Routing strategies in Delay Tolerant Networks: a Survey

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ABSTRACT
Delay Tolerant Network (DTN) is a wireless network that experience frequent and long duration partitions during transmission of data. The fully connected path from source to destination is unlikely to exist. And due to the existence of contemporaneous connectivity between nodes, network topology may change dynamically and randomly. This leads to a problem of how to route a packet from one node to another in DTN. Most of the nodes in DTN are mobile, so that the connectivity is established when they come into the transmission range of each other. The design of a routing protocol for this type of network is an important issue. This work, surveys various routing strategies in Delay Tolerant Networks..

General Terms
Scalability, Resource consumption, Hop count, Delivery ratio.

Keywords
Delay Tolerant Networks (DTN), opportunistic communication, Mobility, flooding.

1. INTRODUCTION
Delay Tolerant Networks (DTN) have the unique feature of intermittent connectivity[15], which provides opportunistic communication [1] and makes routing different from other wireless networks. In standard network, nodes are connected most of the time. But in case of DTN, the connectivity is not constantly maintained but it is still desirable to allow communication between nodes. Hence traditional routing protocols are unable to deliver packets between the hosts. They require end-to-end connectivity between nodes. The node mobility is other cause for lack of end-to-end connectivity. It introduces the problem of lack of knowledge about current position of node, if mobility pattern is unknown.

Delay tolerant networks have a variety of applications in situations such as crisis environments and deep-space communication. In this paper, we study the issues of routing in DTNs. Multicast [22] supports the distribution of data to a group of users, when a service is needed for many potential DTN applications. Due to the unique characteristic of frequent partitioning in DTNs, routing in DTN is a considerably different and challenging problem. In this paper, we study about several routing algorithms with different routing strategies.

Delay in DTN may differ depending upon the location of nodes. There are mainly four types of delays. a) Processing delay- time taken by the routers to process the packet header. b) Queuing delay-time the packet spends in routing queues. c) Transmission time- time it takes to push the packets bits onto the link. d) Propagation delay-time for a signal to reach its destination. DTN lacks instantaneous end-to-end path. Due to this, AODV and DSR protocols may fail to establish route. These protocols first establish a route and after route has been established, forward the actual data to destination. When these instantaneous end –to-end paths are difficult to establish routing protocols, the store-carry-forward scheme is used.

Our objective is to understand that a different routing strategy in DTN is affected by the availability of knowledge about network topology. In addition, accurate topology information is generally more important in routing than up-to-date membership information. We also find that routing algorithms that forward data along multiple paths achieve better delivery ratios.

There are many examples of this network in real life. Many rural connectivity projects involve attempt to provide conventional internet access to remote areas. For example, Wizzy Digital courier service in south Africa provides asynchronous Internet access to schools in remote villages.

2. KEY PROPERTIES OF DTN
There are some key properties of DTN which makes a great deal of divergence from conventional networks. They are briefly described in this section.

2.1 Contemporaneous connectivity [16]
Due to the mobility of wireless communication devices, the DTN networks can be partitioned. In most cases DTN lacks end-to-end connectivity between the source and destination. Hence disconnectivity may occur more frequently than connectivity among nodes. It is due to the network partition and unexpected error occurring during transmission time period.

2.2 Opportunistic communication [17]
Network nodes need to communicate using opportunistic contacts in which sender and receiver make contact at scheduled time. For example moving people, vehicles, aircraft or satellites may make contact and exchange information when they happen to be within line-of-sight and close enough to communicate using their available power.

2.3 Limited longetivity
DTN is sparse mobile network in which nodes can be deployed over hostile environment. Here contemporary source destination path may not exist between a pair of source-destination nodes. Delay may occur because of the limits of wireless radio range, sparsity of mobile nodes, energy resources, attack and noise.

2.4 Large delay
The delay of network specifies how long it takes for a bit of data to travel across the network from source node to destination node. In DTN it may slightly depend on location of the specific pair of communication nodes. It is calculated that queuing delay is extremely large which may take hours or days.

2.5 Low Data rate
The transmission rate may be low due to disconnectivity and long latency of data delivery. If two nodes never meet each other for long time, then data rate will be considerably reduced.

2.6 Disparate Architecture of networks [18]
DTN is an approach to computer network architecture that seeks to address the technical issues in heterogeneous networks that may lack continuous network connectivity. The network topologies of DTN's are flat adhoc and Tiered adhoc. In flat adhoc, nodes dynamically discover other nodes to which they can interconnect and form network that continually changes connections. In

Tiered adhoc, nodes dynamically organize themselves into hierarchical tiers which can move data between subnets.

2.7 Delivery rate
The technique in DTN which make use of same contact pattern among nodes provide high delivery rate. In order to provide maximum success rate, the message is replicated in a hope that at least one will reach destination. There is no guarantee on delivery of message. The delay will be extremely high so that applications that support delay can be supported.

3. ROUTING PROBLEMS IN DTN
Routing protocols developed for DTN are based on the probability that among multiple copies of messages one of them will reach destination. A distance function is used to measure the cost of delivering messages from one place to another. It requires only little information about the network to route the messages and routing is the main challenge in DTN. Some restrictions are taken into considerations.

3.1 Resource allocation [10]
The main goal of conventional routing protocol is to maximize message delivery and minimize resource consumption. In order to maximize message delivery replicate copies of messages to all nodes in the network. Since DTN have no guarantee that message will reach destination, each intermediate node have to store messages in all hosts. This leads to more resource utilization.

3.2 Buffer space
The intermediate nodes have to store all messages in the available buffer space. If there are more pending messages (which are not being delivered to destination), it will lead to more buffer usage. Since disconnection may occur frequently, DTN networks need to store all messages until it reaches destination.

3.3 Limited power
Routing in DTN leads to more utilization of energy resources due to sending, receiving, and storing as well as for computation processes. Hence energy efficient routing protocol should be employed. Mobility and disconnectivity among nodes will consume more energy than conventional routing technique.

3.4 Contacts available [27]
Network nodes try to communicate when opportunistic contacts are available. Since DTN suffers from disconnectivity problem, the sender and receiver make contact at unscheduled time.

3.5 Security of DTN [19]
Security is an important issue in traditional network as well as DTN [25]. Messages are traversed among arbitrary path of hosts in network, so that users must require certain guarantee about authenticity of messages. Here various cryptographic techniques are employed to ensure secure end-to-end routing.

4. DIFFERENT TYPES OF ROUTING TOPOLOGIES
Routing means finding a good path to designated endpoint, i.e., which is the fastest and shortest path between the involved nodes. The efficiency of routing algorithm is defined as the ratio between the total amount of delivered messages and the total amount of traffic generated. A key issue in routing is stability of routes. It is the measure of how long the currently known routes exist. In DTN stability depend on the rate of topological changes. There are different routing types:

4.1 Unicast routing
Source will send single copy of messages to intended receiver. Source node is in charge of transmitting and determines the path based on the topology of network.

4.2 Broadcast routing
Messages are flooded throughout the network in order to reach every node. Here every node becomes carrier and messages can be delivered with high probability.

4.3 Location based routing [20]
A distance function is used to measure the cost of delivering messages from one place to another. It requires only little information about the network to route the messages. But there is no guarantee about the delivery of messages, even if the distances between the nodes are small and node coordinate values change sequentially.

4.4 Tree based routing [21]
The messages are flooded along a tree structure that is rooted at the source and reaches all receivers. Messages are replicated only at nodes that have more than one outgoing path.

4.5 Group based routing [12]
There are some set of nodes responsible for forwarding messages. Messages are flooded within group in order to ensure maximum delivery of messages.

4.6 Hierarchical routing [14]
It offers hop-by-hop routing which is scalable for localized traffic patterns. But it does not need any location information.

5. ANALYSIS OF DIFFERENT ROUTING STRATEGIES
The intermittent connectivity of DTN makes it difficult to ensure end-to-end delivery o f data and longetivity of delays makes it impossible to provide acknowledgements and retransmissions. The main objectives of routing, is to maximize the probability of delivering messages. The efficiency of routing algorithm is defined as the ratio between the total amount of delivered messages and the total amount of traffic generated. A key issue in routing is stability of routes.

There are two strategies for routing in delay tolerant networks: forwarding and replication. It is based on flooding [24] and knowledge [26] based schemes. Forwarding implies message is forwarded to final destination in store-carry-forward scheme without duplication. The delivery rate is quite low in this scheme but network overhead is limited. In order to solve the problem of forwarding, replication has been introduced. In this case, a number of copies of messages are replicated in the network in order to increase network delivery ratio. But it leads to excessive overhead.

5.1 Forwarding approaches

In forwarding based routing algorithms, at least one copy of message is maintained in the network. Bubble Rap [2] is a routing strategy based on forwarding scheme in which nodes are organized into nodes. It is a socio-based forwarding based on centrality of each node and community it belongs. If the destination node and relay node belong to same community, it will transmit bundle which have highest centrality value within its community. Otherwise it will transmit to node which has highest centrality value independent of its community. The main drawback of this scheme is the calculation of centrality value for forwarding bundles from source to destination. In order to take decision, mobility characterization [3] approaches are adopted. Here the distance or location between one node and its neighboring node is represented by an axis. It was defined over virtual dimensional space called Moby space. By identifying Moby point of destination and neighboring nodes, the bundles are forwarded towards its virtual coordinates. If the nodes have no high degree of separation in their mobility patterns, then Moby space do not provide efficient routing. A group of nodes with same mobility pattern forms a cluster [4]. It can exchange and share resources for overhead reduction and load balancing. An exponentially weighted movement average (EWMA) scheme is used for on-line updating nodal contact probability. A set of functions including sync (), Leave () and join () are used to form clusters and gateways are selected to exchange information and perform routing. Due to possible errors and unpredictable errors of contact probabilities among mobile nodes, many small size (fractional) clusters are formed. In DTN, nodes have additional freedom due to contact pattern usage. So that only certain nodes will take part in communication. Therefore incentive aware routing [5] is discussed. It was based on TFT (tit-for-tat) mechanism for selfish nodes to optimize their own performance without degrading system performance. Every node periodically exchanges link state and each source computes the forwarding paths based on link state. After receiving data destination will send acknowledgement to source node which will update its TFT constraints for next interval. A social selfishness aware routing [6] is used to provide services and allocate resources based on social relationship among nodes. The table I below describes the strategies in detail.

5.2 Replication approaches

There are numerous strategies for replication based schemes. Replication leads to scalability issues and excessive overhead. Epidemic routing [7] tries to limit number of replicas in the way similar to disease propagation. It involves random pair wise exchange of messages among mobile hosts to ensure eventual message delivery. PROPHET [8] is a routing protocol which can deliver more messages than epidemic routing with limited overhead. It stores history of encounters and node movements to predict the probability that packet will reach destination. MaxProp [9] is another protocol for effective routing in DTN. MaxProp is based on schedule of packets transmitted to neighboring nodes and packets that are dropped. The priorities are based on probability of path to peers according to previous data and other complementary mechanism such as acknowledgements, a head-start for new packets and list of previous intermediaries. The main difficulty in this protocol is the high processing cost in large scale networks. Efficient adaptive routing [10] protocol dynamically allocates bandwidth between multi hop forwarding and mobility assisted routing protocol to improve bandwidth utility. Since multi-hop forwarding is used, it offers flexible delivery of messages among disconnected network components. The possibility of improving the routing performance of this protocol is based on resource utilization.

RAPID, [11] an intentional DTN routing protocol can measure the fraction of packets delivered to destination with in a deadline. It is a simple approach which can optimize three different routing metric: average delay, worst- case delay and number of packets delivered before deadline. Packets are delivered through opportunistic replication, until a single copy reaches the destination. RAPID replicates only when bandwidth is available. It makes use of as much bandwidth available at the start of transfer opportunity for exchanging metadata. Spray and wait [12] is a flooding based routing scheme which circulates replicas in order to reduce overhead and congestion. It outperforms all existing schemes in average message delivery delay and number of transmissions per message delivered. It consists of two phases: spray phase and wait phase. The main difficulty in this scheme relies that as number of nodes increases, the percentage of nodes in spray and wait to achieve same performance level will decrease. A cyclic Moby Space [13] is a Euclidean space where nodes can be either mobile or static. They can communicate within the range of others. Here an additional delivery probability metric, expected minimum delay (EMD) is introduced which is repetitive but non – deterministic mobility. Markov chain process is used to deliver the EMDs of messages at particular point of time. It leads to more overhead. Scable routing [14] offers hop- by-hop routing which is scalable for localized traffic patterns. The table II below describes in detail.

Table 1.1 Comparison of different forwarding approaches

	BUFFER SIZE	HOP COUNT	LATENCY	DECISION BASED ON	RESOURCE CONSUMPTION
BUBBLERAP[2]	unlimited	Multi	High due to socio-grouping	Socio based forwarding	low
EVALUATING MOBILITY SPACE IN DTN[3]	unlimited	multi	low	Node mobility pattern	less
CLUSTERING[4]	limited	one	less	Grouping of nodes based on mobility pattern	less
INCENTIVE AWARE ROUTING[5]	limited	one	less	Agents who actively contribute are allowed to download files	less
SOCIALLYSELFISH ROUTING IN DTN[6]	limited	multi	Not mentioned	Depends on socio tie with that node	high

Table 1.2 Comparison of different forwarding Approaches

	SCALABILTY	PERFOR-MANCE	DELIVERY ACKNOWL-EDGEMENT	DELIVERY RATIO	DRAWBACK
BUBBLERAP[2]	Less	High	Not mentioned	Less	Need to calculate ranking in the system
EVALUATING MOBILITY SPACE IN DTN[3]	Depends on mobility space	High	Not mentioned	High[depe -nds on entrophy]	The additional bundles are difficult to route
CLUSTERING[4]	High	High	Not mentioned	High	Convergence and stability of nodes
INCENTIVE AWARE ROUTING[5]	High	High	Yes	High	Practical challenges involving in addressing tit for tat
SOCIALLY SELFISH ROUTING IN DTN[6]	High	High	Not mentioned	High	Security limited to one hop

Table 2.1 Comparison of different replication approaches

	BUFFER SIZE	HOP COUNT	LATENCY	DECISION BASED ON	RESOURCE CONSUMPT-ION
EPIDEMIC ROUTING[7]	limited	one	depends on buffer size	flooding	high
PROPHET[8]	depends on queue size	multi	decrease over wide range of communication	probability obtained from previous meeting	high
MAXPROP[9]	unlimited	one	less	Previous node meeting & updated source estimation	high
EFFICIENT ADAPTIVE ROUTING[10]	sufficient	multi	less	estimation based on hop count from source & contact duration	limited
RAPID[11]	limited	single	increase with resource usage	opportunistic replication until a copy reaches destination	high
SPRAY &WAIT[12]	sufficient	multi	depends on load	randomness	less
ROUTING IN CYCLIC MOBYSPACE[13]	sufficient	single or multi	less	depends on mobility and contact pattern of nodes	less

Table 2.2 Comparison of different replication approaches

	SCALABLITY	PERFORMANCE	DELIVERY ACKNOW-LEDGEMENT	DELIVERY RATIO	DRAWBACK
EPIDEMIC ROUTING[7]	limited	low	Not mentioned	high	High resource usage
PROPHET[8]	less	Increase with communication range	yes	high	High communicati on overhead
MAXPROP[9]	High	High	Yes	High	High processing cost in large scale networks
EFFICIENT ADAPTIVE ROUTING[10]	high	high	Not mentioned	Depends on bandwidth utility	Continue spreading after message delivery
RAPID[11]	Limited	High	yes	High	Performance degrades when metadata is restricted
SPRAY &WAIT[12]	High	Depends on node density	Not mentioned	High	Random decision making
ROUTING IN CYCLIC MOBYSPACE[13]	High	High	Not mentioned	High	Additional overhead due

6. CONCLUSION

Routing in DTN is a new area of research, which have the potential to interconnect wide range of regions that current network technologies cannot reach. The main common objective of DTN is trying to increase delivery ratio while decreasing the resource consumption and latency. This paper discovered a wide variety of schemes which are classified according to two strategies: forwarding and replication.The advantages and disadvantages of various routing protocols are discussed with their comparative tables. The survey enabled us to make following observations. Firstly, routing protocol must be more scalable across wide range of networks. The protocol must provide acceptable performance over a wide range of connectivity patterns .Secondly, in order to increase delivery ratio hybrid schemes can be introduced. The most important contribution that can be introduced in DTN is to build real networks and applications.

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