Evolution of Routing Techniques, Routing Protocols and Routing Efficiencies for Delay Tolerant Network

Hemal Shah[1]
Ganpat University
(North Gujarat) India

Yogeshwar P. Kosta
Charotar University of Science & Technology
(Gujarat) India

ABSTRACT

The basic philosophy behind Routing in delay tolerant networks (DTNs) is to design routing protocol that maximizes the overall routing efficiency in a network independent of the underlying Transmission and Switching technology & topology for adhoc environment, and the application environment as well. Most designers approach to solve the real world problem by creatively engineering, enabling higher delivery rates with least overhead and optimized resource consumption – *Green IT*. In this paper the authors study, investigate, pen, and summarize in some detail various routing techniques starting from its evolution and gradually building up newer approach to address complex problems. We discuss and present general aspects relating to role of mobility models, investigate and study routing under specific environment such as application and for adhoc network and finally, we also attempt to explore the possibility to generalize routing by designing algorithm that would work in a complex and dynamically changing environment;adhoc in particular. Summary of a few strategic models showcasing the attributes relating to forwarding and replication techniques is also tabled.

Categories and Subject Descriptors

[Adhoc Networks]: Delay tolerant network (DTN), Routing protocol for DTN

General Terms

Routing techniques, routing efficiencies, protocol

Keywords: forwarding, replication, single copy, multicopy, relay, delivery ratio, delay, throughput

1. INTRODUCTION

Mobile wireless communication technologies have evolved rapidly and to an unprecedented level. Mobility has penetrated every aspect of people's lives and wireless connectivity has covered even the abandoned remote corners of the society with civilization [ITU, 2007].The widespread availability followed by adoption of miniature wireless devices such as PDAs, cellular phones and to some extent laptops is an step towards making "ubiquitous access" a reality. Typically Multi-hop occurs while connecting the last mile, especially when remote or in a growing complex network of networks, with subnets etc. forming dynamically, emerging as an extreme case of multi-hop ad hoc networks, when each node starts to function not only as an end user but also as a router forwarding packets to and from other nodes to enable multi-hop communication. Under those circumstances, the function of the Delay tolerant networks (DTNs) is to go one step further and allow/permit messages to be passed – through creation of an adhoc channel even when the destination and/or intermediate nodes are not online at that point in time. For most data exchanges, this additional delay is acceptable and could even be an advantage as well. The reason for this is the fact that nodes are actually silent processors that not only help channel data packets ("Throw boxes [1] or "Data mule [2]" or relay nodes) to destination but can also provide higher bandwidth. Higher bandwidth attribute of the node will eventually contribute in reducing the number of hops.

Several proposals for efficient routing mechanisms have been devised [3,4,5,6,7] who claim superiority based upon experimental and software simulated data. In this paper, we aim to inspect what are the different techniques available [4,5] Techniques & strategies that recognize: who, whom, & when [8] for routing. We consider mobility models and design routing algorithm/s keeping mobility in mind.

Section 2 describes about DTN routing in general, Section 3 discusses various routing techniques, network environment and efficiency metrics, Section 4 presents summary of routing techniques & conclusion.

2. Routing in DTN

Routing has to find a good path to a designated endpoint, but concurrently to deal with a resource shortage. In an optimal case, all data can be delivered and the protocol finds the fastest and shortest path between the two involved nodes. In the real world or even in simulations restrictions occur, or are defined and therefore initiate the need for economical usage of resources. Depending on the application using the DTN, it can be useful to drop packets and free buffers quite early to give newly sent packets a good chance to be delivered in time while, on the other hand, it may be important to deliver as many packets as possible, no matter how long it lasts.

In the next few sections, we briefly discuss some currently used techniques for routing in DTNs followed by some analysis comparing the different techniques studied. We briefly discuss some currently used techniques for routing in DTNs followed by some analysis comparing the different techniques studied.

3. ROUTING TECHNIQUES

3.1 *Direct delivery*:

In this technique [9,10] the source waits until it comes into contact with the destination before forwarding the data. This technique uses minimal resources since each message is transmitted at most once.

[1]This work is carried out as partial fulfillment of Ph.D. research work at Ganpat University.

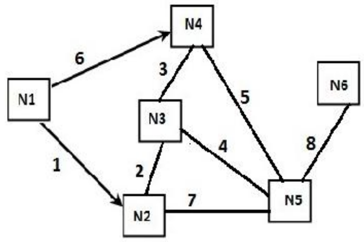

Figure: 1 Example scenario direct delivery and first contact

In figure: 1, node N1 can only deliver messages to nodes N2 and N4, as shown in Figure 4. Additionally, it is faster for node N1 to deliver a message to node N4 via the path N1-N2-N3-N4, which it cannot do.

General Specs	**Remarks**
Network Environment	MANET
Application	Info station Architecture
Algorithm[1]	[9,10]
Efficiency Parameters	
Hop Count	Single
Resource Consumption	Very less
Network Knowledge	Not Required
Delivery Ratio	Inversely proportional to no. of nodes

3.2 First contact:

In this technique [8], a message is forwarded along an edge chosen randomly among all the current contacts. If all edges are currently unavailable, the message waits for an edge to become available and is assigned to the first available contact.

In figure: 1, node N1 may handover messages to nodes N2 or N4 to deliver destination N5. Further, N4 may forward to N3 or N5 upon link availability as shown in figure 1.

General Specs	Remarks
Network Environment	Remote Village & City connectivity, non trivial network topology
Application	Scientific
Algorithm[1]	[8]
Efficiency Parameters	
Delivery Ratio	Poor
Hop Count	Many
Path Loop	Present, if frequent contacts between node pair
Network Knowledge	Local

3.3 *Message ferries [MF]*:

In this technique [12], MF, the network devices are classified as *message ferries* (or *ferries* for short) or *regular nodes* based on their roles in communication. Ferries are devices which take responsibility of carrying messages among other nodes, while regular nodes are devices without such responsibility. With knowledge about ferry routes, nodes can adapt their trajectories to meet the ferries as shown in figure: 2 and transmit or receive messages. By using ferries as relays, nodes can communicate with distant nodes that are out of range.

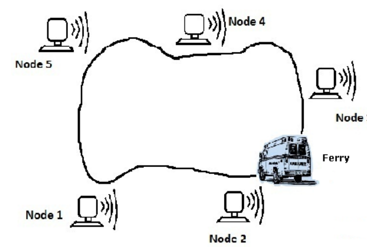

Figure: 2 Message ferries

General Specs	**Remarks**
Network Environment	Sparse mobile network
Application	Battlefield, Disaster, Wide area sensing, Surveillance , Metro-area messaging, Service-driven
Algorithm[1]	[12]
Efficiency Parameters	
Delivery Rate	Proportional to buffer size
Delay (sec)	Proportional to buffer size
Energy Efficiency	better energy efficiency, by 8 to 30 times than epidemic
Node mobility	Impacts greatly on delivery rate

3.4 Throw boxes:

In this technique [1], small and inexpensive devices equipped with wireless interfaces and storage are used. Throw boxes are stationary, thus when two nodes pass by the same location at different times, the throw box acts as a relay, creating a contact opportunity where none existed before. Figure: 3(a) shows an example of using throw boxes in a mobile DTN. In figure: 3 - Node *S* sends data to a throw box. At a later time when node *R* moves close to the throw box, it receives *S*'s data from the throw box, shown in Figure: 3(b).

Throw boxes are most useful for routing algorithms that use multi-path routing and when nodes follow structured mobility patterns. Throw box deployment that incorporates knowledge about contact opportunities perform better than deployment that ignores this knowledge.

[1] Refer original paper for detailed algorithm

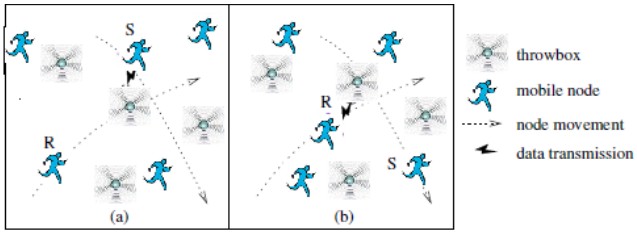

Figure: 3(a) & 3(b) Throw boxes

General Specs	Remarks
Network Environment	Diesel Net Test bed
Application	Vehicular Networks
Algorithm[1]	[1]
Efficiency Parameters	
Throughput	High for regular path
Total Contact duration(sec)	Increase by factor of 20
Average Capacity(Kbps)	Increase by factor of 19
Delay Improvement	High for regular path with high traffic

3.5 Forwarding approach:

In this technique, single copy of the message packet is routed and transmitted during the communication process. The message packet is forwarded by routing towards a reliable relay node, avoiding duplication of message packets. As shown in figure 4. The representative protocols using single copy are Mobyspace [13] and Seek and Focus [4].

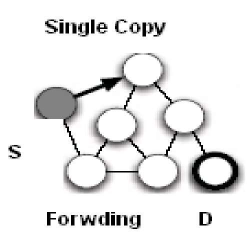

Figure: 4 Forwarding approach

3.6 Seek and Focus:

This technique [4], adopts utility-based/application based as well as randomized routing. By this, they can overcome the slow-start phase and routing jamming by local maximization of utility. The initial step involves discovery of a potential relay neighbor by using the utility-based approach. This helps to avoid being struck for a long time at local maximum of utility, randomized routing is applied in the re-seek phase.

General Specs	Remarks
Network Environment	50 x 50 grid with 40 nodes, transmission range 2-7 meters
Application	General routing protocol for DTN
Algorithm[1]	[4]
Efficiency Parameters	
Expected Delay	Function of Transmission range
Efficiency	Function of Transmission range

3.7 MobySpace:

This technique [13] utilizes a generic routing scheme, using high-dimensional Euclidean space. The main routing idea is that the packet should be forwarded to the node having mobility pattern similar/matching to packet's destination. Since in the MobySpace, the mobility pattern of a node provides its coordinates, its MobyPoint, routing is done by forwarding bundles toward nodes that have their MobyPoint closer and closer to the MobyPoint of the destination.

General Specs	Remarks
Network Environment	Virtual contact space & mobility pattern with power law distribution. Source with full knowledge and partial knowledge of destination mobility pattern
Application	Generic DTN Routing
Algorithm[1]	[13]
Efficiency Parameters	
Average Bundle Delay	Lower
Average Route Length	Lower

3.8 *Epidemic Routing*:

In this technique [6], when a message is sent, it is placed in the local buffer and tagged with a unique ID. When two nodes connect, they send each other the list of all the messages IDs they have in their buffers, called the summary vector. Using the summary vector, the nodes exchange the messages they do not have. When this operation completes, the nodes have the same messages in their buffers. This provides a large amount of redundancy since all nodes receive every message, making this strategy extremely robust to node and network failures. Additionally, since it tries every path, it delivers each message in the minimum amount of time if there are sufficient resources.

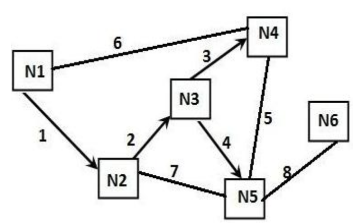

Figure: 5 Example scenarios for epidemic

In the example above, the message will be delivered from N1 to N5 via the fastest path (N1-N2-N3-N5), as shown in figure: 5. All nodes will receive the message except node N6 because node N5 does not replicate messages that are destined for it.

General Specs	Remarks
Network Environment	Adhoc Network
Application	Mobile sensor network, Smart Dust, Military deployment
Algorithm[1]	[6]
Efficiency Parameters	
Delivery Rate	Function of Transmission range & Buffer size
Hop Count	Average 3
Latency	Inversely proportional to Transmission range
Buffer Utilization	Function of Buffer size

*3.9 **PROPHET** (Probabilistic Routing Protocol using a History of Encounters and Transitivity)***:

In this technique [3], when a message arrives at a node which does not have an available contact with other node, it must be stored in the buffer until the node encounters with another node. It only admits that a node can receive the message when its delivery probability exceeds the threshold.

General Specs	Remarks
Network Environment	Partitioned network
Application	Generic Routing for DTN
Algorithm[1]	[3]
Efficiency Parameters	
Message Delivery	Function of buffer size
Message Delivery delay	Larger queue size shorter delay
Message Exchanges	Less compared to Epidemic. Only sends to selected node.

3.10 Spray and Wait:

In this technique [14], in spray phase, spread L message copies to L distinct relays and in wait phase; wait until one of the L relay finds the destination(i.e. direct transmission). It significantly reduces the transmission overhead of flooding-based scheme. The minimum number of copies needed for Spray and Wait to achieve an expected delay is independent of network size and transmission range and depends on number of nodes.

General Specs	Remarks
Network Environment	Intermittently connected mobile networks
Application	Generic routing scheme
Algorithm[1]	[14]
Efficiency Parameters	
Effect of traffic load	Performs less transmission, faster
Delivery Ratio	Above 90 %
Effect of Connectivity	Delay decreases as connectivity increases

3.11 *Spray and Focus*:

This technique [15] aims at improving the protocol of Spray and Wait for mobile users with localized mobility. The difference between them is that the message carrier in Spray and Focus will forward the copy to another suitable neighbor if they have not encountered the destination for a long time.

General Specs	Remarks
Network Environment	Intermittently connected mobile networks
Application	Generic routing scheme
Algorithm[1]	[15]
Efficiency Parameters	
No. of transmission	Function of transmission range
Average delay	

3.12 Simple replication:

In this technique [11], identical copies of the message are sent over the first r contacts, with r known as the replication factor. Only the source of the message is permitted to transmit/sends multiple copies, while the relay nodes are allowed to send /forward only to the destination; they cannot forward it to another relay. This makes a mixture between direct delivery and flooding.

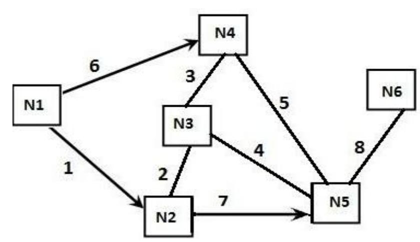

Figure: 6 Example scenarios for simple replication

If node N1 has a message for node N5, it would send copies to both nodes N2 and N4, as shown in Figure. When node N2 connects with node N3, it would not send it the message, since node N3 is not the destination. Finally, the message would be delivered at time 7 when node N2 connects with node N5. At the end, nodes N1, N2, N4 and N5 have all received the message. Node N1 can reach all other nodes via two-hop relay except node N6, since it is a minimum of three hops away.

General Specs	Remarks
Network Environment	Zebra net using GPS collars
Application	Wildlife monitoring
Algorithm[1]	[11]
Efficiency Parameters	
Data success rate	Lower
Data latency	Lower the replication factor higher delay
Routing overhead	Constant

3.13 *History based simple replication*:

In this technique [11,16], the source creates "*r*" identical copies of a message, which are then delivered to the "best" *r* nodes, where quality is determined by history. The intermediate nodes will then individually carry out Direct Delivery.

General Specs	Remarks
Network Environment	Zebra net using GPS collars
Application	Wildlife monitoring
Algorithm[1]	[11,16]
Efficiency Parameters	
Data success rate	Lower
Data latency	Lower the replication factor higher delay
Routing overhead	Constant

3.14 Erasure Coding:

In this technique [17], first encode the message at the source and generate a large number of code blocks. The generated code blocks are then equally split among the first *kr* relays, for some constant *k*, r is replication factor. The message can be decoded at the destination if 1/*r* of the generated code blocks is received. Since code blocks are divided equally among *kr* relays, the message can be decoded as soon as any *k* relays deliver their data if we assume that no code blocks are lost during transmissions to and from a relay.

General Specs	Remarks
Network Environment	Zebra net using GPS collars
Application	Generic routing scheme
Algorithm[1]	[17]
Efficiency Parameters	
Data success rate	Function of deadlines (days)
Data latency	Lowest
Routing overhead	Lower

3.15 EBEC (Estimation-based erasure coding):

In this technique [18]**,** message is divided into K blocks. For each message, the source takes a replication factor R and erasure codes R x K equal sized blocks. When two nodes encounter, these message blocks are re-dispatched between them according to their estimation values. The message can be fully decoded at the destination if at least K generated blocks is received. Note that since each message block is 1/K of the size of the original message, it generates the same overhead as simply replicating R copies of the message.

General Specs	Remarks
Network Environment	Intermittently connected mobile networks
Application	Generic routing scheme
Algorithm[1]	[18]
Efficiency Parameters	
Contact Frequency	Proportional to number of simulation rounds
Message delivery delay	Lower , dependent on R and K
Effect of Connectivity	Delay decreases as connectivity increases

3.16 Island Hopping:

In this technique [19], routing protocol relies on the clusters in network. Through the analysis of mobility trace, the authors introduce a novel model with stable Concentration Points (CP) in which the nodes are assumed to communicate only in same CP. The routing algorithm first discovers the whole graph collaboratively in order to employ a sequence of CPs to forward message. The discovery of such a graph consists of two steps: vertex labeling, which can identify each CP that needs to be stitched and edge discovery that can estimate the edge, sets of possible CP graph. After each node knows the graph and respective position – trace or connecting-the-dot, an approach called *Last Encounter Table* is used to estimate the position of destination. Then the next CP is decided by taking advantage of the shortest path between the source and destination. During the message forwarding, message copies at each CP followed by one-hop acknowledgment scheme makes sure the reliability of transmission. At the same time, the suppression mechanism works when an earlier copy appears in the same CP. The foundation of this algorithm is based upon a stable topology of concentration points (CP's). In an unstable topology, or where group movement of nodes is involved, the performance of such algorithm suffers.

General Specs	Remarks
Network Environment	Environment Monitoring, Self organized pocket switched network. Needs stable topology of CP and heterogeneous partitioned network
Application	Routing in regions where mobile

	nodes have a much higher chance of encountering other nodes than elsewhere
Algorithm[1]	[19]
Efficiency Parameters	
Delivery Rate	Low
Delay	1.5 times higher
Number of transmission per message	Significantly lesser

3.17 *Mobile vehicle routing*:

In this technique [20], the routing decision is based on finding a peer having maximum probability of visiting the region of the destination. Both the source and the selected node try to perform Direct Delivery to the destination, this act results in slightly higher resource consumption than Direct Delivery alone.

General Specs	**Remarks**
Network Environment	Vehicular area network
Application	Generic routing
Algorithm[1]	[20]
Efficiency Parameters	
Message delivery rate	Above Average
Message Latency	Refer [14]
Duplication of delivered message	
Peer Latency	

3.18 Maxprop:

This technique [7], attempts to forward the message to any device in the network having maximum probability of delivering the message to destination. Maxprop process involves calculating the path for each message at each transfer opportunity using a modified Dijkstra algorithm with history as pivotal criterion. Maxprop defines its own way of computing history to dictate the channel path computation. Further it assumes that the network topology on which it is operating does not consume bandwidth. It also incorporates a fancy mechanism of message queuing at peer level that prefers the newly born messages and degrades the priority of messages based on the number of hops they have traveled and the delivery probability [13]. Even without the computational complexity of erasure coding, Maxprop is hungry for processing resources as the maintenance of the local queue is expensive for mobile devices under high message counts.

General Specs	Remarks
Network Environment	Vehicular area disruption tolerant network
Application	Business
Algorithm[1]	[7]
Efficiency Parameters	
Delivery rate	Function of transmission range
Delivery delay	Inversely proportional to transmission range

3.19 Earliest Delivery:

In this technique [8], path of a message is computed using modified Dijkstra algorithm, where the link costs represent the waiting time for the next contact between the vertices. It assumes a contact oracle, which has perfect foresight of future node encounters, equivalent to knowing the time-varying DTN multi-graph. This algorithm is bound to perform better than all of the others because it has the unrealistic knowledge of the future, BUT NOT NECESSARILY TRUE. A message may still fail to reach the destination due to complete lack of a path to destination or congestion

4. SUMARRY & CONCLUSION

This paper is a collective study of 18 different routing techniques; leading to identification of critical & explicit parameters of each of the technique studied and described in some detail and the same consolidated in table immediately below. This is followed by an executive summary of the various routing techniques/schemes studied along with parameter details like mobility models, application environment and protocols captured and showcased under table: 1.

Mobility model based on simulation depicts the movement patterns of mobile nodes; data utilized for the purpose of software based simulation and analysis have been used by other researchers earlier and fairly predicts & approximate the real situations existing while evaluating the model functions - protocol. Moreover, parameter-item relating to application environment expresses the limitations of protocol mentioned by the author(s) in their reported and published paper/s. As detailed under table-1, several schemes can be applied to general mobile network, followed by some assumptions and approximations that steer towards a near optimal routing solution and a network topology; to be evolved.

5. ACKNOWLEDGMENTS

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Table: 1 Summary of Routing Techniques

Sr. No	Protocol	No. of Message Copies	Main Strategy	Mobility Model for simulation	Applicable environment
1	Direct delivery [9,10]	Single	Source waits until it comes into contact	Mobility not evolved.	Info station Architecture
2	First contact [8]	Single	Use any available contact. No oracle used.	Remote village , city bus network scenario	General delay tolerant network
3	Message Ferries [12]	Single	A set of particular nodes called message ferries take charge of forwarding	Message ferry follows the rectangle route and other nodes Adopt random waypoint, limited random waypoint and area-based model	Ferries move in proactive manner for communication

4	Throwboxes [1]	Single	Deploy static relay devices based on different level of information to enhance data transfer capacity	Random waypoint and UMass model [12]	Static nodes are needed for message exchange
5	Seek and Focus [4]	Single	Make use of randomized forwarding and utility based routing	Random Waypoint model and Community based Mobility	General mobile network
6	Mobyspace [13]	Single	Find the node with the similar mobility pattern as that of destination to forward	Power-law based mobility pattern	Assume the mobility pattern of destination is known
7	Epidemic [6]	Multiple	Flood message	Random waypoint model	General mobile network
8	PROPHET [3]	Multiple	Select the relay nodes by Predicting the delivery probability	Random Waypoint model and Community model [26]	General mobile network
9	Spray and Wait [14]	Multiple	Take advantage of limited number of nodes to flood message	Random waypoint model and Community based Mobility	prefers the network with sufficiently mobile nodes
10	Spray and Focus [15]	Multiple	Take advantage of limited number of nodes to flood message	Random waypoint model and Community based Mobility	prefers the network with localized nodes
11	Island Hopping [19]	Multiple	Rely on the cluster to forward message	Random walk with different exponentially distributed pause and move time	Rely on the presence of stable topology of clusters
12	Simple Replication [11]	Multiple	Source of the message is permitted to transmit/sends multiple copies, while the relay nodes are allowed to send /forward only to the destination	Real traced based mobility Zebra net	Wildlife monitoring
13	History based replication [11,16]	Multiple	Source creates "*r*" identical copies of a message, which are then delivered to the "best" *r* nodes, where quality is determined by history.	Real traces using Zebra net	Wildlife monitoring
14	Erasure coding [17]	Multiple	*kr* fragments totaling *r* times the message size are generated and sent to the first *kr* intermediate relays.	Real traces using Zebra net	Generic routing scheme
15	Estimation based erasure coding [18]	Multiple	Two communicating intermediate nodes exchange data until the number of fragments for a given destination is proportional to the nodes' probability of meeting the destination	Restrict random way point model	Generic routing scheme
16	MV Routing [20]	Multiple	Find peer having maximum probability of visiting the region of destination	Synthetic traces of peer movements in geographic area.	Vehicular area network
17	Maxprop [7]	Multiple	forward the message to any device in the network having maximum probability of delivering the message to destination	Map based mobility	Vehicular area network