GEO and IGSO Based Hybrid Global Coverage Satellite Constellation Design

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Abstract. A hybrid global coverage satellite constellation is designed based on GEO and IGSO satellite considering that GEO satellite can provide favorable coverage performance to low latitude region while IGSO satellite can achieve high elevation angle to high latitude area. The designed satellite constellation can offer double-satellite coverage to the Chinese and nearby area, high elevation angle to high latitude area and seamless coverage to global area. The simulation results show that the Chinese and nearby area can achieve 100% single-satellite coverage and 87% double-satellite coverage. Besides, global area can reach more than 95% single-satellite coverage and north pole can get communication elevation angle over 30°.

Keywords: Satellite constellation design · Coverage · IGSO satellite · Communication elevation angle

1 Introduction

Building a satellite mobile communication system with global communication capabilities is one of the important issues to be solved in China's globalization strategy [1]. The low orbit, medium orbit or high orbit satellite constellation can be used to achieve the goal of seamless global coverage. For the design of the low-orbit global coverage satellite constellation, Rider proposed the best polar orbit design method [2], Walker et al. proposed the inclined circular orbit design method [3]. The Iridium is a typical polar orbit low-orbit constellation with a total of 66 satellites evenly distributed on six orbital planes. The inclination of the orbital planes is 90°, the altitude is 780 km, the eccentricity is 0, and the distance between adjacent track surfaces is 60°. It can achieve global continuous coverage in the case of communication elevation angle greater than 8°. Odyssey system is a typical mid-orbit constellation based on the design method of inclined circular orbit. It is composed of 12 stars and distributed on three orbital planes, each of which has 4 stars. The orbital height is 10354 km, which can provide a communication elevation of 22° [4]. Inmarsat is a typical high-orbit constellation system using GEO (Geostationary Orbit) satellites. It consists of 3 GEO satellites. High-orbit and low-orbit systems have distinct characteristics due to their different orbital heights, number of satellites and technical means. Considering the current development situation in China, choosing a GEO system with relatively low technical complexity and high cost performance is a good solution. However, relying on GEO

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satellites alone cannot provide an ideal communication elevation angle for high latitude areas, and there will also be coverage blindness for polar region. The IGSO (Inclined Geosynchronous Satellite Orbit) satellite has an orbital “8” shape due to its non-zero orbit inclination, which can provide high elevation angle coverage for high latitude areas. This paper designs a GEO + IGSO satellite constellation based on such considerations.

2 Features of the IGSO Satellite

The IGSO satellite orbits at the same altitude as the GEO satellite and has the same period of operation as the GEO satellite. It is also synchronized with the earth. However, the orbital inclination of the IGSO satellite is not zero, which determines that the ground track will not be a point like GEO, but an “8” shape, thus providing high elevation angle coverage for high latitude areas.

The orbital parameters of the IGSO satellite mainly include two orbital inclination angles and the longitude of the ground track when crossing the equator. Similar to the ground track of GEO satellite, the ground track of IGSO satellite will always pass through the same point on the equator. Therefore, the longitude of this point can be used for unique identification. The larger the orbital inclination is, the better the coverage of the polar and high latitudes will be, while the coverage of the middle and low latitudes will be reduced. When choosing the IGSO inclination, the influence of these two factors should be considered in a more specific target task.

In Ref. [5], the application of IGSO in the satellite mobile communication system is studied. The research results show that the use of IGSO satellites can significantly improve the low elevation angle problem of GEO satellites in high latitude areas. The constellation composed of two or three relatively small IGSO satellites could achieve better performance than a very large GEO satellite. The IGSO satellite constellation can be used to realize the continuous multi-star coverage of China, and the effective spatial diversity can be realized, which can obviously improve the anti-interference capability of the system. If the coverage of high latitude regions is required, three IGSO satellites are needed to ensure performance. In this paper, three IGSO satellites with common ground track are used to cover the Chinese and nearby area.

3 Hybrid Global Coverage Satellite Constellation Based on GEO + IGSO

3.1 Performance Indicators of Global Coverage Satellite Constellation Design

For a constellation with uninterrupted continuous coverage, the indicators to evaluate its coverage performance include the maximum (average, minimum) coverage weight and the maximum (average, minimum) elevation angle. This paper analyzes the coverage performance of the constellation based on STK (Satellite Tool Kit). The relevant parameters used in the analysis are as follows. The minimum communication elevation angle is 20°. Covered area includes global area, the Chinese and nearby area, Arctic area. Coverage performance and elevation angle statistical accuracy are regional resolutions with a latitude of 10° and a longitude of 1°.

3.2 Design Scheme Based on 2GEO + 3IGSO Hybrid Global Coverage Constellation

The constellation designed in this paper consists of 5 satellites, including 3 IGSO satellites and 2 GEO satellites. The two-dimensional map of the constellation and the coverage of each satellite are shown in Fig. 1, where different satellites are marked with different colors, and the coverage of satellites is represented by the corresponding border lines of the same color. The detailed parameters of each satellite are shown in Table 1.

It can be seen from Fig. 1 that the ground track of the IGSO satellite is an "8" shape. The goal of the constellation design in this paper is to provide multiple coverage of the Chinese and nearby area (70° E–150° E, 10° N–55° N), while taking into account the global coverage. In addition, it is necessary to ensure a high communication elevation angle for high latitude areas. Three IGSO satellites with common ground tracks and evenly distributed phases around the land can provide multiple coverage of the Chinese and nearby area and high elevation angle coverage in high latitude areas. It has better coverage performance than a GEO satellite. GEO1 and GEO2 mainly complete the coverage of low and middle latitudes in Africa and the Americas. In order to prevent coverage blindness, the coverage areas of GEO1 and GEO2 overlap, and the overlap point is located at N60°. This paper uses the IGSO satellite to cover the Chinese and nearby area, so the longitude when crossing the equator was selected near the land, which is E100°. In order to ensure the double-satellite coverage of the Chinese, and also to take into account that the high latitude areas have an ideal communication elevation angle, this paper chooses the inclination angle of IGSO as 45°. At this time, the double-satellite coverage rate of more than 80% can be guaranteed below the latitude of 60°. The average communication elevation angle can reach 55.1°, and the communication elevation angle at the North Pole can also reach nearly 30°.

Table 1. Satellite orbit parameters.

Name	Semi-major axis (km)	Longitude ascending node	Orbital inclination	Argument of perigee	True anomaly
GSO11	42164.2	199.1°	45°	0°	0°
IGSO21	42164.2	79.1°	45°	0°	120°
IGSO31	42164.2	319.1°	45°	0°	240°
GEO1	42164.2	59.1°	0°	0°	0°
GEO2	42164.2	0°	0°	0°	339.1°

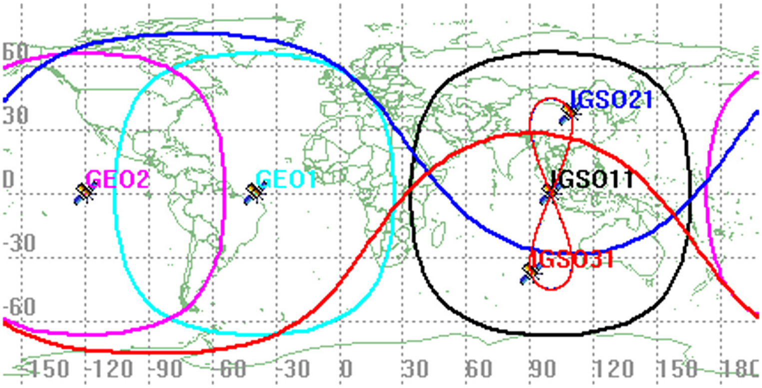

Fig. 1. 2GEO + 3IGSO constellation two-dimensional diagram

4 2GEO + 3IGSO Satellite Constellation Coverage Analysis

Based on the 2GEO + 3IGSO high-orbit hybrid satellite constellation designed above, this paper uses STK (Satellite Tool Kit) to perform coverage analysis. Figure 2 shows the global single-satellite coverage map of this constellation. Figure 3 shows the double-satellite coverage map of the constellation in the Chinese and nearby area. Since the constellation covers the northern and southern hemispheres symmetrically, Fig. 4 shows the coverage of the constellation in the Arctic region (60° N–90° N). The coverage of the Antarctic region is the same.

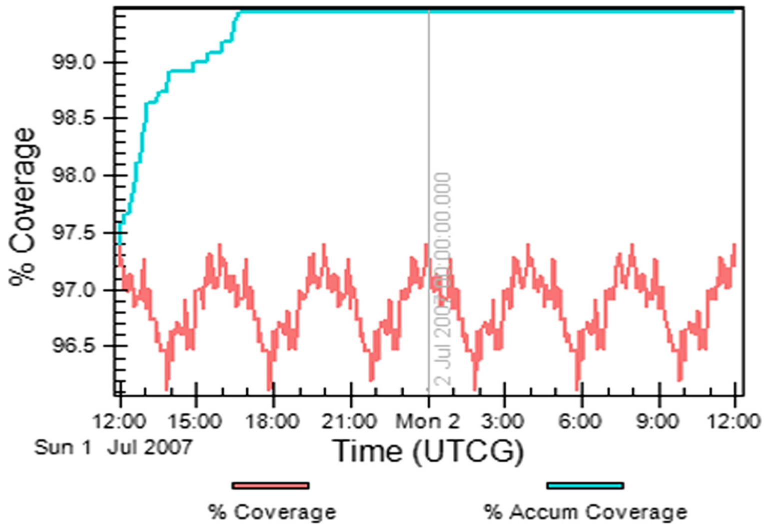

Fig. 2. Global single-satellite coverage of the 2GEO + 3IGSO constellation

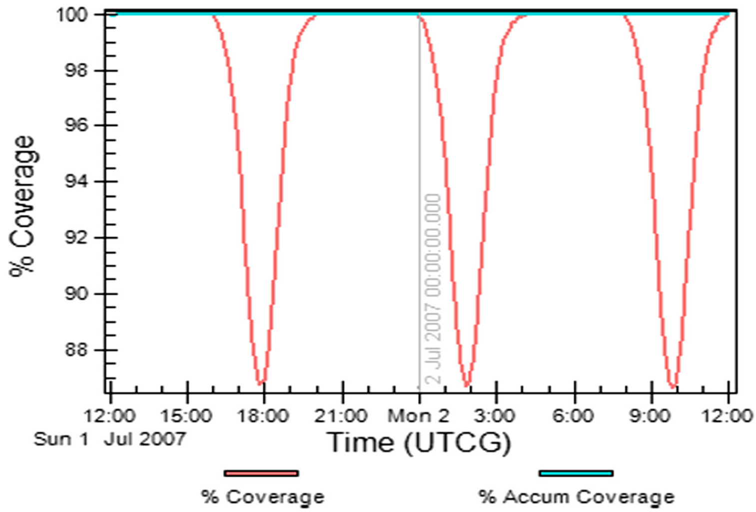

Fig. 3. 2GEO + 3IGSO constellation double-satellite coverage in the Chinese and nearby area

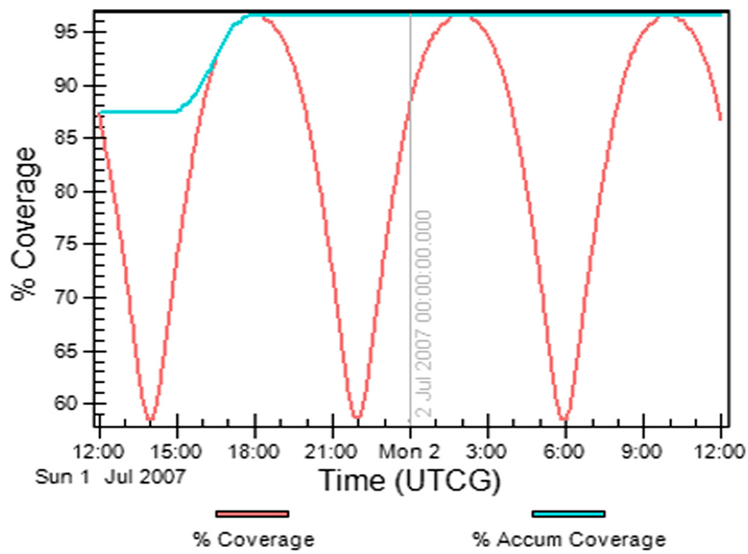

Fig. 4. 2GEO + 3IGSO constellation Arctic region coverage

It can be seen from Fig. 2 that the real-time single-satellite coverage of this constellation can reach more than 95%, and the highest can reach 97.4%. The cumulative coverage rate can reach 100%, indicating that the constellation can achieve seamless global coverage without covering blindness. As can be seen from Fig. 3, the real-time double-satellite coverage of this constellation on the Chinese and nearby area can reach more than 87%, and the highest can reach 100%. The double-satellite cumulative coverage can reach 100%, indicating that at least 2 satellites can be seen anywhere in the Chinese and nearby area within a day. It can also be found that within one day, there are three periods where the real-time double-satellite coverage rate is less than 90%, and each duration is about 1 h. In other words, the Chinese and nearby area can reach a double-satellite coverage rate of more than 90% within 21 h in a day. If the fading characteristics of the two satellite propagation paths can be statistically independent, the diversity technology can also be used to increase the system capacity.

As can be seen from Fig. 4, the real-time single-satellite coverage of this constellation in the polar region can reach more than 58%, and the maximum can reach 100%. Real-time double-satellite coverage can reach 100%, no coverage blind spot. There are three time periods in which a real-time single-satellite coverage rate is less than 80%, each of which is about 3 h. So 62.5% of the time during the day, more than 80% of single-satellite coverage rate can be obtained in the polar region.

5 Conclusion

This paper uses the advantages of IGSO satellites to provide high elevation angle coverage for high latitude areas, and solves the shortcomings that GEO satellites always have low elevation angles at high latitude areas and coverage blindness in the polar region. According to the goal of multiple coverage of the Chinese and nearby area and high elevation angle coverage of high latitude areas, an orbital inclination that can perform well multiple coverage of the target area and provide good communication elevation angles for high latitude areas is selected. The analysis results show that the constellation can provide double-satellite coverage for the Chinese and nearby area more than 80% of the day, the global real-time single-satellite coverage reaches more than 95%, and the communication elevation angle at the two poles reaches 30°.

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