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Assessment of the orbital-frequency resource used by a geostationary satellite communication network

S Series

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Assessment of the orbital-frequency resource used by a geostationary satellite communication network

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1 Introduction

The congestion in the geostationary-satellite orbit (GSO) experienced by FSS and BSS networks is well-known and results from natural constraints of the angular dimension of the unique GSO (360 degrees) and limited frequency bands allocated to satellite communications.

Numerous studies, including those carried out in the framework of ITU-R Study Group 4, have been aimed at increasing the total GSO resource and its efficient use. However, no methodology for evaluation of the resource occupied by a given geostationary satellite network, which could make it possible to compare networks of the same service using a common metric, has been discussed or approved in the framework of the ITU. This Report provides a methodology that could be used to arrive at a metric that would represent the amount of orbital-frequency resource (OFR) occupied by a given GSO satellite network.

The intent of this methodology is to make the assessment of the occupied resource as simple and practicable as possible, in order to allow for comparative evaluation of different GSO networks.

2 Measurement unit

The GSO OFR, occupied by a given FSS or BSS network (OOFR), is considered to be the part of the overall OFR of the GSO which cannot be used by other FSS or BSS networks.

The OOFR of a satellite communication or broadcasting network is directly proportional to two components – the occupied bandwidth, ΔF (Hz), and the occupied GSO arc, $\Delta\varphi$ (degrees), of the network under consideration. For example, the number of similar networks which can be located within the whole GSO equals $(360/\Delta\varphi)\cdot(\Delta f/\Delta F)$, where Δf is the bandwidth allocated to the service. The size of the OOFR is defined as:

$$R = \Delta F \cdot \Delta\varphi \cdot k, \text{ (Hz·degr.)} \tag{1}$$

where:

$k = 1$ if the assessed system uses polarization division and both polarizations (or no polarization division); and

$k = 0.5$ if only one polarization is used, but polarization division is foreseen and allowed.

Given this definition of OOFR, the measuring unit is hertz×degree (Hz·degr.).

The occupied bandwidth as defined by the Radio Regulations is the width of a frequency band where the major part of the total mean power of a given emission is located (RR No. **1.153**). The methodology contained in this Report does not consider the case of several co-located/co-frequency/co-coverage FSS or BSS networks (e.g. wave-form division or CDMA is not considered), so it is supposed that any network at a given notified orbital position occupies the whole notified frequency band irrespective of the pfd level and signal-to-noise ratio.

The term "*occupied orbital arc*" is considered as the part of the GSO on both sides of the satellite position of the assessed network, which cannot be used for deployment of satellites of other networks because of harmful interference between networks.

3 Assessment of the occupied orbital arc

For already operating networks, the minimum angular separation, $\Delta\varphi_-$, $\Delta\varphi_+$, between the assessed network and the nearest adjacent GSO networks operating in the same frequency band can be determined using the current criteria, and it is possible to assume that the assessed network occupies the arc $\Delta\varphi = [(\Delta\varphi_-)+(\Delta\varphi_+)]/2$.

For networks which requested coordination at a given orbital position, the necessary angular separation from submitted or notified adjacent networks, for which the interference level does not exceed permissible limits, could be also defined.

However, it is evident that such assessment is not appropriate for the comparison of the networks because the result will be random, depending on adjacent network parameters such as emitted power, sensitivity to interference, size and location of coverage areas, ES antenna size and so on and, finally, on the number of networks on the given GSO arc. It is also evident that such evaluation is not applicable to assess networks which are prepared for application if their orbital positions have not been determined yet.

An approach [1], [2] provides the description of a method for evaluation of the occupied orbital arc by the necessary angular separation from an adjacent network having exactly the same parameters as the assessed network. The non-applicability of this approach is evident; if, for example, the network under assessment has high emitted power, it will consequently cause high interference to less powerful networks, but this approach will show their compatibility in relation to similar networks at a small angular separation.

Relying on these considerations, it is proposed to accept a method for determining the occupied orbital arc by the value of the necessary angular separation with regard to a *reference network*, applied to assess the occupied orbital arc for all networks in the framework of a certain service and frequency band (see Fig. 1). Parameters of the reference network should be chosen on the basis of operating systems, i.e. they should be *typical and representative for networks in a certain radio service and a certain frequency band*. This approach will put all assessed networks into equal conditions, and in addition this will facilitate the homogeneity of the networks, which will benefit to increased capacity of the GSO.

In equation (1) above, it is assumed that the service areas of the assessed and reference networks overlap, and earth stations are located within the overlapped part of these service areas. These assumptions significantly simplify calculations and correspond to the most difficult and practically the most frequent case. In this case, the coverage area of the assessed system is not taken into consideration.

However, if an ideal radiation pattern (i.e. zero gain of the satellite antenna outside the coverage area) is assumed for both the assessed and reference systems, then the assessed system coverage area may be taken into consideration while assessing the occupied resource by introducing a simple coefficient $s = S_c/S_s$, which represents the ratio of the covered territory S_c to the whole visible Earth's surface S_s, because, evidently, the part of the Earth's surface not being a part of the coverage area of the assessed network is free from interference in this ideal case and the necessary angular separation between satellites equals zero when an earth station of the reference system is located outside the coverage area of the assessed system. In order to account for this geographic coverage aspect of the assessed system, the factor shown in (2) below is added to (1):

$$s = S_c/S_s \tag{2}$$

In other words, the surface area ($S_s - S_c$) can be used by other networks without any angular separation between satellites. Assessment of an interference-free area can be obtained without the presumption of an ideal radiation pattern of the assessed satellite network while determining the value of S_c and ($S_s - S_c$) using pfd_{ed}, pfd_{eup}, pfd_{rid} and pfd_{riup}, pfd_{rd}, pfd_{rup}, pfd_{eid}, pfd_{eiup} values and active compatibility criteria (see their definitions and relationships in Annex 1).

On this basis, the following equation is used for the calculation of the occupied resource rather than (1):

$$R = \Delta F \cdot \Delta\varphi \cdot k \cdot s, \text{ (Hz·degr.)} \tag{3}$$

where $\Delta\varphi$ is the required angular separation of the assessed network relative to the reference network; other values being as defined above.

4 Generalized parameters of the reference system

Parameters of an FSS network in the 6/4 GHz and 14/11 GHz bands were proposed to specify pfd coordination levels on the Earth's surface and at the GSO in order to fully protect satellite networks outside the coordination arc earlier in ITU-R in preparations for previous WRC, and appear to be appropriate for a reference FSS network for interference assessment towards the reference network (RN) as it was stated in the specified documents (see Annex 2). Parameters of a typical BSS network in the 21.4-22.0 GHz band are specified in Annex 1 to Resolution **553 (WRC-12)**.

Based on the technical parameters of the reference network specified in Annex 2, one can determine generalized parameters of the reference network sufficient to analyse interference caused to the reference network by the network under assessment:

– interference power-flux density, pfd_{riup}, acceptable for a reference network in the uplink (at the GSO);

– interference power-flux density, pfd_{rid}, acceptable for a reference network in the downlink (at the Earth's surface), which depends on the diameter of the earth station antenna and angular separation between satellites of the assessed and reference networks.

The necessary angular separation in the downlink, $\Delta\varphi_{rd}$, is derived directly from Fig. 2 (FSS network in the Ku-band or similar in other cases), by finding a point on the envelope corresponding to a maximum permissible pfd created by the satellite of the assessed network at the Earth's surface.

The necessary angular separation in the uplink, $\Delta\varphi_{rup}$, is determined by the value of angular separation under which the pfd at the GSO from all types of ESs in the network under assessment, taking into account their e.i.r.p. and selectivity of the antenna, does not exceed the value of pfd_{riup} given above.

To describe the effect of interference to the network under assessment (specifically for the calculation of the occupied orbital arc using the acceptable level of interference to the network under assessment) it is necessary to complement the above parameters of the reference network with values defining pfd of the wanted signal of the reference network in the uplink and downlink, pfd_{rd} and pfd_{rup}. For that, it is sufficient to choose a typical signal-to-noise ratio in the uplink and downlink, C/N, for the reference network.

5 Interference sensitivity of the assessed network

To define *interference sensitivity of the assessed network*, it is necessary to have the network parameters similar to those shown above for the calculation of interference to the reference network. In the generalized form, it is the permissible interference in the uplink, pfd_{eiup}, for the assessed network (minimum value for the whole set of signal types transmitted in this network) and the permissible interference in the downlink, pfd_{eid}, with the value of the latter depending on the size and radiation pattern of ES antennas of the assessed network, as well as on angular separation. The value of the necessary angular separation in the downlink is determined by the value of $\Delta\varphi_{ed}$ at which the pfd produced by the reference network equals the permissible pfd_{eid} value for the assessed network (minimum value for all notified antenna types), and the necessary angular separation in the uplink is determined by the value of $\Delta\varphi_{eup}$ at which the pfd produced by the reference network equals pfd_{eiup} (also minimum value). The value of $\Delta\varphi_{eup}$ is determined by the necessary selectivity of the reference network ES antenna. If the reference network allows different sizes of ES antennas, it may be convenient for assessment to plot curves similar to Fig. 2.

6 Final evaluation of the occupied orbital arc and of the occupied orbital-frequency resource

The final evaluation of the occupied orbital arc shall use the maximum value of four derived values:

$$\Delta\varphi = \max[\Delta\varphi_{rup}, \Delta\varphi_{eup}, \Delta\varphi_{rd}, \Delta\varphi_{ed}] \tag{4}$$

Then, taking all the above into account and the number of satellites in the network, N, the final evaluation of the orbital-frequency resource occupied by the network is:

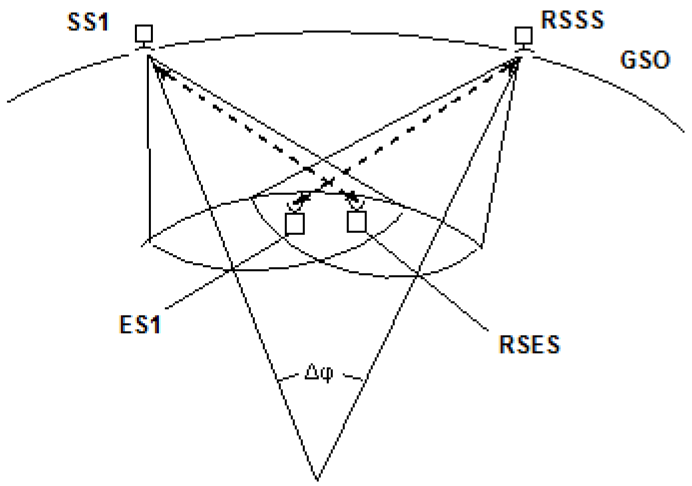
$$R = \sum_{n=1}^{N} (\Delta F \cdot \Delta\varphi \cdot k \cdot s)_n \tag{5}$$

7 Conclusion

The assessment of the orbital-frequency resource used by the network deems necessary to compare systems with regard to their use of the outer space resource. It can also be used to assess the resource necessary for administrations to meet national or regional needs. In the latter case, the number N of GSO positions is determined by the minimum angle of arrival necessary to cover the territory of a country/group of countries. When assessing the required national/regional resource, other factors could also be taken into account determining the necessary use of satellite communication systems [4].

The condition of using the proposed method for assessment of the occupied OFR is the development and approval of reference network parameters for different services and frequency bands, and for this there may be a sufficient basis taking into account previously submitted ITU-R documentation.

FIGURE 1

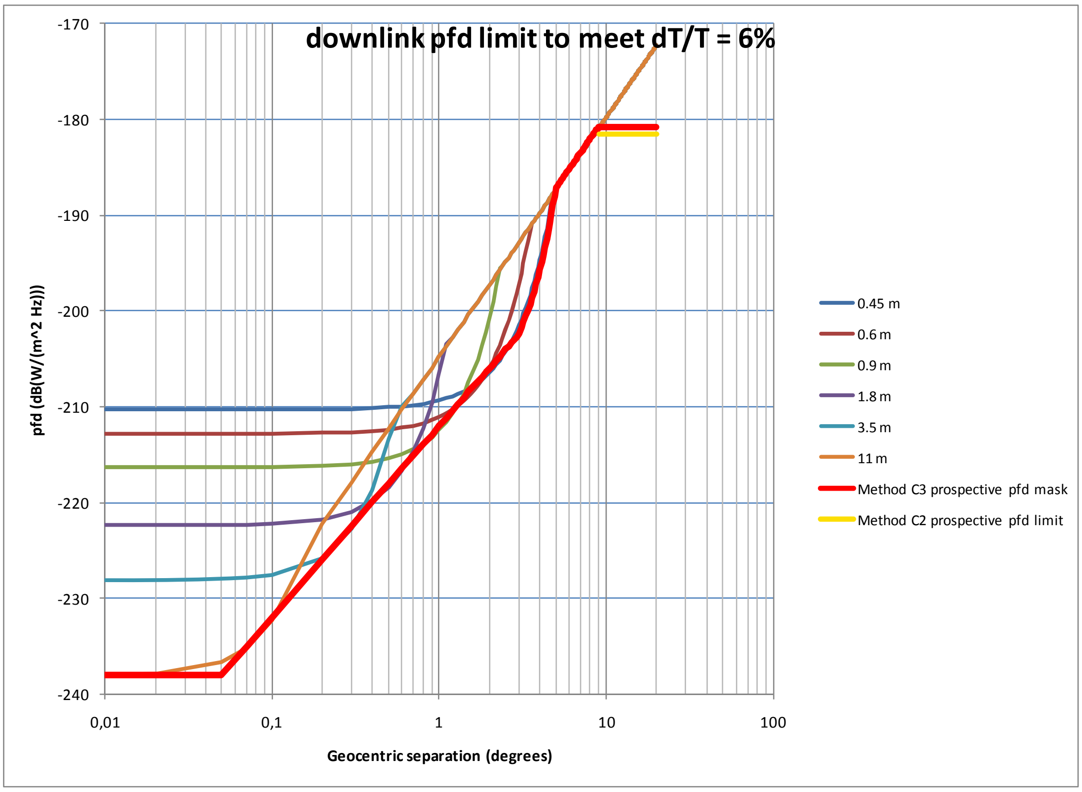


RSSS – space station of reference system
RSES – earth station of reference system

SS1 – space station of the assessed system
ES1 – earth station of the assessed system

FIGURE 2

Acceptable downlink pfd for the Ku-band reference system



NOTE – Geocentric separation angle corresponding to pfd value equal to or more than –181 dB(W/m^2·Hz) is defined by the brown line (i.e. curve for 11 m antenna) for the purpose of this Report.

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(Satellite communications and the problem of the geostationary orbit. L. Kantor, V. Timofeev, Radio-i-svyaz Publishers, 1988.)

[2] CC1R. XV-th Plenary Assembly. Vol. IV–1. – Geneva: ITU, 1982. – 501 P.

[3] WRC-12 Final Acts. Resolution **756 (WRC-12)**.

[4] G. Chouinard. Bringing broadband access to rural and remote areas. ITU News, April 2006.

Annex 1

List of abbreviations and notations, and main relationships between used values

pfd_{rd} – pfd of the wanted signal of reference network in the downlink

pfd_{rup} – wanted signal pfd of reference network in the uplink

pfd_{ed} – wanted signal pfd of assessed network in the downlink

pfd_{eup} – wanted signal pfd of assessed network in the uplink

pfd_{rid} – acceptable interference pfd towards reference network (min) in the downlink

pfd_{riup} – acceptable interference pfd towards reference network (min) in the uplink

pfd_{eid} – acceptable interference pfd towards assessed network (min) in the downlink

pfd_{eiup} – acceptable interference pfd towards the assessed network (min.) in the uplink

Se_{rd} – spatial selectivity of a reference network ES antenna in the downlink

Se_{rup} – spatial selectivity of reference network ES antenna in the uplink

Se_{ed} – spatial selectivity of assessed network ES antenna in the downlink

Se_{eup} – spatial selectivity of assessed network ES antenna in the uplink

ES – Earth station

RN – Reference network

EN – Assessed network

$\Delta\varphi$ – necessary angular separation between EN and RN

$\Delta\varphi_{rd}$ – necessary angular separation between EN and RN due to pfd_{rid} and pfd_{ed}

$\Delta\varphi_{rup}$ – necessary angular separation between EN and RN due to pfd_{riup} and pfd_{eup}

$\Delta\varphi_{ed}$ – necessary angular separation between EN and RN due to pfd_{eid} and pfd_{rd}

$\Delta\varphi_{eup}$ – necessary angular separation between EN and RN due to pfd_{eiup} and pfd_{rup}

$s = S_c/S_s$ – relative coverage area of the assessed network

S_c – coverage area of the assessed network

S_s – Earth surface area visible from the GSO position

C/N, C/I, N/I – required signal-to-noise ratio, signal-to-single entry interference ratio, noise-to-interference ratio in the uplink (up) and the downlink (d) for the assessed network (e) and for the reference network (r).

RELATIONSHIPS BETWEEN USED VALUES

$$pfd_{eid} = pfd_{rd} - Se_{ed}(\Delta\varphi_{ed}) = pfd_{ed} - (C/I)_{ed} = pfd_{ed} - (C/N)_{ed} - (N/I)_{ed}$$

$$pfd_{eiup} = pfd_{rup} - Se_{rup}(\Delta\varphi_{rup}) = pfd_{eup} - (C/I)_{eup} = pfd_{eup} - (C/N)_{eup} - (N/I)_{eup}$$

$$pfd_{rid} = pfd_{ed} - Se_{rd}(\Delta\varphi_{rd}) = pfd_{rd} - (C/I)_{rd} = pfd_{rd} - (C/N)_{rd} - (N/I)_{rd}$$

$$pfd_{riup} = pfd_{eup} - Se_{eup}(\Delta\varphi_{eup}) = pfd_{rup} - (C/I)_{eup} = pfd_{rup} - (C/N)_{rup} - (N/I)_{rup}$$

Annex 2

Example of reference network parameters

The following technical parameters are proposed for FSS networks in the 14/11 GHz band for illustrative purposes:

– criterion for acceptable single entry interference from any other FSS network $\Delta T/T$ = 6% (−12.2 dB);

– ES noise temperature = 125 K;

– satellite G/T = 8 dB/K; ES antenna diameter D_a = 0.45 m, 0.6 m, 0.9 m, 1.8 m, 3.5 m, 11 m; downlink frequency is 11 GHz, uplink frequency is 14 GHz;

– ES antenna pattern complies with Recommendations ITU-R S.580-6, ITU-R S.465, and BR Antenna Pattern Library (APL);

– circular and linear polarization, for both uplink and downlink.

On the basis of these certain technical parameters, generalized parameters can be determined which would simplify the calculations:

– pfd_{riup} = –205 dB (W/m^2·Hz);

– pfd_{rid} – shown in Fig. 2.

For the assessment of interference towards the assessed network it is necessary to evaluate the pfd of the reference network signals in the uplink and downlink. Thus, assuming that under the clear weather conditions this value is the same for both uplink and downlink and equals to C/N = 14 dB, then the pfd on the Earth's surface is equal to pfd_{rd} = −184.12 dB (W/m^2·Hz) for the minimum value of ES antenna diameter 0.45 m (in this case the e.i.r.p. of a reference network satellite is equal to 56 dBW in 36 MHz):

– towards the GSO (to the position of the reference network satellite), pfd_{rup} = −178.2 dB (W/m^2·Hz) from any reference network ES.

An example of assessment of the occupied orbital-frequency resource based on these parameters:

If the assessed FSS network in the Ku-band has the same generalized parameters as the reference network, global coverage and dual polarization, then the occupied GSO arc will be 6.7° (for ES antenna diameter 45 cm); and if the occupied frequency band is 500 MHz, then R = 3 350 MHz·degr.

Annex 3

The effect of network parameters on the occupied orbital-frequency resource

ES antenna diameter

Annex 2 gives pfd_{rd} values for the minimum ES antenna diameter 0.45 m for the reference and assessed networks:

$$D_a = 0.45\text{ m};\ pfd_{rd} = -184.12\text{ dB(W/m}^2\cdot\text{Hz)}.$$

If the minimum antenna diameter for both networks is increased, the relevant pfd will be as follows:

$$D_a = 0.6\text{ m} - pfd_{rd} = pfd_{ed} = -186.62\text{ dB(W/m}^2\cdot\text{Hz)}$$

$$D_a = 0.9\text{ m} - pfd_{rd} = pfd_{ed} = -190.12\text{ dB(W/m}^2\cdot\text{Hz)}$$

$$D_a = 1.8\text{ m} - pfd_{rd} = pfd_{ed} = -196.16\text{ dB(W/m}^2\cdot\text{Hz)}.$$

In accordance with these values, the orbital arc occupied in the downlink by the assessed network, having the same parameters as the reference network, can be derived from Fig. 2, and for different values of minimum ES antenna diameter is equal to:

$$D_a = 0.45\text{ m} - \Delta\varphi_{rd} = \Delta\varphi_{ed} = 6.7°$$

$$D_a = 0.6\text{ m} - \Delta\varphi_{rd} = \Delta\varphi_{ed} = 5.3°$$

$$D_a = 0.9\text{ m} - \Delta\varphi_{rd} = \Delta\varphi_{ed} = 3.85°$$

$$D_a = 1.8\text{ m} - \Delta\varphi_{rd} = \Delta\varphi_{ed} = 2.2°.$$

These results show quantitative assessment of the dramatic effect of small antennas on the orbital-frequency resource occupied by the network.

In addition, the above data shows the importance to choose minimum ES antenna diameter for the reference network because a small size of the reference network antenna would not encourage use of greater ES antennas in the notified networks, taking into account that for large ES antenna diameter in the assessed network the necessary angular separation and occupied orbital arc would be determined by the worst case interference (see equation (4)) towards the assessed network (i.e. by $\Delta\varphi_{ed}$).

Effect of instability of ES antenna pointing

Considerable ES antenna pointing errors towards the satellite of its own network may take place in certain cases. The quantitative assessment of this effect is very simple. With the possible pointing error ±0.2°, the occupied orbital arc values derived above will be higher by 0.2°. The instability of ES antenna pointing should have been assessed taking into account the probability of this event (see Recommendation ITU-R S.1857), however, since the acceptable interference value between GSO FSS networks is defined only for 100% of time, it is sufficient to know the maximum pointing error.

Effect of adaptation of the assessed network parameters

It is known that the signal in the Ku-band, and especially in the Ka-band, is subject to high attenuation in precipitation, and during these periods various adaptation methods are applied.

There are three basic adaptation methods:

1) to increase the pfd of the wanted signal (without changing the data transmission rate and modulation/coding schemes);
2) to decrease the data transmission rate (without changing the pfd and modulation/coding schemes);
3) to change the modulation/coding schemes for more noise-immune options.

Those methods may also be combined.

In the first adaptation method, as the probability of signal attenuation is not significant (fractions of 1% of time), the probability of simultaneous high attenuation at geographically dispersed stations is rather small, i.e. at the stations of other networks (including the reference network) the signal level will not be reduced by precipitation, so the interference level towards the other network will be higher by the value of the power increase; the occupied orbital arc will correspondingly increase, because additional attenuation of interference will be required using better ES antenna selectivity to meet the permissible value of interference level. The necessary increase in angular separation can be assessed using Fig. 2 or corresponding Tables. Thus, increased power by 8 dB will significantly increase required angular separation – up to 14° (for 0.45 m), 11.1° (for 0.6 m), 8.15°(for 0.9 m), 4.65° (for 1.8 m). It should be noted that these considerations refer to downlink only, where stations of interacting systems may be separated, while the increased uplink pfd during attenuation usually will not cause troubles due to high correlation of signal attenuations towards neighbouring satellites.

The second adaptation method – decrease of the data transmission rate without changing the pfd and modulation/coding schemes – will cause reduction of the signal radio frequency bandwidth and corresponding increase of spectral pfd. The effect of increased interference and occupied orbital-frequency resource will be the same as in the first adaptation method.

And only the third adaptation method – change of the modulation/coding schemes without change of the transmitted power and occupied signal bandwidth – will not cause increase of interference and occupied orbital-frequency resource, and from this point of view it is preferable.

Application of higher protection for certain systems (i.e. lower I/N ratio, for example, lower than 6%) will result in the increase in the occupied OFR similarly to the increase in the pfd of the radiated signal.