A Space-Air-Ground Integrated Networking Method for Air Mobile Targets

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Abstract. With the development of communication technology, the integration of space and space information network has become a research hotspot. This network can be used for data transmission and sharing on the ground, in the air and in outer space, which can greatly enhance the coverage and speed of the network. However, the air space integration information network is composed of a large number of mobile nodes, which makes it highly dynamic. Based on the time-varying graph, this paper proposes a dynamic networking method to connect the aircraft in the atmosphere to the space-based satellite network, which transforms the problem into the shortest path solution at a certain time and avoids a lot of calculation. At the same time, according to the established scene, the joint simulation platform is built. And the simulation architecture with MATLAB as the core and STK and NS-3 as the auxiliary is completed. On this platform, the simulation test of air space integration information network can be carried out. Through the test of the algorithm on the built simulation platform, the results show that this networking method has good performance in the dynamic network networking.

Keywords: Space-air-ground integrated network · Graph · Shortest path algorithm

1 Introduction

The space network technology based on satellite is now developing rapidly, gradually realizing the satellite broadband access, satellite mobile data and other services [1, 2]. Because the satellite network can form a good complementary relationship with the network on the ground in terms of coverage and mobile access, the combination of the two is the best solution to the problem that the current network cannot cover the world. Therefore, it is an inevitable trend that the air space integrated network is composed of ground network, UAV network and satellite network system [3, 4].

Satellite networks are different from fixed networks and mobile networks on the ground because satellites move in high-speed periodic motion in orbit outside the earth, which will cause the topological structure of satellite networks to change. So that the inter satellite link will be periodically established and interrupted due to the selection of the

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optimal link [5, 6]. When providing services to a certain place on the ground, the current satellite may be not the best access point due to the change of topology. So it is necessary to switch services to other satellite nodes which have good access conditions. In this way, satellite can provide services to the ground. At present, there are a lot of researches. W. Zhang et al. studies the topological control problem in spatial information network (SIN) by using the method of hierarchical autonomous system (AS) [7]. An AS-TC algorithm is proposed to minimize the delay in sin; J. Spencer et al. proposed using software to define the network application in the integrated network to improve the flexibility and traffic management ability of the network [8]; F. Wang et al. studied the satellite network routing algorithm based on software defined network, which can find the shortest path [9]. F. D. Kronewitter propose a real-time tactical mobile network optimization agent (TNOA) based on real-time simulation is proposed. The near real-time modeling of wired and wireless links is carried out by using a large-scale parallel and high-performance network simulator, QUALNET, to simulate the air space integrated information network [10, 11].

2 Problem Statement and System Model

Since the network nodes on the ground do not have the characteristics of high-speed movement, it is considered that the topological shape of the ground network is unchanged in the study. We only study the connection between the satellite network and the air network of the aircraft in the atmosphere. The flying speed of the air vehicle is slow, and the optimal access point is no longer the optimal access point after a period of operation. This high-speed moving characteristic causes the complexity of the topology structure, which leads to the communication link need to be established and switched from time to time. For the general satellite topology structure, it can be represented by the graph $G(V, E)$, where E is the connection relationship between the satellites. It can be described as fallowed:

$$V = \{s_1, s_2, \ldots, s_n\} \tag{1}$$

where n is the number of satellites in the satellite network topology. Each vertex in the graph represents a satellite. And the relationship between each satellite can be described by the edge set E, which is recorded as:

$$E = \{s_1s_2, s_1s_3, \ldots, s_is_j\}, i \neq j, i \in n, j \in n \tag{2}$$

where i, j are the number of satellite, s_is_j indicates that there is a link between nodes s_i and s_j. Through the mathematical description of nodes and edges, the mathematical model of the whole satellite network is established based on this.

In order to solve the problem that the traditional graph theory cannot accurately describe, the time-varying graph theory used in the delay tolerant network (DTN) is applied to this problem. In reference, Fraire transformed the shortest delay path problem in the delay tolerant network into the shortest path problem in the time-varying graph [12–14]; S. Qi et al. Using software defined network to analyze network traffic of satellite network [15]. Huang et al. studied the link scheduling method in the sensor network [16].

Based on the theory of time-varying graph, it can guarantee the link connectivity in a given period of time, but it considers the reliability in a fixed time interval T, which is not realistic for the integrated information network of Space-Air-Ground. The static topological graph of network in discrete time is used to describe the change of network topology. However, this method is to superimpose the fast photos at different times in the network to form a graph, which will greatly increase the complexity of calculation when the path of large time span needs to be calculated [17]. Therefore, it is only suitable for satellite networks with fewer satellite nodes. P. Yuan et al. the method of event driven graph is used to record the operation of satellite nodes sending and receiving data at different times as events [18]. The vertex set in the event driven graph is composed of all events, and link arcs are used to connect the events of the same link. The continuous events of the same node are connected by storage arcs [19, 20]. Although this method reduces the redundancy of the graph, it is mainly used to describe the data transmission in the network, and the link planning is too complex [21, 22].

Different from the above method, this paper studies the networking mode of satellite network and air target in the atmosphere. The proposed method based on time-graph does not consider complex data transmission. It directly introduces time parameters into general network topology to carve the changing network, so as to solve the problem of rapid change of network topology. Because there is time parameter t in the graph. The exact network topology can be obtained by taking different T and the satellites' orbit motion constraints. Given the starting time and time span, the satellite network topology can be obtained at any time [23–25]. The optimal link switching decision condition can be obtained by this method. This method avoids a lot of mathematical calculation and has no too many constraints. The optimal link path and link switching time can be obtained by simple calculation.

3 A Method of Space-Air-Ground Integrated Network for Air Mobile Target

The network includes:

a) $S = \{s_1, s_2, \ldots, s_m\}$ is the aggregate of m near earth satellites in the space. Each satellite near the earth can establish communication with the ground launch station or other satellites.
b) $A = (a_1, a_2, \ldots, a_j)$ is the aggregate of j aircrafts in the air, which are detected and guided by satellite.

After the satellite detects the air moving vehicle target, the missile is launched from the ground launch station. At this time, the communication among the missile, the satellite network and the air vehicle are established. The satellite network is responsible for the guidance of the missile and the detection of the air vehicle. In this scenario, the main problem to be solved is the movement of missile, satellite and air target vehicle, which results in the connection and switching of satellite network to the other two.

In order to solve the problem of topological dynamic change of satellite network, the time parameter t is introduced to describe the topological map of satellite network, and the time-varying map of satellite network can be recorded as the time-varying map of time t as:

$$G(V, E(t)) \tag{3}$$

Among them, V is the vertex set composed of all communication nodes such as ground station, air target and LEO satellite. $E(t)$ represents the edge set in graph $G(t)$, which represents the link connection relationship and the optimal connection mode. Considered scene is composed of multiple satellites, according to the same or not satellite orbit, the satellites can be divided as:

$$\begin{cases} S_1 = \{s_{11}, s_{12}, \ldots s_{1i}\} \\ S_2 = \{s_{21}, s_{22}, \ldots s_{2i}\} \\ \qquad \cdots \\ S_n = \{s_{n1}, s_{n2}, \ldots s_{ni}\} \end{cases} \tag{4}$$

where S_n represents the set of all satellites in n orbit, and i represents the number of different satellites in the same orbit. At a certain time t_0, consider that all the vertices in the network are stationary, and all the edges in the graph $G(V, E(t_0))$ will not change any more. At the same time, according to the parameters of satellite orbit, all the information of satellite motion can be calculated to obtain the longitude lo_s and latitude la_s of the satellite. And then the satellite and the target can be connected by these. Suppose that the longitude lo_a and latitude la_a of the air moving target are known. Now it is necessary to connect the target to the satellite network. In the past, all the satellites were divided into n different longitudes through the orbit of the satellite. Now, the lo_a longitude of the target aircraft is known, and the absolute value of the difference between the longitude of n orbits and the longitude of the target aircraft is calculated by the following formula:

$$D_i = \left|lo_{s_i} - lo_a\right|, i = 1, 2, 3 \ldots n \tag{5}$$

where D_i represents the difference between the longitude of the ith orbit and the target aircraft. Through the calculation of the above formula, n sets D_i can be recorded as:

$$D = \{D_1, D_2, \ldots, D_n\} \tag{6}$$

All elements in D are sorted, and the minimum value is recorded as D_{m}, m is the orbit of the satellite closest to the air target. When the minimum two values in D are the same, the satellite orbit with small label is taken. The next step is to calculate the distance. Obtain the longitude and latitude of all the satellites on the m orbit, and calculate the distance from the target aircraft according to the following formula:

$$\begin{cases} L = 2 \arcsin \sqrt{\sin^2 \frac{a}{2} + \cos(la_a) \cdot \cos(la_s) \cdot \sin^2 \frac{b}{2}} \cdot R \\ a = la_a - la_s \\ b = lo_a - lo_s \end{cases} \tag{7}$$

where L is the distance between the satellite in m orbit and the target flying object, R is the radius of the earth. Through calculation, the nearest three satellites are obtained. The best communication satellite node is obtained, the communication link between the selected satellite and the air target is established. And the shortest path at the current time has been established too. We get the link connection mode at a specific time. However, due to the motion of the satellite and the target aircraft, we need to predict the position of the next time. Set the next link transformation time t, at this time, the satellite and the aircraft have moved. According to the speed of the satellite and the aircraft, calculate the longitude and latitude of them after t. And then implement the above steps again. Repeat this process until the end of the scenario. Because the missile strikes the air target in this scenario, the missile, as the air target after launch, uses the same method to connect another satellite node to enter the network. At the same time, it is necessary to establish a connection between the satellite nodes connected with the flight target. Because the same satellite network, the topology of the network is fixed at a certain time. Therefore, Djsktra algorithm can find the shortest path with the smallest number. According to this path, satellites, missiles and air targets are networked. If the topology changes, the new topology is input to complete the path finding again. The reasoning process of the whole networking method is given above, and the main steps of this method are given in Algorithm 1.

4 Simulation and Analysis

STK (Satellite Tool Kit) developed by analytical graphics company is used to build the simulation environment. We also need another simulation platform to realize the whole algorithm and establish a connection with STK and send control instructions to control STK. MATLAB has an interface with STK, as shown in Fig. 1. The data exchange between them can be carried out better. By calling the STK function in MATLAB, we can control the satellite and other targets, so as to complete the whole algorithm process. A network simulation system is required to simulate the network in operation. NS-3 (Network Simulator-3) network simulation tool is used for network simulation. MATLAB sends out instructions to control STK and sends calculated parameters to NS-3, which establishes the corresponding network topology to obtain the network simulation parameters. Therefore, in order to complete the whole simulation process, it needs to be completed through the combination of three platforms.

Algorithm 1. Networking algorithm

Input: Satellite adjacency matrix M ,The number of Satellite orbit n
The longitude Lo_a and the latitude La_a of missile,
The number of satellites per orbit m

Output: Nearest access satellite. The j th satellite in the k th orbit

```
function SATELLITECLASSIFICATION( n )
    for i = 1 to n
        Table [i ]= n → longitude
    end for
return Table
end function

function FINDORBIT(Table , Lo_a )
    for i = 1 to n
        d [i ]=| Lo_a − Table [i ]|
        min= 1
        if (i > 1 and d [ min ]> d [i ]) then
            min = i
        end if
    end for
return min
end function

function FINDSATELLITE (Table ,Lo_a , La_a , n , m)
    Table = SATELLITECLASSIFICATION( n )
    k = FINDORBIT(Table ,Lo_a )
    j = 1
    for i = 1 to m
        Lo_a =M[ k] [i ] → longitude
        La_a =M[ k] [i ] → latitide
        L [i ]= GETDISTANCE( Lo_a ,La_a , Lo_s , La_s ) // Equ(7).
        if (i > 1 and d [j ]> d [i ]) then
                j = i
        end if
    end for
    return j , k
end function
```

Figure 2 shows the data relationship between the simulation platforms. In this scenario, 132 low earth orbit satellites are used, which are distributed over 6 different orbits. Each orbit is evenly distributed with 12 satellites, with height of 758.14 km from ground and operation cycle of 6027.15 s. Three ground launch stations, missile everywhere and a target flying object are established. Because NS-3 is on the Linux and the former two simulation tools are on Windows operating system. It is necessary to interconnect the two platforms to transfer the data from MATLAB running algorithm to NS-3 in real time to complete network simulation. MySQL database is used to solve this problem. Because NS-3 bases C++ to program to call internal functions to complete the establishment of simulation scenarios. It is easy to read the data in MySQL which generated by MATLAB in the Windows. And the shell script of Linux is used to control the data receive and the working way of NS-3. According to the above operation scenario, the algorithm completes the animation scenario of missile attacking the UAV. Although the movement of the satellite at this time is the optimal access node, there is a link between the missile, the satellite and the target flying object. As the operation time progresses.

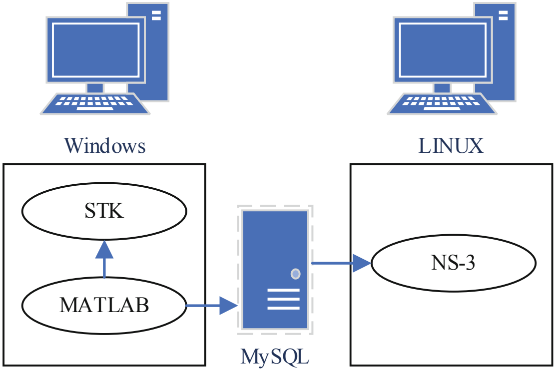

Fig. 1. Simulation platform

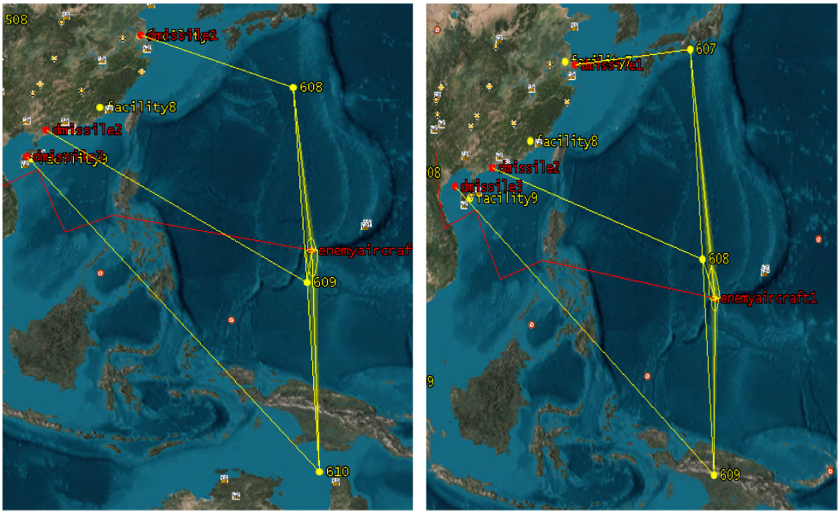

Fig. 2. Experiment result.

Figure 3 shows the link switching which is calculated by MATLAB. The distance between the satellite and the target flying object at the current time is not the shortest distance, so the link will automatically switch to the satellite with the shortest distance. Through the processing of this algorithm, it can be seen that the target flying object can be well connected to the satellite network, and the link can be switched when the satellite topology changes. The Djsktra algorithm is used to calculate the shortest path adjacency matrix which obtained according to the current topology. The detailed information of the system can be obtained by the simulation platform.

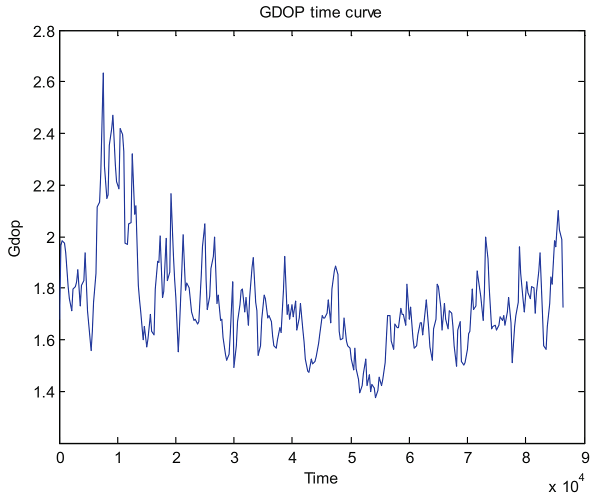

Fig. 3. GDOP time curve

Figure 4 shows the GDOP (Geometric Dilution Precision) which represents the positioning accuracy of the satellite system. In order to show the validity of the algorithm, we record calculation time in Fig. 4. If we do not use this model to calculate the switching time which is based distance, we will use a lot of time in calculation. For a simulation platform, it will waste a lot of computing resources. Because the simulation platform

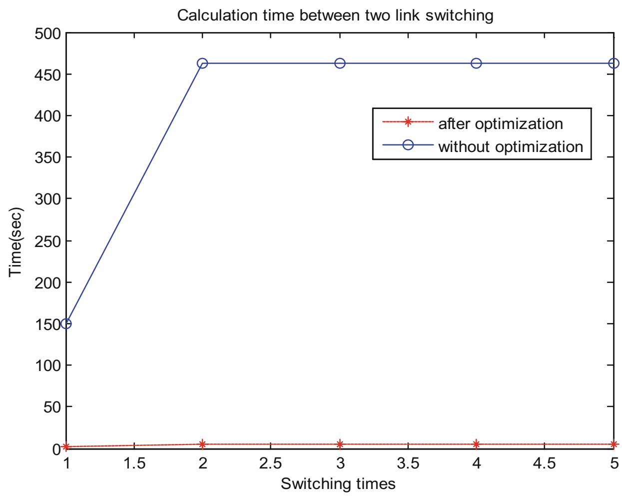

Fig. 4. Time consumption

is composed of many software, the large amount of computation overhead will lead to the incompatibility between the simulation software. The simulation model in this paper can simplify the solution of link switching problem and greatly improve the efficiency of operation. With the proposed simulation platform, the simulation task of air space integrated information network can be completed well. According to the results of the above scenario operation, it can be seen that the algorithm completed the animation scene of missile attacking the target flying object. The link in the scenario can be smoothly switched, and the target flying object and other air flying ground objects can be connected to the satellite network. Compared with the previous method, only the network topology map with equal time interval is calculated.

5 Conclusion

This paper studies the networking problem in the air space integrated information network. Using MATLAB, STK and NS-3 to stimulate. Although the simulation platform built in this paper can simulate most of the problems in the research of air space integrated information network, it includes a large number of programming parts, which need to cross platform and involve the use of a variety of simulation tools. It also requires higher requirements for different programming languages. And simulation has become a big difficulty in the research. Therefore, in the future research, the new model construction of dynamic topology and the construction of network simulation platform will be considered.

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