World Radiocommunication Seminar
Geneva, 12-16 December 2016

INTERNATIONAL TELECOMMUNICATION UNION

Source: Document WRS14/21

Document WRS16/12-E
31 October 2016
Original: English

Space Services Department

ANALYSIS OF COMPATIBILITY BETWEEN GSO SATELLITE NETWORKS

Summary

The purpose of this document is to provide an overview of different criteria used to evaluate the compatibility of geostationary satellite networks, identifying those with which coordination is required and introducing methods which may be used to facilitate coordination and obtain an interference-free operational scenario. It includes the latest updates from WRC-15 and ongoing studies towards WRC-19.

The document also considers the case in which a notifying Administration may submit the characteristics of its satellite network to ITU, illustrating some aspects that may be taken into account when organizing the filing in order to optimize the outcome, while representing as accurately as possible the actual scenario.

At all times, the issues will be approached from both, a conceptual and practical standpoint, with some detail but without losing the sight of the overall objective.

1 Identifying coordination requirements

Appendix **5** to the Radio Regulations indicates the technical criteria to be used in each case, including:

- regulatory provision which contains forms of coordination;
- sharing scenario associated to the case;
- frequency band and Region;
- services;
- threshold/condition;
- calculation method.

Tables 5-1, 5-2 and Annex 1 to Appendix **5** present a detailed description of different cases.

In case of coordination under No. **9.7** between GSO networks, the following criteria can be found:

1.1 Coordination arc

It consists of identifying satellite networks with frequency overlap operating in the same direction of transmission inside a window of ±6, ±7, ±8, ±12, or ±16 degrees (depending on the frequency band, service and region) from the nominal orbital longitude of the incoming network.

This method is utilized by the Bureau to identify the coordination requirements for satellite networks in the unplanned FSS and BSS services, as well as meteorological-satellite, space research and their respective associated frequency assignments for space operations, in specific frequency bands described in Appendix **5**.

A summary of different cases is presented in the table below:

Frequency band, Region	Services and applicable coordination arc
1) 3 400-4 200 MHz 5 725-5 850 MHz (Region 1) 5 850-6 725 MHz 7 025-7 075 MHz	any network in the **FSS** and any associated space operation functions with a space station within an orbital arc of **±7°** of the nominal orbital position of a proposed network in the **FSS**
2) 10.95-11. 2 GHz 11.45-11.7 GHz 11.7-12.2 GHz (Region 2) 12.2-12.5 GHz (Region 3) 12.5-12.75 GHz (Regions 1 and 3) 12.7-12.75 GHz (Region 2) 13.4-13.65 GHz (Region 1) 13.75-14.8 GHz	-any network in the **FSS or BSS, not subject to a Plan**, and any associated space operation functions with a space station within an orbital arc of **±6°** of the nominal orbital position of a proposed network in the **FSS or BSS, not subject to a Plan** -in the band **13.4-13.65 GHz** any network in the space research service (**SRS**) or any network in the **FSS** and any associated space operation functions (see No. **1.23**) with a space station within an orbital arc of **±6°** of the nominal orbital position of a proposed network in the **FSS or SRS** -in the band **14.5-14.8 GHz** any network in the space research service **(SRS) or FSS not subject to a Plan** and any associated space operation functions (see No. **1.23**) with a space station within an orbital arc of **±6°** of the nominal orbital position of a proposed network in the **SRS or FSS not subject to a Plan**
3) 17.7-20.2 GHz (Regions 2 and 3) 17.3-20.2 GHz (Region 1) and 27.5-30 GHz	any network in the **FSS** and any associated space operation functions with a space station within an orbital arc of **±8°** of the nominal orbital position of a proposed network in the **FSS**
4) 17.3-17.7 GHz (Regions 1 and 2) 5) 17.7-17.8 GHz (No. 5.517 applies in Region 2)	any network in the **FSS** and any associated space operation functions with a space station within an orbital arc of **±8°** of the nominal orbital position of a proposed network in the **BSS**, **or vice-versa**
6) 18.0-18.3 GHz (Region 2) 18.1-18.4 GHz (Regions 1 and 3)	any network in the **FSS** or **meteorological-satellite** service and any associated space operation functions with a space station within an orbital arc of **±8°** of the nominal orbital position of a proposed network in the **FSS** or **meteorological-satellite** service
6bis) 21.4-22 GHz (Regions 1 and 3)	any network in the **BSS** service and any associated space operation functions with a space station within an orbital arc of **±12°** of the nominal orbital position of a proposed network in the **BSS**. See also Resolutions **553** and **554 (WRC-12)**

7) Bands above 17.3 GHz, except those defined in § 3) and 6)	any network in the **FSS** and any associated space operation functions with a space station within an orbital arc of **±8°** of the nominal orbital position of a proposed network in the **FSS** (see also Resolution **901 (Rev.WRC-07)**)
8) Bands above 17.3 GHz, except those defined in § 4) , 5) and 6*bis*)	any network in the **FSS or BSS, not subject to a Plan**, and any associated space operation functions with a space station within an orbital arc of **±16°** of the nominal orbital position of a proposed network in the **FSS or BSS**, **not subject to a Plan, except FSS with respect to FSS** (see also Resolution **901 (Rev.WRC-07)**)

In application of Resolution **901 (WRC-15)** and as a result of ITU-R studies and decisions of future conferences, coordination arc values can be extended to other frequency bands and services.

1.2 Criterion of ΔT/T > 6% (Appendix 8 to Radio Regulations)

This method is used by the BR to establish coordination requirements under provision No. **9.7** of the Radio Regulations for any other scenario where the coordination arc is not applied. It is also utilized by Administrations to request BR to include or to exclude its name or satellite networks in the coordination process under provision No. **9.41** of RR.

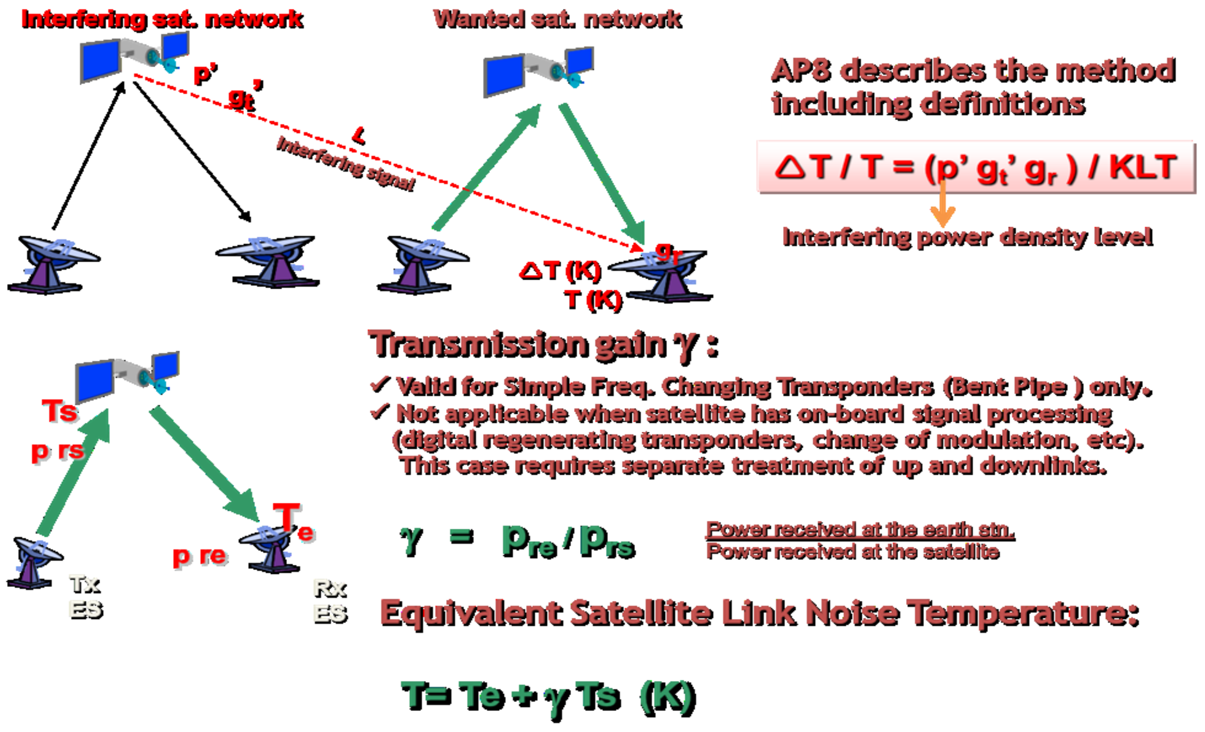
It defines a threshold that, if it is exceeded, harmful interference may occur. However, if it is not exceeded, it ensures compatibility between the related frequency assignments.

Basically, it measures the increase of noise temperature at the receiver due to an Interference.

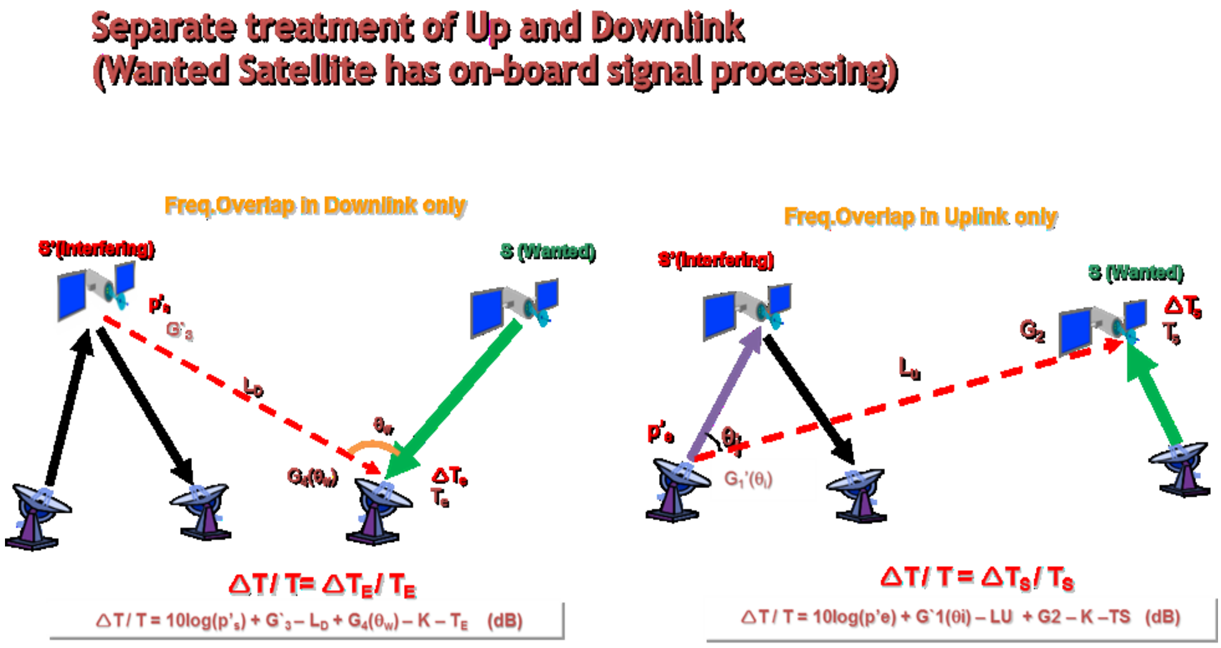
It is very important to highlight that in case ΔT/T > 6%, further analysis is needed to ensure that the assignments under study are not compatible. This is because the ΔT/T criterion does not take into account the wanted signal and the interfering spectrum shape, for example. Other methods like C/I are more accurate.

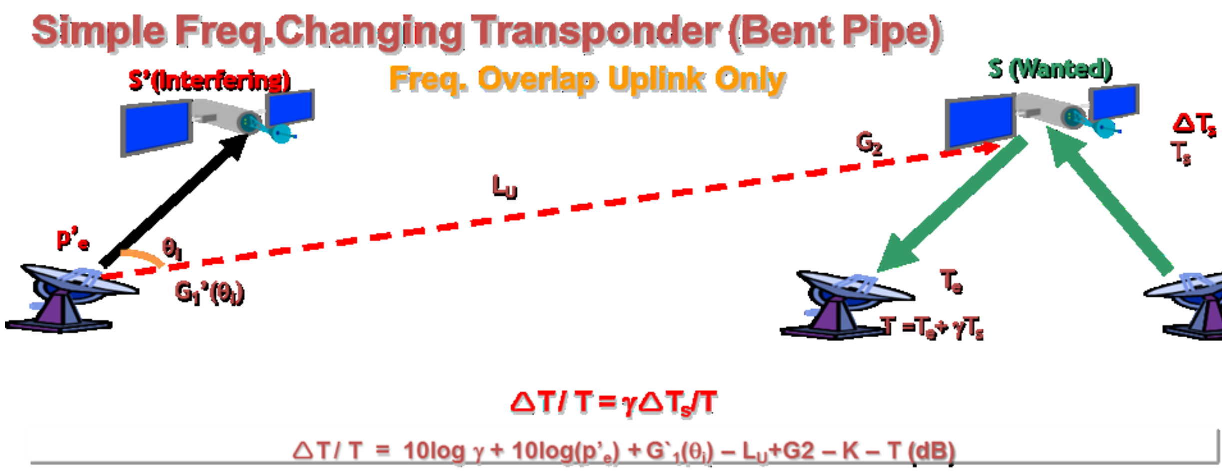
The following images describe the general concept, different possible scenarios and the equations to be applied:

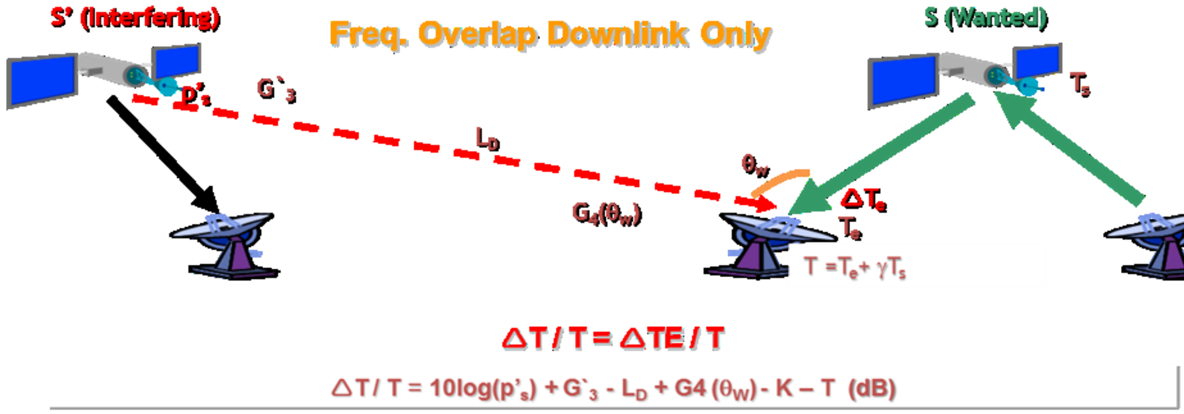
General concept

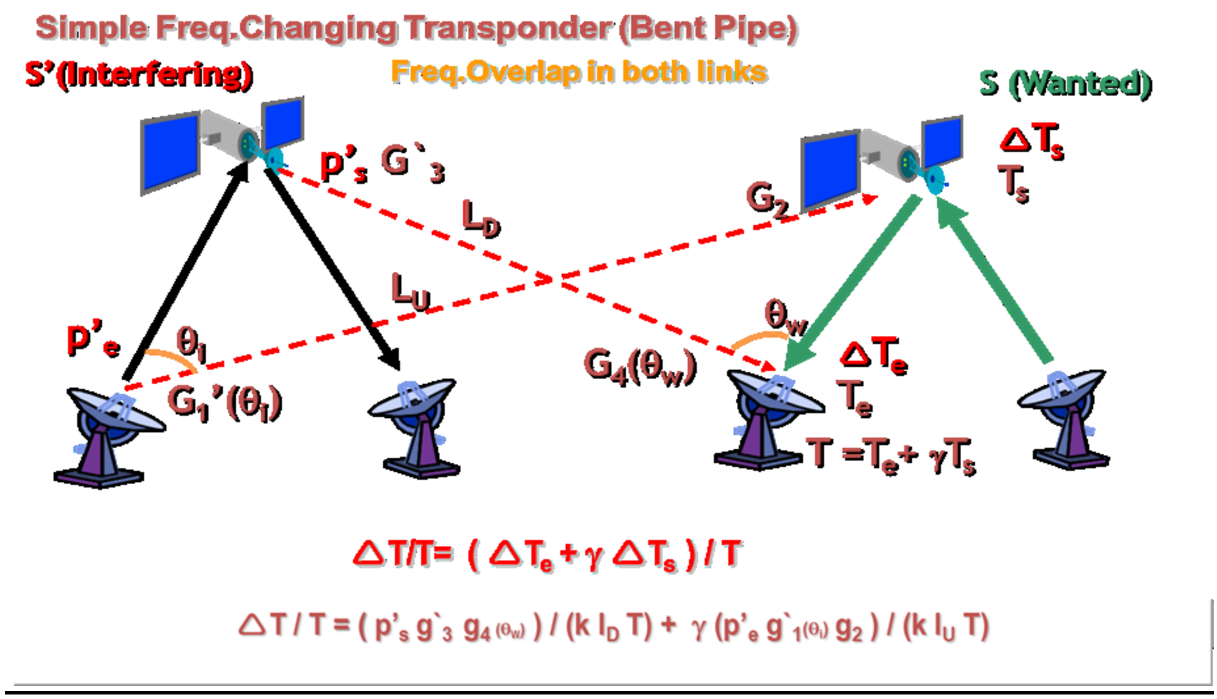


ΔT/T Case I: Freq. overlap co-directional

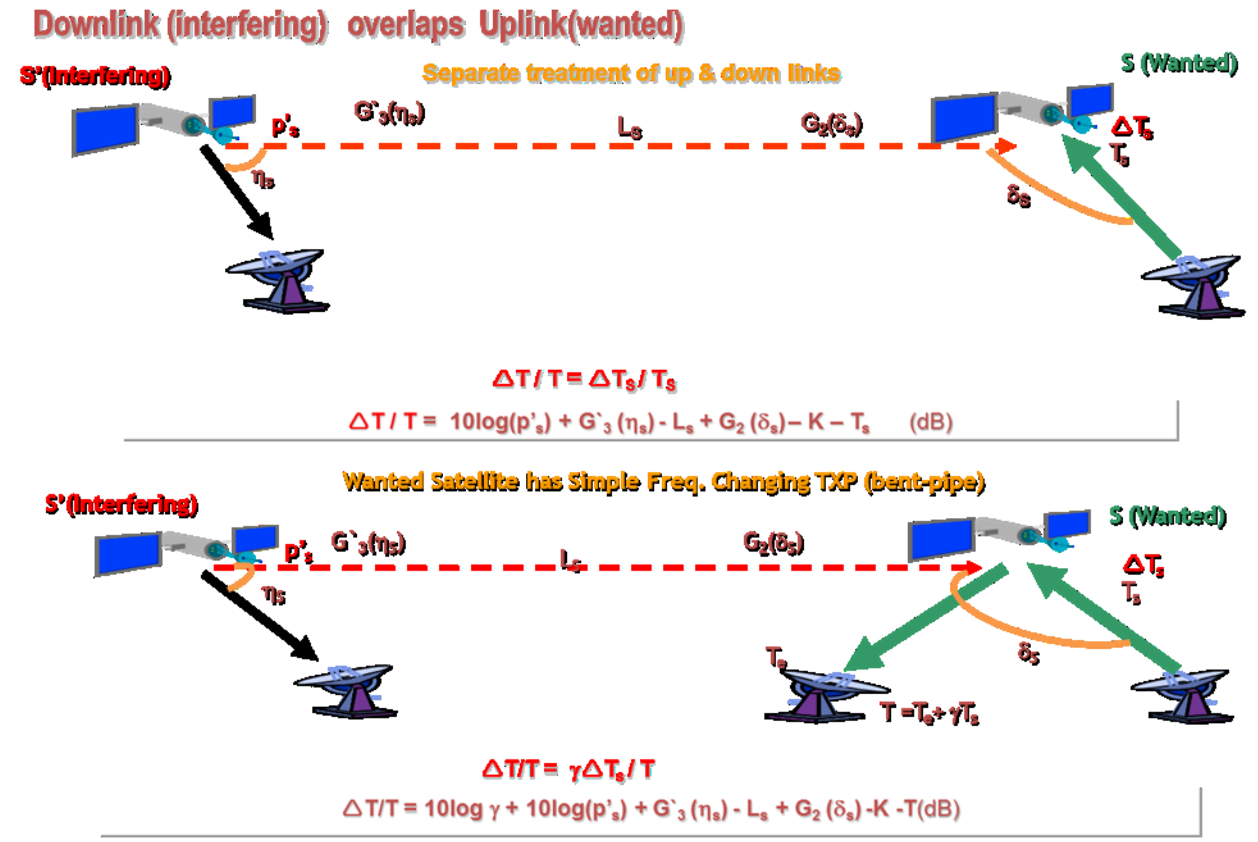



Simple Freq.Changing Transponder (Bent Pipe)
S'(Interfering)
Freq. Overlap Uplink Only
S (Wanted)
ΔTs
Ts
G2
LU
p'e
θi
G1'(θi)
Te
T =Te+ γTs
ΔT / T = γΔTs/T
ΔT / T = 10log γ + 10log(p'e) + G`1(θi) – LU+G2 – K – T (dB)


S' (Interfering)
Freq. Overlap Downlink Only
S (Wanted)
p's
G`3
Ts
LD
θw
G4(θw)
ΔTe
Te
T =Te+ γTs
ΔT / T = ΔTE / T
ΔT / T = 10log(p's) + G`3 - LD + G4 (θW) - K – T (dB)


Simple Freq.Changing Transponder (Bent Pipe)
S'(Interfering)
Freq.Overlap in both links
S (Wanted)
ΔTs
Ts
p's G`3
G2
LD
LU
p'e
θI
G1'(θI)
θw
G4(θw)
ΔTe
Te
T =Te+ γTs
ΔT/T= (ΔTe + γ ΔTs) / T
ΔT / T = (p's g`3 g4(θw) ) / (k lD T) + γ (p'e g`1(θi) g2) / (k lU T)

ΔT/T Case II: Freq. overlap in opposite direction of Tx. (inter-satellite):



η_S = Direction, from Interfering Satellite S', of Wanted Satellite S δ_S = Direction, from Wanted Satellite S, of Interfering Satellite S'

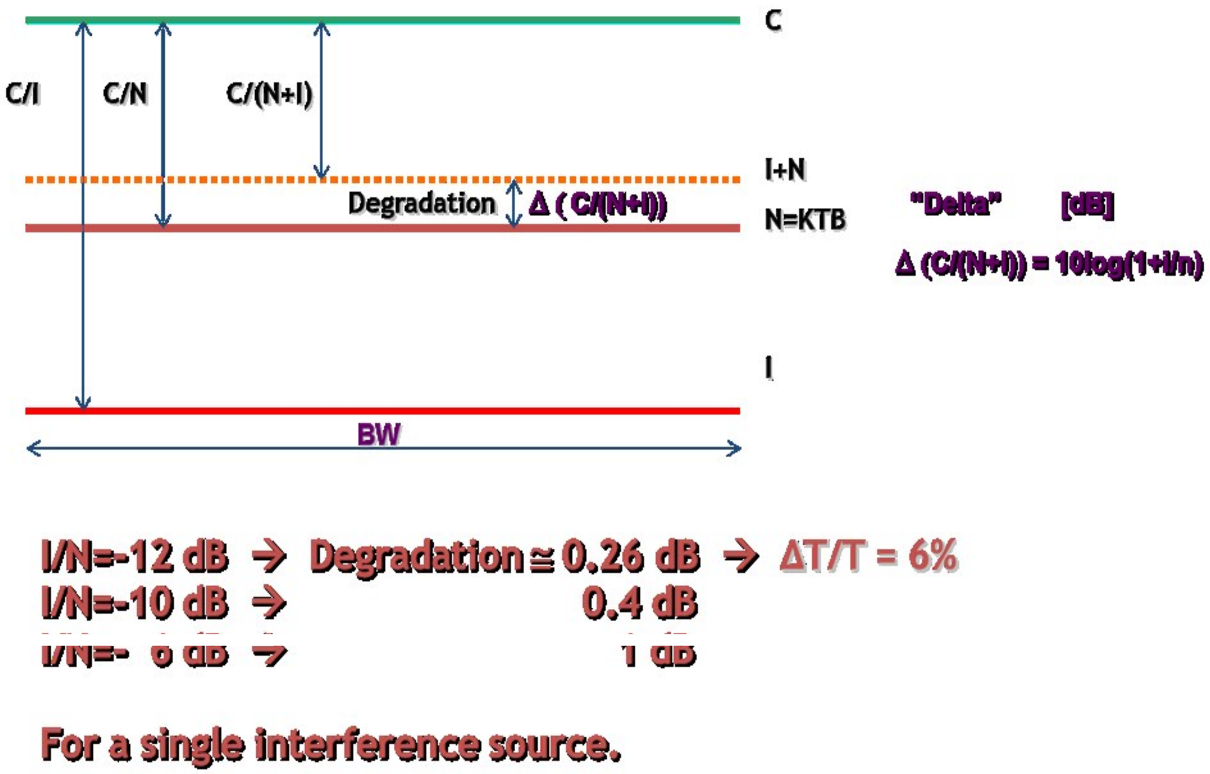
2 C/I criterion

Even though this method is not used in the Radio Regulations to establish coordination requirements, it is applied by the Bureau during examination of notification of satellite networks in order to perform a more detailed examination of probability of harmful interference in accordance with the provision No. **11.32A** when it is requested by the notifying administration. This criterion is often used by satellite operators during coordination meetings.

Examination by BR is based on methodology and protection criteria defined by Recommendations ITU-R S.740, ITU-R S.741-2 and associated Rules of Procedure of the Radio Regulations Board, or those ones informed by common agreement between administrations.

Among other data, it takes into account wanted signal (level and type of carrier-modulation), interfering signal (level and spectrum shape) and overlapped bandwidth, making it more accurate than the simple I/N or ΔT/T criteria presented previously. Particularly, when inter-networks sharing analysis requires to comply with certain quality and availability objectives.

The following figure represents the typical carrier levels and degradation refereed to the receiver noise power (N) caused by the interference:



Without going into the sequence of the C/I analysis, which is being presented in separate documents, some characteristics and advantages are being described, as mentioned in paragraphs above, in order to provide some guidelines to the reader.

In this way, the general concept is expressed by:

$$C/I = C/N + K$$

where:

K = protection ratio (generally, between 12.2-14 dB, depending on the type of carriers)

C/N = result of the link budget (considering objectives like S/N or BER, availability, etc.)

C/I = protection required to ensure compatibility between networks

The result of the above equation can be improved by considering the bandwidth advantage factor, which is the ratio of the interfering carrier power contained in the desired signal bandwidth to the total interfering carrier power.

In principle, the analysis can be performed assuming clear sky conditions, and then considering additional factors like propagation loss (Recommendations ITU-R P.676-8 and ITU-R SF.766 may be very useful).

Feeder and depointing losses may also be considered to achieve more actual results.

When **multiple interference sources** are considered, it can be expressed in terms of C/I as:

$$c/i_{\text{Total}} = \frac{1}{\frac{1}{c/i_{\text{Adj. Sat}}} + \frac{1}{c/i_{\text{Terrest}}} + \frac{1}{c/i_{\text{Other}}}}$$

3 PFD Criterion

Another method to evaluate the compatibility between GSO satellite networks consists of comparing the power flux density level produced at the earth's surface or GSO orbit with a specific trigger limit. If it is exceeded, coordination is required or, in the case of application of No. **11.32A**, it is considered to have the potential to cause harmful interference. A typical example recently introduced by WRC-15 is summarized below:

Resolution 762 (WRC-15)

Application of power flux-density criteria to assess the potential for harmful interference under No. **11.32A** for fixed-satellite and broadcasting-satellite service networks in the 6 GHz and 10/11/12/14 GHz frequency bands not subject to a Plan.

For satellite networks operating in:

– the frequency bands 5 725-5 850 MHz (Region 1), 5 850-6 725 MHz and 7 025-7 075 MHz (Earth-to-space) having a nominal orbital separation in the geostationary-satellite orbit of more than 7 degrees, assignments for a fixed-satellite service (FSS) satellite network with respect to other FSS networks do not have the potential to cause harmful interference if the pfd produced at the location in the geostationary-satellite orbit of the other FSS network under assumed free-space propagation conditions does not exceed −204.0 dB(W/(m^2 ·Hz)).

– the frequency bands 10.95-11.2 GHz, 11.45-11.7 GHz, 11.7-12.2 GHz (Region 2), 12.2-12.5 GHz (Region 3), 12.5-12.7 GHz (Regions 1 and 3) and 12.7-12.75 GHz (space-to-Earth), assignments for an FSS or broadcasting-satellite service (BSS) satellite network not subject to a Plan with respect to other FSS or BSS networks not subject to a Plan having a nominal orbital separation in the geostationary-satellite orbit of more than 6 degrees do not have the potential to cause harmful interference if the pfd produced under assumed free-space propagation conditions does not exceed the threshold values shown below, anywhere within the service area of the potentially affected assignment:

$5.8° < \theta \leq 20.9°$	$\text{pfd} = -187.2 + 25\log(\theta/5)$	dB (W/($m^2 \cdot$ Hz))
$20.9° < \theta$	$\text{pfd} = -171.67$	dB (W/($m^2 \cdot$ Hz))

where θ is the minimum orbital separation in the geostationary-satellite orbit, in degrees, between the wanted and interfering space stations, taking into account the longitudinal station-keeping tolerance.

– the frequency band 13.75-14.5 GHz (Earth-tospace) having a nominal orbital separation in the geostationary-satellite orbit of more than 6 degrees, assignments for an FSS satellite network with respect to other FSS satellite networks do not have the potential to cause harmful interference if the pfd produced at the location in the geostationary-satellite orbit of the other FSS satellite network under assumed free-space propagation conditions does not exceed −208 dB(W/($m^2 \cdot$ Hz)).

4 Study Groups contributions

New proposals or updates to the current interfering criteria and associated regulatory procedures are constantly studied by ITU-R Study Group 4, particularly at Working Parties 4A and 4C.

In preparation for WRC-19, under agenda item 7, analysis are being conducted to consider the introduction of the coordination arc with a value of [8] degrees as trigger for coordination between FSS and MSS systems and MSS systems in the frequency bands 29.9-30 GHz (Earth-to-space)/20.1-20.2 GHz (space-to-Earth) in all 3 Regions and 29.5-29.9 GHz (Earth-to-space)/19.7-20.1 GHz (space-to-Earth) in Region 2. Results of studies presented to WPs 4A and 4C and initials discussions can be found in the Annex 22 to the Working Party 4A Chairman's Report. Also , under agenda item 1.5, analysis are being conducted to consider the use of the frequency bands 17.7-19.7 GHz (space-to-Earth) and 27.5-29.5 GHz (Earth-to-space) by earth stations in motion (ESIMs) communicating with geostationary space stations in the fixed-satellite service.

Background of discussions, technical, operational studies and views at this initial stage of the study cycle may be found under Annex 18 to Working Party 4A Chariman's Report.

The progress of the above mentioned proposals deserves a close follow-up in the upcoming respective meetings as the outcomes of discussions may modify the current criteria and procedures explained in previous chapters of the document.

5 Methods to facilitate coordination and sharing scenario between GSO

At this stage of the text, having introduced the methods to identify satellite networks requiring coordination as well as criteria to determine the level of interference to be mitigated, the remaining question is what to do to make the networks compatible with each other.

Therefore, some methods which are generally used to achieve the desired compatibility and may be helpful to the reader are presented below, knowing that these are only a few of much more. Recommendation ITU-R SM.1132-2 provides further information on this subject.

In principle, the choice of the method to be implemented will depend on the stage of the satellite project.

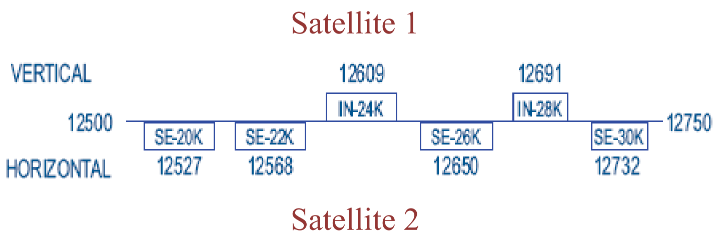
In an early stage of the spacecraft's design, potential modifications to aspects related to space station beams and associated antenna gain contours can be implemented.

By the contrary, if the satellite is already manufactured, the choices will be more limited to the ground segment and the possibilities could be focused on the earth stations for example.

Typical methods are as follows:

5.1 Frequency separation (either band segmentation or channelling plan)

5.2 Polarization advantage

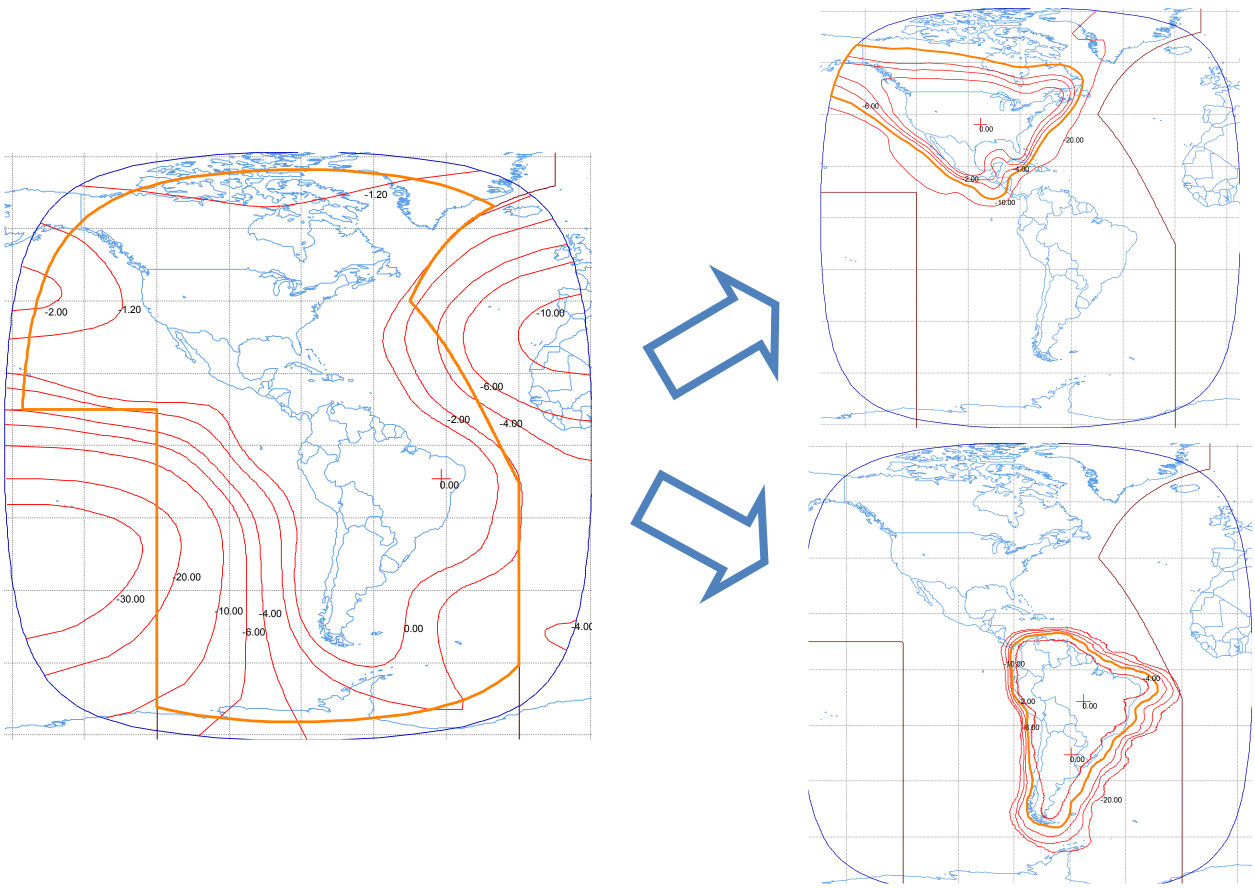


5.3 Improvement of antenna system spatial discrimination

- Redesign or specification of antenna gain contours, spill-off and service areas associated to satellite beams
- Modification of antenna diameters in the ground segment
- Improvement to earth station radiation pattern.

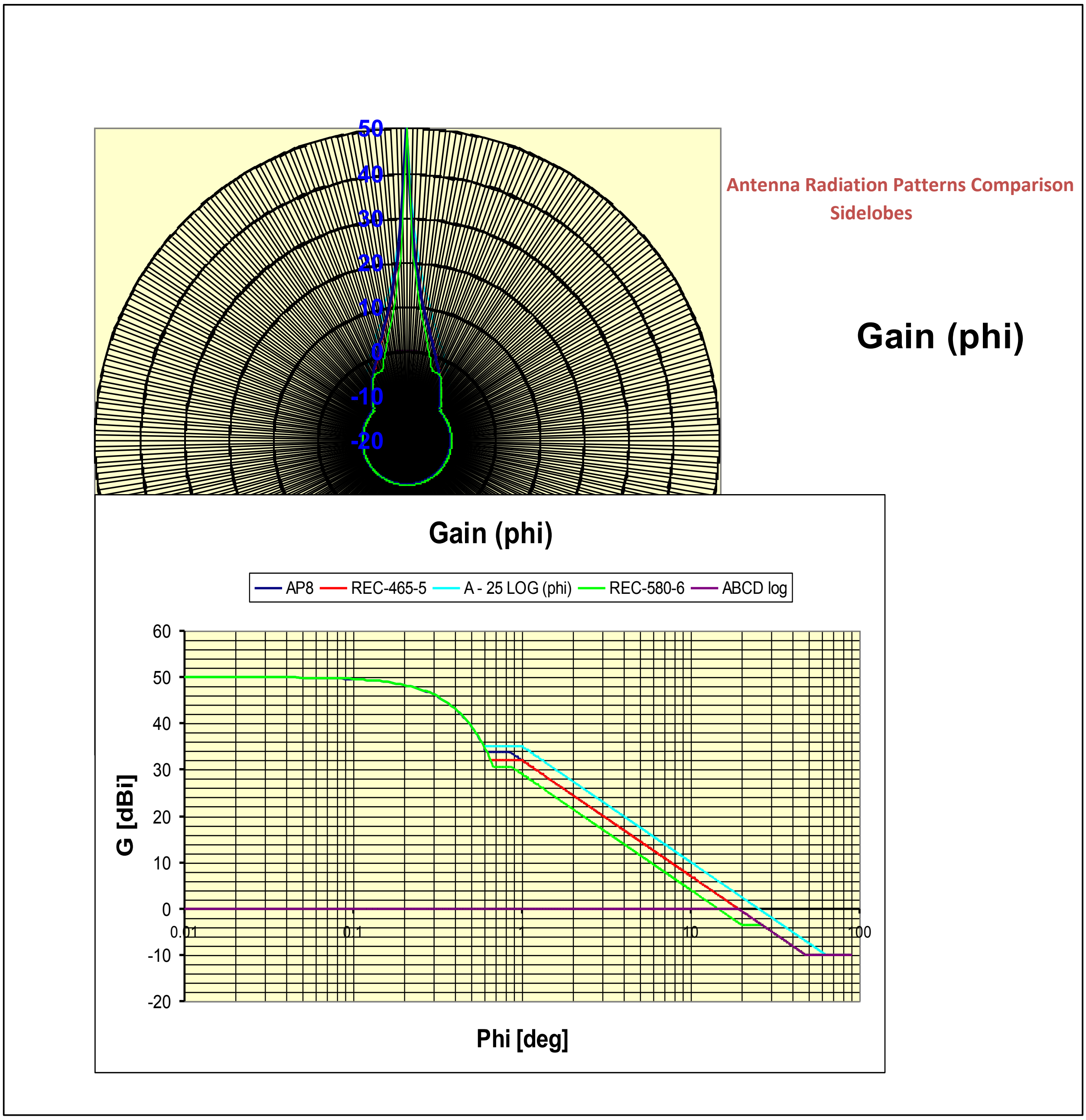
Space segment

The following image shows how two or more different areas can be isolated by using zone or spot beams instead of hemispheric one. In this case, if the coordination with other networks is more difficult in certain area, it doesn't impact to the rest of the service area. In addition to this, it will allow frequency re-use and its respective improvement to the use of the spectrum-orbit resource.



Ground segment

On the next images, it is visualized the impact, in terms of reduction of interference to neighbouring satellites, if the antenna radiation pattern associated to the earth stations is modified:



The following diagram shows how the mainlobe is modified when the antenna diameter is changed, observing a reduction of interference of approximately 5 dB to a satellite located at 1 degree of separation while increasing the antenna diameter from 1.2 to 13 metres.

Ga max [dBi]=	43.2
Gb max [dBi]=	56

Antenna A

G1 =	23.34
Phi m =	1.50
D/L =	59.40
Phi r =	1.68
Phi b=	47.86
Beamwidth=	1.17

Antenna B

G1 =	35.21
Phi m =	0.35
D/L =	259.28
Phi r =	0.56
Phi b=	47.86
Beamwidth=	0.27

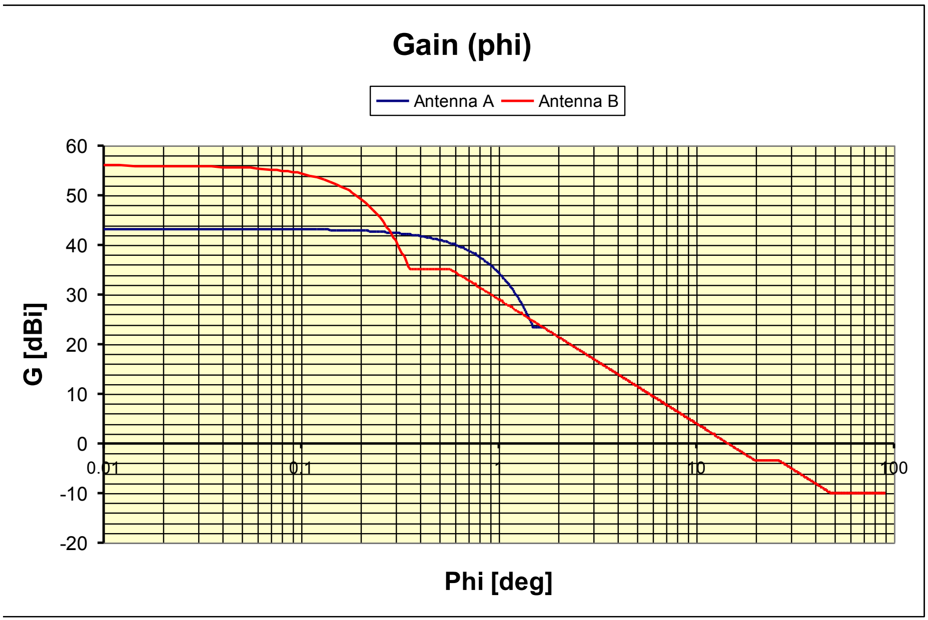
REFERENCES - COMMENTS:

Antenna A= Typical 1.2M

Antenna B= Typical 13M

Mainlobe and Near-Sidelobes

REC-580-6 Antenna Pattern



5.4 Modifying orbital separation between adjacent satellites

The following example illustrates an interference reduction of 4.8 dB if two satellites are being separated each other from 2 to 3 degrees:

Assuming D/λ = 100 ; ES antenna patterns REC 465-5 / REC 580-6

Interference reduction:

$I_f - I_i = 25.\log(\varphi_i / \varphi_f)$

where:

φ_f: minimum final separation between satellites

φ_i: minimum initial separation between satellites

Scenario 1

Θ_{1n}-Θ_{2n} = 2° → nominal orbital separation

$\Delta\Theta_1 = \Delta\Theta_2 = \pm 0.1°$ → E-W station keeping

Scenario 2

Θ_{1n}-Θ_{2n} = 3°

$\Delta\Theta_1 = \Delta\Theta_2 = \pm 0.1°$

Interference Reduction with respect to Scenario 1

$$I_f - I_i = 25.\log(1.8 / 2.8) = -4.8 \text{ dB}$$

Even though it seems to be a good solution in some cases from the technical point of view, it must be highlighted that today, in most of the classic services and frequency bands like FSS in C and Ku band, the impact of shifting in orbital location a satellite will cause an increment of interference (measured in terms of ΔT/T) to certain satellite networks sharing the same frequency band located in the direction towards the first satellite is being shifted.

From the regulatory point of view, according to the Rules of Procedure of the Radio Regulation Board related to No. **9.27** paragraph 2, and considering the current situation of high congestion of satellites in the geostationary orbit for the above-mentioned cases, such increment of interference will generate new or modified coordination requirements, something that it is not always desired and should be evaluated with precaution.

5.5 Reorganizing distribution of different types of carrier

Basically, it consists of the following steps:

– To identify different types of carriers such as:
  - TT&C
  - analogue TV/FM
  - digital data

– To consider their characteristics of diversity in terms of BW, Max. Power and spectral density distribution.

– To group them in the frequency domain taking into account the distribution of similar carriers used by neighbouring satellites.

– Off-axis e.i.r.p masks associated to type of carriers and frequency bands, as well as operational restrictions or relaxations, may be agreed during the coordination process.

5.6 Use of advanced modulation/FEC technologies (e.g. DVB-S2), signal coding and processing techniques (spread spectrum or CDMA, etc.).

5.7 Re-engineering of the link budget, including modulation-FEC, power density levels, adjusting Performance and Availability Objectives in order to tolerate higher levels of interference.

6 How to optimize a filing to be submitted to ITU?

6.1 Situation

At this stage, it has been shown how coordination requirements are identified, several interfering criteria to evaluate compatibility between GSO satellite networks, and possible methods which may be used to facilitate coordination and sharing scenarios between GSO networks.

The entire process stated in the Radio Regulations to reach the main goal of recording frequency assignments in the MIFR, obtaining the international recognition, protection, and associated rights and obligations, is described in Articles **9** and **11**, involving three stages:

- advance publication of information,
- coordination, and
- notification.

Radiocommunication Bureau has developed several software tools to implement the above-mentioned procedures, including the submission of notices.

Each notice has a structure to compile the full set of characteristics of frequency assignments associated to the subject satellite network, either for coordination or notification submissions.

Some characteristics are:

- space station beam
- service area
- frequency band
- power density levels
- associated earth station.

These characteristics and some others are organized in **Groups** of frequency Assignments, which then will be used by Administrations to coordinate and finally to notify the satellite network to ITU.

Each Administration is free to choose the way to organize the full set of frequency assignments in several groups. However, the aim of every notification is to receive as much favourable findings as possible in order to record the respective assignments in the MIFR. In this way, this chapter intends to provide the reader with some guidelines in order to improve the efficiency which could be measured as the ratio between the amount of frequency assignments recorded in the Register referred to the total amount of submitted frequency assignments, depending on the structure used to organize the notice.

Recognizing the freedom to group the assignments to be submitted in a coordination or notification requests, it may be interesting to highlight that should they are submitted in a way that the result of examination at group level is coherent with the actual use of the assignments, not only it will ensure the chances to be recorded without the need of application of No. **11.41** provision, but also it will contribute to the future efficient use of the orbit spectrum resource by other satellite networks due to the improvement of information available in the MIFR.

Having said that, it is also important to understand that during the coordination stage there is a need of more flexibility in terms of several combinations of characteristics which are under study and will be only defined at the end of the coordination with other networks, and once the final needs to be satisfied by the satellite project are well known.

Therefore, it is expected that the request for coordination could be a more general approach than a specific and accurate set of assignments submitted for notification.

6.2 Aspects to consider in the organization of the notice

The characteristics mentioned in paragraph 5.1 may be taken in order to explain a possible optimization of a filing, as follows:

a) Space station beam and service area:

During the analysis with respect to other neighbouring satellite networks, it may be possible to find that operation in some area is more feasible than in another one. Therefore, the service areas could be split into different groups, or even different beams. By doing so, it is ensured that the frequency assignments associated to the most favourable service area will be recorded successfully while the others can continue the coordination or could be modified later.

b) Frequency band

The same concept can be used for frequency planning. The segment of a frequency band which has been successfully coordinated could be organized in a different group than the other segment for which coordination is not yet completed. Otherwise, the full range of frequency assignments would obtain unfavourable findings due to a small set of assignments included in a single group associated to the entire frequency band.

c) Power density levels

Depending on the emission, several power density levels may be found to satisfy the requirements of the desired link budget. Some of these carriers could have been coordinated successfully while other ones still require further progress. In this case, again, it is advisable to split the group taking into account the diversity of power levels.

A typical example could be to separate space operation carriers from digital data or TV-FM Analogue carriers, for which the max. power levels could differ in several dBW.

d) Associated earth station

With respect to earth stations, as it was shown in item 4 above, the antenna diameter will impact to its main-lobe and its capacity to cause or receive interference to/from close separated satellites. Consequently, the compatibility scenario for an earth station using a 9 metres antenna will be more favourable than the one associated to 1.2 metres antenna, for example. Again, the use of different groups depending on the antenna size will ensure to record the assignments accordingly without being affected by the worst case of the same group.

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