Analysis of Distributed Inter-satellite Link Network Coverage Based on STK and Matlab

Zhang Yue, Guo Yunxin, Hong Jiacai
(Aerospace Engineering University, Beijing 101400)
517608555@qq.com;

Abstract. Jointing STK and Matlab to solve the problem of GNSS system inter-satellite measurement and control network coverage. By using the interface provided by both parties, Matlab can directly control STK for task analysis, and obtain professional orbit data and star directly from STK. The distance information is processed and analyzed by Matlab. The preliminary analysis results of the link coverage of distributed inter-satellite link network routings show that the distributed network coverage is low and the satellite antenna resource utilization is low. It is necessary to set optimization conditions to improve network coverage and on-board antenna utilization rate.

1. Introduction
STK (Systems Tool Kit) is a satellite system analysis software developed by Analytical Graphics Inc. of the United States. It is a leader in the aerospace industry software. It has powerful computational analysis functions: analysis capability, orbit generation or ballistic ephemeris, Table, visibility analysis, remote sensor analysis, attitude analysis, visualization calculation results and comprehensive data reporting, including a variety of different modules, this article mainly uses the 3D display module VO and STK / Connect module. [1] Based on STK's powerful 3D display capabilities, professional computing capabilities, it should be used as the best system simulation display software. However, for the subsequent processing of data, STK is slightly inferior, and further analysis of the results requires the use of other professional software.

Matlab (matrix&laboratory) is a mathematical technology application software released by Mathworks Company of the United States. It is second to none in numerical computing capabilities. It can do matrix operations, draw functions and data, implement algorithms, create user interfaces, and connect programs in other programming languages. Etc., mainly used in engineering computing, control design, signal processing and communication, image processing, signal detection, financial modeling design and analysis. Its powerful data analysis capability can make up for the shortcomings of STK, and STK can provide simulation data more conveniently and accurately, avoiding the complexity and accuracy of Matlab simulation program. Therefore, it is considered to use the interface files of the two softwares for joint analysis, which is used for the simulation analysis of the GNSS inter-satellite link network coverage problem.

2. STK and Matlab connection communication
STK and MATLAB can be integrated using connectors, which can be integrated to automate, extend or visualize simulation analysis tasks. They have two interfaces for connection: MexConnect interface for communication via TCP/IP and communication via COM connection COM interface. The choice of interface needs to be decided according to the specific task. Figure 1 provides the decision tree for
the optimal interface selection, and Figure 2 is the schematic diagram of the STK interconnection with the external application:

**Figure 1. Optimal interface selection decision tree**

Which interface should you use to Connect STK and MATLAB?

Do you need to use STK plugin scripts?

- **YES**
  - You must install an STK MATLAB Connector

- **NO**
  - Do you want to use the Object Model API?

- **YES**
  - You can only use the COM Interface to access the Object Model API; it allows you to access both APIs (Connect and Object Model) and connect to any version of MATLAB.

- **NO**
  - Do you want use Aero Toolbox or Mexconnect functions?

- **YES**
  - You must install an STK MATLAB Connector

- **NO**
  - The COM interface is the recommended interface to use; it allows you to access both APIs (Connect and Object Model) and connect to any version of MATLAB. You can, however, use an installed STK MATLAB connector if you prefer.
This simulation analysis uses the COM interface. The official website of AGI provides the COM interface download of STK. The main function of the COM interface is the Connect module [2]. This module provides a connection with the STK and is available on the client side. An easy way to work in a server environment, the library that comes with Connect contains functions, constants, and other messaging features that can be used to connect third-party applications to the STK, making it easy for users to establish communication channels with the STK. It is worth noting that the COM interface does not support sending asynchronous connection commands to the STK.

The large number of formatted Matlab commands and instruction sets provided by STK makes Matlab as convenient as using its own functions when calling STK [3-4]. The communication model of both parties is shown in Figure 3:

The Matlab command is used to establish a connection with the STK. Each control command is transmitted to the STK through Connect to complete a series of preparation operations such as setting up a scene and setting objects. After that, the STK simulation calculation result and report data are also transmitted to Matlab through Connect for further data processing and analysis, and finally the simulation results are obtained.

3. Matlab controls STK to establish walker constellation
The simulated walker constellation parameters N/P/F are set to 24/3/1, the orbital radius is 26561.8Km, and the orbital inclination is 55°. This parameter is calculated by the two-row data TLE of the satellite orbit provided by space-track.org.
3.1 Connect Matlab and STK  
First, it should be ensured that Matlab and STK are in running state, all old scenario in STK are closed, then create a new STK scenario named walker and use STkInit or agInit to initialize STK from Matlab to establish connection [6]. After the connection is established, use the stkExec command to perform a series of operations to establish a walker constellation of the specified parameters. The code is as follows:

```matlab
stkInit;
remMachine = stkDefaultHost;
delete(get(0, 'children'));
conID=stkOpen(remMachine);
scen_open=stkValidScen;
if scen_open == 1
    rtn = questdlg('Close the current STK Scenario?');
    if ~strcmp(rtn,'Yes')
        stkClose(conID)
        return
    else
        stkUnload('/*')
    end
end
scen_nam=['walker',num2str(CONST_simnum)];
stkNewObj('/', 'Scenario', scen_nam);
```

So we built a new scenario called walker.

3.2 Establish a walker constellation  
First, we must establish a seed satellite, named sat:

```matlab
stkExec(conID, 'New */Satellite sat')
Set seed satellite parameters:

```matlab
stkExec(conID, 'SetState */Satellite/sat Classical J2Perturbation "1 Nov 2018 00:00:00.00" "2 Nov 2018 00:00:00.00" 60 J2000 "1 Nov 2000 00:00:00.00"28000000 0.0 55.0 0.0 0.0 0.0')
```

The J2 perturbation model is adopted. The simulation period is from 0:00 on November 1, 2018 to 0:00 on November 2, 2018. 60 refers to the STK sampling interval, J2000 is the coordinate system, and the last six digits refer to the semi-major axis of the orbit, eccentricity, orbital inclination, perigee angular distance, ascending node right ascension and true near point angle.

Construct a walker constellation using the seed satellite sat:

```matlab
stkExec(conID, 'Walker */Satellite/sat Type Delta NumPlanes 3 NumSatsPerPlane 8 InterPlanePhaseIncrement 1 ColorByPlane Yes')
```

Set the walker parameters, 3 tracks, 8 satellites in each track, the phase factor is 1, and each track is distinguished by different colors. The simulation results are shown in Figure 4:
4. Link selection and establishment

4.1 Data acquisition and analysis
We analyze a satellite operating cycle (about 12h), update the link every 10 minutes, and establish a link according to the distance information and the link selection principle. Because of the symmetry of the walker constellation, we take sat11 as an example. The distance parameters between sat12–sat18 and its different track sat21–sat28 are studied separately, and the results are shown in the figure:
Figure 6. Distance inter sat11 between other different orbit satellites

Without considering other constraints, the distance information can be used to determine the selection of partial links. The distributed system selects two satellites adjacent to one satellite and two nearest alien satellites to establish a link.

Navigation satellite systems, unlike their low-orbit communication satellite systems, are different from data relay satellite systems in that they have both the need for communication delay and the need for inter-satellite ranging [5]. Therefore, the consideration of the inter-satellite link of the navigation satellite system cannot be ignored on the one hand, and should be considered according to the needs.

4.2 Distributed system network coverage analysis

According to the shortest distance principle, the shortest communication delay can be obtained. The link network topology established from 2018.11.1 to 0:00 is shown in Figure 7 and Figure 8:

Figure 7. Initial time distributed link network topology (2D)
Figure 8. Initial time distributed link network topology (3D)

It can be calculated from the figure that without considering the inter-satellite link, the inter-track inter-satellite link coverage is 37.5%, which is far from meeting the requirements of inter-satellite measurement and control. In extreme cases, it takes up to 2 hops to make the transmission of its own information into the network of measurement and control links, such as satellite No. 32 → satellite No. 33 → satellite of No. 34 → inter-satellite link network, will bring a lot of delay. At the same time, although the link established by the principle of the shortest distance has the shortest delay, the number of inter-satellite measurements and control does not reach the demand.

If you do not consider the data hopping, only the link connection is used as the inter-satellite measurement and control network. In this way, within 100 nautical satellite system operation period (12h), 100% inter-satellite link coverage is required. The rate needs 190min for about 3h, and the apparent measurement and control efficiency is low. If the data is allowed to "1 hop", then 100% inter-satellite link coverage will take 70min for about 1h, and the efficiency will increase by 200%. If the data is allowed to "2 hops", the inter-satellite link coverage can reach 100% directly, but the problem of relatively large delay is contrary to the original intention of the chain-building strategy.

Therefore, the problem of the distributed network is that the network coverage of the inter-satellite measurement and control link is not high and the utilization of the antenna resources on the satellite is low. In order to improve this problem, constraints should be set. For example, if the 21st satellite has already established a link with a satellite on the 1st orbit, it will no longer accept the measurement and control requests of other satellites on the 1st orbit. Minimize the communication delay, but within the acceptable range, improve the utilization efficiency of the antenna resources on the satellite.

In addition, the analysis in the previous step did not consider the limitation of the number of satellites on the satellite. When the link is established the most, it takes 6 antennas to complete the task. For example, satellites 34 and 38 are the same as 11~14. The 15th to 18th satellites and the two satellites adjacent to them have established links. This situation is extremely extreme, but the number of satellites established by the entire network is still acceptable. In general, the number of antennas on the satellite is four, which can be improved by conditional constraints.

5. Conclusion
The GNSS constellation of the δ-walker configuration of 24/3/1 is simulated by jointing Matlab and STK software. Based on the minimum information transmission delay, the coverage of the distributed inter-satellite measurement and control link network in the whole network is analyzed.
The distributed network topology is simple, and the communication delay can be minimized. However, the measurement and control links are redundant, the network coverage is not high, and the on-board antenna resources are wasted. If the data hopping is used to improve the coverage, the information needs to be sacrificed. The transmission delay is at the cost, and in the extreme case, 6 antennas are required, which challenges the satellite payload load capacity and needs further optimization.

References

[1] Dong Jianqiang. Design and Implementation of Space Flight Visualization Simulation System Based on STK[J]. *Journal of Computer Measurement and Control*, 2010, 18(2): 446-449.

[2] PAN Chengsheng, ZHANG Xin, LI Dingzhu. Application of STK/Connect Module in GPS Simulation Demonstration System[J]. *Fire and Command Control*, 2008, 33(10): 117-120.

[3] Qu Ting, Pei Yiming, Cao Zongjie. STK/MATLAB-based GPS Satellite Visibility Simulation Analysis [J]. *Science and Technology, Engineering*, 2009, 9(13): 3920-3923.

[4] Zhang Zhanyue, Xu Yanli, Zeng Guoqiang. Analysis of Space Mission Simulation Scheme Based on STK[J]. *Journal of the College of Equipment*, 2006, 17(1): 48-51.

[5] McCamish, S. B., and Romano, M., “Simulations of Relative Multiple-Spacecraft Dynamics and Control by MATLAB–Simulink and Satellite Tool Kit,” *AIAA Modeling and Simulation Technologies Conference*, AIAA Paper 2007-6805, Aug. 2007.

[6] Wang Donghui. Research on satellite navigation inter-satellite link networking technology for ranging and communication performance optimization [D]. *National University of Defense Technology*, 2014.