Routing Protocols in Delay Tolerant Networks: A Comparative Survey

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Abstract: *Delay Tolerant Networks* (*DTNs*) are a class of emerging networks that experience frequent and long-duration partitions. Compared with the conventional networks, the distinguished feature is that there is no end-to-end connectivity between source and destination. The network topology may change dynamically and randomly, and the non-existence of an end-to-end path poses a number of challenges in routing in DTNs. In this paper, we survey the state-of-the-art routing protocols and give a comparison of them with respect to the important challenging issues in DTNs. The routing protocols are classified into two categories based on which property is used to find the destination: flooding families and forwarding families. The pros and cons as well as performance are disccused and compared for the routing protocols.

1. Introduction

DTNs are a practical class of emerging networks, which are an occasionally connected network comprised of one or more protocol families and experience frequent and long-duration partitions as well as long delay. Because there is no end-to-end connectivity in DTNs, the routing protocols which have good performance in the conventional networks are not suitable for DTNs, which are characterized by latency, bandwidth limitations, error probability, node longevity, or path stability [1].

DTNs are effectively utilized in various environments subject to disruption, disconnection and long delay. More specifically, DTNs can be applied to wireless sensor networks using intermittent connectivity, terrestrial wireless networks with no end-to-end connectivity, satellite networks with long delay or periodic connectivity, underwater acoustic networks with frequent interruptions, and other commercial applications that allow *long delay* and *intermittent connectivity* [8].

Compared with the conventional networks, the most distinguished difference is that there is no guarantee of end-to-end connectivity between source and destination and, thus, long latency is inevitable [1]. Moreover, while data is transmitted over the network, the network topology is changed randomly and dynamically. Such distinct features pose a number of technical challenges in designing routing protocols. In thos paper, we survey the existing routing protocols in DTNs and give a comparison of them with respect to the important challenging issues and performance metrics. For the two families of *flooding* and *forwarding*, the pros and cons of the routing protocols are comparatively revisited with key performance metrics.

The rest of this paper is organized as follows. In the following section, the key properties of DTNs are briefly reviewed. Routing issues in DTNs are presented in Section 3. The existing routing protocols are summarized in terms of major features and characteristics in Section 4, and they are compared and discussed in Section 5. Finally, the conclusions of this paper are covered in Section 6.

2. Key Properties of DTNs

There are some important key properties of DTNs which have a great deal of discrepancy from the conventional networks [1, 4]. They are briefly reviewed in this section.

2. 1 High Latency and Low Data Rate

These are the fundamental properties of DTNs. The frequent and random mobility of the networks doom that any two nodes in the networks may never meet each other for a long time and the transmit rate of data would maintain at a low level. The transmit rate may be considerably low and largely asymmetric with the long latency of data delivery.

2. 2 Disconnection

In most cases, it is impossible to have an end-to-end path. Hence, disconnection is more usual than connection. Normally, the disconnection may be mainly caused by network partition as well as unexpected fault.

2. 3 Long Queueing Delay

The end-to-end latency of data delivery is often dominated by the queueing delay. In DTNs, the queueing delay is aggravated because the disconnection is more common compared to the conventional networks. It implies that the queueing delay could be extremely large which may take some hours or days in the worst cases.

2. 4 Limited Longevity

End nodes can be deployed in hostile environments such as the battle fields and disaster areas. For example, the sensor nodes used for military detection or disaster recovery are brittle to be broken down by the awful surroundings. It implies that the end-to-end delay from the sensor nodes to the destination sink is longer than the surviving time of the node itself which stores the data temporarily, due to environmental dangers, power exhaustion, or hostile actions.

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2. 5 Limited Resources

In general, the nodes in DTNs are mobile and battery-operated with wireless connection and, thus, they have limited resources. For example, to forward data to the next node, the data should be safely stored within the current node until the connectivity to the next node is available. However, new data can be received and collected and then may occupy another part of the buffer space. Therefore, the limited memory capability will restrict the data buffering.

3. Routing Issues in DTNs

The peculiar properties of DTNs inevitably raise a number of interesting issues [1, 8] which are summarized in this section.

3. 1 Routing Objective

The most important routing objective in DTNs is to maximize the probability of message delivery. To minimize resource (i.e., buffer space, network bandwidth and battery energy) consumption is also an important routing objective. Although DTN applications are expected to be tolerant of delay, this does not mean that they would not benefit from decreased delay but it is still meaningful to minimize the delivery latency.

3.2 Resource Allocation

In general, the routing protocols must balance the goals of maximizing message delivery and minimizing resource consumption which are conflict with each other. On the one hand, for example, only if we can ensure the data can be successfully delivered to the destination, it is unnecessary to store the copies of the data in all hosts in the network. On the other hand, for maximizing the likelihood that a particular message is eventually delivered, the best way is increasing the copies of the message at multiple hosts.

3.3 Buffer Space

To cope with a long time of disconnection, messages must be buffered for a long period of time. The intermediate routers should require buffer space enough to store all the messages to be transmitted. Furthermore, there is a relationship between the buffer space and the number of *pending messages* (which have not been delivered yet to its destination host). More number of pending messages needs more available buffer space.

3.4 Reliability

For the reliable delivery of data in DTNs, any routing protocol should have some acknowledge, which can ensure successful and stable delivery of data. For example, when a message correctly reaches to a destination, some acknowledge messages should be sent back from destination to source for later use.

3.5 Energy

Because of the mobility of nodes and the difficulty of connection to power station, the nodes in delay-tolerant networks are usually lack of energy. During the message routing, however, lots of energy should be consumed for sending, receiving and storing messages as well as performing computation. Therefore, the energy-efficient design of routing protocols is of importance.

3.6 Security

Security is always an important issue not only in the DTNs but also in all the traditional networks. A message may traverse an arbitrary path of hosts before reaching its ultimate destination. Depending on the sensitivity and security requirements of applications, users may require certain guarantees about the authenticity of a message. The cryptographic techniques may be beneficial for secure end-to-end rouitng. Because, in this way, receivers can learn whether a message has been exposed to un-trusted hosts. The security in routing protocols is still an open issue to be studied.

4. Routing Protocols

In general, the *routing protocols* in DTNs are classified into two categories based on which property is used to find the destination: *flooding* families and *forwarding* families. To find the destination, two different approaches of *replication* and *knowledge* are used. The replication is used in the flooding strategy and there are many algorithms to manage multiple copies of a message and to make those copies. While the knowledge is used in the forwarding strategy and some works have been devoted to derive more efficient methods to obtain some network state information and then to use it to make routing decisions [4].

4.1 Flooding Families

In the *flooding* families, each node has a number of copies of each message and transmits them to a set of nodes (sometimes called relays). All the relays maintain the copies and store them in their buffer space until they connect with the next nodes. The earliest works in the area of DTN routing fall into this family. Using the message replication can increase the probability of message delivery. The basic protocols in this family do not need any information about the network. However, if some knowledge of the network is referred to as an additional routing metric, the flooding strategy can be significantly improved. Direct contact, two-hop relay, tree-based flooding, epidemic routing, prioritized epidemic routing, probabilistic routing, and reconfigurable ubiquitous networked embedded systems (RUNES) routing protocols belong to the flooding family.

4.1.1 Direct Contact

This routing protocol only permits that data can be transmitted in one hop [4]. Due to its simple characteristics, it does not consume much resources, and it uses exactly one message transmission when the source can directly contact with the destination.

4.1.2 Two-Hop Relay

The transmission has two hops between source and destination. If there are *n* nodes around the source and directly connect with the source, then there are *n* copies of the message should be generated from the source, and be transmitted to these nodes [4].

4.1.3 Tree-Based Flooding

In this routing protocol, the way of flooding is based on tree structure [4]. Both deciding how to make copies and ensuring the number of copies are important issues in this routing protocol.

4.1.4 Epidemic Routing

In epidemic routing, all the nodes can become the carrier, and it is ensured that messages can be delivered with a high probability [7]. However, the network resources are consumed heavily.

4.1.5 Prioritized Epidemic Routing

The key idea about prioritized epidemic routing is to impose a partial ordering on the message called bundles. Therefore, the priority functions of transmission and deletion are used, which are based upon four inputs such as the current cost to destination, the current cost from source, the expiry time and the generation time [6].

4.1.6 Probabilistic Routing

In this routing, when a message arrives at a node which does not have an available contact with other node, it must be stored in the buffer until the node encounters with another node. We should set a probability threshold on the nodes. It only admits that a node can receive the message when its delivery probability exceeds the threshold [2].

4.1.7 RUNES (Reconfigurable Ubiquitous Networked Embedded Systems)

In RUNES, there is a new metric named "$\{m, n\}$ hop" metric, where the value of *m* means how close a message is to its source and the value of *n* means how close a message is to its destination. If a message is close to the destination or close to the source, it is likely that it will not be dropped.

4.2 Forwarding Families

In the *forwarding* families, the network topology information is effectively utilized to select the best path, and the message is then forwarded from node to node along with the path. Note that the routing protocols in this family require some knowledge about the network. The nodes typically send a single message along with the best path, so they do not use replication. Location-based routing, source routing, per-hop routing, per-contact routing, and hierarchical routing protocols belong to the forwarding family.

4.2.1 Location-Based Routing

A distance function is used to estimate the cost of delivering messages from one to another. The advantage of this protocol is that it requires very little information about the network. However, it has two problems. The first problem is that even if the distance between two nodes is small, there is no guarantee that they will be able to communicate with each other. The second is that a node's coordinates should usually change.

4.2.2 Source Routing

In brief, source routing means the source node is in charge of the whole transmitting and determines the path based on the topology of the network before the message gets into the node. This routing protocol will have good performance only when the source is close to the destination.

4.2.3 Per-Hop Routing

In this routing protocol, the forwarding decision is made by the intermediate node 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 [5].

4.2.4 Per-Contact Routing

In this routing protocol, the routing table is recomputed each time a contact is avaliable, instead of computing the next hop for a message. It ensures that each routing decision is made with the most recent information [5]. However, to gurantee the loop freedom is a big problem.

4.2.5 Hierarchical Routing

Hierarchical routing is a hop-by-hop routing rather than a source routing, whose advantage is that it is scalable for localized traffic patterns and it does not need location information. However, the contact information is time-variant. For solving this problem, we need a method to aggregate the time-varying information [3].

5. Comparison

We compare the state-of-the-art routing protocols proposed so far in the literature. First, we evaluate the flooding families in terms of various characteristics including important performance metrics. Hop count, the number of copies, resource usage, delivery ratio, routing vector/table, multipath support, effectiveness, and latency are studied in the comparative analysis. Table 1 summarizes the comparison results of the flooding families.

We then evaluate the forwarding families as well, where flexibility, resource consumption, information usage, routing vector/table, scalability, loop freedom, effectiveness, delivery ratio, and latency are studied and compared. Table 2 summarizes the comparison results of the forwarding families.

From the two comparison tables and our comparative analysis, some conclusive comments can be inferred: The prioritized epidemic routing is the best of the flooding families even though it has some drawbacks such as poor resource usage. Of the forwarding families, the hierarchical routing can be primarily chosen thanks to its many outstanding features although it has two negative

Table 1. Comparison of the flooding families.

	Hop count	Number of copies	Resource usage	Delivery ratio	Routing vector/table	Multipath support	Effectiveness	Latency
Direct contact	1	No	Low	Min	No	No	Bad	Long
Two-hop relay	2	n{1}	Low	Low	No	Yes	Bad	Long
Tree-based flooding	Many	$\sum_{i=0}^{n}\sum_{a=1}^{k} Ma$ {2}	High	Low	No	Yes	Bad	Long
Epidemic routing	Many	Unlimited	Max	Max	Yes	Yes	Normal	Long
Prioritized epidemic routing	Many	Limited	Limited	Normal	Yes	Yes	Good	Normal
Probabilistic routing	Many	Limited	Limited	Normal	Yes	No	Good	Normal
RUNES	Many	Limited	Limited	Normal	Yes	Maybe	Good	Long

(1) "n" is the number of the nodes in a network.
(2) "n" is the depth of a routing tree, "k" is the number of nodes at the same depth, and "Ma" is the number of copies of a message in node a.

Table 2. Comparison of the forwarding families.

	Flexibility	Resource consumption	Information usage	Routing vector/table	Scalability	Loop-free	Effective-ness	Delivery ratio	Latency
Location based routing	Bad	Little	Little	No	Bad	Yes	Bad	Min	Normal
Source routing	Bad	Normal	Normal	No	Bad	Yes	Bad	Low	Long
Per-hop routing	Bad	Normal	Normal	No	Bad	Yes	Bad	Low	Long
Per-contact routing	Good	Many	Many	Yes	Bad	No	Normal	Normal	Normal
Hierarchical routing	Good	Many	Many	Yes	Good	Yes	Good	Max	Normal

characteristics of poor information aggregation and information compression.

6. Conclusion

Routing in DTNs is a new area of research, with a limited but rapidly growing set of research results. The routing protocols have the common objective of trying to increase the delivery ratio while decreasing the resource consumption and latency. In this paper, we have presented a comparative survey of various routing techniques in DTNs. The advantages and disadvantages of the routing protocols have been discussed with comparition results as well. Although many routing protocols have been studied so far, there are still many challenges to be solved. For example, we should make the routing protocol more scalable for a large network. Loop freedom, energy conservation, and efficient resource usage should be also addressed. Our future work is to design a robust routing protocol for harsh operational environments. By using the comparative results of this paper, the distinguished features of DTNs are being exploited.

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