

Performance Improvement of DTN Routing Protocols with Enhanced Buffer Management Policy



G.R. Sreekanth, R.C. Suganthe, R.S. Latha

Abstract – Delay tolerant network (DTN) is one of the emerging technologies which is applied generally when there is no end-to-end path exists from source to destination all the time. The two major issues in DTN are routing and buffer management. Existing buffer management policies are based on one or more parameters such as message Time-to-Live, message age, message replication count, message size etc.,. There is no efficient approach is available for estimation of message replication count. In this work an efficient approach is proposed to estimate total number of copies of the message. The proposed buffer management approach prioritizes the messages and based on which the messages are forwarded/dropped from the buffer when there is a contact opportunity occurs/when the buffer is full. These priorities are based on message Time-to-Live, message age, message replication count and message size. This proposed buffer management policy is evaluated with two popular DTN routing protocols Spray-and-Wait and Prophet. The simulation results show that delivery probability of messages has increased with reduced buffer time average and minimized latency.

Keywords— Delay tolerant network, routing, buffer management policy, message replication count

I. INTRODUCTION

Delay tolerant networking (DTN) is designed to resolve the issues in computer network that may lack end-to-end network connectivity. These networks are mainly applicable for the areas like terrestrial environments, or planned networks in space. The ultimate aim of the DTN networking is to transmit the data from source to destination whenever an opportunity arises. Traditional ad hoc routing protocols fail in DTN environment due to the absence of end-to-end network connectivity. DTN uses the protocol based on “Store-and-Forward” for messaging service and forwards the message as bundle. There are two types of protocols in DTN that follows “Store-and-Forward” approach:

Forwarding-based and Replication-based approach. The forwarding-based protocols use only one copy of the message and forward it to the destination directly or via intermediate nodes. These protocols are not suitable for Delay tolerant networks due to unpredictable and irregular connections in network. Because of these features of DTN, many of the routing protocols in DTN employ replication based approach.

Replication based protocols propagate several copies of a message into the network to increase the chance of message delivery. These protocols are categorized into Flooding-based protocols and Quota-based protocols[1].

Flooding based protocols tried to flood the messages to all the nodes in the network. Message delivery probability and overhead is high in flooding based protocols due to no limit on number of replicas of a message. Some of the examples of these types of protocols includes Epidemic, Prophet, RAPID, MaxProp [10] etc.,

Quota based protocols set an upper limit on maximum number of replicas for a message which is independent of network size. These protocols suffer from less delivery probability than flooding based protocols due to setting of replication factor for the messages. But it incurs less overhead than flooding based protocols. Spray-and-Wait and Spray-and-Focus[11] are examples of some popular quota based protocols.

In DTN, many copies of a message in the network increase the chance of the message delivery at the cost of very high network overhead and congestion. To reduce the very high overhead, the quota based routing protocols uses a replication factor to restrict the maximum number of copies of a message in the network. But these types of protocols suffer from low delivery ratio. Hence it is necessary to design a protocol such that it achieves high delivery ratio with low overhead.

In this work, a popular DTN protocols Spray-and-Wait and Prophet has been enhanced with buffer management policy to improve delivery probability with less overhead. In this work, scheduling decision is taken based on scheduling priority which is calculated using three important message parameters: the total number of replicas of a message in the network, message’s age, and message size. In the existing methods the value of number of replicas exceeds number nodes in the network. To overcome this shortcomings, new method for estimating number of replicas has been proposed in this paper. The organization of the paper is outlined as follows:

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Section II presents a brief review of the major routing protocol categories of DTN and the different buffer management policies that have been proposed for DTNs in the past literature; Section III describes the methods for estimation of total number of replicas and buffer management scheme; Section IV defines the simulation environment used for evaluation of the proposed work and presents the various simulation results; and Section V concludes the paper and presents future work.

II. RELATED WORK

Routing in DTN is a challenging task due to frequent network partitions and limited network resources. Most of the routing protocols in DTN can be categorized into forwarding-based and replication-based. Forwarding-based protocols allow only one copy of the message in the network but replication-based protocols allow multiple copies of the message in the network at a time. Hence overhead of forwarding-based protocols is very less compared to replication-based protocols.

Direct delivery routing and First contact delivery routing protocols comes under forwarding based category. In direct delivery [25] [26], only when the source node meets the destination node the message is delivered. Even though this approach has lower overhead, but the delay can be very high. This scheme is useful only when the source node may have the direct contact with the destination before the expiry of the message. In First Contact [16] routing, Source node forwards a message to the first encountered node and this node forwards the message to final destination whenever there is a contact opportunity arises with the destination.

Epidemic Routing is a blind flooding approach. In Epidemic Routing [8],[17], each node exchanges all the messages stored in its buffer to all its neighbors. Finally the message may have the opportunity to reach the destination. This approach produces more delivery ratio with a cost of more overhead. In [18], epidemic routing is enhanced based on adaptive compression of vectors has been proposed to reduce the overhead and buffer space occupancy for storing messages.

Spray and Wait protocol [6] sets a limit on number of copies which is present in the network by setting replication factor. It provides the delivery ratio benefit of replication-based protocols and the less resource utilization benefit of forwarding-based routing. This protocol composed of two phases: first is the spray phase and second is the wait phase. In the first phase only L copies are sprinkled into the network by the source. In the wait phase the relay node which receives this copy is responsible for delivering the message directly to the destination.

Spray and Focus [11] approach is almost similar to Spray-and-wait approach. The difference is that the forwarding of messages in the wait phase is guided by utility functions in Spray-and-Focus.

The Probabilistic Routing Protocol using History of Encounters and Transitivity (PROPHET) [14] protocol uses an algorithm which tries to exploit the non-randomness of real-world encounters by keeping a set of probabilities for successful delivery to known destinations in the DTN and

replicating messages during opportunistic encounters. It is one of the routing protocol in DTN.

This protocol uses the knowledge obtained from the history of encounters with other nodes to improve the delivery probability. Each node maintains delivery predictability estimates, and using this knowledge to decide whether an encountered node can be used as a carrier for a data packet. Whenever a node meets another node, the predictability estimates are updated. Another feature called “transitivity” mechanism is also included in this protocol.

A comprehensive survey on different delay-tolerant routing protocols had been presented in [25] and analyzes the performance of these protocols. The author also discussed the advantages and disadvantages of each protocol and concludes it with the shortcomings of the DTN protocols. In DTN environments, a burden is put on the limited buffer space due to requirement of long-term storage and message replication. Since the buffer space is limited, the heavy load of packets may end up with traffic congestion. Many buffer management policies are devised to increase the throughput of the network without maintaining the transmission delay. Buffer Management policy is an essential approach that manages the various resources among different situations as per the technique used. It decides which message is to be removed from the buffer first, if the buffer is full. Few of the familiar buffer management techniques [2],[3],[19],[20] are : Drop Least Recently Received (DLR), Drop Oldest (DO), Drop Front (DF) FIFO, Drop Largest (DLA), MOFO (Evict Most Forwarded First), MOPR (Evict Most Favorably Forwarded First) .

The author review and analyze the performance of various buffer management techniques using Prophet routing protocol for evaluation in [3]. The TTL based routing described in [4],[21],[24] uses the forwarding strategy based on four parameters: message time to live (TTL), message hop count, message replication count and message size. Message TTL gives the chance to a message which will expire soon.

The new message forwarding strategy Contact Quality Based Forwarding Strategy is proposed in [5]. This strategy examines the quality of current contact and selects the best carrier node whose message carrying capability is more. For reducing message drop buffer management policy also was proposed. The Equal-Drop (E-DROP) [7] discarded the queued message only if its size of an incoming message is equal to the previously stored messages. The author reviewed and classified various buffer management policies designed for Opportunistic networks in [9]. They also proposed a Average Contact Frequency based scheduling and Number of replicas based message dropping policy to improve the delivery rate, latency and average hop count. In [12] author takes all information relevant to message delivery and the network resources into account to deal with queuing strategy and cache replacement. In this work message priority is calculated based on two parameters number of relayed hops of the message Hrelay, and the number of forward of the message in this node Nforward.

A new buffer management policy called EBMP was proposed in [13] and it uses three message properties such as the total number of replicas of a message present in the network, the age and the remaining time-to-live (RTTL). The author uses utility functions for finding which message should be dropped/forwarded when buffer is overflowed/when contact opportunity occurs.

Message drop control source relay (MDC-SR) routing protocol [22] was proposed to maximize the delivery probability and buffer time average. It also reduces considerable amount of message relay and hop count. They also made a performance analysis of this new approach with existing buffer management policy like Drop oldest, LIFO and MOFO. Optimal joint scheduling and buffer management policy which is based on global knowledge about the network state was proposed in [23]. To improve the performance the author derives a new distributed scheduling and drop policy which is based on locally collected statistics. To produce more delivery ratio with less buffer time average, a new strategy has to be developed to manage the buffer efficiently.

III. SYSTEM MODEL

The main objective of this work is to use the buffer space of the node more efficiently.

A. Estimation of Number of Replicas

Total number of replicas of a message is the key parameter used to estimate the priority of the message for scheduling and dropping. To measure the number of replicas of message, two variables are introduced in [13]:

- a) Estimated Total of Replicas (ETRs)
- b) My Replica (MR)

Let ETR_i^A be the total number of replicas of messages i as estimated by node A and MR_i^A be the number of replicas of message i which is replicated by node A itself.

If node B meets node A and node A have message i but node B does not have the message i then node B updates its total number of replicas and my forward count as given below

$$ETR_i^B = ETR_i^A$$

$$MR_i^B = 0 \text{ and node A updates its parameters as follows.}$$

$$ETR_i^A = ETR_i^A + 1$$

$$MR_i^A = MR_i^A + 1$$

When node B and node D meets and both have the message i then node B and node D exchange their My-Forward values and updates its total number of replicas ETR_i^B and ETR_i^D respectively which is shown below

$$ETR_i^B = ETR_i^B + MR_i^D$$

$$ETR_i^D = ETR_i^D + MR_i^B$$

Limitation in this approach is that when both nodes which are comes in contact have the message i and both the nodes forwarded the message i to some subset of nodes which are common then it gives wrong estimation of ETR value. This drawback is eliminated in our proposed method by introducing message vector for each message i which gives the information about what are all the nodes having

message i . The value 1 in bit position j of vector i represents message i is in node j and the value 1 in bit position k represents message i is in node k etc.

This vector is maintained by each node and when nodes comes in contact with each other this vector is Bitwise OR-ed to find the nodes having message i . Total number of replica of message i is calculated by counting number of 1s in the corresponding message vector. This value never exceeds actual number of replica in the network. This is illustrated in figure 1.

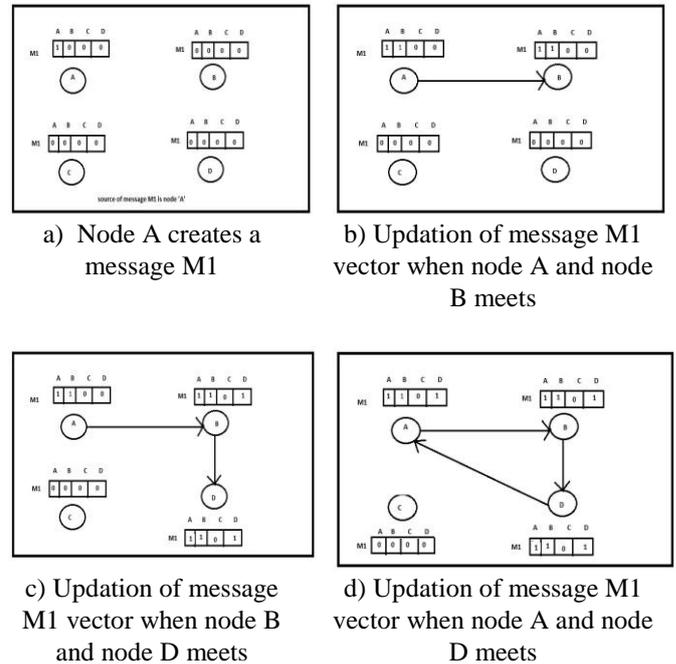


Figure 1. Scenario depicts Message vector updation when two nodes are comes in contact.

B. Packet Scheduling Algorithm

When two nodes contact each other, it has to decide which message has to be forwarded first. In order to prioritize which message to be sent first, scheduling of the messages is done by using the parameters total number of replicas of a message, message size and message age. Message age is the difference between the current time of the simulation and creation time of the message.

$$Ps = \frac{1}{Copies} + \frac{1}{\log AGE} + \frac{1}{\log SIZE}$$

A message with least number of copies, minimum age and smaller size is given higher priority for scheduling. Messages that have less replication count is spread more in the network and hence may have more change for arriving at the destination. Small size messages are given higher priority than larger sized messages to avoid partial transmission of message when transmission contact duration is less. Aged messages having less TTL value who may reaches the deadline soon.

Algorithm Node_Encounter(N_p, N_q)

Begin

For each message $M_i \in BufferN_p$ do

Begin

If $M_i \in DeliveredListN_p$ or $M_i \in DeliveredListN_q$

then

Remove M_i from

$BufferN_p$ and $BufferN_q$



```

if ID of  $M_i$  is in DeliveredListNq then Update
    DeliveredListNp
if ID of  $M_i$  is in DeliveredListNp then Update
    DeliveredListNq
Else if TTL of  $M_i$  is
    expired then
    Remove  $M_i$  from
    BufferNp and
    BufferNq
Endif
End

```

```

For each message  $M_i \in$  BufferNq do
Begin
    If  $M_i \in$  DeliveredListNp or  $M_i \in$  DeliveredListNq
    then
        Remove  $M_i$  from BufferNp and BufferNq
    if ID of  $M_i$  is in DeliveredListNq then Update
        DeliveredListNp
    if ID of  $M_i$  is in DeliveredListNp then Update
        DeliveredListNq
    Else if TTL of  $M_i$  is expired then
        Remove  $M_i$  from BufferNp and BufferNq
    Endif
End

```

```

For each message  $M_i \in$  BufferNp do
Begin
    If  $M_i$  is destined to Nq then
        Deliver  $M_i$  to Nq
        Remove  $M_i$  from Np
        Add ID of  $M_i$  to DeliveredListNp and
        DeliveredListNq
    Else
        Compute Forwarding Priority Ps for  $M_i$ 
    Endif
End

```

```

For each message  $M_i \in$  BufferNq do
Begin
    If  $M_i$  is destined to Np then
        Deliver  $M_i$  to Np
        Remove  $M_i$  from Nq
        Add ID of  $M_i$  to DeliveredListNp and
        DeliveredListNq
    Else
        Compute Forwarding Priority Ps for  $M_i$ 
    Endif
End

```

```

Sort BufferNp based on Priority Ps
//Forwarding of messages based on priority Ps
For each  $M_i \in$  BufferNp do
Begin
    If  $M_i \notin$  BufferNq then
        Insert  $M_i$  to BufferNq
    // When BufferNq is full, Packet dropping algorithm is
    invoked
        Set bit q in VectorNq
    Endif
End

```

```

For  $M_i \in$  BufferNq do
Begin
    If  $M_i \notin$  BufferNp then
        Insert  $M_i$  to BufferNp
        // When BufferNp is full packet dropping
        algorithm is invoked
        Set bit p in VectorNp
    End
End

```

C. Packet Dropping Algorithm

All the incoming messages have to be stored in the node's buffer. Whenever the node's buffer is full, there will be no space to insert a new message into the buffer. Since the buffer cannot accommodate all the messages, dropping of messages is done by using the parameters total number of replicas of a message, message size and message time to live. Message with more number of copies, larger size, and minimum TTL value is given highest priority for dropping. Message with highest number of copies is present in various nodes. It has many routes to reach the destination. So the message with highest number of copies is dropped first. Message with larger size is dropped first because it may or may not reach the destination completely and the bandwidth gets wasted. If a message with smaller size is given priority for transferring, it fully reaches the destination and increases the delivery probability. Message with smaller TTL value gets expired soon, hence it is removed first. To decide which message to be dropped first, following message dropping algorithm is used.

Algorithm Packet_Dropping(Incoming Message M_{new})

```

Begin
    If node's buffer not full
        Insert the message  $M_{new}$  into the buffer
    Else
        For each message  $M_i$  in Buffer
        Begin
            Calculate the dropping priority
             $Pd[i] = Copies_i + \frac{1}{\log(TTL_i)} + \log(Size_i)$ 
        End
        Calculate the dropping priority for the incoming
        message  $M_{new}$ 
             $Pd_{new} = Copies + \frac{1}{\log(TTL)} + \log(size)$ 
        Sort the messages in the buffer based on the dropping
        priority.
        If  $Pd_{new} <$  Highest priority message in the buffer then
            Replace the highest priority message in buffer with
            the message  $M_{new}$ 
        Else Drop the message  $M_{new}$ 
        Endif
    Endif
End

```

IV. PERFORMANCE ANALYSIS

The performance of proposed buffer management technique is evaluated in two well-known popular DTN routing protocols Spray-and-Wait and Prophet routing protocols. In SNW protocol, only limited number of copies can be created. Prophet protocol uses history of encounters for forwarding the packet. In Prophet, when two or more node comes in contact with other node, it transfers the message to the node which has high probability to reach the destination. When a contact opportunity arises, node decides which message to be forwarded first with message scheduling algorithm. Since buffer size is limited, it cannot accommodate all the messages. To decide which message to be dropped first, packet dropping algorithm is used.

A. Parameters for Topology Setup

Topology is created for a city scenario. All the experiments were carried out in ONE Simulator. The table 1 describes the parameters required for topology setup:

Table 1 Topology setup

Parameter	Value
Simulation Time	9000 sec
Routing Protocol	Prophet
Movement model	Map route movement model
Buffer size	50MB
Number of nodes	10, 20, 30, 40, 50
Transmission range	100 m, 200m, 300m, 400m, 500m
Transmit speed	100bytes/s,200byte/s,300bytes/s, 400bytes/s,500bytes/s
Message size	500 KB – 1MB
Message creation rate	One message per 25 – 35 sec

B. Performance Parameters for evaluation

The performance metrics used for the analysis are delivery probability, buffer time average, latency average and overhead ratio. Delivery Probability is the fraction of generated messages that are correctly delivered to the final destination within the time period. Latency Average is the time taken between generation of messages by the source and reception of the messages by the destination. Buffer time average is how long message is present in the buffer. Overhead Ratio is used to measure the additional number of packets needed by the routing protocol for delivering the data packets.

C. Result Analysis

In figure 2 various protocols like SNW, ESNW, PROPHET, EPROPHET are compared by varying number of nodes. The proposed EPROPHET and ESNW protocols have nearly 30% more delivery ratio than PROPHET and SNW protocols respectively. The message delivery is increased because the messages are prioritized and then transmitted to other nodes and the message with smaller size is given highest priority for transmitting.

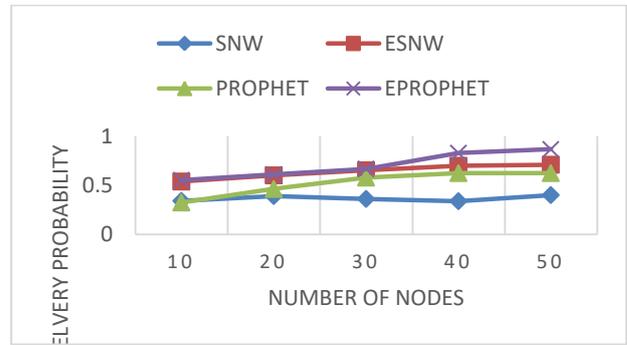


Figure 2 Delivery probability of various protocols

The buffer time average of various protocols like SNW, ESNW, PROPHET, EPROPHET are compared (figure 3) by varying number of nodes. As the delivered messages are deleted from the buffer, the buffer average time is considerably reduced. The proposed protocols ESNW and EPROPHET uses buffer efficiently because total number of replicas of a message does not exceed the total number of nodes in the network as well as delivered messages are deleted from the buffer.

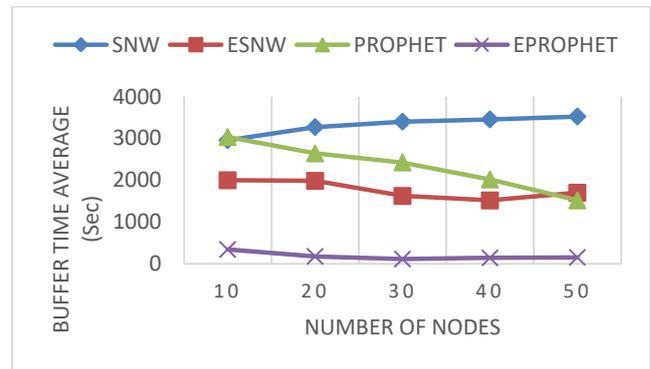


Figure 3 Buffer time average of various protocols

The latency average of various protocols like SNW, ESNW, PROPHET, EPROPHET are compared in figure 4 by varying number of nodes. Proposed EPROPHET and ESNW protocols have latency average slightly more than PROPHET and SNW protocols respectively because when two nodes contact with each other it takes time to check whether the copy is present in the other node and also updating total number of copies and also delivers more messages than SNW and PROPHET.

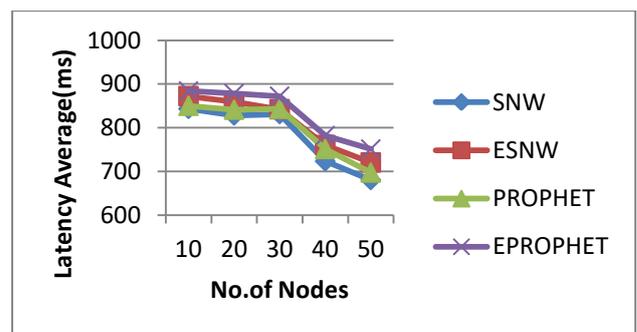


Figure 4 Latency average in various protocols

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The overhead ratio of various protocols like SNW, ESNW, PROPHET and EPROPHET are compared by varying number of nodes is shown in figure 5. Proposed ESNW and EPROPHET protocols produced less overhead than existing protocols PROPHET and SNW respectively since it deletes delivered messages and avoids unnecessary transmissions.

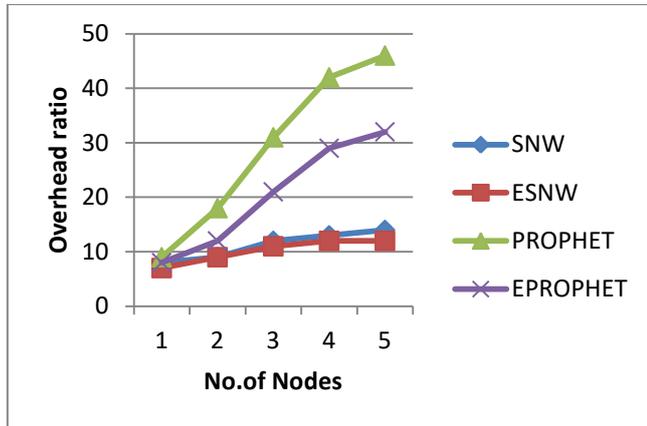


Figure. 5 Overhead ratio in various protocols

V. CONCLUSION

Opportunistic networks ensure reliable communication in an intermittently connected environment. The key issue here is to deliver the messages whenever an opportunity arises. Various factors such as delivery ratio, buffer time average, overhead ratio and latency are analyzed with varying values of speed, buffer size, transmission range and number of nodes. Proposed EPROPHET and ESNW protocols uses buffer space efficiently than PROPHET and SNW Protocols respectively and delivery probability of EPROPHET and ESNW protocols are 30% more efficient than PROPHET and SNW protocols respectively.

Apart from buffer space and delivery ratio, the other metrics like power consumption and overhead ratio can be considered for optimization. Finally, the work can be enhanced for reducing energy consumption during the message transmission which can be done in future.

REFERENCES

- Zhou H (2003) ,A Survey on Routing Protocols in MANETS, MSU-CSE-03-08.
- Hemal Shah, Samina Mansuri, Yogeshwar Kosta(2012) 'Performance Analysis of Drop Policies for Different Mobility Models in DTN', International Journal of Computer Applications (0975 –8887) Volume 59–No.14 pp.28-32.
- Animesha Garpal, Dinesh Singh Baghel ,Shweta Jain(2012) 'An Analysis Optimal Buffer Management Policy to Improve QOS in DTN Routing Protocol',International Journal of Computer Applications (0975 – 888) Volume 48– No.5, pp.7-11.
- Anindya Tahsin Prodhana, Gholamali C. Shoja, Humayun Kabir,Rajkumar Das(2011) 'TTL based routing in opportunistic networks', Journal of Network and Computer Applications Volume 34, Issue 5, pp. 1660–1670.
- Abdul Hanan Abdullah, Qaisar Ayub, M. Soperi Mohd Zahid, Sulma Rashid(2014) 'Contact quality based forwarding strategy for delay tolerant network', Journal of Network and Computer Applications Volume 39, pp. 302–309.
- A. Spyropoulos et al., (2005) "Spray and Wait: An Efficient Routing Scheme for Intermittently Connected Mobile Networks" ACM SIGCOMM Wksp. Delay Tolerant Networking (WDTN-05).

- Sulma Rashid, Qaisar Ayub, et al. E-DROP: An Effective Drop Buffer Management Policy for DTN Routing Protocols. International Journal of Computer Applications (0975 – 8887) Volume 13–No.7, January 2011 pp.8-13.
- Amin Vahdat and David Becker. (2000) "Epidemic Routing for partially connected ad hoc networks", Technical report CS- 200006, Duke University. <http://issg.cs.duke.edu/epidemic/>
- Lijun TANG, Yi CHAI ; Yun LI , Binbin WENG (2012) "Buffer Management Policies in Opportunistic Networks" Journal of Computational Information Systems Volume 8 Issue 12 pp.5149–5159
- J. Burgess, B. Gallagher, D.Jensen and B.N. Levine, (2007) "MaxProp: Routing for vehicle-Based Disruption-Tolerant Networks", in Proceedings of IEEE Infocom, pp 1-11.
- Spyropoulos T, Psounis K, Raghavendra CS.(2007) 'Spray and focus: efficient mobility-assisted routing for heterogeneous and correlated mobility' IEEE PerCom Workshop on Intermittently Connected Mobile Ad Hoc Networks, White Plains, NY, 2007; 79–85.
- Daru Pan, Zhaohua Ruan, Nian Zhou, Xiong Liu and Zhaohui Song (2013) "A comprehensive-integrated buffer management strategy for opportunistic networks" EURASIP Journal on Wireless Communications and Networking Vol.2013 Issue 103 pp.1-10 doi:10.1186/1687-1499-2013-103.
- Mohammad Rahmatullah Dr Priyanka Tripathi, "A New Approach of Enhanced Buffer Management Policy in Delay Tolerant Network (DTN)" International Journal of Computer Science and Information Technologies, Vol. 5 (4) , 2014, pp. 4966-4969.
- S. Grasic, E. Davies, A. Lindgren, and A. Doria, "The Evolution of a DTN Routing Protocol – PROPHETv2," ACM, 2011
- Shin K, Kim S. Enhanced buffer management policy that utilises message properties for delay-tolerant networks. IET Communations 2011; 5(6):753–759.
- Matzakos, P., Spyropoulos, T., & Bonnet, C. (2018). Joint scheduling and buffer management policies for dtn applications of different traffic classes. *IEEE transactions on Mobile Computing*, 17(12), 2818-2834.
- Zhang X, Neglia G, Kurose J, Towsley D. Performance modelling of epidemic routing. *Computer Networks* 2007;51(10):2867–2891.
- Ren Z, Peng S, Che H, Fang J, Chen Q. Epidemic routing based on adaptive compression of vectors: efficient low delay routing for opportunistic networks based on adaptive compression of vectors. International Journal of Communication Systems 2013. DOI: 10.1002/dac.2688.
- Lindgren A, Phanse KS. Evaluation of queuing policies and forwarding strategies for routing in intermittently connected networks. IEEE COMSWARE, New Delhi, 2006; 1–10.
- Soares VNGJ, Farahmand F, Rodrigues JJPC. Performance analysis of scheduling and dropping policies in vehicular delay-tolerant networks. International Journal on Advances in Internet Technology 2010; 3(1 & 2):137–145.
- Suganthe, R. C., & Sreekanth, G. R. (2016). Emergency Health Information and Medical Services in Disaster Areas: A Delay Tolerant Network Approach. *Journal of Medical Imaging and Health Informatics*, 6(8), 1990-1996.
- Rashid S, Ayub Q, Soperi Mohd Zahid M, Hanan Abdullah A. Message drop control buffer management policy for DTN routing protocols. *Wireless Personal Communications* 2013; 653–669.
- Krifa A, Barakat C, Spyropoulos T. Message Drop and scheduling in DTNs: theory and practice. *IEEE Transactions On Mobile Computing* 2012; 11(9):1470–1483.
- Prodhana AT, Das R, Kabir H, Shoja GC. TTL based routing in opportunistic networks. *Journal of Network and Computer Applications* 2011; 4(5):1660–1670.
- P. Puri and M. P. Singh, "A Survey Paper on Routing in Delay-tolerant Networks," 2013 International Conference on Information Systems and Computer Networks (ISCON), IEEE 2013 9-10 March 2013 pp.215-220.
- Ababou, M., Kouch, R. E., & Bellafkih, M. (2019). Dynamic utility-based buffer management strategy for delay-tolerant networks. *International Journal of Ad Hoc and Ubiquitous Computing*, 30(2), 114-126.