Design and Transmission Performance Analysis of Satellite Constellation for Broadband LEO Constellation Satellite Communication System Based On High Elevation Angle

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Abstract. Because of the rapid development of small satellite technology and the advantages of low earth orbit satellite (LEO) satellites compared with traditional geosynchronous orbit satellite (GEO) satellites such as low time delay low propagation loss broadband, LEO constellation satellite communication system has gradually become one of the hot spots in the field of satellite communication. At present, many countries and satellite communication companies in the world are working on broadband satellite communication system programmes. In view of the actual needs of our country, through link computation and comparing the complexity of satellite implementation at different communication elevation angles to meet the terminal rate requirements, the assumption of constructing broadband LEO constellation satellite communication system with high elevation is put forward. The transmission characteristics of OneWeb constellation are simulated by STK and Matlab simulation software.

1. Introduction
Because the traditional GEO satellite network has the characteristics of large propagation delay, high propagation loss, weak on-board processing capacity, low network throughput and high communication cost, it is mainly used as the extension and supplement of the ground communication network. Using GEO satellite to establish a global-oriented and economically competitive broadband satellite communication system is obviously very difficult under the current technical conditions [1].

The LEO satellite orbit is generally between several hundred and more than one thousand kilometers, and the communication propagation delay is tens of milliseconds, which is far lower than the communication delay of GEO. Within the acceptable range of normal communication, the new LEO small satellite has the characteristics of strong on-board processing capability, inter-satellite links and large capacity, which can effectively solve the problem of global mass data transmission and processing [2]. With the rapid development of small satellite technology, the cost of satellites is continuously decreasing. Satellite companies have been able to produce small satellites in quantity, thus greatly reducing the production cost and production cycle of satellites, greatly reducing the cost of establishing and maintaining satellite communication systems, and also laying the foundation for the large-scale establishment of LEO satellite groups in space.
The broadband LEO constellation satellite communication system is one of the important development hotspots in the field of satellite communication. Many countries and satellite communication companies in the world are working out their own broadband satellite communication systems. OneWeb has launched the world's largest satellite Internet programme to launch 648 satellites to establish a global low-orbit satellite high-speed communications network. Following the announcement, 2,400 satellites will be launched to provide broadband Internet access. SpaceX plans to create an Internet constellation STEAM of more than 4,000 small satellites to provide Internet access globally. Currently, SpaceX has reported frequency and orbit to ITU through the Norwegian Government. According to the declarations, the number of satellites is 4,257, operating in 43 orbits using the Ku and Ka bands. LeoSat plans to build a constellation of 140 satellites, operating in the Ka band, dedicated to building 120-140 high-power Ka band constellations and providing broadband data access services to the world. LeoSat will use high-power satellite platforms to reduce the number of satellites by increasing single-satellite capabilities [3].

In order to adapt to the expanding external communication and occupy the orbit and frequency resources of space ahead of time, it is necessary for China to establish its own broadband satellite communication system.

2. Constellation Design

2.1. Constraints
The broadband LEO constellation studied in this paper is mainly designed for the national conditions of our country. The main design constraints are as follows:

1. To meet the conditions for the establishment of stations within the territory;
2. Target global communications, with systems capable of achieving seamless global coverage;
3. With low-cost LEO small satellites, the satellite structure should not be too complex, the satellite beams should not be too many, and the satellite antennas should not be too large;
4. Dominated by domestic business, while the volume of overseas business is relatively small;
5. To meet the needs of high-speed broadband users and miniaturization of user terminals at the same time.

2.2. Basic Ideas
In the constellation configuration, in order to achieve global communication, the constellation needs to achieve global seamless coverage. Therefore, the polar orbit constellation which can cover the north and south poles should be used in the constellation configuration.

The low elevation angle will increase the transmission loss and increase the aperture of satellite or user terminal antenna, while the aperture of satellite antenna will lead to too narrow point beam. The low elevation constellation satellite has a large single satellite coverage area. If the low elevation constellation satellite is adopted, the satellite point beam will be excessive, the satellite complexity will be increased, and the low elevation constellation satellite will be difficult to achieve. The low elevation constellation satellite will also have the shortcomings such as the propagation delay will increase, the communication will be easily blocked and so on [4, 5]. Therefore, the scheme of high elevation constellation system is proposed. The number of point beams per satellite is small and the transmission distance is small, which can be realized by low-cost satellite. Although the number of satellites is large, the robustness of the system is strong (invulnerability).

Through uplink computation, the feasibility of iridium system constellation with low communication elevation to support broadband service is analyzed. Because the OneWeb system is a LEO constellation satellite communication system oriented to broadband services, the service and terminal indexes used in link calculation mainly refer to the related indexes of the OneWeb system.

The user uplink frequency: 12.75-13.25 GHz and 14.0-14.5 GHz, the central frequency of 13.5 GHz is calculated, QPSK modulation is adopted, rainfall loss is 10 dB.
User terminal index: antenna aperture 30-75 cm, 75 cm calculation; the maximum uplink rate is 25 Mb/s, the antenna efficiency is 55%, the noise temperature is 250 K, and the transmit power is calculated according to 2 W.

The main satellite parameters are: the transponder bandwidth is up to 125 MHz, down to 250 MHz, the noise temperature is 500 K, the satellite orbit altitude is 778 km, the half-angle of single satellite coverage is 62 degrees, the lowest communication elevation is 8 degrees, and the farthest distance between satellite and ground is 2 476 km.

\[
[L_f]_u = 20 \log \frac{4\pi df_0}{c}
\]  

(1)

The free space loss of uplink is calculated to be 183 dB.

\[
[G_E]_u = 10 \log \left( \frac{4\pi A}{\lambda^2} \times \eta \right)
\]  

(2)

The transmit gain of the user terminal is calculated to be 38 dB.

QPSK is used in modulation mode and LDPC code is used in channel coding. The normalized ideal threshold signal-to-noise ratio is 3 dB when the BER is better than 1 x 10-6. Considering 1 dB loss and 2 dB system margin, the signal-to-noise ratio is 6 dB.

\[
\left[ \frac{E_b}{n_0} \right]_u = 6 \text{ dB} \ c_2 = a_2 + b_2
\]  

(3)

\[
\left[ \frac{C}{n_0} \right]_u = \left[ \frac{E_b}{n_0} \right]_u + [R_b]
\]  

(4)

The uplink threshold is calculated to be 80 dB.

\[
\left[ \frac{C}{n_0} \right]_u = [P_f] + [G_f] + [G] - [L_f]_u - 10 \log KT - [M]
\]  

(5)

The receiver gain of the satellite antenna is calculated:

\[
[G]_s = 30.1 \text{ dB}
\]  

(6)

\[
[G] = 10 \log \left( \frac{4\pi A}{\lambda^2} \times \eta \right)
\]  

(7)

The aperture of satellite receiving antenna is about 0.27 m.

\[
\theta = \frac{70 \lambda}{D}
\]  

(8)
The 3 dB beam width of the satellite antenna is calculated to be 5.8 degrees.

Since the point beam half angle of the satellite antenna is 2.9 degrees, the Iridium system satellite needs at least 62 degrees [6, 7] to achieve global coverage of the single satellite half angle. Roughly, satellites require at least a thousand dots of beams. It can be found that if the constellation of the iridium system with low elevation is used, the satellite point beams are too many and the satellite is too complex to realize. Therefore, a constellation scheme with high elevation is proposed.

2.3. High Elevation Constellation Programme

From the above analysis, we can see that the construction of broadband LEO constellation satellite communication system, its constellation needs to adopt a high elevation scheme. The space segment of the OneWeb system proposed by OneWeb consists of 648 satellites distributed on 18 orbital planes, with 38 satellites deployed on each orbital plane, with an orbital altitude of 1,200 km and an orbital inclination of 87.9 degrees. The following link computation is used to analyze the feasibility of using a high elevation constellation scheme similar to the OneWeb system.

Through uplink calculation, the aperture of the satellite point beam antenna of OneWeb system can be 0.18 m, the bandwidth of 3dB is 8.64 degrees. The half angle of the coverage area of a single satellite needs at least 32.7 degrees, and the transmission performance of a single satellite needs only a few dozen beams. After further calculation of the downlink, in order to meet the requirement of downlink transmission rate, the transmit power of the satellite is 1.5 W. The calculation shows that the scheme of high elevation constellation in OneWeb system is feasible. Figures 1 and 2 show the planar and spatial distributions of the satellites of the broadband LEO constellation satellite communication system.

![Satellite plane distribution.](image)
3. constellation design

3.1. Satellite coverage analysis Location-based Traffic Model
Figure 3 shows the multi-satellite coverage of satellites with an edge elevation of 50 degrees. Different shaded regions show different degrees of multi-star coverage. The shadow region of the middle layer of Figure 3 is 100% of the single star coverage, the outward layer is 100% of the binary star coverage, and the outermost layer is 100% of the six stars. As latitude increases, constellations can achieve 100% coverage of more satellites.

Figure 3. Multi-satellite coverage of satellites at an elevation of 50 degrees at the edge.

It can be seen that when the elevation of the edge communication is 50 degrees. The satellite can achieve global seamless coverage. High-latitude area can achieve multi-satellite coverage. This constellation scheme ground users have more than 50 degrees of communication elevation.

3.2. Communication elevation
The average communication elevation of the satellite coverage area is shown in figure 4 and figure 5, where figure 4 is the average communication elevation of the satellite coverage global area and figure 5 is the average communication elevation of the domestic area.
Figure 4. Global regional average communication elevation.

Figure 5. Average communication elevation in domestic region.

It can be seen that the average communication elevation of satellites in the global coverage area is above 66 degrees.

3.3. Doppler shift
LEO satellites move fast and there is obvious Doppler shift phenomenon in the communication between LEO satellites and earth stations. Figures 6 shows the variation of Doppler frequency shift between users in Beijing and 36 satellites in a single LEO constellation orbit.
The LEO satellite with the highest elevation is always selected for communication at the Earth station. Because of the large number of satellites in the constellation, the low orbit altitude and the fast motion of the satellite, the earth station switches more frequently between 648 satellites when it communicates with the satellite. When switching, the Doppler frequency shift will jump. Figure 6 shows that the Doppler frequency shift has multiple jumps.

3.4. Pitch and azimuth angles

The pitch angle and azimuth angle between the ground station and the satellite are analyzed below. Because the orbital parameters of each satellite are similar, the constellation is a WALKER constellation based on a seed satellite, and the changes of pitch angle and azimuth between different satellites and ground stations are similar, so it is only necessary to analyze the pitch angle and azimuth between one satellite and ground station. The ground station is chosen in Beijing.

Figure 7 and Figure 8 show the variation of the pitch angle and azimuth between Beijing and an LEO satellite, respectively. Figure 7 shows the variation curve of the pitch angle and Figure 8 shows the variation curve of the azimuth angle.
Figure 8. User azimuth angle change curve in Beijing area.

It can be seen that when users in Beijing communicate with LEO satellites, the elevation of communication is always greater than 50 degrees. Transmission performance of OneWeb constellation are simulated by STK and Matlab, which is of certain reference and guidance significance to the construction of broadband LEO constellation communication system in China.

4. Conclusion
In this paper, the development of broadband LEO constellation satellite communication system is analyzed. Combined with the requirements and practical conditions for the construction of broadband LEO constellation satellite communication systems in China. Through link computation, the feasibility of global broadband communication supported by iridium system with low communication elevation and OneWeb system with high communication elevation is analyzed and compared. The constellation scheme of constructing broadband LEO constellation communication system with high elevation angle is put forward, and the constellation coverage, communication elevation, Doppler frequency shift, pitch angle and azimuth Results of Simulation.

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