

Routing Policies & Strategies in Delay Tolerant Network

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Abstract-

Delay Tolerant Networks (DTNs) represent a class of wireless networks that experience frequent and long lasting partitions due to sparse distribution of nodes in the topology. A traditional network assumes the definite existence of a contemporaneous end-to-end path between a source and destination. But this assumption is unrealistic in many real life applications. Therefore, DTN comes into existence to deal with the networks that assumes partitions among the network. Numerous studies have tackled the challenging problem of routing in DTNs. Routing proposals include stochastic approaches such as random, spray-and-wait and epidemic routing, or deterministic approach such as history-based, model-based, coding - based and variations of these approaches. The number of routing schemes in the literature is increasing rapidly without a clear mapping of which is more suitable for any of the vast array of potential DTN application. This document surveys the main routing schemes in the DTN literature. It provides a detailed insight to the DTN approach and describes in some depth the policies and strategies proposed to manage buffers and queues in DTN nodes. Then, the predominant DTN real-life applications are presented and discussed. The aim of this document is to create a classification basis for the most prominent DTN applications and to map major DTN routing schemes to these categories according to some influential network attributes and characteristics that are related particularly to the type of application.

I. INTRODUCTION

Delay tolerant networking [1] has received considerable attention from the research Community in recent years. Advances in wireless and mobile technologies have enabled new networked systems where intermittent disconnections are not exceptional. Examples include sparse mobile ad hoc networks. The traditional Internet model assumes low error rates, low propagation delays and, most importantly, a steady end-to-end connection between any source/destination pair of nodes.

Delay tolerant networks (DTNs) represent a class of infrastructure-less wireless systems that support the functionality of networks experiencing frequent and long lasting partitions. DTNs are intended to deal

with scenarios involving heterogeneity of standards, intermittent connectivity between adjacent nodes. The key issue of routing for DTN is to find an opportunistic connectivity between the nodes and transmit data to the nodes when they meet with each other if possible [2] [3]. Some methods have been proposed to achieve opportunistic communication in such challenged networks, trying to achieve the higher delivery ratio with the shorter delivery delay. Each of them has its own pros and cons.

1.1 Issues in DTN

In Delay Tolerant Networks, the network may not be connected at any given point of time. The packets are delivered in a store – carry – forward

model. Each node along the path receives the packets from the previous node as it comes in contact with that particular node. After that this node stores the packet locally until it encounters next intermediate node. And when encounter occurs the packet is sent to next intermediate node. This procedure is followed until the destination is reached.

When two nodes come in contact with each other, they may exchange the packets and such an opportunity is known as encounter. In case of traditional networks, the network is connected at any given point of time. Therefore there are no partitions in such a network. But the traditional network fails to consider several real life applications like wildlife and habitat monitoring, deep space communication, underwater infrastructure etc. That's why the delay tolerant network comes into existence, to take into account the above applications [4] [5].

There are several issues in delay tolerant network that needs to be addressed. Some of them are described as per below:

1.1.1 Encounter Schedule

In order to send the data from source to destination, the node can wait till it encounters the destination node and after that directly deliver the packet to the destination. However, this approach may take a long time and may not even happen. But the encounter schedule is very crucial factor, because the delivery of messages depends upon the schedule of the encounter.

1.1.2 Network Capacity

Generally, the duration of an encounter as well as the bandwidth of the network, are the main factors that tells the amount of packets that can be transferred from one node to another node. But the capacity of underlying network is also a vital factor for determining the amount of data that can be delivered. If during an encounter multiple nodes tries to forward data, the network may become congested. Thus, this factor determines whether a

message needs to be fragmented or not in order to send it from source to the destination.

1.1.3 Energy

The transmission of packets as well as the computation carried out at nodes, consumes a significant amount of energy. In some cases, such as battery operated wireless sensor networks, the resources may be highly constrained where it is important to take into account the residual energy of a node while determining whether to exchange data during an encounter. So the energy is an important issue in delay tolerant networks that needs to be considered. However, in case of vehicular ad-hoc networks, the constraint on power may not be as severe as in case of delay tolerant network.

1.1.4 Storage Capacity

The storage capacity of nodes is limited. Whenever an encounter occurs, the nodes try to exchange all the data they currently carry with them. Therefore, if the nodes are storage constrained, the node buffers will overflow and it will result into packet loss.

Therefore, the approach of exchanging all the data during an encounter may not be applicable in all the applications. Certain intelligent schemes are needed that restrict the number of copies of the packets, as well as the schemes that delete the data that has already been delivered to the destination.

1.2 Architecture of DTN

The DTNRG has developed architecture for Delay-tolerant networking that has emerged from the efforts on Interplanetary Internet (IPI). There are many Bundle Protocol implementations, but the most famous protocol is DTN2, that is developed by Intel and at present it is maintained by Dublin Trinity College, and ION (Interplanetary Overlay Network) [6] [7]. The DTN architecture and its protocol stack are shown in Fig 1.

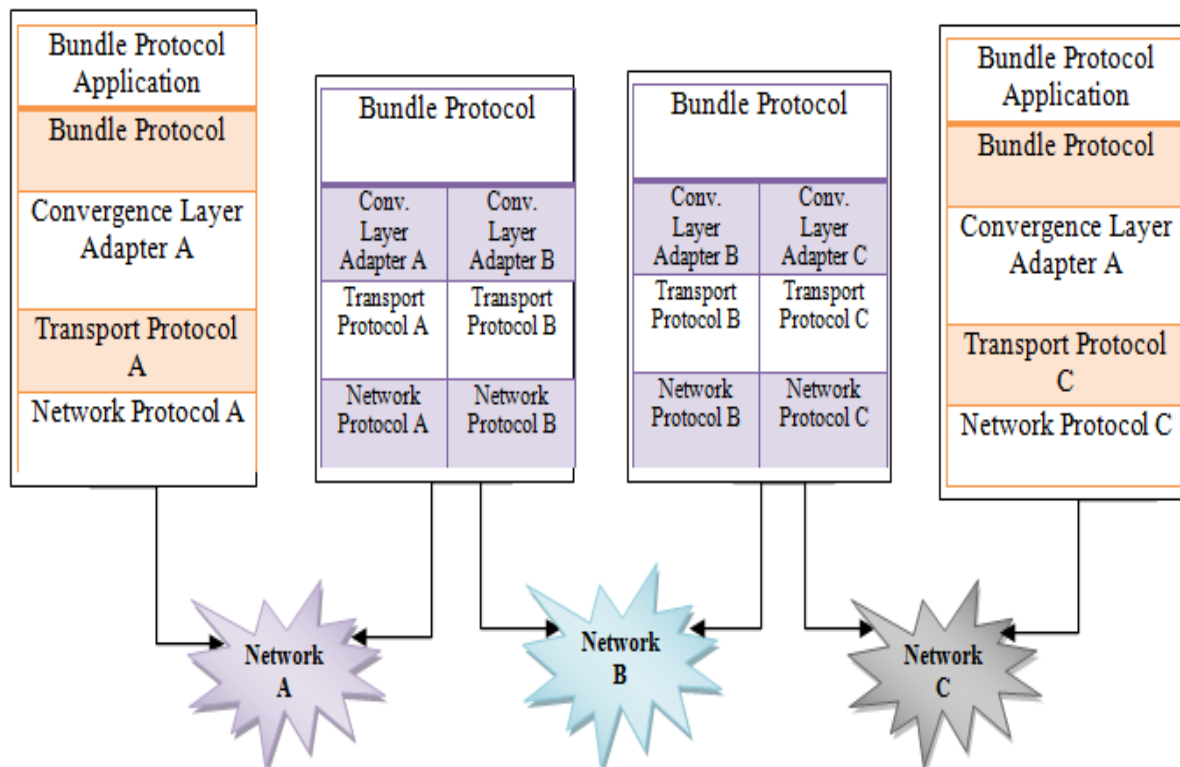


Fig 1: DTN architecture and protocol stack.

1.3 Characteristics of DTN

Delay Tolerant networks may be characterized by the combination of the following characteristics:

- **Intermittent Connectivity:** If there is no consistent end-to-end path between the source and destination - a phenomenon known as network partitioning, end-to-end communication using the TCP/IP protocols does not work. Other protocols are required.
- **Asymmetric data rates:** The Internet does support some forms of asymmetric bi-directional data, as in cable TV or asymmetric DSL access. But if asymmetries increase then they will hinder traditional interactive protocols such as TCP.
- **High error rates:** The delay tolerant networks have high error rates. Ambiguous mobility patterns: Unlike the case with public bus services that maintain fixed routes or planetary trajectories, future behavior of a node is not fully known for

many DTN applications. It is widely assumed, however, that node mobility patterns (while random) are generally recurrent.

- **Long or variable delay:** Long propagation delays between nodes, in addition to variable queuing delays at node buffers, all create end-to-end path delays that far exceed the threshold levels usually tolerated by Internet protocols and applications that rely on quick return of acknowledgements.

II. ROUTING STRATEGIES

Data is delivered in a DTN using a store-carry-forward model. The main categories of routing schemes for delay tolerant networks are given below:

2.1 Epidemic routing

The epidemic routing is one of the simplest and earliest routing schemes for DTN [8]. In this routing strategy, whenever two nodes come in

contact with each other, they exchange all the messages they currently carry at that point of time. In other words, the packets are spread like a viral epidemic. So this routing strategy is fastest possible routing scheme.

In [9], authors improved the basic epidemic scheme by introducing the adaptive dropping policies like Drop-Random (DRA), Drop-Least-Recently-Received (DLR), Drop-Oldest (DOA) and Drop-Least-Encountered (DLE).

In [10], authors proposed a set of strategies for controlled flooding in Delay Tolerant Networks. These schemes have a Time-To-Live (TTL) field to control message flooding. In epidemic routing, the data delivery results in inefficient use of the network resources such as power, bandwidth, and buffer at each node. Moreover, messages may continue to exist in the network even after they have been delivered to the destination.

2.2 Probability-based Routing

If network resources are unlimited, Epidemic Routing is likely to be good at message delivery. But in reality, the network resources like bandwidth, buffer space are constrained. Therefore, in order to leverage mobility and use scarce resources efficiently, the Probabilistic Routing Protocol using History of Encounters and Transitivity (PRoPHET) has been proposed [11] [12].

The sender forwards the message to the node having the highest probability of successful message delivery. This mechanism relies on the implicit assumption that all the nodes cooperate to message forwarding.

2.3 Spray and Wait Routing

A novel way to achieve efficient routing in DTNs is presented [13]. This protocol consists of two phases:

- a.) Spray phase (only once): L message copies are initially spread to L distinct "relays".
- b.) Wait phase: If the destination is not reached in the spray phase, the L nodes carrying a message copy perform direct transmission. The forwarding technique is a mix of always (Spray) and direct delivery (Wait). The replication is limited (the

bound is L) and the queue management is FIFO.

2.4 Location Based Routing

In some cases, the location of the nodes may be known, that can be used in case of opportunistic forwarding of messages in DTN. The location information of the nodes may be known in either a physical (for example, from GPS devices attached to nodes or through a location service) or a virtual coordinate space (designed to represent network topology taking obstacles into account) [4]. When an encounter occurs, the node forwards data to another node only if it is closer to the destination. Hence, location-based routing is a form of greedy, geographical-based routing.

2.5 Context-aware Adaptive Routing (CAR)

CAR routing scheme does not require any previous knowledge of the routes of the hosts like other approaches. This protocol is based on a single copy of message in the system, instead of multiple replicas. According to this routing scheme, if a host wants to send a message to another host, it uses Kalman Filter prediction and multi criteria decision theory [14].

III. QUEUING POLICIES AND FORWARDING STRATEGIES

Nodes may have to buffer messages for a long time and in case of congestion these needs to decide which messages to drop from its queue. The queuing policies are responsible for deciding which message should be dropped whenever there is overflow or congestion in the network. They also have to decide which messages to forward to another node that is encountered [15] [16].

3.1 Queuing Polices

The queuing polices defines which message should be dropped when the buffer is full. There are many queuing polices that has been proposed for selecting the most vulnerable message. Some of them are described below:

- a.) **FIFO -First in first out:** In this queuing policy, the message that was firstly entered into the queue is the first message to be dropped.

b.) **MOFO -Evict most forwarded first:** In this scheme, the message that has been forwarded the most number of times is the first to be dropped.

c.) **MOPR -Evict most favourably forwarded first:** In this, every node maintains a value FP (initialized to zero) for each message in its queue. Each time the message is forwarded, FP is updated according to the equation:

$$FP = FP_{old} + P \quad (2)$$

The message with the highest FP value is the first to be dropped.

d.) **SHLI -Evict shortest life time first:** In the DTN architecture, each message has a timeout value which specifies when it is no longer useful and should be deleted. If this policy is used, the message with the shortest remaining life time is the first to be dropped.

e.) **LEPR -Evict least probable first:** Since the node is least likely to deliver a message for which it has a low P-value, drop the message for which the node has the lowest P-value.

More than one queuing policies can be combined together to provide a more efficient queuing policy.

3.2 Forwarding Strategies

The forwarding strategies decide which message should be forwarded from the queue whenever an encounter occurs. Let A and B are the nodes that meet. Destination node is D and all other nodes are followed by node A. $P(x,y)$ is the delivery predictability that node x has for destination y. Now, the forwarding strategies are described as per below:

- a.) **GRTR** - Forward the message only if :
 $P(B,D) > P(A,D)$
- b.) **GRTRSort** - Select messages in descending order of the value of $P(B,D)$ and $P(A,D)$. Forward the message only if :
 $P(B, D) > P(A,D)$
- c.) **GRTRMax** - Select messages in descending order of $P(B,D)$. Forward the message only if :
 $P(B,D) > P(A,D)$.
- d.) **COIN** - Forward the message only if :

$$X > 0.5$$

- where $X \in U(0, 1)$ is a random variable.

IV. DTN APPLICATIONS

There are many real-life applications where wireless nodes, mobile or stationary, are forced to undergo extreme operational conditions and/or wait for extended intervals of time that exceed traditional IP forwarding times (that are usually measured in milliseconds) before being able to forward their data to next hops.

Some of these applications are listed below:

- **Wildlife Monitoring:** This application is concerned with gathering data about wild faunae species and their habitats. Monitoring is conducted by attaching a sensing device to each animal (i.e. mobile node). These devices may contain microcontrollers, global positioning systems (GPS), and orientation and temperature sensors.
- **Forestry and Underwater Sensors:** Using forestry and underwater sensors Measurements regarding temperature, air pressure, intensity of natural lighting, chemical contamination in the soil or the water, fire hazards, radiation levels and other measurements can be gathered.
- **Village Networks:** Village networks represent a very promising public application for DTNs, especially in secluded areas lacking communication infrastructure.
- **Inter-planetary Networks:** The massive distances separating terrestrial artificial objects and the need for these objects to exchange data among each other or with base-stations on earth –or perhaps other planets-represent an extreme case of DTN communication [17].
- **Military Applications:** In military, as in the case of wildlife monitoring, there is a need to monitor extended geographical planes their objects and inhabitants – i.e. soldiers-who would be equipped with wireless sensors in order to indicate their locations.

V. COMPARATIVE ANALYSIS

In this section different real life applications are mapped on different network characteristics. The Table 1 shows this mapping.

Table 1: Mapping DTN fields of application to network characteristics.

	Higher Node-Loss Ratio	Higher Level of Partitioning	Delay is Significant	Buffer Constraints	Energy Constraints
Wildlife Monitoring	✓	✓			✓
Underwater Sensing		✓		✓	✓
Inter-Planetary Networks		✓	✓	✓	
Village Networks		✓			
Military applications	✓	✓	✓	✓	✓

Now, the table showing the mapping of different routing protocols on different parameters is shown with the help of Table 2:

Table 2: Mapping routing schemes to network parameters [18].

	Delivery ratio	Routing delay	Vulnerability to Malicious nodes attack	Number of messages sent
Epidemic routing	High	High	High	Highest
PRoPHET	Medium	Medium	High	Medium
C.A.R.	Low	Low	Very low	Low

VI. CONCLUSION

In this paper, various routing protocols for delay tolerant networks, the queuing and forwarding strategies for DTN has been covered. Choosing the correct buffer management policy and forwarding strategy, and combining them to the suitable routing method, represent the best recipe for improving performance of DTN. And also various real life applications are mapped on major DTN routing schemes according to some influential network attributes and characteristics that are related particularly to the type of application.

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