# ECC Report 304

Advanced technologies for fixed GSO FSS Earth Stations in the 27.5-29.5 GHz band

**approved 2 October 2019**

# 0 EXECUTIVE SUMMARY

This Report considers the possibility of operation of typical uncoordinated GSO fixed satellite service (FSS) earth stations (user terminals) in the band segments where the FS is deployed (27.8285-28.4445 GHz and 28.9485-29.4525 GHz), to determine if opportunistic usage of this spectrum is possible. It analyses therefore the deployment of fixed service (FS) links within the CEPT described in ECC Report 173 [5] and the likelihood of interference into FS from FSS Earth Stations.

The Report explores the feasibility of using newly developed technologies to enable opportunistic use, by FSS Earth Stations that are not individually coordinated and licensed, in portions of the 27.5-29.5 GHz band currently identified for FS use under ECC Decision (05)01. New high throughput satellites (HTS) offer connection speeds up to 100+ Mbit/s. In order to provide such broadband connectivity to a large number of users, HTS systems use a number of innovative new technologies.

This Report does not propose to change the band plan contained in ECC Decision (05)01. Instead, it assumes that the entry of one service into another service's reserved spectrum is possible only on a non-interference basis, ensuring that the incumbent service in its reserved spectrum is protected from interference also with respect to its future development.

One important characteristic of both the FS and the FSS services operating in this band is that the antenna patterns at this frequency are highly directive (apart from P-MP base stations), meaning that the highest risk of interference occurs in a very limited range of azimuth and elevation angles.

The Report first analyses the existing usage of the band segments identified for use by FS in ECC Decision (05)01 within the 27.5-29.5 GHz band (27.8285-28.4445 GHz and 28.9485-29.4525 GHz). Currently under this ECC Decision, FSS also may access this 1120 MHz of spectrum on an individually licensed and coordinated basis.

MCL calculations show that the directivity of antennas operating in the FS portions of the 27.5-29.5 GHz band result in separation distances outside the main beam of the FS antenna in the range of 4.9 km at 5° azimuth offset to 0.3 km at 55°and above. In the case of alignment in the azimuthal plane, the separation distances in general will be higher, ranging from 0.4 km up to nearly 60 km, (depending on FSS earth station elevation angle). The results are summarised in sections 5.1 and 6.

In case of uncoordinated FSS ES deployment in an area containing a high density network of point to point links there is a potential degradation of the FS in terms of interference probability which should be addressed by using various interference mitigation techniques, as described below.

Finally, to address cases of potential interference, the Report analyses the effectiveness of active and passive mitigation techniques in protecting existing FS links, such as sense and avoid, the use of geolocation databases and shielding.

In general sense and avoid offers advantages over the geolocation database and shielding, because it does not require a precise and updated knowledge of the FS systems and it allows coexistence with FS future development. The sensing mechanism is based on the assumption that the channelization of the FS in the band is known in advance and that the links are bi-directional. Consequently, the feasibility of implementing spectrum sensing depends on the specific situation of each country.

In particular, the feasibility of sensing strongly depends on the value of the FS output power that needs to be detected. For a given FSS ES, if one sets the target of protecting any possible FS link potentially interfered with, detection should be performed below the noise floor. The combination of sensor antenna gain, sensor sensitivity and integration time are the main parameters to define the feasibility of the sensor. The improvement of the parameters mentioned is practically limited and the feasibility of the sensing concept is therefore depending on the possibility to design a fitting sensor.

Although sensing could be an effective interference mitigation technique under certain conditions (see Section 8), it is also recognised that a sensor threshold could be set at a level that does not protect 100% of operational FS links. In fact, Administrations may deem appropriate to use different values of FS output power for defining the requirements of the sensor, based on their deployment scenarios. In this case, the Report suggests means of improving sensing.

This Report does not cover the issue of selecting an appropriate sensing threshold and the subsequent implementation of the sensor.

The performance requirement of the sensor is a regulatory parameter that depends, inter alia, on the deployment scenario of the FS.

In order to define a given performance requirement, there are in principle multiple choices for the actual implementation of the sensor. Moreover, the performance requirement itself is a regulatory aspect that must be defined before the sensor design and depends on information on actual deployment scenarios. These aspects were therefore not defined in this Report.

The Report also considered hydrometeor scattering a possible mechanism impairing the performance of spectrum sensing and it was found that the influence of this phenomenon is limited.

Regarding the geolocation database approach, its feasibility/performance is subject to the issue of data integrity, availability and accuracy. Its overall feasibility will depend on the specific situation of each country.

Regarding additional passive mitigation techniques, shielding is the most effective, but requires professional installation and therefore in this Report it has been considered only for enterprise terminals.

The mitigation techniques mentioned above should reduce the risk of interference into FS receivers to a point that use of FSS Earth Stations on an uncoordinated basis maybe feasible in these bands identified for FS use. Without those mitigation techniques uncoordinated use of these portions of the band by the FSS is not feasible.

The European Common Table of Allocations does not contain any allocation to the Mobile Service and ECC Decision (05)01 allows only FSS and FS in the 27.5-29.5 GHz band. The Report therefore does not analyse FSS coexistence with other services, nor would its results be applicable to them.

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# LIST OF ABBREVIATIONS

| Abbreviation | Explanation |
|---|---|
| **ATM** | Air tTaffic Management |
| **BW** | Bandwidth |
| **BWA** | Broadband Wireless Access |
| **CEPT** | European Conference of Postal and Telecommunications Administrations |
| **e.i.r.p.** | equivalent isotropically radiated power |
| **DRRS** | digital radio-relay system |
| **ECC** | Electronic Communications Committee |
| **ESIM** | Earth Stations In-Motion |
| **ES** | Earth Station |
| **FS** | Fixed Service |
| **FSS** | Fixed-Satellite Service |
| **GSO** | Geostationary Satellite Orbit |
| **HTS** | High Throughput Satellites |
| **IP** | Interference Probability |
| **LOS** | Line of Sight |
| **MCL** | Minimum coupling loss |
| **NLOS** | Non Line of Sight |
| **P-MP** | Point-to-Multipoint |
| **P-P** | Point-to-Point |
| **PSD** | Power Spectral Density |
| **SAA** | Sense and Avoid |
| **SMEs** | Small to Medium Enterprises |
| **TDD** | Time Division Duplex |
| **BER** | Bit Error Rate |
| **BS** | Base Station |
| **C/I** | Carrier to Interference ratio |
| **C/N** | Carrier to Noise ratio |
| **ET** | Enterprise Terminal |
| **MW** | MicroWave |
| **PLE** | Path Loss Exponent |
| **QAM** | Quadrature Amplitude Modulation |
| **RT** | Residential Terminal |
| **SNR** | Signal to Noise Ratio |
| **TPC** | Transmit Power Control |
| **TS** | Terminal Station |
| **VSAT** | Very Small Aperture Terminal |

# 1 INTRODUCTION

A new generation of High Throughput Satellites (HTS) has begun to operate recently that can deliver telecommunications services as an alternative to terrestrial technologies and in areas that terrestrial technologies do not and may not serve.

These new HTS systems provide faster speeds to support streaming applications; higher capacity to support more users with more applications; and greater reliability. Perhaps most important, HTS systems provide consistent services anywhere and at any time with broad geographic coverage.

There are current examples of satellite networks that are providing 100 Mbit/s download speeds over satellite. While the current generation of HTS satellites have a capacity in excess of 300 Gbit/s, the next-generation of satellites under construction today and scheduled to begin service in a few years will have a per-satellite capacity of over 1 Tbit/s and will support even higher download speeds to end users.

To deliver the envisaged the envisaged capacity these satellite networks need access to spectrum beyond the frequency bands currently identified for use by license-exempt Fixed-Satellite Service Earth Stations (FSS ES):

1. at 29.5-30.0 GHz (Earth-to-space) and 19.7-20.2 GHz (space-to-Earth) (according to ECC Decision (06)03 [9]) and

2. at 27.5-27.8285 GHz, 28.4445-28.9485 GHz and 29.4525-29.5 GHz (Earth-to-space) (according to ECC Decision (05)01 [1]) and at 17.7-19.7 GHz (space-to-Earth) (according to recently amended ECC Decision (00)07 [2]).

Specifically, access to spectrum for license-exempt FSS Earth Stations in the 1120 MHz identified in ECC Decision (05)01 for use by the FS also is needed. In order to facilitate the license-exempt use of these bands by FSS Earth Station, additional work is required within the CEPT.

Next generation HTS systems take advantage of a number of advanced technologies that merit further study to facilitate increased FSS/FS sharing in the 1120 MHz portion of the 27.5-29.5 GHz band currently identified for FS use, through:

1. The use of much higher transmit channel bandwidths, with signals spread across up to several hundred MHz of bandwidth, resulting in very low Power Spectral Density (PSD). ECC Recommendation T/R 13-02 [22] provides recommended channel bandwidths for FS systems varying from 3.5 MHz to 224 MHz. HTS systems can spread transmit signals over several hundred MHz of bandwidth, resulting in a very low relative PSD into FS links.

2. Cognitive radio techniques such as transmit band activity sensing, Dynamic Channel Assignment, and the use of geographic databases to avoid co-frequency interference. Cognitive radio techniques have already been extensively studied within the CEPT (ECC Report 241 [25]) and ETSI TR 103 263 [3]) and have formed the basis already for allowing increased access of FSS terminals in the 17.7-19.7 GHz band. Such techniques – including the use of Sense-and-Avoid techniques and geolocation-based systems that use up-to-date databases containing geographic deployment and transmission characteristics of FS links – can enable increased use of spectrum by FSS user terminals on an opportunistic basis.

In addition, by imposing limitations on the minimum elevation angle of FSS user terminals, the possibility of interference can be virtually eliminated, and the impact of side lobe emissions can be reduced to meet the protection criteria of the FS.

The above-mentioned techniques could allow access by FSS user terminals to use the 1120 MHz portion of the 27.5-29.5 GHz band currently identified for FS use, without those FSS user terminals causing harmful interference.

Therefore, this Report explores the feasibility of using these technologies to enable earth stations that are not individually-licensed to make opportunistic use of the 1120 MHz portion of the 27.5-29.5 GHz bands identified for FS use. When used in combination, these techniques should reduce the risk of interference into FS receivers to a point that individual licensing of FSS Earth Station may not be required in those band segments. This Report aims to determine:

- How new technologies employed by FSS Earth Stations operating with HTS can allow increased sharing between FS and FSS applications in the 1120 MHz portion of the 27.5-29.5 GHz band identified for FS use;
- How advanced cognitive radio technologies (e.g. those described above and also in ETSI TR 103 263 [3]) can improve coexistence between fixed GSO FSS Earth Station that are not individually licensed and FS in such frequency segments.

The ECA Table [31] does not contain any allocations to the Mobile Service (MS) and ECC Decision (05)01 does not allow Mobile Service operations in the 27.5-29.5 GHz band. This Report therefore does not analyse coexistence with MS, nor should any results contained herein be construed as applying to MS systems.

## 2 FSS SYSTEMS OPERATING IN 27.5-29.5 GHZ BAND

Use of the band 27.5-29.5 GHz within the CEPT is currently covered by ECC Decision (05)01 (see Figure 1). The majority of CEPT administrations have implemented this Decision, although the number and type of FS links operating in the bands identified for FS varies widely from country to country. Whereas in some CEPT countries, large numbers of FS links operate in the 28 GHz band, in other countries this band is currently largely unused by FS.

No Mobile Service (MS) is allowed in this band under ECC Decision (05)01 [1]. In addition, the CEPT Roadmap [32] on 5G explicitly states that “Europe has harmonised the 27.5-29.5 GHz band for broadband satellite and is supportive of the worldwide use of this band for ESIM. This band is therefore not available for 5G.” MS operations in this band therefore are not the subject of this Report.

At the time when studies leading to the development of ECC Decision (05)01 were carried out, there were no commercial Ka-band satellites in operation. Thus, the FSS parameters on which that Decision was based were most likely taken from Ku-band and C-band satellites which were in operation at the time. Those satellites generally used wider beams, narrow bandwidth transponders and the characteristics of the earth stations generally did not allow successful operation in the immediate vicinity of terrestrial systems. As a result, ECC Decision (05)01 adopted a frequency usage plan according to which FS networks were prohibited in the FSS bands and FSS Earth Stations were allowed in FS bands only on an individually licensed basis[1].

On the base of the studies, the reciprocal situation with FS possibly deployed in the rest of the 27.5-29.5 GHz band may be feasible as well, provided that similar studies are carried out within the CEPT and applied to protect existing and future FSS applications.

Current advanced satellite technologies employed by HTS Earth Stations allow FSS networks to more broadly share spectrum currently identified for use by FS and allow more efficient usage of this spectrum. This Report therefore focuses on usage of the 1120 MHz comprising those frequency bands; namely, 27.8285-28.4445 GHz and 28.9485-29.4525 GHz. Detailed characteristics of Earth Stations used in this study are presented in section 4.1. FS characteristics operating in those frequency segments are provided in section 4.3.

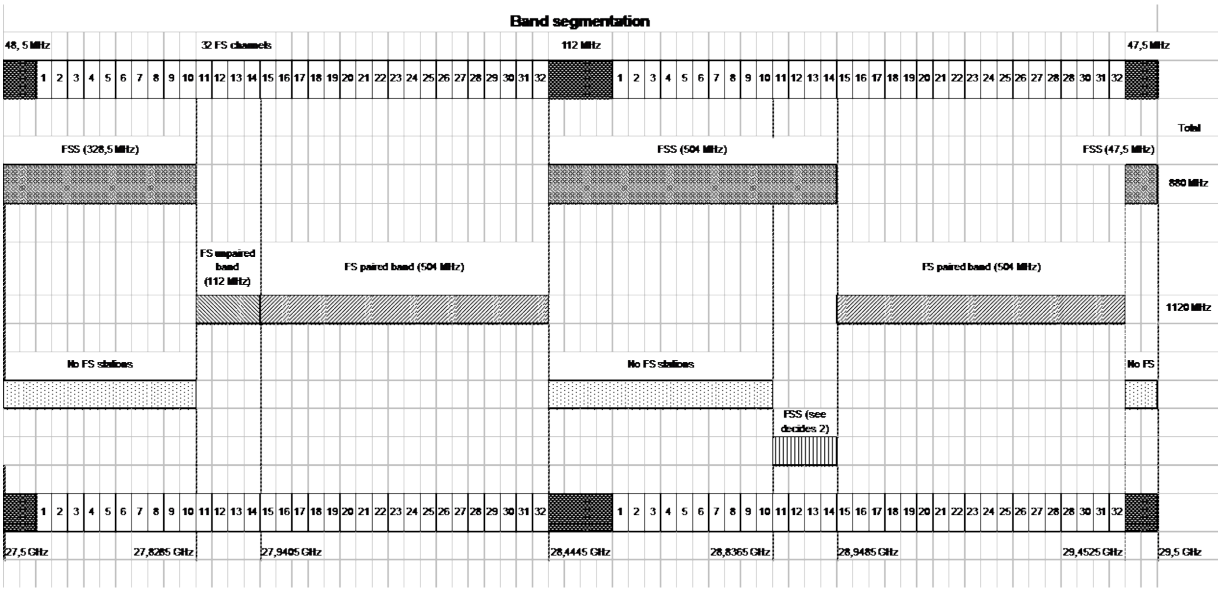



**Figure 1: CEPT 28 GHz band plan**

[1] ECC Decision (05)01 [1] under Decides 1-3, the frequency bands 27.8285-28.4445 GHz and 28.9485-29.4525 GHz are identified for the use of FS systems, and also may be used by individually-licensed FSS Earth Stations. Uncoordinated FSS Earth Stations are allowed in the bands 27.5-27.8285 GHz, 28.4445-28.9485 GHz and 29.4525-29.5 GHz.

## 3 FIXED SERVICE (FS) DEPLOYED BY CEPT COUNTRIES

CEPT has revised ECC Report 173 [5] 'Fixed Service in Europe', which was prepared between 2010 and 2012 to update previous ECC Report 003 of 2002. A questionnaire was issued from April to October 2016, requesting information from administrations on Fixed Service usage in all bands. The outcome of the questionnaire has been taken into account in the revision process.

This section summarises information provided by CEPT administrations regarding FS usage of portions of the 27.5-29.5 GHz band in accordance with ECC Decision (05)01 [1]:

- 2600 links and about 380 P-MP Base Stations are reported in 31 countries. In many countries the block allocation does not require any notification of individual links. Therefore, the figures provided for this kind of allocation could be underestimated. The 95% percentile "typical" hop length indicated in the responses to the survey is about 4 km (2.5 km is indicated as "minimum");
- Usage for medium and high capacity links is mostly reported. Licenses are assigned by blocks or by link, according to the use. The majority of links are allocated to fixed and mobile infrastructure;
- 9 countries indicate expectations to increase FS use in the next years (10 indicated no growth; Finland indicated 90% growth with local congestion). No respondent expected usage to decrease;
- Currently the most common FS channel spacing is 28 MHz. This value has been considered in this Report for statistical analysis. Nevertheless, it has to be taken into account that Recommendation T/R 13-02 [22] and ECC Decision (05)01 allow usage of wider channels (up to 224 MHz).

| Respon | Frequency band (MHz) | Topo-logy FWA | | Number of P-P lin | | umber c | | Link characteristics Capacity | | | Hop length (km) | | | Future trends (e.g. in the next 5 years) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P-P | P-MP | unidirection | bidirectional (1 bidirectional link counts 1) | (applicable only for P-MP and mesh networks) | Channel/Frequency plan used (e.g. ERC/ECC Rec. ITU-R Rec.) | LOW (<10 Mbit/s) | MEDIUM (10 to 100 Mbit/s) | HIGH (>100 Mbit/s) | MIN | Typical figure | MAX | Anticipated growth/reduction (+/-%) | Currently congested | Planned reallocation to other service/application | Other (please describe) (see Question 3 of the Questionnaire) | |
| Austria | 27500-29500 | X | X | | 1339 | | T/R 13-02 Annex C | | | X | 1 | 2 | 4 | | | | | |
| Bosnia and | 27500-29500 | X | X | | 0 | 0 | T/R 13-02 Annex C | | | | | | | | | | | |
| Bulgaria | 27500-29500 | **X** | | **0** | **946** | | T/R 13-02 Annex C | **X** | **X** | **X** | **0.07** | **2** | **10** | **+50 %** | | | | |
| Czech Repu | 27500-29500 | | X | | | 137 | see the EFIS | N/A | N/A | N/A | | | | | | | | |
| Czech Repu | 27500-29500 | | X | | | 60 | | N/A | N/A | N/A | | | | | | | | |
| Germany | 27500-29500 | x | | | 1900 | | T/R 13-02 Annex C | | x | x | 2 | 3 | 13 | + | | | | |
| Germany | 27500-29500 | | x | | | 80 | | | | | | | | | | | | |
| Estonia | 27500-29500 | | | | | | T/R 13-02 Annex C | | | | | | | | | | | |
| Finland | 27500-29500 | x | | 0 | 500 | | T/R 13-02 Annex C | | x | x | 0.1 | 1.3 | 17.3 | +2 | | | | |
| UK | 27500-29500 | | | | | | | | | | | | | | | | | |
| Greece | 27500-29500 | X | X | 7 Regional Coverage Licenses | 7 Regional Coverage Licenses | 7 Regional Coverage Licenses | ECC/DEC/(05)01, ECC/REC/(11)01 | | | | | | | growth | | | | |
| Hungary | 27500-29500 | | | | | | ECC/DEC/(05)01 | | | | | | | | | | | |
| Netherland | 27500-29500 | x | | | 191 | | T/R 13-02 Annex C | | | x | 2 | 4 | 7 | + | | | | |
| Croatia | 27500-29500 | X | | | 4 | | T/R 13-02 Annex C | | | X | 0.46 | 1.02 | 1.77 | 500 | | | | |
| Ireland | 27500-29500 | X | | | 197 | | T/R 13-02 Annex C | | 45 | 153 | 3 km for links ≤ 34 MBit/s. | | | | | | | |
| Ireland | 27500-29500 | | | | | | | | | | 0 km for links > 34 Mbit/s, or 34 Mbit/s in 14 MHz channel spacing. | | | | | | | |
| Norway | 27500-29500 | | | 0 | 1 | | T/R 13-02 Annex C | | x | x | | | | | | | | |
| Norway | 27500-29500 | | | | | | | | | | | | | | | | | |
| Portugal | 27500-29500 | | X | | | | T/R 13-02 Annex C | | X | | | 5 | | No use at tl | No use at the moment. | No use at the moment. | No use at the moment. | Only planned for PP, PMP |
| Sweden | 27500-29500 | | | | N/A | | T/R 13-02 Annex C | | | | | | | | | | | |
| Switzerland | 27500-29500 | x | | | 540 | | T/R 13-02 Annex C | | x | x | 1.8 | 4.2 | 6.8 | 100 | | | | |
| Slovak Repu | 27500-29500 | x | x | | 244 | | ECC/DEC/(05)01 | x | x | x | 0.05 | 1.2 | 4.2 | 15 | | | | |

**Figure 2: Excerpt of CEPT administrations responses to the questionnaire regarding FS usage of portions of 27.5-29.5 GHz**

# 4 TECHNICAL CHARACTERISTICS USED FOR SHARING STUDIES

## 4.1 DEPLOYMENT SCENARIOS AND TECHNICAL CHARACTERISTICS OF GSO FSS EARTH STATIONS IN THE 27.5-29.5 GHZ FREQUENCY BAND

The range of services delivered by satellite operators is very wide and is covered by a number of different ECC Decisions and Reports addressing terminals that are at fixed locations and those designed for mobility. This ECC Report addresses only earth stations at fixed locations intended either for residential usage (75 cm diameter parabolic antennas) or antennas with 1.8 m diameter intended for commercial use, and in either case, that would be deployed on a license-exempt basis.

Studies were conducted considering the following range of satellite orbital positions: 20W to 45E, representing a range within which the majority of CEPT countries can be served. From these orbital locations, earth station elevation angles will range from 10 to 50 degrees for Continental Europe. When considering Continental Europe, the following area can be considered: approximately 65º N (most North point) to 35 ºN (most South point); 10ºW (most West point) 60º E (most East point)).

The elevation angle is one key factor influencing the amount of interference that might be received by Fixed Service receiver. This has been demonstrated by the Minimum Coupling Loss analysis summarised in section 6).

Table 1 below provides some characteristics for commercially available FSS Earth Stations for user terminals intended for broad deployment to operate in the band 27.5-29.5 GHz.

**Table 1: FSS Earth Station (user terminal) parameters in the band 27.5-29.5 GHz**

| GSO FSS ES characteristics (user terminal) | | |
|---|---|---|
| | Enterprise Terminal (Note 1) | Residential Terminal |
| Antenna height<br>(Note 2) | 2 m,10 m and 30 m urban<br>2 m and10 m suburban | 2 m,10 m and 30 m urban<br>2 m and 10 m suburban |
| Antenna diameter | 1.8 m | 0.75 m |
| Antenna pattern | Recommendation ITU S. 465[26] | Recommendation ITU S. 465 |
| Frequency considered | 28.35 GHz | 28.35 GHz |
| Higher Range transmit power(for MCL) | 14.1 dBW | 17.1 dBW |
| Lower (nominal) Range transmit power | 7.1 dBW | 9.1 dBW |
| Range of elevation angles | 10- 50 degrees | 10-50 degrees |
| Max. Gain | 52.91 dBi | 43.9 dBi |
| Equivalent bandwidth | 320 MHz | 80/160 MHz |
| Lower Range input power spectral density (PSD) | -17.91 dB(W/MHz) | - 12.9 dB(W/MHz) |
| Higher range input power spectral density (PSD) | -10.9 dB(W/MHz) | -1.9 dB(W/MHz) |
| Polarisation | Circular | Circular |

Note 1: Due to the antenna size and cost they will likely be professionally installed. Shielding for the enterprise antenna would also be possible.
Note 2: Antenna height can be higher than 10 m (e.g. installed on an apartment building) – this situation is partially addressed in the ANNEX 2 containing examples of measurements conducted by Comsearch http://comsearch.com/services/site-services/rf-test-measurements/. It is worth noting that the 10 m height is representative of roof-mount installations for a typical single-story dwelling, but multi-story dwellings are certainly a possibility. However, clutter height increases as the average number of stories in the area increases.

In summary, the Power Spectral Density (PSD) used in the subsequent calculations are:

- For the enterprise antenna 1.8 m: -17.9 dBW/MHz (based on a bandwidth = 320 MHz) and -10.9 dBW/MHz (based on a bandwidth = 320 MHz);
- For the residential antenna 0.75 m: -12.9 (based on a bandwidth= 160 MHz) dBW/MHz and -1.9 dBW/MHz (based on a bandwidth= 80 MHz). The value of -10.9 dB(W/MHz) has been considered for sensitivity analysis (based on bandwidth = 160 dBW/MHz, transmit power 11.1 dBW).

Maximum Fixed-Satellite Service (FSS) transmit e.i.r.p. can have a significant influence on sharing results, therefore a range of FSS transmit e.i.r.p. was used in these studies. Future regulations may consider, among other tools, adopting transmit e.i.r.p. limits on uncoordinated FSS Earth Stations to facilitate sharing with FS.

**FSS Earth Station Duty cycle consideration**

A new generation of earth stations transmit bursts of information at designated times that are assigned to the terminal by the network. Terminals are neither designed for nor capable of continuous transmission. Depending upon the manufacturer and satellite network on which it operates, the average duty cycle for a given earth station may range from as little as 0.5% to up to 20%. The length and carrier frequency of each transmission burst depend on the earth station's traffic requirements.

Duty cycle of FSS Earth Stations is only considered in simulations that consider the aggregate effect of multiple interferers.

Therefore, in aggregate interference studies, considering that all modern VSATs operate with a low duty cycle, the assumption has been made to consider average transmitting power of earth station in calculations throughout this Report. Average transmitter power is calculated according to the formula:

- Transmitter average output (watts) = Transmitter peak output (watts) * Duty cycle.

## 4.2 ANTENNA PATTERNS CONSIDERED IN THE ECC REPORT

### 4.2.1 FS antennas used in the study

The following antenna patterns presents the Recommendation ITU-R F.699 [18] (for FS P-P and P-MP terminal) and), Recommendation ITU-R F.1336 [19] (for P-MP sectoral), **Recommendation ITU-R F.699-8**

$$G(\varphi) = G_{max} - 2.5 * 10^{-3}\left(\frac{D\varphi}{\lambda}\right)^2 \qquad for\ 0° < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \qquad for\ \varphi_m \le \varphi < 100\frac{\lambda}{D}$$

$$G(\varphi) = 52 - 10log\left(\frac{D}{\lambda}\right) - 25log\varphi \qquad for\ 100\frac{\lambda}{D} \le \varphi < 48°$$

$$G(\varphi) = 10 - 10log\left(\frac{D}{\lambda}\right) \qquad for\ 48° \le \varphi \le 180°$$

Where:

$$G_1 = = 2 + 15\ log\ D/\lambda\ (dBi)$$

**Recommendation ITU-R F.1336-5 [19] (Recommend 3.2)**

where:

- $\varphi_{3m}$: the equivalent 3 dB beamwidth in the azimuth plane for an adjustment of horizontal gains (degrees);

$$\varphi_{3m} = \varphi_3 \quad \text{for} \quad 0° \le |\varphi| \le \varphi_{th}$$

$$\varphi_{3m} = \frac{1}{\sqrt{\left(\frac{\cos\left(\frac{|\varphi|-\varphi_{th}}{180-\varphi_{th}}\cdot 90\right)}{\varphi_3}\right)^2 + \left(\frac{\sin\left(\frac{|\varphi|-\varphi_{th}}{180-\varphi_{th}}\cdot 90\right)}{\theta_3}\right)^2}} \quad \text{for} \quad \varphi_{th} < |\varphi| \leq 180°$$

$\varphi_{th}$: the boundary azimuth angle (degrees)

$$\varphi_{th} = \varphi_3$$

Other variables and parameters are as defined in recommends 2.1 and 3.1.1 of Recommendation ITU-R F.1336;

$$G_{ref}(x) = G_0 - 12x^2 \quad \text{for} \quad 0 \leq x < 1$$

$$G_{ref}(x) = G_0 - 12 - 15\log(x) \quad \text{for} \quad 1 \leq x$$

Recommendation ITU-R F.699 gives the reference radiation patterns of point-to-point fixed service antennas, based on the peak envelope of side-lobe levels. Therefore, the interference assessment using this Recommendation may lead to overestimation of interference.

Recommendation ITU-R F.1245 gives a mathematical model for average radiation patterns of point-to-point fixed service antennas, representing average side-lobe levels. Therefore it can be used in the case of multiple interference entries (statistical analysis).

### 4.2.2 FSS antennas used in the study

For FSS antennas the assumption has been made that they will be parabolic reflector antennas, and the Recommendation ITU-R S.465 [26] has been used for their diagram.

$$G(\varphi) = 32 - 25\ log\ \phi\ dBi \quad for \quad \phi min \leq \phi < 48°$$

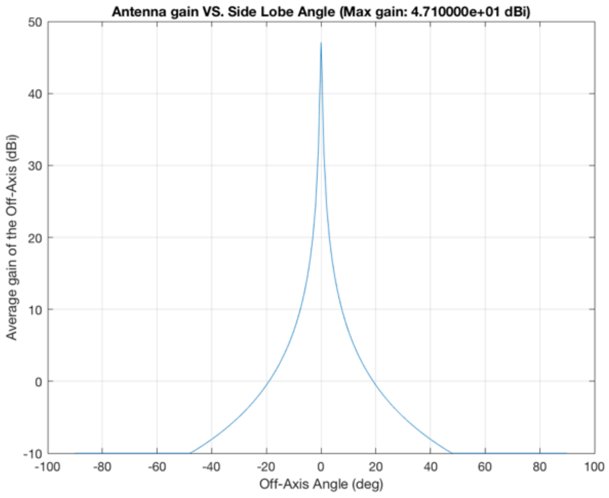
$$G(\varphi) = -10\ dBi \qquad for \qquad 48° \leq \phi \leq 18$$

In addition, the antenna patterns Recommendation ITU-R S.465 and Recommendation ITU-R F.699 show similar behaviour as the governing equations for the patterns are similar (see Figure 3). For antenna pattern ITU-R F.699, the ratios $\frac{D}{\lambda} = 108$ (for frequency 28 GHz and diameter 1.2 m). Therefore, the governing equation for gain for the Recommendation ITU-R F. 699 pattern in the range 0.9º to 48º reduces to
The following figures show the antenna pattern Recommendation ITU-R F.699, Recommendation ITU-R S.465 (using a dBi max gain) and Recommendation ITU-R F.1336.

$$G(\varphi) = 31.7 - 25 log\varphi \quad \text{(for frequency 28 GHz and diameter 1.2 m)}$$

Which is very similar to the gain pattern in ITU-R S.465 for $\phi < 48°$.

**FS mask: 1.2 m and max gain of 47 dBi**




**FSS mask: 1.8 m and max gain of 52.9 dBi**

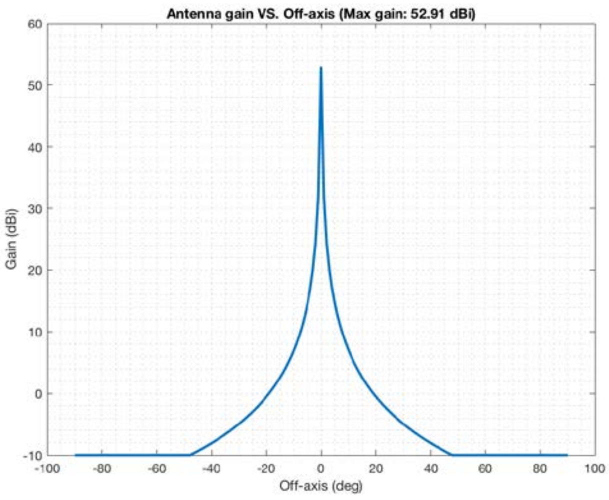



Figure 3: Comparison of Recommendation ITU-R S.465-5 and ITU-R F.699-8 antenna masks

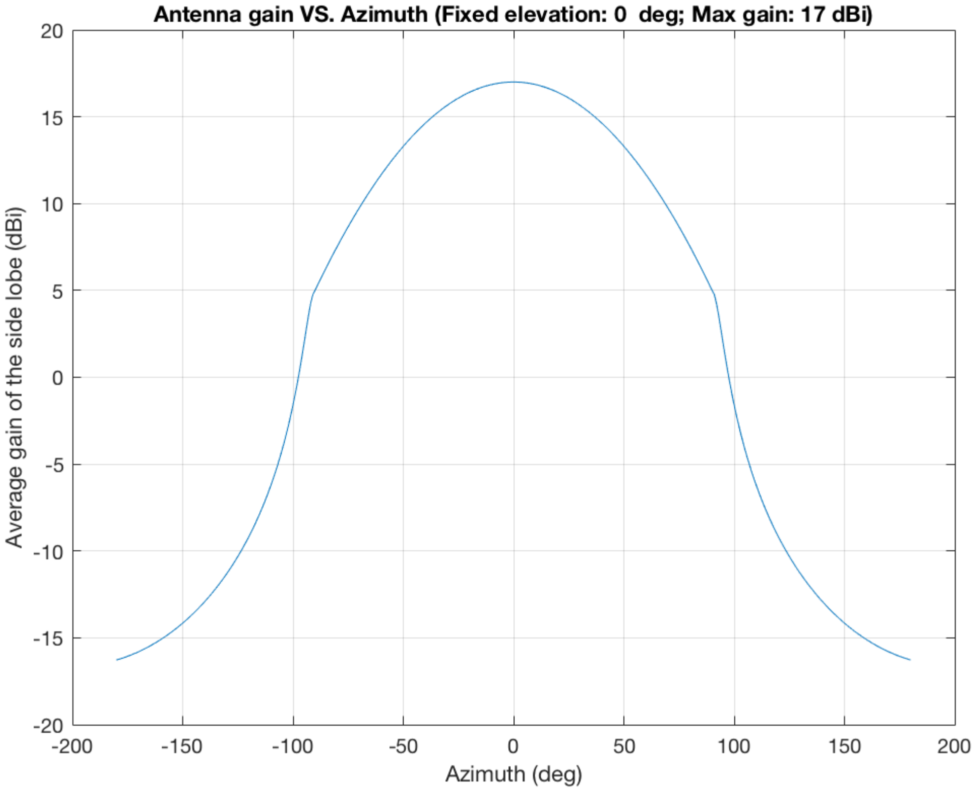



**Figure 4: Recommendation ITU-R F.1336-5 antenna model, 90° sector and max gain of 17 dBi**

It can be seen that a significant drop in gain is observed for a slight offset in off-axis for each of these patterns. Because of this, and as demonstrated in the section on Monte Carlo analysis, the probability of an azimuthal alignment between the FS receiver and the FSS transmitter is very low (As can be seen from Figure 3, the FS and FSS antenna models match each other (except for the angle within 1 degree). The main difference in interference characteristics between the two is that FSS Earth Stations have higher elevation angles and are pointing in a southerly (120° to 220°) azimuth. Calculations show that in cases where FSS ES is at 10 m, it is enough to have a roughly 30° azimuth offset from FS main beam to meet FS protection criteria based on this mask. In cases where the FSS ES is at 2 m, the required offset is about 10°.

#### *4.2.2.1 Comparison between different maximum gain of P-P FS antenna*

The figure below also shows different FS P-P (Recommendation ITU-R F.699-8 [18]) patterns depending on the antenna diameter and antenna gain. The patterns are representative for the following antenna diameters:

- 0.2 m antenna diameter: 31.5 dBi;
- 0.3 m antenna diameter: 36.6 dBi;
- 0.6 m antenna diameter: 42 dBi;
- 1.2 m antenna diameter: 47 dBi.

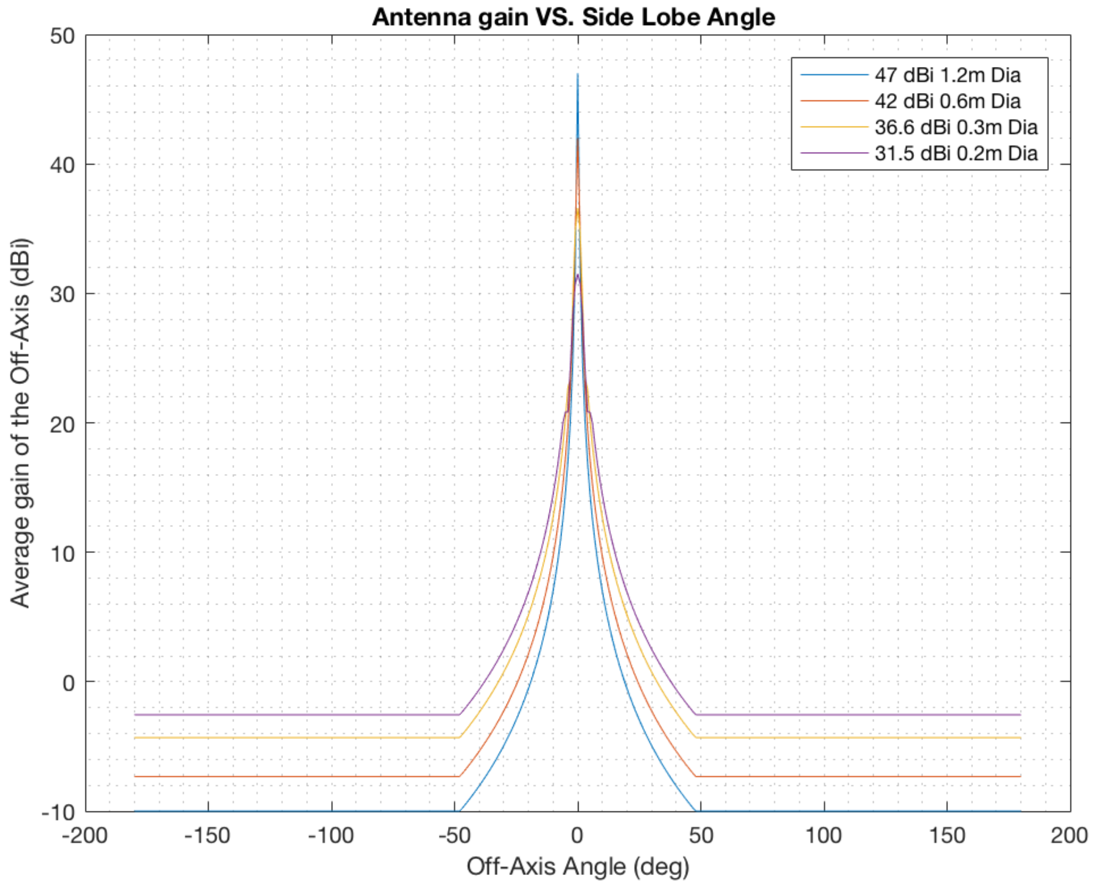



**Figure 5: Comparison of antenna patterns for P-P FS stations**

Section 5.1 contains tables showing FS antenna values calculated for different orientations towards FSS antenna. These values are indicative and can be used to evaluate impact on different FS antenna sizes.

#### 4.2.2.2 Comparison between different maximum gain of FS P-MP antenna

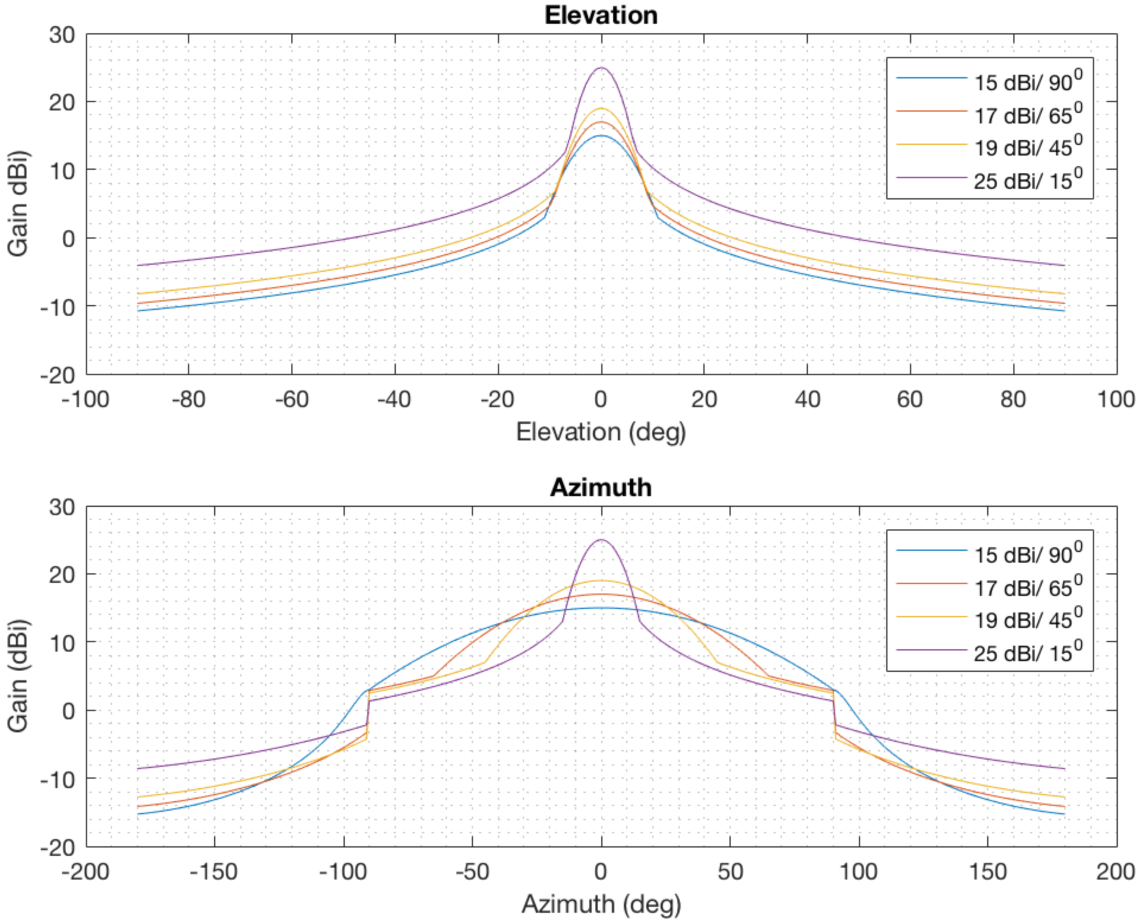



**Figure 6: Comparison of antenna patterns for FS P-MP base stations**

**Elevation plane**

The trend observed by antenna pattern along the elevation angle is similar for different 3 dB azimuth beamwidths. The size of the elevation plane 3 dB beamwidth is also observed to be proportional to their corresponding 3 dB azimuth plane beamwidth size (see the table below).

**Table 2: Trend of azimuth and elevation patterns for different antenna gains**

| Gain | Azimuth 3 dB Beamwidth | Elevation 3 dB Beamwidth |
|---|---|---|
| 15 | 90 | 8.5 |
| 17 | 65 | 8.2 |
| 19 | 45 | 8.05 |
| 25 | 15 | 7.2 |

After 10 degrees, the gain is observed to decrease in a similar fashion for all the sectoral antennas:

**Azimuthal plane**

The difference in size of 3 dB azimuth beamwidth is clearly shown in the variation of gain in the azimuthal plane. For sectoral antennas with azimuth beamwidth less than 90°, a similar trend is observed after the end of their corresponding beamwidth. All the antennas patterns experience a break at 90°.

## 4.3 FS CHARACTERISTICS CONSIDERED IN THIS REPORT

### 4.3.1 FS receiver parameters in the 27.5-29.5 GHz frequency band

Table 3 provides some characteristics for FS stations operating in portions of the band 27.5-29.5 GHz given in Recommendation ITU-R F.758-6 [26]. This ITU Recommendation has been updated since ECC Report 217 was published in 2015 [4].

**Table 3: FS parameters for both P-P and P-MP in portions of the band 27.5-29.5 GHz**

| Frequency range (GHz) | 27.5-29.5 GHz | |
|---|---|---|
| | P-P/P-MP Terminal station | P-MP BS (sectoral antenna) |
| Feeder/multiplexer loss range (dB) | 0 | 0 |
| Antenna pattern (single entry) | Recommendation ITU-R F. 699 [18] | Recommendation ITU-R F.1336 [19] |
| Antenna pattern (statistical case) | Recommendation ITU-R F.1245 [21] | Recommendation ITU-R F.1336 |
| Typical elevation angle (single entry) | 0 | 0 |
| Typical elevation angle (statistical case) | -2.5° – 2.5° | -2.5° – 2.5° |
| Channel spacing | 28 MHz | 28 MHz |
| Receiving antenna height, m | 5, 15, 30 and 60 m | 5, 15, 30 and 60 m |
| Typical antenna diameter (m)/sector size | 1.2<br>0.6<br>0.3 | 90° sector<br>15° sector |
| Antenna gain (dBi) | 47<br>42<br>36.6 | 17 (90° sector)<br>27 (15° sector) |
| Typical receiver noise figure (dB) | 6.5 | 6.5 |
| Polarisation | V and H | V and H |
| Typical receiver noise power density (=NRX) (dBW/MHz) | −137.5 | -137.5 |
| Nominal long-term interference power density (dBW/MHz) | −137.5 + I/N | -137.5 + I/N |
| I/N (dB) | -10 | -10 |

Currently the most commonly deployed FS channel spacing is 28 MHz, consequently this value has been considered in this Report for statistical analysis. Nevertheless, it has to be taken into account that Recommendation T/R 13-02 [22] and ECC Decision (05)01 [1] allow usage of wider channels (up to 224 MHz), noting that the calculations have been performed considering spectral densities.

### 4.3.2 FS (P-P and P-MP) protection criteria

The resulting nominal separation distances, which were calculated taking into account the long-term FS protection criteria (i.e. I/N = -10 dB for 20% of the time), based on Recommendation ITU-R F.758 [26], are presented in sections 6.1 and 6.2.

It is to be noted that for both MCL and Monte Carlo analysis, long-term protection criteria is assumed where the interference is characterised as the interference power that is exceeded by 20% of the time at the victim receiver input.

The short-term criteria is based on 0.001% of the time for I/N = + 9 dB. The increase in the value of the protection criteria will tend to reduce the separation distance. However, this increase of the protection criteria is linked to a decrease of the percentage of time which is linked to a lower propagation loss for a given distance. Therefore, for cases exceeding certain separation distances the short-term protection criteria will dominate the long-term protection criteria. This analysis is shown in ANNEX 3. However, the probability of longer separation distances (see also Section 5.2) occurring is very low as shown in the statistical study in this ECC Report. Therefore, throughout this Report the long-term protection criteria are used.

# 5 METHODOLOGY FOR SHARING STUDIES

This Report first calculates separation distances as an initial step in the analysis based on main beam coupling conditions. Once the separation distances are calculated, a statistical analysis is used to examine likely deployment scenarios, and factor in the effects of mitigating conditions such as realistic antenna pointing and shielding.

The following sections analyse the impact of various FS receiver and FSS transmitter parameters on sharing as well as the probability of interference in various scenarios. The results of these studies are presented as follows:

1. Sensitivity Analysis
   a) Sensitivity of FS receiver to FSS interference varying in angle of arrival in the elevation plane;
   b) Sensitivity of FS receiver to FSS interference varying in angle of arrival in the azimuthal plane.
2. Monte Carlo analysis – Assuming realistic deployments of FSS transmitters and FS receivers, determine the likelihood of the longest required separation distances
3. MCL studies with the FS P-P and P-MP taking into account long-term FS protection criteria. Effect on received interference with changes in FSS antenna elevation angle is analysed.

Figure 7 shows the interference scenario from FSS ES to FS receiver.

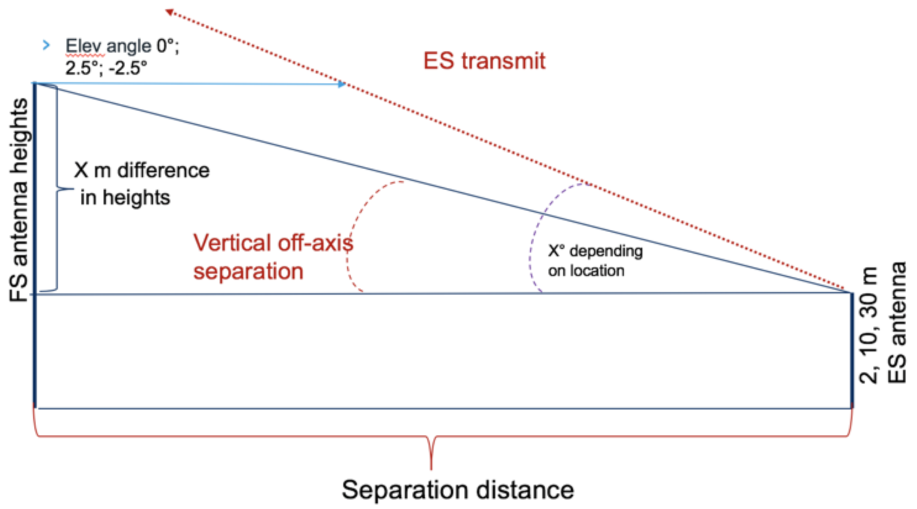



**Figure 7: Illustration of interference scenario**

The interfering signal power density (I) at an FS (P-P and P-MP) receiver is determined by the following equation:

**Equation 1:** $I\ (dB(W/MHz)) = PSD_{tx} + G_{tx}(\alpha) + G_{rx}(b) - L_{NLOS} - R - 1.5\ dB$

where:

- $PSD_{tx}$: FSS ES transmitted power spectral density (dB(W/MHz));
- $G_{tx}(\alpha)$: Antenna gain of FSS ES transmitter towards FS receiver (dBi);
- $G_{rx}(b)$: Antenna gain of FS receiver towards ES transmitter (dBi);
- $L_{NLOS}$: Propagation loss (Recommendation ITU-R P.452-16) [20] ;
- R: Attenuation from shielding applied around 1.8 m FSS ES terminals (0-30 dB);

- 1.5 dB polarisation loss is considered for the MCL study in case of main beam alignment of two antennas.

The frequency used for the calculation was set to the centre frequency of 28.35 GHz. The nominal clutter distance and height values are related to a specific terrain category. For the studies that follow, propagation in rural, suburban and urban areas was considered. These scenarios are propagation models only and are not meant to suggest potential earth station deployment scenarios. The following table presents the corresponding nominal distances and heights assumed for each of these terrain categories.

**Table 4: Nominal heights and distances for different clutter category**

| Clutter (ground-cover) category | Nominal height, ha (m) | Nominal distance, DKK (km) |
|---|---|---|
| High crop fields<br>Park land<br>Irregularly spaced sparse trees<br>Orchard (regularly spaced)<br>Sparse houses | 4 | 0.1 |
| Suburban | 9 | 0.025 |
| Urban | 20 | 0.02 |

The following table summarises the attenuations due to clutter loss for different FSS antenna configurations and category of terrain as defined by ITU-R Recommendation P.452-16.

**Table 5: Clutter attenuations for different deployment scenarios**

| Clutter Attenuations (Rec. ITU-R P.452-16 model, equation (57)) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Rural Prop | | Suburban | | Urban | | |
| Height of the Antenna (m) | 2 | 10 | 2 | 10 | 2 | 10 | 30 |
| Clutter Attenuation (dB) | 14.84 | 0 | 19.51 | 0 | 19.73 | 16.10 | 0 |

As shown in the table above, when the FSS antenna height is above the nominal clutter height, no attenuation for clutter loss is considered. This is the case for an antenna height of 10 meters in the suburban and rural models, and 30 meters in the urban propagation models. It can also be noted that for an FSS antenna height of 2 meters in suburban and urban propagation models, the clutter loss values are very similar.

The propagation model is based on Recommendation ITU-R P.452-16. An array of distances ranging from 0 to 500 km is considered for the simulations with steps varying from 5 to 100 meters. The lower the step size, the longer the simulation. Therefore, step size is adapted to allow for good precision on overall distances as well as a limited running time of the study case. For every step of distance, the propagation loss and I/N for all FSS ES elevation angles is calculated. Therefore, for every elevation angle, a nominal separation distance is calculated for when the calculated I/N meets the protection criterion of the FS receiver, but without factoring in any mitigating conditions.

MCL results for both urban and suburban deployment scenarios are contained in Section 6 this Report. Note that it is expected that the separation distances between FSS ES and FS terminal could increase in a rural environment. In the case of enterprise terminals, an additional shielding up to 30 dB can be achieved when a roof parapet or safety wall at the borders of the building exists or when the antenna is mounted on the side of a roof or building (see a description of the measurements report in ANNEX 2). The extent of such shielding depends on the relative positioning of the parapet between the FSS transmitter and the FS receiver.

## 5.1 SENSITIVITY ANALYSIS

Two different scenarios were analysed to determine the impact of FSS transmission on FS receivers:

1 Analysis of elevation offset between FSS and FS;

2 Analysis of azimuth offset between FSS and FS.

In the first case, it was assumed that the FSS transmitter and FS receiver were aligned in azimuth. Simulations were run to determine the impact on received interference of different elevation offsets. Since FS deployments vary in height, this analysis shows which FS antenna heights are most sensitive to interference in cases of azimuthal alignment.

In the second case, fixed deployment heights for both FSS and FS antennas were assumed, and the simulation was run using different FSS antenna azimuthal alignments relative to the FS receiver. This analysis shows the sensitivity of the FS receiver to various azimuthal offsets relative to the FSS transmitter.

The sensitivity analysis was performed using typical FS service deployment scenarios in CEPT countries to demonstrate that the MCL analysis carried out in this Report takes into account the most common parameters and operational conditions of the FS deployment. The technical parameters for FSS and FS used in the studies are taken from Table 1 and Table 3. The suburban scenario of ITU-R P.452 has been considered in this section.

Recommendation ITU-R F. 2086 [23] provides antenna height and elevation angle information for some CEPT countries. Considering this Recommendation, an analysis has been carried out using the commonly used FS P-P and P-MP antenna heights of 5, 15, 30 and 60 m and commonly used FS antenna elevation angles in the range between −2.5 to 2.5 degrees.

Antenna gain of the FS system was considered in the range between 15 dBi and 47 dBi (covering both P-P stations and P-MP terminal stations).

Antenna gain of the FS P-MP system base station was considered at 27 dBi for the MCL analysis.

The long-term protection criteria has been considered the same for the MCL analysis.

Enterprise and residential FSS Terminals antenna parameters were considered in the sensitivity analysis calculations.

The tables below demonstrate the results of the analysis for the FSS Enterprise Terminal (ET) using Lower Range Power given in Table 1. The results for the FSS Residential Terminal (RT) are calculated with a power spectral density of -10.9 dBW/MHz.

### 5.1.1 Analysis Using Elevation Offset

#### *5.1.1.1 Results of the sensitivity analysis for 1.8 m FSS antenna*

The tables below demonstrate the results of the analysis for the FSS Enterprise antenna when aligned in the azimuthal plane with an FS receiver. This represents the separation distance (see Figure 7) in a worst-case alignment which, in practice, will occur only in very rare cases.

**Table 6: Results of the sensitivity analysis for 1.8 m FSS antenna (at 10 m) into FS P-P for different FS antenna heights, elevation angle 0°, -2.5°, +2.5° and antenna heights**

| (FSS height always at 10 m) | Separation distances (km) | | | |
|---|---|---|---|---|
| FS antenna height (m) | 5 | 15 | 30 | 60 |
| FS elevation 0°; 47 dBi | 30.2 | 39.1 | 45.7 | 54.2 |
| FS elevation 0°; 42 dBi | 28.2 | 37.2 | 43.7 | 51.6 |
| FS elevation 0°; 36.6 dBi | 24.8 | 35.0 | 40.9 | 48.8 |
| FS elevation 0°; 31.5 dBi | 22.2 | 33.0 | 38.2 | 45.5 |
| FS elevation 0°; 27 dBi | 20.1 | 30.3 | 35.1 | 42.8 |
| FS elevation 0°; 15 dBi | 6.2 | 23.9 | 25.9 | 25.9 |
| FS elevation -2.5°; 42 dBi | 17.9 | 28.8 | 34.0 | 42.1 |
| FS elevation +2.5°; 42 dBi | 18.1 | 28.7 | 33.8 | 41.8 |

**Table 7: Results of the sensitivity analysis for 1.8 m FSS antenna (at 2 m) into FS P-P, different FS antenna heights, elevation angle 0°, -2.5°, +2.5° and antenna heights**

| (FSS height always at 2 m) | Separation distances (km) | | | |
|---|---|---|---|---|
| FS antenna height (m) | 5 | 15 | 30 | 60 |
| FS elevation 0°; 47 dBi | 19.8 | 30.2 | 40.8 | 42.4 |
| FS elevation 0°; 42 dBi | 14.1 | 26.8 | 32.2 | 40.4 |
| FS elevation 0°; 36.6 dBi | 7.9 | 24.2 | 29.9 | 31.2 |
| FS elevation 0°; 31.5 dBi | 4.5 | 19.4 | 19.4 | 19.4 |
| FS elevation -2.5°; 42 dBi | 2.3 | 10.1 | 10.6 | 11.4 |
| FS elevation +2.5°; 42 dBi | 2.1 | 9.4 | 9.1 | 8.4 |

#### *5.1.1.2 Results of the sensitivity analysis for 0.75 m FSS antenna*

The tables below demonstrate the results of the analysis for the FSS Residential antenna when aligned in the azimuthal plane with an FS receiver using Lower Range Power given in Table 3. This represents a worst-case alignment which, in practice, will occur only in very rare cases.

**Table 8: Results of the sensitivity analysis for 0.75 m FSS antenna (at 10 m) into FS P-P, different FS antenna height, elevation angle 0°, -2.5°, +2.5° and antenna heights**

| FSS height always at 10 m | Separation distances (km) | | | |
|---|---|---|---|---|
| FS antenna height (m) | 5 | 15 | 30 | 60 |
| FS elevation 0°; 47 dBi | 30.8 | 39.5 | 46.2 | 54.9 |
| FS elevation 0°; 42 dBi | 28.8 | 37.7 | 44.2 | 52.3 |
| FS elevation 0°; 36.6 dBi | 25.8 | 35.6 | 41.6 | 49.5 |

| FSS height always at 10 m | Separation distances (km) | | | |
|---|---|---|---|---|
| FS elevation 0°; 31.5 dBi | 22.8 | 33.6 | 38.9 | 46.5 |
| FS elevation 0°; 27 dBi | 20.0 | 30.2 | 35.0 | 42.7 |
| FS elevation 0°; 15 dBi | 6.1 | 23.8 | 25.5 | 25.6 |
| FS elevation -2.5°; 42 dBi | 19.7 | 29.8 | 34.7 | 42.6 |
| FS elevation +2.5°; 42 dBi | 19.8 | 29.7 | 34.5 | 42.4 |

**Table 9: Results of the sensitivity analysis for 0.75 m FSS antenna (at 2 m) into FS P-P, different FS antenna height, elevation angle 0°, -2.5°, +2.5° and antenna heights**

| FSS height always at 2 m | Separation distances (km) | | | |
|---|---|---|---|---|
| **FS antenna height (m)** | **5** | **15** | **30** | **60** |
| FS elevation 0°; 47 dBi | 20.3 | 31.0 | 35.9 | 43.5 |
| FS elevation 0°; 42 dBi | 16.2 | 27.5 | 32.8 | 40.9 |
| FS elevation 0°; 36.6 dBi | 9.2 | 24.9 | 30.5 | 35.0 |
| FS elevation 0°; 31.5 dBi | 5.2 | 22.0 | 22.0 | 22.1 |
| FS elevation -2.5°; 42 dBi | 2.4 | 10.9 | 10.6 | 9.9 |
| FS elevation+2.5°; 42 dBi | 2.6 | 11.6 | 12.1 | 12.9 |

### 5.1.2 Analysis Using Azimuthal Offset

The calculations below show separation distances between the victim system receiver and an FSS Earth Station when azimuth offset is applied on FS sides meaning that the FSS signal is not arriving in the main lobe of the FS antenna. This scenario represents a more realistic scenario than the MCL calculations since, as shown by Monte Carlo analysis, the main beam to main beam scenario is very unlikely due to the fact that the main beam of the FS antenna is very narrow (Figure 3).

The scenario used for the deterministic analysis using azimuthal offset is illustrated in the figure below.

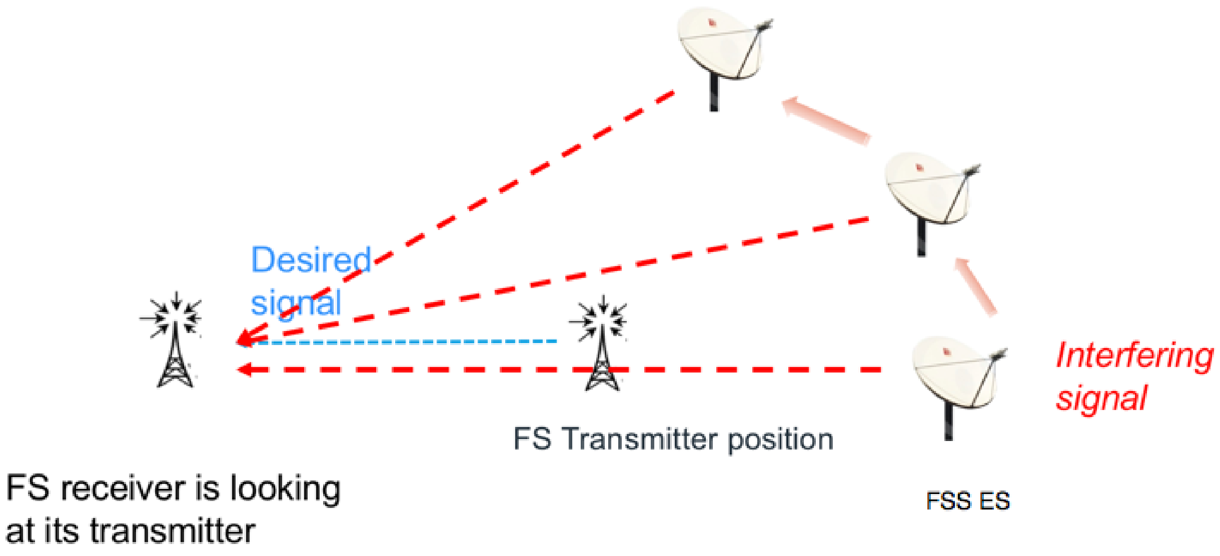



Figure 8: Illustration of the scenario when azimuth offset applied on FS side

Table 10: Separation distances when FSS RT signal arrives at different azimuth offsets of the FS system; FS is at 15 m; FS gain is 42 dBi

| Antenna Azimuth Changing | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance (km) - FSS at 10 m | 37.7 | 25.5 | 17.8 | 11.3 | 8.0 | 6.2 | 4.9 | 4.1 | 3.5 | 3.0 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |

Table 11: Separation distances when FSS RT signal arrives at different azimuth offsets of the FS system; FS is at 30 m; FS gain is 42 dBi

| Antenna Azimuth changing | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance (km) - FSS at 10 m | 44.2 | 31.1 | 18.0 | 11.3 | 8.0 | 6.2 | 5.0 | 4.1 | 3.5 | 3.0 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |

The table below shows separation distances in km when FSS ET signal arrives at different azimuth offsets of the FS and FSS system. FSS ET e.i.r.p. is considered to be 61 dBW. FS in this example is at 15 m and FS gain is considered being 42 dBi. Vertical column shows FSS azimuth changes and horizontal column shows FS azimuth changes.

**Table 12: Separation distances (km) when FSS ET signal arrives at different azimuth offsets of the FS and FSS system. FS is at 15 m, 42 dBi elev. 0°; FSS ET height=2 m.**

| Antenna Azimuth changing | Azimuth of FS, changing | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FS Antenna Azimuth | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
| FSS Azimuth 0 | 26.8 | 4.2 | 1.83 | 1.13 | 0.81 | 0.63 | 0.52 | 0.44 | 0.38 | 0.34 | 0.32 | 0.3 |
| FSS Azimuth 5 | 26.6 | 4.1 | 1.75 | 1.1 | 0.78 | 0.61 | 0.5 | 0.42 | 0.37 | 0.33 | 0.31 | 0.3 |
| FSS Azimuth 10 | 26.2 | 3.7 | 1.6 | 1 | 0.71 | 0.55 | 0.45 | 0.38 | 0.33 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 15 | 25.6 | 3.2 | 1.4 | 0.85 | 0.62 | 0.48 | 0.4 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 20 | 25 | 2.8 | 1.2 | 0.75 | 0.53 | 0.42 | 0.34 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 25 | 24.4 | 2.4 | 1.05 | 0.65 | 0.46 | 0.36 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 30 | 23.8 | 2.1 | 0.9 | 0.56 | 0.4 | 0.31 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 35 | 23.3 | 1.8 | 0.8 | 0.48 | 0.35 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 40 | 22.8 | 1.6 | 0.7 | 0.43 | 0.31 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 45 | 21.3 | 1.4 | 0.6 | 0.38 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 50 | 21.3 | 1.4 | 0.6 | 0.38 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |

The table below shows separation distances in km when FSS RT signal arrives at different azimuth offsets of the FS and FSS system. FSS RT power spectral density is considered -10.9 dBW/MHz and height is at 2 m. FS in this example is at 15 m and FS gain is considered being 42 dBi. Vertical column shows FSS azimuth changes and horizontal column shows FS azimuth changes.

**Table 13: Separation distances (km) when FSS RT signal arrives at different azimuth offsets of the FS system; FS is at 15 m; FS gain is 42 dBi corresponding to a 0.6 m diameter antenna, elev. 0°; FSS RT height=2 m.**

| Antenna Azimuth changing | Azimuth of FS, changing | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FS Antenna Az | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
| FSS Azimuth 0 | 27.5 | 4.9 | 2.1 | 1.3 | 0.95 | 0.7 | 0.6 | 0.5 | 0.4 | 0.4 | 0.4 | 0.4 |
| FSS Azimuth 5 | 27.3 | 4.8 | 4.3 | 1.3 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 | 0.4 | 0.4 | 0.4 |
| FSS Azimuth 10 | 26.9 | 4.3 | 1.85 | 1.14 | 0.82 | 0.63 | 0.5 | 0.4 | 0.4 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 15 | 26.3 | 3.8 | 1.6 | 1 | 0.72 | 0.55 | 0.45 | 0.39 | 0.34 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 20 | 25.7 | 3.3 | 1.4 | 0.86 | 0.62 | 0.48 | 0.39 | 0.33 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 25 | 25 | 2.8 | 1.2 | 0.74 | 0.53 | 0.42 | 0.34 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 30 | 24.5 | 2.4 | 1.1 | 0.64 | 0.47 | 0.36 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 35 | 23.9 | 2.1 | 0.9 | 0.57 | 0.41 | 0.32 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 40 | 23.4 | 1.9 | 0.8 | 0.5 | 0.36 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 45 | 23 | 1.65 | 0.71 | 0.45 | 0.32 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| FSS Azimuth 50 | 22.2 | 1.65 | 0.71 | 0.45 | 0.32 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |

The table below shows separation distances in km when FSS RT signal arrives at different azimuth offsets of the FS and FSS system. FSS RT power spectral density is considered -10.9 dBW/MHz and height is at 10 m. FS in this example is at 15 m and FS gain is considered being 42 dBi. Vertical column shows FSS azimuth changes and horizontal column shows FS azimuth changes.

**Table 14: Separation distances (km) when FSS RT signal arrives at different azimuth offsets of the FS system; FS is at 15 m; FS gain is 42 dBi corresponding to 0.6 m diameter, elev. 0°; FSS RT height=10 m.**

| Antenna Azimuth changing | Azimuth of FS, changing | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FS Antenna Az | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| FSS Azimuth 0 | 37.7 | 25.5 | 17.8 | 11.3 | 8.0 | 6.2 | 4.9 | 4.1 | 3.5 | 3.0 | 2.8 |
| FSS Azimuth 5 | 37.55 | 25.35 | 17.4 | 10.9 | 7.75 | 5.9 | 4.7 | 3.9 | 3.3 | 2.9 | 2.65 |
| FSS Azimuth 10 | 37.2 | 25 | 15.9 | 10 | 7 | 5.4 | 4.3 | 3.55 | 3 | 2.6 | 2.4 |
| FSS Azimuth 15 | 36.8 | 24.4 | 14 | 8.8 | 6.2 | 4.7 | 3.75 | 3.1 | 2.6 | 2.3 | 2.1 |
| FSS Azimuth 20 | 36.2 | 23.9 | 12.3 | 7.6 | 5.3 | 4 | 3.2 | 2.65 | 2.25 | 1.95 | 1.8 |
| FSS Azimuth 25 | 35.7 | 22.8 | 10.6 | 6.5 | 4.6 | 3.5 | 2.75 | 2.3 | 1.95 | 1.675 | 1.55 |
| FSS Azimuth 30 | 35.2 | 20.4 | 9.3 | 5.7 | 4 | 3 | 2.4 | 2 | 1.675 | 1.45 | 1.35 |
| FSS Azimuth 35 | 34.7 | 18 | 8.1 | 4.9 | 3.5 | 2.6 | 2.1 | 1.72 | 1.45 | 1.25 | 1.15 |
| FSS Azimuth 40 | 34.3 | 16 | 7.2 | 4.4 | 3.1 | 2.3 | 1.83 | 1.51 | 1.3 | 1.1 | 1 |
| FSS Azimuth 45 | 33.9 | 14.5 | 6.5 | 3.9 | 2.75 | 2.1 | 1.65 | 1.35 | 1.15 | 1 | 0.925 |

## 5.2 MONTE CARLO SIMULATIONS

A representation of the actual statistical single-entry scenario can be shown by performing a Monte Carlo simulation.

In this section the case of one FS link interfered by FSS is considered; the case with high density of FS links is evaluated in Annex 6.

This type of simulation runs 100000 different deployments of FSS Earth Station transmitters around the FS P-P/P-MP receiver. The probability of interference to the FS receiver is calculated based on FS protection criteria (i.e., I/N = -10 dB for long-term protection criteria).

The FSS Earth Station transmission gain towards an FS station depends on the FSS Earth Station location and antenna pointing and elevation angle. The FS antenna gain towards the FSS Earth Station depends on the earth station's location. Therefore, the simulations have been performed for different earth station elevation and azimuth angles (FSS Earth Station pointing).

The following steps have been performed to derive the minimum separation distance CDF between a single FS and an FSS Earth Station.

Step 1: Compute the FSS antenna gain towards the FS P-P/P-MP based on the following input parameters:

- 0° is taken for the elevation angle towards the FS;
- 0° is taken for the azimuth towards the FS;
- The off-axis angle (i.e. angle between FS pointing direction and the line joining FS and FSS ES) is taken as the elevation angle towards the FS;
- FSS antenna height:
  - Urban - random variable with a uniform distribution between 2 m and 30 m;
  - Suburban - random variable with a uniform distribution between 2 m and 10 m.
- FSS station antenna pointing azimuth range: random variable with a uniform distribution between -120° to 220°;

- FSS station antenna pointing elevation range: randomised elevation with the lower bound being set by the minimum elevation (10-50 degrees);
- FSS maximum antenna gain: 43.9 dBi for 0.75 m diameter and 52.9 dBi for 1.8 m diameter;
- FSS antenna pattern: Recommendation ITU-R S.465-6:
- FSS station nominal power spectral density:
  - for 1.8 m Antenna Diameter: -17.9 dB(W/MHz);
  - for 0.75 m Antenna Diameter the following range of e.i.r.p. is considered:
    - the lower range e.i.r.p.= 53 dBW in 160 MHz -> PSD = -12.9 dBW/MHz;
    - the higher range e.i.r.p.= 61 dBW in 80 MHz -> PSD = -1.9 dBW/MHz.

Step 2: Compute the FS antenna gain towards the FSS based on the following input parameters:
- 0° is taken for the elevation angle towards the FSS ES;
- 180° is taken for the azimuth towards the FSS ES;
- FS antenna height: 30 m;
- FS station antenna pointing azimuth: random variable with a uniform distribution between -180° to 180°;
- FS station antenna pointing elevation: uniform distribution n between -2.5° and 2.5°.

FS station maximum antenna gain:
  - FS P-P: 47.1 dBi for the FS P-P (1.2 m antenna)
  - FS P-MP: 17 dBi for 90-degree sectoral antenna and 47.1 dBi for 1.2 m terminal antenna

FS antenna pattern:
  - FS P-P: Recommendation ITU-R F.1245-2
  - FS P-MP: Recommendation ITU-R F1336-4 for 90-degree sectoral antenna and Recommendation ITU-R F.699-8 for 1.2 m terminal antenna

*Note: For FS P-MP 90-degree sectorial antenna, the off-axis of the pointing direction with respect to the direction of the interfering link is calculated along both the elevation plane and the azimuthal plane.*

Step 3: Compute the minimum separation distance needed to meet the FSS interference level
- FSS station nominal power spectral density: -1.9 dBW/MHz and -12.9 dBW/MHz for 0.75 m diameter and -17.9 dBW/MHz for 1.8 m diameter respectively;
- Propagation model used: Recommendation ITU-R P.452 with p= 20% for long-term protection criteria.

Step 4: Store the calculated separation distance and repeat steps 1 through 3 for 100-000 iterations.

Note that the percentage of deployment determines the number of cases in which a corresponding separation distance is occurring out of 100000 cases/iterations.

For example, for the largest separation distance case, it is observed that the percentage of deployments is 0.001%. This implies

$$\begin{aligned}&Total\ number\ of\ cases\ with\ the\ largest\ separation\ distance\\&= \frac{\%\ of\ deployments}{100} \times total\ number\ of\ iterations = \frac{0.001}{100} \times 100\,000 = 1\end{aligned}$$

Therefore, it can be concluded that the case with the largest separation distance happens only once in 100000 iterations. The analysis shows that this scenario is very unlikely to happen.

The Monte Carlo provides CDF of the separation distance between FSS ES and FSS terminal deployed in an urban and suburban environment. The separation distances between FSS ES and FS terminal could increase in a rural environment due to less clutter loss related to buildings.

### 5.2.1 Results for Monte Carlo analysis for Point-to-Point FS

#### *5.2.1.1 Results for FSS ES with 1.8 m antenna diameter*

The following figures present the distribution of possible separation distances between FSS ES and FS.

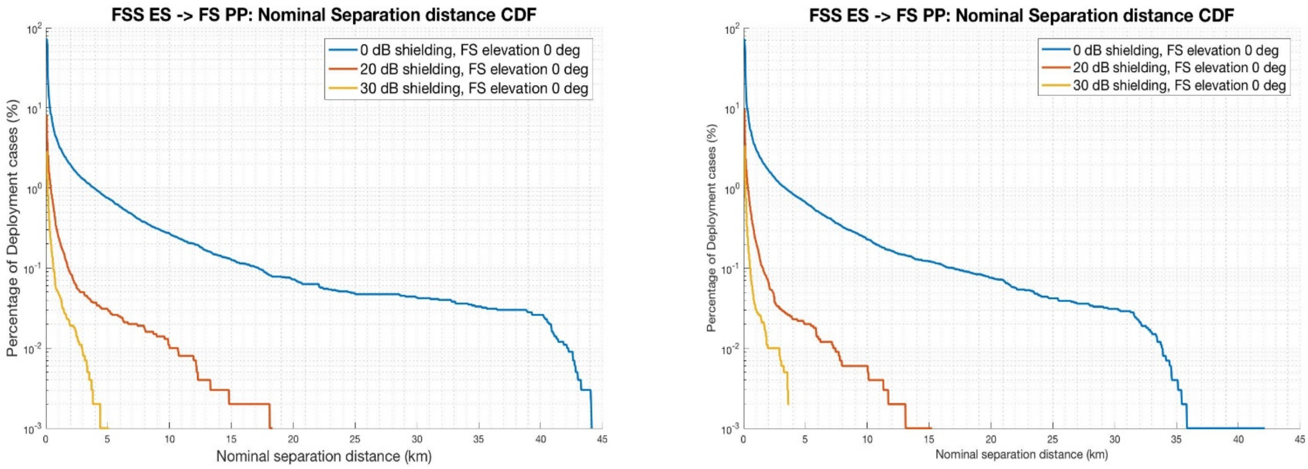



**Figure 9: 1.8 m Diameter FSS ES antenna → FS P-P (Percentage of deployments for various separation distances: urban on the left and suburban on the right)**

#### *5.2.1.2 Results for FSS ES with 0.75 m antenna diameter*

**FS P-P lower range power case (PSD = -12.9 dBW/MHz)**

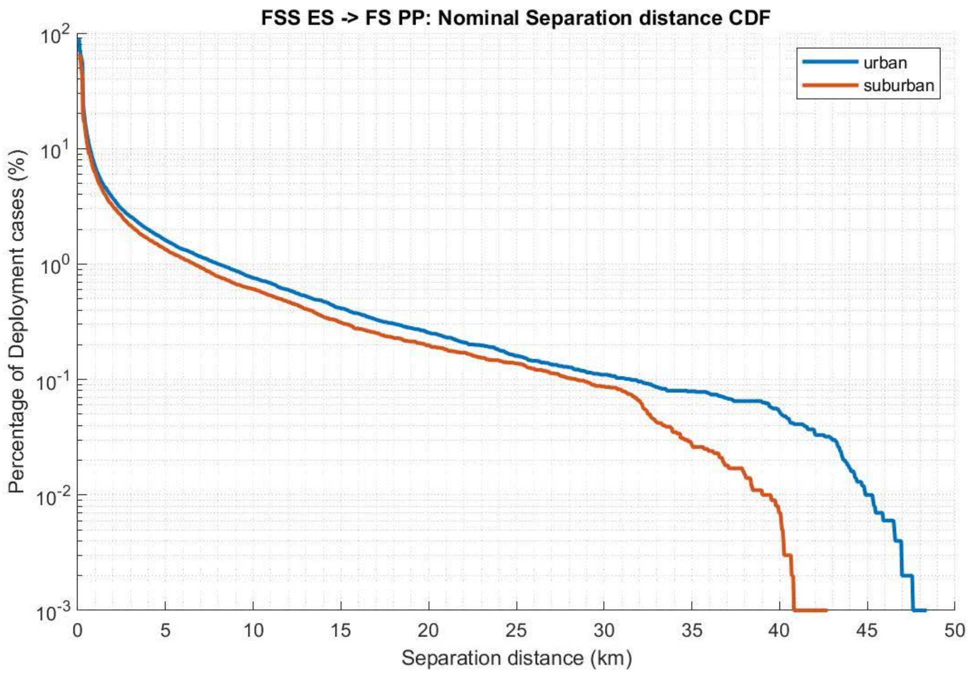



**Figure 10: 0.75 m Diameter FSS ES antenna → FS P-P (Percentage of deployments for various separation distances)**

**FS P-P** high **range power case (PSD = -1.9 dBW/MHz)**

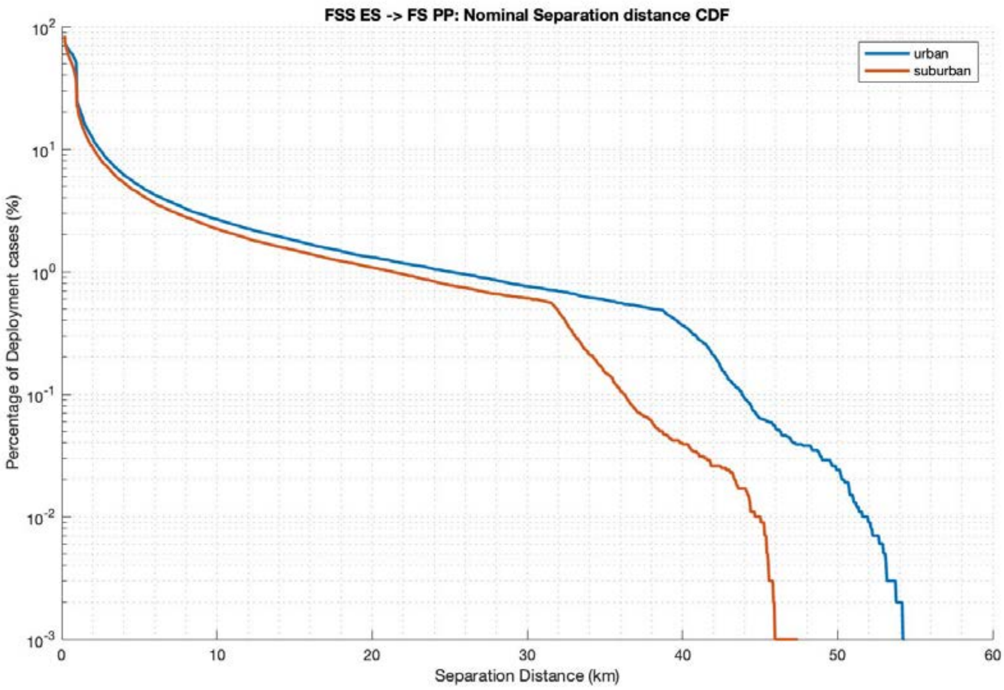



**Figure 11: 0.75 m Diameter FSS ES antenna → FS P-P (Percentage of deployments for various separation distances)**

From Figure 11 it can be noted that 10% of deployments require about 1 km separation distance.

### 5.2.2 Monte Carlo analysis for FS P-MP

#### *5.2.2.1 Results for FS P-MP terminal (TS) antenna and FSS 1.8 m antenna*

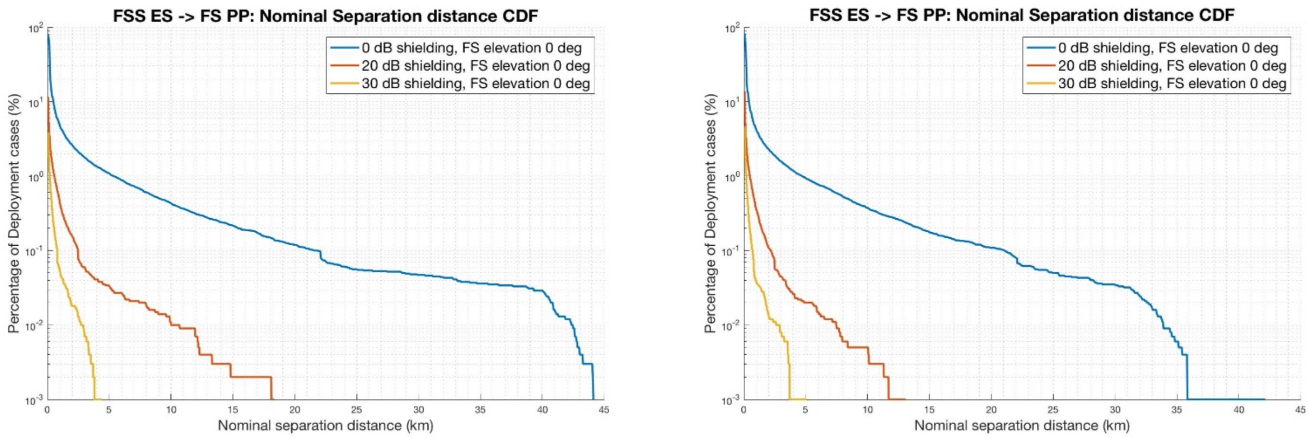



**Figure 12: 1.8 m Diameter FSS ES antenna → FS P-MP terminal (TS)(Percentage of deployments for various separation distances urban on the left and suburban on the right)**

#### 5.2.2.2 Results for FS P-MP Sectoral antenna (BS) using the Monte Carlo approach for 1.8 m antenna

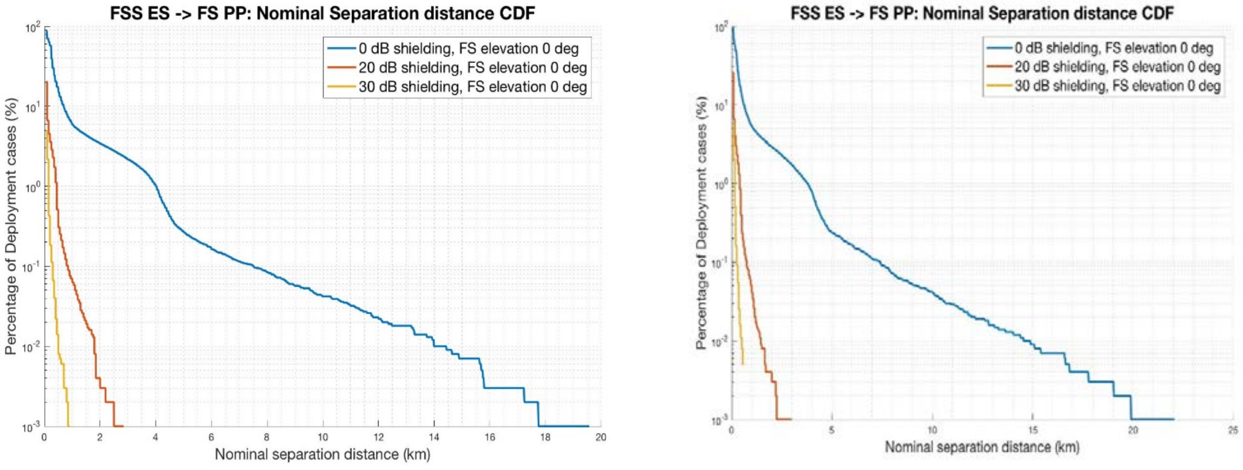



**Figure 13: 1.8 m Diameter FSS ES antenna → FS P-MP Sectoral (Percentage of deployments for various separation distances urban on the left and suburban on the right)**

#### 5.2.2.3 Results for FS P-MP terminal (TS) antenna using the Monte Carlo approach for 0.75 m antenna

**FSS ES Lower power range (PSD = -12.9 dBW/MHz) case:**

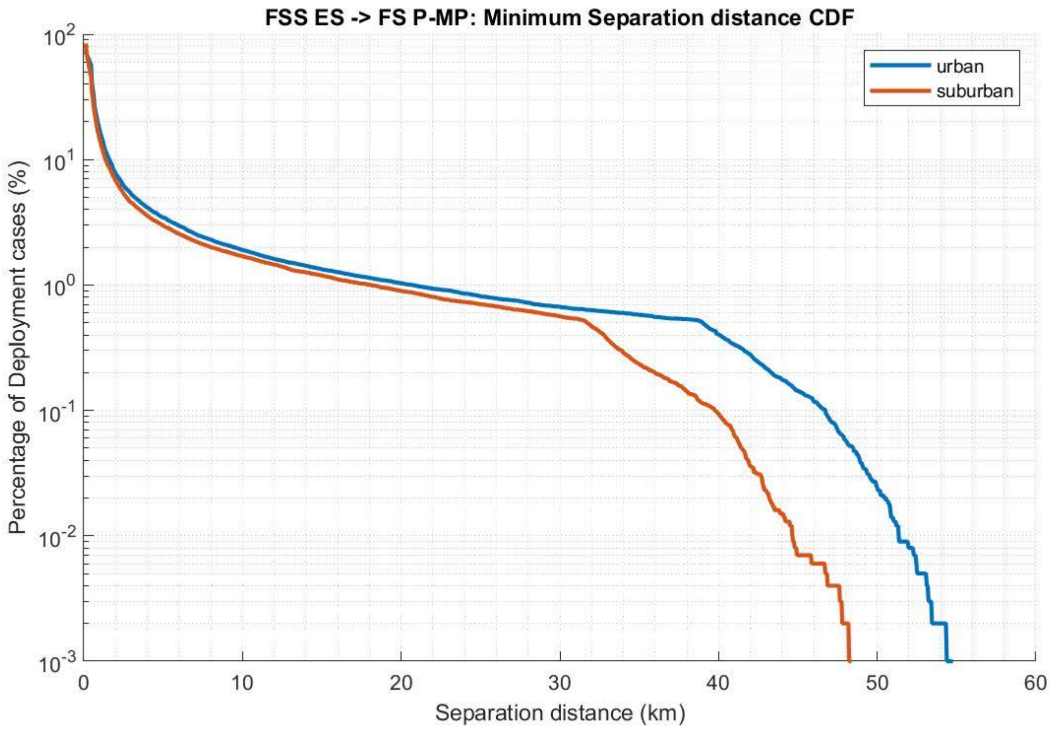



**Figure 14: 0.75 m Diameter FSS ES antenna → FS P-MP (percentage of deployments for various separation distances)**

From Figure 14 it can be noted that 10% of deployments require about 1 km separation distance.

#### *5.2.2.4 Results for FS P-MP sectoral antenna (BS) using the Monte Carlo approach for 0.75 m antenna*

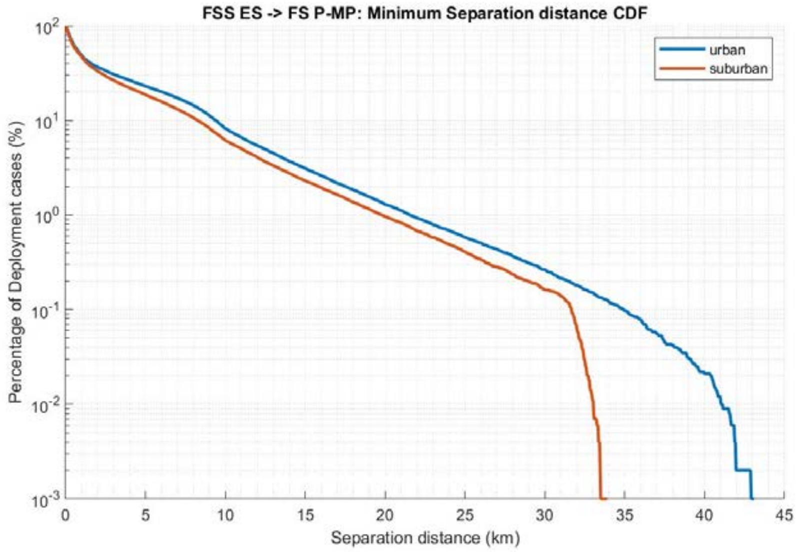



**Figure 15: 0.75 m Diameter FSS ES antenna → FS P-MP**
**(Percentage of deployments for various separation distances)**

From Figure 15 it can be noted that 10% of deployments require about 10 km separation distance.

#### *5.2.2.5 Results for FS P-MP terminal (TS) antenna using the Monte Carlo approach for 0.75 m antenna*

**FSS ES Higher power range Case (PSD = -1.9 dBW/MHz) case:**

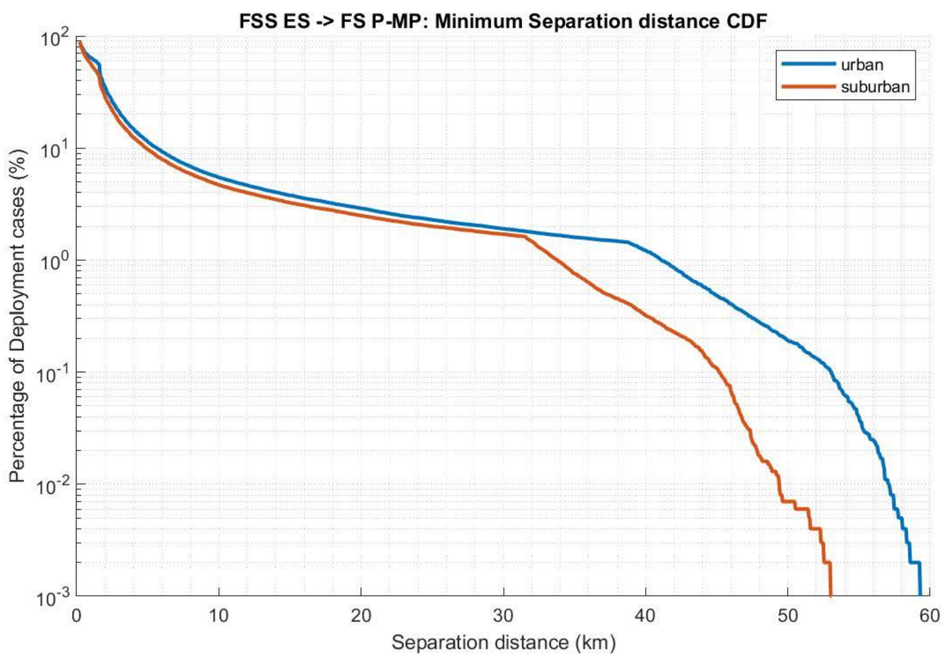



**Figure 16: 0.75 m Diameter FSS ES antenna → FS P-MP**
**(Percentage of deployments for various separation distances)**

From Figure 16 it can be noted that 10% of deployments require about 5 km separation distance.

#### 5.2.2.6 Results for FS P-MP sectoral antenna (BS) using the Monte Carlo approach for 0.75 m antenna

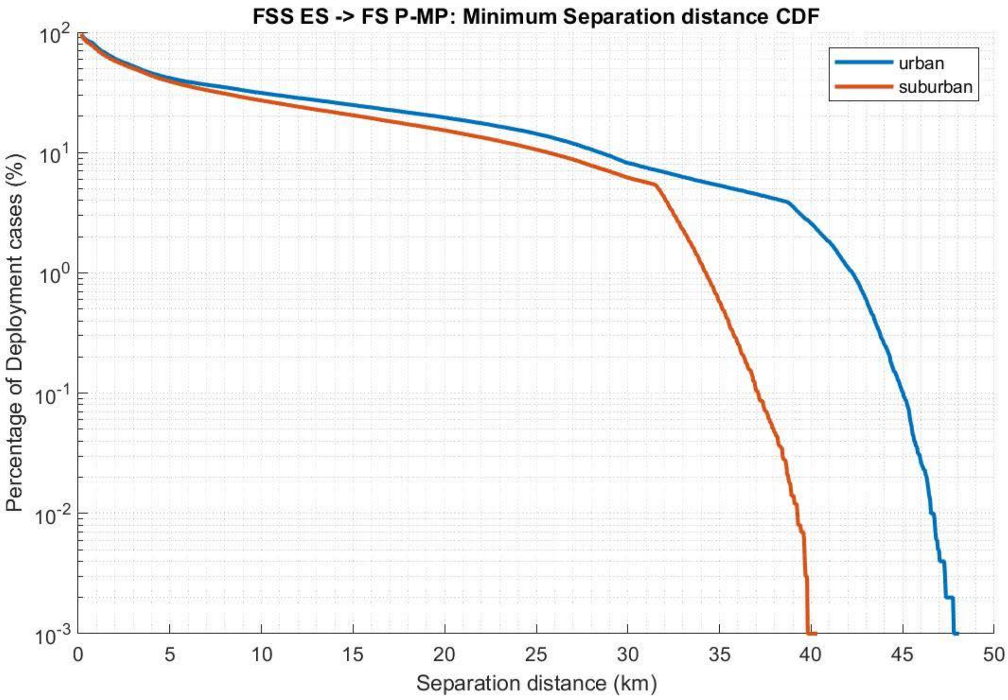



**Figure 17: 0.75 m Diameter FSS ES antenna → FS P-MP**
**(Percentage of deployments for various separation distances)**

From Figure 17 it can be noted that 10% of deployments require about 30 km separation distance.

### 5.2.3 Conclusion for Monte Carlo simulations

This section summarises the results of Monte Carlo calculations where the pointing direction of both the antennas (FSS ES and FS P-P/P-MP) are randomised for 100000 iterations, thus capturing all the cases of pointing, i.e., all possible deployments. It can be seen that in the case where the separation distance is the highest, which is the MCL case, there is a very low probability of occurrence, i.e., only one case in 100000 iterations, nevertheless the probability that separation distances of more than 5 km are needed of about 1% cases for all studied scenarios for 75 cm FSS ES, without additional mitigation techniques. For the case of 1.8m FSS ES, separation distances of more than 2 km are needed for about 1% of cases without additional mitigation techniques. Therefore, the case where both antennas point at each other with no azimuth discrimination, the worst case, happened very rarely in reality. It can be also seen that a slight off-axis for the antennas correlates to a significant reduction in the separation distances.

# 6 MCL STUDIES

This section conducts MCL (Minimum coupling loss) studies with the FS P-P and P-MP taking into account long-term FS protection criteria. The effect on received interference with changes in FSS antenna elevation angle is analysed. Lower range FSS transmit power is considered in this section; higher range FSS transmit power is considered in Annex 5. Another MCL study with some different assumptions is considered in Annex 9.

## 6.1 DETERMINISTIC ANALYSIS OF FS P-P

This is a worst-case theoretical analysis to assess the maximum separation distances that would be required without other mitigation techniques.

For this study, the worst-case sets of FS P-P parameters are considered with a max gain of 42 dBi and a minimum elevation varying between 0 and 2.5 degrees.

Also note that calculations assumed that the FSS ES transmitter is pointing directly towards the Fixed Service receiver in azimuth; i.e. no azimuthal separation is considered in the MCL calculations (see Figure 7). Such an alignment would, in practice, be extremely rare and is used only as a preliminary step in the analysis

The FSS Earth Station (user terminal) elevation angle varies from 10 to 50 degrees. The calculated nominal separation distance between an FSS Earth Station and the FS P-P receiver depends on the antenna pointing angles between the stations and the deployment scenario.

As further discussed in this section, illustration of deterministic scenario and section 5.2, Monte Carlo analysis, randomly altering the bearing between the FSS Earth Station transmitter and Fixed Service receiver demonstrates – as one would expect in real-world deployments of FS and FSS stations - that the actual separation distance is much smaller than the initial, nominal calculation.

### 6.1.1 FSS Earth Station (1.8 m diameter), based on long-term protection criteria

The FSS Earth Station bandwidth over which the transmitted power to the 1.8 m antenna would be spread is 320 MHz with a power spectral density of -17.9 dB(W/MHz). The calculations also take into account that for antennas located on the roof of a building, shielding up to 30 dB can be provided when a roof parapet or safety wall at the borders of the building exists or when the antenna is mounted on the side of a roof or building (see a description of the measurements report in Annex 2). The amount of shielding achievable depends on the relative positioning of the parapet between the FSS transmitter and the FS receiver. The step size in calculations is limited by the nominal distances according to the clutter model of Recommendation ITU-R P.452-16 without any additional terrain model. Therefore, the step size for rural was from 0.2 km and for urban and suburban was 0.04 km.

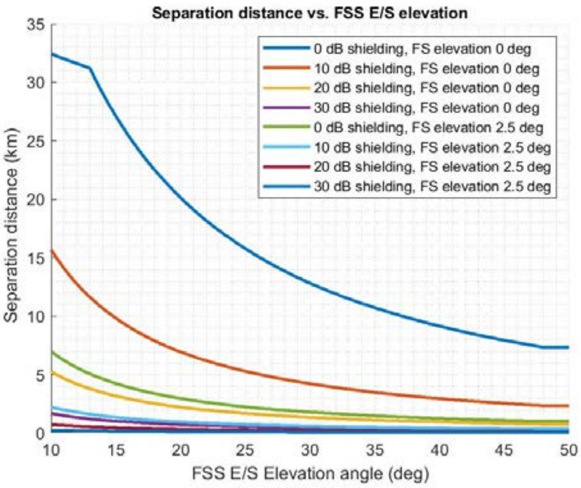
Table 4 shows the range of nominal separation distances between FSS Earth Station transmitter placed at 2 m and 10 m antenna heights and FS P-P receiver located at 15 m while using urban, suburban and rural propagation models in the calculations. FS elevation angle considered to be either 0 or 2.5 degrees.

Different shielding solutions have been considered giving up to 30 dB attenuation depending on the amount of needed attenuation in the different scenarios. Shielding is considered feasible for this larger class of earth station since they will be a used in specialised applications instead of as a mass-market product.

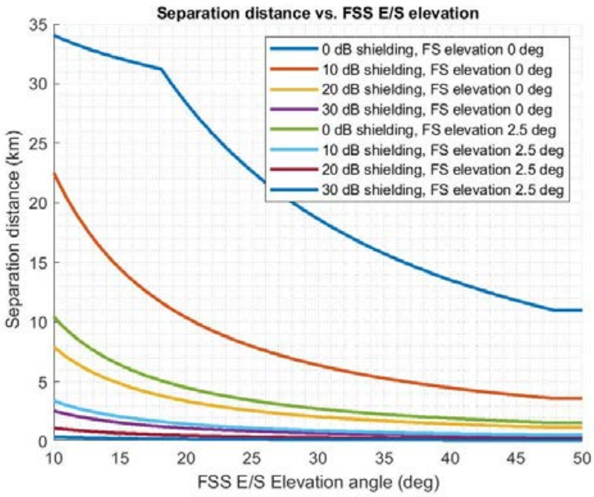
**1.8 m Diameter FSS ES antenna**

**(Nominal separation distances (km) vs. FSS ES elevation angles (deg))**

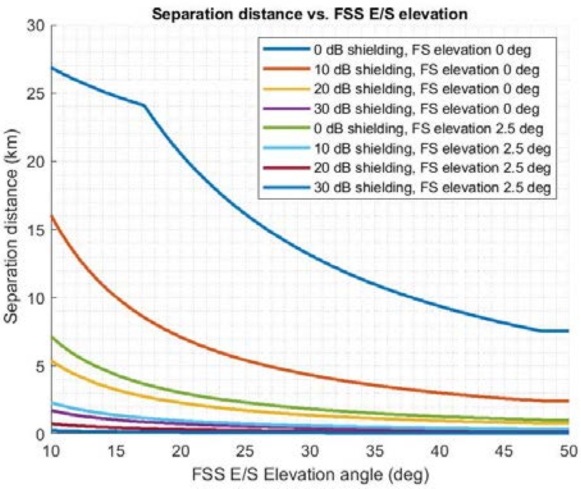
**Urban (Antenna Height = 2 m)**




**Urban (Antenna Height = 10 m)**




**Suburban (Antenna Height = 2 m)**




**Suburban (Antenna Height = 10 m)**

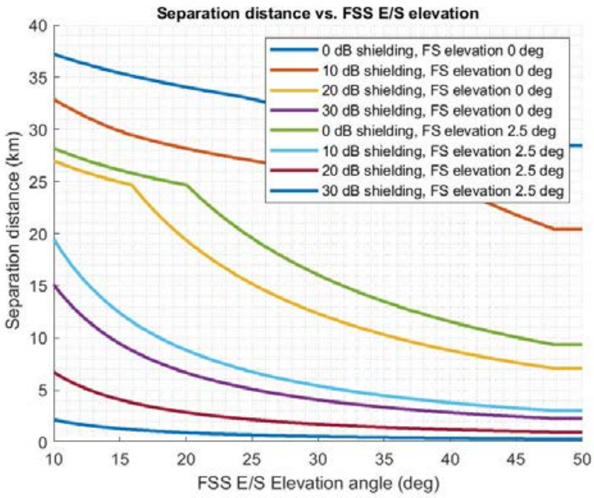



**Figure 18: Nominal separation distance in cases of azimuth plane alignment between FSS ES transmitter (1.8 m) and FS P-P receiver for urban/suburban/rural deployment, when the FSS ES antenna height is at 2 m and 10 m**

Simulations were run where both antennas are looking at each other in the azimuthal plane, therefore no azimuthal off-axis discrimination is applied in the calculations.

The maximum value of the range represents the case of 0 dB shielding factor and FSS ES elevation angle of 10°, whereas, the minimum value of the range represents the case of 30 dB shielding factor and FSS ES elevation angle of 10°. As seen from the figures above, when the FSS ES elevation angle increases, the nominal separation distance decreases significantly.

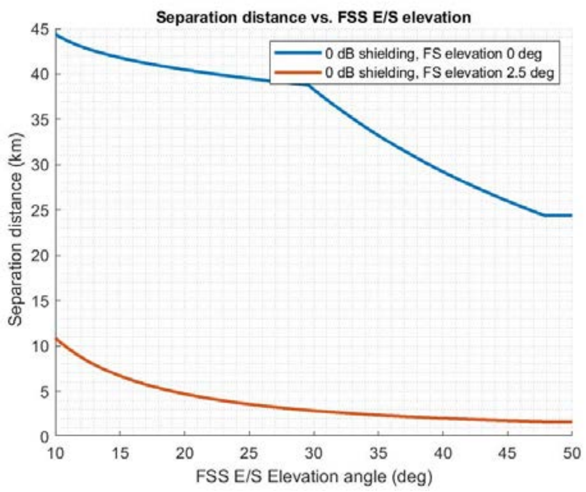
Note that to consider the clutter model, it was assumed that the distance step size was set greater or equal to the nominal distance from the clutter model in Recommendation ITU-R P.452-16 [20] (see Table 5).

The calculations also take into account that for antennas located on the roof of a building, shielding up to 30 dB can be provided when a roof parapet or safety wall at the borders of the building exists or when the antenna is mounted on the side of a roof or building (see a description of the measurements report in ANNEX 2). The amount of shielding achievable depends on the relative positioning of the parapet between the FSS transmitter and the FS receiver.

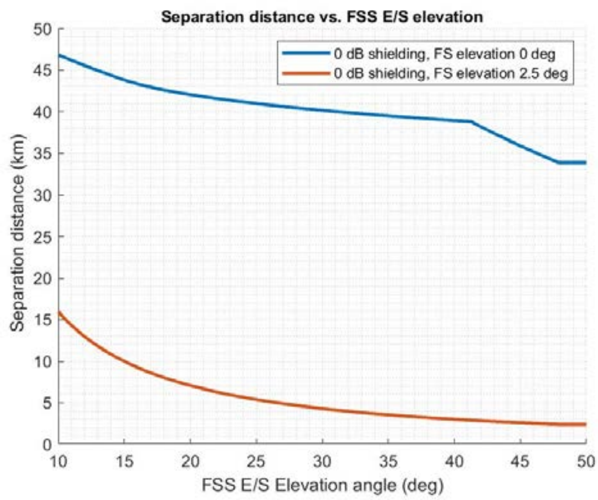
### 6.1.2 FSS Earth Station (0.75 m diameter), based on long-term protection criteria

The FSS Earth lower range power spectral density of -12.9 dB(W/MHz) is considered for this case. Calculations were performed without shielding for residential antennas. The following figures show the range of nominal separation distances between FSS Earth Station transmitter (0.75 m user terminal) placed at 2 m and 10 m antenna heights and FS P-P receiver located at 30 m while using urban, suburban propagation models in the calculations. FS elevation angle is considered to be either 0 or 2.5 degrees.

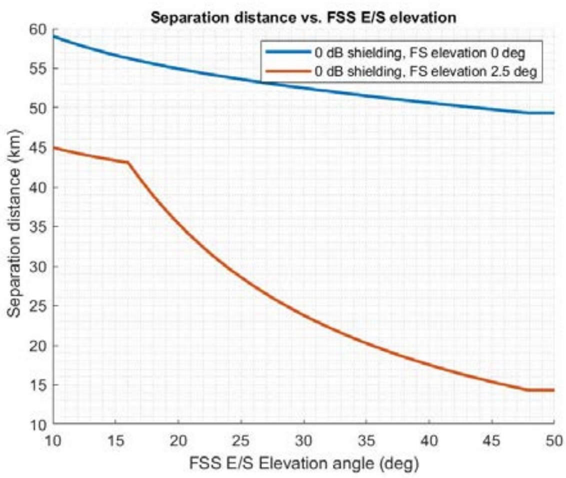
**Urban (Antenna Height = 2 m)**



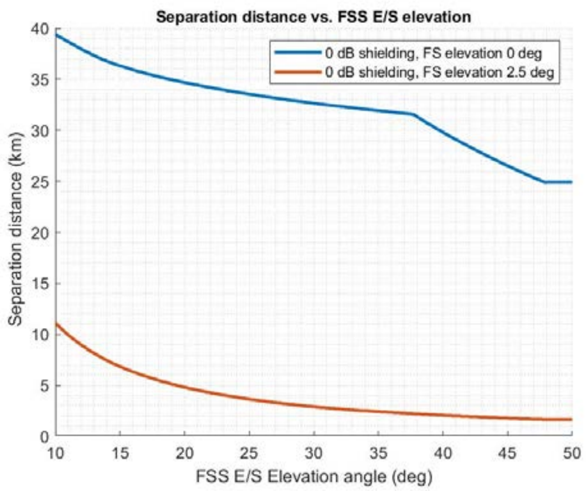

Urban (Antenna Height = 10 m)




**Urban (Antenna Height = 30 m)**




**Suburban (Antenna Height = 2 m)**




**Suburban (Antenna Height = 10 m)**

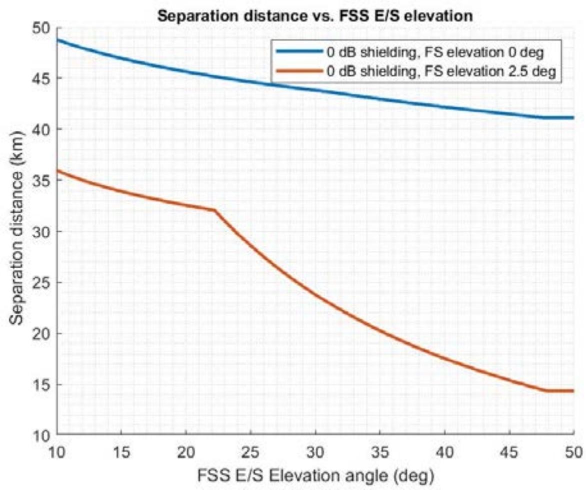



**Figure 19: Nominal separation distance between FSS ES transmitter (0.75 m) and FS P-P receiver for urban/suburban deployment, when the FSS ES antenna height is at 2 m and 10 m**

Simulations were run where both antennas are looking at each other in the azimuthal plane, therefore no azimuthal off-axis discrimination is applied in the calculations.

The range of separation distances depends on the FSS ES antenna height and the off-axis angle between FS and FSS ES. Note that shielding has not been considered for this type of FSS ES antenna type. The maximum value of the range represents the case of FSS ES elevation angle of 10° and FS elevation angle of 0°, whereas, the minimum value of the range represents the case of FSS ES elevation angle of 10° and FS elevation angle of 5°. As seen from the figures above, when the FSS ES elevation angle increases, the nominal separation distance decreases significantly.

Note that to consider the clutter model, it was assumed that the distance step size was set greater or equal to the nominal distance from the clutter model in Recommendation ITU-R P.452-16 [20].

The calculations also take into account that for antennas located on the roof of a building, for an enteprise terminal, a shielding up to 30 dB can be provided when a roof parapet or safety wall at the borders of the building exists or when the antenna is mounted on the side of a roof or building (see a description of the measurements report in Annex 2). The amount of shielding achievable depends on the relative positioning of the parapet between the FSS transmitter and the FS receiver.

## 6.2 DETERMINISTIC ANALYSIS OF POINT-TO-MULTIPOINT FS

### 6.2.1 Results for FS P-MP based on long-term protection criteria

For this study, sets of FS P-MP parameters are considered with a maximum gain of 27 dBi and a minimum elevation of 0 and 2.5 degrees. In the following sections the nominal separation distance is derived considering with the maximum long-term interference-to-noise criterion (i.e., I/N = -10 dB). The FS P-MP receiver elevation angle is 0 and 2.5 degrees and the FSS Earth Station elevation angle varies from 10 to 50 degrees.

The FS elevation angle 2.5 degrees was not considered for this analysis as the antenna gain for this case is almost the same as the elevation angle of 0 degrees for the antenna pattern ITU-R F.1336 (i.e., $Gain_{1336}$ ($\theta=0^0$) = $Gain_{1336}$ ($\theta=2.5^0$) where θ is the off-axis see section 4.2). As the nominal separation distance between an FSS Earth Station and the FS P-MP receiver depends on the antenna pointing angles between the stations and the deployment scenario, nominal separation distances for 0 and 2.5 degrees for every deployment scenario will be the same.

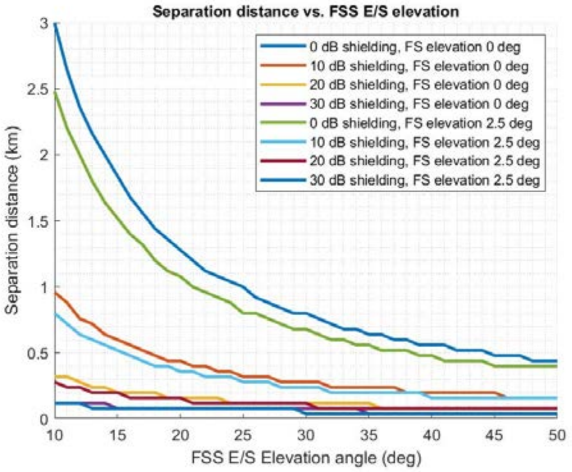
#### *6.2.1.1 FSS Earth Station (1.8 m), based on long-term protection criteria*

The FSS Earth Station bandwidth over which the transmitted power to the 1.8 m antenna would be spread is 320 MHz with a power spectral density of -17.9 dB(W/MHz). The calculations also take into account that for antennas located on the roof of a building, shielding up to 30 dB can be provided when a roof parapet or safety wall at the borders of the building exists or when the antenna is mounted on the side of a roof or building (see a description of the measurements report in ANNEX 2). The amount of shielding achievable depends on the relative positioning of the parapet between the FSS transmitter and the FS receiver.

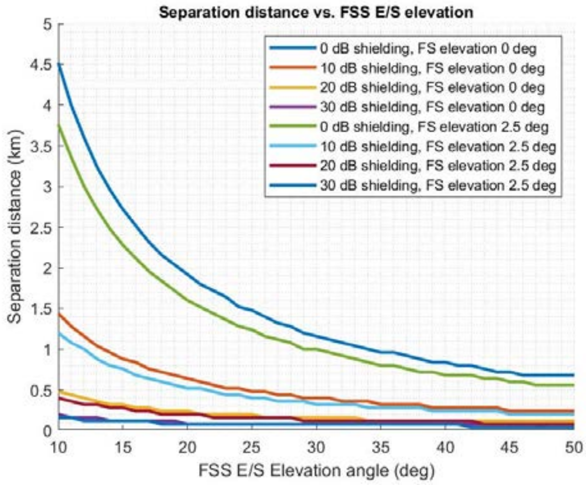
In this case, the height of FS antenna is 15 m.

**1.8 m Diameter FSS ES antenna → FS P-MP**
**(Nominal separation distances (km) vs. FSS ESelevation angles (deg))**

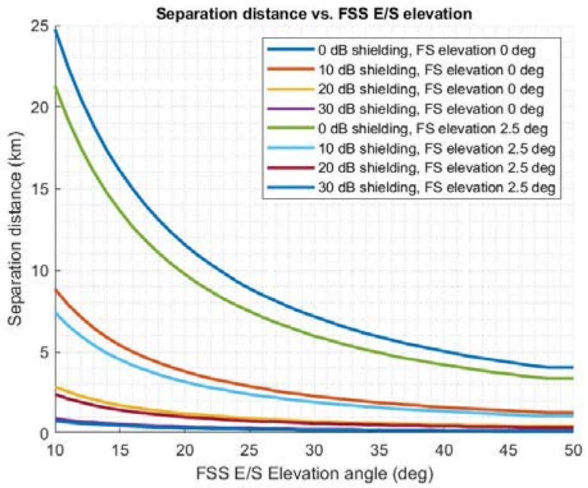
**Urban (Antenna Height = 2 m)**



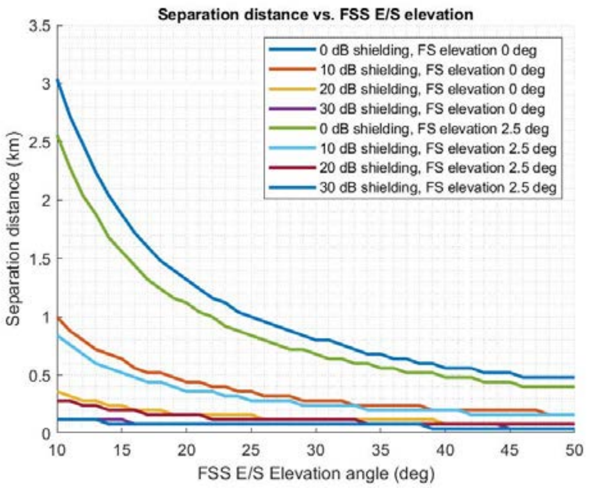

**Urban (Antenna Height = 10 m)**




**Urban (Antenna Height = 30 m)**




**Suburban (Antenna Height = 2 m)**




**Suburban (Antenna Height = 10 m)**

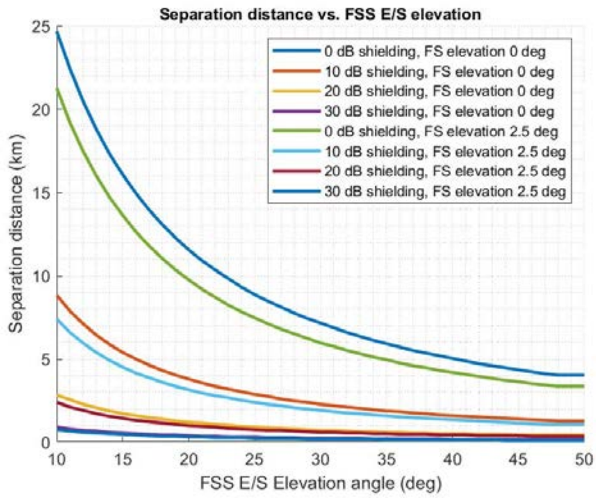



**Figure 20: Nominal separation distance for long-term protection criteria between FSS ES transmitter (1.8 m) and FS P-MP receiver for urban/suburban/rural deployment, when the FSS ES antenna height is at 2 m and 10 m**

Simulations were run where both antennas are looking at each other in the azimuthal plane, therefore no azimuthal off-axis discrimination is applied in the calculations.

The range of nominal separation distance depends on the shielding factor, FSS ES antenna height, and the off-axis angle between FS and FSS ES.

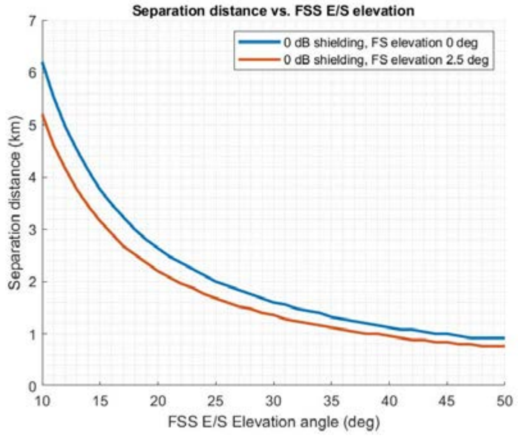
The maximum value of the range represents the case of 0 dB shielding factor and FSS ES elevation angle of 10°, whereas, the minimum value of the range represents the case of 30 dB shielding factor and FSS ES elevation angle of 10°. As seen from the figures above, when the FSS ES elevation angle increases, the nominal separation distance decreases significantly.

Note that to consider the clutter model, it was assumed that the distance step size was set greater or equal to the nominal distance from the clutter model in Recommendation ITU-R P.452-16 [20] (see Table 5).

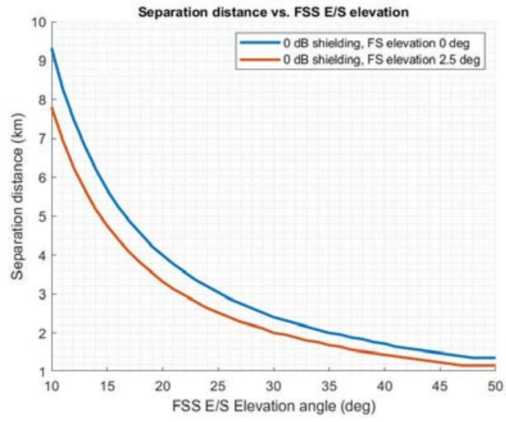
#### *6.2.1.2 FSS Earth Station (0.75 m), based on long-term protection criteria*

The FSS Earth lower range power spectral density of -12.9 dB (W/MHz) is considered for this case. Calculations performed without shielding for residential antennas. The following figures show the range of nominal separation distances between FSS Earth Station transmitter (0.75 m user terminal) placed at 2 m and 10 m antenna heights and FS P-P receiver while using urban, suburban propagation models in the calculations. FS elevation angle is considered to be either 0 or 2.5 degrees. FS antenna height is 30 m.

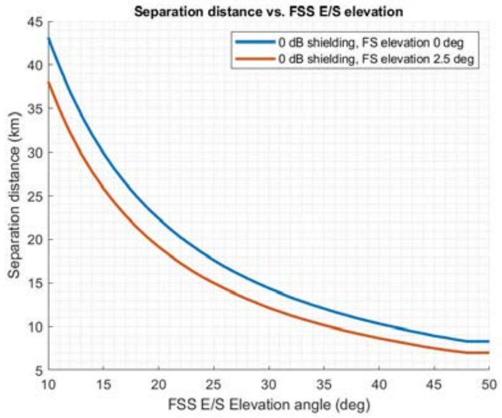
**Urban (Antenna Height = 2 m)**



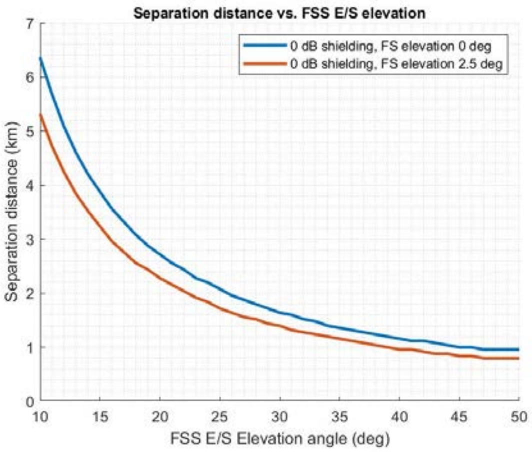

**Urban (Antenna Height = 10 m)**




**Urban (Antenna Height = 30 m)**




**Suburban (Antenna Height = 2 m)**




**Suburban (Antenna Height = 10 m)**

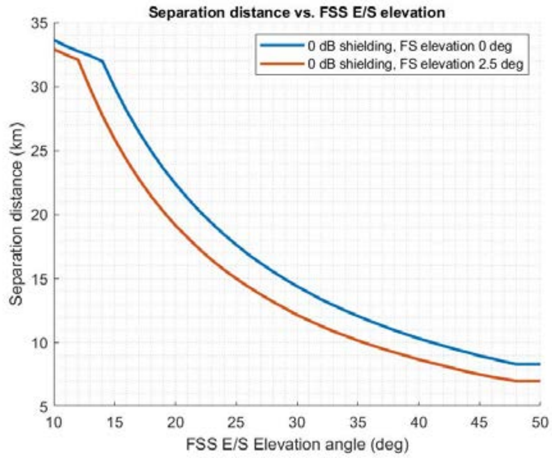



**Figure 21: Nominal separation distance for long-term protection criteria between FSS ES transmitter (0.75 m) and FS P-MP receiver for urban/suburban deployment, when the FSS ES antenna height is at 2 m and 10 m**

Simulations were run where both antennas are looking at each other in the azimuthal plane, therefore no azimuthal off-axis discrimination is applied in the calculations.

The range of nominal separation distance depends on the FSS ES antenna height and the off-axis angle between FS and FSS ES. Note that shielding has not been considered for this type of FSS ES antenna type.

The maximum value of the range represents the case of FSS ES elevation angle of 10° and FS elevation angle of 0°, whereas, the minimum of the range represents the case of FSS ES elevation angle of 10° and FS elevation angle of 2.5°. As seen from the figures above, when the FSS ES elevation angle increases, the nominal separation distance decreases significantly.

Note that to consider the clutter model, it was assumed that the distance step size was set greater or equal to the nominal distance from the clutter model in Recommendation ITU-R P.452-16 [20].

The calculations also take into account that for antennas located on the roof of a building, for an enterprise terminal, a shielding up to 30 dB can be provided when a roof parapet or safety wall at the borders of the building exists or when the antenna is mounted on the side of a roof or building (see a description of the measurements report in Annex 2). The amount of shielding achievable depends on the relative positioning of the parapet between the FSS transmitter and the FS receiver.

## 6.3 CONCLUSION

This MCL approach is a worst-case assumption, as the FSS ES transmitter is pointing directly towards the Fixed Service receiver in azimuth (see section 5.1).

The range of separation distances depends on the FSS ES antenna height and the off-axis angle between FS and FSS ES (and on shielding when applicable).

The probability of this scenario happening is extremely low. Therefore, statistical analysis (see sections 5.2 and section 0) is necessary to illustrate the realistic scenario by randomly altering the bearing between the FSS Earth Station transmitter and Fixed Service receiver. The statistical approach demonstrates that the actual separation distance most of the times is quite small.

# 7 AGGREGATE INTERFERENCE FROM FSS ES TO P-P/FS P-MP

The area considered for the study between FSS ES and FS P-P/P-MP stations corresponds to area within which a FS P-P/P-MP and FSS ES can be deployed and still be in line of sight (LOS). The maximum distance at which the two stations can perceive each other is calculated with the approximated equation:

$$\text{Equation 2: } LoS_{distance} = (3.57\left(\sqrt{H_{FSS}} + \sqrt{H_{FS}}\right)$$

Where:

- $H_{FSS}$: height of the FSS ES in meters; (10 meters are used in the following);
- $H_{FS}$: height of the FS station in meters (30 meters are used in the following).

The line of sight distance is therefore equal to 30.84 km.

The spherical cap area of study is also given by the following formula:

$$\text{Equation 3: } S_{area} = 2\pi R_{earth}{}^{2}(1 - cos(sin^{-1}(R_{cap}/R_{earth})) \approx 2980\ km^{2}$$

Where:

- $R_{earth}$ is the radius of the earth;
- $R_{cap}$ is the maximum separation distance between the two stations i.e. $LoS_{distance}$.

The FSS ES density is calculated considering real subscriber density data provided by one satellite operator:

**Table 15: Data supporting calculations of FSS ES density**

| Scenario | Number of subscribers | Area, km$^2$ | Number of subscribers per km$^2$ |
|---|---|---|---|
| Urban | 275761 | 208413571.9 | 0.00019 |
| Suburban | 55682 | 91255.32139 | 0.00078 |

Additionally, this FSS ES density deployment considered only stations that emit co-frequency with the FS.

The number of FSS ES deployed in that area is determined by multiplying the surface area with the FSS ES density, which was calculated using actual subscriber numbers for rural, suburban and urban postal codes in North America. The subscriber density used in calculations is taken from the number of subscribers per km$^2$ in the table above and then multiplied by a factor of 4 to take into account the difference in population density between Europe and Americas and also the potential that multiple satellite operators will use the entire Ka-band. Under these assumptions FSS ES terminal density for urban and suburban case is 7.8*10$^{-4}$ per 1 km$^2$.

$N_{FSS\ E/S} = S_{area}.Density$

For the suburban case: $N_{FSS\ E/S} = 2$

For the urban case: $N_{FSS\ E/S} = 2$

Those stations are deployed randomly within the line of sight spherical cap. The following figure is an example of FSS ES deployment scheme for a given iteration. This deployment will be randomised and generated at each new iteration.

The notation of exclusion zone on the figure below refers to nominal distances defined according to different deployment scenarios described in Table 4, section 4.5.3 of Recommendation ITU-R P. 452.

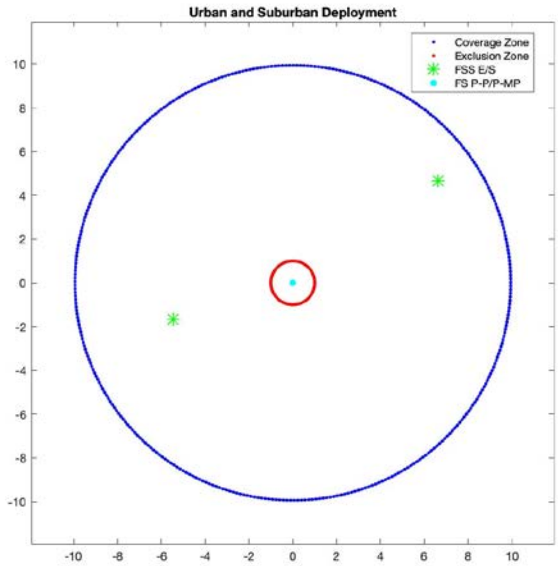



**Figure 22: Deployment density for urban and suburban terrain**

## 7.1 METHODOLOGY

This section is listing steps that have been followed to derive the aggregate interference into a single FS victim receiver from several FSS ES transmitters (interferers).

The following FSS ES parameters are considered for this study:

- FSS antenna height:
  - Urban - random variable with a uniform distribution between 2 m and 30 m;
  - Suburban - random variable with a uniform distribution between 2 m and 10 m.
- FSS station lower (nominal) power spectral density for antenna diameter 0.75 m:
  - -12.9 dB(W/MHz) corresponding to e.i.r.p. of 53 dBW in 160 MHz[2].
- Polarisation loss of 3 dB.
- FS P-P/P-MP antenna height: 30 m.

**Step-by-step methodology used in the study:**

Step 1: Compute the FS P-P/P-MP antenna gain towards each FSS Earth Station (the deployment of the FSS Earth Stations is randomised and generated at each iteration) based on the following input parameters:

- FS station antenna pointing azimuth: random variable with a uniform distribution between 120° to 220°;
- FS station antenna pointing elevation: uniform distribution n between -2.5° and 2.5°;
- FS station maximum antenna gain;
  - FS P-P: 47 dBi for the FS P-P (1.2 m antenna);
  - FS P-MP: 17 dBi for 90-degree sectoral antenna and 47 dBi for 1.2 m terminal antenna.

Antenna patterns considered in the study:

- FS P-P: Recommendation ITU-R F.1245-3;
- FS P-MP: Recommendation ITU-R F1336-4 for 90-degree sectoral antenna and Recommendation ITU-R F.699-8 for 1.2 m terminal antenna.

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[2] This vales takes into account the duty cycle to determine the aggregate interference of multiple sources.

Step 2: Compute the FSS ES antenna gain for each station towards the FS P-P/P-MP based on the following input parameters:

- FSS station antenna pointing azimuth: random variable with a uniform distribution between 0 and 180 degrees;
- FSS station antenna pointing elevation: 26.5° for the following range of satellite orbital positions: 20W to 45E.

The off-axis angle (i.e. angle between FSS pointing direction and the line joining FS and FSS ES) is taken as the elevation angle towards the FS;

- FSS maximum antenna gain: 52.9 dBi for 1.8 m diameter and 43.9 dBi for 0.75 m diameter;
- FSS antenna pattern: Recommendation ITU-R S.465-6.

Step 3: Compute the aggregate interference (dBW/MHz) from FSS ES towards FS P-P/P-MP as follow;

**Equation 4:** $I_{aggregate} = 10 \times \left(log_{10} \sum_{i=1}^{n} 10^{\frac{I_i}{10}}\right)$

where:

- $I_i$ is the interference of i^th interferer
- $I_i = P_{tx} + Gt_i(\theta) + Gr_i(\theta) - PL_i - L_{Pol}$
- $P_{tx}$ is the FSS ES nominal power spectral density:
- $Gt$ is the FSS ES gain towards the FS P-P/P-MP;
- $Gr$ is the FS P-P/P-MP gain towards the FSS E/S;
- $PL$ is propagation loss based on ITU-R P.452 (ρ= 20%);
- $L_{Pol}$ is the polarisation loss = 3 dB;
- θ is the off axis between FS P-P/P-MP and FSS ES.

Step 4: Store the calculated aggregate interference and repeat steps 1 through 3 for 100000 iterations.

### 7.1.1 Results for FS P-P (Residential terminal)

Figures below show the results for a 0.75 m antenna diameter with lower range power spectral density of -12.9 dB(W/MHz). The number of iterations is 100000.

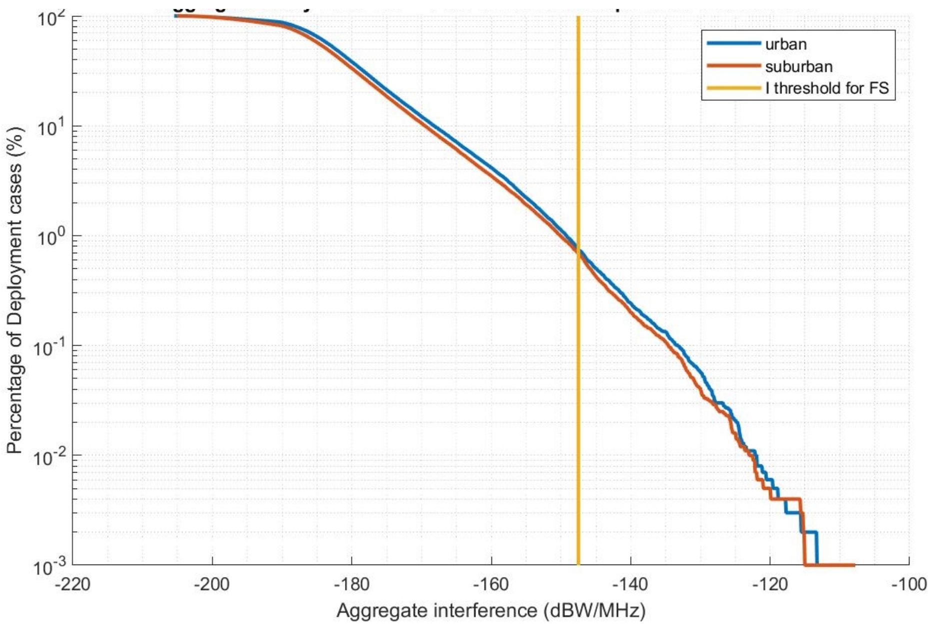



**Figure 23: 0.75 m diameter FSS ES antenna → FS P-P (different deployment scenarios)**

**Table 16: Probability of interference registered for different scenarios**

| Terrain | Probability of Interference (%) |
|---|---|
| Urban | 0.755 |
| Suburban | 0.692 |

### 7.1.2 FS P-MP case scenario (residential terminals)

#### *7.1.2.1 Terminal antenna P-MP*

Figures below show results of 0.75 m antenna diameter with lower range power spectral density of -12.9 dBW/MHz, number of iterations is 100000.

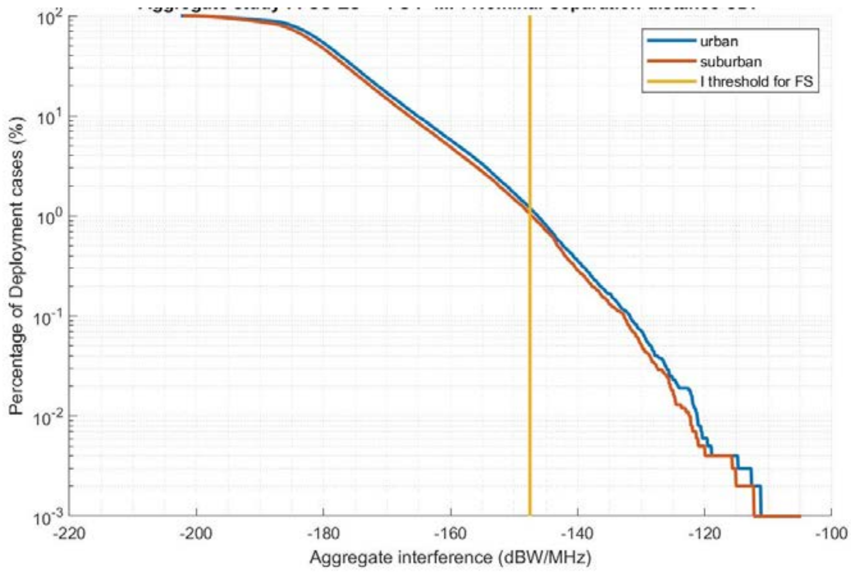



**Figure 24: 0.75 m Diameter FSS ES antenna → FS P-MP Omni (different deployment scenarios)**

**Table 17: Probability of interference registered for different scenarios**

| Terrain | Probability of Interference (%) |
|---|---|
| Urban | 1.194 |
| Suburban | 1.049 |

#### *7.1.2.2 Sectoral antenna P-MP*

Figures below show results of 0.75 m antenna diameter with lower range power spectral density of -12.9 dB(W/MHz), number of iterations is 100000.

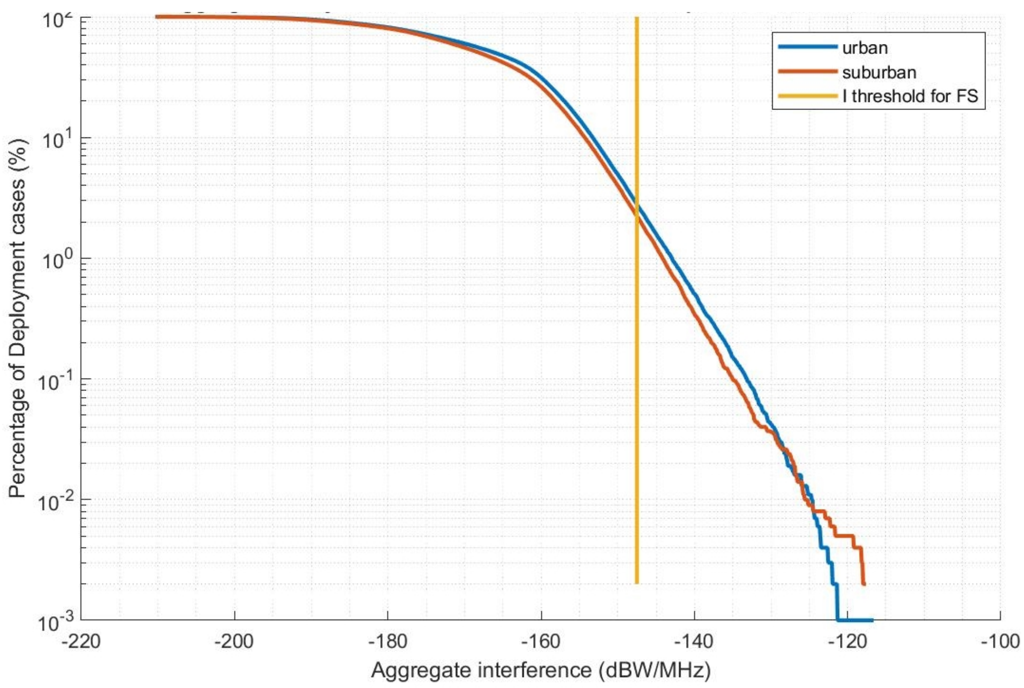



**Figure 25: 0.75 m Diameter FSS ES antenna → FS P-MP Sectoral (different deployment scenarios)**

**Table 18: Probability of interference registered for different scenarios**

| Terrain | Probability of Interference (%) |
|---|---|
| Urban | 2.817 |
| Suburban | 2.253 |

NOTE: Calculation of the FS P-P/FS P-MP protection criteria was achieved as follows:

$I_{thresh} = I/N + N_{RX}$

Where:

- $I/N$: FS protection criteria of -10 dB for 20% of the time was assumed;
- $N_{RX}$: Receiver noise power density = -137.5 dBW/MHz.

### 7.1.3 Conclusions

The aggregate interference analysis above shows that the aggregate interference based on the assumed FSS deployment scenarios into P-MP and P-P FS links is expected to be below 1 % for P-P case and in the range between 1 - 2.8 % for the P-MP case.

# 8 SENSE AND AVOID MITIGATION TECHNIQUE

## 8.1 THE PRINCIPLE OF SENSING APPLIED TO SHARING WITH THE FS

In this section the technical requirements and feasibility of spectrum sensing are investigated.

Spectrum sensing, also defined as Sense and Avoid (SAA), is an active cognitive technique based on the principle that the cognitive device, prior to using the spectrum, listen to emissions of potential victims. If their presence is detected, the device refrains from emitting.

In the case of a shared use of spectrum between FSS and FS considered in this Report, this in practice means that the FSS Earth Station will monitor the channels used by the FS and if they are occupied, it will not use them. More precisely, when one channel will be detected as used, the FSS will have to avoid transmitting on this channel or the corresponding receiving channel in the FS channel plan. Figure 26 below helps understanding the situation:

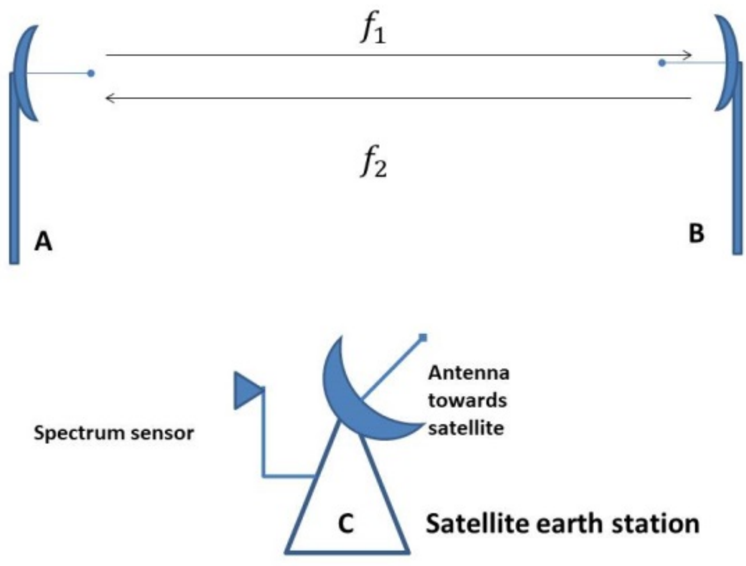



Figure 26: Scenario for spectrum sensing

In Figure 26, the FS has two poles, situated in A and B. The antenna in A emits over frequency f1 and receives over frequency f2. The station in B does vice versa. The FSS Earth Station is located in C, it is equipped with the spectrum sensor and the antenna for the communication with the satellite.

In general, the following two approaches can be considered:

1) In order to protect a station (e.g. station A in Figure 26), the sensor listens to its emitting channel (frequency f1), if an emission is detected, the FSS will refrain from using its receiving channel (frequency f2). The converse is simultaneously done for the protection of the station in B. In this approach, the stations are protected individually. In fact, in order to protect a station, the sensor must listen to its emitting frequency and decide not use its receiving frequency. Obviously, the channel arrangement in the band must be known in advance.

2) In a slightly modified version of the algorithm, if the sensor detects activity over f1 (or f2) it precludes emission on both f2 and f1. This corresponds to the idea that in order to protect a station, say A, the sensor uses the information available not only from A but also from B. This approach is evidently more conservative. In addition, in this case the channel arrangement must be known in advance.

The FS transmitter power depends on link length and availability and the most critical scenario for sensing is a shorth FS link with a low availability which results in a low FS output power.

It should be noted, that ETSI Recommendation T/R 13-02 allows bandwidths between 3,5 MHz and 224 MHz for FS links which should be taken into account when choosing the measurement bandwidth for the sensor.

Sensing can be improved by combining the data of multiple sensors in a given area to improve the probability that an FS station in the area is detected. This technique (cooperative sensing) would require all the sensors in an FSS network to transmit their sensing data to a centralised point for analysis. All earth stations in the FSS network would also need to be under central control and their location would need to be known by the Network Operations Center (NOC). In this way, data from multiple sensors is gathered from multiple reference points and can be used to increase the probability that FS is detected. Once detected, the NOC could calculate whether any FSS Earth Stations in the area sensed are likely to cause interference to the FS and appropriate mitigation is implemented to avoid interference.

## 8.2 FEASIBILITY OF SENSING IN THIS SCENARIO

Once the idea behind sensing is explained, the subsequent step is to investigate whether it is technically feasible in practice. By this, it is meant to verify that the resulting requirements in terms of minimum antenna size, sensitivity of the sensor etc. are practically doable. In general, the problem will be a function of the following variables:

- The power radiated from the FS towards the FSS. The lower this power, the more difficult will be for the sensor to detect the presence of the FS;
- The distance and the resulting propagation loss between the FSS ES and the FS stations;
- The power of the FSS ES radiated towards the FS stations. The higher this power, the further the sensor will have to be able to detect the presence of the FS stations, or equivalently, the lower the level of the FS that it must be able to detect;
- The sensitivity of the sensor. Given the emitted power of the FS towards the FSS and of the FSS towards the FS, it will be possible to determine the minimum FS signal level that the sensor must be able to detect. This sensing threshold must be implementable given the available technology.

Considering the problem of detecting the emissions of an FS station, the following methodology can be adopted:

- $P_v$ : the transmission power of the VSAT station;
- $G_v$ : the gain of the VSAT towards the FS station;
- $L_1$ : the propagation loss from the VSAT station to the FS station (at the frequency of reception of the victim FS station);
- $KTBF_{LINK}$ : the noise level of the FS victim station;
- $\frac{I}{N}$ : the required protection criterion for the victim FS station;
- $P_F$ : transmission power of the FS station;
- $G_F$ : gain of the FS station towards the sensor;
- $G_S$ : gain of the sensor antenna;
- $L_2$: propagation loss from the FS station to the sensor. Since the sensor and the VSAT are co-located and the sensor detects the FS emissions of the FS stations that it is supposed to detect, one might think that L2 is equal to L1 for reciprocity, but, since the FS emits and receives at different frequencies, this may not be the case, due to multipath fading;
- $P_{th}$: sensitivity of the sensor, i.e. minimum power level that is detected with a sufficiently low probability of missed detection. $Pth = KTBF_{SENSOR} + Detection\ SNR$, where $KTBF_{SENSOR}$ is the noise level of the sensor and $Detection\ SNR$ is the required signal to noise level of the sensor for a reliable detection. This value can be negative or positive depending on the integration time.

A first question is whether it is possible to physically implement a sensor sensitive enough to protect the FS station.

To this end, it is considered when the VSAT terminal can interfere with the FS station. This condition can be expressed by the equation:

$$\textbf{Equation 5: } P_v + G_v + G_F - L_1 \geq KTBF_{LINK} + \frac{I}{N}$$

Logically, spectrum sensing must be able to work when there is potential for interference, i.e. when Equation 5 holds.

The condition for spectrum sensing being effective is:

$$\textbf{Equation 6: } P_F + G_F + G_S - L_2 \geq P_{th}$$

In order to derive the required performance of the sensor, one can consider the two equations when they are valid at their limit:

$$\textbf{Equation 7: } \begin{cases} P_v + G_v + G_F - L_1 = KTBF_{LINK} + \frac{I}{N} \\ P_F + G_F + G_S - L_2 = P_{th} \end{cases}$$

By subtracting and rearranging one gets:

$$\textbf{Equation 8: } (P_v - P_F) + (G_V - G_S) + (L_2 - L_1) = KTBF_{LINK} + \frac{I}{N} - P_{th}$$

And with:

$$\textbf{Equation 9: } P_{th} = KTBF_{SENSOR} + Detection\ SNR$$

One gets:

$$\textbf{Equation 10: } (P_v - P_F) + (G_V - G_S) + (L_2 - L_1) = KTBF_{LINK} + \frac{I}{N} - (KTBF_{SENSOR} + Detection\ SNR)$$

And finally:

$$\textbf{Equation 11: } (P_v - P_F) + (G_V - G_S) + (L_2 - L_1) = (KTBF_{LINK} - KTBF_{SENSOR}) + \frac{I}{N} - Detection\ SNR$$

From Equation 8 to Equation 11,it follows that factors affect the feasibility of spectrum sensing:

- The difference between the emission powers of the FS and the VSAT;
- The difference between the gain of the sensor and gain of the VSAT antenna, noting that the antenna of the FS stations plays no role;
- The difference between the propagation losses over the forward and reverse channel, i.e. from the FS stations to the sensor and from the sensor/VSAT to the FS station;
- The difference between the maximum allowable interfering power at the FS station and the sensitivity of the sensor;
- The detection SNR, i.e. the required signal to noise ratio of the sensor, which in turns depends on the integration time.

Regarding the term $L_2$-$L_1$ in Equation 8, this term represents the difference between the propagation losses over the same path, from the station to the sensor, but at two different frequencies: the frequency of emission of the FS station and its frequency of reception.

Returning to the general case, where $L_1 \neq L_2$, which applies to this situation, the problem becomes the statistical characterization of $L_2$-$L_1$.

In LOS conditions, since the Tx and Rx channels are in the same band, the difference is small. Impairments due to rain are also likely to affect the two channels in the same way. Therefore, in LOS conditions the term $L_2$-$L_1$ does not play a fundamental role in the dimensioning of the sensor. On the contrary, in NLOS conditions the effect of multipath propagation, where incoming rays arrive with different phases and from different angles, makes it possible that $L_2$ significantly differs from $L_1$. Therefore, multipath effects need to be factored in the evaluation of the required characteristics of the sensor.

In order to assess the impact of multipath fading on the term $L_2$-$L_1$, and to put an upper bound to it, a literature research has been performed [14][15][16]. From an analysis of those references it appears that 20 dB can be considered as a conservative margin for the term $L_2$-$L_1$. Considering also that the depth and centre frequency of multipath fading will vary over time, the sensor integration over a sufficient length of time will capture the average fade value.

The SNR that the sensor will achieve will depend on its implementation and, among other parameters, on the integration time[3]. Considering also that the depth and centre frequency of multipath fading will vary over time, and the sensor integration over a sufficient length of time will capture the average fade value.

The required protection criterion for 20% of the time for the FS stations $\frac{I}{N}$ is assumed to be -10 dB (see section 4.3.2 for further details).

The value of the antenna gain of the FSS ES towards the FS can be estimated using Recommendation ITU-R S.645 (see also Figure 3). For different elevations of the FSS ES it is possible to estimate, over all the possible azimuth relative to the FS station, the maximum gain that Gv can have.

When determining a threshold for the FSS sensor, the following range of parameters are needed:

- Range of FS transmit power (identified TX output power range is -10 dBm to 30 dBm);
- Real FSS antenna patterns in vertical and horizontal dimensions (to be used by the sensor designer);
- The SNR that the sensor will have to achieve;

These factors may be used in further studies to determine the appropriate sensing threshold to be implemented in eventual regulations allowing sharing using the sense and avoid technique.

The MCL calculations in this Report assumed worst case and generalised characteristics for the FS and FSS antennas. For the calculation of the sensor threshold, it is more appropriate to use practical values e.g. the real FSS antenna pattern. Also, terminals could be equipped with GPS to take into account topological and morphological data (i.e. terrain and clutter). In addition, an appropriate multipath fade margin for detection of FS in non-line of sight condition, which can vary in the range of -25 dB to 25 dB (see Annex 4), should be taken into account.

Datasheets of equipment currently on the market provide the minimum FS transmit power of -10 dBm. National regulators' actual FS operational requirements provide the minimum FS transmit power of -3 dBm. It can be assumed that the majority of links will operate at a level greater than the minimum transmit power of -10 dBm specified in the datasheet. It is therefore expected that the link would transmit occasionally at a higher power in order to adjust for various fading conditions and maintain the required link performance. The link might then be sensed at this higher transmit power level. However, these fading conditions might also occur in the sensing path.

It should be noted that the maximum possible output power of 30 dBm will also only occur in a very few cases and is not the appropriate value for the design of the sensor.

Administrations may deem appropriate to use different values of FS output power for defining the requirements of the sensor, based on their deployment scenarios. It is up to administrations to set an appropriate sensor threshold to reflect their national framework. This needs to be considered further for the implementation of the sensor.

Although sensing is considered feasible under certain conditions, it is recognised that a sensor threshold could be set at a level that does not protect 100% of operational FS links.

The following factors should be considered further by administrations in setting the sensing threshold:

---

[3] To obtain the maximum sensitivity in the sensor, some calibration or other means of determining the true background noise will have to be done on a regular basis as there will be temporal variations in true noise.

Factors that can improve sensing:

- Increasing integration time of sensing to improve sensitivity
- Increasing the observation period to capture variations in power output of the FS; Improve sensor antenna gain;
- Improve noise figure of the sensor;
- Knowledge of Waveform and modulation of FS will help increasing SNR value, if available;
- Require cooperative sensing/minimum FSS sensor density in areas of heavy FS concentration; Adjust regulatory framework for FS to facilitate sharing.

Means of addressing links that might not be sensed:

- Establishing coordination zones around links which may not be protected by sensing;
- Require FSS operators to notify/track location of deployed ESs and eliminate interference if it occurs.

## 8.3 OPERATIONAL REQUIREMENTS FOR THE SENSING ALGORITHM

The additional features that the sensing algorithm should have are described below.

The algorithm is based on the knowledge of the channel arrangement of the FS. The current channel arrangement is presented in the figure below, taken from Recommendation T/R 13-02 [22]. Since the channel arrangement can vary over time, the sensor should be able to update regularly its knowledge of the channel plan.

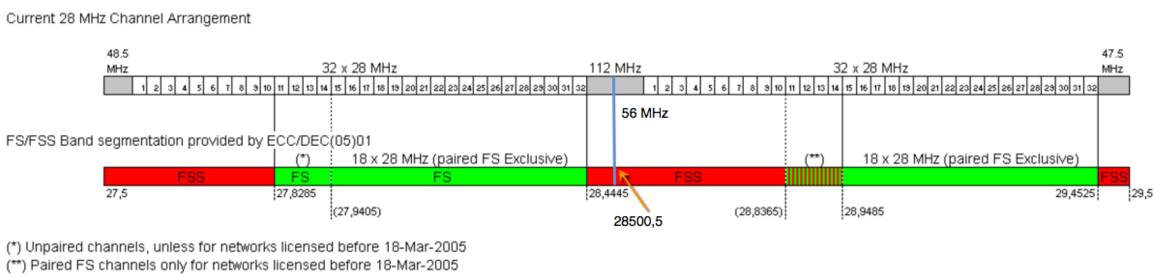



**Figure 27: Channel plan, T/R 13-02**

In the studies within this Report, a channel bandwidth of 28 MHz for the FS has been considered being the most commonly deployed value; nevertheless Recommendation T/R 13-02 and ECC Decision (05)01 [1] allow usage of wider up to 224 MHz channels and the implementation of the sensor has to take into account the need to detect also these wider channels if in use**.**

Since new links could be installed in the proximity of the FSS station, the sensor should periodically (for instance at least once per day) check for the availability of the channels.

Considering that the FSS station typically has a low duty cycle, it is expected that it will be possible to perform sensing during the idle time of the FSS. The sensor antenna, in fact, could be synchronised with the FSS Earth Station operation so that the sensor reception is active only when that earth station is not transmitting (e.g. between bursts). Taking into account that the duty cycle of the FSS Earth Station, according to Recommendation ITU-R S. 1594 [6], is less than 20%, the sensor can ideally receive during 80% of the time, whereas the FS signal is supposed to be active all the time in P-P and P-MP systems. In practice, any analysis of a system's compliance should take into account its actual duty cycle, therefore system with the lower duty cycle will have longer sensing time compared to the one with higher duty cycle.

As it has been seen, in the implementation of the sensing mechanism there is a trade-off between the sensor antenna gain and the minimum level of signal that the sensor can detect.

Depending on the sensor sensitivity two cases can be considered:

- If the FS signal is received with a C/N below 0 dB then extended sample time will be required;

- If the FS signal is received with a C/N above 0 dB then a simple spectral analysis will allow to detect the difference between the signal and the noise, and to determine both its central frequency and bandwidth.

The proper design of the observation and integration time needs further consideration.

## 8.4 HYDROMETEOR SCATTERING INTERFERENCE MECHANISM

The situation of the interference mechanism due to hydrometeor scattering is shown on Figure 28.

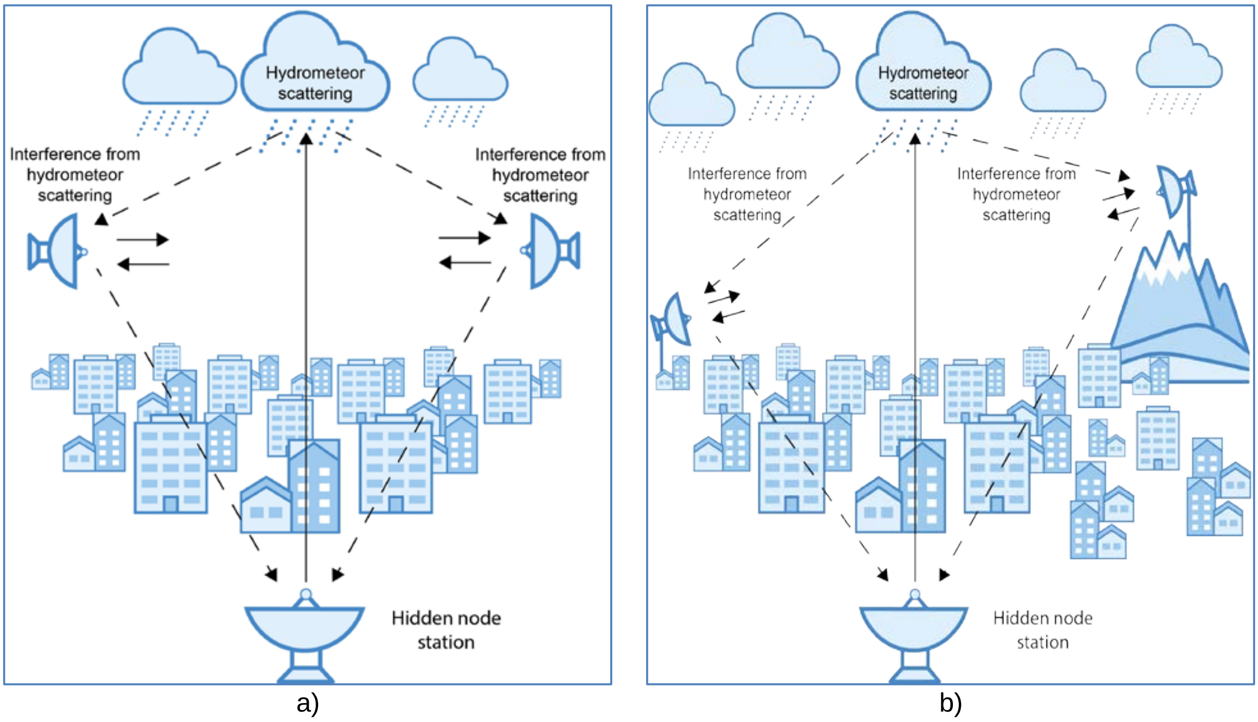



**Figure 28: Hydrometeor scattering interference case with the hidden node scenario a) typical elevation angles FS stations, b) high elevation angles FS stations**

The effective transmission loss is defined as the transmission loss minus the extra attenuation suffered by the signal. In case of hydrometeor scattering for interfering path from the FSS station to the FS station power of interference can be evaluated by using the Bistatic Radar Equation (BRE). Depending on rainfall rates, climatic zone and atmospheric conditions the power reflected from the hydrometeors provides 20-30 dB additional attenuation for the basic free space loss calculations on the analysed path.

The scattering effect mainly occurs when the divergence of the main beam of the emission source and the receptor differs by no more than 3 θ, where θ is the width of the radiation pattern on the level of half power. Outside 3 θ geometry, there is a significant decrease of the scattering effect (see below).

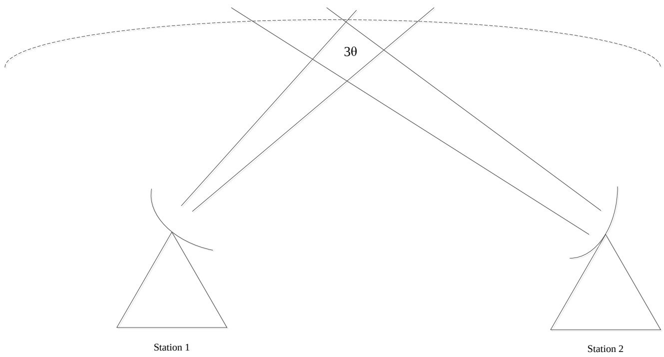



**Figure 29: Illustration for the scattering geometry**

The direction of the main beam of the earth station radiation pattern in Europe (typical elevation angle of 25-40 degrees and half power level beamwidth from 0.4 deg. to 1 deg.) will unlikely be combined by 3 θ with the beam of the receiving antenna pattern of the FS station (typical antenna gain 36.6 dBi, 42 dBi, 47 dBi).

Since, with the FSS and FS deployment model, the 3 θ scattering geometry is unlikely to occur, this interference mechanism will have limited effect

## 8.5 PRACTICAL MEASUREMENTS

In the framework of the studies described in this Report, two sets of measurements were provided and analysed.

### 8.5.1 Tests in the Jackson County test range

The first set of measurements was aimed at measuring the level of field strength generated by an FS stations and received by a sensor installed in proximity of an FSS station. It was conducted in LOS conditions; therefore, its results can be used to evaluate the feasibility of sensing in LOS and quasi-LOS conditions. For the generalisation to the NLOS case one should refer to the theoretical calculations provided in Section 8.2 and based on a research of the available literature for NLOS conditions. This set of measurements is described in Annex A7.1.

The measurements, in LOS conditions, achieved a sufficient margin for sensing to work, with an antenna with 20 dBi gain.

As expected, the headroom on the Sensor measurement is independent of the FS pointing.

### 8.5.2 Tests in Saint Petersburg

The second set of measurements was aimed at verifying the required sensing threshold for a sensor, in a real case scenario. The main objective of this study was to determine based on operational parameters of real FS systems in the considered frequency band to what measured power level should be sufficient to indicate with certainty that a given channel is occupied by FS system. Also this experiment was conducted under the assumption of LOS or quasi LOS conditions, because the difference between the propagation losses over the same path but at different frequencies was bound to 5 dB.

The study considered an implementation where the sensing mechanism is a band scanner that has a simple power measurement function. Such receiver should be measuring the received power of emissions in the 28 MHz channel, without any regard to the type of emission. The mechanism would scan the band 27.5-29.5 GHz with the aim of identifying channels that are used by the FS systems (in accordance with ECC Recommendation T/R 13-02 [22]).

The study consisted in determining, based on two instances of real FS equipment (a BWA P-MP system and a DRRS P-P system), the required protection ratio and the sensing threshold that the spectrum sensor would need to have in order to protect the FS systems. The results indicated that, under the adopted conditions, spectrum sensing is feasible, implementable in real case scenarios and could be designed and implemented so as to ensure automatic and periodic detection of channels employed by FS systems such as P-P and P-MP microwave links in directions where FSS ES transmit power is significant and might result in interference to FS receivers. Details of the test are provided in Annex A7.2.

## 8.6 COMPARISON OF STRATEGIES FOR SPECTRUM SENSING

In order to compare different strategies for spectrum sensing, a Monte Carlo simulation was carried out. For the discussion of the feasibility of sensing see section 8:

- The microwave link is fixed in the simulation space. Its parameters do not vary during the simulation. Its two ends are located in A and B and both A and B are fixed points.
- The FSS Earth Station is located in C. At each trial during the simulation, the position of C is varied around the MW link. The elevation of the satellite antenna is not varied during the simulation, but the azimuth is varied randomly between 0° and 360°. This is a simpler way to simulate a station with fixed azimuth and a random orientation of the MW link.
- At each trial, the following data are recorded:
  - Would the sensor in C be able to detect the power radiated from A?
  - Would the sensor in C be able to detect the power radiated from B?
  - Would the satellite earth station in C interfere with the receiver in A, if it transmitted?
  - Would the satellite earth station in C interfere with the receiver in B, if it transmitted?

The simulations were repeated for different types of microwave links and different types of satellite earth stations.

It assumed that the sensor adopts energy sensing. This is reasonable considering that the modulation and coding scheme of the FS link are not known a priori. When performing an energy detection of a signal, there is trade-off between a probability of false alarm and a probability of missed detection. The conditions of the trade-off become better with: a) a higher integration time b) a better C/N ratio. For the sake of simplicity, it is assumed that the sensing algorithms become reliable when the signal to be detected is 3 dB above the noise level of the sensor.

The following assumptions are also made:

- The sensor bandwidth is matched to that of the signal to be detected. This is an optimistic hypothesis and it is not given per se that this will be the case in reality, but one might assume that the sensor will shift its tuning range spanning the band in order to match the emissions of the MW link;
- The sensor has a scanning antenna, whose gain is varied in different simulations;
- The noise figure of the sensor is 6.5 dB.

Three sensing strategies are considered and compared:

- Strategy 1: the sensor senses all channels and if no power is detected in one channel, the satellite earth station can use it. This strategy is the most aggressive one. It is assumed that spectrum sensing would work even in the case of bistatic systems;
- Strategy 2: the sensor senses all the channels and if power is detected on any of them, the satellite earth station remains mute. This strategy is much more conservative;
- Strategy 3: the sensor senses the presence of each of the two stations of the FS link by means of its emission and, if the emission is detected, avoids emitting on its receiving channel. This strategy implies an a priori knowledge of the channel plan of the FS service in the band (see also general description in 8.1. The parameters of the sensor are described in Table 19.

**Table 19: Parameters of the spectrum sensor**

| Parameter | Value |
|---|---|
| Antenna gain | gain between 0-70 dBi gain tested |
| Noise figure | 6.5 dB |
| Sensing threshold | 3 dB above noise level |
| Bandwidth | 28 MHz |

The following parameters were taken for the FSS Earth Station.

**Table 20: Parameters of FSS Earth Station**

| Parameter | Value |
|---|---|
| Antenna diameter | 1.8 m |
| Antenna gain | 52.9 |
| Tx power | 7.1 dBW |
| Elevation | 30° |
| Azimuth | Random, uniformly distributed between 0° and 360° |
| Pattern | ITU-R S.465-6 [26] |
| BW | 320 MHz |

The simulation considers a point-to-point microwave link, whose characteristics are given in Table 21.

**Table 21: Parameters of the P2P microwave link**

| Parameter | Value |
|---|---|
| Antenna height | 15 m |
| Antenna pattern | ITU-R F. 699-8 [18] |
| Antenna gain | 43 dBi |
| Channel bandwidth | 28 MHz |
| Tx power | 30 dBm |
| Protection criterion I/N | -10 dB |
| Fade margin | 20 dB |
| Required C/N | 20 dB |
| Long-term interference power density | -147 dBW/MHz |

The output power of the FS assumed in Table 31 is not representative of the majority of FS links, see also Section 8.2.

The performance of spectrum sensing (or lack of it) is essentially due to propagation condition on the two paths AC and CB. To this end, propagation conditions are simulated as follows. For each trial of the Monte Carlo simulation, and for each of the two propagation paths, namely AC and CB. The propagation channel is simulated as it follows:

- Basic transmission loss in free space plus.

One edge obstacle, that causes a simple diffraction loss. The diffraction is modelled as an edge obstacle of random height, so that the normalised parameter $v = h\sqrt{\frac{2 \cdot (d1+d2)}{\lambda \cdot d1 \cdot d2}}$ has a uniform distribution between -5 and 5. Figure 30 below clarifies the formula:

- Slow fading, lognormally distributed (Gaussian in dB) in dB the variance is 4 dB.

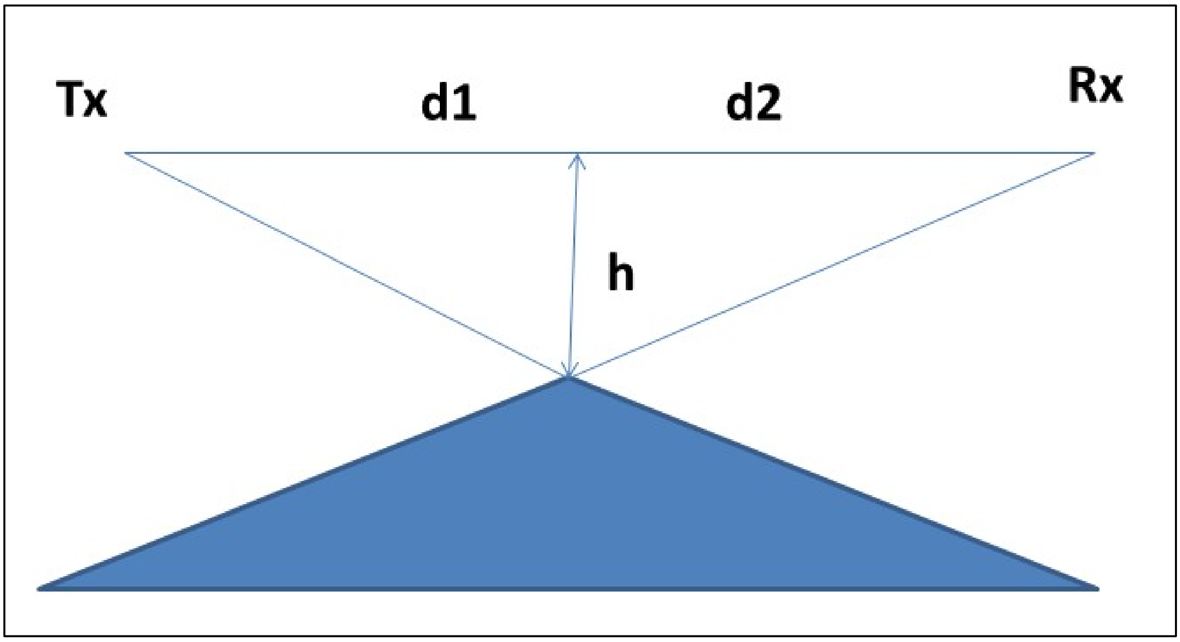



**Figure 30: Illustration of the diffraction effect**

The following set of figures show the performance of the three sensing strategies for an elevation angle of the earth station of 30 degrees, a noise figure of sensor equal to 6.5 dB and a number of iterations equal to 100000. The curves in the same figure show the probability of interference, as a function of distance between the FSS and FS middle point, for different values of the sensor antenna gain (the values are 0 dBi, 10 dBi, 20 dBi, 30 dBi, 40 dBi, 50 dBi, 60 dBi and 70 dBi)[4]. In the following figures the effect of multipath fading is modelled with a uniform random variable that varies between 0 and 25 in one case and 0 and 15 in the other.

[4] The multipath propagation component is NOT used in the calculation of interference at A or B of the MW link from sensor C.

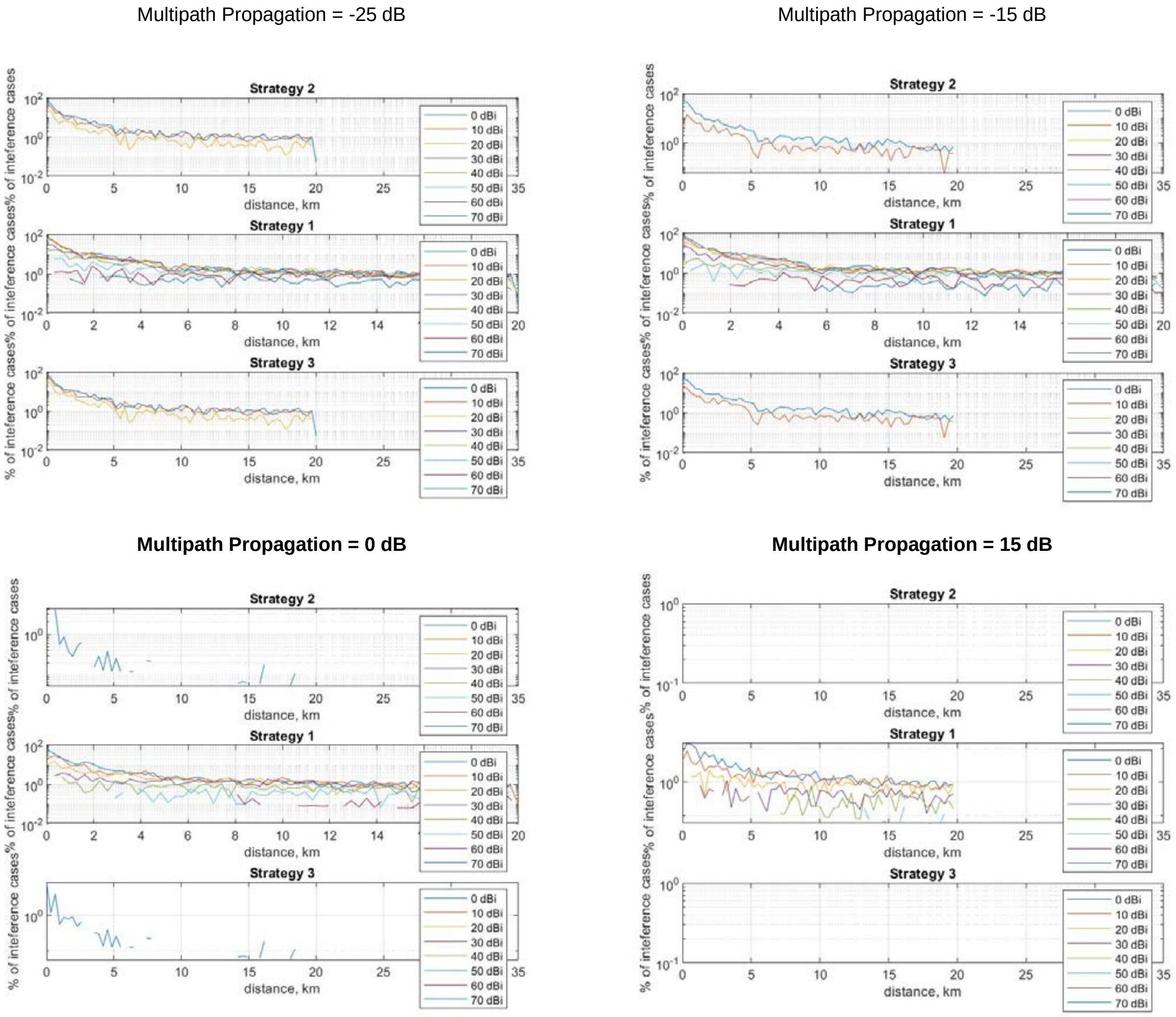



**Figure 31: Performance of the three sensing strategies**

The probability of interference decreases with increase in the value of multipath propagation. For the values of 0 dB and 15 dB, it is observed that the probability of interference is zero for strategy 2 and strategy 3 for with 0 dBi sensor gain.

It might be observed that as noise figure increases, the noise floor increases, thereby increasing the power above which a signal is detected at the sensor C. Therefore, there is a number of iterations in which a detected signal decreases. But this is not the only parameter which determines the probability of interference, it is a combination of factors which determines the probability of interference (see the illustration of the sensing approach on Figure 26)

The following set of figures is a simulation where the assumptions are the same as before, but the multipath fading is assumed to follow a Rayleigh distribution with scale parameter 0.7 in the range of -25 dB to +10 dB and the minimum elevation angle of the FSS Earth Station is variable, in order to have a sensitivity of the results in relation to the latitude of the earth station.

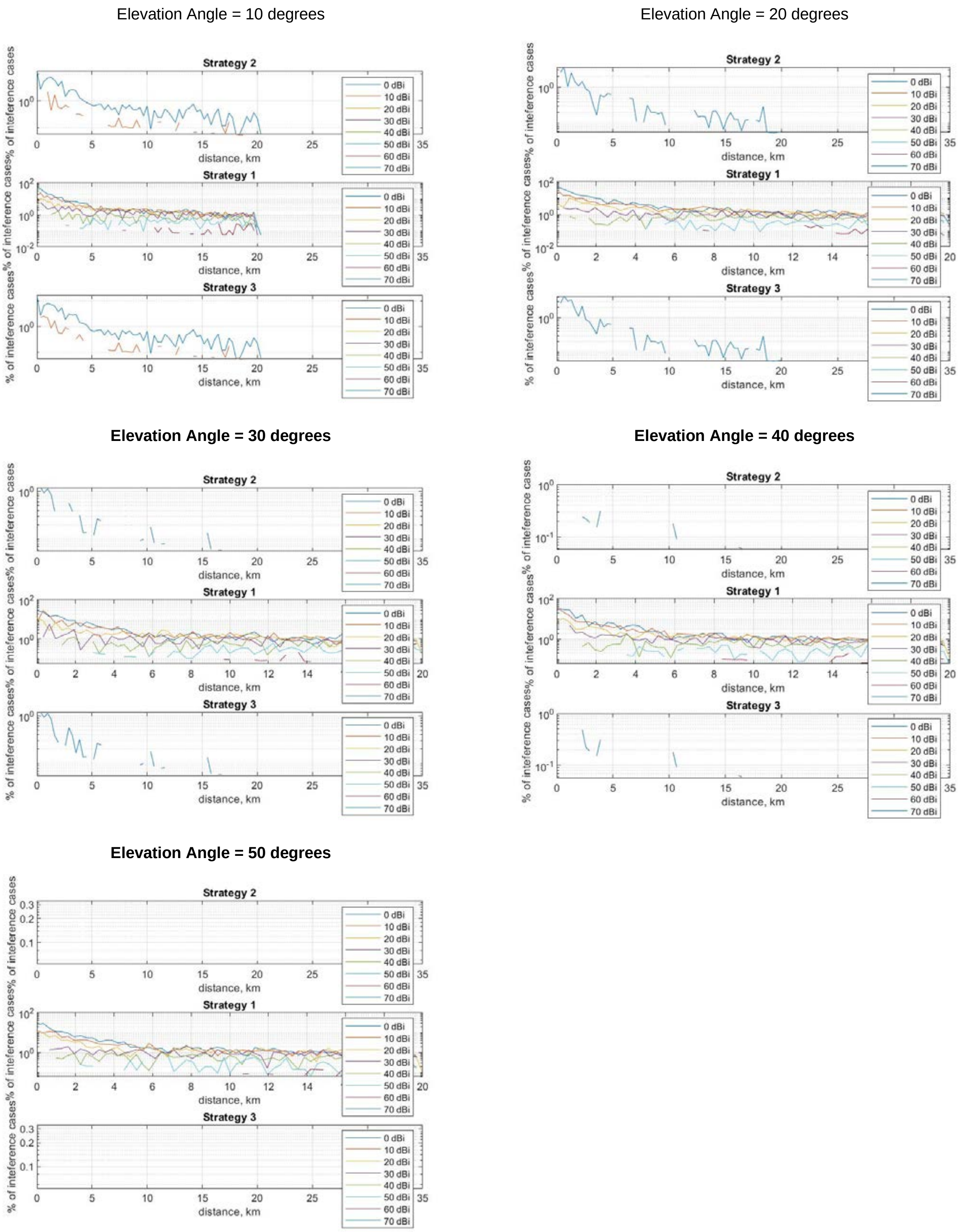



**Figure 32: Sensitivity to different Elevation Angles**

The figures above refer to a sensor with a noise figure of 6.5 dB; better performance would be obtained with an improved (lower) noise figure.

As it can be seen from the figures, strategy 2 and strategy 3 are relatively similar in their performance, and largely outperform strategy 1.

## 8.7 CONCLUSION

The combination of sensor antenna gain, sensor sensitivity and integration time are the main parameters to define the feasibility of the sensor. The improvement of the parameters mentioned is practically limited and the feasibility of the sensing concept is therefore depending on the possibility to design a fitting sensor.

In particular, the feasibility of sensing strongly depends on the value of the FS output power that needs to be detected. For a given FSS ES, if one sets the target of protecting any possible FS link potentially interfered with, detection should be performed below the noise floor.

Although sensing could be an effective interference mitigation technique under certain conditions, it is also recognised that a sensor threshold could be set at a level that does not protect 100% of operational FS links. In fact, Administrations may deem appropriate to use different values of FS output power for defining the requirements of the sensor, based on their deployment scenarios. In this case, the Report suggests means of improving sensing. This Report does not cover the issue of selecting an appropriate sensing threshold and the subsequent implementation of the sensor.

It is noted that the performance requirement of the sensor is a regulatory parameter that depends, inter alia, on the deployment scenario of the FS.

It is noted that in order to define a given performance requirement, there are in principle multiple choices for the actual implementation of the sensor. Moreover, the performance requirement itself is a regulatory aspect that must be defined before the sensor design and depends on information on actual deployment scenarios. These aspects were therefore not defined in this Report.

# 9 COGNITIVE RADIO AND GEO-LOCATION DATABASE TECHNIQUES

The use of geo-location database is often viewed as baseline techniques in cognitive radio systems. These techniques allow spectrum availability awareness, enabling licensing schemes such as Licenced Spectrum Access, Dynamic Spectrum Access, and license exempt.

These techniques require the FSS operator to access a list of RF technical and geographic characteristics of the Fixed Service which would enable the FSS network to optimise, hence, allowing uncoordinated FSS Earth Station deployment in the portions of the 27.5-29.5 GHz band identified for FS use without causing interference to FS operations.

It should be noted, that in some circumstances it might be not possible for the administration to provide necessary data in a publicly available database because of lack of information or confidentiality issues. For instance, the feasibility of geo-location database technique is limited in the cases in which the FS licensing is assigned by block, because no public information on individual links within the block would be available. Whilst the geolocation database techniques can maximise spectrum efficiency, it also relies on human input to ensure the Fixed Service technical information is regularly updated at an administration level and the FSS terminal would require regular updates to ensure that both services can operate in an interference free environment. Such a sharing technique can be used in conjunction with other techniques such as spectrum sensing.

Analysis software can be used to identify “white spaces” whereby uncoordinated FSS Earth Stations can operate. ECC Report 241 outlines how dynamic cognitive radio techniques can be applied in the 17.7-19.7 GHz FSS downlink band, although in this case the victim is the FSS Earth Station receiving interference from transmitting terrestrial fixed links. Such cognitive sharing techniques can also be applied to the portions of the 27.5-29.5 GHz band identified for FS use, where the FSS stations are in transmission mode, so the geo-location database would be required to protect existing fixed links from interference the FSS terminal. This technique is not dissimilar to those used to coordinate TV signals with IMT “white space devices” at frequencies under 10 GHz.

In order to decrease the probability of interference to FS, the uncoordinated FSS Earth Stations would implement mitigation techniques such as

1 Automatic Transmitter Power Control;

2 e.i.r.p. limited to the minimum necessary to fulfil the performance objectives of the FSS Earth Stations

On a technical level, assessing the interference between FSS transmitters to FS receivers in the portions of the 27.5-29.5 GHz band identified for FS use is similar to that currently used between fixed links. Therefore, a software module which can detect the aggregate level of the FSS power at the location of the FS (assuming full data integrity).

In order to implement this software, the following process is necessary:

1 The database is converted from its native format used by the administration into a format which is used by the interference calculation software using a “interface module”. It would be the administration/FS operator’s role to keep the database up to date.

2 The interface calculation software would interact with web interface, manage calculations and reports as well as completing and presenting the interference results.

3 The software module would be unique and can run on the administration website and provide a template to enter data and collates all technical inputs.

Typical Fixed Service inputs to the filing are as follows:

- Height of antenna above ground;
- Height of the station site above sea level;
- Azimuth and elevation (or associated GSO orbital location);
- Antenna gain pattern;

- Clutter losses per azimuth (if available);
- Frequency/channel plan;
- Geographical Coordinates;
- Receiver selectivity mask;
- Polarisation;
- Receiver noise power level;
- Calculation configuration: e.g. percentage of time for propagation calculations.;
- Outputs: file (e.g. csv) containing spectrograms of a resolution typically of 1 MHz across the bands with the level of interference predicted described below.

Three different options were discussed and can be summarised in the following table:

**Table 22: Options for implementing database techniques**

| Input data from user | Calculation results | Comment |
|---|---|---|
| Option 1:<br>Coordinates of FS victim station + pointing direction and antenna pattern | Spectrograph of interference across the whole uncoordinated 27.5-29.5 GHz band | Operations possible for all frequencies for a given location and direction where the interference threshold is low. |
| Option 2:<br>Coordinates of FS Victim, pointing direction, antenna pattern, interference threshold and desired FSS frequency assignment | Is the location OK or not?<br>i.e., is the interference received at the FS receiver below or above the defined interference threshold. | The deployment of FSS requires a large number of data points and will require full automation. The output could include a traffic light interference map identifying areas where interference is likely. |
| Option 3:<br>Area of interest, pointing direction, antenna pattern, threshold and desired FSS assignment. | Mapping of locations available for the frequency range | Allows precise mapping of the “white spaces” and assumes the software can work to 100 m resolution with large calculation volumes. |

In summary, cognitive radio sharing is one such spectrum sharing technique such that the FS and FSS can avoid co-frequency interference in the portions of the 27.5-29.5 GHz band identified for FS use and allow that both can exist in the same frequency band without further coordination. Whilst the method of sharing relies on FSS operating within “white space” frequencies can maximise spectrum efficiency, it also relies on human input to ensure the Fixed Service technical information is regularly updated at an administration level and the FSS terminal would require regular updates to ensure that both services can operate in an interference free environment. Such a sharing technique can be used in conjunction with other dynamic frequency access techniques.

# 10 OTHER PASSIVE MITIGATION TECHNIQUES

Passive techniques including building fences or placing absorbing material around the terminal to limit radiations in the horizontal directions can be used in order to mitigate FSS Earth Stations emissions towards Fixed Service stations

Passive techniques can be applied on a case by case basis. Depending on the relative satellite direction, the possibility to have an FS receiver in the direction of the earth station beam can vary drastically. These solutions can be explored for a limited number of cases where the local configuration is well contained:

- Sufficient land is owned by the terminal user to prevent close by installation of Fixed Service users;
- Terrain topology of neighbouring buildings provides masking or makes Fixed Service tower installation impossible (see illustration of different situations for VSAT in Annex 1)
- It should be noted that the implementation of passive mitigation techniques described above are only possible for the enterprise terminals, because it is likely be professionally installed;
- For terminal solutions, passive techniques are not applicable.

The following recommendations were considered as background information regarding shielding techniques in order to demonstrate the mitigation techniques ability to reduce separation distances and facilitate compatibility between considered services:

- Recommendation ITU-R S.1063: ‘It can be shown that nearly all these values for the required attenuation (0.01% of the time) would result in site separation distances of less than 100 km, in some cases much less. If, in addition, site shielding was available to provide additional isolation between the sites, even shorter separation distances would be necessary’;
- Recommendation ITU-R SF.1486 [29] contains the reference to the applicability of up to 40 dB shielding on VSAT stations. In this Recommendation, these stations operate at 20 degrees elevation considered. This shielding can be achieved with a physical metallic mesh or with existing terrain.

## 11 CONCLUSIONS

This Report considers the possibility of operation of typical uncoordinated GSO fixed satellite service (FSS) earth stations (user terminals) in the band segments where the FS is deployed (27.8285-28.4445 GHz and 28.9485-29.4525 GHz), to determine if opportunistic usage of this spectrum is possible. It analyses therefore the deployment of fixed service (FS) links within the CEPT described in ECC Report 173 [5] and the likelihood of interference into FS from FSS Earth Stations.

The Report explores the feasibility of using newly developed technologies to enable opportunistic use, by FSS Earth Stations that are not individually coordinated and licensed, in portions of the 27.5-29.5 GHz band currently identified for FS use under ECC Decision (05)01. New high throughput satellites (HTS) offer connection speeds up to 100+ Mbit/s. In order to provide such broadband connectivity to a large number of users, HTS systems use a number of innovative new technologies.

This Report does not propose to change the band plan contained in ECC Decision (05)01. Instead, it assumes that the entry of one service into another service's reserved spectrum is possible only on a non-interference basis, ensuring that the incumbent service in its reserved spectrum is protected from interference also with respect to its future development.

One important characteristic of both the FS and the FSS services operating in this band is that the antenna patterns at this frequency are highly directive (apart from P-MP base stations), meaning that the highest risk of interference occurs in a very limited range of azimuth and elevation angles.

The Report first analyses the existing usage of the band segments identified for use by FS in ECC Decision (05)01 within the 27.5-29.5 GHz band (27.8285-28.4445 GHz and 28.9485-29.4525 GHz). Currently under this ECC Decision, FSS also may access this 1120 MHz of spectrum on an individually licensed and coordinated basis.

MCL calculations show that the directivity of antennas operating in the FS portions of the 27.5-29.5 GHz band result in separation distances outside the main beam of the FS antenna in the range of 4.9 km at 5° azimuth offset to 0.3 km at 55°and above. In the case of alignment in the azimuthal plane, the separation distances in general will be higher, ranging from 0.4 km up to nearly 60 km, (depending on FSS Earth Station elevation angle). The results are summarised in sections 5.1 and 6.

In case of uncoordinated FSS ES deployment in an area containing a high density network of point to point links there is a potential degradation of the FS in terms of interference probability which should be addressed by using various interference mitigation techniques, as described below.

Finally, to address cases of potential interference, the Report analyses the effectiveness of active and passive mitigation techniques in protecting existing FS links, such as sense and avoid, the use of geolocation databases and shielding.

In general sense and avoid offers advantages over the geolocation database and shielding, because it does not require a precise and updated knowledge of the FS systems and it allows coexistence with FS future development. The sensing mechanism is based on the assumption that the channelization of the FS in the band is known in advance and that the links are bi-directional. Consequently, the feasibility of implementing spectrum sensing depends on the specific situation of each country.

In particular, the feasibility of sensing strongly depends on the value of the FS output power that needs to be detected. For a given FSS ES, if one sets the target of protecting any possible FS link potentially interfered with, detection should be performed below the noise floor. The combination of sensor antenna gain, sensor sensitivity and integration time are the main parameters to define the feasibility of the sensor. The improvement of the parameters mentioned is practically limited and the feasibility of the sensing concept is therefore depending on the possibility to design a fitting sensor.

Although sensing could be an effective interference mitigation technique under certain conditions (see Section 8), it is also recognised that a sensor threshold could be set at a level that does not protect 100% of operational FS links. In fact, Administrations may deem appropriate to use different values of FS output power for defining the requirements of the sensor, based on their deployment scenarios. In this case, the Report suggests means of improving sensing.

This Report does not cover the issue of selecting an appropriate sensing threshold and the subsequent implementation of the sensor.

The performance requirement of the sensor is a regulatory parameter that depends, inter alia, on the deployment scenario of the FS.

In order to define a given performance requirement, there are in principle multiple choices for the actual implementation of the sensor. Moreover, the performance requirement itself is a regulatory aspect that must be defined before the sensor design and depends on information on actual deployment scenarios. These aspects were therefore not defined in this report.

The report also considered hydrometeor scattering a possible mechanism impairing the performance of spectrum sensing and it was found that the influence of this phenomenon is limited.

Regarding the geolocation database approach, its feasibility / performance is subject to the issue of data integrity, availability and accuracy. Its overall feasibility will depend on the specific situation of each country.

Regarding additional passive mitigation techniques, shielding is the most effective, but requires professional installation and therefore in this report it has been considered only for enterprise terminals.

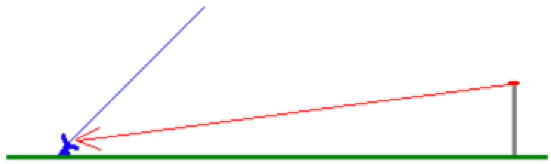
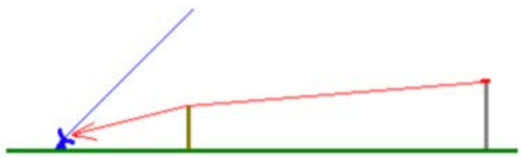
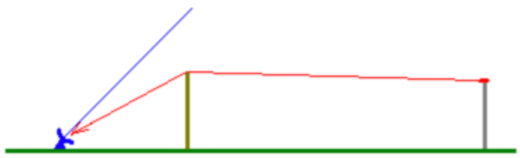
The mitigation techniques mentioned above should reduce the risk of interference into FS receivers to a point that use of FSS Earth Stations on an uncoordinated basis maybe feasible in these bands identified for FS use. Without those mitigation techniques uncoordinated use of these portions of the band by the FSS is not feasible.

The European Common Table of Allocations does not contain any allocation to the Mobile Service and ECC Decision (05)01 allows only FSS and FS in the 27.5-29.5 GHz band. The Report therefore does not analyse FSS coexistence with other services, nor would its results be applicable to them.

## ANNEX 1: SITE SHIELDING EXAMPLES

In order to reduce interference into satellite dish reception, the following methods described in the Table below have been developed [7]. These same techniques can be employed to protect FS stations from the interference coming from the earth stations.

**Table 23: Illustrations of different options for shielding**

<table>
<tr><th>Description</th><th>Illustrations</th></tr>
<tr><td>The idea of site shielding is to reduce the interference by physically obstructing the line of sight path from the interfering source to the dish. If the interfering source is visible from the satellite antenna as in top figure, interference may occur. Shielding would be employed along the red path to mitigate interference.<br><br>One way to do this is to move the dish to the back of some building or hill or by putting one or more walls, RF fences or earth banks in the way. The height of the shielding should obstruct the path between the transmitter and receiver. The losses in this arrangement are modelled using double knife edge diffraction theory.<br><br>The top of the obstruction or shielding is generally not made of metal but preferably some radio absorbing material (RAM).</td><td>1) Interference path not obstructed<br><br>2) Single wall obstruction leading to the reduction of unwanted signal<br><br>3) Larger angle across the top, significantly reduces interference<br><br>4) Usage of radio absorbing foliage also provides significant attenuation<br></td></tr>
</table>

## ANNEX 2: RESULTS OF EARTH STATION SHIELDING MEASUREMENT CAMPAIGN

The table below illustrates results of a measurement campaign carried out by one operator [8].

One can compare values of the expected signal calculated using a free space propagation model with the recorded signal. The last column of the table demonstrates additional losses of up to 42 dB was measured due to the presence of a roof top parapet (wall) on the building where the measured earth station was located.

**Table 24: Measurements results summary**

| Measurement Location | Measurement Height (m) | Free Space Loss (dB) | Recorded Signal (dBW) | | | Expected Signal (dBW) | Additional Losses (dB) | | |
|---|---|---|---|---|---|---|---|---|---|
| Site 1 | 10 | 97.86 | -137.51 | | | -115.67 | | | 21.84 |
| Site 1 | 2 | 97.86 | -158.19 | NF | | -115.67 | | >> | 42.52 |
| Site 2 | 10 | 98.30 | -149.10 | | | -116.11 | | | 32.99 |
| Site 2 | 2 | 98.30 | -155.56 | NF | | -116.11 | | >> | 39.45 |
| Site 3 | 10 | 103.43 | -141.30 | | | -123.24 | | | 18.06 |
| Site 3 | 2 | 103.43 | -159.65 | NF | | -123.24 | | >> | 36.41 |
| Site 4 | 10 | 107.46 | -133.25 | | | -125.27 | | | 7.98 |
| Site 4 | 2 | 107.46 | -160.00 | NF | | -125.27 | | >> | 34.73 |
| Site 5 | 10 | 111.46 | -140.68 | | | -129.27 | | | 11.41 |
| Site 5 | 2 | 111.46 | -147.78 | | | -129.27 | | | 18.51 |
| Site 6 | 10 | 112.33 | -144.95 | | | -130.14 | | | 14.81 |
| Site 6 | 2 | 112.33 | -154.82 | | | -130.14 | | | 24.68 |
| Site 7 | 10 | 110.59 | -155.96 | NF | | -128.40 | | >> | 27.56 |
| Site 7 | 2 | 110.59 | -158.19 | NF | | -128.40 | | >> | 29.79 |
| Site 8 | 10 | 109.03 | -158.63 | NF | | -126.84 | | >> | 31.79 |
| Site 8 | 2 | 109.03 | -158.63 | NF | | -126.84 | | >> | 31.79 |
| Site 9 | 10 | 111.04 | -158.10 | NF | | -128.85 | | >> | 29.25 |
| Site 9 | 2 | 111.04 | -159.44 | NF | | -128.85 | | >> | 30.59 |
| Site 10 | 10 | 112.47 | -158.60 | NF | | -130.28 | | >> | 28.32 |
| Site 10 | 2 | 112.47 | -158.77 | NF | | -130.28 | | >> | 28.49 |
| Site 11 | 10 | 98.87 | -157.48 | NF | | -116.68 | | >> | 40.80 |
| Site 11 | 2 | 98.87 | -158.78 | NF | | -116.68 | | >> | 42.10 |

It is important to note that these measurements were of an in-situ antenna with parapet walls designed for aesthetic screening, not RF screening and a gap in the parapet was present along a range of azimuths which resulted in higher recorded signal values in that range.

# ANNEX 3: COMPARISON BETWEEN THE SHORT-TERM AND THE LONG-TERM PROTECTION CRITERIA

For the protection of the FS, two protection criteria are compared, one short-term and the other on long-term. These criteria are being used together with a propagation model (namely ITU-R P. 452) that in its turn used the percentage of time as an input parameter. Thus, it is not self-evident which protection criterion is the most stringent. This annex summarises results of investigations demonstrating an impact of both criteria on sharing studies.

The values for the two criteria are:

- Short-term: p=0.001% of the time and I/N = + 9 dB;
- Long-term p=20% of the time and I/N = -10 dB.

When switching from the long-term to the short-term studies, two major changes need to be taken into account in the interference calculation:

- The change protection criterion value.

The long-term protection criterion is I/N = -10 and the short-term criterion is I/N = +9 dB. When considering this change only, this would make lower separation distances because of an increase of the threshold by 19 dB. However, the second change in the time percentage is also important:

- The change of time percentage to input in propagation model P.452:

The following plot shows the difference in attenuation based on the P.452 vs distance. This makes a great impact on the results.

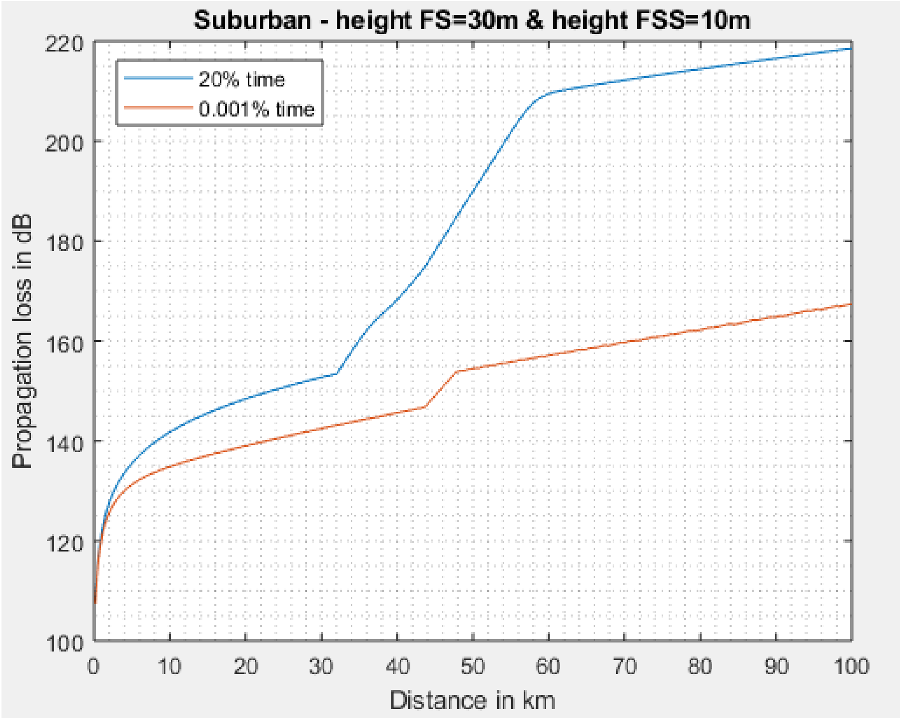
The increase in the value of the protection criteria will tend to reduce the separation distance. However, this increase of that protection criteria is linked to a decrease of the percentage of time which is linked to a lower propagation loss for a given distance. The following case tries to assess the point at which one of the factors becomes dominant.

## A3.1 CASE 1 (FS AND FSS ES ARE AT DIFFERENT HEIGHTS):

**Table 25: Parameters used in calculations for case 1**

| Parameter | Value |
|---|---|
| Frequency | 28.5 GHz |
| Type of path: | Land path, over flat terrain, inland |
| Antenna height TX | 10 m |
| Antenna height RX | 30 m |
| Antenna gain TX | 30 dBi |
| Antenna gain RX | 30 dBi |
| Percentage of time | 20% and 0.001% |
| Representative latitude | 51° |
| Atmospheric conditions | T=15°, pressure=1013; No=328, deltaN=53 |

Suburban case is presented in the figure below:



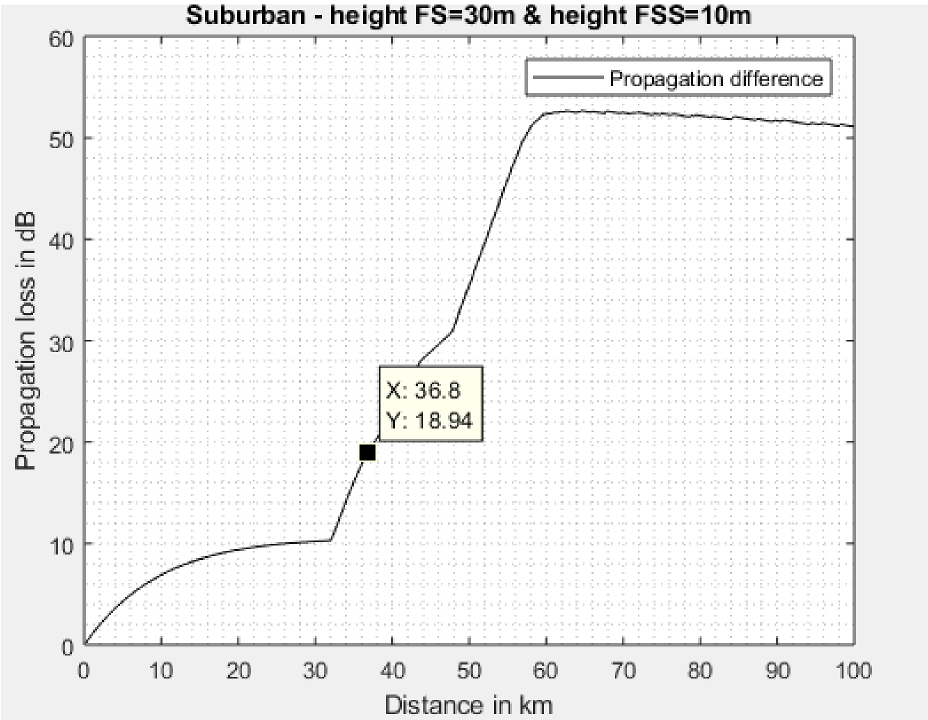
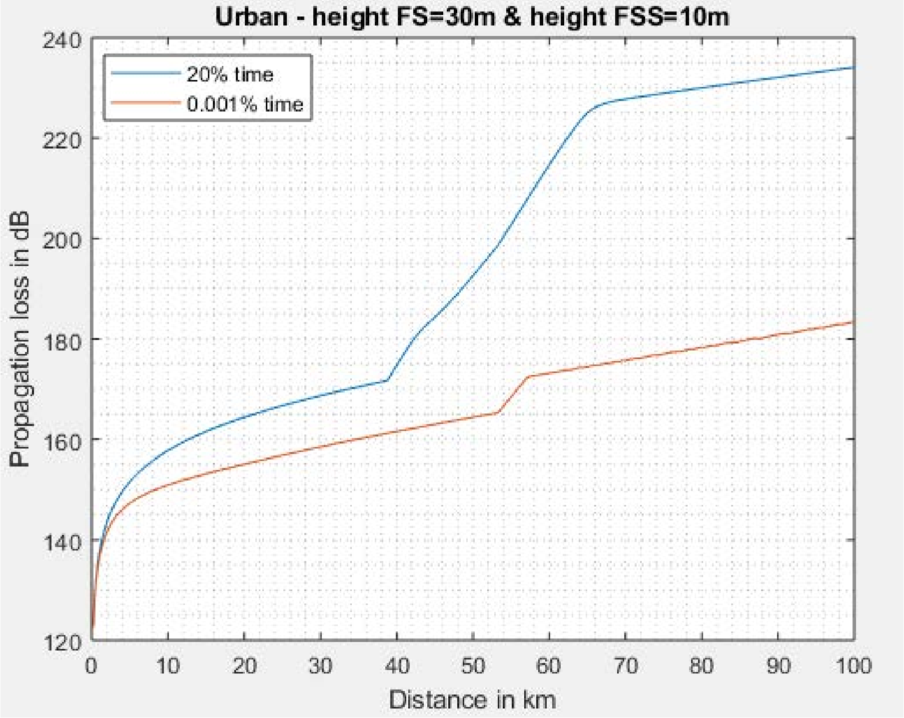




**Figure 33: Top figure is attenuation vs. distance with 20% and 0.001% of time (I/N protection criteria isn't included). Bottom figure is the difference between long-term and short-term criteria**

For this case, at 36.8 km distance, the attenuation difference between the short-term (0.001%) and long-term (20%) propagation loss is around 19 dB (difference between I/N = -10 dB and I/N = +9 dB). This corresponds to a separation distance of 36.8 km as shown above.

Therefore for the combination of heights shown in Table 26, for distances greater than 36.8 km, the analysis using the short-term protection criteria will yield worse results than the analysis with the long-term protection criteria. For distances shorter than 36.8 km, it is the other way around with the analysis using the long-term protection criteria yielding the worst-case results.

Urban case is presented in below figure:



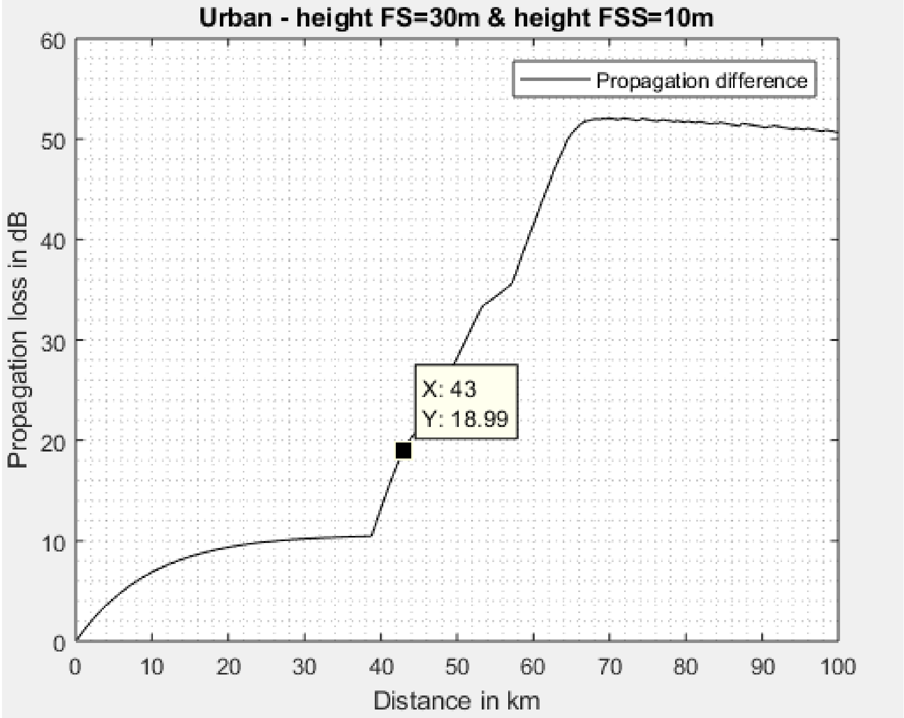




**Figure 34: Top figure is attenuation vs. distance with 20% and 0.001% of time (I/N protection criteria isn't included). Bottom figure is the difference between long-term and short-term criteria**

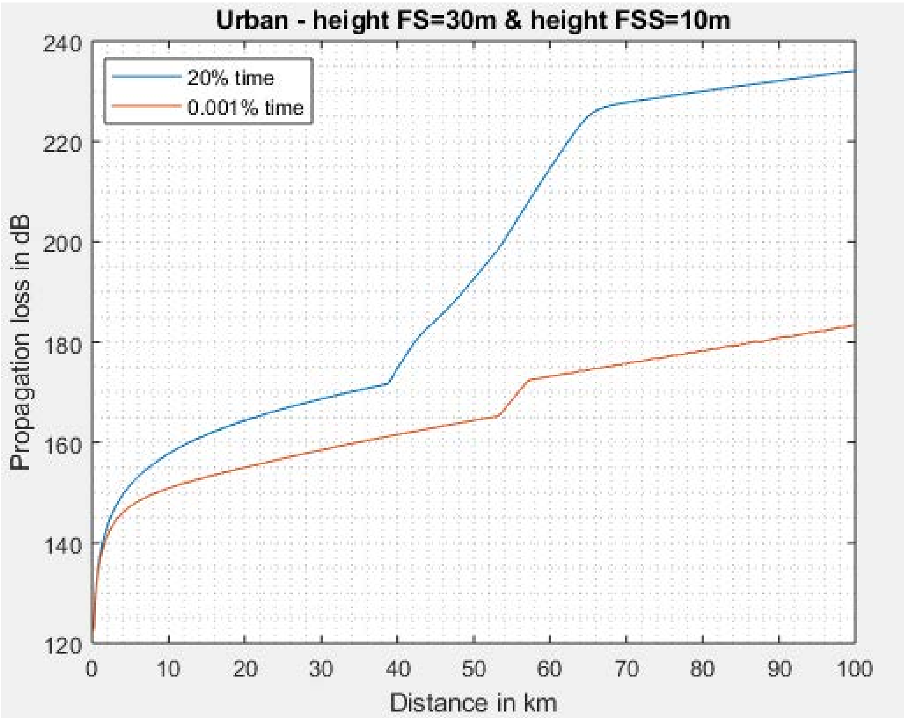
For this case, at 43 km distance, the attenuation difference between the short-term (0.001%) and long-term (20%) propagation loss is around 19 dB (difference between I/N = -10 dB and I/N =+9 dB). The same explanation is applicable for this case as the one presented in the suburban case. Therefore for the combination of heights shown in Table 27, the long-term analysis will yield the worst-case result when distances are below 43 km and the short-term analysis will yield the worst-case result when distances are greater than 43 km.

### A3.2 CASE 2 (FS AND FSS ES ARE AT THE SAME HEIGHTS)

**Table 28: Parameters used in calculations for case 2**

| Parameter | Value |
|---|---|
| Frequency | 28.5 GHz |
| Type of path | Land path, over flat terrain, inland |
| Antenna height TX | 10 m |
| Antenna height RX | 10 m |
| Antenna gain TX | 30 dBi |
| Antenna gain RX | 30 dBi |
| Percentage of time | 20% and 0.001% |
| Representative latitude | 45° |
| Atmospheric conditions | T=20°, pressure=1013; $N_o$=330, deltaN=60 |

- Suburban case is presented in the figure below:



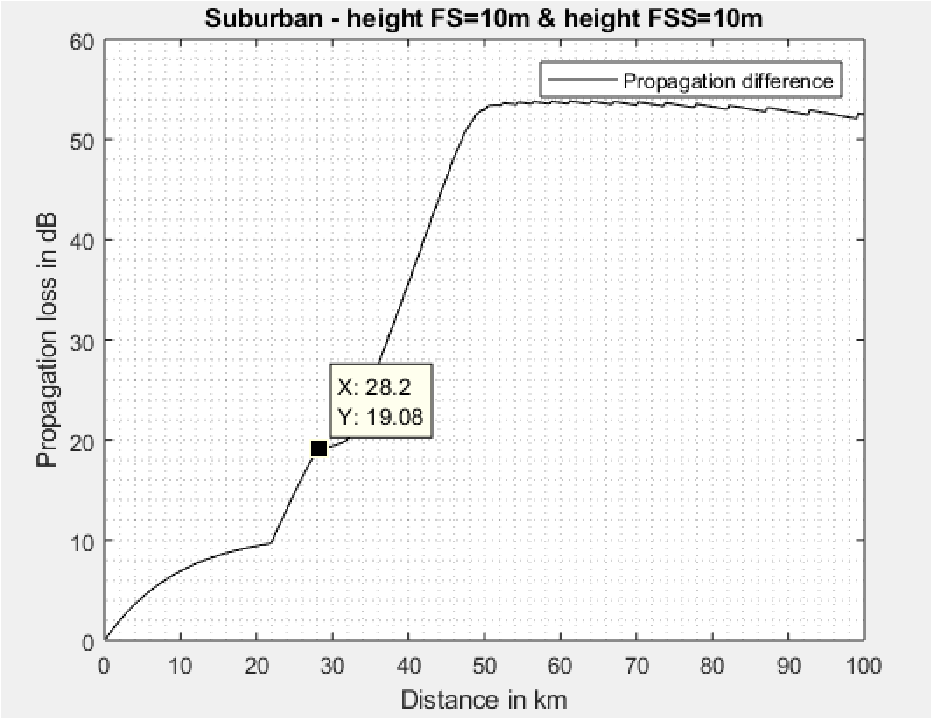



**Figure 35: Top figure is attenuation vs. distance with 20% and 0.001% of time (I/N protection criteria isn't included). Bottom figure is the difference between long-term and short-term criteria**

For this case, at 28.2 km distance, the attenuation difference between the short-term (0.001%) and long-term (20%) criteria is around 19 dB (difference between I/N = -10 dB and I/N =+9 dB). Therefore for the combination of heights shown in the Table 28, long-term analysis will yield the worst-case result when distances are below 28.2 km and the short-term analysis will yield the worst-case result when distances are greater than 28.2 km.

# ANNEX 4: DESCRIPTION OF VARIOUS PROPAGATION EFFECTS FOR COGNITIVE RADIO TECHNIQUES

## A4.1 INTRODUCTION

The Cognitive Radio Sense and Avoid approach to mitigating interference from Fixed-Satellite Service (FSS) user terminals to Fixed Service (FS) terrestrial systems in the Ka-band is presented in this Report. The basic theory for the Sense and Avoid approach was presented along with the equations that define the model. The model showed that the approach was independent of the path loss between the FSS and the FS as long as reciprocity[5] of the link held. Indeed, the test data shown in ANNEX 2 show that this assumption is valid. In that ideal environment, the Sense and Avoid concept was validated. However, it is recognised that, in a real deployment of FSS and FS terminals, the impacts of propagation effects must be considered where reciprocity may not be present. This Report discusses qualitatively how these impacts affect the Sense and Avoid approach but no quantitative results are presented.

The objective of this Annex is to qualitatively discuss the types of propagation effects that are called out in Recommendation ITU-R P.530-17 [12]. In particular, those propagation effects which are frequency dependent are not reciprocal in the paired-band links to and from the FSS and the FS. The overall conclusion of this Annex is that, while some field testing is helpful to validate the impact of the propagation effects, a qualitative assessment can identify effects that must be considered and overcome by mitigation techniques with added margin to the sensing link budgets. Sensor design must consider these effects.

## A4.2 PROPAGATION EFFECTS TO CONSIDER

The effects considered in this section are taken from the list in Recommendation ITU-R P.530-17[12]. Some of the propagation effects that are clearly not of concern such as minor variations due to frequency for rain or particles are not considered. Other atmospheric multipath and refraction fading on the relatively short links being considered are also not specifically examined. The list has been reduced to the primary concerns, diffraction fading and surface reflection multipath fading.

### A4.2.1 Diffraction Fading

In realistic environments, the number, height, and shape of diffracting objects is highly variable and accurate modelling is not possible. However, to understand how diffraction fading impacts the link budgets, a relatively simple example of a single diffracting object between the FSS and the FS is useful. Note that the largest part of the signal strength reduction due to diffraction is reciprocal and only the frequency dependent differences will impact the Sense and Avoid scheme.

In standard references, the diffraction loss is described in terms of a dimensionless Fresnel-Kirchoff diffraction parameter, $\upsilon$, given by

$$\upsilon = h\sqrt{\frac{2\bullet(d1+d2)}{\lambda\bullet d1\bullet d2}}$$

Where:

- h is the height of the diffracting edge above the line of sight;
- d1 and d2 are the distances to the diffracting edge from the FSS and FS respectively;
- $\lambda$ is the wavelength of the radio wave.

This parameter is used in most diffraction assessment models. While the formula for the diffraction parameter is an approximation, a rough idea of the frequency dependence can be inferred from some calculation

[5] Any impairment that equally contributes to both the FS to the FSS sensor link budget and to the FSS as an interferer to the FS link budget (reciprocity) appears in the same way as a change in range would in the overall analysis and so does not impact the sense and avoid calculations. It is only where the impairment contributes unequally to one link or the other that it must be explicitly addressed.

examples which use this parameter. For example (using a simple web-based calculator), with a single Knife Edge barrier at a height of between 10 and 30 meters located half way between an FSS and a FS at a 1 km distance, the diffraction loss difference for a 1 GHz paired band separation at Ka-band is 0.15 dB. Other range and barrier height examples show a similar difference. For all practical purposes, the model indicates that the deviation from reciprocal path loss for diffraction in the frequencies of the paired band case is insignificant.

### A4.2.2 Fading Due to Multipath from Surface Reflection

The largest concern for the paired band Sense and Avoid technique is the variation in the effective path loss due to the surface reflection fading at the paired frequencies. Since the fading loss is highly dependent on the phase of the multiple reflected, received signals, the added losses due to multipath at the receive locations are, for all practical purposes, independent. In the analysis contained in this Report, the difference in path loss in the two directions contributes directly to the fading margin needed in the FSS sensor, i.e. the fading margin at the FSS sensor is a statistical combination of the difference (the mean fade value of the links can be considered a common path loss and does not contribute to the required margin) of two independent contributors.

In a review of the literature on multipath, surface reflective fading for radio channels, a distinction is made for Line-of-Sight (LOS) channels where a direct path between the transmitter and receiver exists and Non-LOS channels where all of the signal power arriving at the receiver comes from reflected power. In terms of the statistical models for these conditions, the common practice is to use a Rician Channel model for the LOS case and a Rayleigh Channel model for the NLOS case. Since reflected signals (particularly at higher frequencies) are significantly attenuated, the path loss assumptions in the LOS and NLOS cases are modelled differently as well. This will impact the qualitative analysis here since while the variation in Rayleigh channels is more significant than the Rician Channel, the range at which the NLOS signal can be received is significantly less than the signal with a LOS path between the transmitter and the receiver.

All literature sources studied the two types of fading phenomena: large-scale and small-scale fading for both NLOS (non-line of sight) and LOS (line of sight) environments in the 28 GHz frequency band.

#### *A4.2.2.1 Large-scale fading*

Large-scale fading is the result of signal attenuation due to signal propagation over large distances (hundreds of wavelengths) and diffraction around large objects in the propagation path. Multipath fading in this type of fading phenomena is accounted for by Log-normal shadow fading model.

**Table 29: Summary table of measurements results for LOS/NLOS path loss**

| First Author | NLOS path loss | LOS path loss | Comments |
|---|---|---|---|
| Azar [14] | 51-156 dB for Tx-Rx separation varying from 1 m to 200 m | 70-116 dB for Tx-Rx separation varying from 1 m to 200 m | Studies performed in an urban environment (NYC)<br>High probability of outages for cell radius greater than 200 m |
| Nguyen [15] | 70–149 dB for Tx-Rx separation varying from 1 m to 1400 m | 66-132 dB for Tx-Rx separation varying from 1 m to 1400 m | Valid for distances up to 1400 m in urban environments<br>NLOS path loss is also dependent on the height of transmitter |
| Zhang [16] | 130-143 dB for Tx-Rx separation varying from 80 m to 1000 m | 103-133 dB for Tx-Rx separation varying from 80 m to 1000 m | Valid for distances from 80 m to 1000 m in suburban environments<br>ABG model is chosen as it has the least RMSE |

#### *A4.2.2.2 Small scale fading*

This phenomenon is used to describe the signal level at the receiver after encountering obstacles near (in the order of several wavelengths to fractions of wavelengths) the receiver. It is the type of the fading which occurs due to the scattering of the signal into a large number of rays at the receiving end arriving from all possible directions. The signals add in and out of phase giving rise to amplitude fluctuations.

Multipath fading in this type of fading phenomena is usually represented using the following models:

- Rician fading:
- Rayleigh fading.

M.K. Samini et al [11] considered small-scale multipath fading using the Rician model and results presented for both co-and cross-polarisation scenarios. The distances from the TX antenna to centre of the RX local area ranged from 8 m to 12.9 m.

**Table 30: Summary of K-factors for the Rician distributions**

| K- factor (dB) | V-V | V-H |
|---|---|---|
| LOS | 9-15 | 3-7 |
| NLOS | 5-8 | 3-7 |

Where K-factor = signal power in dominant component (LOS component) / local-mean scattered power. This shows that the signal strength is the strongest for LOS co-polarisation scenarios for this phenomenon.

M.K. Samini et al. [11], presents both theoretical and measured fading information. The measurements were done at the New York University Brooklyn campus for both the LOS and NLOS environments. The results show that in 99.7% of the measurements, the NLOS fading was less than 15 dB and the LOS fading was less than 8 dB. In the NLOS case, these results exhibited performance about 10 dB better than the pure Rayleigh model. For the LOS case, the results tracked the Ricean model with a K-factor (ratio of dominant path power to the average of reflected path powers) in the range of 10 to 15 dB.

It is also known from other studies conducted by authors [11] that the effective Path Loss Exponent (PLE) that describes the NLOS propagation in a urban or suburban environment is on the order of 4 (signal energy falls off as the fourth power of the range) as opposed to the LOS PLE which is very close to 2 (free space model). So, while the fading depths are more severe for the NLOS case, designing fading margin to cover the NLOS more extreme fading may not be necessary due to the very limited range of NLOS propagation – there may be other ways to mitigate interference in these few cases such as based on the FS locations.

The design of sensors to be used at the FSS ES will need to either have adequate detection margin to account for ~15 dB of unbalance due to fading (through high gain antennas or using extended measurement times) or make use of known fade mitigation techniques such as diversity reception. Diversity antennas in this frequency band will likely become common and relatively inexpensive through technologies. Also, by examining the relationships developed in this Report, shielding and beamforming approaches for the FSS ES will diminish the interference power toward the FS and provide added margin to overcome the uncertainties in fade depths.

### A4.3 MITIGATION APPROACHES

As preparations for sensor design and field testing are being planned, several fade mitigation approaches will be considered to arrive at a cost-effective solution for the sensor to be used at the FSS to implement the Sense and Avoid approach. As alluded to above, these mitigation techniques include:

- Sensor antenna spatial diversity to mitigate fade impacts;
- Improved energy detection algorithms using longer integration times and time diverse sampling;
- Added FSS shielding or beam shaping to reduce interference power;
- Cooperative sensing and usage of the FS database where possible at a local level.

# ANNEX 5: RESULTS FOR THE DETERMINISTIC APPROACH USING HIGHER TRANSMIT E.I.R.P.

The FSS Earth Station (user terminal) elevation angle used in this study varies from 10 to 50 degrees. The calculated maximum separation distance between an FSS Earth Station and the FS receiver depends on the antenna pointing angles between the stations and the deployment scenario.

Note that calculations assumed that the FSS Earth Station transmitter is pointing directly towards the Fixed Service receiver in azimuth; i.e. no azimuthal separation is considered in the MCL calculations (see Figure 7). Such an alignment would, in practice, be extremely rare (as shown in Figure 7) and is used only as a preliminary step in the analysis. It does not represent realistic deployment scenarios.

Note that for this approach, the higher power range from Table 1 is considered for the calculation of the separation distances.

## A5.1 RESULTS FOR FS P-P USING THE DETERMINISTIC APPROACH

For this study, the following FS P-P parameters were considered:

- Max gain of 47 dBi and a minimum elevation of 0 degrees;
- ITU-R F.699 antenna pattern;
- 30 m antenna height.

### A5.1.1 Enterprise FSS Earth Station (1.8 m)

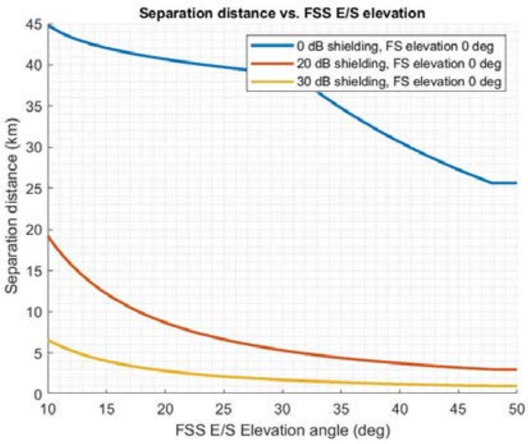
The FSS Earth Station bandwidth over which the transmitted power to the 1.8 m antenna would be spread is 320 MHz with a max power spectral density of -10.9 dB(W/MHz). The calculations also take into account that for antennas located on the roof of a building, shielding of up to 30 dB can be provided when a roof parapet or safety wall at the borders of the building exists or when the antenna is mounted on the side of a roof or building (see a description of the measurements report in Annex 2). The amount of shielding achievable depends on the relative positioning of the parapet between the FSS transmitter and the FS receiver. The step size in calculations is limited by the nominal distances according to the clutter model of P-452. Therefore, the step size for urban and suburban was 0.05 km.

Figure 36 shows the range of separation distances between FSS Earth Station and FS P-P receiver for FSS antenna heights placed at 2 m, 10 m, and 30 m, for urban case, and at 2m and 10 m, for suburban case. The FS P-P receiver antenna height is assumed to be 30 above ground for all deployment scenarios. Note that the FS elevation angle considered to be either 0 degrees for  worst-case analysis.

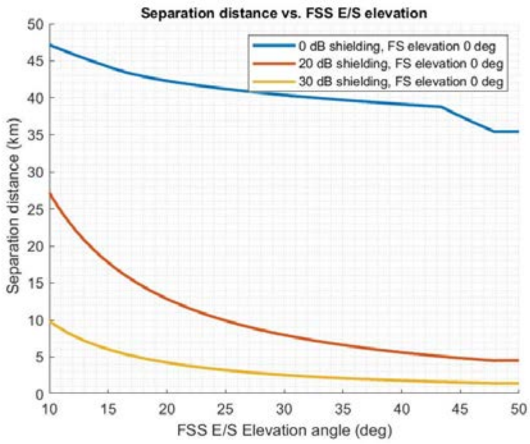
Different shielding solutions have been considered giving (i.e., 0 dB, 20 dB and 30 dB attenuation) depending on the amount of needed attenuation in the different scenarios. Shielding is considered feasible for this larger class of earth station since they will be a used in specialised applications instead of as a mass-market product.

**1.8 m Diameter FSS ES antenna → FS P-P**
**(Separation distances (km) vs. FSS ES elevation angles (degrees))**
**In cases of main beam to main beam alignment in azimuth plane**

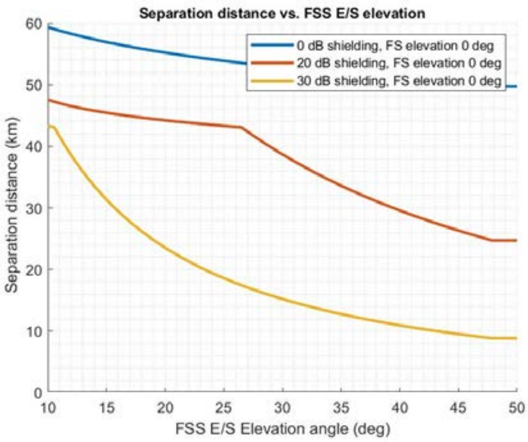
**Urban (Antenna Height = 2 m)**



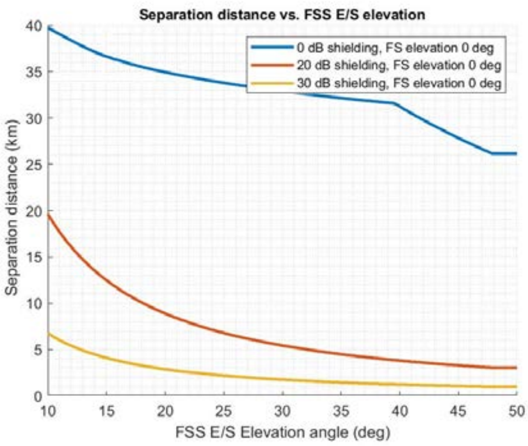

**Urban (Antenna Height = 10 m)**




**Urban (Antenna Height = 30 m)**




**Suburban (Antenna Height = 2 m)**




**Suburban (Antenna Height = 10 m)**

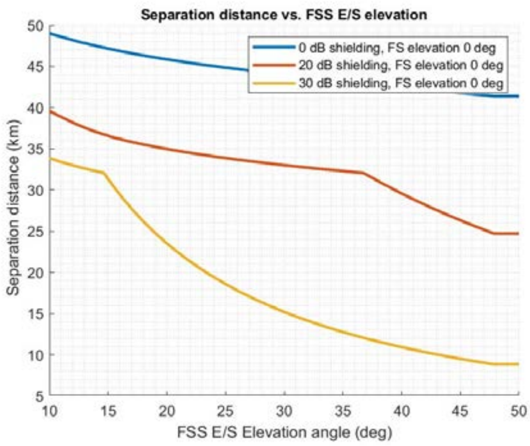



**Figure 36: Separation distance in cases of main beam to main beam alignment in the azimuth plane between FSS ES transmitter (1.8 m) and FS P-P receiver for urban/suburban deployment**

#### *A5.1.1.1 Summary results for the 1.8 m FSS Earth Station*

This section summarises the results of MCL calculations (see illustration in Figure 36) where both antennas are looking at each other in the azimuthal plane, therefore no azimuthal off-axis discrimination is applied in the calculations.

The maximum value of the separation distance represents the case of no shielding and FSS Earth Station elevation angle of 10°, whereas, the minimum value of the range represents the case of 30 dB shielding factor and FSS Earth Station elevation angle of 50°. As seen from the figures above, when the FSS Earth Station elevation angle increases, the separation distance decreases significantly.

Note that to consider the clutter model, it was assumed that the distance step size was set greater or equal to the nominal distance from the clutter model in ITU-R Recommendation P.452-16 (see Table 5), hence the resulting lower bound nominal distances presented in the table below (i.e., < 0.04 km)

In addition, when considering placing of antennas on the roof of a building, shielding up to 30 dB can in most cases be provided depending on the presence of a roof parapet.

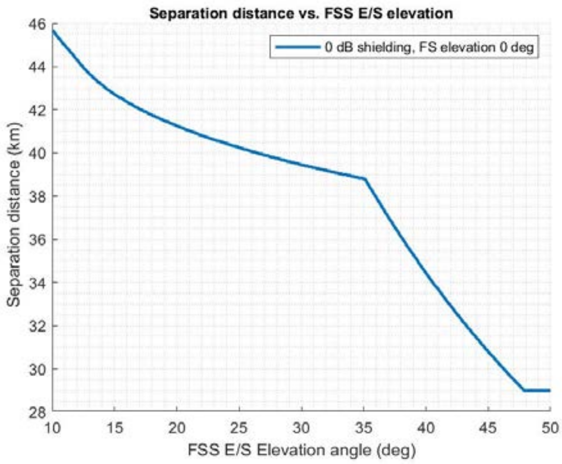
### A5.1.2 FSS Earth Station (0.75 m)

The FSS Earth Station bandwidth over which the transmitted power to the 0.75 m antenna would be spread is 320 MHz with a max power spectral density of -11.1 dB(W/MHz). Calculations performed without shielding for residential antennas.

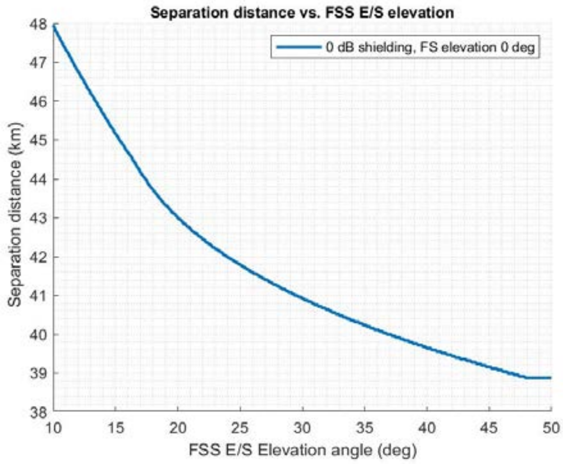
The following figures show the range of separation distances between FSS Earth Station and FS P-P receiver for FSS antenna heights placed at 2 m, 10 m, and 30 m, for urban case, and at 2 m and 10 m, for suburban case. The FS P-P receiver antenna height is assumed to be 30 above ground for all deployment scenarios. Note that the FS elevation angle is considered to be either 0 degrees for  worst-case analysis.

**Diameter FSS ES antenna → FS P-P**
**(Separation distances (km) vs. FSS ES elevation angles (deg))**
**In cases of main beam to main beam alignment in the azimuth plane**

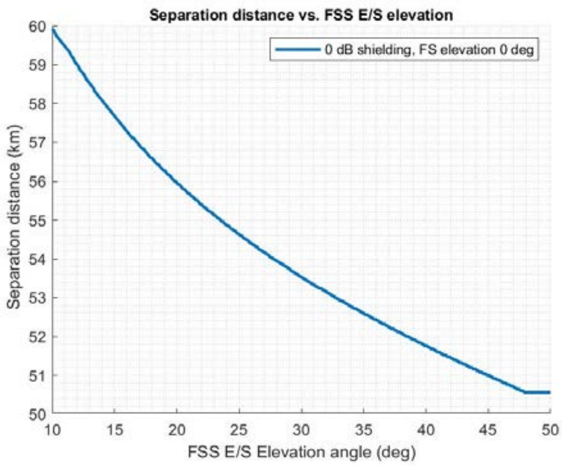
**Urban (Antenna Height = 2 m)**



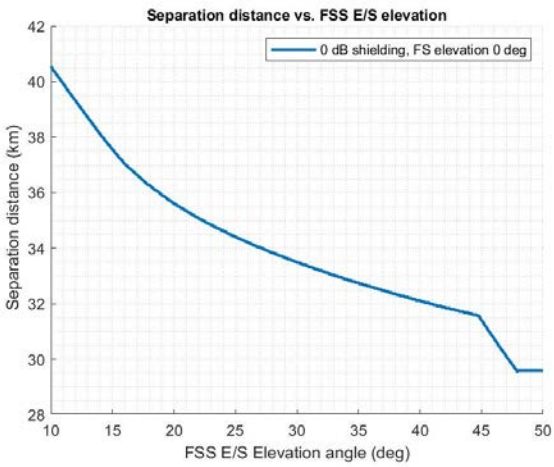

**Urban (Antenna Height = 10 m)**




**Urban (Antenna Height = 30 m)**




**Suburban (Antenna Height = 2 m)**




**Suburban (Antenna Height = 10 m)**

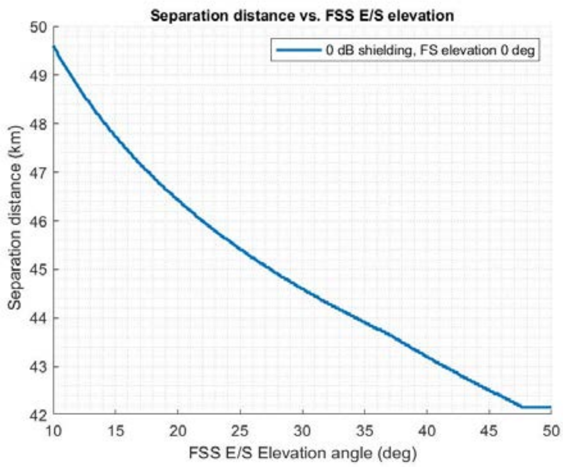



**Figure 37: Separation distance between FSS ES transmitter (0.75 m) and FS P-P receiver for urban/suburban deployment**

#### *A5.1.2.1 Summary results for the 0.75 m FSS Earth Station*

This section summarises the results of MCL calculations (see illustration in Figure 37) where both antennas are looking at each other in the azimuthal plane, therefore no azimuthal off-axis discrimination is applied in the calculations.

The range of maximum separation distances depends on the FSS Earth Station antenna height and the off-axis angle between FS and FSS Earth Station. Note that shielding has not been considered for this type of FSS Earth Station antenna type. As seen from the figures above, when the FSS Earth Station elevation angle increases, the separation distance decreases significantly.

Note that to consider the clutter model, it was assumed that the distance step size was set greater or equal to the nominal distance from the clutter model in Recommendation ITU-R P.452-16.

## A5.2 RESULTS FOR FS P-MP USING THE DETERMINISTIC APPROACH

For this study, the following FS P-MP parameters considered are

- Max. gain of 47.1 dBi and a minimum elevation of 0 degrees for omni terminal and;
- Max. gain of 17 dBi and a minimum elevation of 0 degrees for sectoral antenna (900 sector);
- ITU-R F.699 antenna pattern for terminal antenna;
- ITU-R F.1336 antenna pattern for sectoral antenna;
- 30 m antenna height.

It can be seen that FS P-MP for terminal antenna and FS P-P share the same parameters (i.e., max gain and antenna pattern are the same). As the separation distance between an FSS Earth Station and the FS P-MP receiver depends on the antenna pointing angles between the stations and the deployment scenario, separation distances for these two cases for every deployment scenario will be the same. Therefore, FS P-MP for terminal antenna was not considered for this analysis.

The separation distance considers with the maximum long-term interference-to-noise ratio (i.e., I/N = -10 dB) in the following sections. The FS P-MP receiver elevation angle is 0 degrees and the FSS Earth Station elevation angle varies from 10 to 50 degrees.

The separation distance between an FSS Earth Station and the FS P-MP receiver depends on the antenna pointing angles between the stations and the deployment scenario.

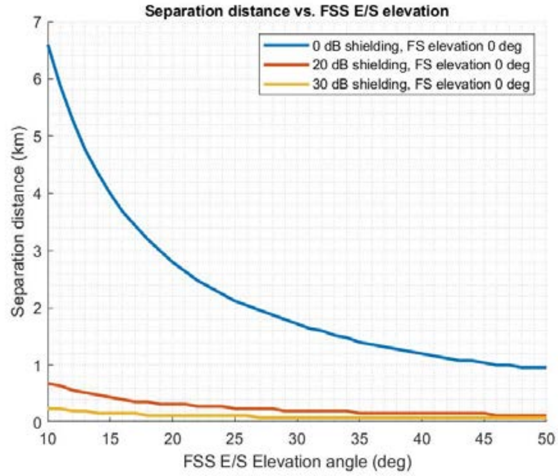
Note that it is considered that the FSS Earth Station transmitter is pointing directly towards the Fixed Service receiver in azimuth.

### A5.2.1 Enterprise FSS Earth Station (1.8 m)

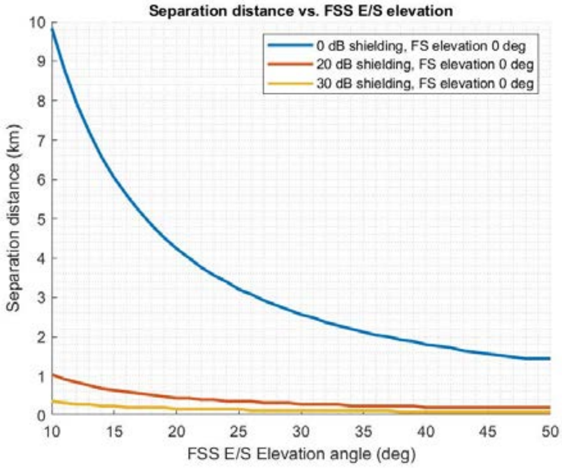
The FSS Earth Station bandwidth over which the transmitted power to the 1.8 m antenna would be spread is 320 MHz with a maximum power spectral density of -10.9 dB(W/MHz). Note that shielding up to 30 dB can be used around the FSS Earth Station in order to reduce unwanted energy in the direction of FS P-MP terminals and reduce the separation distance.

**1.8 m Diameter FSS ES antenna → FS P-MP**
**(Separation distances (km) vs. FSS ES elevation angles (deg))**

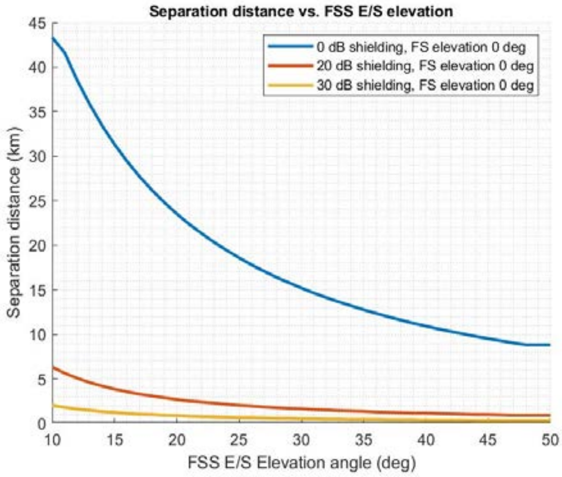
**Urban (Antenna Height = 2 m)**



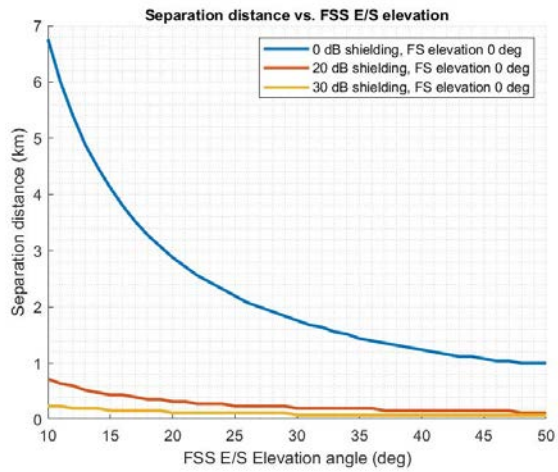

**Urban (Antenna Height = 10 m)**




**Urban (Antenna Height = 30 m)**




**Suburban (Antenna Height = 2 m)**




**Suburban (Antenna Height = 10 m)**

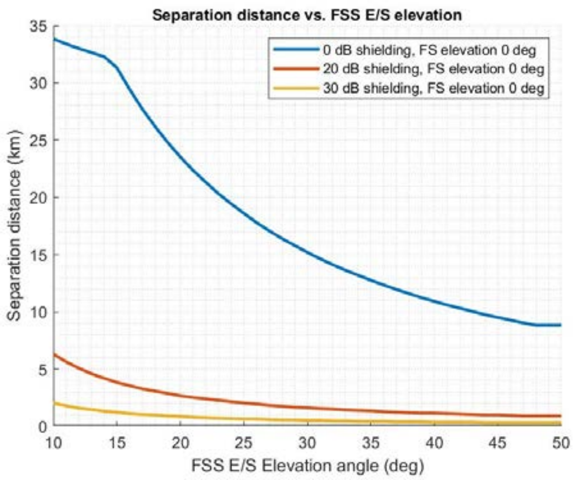



**Figure 38: Separation distance between FSS ES transmitter (1.8 m) and FS P-MP receiver for urban/suburban deployment**

#### *A5.2.1.1 Summary results for the 1.8 m FSS Earth Station*

This section summarises the results of MCL calculations (see illustration in Figure 38) where both antennas are looking at each other in the azimuthal plane, therefore no azimuthal off-axis discrimination is applied in the calculations.

The range of separation distance depends on the shielding factor, FSS Earth Station antenna height, and the off-axis angle between FS and FSS Earth Station.

The maximum separation distance of the range represents the case of no shielding and FSS Earth Station elevation angle of 10°, whereas, the minimum separation distance of the range represents the case of 30 dB shielding factor and FSS Earth Station elevation angle of 50°. As seen from the figures above, when the FSS Earth Station elevation angle increases, the separation distance decreases significantly.

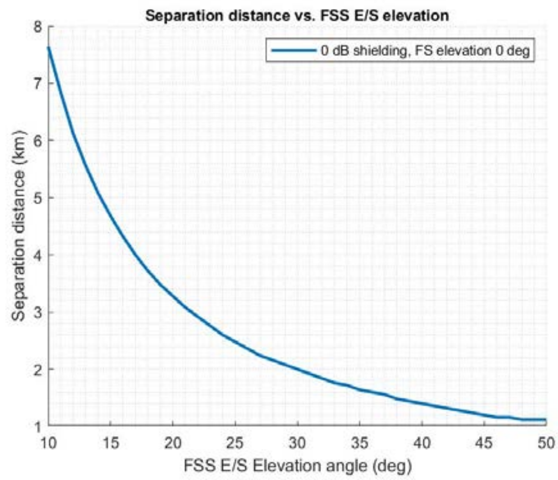
Note that to consider the clutter model, it was assumed that the distance step size was set greater or equal to the nominal distance from the clutter model in Recommendation ITU-R P.452-16 (see Table 5).

### A5.2.2 Residential FSS Earth Station (0.75 m)

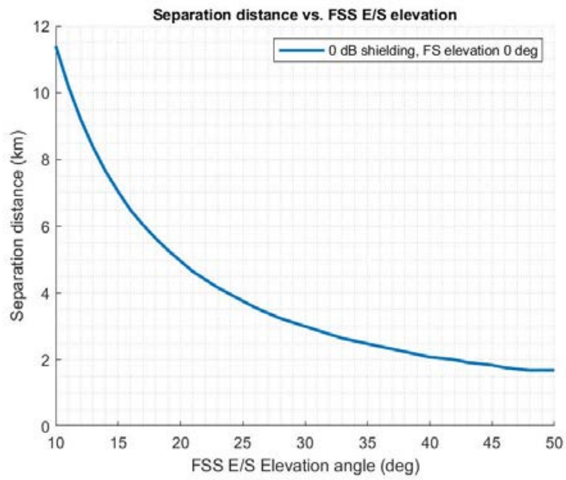
The FSS Earth Station (user terminal) bandwidth over which the transmitted power to the 0.75 m antenna would be spread is 320 MHz, resulting in a maximum power spectral density of -11.1 dB(W/MHz). The long-term FS protection criteria of I/N= -10 dB for 20% of the time was used in the calculations. No shielding is considered for this type of residential antenna.

**0.75m Diameter FSS ES antenna → FS P-MP**
**(Separation distances (km) vs. FSS ES elevation angles (deg))**
**In cases of main beam to main beam alignment**

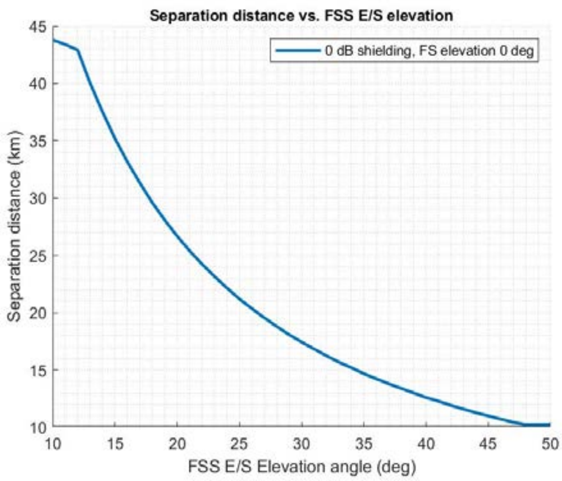
**Urban (Antenna Height = 2 m)**



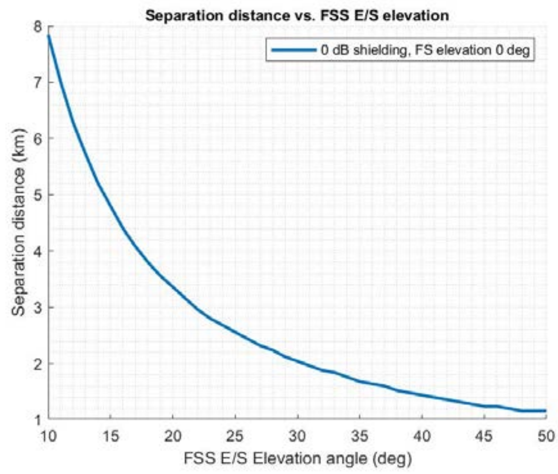

**Urban (Antenna Height = 10 m)**




**Urban (Antenna Height = 30 m)**




**Suburban (Antenna Height = 2 m)**




**Suburban (Antenna Height = 10 m)**

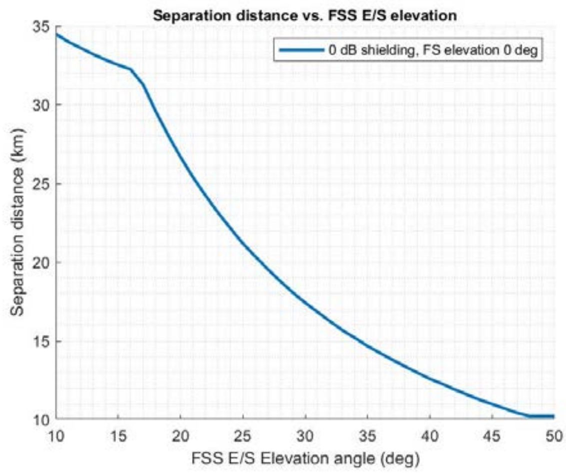



**Figure 39: Separation distance between FSS ES transmitter (0.75 m) and FS P-MP receiver for urban/suburban deployment**

#### *A5.2.2.1 Summary of the results for the 0.75 m FSS Earth Station*

This section summarises the results of MCL calculations (see illustration in Figure 39), where both antennas are looking at each other in the azimuthal plane, therefore no azimuthal off-axis discrimination is applied in the calculations.

The range of separation distances depends on the FSS ES antenna height and the off-axis angle between FS and FSS ES. Note that shielding has not been considered for this type of FSS ES antenna type. As seen from the figures above, when the FSS ES elevation angle increases, the separation distance decreases significantly.

Note that to consider the clutter model, it was assumed that the distance step size was set greater or equal to the nominal distance from the clutter model in Recommendation ITU-R P.452-16.

## A5.3 CONCLUSION

This MCL approach is a worst-case assumption, as the FSS Earth Station transmitter is pointing directly towards the Fixed Service receiver in azimuth.

The range of separation distances depends on the FSS ES antenna height and the off-axis angle between FS and FSS ES (and on shielding when applicable).This approach is unrealistic and the probability of this scenario happening is extremely low. Therefore, Monte Carlo analysis (see section 7) is necessary to illustrate the realistic scenario by randomly altering the bearing between the FSS Earth Station transmitter and Fixed Service receiver. The statistical approach demonstrates that the actual separation distance required in real-world conditions is quite small. In addition, it also demonstrates that the probability of the MCL analysis occurring is remote, i.e., a single case out of 100.000 deployment cases.

# ANNEX 6: ANALYSIS OF PROBABILITY OF INTERFERENCE FROM ONE FSS EARTH STATION TO MULTIPLE FS STATIONS

The first study in this annex (A6.1) is based on a specific real deployment in one city. The assumptions used in the study do not fully correspond to the parameters assumed in the main body of the Report as being generally representative of FS systems. The difference is mainly the antenna height of some stations and the antenna patterns.

The second study (A6.2) simulated progressively increasing numbers of FS terminals to analyse the change in probability of interference from FSS with increased numbers of FS terminals.

## A6.1 ANALYSIS ON A REAL DEPLOYMENT

The purpose of this analysis is to evaluate interference probability for a network of P-P links from one FSS ES. A real network example of Vilnius city has been selected containing 88 links in an area of 63,25 km2.

Two types of FSS ES parabolic antenna are used in this analysis: 0.75m and 1.8m.

### A6.1.1 FSS ES terminal technical characteristics

Recommendation ITU S.465-6 has been considered for antenna pattern side-lobes of FSS ES while the main lobe has been calculated according to ITU-R Report S.2196.

Antenna patterns for Enterprise and Residential usage are depicted in Figure 40.

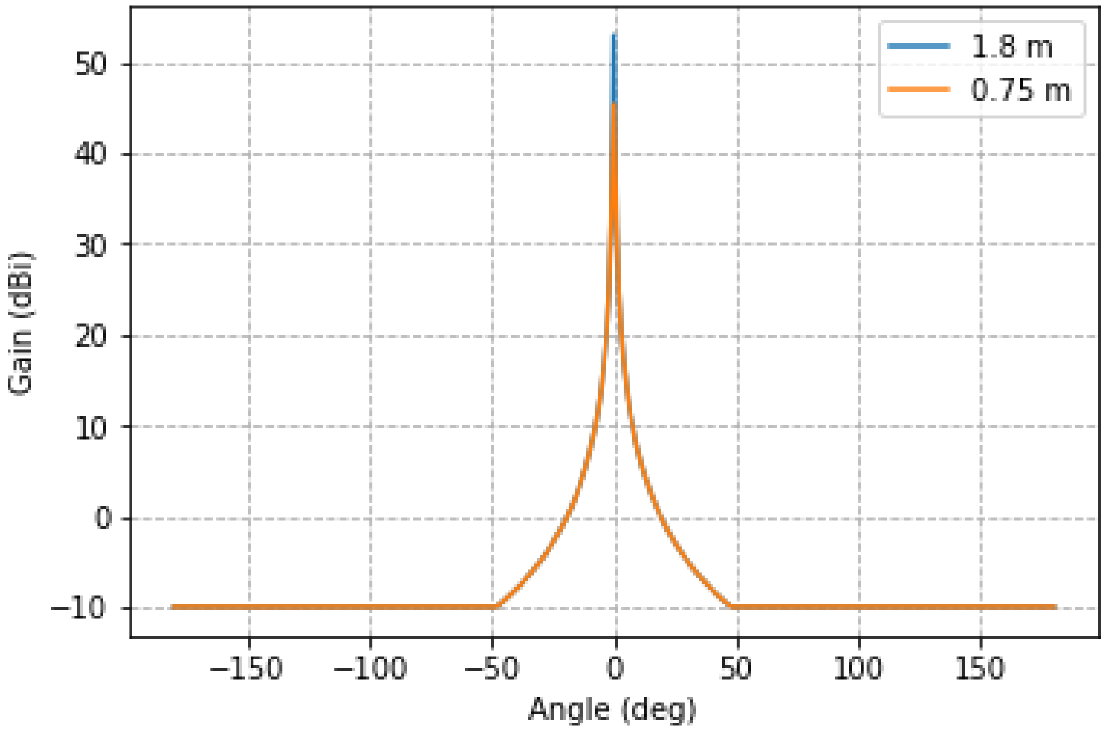



Figure 40: FSS antenna pattern for different antenna diameters (enterprise and residential)

FSS ES antenna height is generated randomly in the interval of 2-30 m for urban case scenario and of 2-10 m for suburban case scenario.

For the purpose of this analysis 1 FSS ES for Vilnius city centre area (about 63,25 km2) for 20000 Monte Carlo iterations is used. A square of Vilnius urban area, between the listed points, had been taken into consideration (see Figure 41):

- Point A – (54.65, 25.21);
- Point B – (54.65, 25.32);
- Point C – (54.73, 25.32);
- Point D – (54.73, 25.21).

### A6.1.2 FS characteristics considered in analysis

For the calculations total of 88 links have been used which corresponds to a real case scenario in Vilnius city (see Figure 41).

**Table 31: FS P-P parameters in the band 27.5-29.5 GHz**

| FS RRL characteristics | |
|---|---|
| Antenna pattern | ITU-R F.699-8 |
| Antenna height | 10-81 m |
| Average antenna height | 34 m |
| Bandwidth | 69 links: 28 MHz<br>19 links: 56 MHz |
| Antenna gain | 38 dBi |
| Polarisation | V, H |
| Receiver noise figure | 6.5 dB |
| I/N | -10 dB |

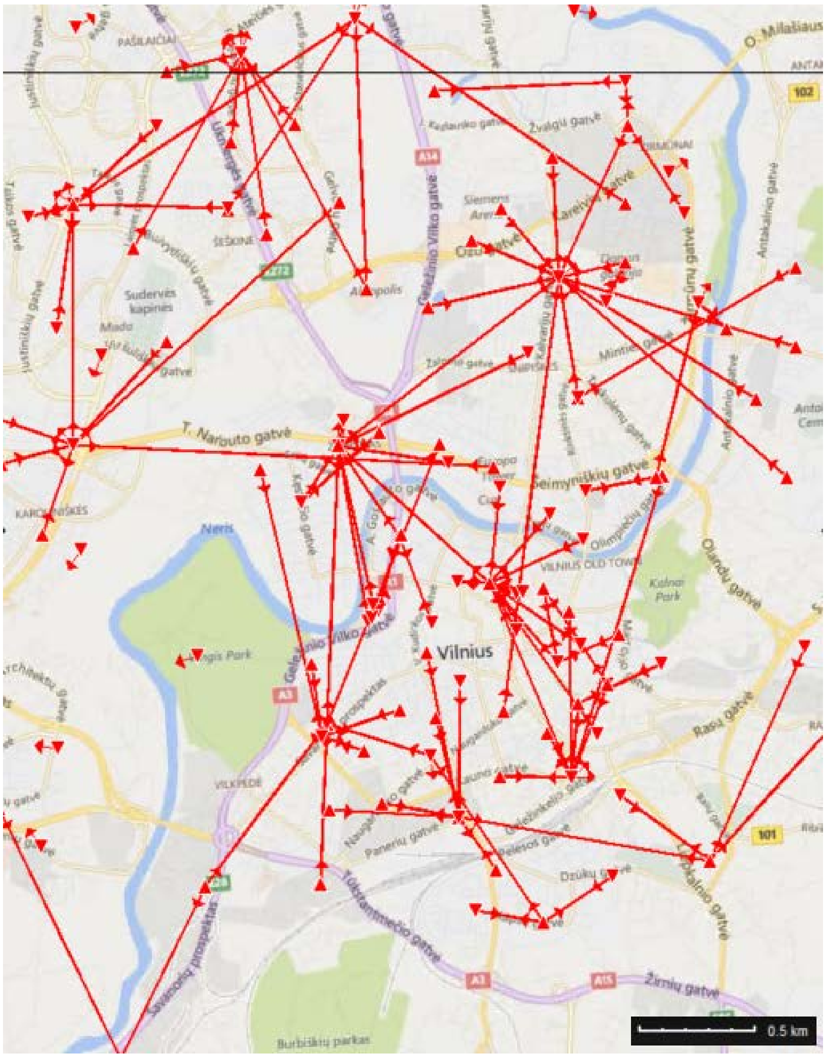



**Figure 41: FS P-P links in Vilnius city (band 27.5-29.5 GHz)**

Antenna pattern of FS was created according to Recommendation ITU-R F.699-8.

### A6.1.3 Methodology for interference analysis

Interference probability evaluation is implemented by performing Monte Carlo simulation with 20000 simulation runs for Vilnius city. There are different sets of calculations for residential and enterprise antenna types for urban and suburban clutter environments. For every Monte Carlo iteration, a new FSS ES is generated with randomly assigned characteristics:

- Location;
- Antenna height;
- Elevation angle;
- Azimuth.

Interference evaluation scheme is illustrated in Figure 42. The interference probability to FS receiver is calculated based on FS protection criteria, which, in this case is I/N = -10 dB for long-term protection criteria. Path loss of FS radio link is calculated according to Recommendation ITU-R P.452-16 . Power loss due to the polarisation mismatch is 1.5 dB.

All calculations have been performed in Python. For certain types of calculations Pycraf library was used since it already has implemented Recommendations ITU-R P.452-16 and ITU-R F.699-8.

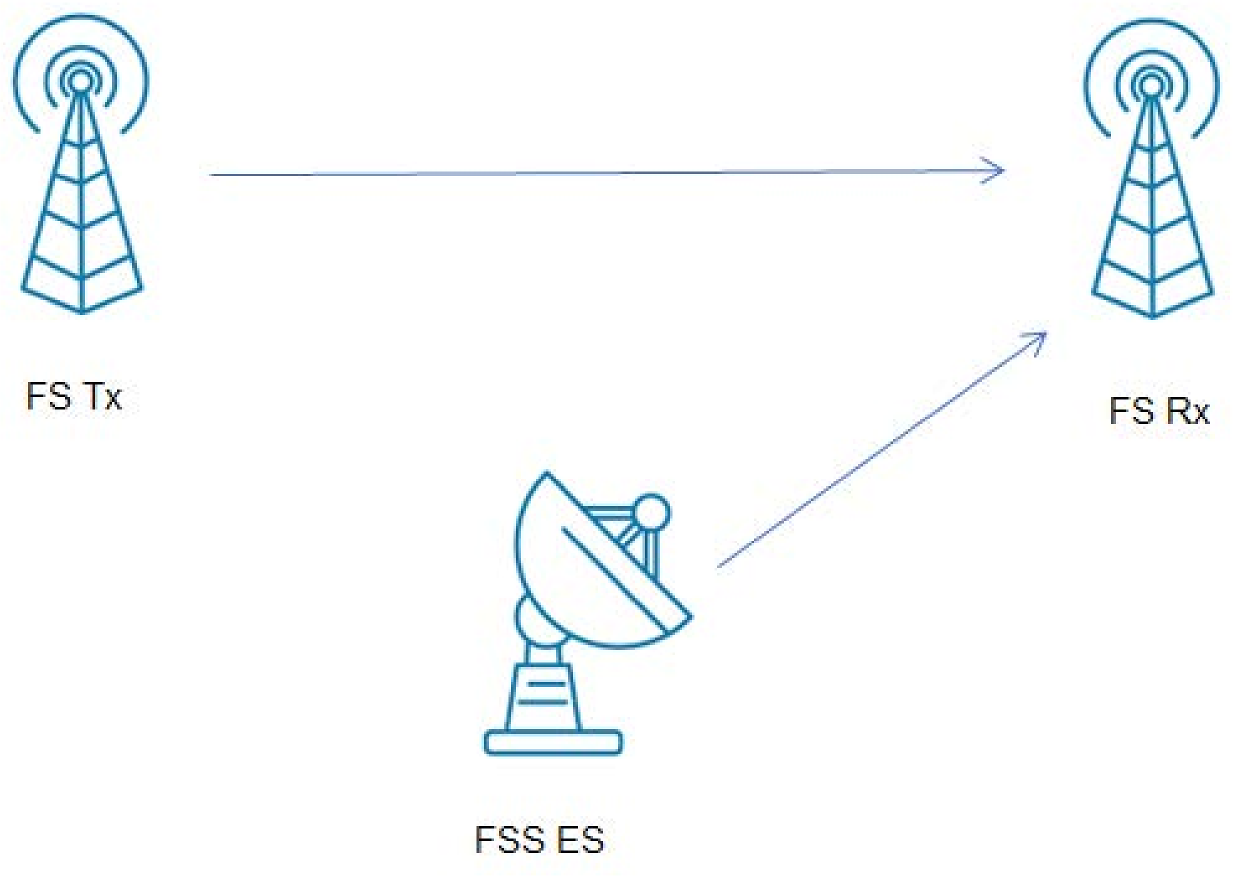



Figure 42: Interference between FSS ES and FS Rx evaluation scheme

### A6.1.4 Clutter loss (ITU-R P.452-16)

Reception of signal by the antennas that are surrounded by local ground clutter, like buildings or vegetation, are affected by additional clutter losses. For clutter loss predictions GlobeCover'09 clutter dataset is selected as it is open source and offers complete and wide coverage. Recommendation ITU-R P.452-16 proposes that the loss due to protection from local clutter is given by the expression:

$$A_h = 10.25 F_{fc} e^{-d_k} \left(1 - \tanh\left[6\left(\frac{h}{h_a} - 0.625\right)\right]\right) - 0.33 \text{ [dB]}$$

$$F_{fc} = 0.25 + 0.375(1 + \tanh(7.5(f - 0.5)))$$

Where: $d_k$ – nominal clutter distance, distance (km) from nominal clutter point to the antenna, $h$ – antenna height (m) above local ground level, $h_a$ – nominal clutter height (m) above local ground level. Such losses are calculated for both interferer and interfered-with. Maximum additional loss due to clutter is not more than 20 dB according to the formula. Nominal clutter heights and distances are listed in Table 32. For this analysis, three types of clutter have been used: unknown (i.e. no clutter), urban and suburban.

Table 32: ITU-R 452-16 nominal clutter heights and distances

| Clutter type | Nominal height, $h_a$ [m] | Nominal distance, $d_k$ [km] |
|---|---|---|
| Unknown | 0 | 0 |
| Suburban | 9 | 0.025 |
| Urban | 20 | 0.02 |

### A6.1.5 Clutter loss (ITU-R P.2108-0)

Clutter loss result, according to ITU-R P.2108-0 Recommendation, gives a statistical distribution of clutter loss for urban and suburban environments. This clutter loss method should not be applied, if a propagation model used includes clutter losses calculated along entire path. However, model used in this analysis takes into account clutter losses only in the end parts of the path. Minimum path length has to be 0.25 km (for the correction to be applied at only one end of the path), and 1 km (for the correction to be applied at both end of the path). The clutter loss not exceeded for p% of locations for the terrestrial path, $L_{ctt}$, is given by:

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

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

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

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

Where d is the total path length.

It should be noted that this method calculates clutter loss even in case of line-of-sight conditions between FSS ES transmitter and FS receiver.

### A6.1.6 Results

Figures below illustrate the comparison between probability for interference using different methods of clutter loss and FSS ES terminal types.

Calculations were performed using both, ITU-R P.2108-0 and ITU-R P.452-16 Recommendations for clutter loss prediction.

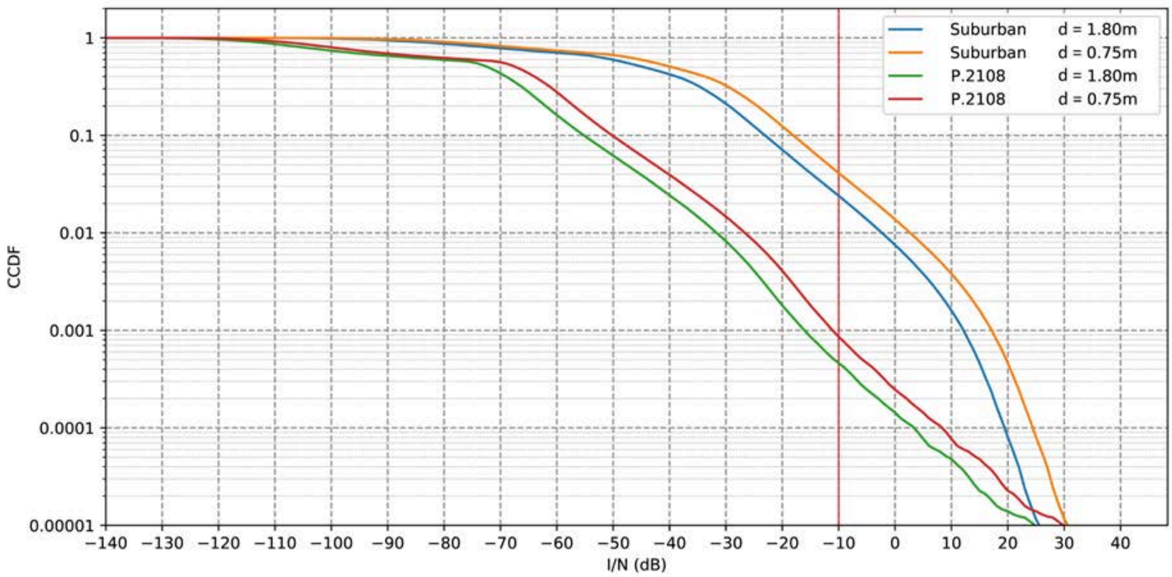



**Figure 43: Interference probability for both Enterprise and Residential terminals for suburban clutter**

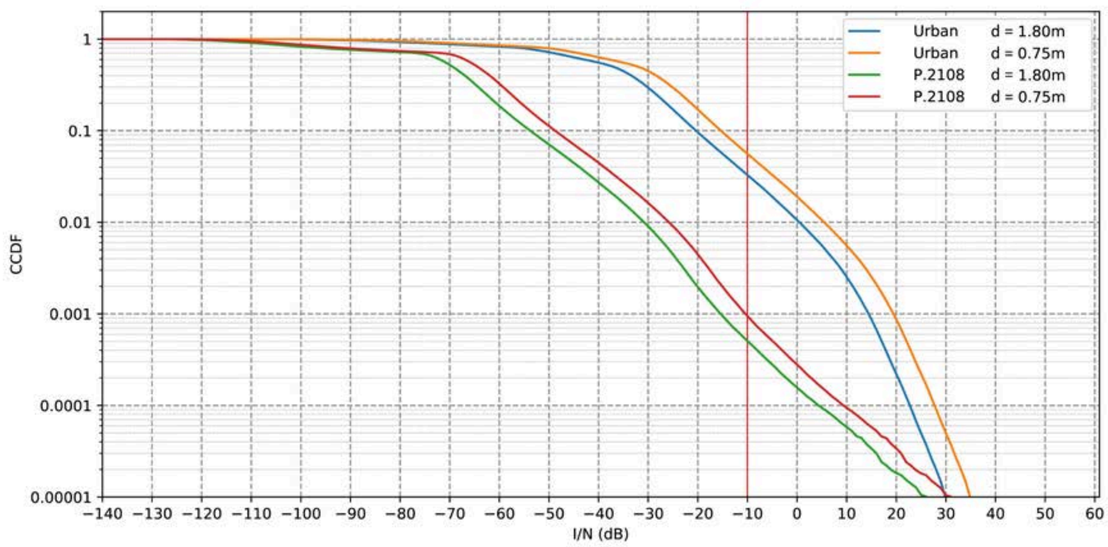



**Figure 44: Interference probability for both Enterprise and Residential terminals for urban clutter**

**Table 33: Interference probability for I/N = 10 dB**

| Clutter type | FSS ES terminal type | Clutter model | Interference probability for I/N = -10 dB, % |
|---|---|---|---|
| Suburban | Enterprise | ITU-R P.452-16 | 2.4 |
| Suburban | Enterprise | ITU-R P.2108-0 | 0.05 |
| Suburban | Residential | ITU-R P.452-16 | 4.1 |
| Suburban | Residential | ITU-R P.2108-0 | 0.09 |
| Urban | Enterprise | ITU-R P.452-16 | 3.3 |
| Urban | Enterprise | ITU-R P.2108-0 | 0.05 |
| Urban | Residential | ITU-R P.452-16 | 5.6 |
| Urban | Residential | ITU-R P.2108-0 | 0.095 |

### A6.1.7 Conclusions

FS and FSS ES compatibility analysis are performed for a real case scenario, taking into account existing microwave links operating in 28 GHz band in Vilnius city using propagation model defined in Recommendation ITU-R P.452-16.

Two different clutter evaluation methods are applied, ITU-R P.452-16 and ITU-R P.2108-0, resulting in different interference probability. Recommendation ITU-R P.2108-0 is based on statistical distribution of clutter loss along the path. In this case clutter loss has been calculated even for line-of-sight conditions, which resulted in very low interference probability. In contrary, Recommendation ITU-R P.452-16 calculates clutter loss mainly for interfering transmitter, since FS receiver is usually located above the clutter. This method does not calculate clutter loss for line-of-sight cases.

The study demonstrates that in case of uncoordinated FSS ES deployment in an area containing a high density network of point-to-point links there is a potential degradation of the FS in terms of interference probability which should be addressed by using various interference mitigation techniques.

In this analysis interference calculations have been performed from FSS ES to a network of P-P links only.

The results above can be improved up to 6 dB taking into account the antenna pattern in Recommendation ITU-R F. 1245 [17].

## A6.2 SIMULATION OF PROGRESSIVELY INCREASING NUMBERS OF FS TERMINALS

This study lists out the steps that have been followed to derive the interference probability of high-density FS P-P from one FSS ES transmitter (i.e. the interferer). It must be noted that this study only considers the residential terminals (0.75 m FSS ES).

FS P-P deployment in this study is based on the FS P-P links in Vilnius city centre in an area of 63.25 km2.

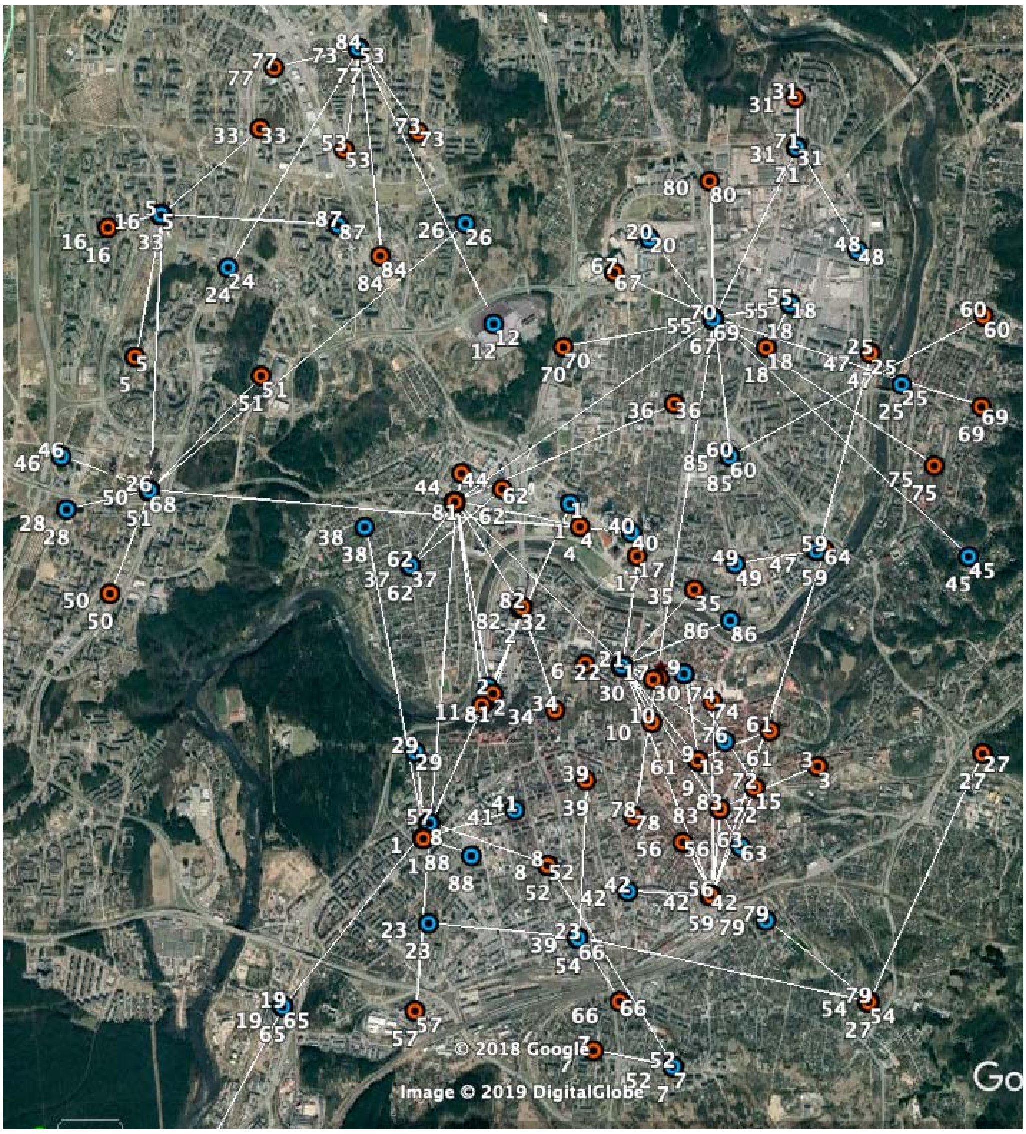



**Figure 45: FS P-P links**

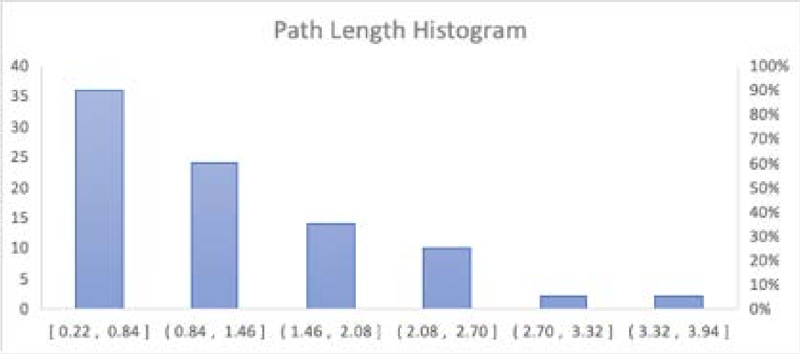



**Figure 46: Path length histogram**

The victims of interest here are FS P-P receiver only.

The following FSS ES parameters are considered for this study:

- FSS antenna height:
  - Urban - random variable with a uniform distribution between 2 m and 30 m;
  - Suburban - random variable with a uniform distribution between 2 m and 10 m.
- FSS station maximum power spectral density for antenna diameter 0.75 m: -4.93 dB(W/MHz) corresponding to e.i.r.p. of 58 dBW in 80 MHz;
- Polarisation loss of 1.5 dB.

The parameter of FS P-P considered for this study (two sets of results provided) considering:

- FS antenna height randomised according to the real dataset provided by Lithuania (uniform distribution between 10 m and 54 m);
- FS antenna height: 34 m.

- **Step-by-step methodology used in the study:**

Step 1: Compute the FS P-P antenna gain towards the FSS Earth Station (the deployment of the FSS ES is randomised and generated at each iteration) based on the following input parameters:

- FS station antenna pointing azimuth: random variable with a uniform distribution between -180° to 180°;
- FS station antenna pointing elevation: uniform distribution between -2.5° and 2.5°;
- FS station maximum antenna gain: 38 dBi;
- Antenna patterns considered in the study for FS P-P: Recommendation ITU-R F.1245-2.

Step 2: Compute the FSS ES antenna gain for each station towards the FS P-P based on the following input parameters:

- FSS station antenna pointing azimuth: random variable with a uniform distribution between 120° to 220°;
- FSS station antenna pointing elevation is above 15.6° for earth stations positioned at Vilnius. (based on the orbital position of 20W to 45E given in the report);

The off-axis angle (i.e. angle between FSS pointing direction and the line joining FS and FSS ES) is taken as the elevation angle towards the FS:

- FSS maximum antenna gain: 43.9 dBi for 0.75 m diameter (ITU-R S.2196 is not used);
- FSS antenna pattern: based on Annex 3 of RR Appendix 8, which is based in Recommendation ITU-R S.465-6 for the side lobe.

Step 3: Compute the interference (dBW/MHz) from the FSS ES towards each FS P-P receiver (victim) as follows:

$I_i = P_{tx} + Gt_i(\theta) + Gr_i(\theta) - PL_i - L_{Pol}$

- $I_i$ is the interference of victim i;
- $P_{tx}$ is the FSS ES nominal power spectral density;
- $Gt$ is the FSS ES gain towards the FS P-P;
- $Gr$ is the FS P-P gain towards the FSS E/S;
- $P_L$ is propagation loss based on ITU-R P.452 (ρ= 20%);
- $L_{Pol}$ is the polarisation loss = 1.5 dB;
- θ is the off axis between FS P-P and FSS E/S.

Step 4: Store the calculated interference for each FS P-P victim and repeat steps 1 through 3 for X iterations.

### A6.2.1 Results

#### *A6.2.1.1 Results for FS P-P (Residential terminal)*

Figures below show the results for a 0.75 m antenna diameter with a power spectral density of -4.93 dB(W/MHz).

No of FS victims considered = 38. This is because the maximum number of FS victims that can operate in the 80 MHz transmission bandwidth of the FSS Tx is 38 (from the datasheet provided).

The number of iterations is 50000.

FS height was considered according to the dataset provided by Lithuania

**P.452 Clutter at both ends**

FS antenna height: random variable with a uniform distribution between 10 m and 54 m.

Clutter can be applied at both ends if the height is less than the nominal height in that terrain.

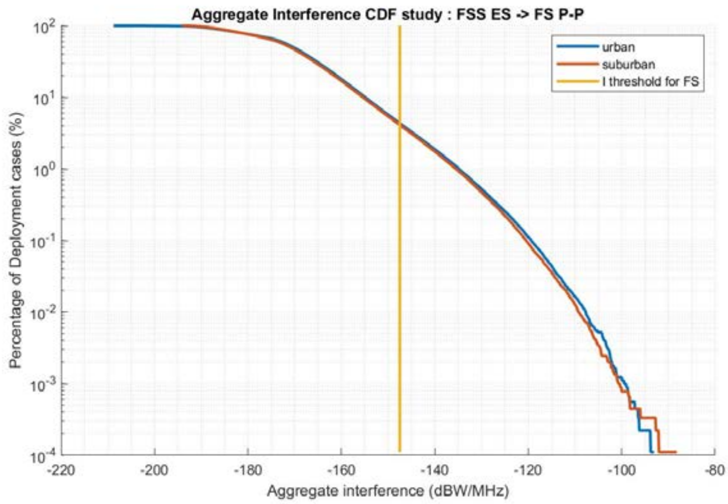



**Figure 47: Aggregate interference, for the urban and suburban cases, clutter applied at both ends**

**Table 34: Probability of interference**

| Terrain | Probability of Interference (%) |
|---|---|
| Urban | 4.11 |
| Suburban | 4.31 |

**P.452 Clutter at the shorter end only**

- FS antenna height: random variable with a uniform distribution between 10 m and 54 m;
- Clutter is only applied at the shorter end. For example, in the urban scenario, if transmitter's height is 15m, and the receiver's height is 10 m. Then clutter is only applied at the receiver end;
- Note: Clutter is only applied if the height of Tx/Rx is less than or equal to the nominal height in the terrain.

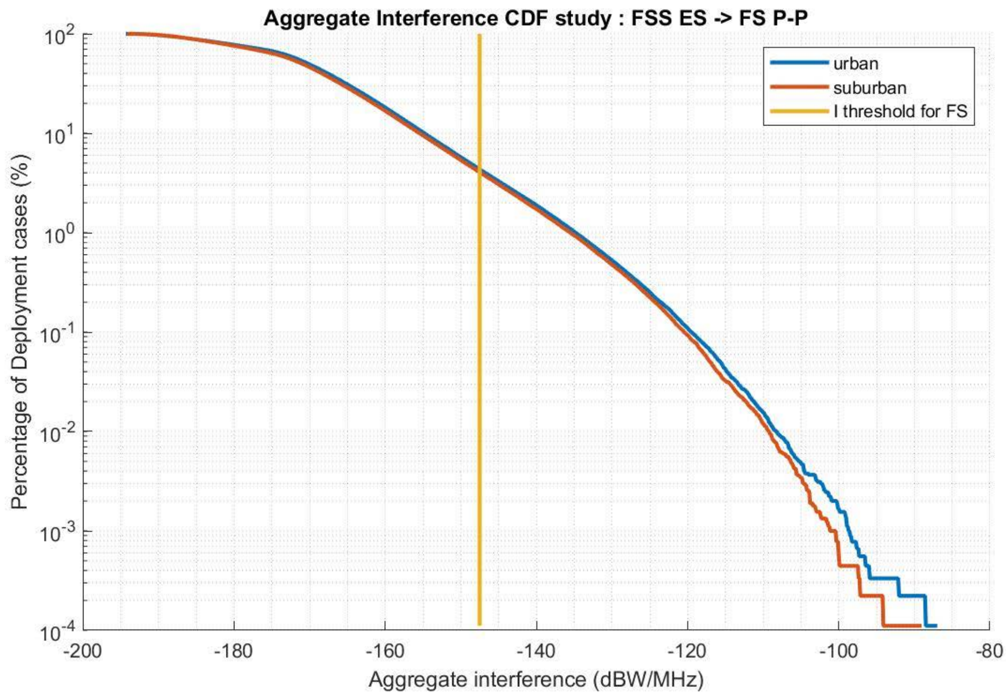



**Figure 48: Aggregate interference for urban and suburban cases, clutter applied only at the shorter end**

**Table 35: Probability of interference**

| Terrain | Probability of Interference (%) |
|---|---|
| Urban | 4.38 |
| Suburban | 4.02 |

### A6.2.2 Sensitivity with clutter models

The statistical analysis results presented in the previous section of this Report use the clutter model as defined in the Recommendation ITU-R P.452 [20]. However, the Recommendation ITU-R P.2108 [24] provides an alternative way of calculating clutter losses for a ground-to-ground interference analysis. Section 3.2 of ITU-R P.2108 defines the statistical model that can be applied for modelling the clutter loss distribution for urban and suburban environments. According to the model, clutter loss can be applied depending on the distance between the emitting and receiving station:

- If the path length is shorter than 250 m, no clutter is considered;
- If the path length is greater than 250 m and shorter than 1 km, clutter loss is only applied at one end of the path (either at the transmitter or at the receiver);
- If the path length is greater than 1 km, clutter loss can be applied at both ends of the path (at the transmitter and at the receiver).

Additionally, section 3.2 does not specify any nominal height for the clutter loss. In order to study a realistic scenario, the nominal heights defined in section 3.1 of the Recommendation ITU-R P.2108 were considered.

The nominal heights, for the propagation environments considered, are summarised below for both ITU Recommendation P.2108 and P.452:

**Table 36: Nominal clutter heights for suburban and urban environments for both clutter models**

| Terrain | Clutter Height (m) | |
|---|---|---|
| | P.2108 [24] | P.452 [20] |
| Suburban | 10 | 9 |
| Urban | 15 | 20 |

Before applying clutter losses at the transmitter or the receiver, the heights of the transmitter and the receiver were verified to be below the relevant nominal clutter height.

The results presented below depict its sensitivity with various clutter models – Recommendation ITU-R P.452, Recommendation ITU-R  P.2108 and no clutter.

#### *A6.2.2.1 Results for FS P-P (Residential terminal)*

Figures below show the results for a 0.75 m antenna diameter with a power spectral density of -4.93 dB(W/MHz).

No of FS victims considered = 38. This is because the maximum number of FS victims that can operate in the 80 MHz transmission bandwidth of the FSS Tx is 38 (from the datasheet provided by Lithuania).

The number of iterations is 50000.

**Clutter using** Recommendation ITU-R **P.452**

FS antenna height: 34 m

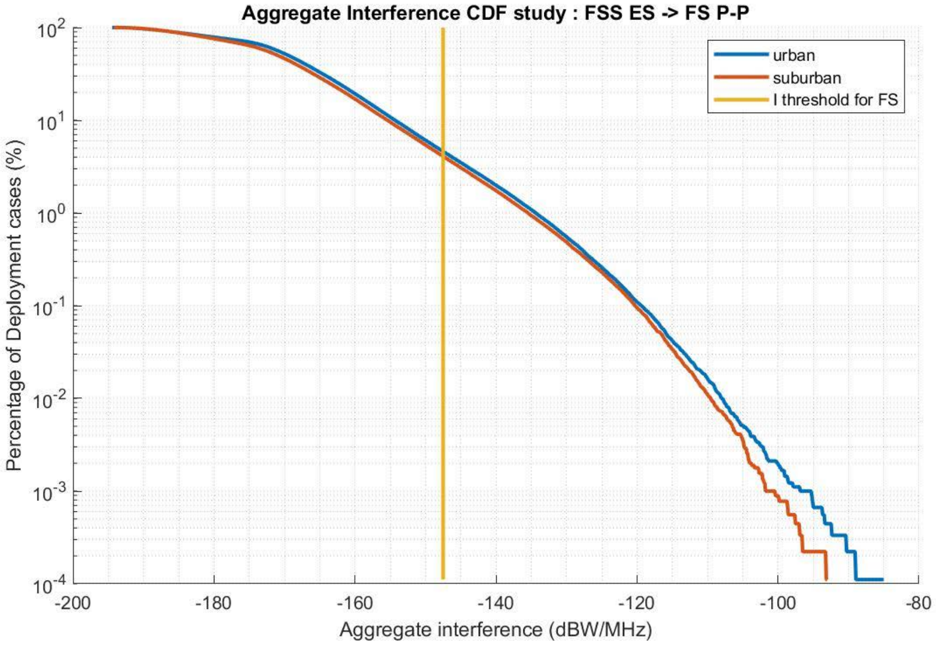



Figure 49: Impact of FFS ES on 38 FS receiving terminals (ITU-R P.452-16)

Table 37: Interference probability at the FS threshold

| Terrain | Probability of Interference (%) |
|---|---|
| Urban | 4.68 |
| Suburban | 4.08 |

**Clutter using P.2108 [24]**

- FS antenna height: 34 m

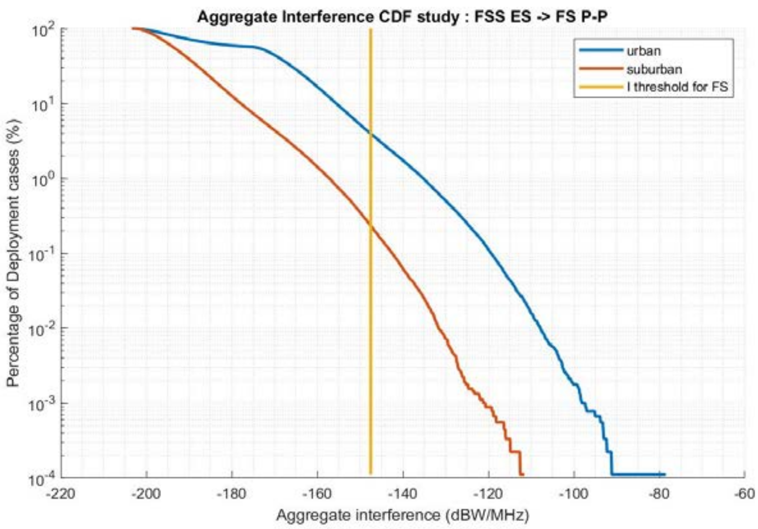



Figure 50: Aggregate interference, P.2108 clutter

**Table 38: Interference probability at the FS threshold**

| Terrain | Probability of Interference (%) |
|---|---|
| Urban | 3.88 |
| Suburban | 0.24 |

The significant difference between the urban and the suburban results is due to fact that the transmitting end (FSS) in the suburban case has clutter in all the iterations as its height is always < 15 m (criteria for clutter loss in P.2108 for distances > 0.25km).

### A6.2.3 Sensitivity with number of FS victims

Sensitivity analysis of the probability of interference is carried out for a 0.75 m antenna diameter with a power spectral density of -4.93 dB(W/MHz).

The number of iterations is 50000.

FS antenna height: 34 m.

#### *A6.2.3.1 No: of victims = 18*

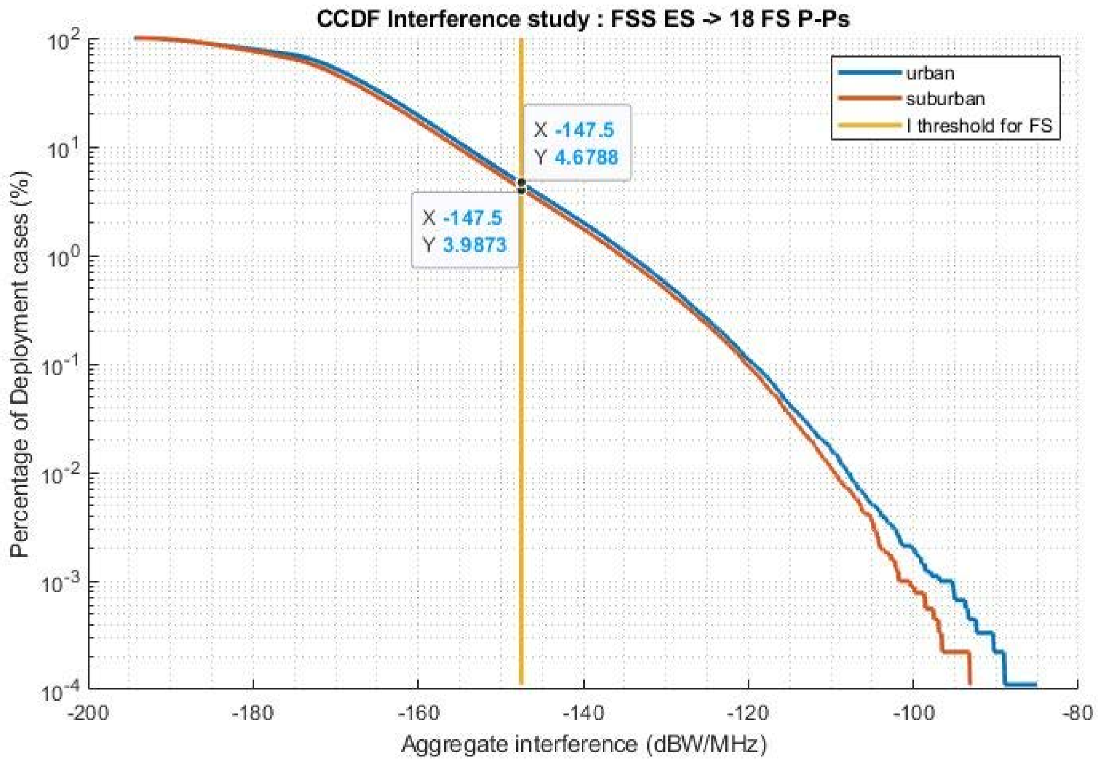



**Figure 51: Aggregate interference, 18 victims**

**Table 39: Interference probability at the FS threshold**

| Terrain | Probability of Interference (%) |
|---|---|
| Urban | 4.68 |
| Suburban | 3.98 |

### *A6.2.3.2 No: of victims = 54*

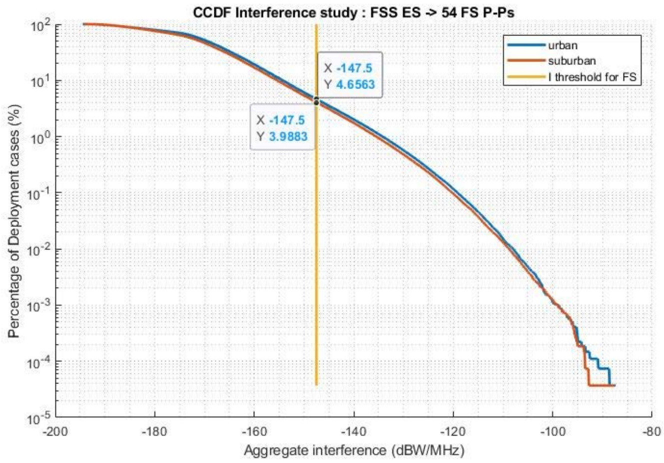



**Figure 52: Aggregate interference, 54 victims**

**Table 40: Interference probability at the FS threshold**

| Terrain | Probability of Interference (%) |
|---|---|
| Urban | 4.66 |
| Suburban | 3.98 |

### *A6.2.3.3 No: of victims = 88*

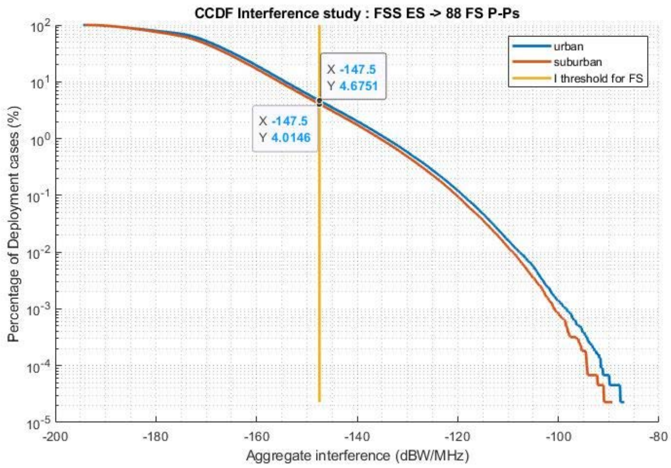



**Figure 53: Aggregate interference, 88 victims**

**Table 41: Interference probability at the FS threshold**

| Terrain | Probability of Interference (%) |
|---|---|
| Urban | 4.68 |
| Suburban | 4.01 |

*A6.2.3.4 No: of victims = 130*

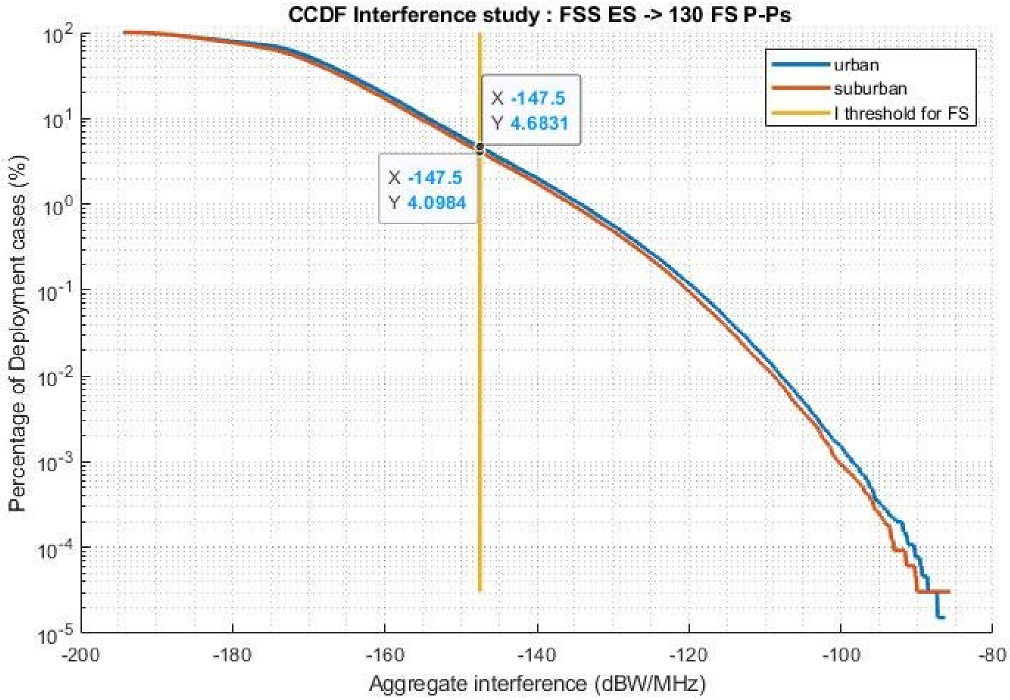



**Figure 54: Aggregate interference, 130 victims**

**Table 42: Interference probability at the FS threshold**

| Terrain | Probability of Interference (%) |
|---|---|
| Urban | 4.68 |
| Suburban | 4.01 |

## A6.2.4 Conclusions

The results show that the change in probability of interference with increase in the number of victims is insignificant. The probability of interference is in the same order of values given by the study in A6.1 and requires the application of mitigation techniques in order to counteract it. Also, the results show that the change in the probability of interference with the increase in the number of victims is insignificant.

# ANNEX 7: PRACTICAL MEASUREMENTS ON SPECTRUM SENSING

## A7.1 MEASUREMENTS IN THE JASON PEAK COUNTY TEST RANGE

The objective of the concept validation test is to show that whenever FSS Earth Station generated interference power received at an FS terminal (victim) would degrade the reception performance of the FS, an appropriately specified sensor at the earth station can sense the presence of the FS and avoid an earth station transmission in the FS reception band. For the paired band FS, this means that the FSS Earth Station would avoid transmission in the paired band of the transmission it senses.

From the specifics in the section 8.2, this objective means that whenever the received power ($P_V$) at the FS receiver due to FSS Earth Station transmissions would be such that

$P_V$ > -147.5 dBW/MHz, i.e. added interference power is greater (or equal) than 10 dB below the noise floor the measured power at the FSS sensor, $P_S$, due to receiving of FS transmission needs to exceed the sensor detection threshold so that the FSS Earth Station can avoid transmitting in the band:

- $P_S$ > -137.5 dBW/MHz + Δ; where Δ is a detection margin above the noise floor for the sensor.

For a verification approach, it is not practical to measure interference levels below the noise floor of the FS so any measurement criteria cannot be verified directly when the victim received power is below its noise floor. However, the following method can be used to validate the approach in practice.

Using a test configuration as depicted in the figure below with the power at the FS due to the FSS Earth Station well above the FS noise floor, measurements of both $P_V$ (at FS receiver) and $P_S$ (at FSS Earth Station sensor) can be simultaneously made over a range of test conditions and the difference calculated. Theory predicts (see below) that the power difference ($P_S$ – $P_V$) is not dependent on the absolute path loss level, so the difference measurement for any range is a valid indicator of what will happen as the path loss increases and hence the victim power drops below the noise floor of the FS. One of the objectives of the testing is to validate this key assumption.

The approach that follows will show that from the selection of an appropriate gain for the FSS Earth Station sensor ($G_S(\psi)$),will be able to infer that the value of $P_V$ is below the criteria value just from the measurement of $P_S$. By selecting a $G_S$ that results in a difference ($P_S$ – $P_V$) greater than 10 dBW/MHz + Δ for any LOS (line of sight) path loss (a margin for differences in path loss due to asymmetries of frequency will be included) and antenna pointing angle, then the criterion will be satisfied, i.e., if $P_S$ – $P_V$ > 10 dBW/MHz + Δ, then $P_V$ is less than -147.5 dBW/MHz when $P_S$ is less than -137.5 dBW/MHz + Δ and thus the 'avoiding' approach can be effectively implemented.

In terms of the test setup parameters:

**Equation 12:** $$P_S - P_V = (P_{FS} + G_{FS\rightarrow ES} - L_{FS\rightarrow ES} + G_S(\psi)) - (P_{ES} + G_{ES\rightarrow FS} - L_{ES\rightarrow FS} + G_{FS\rightarrow ES})$$

Where as in section 8.2 of the report, the symbols are defined as: $P_{FS}$ is the power of the FS transmitter, $G_{FS\rightarrow ES}$ is the gain of the FS antenna in the direction of the FSS Earth Station, $L_{FS\rightarrow ES}$ and $L_{ES\rightarrow FS}$ are the free space losses in the respective directions, $G_S(\psi)$ is the FSS Earth Station sensor antenna gain, $P_{ES}$ is the transmitter power of the FSS Earth Station, and $G_{ES\rightarrow FS}$ is the gain of the FSS Earth Station antenna in the direction of the FS.

In practice, since the FS and FSS Earth Station transmissions are not at the same frequency (paired FS band case), the difference in path loss in the LOS paths is bounded by using an estimate bound (Δ =~5 dB) to account for the differential path loss arising from the combination of frequency dependence of the path loss (~3 dB from the Friis formula) and the variation in fading (see explanations section 9.2.4). Here, note the FSS Earth Station sensor antenna gain is assumed constant across the azimuth as it will have to be a scanning sensor to achieve the high gain needed to close the loop on the sense and avoid approach.

Then Equation 12 is reduced to:

**Equation 13:** $$P_S - P_V = P_{FS} + G_S - (P_{ES} + G_{ES\rightarrow FS}) + \Delta$$

Examining this equation, the difference in measured power is not a function of the FS pointing angle relative to the FSS Earth Station (therefore the technique is valid for the FSS Earth Station in the main lobe or any sidelobe of the FS) and that the selection of the sensor gain is the only independent variable that can be used to implement the approach. The sensor gain can be selected to operate for the lowest FS power used within a range.

In the test configuration, each of the FS and FSS Earth Station parameters on the right-hand side of the Equation 13 are specified in their respective system specifications while the FSS Earth Station sensor gain can be selected to assure the FS protection criterion is met over a wide range of FS and FSS Earth Station power levels. The validation test consists of taking $P_e$ and $P_V$ measurements with a selected sensor antenna gain and using FS and FSS Earth Station representative parameters while varying the pointing angles of the FS and FSS Earth Station antennas to see if the data validates the theory, i.e. the measured power difference is constant (within measurement error and fading bounds explained in section 9.2.4) and exceeds the protection criterion value across FS pointing angle variations to indicate the presence of the FS to the FSS Earth Station.

The test assumes that selected FS and FSS Earth Station power levels are specified in the same bandwidth. In reality, the implemented bandwidth of the sensor will be 1 MHz. When considering FS and FSS Earth Station channels with different transmit bandwidths, the power levels should be equated to the power within a common bandwidth. For the convenience of testing, a common 1 MHz, 10 MHz, 28 MHz and 56 MHz can be used for demonstration and the results will hold.

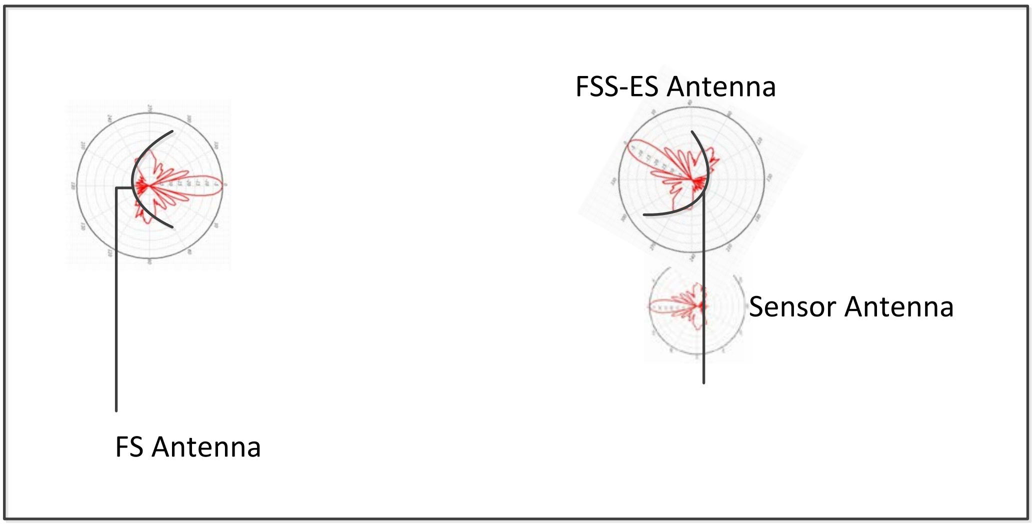



**Figure 55: Illustration of measurements setup**

**Comments on the proposed test setup**

The current proposal is to use the antenna range at the Viasat Duluth GA office. The test range will have a free space distance of 457.2 m between the FSS Earth Station and the FS surrogates. For the testing of the paired band sense and avoid, the frequencies 28.6 GHz and 29.6 GHz can be used. The free space path losses for these frequencies at a 457.2 m range are 114.76 dB and 115.06 dB respectively.

**Transmit Characteristics**

Typical transmit power for the FS from the body of this Report is 24.0 dBm in 28 MHz (~10 dBm/MHz).

Typical transmit power for the FSS Earth Station from the body of this Report is 44.0 dBm in 320 MHz (~19 dBm/MHz).

Since the FS and the FSS Earth Station transmissions look like noise to the other, a noise-like waveform can be used to drive each transmitter. By limiting the testing to a 1 MHz signal bandwidth, lab test equipment should be usable for the validation testing.

### Test Antenna Characteristics

On the FSS Earth Station side of the test configuration, two antennas are needed – one for transmit only (FSS ES surrogate) and one for receive only (Sensor surrogate). The transmit antenna should have the characteristics of a user terminal (such as a 75 cm dish) with a feed driven either by a TRIA or a lab signal generator. The transmit antenna should have both azimuth and elevation adjustability to simulate typical geometries relative to the FS (Elevation +15 to +45 degrees; Azimuth 0 to +90 degrees). The receive antenna, the sensor surrogate, needs to have about 30 dB of gain along its boresight. The sensor receive antenna will be positioned with its boresight pointed at the FS throughout the testing.

On the FS side of the configuration, a single antenna is needed with both transmit and receive required (though measurements can be made sequentially if the test equipment constraints limit simultaneous operation).

### Simple Link Budgets

Looking at the sensor surrogate and a range of FS antenna gains from +40 dB at boresight to -30 dB at large angles shows that the sensor should be able to detect the FS signal according to the Table below:

**Table 43: Calculations of the power received at FSS sensor**

| | Boresight | Near boresight | Extreme Sidelobe |
|---|---|---|---|
| Transmit power | +10 dBm | +10 dBm | +10 dBm |
| FS Antenna gain | +40 dBi | 0 dBi | -30 dBi |
| Path loss | -115 dB | -115 dB | -115 dB |
| Sensor Antenna gain | +30 dBi | +30 dBi | +30 dBi |
| Power at sensor | -35 dBm | - 75 dBm | -105 dBm |

Looking at the FS received power for FSS Earth Station elevation angles of 15 and 45 degrees with the FS receive gain at +40 dBi and -30 dBi.

**Table 44: Calculations of the power received by FS**

| | FS at Boresight | | FS Sidelobe | |
|---|---|---|---|---|
| | Low Elevation | High Elevation | Low Elevation | High Elevation |
| Transmit power | 19 dBm | 19 dBm | 19 dBm | 19 dBm |
| FSS Antenna gain | -2 dBi | -15 dBi | -2 dBi | -15 dBi |
| Path loss | -115 dB | -115 dB | -115 dB | -115 dB |
| FS Antenna gain | +40 dBi | +40 dB | -30 dB | -30 dB |
| Power at victim | -58 dBm | -71 dBm | - 128 dBm | -141 dBm |

### Expected Results

The results of actual measurements with parameters close to those in the table should substantiate two points to be successful.

The power measured at the victim from the FSS Earth Station transmission should be >20 dB below the power measured at the sensor in set orientation, and

The difference in the received power at the victim and the received power at the sensor should be independent of the azimuth of the FS to FSS Earth Station pointing. For example, in the tables above, the difference in the yellow shaded entries - with the FSS Earth Station in the boresight of the FS, is the same as the difference in the blue shaded entries - with the FSS Earth Station in an extreme sidelobe of the FS.

**Test Results from Jackson County Test Range**

On November 28, 2018, test measurements were made at the Jackson County Test Range. The outdoor test range is used to do antenna pattern measurements for its line of large antennas. The test range consists of a tower and control room for mounting and pointing the subject antennas for test and a measurement tower located at 457 meters for collecting test data. The figures below depict the components of the test range.

Jackson County Pattern Range
Transmit Tower

Jackson County Pattern Range
Receive Tower and Control Room

Jackson County Pattern Range

**Figure 56: Illustration of the Test Range**

Referencing Figure above, the FSS ES antenna and the Sensor Antenna Surrogate were placed on the Receive Tower and FS Antenna surrogate was placed on the Transmit tower. For the test configuration, all of the antennas were 75 cm. Viasat User equipment terminals, one for the FS surrogate (Transmit Tower), one for the FSS ES (Receive Tower) and an additional one for the Sensor Surrogate (Receive tower approximately 6 meters below the FSS ES for mounting convenience). The nominal gains for the 75 cm antennas at Ka band (~29.6 GHz) are 45 dBi at boresight. Path loss at the range distance is 115 dB. In the boresight aligned configuration, the Sensor Surrogate is approximately 75 degrees misaligned due to the installation constraints. This meant that the maximum gain of the sensor pointed at the FS Surrogate was approximately 33 dBi.

For reference, link budgets were computed to include the various components in the test configurations. For the FS Transmit to FSS Sensor path, the simplified link budgets for both the on-axis transmission (boresight aligned) and FS off axis pointing (off axis pointing was limited by the receive instrumentation to about 1.4 degrees, ~18 dB down from the peak). The budgets are shown in the table below.

**Table 45: Link Budget for FS to Sensor Antenna**

| Path 1 - FS to Sensor | Axis Aligned | Off Axis |
|---|---|---|
| Input Power | 20 dBm | 20 dBm |
| Cable to FS | 11 dB | 11 dB |
| FS Antenna Gain | 45 dBi | 27 dBi |
| Pointing error | 12 dB | 12 dB |
| Path loss | 115 dB | 115 dB |
| Sensor Antenna Gain | 45 dBi | 45 dBi |
| Cable Loss | 8 dB | 8 dB |
| Predicted Power | -36 dBm | -54 dBm |

For the FSS ES Transmit to FS path, the budgets were computed for various FSS ES Elevation and Azimuth orientations. Elevations of 15, 30, and 45 degrees were used for reference calculations. The link budgets are in the table below.

**Table 46: Link Budget for FSS ES to FS (Victim)**

| Path 2: FSS ES to FS | FSS 15 Degree El; FS Axis Aligned | FSS 30 Degree El; FS Axis Aligned | FSS 45 Degree El; FS Axis Aligned |
|---|---|---|---|
| Input Power | 20 dBm | 20 dBm | 20 dBm |
| Cable to FSS-ES | 8 dB | 8 dB | 8 dB |
| FSS ES Ant Gain | -3 dBi | -12 dBi | -15 dBi |
| Path Loss | 115 dB | 115 dB | 115 dB |
| FS Ant Gain | 45 dBi | 45 dBi | 45 dBi |
| Cable Loss | 11 dB | 11 dB | 11 dB |
| Predicted Power | -72 dBm | -81 dBm | -84 dBm |

Actual test cases were run for three FSS ES Elevation and three FSS ES Azimuth orientations and two FS azimuth orientations as indicated. The results of the measurements are shown in the table below.

**Table 47: Measurement Data from Test**

| Test case | FSS ES El | FSS ES Az | FS Az | FS Rcvd Power | Sensor Rcvd Power |
|---|---|---|---|---|---|
| | Degrees | Degrees | Degrees | dBm | dBm |
| 1 | 15 | 0 | 0 | -72.5 | -34.7 |
| 2 | 15 | 5 | 0 | -68.5 | -34.7 |
| 3 | 15 | 30 | 0 | -91 | -34.7 |
| 4 | 30 | 0 | 0 | -79 | -34.7 |
| 5 | 30 | 5 | 0 | -77.3 | -34.7 |
| 6 | 30 | 30 | 0 | -82.5 | -34.7 |

| Test case | FSS ES El | FSS ES Az | FS Az | FS Rcvd Power | Sensor Rcvd Power |
|---|---|---|---|---|---|
| | Degrees | Degrees | Degrees | dBm | dBm |
| 7 | 45 | 0 | 0 | -83 | -34.7 |
| 8 | 45 | 5 | 0 | -81.5 | -34.7 |
| 9 | 45 | 30 | 0 | -81.8 | -34.7 |
| 10 | 15 | 0 | -1.4 | -88.2 | -50.5 |
| 11 | 15 | 5 | -1.4 | -84.3 | -50.5 |
| 12 | 15 | 30 | -1.4 | -97.3 | -50.5 |
| 13 | 30 | 0 | -1.4 | -95.8 | -50.5 |
| 14 | 30 | 5 | -1.4 | -95 | -50.5 |
| 15 | 30 | 30 | -1.4 | -97 | -50.5 |
| 16 | 45 | 0 | -1.4 | -99.3 | -50.5 |
| 17 | 45 | 5 | -1.4 | -98 | -50.5 |
| 18 | 45 | 30 | -1.4 | -98.5 | -50.5 |

Some differences from the predicted link budgets are to be expected as any off axis, either in the elevation or azimuth, is subject to exactly where on the sidelobe the signal is received. However, fairly good correspondence between the predicted and the measured can be seen, particularly in the boresight aligned cases (test cases 1, 4 and 7) where the FS received power was measured as -72.5, -79, and -83 dBm respectively compared to predicted levels of -72, -81, and -84 dBm. Other measurements compare well to the predicted level with somewhat larger deviations.

The data collected supports the two points suggested under the expected results above, namely,

With a good sensor antenna, it is possible to get enough power to make the sense and avoid work, i.e. more than 20 dB. In fact, this data demonstrates that an antenna with gain on the order of 20 dB should be adequate depending on fading differences (Δ) in real implementation environments. Follow on efforts will have to be done once a sensor design is selected.

The headroom on the Sensor measurement is independent of the FS pointing – at least for the two points which have been measured. This is exemplified in cases 1 and 10 where the FSS ES elevation is constant and the FS is moved in azimuth. In each case, the measured power difference is approximately 38 dB. In tests cases 4 and 13 (with a higher FSS ES elevation and less power transmitted in the direction of the FS), the differences are approximately 45 dB. This also demonstrates that the sensor threshold function of FSS ES antenna gain in the direction of the FS as pointed out earlier. The implication of this on the sensor design will be explored in the design of an actual sensor.

As noted earlier, we could not measure below the noise floor at the FS terminal, however  we were able to get close to the noise floor in the most extreme cases (cases 12 -18) where measurements below -125 dBW were achieved. While much work has to be done on finding suitable, cost effective sensors and testing in real world fading channel environments, the test measurements do demonstrate the feasibility of the sense and avoid concept.

The sense and avoid approach proposed has been validated by the measurement data presented in this Report for the LOS case with no multi-path interferers, i.e. no signal fading. For the LOS case, measurements from a dense urban environment in the paper written by M.K. Samini et al. [11], indicate that a 10 dB fade margin for a 3-sigma case should be adequate for the design of the sense and avoid system parameters. It contains detailed qualitative description of major propagation effects impacting reciprocity of paths between FSS ES and FS.

Furthermore, the simulations presented in the paper show that even a 20 dB fade margin allocation can be overcome by proper design of the sense and avoid approach proposed to sharing. The higher fading in a NLOS signal environment is unlikely to be of concern since the NLOS ranges of concern for the 28 GHz interference are extremely small and, in any case, the necessary margin (15 dB) for the NLOS case based on the referenced measured data is less than the value used in the simulations.

## A7.2 MEASUREMENTS IN SAINT PETERSBURG

The study considers standard option where SAA mechanism is using band scanner that has a simple power measurement function. Such receiver should be measuring received power of emissions in the 28 MHz channel, without any regard to the type of emission. The SAA mechanism would scan the band 27.5-29.5 GHz with the aim of identifying channels that are used by the FS systems (in accordance with ECC Recommendation T/R 13-02). It is therefore of utmost importance to decide as to what measured power level should be sufficient to indicate with certainty that a given channel is occupied by FS system.

It is obvious, that the interference will occur when FSS ES site will be located closer to the victim FS station than a minimum separation distance (dinterf) which corresponds to a distance where the path loss (L) will be equal to the necessary Minimum Coupling Loss (MCL). Accordingly It is clear that for all distances beyond dinterf the increasing path loss will yield received interference power below the victim's threshold sensitivity level taking into account the protection criteria (I/N=-10 dB), whereas any distances smaller than dinterf will have lower path loss that will make received interference power larger than victim's threshold sensitivity plus protection criteria, thus causing interference.

Based on the power budget (the power of FSS ES emissions received by the FS receiver) the critical path loss that would trigger interference could be derived as follows:

**Equation 14: $L_{interference}$ = MCL = PTxES + GTxES + GRxFS – (PSensFS+ I/N)**

Based on the power budget in the opposite direction (the power of FS station emissions received by the SAA receiver) the minimum L for detecting the emissions of FS station could be derived as follows:

**Equation 15: $L_{threshold}$ = PTxFS + GTxFS + GRxSAA – PSensSAA**

In order to define the SAA threshold, it is possible to merge the two described power budgets in one inter-related system by requiring that distance d= dinterf.

As it was showed in this Report for such condition since the FS station and FSS Earth Station transmissions are not at the same frequency (paired FS band case), the difference in path loss is bounded by using an estimate bound $\Delta$ =~5 dB. Taking this into account Equation 14 and Equation 15for the worst case ($L_{interference}$ = $L_{threshold}$ -Δ=MCL) may be merged as follows:

**Equation 16: PTxES + GTxES + GRxFS – (PSensFS+ I/N) = PTxFS + GTxFS + GRxSAA – PSensSAA – Δ**

And then SAA channel detection threshold PSensSAA may be expressed as follows:

**Equation 17: PSensSAA = PTxFS + GTxFS + GRxSAA - PTxES - GTxES - GRxFS + (PSensFS+ I/N) – Δ**

Noting that GTxFS =~ GRxFS.

Finally, by defining SAA receiver threshold before antenna in order to eliminate the SAA antenna gain from the regulatory limits, the Equation 17 could be simplified to:

**Equation 18: PSensSAA (before antenna) = PTxFS - PTxES - GTxES + (PSensFS+ I/N) – Δ**

Substituting in Equation 18relevant values for powers as defined in report, fixed radio systems typical sensitivity threshold taking into account ETSI EN 300 431 [30], interference threshold 10 dB below the sensitivity threshold level for performance objective requirements (BER of 10-6) and estimated bound for $\Delta$ =~5 dB it is possible to derive the SAA threshold (before antenna) for identifying FS channels:

1. PTxFS = 24.0 dBm/28 MHz
2. PTxES = 44.0 dBm/320 MHz = 33.5 dBm/28 MHz
3. GTxES = -2 dBi (Low elevation)
4. PSensFS = -85 dBm (typical sensitivity for BER=10-6 and channel spacing 28 MHz)
5. PSensSAA (before antenna) = 24 – 33.5 – (–2) + (-85 - 10) – 5 = – 107.5 dBm/28 MHz

The threshold -107.5 dBm/28 MHz or -137.5 dBW/28 MHz is derived before antenna. Assuming sensor antenna gain GRxSAA = 30 dBi as was proposed in some other studies threshold value referred to the SAA receiver input will correspond to a -107.5 dBW/28 MHz or a -122 dBW in 1 MHz reference band.

**Experimental test results**

In order to confirm the performed calculations, the results of an experimental study are presented which contain the measured values of the permissible levels of C/I protection ratio for Rx broadband wireless access (BWA) and digital radio-relay system (DRRS) receivers when operating in the common frequency band with the FSS transmitters.

General characteristics of the tested DRRS and BWA systems are given in ETSI EN 300 431 [30] and Table 48.

Digital radio-relay system MINI-LINK TN is microwave transmission node in mmWave bands (23, 26, 28 GHz), handling single hops and access sites as well as advanced hub sites for large networks, optimised for traffic aggregation and capacity savings. This DRRS fully supports all-IP RAN over Ethernet Backhaul preferred in new mobile networks, giving the required Ethernet quality of service. The Radio Link supports hitless adaptive modulation for 256 QAM over 28 MHz channels.

The BWA system MINI-LINK BAS has symmetrical capacity of up to 37 Mbit/s per carrier in mmWave band (24-31 GHz) over an area of up to 5 km or more. The BWA allow to implement Point-to-Multipoint networks and to offer capacity ranging anywhere from 37 Mbit/s to 220 Mbit/s with up to 360º coverage. The MINI-LINK BAS solution has E1 (structured/unstructured, ATM) interfaces.

**Table 48: Technical parameters of BWA (ERICSSON MINI-LINK BAS) and DRSS (ERICSSON MINI-LINK TN)**

| Parameters | Dimension | Value of Parameters | |
|---|---|---|---|
| | | Ericsson MINI-LINK BAS | Ericsson MINI-LINK TN |
| Frequency band TRX, | GHz | 27.5-29.5 | |
| Receiver Threshold (BER = 10-6) | dBm | -77 | -84 |
| Receiving antenna gain | dB | 34.5 | |
| Height of the phase centre of above the roof level | Meters | 2.4 | |
| Receiving antenna beamwidth | grad | 3.3 | |
| Channel bandwidth | MHz | 28 | |
| Type of modulation | | QPSK | |

Typical parameters were used to form FSS signals by simulator of FSS transmitter when determining the protection criteria of the BWA and DRRS during the experimental evaluation carried out.

The aims of the conducting experimental study were:

- experimental evaluation of the permissible level of interference from the FSS transmitters on to input of Fixed Service system receivers;
- determination of the conditions for ensuring the compatibility of FSS transmitters and Fixed Service in the radio frequency band 27.5-29.5 GHz.

The program of conducting experimental study included the following tasks:

- conducting an assessment of the electromagnetic environment in the location area of BWA and DRRS receivers in order to identify sources of extraneous radiation that could affect the results of experimental studies;
- determination of the wanted signal minimum power level, which ensures the required performance objectives for the BWA and DRRS receivers;
- determination of the minimum power level radiated from the signal simulator of FSS transmitter, which create an unacceptable interfering effect, when operating in the common frequency band;
- determination of the protection ratio, defined as the minimum allowable C/I ratio for BWA and DRRS receivers, ensuring the required performance objectives when exposed to interference in common frequency bands with the FSS networks.

The compatibility criterion for BWA and DRRS operations is C/I ratio ensuring the required BER, not worse than 10-6 in a standard channel under the influence of interference.

The following indicators of the compatibility were selected in the course of the experimental studies:

- performance objectives for the standard receiving channel (ensuring the required BER) of BWA and DRRS operations under the influence of radio interference;
- equivalent power of the wanted signal at an input of the BWA and DRRS radio link receivers at the place of location for these receiving antennas, measured by a receiver of the spectrum analyzer (Ps, dBm) and ensuring the required performance objectives of the BWA and DRRS;
- equivalent power of the harmful signal (interference) generated by the simulator of FSS transmitters at the input of the BWA and DRRS radio link receivers at the place of location of these receiving antennas, measured by the receiver of the spectrum analyzer (Pi and dBm) in the common frequency bands.

For experimental studies, a field experimental testbed was deployed in accordance with the type use of BWA and DRRS operating in transport communication networks.

These scenarios included:

- Scenario 1: The link between transmitting DRRS and receiving DRRS;
- Scenario 2: The link between BWA hub equipment (the outdoor radio module and antenna) and BWA access user equipment (access terminals located at the customer sites).

The scheme of the experimental testbed is shown in Figure 57 below:

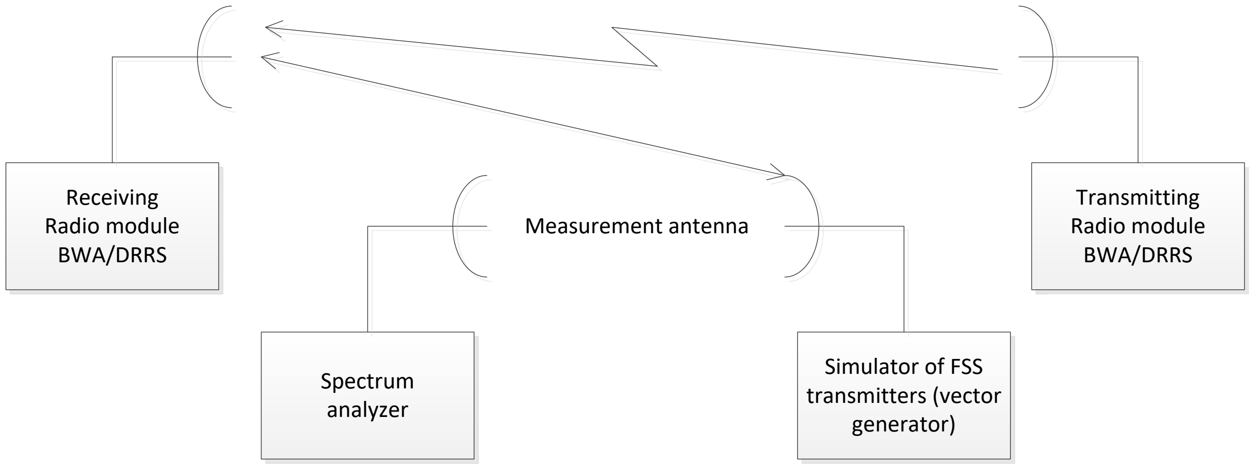



**Figure 57: Experimental testbed for compatibility studies**

Experimental testbed used for various test scenarios included the following set of equipment.

- Measuring test complex consisting of:
  - measurement instrumentation antenna HL050;
  - spectrum analyzer Anritsu MS2726C;
  - set of calibrated cables.

- Simulator of FSS signals:
  - measurement instrumentation antenna HF906;
  - vector signal generator Keysight E8267D -532;
  - set of calibrated cables.

**Radio modules BWA (Ericsson MINI-LINK BAS) and DRRS FS (Ericsson MINI-LINK TN)**

The measuring antenna of the field experimental testbed was deployed in close proximity in the vicinity of the antennas phase centre of the BWA and DRRS receivers.

The signal levels at the receivers input of the BWA and DDRS were set in accordance with the minimal sensitivity of the BWA and DDRS equipment, corresponding to the values of Table 1.

During the measurement tests, the following Rx BWA and DDRS equipment parameters were selected: channel bandwidth - 28 MHz, modulation type - QPSK and the level of a wanted signal at the input of the BWA and DRRS receivers, which provides the value of the parameter BER = 10-6, was set at a value of at least -70 dBm.

Transmitter power Tx for BWA and DRRS was set in such a way as to ensure the specified level of the wanted signal at input of BWA and DRRS receivers in an absence of interference. Signal level at the input of Rx BWA and DRRS was determined by regular internal controls means. An example of data received via the internal control interface is shown in Figure 58.

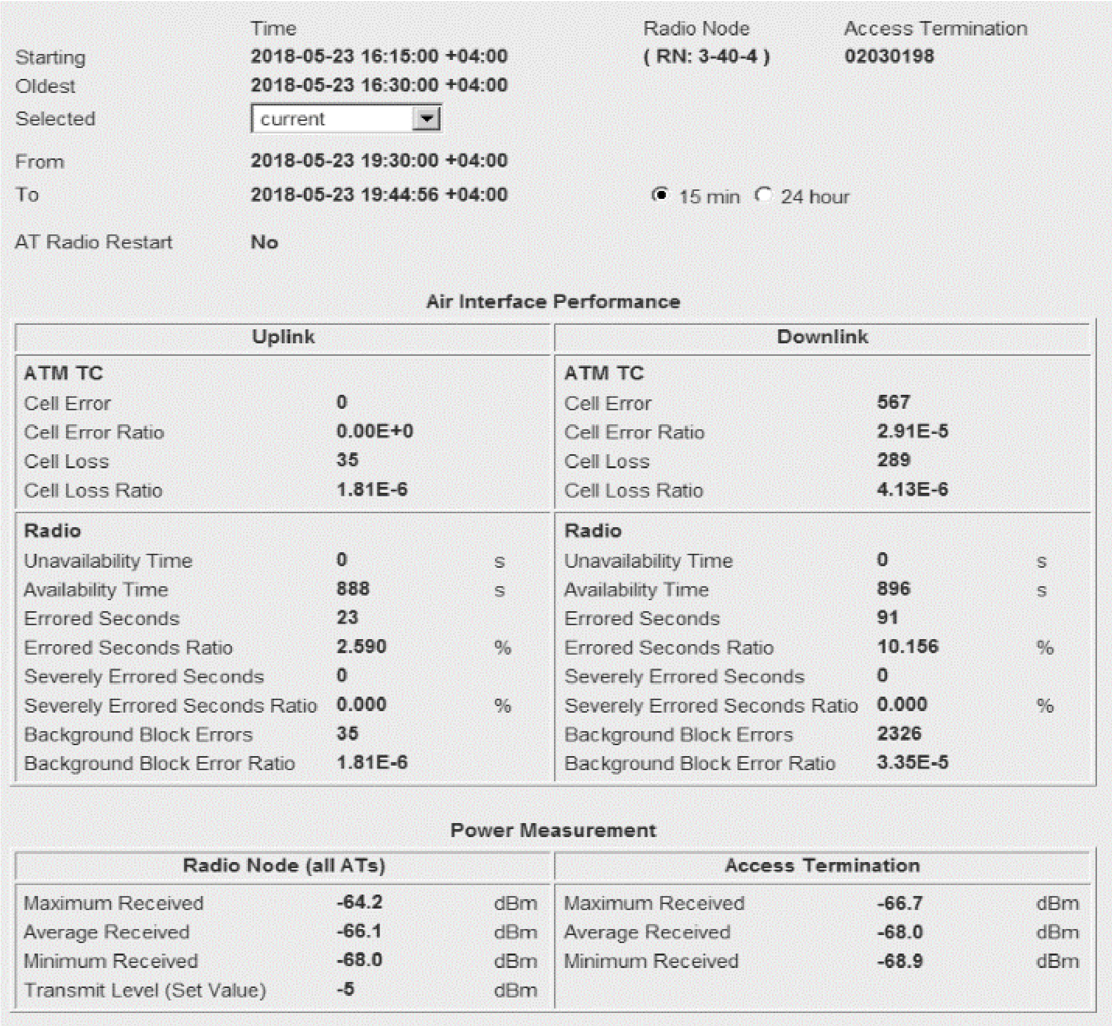



**Figure 58: Screen of control interface of BWA system**

Upon reaching the required receiving signal power at the input of the Rx BWA and DRRS receivers, the signal power at input Rx-s were measured by using a spectrum analyzer for Rx-s BWA and DRRS receivers under conditions on ensuring the normal operation of the BWA and DRRS.

The next step was determination of the minimum power level radiated from FSS transmitter simulator.

The signal simulator antenna of the FSS transmitter (vector generator) was located in the far zone of the receiving antennas BWA and DRRS at a distance of 10.6 m and in the line of sight of the antennas. The polarisation of the antenna for the FSS transmitter simulator signal was set an equal to the corresponding polarisation of the BWA and DRRS antennas. The initial antenna alignment is performed at the operating frequencies of the BWA and DRRS transmitters using a spectrum analyzer based on the maximum level of received useful signal.

Using a Keysight E8267D-532 vector generator, applied as the simulator of a FSS transmitter at the operating frequencies of the Rx BWA receiver and DRRS, a signal was formed that is equivalent in spectral characteristics to the Tx FSS signal with a channel bandwidth of 50 MHz.

The values of the permissible levels of C/I protection ratio for Rx BWA and DRRS receivers when operating in the common frequency band with the FSS transmitter, estimated using the measured values of Ps and Pint are presented in Table 49.

**Table 49: C/I ratio for BWA and DRSS when operating in the same band with FSS**

| № | Name of BWA/DRRS | Level of signal power (Ps) at input of Spectrum analyzer (dBm) | Acceptable level of interference (Pint) at input of Spectrum analyzer (dBm) | C/I ratio, dB |
|---|---|---|---|---|
| 1 | MINI-LINK BAS | -84.8 | -87.4 | 2.6 |
| 2 | MINI-LINK TN | -83.2 | -86.1 | 2.9 |

Analysis of the measurement results in Table 49 showed the C/I protection ratios at Rx input of the MINI-LINK BAS and MINI-LINK TN differ slightly and amount to 2.6 - 2.9 dB, which is explained by the similarity of the radio interface used in BWA and DRRS systems.

Accordingly the measured minimum allowable signal-to-interference ratio is 3 dB for the considered case (to ensure BER = 10-6) and then the interference threshold level will be -73 dBm/28 MHz taking into account minimum wanted signal at the receiver input of -70dBm. This value -73 dBm/28 MHz corresponds to interference criteria of -103 dBW/28 MHz or -117.5 dBW in 1 MHz reference band.

In order to compare this value with detection threshold calculated in the beginning of section A7.2 it is possible to derive the interference criteria before the BWA/DRSS antenna which has a gain of G=34.5 dBi (see Table 48). The interference threshold before antenna for the considered case will be -103 dBW/28 MHz – 34.5dBi = -137.5 dBW/28 MHz or -107.5 dBm/28 MHz which is identical to the result in the beginning of section A7.2.

## ANNEX 8: EXAMPLE OF IMPLEMENTATION

This annex describes an example implementation of sensing and blanking using real deployment parameters in conjunction with the values determined in the previous section to facilitate uncoordinated FSS Earth Station deployment on the 1120 MHz of the 27.5-29.5 GHz band identified for FS use.

The sensing device definition is based on an existing active antenna based on TDD access method. This means that each element is used in turn to both transmit and receive.


**Figure 59: Example of candidate sensor device**

If deployed as a cognitive radio sensor, the antenna is only used in receive mode and will be synchronised with the FSS Earth Station operation so that the sensor reception is active only when that earth station is not transmitting (e.g. between bursts). Taking into account that the duty cycle of the FSS Earth Station, according to Recommendation ITU-R S. 1594 [6], is less than 20%, the sensor can ideally receive during 80% of the time, whereas the FS signal is supposed to be active all the time in P-P and P-MP systems. In practice, any analysis of a system’s compliance should take into account its actual duty cycle, therefore system with the lower duty cycle will have longer sensing time compared to the one with higher duty cycle.

The antenna block is slightly bigger than the transceiver placed in front of the parabolic dish so it could be placed behind the transceiver facing the radiating direction but looking horizontally in order to improve its sensitivity towards the FS stations.

Because the sensor is formed of an active 2D array, it can scan both in azimuth and elevation at angles varying between +/-60°.

The typical performance of the example device is above -8 dB/K on axis in the frequency range with a scan loss of less than 2 dB in the proposed scan angles.

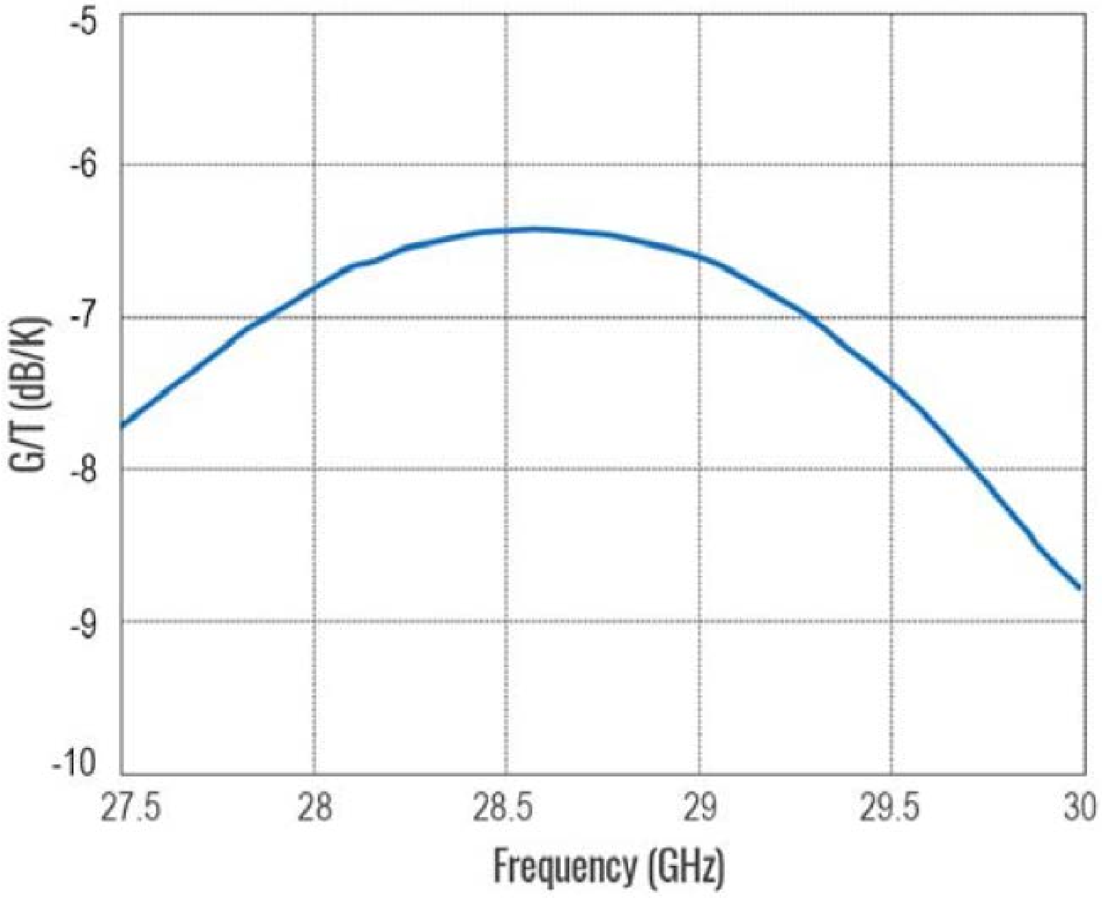



**Figure 60: Sensor performance figure with frequency**

It should be noted that this example device has been designed for other purposes than sensing. Due to its TDD mode it is possible that the receive RF chain contains switches and circulators that degrade the G/T. A dedicated device is expected to have about -4 dB/K of G/T on axis over the frequency range.

## ANNEX 9: MCL ANALYSIS FOR COEXISTENCE

This study considers an MCL evaluation to be compared to the one at section 6. All the parameters and assumptions are taken from report at section 4.

The main differences from the section 6 are:

- No additional shielding effect is considered since this cannot be guaranteed in reality deployment.
- All the antenna height combinations cases between FSS ES (2 m,10 m and 30 m urban case; 2 m, 10 m suburban case) and FS (5, 15, 30 and 60 m) are evaluated, which can provide the whole picture of coexistence situation.
- the higher range power FSS is used instead of lower range power
- 80 MHz bandwidth for 0.75 m FSS Earth Station is used
- 47dBi FS maximum antenna gain is used instead of 42 dBi.

### A9.1 SIMULATION SCENARIOS

Both P-P and P-MP cases are considered. For each FS case, 1.8 m (320 MHz bandwidth) and 0.75 m (80 MHz) FSS antenna diameter are considered. All the antenna height combinations cases between FSS (2 m/10 m/30 m urban case, 2 m/10 m suburban case) and FS (5, 15, 30 and 60 m) are evaluated, which can provide the whole picture of coexistence situation. Based on Table 1, higher range transmit power is considered for MCL calculation. 10 degree FSS elevation angle is considered as the baseline. Based on Table 3, 0 degree FS elevation angle is considered for single entry case. 47 dBi and 27 dBi maximum FS antenna gain is considered for P-P and P-MP.

### A9.2 SIMULATION PARAMETERS

FSS parameters refer to Table 1 of the Report, FS parameters refer to Table 3 Recommendation ITU-R P.452 (20%) propagation model is considered without terrain profile.

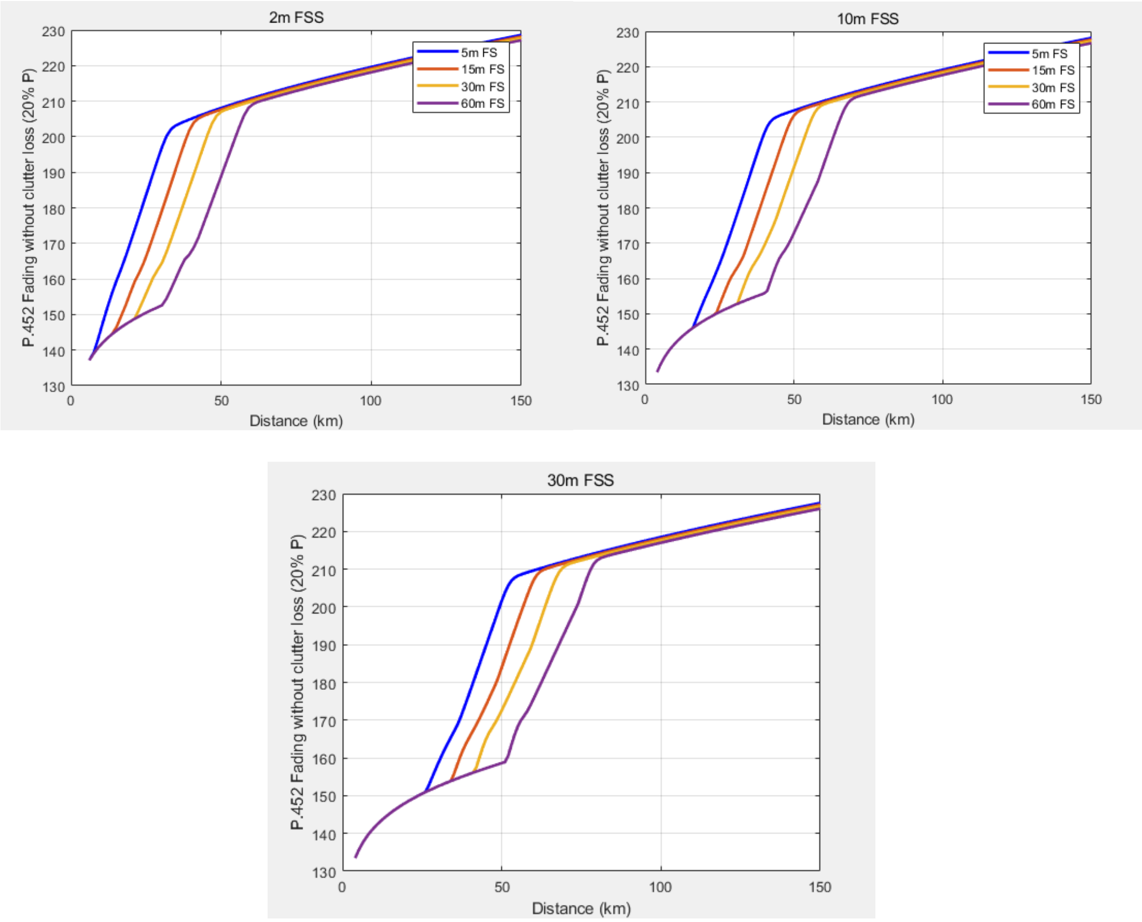



Figure 61: MCL ANALYSIS

Additional clutter loss is considered as the following:

Table 50: Clutter attenuations (P.452-16 model, equation (57))

| | Clutter Attenuations (P.452-16 model, equation (57)) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Rural | | Suburban | | Urban | | |
| Height of the Antenna (m) | 2 | 10 | 2 | 10 | 2 | 10 | 30 |
| Clutter Attenuation (dB) | 14.84 | 0 | 19.51 | 0 | 19.73 | 16.1 | 0 |

1.5 dB polarisation loss is considered between FSS and FS.

### A9.3 SIMULATION RESULTS

In this section, 10 degree FSS elevation angle is considered. Calculations assumed that the FSS ES transmitter is pointing directly towards the Fixed Service receiver in azimuth.

#### *A9.3.1.1 P-P and Enterprise FSS Earth Station (1.8 m), based on long-term protection criteria*

5 m height P-P case is evaluated at first. Detail parameters assumptions can also be found in the following table.

**Table 51: Simulation parameters**

| Case | 2 m height , 5 m height Rural | 10 m height, 5 m height Rural/Suburban | 2 m height, 5 m height Urban/Suburban | 10 m height , 5 m height Urban | 30 m height , 5 m height Urban |
|---|---|---|---|---|---|
| FSS Bandwidth [MHz] | 1 | 1 | 1 | 1 | 1 |
| **FSS Transmitter** | | | | | |
| Higher range TX power [dBm] | 19.10 | 19.10 | 19.10 | 19.10 | 19.10 |
| Tx antenna gain (10 degree elevation angle) [dBi] | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Feeder loss [dB] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tx antenna gain with feeder loss [dBi] | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Transmitter factor [dB] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| e.i.r.p. [dBm] | 26.10 | 26.10 | 26.10 | 26.10 | 26.10 |
| **P-P Receiver** | | | | | |
| Rx antenna gain [dBi] | 47 | 47 | 47 | 47 | 47 |
| Rx feeder loss [dB] | 0 | 0 | 0 | 0 | 0 |
| Rx antenna gain with feeder loss [dBi] | 47 | 47 | 47 | 47 | 47 |
| Max tolerable interference [dBm] | -117.33 | -117.33 | -117.33 | -117.33 | -117.33 |
| **Propagation loss [dB]** | | | | | |
| Clutter loss [dB] | 14.84 | 0 | 19.5 | 16.1 | 0 |
| Polarisation loss [dB] | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 |
| FSS single entry interference [dBm] | 58.26 | 73.10 | 53.60 | 57.00 | 73.10 |
| Additional isolation requirement [dB] | 174.09 | 188.93 | 169.43 | 172.83 | 188.93 |
| Co-channel protection distance [km] | 21.00 | 34.00 | 19.00 | 29.00 | 44.00 |

For 15 m, 30 m and 60 m P-P/P-MP antenna height, the co-channel separation distance will be different considering different P.452 propagation fading (see the following table).

**Table 52: Co-channel separation distance (km)**

| Case | 2 m height, rural | 10 m height, rural/suburban | 2 m height, urban/suburban | 10 m height, urban | 30 m height, urban |
|---|---|---|---|---|---|
| 15 m P-P | 28 | 41 | 26 | 35 | 52 |
| 30 m P-P | 35 | 48 | 32 | 41 | 59 |
| 60 m P-P | 43 | 58 | 41 | 49 | 67 |

#### *A9.3.1.2 P-P and Residential FSS Earth Station (0.75 m), based on long-term protection criteria*

5 m height P-P case is evaluated at first. Detail parameters assumptions can also be found in the following table.

**Table 53: Simulation parameters**

| Case | 2 m height, 5 m height Rural | 10 m height, 5 m height Rural/Suburban | 2 m height, 5 m height Urban/Suburban | 10 m height, 5 m height Urban | 30 m height, 5 m height Urban |
|---|---|---|---|---|---|
| FSS Bandwidth [MHz] | 1 | 1 | 1 | 1 | 1 |
| **FSS Transmitter** | | | | | |
| Higher range TX power [dBm] | 28.10 | 28.10 | 28.10 | 28.10 | 28.10 |
| Tx antenna gain (10 degree elevation angle) [dBi] | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Feeder loss [dB] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tx antenna gain with feeder loss [dBi] | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Transmitter factor [dB] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| e.i.r.p. [dBm] | 35.10 | 35.10 | 35.10 | 35.10 | 35.10 |
| **P-P Receiver** | | | | | |
| Rx antenna gain [dBi] | 47 | 47 | 47 | 47 | 47 |
| Rx feeder loss [dB] | 0 | 0 | 0 | 0 | 0 |
| Rx antenna gain with feeder loss [dBi] | 47 | 47 | 47 | 47 | 47 |
| Max tolerable interference [dBm] | -117.33 | -117.33 | -117.33 | -117.33 | -117.33 |
| **Propagation loss [dB]** | | | | | |
| Clutter loss [dB] | 14.84 | 0 | 19.5 | 16.1 | 0 |
| Polarisation loss [dB] | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 |
| FSS single entry interference [dBm] | 67.26 | 82.10 | 62.60 | 66.00 | 82.10 |
| Additional isolation requirement [dB] | 183.09 | 197.93 | 178.43 | 181.83 | 197.93 |
| Co-channel protection distance [km] | 25.00 | 39.00 | 23.00 | 33.00 | 48.00 |

For 15 m, 30 m and 60 m P-P antenna height, the co-channel separation distance will be different considering different P.452 propagation fading (see the following table).

**Table 54: Co-channel separation distance (km)**

| Case | 2 m height, rural | 10 m height, rural/suburban | 2 m height, urban/suburban | 10 m height, urban | 30 m height, urban |
|---|---|---|---|---|---|
| 15 m P-P | 32 | 46 | 30 | 40 | 56 |
| 30 m P-P | 38 | 53 | 36 | 46 | 63 |
| 60 m P-P | 47 | 62 | 45 | 55 | 72 |

### A9.3.2 P-MP and Enterprise FSS Earth Station (1.8 m), based on long-term protection criteria

5 m height P-MP case is evaluated at first. Detail parameters assumptions can also be found in the following table.

**Table 55: Simulation parameters**

| Case | 2m height, 5m height rural | 10 m height, 5 m height rural/suburban | 2 m height, 5 m height urban/suburban | 10 m height, 5 m height urban | 30 m height, 5 m height urban |
|---|---|---|---|---|---|
| FSS Bandwidth [MHz] | 1 | 1 | 1 | 1 | 1 |
| **FSS Transmitter** | | | | | |
| Higher range TX power [dBm] | 19.10 | 19.10 | 19.10 | 19.10 | 19.10 |
| Tx antenna gain (10 degree elevation angle) [dBi] | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Feeder loss [dB] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tx antenna gain with feeder loss [dBi] | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Transmitter factor [dB] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| e.i.r.p.[dBm] | 26.10 | 26.10 | 26.10 | 26.10 | 26.10 |
| **P-P Receiver** | | | | | |
| Rx antenna gain [dBi] | 27 | 27 | 27 | 27 | 27 |
| Rx feeder loss [dB] | 0 | 0 | 0 | 0 | 0 |
| Rx antenna gain with feeder loss [dBi] | 27 | 27 | 27 | 27 | 27 |
| Max tolerable interference [dBm] | -117.33 | -117.33 | -117.33 | -117.33 | -117.33 |
| **Propagation loss [dB]** | | | | | |
| Clutter loss [dB] | 14.84 | 0 | 19.5 | 16.1 | 0 |
| Polarisation loss [dB] | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 |

| Case | 2m height, 5m height rural | 10 m height, 5 m height rural/suburban | 2 m height, 5 m height urban/suburban | 10 m height, 5 m height urban | 30 m height, 5 m height urban |
|---|---|---|---|---|---|
| FSS single entry interference [dBm] | 38.26 | 53.10 | 33.60 | 37.00 | 53.10 |
| Additional isolation requirement [dB] | 154.09 | 168.93 | 149.43 | 152.83 | 168.93 |
| Co-channel protection distance [km] | 13.00 | 27.00 | 11.00 | 19.00 | 36.00 |

For 15 m, 30 m and 60 m P-MP antenna height, the co-channel separation distance will be different considering different P.452 propagation fading (see the following table).

**Table 56: Co-channel separation distance (km)**

| Case | 2 m height, Rural | 10 m height, Rural/Suburban | 2 m height, Urban/Suburban | 10 m height, Urban | 30 m height, Urban |
|---|---|---|---|---|---|
| 15 m P-MP | 19 | 34 | 17 | 25 | 42 |
| 30 m P-MP | 24 | 40 | 21 | 31 | 47 |
| 60 m P-MP | 31 | 48 | 21 | 31 | 55 |

### A9.3.3 P-MP and FSS Earth Station (0.75 m), based on long-term protection criteria

5 m height P-MP case is evaluated at first. Detail parameters assumptions can also be found in the following table.

**Table 57: Simulation parameters**

| Case | 2 m height, 5 m height Rural | 10 m height, 5 m height Rural/Suburban | 2 m height, 5 m height Urban/Suburban | 10 m height, 5 m height Urban | 30 m height, 5 m height Urban |
|---|---|---|---|---|---|
| FSS Bandwidth [MHz] | 1 | 1 | 1 | 1 | 1 |
| **FSS Transmitter** | | | | | |
| Higher range TX power [dBm] | 28.10 | 28.10 | 28.10 | 28.10 | 28.10 |
| Tx antenna gain (10 degree elevation angle) [dBi] | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Feeder loss [dB] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tx antenna gain with feeder loss [dBi] | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Transmitter factor [dB] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| e.i.r.p. [dBm] | 35.10 | 35.10 | 35.10 | 35.10 | 35.10 |
| **P-P Receiver** | | | | | |

| Case | 2 m height, 5 m height Rural | 10 m height, 5 m height Rural/Suburban | 2 m height, 5 m height Urban/Suburban | 10 m height, 5 m height Urban | 30 m height, 5 m height Urban |
|---|---|---|---|---|---|
| Rx antenna gain [dBi] | 27 | 27 | 27 | 27 | 27 |
| Rx feeder loss [dB] | 0 | 0 | 0 | 0 | 0 |
| Rx antenna gain with feeder loss [dBi] | 27 | 27 | 27 | 27 | 27 |
| Max tolerable interference [dBm] | -117.33 | -117.33 | -117.33 | -117.33 | -117.33 |
| **Propagation loss [dB]** | | | | | |
| Clutter loss [dB] | 14.84 | 0 | 19.5 | 16.1 | 0 |
| Polarisation loss [dB] | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 |
| FSS single entry interference [dBm] | 47.26 | 62.10 | 42.60 | 46.00 | 62.10 |
| Additional isolation requirement [dB] | 163.09 | 177.93 | 158.43 | 161.83 | 177.93 |
| Co-channel protection distance [km] | 17.00 | 31.00 | 15.00 | 24.00 | 40.00 |

For 15 m, 30 m and 60 m P-MP antenna height, the co-channel separation distance will be different considering different P.452 [20] propagation fading (see the following table).

**Table 58: Co-channel separation distance (km)**

| Case | 2 m height, Rural | 10 m height, Rural/Suburban | 2 m height, Urban/Suburban | 10 m height, Urban | 30 m height, Urban |
|---|---|---|---|---|---|
| 15 m P-MP | 24 | 38 | 21 | 30 | 47 |
| 30 m P-MP | 30 | 44 | 26 | 35 | 53 |
| 60 m P-MP | 36 | 52 | 34 | 43 | 61 |

### A9.4 SUMMARY

For FSS and P-P scenario, the separation distance (km) is summarised in the following table, containing a range due to different Tx/Rx height assumption.

**Table 59: FSS and P-P scenario co-channel separation distance (km)**

| Scenario | 1.8 m FSS | 0.75 m FSS |
|---|---|---|
| Rural | 21~58 | 25~62 |
| Suburban | 19~58 | 23~62 |
| Urban | 19~67 | 23~72 |

For FSS and P-MP scenario, the separation distance (km) is summarised in the following table with the range due to different Tx/Rx height assumption.

**Table 60: FSS and P-MP scenario co-channel separation distance (km)**

| Scenario | 1.8 m FSS | 0.75 m FSS |
|---|---|---|
| Rural | 13~48 | 17~52 |
| Suburban | 11~48 | 15~52 |
| Urban | 11~55 | 15~61 |

## ANNEX 10: LIST OF REFERENCES


[1] ECC Decision (05)01: “The use of the band 27.5-29.5 GHz by the Fixed Service and uncoordinated Earth stations of the Fixed-Satellite Service (Earth-to-space)”

[2] ECC Decision (00)07: “The shared use of the band 17.7-19.7 GHz by the fixed service and earth stations of the fixed-satellite service (space-to-Earth)”

[3] ETSI TR 103 263: “Cognitive radio techniques for Satellite Communications operating in Ka band”

[4] ECC Report 217 ‘The Use of Land and Maritime Earth Stations on Mobile Platforms Operating with NGSO FSS Satellite Systems in the Frequency Range 17.3-20.2 GHz, 27.5-29.1 GHz and 29.5-30.0 GHz” (2015)

[5] ECC Report 173: “Fixed Service in Europe - Current use and future trends post 2011”

[6] Recommendation ITU-R S.1594: “Maximum emission levels and associated requirements of high density fixed-satellite service earth stations transmitting towards geostationary fixed-satellite service space stations in the 30 GHz range”

[7] Site shielding: Reducing interference into satellite dish reception (here)

[8] Viasat measurements report: (here)

[9] ECC Decision (06)03: “Exemption from Individual Licensing of High e.i.r.p. Satellite Terminals (HEST) with e.i.r.p. above 34 dBW operating within the frequency bands 10.70 - 12.75 GHz or 19.70 - 20.20 GHz space-to-Earth and 14.00 - 14.25 GHz or 29.50 - 30.00 GHz Earth-to-space”

[10] T. S. Rappaport et al. “Wideband Millimeter-Wave Propagation Measurements and Channel Models for Future Wireless Communication System Design”, IEEE Transactions on Communications, Vol. 63, no 9, September 2015

[11] "28 GHz Millimeter-wave Ultrawideband Small-Scale Fading Models in Wireless Channels" by M.K. Samini et al. in 2016 IEEE Vehicular Technology Conference, May 2016 (here )

[12] Recommendation ITU-R P.530-17: “Propagation data and Prediction methods required for the design of terrestrial line-of-sight systems"

[13] HCM agreement 'on the co-ordination of frequencies between 29.7 MHz and 43.5 GHz for the fixed service and the land mobile service': (here)

[14] Azar. (2013): “28 GHz Propagation Measurements for Outdoor Cellular Communications Using Steerable Beam Antennas in New York City. IEEE International Conference on Communications”

[15] Nguyen. (2016): “An Empirical Study of Urban Macro Propagation at 10, 18, and 28 GHz. Proceedings of the Vehicular Technology Conference”

[16] Zhang. (2017). 28 GHz Channel Models and Modeling for Suburban Environments. Purdue University

[17] Recommendation ITU-R S.465-6: “Reference radiation pattern for earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz”

[18] Recommendation ITU-R F.699: “Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 86 GHz”

[19] Recommendation ITU-R F.1336: “Reference radiation patterns of omnidirectional, sectoral and other antennas for the fixed and mobile services for use in sharing studies in the frequency range from 400 MHz to about 70 GHz”

[20] Recommendation ITU-R P.452-16: “Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz”

[21] Recommendation ITU-R F.1245-3: “Mathematical model of average and related radiation patterns for point-to-point fixed wireless system antennas for use in interference assessment in the frequency range from 1 GHz to 86 GHz”

[22] ECC Recommendation T/R 13-02: “Recommendation T/R of 1993 on preferred channel arrangements for fixed service systems in the frequency range 22.0-29.5 GHz”

[23] Recommendation ITU-R F. 2086: “Deployment scenarios for point-to-point systems in the fixed service”

[24] Recommendation ITU-R P.2108: “Prediction of clutter loss”

[25] ECC Report 241: “Enhanced access to spectrum for FSS uncoordinated earth stations in the 17.7-19.7 GHz band”

[26] Recommendation ITU-R F.758-6: System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference

[27] Recommendation ITU S. 465: “Reference radiation pattern for earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz”

[28] Recommendation ITU-R S.1063: “Criteria for sharing between BSS feeder links and other Earth-to-space or space-to-Earth links of the FSS”

[29] Recommendation ITU-R SF.1486 (05/2000): “Sharing methodology between fixed wireless access systems in the fixed service and very small aperture terminals in the fixed-satellite service in the 3 400-3 700 MHz band”
[30] ETSI EN 300 431 V1.4.1: “Fixed Radio Systems; Point-to-point equipment; Parameters for radio system for the transmission of digital signals operating in the frequency range 24,50 GHz to 29,50 GHz”
[31] ECA Table: “the European table of frequency allocations and applications in the frequency range 8.3 kHz to 3000 GHz (ECA TABLE)
[32] CEPT Roadmap: “CEPT roadmap for 5G” (Version 8, Revised 8 March 2019), (here)