Delay Tolerant Network and the Algorithms of DTN Routing

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Abstract. Delay Tolerant Network (DTN) is a new type of network, which is different from traditional TCP/IP communication protocol network. It is suitable for extreme environment where end-to-end communication connection cannot be established stably. Firstly, the characteristics and structure of DTN are analyzed, then the characteristics of nodes in the network are also analyzed. Secondly, the DTN routing problem is explained. Next, the classification of DTN routing algorithms and some classical routing algorithms are introduced. Finally, some other problems of DTN are proposed.

1. Introduction

With the rapid development of technology and the widespread establishment of communication networks, communication has broken the constraints of time and distance. People can access the network in most parts of the earth and communicate directly and effectively [1], which benefits from the mature Internet architecture and TCP/IP communication protocol. The stable operation of the TCP/IP protocol relies mainly on three underlying link features:

(1) There is a stable and reliable end-to-end link between the source node and the destination node;

(2) The maximum round trip time RTT (Round Trip Time) between any nodes is not long;

(3) The probability of message loss during transmission is low [2].

In fact, this end-to-end communication process cannot be completed when the above three points cannot be met in some disturbed environments. For the extreme communication environment, in 2003, K. Fall and other scientists proposed the Delay Tolerant Network (DTN) architecture [3]. DTN absorbs some contents from MANET (mobile Adhoc network) and WSN (wireless sensor network), mainly inheriting the architecture and partial protocols of IPA (inter-planetary network) established by NASA in 1998 to develop interstellar network communication. However, the latter experimental cost is very expensive. DTN extends the application of IPN to terrestrial mobile communications, emergency communications, underwater communications and wildlife monitoring. DTN can make up for the shortcomings of existing communication networks and realize communication connections in extreme or special environments.

In recent years, research on DTN has made great progress. Further in-depth research on the DTN network in the future will inevitably promote and promote network communication.
communications, underwater communications and wildlife monitoring. Since DTN can make up for the shortcomings of existing communication networks and realize communication connections in extreme or special environments, in recent years, research on DTN has made great progress. Besides, researchers have made significant achievements in routing protocols, evaluations and applications. This paper first describes the whole DTN network including its characteristics and architecture, and then summarizes its routing characteristics and protocols. Finally, it introduces the development of DTN applications [4].

2. DTN features and structure

2.1. DTN concept and characteristics

2.1.1. The concept of DTN. DTN is an abstract network model that does not target any layer of a particular network, but for all networks with delay tolerance. Delay tolerance means that the network protocol can still communicate without crashing even under extreme conditions. The extreme cases of DTN include [5]:

1. The overall topology of the network is unstable, and long-term segmentation may occur;
2. Node channel between nodes is unstable and asymmetrical;
3. Node processing capabilities are different.

The most important feature is network topology instability in some extreme cases. The basic premise of the traditional TCP/IP protocol implementation is that there must be one or more communication links from the source node to the destination node in the process of transmitting data packets. DTN is to solve the problem of network communication when the communication link from the source node to the destination node exists. The emergency network communication after the disaster such as traffic network, interplanetary network communication, battlefield network communication, earthquake, etc. and remote areas such as regional network communications are widely used.

2.1.2. DTN node features. In the communication network, a node may be a data communication device (DCE), such as a switch or hub, a bridge, etc., or a data terminal device such as a printer, router, workstation, server and so on.

The nodes in the DTN network are compared with the traditional communication network nodes as shown in Table 1.

| Characteristics     | DTN                              | Traditional communication network |
|---------------------|----------------------------------|----------------------------------|
| survival time       | Nodes with short survival time   | Do not consider the survival time problem |
| Space ratio         | Reduce the space ratio to extend node working time | The bigger the better |
| Storage capacity    | High demand for storage function and extra storage required for long queue time | Memory and cache, low memory requirements |

2.1.3. DTN characteristics. Due to the different environments applicable to traditional communication networks, DTN has the following characteristics:

1. The uncertainty of network delay

The network topology in DTN is dynamic, and the transmission medium is relatively special. Therefore, the network delay is uncertain. For example, in interstellar communications, the delay is usually several minutes or even longer. In an underwater acoustic modem network, the transmission...
rate is low, but the time of transmission delay is relatively long.

(2) Unstable connection

In DTN network, link connection occurs frequently. Factors such as attacks on nodes during military operations and natural conditions in earthquake emergency networks can cause active or passive disconnection between nodes. In addition, in an infinitely self-organizing network, most links are interrupted because of the large-scale high-speed motion of nodes (such as the motion of satellite nodes) or low duty cycle operation. These link disconnections are contingent and predictable.

(3) Long queue time

The DTN network link is disconnected frequently. To realize the function of normal communication, the network must require the node to save data for a long time to avoid discarding due to the pathfinding timeout. This causes the waiting time of the node to be basically unpredictable. Sometimes it can even reach hours or even days [6].

(4) The high rate of data transmission error and error

Dynamic changes in network topology and frequent movement of nodes make data transmission more unstable than traditional communication networks, resulting in a greater probability of packet loss than traditional communication networks.

(5) Asymmetric link transmission rate

In the DTN network, not only the communication link between the nodes may have a large difference, but also the uplink and downlink data transmission rates may have large differences even if there is a certain communication link between the determined two nodes. There is also a one-way data communication link. For example, in the interstellar communication process, the ratio of bidirectional data transmission rates is on the order of a thousand times.

2.2. DTN architecture

Like the Internet which is a network structure of interconnected heterogeneous regular subnets, DTN is a network that interconnects regional subnets. The difference between DTN and TCP/IP in architecture is a Buddle layer added between the transport layer and the application layer of the DTN network, as shown in Figure 1. This layer implements a DTN custody transport mechanism through a message persistence store to reduce the impact of link down on messaging. Under the system of escrow and transfer mechanism, each node’s cache holds a summary vector (SV, Summary Vector) that records the status information of its own node [7]. When the two nodes meet, the SV is exchanged to know the status information of the other node, and the message is also stored. In the node cache, the holding node of the message determines whether to forward or not delete the message in the cache according to a certain rule. Schematic diagram is shown in Figure 1

![Figure 1. The comparison of end-to-end transmission mechanism and storage and transmission mechanism.](image-url)
The convergence adaptation layer is introduced under the package layer and above the transmission layer. The package layer and the convergence adaptation layer provide a unified interface for the heterogeneous network environment in the transmission medium of lower layer to meet communication needs in different environments [8]. The message transmission of packet layer is based on the underlying protocol, such as TCP, UDP, IP and so on. The parcel layer passes different aggregation adaptation layer protocols, such as TCPCLP, Saratoga, LTP, etc., does not change the original TCP/IP underlying protocol, and corresponds to TCP, UDP and IP protocols, forming a network with "storage-carry-forward" characteristics. Structure, tolerant of intermittent connectivity, large delay and high error rate links, and finally complete the message transmission. Schematic diagram is shown in Figure 2.

![Figure 2. TCP/IP layered architecture and DTN layered architecture](image)

3. DTN routing

3.1. DTN routing problem

DTN completes the communication network under extreme conditions, accessing terminals which has the large number, varied kinds and huge differences. Therefore, routing has more problems than traditional communication networks, including the following two aspects:

1) Node connection

The end-to-end delay consists of waiting delay, queuing delay, propagation delay and transmission delay. The waiting delay is most important, and the size may be several seconds or even several days, resulting in connection delay between nodes. Unpredictable, this is also related to the movement of the node and the overall environment of the DTN. The data traffic transmitted by the link during it is built and disconnected cannot be accurately calculated, which is mainly determined by link performance and connection time. In the routing algorithm design [9], transmission data increase should choose the link with large bandwidth for transmission because of some factors.

2) Node performance

Nodes in the DTN network use the "storage-carry-forward" mode for data transfer. When the link is disconnected, the node stores the data. When the amount of data is too large to exceed the storage capacity of the node, data overflow will result in loss of information. There are many types of nodes in the DTN network. Some nodes have low processing power and are not suitable for running complex routing algorithms. Nodes that cannot continuously replenish energy should reduce computational overhead to reduce node energy consumption and extend node uptime.

According to the above problems, the following factors should be considered in the design of the DTN network routing algorithm: network topology dynamic change rate, communication link capacity, node cache capacity and average traffic volume between nodes.
3.2. Classic routing algorithm

3.2.1. Classic routing algorithm based on replication. In the DTN routing algorithm based on replication, nodes in the network relay messages by copying information when they meet. Therefore, during the delivery process, there will be a large number of message replicas in the network, which inevitably consumes a large amount of network resources.

Direct Contact algorithm. The algorithm is that the source node directly transmits the message to the destination node after the link between the source node and the destination node is connected. In the pathfinding process, it is not necessary to pay attention to the whole network environment, but only complete the communication between the source node and the destination node, which can be regarded as a special path-finding method based on Hongfan. However, the algorithm has a large network communication delay for a communication network with frequent link interruption.

The Epidemic algorithm is the most basic multi-copy routing algorithm [10]. It adopts a multi-replication flooding routing mechanism. Two nodes copy and forward message as soon as they meet. If the current node has no reachable target path, then the message is cached, and the message is stored for a long time. With sufficient resources, the Epidemic algorithm can spread the message copy as quickly as possible to achieve maximum delivery rate and minimum transmission delay. However, in practice, the resources of the node are limited. As the number of messages increases, the competition for resources causes the Epidemic performance to drop drastically. At the same time, a large amount of bandwidth, energy, cache and other resources are consumed in the message transmission process. Schematic diagram is shown in Figure. 3

![Figure 3. Epidemic algorithm](image)

Spray and Wait algorithm. The Spray and Wait algorithm are equivalent to a modified version of the Epidemic algorithm. By implementing a limit on the maximum number of message copies in the network, only a limited number of message copy transmissions are performed. The source node forwards the message to the next node through the flooding mechanism until the target node is encountered to complete the delivery of the message, which reduces the resource consumption and competition conflict caused by the excessive replication of the message, and improves the resource utilization to some extent. The message determines its maximum number of copies when it is generated. In the Spray phase, when a node that has a copy of a message does not meet a node that have the message, the former passes half of the message copy to the latter, and then enters the second stage until a node has only one copy of the message. The second stage is the Wait stage. Each node entering the Wait phase holds only one copy of the message. If these nodes are not the destination node, the message forwarding will not be completed until the destination node is transmitted.

Although the Spray and Wait algorithm can effectively avoid congestion compared to the Epidemic algorithm, its time of delay is still long.

3.2.2. Routing Algorithm Based on Forwarding Policy. The routing algorithm based on the forwarding policy is also called a routing algorithm based on prior knowledge. In this algorithm, the node selects an optimal transmission path by certain criteria according to the network topology
dynamic change information obtained by the node. Jian et al. abstract the DTN network into a directed multi-graph. Each edge corresponds to the relationship between two nodes. There may be multiple edges between a pair of nodes. So, there may be multiple different circuits only in different Time is available. According to the obtained network topology information, the algorithm can be divided into the following [11]:

FC (First Contact) algorithm. The node does not get any a priori information, forwards the message to the first node encountered, and then waits to meet the target node. This algorithm is the least efficient and does not guarantee that messages can be forwarded to the destination node.

MED (Minimum Expected Delay) algorithm. The node has a summary knowledge of the network, and uses the average waiting time to calculate the cost of the edge that changes with time. Finally, it finds the node that selects to forward through the shortest path first algorithm (Dijkstra).

ED (Earliest Delivery) algorithm. Under the premise of obtaining the prior knowledge of all contacts in the network, the algorithm uses the Dijkstra algorithm to solve the nodes selected for forwarding.

EDAQ (Earliest Delivery with All Queue) and EDLQ (Earliest Delivery with Local Queue) algorithm. Based on the ED algorithm, the global node cache queue information and the local node cache queue information are respectively introduced to further improve the network performance.

LP (Linear Program) algorithm. The algorithm adds a priori knowledge of traffic and uses the linear programming method to complete the selection of forwarding nodes through all the information touched by the network, global node queue cache information and traffic.

In fact, in an intermittent network, the more detailed the prior knowledge is paid, the higher the cost.

4. Other issues in DTN

4.1. Excess copy elimination

According to the number of message copies in the network, routing protocols can be divided into single-copy routing protocols and multi-copy routing protocols. A single-copy routing protocol keeps only one copy of the message in the network, while a multi-copy routing protocol propagates multiple copies of the message across the network. The node will carry and forward the message until the node receives the message and arrives at the destination node. After the message arrives at the destination node successfully, there will still be a copy of the message stored in the source node and the intermediate node, which inevitably causes duplicate redundancy and waste of resources. At present, for the redundant copy problem, the purpose to eliminate the redundant copy is to compare Small overhead removes messages that have already been delivered on the network without relying on specific routing protocols.

The elimination scheme of existing redundant copy can be divided into two types according to whether or not the acknowledgment mechanism is included: ACK and ACK. The ACK copy elimination mechanism is to generate a corresponding ACK after the destination node receives the message for the first time and flood the ACK in the network, so that the node having the corresponding message copy deletes the message copy in the cache, and all the nodes are not. The message [8] is accepted again. The ACK-free copy elimination mechanism relies on setting a threshold, which can be based on time or based on the number of nodes that are buffered in the message. When the threshold is reached, the node deletes the message copy. The difficulty of this solution lies in the threshold selection and the establishment of the size.

4.2. Security issue

According to the applicable environment and characteristics of the DTN network, the external device can access the network arbitrarily. At the same time, the node sends the message to all the connectable nodes as much as possible to ensure that the message is sent to the destination node. This makes the DTN network larger. Security risks - transmission of message leaks, attackers incoming malicious
messages. For such problems, the transmission message can be encrypted. The existing security mechanism is to insert a postmark for each message [12]. The postmark contains encrypted information for verifying the identity of the sender, the type of service and the correctness of the message content. On the hop node, the DTN network checks the postmark and discards the message as verified as early as possible. Such a security mechanism not only improves the security of the DTN network message transmission, but also improves the overall transmission performance of the network.

In addition to security verification, DTN networks face security threats such as denial of service and privacy breaches, which require in-depth research.

5. Conclusion
The DTN network is a good complement to existing network communications and has evolved into an independent research area. In recent years, many researchers have proposed excellent solutions for better data transmission in DTN networks. Each method has its own focus and shortcomings on network transmission performance and network resources, and is characterized by different network environments, such as links. Intermittent, number of nodes and characteristics, application environment, etc., can use different routing protocols and algorithms to achieve better communication quality and efficiency. Further in-depth research on the DTN network in the future will inevitably promote and promote network communication.

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