Exploring and Exploiting Opportunistic Network Routing in a DTN Environment

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Abstract

A communications network that is capable of storing packets temporarily in intermediate nodes, until the time an end-to-end route is re-established or regenerated is known as a delay tolerant network/s, in short, DTN. This paper aims to detail basic & general aspects specific to information needs in DTN routing and present classification chart. We start with evolution of some relevant routing objectives and issues since their inception, discuss in some detail routing types, groups and classifications. Our study culminates in identification of various schemes and techniques that will provide an insight and help us to exploit the delay and effectively utilize the time in a judicious manner to help improve the efficiency of information exchange in a DTN network. The basic objective is to utilize efficiently this temporal-period or adhoc-period by opportunistically establishing connectivity - in a strategic manner, to exchange information across locally distributed resources, thus making optimal use of available network resources and enhancing the efficiency of information exchange.

Keywords: *DTN, Routing protocols, adhoc-period, opportunistic connectivity, efficiencies, routing classification*

1. Introduction

Delay Tolerant Networks (DTN), are characterized by the absence of continuous end-to-end connections, and the limited power constraints sources and data storage space [11]. This type of networks has found its applications in many challenging environments such as providing Internet services to remote areas [12], and to vehicles [13]. In addition, DTN have its promising applications in monitoring and tracking wildlife and whales in oceans [14], environmental monitoring such as lake water quality monitoring [15], and many others. The basic idea behind DTN network is that endpoints connectivity is not constant – for other obvious reasons as well. But, as a specific situation, in order to facilitate data transfer, DTN uses "*store-and-forward*" approach across routers that are more disruption-tolerant (delay) compared to TCP/IP, particularly in case of network-routing. However, DTN approach does not necessarily mean that all DTN routers on a network would require large storage capacity instantaneously or otherwise to maintain end-to-end data integrity.

Routing protocols developed for DTN adapt themselves to this challenging environment by probabilistically sending multiple copies of data packets so that one of them may reach the destination. Nodes receiving the packets store them until they meet other nodes or meet their destinations. Simple DTN routing protocols blindly send data packets to the nodes they meet without having a selection criterion. They range from the full network flooding to the limited flooding. This approach has its drawbacks, such as burdening the buffer and the inefficient use of the contact duration. Other routing protocols tend to restrict forwarding of data packets to selected nodes. Using some information collected about the network, they guide the packets to their destinations. This approach fails when the network topology is changing faster than the rate of information gathering.

Several proposals for efficient routing mechanisms have been devised [3,4,5,6,7], claiming superiority based upon experimental and software simulated data results. In this paper, we aim to broadly classify routing techniques into Uni-cast, Multi-Cast and Any-Cast, further, classification for each of this based on forwarding, replication, knowledge based, network coding base, intra-domain, interdomain etc. ,What are the different techniques available [4,5]. Techniques & strategies that recognize: who, whom, & when [8] for routing.

In Section-2, we address and discuss general aspects relating to DTN routing, outing objectives, & routing challenges, Section 3 discusses Routing classification, proactive routing Vs reactive routing, routing types, group & classification criteria. Section 4 presents conclusion and future work we arrive at.

2. Routing in DTN

Routing in a lay man terms, means, finding a good path to a designated endpoint - but concurrently to a network engineer, working in a real world situation, it means optimization of resources leading to efficiencies of network and information and economies of scale in terms of usage, the data can be delivered and the protocol finds the fastest and shortest path between the two involved nodes. Depending on the application using the DTN, it can be useful to drop packets and free buffers quite early paving way to newly sent packets, and a good chance to deliver in time, while, on the other hand, it may be important to deliver as many packets as possible, no matter how long it lasts.

2.1 Routing Challenges

Routing is with no doubt the most challenging issue within a DTN. Many restrictions have to be taken into account and traditional network routing protocols will not satisfy the expectations. Links become available without any previous knowledge and the destination node may never be reachable immediately with a contemporaneous end-to-end path. Nodes change their routes randomly or may follow a predictable path, buffer and bandwidth restrictions force the protocol to send its discovery and topology information as sparingly as possible and avoid resource consuming mechanisms.

The routing algorithm further needs to know

- When to send/forward a message,
- Where to send a message,
- Which message to send/forward,
- Which message to delete,
- If it follows a single- or multi-copy strategy,
- If it acts in a pro- or reactive manner

2.2 Routing Objectives

For any routing algorithm, a basic objective is to maximize the probability of delivering messages. In addition, we define the routing efficiency of an algorithm as the ratio between the total amount of delivered messages and the total amount of traffic generated in the network. This metric measures how efficient a routing algorithm is in utilizing resources.

In this paper, we study several classes of routing algorithms that are expected to achieve different balance of delivery ratio and routing efficiency. For each class of algorithms, we focus on minimizing the delay for each intended receiver.

2.2.1 Goals of Routing Protocols

A lot of Routing protocols [1,2,3] have been developed for this purpose they all vary in the way they accomplish the task, but they all have more or less common goals.

The main goals are [4,5]:

- **Low latency:** Latency is the time taken by the packet to reach its destination from its source.
- **Low latency jitter**: Latency jitter is the variation in latency, for real time applications such as streaming video, the requirement for low latency jitter is more important than the requirement of low latency.
- **High throughput**: Throughput can be defined as the number of data packets delivered per second. Throughput is affected by packets being dropped, and protocol data units that are used by protocols to set up communication with peers.
- **Low packet loss or High Reliability**: Packet loss causes decrease in throughput and increases latency.
- **Low convergence:** time in case of changes in network topology. It is necessary for routing algorithm to adapt to changes in network as quickly as possible, so that utilization of network resources is maximized.
- **Low routing overhead**: Routing overhead is caused by the update packets that are exchanged by routing protocols to convey network information to its peers. Routing overhead decreases throughput.

It is not possible for a routing protocol to achieve all the goals. As some of the above stated goals are conflicting in nature, for example to achieve Low convergence time in case of change in topology certainly requires high routing overhead which in turn reduces the throughput for end to end communication.

3. Routing Classification

3.1 Proactive Routing Vs. Reactive Routing

In proactive routing, routes are computed automatically and independently of traffic arrivals. Most Internet standard routing protocols and some ad-hoc protocols such as DSDV (Destination Sequenced Distance Vector) and OLSR (Optimized Link-State Routing) are examples of this style [6]. In a DTN, these protocols are capable of computing routes for a connected sub graph of the overall DTN topology graph. They fail when asked to provide paths to nodes, which are not currently reachable. Despite this drawback, proactive network-layer routing protocols may provide useful input to DTN routing algorithm by providing the set of currently reachable nodes from which DTN routing may select preferred next hops. In reactive routing, routes are discovered on-demand when traffic must be delivered to an unknown destination. Ad-hoc routing protocols such as AODV (Ad-hoc On-demand Distance Vector) and DSR (Dynamic Source Routing) are examples of this style [6]. In these systems, a route discovery protocol is employed to determine routes to destinations on demand, incurring additional delay. These protocols work best when communication patterns are relatively sparse. For a DTN, as with the proactive protocols, these protocols work only for finding routes in a connected sub graph of the overall DTN routing graph. However, they fail in a different way than the proactive protocols. In particular, they will simply fail to return a successful route (from a lack of response), whereas the proactive protocols can potentially fail more quickly (by determining that the requested destination is not presently reachable). In a DTN, routes may vary with time in predictable ways and can be pre-computed using knowledge about future topology dynamics. Employing a proactive approach would likely involve computing several sets of routes and indexing them by time. The associated resource requirements would be prohibitive unless the traffic demand is large and a large percentage of the possible network nodes exchange traffic. Reactive routing will fail to discover a complete path, while proactive protocols will fail to converge, resulting in a deluge of topology update messages.

A related issue is route stability, a measure of how long the currently known routes are valid. Route stability depends on the rate of topological change. With relatively stable routes one can employ route caching to avoid unnecessary routing protocol exchanges. With future knowledge about topology changes, caching could be especially effective in a DTN because it may be possible to know ahead of time exactly when to evict existing cached route entries.

3.2 Routing Types

- **Unicast Routing**: Source will send a copy of the message to intended receiver.
- **Broadcast Routing**: Messages will be flooded throughout the network in order to reach all nodes.
- **Tree-Based Routing**: Messages are forwarded along a tree in the DTN graph that is rooted at the Source and reaches all receivers. Messages are duplicated only at nodes that have more than one outgoing path.
- **Group-Based Routing [6]:** This is a set of nodes that are responsible for forwarding the message. Messages will be flooded within the forwarding group to increase the chance of delivery.

3.3 Routing Groups

- **Source Routing** is where the source specifies the path a packet should traverse to reach its destination. This requires each node in the network to have a precise knowledge of the network, which seems almost impossible to accomplish on the networks, which are dynamic in nature, and hence hampers the adaptability.
- **Destination Routing** is where each node knows in which direction to forward a packet for a given destination. Here the source node has no control over the path a packet traverses. The Internet works on this kind of routing. In dynamically changing networks source routing is not deployed and Destination Routing is the obvious choice.
- **Per-contact Routing:** The routing table is recomputed each time a contact is available, Instead of Computing the next hop for a message. It ensures that each routing decision is made with most recent information [5]. However to guarantee the loop freedom is a big problem.
- **Per-Hope Routing:** The intermediate node makes the forwarding decision when a message arrives at the node. The node determines the next hop for the destination and places it in a queue for that contact [7] .

3.3.1 Source Routing Versus Per-hop Routing: In source routing the complete path of a message is Determined at the source node, and encoded in some way in the message. The route is therefore determined once and does not change as the message traverses the network. In contrast, in per-hop routing the next-hop of a message is determined at each hop along its forwarding path. Per-hop routing allows a message to utilize local information about available contacts and queues at each hop, which is typically unavailable at the source. Thus, per-hop routing may lead to better performance. Unfortunately, due to its local nature, it may lead to loops when nodes have different topological views (e.g. due to incomplete or delayed routing information.

3.4 Classification Criteria

Routing protocol for DTN can be broadly classified into unicast, multicast and any cast. Further it bifurcation can be shown based on forwarding, replication, knowledge oracle, network coding based etc. Figure-1 shows DTN routing classification chart with example routing protocols for respective category. Figure-2 shows further classification and recent routing protocol for unicast routing with example protocols for each category.

- **Stateless: Most** propositions are based on a stateless routing algorithm, meaning in general no further (past or future) location or contact data is needed to make the forwarding decisions.
- **History-Based**: These algorithms use data of the past to find an efficient route to the destination node. Logged data can be a history of recent encounters with other contacts as well as for example contact-time, contact-frequency, and contact-time-location tuples. History-based algorithms usually need some time to warm up, but in return often are more adaptive to topology and mobility changes.
- **Movement-Based**: Some routing ideas are based on feeding the probability function to determine forwarding decisions with movement and velocity data. In simulations purely movement-based algorithms perform quite poor, but can add valuable infor-mation in combination with other approaches
- **Scheduling-Based:** Approaches based on scheduling are mainly of supportive nature and so far no routing algorithm is purely based on scheduling principles.
- **Beacons-less:** Most routing protocols require knowledge of a node's neighbors to make their routing decisions. This information is generally gathered by the use of beacons, messages broadcasted regularly that will be heard by all nodes within communication distance. Knowledge of your neighbors makes more informed routing decisions possible, but beacons have their drawbacks.
- **Topological:** Set of protocols that use information about the links (metrics such as next-hop bandwidth, etc) to perform packet forwarding. Proactive Algorithms (such as DSDV or OLSR) build the routing table obtaining information about the links, even when these links are not used. DSDV is a distance-vector protocol, while OLSR is a link-state protocol.
- **Position-Based:** Set of protocols that need the position (e.g. via GPS) of the participating nodes. In general, these algorithms look the position of the destination nodes using a Location Server and add this position in the packet header. Nodes that receive the packet apply a forwarding strategy to retransmit the packet. Each node stores a node ID, the direction and distance to the node, as well as an age time. Forwarding Strategies decide towards which node or area the packet forwarded. Greedy Packet Forwarding forwards the packet to a neighbor lying in the direction of the destination. Some examples [9] are:

Forwarding strategies:

- **Most forward** Within r (MFR) that forwards packets towards the node that makes more progress towards destination.
- **Nearest with forward progress** (NFP) that forwards packets towards the node that is nearest the source and closer to destination.
- **Compass routing** selects the neighbor closest to the straight line between sender and destination.
- **Random forwarding** chooses randomly one among the neighbors closer to the destination than the sender.

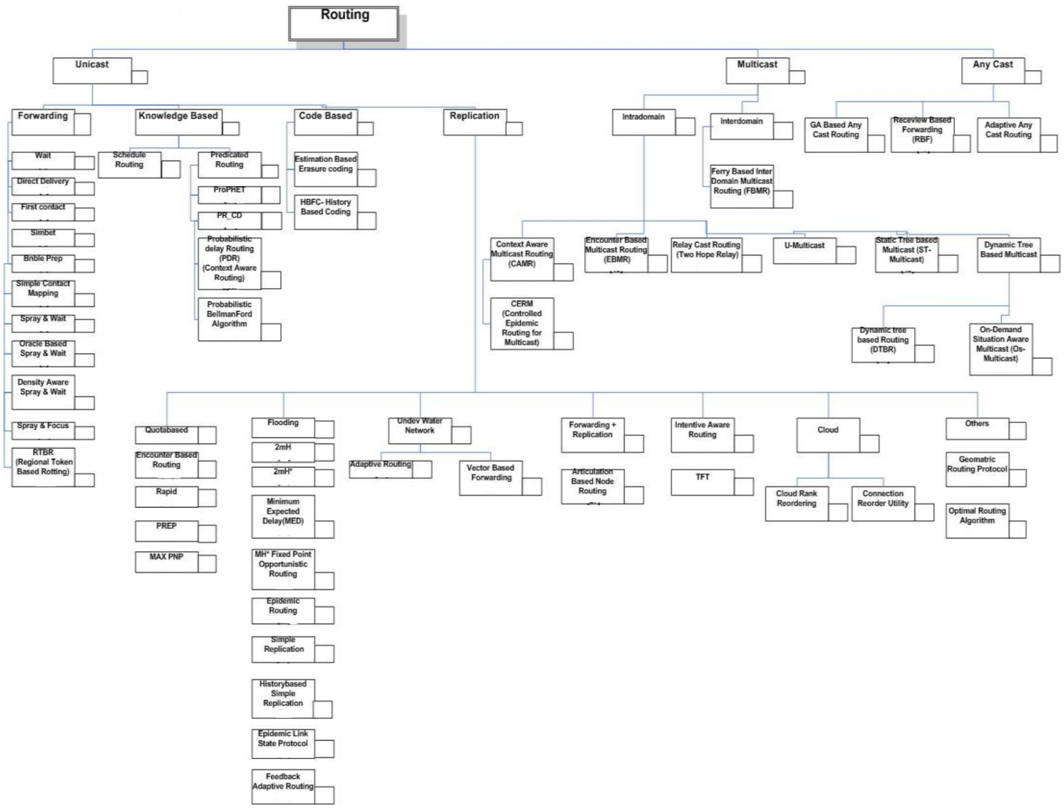

Figure: 1 DTN Routing Classification Chart

- **Opportunistic: New** routing techniques have to be devised to take into account sparse and intermittent networks in which nodes communicate either scheduled over time or randomly. Pelusi et al in paper [10] give a review of opportunistic techniques in ad hoc networks. In an opportunistic network, each node decides locally to which next hop the packet will be forwarded. This next-hop may decide to store the packet until a new opportunity to forward the packet appears.
- **Oracle Based:** Although most approaches use some kind of probability function or metric to decide whether to forward or not the data-packet, they highly differ in which values and properties have been taken into account. We decided to classify algorithms based on their source of routing knowledge. We can distinguish between five types of approaches.
  - **Knowledge Oracle:** The DTN routing problem has many input variables such as dynamic topology characteristics and traffic demand. Complete knowledge of these variables

facilitates the computation of optimal routes. However, with partial knowledge, the ability to compute optimal routes is hampered, and the performance of the resultant routing is expected to be inferior. To understand this fundamental trade-of between performance and knowledge, we create a set of abstract knowledge oracles, each able to answer questions we ask of them. These oracles are notational elements used to encapsulate particular knowledge about the network required by different algorithms. A key objective of our study is to understand the relationship between algorithm performance and the use of these oracles.

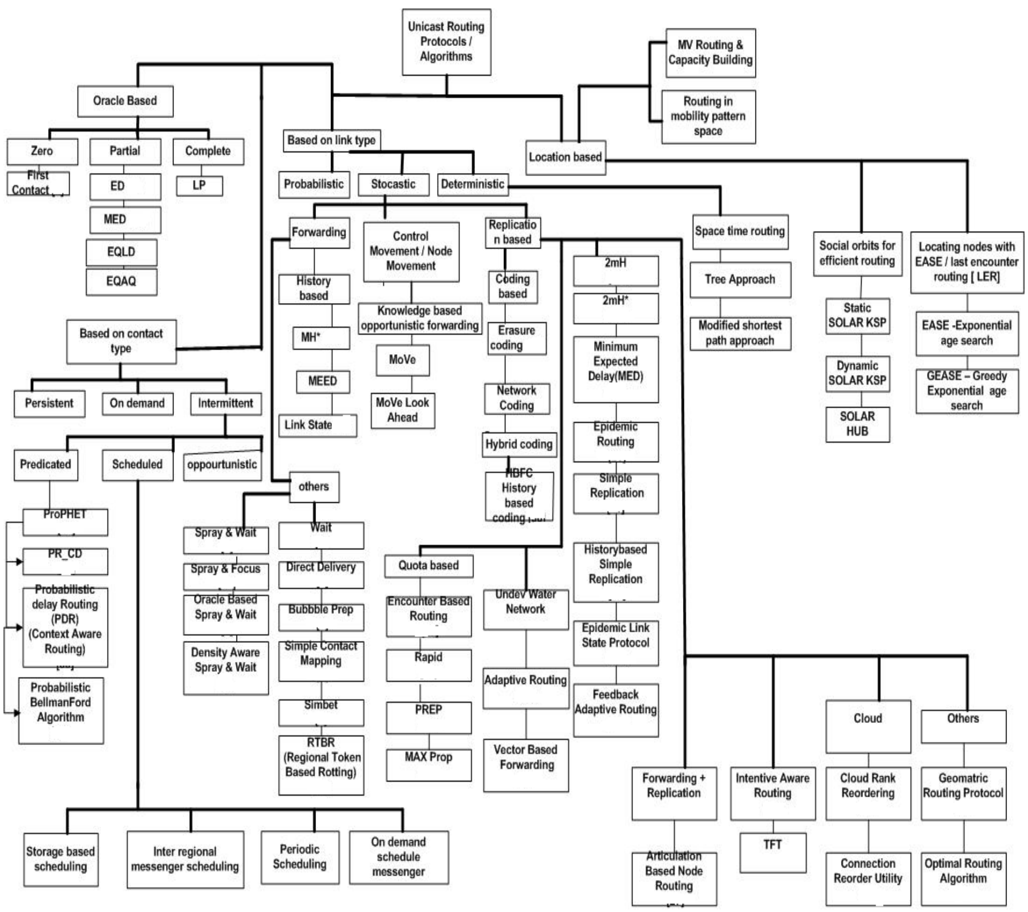

Figure:2 DTN Unicast Routing Classification Chart

- **Contacts Summary Oracle:** This oracle can answer questions about aggregate statistics of the contacts. In particular, the contacts summary oracle provides the average waiting time until the next contact for an edge. Thus, the contacts summary oracle can only respond with time-invariant or summary characteristics about contacts.
- **Contacts Oracle:** This oracle can answer any question regarding contacts between two nodes at any point in time. This is equivalent to knowing the time-varying DTN multi-graph. The contacts summary oracle can be constructed using the contacts oracle, but not vice versa.
- **Queuing Oracle:** This oracle gives information about instantaneous buffer occupancies (queuing) at any node at any time, and can be used to

route around congested nodes. Unlike the other oracles, the queuing oracle is affected by both new messages arriving in the system and the choices made by the routing algorithm itself. We expect it to be the most difficult oracle to realize in a distributed system.

- **Traffic Demand Oracle** This oracle can answer any question regarding the present or future traffic demand. It is able to provide the set of messages injected into the system at any time.

4. Conclusion & Future Work

This paper helps to classify and categorize routing under unicast, multicast and any cast in a network environment where data loss and error rates are high due to non-linear nature of communication data-traffic load, suggesting schemes and conflicts associated with them. Further, it captures all routing algorithm operating across and associated under various data schemes. Both the classification chart helps in providing an insight and suggests possible solutions for better data transfer and information exchange through exploitation of spontaneous opportunistic networks in a successful manner by effective utilization of the algorithm and the protocol scheme/s.

Acknowledgement

We express our sincere gratitude to the management of Ganpat University – Mehsana & Marwadi Education Foundation - Rajkot; for providing us research opportunities and their wholehearted support for such activities. Finally, our acknowledgement cannot end without thanking to the authors whose research papers helped us in making this research.

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