Interference Coverage Prediction of EESS Satellite Earth Station Based on WRAP Software

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Abstract. In the construction and network planning of the ground 5G system around the satellite earth station, we need to predict the distribution of the field strength to evaluate the coverage effect. The field strength distribution of satellite earth station and 5G system is simulated by using WRAP radio network programming software. Combining the actual antenna direction characteristic parameters and terrain database, the DETVAG 90/FOI propagation model and ITU-R P.2108 recommendation are selected to calculate the field strength coverage, and displayed on the electronic map directly. The prediction of field strength interference coverage around Beijing and Jiamusi satellite earth stations is realized, which provides technical basis for scientific layout of the two systems.

1. Introduction
International frequency coordination below 6 GHz has basically been completed. The new research focuses on millimeter wave band, which is more than 24 GHz frequency [1] [2]. According to the IMT (International Mobile Telecommunications, 5G) spectrum plan issued by some major countries and regions [3], the candidate frequency bands of millimeter wave are concentrated in the 24.75-29.5 GHz frequency band, and our country also tends to use this frequency band. In full use of the spectrum allocated to part of the satellite earth station, in order to improve the efficiency of the spectrum, the scope of the use of 5G around these satellite earth stations needs to be evaluated to avoid radio interference.

This paper uses WRAP software for technical analysis. WRAP software is a radio spectrum planning and simulation analysis software. The software is developed by the Swedish Saab group to meet the technical management and administrative needs of the radio spectrum. It can be used in the fields of civil aviation, military radar communication and so on. The main feature of the WRAP software is the transmission of the radio wave. The combination of computation and geographic information data will greatly improve the accuracy of software simulation. WRAP software includes a full band (10kHz-300GHz) wave propagation model, which can support the planning requirements of different radio services, and integrate important proposals and reports such as ITU-R P.2108 [4], which is one of the important safeguards for the completion of 5G business planning. The WRAP software includes the public mobile communication, the coverage calculation related to the satellite earth station, the calculation of interference and the calculation of frequency distribution, which provide an important basis for the rational and effective use of radio frequency resources.

2. System parameters and protection criterion
This section provides the specific parameters used in the study, as below.
2.1 Technical and operational characteristics of 5G systems operating in the 25.5-27 GHz frequency range

According to the liaison statement from WP 5D to TG 5/1 [5], characteristics of 5G systems for frequency sharing/interference analyses in the frequency range 24.25-33.4 GHz are listed in Table 1 as below.

| Parameter                        | Value       |
|----------------------------------|-------------|
| Bandwidth (MHz)                  | 200         |
| BS Tx power (dBW)                | -5          |
| UE Tx power (dBW)                | -11         |
| Network topology and characteristics | 30 BSs/km² |
| Frequency reuse                  | 1           |
| BS antenna height (m)            | 6           |
| UE antenna height (m)            | 1.5         |
| Sectorization                    | Single sector |
| Downtilt (degree)                | 10          |

2.2 Technical and operational characteristics of Earth exploration-satellite service operating in the 25.5-27 GHz frequency range

Table 2 lists locations of earth stations that use the frequency bands given in the following sections [6].

| Non-GSO and GSO earth stations       | Longitude (deg) | Latitude (deg) |
|--------------------------------------|-----------------|----------------|
| Beijing [GSO]                        | 116.3 E         | 40.1 N         |
| Jiamusi [Non-GSO]                    | 130.3 E         | 46.7 N         |

This section provides the RF parameters needed to conduct interference assessments and sharing studies for space-to-Earth data transmission from typical non-GSO satellites [6]. These downlinks originate from instruments on the spacecraft. The characteristics for Non-GSO systems can be found below in Table 3.

| Parameter                        | Science data dissemination |
|----------------------------------|-----------------------------|
| Carrier centre frequency (MHz)   | 26 703.4                    |
| Necessary Bandwidth (MHz)        | 300                         |
| Polarisation                     | RHCP                        |
| Earth station antenna diameter (m)| 6.5                         |
| Antenna height (m)               | 10                          |
| Earth station antenna gain toward satellite (dBi) | 64.5                        |
| Earth station antenna radiation diagram | Rec. ITU-R S.465-6 [7]     |
| Minimum elevation angle (degree) | 5                           |
This section provides the RF parameters needed to conduct interference assessments and sharing studies for raw data downlink and data dissemination for GSO systems. Table 4 includes a typical characteristics for GSO systems [6].

**Table 4.** System parameters for recorded data playback services in the band 25.5-27 GHz

| Parameter                                      | Stored Mission Data |
|------------------------------------------------|---------------------|
| Carrier centre frequency (MHz)                | 26 760              |
| Necessary Bandwidth (MHz)                     | 452                 |
| Polarisation                                   | RHCP                |
| Earth station antenna diameter (m)            | 6.5                 |
| Antenna height (m)                            | 10                  |
| Earth station antenna gain toward satellite (dBi) | 61.4               |
| Earth station antenna radiation diagram       | Rec. ITU-R S.580[8] |
| Minimum elevation angle (degrees)             | 5                   |

2.3 *Interference criteria*

Recommendation ITU-R SA.1026 [9] contains the interference criteria for space-to-Earth data transmission systems operating in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit. The Protection criterion is listed in Table 5.

**Table 5.** Interference criteria for earth exploration-satellite and meteorological-satellite earth stations using spacecraft in low-earth-orbit

| Item                                                      | Value                                      |
|-----------------------------------------------------------|--------------------------------------------|
| Protection criterion long-term(no more than 20% of the    | -140 dBW per 10 MHz                        |
| time)                                                     |                                            |
| Protection criterion short-term(no more than 0.0125% of   | -116 dBW per 10 MHz                        |
| the time)                                                 |                                            |

Recommendation ITU-R SA.1160 [10] contains the interference criteria for data dissemination and direct data readout systems in the Earth exploration-satellite and meteorological-satellite services using satellites in the geostationary orbit. The Protection criterion is listed in Table 6.

**Table 6** Interference criteria for stations in the eess and metsat service using spacecraft in the geostationary orbit

| Interfering signal power (dBW) in the reference bandwidth | Interfering signal power (dBW) in the reference bandwidth |
|-----------------------------------------------------------|-----------------------------------------------------------|
| to be exceeded for no more than 20% of the time           | to be exceeded for no more than p% of the time             |
| -144.6 dBW per 10 MHz                                     | -133.0 dBW per 10 MHz                                     |
| p = 0.25                                                  | p                                                        |

The protection threshold of the most stringent - 116 dBW per 10 MHz and - 133 dBW per 10 MHz is used for calculation in the Non-GSO scene and the GSO scene for conservatively giving the coverage of the interference field strength.
3. Propagation models

Radio wave propagation should take into account the effects of terrain and geomorphology in real geography. The DETVAG 90/FOI model and ITU-R P.2108 in WRAP software are applied to the effects of real geomorphology and terrain on radio wave propagation. The following two models are briefly introduced:

3.1 Detvag 90/FOI model

Detvag consists of a number of different propagation models. For most of themodels, a number of different methods or approaches can be chosen. Furthermore, some optional methods are also available; such as methods for vegetation effects and methods for built up areas. The models supported in Detvag right now are: free-space model, Knife-edge model, spherical-earth model, square-root model, GTD model.

The idea behind the knife-edge model is that the interaction between the electro-magnetic waves and the terrain mainly are due to diffraction effects. These effects occur when the direct propagation path, between the transmitter and the receiver, is shadowed by obstructing obstacles. The three different knife-edge methods available in Detvag are: Epstein-Petersen, Giovaneli and Vogler.

Spherical-earth model assumes a propagation path over a smooth spherical earth. This is a good assumption for low frequencies, i.e., when the terrain irregularities are small compared to the wavelength.

Square-root model is an empirical combination of a knife-edge model and a spherical-earth model. One motivation for this is that the knife-edge model is a good high frequency approximation, and that the spherical earth model is a good low-frequency approximation. By combining these methods, a method with a realistic frequency response in irregular terrain is obtained. The propagation loss is calculated separately for both sub models and the results are weighted together.

The Geometric Theory of Diffraction (GTD) is a ray-based theory, extending the Geometrical Optics (GO) by the inclusion of diffracted rays. Handling reflection and diffraction within the same framework makes it possible to solve wave propagation problems over complex geometries.

3.2 P.2108 Recommendation model

This Recommendation describes a set of models that can be used for estimating the loss due to clutter for a number of different environments. These models can be used as an end correction to long distance or over the rooftop models. The clutter loss not exceeded for p% of locations for the terrestrial to terrestrial path, \( L_{cett} \), is given by:

\[
L_{cett} = -5\log(10^{-0.2L_f} + 10^{-0.2L_s}) - 6Q^{-1}(p/100) \quad \text{dB}
\]  

where \( Q^{-1}(p/100) \) is the inverse complementary normal distribution function, and

\[
L_f = 23.5 + 9.6\log(f) \quad \text{dB}
\]

\[
L_s = 32.98 + 23.9\log(d) + 3\log(f) \quad \text{dB}
\]

where \( d \) is the total path length.

Those models and methods can be selected automatically or manually according to frequency, path, terrain condition, antenna height, etc.

4. Methodology

When calculating the coverage, we need to calculate interference from 5G BS to satellite earth station that consider the geographical location, transmission power, antenna gain, propagation loss and protection threshold of the two systems. The interference power for 5G BS to satellite earth station is given as:

\[
I = Tx + G_{es} + G_{IMT} - PL \quad \text{dB}
\]

where,

\( Tx \): the emission power of IMT BS, in dB;

\( G_{es} \): the antenna gain of satellite earth station, in dBi;

\( G_{IMT} \): the antenna gain of IMT BS, in dBi;
PL: transmission losses for the path from IMT BS to satellite earth station, in dB;

As for the GSO scene, because the satellite earth station needs to point to the geostationary satellite all the time, the gain of the satellite earth station is taken into account in the calculation, and the Non-GSO scene, because the satellite earth station needs to be directed to the low earth orbit satellite, is constantly changing the antenna direction. To assess the worst cases, the 5G base station uses the antenna main lobe maximum gain to point to the satellite earth station, the maximum power and gain transmission, and real geographic environment. The interference coverage range is strictly determined by the criterion value of interference.

5. Results
The coverage calculation results are given below by using WRAP software.

5.1 GSO scenes
The corresponding results are given in Figure 1.

Figure 1. The calculation results of Beijing satellite earth station interference coverage area (location percentages are 1%, 50% and 100% respectively).

According to the result, the maximum interference distance of IMT and Beijing GSO earth station are 4.932 km, 1.020 km and 970 m respectively.

5.2 Non-GSO scenes
The corresponding results are given in Figure 2.

Figure 2. The calculation results of Jiamusi satellite earth station interference coverage area (location percentages are 1%, 50% and 100% respectively).

According to the result, the maximum interference distance of IMT and Jiamusi Non-GSO earth station are 9.95 km, 5.113 km and 2.850 km respectively.

6. Summary
From the above results, it is feasible to deploy 5G base stations within a few kilometers around the satellite earth station in Beijing and Jiamusi, and the two services can coexist through geographical isolation. The results of the study strongly support the national radio frequency and station planning management. Generally speaking, the geographic location of the EESS satellite earth station is more
remote, and the isolation distance of a few kilometers does not affect the large-scale deployment of 5G system in this band.

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Reference
[1] Bleicher A. The 5G phones future. IEEE Spectrum, 2013, 50(7): 15-16.
[2] Tan Wang, Gen Li, Jiaxin Ding, Qingyu Miao, Jingchun Li, and Ying Wang, "5G Spectrum: Is China Ready?", IEEE Communications Magazine, pp. 58-65, 2015.
[3] S. Y. Geng, Xing Li, Wei Hong, and X. W. Zhao, “Mm-wave 26 GHz channel characterization for future wireless communications,” in 2016 International Conference on Control and Automation, 2016, pp. 475-480.
[4] Recommendation ITU-R P.2108-0, “Prediction of Clutter Loss,” 2017
[5] Liaison statement from WP 5D to TG 5/1, “Spectrum needs and characteristics for the terrestrial component of IMT in the frequency range between 24.25 GHz and 86 GHz,” 2017.
[6] DRAFT NEW REPORT ITU-R SA.[EESS/MET CHAR], “Characteristics to be used for assessing interference to systems operating in the Earth exploration-satellite and meteorological-satellite services, and for conducting sharing studies,” 2017.
[7] Recommendation ITU-R S.456-6, “Reference radiation pattern of earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz,” 2010.
[8] Recommendation ITU-R S.580-6, “Radiation diagrams for use as design objectives for antennas of earth stations operating with geostationary satellites,” 2004.
[9] Recommendation ITU-R SA.1026-5, “Aggregate interference criteria for space-to- Earth data transmission systems operating in the Earth exploration-satellite and meteorological satellite services using satellites in low-Earth orbit,” 2017.
[10] Recommendation ITU-R SA.1160-3, “Interference criteria for data dissemination and direct data readout systems in the earth exploration-satellite and meteorological satellite services using satellites in the geostationary orbit,” 2017.