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Availability Analysis of Remote Sensing Satellite Systems Using 25.5-27 GHz Band for Data Transmission Applications

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***Abstract*—With OneWeb, Starlink and other LEO satellite systems being well known, commercial space industry has become a focus of worldwide attention and a key word in the development of China's space industry in recent years. Due to the loose technical threshold and easy networking, remote sensing satellites have become the fastest growing category of satellites in China in the commercial space industry, which directly leads to X band, the traditional data transmission band of remote sensing satellite systems, being saturated rapidly. At the same time, with the development of science and technology in the field of Earth exploration-space service, the amount of data needed to be transmitted by remote sensing satellite systems has also increased geometrically. These new situations force the data transmission band to shift to Ka band with higher frequency and wider bandwidth. This paper will discuss the availability of using Ka band as data transmission band of remote sensing satellites from the aspects of Ka band characteristics, satellite network filings reserve and compatibility with the same frequency IMT system.**

Keywords—scientific satellites; Ka band; data transmission applications; frequency availability

I. Introduction

Satellite frequency resource is the basic element of satellite systems construction. It is not only the foundation of the design and construction of satellite systems, but also the necessary condition for the normal operation of satellite system after its completion. With the rapid development of commercial space industry around the world, the frequency compatibility among different satellite systems has become increasingly prominent, and the situation of interference between satellite networks has become increasingly complex. Therefore, in order to ensure that China's scientific satellite systems can legally and reasonably acquire internationally recognized satellite frequency resources, it is of far-reaching significance to carry out frequency availability demonstration of scientific satellite systems and to do well in frequency selection and utilization planning in advance.

In ITU's Radio Regulations[1], forty-two kinds of radio services are defined. Based on this classification and definition, rules for radio frequency demonstration, declaration, coordination and registration in satellite networks are formulated. In China, satellite systems missions have been divided into three areas: communication, remote sensing and navigation. The difference between domestic classification[2] and international rules leads to the situation that they cannot be strictly matched. Therefore, if we want to carry out the frequency availability demonstration of scientific satellite systems, we need to define the scientific satellite systems first.

According to the definition in the Radio Regulations, the application of data transmission of remote sensing satellite systems mainly corresponds to the Earth exploration-satellite service. In another word, the application of data transmission can mainly use the radio frequency allocated to Earth exploration-satellite service in the table of frequency allocations in the Radio Regulations. By sorting out the table of frequency allocations, the frequency for Earth exploration-satellite service can be summarized, as shown in Table 1.

TABLE I. FREQUENCY ALLOCATED TO EARTH EXPLORATION-SATELLITE SERVICE

Frequencies	Primary or Secondary	Direction
401-403MHz	Primary	Earth-to-space
460-470MHz	Can not cause harmful interference to the radio stations used in this frequency band	space-to-Earth
1525-1535MHz	Secondary	
1690-1710MHz	Can not cause harmful interference to the radio stations used in this frequency band	space-to-Earth
2025-2110MHz	Primary	space-to-Earth/Earth-to-space
2200-2290MHz	Primary	space-to-Earth/Earth-to-space
8025-8400MHz	Primary	space-to-Earth
13.75-14GHz	Secondary	
25.5-27GHz	Primary	space-to-Earth
28.5-30GHz	Secondary	Earth-to-space
37.5-40.5GHz	Secondary	

Considering that the amount of data transmitted by remote sensing satellites is quite large, wider bandwidth is usually needed to achieve higher transmission rate. While S band is mainly used in satellite systems TT&C tasks, it is difficult to simultaneously carry out data transmission applications to the ground. Therefore, the main frequency band for data transmission of remote sensing satellite systems is X band, i.e. 8025-8400 MHz band.

However, with OneWeb, Starlink and other satellite systems being well known, commercial space industry has become a focus of worldwide attention, and Chinese space industry has also ushered in a period of rapid development of commercial space industry. Due to the loose technical threshold and easy networking, remote sensing satellites, as an important branch of commercial satellite systems, have become the fastest growing category of satellites in China. This situation directly leads to X band, the traditional data transmission band of remote sensing satellite system, being saturated rapidly. At the same time, with the development of science and technology in the field of Earth exploration-satellite service, the amount of data needed to be transmitted in remote sensing science has also increased geometrically. These new situations force the data transmission band to shift to Ka band (25.5-27 GHz) with higher frequency and wider bandwidth.

II. Characteristics of Ka band for Earth exploration-satellite service

Ka band for satellite communication has many advantages, such as larger bandwidth, higher capacity, less interference, small size of user equipment, etc. After more than 20 years of research and experiments, Ka band has been widely used in high-throughput communication satellites, and has become the widely recognized frequencies for future communication satellite systems. The progress of Ka band application in the field of communication satellites has also brought the development of Ka band communication devices and the progress of communication technology. It also verifies the possibility of applying 25.5-27 GHz band for data transmission of remote sensing satellite systems.

Compared with the traditional X band for remote sensing satellite systems, Ka band has the following characteristics.

A. Wider Bandwidth and Faster Transmission Rate

As can be seen from Table 1, the X band used in Earth exploration-satellite service refers to 8025-8400 MHz bandwidth, totaling 375 MHz bandwidth. While the Ka band of Earth exploration-satellite service refers to 25.5-27 GH bandwidth, totaling 1500 MHz bandwidth, which is four times the maximum available bandwidth of X band. According to Shannon's theorem, the relationship between channel capacity R_{max}, channel bandwidth W and signal-to-noise ratio S/N is as follows:

$$R_{max} = W\log_2(1+\frac{S}{N}) \quad (1)$$

Therefore, the increasement of available bandwidth will lead to a significant increase in the channel capacity when the signal-to-noise ratio is fixed.

From another point of view, when the data transmission rate of remote sensing satellite systems is constant, the Ka band has wider bandwidth than the X band, which can accommodate more satellite systems to work at the same time. To a certain extent, it will alleviate the X band saturation caused by the rapid growth of the amount of remote sensing satellite systems.

B. Free Space Loss and Rain Attenuation

According to the free space loss formula:

$$L_S = 32.45 + 20\log f + 20\log d \quad (2)$$

Higher frequency will lead to higher free space loss in the transmission process. Compared with X band, the free space loss of Ka band increases by about 12 dB at the same transmission distance. This requires that if we want to achieve the same transmission effect as the X band, we need to improve the transmitting power of the satellite or the receiving antenna gain of the earth station.

At the same time, because the wavelength of Ka band signal is more like the size of raindrops, Ka band signal transmission is more affected by rain attenuation than X band. The same problem also exists in the application scenarios of communication satellites. However, unlike communication satellite systems, because of the limited number of earth stations needed in the system, remote sensing satellite systems can try to avoid the impact of rain attenuation by choosing the location of earth stations carefully.

C. Industrial Application

As the main data transmission band of remote sensing satellite system, X band communication device industry has developed more mature, and the ground receiving systems also have developed more perfect. If the Ka band is to be used for data transmission applications, due to the change of wavelength, both the transmitter and the receiver will have changes in demand, requiring the re-development of the communication devices. At the same time, the ground receiving systems also need to be re-planned and constructed.

III. Situation on declaration of satellite network filings containing X/Ka band Earth exploration-satellite service

From the available frequency resources of Earth exploration-satellite service in Table 1, the available frequency resources for data transmission applications are not that much, mainly X band and Ka band. Therefore, this paper mainly focuses on the declaration of X band and Ka band satellite network filings.

Up to ITU 2878 IFIC data (published on September 4, 2018), with the frequency range of 8025-8400 MHz and the type of service being Earth exploration-satellite service, the declaration of X band Earth exploration-satellite service satellite network filings can be inquired through the database published by ITU. In the X band, 291 satellite network filings were declared by 39 Administrations. Among them, China has declared the largest number of satellite network filings, reaching 57 copies, supporting more than 50 satellites in orbit for downlink data transmission frequency requirements. Therefore, 8025-8400MHz is the hottest frequency band for downlink data transmission application when satellites in orbit carry out Earth exploration-satellite service. Many satellites use this frequency band for data transmission application, and the domestic competition is particularly fierce. More details are shown in Figure 1.

With the frequency range of 25.5-27 GHz and the type of service being Earth exploration-satellite service, the declaration of Ka band Earth exploration-satellite service satellite network filings can be inquired through ITU database. In Ka band, the declared total amount of satellite network filings of Earth exploration-satellite service is far less than that of X band, which can be seen in Figure 2. Among them, Britain declared the most satellite network filings, followed by China. However, most of these satellite network filings has not yet been put into use. Therefore, whether from the perspective of international declaration or domestic use, Ka band has wider bandwidth, but is not popular compared with X band, so the competition is relatively smaller. At the same time, the frequency resources reserve work needs to be continued.

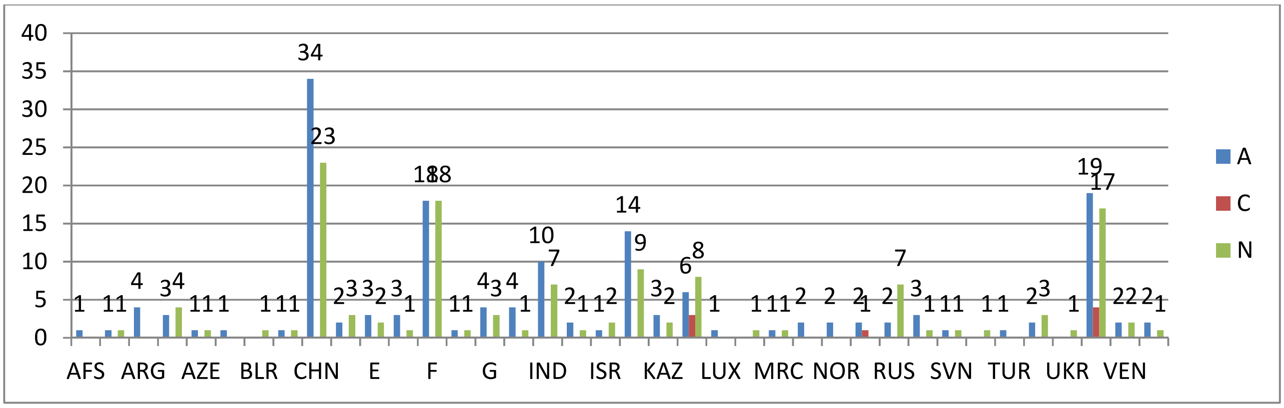

FIGURE I. SITUATIONS ON DECLARATIONS OF SATELLITE NETWORK FILINGS CONTAINING X BAND

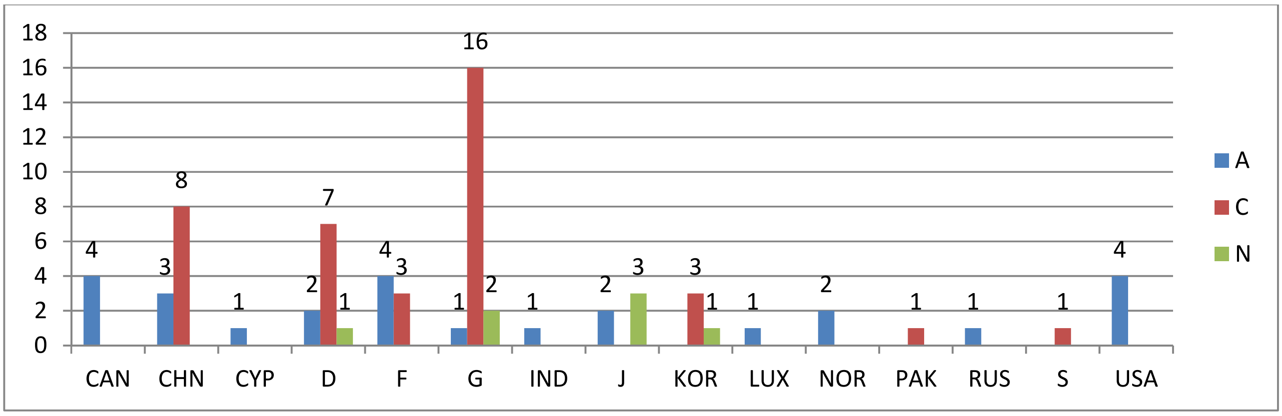

FIGURE II. SITUATIONS ON DECLARATIONS OF SATELLITE NETWORK FILINGS CONTAINING KA BAND

IV. FREQUENCY COMPATIBILITY BETWEEN EARTH EXPLORATION-SATELLITE SERVICE AND IMT SYSTEM IN KA BAND

According to the Regulations on the Radio Frequency Allocation of the People's Republic of China, the radio service allocation in the 25.5-27 GHz band is shown in Table 2 below:

TABLE II. ALLOCATION TO SERVICES IN 25.5-27GHZ

Frequency	Allocation to services in mainland China
25.5-27GHz	EARTH EXPLORATION-SATLLITE (space-to-Earth)[1] FIXED INTER-SATELLITE[2] MOBILE SPACE RESEARCH (space-to-Earth) Standard frequency and time signal-satellite (Earth-to-space)

1. In the 25.5-27 GHz band, the establishment of receiving earth stations using Earth exploration-satellite service (space-to-Earth), which requires the protection of harmful interference from fixed and mobile services, needs to get consent from the state radio Administration.
2. Use of the 25.25-25.75 GHz band by the inter-satellite service is limited to space research and Earth exploration-satellite applications, and also transmissions of data originating from industrial and medical activities in space.

In the 25.5-27 GHz band, considering the direction of signal transmission of Earth exploration-satellite service, the data transmission links between different satellite systems are compatible and shared mainly through geographic isolation of receiving earth stations. In addition, the receiving earth stations may be mainly interfered by fixed or mobile service systems from the ground. Because of the high transmission loss of Ka band, there was no fixed or mobile service systems using this band in China before. However, with the rapid development of the public mobile communication system, the shortage of frequency resources has become increasingly prominent. The IMT system has been aiming at the millimeter-wave band as a supplement to the hotspot areas. In order to study this issue[3], ITU set up 1.13 agenda item[4] in the WRC-15 conference to seek new allocation for IMT system in 11 candidate bands, including 25.5-27 GHz bands.

A. Sharing Criteria

In order to achieve frequency compatibility between remote sensing satellite systems and other radio service systems, ITU has formulated recommendations ITU-R SA.1027[5] and ITU-R SA.1161[6], listing the sharing criteria of geostationary orbit satellites and low-Earth orbit satellites in different frequency band respectively. The sharing criteria in 25.5-27 GHz band are shown in Table 3 below.

TABLE III. SHARING CRITERIA IN 25.5-27GHZ BAND

Orbit type	Interfering signal power (dBW) in the reference bandwidth to be exceeded for no more than 20% of the time		Interfering signal power (dBW) in the reference bandwidth to be exceeded for no more than p% of the time	
	Space	Terrestrial	Space	Terrestrial
Geostationary	-164.6dBW per 10MHz1	-147.7dBW per 10MHz[1]	-133.3dBW per 10MHz[1] p=0.05	-133.0dBW per 10MHz[1] p=0.1
Low-Earth orbit	-160dBW per 10MHz	-143dBW per 10MHz	-116dBW per 10MHz p=0.0025	-116dBW per 10MHz p=0.0050

1. The interfering signal power (dBW) in the reference bandwidth are specified for reception at elevation angles≥5°.

B. Simulation on Compatibility Analysis

According to the parameters of IMT system provided by ITU 5D research group[7], the base station of IMT system may be deployed in four scenarios[8]: outdoor suburban open space, outdoor suburban, outdoor urban and indoor. Compared with the other three outdoor situations, when the IMT system base station is deployed indoors, the building penetration loss will significantly attenuate the IMT signal, so the aggregated interference signal power will be less than that in the other three cases. For outdoor suburban open space scenario, the base station density is 0 or 1 base station per square kilometer, while the base station density in outdoor suburban scenario and outdoor urban scenario are 10 and 30 base stations per square kilometer, respectively. A smaller number of base stations is most likely to result in a smaller aggregated interference signal power. Compared between outdoor suburban and outdoor urban scenarios, outdoor urban scenario has larger base station density, so aggregated interference is larger. At the same time, considering the current deployment mode of remote sensing satellite data receiving earth station, this kind of earth station is usually deployed in the suburbs far from the city center, so it is necessary to consider the deployment of base stations in outdoor open space scenario from a practical point of view. In summary, the following two simulation scenarios can be set for the frequency compatibility analysis of remote sensing satellite systems and IMT system.

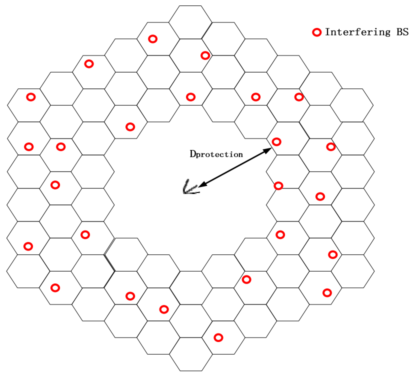

FIGURE III. OUTDOOR URBAN SCENARIO, CONSIDERING AGGREGATED INTERFERENCE

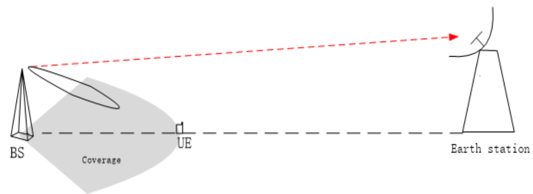

FIGURE IV. OUTDOOR SUBURBAN OPEN SPACE SCENARIO, CONSIDERING THE POINT-TO-POINT INTERFERENCE

C. Simulation Results

According to the method given in recommendation ITU-R M.2101 of ITU, the interference caused by IMT system to Earth exploration-satellite systems is simulated and analyzed in two different scenarios[9]-[10]. The simulation results in two scenarios can be obtained respectively.

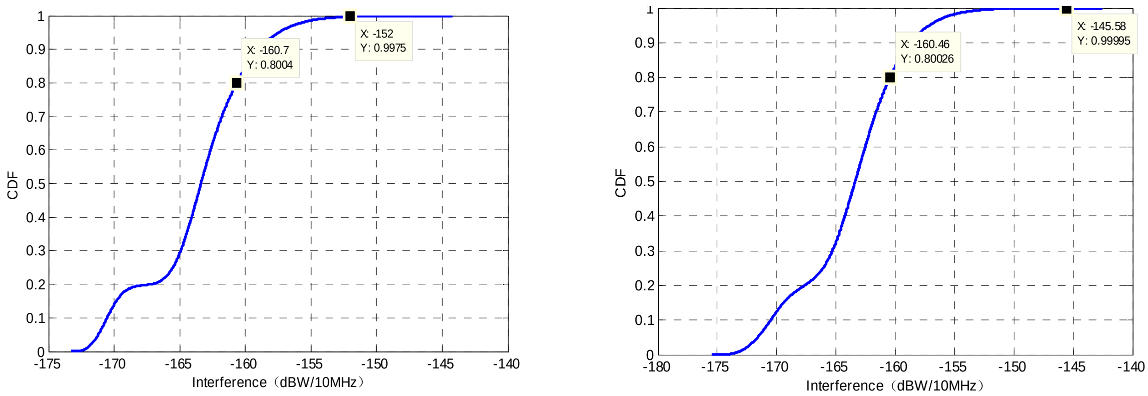

FIGURE V. INTERFERENCE PROBABILITY CDF CURVE UNDER OUTDOOR URBAN SCENARIO

1) Outdoor urban scenario

Results in Figure 5 (GEO system earth station on the left side and low-Earth orbit one on the right) are obtained when the protection distance is set to 400 meters (the distance between the inner ring base station and the earth station). The simulation curve reflects the probability of different interference power values occurring to the earth station. For the geostationary earth station, the interference power does not exceed -160.7dBW/10MHz in 20% of the time and -152dBW/10MHz in 0.25% of the time. For the low-Earth orbit earth station, the interference power does not exceed -160.46dBW/10MHz in 20% of the time and -145.58dBW/10MHz in 0.005% of the time. The simulation results show that the interference caused by IMT system does not exceed the sharing criteria of ITU recommendations when the protection distance is 400 meters.

2) Outdoor suburban open space scenario

Considering the possible interference of IMT system to the earth station in the worst case, that is, the earth station points to the base station of IMT system in the horizontal direction. Because the base station is deployed in open space in this simulation scenario, the influence of buildings or forests on the transmission loss is not considered in the simulation. According to the sharing criteria, we can deduce the protection distance between the base station of IMT system and the earth station: under the long-term sharing criteria, the protection distance is about 4.48-6.97 kilometers; under the short-term sharing criteria, the protection distance is about 1.87-2.04 kilometers.

V. CONCLUSION

This paper discussed the availability of using Ka band as the data transmission band for remote sensing satellite systems from three aspects: the characteristics of Ka band, the storage of Ka band satellite network filings and the frequency compatibility with the same frequency IMT system. According to the above-mentioned demonstration, we can basically confirm that using Ka band for data transmission application of remote sensing satellite systems is feasible, but there is still much work to be urgently promoted. Suggestions for follow-up work are as follows:

1) Promote the development of Ka band devices industry and accelerate the application of Ka band in practical systems

Although compared with traditional X band, Ka band has many problems, such as high transmission loss, heavy rain attenuation and immature devices, these problems will be solved one by one in the near future with the rapid development of Ka band in satellite systems. The users of remote sensing satellite systems can start to carry out the study and application of Ka band data transmission in advance.

2) Declare the Ka band Earth exploration-satellite service satellite network filings early

At present, the number of Ka band satellite network filings registered in ITU's database is not that large. If domestic satellite network operators have the need to apply Ka band data transmission in the proposed scientific satellite system, they should declare satellite network filings to ITU as soon as possible to ensure the acquisition of frequency resources when deploying real systems.

3) The impact of IMT system development should be fully considered when deploying earth stations of remote sensing satellite systems

The simulation results show that the interference of IMT system to the earth stations is within the sharing criteria, and the IMT system uses 25.5-27 GHz only as a supplement to the hot spot area, which is geographically isolated from the service area of the earth station. However, in the worst case, the maximum protection distance between the base stations of IMT system and the earth stations is still up to 7 kilometers. Therefore, when the users of remote sensing satellite systems deploy the earth stations, they should seek opinions from the national radio Administration in advance to ensure that sufficient protection distance is separated from the same frequency base stations of IMT system. This is necessary, not only to avoid the harmful interference from IMT system, but to ensure the normal use of the earth stations.

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