Inter Satellite Link Interference Detection and Analysis of NGSO Satellite System

Shiyao Meng(✉), Min Jia, Qing Guo, and Xuemai Gu

School of Electronics and Information Engineering, Harbin Institute of Technology, Harbin, Heilongjiang, China
jiamin@hit.edu.cn

Abstract. In view of the fact that non geostationary satellite constellation is becoming more and more complex and it is difficult to calculate and observe directly, this paper mainly studies the inter satellite interference of NGSO constellation. Firstly, the distribution of NGSO and various interference scenarios are comprehensively analyzed to enrich and improve the existing inter constellation interference scenarios of satellite system, and the direct interference between constellations in the same system is analyzed. Then, the data of Leo electromagnetic satellite are analyzed, and the inter satellite link interference of NGSO constellation system is calculated. Using the concept of relative interference time, the time distribution characteristics of interference are visualized, and the time characteristics of interference in different scenes are analyzed. The inter satellite link interference of large-scale NGSO satellite constellation system is analyzed from multi-dimensional perspective, and the simulation is carried out. The implementation results of the strategy prove that there is interference in the inter satellite links of large NGSO satellite constellation system. The corresponding signal analysis strategy is designed, and the data processing method of interference data is proposed.

Keywords: NGSO · Inter satellite link · *EIRP* · Electromagnetic situation

1 Introduction

1.1 Development of NGSO Constellation Status of NGSO Constellation

The Internet of things is the key direction and an important part of the current development of information technology. The current ground Internet of things is facing a variety of difficulties, including the impact of weather, capacity, network resources and so on. Therefore, people begin to expand the current ground Internet of things, and open up its re air field, in which the largest main battlefield is the space information network. The space information network integrates geosynchronous orbit satellites, medium orbit satellites and low orbit satellites to process the network information in space [1, 2].

Among them, NGSO satellite communication system has small time delay, strong anti attenuation ability of signal, and can achieve global seamless satellite coverage by improving the coverage ability of the system.When the electromagnetic data of NGSO satellite is modeled, it is necessary to mine the electromagnetic data of NGSO satellite.

Q. Guo et al. (Eds.): WiSATS 2021, LNICST 410, pp. 3–13, 2022.
https://doi.org/10.1007/978-3-030-93398-2_1

So far, the number of NGSO satellite systems has been increasing, and the latest SpaceX project will eventually reach more than 4000 NGSO constellations [3–5].

1.2 Research of Interference Analysis for NGSO Constellation

There are all kinds of interference in satellite communication. The construction of electromagnetic interference model for different scenarios has always been a key research direction of the majority of scholars.

Satellite communication links are divided into uplink and downlink. Some scholars have studied the coordination method of uplink and downlink interference in multi beam satellite communication system and the co channel interference cancellation technology [6].

However, there is still a lack of inter satellite link interference for NGSO satellites, which can not accurately reflect the different gain of different angles and the continuous interference changes at different times [7, 8].

So the main purpose of this paper is to complete the inter satellite link interference of NGSO constellation. According to ITU report, if the inter satellite links of two NGSO constellations use the same fixed service frequency band of satellites and the inter satellite links increase continuously, it may cause the interference of inter satellite links to affect the system. At present, the main NGSO constellation is basically used Ka and Ku band, and the service frequency bands used by each system may produce coincidence. In addition, NGSO constellation, such as Starlink, has launched two groups of more than 1000 satellites, and there are still a third batch of launch plans. Moreover, there are inter satellite links in Starlink system, which will lead to the future low orbit satellite system more complex and need to consider inter satellite interference [9–11].

2 Construction of Inter Satellite Link Interference Model

2.1 NGSO Constellation Construction

Several common NGSO satellite constellations are simulated: Oneweb, Starlink, to obtain satellite orbit related parameters, the electromagnetic interference model is used to calculate several electromagnetic parameters including antenna gain and *EIRP*, and the *EIRP* of uplink ground station transmitter and downlink satellite transmitter in inter satellite interference is calculated [8, 11]. *EIRP* is the effective isotropic radiated power. In satellite communication, the radiation power of satellite or ground station in a specified direction is equal to the transmitting power of power amplifier multiplied by the gain of antenna in ideal state, which is used to measure the intensity of interference and the ability of transmitter to transmit strong signal [9, 12].

The position of the ground station (72.826 ° e, 0) is set. In the constellation of simulation, a period of time when the satellite passes the top is selected for simulation, and the step is set to 1s. The azimuth and distance data of the satellite to the ground station and the ground station to another satellite are obtained. The constellation satellite transmission power, ground station transmitter transmission power, satellite communication frequency and other data are obtained by consulting literature.

2.2 System Model

Interference Scene Analysis

In NGSO satellite communication, an important situation that may produce interference is the interference scene of inter satellite link. A satellite in NGSO constellation will be subject to a variety of potential interference scenarios. It is mainly divided into uplink and downlink scenarios. For the communication between constellation A and earth station A in Fig. 1, the interference in the uplink is mainly the interference from satellites of other constellations and other possible earth stations. The main interference in the downlink is divided into the interference of other constellation to the earth station and the possible interference of GSO constellation to the earth station.

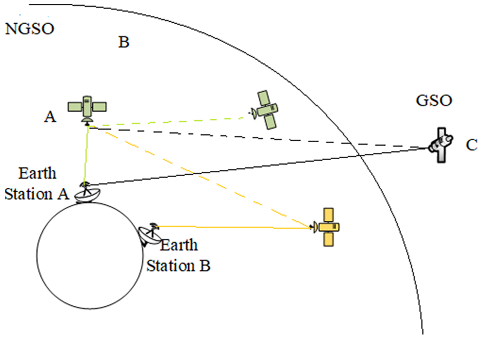

Fig. 1. Schematic diagram of electromagnetic spatial distribution and interference complexity

In the discussion of inter satellite interference scenarios, the adjacent satellite interference scenarios are generally considered. In this problem, we mainly consider the interference of the uplink channel in the satellite adjacent system. In other words, the actual useful signal in the process of satellite communication is the useful signal strength sent by the ground station, while the interference is caused by the information sent by other constellations.

However, in some scenarios, when the local satellite a exchanges information with the local earth station, the output information of the neighboring satellite B may also be transmitted to the receiver of the local satellite a, causing direct interference between the two stars. It can be seen that this situation will occur in the uplink state of the main link.

In analyzing the interference in the uplink of non-geostationary orbit constellations, the overall model is shown in Fig. 1. In complex interference analysis, geostationary orbit satellites and non-geostationary orbit satellites need to be considered. When examining the uplink of non-geostationary satellites, The main link of communication is the link transmitted to the constellation by the Earth station of a non-geostationary orbit satellite, Among them, the most important interference scenario is the useless signals emitted by other earth stations. In addition, it is necessary to consider the interference of signals emitted by other non-geostationary satellites and the interference caused by some geostationary satellites.

Interference Calculation

No matter what kind of inter satellite interference is caused, the same data processing method can be used to quantify the interference and know whether it is necessary to adjust the system, such as adaptive power control. Then we need to calculate the best sampling time of the system, which can reduce the amount of data calculation as much as possible on the premise of correctly judging the interference between the systems. The following formula is needed to calculate the optimal sampling time:

$$\Delta t_{step-down} = \frac{\Delta t_{down}}{N_{step-down}} \tag{1}$$

In the calculation, we need to obtain the selected constellation orbit height and satellite angular velocity data.

In the above formula, $\Delta t_{step-down}$ means the step size of the downlink time of the system, that is the best sampling time interval of the system, Δt_{down} is the time required to interfere with the main lobe radiation range of the antenna of the NGSO satellite passing through the earth station, which will be affected by the antenna type and amplification capacity of the system, as well as the orbit height of the satellite. $N_{step-down}$ indicates the sampling times of the main lobe radiation area of the receiving antenna in the ground station of the disturbed system. It is affected by the main lobe width and other factors. It is the ratio of the 3 dB width to the off-axis angle sampling interval of the main lobe of the receiving antenna in the earth station of the disturbed NGSO system. Its value can also be replaced by a value greater than or equal to $\sqrt{\frac{24}{\Delta R}}$, where ΔR is the resolution dI of the interference signal power I received by the NGSO disturbed earth station. According to experience, its value can be set as 0.5dB.

The value of can be determined by the ratio of the angle of the main lobe radiation area of the satellite receiving antenna through the earth station to the angular velocity of the satellite in the circular orbit. In this scene, the final time step is 6 s according to the above method.

Generally, according to the regulations of the International Telecommunication Union, as long as the influence of the interference signal from the adjacent satellite on the equivalent noise of the receiving system of the satellite reaches 6%, it is generally recognized that there is interference in the adjacent satellite system and needs to be adjusted. Therefore, 6% is regarded as the threshold. If the relative increment of equivalent noise temperature can be expressed as $\frac{\Delta T}{T}$, it can be expressed as:

$$\frac{\Delta T}{T} = 6\% \tag{2}$$

The conversion to DB is 12.2 db.

When considering inter satellite interference, power is chosen to judge. In the calculation process, the data processing of load-to-dry ratio is needed. So the relationship between the load-to-dry ratio of the final transmission and the carrier to dry ratio transmitted by the inter satellite link itself is as follows:

$$\frac{C}{I_{th}} = \frac{C}{N_{th}} + 12.2\ \text{dB} \tag{3}$$

The downlink carrier to interference ratio is:

$$\frac{C}{I_{dn}} = C_{dn} - I_{dn} = \frac{C}{T_{dn}} - \frac{I}{T_{dn}} \tag{4}$$

When considering the power spectral density to analyze the above, the above formula can be changed into:

$$\frac{C}{I_{dn}} = (\text{EIRPD} + G_{er} - L_d) - (\text{EIRPD}' + G'_{er} - L'_d) \tag{5}$$

When the power spectral density is considered to analyze the above, in the calculation of the uplink load to dry ratio, the carrier power of the antenna output end of the earth station at the receiving end can be changed into:

$$C_{dn} = EIRP_s - L_d + G_{er} \tag{6}$$

$EIRP_s$ is $EIRP$ value of carrier satellite, L_d is loss value of downlink, G_{er} is the receiving gain of ground station.

When considering the system margin, M can get the formula according to the threshold calculated before:

$$M = \frac{C}{I} - \left(\frac{C}{N_{th}} + 15.2\right) \tag{7}$$

According to the radio rules, when judging whether there is interference, the system margin can be used. When the system margin is greater than 0, the interference of the system is not serious and will not affect the channel of the main link. When it is less than 0, the interference will affect the communication of the main link, so the system needs to be operated, such as adaptive power control, to improve the channel environment.

For the general system, the frequency band overlap between uplink and downlink, so in order to meet the above requirements, the threshold will be increased by 3 dB. Therefore, the downlink carrier to interference ratio threshold will be 15.2 db higher than the system's own carrier to noise ratio, and the carrier to noise ratio of the system can be obtained as follows:

$$\frac{C}{N_{th}} = \frac{E_b}{N_0} + R_s - BW_0 + M(dB) \tag{8}$$

Table 1. Inter satellite link interference analysis algorithm.

Computational Procedure	
1.	Obtain the inter satellite data and calculate the data acquisition step size $\Delta t_{step-down}$.
2.	Calculated the inter satellite link angle to obtain the antenna amplification G_{er}.
3.	Calculate the signal-to-noise ratio of the originator $\frac{C}{I_{th}}$.
4.	Calculate the interference received by the system L_d.
5.	Calculate the carrier to noise ratio received by the receiver C_{dn}.
6.	Comparison with the system decision value M specified by ITU.

The specific algorithm is shown in Table 1. In this way, the relative increment of equivalent noise temperature can be calculated according to the satellite constellation parameters, and it can be judged according to ITU-R S.324 [13] whether the two systems need to coordinate.

2.3 Analysis of Interference Problem

There are many kinds of interference and environmental factors in satellite communication system. When considering the interference between satellites, the free space transmission model is generally considered, and the atmospheric loss is also considered.

Free Space Loss

Free space is an ideal model for long-distance transmission of radio waves. Suppose that the transmitting power of a directional antenna is P_T, the power gain of the transmitting end is G_T, the opening area of the receiving end is A_R, and the power gain of the receiving end is G_R. The free space transmission loss is defined as L_f as follows:

$$Lf = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2 \tag{9}$$

When the free space transmission loss is converted to dB, it is:

$$[Lf] = 92.44 + 20\lg d(km) + 20\lg f(GHz) \tag{10}$$

Then the power P_R to the receiving end is as follows:

$$PR = \frac{P_T G_T A_R \eta}{4\pi d^2} = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 = \frac{P_T G_T G_R}{L_f} \tag{11}$$

Atmospheric Loss

In addition, the attenuation of electromagnetic wave transmission in clear weather is mainly due to the absorption of water vapor and oxygen in the lower atmosphere, and the density of water vapor and oxygen is uneven, which decreases with the increase of altitude. In addition, along the ray path, the temperature of atmospheric environment decreases with the increase of height, so some environmental models require temperature correction.

Rain Loss

The influence of rain on communication system is considered. According to the calculation method of rain attenuation specified by ITU-R P.681-1 [14], it can be concluded that the rain attenuation of space is related to transmission distance and communication frequency. In the actual communication system, the communication spectrum may not be fixed, but the fixed transmission distance should be. At the same transmission distance, the larger the communication frequency, the greater the free space loss and atmospheric attenuation loss.

3 Simulation Setup133

Through the real-time data of NGSO satellite system obtained by communication system simulation, the angle relationship, distance relationship and current time of two independent satellites in the system at a certain time can be obtained. Because at some time, there may be no signal transmission between the two satellites, there is no interconnection, so the data will not be obtained at this time. In the final data processing, the interference value is shown as Nan, that is, it does not exist.

After that, we need to classify each group of data, extract the data according to the interference situation, then select the appropriate system parameters for various interference situations, and design and calculate the relationship between inter satellite interference and its influencing factors.

Considering different interference scenarios, cosine theorem is used to calculate various angles to obtain antenna gain of different angles, and finally interference situation is obtained, as shown in Fig. 2 and Fig. 3.

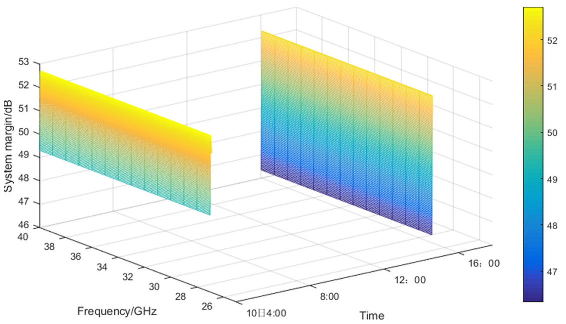

Fig. 2. Inter satellite interference of Starlink system to OneWeb system.

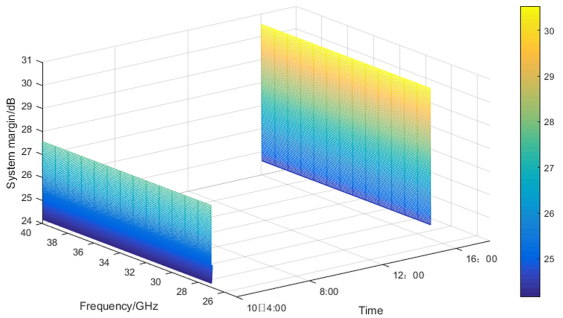

Fig. 3. Inter satellite interference of OneWeb system to system Starlink.

According to the simulation, the judgment value of interference between Starlink, and Oneweb on the same layer is always greater than 0, so it can be seen that it will not interfere with the communication of the current link. In the case of Starlink on the same layer, it is within 3 km, so the interference situation is basically unchanged, and the decision value is about 6 dB. The analysis of the judgment value shows that the interference of Oneweb to Starlink system is slightly larger than that of Starlink to Oneweb system. When the communication frequency is about 20 GHz, the rainfall attenuation is about 5 dB under the condition of light rain with daily rainfall of about 5 to 10 mm. In Starlink system, the inter satellite interference may be caused at some time under the condition of rainfall, which may cause interference to NGSO communication system, but it is relatively small.

The multi-dimensional analysis of interference and time and frequency shows that in the frequency range from 26 GHz to 40 GHz, in another word, in the range of Ku, with the increase of frequency and free space loss, the final SINR of the system will decrease and the possibility of interference will increase. As for the relationship between interference and time, with the change of time, the angle and distance between satellites will also change, and the final interference decision will be as follows.As is shown in the previous image, this is the interference feature of inter satellite data. When considering the time distribution characteristics of inter satellite interference, a new reference standard is introduced, which is defined as the relative interference time, that is, the ratio of the time that a system is affected by interference in one day to the total operation time of the system.

When analyzing and mining the data of inter satellite interference between NGSO satellite constellations, an important analysis standard is the relative interference time of the system. In the adjacent satellite system, the longer the relative interference time is, the longer the interference time is, and the worse the environment is, so the system needs to be adjusted.

For the relative interference time of electromagnetic data processing, Starlink constellation 1007 to 1027 are selected to analyze the interference of Oneweb constellation 0007 in one day. In the test frequency range of 1 to 24 MHz, the relative interference time is shown in Fig. 4. It can be seen that there are great differences in the relative time of communication interference between different satellites on this day.

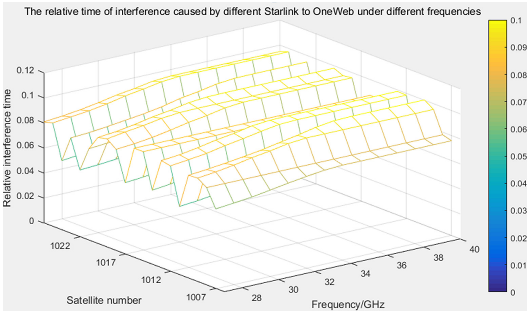

Fig. 4. Relative interference time of Starlink to OneWeb in one day under different frequencies.

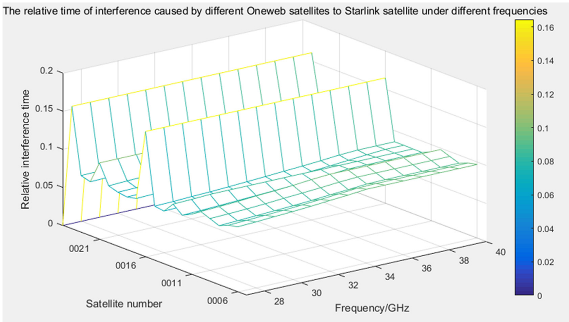

Fig. 5. Relative interference time of OneWeb to Starlink in one day under different frequencies.

Among these 20 satellites, the average time of communication interference between different satellites is 1 The time of communication interference between 1016 and 1017 satellites is about 2 h, and the time of interference between 1012, 1018, 1022 and 1024 satellites is the smallest, about 50 min. In addition, it can be seen that the greater the frequency of communication, the more time of system interference.

Accordingly, the interference of OneWeb on Starlink is shown in Fig. 5.

For the interference analysis and data processing of the system, in order to obtain the characteristics of the interference data, it is necessary to process the data according to the following steps:

(1) Obtain the real jamming situation of the jammed area, including its time, location, respective emitter parameters and other data.
(2) The jamming data are classified according to different jamming sources.
(3) According to the interference data, an appropriate interference data analysis model is established, and the prediction data are obtained by using the model, and then the model parameters are optimized by comparing with the actual data.

When building prediction model based on actual data, Markov prediction method is usually used to analyze and predict situation information according to probability transfer matrix. However, Markov model has the following disadvantages:

(1) The state partition of data is more based on experience, and the partition results vary from person to person.
(2) Markov prediction method uses the principle of probability maximization to calculate, ignoring the possible low probability information.

In addition, we can use the interference analysis algorithm designed before to analyze the interference data in the region by combining the emitter location algorithm, the source division and the desired emission data. Assuming that there are k radiation sources in the region, the center frequency of each radiation source and the distance from the grid point to the radiation source are known, the field strength of the grid point can be obtained.

4 Conclusion

According to the analysis, we can see that the space electromagnetic interference phenomenon has always existed and is very complex. The interference caused by the inter satellite link proposed in this paper exists in Ka and Ku band, and will have an impact on the system, and will be more serious in rain and other scenarios.

In addition, the main trend of interference in Ka and Ku frequency bands is that the higher the frequency, the greater the interference. Under conditions such as rain, it may have a great impact on the communication system. Therefore, it is necessary to adopt some power control methods to improve the system performance. We should also give full consideration to allocating appropriate frequencies in Ka and Ku frequency bands to reduce system interference.

References

1. Han, H.: Analysis of LEO communication constellation inter satellite links. Satellites Netw. (08), 40–42 (2018)
2. Dong, S., Yao, X., Gao, X., Han, Z., Yan, Y., Sun, Y.: Evaluation method of communication interference in GSO satellite system deployment. J. Beijing Univ. Aeronaut. Astronaut. **46**(11), 2184–2194 (2020)
3. Liu, J., Shi, Y., Fadlullah, Z.M., Kato, N.: Space-air-ground integrated network: a survey. IEEE Commun. Surv. Tutor. **20**(4), 2714–2741 (2018)
4. Wang, Y., Ding, X., Zhang, G.: A novel dynamic spectrum-sharing method for GEO and LEO satellite networks. IEEE Access **8**, 147895–147906 (2020)
5. Han, Q., Nie, J., Liu, W., Wang, F.: Interference intensity and feasibility analysis of Ka band inter satellite link. J. Cent. South Univ. (Nat. Sci. Edn.) **45**(03), 769–773 (2014)
6. Xie, X., Yan, S., Chen, J.: Anti jamming performance analysis of inter satellite link. Aerosp. Meas. Technol. **31**(06), 53–56 (2011)
7. Author, F.: Contribution title. In: 9th International Proceedings on Proceedings, pp. 1–2. Publisher, Location (2010)
8. Dai, J., Feng, X.: Simulation and analysis of spectrum interference and its avoidance in LEO satellite system. Inf. Technol. (02), 79–84 + 91 (2021)

9. Xi, C., Deng, Y., Yang, B., Wen, X., Cai, J., Yuan, Y.: Research on electromagnetic emission visualization technology of LEO constellation system. Electron. Test (09), 49–51 (20200)
10. del Portillo, I., Cameron, B.G., Crawley, E.F.: A technical comparison of three low earth orbit satellite constellation systems to provide global broadband. Acta Astronaut. **159**, 123–135 (2019)
11. Chen, Z., Jin, J., Hao, Z., Ting, L.: Spectral coexistence between LEO and GEO satellites by optimizing direction normal of phased array antennas. China Commun. **15**(06), 18–27 (2018)
12. Xiao, Q., Geng, X., Chen, J., Meng, L., Li, N., Zhang, Y.: Study on the calibration method of interference magnetic field of Leo magnetic survey satellite. Acta Geophys. Sinica **61**(08), 3134–3138 (2018)
13. ITU-R. Analytical method for estimating interference between non-geo stationary mobile-satellite feeder links and geostationary fixed-satellite networks operating co-frequency and codirectionally: ITU-R S.1324 [S]. ITU, Geneva (1997)
14. ITU-R P.681-11 Propagation data and prediction methods required for the design of telecommunication systems. ITU-R P Serise Recommendations Radio wave Propagation, Gevena (2007)