

REPORT ITU-R SF.2046

Determination of the interference potential, and its possible reduction by mitigation techniques, between earth stations in the fixed-satellite service operating with non-geostationary satellites and stations in the fixed service in the 18/19 GHz band

(Questions ITU-R 237/4 and ITU-R 206/9)

(2004)

1 Introduction

Frequency bands have been allocated and identified for use by GSO and non-GSO FSS systems in bands shared on a primary basis with the FS. WRC-95/97 adopted a different set of provisions through No. 5.523A of the Radio Regulations (RR) to the non-GSO FSS utilizing the bands 18.8-19.3 GHz and 28.6-29.1 GHz from those provisions for non-GSO FSS utilizing bands outside these bands. This Report addresses only the 18.8-19.3 GHz band, which is referred to throughout as the 18/19 GHz band.

Sharing between the FSS and the FS should also take into consideration the impact of the proposed high-density deployment of both services, which requires special attention to the required separation distances. Such restrictions could impair the use of both services in the same areas, however, the sharing situation could be improved by the use of mitigation techniques.

2 Interference from an FS transmitter into a non-GSO FSS satellite earth station

The progressing deployment of FS stations or FSS earth stations may affect the future expansion of either service in the same frequency band. Accordingly, the FS station deployment patterns and the FSS earth station deployment patterns required for the introduction and growth of viable services have a major impact on the planning of band sharing. Studies to date are limited to the considered interference from FS transmitters into the LEOSAT-1 non-GSO FSS earth stations operating in the 18.8-19.3 GHz band.

2.1 Interference criteria and methodology

The interference calculations were performed by several administrations using FS parameters obtained from their administration databases.

Deterministic studies assume line-of-sight (LoS) transmission and were based on the use of a free-space loss plus atmospheric absorption propagation model. Some studies also took into account diffraction due to terrain and man-made obstacles.

The interference level into the earth station was calculated for each FS transmitter in the database and for all azimuths around each of these transmitters. The resulting exclusion zones were then superimposed graphically on maps of some major metropolitan areas. In all cases the minimum earth station antenna gain (backlobe) was used and the calculations were not dependent on anomalous propagation conditions, therefore, a long-term I/N criterion corresponding to 6% to 10% of the thermal noise level was used.

This criterion may require further study to take into account the effects of multiple FS transmitters simultaneously interfering into a non-GSO FSS user terminal receive bandwidth. In the case of LEOSAT-1, this would be the full 500 MHz receive bandwidth. When the non-GSO FSS user terminal receive bandwidth is reduced, the probability of having multiple FS transmitters interfering simultaneously is reduced.

Statistical studies evaluate, based on certain assumptions, the interfering power spectral density levels suffered by FSS receivers distributing these terminals in the satellite spot-beam with respect to assumed penetration rates in the different ground clutter classes. During the interference calculation procedure the FSS terminal location is selected randomly out of the predefined locations according to the penetration scenario with the following assumptions:

- the assigned frequency channel in the FSS downlink is randomly selected inside the FS frequency band with a bandwidth according to a randomly selected transmission capacity by combining the frequency channels for the FSS terminal under consideration (although this study assumes varying bandwidth such studies should be based on 500 MHz in the case of LEOSAT-1);
- the satellite responsible for communication with the FSS cell/spot-beam under consideration is determined by the criterion of the shortest distance;
- the antenna of the FSS terminal is placed on top of the buildings or above the vegetation.

The received power level from the serving satellite is calculated according to the elevation angle and the propagation conditions concerned. All FS transmitters within a distance of 60 km to the FSS receiver are selected in the affected frequency band. The resulting interference power density level is evaluated by aggregation of the signals of all FS transmitters considered.

The C/I ratio at the FSS receiver is calculated by comparing the interference power level with the received power level from the serving satellite. The interference level can also be referred to the receiver noise level, N . These interference levels are compared with a reference interference level of -145 dB(W/MHz) (i.e. -10 dB I/N). The cumulative distributions of the C/I ratios for standard propagation conditions (losses exceeded for less than 20% of time) as well as for rainy conditions (worst case: 0.001% of time) on the space-to-Earth path have been derived.

2.2 Possible application of a convolution process for assessing interference

One study presented a possible method for assessing interference from FS transmitters into non-GSO FSS earth station receivers, based on an application of a methodology similar to that of Recommendation ITU-R S.1323. The method accommodates the time-varying nature of the interference by convolving the probability density functions (pdf) of the rain degradation and the interference degradation, obtained through computer simulation, to generate the total degradation pdf.

3 Potential interference from point-to-point FS transmitters into non-GSO FSS earth station receivers without mitigation techniques

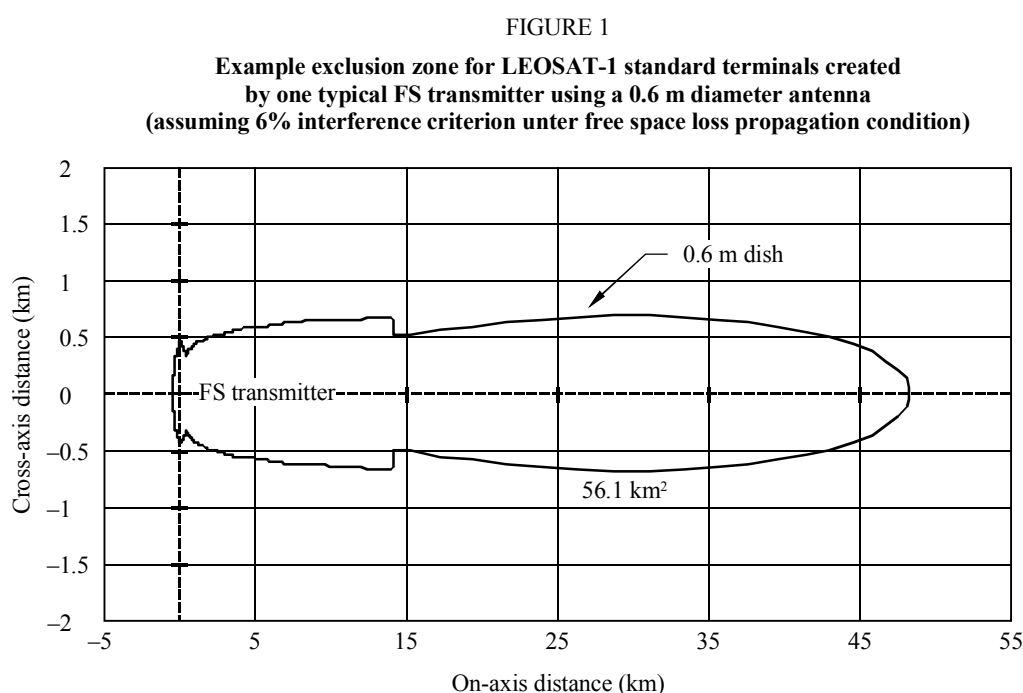
3.1 Interference without mitigation techniques

3.1.1 Deterministic studies

FS transmitters impose regions around themselves in which reliable operation of non-GSO user terminals may be precluded due to excessive interference. These blocked regions are referred to as “exclusion zones”. A single point-to-point FS transmitter will (under clear sky, clear terrain conditions) impose a circular exclusion zone in the area immediately surrounding it (off-axis directions) and a elliptical exclusion zone extending a long distance along its on-axis direction of transmission.

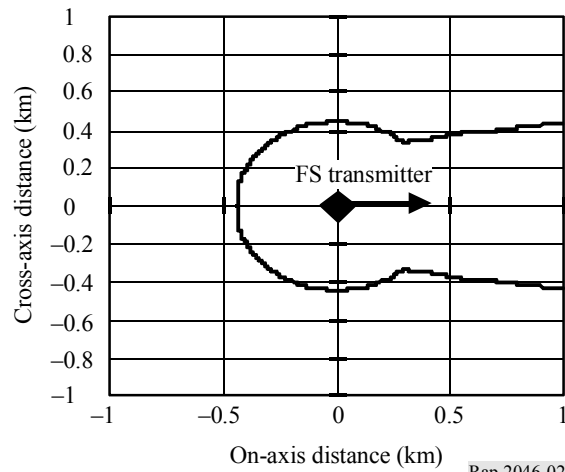
3.1.1.1 Results using free-space loss calculations and no blockage

Figure 1 presents an example exclusion zone calculated using the parameters of a typical point-to-point FS transmitter with a 0.6 m parabolic dish. The boundary is based on a single-source, conservative long-term interference criterion of 6% of the non-GSO user terminal system noise (i.e. $I/N = -12.2$ dB) under clear sky, clear terrain conditions. Non-GSO user terminals would need to be kept outside of this contour in order to guarantee that interference levels from the FS transmitter would be acceptably low. It can be observed in the expanded view in Fig. 2 that the diameter of the exclusion zone around the terminal can be nearly 1 km and the length of the exclusion zone in the direction of transmission can be well over 45 km. However, this distance and the affected area would be reduced using a more appropriate long-term interference criterion of 10%.



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FIGURE 2
Expanded view of Fig. 1



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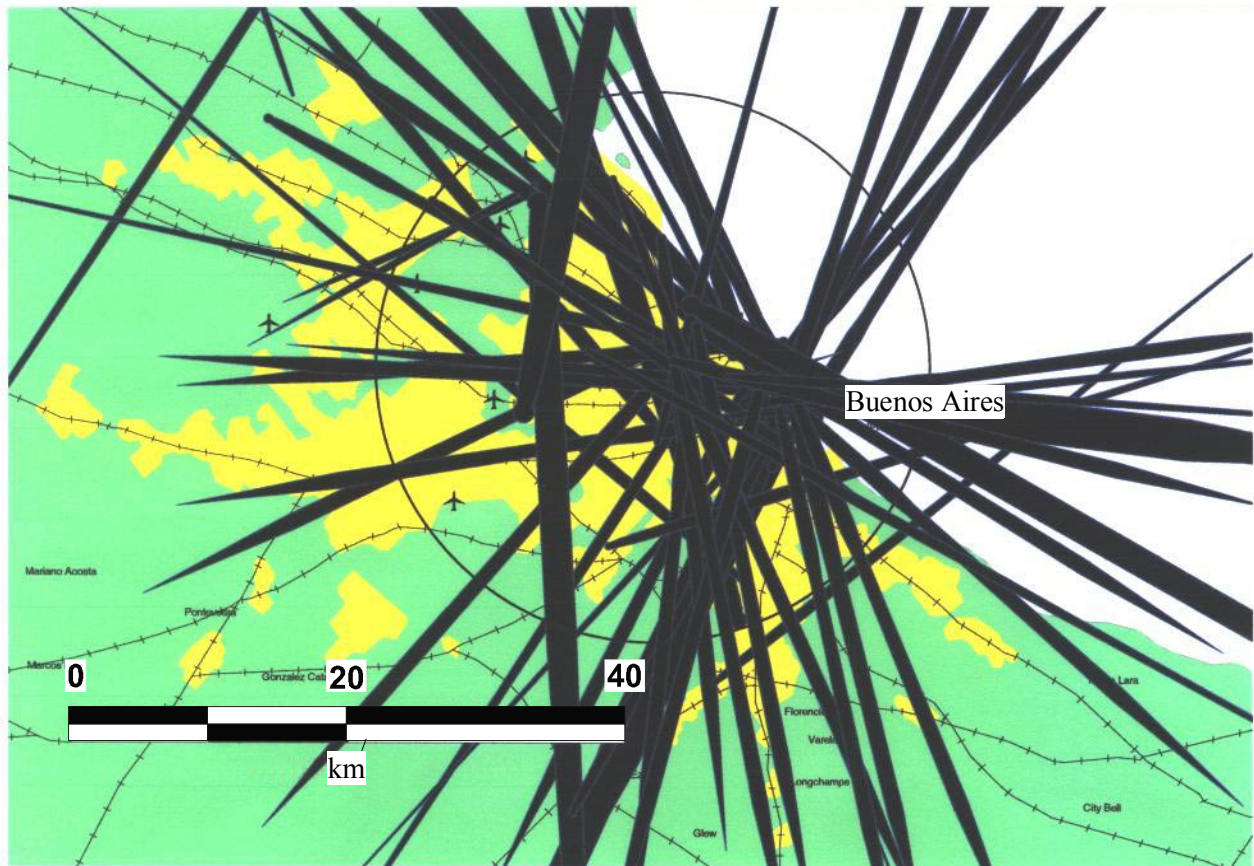
A study analysed the effects of interference from FS transmitters in Canada into a receiving non-GSO FSS earth station in the 18.8-19.3 GHz band. The calculations were performed using a database of FS parameters obtained from the Canadian licensing database and the resulting exclusion zones were then superimposed graphically on maps of some major metropolitan areas in Canada. The results of the deterministic interference calculations showed that the exclusion zone caused by the FS transmitters would be very long in the main direction of transmission, on the order of 40 to 80 km typically, but would be small in other directions well away from the FS main beam. In all cases, it was found that there was a significant area in each city where the non-GSO FSS terminal siting would be very difficult or perhaps even impossible. In fact, calculating the area of the exclusion zone within a 40-km diameter circle, representative of the metropolitan sites, indicated that areas of 35%, 48% and 47% would be unavailable for non-GSO FSS terminals in the three cases studied, in the absence of some blocking.

Another study analysed the interference that could be generated by typical FS transmitters into non-GSO FSS user terminals where they operate co-frequency and in close proximity, in the 18.8-19.3 GHz band. This analysis calculated these exclusion zones using the actual characteristics of the FS transmitters contained in a database of FS transmitters from Argentina.

Figure 3 shows the computed exclusion zones corresponding to each potentially interfering FS transmitter in the Buenos Aires urban region (assuming clear sky, flat and clear terrain conditions). The size variation between some exclusion zones is due to the differences in FS characteristics found in the database, such as transmitter power and antenna size. A circular region with a 40 km diameter was used as the reference area. In the high FS density urban region, 65% of the area would result in FSS terminals not meeting their performance objectives and would potentially be excluded from LEOSAT-1 service in the band 18.8-19.3 GHz.

FIGURE 3

Potential FSS earth station exclusion area in the Buenos Aires urban region due to 18.8-19.3 GHz FS terminal locations: composite exclusion zone 65% in reference 40 km circle



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The conclusion of this study is that, assuming free-space propagation and no blockage, deployment of FS stations in the band 18.8-19.3 GHz could significantly constrain the placement of non-GSO FSS user terminals. This is particularly true for areas that have a high density of FS stations. As FS deployment density increases, the placement of non-GSO FSS user terminals becomes more constrained.

3.1.1.2 Results using topographical data and building blockage environment

When topographical databases are used in the calculation of the exclusion zones, the area covered by exclusion zones can be significantly reduced. Table 1 compares the cases of two simulations where the exclusion zones correspond to areas where the long-term criterion ($I/N = -10$ dB) is not fulfilled and where:

- *Case 1:* the propagation model assumes that there are no terrain or man-made obstacles within the LoS around each FS and is based on the use of free space loss and atmospheric absorption.
- *Case 2:* the propagation model takes into account propagation loss and diffraction over terrain as well as man-made obstacles, using a topographical database (the non-GSO FSS receivers are placed 1 m above the building roofs).

TABLE 1
Comparison of exclusion areas with and without blockage

Simulation	Percentage of exclusion zone relatively to the global area (14 km × 14 km centred on Paris)
Case 1 (without taking into account any terrain or man-made obstacles)	20.6
Case 2 (taking into account terrain and man-made obstacles)	5.2

The studies have been made with a radio planning software which includes digital terrain modelling and ground occupancy layers (buildings, population, ...) and calculates the areas where the interference level into the ground stations receivers exceeds -97 dBm (10 dB below the receive system noise) from any of the fixed links.

The fixed links that have been taken into account in this study are those transmitting in the band 18.8-19.3 GHz and located in a square area of 14 km × 14 km around Paris (23 links).

3.1.2 Statistical studies

Two statistical studies have been carried out.

3.1.2.1 First statistical study

Statistical interference simulations between actual and planned FS links and non-GSO FSS user terminals at 18/19 GHz (LEO-SAT-1 system) in a 118×118 km square centred on Paris have been carried out.

The principle of the methodology used was to create, on a studied area, a hypothetical FSS user terminals network by a random deployment and then to calculate, for each user terminal, the aggregate interference from the existing FS microwave links in this area.

The FSS user terminals were implemented on the studied area according to penetration ratios (random stations/km²) associated with each ground clutter class. The C/I required was assumed to be 20 dB.

This active satellite is chosen, at the beginning of the simulation, as the one with the higher elevation (closer satellite) and is kept as long as its elevation is higher than the minimum (40° for LEOSAT-1).

The interference simulations consist of interference calculations (C/I) for each user terminal, taking into account: the constellation geometry (elevation and azimuth); the Earth-to-space propagation conditions, according to Recommendation ITU-R P.618 (for this purpose, the rain attenuation and the scintillation attenuation are associated to a random percentage to provide, for each calculation, the space-to-Earth attenuation); the propagation loss according to Recommendation ITU-R P.452 (visibility, diffraction, tropospheric scattering, including all statistical factors); the characteristics of the microwave links (power, azimuth, antenna, ...) and of the user terminal (receiver characteristics, antenna, ...). Each C/I calculation is called a “sample” and, at the end of the simulation, the results are presented as a graph representing the C/I distribution.

Table 2 gives the results for a simulation with FSS terminal distribution in the dense urban zone.

TABLE 2
Results of the first statistical simulation

Simulation	Percentage of FSS user terminals for which $C/I < 20$ dB
Urban areas	1.5

It was noted that a higher percentage of blocking would be indicated if this study were to take into account the 500 MHz downlink receiver bandwidth which is the normal bandwidth for LEOSAT-1.

3.1.2.2 Second statistical study

A particular study addressed the sharing between FS and FSS applications in the 18/19 GHz band taking into account heavy deployment of FS stations in a geographical area. The methodology applied differs from that of the previous study in that it includes the use of terrain and the use of the most common parameters and characteristics for the radio systems deployed in the 18/19 GHz band in the United Kingdom.

3.1.2.2.1 Approach

The study investigated the effects that FS links and receiving earth stations will have on each other when these are deployed in the same band and in the same geographical area.

The study looked into the reduction of FS links that can be deployed in a certain study area when HD-FSS receivers are present, but also investigated the possible reduction of suitable locations for the satellite receivers when the band is heavily used by FS links in a defined area.

This study used an approach that considered unequal deployments of FS links and satellite receivers, with larger number of satellite terminals than FS links in a $10 \text{ km} \times 10 \text{ km}$ area in a suburban environment.

3.1.2.2.2 Parameters and characteristics of the simulated systems

FS link characteristics

In this study three FS systems have been modelled corresponding to 8 Mbit/s, 34 Mbit/s and 155 Mbit/s systems. The common FS parameters for the three systems are summarized in Table 3 and the specific ones to each system are shown in Table 4.

TABLE 3

FS common characteristics to the three simulated systems

Parameter	Value
Minimum required transmit power	Calculated
Tower location and antenna height	As in the tower's database
Transmitter antenna height	15 m
Antenna gain ⁽¹⁾	38.4 dBi
Antenna aperture size	0.6 m
Radiation pattern ⁽¹⁾	Compliant with Recommendation ITU-R F.699
Polarization	Vertical
Microwave interference prediction procedure	Recommendation ITU-R P.452
Atmospheric loss	Recommendation ITU-R P.676
Rain loss	Recommendation ITU-R P.530 (99.999% availability)

- ⁽¹⁾ Provided by manufacturer. It was acknowledged that in the United Kingdom many links in this band use antennas with 25-32 dBi gain.

TABLE 4

FS specific characteristics for the three simulated systems

Parameter/system	8 Mbit/s system	34 Mbit/s system	155 Mbit/s system
Path length	4 km-14 km	4 km-14 km	300 m-6 km
Channel spacing	10 MHz	27.5 MHz	55 MHz
Receiver IF bandwidth	7 MHz	18 MHz	55 MHz
Modulation	QPSK	QPSK	32-QAM
C/N threshold ⁽¹⁾	13.5 dB	13.5 dB	23.5 dB
Receiver threshold ⁽²⁾ (BER = 1×10^{-6})	-119.5 dBW	-105 dBW	-95 dBW

- ⁽¹⁾ ITU-R Handbook – Digital Radio-Relay Systems, Geneva 1996, pp.139-140, Table 4.2.2-1.
- ⁽²⁾ Provided by manufacturer. It was acknowledged that in the United Kingdom many links in this band use antennas with 25-32 dBi gain.

Satellite parameters

The satellite parameters used to carry out the simulations are summarized in Table 5.

TABLE 5
FSS parameters

Parameter	Value
Downlink frequency range	18.8-19.3 GHz
Bandwidth	500 MHz
Antenna side-lobe gain	−3.2 dBi
System noise power	−117 dBW

3.1.2.2.3 Methodology

The study had two main parts:

In the first one, the study area was saturated with FS links and the results compared with the ones obtained if the same exercise is carried out in an area where a large deployment of receiving earth stations exists. In this way, it is possible to assess whether the spectral efficiency is maximized by a shared use of the spectrum by the two different services or by separating both services in frequency.

In the second part of the study, a large number of receiving earth stations are deployed over a saturated FS link scenario. Then, analysing the number of receiving earth stations that cannot be placed provides an indication of how much of the area would suffer an interference level that would be above the interference assessment criterion.

It must be noted that for the purpose of this study only five of the existing possible FS channels were used and that the term saturated relates to a saturation of these five channels and not the real saturation situation that will happen if all the FS channels are used. However, the I/N analysis is done on a per Hertz basis which is believed to be equivalent, for the I/N analysis, to make use of all the FS channels.

For both parts, a study area of 10 km × 10 km was used.

3.1.2.2.3.1 Deployment of FS links on top of a large deployment of receiving earth stations

In this first part of the study, the first step was to saturate the area of study in order to calculate how many FS links could be deployed in the area if no satellite receivers were present. The second step was to introduce a large number of receiving earth stations and determine how many FS links could be deployed in that case. Comparing the results for both exercises it can be seen whether, from the spectral efficiency point of view, it is better to have the FS and HD-FSS applications sharing the same spectrum in the same geographical area or whether it is better to employ band segmentation by allocating separate parts of the spectrum for each application.

Saturation of the study area

In this first phase, the user defines the rectangular area to be used and the appropriate radio systems characteristics and terrain data are loaded into the simulation input parameters. After this, the links start to be placed by selecting a random location and determining which of the towers in the study area are in LoS with the location chosen. There is then an attempt to place the link by calculating interference levels between all the radio systems in the area making use of Recommendation ITU-R P.452 for all the interference calculations. To do this the tool tries to place the link between the random location and the nearest LoS tower, the latter being at a distance of at least the minimum path length, in any of the available channels, while not exceeding the interference criterion with the previously inserted links. The interference criterion corresponds to an aggregate interference allowance I/N of -6 dB. If that process fails, the process is repeated with the next closest tower. A failure is considered, if after trying all the available channels for all the LoS towers, the link could not be placed and a new random location is chosen. The simulation is terminated, if after 20 consecutive attempts a link could not be placed in the network.

After this phase, the maximum number of FS links that can be deployed in the study area is obtained. This result will be compared with the number of links that can be deployed when satellite receivers are present.

Introduction of receiving earth stations and FS links

In order to compare the effect of the existence of receiving earth stations in an area of FS deployment, in the second phase of this part of the study, a large number of satellite receivers are introduced in the study area and then the tool introduces as many FS links as possible. In the link placement process, it is not only checked that the new link is not interfered with by the existing FS links but that the new link does not cause any interference to the previously introduced receiving earth stations and FS links. As in the previous case, the interference criterion corresponds to an aggregate interference allowance I/N of -6 dB.

This process is repeated for different numbers of introduced receiving earth stations in order to see the evolution of the number of FS links when the number of receiving earth stations increases.

3.1.2.2.3.2 Deployment of receiving earth stations on top of saturated FS link scenario

Although the maximum spectral efficiency may be obtained by forcing both applications, FS and HD-FSS, to share the same spectrum, this may lead to a percentage of the area where the level of interference, may be higher than the aggregate interference allowance of the receiving earth stations.

In this sense, the methodology described in this section aims to answer that aspect of the discussion and determine what proportional part of an hypothetical study area will not be suitable for HD-FSS receivers deployment due to interference from the FS links.

Generation of the FS links saturated area

In this step of the methodology, an FS link saturated area is generated in the same way as described in the previous methodology. However, this time the result of that generation will be saved and used to initialize a simulation where the receiving earth stations will be deployed on top of the FS link saturated area.

Introduction of receiving earth stations

After the saturated FS link area has been generated, the software tool introduces the receiving earth stations. In the satellite earth station receiver placement process, each of the receiving earth stations is introduced only if it is not interfered by any of the FS links. The insertion of new receiving earth stations continues until no more receiving earth station can be placed or the number of those inserted has reached a very high number.

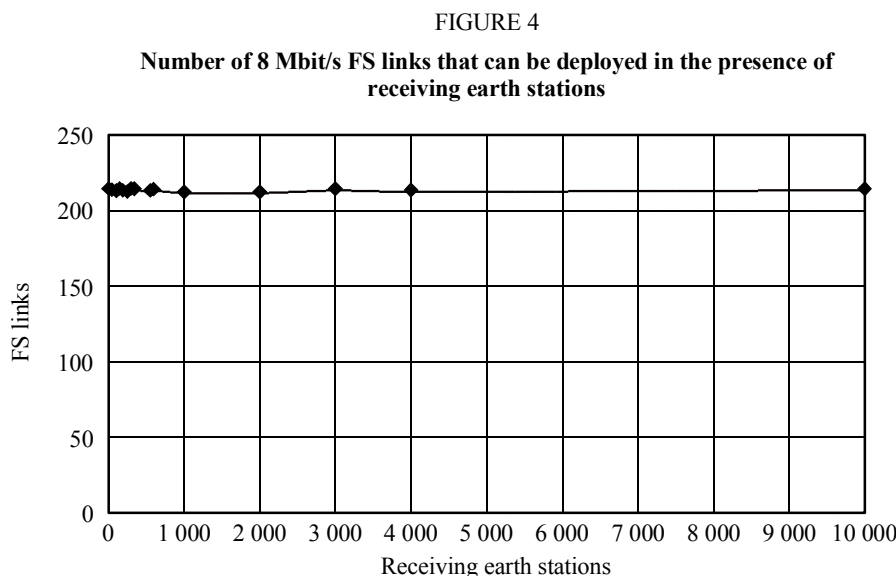
3.1.2.2.4 Results

Following the two methodologies described in the previous sections, a set of simulations was carried out. The results of the simulations for different FS systems are summarized below.

3.1.2.2.4.1 Deployment of FS links on top of a large deployment of receiving earth stations

Number of 8 Mbit/s FS links that can be deployed in the presence of receiving earth stations

In the first phase of the simulation for this scenario, the maximum number of FS links that could be deployed in the study area was calculated. The exercise resulted in 216 FS links being deployed for the 10 km × 10 km area. When introducing receiving earth stations the number of FS links that could be deployed for progressively large numbers of receiving earth stations can be seen in Figure 4.



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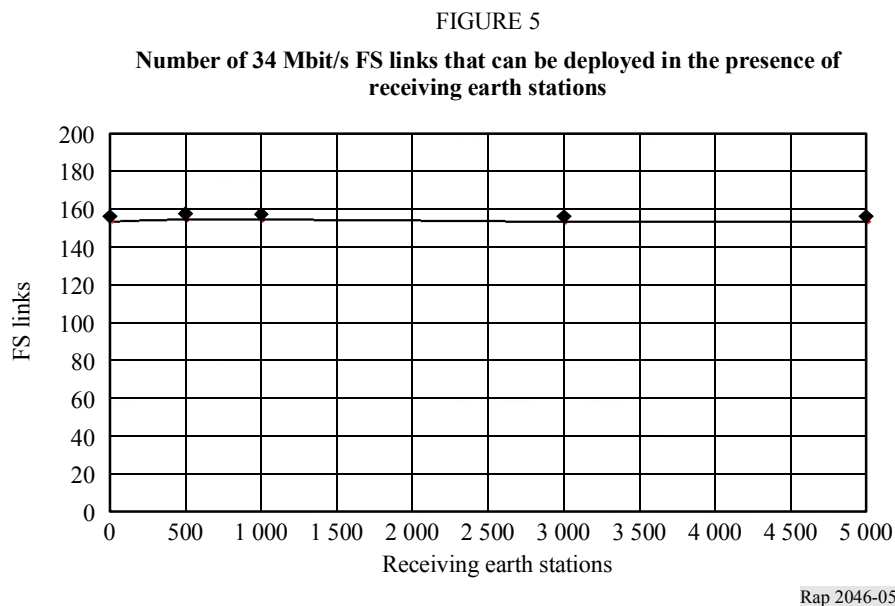
Figure 4 indicates that the presence of satellite receivers even in very high concentrations (up to 100 satellite receivers/km²) does not affect the possible deployment of 8 Mbit/s FS links, as the minimum differences between simulations are due to the random effect of choosing the FS link locations. Although even higher deployments of satellite receivers have not been simulated, due to the long processing time, the same results as the ones obtained for the HD-FSS deployments shown can be expected.

These results show that the effect that receiving earth stations have on 8 Mbit/s FS links as well as the one that 8 Mbit/s FS links have on the receiving earth stations is negligible.

Hence, these results show that the most spectrally efficient way to allocate HD-FSS and FS applications (8 Mbit/s systems) in parts of the band 18/19 GHz would be to share the spectrum among both services.

Number of 34 Mbit/s FS links that can be deployed in the presence of receiving earth stations

Following the described methodology applied to the 8 Mbit/s case, a total of 156 FS links could be deployed in the study area if this would be free of receiving earth stations. Thus, the effect of introducing HD-FSS terminals can be seen in the graph in Fig. 5.



As for the 8 Mbit/s case, the presence of satellite receivers in very high concentrations does not affect the possible deployment of 34 Mbit/s FS links. As already explained, the minimal differences between simulations are due primarily to the effect of randomness when choosing the FS links location.

Hence, these results show that the most spectrally efficient way to allocate HD-FSS and FS applications (34 Mbit/s systems) in parts of the band 18/19 GHz would be to share the spectrum between both services.

Number of 155 Mbit/s FS links that can be deployed in the presence of receiving earth stations

For this case the number of FS links that could be deployed in the absence of receiving earth stations is 89 links and as can be seen in the solid line of Fig. 6, for this case, the presence of even a low number of receiving earth stations will cause a reduction in the number of FS links that could be deployed without causing unacceptable interference to the receiving earth stations.