Improvement of Contact Graph Routing Algorithm in LEO Satellite DTN Network

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Abstract. As a space network technology, DTN (Delay/Disruption Tolerant Networks) has a wide range of applications in space system networking, and the application of DTN in LEO (Low Earth Orbit) satellite network is also a hot topic. Aiming at the problem of DTN routing technology in LEO satellite network, this paper proposes a routing algorithm for LEO satellite DTN network, which is based on throughput constrained minimum delay backup path of CGR (Contact Graph Routing) algorithm. By comparing the existing routing algorithms, this paper summarizes the problems existing in the application of existing routing algorithms in LEO satellite DTN network, proposes to calculate the shortest delay path of the whole network under the condition of throughput constraints, and select the best transmission path and backup path for data transmission. It solves the problems that the increase of queuing delay caused by the rapid change of network topology, the limited transmission capacity caused by single path transmission, and the active avoidance of node congestion. The simulation results show that compared with the traditional CGR algorithm and ECGR algorithm, the algorithm proposed in this paper is better in average delay and loss packet rate, and more suitable for LEO satellite DTN network.

Keywords: LEO satellite network · DTN · Contact Graph Routing

1 Introduction

In recent years, as the construction of LEO Mobile Communication satellite system in China is developing rapidly, some LEO satellite communication systems have been proposed successively, such as Hongyun and Hongyan [1]. However, the current networking technology of these satellite systems is still based on the ground IP networking technology.

Delay/Disruption Tolerant Networks [2] have the characteristics of intermittent connectivity, large delay and weak processing capacity of nodes, which makes DTN widely used in spatial information networks, such as [3, 4].

The successful application of DTN in space information network proves that DTN can also be used in LEO satellite network.

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In recent years, the application of DTN in LEO satellite network has attracted more and more attention. However, due to the direct application of DTN, there are a series of problems, especially in the aspect of routing. The existing DTN routing algorithms are designed according to special scenarios. Critical factors in the network (links or nodes) and network traffic are not considered; the drastic change of network topology leads to frequent interrupt of links; the storage capacity and computing capacity of nodes are limited; most of the existing DTN routes are single-path transmissions and so on.

In 2008, NASA(National Aeronautics and Space Administration) proposed CGR algorithm based on DTN Network [5]. CGR algorithm uses the periodicity of spatial network nodes. It generates contact graph through the known contact plan of each transmission node, and then determinies the transmission path of data according to the generated contact graph. Duing to its advantages of occupying less storage and computing resources, CGR algorithm has been widely used in spatial DTN network since it was proposed. [6, 7] have respectively verified the feasibility of applying CGR algorithm to LEO network. However, there are still a series of problems in applying the exsting CGR directly to LEO satellite network.

This paper will focus on the existing CGR routing algorithm and the problems of its application to LEO satellite network, and proposes a CGR algorithm suitable for LEO satellite DTN network, as well as carrys out simulation test on it.

2 CGR Algorithm

CGR is a routing based on prior knowledge. Becaues of the pre-planning and periodicity of the link between communication nodes, and according to the contact plan (connect information and distance information) of each node in the network, the contact diagram is generated. Contact plans include two types: connection messages and distance messages. Each connection message includes the start time, end time of the connection, the node number of the sender, the node number of the receiver, and the planned transmission rate; Each distance message includes the start time of the connection, the end time, the node number of the sender, the node number of the receiver, and the planned transmission distance. Once a connection plan information is obtained, the CGR routing algorithm can be applied.

When a message is sent from a communication node, the CGR algorithm will analyse the contact graph and calculate as well as generate a collection of next-hop nodes. And then it will select the transmission path in the collection. When the data reaches the next-hop node, the CGR algorithm will continue to run the process on the next- hop node [8–10]. CGR is a completely connection plan-dependent routing algorithm that uses less storage and computing resources than other routing algorithms in periodic application scenarios.

In order to avoid the loop and route oscillation caused by CGR algorithm in routing calculation, [11] proposes an improved algorithm–ECGR(Enhanced Contact Graph Routing), which uses Dijkstra algorithm to calculate the shortest path. And it reduces the cost of routing algorithm. It has become the core of CGR algorithm at present. In [12], based on the consideration of reducing the amount of nodes computation, CGR-EB algorithm is proposed and added extension block choreography into packets. In

[13], CGR-ETO(Contact Graph Routing Earliest Transmission Opportunity), the earliest transmission opportunity algorithm, is proposed. Considering the queuing delay of three different priority data, CGR-ETO improve the accuracy of arrival time of each priority bundle, and proposes the Overbooking Management mechanism to deal with the case of over-contact. This algorithm is the most recognized CGR algorithm at present. In [14], MD-CGR(Multi-Destination Contact Graph Routing). It analyse the path coding method and orchestrates the path information into the data. The intermediate node only recalculates the path when the contact changes. Thus, it reduce the calculation amount of the intermediate node in the resource-constrained environment.

These improved CGR algorithm all have their advantages, but the application of CGR algorithm to LEO satellite networks needs to be further improved.

[1]. Due to the high dynamic nature of LEO satellite nodes and the poor connection stability between nodes, it eventually lead to the inconsistency between the connection plan and the actual networking topology. The reliability of the transmission is poor, resulting in unreliable connection plans, and the final computed path may be invalid. At this time, the packet is temporarily stored in the satellite node, which greatly increases the queuing delay of the packet and the possibility of satellite node congestion.

[2]. CGR does not fully consider the state of link and queuing delay in calculation, which may cause packet loss due to excessively large transmission delay or even cache overflow in some special cases.

[3]. In LEO satellite DTN network, there will be some relatively "important" nodes, which exist on many paths and receive many packets at the same time. Under limited processing conditions, many packets will be cached in the nodes, which not only increases the packet queuing delay, but also causes node congestion very easily.

[4]. CGR algorithm is based on a single copy of the satellite, which is the data transmission between the source and destination only exist a transmission path. In this mode of transmission, transmission ability of CGR algorithm is limited. And CGR algorithm can not make full use of network resources, especially in LEO satellite network, which is the node with limited resources. Once the business conflict, the network is likely to cause the network congestion, and even partial paralysis.

Aiming at the above four problems, this paper improves the CGR algorithm, and proposes the Based on Throughput Constrained Minimum Delay Backup Path of CGR Algorithm.

3 Based on Throughput Constrained Minimum Delay Backup Path of CGR Algorithm

Based on throughput constrained minimum delay backup path of CGR algorithm (TCMDB_CGR) is divided into link checking and message forwarding. The link checking process adopts the link checking process of CGR algorithm.

3.1 The Connection Check Process

The connection check process computes the path recursively until a complete path without loops is found. The connection checking process traverses all the connection plan. If the receiving node of the connection plan information is not the destination node, then the node is skipped. For the receiving node of the connection plan information, it is the destination node:

If the sending node is a local node, it is directly added to the alternative node set;

If the sending node is a node in the alternative node set, it is skipped;

If the sending node is neither a local node nor a node in the alternative set of nodes, it is used as the destination node and the connection check process and is performed again;

Until all connection plans are traversed, an alternate set of nodes is obtained.

3.2 The Message Forwarding Process

After obtaining alternative nodes set through link checking process, TCMDB_CGR algorithm consider the link cache and throughput. It will set a threshold τ for the residual capacity of the link. If the residual capacity of the link is less than this threshold, the path will be deleted. In this way, it can reduce queuing delay caused by the heavy load of data packet forwarding to the link, and even avoid the packet loss caused by link overflow.

When there is no overflow in the link, we calculate the throughput according to the link connection time, and compare it with the expected volume of business. If the throughput is less than the expected traffic volume, the path will be deleted. If the throughput can meet the expected requirements, the transmission delay of the packet is considered.

Then, after two "filtering" of alternative nodes set, the total delay of packet transmission is calculated. The total delay sums transmission delay, propagation delay, queuing delay and waiting delay. The specific calculation process is as follows:

[1]. Link throughput:

$$W = \int_{t_{m,n-start}}^{t_{m,n-end}} c_{m,n}(t)dt \tag{1}$$

t_{m,n_start}: The node of "m" and "n" start contract time; t_{m,n_end}: The node of "m" and "n" end contract time; $C_{m,n}(t)$: The node of "m" and "n" information transmission rate.

[2]. Propagation delay: The propagation delay can be obtained by dividing the physical distance $D_{m,n}$ between the source node and the destination node by the speed of light.

$$t_{m,n} = \frac{D_{m,n}}{c} \tag{2}$$

$D_{m,n}$: The physical distance between the nodes of "m" and "n"; c: The speed of light (3*10^8 m/s).

[3]. Transmission delay: the processing time of the link layer.

$$t_{send} = \frac{L_{data}}{BW} \tag{3}$$

L_{data}: The frame length of the transmitted data packet, Unit: bit; BW: The channel bandwidth, Unit: bit/s.

[4]. Queuing delay: the sum of all data transmission delays waiting to be forwarded before forwarding the data.

$$t_q = \sum\nolimits_{i=0}^{n} \frac{L_{data}}{BW} \tag{4}$$

L_{data}: The frame length of the transmitted data packet, Unit: bit; BW: The channel bandwidth, Unit: bit/s.

[5]. Waiting delay: Not all data will be forwarded to the destination node immediately. There is a connection time between the source node and the destination node. If the current time is not within the connection time range, you need to wait for the link to connect before forwarding.

$$t_{wait} = \begin{cases} 0 & (t_{contract} \le t_{now}) \\ t_{contract} - t_{now} & (t_{contract} \ge t_{now}) \end{cases} \tag{5}$$

$t_{contract}$: Two nodes start contact time; t_{now}: The current time.

[6]. Dpath: Total delay time.

$$D_{path} = t_{m,n} + t_{send} + t_q + t_{wait} \tag{6}$$

According to the above method, the total delay time is arranged the delay in ascending order. And TCMDB_CGR algorithm will select the two paths with the minimum total delay. The path with the least total delay is selected as the best transmission path, and the path with the less total delay is selected as the backup path.

In order to avoid node congestion, TCMDB_CGR algorithm set a threshold set for each node to receive packets. Judge whether the capacity of the destination node of the optimal path reaches the threshold or not, and adopt the optimal path to transmit if the threshold is not reached; Otherwise, judge whether the threshold value of the destination node of the backup path reaches the threshold value. If the threshold value is not reached, the backup path is adopted for transmission; Otherwise, the two paths are removed and the new best path and backup path are re-selected from the alternative nodes set.

This scheme can effectively avoid some nodes with heavy link burden on the basis of guaranteed traffic and select other paths with smaller delay, so as to effectively reduce the impact of queued delay on the whole network performance. And the backup path scheme can reduce the computation of nodes to a certain extent, and it is more suitable for the network with limited resources of LEO satellite nodes.

The flow chart of forwarding decision is as follows (Fig. 1):

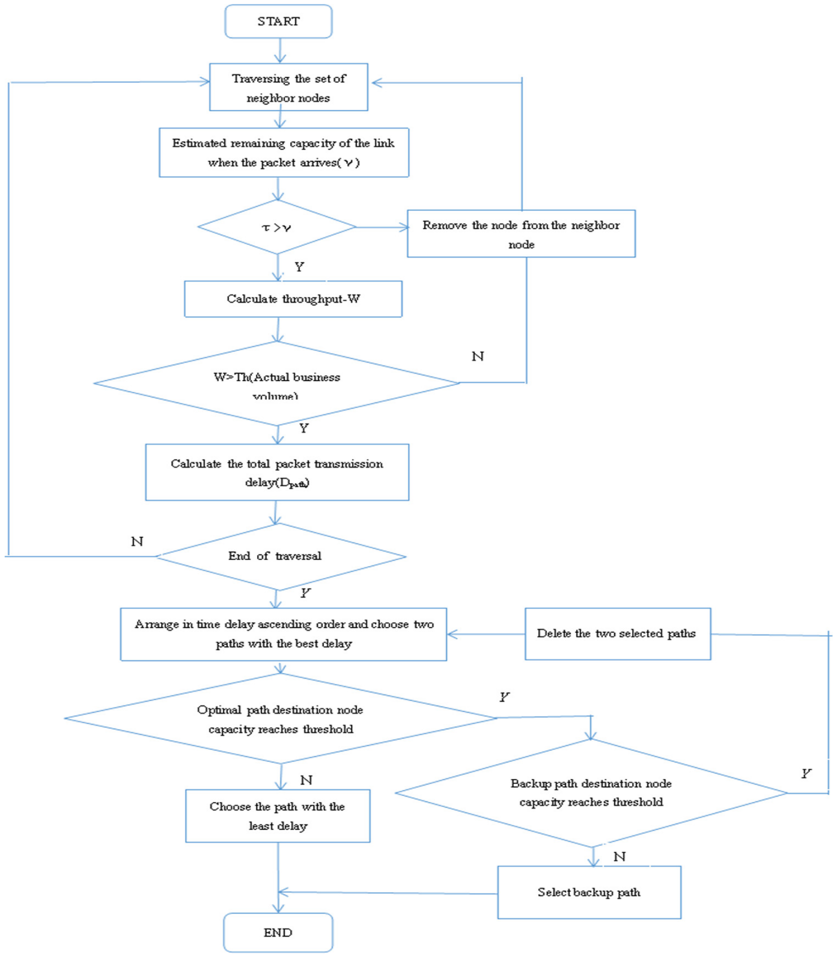

Fig. 1. The flow chart of forwarding decision

4 Simulation Test

The simulation in this paper is based on the SNSim simulation platform independently developed by the laboratory. The DTN nodes model is developed to build the LEO satellite network scenario. And the protocol is added to the node to set the motion trajectory and carry out simulation processing. In this scenario, 48 LEO satellite nodes, one space station node, one cargo spacecraft node, and one ground center node were designed and added. The ground center node transmits the data to the space station node or the cargo spacecraft through the LEO satellite network, and can realize the communication between the ground center node and the space station or the cargo spacecraft. The simulation scenario is initiated by the space station, the cargo spacecraft and the ground center. The transmission rate was 1 Mbps–2 Mbps, and the size of each packet was 1000Byte. In this simulation, all messages are normal (non-critical Bundle), that is, CGR algorithm is forwarded only as a single copy.

Carried out in the above network simulation scenario simulation, this paper realize the CGR based on the LEO satellite DTN network simulation. Under the scenario, packet loss rate and the end-to-end delay of CGR algorithm, ECGR algorithm (the most commonly used CGR routing algorithm) and TCMDB_CGR three routing algorithm has carried on the contrast, and confirmed that the improvement of CGR algorithm has optimal performance (Fig. 2).

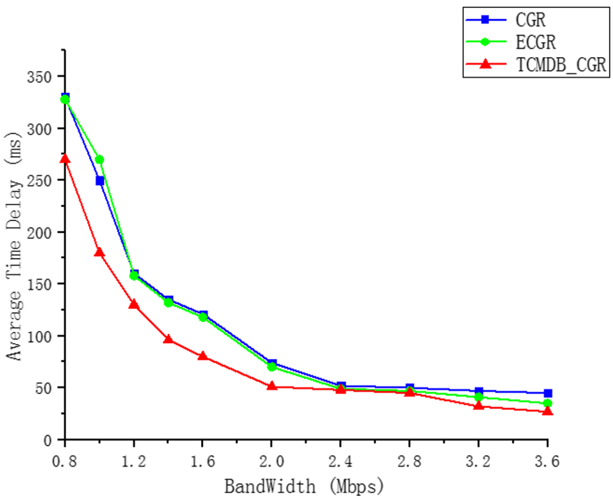

Fig. 2. Relationship between average time and bandwidth

The simulation results of average delay can be seen as follows:

With the increase of link bandwidth, the average delay of the three routing algorithms presents a downward trend. This is because with the increase of link bandwidth, the node processing cache speed is faster, and the packet sending delay and queuing delay are greatly reduced. However, on the whole, the delay curves of CGR algorithm and ECGR algorithm are not significantly different, while the average delay of TCMDB_CGR algorithm is significantly smaller than the above two algorithms. Especially in the case of poor link performance, TCMDB_CGR algorithm can significantly improve the average delay of the whole network. This shows that TCMDB_CGR algorithm has more advantages in network performance under the condition of limited link resources.

This is because the TCMDB_CGR algorithm fully considers the link state and queueing delay. In the case of a link queue with too high occupancy rate or a node with too high cache, it can choose a more "idle" path to avoid a long queued waiting transmission (Fig. 3).

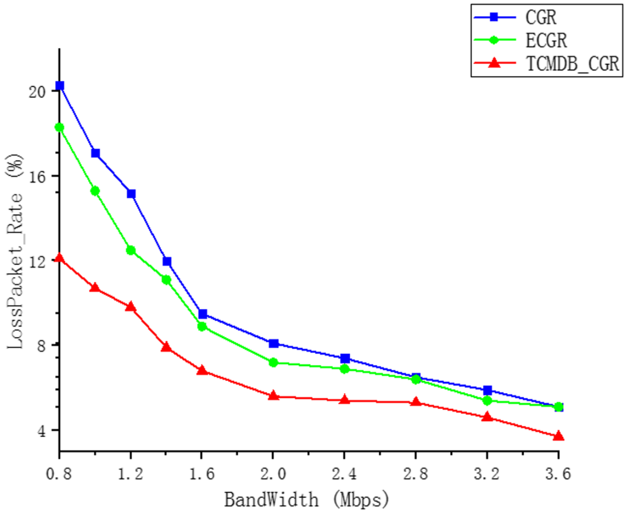

Fig. 3. Relationship between loss_packet_Rate and bandwidth

The simulation results of packet loss rate can be seen as follows:

With the increase of link bandwidth, the packet loss rate of the three routing algorithms decreases. This is because the link bandwidth increases, queue processing speeds up, and the packet loss caused by queue overflow is reduced under the premise of constant node caching capacity. But on the whole, ECGR algorithm and CGR algorithm, the packet loss rate is slightly smaller, but the difference is not big. The packet loss rate of TCMDB_CGR algorithm is much lower than that of the other two algorithms, especially in the case of poor link performance. With the increase of link bandwidth, the packet loss rate of TCMDB_CGR algorithm drops faster.

This is because the TCMDB_CGR algorithm fully considers the link state and the reliability of the connection plan, bypasses the path that may cause congestion and nodes near congestion, makes full use of the entire network resources, and reduces the packet loss caused by cache overflow. At the same time, it avoids the unstable link, ensures the traffic volume of network transmission, increases the reliability of network, and reduces the packet loss caused by packet failure due to queuing delay.

5 Conclusion

In this paper, CGR algorithm based on throughput constraint minimum delay backup path is proposed for LEO satellite DTN network. It is introduced and compared with simulation. Simulation results show that compared with CGR algorithms and ECGR algorithms, TCMDB_CGR has better end-to-end delay and packet arrival rate, which proves that the routing algorithm proposed in this paper is more suitable for LEO satellite DTN network.

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