250KBps
Transmission Range	30m
Buffer Size	50M
Node speed	0.5-1.5 m/s
Pause time	0-120s
Message Size	500KB-1MB
Message generation interval	25-35 s
Message TTL	300 minutes
Value of L	6

A. Impact of network size on Network Performance

For evaluating the impact of network size, we compare the routing algorithms in two different scenarios where we vary the number of nodes. The scenarios are different with respect to the mobility models used. Firstly a Map based movement model has been used to simulate a city environment. The parameters used in simulation are given in Table 1. For evaluating the performance in a random environment, Random way point mobility model has been used. The parameters used in this scenario are shown in Table 2.

Map Based Movement Model

The ONE simulator uses the map of Helsinki city to simulate the map based movements. A 4500 × 3400 m section of this map has been considered for simulating based Map based movement model. This mobility model tries to restrict the movement of the nodes along the paths specified in the map, like pedestrians can move everywhere, trams only along the tram paths and cars only along the roads and main roads. The number of nodes has been varied from 50 to 200 nodes in steps of 25; this is to evaluate the performance of the protocols presented in terms of the node density. The results for delivery ratio, overhead ratio and average latency are shown in figure 1 (a), (b), and (c) respectively.

From the graph in figure 1(a), it may be seen that as the number of nodes increases, the Spray and Wait based routing protocols maintain their delivery ratio. This proves that the Spray and Wait based approaches are scalable in environments with high node density. The delivery ratios of SSaW, BSaW as seen from figure 1(a) are lower as compared to other protocols. SnF provides slight improvement over the BSaW and SSaW in delivery ratio as it uses the information from the timers to forward the message copy instead of relying on the direct transmission. But ADPBSW and CMSnW show best results for delivery ratio than all other spray based routing protocols. This is due to the fact that in these protocols forwarding is based on node meeting probabilities with the destination node. This also supports the assumption that in a realistic scenario where node movements are often restricted to a particular locality, the nodes that met once have high probability to meet again, and thus they can be good relays. Thus the usage of ProPHET is justified in both the algorithms. However CMSnW provides a slightly better performance than ADPBSW, due to the usage of ACKs to drop the already delivered messages from the nodes' buffer.

The graph shown in figure 1(b) indicates that as the number of nodes increases, overhead ratio also increases. This is because as the number of nodes increases, the number of relays used to spread the message also increases. However, for BSaW and SSaW the overhead ratio does not have many variations as they switch to direct transmission in the wait phase. The overhead ratio is the highest for CMSnW and ADPBSW because in wait phase, instead of just waiting for the destination node as in SSaW and BSaW, these protocols forward the message to nodes which are better relays than the node currently carrying the message. The forwarding decision taken by them in the wait phase is according to the delivery predictability metric of the Prophet [4, 9]. As the number of nodes increases, one node gets the chance to meet more number of nodes and therefore, the probability of nodes to meet each other increases. The CMSnW overhead is larger than ADPBSW as it does not consider the overall network performance whereas the ADPBSW uses the average of the delivery predictabilities which is a better estimate. Higher overhead ratios of ADPBSW and CMSnW also lead to higher delivery ratios as may be seen from figures 1(a) and 1(b) respectively. Also higher overhead ratios of CMSnW and ADPBSW can be compensated by the lower average latencies in delivering the messages as observable from figure 2 (c). CMSnW and ADPBSW find better nodes to relay the messages and hence reduce the delay, whereas SnF, BSaW and SSaW try to reduce the overhead ratio at the cost of increased delay as they wait to meet the destination node.

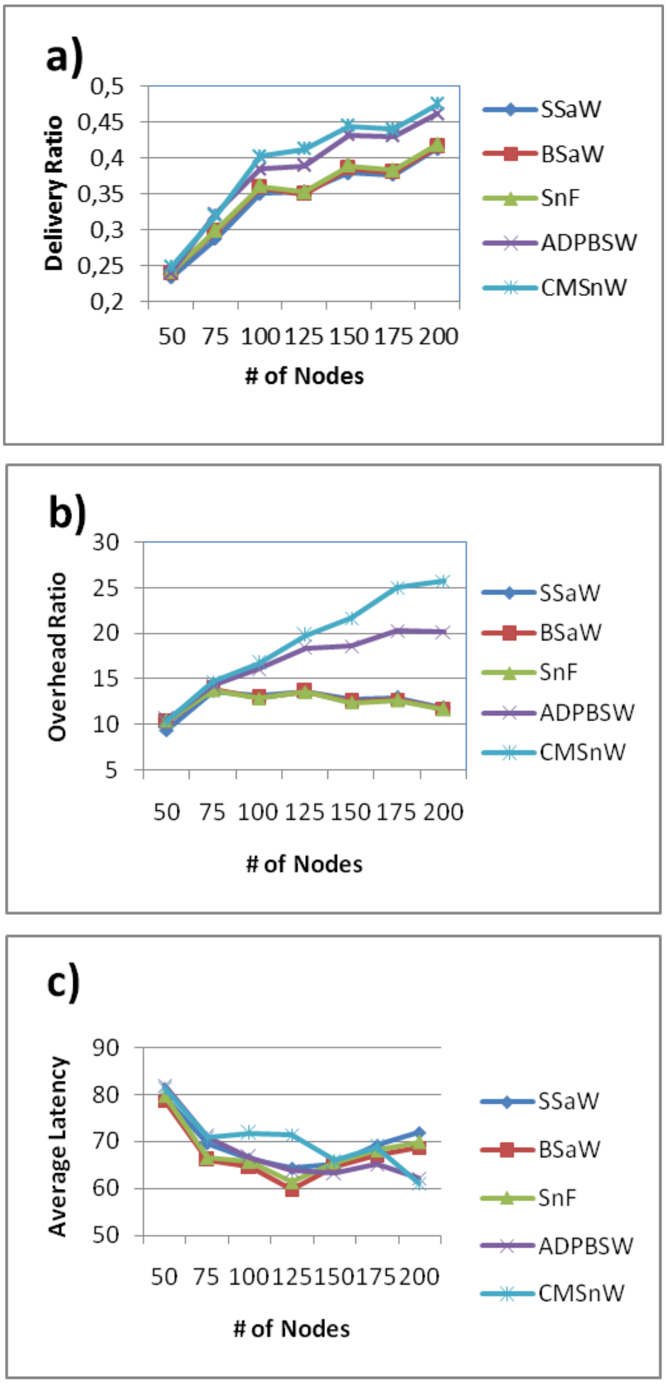

Figure 1 Impact of number of nodes in network on (a) Delivery Ratio, (b) Overhead Ratio, and (c) Average Latency in Map based movement model

Random Way Point Movement Model

The performance analysis of the different spray based routing protocols under Random Waypoint movement model with varying network density is presented in this section. In Random way point mobility model, the nodes follow zig-zag movement thereby reducing the probability of predicting future encounters. The simulation results for delivery ratio, overhead ratio and average latency are shown in figure 2 (a), (b) and (c) respectively.

From figure 2(a), it may be observed that CMSnW performs the best in terms of delivery ratio as compared to other algorithms. ADPBSW also gives good performance when compared to SnF, BSaW and SSaW. It may be seen that even though the performance of ProPHET [11] remains low in a random environment, but when combined in the wait phase of Spray and Wait, it can give better performance than simple spray and wait routing algorithms. This may be attributed to the use of better relays for message forwarding. SnF has better performance when the number of nodes is less, but as the number of nodes increases beyond 100 it does not show considerable increase in the delivery ratio. This is because timers may become obsolete due to high node density and mobility. Also timers may not be a very effective metric as compared to delivery predictability metric of ProPHET, which does proper updation of the metric depending on node meeting frequency.

The overhead ratio of CMSnW is higher in comparison to ADPBSW, SnF, BSaW and SSaW as visible from figure 2(b). This is followed by ADPBSW. The overhead ratio of SnF remains the lowest in the random environment as the utility function cannot find appropriate relays to forward when the node mobility is random. SnF seems to be resource friendly at the expense of slightly low delivery ratio and high latency for delivering the messages. The average latencies are low for all the other protocols and comparable with BSaW except for SnF.

In a random environment, SnF shows poor performance when node density is high. Just being resource friendly does not help if the delivery performance is too low. Hence it may be concluded that SnF is not recommended in a random environment and is better suited in a heterogeneous environment where node movements are slow and controlled.

From the above results, it may be concluded that CMSnW is the best in terms of delivery ratio and average latency. The only disadvantage is that it consumes more resources as it uses many relays for the faster delivery of messages. ADPBSW also provides better performance and can be used instead of CMSnW as the overhead is less than that of CMSnW and still can provide delivery ratio comparable to CMSnW. ADPBSW is also better as it alleviates the routing jitter problem of ProPhet that can induce noise in the algorithm. SnF is best in a heterogeneous environment in terms of the overhead ratio; it has very less overhead ratio and a comparable Delivery ratio although not as high as that of CMSnW or ADPBSW. SSaW and BSaW do not have much difference in their performances; yet BSaW can deliver messages faster than SSaW.

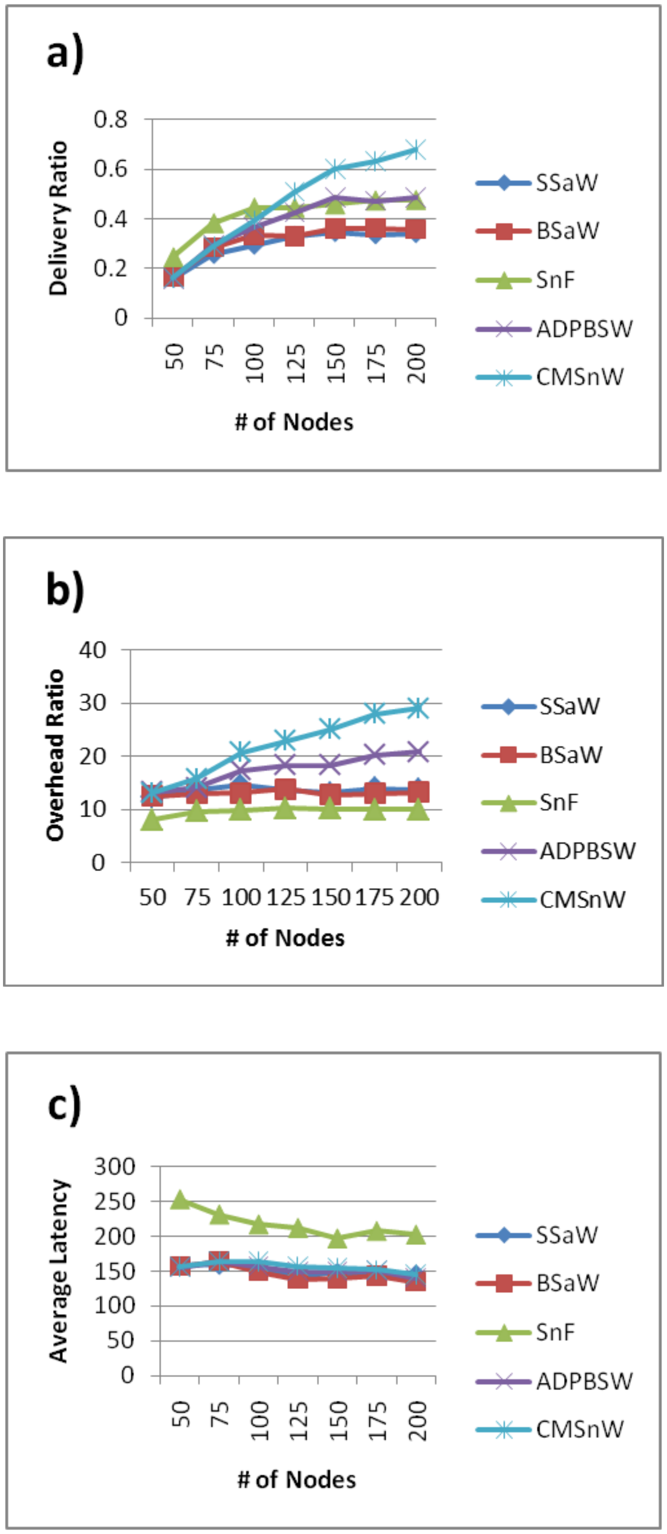

Figure 2 Impact of number of nodes on (a) Delivery Ratio (b) Overhead Ratio and (c) Average Latency in Random way point mobility model

B. *Impact of Buffer Size on Network Performance*

This section presents the impact of increasing buffer size on the performance of various spray and wait based routing protocols. Figures 3(a), (b) and (c) show the DR, OR and ALat of the routing algorithms namely SSaW, BSaW, SnF, ADPBSW and CMSnW. The scenario settings under which these results were computed are given in Table 4. From the graph in figure 3(a), it may be seen that the delivery ratio of all the algorithms increases with increasing buffer size of nodes. This is due to the fact that with the increase in buffer size, each node has the capability to store more messages from other nodes and thus prevent message drops due to buffer overflow, which in turn enables better spread of the message copies within the network. It may be seen that ADPBSW and CMSnW perform better than SSaW, BSaW and SnF, with ADPBSW performing slightly better than CMSnW. This is because ADPBSW uses Advanced ProPHET[9] in the forwarding phase which uses average predictabilities as compared to CMSnW which uses basic delivery predictability metric of basic ProPHET[4]. SnF performs slightly better than BSaW and SSaW due to the utility function used in the forwarding phase, nevertheless it does not perform better than CMSnW and ADPBSW as both of them use history of encounters metric which is a better measure for forwarding in a map based scenario.

The overhead ratio for CMSnW and ADPBSW are higher in comparison to any other algorithms. The trends are similar to those observed in previous sections for the same reasons. Increasing the buffer size does not seem to have any profound impact on the overhead ratio as seen from the results in figure 3(b).

From the results in figure 3(c) it is noticeable that average latency tends to increase with buffer size for SSaW, BSaW and SnF. This is because as the buffer size increases the number of messages stored in the buffer also increases and the average time of the message copies spent in each buffer therefore increases. However for ADPBSW and CMSnW the average latency increases up to a buffer size of 12M and then decreases. This attributes to the better forwarding decision of ADPBSW and CMSnW. These algorithms forward more messages to the relays from their buffer as compared to BSaW and SSaW which keep the messages in their buffer until the destination is reached.

TABLE III
SIMULATION ENVIRONMENT FOR STUDYING IMPACT OF BUFFER SIZE OF NODES

Parameters	Values
Mobility Model	Shortest Path Map Based Movement Model
Simulation time	12 hours
Simulation area	4500 × 3400 m
Number of Group of nodes	1
Number of nodes	100
Transmission Speed	250KBps
Transmission Range	30m
Node speed	0.5-1.5 m/s
Pause time	0-120s
Message Size	500KB-1MB
Message generation interval	25-35 s
Message TTL	300 minutes

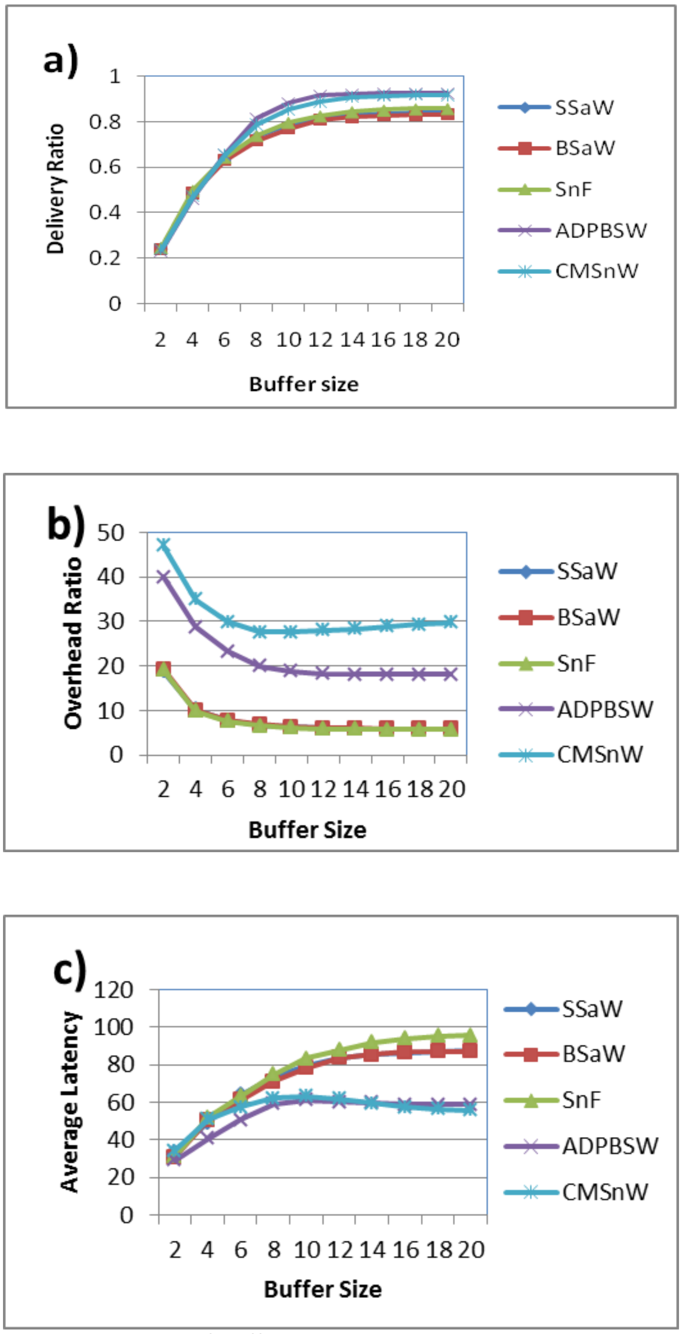

Figure 3: Impact of Buffer size- (a) Delivery Ratio, (b) Overhead ratio and (c) Average Latency.

V. CONCLUSION

Delay Tolerant Networks aim to provide data delivery in sparse and intermittent networks where network partitions restrict the use of end-to-end connectivity based traditional routing protocols. The goal of any routing protocol in a DTN is to achieve high delivery ratio with less overhead. The routing protocols designed in DTN offer a tradeoff between high delivery ratio and small overhead ratio. Even though as the name DTN suggests that delay is tolerable in these networks, the basis of any routing protocol is to arrange the timely delivery of the messages buffered in the nodes. Many routing protocols in DTN try to flood the messages across the network to ensure high delivery ratio and low latency. But such protocols are not resource friendly. In this paper, a review of the Spray and wait routing algorithm which is a controlled replication based algorithm and some of the algorithms that are improvements over the basic Spray and Wait protocol have been presented. It presents a brief overview of these algorithms, their advantages and disadvantages. Also a detailed simulation study of these algorithms in varying environments has been presented to do a performance analysis of them.

From the results presented here, it may be concluded that CMSnW has better performance in terms of delivery ratio and average latency, whereas it might be better to use ADPBSW also since it solves the routing jitter problem that appears in ProPHET routing algorithm. Although, SnF results in the highest latency in random environment, it may still be preferred over other routing protocols as it is resource friendly and has comparable delivery ratio as compared to ADPBSW. Also SnF shows best result for delivery ratio in low density networks.

SSaW and BSaW are simple algorithms and do not consider any prediction metric or utility function for forwarding and hence delivery ratios achieved are the lowest, but they also have the lowest overhead ratios for the same reason. Enhanced versions of basic Spray and Wait namely, CMSnW and ADPBSW, achieve higher delivery ratios in all environments due to additional guided forwarding of messages in the wait phase at the cost of increase overheads.

For future work we would like to reduce the overhead in CMSnW by making better forwarding decisions so that CMSnW appears more resource friendly in a DTN environment. This may be done by including a threshold on the utility metric in the algorithm and do forwarding only if this particular threshold is exceeded, thereby limiting the number of relays along to make intelligent forwarding decisions.

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Sweta Jain is a PhD student in Computer Science and Engg. Department at the Maulana Azad National Institute of Technology, Bhopal, India, under supervision of Professor Meenu Chawla. She received her B.Tech.(CSE) degree and M.Tech.(CSE) from MANIT, Bhopal in the years 2004 and 2009 respectively. She is also working as an Assistant Professor in the Computer Science Engg. Department at the same institute. Her current research areas are Delay Tolerant Networks, and Sensor Networks. She has authored or co-authored 12 international journal papers, 6 international conference papers and 2 national conference papers. She has been a review committee member of IEEE SCEEE conference in the year 2012, 2013, and 2014.

Meenu Chawla is a Professor at the Department of Computer Science and Engg. At Maulana Azad National Institute of Technology, Bhopal, India. She received her PhD degree in CSE from MANIT, Bhopal in the area of Mobile Ad Hoc Networks. She completed her M.Tech. degree in CSE from IIT, Kanpur in 1995 and B.Tech. degree in CSE from MACT, Bhopal (REC) in 1990. Her main research interests include wireless networks, and cloud computing. She has 19 international journal papers, 11 international conference papers and 19 other papers to her credit.