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LINK-RECONFIGURATION ALGORITHM OF LOW-ORBIT INTRA-LAYER INTER-SATELLITE LINK BASED ON WEIGHT VALUE

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Abstract. *In satellite network, a link-reconfiguration algorithm based on weight value is proposed to solve the problem of delay increases and short link duration. The algorithm assigns weight values for satellites, firstly builds inter-satellite links of the satellite whose weight value is biggest, guarantees longest link duration, meanwhile, chooses links in which link delay is least to build, reduces link transmission delay, and then completes the rebuilding of inter-satellite links. The article constructs network topology and the link-reconfiguration scenario by STK simulation software, and then completes simulation verification of the algorithm performance by NS2 simulation software. The result to the simulation has shown that the link-reconfiguration algorithm extends the duration of new links by a large range, and reduces the end-to-end link delay in satellite network.*

Keywords: Connectivity degree, Link delay, Link duration, Link-reconfiguration

1. **Introduction.** The network layer of low-orbit satellite takes on network pivot in the satellite network, whose stability plays the key role in the whole satellite network. In the network, there will be satellite failure due to overload imbalance or abnormal work, which may lead to link failure around the satellite, and especially in the military satellite network, the satellite failure will appear more frequently. In the case of satellite failure, link-reconfiguration can avoid the failure satellite by building new inter-satellite links. The existing link-reconfiguration algorithm mainly includes: link-reconfiguration algorithm based on minimum link delay (Distance Algorithm for short), link-reconfiguration algorithm based on maximum visible time (Time Algorithm for short), link-reconfiguration algorithm based on maximum available resource (Resource Algorithm for short), and the main distinction of the three algorithms is the way of rebuilding satellite links [1]; Table 1 shows the comparison.

Giving consideration to advantages and disadvantages of the three algorithms, the TDR (Time-Distance-Resource) mixed type link-reconfiguration algorithm is proposed; the algorithm promotes link duration, and has outstanding contribution to the aspects of distance and resource optimization. Relative to the distance algorithm and time algorithm, the proposed TDR algorithm sets a connectivity degree threshold for each node. Once a satellite reaches its connectivity degree threshold, the satellite will not be connected with other satellites. Then the problem of the node resources caused by overloading is avoided. Compared with the resource algorithm, TDR algorithm prefers to select the node which gets the largest weight calculated by its position, so it can improve the communication time of the link.

Table 1. Comparison of three algorithms

Name	*Advantage*	*Disadvantage*	*Principle of reconfiguration*
Distance algorithm	*Minimum delay*	*Building links more frequently,* *Not consider satellite overload (resource problem)*	*Choose the minimum link delay satellite*
Time algorithm	*Maximum visible time*	*More link delay,* *Not consider satellite overload (resource problem)*	*Choose the maximum visible time satellite*
Resource algorithm	*Utilize resource to the full*	*More link delay*	*Choose most idle resource satellite*

2. **Algorithm Theory and Steps.**

2.1. **Algorithm theory.** The idea of the TDR based on weight value. TDR algorithm is to assign weight values to satellites which need link-reconfiguration, the assignment of weight values relates to the latitude of satellites. Firstly build links around the satellite which has the biggest weight value, and guarantee new links to have the longest connecting time; meanwhile, when building links, satellites should choose the links which have the minimum link delay, and satellites cannot exceed personal connectivity degree threshold. The algorithm includes the following three steps:

(1) Algorithm sets a latitude threshold for each satellite, when designing the topology structure, that is, satellites cannot build inter-orbit link when their latitudes exceed latitude threshold.

In order to keep the rebuilding inter-satellite links for more time, the algorithm assigns weight values for satellites by the latitude, by which it decides the order to build links. Supposing latitude threshold to be $lat\_threshold$, that is, when latitude value of satellite $lat(i)$ is in the range $[-lat\_threshold, lat\_threshold]$, satellite can build inter-satellite link, the method of computation of weight value is that:

i) when satellites move from south to north, that is, the last-time latitude value of satellite is less than current latitude value, lower latitude, bigger weight value. Mapping the latitude value into interval $[-2*lat\_threshold, 0]$ by function $f(x) = x - lat\_threshold$;

ii) when satellites move from north to south, that is, the last-time latitude value of satellite is more than current latitude value, higher latitude, bigger weight value. Mapping the latitude value into interval $[0, 2*lat\_threshold]$ by function $f(x) = x + lat\_threshold$;

So that the weight value [2] of each satellite is shown as Formula (1):

$$\text{weight}(i) = \frac{|f(lat(i))|}{\sum\limits_{i} |f(lat(i))|} \qquad \text{weight}(i) \in (0, 1) \tag{1}$$

(2) The connectivity degree of node is defined to the number of links that some node builds with other nodes in the network. To avoid the new building links making connectivity degree of other satellites bigger, which will make satellites paralysis, the algorithm sets a connectivity degree threshold for each satellite, and when the connectivity of satellites reaches to threshold, they will not build any links, so it supply guarantee for network stability. Algorithm sets the threshold to be the initial value of satellites, and the threshold will not change in the whole link-reconfiguration.

(3) Link failure will directly lead to link length of data transmission increasing, and then lead to link delay increasing by a large margin, which is unbearable to real-time

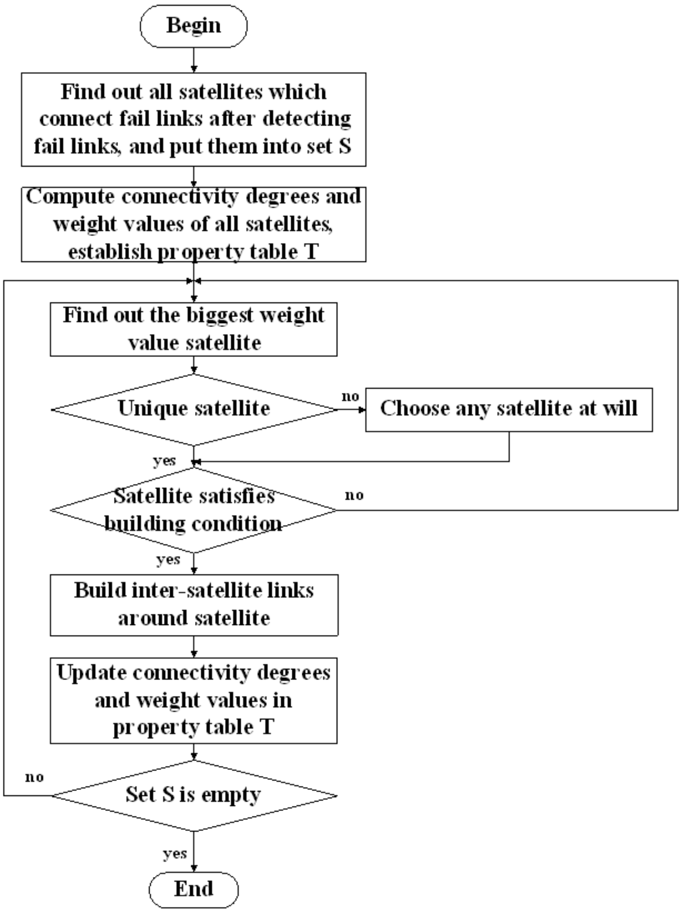

FIGURE 1. The TDR mixed type based on weight value link-reconfiguration algorithm flow chart

traffic. When link fails, the algorithm chooses the smallest delay link to build to recover normal network communication, and reduces link delay increment to the utmost.

2.2. **Algorithm steps.** In the LEO constellation of TDR algorithm implementation, the assumptions of this paper are as follows:

(1) LEO satellite connectivity threshold is greater than 1. As one LEO satellite communicates with less than two satellites, it cannot constitute a satellite network. When a satellite node failed, it cannot complete the reconstruction with this algorithm.

(2) The account of LEO satellite constellation cannot be less than three. It must exist 3 satellite nodes in network at least, otherwise there is no alternative node for reconstruction.

(3) Each LEO satellite is able to calculate the position of itself. When TDR algorithm worked, calculating the value of each satellite's latitude is needed. TDR algorithm selects the reconstruction node based on the weight value.

Algorithm flow chart is shown as Figure 1, and the steps are:

Step 1: Connectivity degree table building

Find out all satellites which connect fail links, N satellites supposed, put them into set S, that is, $\mathrm{S} = \{\mathrm{S}(1), \mathrm{S}(2), \ldots, \mathrm{S}(N)\}$, and establish the property table T of these N satellites, compute the weight values, current connectivity degrees and connectivity degree threshold of satellites, the format of table T is shown as Table 2.

The intentions of table T are that on the one hand finding out the satellite which weight value is biggest, and firstly doing link-reconfiguration to it; on the other hand we

Table 2. Table T of satellites property

Satellite	*Satellite 1*	*Satellite 2*	...	*Satellite N*
Weight value				
current connectivity degree				
connectivity degree threshold				

can judge which satellite reaches connectivity degree threshold from table T, and get rid of these satellites when building links;

Step 2: Link-reconfiguration satellite confirmation

Finding out the satellite which weight value is biggest from table T, marked as *S_Wmax*, which connectivity degree is marked as *C_Wmax*, when there are not only one satellite weight value equal, choose one at will and firstly build links for it;

Step 3: Building reconfiguration link

Firstly build inter-satellite link around *S_Wmax* satellite, the number of building links is *C_ threshold* -*C_Wmax*, *C_ threshold* is the connectivity degree threshold of satellite *S_Wmax*, and choose other satellite in set S to build link. The choice to build link need to follow three conditions: firstly guarantee the visibility between *S_Wmax* and the other satellite, secondly guarantee that respective connectivity degree of these two satellites must be less than respective connectivity degree threshold, thirdly build link with the satellite which link distance between them is shortest. If one condition of them do not satisfy, choose again from other satellite. If no satellite satisfies condition until the last satellite, choose the next *S_Wmax* which weight value is biggest from set S, execute Step 3. When no satellite is in set S, jumping to Step 6;

Step 4: Link updating

If finding out the link which according with the three condition in Step 3, building links around *S_Wmax*, and recalculate weight values and connectivity degrees in property table T, choosing the next *S_Wmax* which weight value is biggest form other satellites, jumping to Step 3, building links around *S_Wmax*, until set S is empty, the purpose is to do its best to build new links for each satellite which connecting fail link. If no new link is to build when set S is empty, link-reconfiguration completed, jumping to Step 6;

Step 5: Execute Steps 2-4 circularly, until set S is empty, jumping to Step 6;

Step 6: Link-reconfiguration completed, waiting for next link-reconfiguration.

After the usage of the TDR mixed type based on weight value link-reconfiguration algorithm, the algorithm not only rebuilds inter-satellite link which can keep the longest visible time, but also gives guarantee to delay and satellite network stability. Then we are going to do the simulation to verify performances in time, delay and stability.

3. Scenario Modeling and Simulation Verification of Algorithm Performances.

The experimental parameters include three ones, namely, the latitude value of the satellite node, connectivity degree, and connectivity degree threshold. The latitude value of the satellite nodes can be obtained by satellite position system, connectivity degree is determined by the current connection status of the satellite, and connectivity degree threshold is upon the pre-production design of satellite. Therefore, the different satellite constellation connectivity degree threshold is different, but the choice of the TDR algorithm does not depend on a particular constellation.

3.1. Scenario modeling.

The article uses STK 8.1 [3,4] to construct satellite network simulation environment and complete scenario modeling of algorithm, the Iridium system

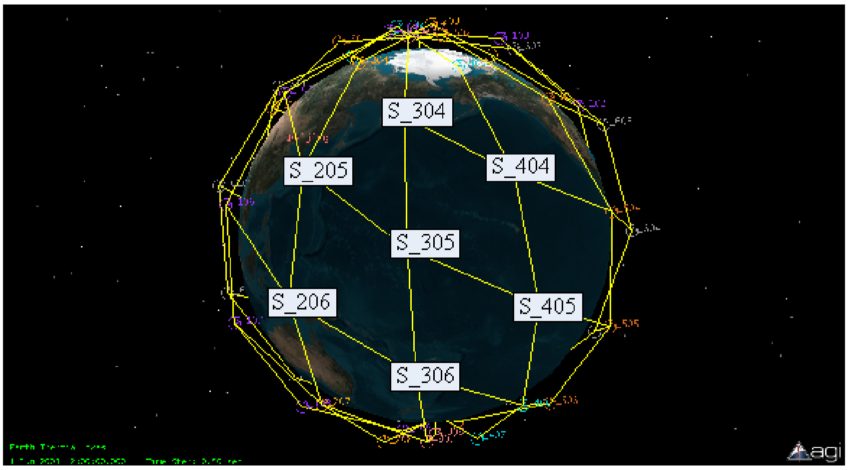

Figure 2. Network topology 3D

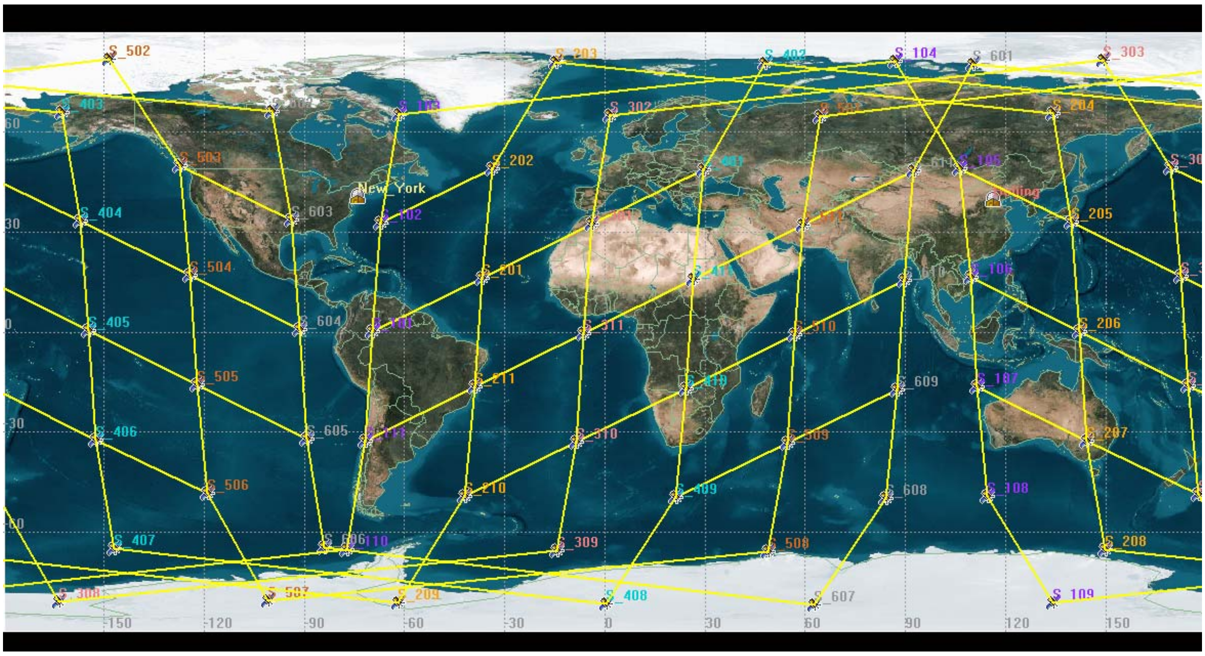

Figure 3. Network topology 2D

which has higher stability and anti-destructive is prototype, the 3D and 2D topology are shown as Figures 2 and 3.

Iridium system constructs a polar orbit constellation, which includes 6 circle orbit plane, each orbit plane has 11 low-earth-orbit satellites, the altitude of each satellite is 780km, the whole low-earth-orbit layer forms a net type topology structure. The initial connectivity degree of each satellite in the network is 4, that is, the connectivity degree threshold is 4, including 2 intra-orbit links and 2 inter-orbit links, the intra-orbit links are keeping connection, but the inter-orbit links have the case of cutoff. The latitude threshold of satellite network is 60o, so the inter-orbit links between satellites whose latitudes are beyond 60o have cut off as shown in Figure 3.

The analysis of algorithm performances which is about that single satellite fails is as follows:

Supposing satellite S_305 in Figure 2 fails in data transmission, link-reconfiguration starts after link detecting. The steps in Section 2.2 are executed as follows:

(1) The set S = $\{205, 304, 306, 405\}$, which includes satellites that connect failure link, and then we construct the satellite property table T which is shown as Table 3;

(2) Choosing satellite 304 which weight value is biggest, firstly building links around 304 following three conditions in Step 3, the number of building is 1 ($4 - 3 = 1$), and the result is satellite 205;

(3) After building, it needs to recalculate the connectivity degree in the property table T, which is shown as Table 4;

(4) Continue to choose satellite 405 which weight value is biggest from the rest of satellites, the link number to build is 1, the result is satellite 306;

(5) The completed link-reconfiguration is shown as Figure 4; the final status of property T is shown as Table 5.

Table 3. Table T instance of satellite-property initial status

Satellite	*205*	*304*	*306*	*405*
Weight value	*0.30*	*0.36*	*0.14*	*0.20*
Current connectivity degree	*3*	*3*	*3*	*3*
Connectivity degree threshold	*4*	*4*	*4*	*4*

Table 4. Table T instance-II of satellite-property update status

Satellite	*205*	*304*	*306*	*405*
Weight value	*0.30*	*0.36*	*0.14*	*0.20*
Current connectivity degree	*4*	*4*	*3*	*3*
Connectivity degree threshold	*4*	*4*	*4*	*4*

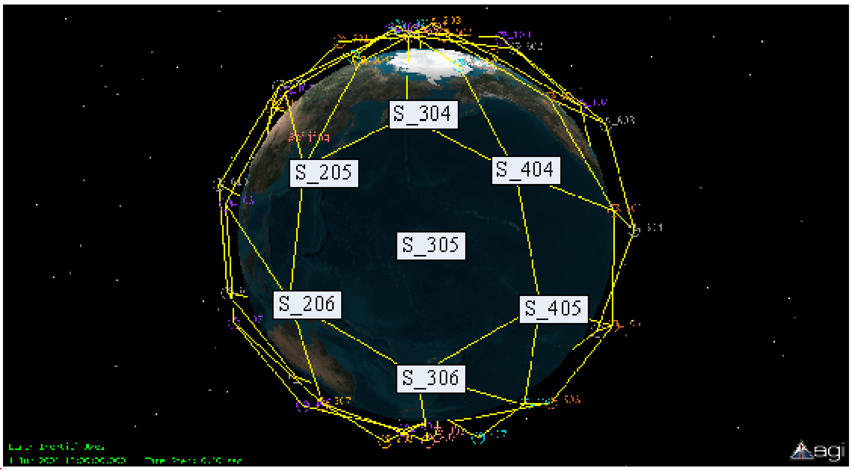

Figure 4. Network topology after reconfiguration

Table 5. Table T instance of satellite-property final status

Satellite	*205*	*304*	*306*	*405*
Weight value	*0.30*	*0.36*	*0.14*	*0.20*
Current connectivity degree	*4*	*4*	*4*	*4*
Connectivity degree threshold	*4*	*4*	*4*	*4*

3.2. **Simulation verification of algorithm performances.** The algorithm execution time is mainly concentrated in selecting the reconstruction node from the candidate set. When select the reconstruction node, the algorithm depends on the satellite attribute table. So each node should store weight values of every satellite, connectivity degree and the degree threshold of the satellite. Choose a reconstruction node requires o(1) time, so choose the n reconstruction nodes need o(n) time complexity. In addition, storing satellite attribute requires o(n) space complexity.

(1) Analysis of link duration

Computing the link duration from the beginning of building to the next disconnection by STK simulation. If firstly choosing satellite 304 which weight value is biggest to build links, the duration of link 205-304 is 1486.4s, if firstly choosing satellite 306 which weight value is smallest to build links, the duration of link 306-405 is 666.2s, the difference is near to 820.2s. If computing by the average, each link difference is $820.2/2 = 410.1$s, that is, if building 9 new links, the link duration difference will be 1 hour.

(2) Analysis of satellite resource

As Figure 4 shown, after link-reconfiguration by the algorithm, the algorithm successfully gets rid of the failure satellite 305 from the whole network topology, and builds two new links; meanwhile, it makes the connectivity degree of losing link satellite to be the maximum, from Table 5, we can see that the connectivity degrees of four satellites have reached connectivity degree threshold 4, which makes the best of the resource on satellites.

(3) Analysis of delay

In order to compare the change of the algorithm performance more distinctly, we join the scenario which shows the formal Iridium constellation into comparison:

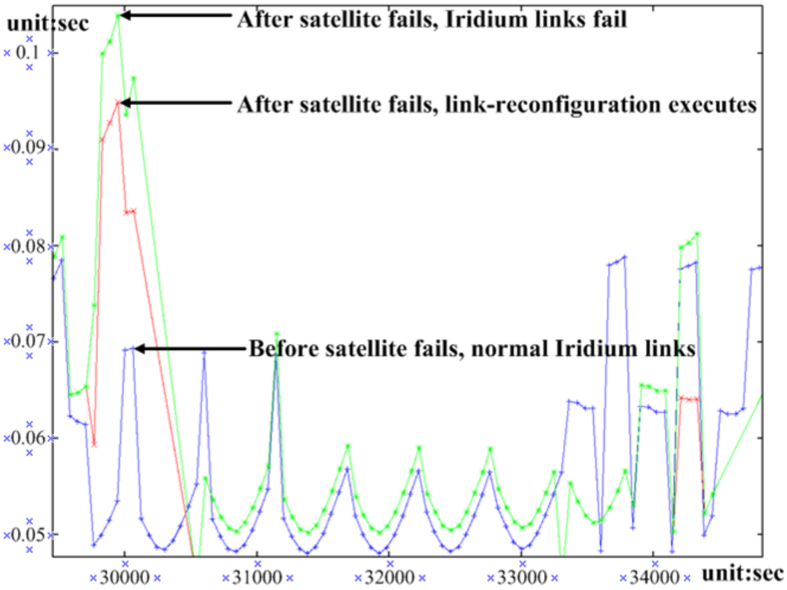

FIGURE 5. Simulation of algorithm delay

Simulation comparison figure of three cases is shown as Figure 5. The simulation time is 24 hours, Figure 5 is an abstracted simulation figure in a stretch, the abscissa is the simulation time, and the ordinate is the end-to-end delay [5]. We can see from Figure 5 that, relating to the link delay of normal Iridium system, the delay after satellite fails increases by a large range, especially in 30000s, the range of increment is most obvious, the duration is about 750s. But after link-reconfiguration by the algorithm, the end-to-end delay decreases obviously, the average range is about 27.7ms. That is to say, the end-to-end delay will decrease 27.7ms in 750s, it has great signification to real-time traffics.

4. **Conclusions.**

The TDR mixed type based on weight value link-reconfiguration algorithm synthetically considers the advantages of the existing link-reconfiguration algorithm, in the three aspects of link duration, link delay and satellite resource, and does link-reconfiguration to low-orbit-layer intra-layer inter-satellite link. The algorithm is applied for any form of constellation network topology, decreases the end-to-end delay in maximum, increases link duration, utilizes the satellite resource in maximum, and guarantees network topology stable.

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