



Constrained Multipath Routing Algorithm Based on Satellite Network

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Abstract. Due to dynamic changes in network topology and constant changes in links between satellites, the routing paths calculated by the traditional shortest multipath routing algorithm are not updated in time, resulting in that the problematic paths are still transmitting data, so a large number of problems such as packet loss and service failure exist in the network. This paper designs a multipath routing algorithm for the satellite network topology which changes frequently, constrained multipath routing algorithm (CMRA). By calculating all feasible path of the entire network topology, CMRA will choose the multiple paths which satisfy the constraint conditions. After that, it will choose the lowest cost value of these paths. Repeatedly performing these operations, select multiple high-quality paths which satisfy the constraint conditions for traffic. Simulation results show that compared with the traditional shortest multipath routing algorithm and single path routing algorithm, the proposed routing algorithm is better in packet loss rate and average time delay.

Keywords: Satellite network · Constraint condition · CMRA

1 Introduction

Satellite communication systems, which cover a wide range of areas and are not affected by geographical and climatic conditions, have received widespread attention [1]. Satellite networks are characterized by frequent changes of network topology caused by the high-speed movement of satellite nodes, high density and short bursts of data received in places with large population, and unequal distribution of traffic, resulting in a large number of packet loss and service failure. The so-called multi-path routing refers to finding multiple paths from the source node to the destination node in the network through certain constraint rules [2]. The traditional shortest multipath routing algorithm selects multiple paths with the smallest path length after relaxing all the edges. It does not take the problem of route consumption, time delay and path failure caused by the change of satellite link into account [3]. Literature [4] proposes a perceived more energy path load balancing routing algorithm which uses energy perception to choose node which meets the condition as a routing node, and establishes more efficient way of connecting the source node and destination node. Through the analysis of the hop count of path and the buffer occupancy of nodes, it chooses the high quality path to transmit traffic. Literature [5] proposes a LEO load balancing routing

algorithm based on ant colony. It makes routing decisions by collecting physical layer information and uses multi-objective optimization model to realize load balancing, which performs well in balancing load and improving message transmission rate. Literature [6] proposed a tunable accuracy multiple constraints routing algorithm, TAMCRA. Although the algorithm can solve the multi constraint routing problem, the performance and cost of the algorithm depend on the number of shortest paths, K . If K is large, the algorithm can provide good performance, but at the cost of sacrificing too much computing cost. The routing algorithms above can do well in traffic balance, but they do not take the comprehensive quality of the path, the routing path failure problems caused by the changes of satellite links and the failure of satellite nodes into account.

In this paper, constrained multipath routing algorithm (CMRA) is proposed. After calculating all the possible paths in the network, CMRA filters the feasible paths by multiple constraints, and chooses the path with the lowest cost which meets the set constraints. Then, the network topology is simplified. Repeat the previous operation many times, and more paths which meet the set constraints will be selected. Finally, the traffic is carried by these paths according to a certain traffic allocation ratio. The aim of simplifying the network topology is that all selected paths do not interfere with each other, which means that if there are some problems with one node in the path, other paths can carry the traffic normally. Simplifying the network topology improves the reliability of multiple paths and reduces the possibility that multiple paths cannot transmit data due to node failure. Experimental results show that CMRA is superior to the shortest multipath routing algorithm in terms of packet loss and average time delay.

2 Constrained Multipath Routing Algorithm

2.1 General Introduction

The routing algorithm proposed in this paper is a multi-path routing algorithm based on Bellman_Ford algorithm combined with constraint mechanism, named constrained multipath routing algorithm (CMRA). CMRA mainly includes three aspects: the determination of multiple constraints, the network topology simplification and the allocation of traffic.

After relaxing the network topology, CMRA selects all the routing paths that meet the conditions according to the multiple constraints, and selects the path with the lowest cost value from the paths. The network topology simplification operation is performed on the network topology according to the selected routing path so that the first path and the second path do not interfere with each other. The second routing path that meets the constraints is selected after the operation of simplifying network topology until there is no path that meets the multiple constraints. At last, the traffic is carried according to a certain traffic allocation ratio.

The general process is shown in the figure below (Fig. 1):

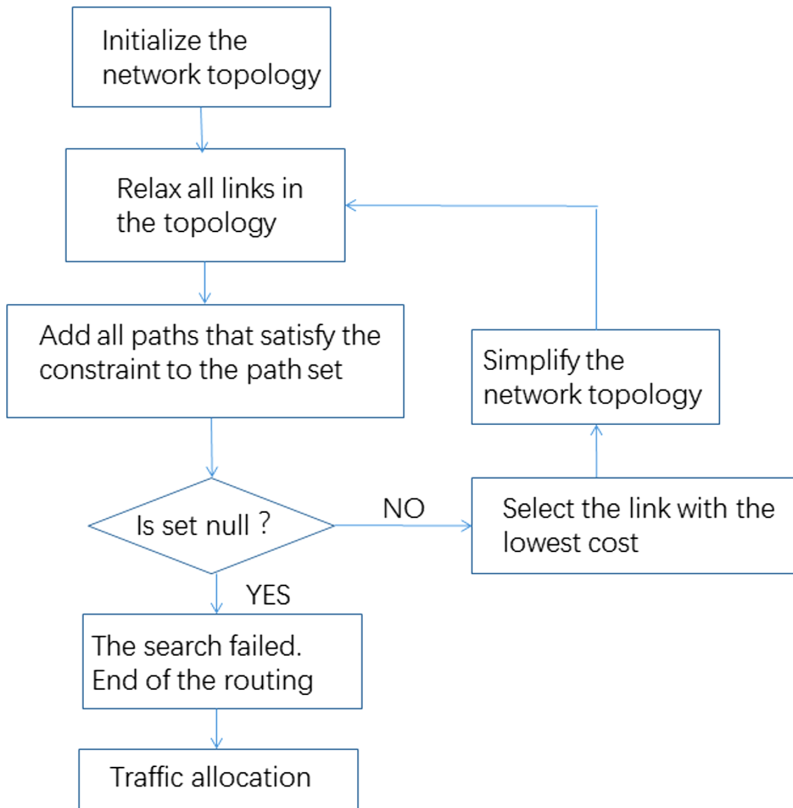


Fig. 1. The general process.

Its concrete realization is as follows:

- (1) Relax the initialized network topology;
- (2) According to Bellman_Ford routing algorithm, all feasible paths are calculated, and all paths that satisfy multiple constraints are found. If the path does not exist, the search fails and the route ends. if there is, the next step is carried out;
- (3) Find the path with the lowest cost value among all the paths selected in the previous step and set it as the first path;
- (4) The simplified network topology G_1 is obtained by simplifying operation of network topology G ;
- (5) Relax the network topology G_1 ;
- (6) According to Bellman_Ford routing algorithm calculates all feasible paths in G_1 and finds out all paths that satisfy multiple constraints. If there are no paths, the search fails and the route ends; if there is, the next step is carried out;
- (7) Find the path with the lowest cost value among all the paths selected in the previous step and set it as the second path;
- (8) Go back to (4) to get the third path, the fourth path until the end of the route.

2.2 The Initialization of Network Topology and Relaxation Operation

Firstly, the whole network topology is initialized, that is to update all node information including location information and link connection information.

Relaxation operation is if there is another path between two points, and the distance between the two points is less than the current distance between the two points, then the shortest path length between the two points is updated to this smaller distance. If there is a vertex that can not be relaxed, it is said that the vertex has converged. As shown in Fig. 2, the distance from a to b is 5, but the distance from a to b via c is 3 which is smaller than 5 for $d_{ac} + d_{cb} = 1 + 2 = 3 < d_{ab} = 5$. Therefore, the distance between a and b is updated to 3, and all points have converged.

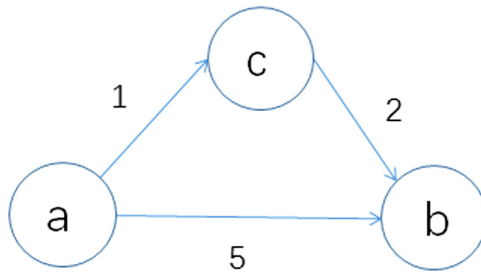


Fig. 2. A network topology for showing relaxation operation.

2.3 The Determination of Multiple Constraints

Multiple constraint condition is a routing mechanism which can select feasible paths that satisfy various constraints according to the different requirements of QoS measurement parameters in network state information [6]. The commonly used QoS metrics parameter include three types: additive metrics parameter, such as typical cost, hops, time delay, jitter and forwarding hops; multiplicative metrics parameter, such as loss rate and reliability; concave metrics parameter, such as bandwidth.

For a path P in the network, if $w(e)$ is an additive metric parameter for each link on path P , then the value of the QoS metric parameter of path P is the cumulative value of the QoS metric parameters of each link on the path P , namely:

$$w(P) = \sum w(e) \quad (1)$$

If $w(e)$ is the multiplicative metric parameter for each link on path P , then the value of the QoS metric parameter of path P is the product value of the QoS metric parameters of each link on the path P , namely:

$$w(P) = \prod w(e) \quad (2)$$

If $w(e)$ is the concave metric parameter for each link on path P, then the value of the QoS metric parameter of path P is the minimum value of the QoS metric parameters of each link on the path P, namely:

$$w(P) = \min w(e) \tag{3}$$

There are many classical multi constraint routing algorithms such as heuristic multi constraint optimal path routing algorithm, named H_ MCOP algorithm. H_ MCOP algorithm is to ensure to find the path that satisfies multiple constraints and costs the least [7]. Its comprehensive measurement parameters are as follows:

$$g_\lambda(p) = \left(\frac{w_1(p)}{c_1}\right)^\lambda + \left(\frac{w_2(p)}{c_2}\right)^\lambda + \dots + \left(\frac{w_k(p)}{c_k}\right)^\lambda \tag{4}$$

Where $w_k(p)$ is the k'th metric parameter of path P and C_k is the k'th constraint parameter of path P. As λ tends to be positive infinity from 1, the success rate of the algorithm to find the path that satisfies multiple constraints and costs the least is also increasing [8].

G(V, E) is assumed to be the basic model of satellite network topology, where $V = \{v_1, v_2, \dots, v_N\}$ represents the set of N switching nodes and $E = \{e_1, e_2, \dots, e_N\}$ represents N links in the satellite network topology, and constraint parameters are added for each link. In this paper, constraint parameters include the reliability in the multiplicative measure parameters, which are represented by $d(e)$, and the hops and time delay in the additive measure parameters, which are represented by $w_k(e), k = 1, 2, \dots, K$. Each parameter is:

- (1) Reliability: conditions of actual communication links;
- (2) The number of hops: the number of the output ports of routing node through which the packet will pass from the source node to the destination node;
- (3) Time delay: the time delay is the total delay of data packet transmission, which is the sum of propagation delay, sending delay, queuing delay and waiting delay. The propagation delay is the physical distance between the source node and the destination node divided by the speed of light. The transmission delay is the processing time of the link layer. The queuing delay is the sum of all the data transmission delays waiting to be forwarded before the data is to be transmitted. The waiting delay is the time waiting for the link to be connected to forward the data.

If the source node is S and the destination node is T in the satellite network topology, the parameter is $C(C_1, C_2, \dots, C_K)$ for K additional constraints. Let P1 and P2 be the paths from source node S to destination node T, (i, j) be the subpath on path P1, and (a, b) be the subpath on path P2. Then the cost of P1 is:

$$\text{cost}(P1) = \sum_{(i,j) \in P1} \cos t(i,j) \tag{5}$$

So, using the cost of P1, we can know that its constraint condition is:

$$w_k(P1) = \sum_{(i,j) \in P1} w_k(i,j) \leq C_k, k = 1, 2, \dots, K \quad (6)$$

In the same way, the constraint condition of P2 is obtained as follows:

$$w_k(P2) = \sum_{(i,j) \in P2} w_k(a,b) \leq C_k, k = 1, 2, \dots, K \quad (7)$$

Finally, the paths are then filtered again based on the overall reliability metrics of P1 and P2.

The general process is shown in the Fig. 3.

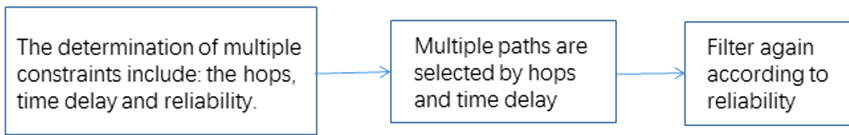


Fig. 3. The process of the determination of multiple constraints.

2.4 The Network Topology Simplification

Due to the change of satellite network topology, in order to reduce the impact of satellite link changes and node failure resulting that routing path can not normally transmit data, this paper designs a simplification of network topology. Network topology simplification is to delete some links or nodes according to a routing path selected, so that there is no common link between the routing path calculated by the network topology before simplifying and the routing path calculated by the simplified network topology. This also realizes that when the link changes or the node fails on a certain routing path, it will not cause multiple paths to be unable to transmit data normally.

The main ideas of network topology simplification are as follows:

- (1) Find out the subnet of source node and destination node;
- (2) After calculating the first path satisfying the constraint conditions, the sub network of each node in the path except the source node and the destination node is found;
- (3) Judge whether the sub network is the same as the sub network of the source node or the sub network of the destination node. If yes, delete the node and the link associated with the node; if not, delete all the nodes in the sub network and the link associated with each node in the sub network.

For example, if the network topology is as follows:

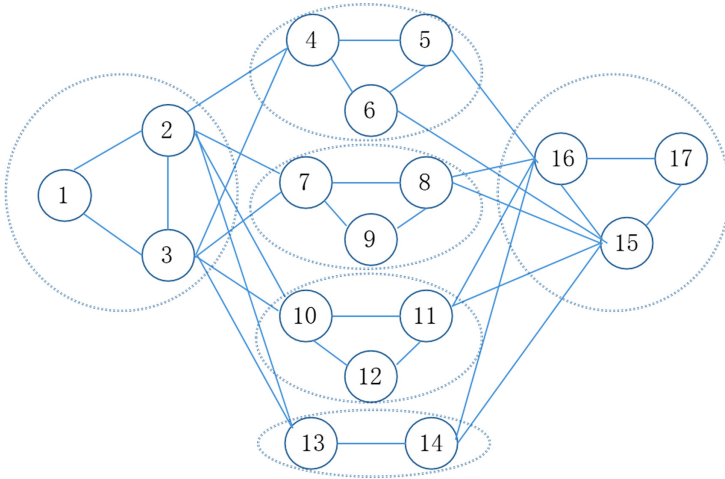


Fig. 4. A network topology.

The source node is node 1 and the destination node is node 17. The subnet of each node is shown in the Fig. 4. The first path is assumed to be: 1->2->4->5->16->17. As shown in the Fig. 4, the subnet of node 2 coincides with that of source node 1. Then delete node 2 and link 1-2, link 2-3, link 2-4, link 2-7, link 2-10 and link 2-13. The subnet of node 4 and node 5 is different from that of source node 1 and destination node 17. Therefore, delete all nodes of the subnet, including node 4, node 5, node 6, and their associated links, including link 4-5, link 4-6, link 5-6, link 4-2, link 4-3, link 5-16, and link 6-15. For node 16, its subnet is the same as that of destination node 17. So delete node 16 and the links associated with node 16, including links 5-16, link 8-16, link 11-16, link 14-16, link 16-17, and link 16-15.

Therefore, the new network topology after simplifying the above network topology is shown in the Fig. 5:

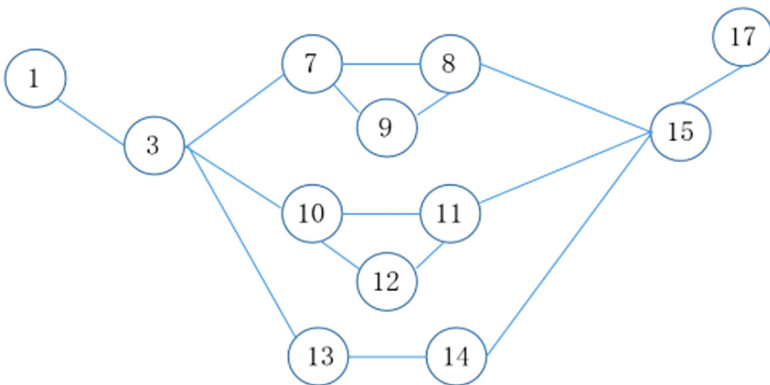


Fig. 5. The simplified network topology.

The process of the network topology simplification is (Fig. 6):

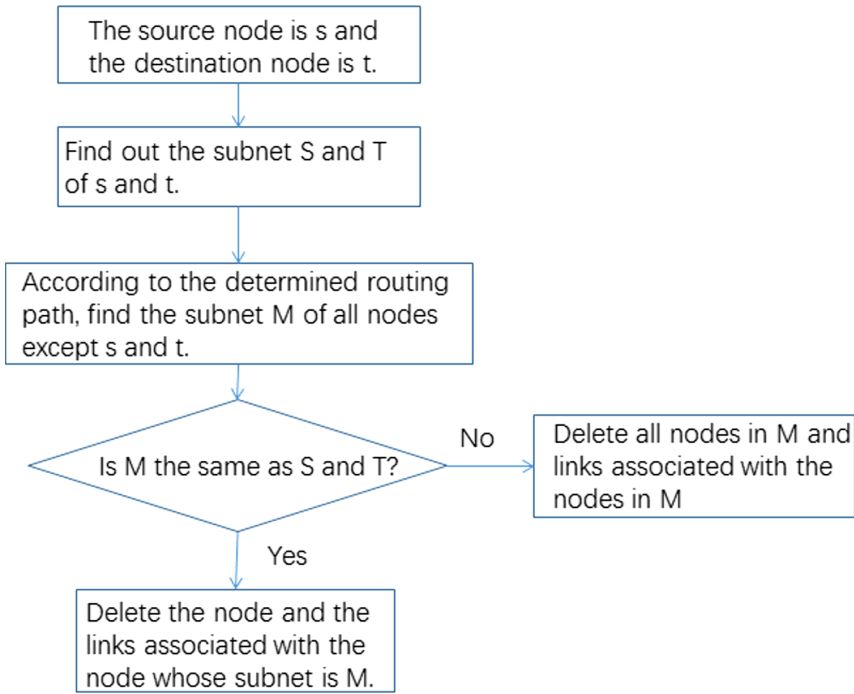


Fig. 6. The process of the network topology simplification.

2.5 The Allocation of Traffic

In order to avoid congestion and achieve traffic balance, it is necessary to allocate traffic according to the information of path when transmitting data through multi-path routing. Firstly, two definitions are given.

- (1) Link bandwidth utilization: For $\forall(i,j) \in E$, the link bandwidth utilization of (i, j) is:

$$U_{ij} = [1 - (R_{ij} - b) / C_{ij}] \times 100 \tag{8}$$

- (2) Path bandwidth utilization: For $\forall(i,j) \in P_1$, the path bandwidth utilization of P_1 is:

$$U(P_1) = \max_{(i,j) \in P_1} U_{ij} \tag{9}$$

R_{ij} is the residual bandwidth of link, b is the number of bandwidth requested by the call and C_{ij} is the link capacity.

Link bandwidth utilization reflects the bandwidth usage of a link, and usually also reflects the load of the link. The path bandwidth utilization is represented here by the bandwidth utilization of the most heavily loaded link on the path [9].

In this paper, in order to better balance the traffic, the path is weighted according to the path bandwidth utilization, and the weight is called the path equalization weight, named W . A smaller W indicates a lighter load on the path, while a bigger W indicates a heavier load on the link. Finally, carry on the traffic allocation according to W .

3 The Simulation Test

3.1 The Simulation Scene

The simulation in this paper is based on the SNSim simulation platform independently developed by the laboratory. The TELEDESIC satellite constellation is the satellite network scenario used in this paper. The satellites in the TELEDESIC constellation orbit the Earth at a nominal altitude of 1,375 km and have 12 circular orbits with near-polar dip angles and adjacent ascending points. Each orbit plane contains at least 24 active satellites with uniform spacing. That is to say, there are 288 satellites in the whole satellite constellation with an orbit inclination of 84.7° . Set up three domestic earth stations, one foreign station. They are Beijing, Sanya, Kashi, and Greenbell in the United States. In this paper, three domestic ground stations receive services and send them to Greenbell ground stations. The size of each packet is 1000 bytes.

3.2 Simulation Data Analysis

In this paper, we simulate the constrained multipath routing algorithm in the above satellite network scenarios, and compare with RIP routing algorithm and classical shortest multipath routing algorithm in packet loss rate and average time delay.

The simulation data of constrained multipath routing algorithm (CMRA), shortest multipath routing algorithm (SMRA) and single path RIP routing algorithm are as follows:

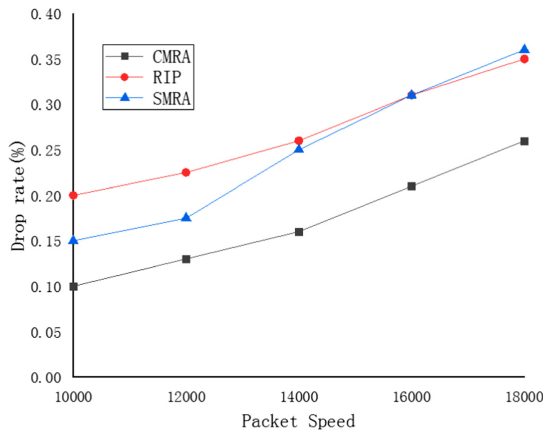


Fig. 7. Comparison of packet loss rate of different algorithms.

From the simulation data in Fig. 7, it can be seen that with the increase of packet speed, the packet loss rate of CMRA, RIP and SMRA increases, but the performance of multipath routing algorithm under constraints is better. This shows that with the increase of the number of packets received by nodes, CMRA can reasonably consider the path of data transmission according to the network link conditions, which greatly reduces the packet loss rate (Fig. 8).

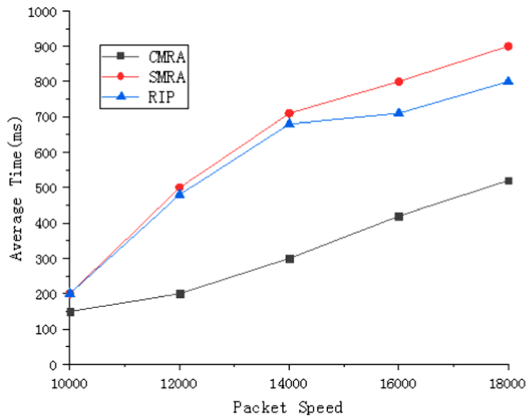


Fig. 8. Comparison of average time delay of different algorithms.

It can be seen from the simulation data, with the increase of package speed, the average time delay of CMRA, RIP and SMRA increases, but on the whole, CMRA greatly reduces the average time delay. This shows that CMRA can choose the idle path when a certain path's load is too heavy.

In general, with the increase of packet speed, the performance of CMRA in packet loss rate and average time delay is better than that of traditional multipath routing algorithm. The constrained multipath routing algorithm fully considers the specific situation of the link, and selects a better path for traffic transmission to alleviate the pressure of congested path. Constrained multipath routing algorithm can greatly reduce the impact of node failure or link changes which does not reflect in the routing path in time. With the increase of packet speed, the effect is more obvious.

4 Conclusion

In order to solve the problems of packet loss and average time delay caused by the dynamic changes of satellite network topology, this paper proposes a multipath routing algorithm under the constraint which can effectively solve the link frequency change, satellite node failure and the overall traffic balance problem in satellite network. The algorithm selects the high-quality path to transmit traffic through the constraint conditions, and simplifies the network topology.

This paper completes the simulation of CMRA, RIP and SMRA, and compares the three routing algorithms in packet loss rate and average time delay. From the simulation data, we can see that CMRA greatly reduces the packet loss rate and average time delay, and can better achieve the overall traffic balance of satellite network.

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