Routing Strategies and Buffer Management in Delay Tolerant Networks

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***Abstract*—The Delay Tolerant Networks (DTN) is an intermittently connected network that enables communication among wireless nodes in the heterogeneous environments where end-to-end connectivity between nodes does not exist. These networks are characterized by a long delay, asymmetric data rate and low data rate. DTN uses store and forward mechanism to transmit messages from the source node to destination node. Routing in DTN is challenging because of frequent and long duration periods of disconnectivity. Therefore, the selection of routing protocol in DTN depends on the application environment in which it is used. This study presents a comprehensive survey on DTN and brief outlines of popular routing protocols in DTN. This paper also highlights the buffer management technologies that are used in DTN. Where an efficient buffer management scheme is required to choose at each step which of the messages should be transmitted in case of limited bandwidth and which of the messages should be dropped when the buffer is full. Regardless of which routing algorithms used.**

***Index Terms*—Delay Tolerant Networks; Intermittent Connectivity; Routing Protocols.**

I. Introduction

Delay Tolerant Networks (DTN) is a type of networks that was conceived to support interplanetary networks (IPN) [1]. These networks are more suitable to enable communication in environments where end-to-end connectivity does not exist. Therefore, routing is the main problem that affecting the performance of these networks in terms of resources consumption, latency, and data delivery. Before addressing the routing problem in DTN, first we need to summarize the most important characteristics of DTN. These characteristics are listed as follow:

- Intermittent connectivity.
- Delivery latency and low data rate.
- Long queuing delay.
- Resource limitation.
- Limited longevity.
- Security.

These characteristics of DTN made the standard routing protocols usually designed for mobile networks are inadequate to serve the communication and new routing protocols are needed.

The concept of DTN is adopted by some applications such as sensor networks in suburban and rural areas, vehicular networks, military networks, sparse mobile ad-hoc networks and many other applications.

The Store-and-Forward (SF) mechanism is implemented in DTN architecture by overlaying a new protocol layer named Bundle Layer [2]. This layer is located between the application layer and the transport layer as shown in Figure 1. In some studies, bundles are also named messages. That means there is no a contemporaneous route between the source node and destination, unlike traditional protocols. To cope with hardware failures and to increase reliability, bundles are typically stored in persistent storage.

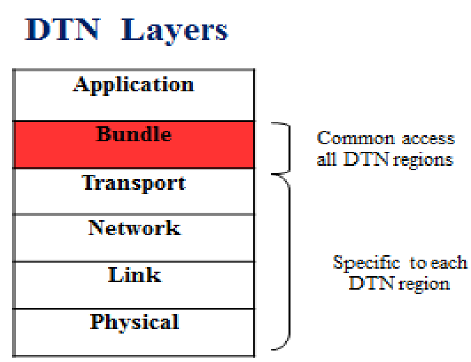

Figure 1: DTN Layers adopted from [2].

The SF mechanism is like an e-mail system. Along the route from the source node to the destination, the intermediate node holds bundles in storage for a while until the next node becomes available as shown in Figure 2. Each node in the network has a storage device such as a hard disk, where the node can store messages. This storage device is called persistent storage as it can store the messages for a long interval of time, unlike short-term memory devices. The importance of the persistent storage appears in cases when the rate of incoming messages is higher than the rate of outgoing messages, or when the next node is not available for a very long time [3].

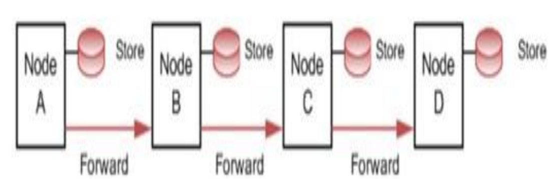

Figure 2: Store-and-forward mechanism adopted from [4]

The structure of this paper is as follows: Section II introduces the main challenges in DTN. Section III discusses the routing in DTN. Section IV outlines the contacts between nodes in DTN. Section V details the buffer management in DTN. Section VI concludes the paper.

II. Routing in DTN

The traditional routing protocols which consider an essential platform for most traditional mobile networks do not work well in DTN since these protocols assume an existing of the continuous route between the source node and destination [2]. Since the DTN are intermittently connected networks where a continuous end-to-end path may not exist, the main objective of routing in DTN is to maximize message delivery to the destination while minimizing end-to-end delay. The routing protocols in DTN can be differentiated based on queue management, the amount of information available when making the forwarding decisions and the number of destinations a message can have [5].

Routing in DTN is the main issues and challenging because of frequent and long duration periods of disconnectivity [6]. The properties of DTN certainly raise a number of interesting issues in routing [7] which are summarized as follow:

A. Routing Objectives

The main and most important routing objectives in DTN are to minimize resource consumption such as network bandwidth, battery energy, and network bandwidth as well as maximize message delivery probability.

B. Buffer space

Since DTN are intermittently connected networks, messages in these networks must be buffered for long periods of time. This means that the intermediate nodes require enough buffer space to store all messages until that intermediate nodes meet the specific destination nodes. The process of storing messages requires sufficient buffer space to store all pending messages as required.

C. Energy

Nodes in these networks normally have a low level of energy because of the mobility of nodes and the difficulties of connection to the power station. Much of energy is consumed during messages routing, as well as energy consumed for sending, receiving, storing, and computation of messages.

D. Reliability

Routing protocols in DTN should have some acknowledge for reliable delivery of data, which guarantee successful and stable delivery of information. Where some acknowledgment messages should be sent back when messages correctly reach to the final destination.

E. Security

Security has always been a significant problem for both traditional and DTN networks. The messages may go along arbitrary path through intermediate nodes before reaching their final destination. Therefore, based on the requirements of security of applications, users may require securing guarantees about the authenticity of a message. The cryptographic mechanisms may be useful to secure intermediate routing. To overcome the problem of intermittent connectivity and partitions in the networks, routing in DTN utilizes nodes mobility and messages buffering which makes it possible for a node to carry a message and bridge partitions in the networks.

Routing in DTN can be classified into different categories based on their characteristics as deterministic and stochastic. In deterministic scheme the network topology and/or its characteristics are assumed to be known. Contrarily, for stochastic case no exact knowledge of topology is assumed.

Next different routing protocols that are classified under the stochastic category are used to overcome the intermittent connectivity in DTN are discussed such as Epidemic, Spray and Wait, PRoPHET, and MaxProp.

A. Epidemic Protocol (EP)

In this protocol all nodes can become the carrier, and it is ensured that messages can be delivered with a high probability. However, the network re-sources are consumed heavily [8]. In other words, to deliver messages to the final destination, EP provides a redundant number of random messages exchange. This leads to guaranteeing the destination node receiving the messages in anyway.

B. Spray and Wait (SnW)

The SnW [9] algorithm is the advanced version of the epidemic routing protocol. In this algorithm the nodes are not distributing the message to each and every node but an optimal number of nodes (L) are selected to which the source node will relay the message. This algorithm consists of two phases spray phase and wait phase. In the spray phase, the source node replicates the message to the L-nodes and these L- nodes will further relay the message to L relay nodes. The relay nodes will store the message and perform direct transmission if the destination is not found in spray phase.

C. PRoPHET

PROPHET is proposed in [10]. The protocol estimates a node metric called delivery predictability, *P (a, b),* at each node *a* for each destination *b*. When two nodes meet, they update their delivery predictability toward each other. Then, the two nodes exchange their delivery predictability list toward other nodes update their delivery predictability using the following equations.

$$P(a,b) = P_{old(a,b)} + (1 - \delta - P_{old(a,b)}) \times P_{init} \tag{1}$$

The value of δ should normally be very small e.g. (0.01).

$$P(a,b) = P_{old(a,b)} + (1 - P_{old(a,b)}) \times P_{old(a,b)} \times \beta \tag{2}$$

where, $0 \leq \beta \leq 1$ is a constant that determines the impact of transitivity on the delivery predictability.

$$P_{(a,b)} = P_{old(a,b)} \times \gamma^{k} \tag{3}$$

where, γ is an aging constant and k is the number of time units that have elapsed since the last time the metric was added.

D. MaxProp

MaxProp [11] is a flooding-based routing protocol designed for vehicle-based delay tolerant networks. The buffer of this protocol is divided into two phases. First, messages are stored from low to high based on hop count information. Secondly, messages are arranged by cost from high to low. The first phase uses the front end of the buffer, while the second phase uses the back end of the buffer as in Figure 3.

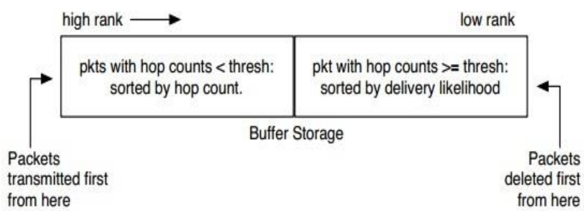

Figure 3: Buffer Management in MaxProp [11].

Table 1 outlines the advantages and shortages of the main DTN routing protocol.

Table 1
Advantages And Drawbacks Of Routing in DTN

Protocol	Epidemic	SnW	PRoPHET	MaxProp
Mechanism	Flooding	Flooding	Flooding	Flooding
No. of Copies	Unlimited	N-copies	Unlimited	Unlimited
Hop Count	One	Multiple	Multiple	One
Drawbacks	High resources consumption	Relay nodes waits until it encounter the destination node Nodes must keep track of other nodes and contacts	High message overhead	High processing cost
Advantages	Find the optimal path Small delay Robust against node and network failure	Control level of flooding	Less using of network resource	Based on the priority

Routing in DTN is a big challenge because of frequency and length of the disconnection time between nodes in the network. However, the main role of routing in DTN is to find an opportunity to connect nodes and to transmit data between them when the nodes meet each other if possible.

In general, DTN routing protocols are designed to be as efficient as possible in cases of highly sparse networks and intermittent connectivity. Furthermore, an efficient routing protocol should be simple, scalable and capable of working at both low and high message load. Moreover, it should have optimal delivery probability, low delay and low overhead ratio

III. Challenges in Delay Tolerant Networks

Routing in DTN presents many challenges that are not available in mobile ad hoc networks (MANETs). Most of these challenges stem from the connectivity problem in DTN which have the direct impacts on forwarding and routing mechanism. Furthermore, routing strategies in such networks needs to be aware of, such as dealing with limited resources. Other challenges include:

- contact schedules
- contact capacity
- buffer space
- processing
- energy

The concept of DTN emerged when the traditional routing protocols failed to work in the extreme environment. The extreme environment characterized by frequent interruption, no constant end-to-end connectivity, and limited resources. Therefore, routing of the messages in DTN is mainly based on the store-and-forward mechanism. That is, when a node receives a message and there is no continuous end-to-end path to the destination node, the message is buffered in the current node till it encounters other nodes. Thus, routing in DTN is one of the major issues affecting the overall performance of DTN networks in terms of data delivery and resource consumption.

IV. Buffer Management in Delay Tolerant Networks

In DTN, the “store-carry-forward” mechanism is used for message transmission. These messages are delivered to their final destinations in a hop-by-hop manner. As a result, many problems arise such as how to drop and how to schedule the messages, in the buffer due to the impulsive nature of the nodes. Many changeable situations may occur like limited storage node capacity, short contact duration between the two nodes, and so on [12]. Buffer Management technology is a fundamental approach that manages the various resources among different situations as per the technique used. An efficient buffer management technique decides at each step which of the messages is to be dropped first, when the buffer is full as well as which messages are to be transmitted, when bandwidth is limited [13].

The nodes in the DTN require proper buffer management approach to get low delay and high data delivery. The buffer management, in this case, refers to the proper use of scheduling and dropping policies used by the nodes at the time of the buffer overflow and congestion [14].

Next the popular dropping policies techniques used in DTN are described.

A. Drop Least Recently Received (DLR)

In the DLR buffer management technique, as the name implies, the packet which is stays for a long time in the buffer will be dropped first. This is due to the fact that it has less probability of being conceded to the other nodes [15]

B. Drop Oldest (DOA)

In the DOA technique, the message with the shortest remaining life time (TTL) is dropped first. The idea behind dropping such messages is that of the messages whose TTL is small, then these are in the network from a long period of time and, thus, have the high probability of having already been delivered [15].

C. Drop Front (DF)

This technique drops the messages on the basis of the order in which they enter into the buffer. For example, the first message that enters the queue will be the first to be dropped [16].

D. Drop Largest (DLA)

In the Drop Largest (DLA) buffer management technique, the message with a large size will be selected in order to be dropped [15].

E. Evict Most Forwarded First (MOFO)

MOFO attempts to maximize the propagation of the messages through the network by dropping those messages that have been forwarded the maximum number of times. As such, the messages with a lower hop count are able to travel further within the network [16].

F. Drop Last (DL)

Drop the newly received message, irrespective of whether it is new or old, that is why responsible for maximize drop ratio.

G. Evict Most Favorably Forwarded First (MOPR)

MOPR maintains the value of each message in its queue. Thus, each time when a message is replicated the value in the message is increased based on the predictability of the message being delivered. Therefore, the message with the highest value is dropped first [16].

H. Evict Shortest Life Time First (SHLI)

This technique uses the timeout value of the message, which indicates when it is no longer useful. This means that a message with the shortest remaining life time is dropped first [16].

I. Evict Least Probable First (LEPR)

This technique works by a node ranking the messages within its buffer based on the predicted probability of delivery. The message with the lowest probability is dropped first [16]. Table II summarizes the advantage and disadvantage of each strategy.

Basically buffer management policies can be divided into three types [17]:

- Global buffer management policy which utilize network-wide information regarding all messages.
- Local buffer management policy which use partial network knowledge like number of copies of message in the network, instead of all network-wide information correlated with messages and additional message properties like remaining TTL, size etc.
- Traditional buffer management policies like drop head, drop tail, drop random.

Table 2
Buffer Management in DTN

Strategy	Message dropping policy	Advantages	Drawbacks
DLR	Long stay time in buffer	Packets have enough replies in other nodes.	Has the less probability to be conceded to the other nodes.
DOA	Smallest TTL	Messages with smallest TTL have high probability to drop.	Messages are in the network from a long period of time.
DF	First In First Out	Simple.	Maximize the drop.
DLA	Based on message size	Simple.	Maximize the drop.
MOFO	Max number of forwarding	Improved buffer time average.	Maximize number of hops.
DL	Drop the newly received message	Simple.	Maximize the drop.
MOPR	Based on the predictability of the message being delivered	Less message drop.	Each message in node is related with a forwarding predictability (FP).
SHILL	Shortest TTL	Maximize delivery probability.	Maximize the drop.
LEPR	Message delivery probability	Less message drop.	Deciding P is complex.

V. CONCLUSION

To design a routing protocol that satisfies the main characteristics of DTN, it's necessary to study different routing protocols of DTN. This study gives the ability to characterize the performance and behavior of diverse routing mechanisms. The DTN routing protocols differ in the number of replication they make and knowledge that they use in making the routing decision. Epidemic (EP), Spray and Wait (SnW), PRoPHET and MaxProp routing protocols are the most popular routing protocols in DTN which used in the comparison.

DTN routing protocols exploit node mobility and message buffering to cope with problems in the network such as intermittent connection and partitions. This makes it possible for a node to carry messages and thus bridge partition in the network. Moreover, Buffer management schemes in a DTN should be designed considering the limited storage of nodes and the short contact duration between nodes.

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