Adaptive Routing Techniques in Disruption Tolerant Networks

Mohammad Arif[1] and Abu Daud[2]

[1] Department of CSE, GSMVNIET, Palwal, Haryana, India
arif_mohd2k@yahoo.com
[2] Department of CSE, AFSET, Faridabad, Haryana, India
abu.daud@gmail.com

Abstract. It is very tough to use today's Internet efficiently on poles, disasters or in the environments which are characterized by very long delay paths and frequent network partitions. DTN is a new area of research to improve network communication when connectivity is periodic, intermittent, and/or prone to disruptions. Delay Tolerant Networks (DTNs) is used to interconnect devices in regions in which an end-to-end connection may never be present. It is based on store and forward principle as to make communication possible, intermediate nodes stores the data and forward it as the opportunity arises. In a DTN, however, an end-to-end path may be unavailable at all times, routing is performed to achieve eventual delivery by employing long-term storage at the intermediate nodes. This paper surveys the area of routing in delay tolerant networks and presents a system for classifying the proposed routing strategies.

Keywords: Routing, Delay Tolerant Network, Ad-hoc Networks, Intermittent Connectivity, Routing Protocols, Wireless Communication.

1 Introduction

The traditional Mobile Ad-hoc Network (MANET) routing protocols establishes end-to-end paths between communicating nodes and thus support end-to-end semantics of existing transports and applications. In contrast, DTN-based communication schemes imply asynchronous communication (and thus often require new applications) but achieve better reachability, particularly in sparsely populated environments. [7]

Delay tolerant network can be said as a type of network of regional networks. It is an overlay on top the regional network including Internet. DTN is used between and within regional networks. DTN accommodates the mobility and limited power of evolving wireless communication devices. Delay Tolerant Networks (DTNs) is a class of useful but challenging networks. DTN have many challenges. First is to cope up large transmission delays. These delays may result either from physical link properties or extended periods of network partitioning. A second one is efficient routing in the presence of frequent disconnection, pre-scheduled or opportunistic link availability. In some cases, an end-to-end path may not even exist at any single point in time. A third challenge is that high link-error rates make end-to-end reliability difficult. Finally,

N. Meghanathan et al. (Eds.): NeCoM, WiMoN, and WeST 2010, CCIS 90, pp. 336–348, 2010.

heterogeneous underlying network technologies (including non-IP-based internetworks) with very different communication characteristics may need to be embraced [3].

The rest of the paper is organized as follows: Section 2 presents the description of Delay Tolerant Network and its evolution. Section 3 explains routing process, routing issues and some routing algorithms. Section 4 presents various routing strategies and explains the overall categorization of routing approaches in broad way and Section 5 summarizes the matter.

2 DTN Architecture

The present Internet service model as explained in [14] provides end-to-end communication using a concatenation of potentially dissimilar link-layer technologies. In IP protocol, the mapping into network-specific link-layer data frames at each router supports interoperability using the packet-switching model. A number of key assumptions are also made regarding the overall performance characteristics: an end-to-end path exists between source and its peer(s), the maximum round-trip time between any node pairs in the network is not excessive, and the end-to-end packet drop probability is low. Unfortunately, classes of *challenged networks*, which may violate one or more of the assumptions, are becoming important and may not be well served by the current end-to-end TCP/IP model. Examples include:

- **Terrestrial Mobile Networks:** These networks are unexpectedly partitioned due to node mobility or changes in signal strength, while others may be partitioned in a periodic, predictable manner.
- **Exotic Media Networks:** These include near-earth satellite communications, very long distance radio or optical links, audio links in air or water, and some free-space optical communications.
- **Military Ad-Hoc Networks:** These systems operate in the environments where mobility, environmental factors, or intentional jamming may be cause for disconnection. In addition, data traffic on these networks may have to compete for bandwidth with other services at higher priority.
- **Sensor/Actuator Networks:** These networks are characterized by extremely limited end-node power, memory, and CPU capability. Communication within these networks is often *scheduled* to conserve power, and sets of nodes are frequently named (or addressed) only in aggregate. [14]

The Delay Tolerant Networking (DTN) architecture mentioned in [16] wants to address the communication needs of these challenged environments. This proposes a message based store-and-forward overlay network that uses a set of convergence layers to adapt to a wide variety of underlying transports.

3 Routing in a Delay Tolerant Network

3.1 Example: Connecting a Remote Village

In this example the scenario of communications to remote and rural areas is shown. A digital courier service provides disconnected Internet access to schools in remote villages of a country [14]. In this example, a courier on a motorbike, equipped with a USB storage device, travels from a village school to a large city which has permanent Internet connectivity. It takes a few hours for the courier to travel from the village to the city. Thus, we consider a simple scenario, based on this real-world example, which motivates the DTN routing problem. Figure 1 shows a village served by a digital courier, a wired dialup Internet connection, and a store-and-forward LEO satellite. These satellites have low bandwidth (around 10 Kbps) and are visible for 4-5 short periods of time (“passes") per day (lasting around 10 minutes per pass, depending on the orbit inclination and location on Earth).

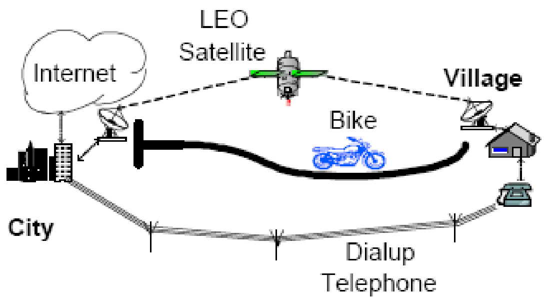

Fig. 1. Scenario illustrating a variety of connectivity options between a remote village and a city. Even in this simple scenario, many route choices are possible.

Depending on the type of connection used, buffering constraints should also be considered. The digital courier service represents a high-bandwidth, high-latency contact, the dialup represents a low-bandwidth, low-latency contact, and the LEO satellite represents a moderate-bandwidth, moderate-latency contact. The problem is to select which contacts should carry messages. Selection of route depend on a variety of factors including source and destination, message size, time of request, available contacts, traffic in the system, or other factors (e.g. cost, delay, etc.).

3.2 DTN Routing Issues

This section explains a number of important issues in any routing algorithm including the routing objective, the amount of knowledge about the network required by the scheme, when routes are computed, the use of multiple paths, and the use of source routing. Here we focus on these issues in the context of the DTN routing problem.

3.2.1 Routing Objective

There are various routing objectives, among them are: to select a shortest path, to maximize the probability of message delivery and to minimize the delay of a message (the time between when it is injected and when it is completely received). Minimizing delay lowers the time messages spend in the network, reducing contention for resources (in a qualitative sense). Therefore, lowering delay indirectly improves the probability of message delivery. [12]

3.2.2 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 [13]. Despite the drawback that they fail to provide paths to nodes which are not currently reachable, 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 [13]. 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. They fail in the sense that they fail to return a successful route.

3.2.3 Source Routing vs Per-hop Routing

In *source routing* the source node is responsible for determining the complete path of a message and encoding in some way in the message. The route is therefore determined once and does not change as the message traverses the network. In *per-hop routing* at each hop along its forwarding path the next-hop of a message is determined. 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.

3.2.4 Message Splitting

The splitting of a message is done in such a way that different parts (fragments) are routed along different paths. This technique may reduce the delay or improve load balancing among multiple links. It can be used in DTNs because messages can be arbitrarily large and may not fit in a single contact. However, splitting complicates routing because, in addition to determining the sizes of the fragments, we also have to determine corresponding paths for the fragments.

3.3 Knowledge

The figure shows that more knowledge is required to attain better performance.

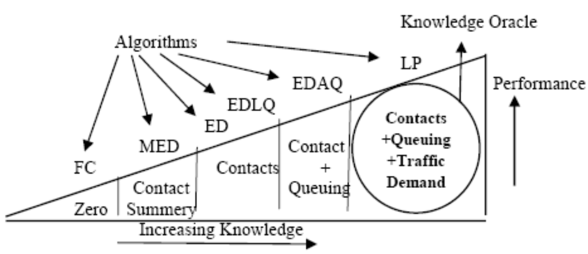

Fig. 2. Conceptual performance vs knowledge trade-off

In Figure 2, the x-axis depicts the amount of knowledge (increasing in the positive direction). The y-axis depicts the expected performance that can be achieved using a certain amount of knowledge. Labels on top show algorithms developed in this paper using the corresponding oracles.

3.3.1 Routing with Zero Knowledge

a) First Contact (FC)

Knowledge Oracles: None

An edge is chosen randomly among all the current contacts and the message is forwarded along it. If all edges are currently unavailable, the message waits for an edge to become available and is assigned to the first available contact. FC poorly performs because the chosen next-hop is random and forwarding along the selected edge may not make any progress toward the destination. A message may also oscillate forever among a set of nodes or be delivered to a dead end. FC requires only local knowledge about the network and is easy to implement. [12]

3.3.2 Routing with Partial Knowledge

a) Minimum Expected Delay (MED)

Knowledge Oracles: Contacts Summary

As the route of a message is independent of time so a proactive routing approach can be used. MED uses the same path for all messages with the same source-destination pair. No mechanism is employed to route around congestion or avoid message drops if storage space is unavailable. The key property of MED is that it minimizes the average waiting time.

b) Earliest Delivery (ED)

Knowledge Oracles: Contacts

Paths are computed by the Dijkstra's shortest path algorithm, so loop free. The route is determined once at the source making, ED a form of source routing. Paths are computed without considering the availability of storage (buffers) at intermediate nodes on the path and this may lead to drops when buffers overflow. ED is efficient if the nodes on the selected path have no queued messages or if buffers are large. Paths computed by ED do not take into account queuing delays. However, if many other messages are ahead in the queue, the contact may finish before the message is sent.

c) Earliest Delivery with Local Queuing (EDLQ)

Knowledge Oracles: Contacts

In EDLQ, we recomputed the route at every hop (per-hop routing), unlike ED. The EDLQ may lead to loop formation and the messages may oscillate forever which can be avoided by performing a re-computation of fixed routes (e.g. calculated using ED) when a loop is detected. Like ED, messages might get dropped because of buffer overrun.

d) Earliest Delivery with All Queues (EDAQ)

Knowledge Oracles: Contacts, Queuing

EDAQ uses the queuing oracle to determine the instantaneous queue sizes across the entire topology at any point in time. After computing the best route for a message, edge capacity must be reserved for the message over all edges along its path. Such reservations ensure that messages will have been moved in sufficient time to avoid missing scheduled contacts. A bandwidth reservation is a challenge for a DTN, where communication with some nodes may be significantly delayed. For systems where centralization is practical bandwidth allocation would be greatly simplified. In EDAQ an optimal route is determined for a new message given existing reservations for the previous messages. EDAQ is also unaware to available buffer capacity. Comparison is mentioned in Table 1. [12]

Table 1. Overview of different routing algorithms. All Dijkstra-based, incorporate a cost functions sensitive to edge propagation and transmission delays. Costs are ascertained by consulting the respective oracles. [12]

Abbr.	Name	Description	Oracle Used
FC	First Contact	Use any available contact	None
MED	Minimum Expected Delay	Dijkastra with time invariant edge costs based on waiting time	Contacts Summery
ED	Earliest Delay	Modified Dijkastra with time varying cost function based on waiting time	Contacts
EDLQ	Earliest Delay with Local Queue	ED with cost function incorporating local queuing	Contacts
EDAQ	Earliest Delay with all Queue	ED with cost function incorporating queuing information at all nodes & using reservation	Contacts & Queuing

4 Routing Strategies for DTN

4.1 Unicast Routing in DTN

As DTN can be represented as a directed multi-graph, thus there may exist multiple edges between two nodes. As in [12] each edge represents a connection between nodes having two arguments i.e. time-varying capacity and propagation delay. The capacity of an edge is zero when the corresponding connection is unavailable. A *contact* is defined as an opportunity to send data between nodes, i.e., an edge and the time interval during which the edge capacity is positive.

4.2 Anycast Routing in DTN

In Anycast a node is allowed to send a message to at least one, and preferably only one, of the members in a group. DTN Anycast means that a node wants to send a message to any one of a destination group and intermediate nodes help to deliver the message when no direct path exists between the sender node and any node of the destination group. DTN anycast can be used in a disaster rescue field, in which people may want to find a doctor or a fireman without knowing their IDs or accurate locations. In DTN anycast, the destination can be any one of a group of nodes. The path to a group member and the destination can change dynamically according to mobile device movement situation during routing.

4.3 Delay-Tolerant Broadcasting

It is also called BBR (Broadcast Based Routing).In this method the data is forwarded in the form of chunks through mobility of wireless nodes. It is a receiver-driven system. It has a public broadcast channels, which is used for both transmission and reception. This system is useful where the population of users is dense. In broadcasting each channel provides a particular type of content. Contents originated from the mobile nodes could be broadcast without any infrastructure. The data chunks can be delivered in or out of order, with or without assured completeness. There are many applications for which order and completeness are not necessary such as the distribution of a mixture or music, news, traffic and weather information [4].

4.4 Multicasting Routing in DTN

As DTN has a unique characteristic of frequent partitioning, multicasting is a considerably different problem in DTNs. DTN applications often requires different network support communication. In a disaster recovery scene, it is essential to distribute information about victims and risks among rescue workers. In a battlefield, soldiers need to inform each other about their surrounding situation. Although unicast can be used by sending a separate unicast packet to each user of the group. This approach suffers from poor performance. The efficient multicast services are needed as available bandwidth and storage are generally limited.

There may be no end-to-end path between nodes in DTNs. Thus multicast routing in DTNs needs to operate in the presence of network partitions. As proposed in [11], data transfer in DTNs is in application data units called *messages* (or bundles). This is different from the use of flows in traditional multicasting. Information about nodes joining or leaving a group may be available only after significant. As DTN can have large transfer delays group membership may change during a message transfer. So it is necessary to make a distinction between *group members* which may change with time as endpoints join and leave the group and the *intended receivers* which are fixed based on group membership.

4.5 Multicast Routing Algorithms

4.5.1 STBR

In Static Tree Based Routing (STBR), a shortest path tree in the DTN graph is constructed from the source to the intended receivers at message generation time. As a node enters or leaves the group, nodes update the shortest path tree. Messages are then forwarded along the tree. In STBR, the route is static. Thus if a message does not get a contact with a node, it waits for the next opportunity to connect to this node, which may increases the delay. The use of static routes does not allow nodes to use local information to forward messages along better paths. [11]

4.5.2 DTBR

This is a Dynamic Tree-Based Routing (DTBR) designed for DTNs. In DTBR, the receiver list will be assigned to the downstream nodes by upstream node. The bundles will be forwarded to only those receivers which are mentioned in the list, even if a new path is discovered for another receiver. In Figure 3(a), suppose link 1-2 is not available when the multicast bundle reaches node 1. Then, node 1 will use node 3 as intermediate node to deliver to nodes 5 and 6 and store a copy of the bundle so that node 1 can send to node 2 when the link 1-2 becomes available again since this is the only route to reach node 4. DTBR assumes that each node has complete knowledge or the summary of the link states in the network. [11]

4.5.3 OS-multicast

The On-demand Situation-aware multicast (OS-multicast) approach is a dynamic tree-based method that integrates DTN multicasting with the situation discovery mechanism provided by the underlying network layer. For each bundle a unique tree is constructed and this tree is adjusted according to the current network conditions. Upon receiving a bundle, the node will dynamically update the tree based on its current knowledge of the network conditions. Thus any newly discovered path can be quickly utilized. For example, in Figure 3(b), the link between 2-5 is broken but when the bundle reaches node 3, it will send a copy to both nodes 5 and 6. The drawback of the OS-multicast approach is that a receiver may receive many copies of the same bundle. [17]

4.5.4 CAMR

It is also a multicast routing scheme based on node-density. The authors of [2] showed that CAMR scheme achieve better message delivery ratio, with higher transmission efficiency and similar delay performance especially when the nodes are very sparsely connected or the network scenarios where an instantaneous end-to-end path between a source and destination may not exist because of opportunistic links. It is a node-density based adaptive multicast routing scheme for DTNs that is based on five components: (a) Local Node Density Estimation, (b) 2-Hop Neighbor Contact Probability Estimate, (c) Route Discovery, (d) Route Repair, and (e) Data Delivery.

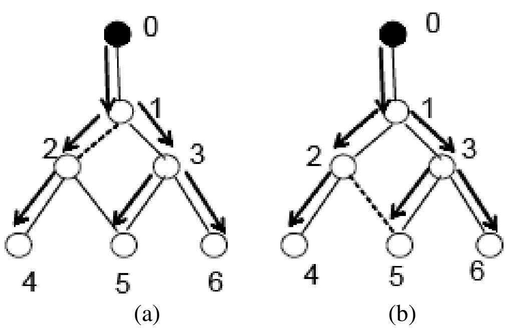

Fig. 3. Multicast approaches in DTN (a) DTBR, (b) OS multicast: when link 2→5 is unavailable and link 3→5 becomes available, node 3 will take advantage of the current available link immediately.

Table 2. Comparison between some multicast techniques

	Delivery Ratio	Average Delay	Data Efficiency
CAMR	90.5%	21 seconds	0.32
DTBR	74.0%	0.2 seconds	0.42
OS-multicast	48.9%	20 seconds	0.08
u-multicast	42.0%	0.1 seconds	0.46

4.6 Mobility Pattern Based Routing Scheme

This is designed on the basis of mobility patterns for routing in a delay tolerant network (DTN). As DTN architecture defines scheduled, opportunistic, and predicted types of contacts. Scheduled contacts exist between a base station on earth and a low earth orbiting relay satellite. Opportunistic contacts exist between two entities at the same place that was neither scheduled nor predicted. In predicted contacts predictions of their existence can be made. They are also not scheduled.

The mobility pattern based routing schemes are compared against the following:

- **Epidemic:** As described by [6] each time two nodes meet, they exchange their bundles. It provides the optimum path and thus the minimum delay. In general, there is high buffer occupancy and high bandwidth utilization.
- **Opportunistic:** In this method it involves only one transmission per bundle. A node has to wait to meet the destination in order to transfer its bundle.
- **Random:** When the bundle's destination in not there and the node are at a location, the node transfers the bundle to a randomly chosen neighbor. Bundles will jump to other nodes without any preference ordering. This makes extraordinarily high average route lengths.

The author of [5] tested two variants of the mobility pattern based routing scheme. In the first, it is assumed that a node that is sending a bundle has full knowledge of the destination's mobility pattern, and that it addresses the bundle accordingly. In the second, it is assumed that nodes communicate only the major components of their mobility patterns. By this, the amount of traffic exchanged between nodes is reduced.

4.7 Mobility Profile Based Routing

In this method we assume that a user regularly visits a small set of socially significant and geographically distant places called "hubs". By using the knowledge of the users' sociological hub based orbital mobility profiles, throughput of routing protocols can be increased and overhead can be decrease. The main contribution of the author is a routing protocol called *SOLAR-HUB* that takes advantage of user mobility profiles to perform "hub-level" routing. In SOLAR-HUB, when the sender, or an intermediate user carrying the message, moves into the hub(s) where the receiver can retrieve the message, a message from a sender will be routed to one or more hubs visited by the receiver called destination hub(s). Such a hub-level routing differs from any contact-probability based routing in several aspects. First, the contact probability of two users based on all users' hub-visit probabilities can be computed but not vice versa (since most users' contact information is location independent). Secondly, we can generalize the concept of hub-based routing such that a user may deliver a message to another by giving the message to a destination hub(s) even when the contact probability of the two users may be zero, which is possible when the two are never in the same hub at the same time and there are no other intermediate users in the system. [8]

4.8 Redundancy-Based Routing

In DTN the exact contact information between any two nodes is usually unknown in advance. So there is a class of routing in DTN that uses redundancy to reduce the delay and increase the delivery rate. One simple redundancy-based scheme is flooding-based routing which can cause too much overhead for the network and overflow the buffer of the nodes. To control the overhead of flooding-based routing schemes, the authors of [9] propose to dispatch a certain number of identical message copies to a fixed number of relay nodes, instead of every node in the network. When a message is generated by a source node, a "quota" is attached to that message, which represents how many identical copies of the message can be inserted in the network. When a node forwards a copy to another node, the remaining quota of the message is distributed between the two copies on the two different nodes. The node will not forward the message to somebody else if the carried message does not have enough quota.

The author proposed a model using continuous time Markov chain with absorbing state to study the performance. The non-absorbing states of the Markov chain are the number of relays carrying copies of the same message. When the message is successfully delivered to its destination node, the chain enters its absorbing state.

4.9 Spray and Wait Scheme

Spray and Wait is highly scalable having good performance under a large range of scenarios, unlike other schemes. It is simple to implement and optimize in order to achieve given performance goals in practice.

Definition: *Spray and Wait routing consists of the following two phases:*

- Spray phase*: for every message originating at a source node, L message copies are initially forwarded by the source and possibly other nodes receiving a copy to L distinct "relays".*
- Wait phase*: if the destination is not found in the spraying phase, each of the L nodes carrying a message copy performs direct transmission i.e. will forward the message only to its destination.* [10]

In Spray and Wait the total number of copies and transmissions per message are bound, without compromising performance. Under low load, Spray and Wait results in much fewer transmissions and smaller delays than flooding-based schemes. In case of high load, it gives better delays and fewer transmissions than flooding-based schemes. It exhibits good and predictable performance for a large range of network sizes, node densities and connectivity levels. As the size of the network and the number of nodes increase, the number of transmissions *per node* decreases in order to achieve the same performance. When enough copies have been spread to guarantee that at least one of them will find the destination, it stops and lets each node carrying a copy perform direct transmission. Its performance is better with respect to both number of transmissions and delay than all other practical single and multi-copy schemes, in most scenarios considered. [10]

4.10 Inter-domain Routing Schemes

There are two methods for interdomain routing for delay tolerant networks. [15]

4.10.1 GBIR

Gateway-Based Inter-domain Routing (GBIR) has following three components.

a) Leader Selection and Transfer

The node will be selected as the leader which sends the claim first and which are one hop away from the center of the subnetwork. If more than one leader succeeds almost the same time, the one closest to the subnetwork center will be selected. When a leader moves out of the one hop area from the center, it checks all its neighbors and chooses the one which is closest to the subnet center to take over its leadership.

b) Gateway registration, deregistration and transfer

A node sends a gateway registration message to the leader of its own subnet when it hears messages from other groups. Since the leader is always within the one-hop area from the subnet center, geographical routing will be used to forward registration message. Thus the gateway can register successfully with its leader without knowing the identity of its current leader. The registration message contains gateway location information. If a registered gateway does not hear from other groups, it sends a de-registration message to its leader. If a gateway node is away from the overlapping area, it finds a neighboring subnet, currently in the overlapping area to take over.

c) Data Delivery

Node requires gateway information to send data to another group. The leader does not provide the exact location of the gateway that is why upon receiving the response from the leader it uses the multihop routing to send the data to the gateway.

4.10.2 FBIR

Assumptions for Ferry-Based Inter-domain Routing (FBIR) are that each group has one ferry which sends inter-group messages and that each group member knows the identifier of its own group's ferry. A ferry can be either local to its own group or roaming i.e. visiting other groups. When a ferry crosses the area of its own group, it broadcasts a service announcement message periodically to discover nodes from other groups. Ferry periodically checks its buffered packets to see that are there *some packets queued for more than w seconds* or the *buffer capacity exceeds 99%*. If any of the above conditions occurs, the ferry will start moving towards the destination group of the oldest message among those queued messages. If buffer exceeds then the ferry will visit the destination group which has maximum number of queued messages. As ferry knows the approximate location of the destination group, it issues hello messages periodically to look for nodes from the destination group and transfers the message when node is discovered. The ferry will move to other groups only if there are messages destined to other groups the buffer otherwise, the ferry stays in its own group. [15]

5 Conclusion

In this paper, we have surveyed many existing algorithms for evaluating DTN routing algorithms. While discussing abut DTN routing it is necessary to pay attention on various tasks like selection of paths, transmission schedules, estimated delivery performance, and management of buffers. The problem of frequent disconnection in devices which may be mobile is more important. In many such cases, communication opportunities may be predictable. The algorithms mentioned in this paper focus on these situations. This survey suggests that in situations where resources are limited smarter algorithms will be beneficial. Our survey and classification also enabled us to make the following observations.

First, hybrid techniques that are based on both knowledge of the topology and replication will give high delivery ratio with low resource consumption. But determining the correct balance between consumption of resources and redundancy of replication is a challenge. Second, epidemic routing will be useful in the cases where message are small.

References

[1] Gong, Y., Xiong, Y., Zhang, Q., Zhang, Z., Wang, W., Xu, Z.: Anycast Routing in Delay Tolerant Networks. In: IEEE GLOBECOM 2006 proceedings (2006)

[2] Yang, P., Chuah, M.C.: Context-Aware Multicast Routing Scheme for Disruption Tolerant Networks. In: Proceeding of PE-WASUN 2006, Torremolinos, Malaga, Spain, October 6 (2006)

[3] Brunner, M., Eggert, L., Fall, K., Ott, J., Wolf, L.: Seminar on Disruption Tolerant Networking. ACM SIGCOMM Computer Communication Review 35(2) (July 2005)

[4] Karlsson, G., Lenders, V., May, M.: Delay-Tolerant Broadcasting. In: The proceedings of SIGCOMM 2006 Workshops, Pisa, Italy, September 11-15 (2006)

[5] Leguay, J., Friedman, T., Conan, V.: DTN Routing in a Mobility Pattern Space. In: The proceedings of SIGCOMM 2005 Workshops, Philadelphia, PA, USA, August 22–26 (2005)

[6] Vahdat, A., Becker, D.: Epidemic routing for partially connected ad hoc networks. Technical Report CS-200006, Duke University (April 2000)

[7] Ott, J., Kutscher, D., Dwertmann, C.: Integrating DTN and MANET Routing. In: The proceedings of SIGCOMM 2006 Workshops, Pisa, Italy, September 11-15 (2006)

[8] Ghosh, J., Ngo, H.Q., Qiao, C.: Mobility Profile based Routing Within Intermittently Connected Mobile Ad hoc Networks (ICMAN). In: The proceedings of IWCMC 2006, Vancouver, British Columbia, Canada, July 3-6 (2006)

[9] Liao, Y., Tan, K., Zhang, Z., Gao, L.: Modeling Redundancy-based Routing in Delay Tolerant Networks. In: The proceedings of IEEE 2007, pp. 212–216 (2007)

[10] Spyropoulos, T., Psounis, K., Raghavendra, C.: Spray and wait: an efficient routing scheme for intermittently connected mobile networks. In: WDTN 2005: SIGCOMM 2005 DTN workshop, pp. 252–259 (2005)

[11] Zhao, W., Ammar, M., Zegura, E.: Multicasting in Delay Tolerant Networks: Semantic Models and Routing Algorithms. In: The proceedings of SIGCOMM 2005 Workshops, Philadelphia, PA, USA, August 22–26 (2005)
[12] Jain, S., Fall, K., Patra, R.: Routing in a Delay Tolerant Network. In: The proceedings of SIGCOMM 2004, Portland, Oregon, USA, August 30–September 3 (2004)
[13] Broch, J., Maltz, D.A., Johnson, D.B., Hu, Y.C., Jetcheva, J.: A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols. In: ACM Mobicom (August 1998)
[14] Fall, K.: A Delay-Tolerant Network Architecture for Challenged Internets. In: The proceedings of SIGCOMM 2003, Karlsruhe, Germany, August 25-29 (2003)
[15] Yang, P., Chuah, M.: Performance Comparison of Two Interdomain Routing Schemes for Disruption Tolerant Networks
[16] Warthman, F.: Delay Tolerant Networks – A Tutorial. DTN Research Group Internet Draft, Vreson No. 1.1 (March 2003), http://www.dtnrg.org
[17] Ye, Q., Cheng, L., Chuah, M., Davison, B.D.: On-Demand Situation Aware Multicasting in DTNs. In: Proceedings of IEEE VTC, Spring (2006)