INTERNATIONAL CIVIL AVIATION ORGANIZATION

WESTERN AND CENTRAL AFRICA OFFICE

Fourth Meeting of the Central Atlantic FIR Satellite Network (CAFSAT) Management Committee (CNMC/2)
(Buenos Aires, Argentina, 4-5 August 2014)

Agenda Item 5:-Outcome of WRC-12 and preparation of WRC-15

Resolution 154 (COM6/24)- WRC-12 and challenges for the safe operation of AFISNET in the 3 400-4 200 C-band

(**Presented by the secretariat**)

SUMMARY

The purpose of this paper is to provide the meeting with a summary of the Finals Acts of ITU World Radicommunication Conference (**ITU WRC**) held in Geneva from 23 January to 17 February 2012, in particular those related to the protection of the down link **F**ixed **S**atellite **S**ervice (**FSS**) C-Band operated by AFI satellite based networks (CAFSAT, AFISNET, REDDIG, MEVA).

Reference:

Report on ACP Working Group F Meetings
Finals Acts of ITU WRC-12
ITU Recommendation 724-WRC-07
ITU Resolution 154 (COM6/24)-WRC 12
Report on APIRG/18 Meeting

Related ICAO Strategic Objectives: **A:** ***Safety***; **B:** ***Air Navigation Capacity and Efficiency***

Related ASBU Bloc 0 Modules, Performance Improvement Aerias and Applications:

B0-FRTO/PIA3-*PBN En Route Trajectories;*
B0-FICE/PIA2-*AIDC,*
B0-DATM/PIA2-*AIM,*
B0-TBO/PIA4-*Datalink*
B0-AMET/PIA2-*MET*

Action by the meeting see paragraph 3

1. Introduction

1.1 In order to ensure efficient and seamless interregional communication provision for aviation, ICAO through PIRGs meetings promoted the use of VSAT technology to support the provision of Aeronautical **F**ixed **S**ervice (**AFS**), **A**eronautical **M**obile **S**ervice (**AMS**), **A**eronautical **R**adio **N**avigation **S**ervice (**ARNS**) and aeronautical Surveillance data exchange, mainly due to the difficulties encountered to install and/or maintain aeronautical telecommunication facilities in non-accessible areas, such as deserts, oceanic areas and deep forests.

This provision relies on available technology proposed by the satellite service providers namely INTELSAT and IMARSAT for the SAT region.

1.2 Since the early time of the implementation of VSAT technology for the provision of Air Navigation Service within AFI and SAM Regions, the C-Band was recognized as the best technology band range candidate to provide a weather insensitive signal radiation to carry both Aeronautical Fixed and Mobile Service as well as Aeronautical radio navigation and Surveillance data. This band is not subject to the attenuation by oxygen and by rainfall water that are very dense in the tropical region.

Therefore the strategies of the SAM and AFI Regional Aeronautical Communication Plans have been based on the implementation of C-Band VSAT networks that operate on the ITU Fixed Satellite Service (**FSS**) in the range of **3.4-4.2 GHz** for the downlink.

For the same reasons, other ICAO regions like the Caribbean (CAR), Middle East (MID) are making an extensive use of VSAT technology in C-Band for civil aviation services.

2. Discussion

2.1 The operation of aeronautical VSAT on FSS C-band has been encountering more and more threat from new candidate to the usage of this spectrum in particular the **I**nternational **M**obile **T**elecommunication (**IMT**) identified as potential cause of harmful interferences to the satellite downlink and therefore to the provision of the backbone supporting CNS components within the AFI region. The conclusions of ITU-R studies on the colocation between broadband mobile devices and FSS earth stations are attached at **Appendix A**.

2.2 This threat was earlier identified and during the ITU World Radiocommunication Conference held in Geneva on 2007, lobbying between AFI States and AFI Air Navigation Service providers (Cameroun, Nigeria, Ghana, ASECNA, GCAA, NAMA...) and satellite manufacturers (Intelsat, Inmarsat..) under ICAO auspices allowed through **Recommendation 724 WRC 07** ***Use by civil aviation of frequency allocations on a primary basis to the fixed-satellite service,*** to prevent allocation on a primary basis of this band to IMTs.

2.3 **Recommendation 724 WRC 07** attached at **Appendix B,** calls upon administrations, in particular in developing countries and in countries with remote and rural areas to recognize the importance of VSAT operations to the modernization of civil aviation telecommunications systems, encourages the implementation of VSAT systems that could support both aeronautical and other communication requirements, as well as, to the maximum extent possible and as necessary, the expedition of the authorization process to enable aeronautical communications using VSAT technology**.** However, some States agreed with footnotes on the usage of this band by IMT and deployment has started in some AFI countries and during further implementation of Aeronautical VSATs stations, some ANSPs have been encountering risk of harmful interferences.

2.4 Pursuing its efforts, the AFI Frequency Management Group brought to the agenda of ACP WGF 25th meeting (Dakar, Senegal, 10-14 October 2011) the issue of the protection of the C-Band and after discussion the meeting considered how best to tackle this concern and although some radio regulatory method might provide an option it was realized that this would not be achievable at WRC in 2012. The meeting formed a small correspondence group which developed a proposal for a future Resolution of WRC that was circulated and transmitted to ATU by the AFI/FMG Rapporteur.

2.5 Moreover, a coordinated ICAO state letter was issued by ICAO WACAF and ESAF Offices to address AFI state and call upon them to approach their National Telecommunications Regulation Authority to present the concern and ask for their support during the ATU preparatory meetings and during the conference itself. The AFI/FMG Rapporteur worked closely with ICAO and ITU by participating in ATU preparatory meetings.

2.6 The draft Resolution was introduced by ATU prior to its endorsement by at least 11 ATU States members. One must note that this endorsement was achieved during the conference itself after one week of negotiation and lobbying towards the AFI states.

The commitment of some AFI States and their promises to support the resolution were not translated into practical achievement.

2.7 Fortunately, in the other hand AFI States and Organization amongst which SAT members such as Cote d’Ivoire, Ghana, Senegal, South Africa, and ASECNA played a key role during the debate on the issue. Support was also gained from ATU, Algeria, United States of America, INTELSAT and IATA.

2.8 After debate the resolution was adopted as **Resolution COM6/24-WRC 12,** currently renamed **Resolution 154-WRC 12**.
This resolution attached at **Appendix C** resolves to invite ITU-R to provide after studies, for next WRC-15/16 a set of "***possible technical and regulatory measures in some countries in Region 1 to support the existing and future FSS earth stations in the 3 400-4 200 MHz band used for satellite communications related to safe operation of aircraft and reliable distribution of meteorological information***".

The resolution invites States and ICAO and WMO to participate in these studies.

2.8 This important result implies that the aeronautical VSAT operators in the AFI Region therefore concerned SAT states, should actively participate through their national Authority of Regulation of Telecommunication in the preparatory activities of WRC-15/16.
In particular by providing the status of deployment of VSATs operating in the FSS C-Band in support to aeronautical services, they will contribute to the study called upon by Resolution 154.

To successfully address this critical issue, the AFI region needs to build a solid cooperation with other AFI FSS users operating in the same **3400-4200 MHZ** C-Band and with Aeronautical VSAT operators in the neighbouring Regions (MID, CAR, EUR, APAC…).
During this conference, ASECNA, GCAA, Cote d'Ivoire, Senegal as CNMC core members provided useful support to the initiative and this should be recognized and encouraged.

The difficulties encountered by the Secretariat and the AFI/FMG Rapporteur to have feedback for the endorsement of the draft Resolution requires that each CNMC member nominated a focal point to address VSAT spectrum issues.

2.9 The experience gained during this conference shows that an earlier and good preparation for the forthcoming Conference must be taken through dialogue with stakeholders such as CAAs, National Authorities of Regulation of Telecommunication and ANSPs.
The AFI Frequency Management Group (AFI/FMG) should draft a strategy in conjunction with the VSAT networks management committees (CNMC, SNMC, NAFISAT & SADC management Boards) to actively participate in and follow up the studies called upon by Resolution 154-WRC 12.

2.10 ICAO Regional Offices WACAF and ESAF continued the necessary coordination actions with the other neighbouring ICAO regions (MID, SAM, EUR, and APAC) to populate and share Resolution 154-WRC 12 that also addresses the issues of safe operation of satellite based VSAT networks supporting Aeronautical Fixed Services between these regions.

3. Action by the meeting

The meeting is invited to:

a) Take note of the information given above
b) Encourage CNMC Sates/Organizations to populate WRC-12 outcome on issues related to the provision of spectrum for civil aviation;
c) Actively participate in the studies called upon by Resolution COM6/24-WRC 12 through the activities of AFI/FMG, ACP WG F meetings and ATU regional meetings;
d) Strength their collaboration with their National Authority of Regulation of Telecommunication in order to submit and support the position of ICAO for the future WRC-15

REPORT ITU-R M.2109

Sharing studies between IMT-Advanced systems and geostationary satellite networks in the fixed-satellite service in the 3 400-4 200 and 4 500-4 800 MHz frequency bands

(2007)

Executive summary

This Report provides a summary of the sharing studies between IMT-Advanced systems and geostationary satellite networks in the fixed-satellite service (FSS) in the 3 400-4 200 and 4 500-4 800 MHz frequency bands. It was conducted by ITU-R in the framework of Agenda item 1.4 of WRC-07, in accordance with *resolves* 5 to Resolution 228 (Rev.WRC-03), as these bands were identified as candidate bands for future development of IMT-2000 and IMT-Advanced systems, as described in the Report ITU-R M.2079.

The bands 3 400-4 200 MHz and 4 500-4 800 MHz are allocated worldwide on a primary basis to the FSS. This Report presents the results of the sharing studies performed between geostationary satellite networks in the FSS and IMT-Advanced systems.

The following areas are covered in this Report:

- Regulatory information.
- Frequency usage by satellite services in these bands, provided on a global and regional basis.
- FSS space and earth station deployments.
- Considerations on potential identification of the 3 400-4 200 MHz and 4 500-4 800 MHz bands for IMT-Advanced.
- Parameters of the systems considered in this Report.
- Sharing studies (methodologies and results) between the two services from two aspects:
  - Interferences from IMT-Advanced transmitters to receiving FSS earth stations (in-band and adjacent band, and overdrive of the FSS receivers).
  - Interferences from transmitting FSS space stations to IMT-Advanced receivers.
- Results from one measurement study on interference from IMT-Advanced transmitter into one television receive only (TVRO) earth station.
- Mitigation techniques and spectrum management techniques to improve the sharing possibilities.
- Sensitivity analysis with respect to certain parameters to show the effect of their variation on the sharing situation between both systems.

The main conclusions are provided in § 11.

Table of abbreviations:

3GPP	3rd generation partnership project
ACLR	Adjacent channel leakage power ratio
ACS	Adjacent channel selectivity
ATPC	Automatic transmit power control
BER	Bit error rate
C/N	Carrier-to-noise power ratio
CDMA	Code division multiple access
DOE	Direction of earth station
EIRP	Effective isotropic radiated power
FEC	Forward error correction
FSS	Fixed-satellite service
GSO	Geostationary satellite orbit
IMT	International Mobile Telecommunications
ITU	International Telecommunication Union
LNA	Low noise amplifier
LNB	Low noise block downconverter
LoS	Line-of-sight
MIFR	Master International Frequency Register
MIMO	Multiple input multiple output
NLoS	Non line of sight
OFDM	Orthogonal frequency division multiplexing
OFDMA	Orthogonal frequency division multiple access
OOB	Out of band
PSD	Power spectrum density
PSK	Phase shift keying
SDMA	Space division multiple access
TDMA	Time division multiple access
TT&C	Tracking, telemetry and command
TVRO	Television receive only
UMTS	Universal mobile telecommunications System
UWB	Ultra-wideband
VSAT	Very small aperture terminal

WMO	World Meteorological Organization

1 Introduction

During the preparatory work for WRC-07 performed within ITU-R, in accordance with Resolution 228 (Rev.WRC-03), the frequency bands 3 400-4 200 MHz and 4 400-4 990 MHz have been considered as two of the candidate bands for the future development of the terrestrial component of IMT-2000 and IMT-Advanced systems with the understanding that the use of these bands will be limited to the terrestrial component of IMT-Advanced.

2 Scope of the report

As the bands 3 400-4 200 MHz and 4 500-4 800 MHz are allocated worldwide on a primary basis to the FSS, this Report presents the results of the sharing studies performed between the FSS networks using the geostationary satellite orbit (GSO) and IMT-Advanced systems.

The sharing studies have been performed based on:

- the current band usage by GSO-FSS and the associated generalized characteristics, which could evolve during the period while IMT-Advanced is being further developed and implemented;
- assumptions on the future characteristics of IMT-Advanced.

3 Regulatory information

3.1 Table of the frequency allocations

Table 1 lists the various allocations contained in Article 5 of the Radio Regulations (RR) (Edition of 2004) together with their respective status in the frequency range 3 400-4 200 MHz, as well as in the frequency range 4 500-4 800 MHz.

TABLE 1

Table of frequency allocations in the bands 3 400-4 200 MHz and 4 500-4 800 MHz

<table>
<tr><th>Region 1</th><th>Region 2</th><th>Region 3</th></tr>
<tr><td>3 400-3 600
FIXED
FIXED-SATELLITE (space-to-Earth)
Mobile
Radiolocation
5.431</td><td colspan="2">3 400-3 500
FIXED
FIXED-SATELLITE (space-to-Earth)
Amateur
Mobile
Radiolocation 5.433
5.432</td></tr>
<tr><td rowspan="2">3 600-4 200
FIXED
FIXED-SATELLITE (space-to-Earth)
Mobile</td><td colspan="2">3 500-3 700
FIXED
FIXED-SATELLITE (space-to-Earth)
MOBILE except aeronautical mobile
Radiolocation 5.433
5.435</td></tr>
<tr><td colspan="2">3 700-4 200
FIXED
FIXED-SATELLITE (space-to-Earth)
MOBILE except aeronautical mobile</td></tr>
<tr><td>4 500-4 800</td><td colspan="2">FIXED
FIXED-SATELLITE (space-to-Earth) 5.441
MOBILE</td></tr>
</table>

Note – Footnote 5.441 indicates, inter-alia, that the use of the band 4 500-4 800 MHz (space-to-Earth) by the FSS shall be in accordance with the provisions of RR Appendix **30B**.

3.2 International considerations between FSS earth stations and IMT-Advanced stations

International protection of FSS earth stations and their coordination are governed by RR Nos **9.17** and **9.18** and is applicable only to specific FSS earth stations (those whose geographical coordinates are known). The thresholds/conditions to be used to trigger coordination are those specified in RR Appendix **5**, together with the calculation method (contained in RR Appendix **7**). This coordination procedure is a regulatory concept.

It is up to each administration to decide which stations within its own territory it wishes to protect in accordance with the RR. For Example, if an administration wishes to ensure the protection of the receiving FSS earth station located in its territory from the transmitting terrestrial station located in the adjacent countries and within the coordination area of the earth station, a set of specific earth stations located at the edge of the territory should be registered to the ITU through the coordination and notification procedure under the provisions of RR Articles **9** and **11**.

Particularly, as specified in RR No **9.6**, an administration intending to bring into use terrestrial services, whose territory falls within the coordination contours of the earth stations under the coordination or notification procedure or notified under RR Articles **9** and **11**, shall effect coordination with other administrations having these earth stations.

The Radio Regulations do not provide any criteria or procedures for all kinds of required coordination under RR Article **9**, such as between GSO FSS networks and between FSS and terrestrial network, for how this bilateral coordination is to take place.

Annex C gives examples of coordination contours at some locations.

3.3 National considerations between FSS earth stations and IMT-Advanced stations

In countries where FSS earth stations are deployed, national arrangements are likely to be required within national borders, by administrations willing also to deploy terrestrial systems in these bands.

4 FSS space stations and earth stations deployment[1] in the 3 400-4 200 MHz and 4 500-4 800 MHz bands

4.1 Band 3 400-4 200 MHz

There is extensive utilization by the FSS of the frequency band 3 625-4 200 MHz in all ITU Regions of the world (except certain countries in Europe and in Asia) and of the frequency band 3 400-3 625 MHz in ITU Region 1 (except parts of Europe) and Region 3 (except some countries of Asia). The low atmospheric absorption in these bands enables highly reliable space-to-earth communication links with wide service coverage, particularly in, but not limited to, geographical areas with severe rain fade conditions. The wide coverage enables services to be provided to developing countries, to sparsely populated areas and over large distances.

The 3 400-4 200 MHz band has been used by the FSS for over 40 years. The technology is mature and offers equipment at low cost. This, together with the wide coverage, has lead to satellites in this band being an important part of the telecommunications infrastructure in many developing countries.

Satellite services in this band currently include very small aperture terminal (VSAT) networks, internet services, point-to-point links, satellite news gathering, TV and data broadcasting to satellite master antenna television (SMATV) and direct-to-home (DTH) receivers, feeder links for the mobile satellite service. Due to their wide coverage characteristics, satellites operating in this band have been extensively used for disaster relief operations.

The use of the band 3 400-4 200 MHz by FSS includes governmental uses and international commitments within the WMO. WMO usages of the band, which are essential for civil aviation and weather, water, climate and environmental alerts, are currently using only a few channels in the 3 600-3 800 MHz band.

The 3 400-4 200 MHz band is also utilized for tracking, telemetry and command (TT&C) purposes, under the FSS allocation, by a majority of FSS satellites operating in this band. Furthermore, there are

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[1] Additional band usage information on the FSS in the 3 400-4 200 MHz and 4 500-4 800 MHz bands is summarized in Table 1 of Report ITU-R M.2079.

additional satellites with service links operating in other frequency bands which have their TT&C in the 3 400-4 200 MHz band.

At the time of development of this Report, there were approximately 160 geostationary satellites operating in the band 3 400-4 200 MHz, comprising a total capacity exceeding two thousand 36 MHz transponders. The location and coverage areas of most of these satellites are provided in Table A2 of Annex A of this Report.

With regard to FSS earth stations receiving transmissions from FSS space networks, according to the ITU earth station database, there are more than 1 500 registered earth stations operating with geostationary satellites in the 3 400-4 200 MHz band. However, it should be noted that the majority of the FSS earth stations are not required to be notified to the ITU under the national regulations, and for each satellite system their characteristics are recorded in the Master International Frequency Register (MIFR) database under the "Typical earth station" category. In some rare cases, an FSS network filing with the ITU may contain few "Specific" earth stations filed in association with the satellite network.

Moreover, in many countries, the local administration does not individually license/register receive only earth stations or VSAT terminals and their number, location or detailed operating characteristics are not known. Also, even transmit stations are for the most part not registered with the ITU because their location does not raise interference issues with other countries.

FSS earth stations are deployed, in varying degrees, all around the world in the band 3 400-4 200 MHz. Some examples of such deployment are provided below.

– One major satellite operator has more than 9 900 registered earth stations, in its data base, deployed across the globe operating in the 3 400-4 200 MHz band. The location of these earth stations is shown in Fig. A4 through A6 of Annex A of this Report. The operating earth stations shown in these figures do not include all FSS earth stations dedicated to signal reception such as television receive-only (TVRO) terminals.

– In Brazil, in the band 3 700-4 200 MHz, there are more than 8 000 nationally registered earth stations pointing to one of the Brazilian satellites in and 12 000 nationally registered earth stations pointing to one of the non-Brazilian satellites that cover the country plus an equal number of earth stations in the 3 625-3 700 MHz band (see Fig. A7 of Annex A). There are also an estimated 20 million TVRO terminals deployed across the country.

– A provider of television programming in the USA provides programming via satellite directly to the general public in areas that are outside the coverage area of its terrestrial television stations. As of December 2005, there were approximately 122 000 receive-only earth stations that received programming from that provider in that country.

– Members of one Broadcasting Association utilize more than 31 000 earth stations in North America to reach over 66 million cable television households.

– In the Russian Federation, there are approximately 6 000 nationally registered earth stations that receive transmissions in the 3 400-4 200 MHz band (see Figs. A4, A5 and A6 of Annex A). This figure does not include TVRO earth stations that are deployed across the country.

– In France and Korea (Republic of), there is a limited number per country, twenty or less, of nationally registered FSS earth stations on their territories.

– In Finland and Sweden, there is a limited number per country, less than 5, of nationally registered FSS earth stations.

Different earth stations, depending on the application and traffic requirement may access different amounts of spectrum. For example, in Sweden, a particular earth station only uses a total of 2 MHz spectrum.

In other countries such as the United Kingdom, some earth station locations use a large number of antennas to communicate with different satellites and may therefore use the whole allocated band. An earth station antenna may also receive several carriers at different frequencies and may also switch between different receive frequencies (e.g. TVRO).

4.2 Band 4 500 – 4 800 MHz

The band 4 500-4 800 MHz is part of the FSS Plan, specified in RR Appendix **30B**, and is therefore intended to preserve orbit/spectrum resources for future use, in particular for countries that may not have the possibility to implement satellite systems in unplanned bands in the short- and mid-terms.

5 Considerations on potential identification of the 3 400-4 200 MHz and 4 500-4 800 MHz bands for IMT-Advanced

This section provides some information about the main reasons why these bands are of interest for use by IMT-Advanced systems.

The size of these bands would accommodate IMT-Advanced systems which are envisaged with large bandwidth and would provide significant capacity, according to the ITU-R spectrum requirement estimations (see Report ITU-R M.2078).

The use of these bands may facilitate the convergence between cellular and broadband wireless access systems already deployed in the lower part of the band 3 400-4 200 MHz in some countries.

In some administrations, FSS is not deployed in the sub-band 3 400-3 600 MHz.

These frequency bands allow use of smaller antenna size for terminals and base stations, which is a favorable feature to implement multiple-antenna techniques enabling high spectrum efficiency.

6 FSS Parameters including the interference criteria

The parameters listed in § 6.1 provide key FSS parameters to be used in calculation of interference into FSS receive earth stations. Section 6.2 provides the interference criteria for FSS and § 6.3 addresses the apportionment of the interference for the FSS receivers.

6.1 System parameters

TABLE 2

Typical downlink FSS parameters in the 4 GHz band

Parameter	Typical value						
Range of operating frequencies	3 400-4 200 MHz, 4 500-4 800 MHz						
Earth station off-axis gain towards the local horizon (dBi)$^{(1)}$	Elevation Angle$^{(2)}$	5°	10°	20°	30°	48°	>85°
	Off-axis gain	14.5	7.0	–0.5	–4.9	–10	0

Antenna reference pattern	Recommendation ITU-R S.465 (up to 85°)
Range of emission bandwidths	40 kHz – 72 MHz
Receiving system noise temperature	100 K
Earth station deployment	All regions, in all locations (rural, semi-urban, urban) (3)

(1) The values were derived by assuming a local horizon at 0° of elevation.

(2) 5° is considered as the minimum operational elevation angle.

(3) FSS antennas in this band may be deployed in a variety of environments. Smaller antennas (1.8 m-3.8 m) are commonly deployed on the roofs of buildings or on the ground in urban, semi-urban or rural locations, whereas larger antennas are typically mounted on the ground and deployed in semi-urban or rural locations.

In order to conduct the simulations, the additional parameters were considered:

– Antenna diameter: 2.4 m and 11m (feeder link).

– Antenna height: 30 m (urban case) and 3m (rural case).

NOTE 1 – This set of parameters is representative of most of the earth stations deployed.

6.2 FSS interference criteria

Two interference criteria were identified for use when assessing the interference from IMT-Advanced to FSS.

6.2.1 Long-term interference criterion

Based on the Recommendation ITU-R S.1432, two cases have been considered, depending on the type of the scenarios studied:

– In-band sharing studies: $I/N = -12.2$ dB ($\Delta T/T = 6\%$) corresponding to the total interference from other systems having co-primary status, for 100% of the worst month or $I/N = -10$ dB ($\Delta T/T = 10\%$) corresponding to the aggregate interference from co-primary allocation for 20% of any month (*Note*: for typical BER-vs–C/N characteristics of PSK/FEC demodulators, the two criterion are effectively the same – i.e. if one is met the other will be met).

– Adjacent band sharing studies: $I/N = -20$ dB ($\Delta T/T = 1\%$) corresponding to the aggregate interference from all other sources of interference, for 100 % of the time.

where N is the clear-sky satellite system noise as described in Recommendation ITU-R S.1432.

Suitable apportionment of this criterion must be considered (see § 6.3).

6.2.2 Short-term interference criterion

The ITU-R reference for this criterion is Recommendation ITU-R SF.1006. This criterion also appears in Annex 7 (see both text and Table 8b) of RR Appendix **7**:

– $I/N = -1.3$ dB which may be exceed by up to 0.001667% time (single entry)

It is noted that:

– the criterion above is also used to define a coordination area as defined in Annex 7 of RR Appendix **7**, in conjunction with the methodology (e.g. propagation model) and other parameters described therein.

- Recommendation ITU-R SF.1006 recommends the methods that may be used for assessing interference potential between earth stations and the specific stations in the fixed service within the coordination area.

6.2.3 Guidance to use the two interference criteria

The interference potential into a FSS earth station should be evaluated taking into account both long-term and short-term interference criteria.

Studies have shown that for all types of terrain and paths, the separation distances calculated using the short-term criterion are significantly different from those calculated using the long-term.

It was noted by ITU-R that the propagation model described the Recommendation ITU-R P.452 should not be applied with a smooth earth terrain, but should use a representative terrain profile.

However, some studies have considered that the terrain profile associated with a smooth earth model is representative of areas such as coastal and flat inland plain regions. It should be noted that it is not representative of areas that have different characteristics and the use of such a model may result in the overestimation of the interference into a receiving FSS earth station.

6.3 Apportionment of the interference

As shown in § 8.1.4, two cases regarding the apportionment of the interference were investigated based on the following two assumptions.

- In one case, 100% of the interference to the FSS was allocated to IMT-Advanced systems, which corresponded to the case where both IMT-Advanced and the fixed service systems were assumed to be not deployed in the same band, in the same geographical area.
- In the other case, 50% (I/N = –15.2 dB) apportionment of the allowable interference IMT-Advanced was evaluated, i.e., splitting the 6% allowance for other systems having a co-primary status equally between two such systems, which corresponded to the case when the FSS would share this band with the fixed service as well as IMT-Advanced systems.

Similarly, in the case of interference from other sources, including spurious emission and out-of-band (OoB) emissions from adjacent bands, it may be necessary to apportion the allotted increase in noise due to such sources of interference between various other sources of interference. No guidance has been provided by ITU-R regarding the apportionment of interference from the various other sources.

7 IMT-Advanced parameters including the interference criterion

The following values have been used to conduct the sharing studies presented in this Report.

7.1 In-band parameters

This paragraph contains the IMT-Advanced parameters assumed for the comparison of the different studies, which represent one possible scenario of an IMT-Advance deployment.

TABLE 3

IMT-Advanced base station parameters

Parameter	**Value**	**Value considered in the simulations**
EIRP density range: macro base station scaled to 1 MHz bandwidth	39 to 46 dBm/MHz	46 dBm/MHz
EIRP density range: micro base station scaled to 1 MHz bandwidth	15 to 22 dBm/MHz	22 dBm/MHz
Maximum EIRP(1) (Transmitter output power + antenna gain – feeder loss)	59 dBm (macro base station) 35 dBm (micro base station)	
Antenna type (Tx/Rx) (the gain is assumed to be flat within one sector)	Sectored for macrocell omni for microcell	
Receiver thermal noise (including noise figure)	–109 dBm/MHz	
Protection criterion (*I*/*N*) interference to individual base station	–6 dB or –10 dB(2)	
Protection criterion (*I*/*N*) vs satellite systems	–10 dB	

(1) EIRP range of values assume range of frequency bandwidth between 20 and 100 MHz.

(2) This value has to be used when assessing compatibility between a non primary allocated system and a primary allocated system (e.g. between UWB and IMT-Advanced).

TABLE 4

IMT-Advanced mobile station parameters

Parameter	**Value**	**Value to be considered in the simulations**
Maximum Tx PSD range output power(1)	4 to 11 dBm/MHz	7.5(2) dBm/MHz
Maximum EIRP	24 dBm	
Receiver thermal noise (dBm/MHz) (Including noise figure)	–109 to –105 dBm/MHz	
Protection criterion (*I*/*N*)	–6 dB	

(1) With reference signal bandwidth between 20 and 100 MHz.

(2) A median value is selected considering the effect of automatic transmit power control (ATPC).

TABLE 5

IMT-Advanced network parameters

Parameter	Value
Macro cell antenna gain	20 dBi
Micro cell antenna gain	5 dBi
Macro cell feeder loss	4 dB
Micro cell feeder loss	0 dB
Antenna pattern for vertical sharing	Rec. ITU-R F.1336(1)
Mobile station antenna gain	0 dBi
Base station Antenna downtilt (Micro)	0 degree
Base station Antenna downtilt (Macro)	2 degrees
Base station antenna height (Micro)	5 m
Base station antenna height (Macro)	30 m
Mobile station antenna height (mobile station)	1.5 m
Intersite distance (Micro)	600 m
Intersite distance (Macro)	5 km
Intersite distance (Macro) for urban case	1,5 km
Active users density (Dense Urban/Macro)	18/km²
Active users density (Dense Urban/Micro)	115/km²
Active users density (Suburban/Macro)	15/km²
Active users density (Suburban /Micro)	19/km²
Frequency reuse pattern	1(2) and 6(3)

(1) Recommendation ITU-R F.1336 has generally been used in the studies. However, STUDY 2 of this report has used the Recommendation ITU-R F.1336-2 (see § 8.2.2).

(2) The same frequency is used by all sectors.

(3) Except STUDY 6 in § 8.1.2, all the other studies have only applied 1.

7.2 Out-of-band parameters

The following values were assumed to define the spectrum mask, valid for the bandwidths between 20 MHz and 100 MHz:

TABLE 6

IMT-Advanced out-of-band parameters

Offset	ACLR limit
1st adjacent channel	45 dB
2nd adjacent channel	50 dB
3rd adjacent channel and above	66 dB

Regarding the spurious emissions, the document 3GPP TS 25.104, which is referred to in Recommendation ITU-R M.1457, specifies the data relating to the bandwidth of 5 MHz. The Table 6.9E in the document gives the absolute level of –30 dBm/MHz after the 2nd adjacent channel (i.e., above 2 700 MHz). For a base station transmitting a level of 43 dBm/5 MHz (i.e., 36 dBm/MHz), this leads to a relative value of 66 dB.

Some studies have been based on the spurious emission limits prescribed in RR Appendix **3**. In accordance with Appendix **3** of the RR, it is assumed that the IMT-Advanced transmitters would be specified such that its spurious emission at frequency separation of 2.5 x (necessary bandwidth) from the center frequency of the IMT-Advanced carrier, measured in bandwidth of 1 MHz, would be attenuated by 43 + 10 log(P) dB or 70 dBc, whichever is less stringent, below the transmitter power level P (W). The OoB domain emission masks contained in Annex 10 of the Recommendation ITU-R SM.1541 does not present a suitable model that may be applicable to IMT-Advanced systems. As a result, the impact of OoB emission of IMT-Advanced transmitters into FSS receivers has not been evaluated in these studies.

8 Sharing study results

This paragraph provides a summary of the methodologies and assumptions incorporated by the various sharing studies and their respective results. Additionally, a number of possible mitigation techniques that may be taken into consideration to improve the sharing between FSS and IMT-Advanced systems are described in § 8.1.5.

8.1 Interference from IMT-Advanced systems to FSS receiving earth stations

The studies presented in this Report have considered one or more of the following interference mechanisms:

- In-band interference where IMT-Advanced and FSS operate at the same frequency.
- Interference from unwanted emissions of IMT-Advanced stations (OoB and spurious emissions) operating in one portion of the 3 400-4 200 MHz band into FSS receivers operating in another portion of this band.
- Overdrive and non-linear operation of FSS receive low noise block (LNB) due to the power levels of IMT-Advanced emissions within the receive band of these, driving them outside their dynamic range.

There are some differences in the calculation methodologies, parameters and assumptions used in the different studies. Therefore:

- A description of the methodologies are given in the § 8.1.1.
- The assumptions and methodologies associated with each sharing study are summarized in Tables of § 8.1.2 and 8.1.3. These tables also indicate the extent to which each sharing study employed the common FSS and IMT-Advanced parameters that are specified in Tables 2 through 5.

The studies examined single entry and/or aggregate interference effects. A number of these studies were non-site specific (also called generic) while others were site specific and employed terrain information specific to that site and its surrounding area. The results of the generic and site specific sharing studies are summarized in the tables in § 8.1.4.1 and § 8.1.4.2, respectively.

8.1.1 Methodologies used in the simulations

This paragraph provides additional information regarding the assumptions and methodologies incorporated by the various sharing studies. The information provided herein is meant to complement that which is contained in § 8.1.2 and § 8.1.3.

The STUDY 3 analyses the single-entry interference cases only, for both short-term and long-term criteria.

The analyses are based on the propagation models described in ITU-R P.452. Due to the generic nature of the analysis, for the long-term protection cases, the propagation is calculated over a smooth earth surface, utilizing the propagation model described in § 4.3 of ITU-R P.452. Building losses and clutter effects have been assumed to represent suburban environment in these analyses.

In the case of short-term propagation, the ducting mode of propagation model described in § 4.5 of ITU-R P.452 has been utilized. In order to simplify the model, rain scatter and tropospheric scatter were not considered.

This study presents the results of analyses on impact of interference into FSS receivers from spurious emission from IMT-Advanced equipment based on the prescribed guidelines of RR Appendix 3 and the propagation models described in ITU-R P.452.

The STUDY 4 considered the following assumptions:

Single-entry

In order to generally evaluate the interference from the IMT-Advanced systems on application cases using the specific terrain profile information, in each trial of the simulation, the location of the base station of the IMT-Advanced systems is randomly changed in the area of 1 km-radius with the resolution of 50 m × 50 m, and then the interference into the FSS earth station is computed. By the sufficient number of trials, the possibility of sharing between IMT-Advanced and FSS systems is statistically evaluated.

Aggregate

In the case of the aggregated interference from the multiple IMT-Advanced base stations is evaluated, it assumed a 10-cell hexagonal deployment with specified inter-site distance scenario. The simulation methodology is the same as that of single-entry case, except that the aggregated interference from the multiple IMT-Advanced base stations is taken into account.

The STUDY 7 considered the following assumptions:

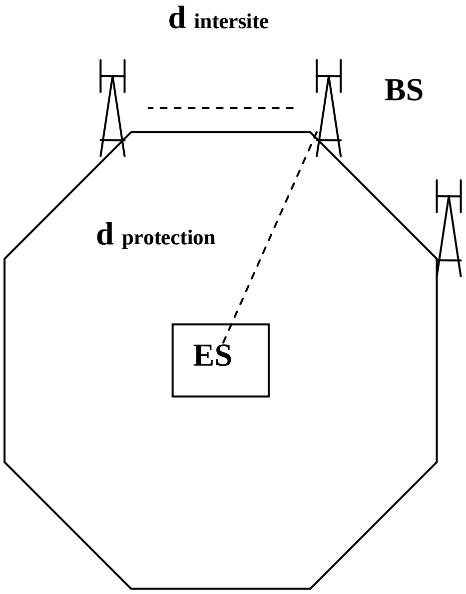
Single Entry

For each environment, results are expressed in terms of separation distance between IMT-Advanced base station and FSS earth station to meet the long term protection criterion. These separation distances are assessed regarding the FSS earth station elevation angle and additionally azimuth between earth station and single base station.

Aggregate case (without terrain data model)

For the aggregate case, the effect of all the IMT-Advanced base station is taken into account i.e. a certain number of base station equi-spaced have been uniformly located on a circle around the FSS earth station. Thus radius is the result of the required separation distance meeting the interference criterion. The number of IMT-Advanced base station is assessed according to the separation distance and the base station intersite distance range as following:

FIGURE 1



The number aggregate base station assessed is as following:

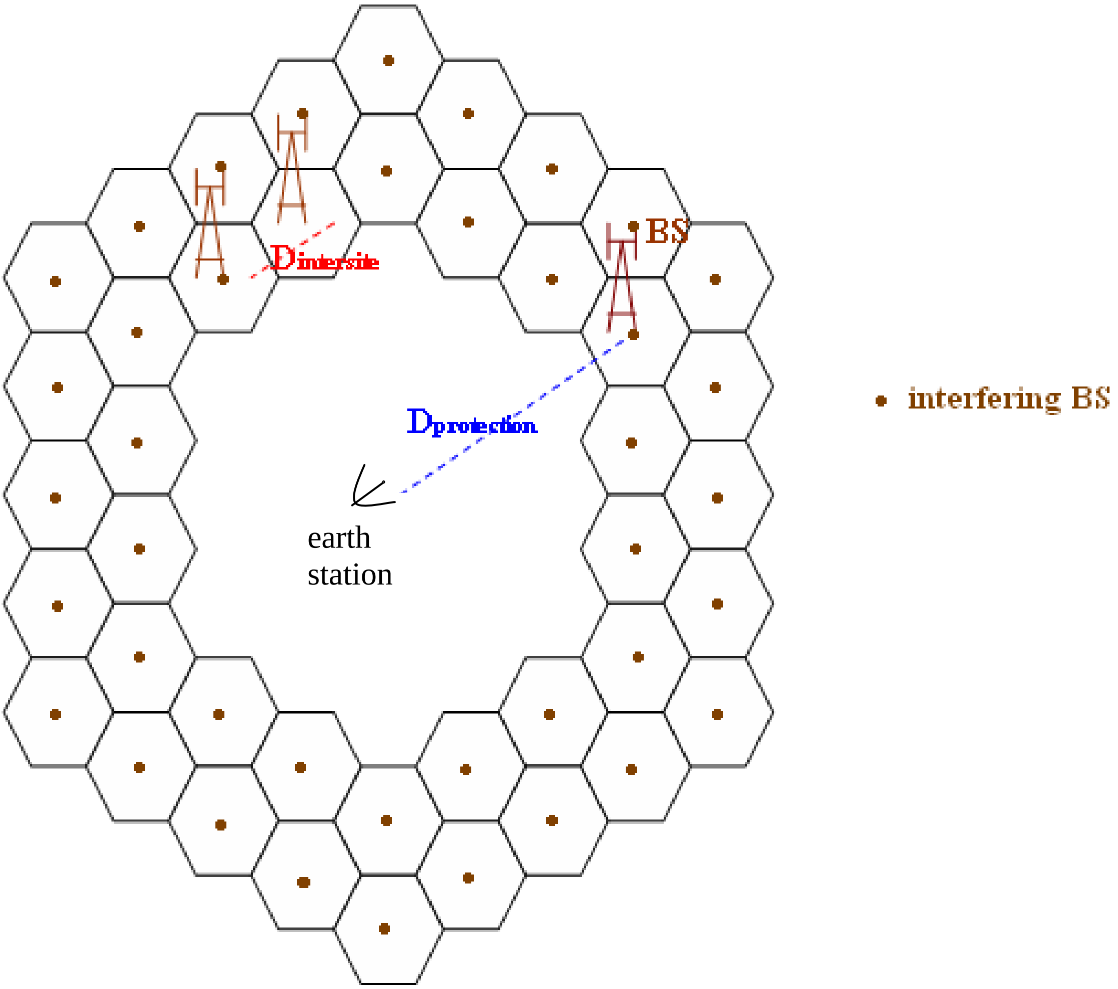
Number of aggregate base station = (2*pi* d $_{\text{protection}}$) /d $_{\text{intersite}}$

Aggregate IMT-Advanced base station case (with terrain data model)

Based on the consideration of a cellular network modeling and base station intersite distance, this aggregate case modeling takes into account the effect of all the IMT-Advanced base station whose interference contribution is significant is considered in the calculation. These base station are uniformly (equi-spaced) located on rings around the FSS earth station. The total sum of the interference takes into account the interference of all base station up to the farthest ring of potential interference contributors. The radius of the closest ring is the required separation distance resulting from the calculation of the total sum of the interference contribution.

FIGURE 2

Aggregate base stations scenario



The radius of the i^{th} ring is:

$D(i) = D_{protection} + (i-1) * D_{intersite}$

The number N(i) of IMT-Advanced base station located on the i^{th} ring is assessed according to the corresponding distance D(i) and the base station intersite distance range as following:

$N(i) = pi / (\arcsin (D_{intersite} / (2*D(i))))$

Aggregate mobile station contribution

This study assumes a random distribution of agreed number of user density of mobile stations within each cell whose base station is interfering into the FSS earth station. The distance $D_{mobile\ station}$ of the closest mobile station is defined as following:

$$D_{mobile\ station} = D_{protection} - D_{intersite}/2$$

Study 9 investigated overdrive of LNB's and interference from unwanted emissions. It was expected that these phenomena will occur at smaller distances than in-band interference. It was therefore assumed that such interference from IMT-Advanced transmitters beyond the horizon are most unlikely.

The calculations therefore have not taken trans-horizon propagation into account and are based on LoS calculations.

It is understood that multipath and focusing effects may significantly increase the received signal levels for short periods of time and increase the required separation distance. However, in these calculations, these effects have not been taken into account.

This study also only calculated required separation distances with respect to single entry interference contributions from IMT-Advanced stations and did not consider the aggregation of several IMT-Advanced base stations and/or user terminals.

Detailed description of the methodology, assumptions, calculations and results of STUDY 9 can be found in Annex E.

For LNB overdrive calculations, some additional parameters which have not yet been specified in Tables 3 to 5 are required. Amongst these are input levels that will make the LNB exhibit non-linear behaviour. For this purpose, the LNB 1 dB compression point was assumed to correspond to a level of –50 dBm at the LNB input and that the LNB would start to show non-linear behaviour at an input level about 10 dB below this level (i.e. –60 dBm). For estimation of the total received satellite power, 36 MHz satellite transponders in the full 800 MHz bandwidth, each with an EIRP of 41 dBW was assumed for this study.

In STUDY 10, the aggregate interferences have been calculated with the following assumptions:

- Base Station Case – 42 cells distributed (static distribution) within a radius of 3 km from the FSS receive station. Six-cell reuse for TDMA / single cell reuse for CDMA. Simulation assumed FSS earth station located amongst macro cells. Result was a measure of the exceedence of the required *I*/*N* protection requirement for the FSS.
- Mobile Station Case – Monte Carlo simulation, mobile stations randomly distributed within a circular area of 2.95 km about the FSS receive station. Simulation assumed FSS earth station located amongst a population of mobile IMT-Advanced stations. Result was a measure of the exceedence of the required *I*/*N* protection requirement for the FSS

The goal of the STUDY 11 is to consider the combined exclusion zone for multiple earth stations deployed in the same region. The study considers 9 existing and operational earth station receiving in the band 3 700-3 800 MHz. Aggregation over 100 MHz is based on anticipated IMT-Advanced network bandwidth. For each earth station the interference from single macro base station is evaluated for short-term and long-term interference criteria taking into account terrain, actual frequency, azimuth, elevation angle and antenna height. Other parameters have been taken from § 6 and 7 of this Report. Two extreme cases have been considered with one 100 MHz channel and with five 20 MHz channels corresponding to 39 dBm/MHz and 46 dBm/MHz EIRP accordingly. All other possible channel bandwidths and channel arrangements will be enclosed within these two cases.

During analysis macro base station has been moved from one position to another within 5 km grid, for each position short-term and long-term interference and *I*/*N* have been calculated for each earth station. Square area with approximately 5 km sides is treated as an exclusion zone if macro base station positioned in the centre of such area creates interference in earth station receiver leading to *I*/*N* higher than criterion. For long-term interference *I*/*N* is allowed to be higher than –10 dB only for 20% of time, for short-term interference *I*/*N* could exceed –1.3 dB only for 0.001667% of time. As a result aggregated exclusion zones have been drawn based on the worst value of interference among all earth station for each point of the grid.

Additional information on this study could be found in Annex B.

8.1.2 Compliance with the common parameters

	STUDY 1	STUDY 2	STUDY 3	STUDY 4	STUDY 5	STUDY 6	STUDY 7	STUDY 8	STUDY 9	STUDY 10	STUDY 11
Compliance with the common set of IMT-Advanced parameters shown in Tables 3 to 5	Fully compliant	N.A	Fully Compliant Except the OoB parameters of IMT, which are based on Appendix 3 of the RR	Fully compliant with additional cases Chosen parameters – Frequency: 3.9 GHz Additional parameters: – Antenna height: 20m (rural) – Antenna tilt: 7°	Fully compliant, except for adjacent band analysis: the spectrum mask for OoB emissions of orthogonal frequency division multiplexing (OFDMA). Since no mask for this case was addressed, the spectrum with filtration having roll-off factor of 0.2, theoretical mask, was used	Frequency reuse pattern of 1 (CDMA) and 6 (TDMA)	Fully Compliant OFDMA cases consider a transmitted power reduced by 5 to 7 dB compared to the maximum value of the range expressed in Table 3	Fully compliant, except assuming base station antenna height (Micro, dense urban of Beijing) to be 20 m, not 5 m	Fully compliant except for unwanted emissions (see § 8.1.1 and Annex E for mask for unwanted emission and additional parameters not specified in Tables 3 to 5)	Fully compliant	Fully compliant

	STUDY 1	STUDY 2	STUDY 3	STUDY 4	STUDY 5	STUDY 6	STUDY 7	STUDY 8	STUDY 9	STUDY 10	STUDY 11
Compliance with the common set of FSS parameters shown in Table 2	Antenna height a.g.l Stn-1:5 m ; Stn-2: 25 m Antenna Gain: Stn-1:47.7; Stn-2: 59.8 dBi Locations: Stn-1: N51:43:44 W0:10:39 Stn-2: N50:02:55; W5:10:46	N.A	Fully compliant	Chosen parameters – Frequency: 3.9 GHz – Antenna diameter: 2.4 m non-compliant parameters – Antenna height: 10 m (urban) 3 m (rural)	Fully compliant	Fully compliant except: Earth station off-axis gain: Appendix 7 Long-term protection criterion: –15.2 dB	Fully compliant	Fully compliant, except assuming FSS antennas deployed in suburban and dense urban locations in Beijing: Antenna height: 2 m (on the ground, suburban and dense urban); 10 m (on the roofs of buildings, Suburban); 30 m (on the roofs of buildings, dense urban)	Only IMT-Advanced interference allowance of 6% and 1% considered in the studies, not 3% and 0.5%	Fully compliant except with respect to 1) the height of the FSS earth station antenna, where a height of 2 m was assumed 2) for off-axis azimuth of greater than 85°, where an antenna gain of –10 dBi was assumed	Only thermal noise and antenna pattern are compliant. Other parameters are actual values for earth station under study and within following ranges: Antenna height from 2.5 to 24 m. Elevation angle from 3° to 22.5°. Azimuth from 107° to 146°

8.1.3 Propagation assumptions

	STUDY 1	STUDY 2	STUDY 3	STUDY 4	STUDY 5	STUDY 6	STUDY 7	STUDY 8	STUDY 9	STUDY 10	STUDY 11
Use of the Recommendation ITU-R P.452	Yes. Delta *N*: 45 Long term $p = 20\%$ Short term $p = 0.00167\%$	N.A	Diffraction and ducting models used	– Path type: LoS with sub-path diffraction/trans-horizon – 100 m × 100 m clutter data for clutter loss (uniform average height of each clutter category)	Yes Long term $p = 20\%$	– Long-term: smooth-earth, diffraction mode – Short-term: smooth-earth, diffraction/troposcatter/ducting modes	Yes. Long term $p = 20\%$	Diffraction over a spherical path	Path type: LoS without sub-path diffraction, multipath or focusing effects. Only long-term propagation conditions.	All propagation modes included, except hydrometeor scatter	Yes. Delta *N*:45 Long term $p = 20\%$ Short term $p = 0.00167\%$
Use of a terrain data model	Terrain data specific to UK region is considered	N.A	Clutter losses in accordance with suburban settings given in Table 6 of Rec. ITU-R P.452	Used with 50 m × 50 m resolution and smoothed to 500 m × 500 m resolution by filtering	Used with 1 m × 10 m resolution real terrain data (Seoul Korea) with artificial object (buildings)	None. (Estimated 15 dB clutter losses added for aggregate base station case; 30 dB clutter/shielding for aggregate mobile station case)	Both generic and application cases studied	Clutter losses in accordance with suburban and dense urban settings given in Rec. ITU-R P.452	No (Non-specific earth station location)	Global terrain data base	Terrain data specific to Kaliningrad region (Russian exclave) is considered

8.1.4 Results

The following paragraph contains three types of study results: co-channel interferences, adjacent band interferences and saturation of the low noise amplifier (LNA) of a receiving FSS earth station. The studies have been derived for typical FSS earth station cases (generic study) as well as for specific FSS earth station cases (application case) for the three interference scenarios.

For each of the three scenarios, geographical separations between the IMT-Advanced station and the FSS earth station would be required. For these three types of study results, distances are provided. They represent the required distances to meet the interference criteria.

When performing the calculations whose results are given below, it was advised by the ITU-R that "Recommendation ITU-R P.452-12 is the appropriate propagation model for predicting interference between terrestrial stations in the frequency range from about 700 MHz up to above 6 GHz when the distance between the transmitter and receiver is longer than 1 km. Recommendation ITU-R P.1411-3[2] could be used for short paths up to about 1 kilometre, while Recommendation ITU-R P.1546-2 can be used for frequencies from 30 to 3 000 MHz and for time percentages down to 1%."

8.1.4.1 Typical FSS earth station case (Generic study)

Generic studies are based on a flat terrain model.

NOTE 1 – In the case of calculations using short-term criterion, distances derived using a flat earth model are provided to assess the maximum range of distances (see § 6.2.2) and should not be applied by default to define an exclusion zone around an earth station, as it is not representative of all areas around the world.

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[2] Recommendation ITU-R P.1411 – Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz

	STUDY 1	STUDY 2	STUDY 3	STUDY 4	STUDY 5	STUDY 6	STUDY 7	STUDY 8	STUDY 9	STUDY 10	STUDY 11
Co-channel Results											
Long-term interference criterion / Single entry											
Minimum distance (*I*/*N* = –12.2 dB)	N.A	N.A	Macro base station: 55 km Mobile station: 1 km	37-54 km (Macro urban) 15-23 km (Micro urban) 40-59 km (Macro rural) with a downtilt varying from 2 to 7°	Base station: 45-58 km (FSS earth station elevation angle: 5°-48° and bandwidth: 75 MHz)	33-57 km (5º elevation) 33-37 km (15º elevation)	CDMA Macro base station: from 47 to 65.5 km CDMA Micro base station: from 39 to 49.5 km CDMA Mobile station: 0 km OFDMA Macro base Station: from 43 to 55 km OFDMA Micro base station: from 29 to 47 km OFDMA Mobile station: 0 km	N.A	N.A	N.A	N.A
Minimum distance (*I*/*N* = –15.2 dB)	N.A	N.A	Macro base Station: 70 km Mobile station: 1.5 km	N.A	N.A	36-60 km (5º elevation) 36-40 km (15º elevation)	N.A	N.A	N.A	N.A	N.A

	STUDY 1	STUDY 2	STUDY 3	STUDY 4	STUDY 5	STUDY 6	STUDY 7	STUDY 8	STUDY 9	STUDY 10	STUDY 11
Long-term interference criterion / aggregate case											
Minimum distance (*I*/*N* = –12.2 dB)	N.A	N.A	N.A	N.A	Base stations: 51-60 km (FSS earth station elevation angle: 5°-48° and bandwidth: 75 MHz) mobile stations: 0.5-1.5 km (base station numbers : 10)	*I*/*N* exceedence (same geographical area) Macro base station: 51-64 dB Mobile station: 22-65 dB	CDMA Macro base station: from 56 to 87 km CDMA Micro base station: from 49 to 58 km CDMA Mobile station: 0 km OFDMA Macro base station: from 51 to 61 km OFDMA Micro base station: from 46 to 53 km OFDMA Mobile station: 0 km	N.A	N.A	N.A	N.A
Minimum distance (*I*/*N* = –15.2 dB)	N.A	N.A	N.A	N.A	NA	*I*/*N* exceedence (same geographical area) Macro base station: 54-67 dB Mobile station: 25-68 dB	N.A	N.A	N.A	N.A	N.A

	STUDY 1	**STUDY 2**	**STUDY 3**	**STUDY 4**	**STUDY 5**	**STUDY 6**	**STUDY 7**	**STUDY 8**	**STUDY 9**	**STUDY 10**	**STUDY 11**
Short-term interference criterion											
Minimum distance	N.A	N.A	Macro base station: 140 km Mobile station: 1.5 km		N.A	187-430 km (5º elevation, considering all propagation modes) 187-282 km (15º elevation considering all propagation modes) 34-120 km (5º elevation, considering troposcatter/ diffraction propagation modes only) 34-50 km (15º elevation, considering troposcatter/ diffraction propagation modes only)	N.A	N.A	N.A	N.A	N.A

	STUDY 1	**STUDY 2**	**STUDY 3**	**STUDY 4**	**STUDY 5**	**STUDY 6**	**STUDY 7**	**STUDY 8**	**STUDY 9**	**STUDY 10**	**STUDY 11**
Adjacent band Results											
Long-term interference criterion / Single entry											
Minimum distance ($I/N = -20$ dB)	N.A	N.A	Macro base station: 18 to 25 km Mobile station: 300 to 450 m	N.A	CDMA Case from 10 to 34 km OFDMA Case from 0.07 to 19 km	N.A	CDMA Macro base station: from 10 to 42.5 km CDMA Micro base station: from 2 to 14 km OFDMA Macro base station: from 5 to 29 km OFDMA Micro base station: from 2.4 to 8.7 km	N.A	Macro base station: from 49.5 to 80.5 km Micro base station: from 39.5 to 51 km User terminal: from 25 km to 32.5 km	N.A	N.A
Long-term interference criterion / aggregate case											
Minimum distance ($I/N = -20$ dB)	N.A	N.A	N.A	N.A	CDMA Macro base station: from 15 to 37 km OFDMA Macro base station: from 0.35 to 21 km	N.A	CDMA Macro base station: from 27 to 45.5 km CDMA Micro base station: from 11 to 35 km OFDMA Macro base station: from 15 to 41 km OFDMA Micro Base station: from 4 to 8.5 km	N.A		N.A	

	STUDY 1	STUDY 2	STUDY 3	STUDY 4	STUDY 5	STUDY 6	STUDY 7	STUDY 8	STUDY 9	STUDY 10	STUDY 11
Saturation of LNA/LNB Results											
Long-term criterion/Single entry											
1 dB compression											
Mobile station	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	170 m	N.A	N.A
Micro cell base station	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	600 m	N.A	N.A
Macro cell base station	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	9.5 km	N.A	N.A
Non-linear operation											
Mobile station	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	550 m	N.A	N.A
Micro cell base station	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	1.95 km	N.A	N.A
Macro cell base station	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	30.5 km	N.A	N.A

8.1.4.2 Specific FSS earth station case (Application case)[3]

	STUDY 1	STUDY 2	STUDY 3	STUDY 4	STUDY 5	STUDY 6	STUDY 7	STUDY 8	STUDY 9	STUDY 10	STUDY 11
Co-channel Results											
Long-term interference criterion / Single entry											
Minimum distance (I/N = 12.2 dB).	Stn-1: base station-1: 90 (km) base station-2: 40 (km) mobile station-1: 30 (km) Stn-2 base station-1:110 (km) base station-2: 50 (km) mobile station-1: 20 (km) Note: It is assumed that there are two co-frequency interferers and an interference criterion of I/N = -13 dB is applied with respect to each IMT-Advanced station.	N.A	N.A	17-38 km (Macro urban) 8-14 km (Micro urban) 11-55 km (Macro rural).	Urban macro (see § 4.2.1.2, Fig. 5) 20° (FSS): 1-50 km.	N.A	CDMA Macro base station: from 22.8 to 29 km OFDMA Macro base station: from 4 to 23 km Mobile station: 0 km.	45.2 km – 61 km (on the roofs of buildings, macro, suburban); 23.2 km – 38.5 km (on the ground, macro, suburban); 33.9 km – 49.6 km (on the roofs of buildings, micro, dense urban); 5.3 km – 18.4 km (on the ground, micro, dense urban).	N.A	$I/N \le -10$ dB for all but 20% of time Contours plotted around earth stations in four types of terrain – flat, moderately hilly, very hilly and offshore. Macro base station with zero tilt – 40 km average minimum distance. Macro base station with 120° sector and 2° tilt – 35 km average minimum distance.	For single earth station and I/N = –10 dB distance varies from 30 to 100 km depending on earth station configuration and azimuth. Multiple earth station deployment causes the spread of exclusion zone compared to any single earth station.

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[3] Application case refers to the use of a specific terrain profile considered in all the contributions except STUDY 7 that contains results relating to a multi-carrier scheme (IMT-Advanced) with a flat terrain profil.

	STUDY 1	STUDY 2	STUDY 3	STUDY 4	STUDY 5	STUDY 6	STUDY 7	STUDY 8	STUDY 9	STUDY 10	STUDY 11
Minimum distance (I/N = –15.2 dB)	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A
Long-term interference criteria / Aggregate case											
Minimum distance (I/N = –12.2 dB)	N.A	N.A	N.A	21-42 km (Macro urban) 11-18 km (Micro urban) 15-58 km (Macro rural)	N.A	N.A	N.A	N.A	N.A	N.A	N.A
Minimum Distance (I/N = –15.2 dB)	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A
Short-term interference criterion											
Minimum distance	Stn-1: base station-1: 270 (km) base station-2: 90 (km) mobile station-1: 30 (km) Stn-2 base station-1:280 (km) base station-2: 80 (km) mobile station-1: 20 (km)	N.A	N.A	21 to 128 km for macro urban 8 to 17 km for micro urban 28 to 107 km for macro rural	N.A	N.A	N.A	N.A	N.A	Macro base station with zero tilt –> 150 km average minimum distance. Macro base station with 120° sector and 2° tilt –> 125 km average minimum distance.	For single earth station and I/N = –1.3 dB distance varies from 50 to 400 km depending on earth station configuration and azimuth, and IMT-Advanced deployment. Multiple earth station deployment causes the spread of exclusion zone compared to any single earth station.

8.1.5 Techniques to improve the sharing

This section covers the techniques that would improve the sharing between IMT-Advanced and FSS. The use of these techniques result either in co-frequency operation of both systems or adjacent band operation of both systems.

The feasibility and practicability of implementing these techniques have not been studied in the various FSS deployment scenarios.

Furthermore, some of the techniques listed in this section would need to be further studied.

Techniques implying the use, by IMT-Advanced base stations, of frequencies different from those used by the FSS earth stations would need to ensure not causing unacceptable interference to FSS receiving earth station (including unwanted emissions and LNA overdrive).

8.1.5.1 Possible mitigation techniques

The mitigation techniques described in this section would only apply to the situation where the location of the FSS receive earth station, subject to interference (further referenced as victim FSS earth station), is known. All of them have been studied with respect to one victim FSS earth station only.

8.1.5.1.1 Sector disabling

The aim of this technique is to reduce, in the direction of the victim FSS earth station, the transmitting output power of base stations that are located at a distance smaller than the separation distance. Generally, base stations utilize tri-sectorial antennas. Accordingly, one way to reduce the transmitting output power level could be to disable the antenna sector that points towards the FSS earth station, noting that such an area would be covered through the use of other frequency bands by IMT-Advanced systems.

As shown in the following figures, when compared with normal full active sector mode, the application of this mitigation technique has shown that the separation distance ranges are reduced by between 0 and 49% in generic studies (without terrain horizon profile) and between 0 and 83% for one specific site (with terrain horizon profile) depending on the access mode (see table of § 8.1.2, STUDY 7) and on the elevation angle of FSS earth station. These results are valid for base stations employing CDMA as well as OFDMA access modes.

FIGURE 3

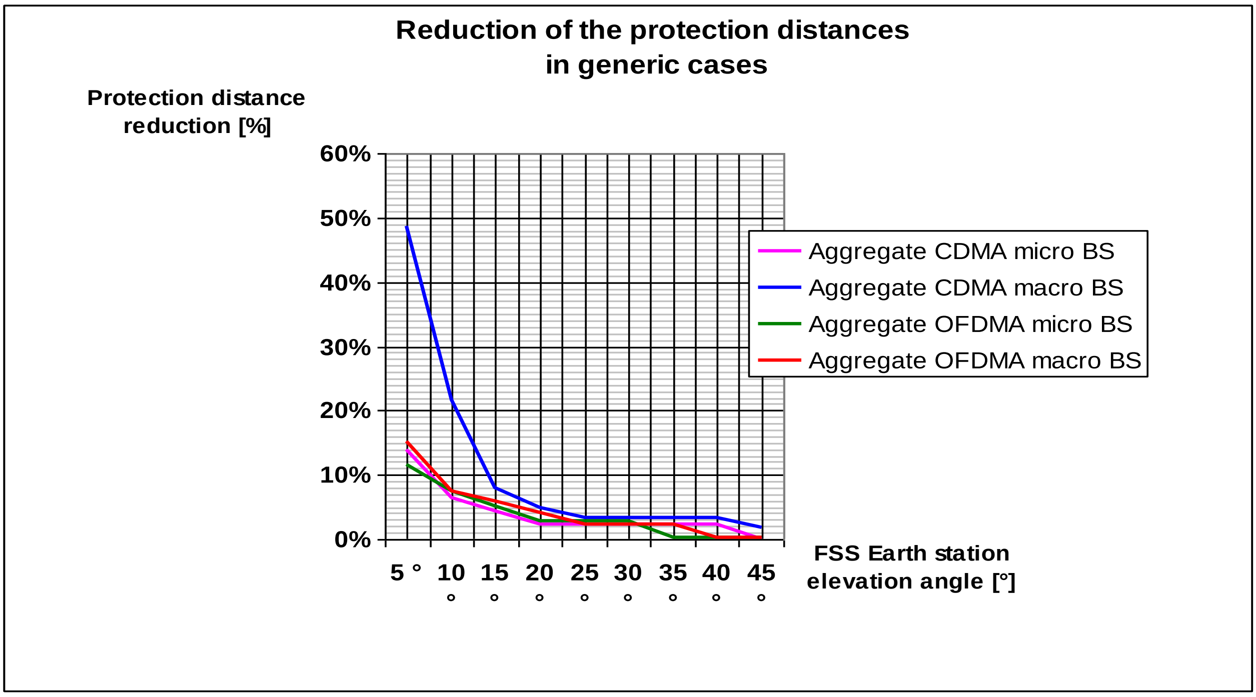
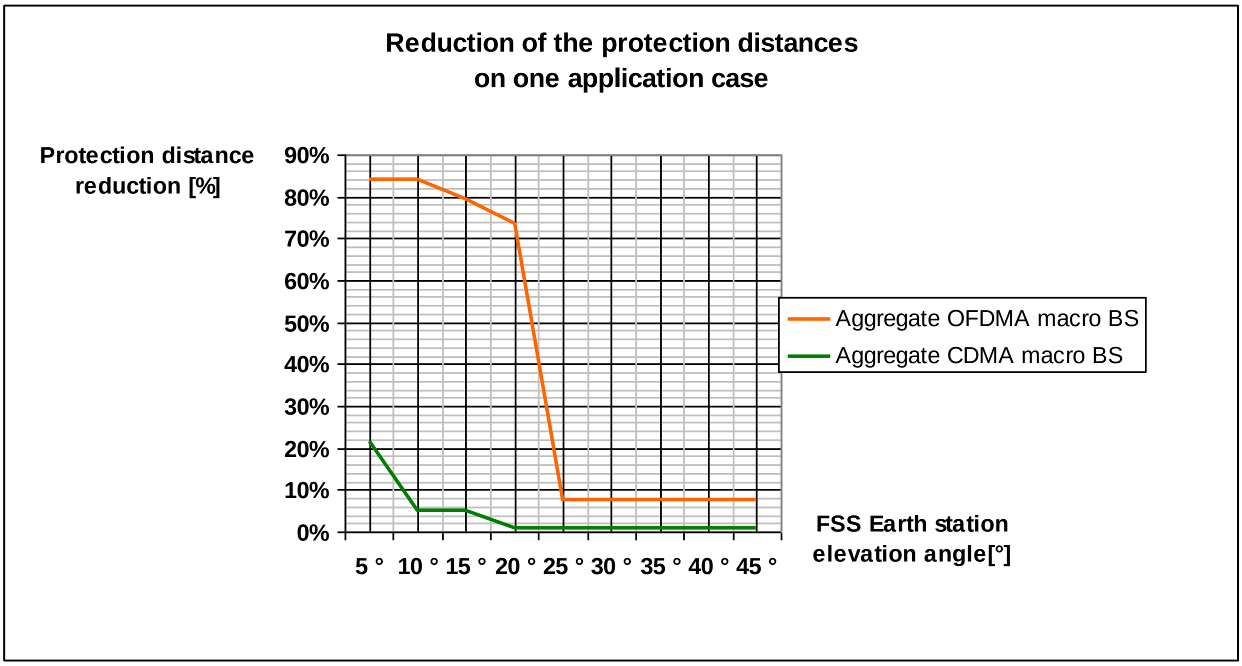


FIGURE 4



8.1.5.1.2 Multiple input, multiple output (MIMO)

In order to improve sharing between IMT-Advanced and FSS, an interference mitigation technology known as MIMO space division multiple access (SDMA) can be utilized.

By using this technique, a gain reduction in the base station transmit antenna diagram is generated towards the interfered FSS earth station. By using the MIMO technique, the minimum separation distance is 35 m in case of an IMT-Advanced base station and single FSS receiving earth station under the assumption of 0^o direction of earth station (DOE) estimation error which implies that null beam to the FSS receiving earth station is formulated perfectly. In the case of an IMT-Advanced base station and 3 FSS receiving earth stations, the minimum separation distance increases up to 3.5 km under the same assumptions. Other results have shown that under the assumption of 8° DOE estimation error, the minimum separation distances is 22 km, but this still reduces the minimum separation distance by approximately 50% in the considered case.

As for the sector disabling technique, this approach would require the use of other frequencies to cover the area where the base transmit antenna gain is reduced.

Some detailed information about this mitigation technique is provided in Annex D.

8.1.5.1.3 Site shielding

In Recommendation ITU-R SF.1486, interference attenuation effect, in a range about 30 dB, due to the site shielding isolation obtained by providing physical or natural shielding at the FSS earth stations is described. If such shielding isolation is taken into account, the required separation distance to protect FSS earth station receivers from IMT-Advanced transmitters can be reduced.

However, the required distance separation between IMT-Advanced transmitter and a FSS receiving earth station using site shielding has to be evaluated on a site-by-site basis and is dependent on characteristics and location of each site. The possibility of applying site shielding may not be guaranteed for all sites.

8.1.5.1.4 Antenna donwtilting

A possible mitigation technique to improve sharing is antenna downtilting at the IMT-Advanced base stations. In the deployment scenarios envisaged in IMT-Advanced systems, the cell size will be reduced to support high-speed transmissions assuming a limitation of transmission power. The deployment based on the small cell size is also indispensable for IMT-Advanced systems in order to achieve high frequency efficiency. Since the degree of antenna downtilting will be increased in the case of small cell size in order to avoid inter-cell interference in IMT-Advanced systems using the frequency reuse, this will also result in the reduction of interference from an IMT-Advanced base station to FSS earth stations and the reduction of the required minimum distance.

STUDY 4 shows that, for one specific site in urban macro environment, the required separation distance is decreased by approximately 30% and 50% for the long-term and short-term interference criteria, respectively, when the antenna-downtilt at IMT-Advanced transmitter is changed from 2° to 7°. However, the impact of this technique may vary for different locations and results may be different at other locations.

By increasing the downtilt of the base station antenna, there is a potential:

– for an increase of the number of IMT-Advanced base stations required to provide service in a given area;

– for a decrease of transmission power per IMT-Advanced base station.

Accordingly, when computing aggregate interference into an FSS receives station, these two elements would have to be taken into account.

8.1.5.2 Spectrum management techniques

In areas where all the frequency resources are not fully utilized by the FSS earth station, it may be possible to introduce IMT-Advanced services. The following spectrum management techniques may be of interest to administrations wishing to introduce new services in specific geographical areas.

8.1.5.2.1 Dynamic spectrum allocation

The distribution of radio resources could either be static or dynamic depending on the local situation in a given area. For spectrum efficiency, the most favorable method would be to use the dynamic method. Local arrangements may be made to facilitate usage of both systems. In areas where not all the frequency resources are fully utilized, it may be possible to introduce additional services either of the same type or other types or a mix. The IMT-Advanced systems need then to be informed whether the FSS bands can be utilized or not. In the case when an earth station changes its frequency of operation, the IMT-advanced system may also have to change its frequency in the surrounding area.

A way for the administration to provide such information to the IMT-Advanced systems may be to have a data base where all relevant information of the current services or stations, such as FSS earth stations, using the radio resources in the area. The data base would need to be up to date and would include information such as central carrier frequency, channel bandwidth etc.

8.1.5.2.2 Usage of beacon

Broadcasting beacon or a network of beacons, or control information co-located with the FSS earth station (respectively IMT-Advanced base station) provide dynamic and active information on its spectrum usage to the IMT-Advanced system (respectively FSS earth station) to allow optimum usage of the unused spectrum to eliminate the inter-system interference.

8.1.6 Proposed methodology to be utilized with mitigation techniques

8.1.6.1 Interference area ratio methodology

This section describes a new methodology to be utilized in assessing the level of coordination difficulty on the basis of the actual terrain profile between two services for a specific site. This methodology may be used to assess the effectiveness of mitigation techniques based on the use of directional antennas, which takes into account the actual shielding effect by terrain profile and clutter losses associated with the artificial objects. In order to quantitatively evaluate this shielding effect, the methodology called “interference area ratio”, is employed in some studies, where its definition is shown in Fig. 5. When applying the interference area ratio of x%, we exclude the x% of area that has the larger separation distance over $d + \Delta d$. Then, the required separation distance becomes $d + \Delta d$. When $x > 0$%, the additional mitigation technique is adopted in order to protect the FSS earth stations located in the x% of the area. A possible mitigation technique is to employ directional-beam antenna, such as sectorized- or adaptive-beamforming antenna at an IMT-Advanced transmitter. The details of the methodology “interference area ratio” can be found in Annex F.

FIGURE 5

Definition of interference area ratio

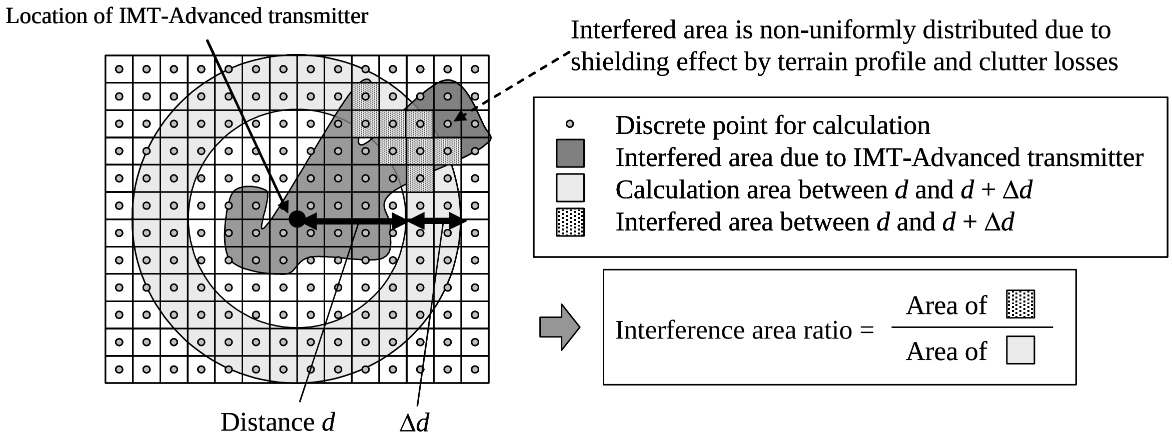
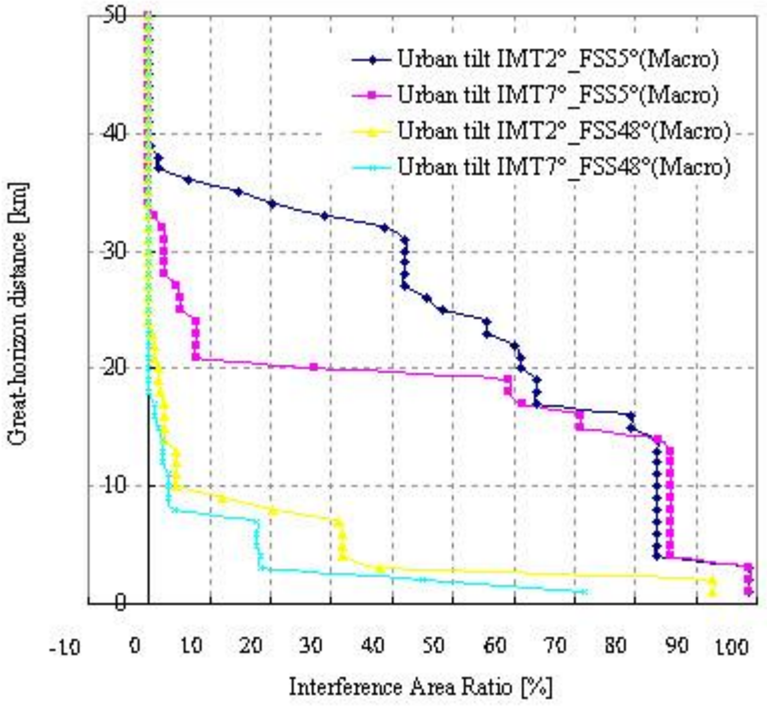


Figure 6 shows the required minimum distance as a function of the interference area ratio. As shown in this figure, according to increase in the interference area ratio value, the required minimum separation distance can be reduced.

FIGURE 6

Required minimum distance as a function of interference area ratio (urban area, macro-cell, single-entry)



In Table 7, the required minimum distance is summarized for an assumed interference area ratio of 10%, as an example. For the comparison, the required minimum distance is also shown in the case of the interference area ratio of 0%, which is equivalent to the separation distance without considering the interference area ratio. As shown in this table, by introducing the measure "interference area ratio" associated with the mitigation technique using the directional beam antenna, the required minimum distance is reduced by about 5% to 60% depending on the scenarios in IMT-Advanced systems.

TABLE 7

Required minimum distance for interference area ratio of 10%
(urban area, single-entry, FSS earth station elevation angle = 5°)

Environment	IMT-Advanced base station antenna downtilt (degrees)	Interference area ratio = 10% (km)	(Reference) Without considering interference area ratio (km)
Macro	2	36	38
Macro	7	21	32
Micro	2	12	14
Micro	7	5.8	14

8.2 Interference from FSS transmitting space station to IMT-Advanced systems

A number of sharing studies examined the impact of FSS interference upon IMT-Advanced receive stations. The assumptions and methodologies associated with each sharing study are summarized in tables of § 8.2.2 and 8.2.3. These tables also indicate the extent to which each sharing study employed the common FSS and IMT-Advance parameters that are specified in Tables 2 through 5 of this Report as well as the operational FSS scenarios recommended by the ITU-R (see § 8.2.1). The results of the studies are contained in the table in § 8.2.4.

It should be noted that only STUDIES 2, 3, 6 and 7 have provided some results for the § 8.2.

8.2.1 Methodologies used in the simulation

Two scenarios were considered:

– SCENARIO 1 was based on one GSO satellite every 10° of longitude transmitting a maximum EIRP of 11 dBW per 4 kHz at all elevation angles of 0°-90°, with all such satellites operating co-frequency and with overlapping areas of coverage.

– SCENARIO 2 was based on one GSO satellite every 4° of longitude transmitting an EIRP compliant to the RR Article **21** (11.3 dBW per 4 kHz at the 0°-5° elevation angles, $\{11.3 + 0.5(\delta - 5)\}$ dBW per 4 kHz for δ between 5°-25° and 20.1 dBW per 4 kHz at the 25°-90° elevation angles), with all such satellites operating co-frequency and with overlapping areas of coverage (δ is the elevation angle).

These scenarios may not be representative of the current satellite deployments but could be representative of future satellite deployments.

8.2.2 Compliance with the common parameters

	STUDY 2	**STUDY 3**	**STUDY 6**	**STUDY 7**
Compliance with the common set of IMT-Advanced parameters as shown in Tables 3 to 5	Fully compliant. (Use of Rec. ITU-R F.1336-2)	Fully Compliant	Fully Compliant	Fully Compliant
Compliance with the common set of FSS parameters as shown in Table 2	Fully Compliant.	Fully Compliant.	Fully Compliant.	Fully Compliant.

8.2.3 Compliance with the methodology of § 8.2.1

	STUDY 2	**STUDY 3**	**STUDY 6**	**STUDY 7**
Compliance with the proposed FSS scenarios	Compliant to SCENARIOS 1 and 2	Compliant to SCENARIO 2	Supplementary Scenario Space station orbital separation: 10° Maximum space station space-to-Earth PFD: 11.3-20.1 dB(W/4 kHz) depending on angle of arrival Scenario 1 11.3 dB(W/4 kHz) for all angles of arrival	Compliant to SCENARIO 1

Results (co-channel only)

	STUDY 2	**STUDY 3**	**STUDY 6**	**STUDY 7**
I/*N* for the Macro-cell base station	SCENARIO 1 – Typical antenna: from –15.6 to –14.4 dB – Improved antenna: from –16.4 to –14.8 dB dB, for the 4 latitudes considered	SCENARIO 2 –3.6	Supplementary Scenario 0.3-4.2 dB Scenario 2 No Exceedence	SCENARIO 1 From -18.8 to –14.9 dB, for the 4 latitudes considered

	STUDY 2	STUDY 3	STUDY 6	STUDY 7
	SCENARIO 2 – Typical antenna: from –11.3 to –9.9 dB – Improved antenna: from –13.6 to –12.2 dB (4 latitudes have been considered)			
I/*N* for the Micro-cell base station	SCENARIO 1 from –10.8 to –7.4 dB, for the 4 latitudes considered	N.A	N.A	SCENARIO 1 from –7.2 to –6.2 dB, for the 4 latitudes considered
	SCENARIO 2 from –2.4 to 0.9 dB, for the 4 latitudes considered			
I/*N* for the mobile station	SCENARIO 1 from –14.4 to –13.3 dB, for the 4 latitudes considered	SCENARIO 2 –1.4	Supplementary Scenario 1.3-5.2 dB Scenario 1 No Exceedence	SCENARIO 1 from –14.6 to –13.3 dB, for the 4 latitudes considered
	SCENARIO 2 from –4.9 to –0.99 dB, for the 4 latitudes considered			

9 Results from one measurement study on interference from IMT-Advanced transmitter into one TVRO earth station

As shown in § 4, in the 3 400-4 200 MHz band, TVRO is one of the FSS applications that is implemented in some parts of the world. Annex G of this report provides the results of a set of measurements carried out regarding the impact of interference into a commercial TVRO terminal using two different types of LNBs in the 3 400-4 200 MHz band, where interference is caused by an assumed IMT-Advanced transmitter.

The IMT-Advanced transmitter used in this experiment was set to transmit a carrier with an EIRP density of 35 dBm/MHz, which is 11 dB lower than a macro base station defined maximum EIRP density and 13 dB higher than a micro base station defined maximum EIRP density.

This experiment was performed at an arbitrary chosen location in Japan. The EIRP of the satellite chosen for the measurement is about 39 dBW per transponder at this location. The satellite transponder chosen for the co-channel measurement contains two carriers with a bandwidth of approximately 5 MHz each. It is not common to assign only two 5 MHz carriers in a 36 MHz wide transponder. The adjacent-channel measurements were done using a different transponder containing five 5 MHz wide carriers. This represents a more typical transponder utilization.

Summary of the measurement is given as follows:

1) When the distance between an IMT-Advanced transmitter and a TVRO terminal was in the range of 345 to 5,420 m comprising different 26 locations, no influence on the quality of the received TV picture was observed at 25 and 26 locations in the case of the co-channel and adjacent interference scenarios, respectively, with FEC coding rate of 3/4.
2) TV channel employing FEC coding rate of 3/4 was more robust against the increase in the co-channel interference power level by approximately 2 dB compared to that of 7/8 in maintaining the same quality of the received TV picture.
3) The influence on the quality of the received TV picture for adjacent-channel interference scenario was smaller compared to that for co-channel scenario. In order to maintain the same quality of the received TV picture, approximately 14 dB more power of an IMT-Advanced transmitter was permitted in the adjacent-channel interference scenario compared to the co-channel interference scenario.

This test was conducted for one arbitrarily chosen location in Japan. Moreover, only one specific satellite with the transmissions characteristics of the selected TV carriers was used in the test. The test reflects one snapshot of one case and does not take into account short-term effects, aggregation or other applications or modulation/error correction schemes. Therefore results with regard to potential interference from IMT-Advanced into TVRO or other applications cannot by default be extended to other cases.

10 Sensitivity analysis

Although the common simulation parameters for IMT-Advanced systems are summarized in § 6 and 7, in actual deployment scenarios some of the parameters will be within a range of values. In the following analyses, the influence of variation of several parameters of IMT-Advanced and FSS systems are analyzed and the impact on the required separation distance is investigated.

10.1 Interference from IMT-Advanced systems to FSS receive earth stations

10.1.1 Influence of the IMT-Advanced base station antenna downtilt

Figures 7 and 8 show the influence of the antenna downtilt angle of the IMT-Advanced base station on the minimum required separation distance with respect to a generic and a specific FSS receiving earth station, respectively. As shown in these figures, as the antenna downtilt is increased, the required minimum distance is decreased due to the reduced interference from IMT-Advanced base station.

FIGURE 7

Influence of down-tilt of IMT-Advanced base station transmitters
Generic study, Urban, Macro-cell

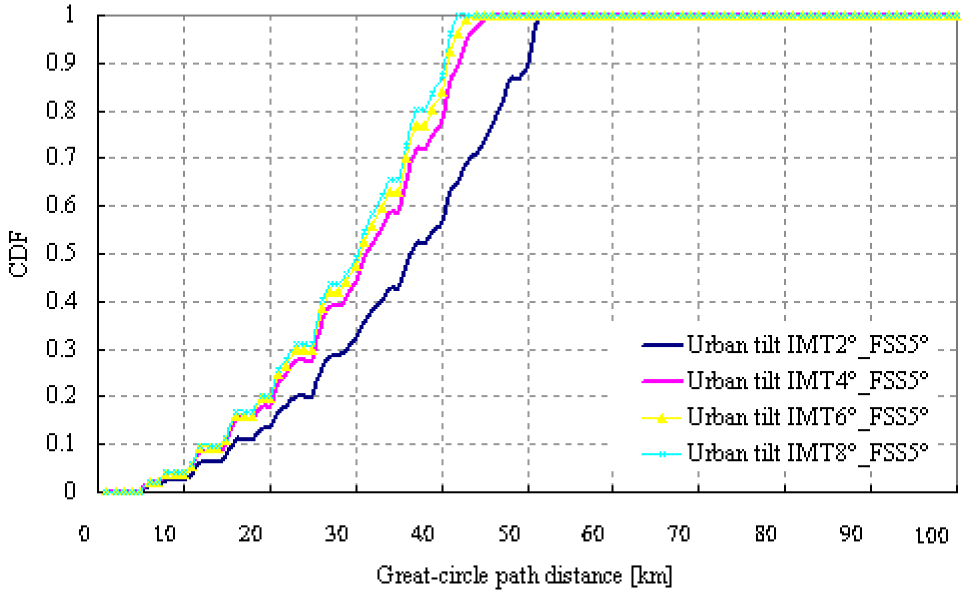
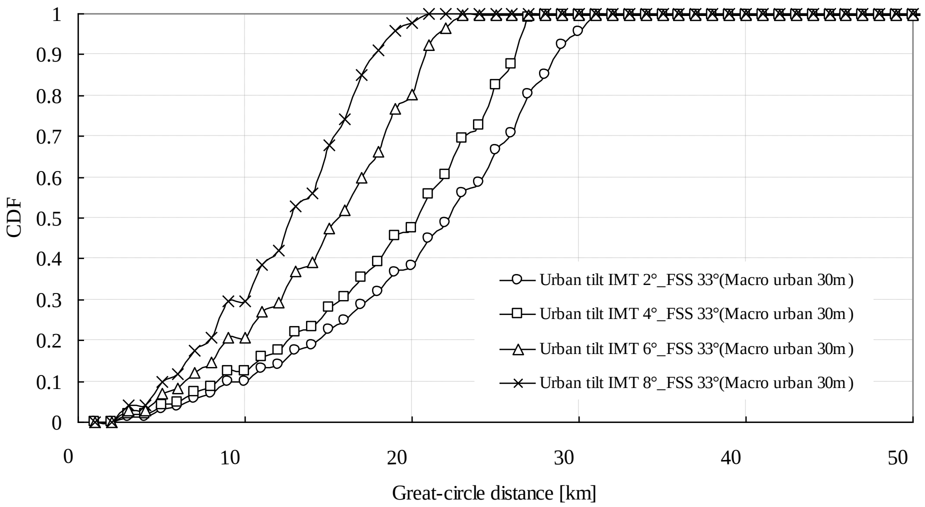


FIGURE 8

Influence of down-tilt of IMT-Advanced base station transmitters
Specific study using terrain data, Urban, Macro-cell (Kyobashi)



10.1.2 Influence of the IMT-Advanced base station antenna height

Figures 9 and 10 show the influence of the IMT-Advanced base station transmitting antenna height on the minimum required separation distance with respect to a generic and a specific FSS receiving earth station, respectively. This figure indicates that the lower antenna height brings about the reduction of the required minimum distance in urban environment, since the large shielding effect can be observed due to the clutter loss associated with the artificial objects, such as tall buildings. Meanwhile, in a rural environment, the lower antenna height is not always effective to reduce the required minimum distance, since the large clutter loss is not expected due to the lower average building height in this environment.

FIGURE 9

Influence of antenna-height of IMT-Advanced base station transmitters
Generic study, Macro-cell

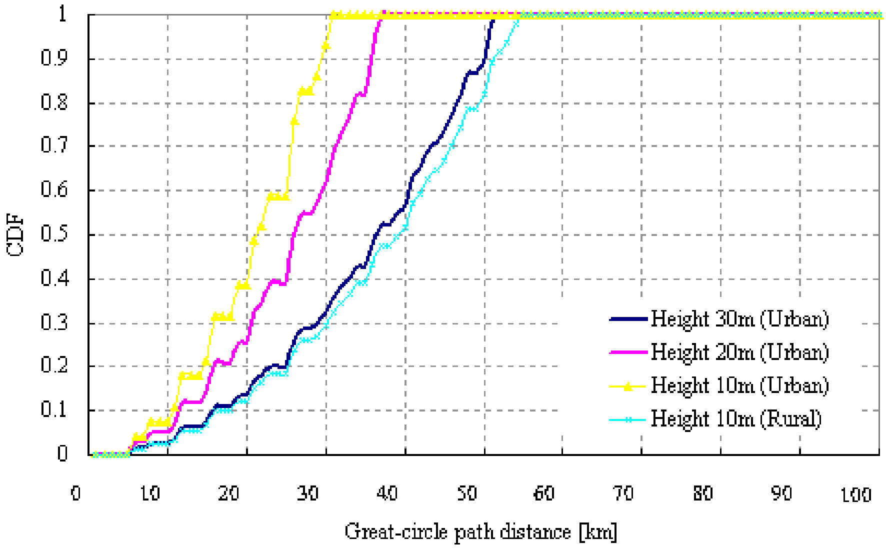
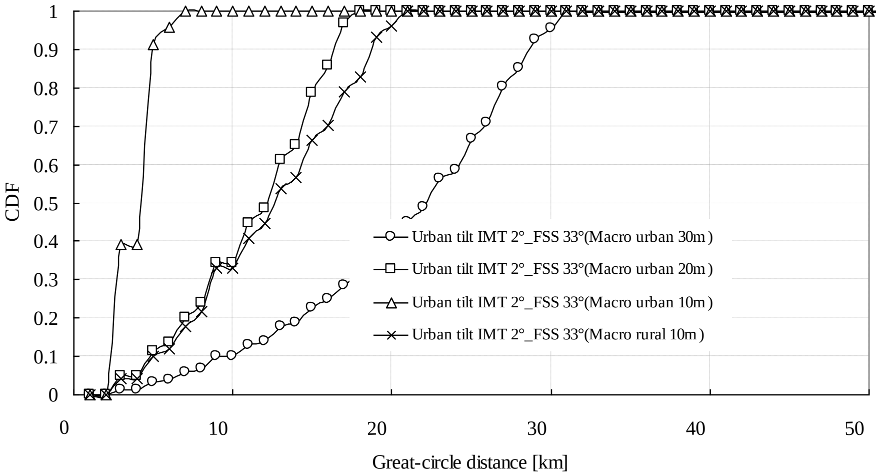


FIGURE 10

Influence of antenna-height of IMT-Advanced base station transmitters
Specific study, Macro-cell (urban: Kyobashi , rural: Kumagaya)



10.1.3 Influence of the IMT-Advanced base station EIRP

The sharing studies have been based on the maximum value of the macro and micro base stations EIRP, shown in Table 3. When deploying an IMT-Advanced network, the maximum EIRP for IMT-Advanced base station can vary from 59 to 35 dBm according to the type of the base station. The variation of this maximum EIRP would influence the sharing leading to the reduction of the size of the required separation distance between IMT-Advanced base station and FSS earth station. This is a static setting and the reduction of the distance can be derived deterministically.

Additionally, IMT-Advanced systems will implement the dynamic downlink power control (in CDMA and OFDMA networks). This feature will have the effect of reducing the EIRP of base stations, depending on the load of the cells, the distribution of the mobile stations within a cell and the time. It should be noted that:

- For a single IMT-Advanced base station to FSS earth station path, this would have no impact on the required distance separation between the IMT-Advanced transmitting base station and the FSS earth station given that the required distance separation would be based on the IMT-Advanced base station's maximum EIRP level.
- For the aggregate case, experience to date shows that it is unlikely that all the IMT-Advanced base stations transmit at the maximum EIRP at the same time. Consequently, the use of the downlink power control could result in reducing the required distance separation. However, the statistical and temporal impact of the downlink power control has not been quantified

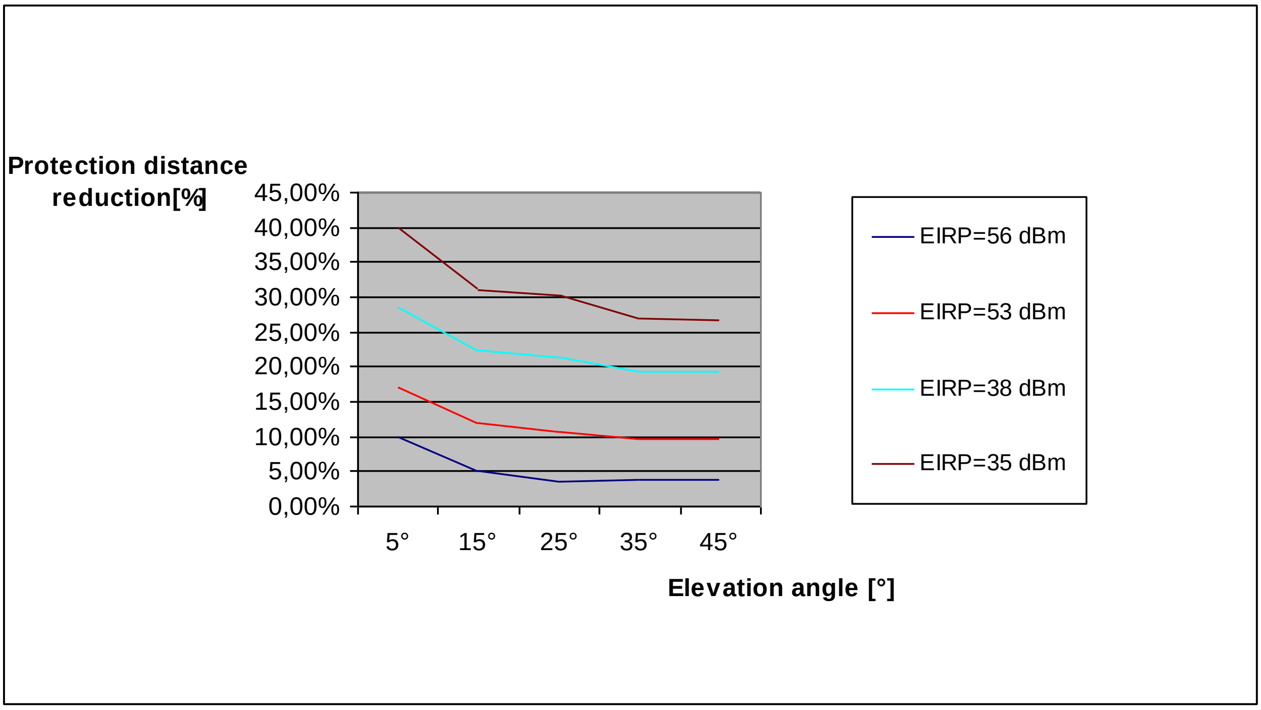
10.1.3.1 Influence of the IMT-Advanced base station maximum EIRP

The maximum EIRP of an IMT-Advanced base station can vary from 59 to 35 dBm for the 20 MHz minimum bandwidth, according to the Table 3 of this Report. E.i.r.p. below the maximum level of 59 dBm could reduce the required distance separation between the IMT-Advanced transmitting base station and the FSS earth station.

Figure 11 shows the impact on the required distance between an FSS earth station and an IMT-Advanced base station, taking into account the different types of aggregate base stations with a maximum EIRP value between 35 dBm and 56 dBm. The variation of the base stations deployment density and antenna type has been taken into account accordingly[4].

FIGURE 11

Protection distance reduction) versus earth station antenna elevation angles a function of EIRP



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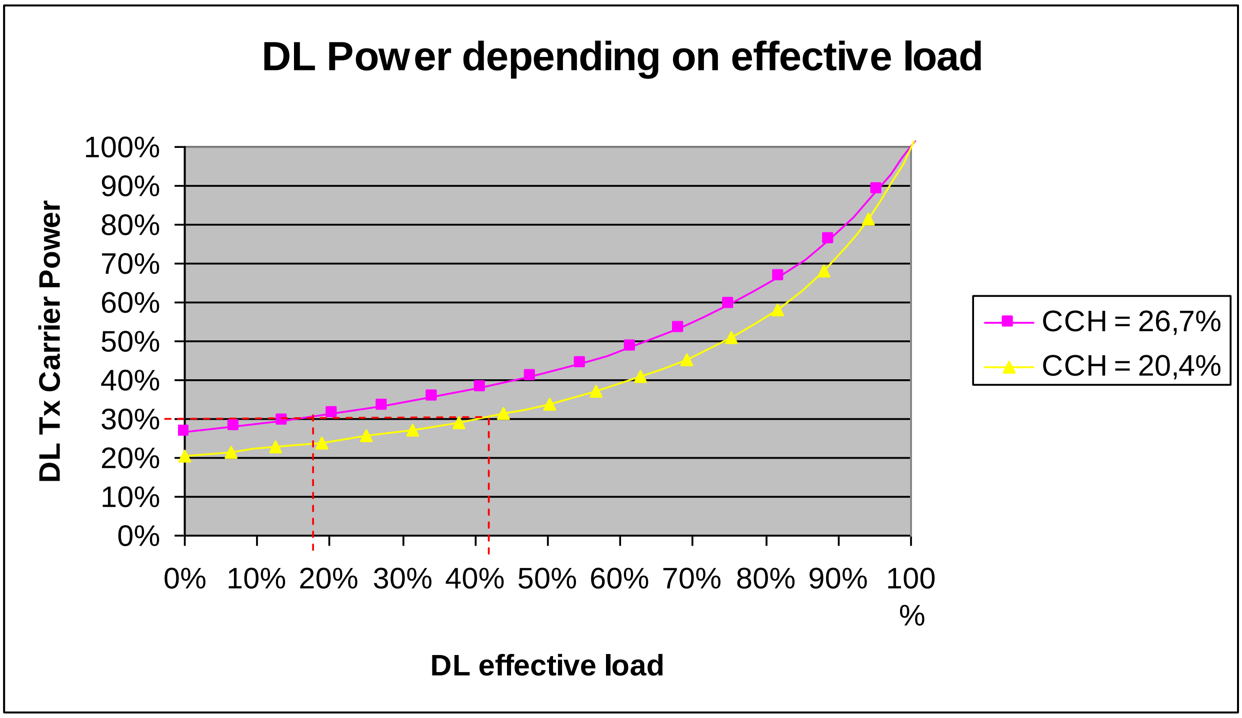
[4] The number of the aggregate base stations is determined according to the methodology defined in the § 8.1.1 and the cell size values defined in the Table 3.

NOTE 1 – The baseline protection distance is obtained with an EIRP of 59 dBm.

10.1.3.2 IMT-Advanced down link power control analysis

Considering experience to date on terrestrial mobile networks, IMT-Advanced base stations will not always transmit at their maximum EIRP. Downlink power control is a key feature of an IMT-Advanced radio network, which has the effect to adjust the transmit power to the minimum necessary value so as to not waste power as well as to limit intra-system interference. Its use will also have the effect of reducing the inter-system interference. Depending on the cell coverage and capacity, the maximum value of an IMT-Advanced base station power will be only transmitted when the cell is 100% loaded, as follows:

FIGURE 12



NOTE 1 – CCH are the common channels.

Down link power control reflects the expected operational IMT-Advanced deployment conditions. The impact of the dynamic downlink power control, on the compatibility between IMT-Advanced and FSS has not been quantified, and would have to take into account:

– the statistical distribution of the mobile stations in a cell (geographical and time distributions),

– the fact that the base station power varies temporally.

However, its use has the effect of reducing the required distance separation between a FSS earth station and an IMT-Advanced base station.

10.1.4 Influence of the IMT-Advanced spurious emissions

The Table 8 provides the minimum required separation distances, as determined in STUDY 3, to protect FSS receive earth stations from the interference by the spurious emissions generated by a single IMT-advanced transmitter. The study assumed various levels of IMT-Advanced transmitter spurious emissions, with the reference being the level stipulated in RR Appendix 3. Distances are also given on the basis of assumed improved spurious levels by 10, 40 and 50 dB.

The analyses were based on the propagation models described in ITU-R P.452-12. Due to the generic nature of the analysis, for the long-term protection cases, the propagation was calculated over a smooth earth surface, utilizing the propagation model described in § 4.3 of ITU-R P.452-12. The models in ITU-R P.452-12 can include the effects of building losses and clutter where the topography of surrounding obstacles etc. is known. However, due to lack of information for these parameters, the building losses and clutter effects have been assumed to represent suburban environment in these analyses.

TABLE 8

Percentage Increase of FSS system noise	**1.0%**	**0.5%**		**1.0%**	**0.5%**
Additional reduction of IMT-Advanced transmitter spurious emission level (dB)	**0**	**0**		**10**	**10**
IMT-Advanced macro base station	18 km	25 km		5 km	7.5 km
IMT-Advanced mobile station	300 m	450 m		100 m	140 m
Percentage Increase of FSS system noise	**1.0%**	**0.5%**		**1.0%**	**0.5%**
Additional reduction of IMT-Advanced transmitter spurious emission level (dB)	**40**	**40**		**50**	**50**
IMT-Advanced macro base station	115 m	150 m		35 m	50 m

NOTE – The results corresponding to 0,5% are only given as an example, since no guidance was provided by ITU-R on the apportionment for the interference from other sources.

The results of this study showed that operation of IMT-Advanced systems and the FSS in adjacent bands in the 4 GHz frequency range would be very difficult and may not be feasible in the same geographical area if the IMT-Advanced transmitter spurious emission is defined in accordance with the limits specified in RR Appendix **3**.

Additional information on this study can be found in Annex H.

10.1.5 Influence of FSS earth station elevation angle and losses from local clutter on adjacent band separation distances

From STUDY 9, it was noted that the required separation distances will depend significantly on the elevation angle of the FSS earth station. Also, if the propagation is attenuated by local clutter that blocks direct line-of-sight, this will have a significant impact on the received interference.

To ascertain the impact of elevation angle and clutter loss, STUDY 9 also calculated the required separation distance (both with respect to overdrive of LNA’s and unwanted emissions) as a function of the elevation angle, assuming two values for clutter loss; 0 dB and 20 dB.

From the results of the study, it can be noted that:

– An elevation angle of 20° will reduce the separation distance to 17.7% compared to that of 5°.

– An elevation angle of 45° will reduce the separation distance to 6.4% compared to that of 5°.

– 20 dB clutter loss will reduce the separation distance to 10% compared to that of 0 dB.

10.2 Interference from FSS transmitting space station to IMT-Advanced systems

10.2.1 Influence of the antenna downtilt and the latitude of a base station

This section provides *I*/*N* ranges according to the FSS networks parameters scenario and the IMT-Advanced downtilt parameter chosen.

Range of *I*/*N* (dB), as a function of the downtilt (from 0° to 2°) and latitude of the IMT-Advanced base station.

TABLE 9

FSS network scenario	**Macro-cell base station**		**Micro-cell base station**
	Typical antenna	**Improved antenna**	
Scenario 1	From –14.4 to –7.0	From –14.8 to –7.1	From –7.9 to –7.4
Scenario 2	From –9.9 to –5.5	From –12.2 to –6.2	From 0.3 to 0.9

NOTES:

1 See § 7.2.1 for a description of FSS network scenarios 1 and 2.

2 These results have been assessed using the approved draft new Recommendation ITU-R F.1336-1, i.e., Rec. ITU-R F.1336-2.

3 It has to be noted that typical values for the antenna downtilt are as follows:

a) Macro base station IMT-Advanced (height = 30 m): between 2° and 20°.

b) Micro base station IMT-Advanced (height = 5 m): between 0° and 20°.

11 Conclusions

Sharing studies have been performed to assess the technical feasibility of deploying IMT-Advanced systems in the 3 400-4 200 MHz and 4 500-4 800 MHz bands, that are utilized by FSS (amongst other services).

To provide protection of the FSS receive earth stations, some separation distance relative to the stations of the mobile terrestrial network is required. The magnitude of this separation distance depends on the parameters of the networks and the deployment of the two services. The magnitudes of these required separation distances to protect the FSS receive earth stations have been studied, taking account of the need to meet both short-term and long-term interference criteria requirements, with respect to the three following interference mechanisms:

1. In-band, co-channel operations

The minimum required separation distances from IMT-Advanced base stations, when using the long-term interference criterion derived in the studies to date, are at least in the tens of kilometres.

The minimum separation distances associated with short-term interference criterion, generally, but not in all cases, exceed one hundred kilometres in the considered cases with similar assumptions as the ones used for the long-term.

2. Adjacent band operations

Concerning interference from unwanted emissions arising from out-of-band and spurious domains of IMT-Advanced base station transmitters and falling within the band used by the FSS receiver, the minimum required separation distances, when using the long-term interference criterion derived in the studies to date, are up to tens of kilometres (with no guard band) and decreasing as the guard band increases.

3. Overdrive of the FSS receiver

One study has shown that emissions from one IMT-Advanced station can overdrive the FSS receiver LNA, or bring it into non-linear operation, if the separation distance is less than some kilometres or some hundreds metres with respect to base stations and user terminals respectively.

An administration intending to bring into use IMT-Advanced systems, whose territory falls within the coordination contours of the earth stations under the coordination or notification procedure or notified under the Articles 9 and 11, shall effect coordination with other administrations having these earth stations.

Although the studies have differences in assumptions and methodologies, they all show that sharing between IMT-Advanced and an FSS earth station is not feasible within the area delineated by the minimum required separation distances for each azimuth to protect that specific FSS earth station, as explained above. Therefore, sharing is feasible only when the receiving earth station is specific under the condition that the required permissible interference level (which can be translated into appropriate transmission parameters for the IMT-Advanced stations such as maximum power or minimum separation distance between the stations concerned taking into account propagation environment) within individual administrations is observed, and any coordination agreements that may have been reached between the concerned administrations are observed.

If FSS is deployed in a ubiquitous manner and/or with no individual licensing of earth stations, sharing is not feasible in the same geographical area since no minimum separation distance can be guaranteed.

The effect of use of terrain information, including clutter losses, on the reduction of the separation distance has been studied. Studies have also shown that the use of local terrain information, including clutter losses, will reduce the separation distance. The degree of this reduction will depend on the specific circumstances. However, the reliability of local terrain information has not been proven for all countries.

Site shielding for FSS earth stations, where possible, would mitigate interference from IMT-Advanced systems. Other mitigation techniques for IMT-Advanced systems, such as narrow-beam transmission based on sectorized- or adaptive-beamforming antenna, sector disabling and antenna down-tilting will reduce the required minimum separation distance where they are effective. Some of these mitigation techniques could increase the deployment density of IMT-Advanced base stations in a given area. The impact of this increase in the number of IMT-Advanced cells as well as the reduction of the transmission power per IMT-Advanced base station should be taken into consideration when computing the aggregate interference.

The deployment scenarios of FSS earth stations and IMT-Advanced systems may be taken into account to take the full advantage of the mitigation techniques. The impact of the various mitigation techniques and spectrum management techniques on operation of the existing and /or planned FSS receive stations has not been fully studied.

According to the available studies, the effectiveness of the above-mentioned mitigation techniques is dependent on their application to individual site situations and can be applied only when the specific location of the FSS earth stations are known. Further studies would be necessary to determine the circumstances which would permit the effective use of such techniques, on a case-by-case basis.

With respect to interference from FSS into IMT-Advanced, studies have provided a range of margins relative to the required *I*/*N* criterion (from 9 to –11 dB) depending on the assumptions (particularly the type of IMT-Advanced base station considered and the FSS space station EIRP density). As a result, the IMT-Advanced base and mobile stations may experience interference from emissions of authorized satellite networks.

Annex A

Examples of interference exclusion plots for FSS earth stations

1 Summary of a study on the impact of the FSS protection requirements

Using the receive characteristics and protection criteria of 4/6 GHz FSS earth stations, and the transmit characteristics for IMT-advanced macro base stations given in § 6 of the main Report, protection contours were plotted for four different types of terrain found in Europe, with the earth station antenna axis at 20° elevation in each case. Each IMT-Advanced base station antenna was assumed to have 120° sector beams with 2° down-tilt. The following table gives the earth station locations selected, and the corresponding satellite longitudes.

TABLE A1

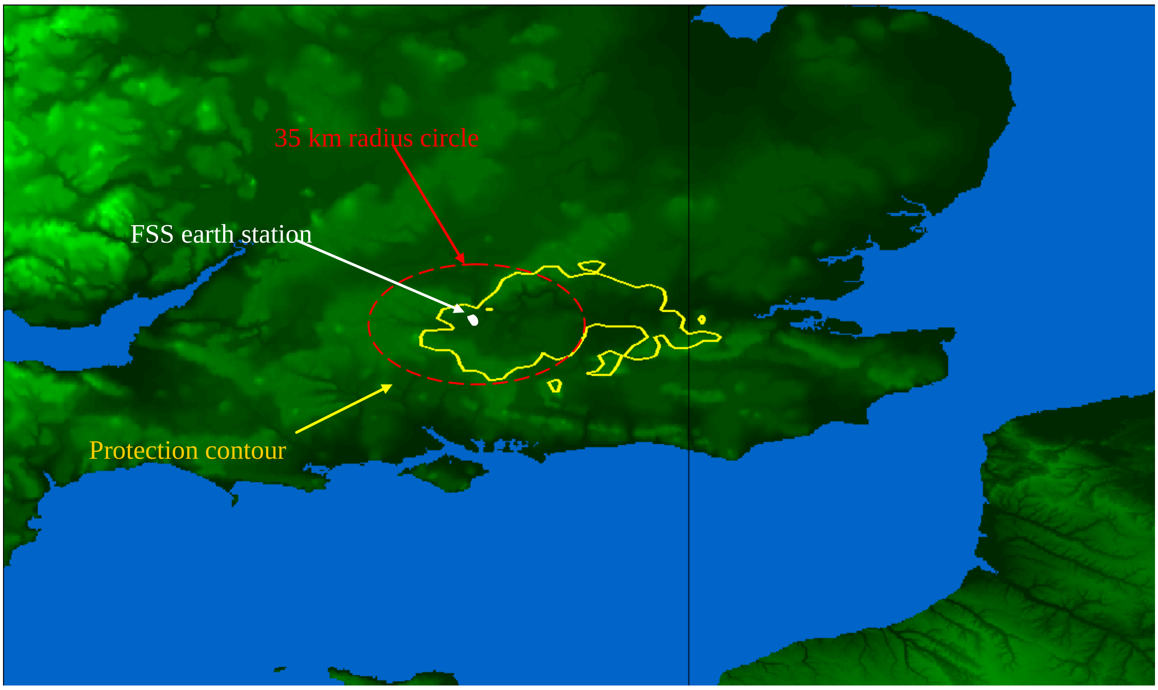
Type of terrain	**Location of FSS earth station**			**Longitude of satellite at 20° elevation (°E)**
	Latitude (°N)	**Longitude (°E)**	**Country**	
Flat	52.0	4.8	The Netherlands	44.7
Moderately hilly	51.5	–0.8	Southern England	39.8
Very hilly	46.32	8.0	Switzerland	–38.75
Off-shore	57.1	21.3	Latvia	50.9

The propagation losses were computed using the methods in Recommendation ITU-R P.452 with a terrain database, and for each type of terrain separate contours were plotted to meet single-entry the long-term criterion *I*/*N* not to exceed –10 dB for more than 20% of the time, and the single-entry short-term criterion *I*/*N* not to exceed –1.3 dB for more than 0.0017% of the time. For the Southern England example these plots are given in Figs. A1 and A2. Protection contours were also plotted for locations within 13 capital cities in Europe. Thus it was shown that, although terrain causes some irregularity in contour shapes, for the majority of earth stations the long-term protection zones encompass areas of similar order to that of a circle of 35 km in radius, and the short-term protection zones encompass areas greater than that of a 125 km circle. These findings were combined with information supplied by three major satellite operators (Intelsat, Inmarsat and SES New Skies), on the locations of the 4/6 GHz earth stations in Europe indicated in their data-bases as receiving from their satellites, and C-band receiving earth stations recorded in the MIFR as of August 2006. Figure A3 gives an indication of the interference areas in which long term interference criterion might not be met.

From this study it can be observed that that sharing between IMT-Advanced base stations and the specific sites as indicated in the table above may be difficult.

FIGURE A1

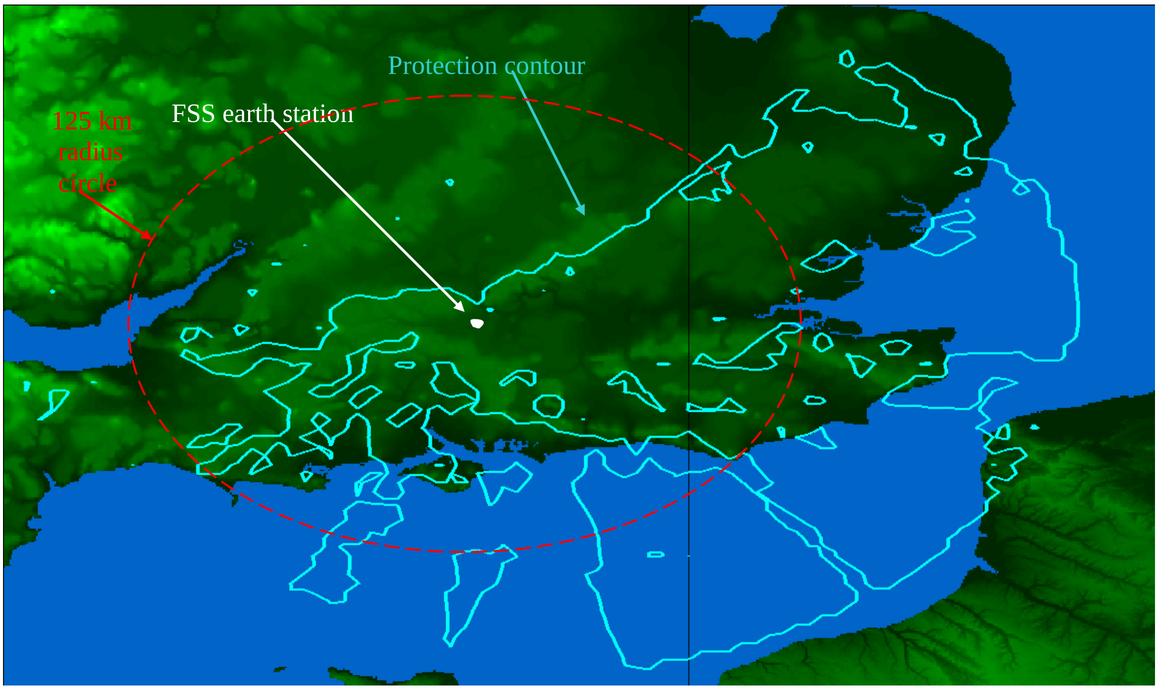
Example of zone for long-term interference protection* in moderately hilly area



* *I/N* not to exceed -10.0 dB for more than 20% of the time.

FIGURE A2

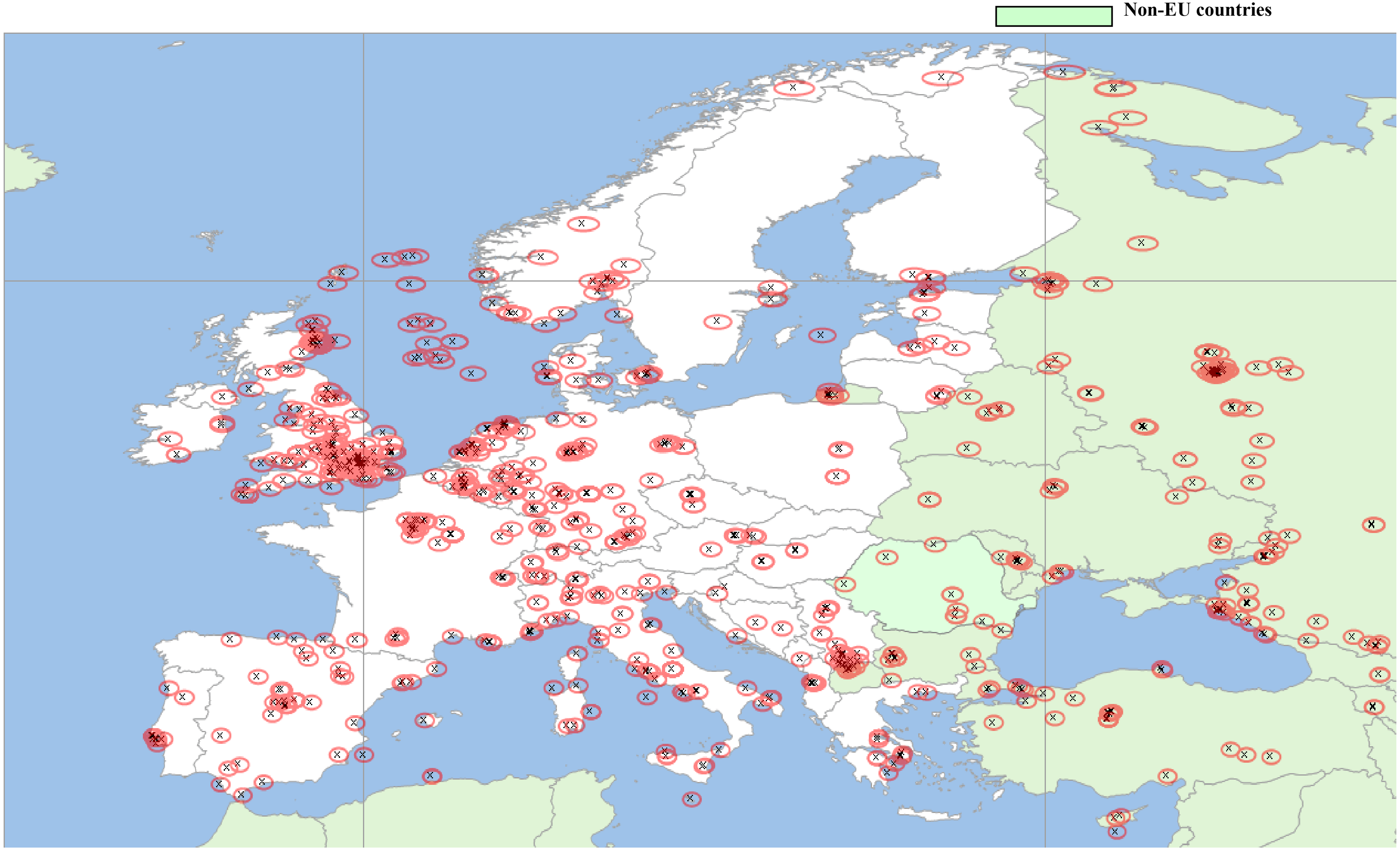
Example of zone for short-term interference protection* in moderately hilly area



* *I/N* not to exceed -1.3 dB for more than 0.001667% of the time.

FIGURE A3

Earth stations (except TVROs) in Europe operating to satellites within 3 400-4 200 MHz



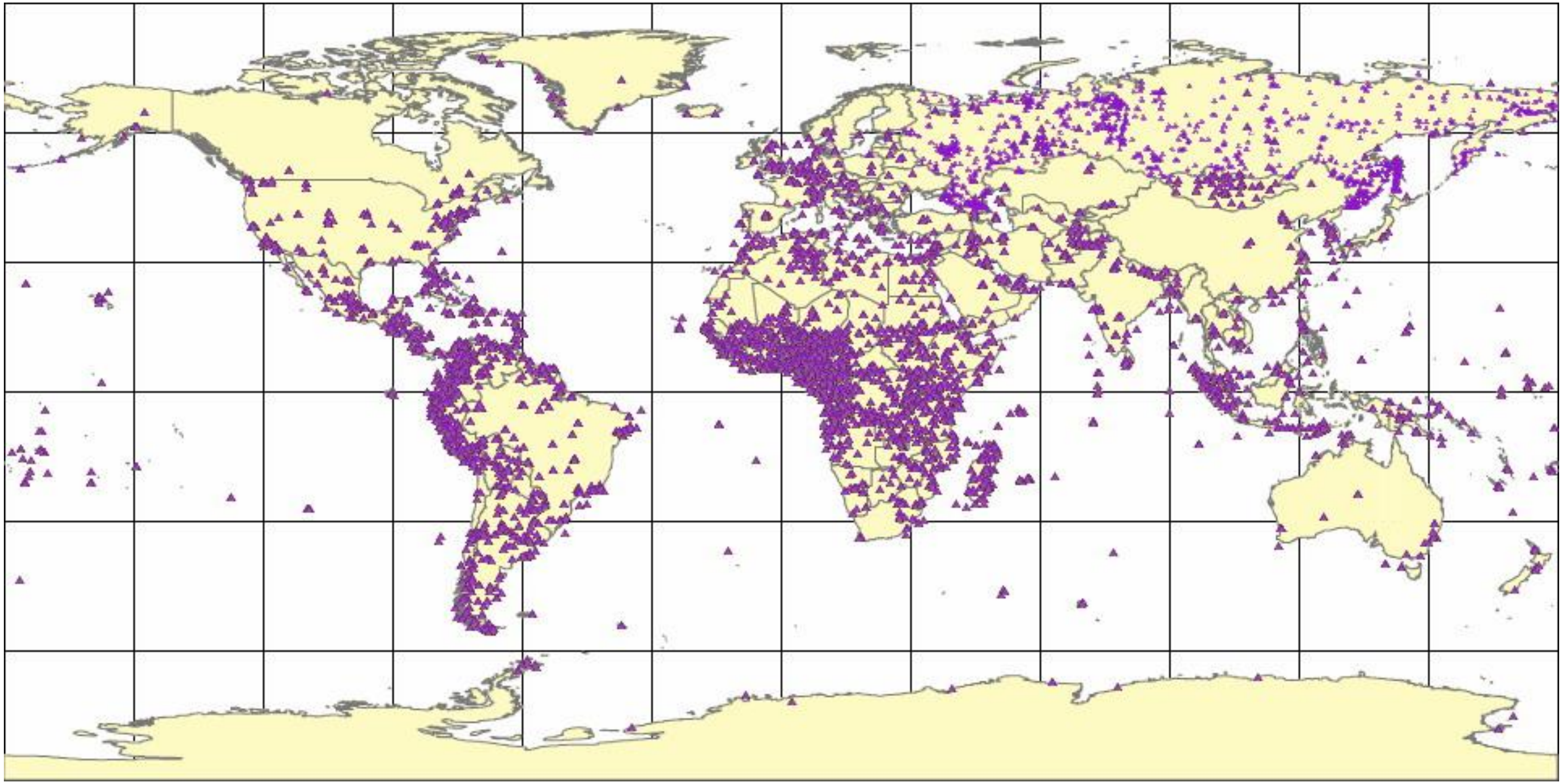
○ Circles of 35 km radius around earth stations

2 Locations of FSS earth stations

Figures A4, A5 and A6 show the locations of some earth stations registered with several satellite operators receiving authorised transmissions from the operating satellites of one FSS operator in the 3 700-4 200 MHz, 3 625-3 700 MHz and 3 400-3 625 MHz bands respectively. Also Fig. A7 provides information regarding the use of 3 625-4 200 MHz band by the FSS in Brazil. The earth stations shown in these figures do not include un-registered earth stations such as TVRO terminals

FIGURE A4

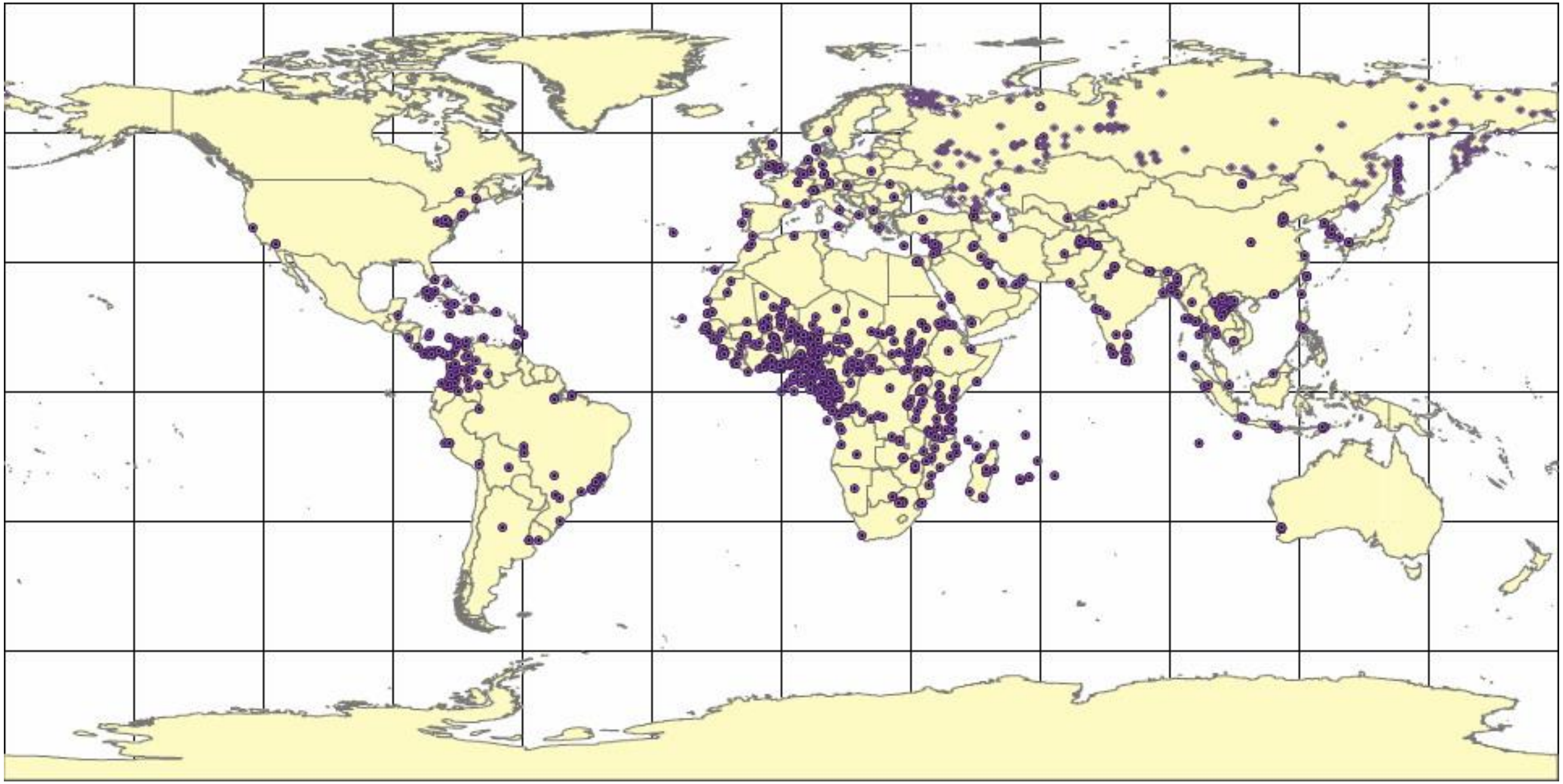
Locations of earth stations registered with several satellite operators and receiving in the 3 700-4 200 MHz band



Denotes a site that may include one or more stations.

FIGURE A5

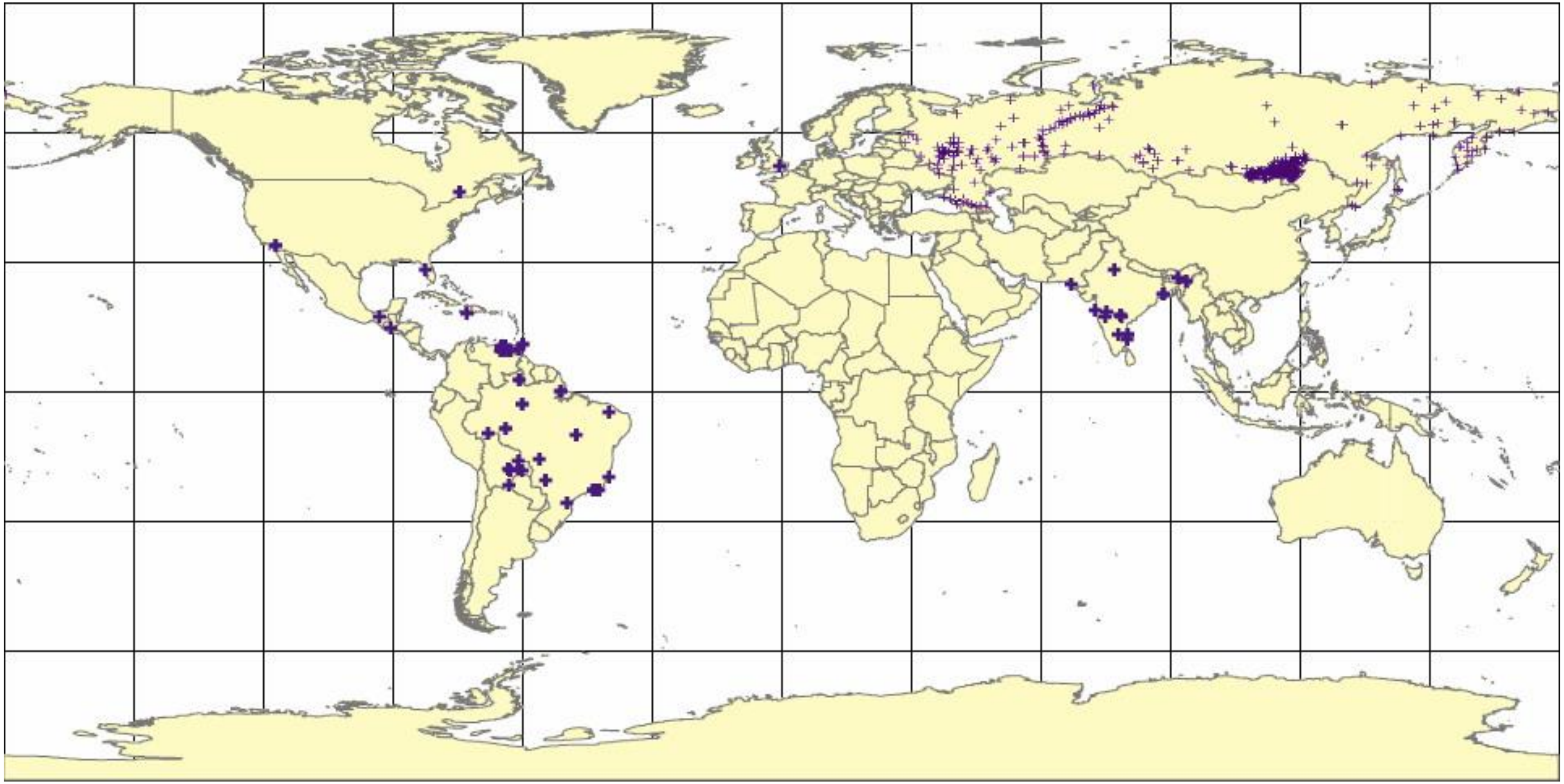
Locations of earth stations registered with several satellite operators and receiving in the 3 625-3 700 MHz band



● Denotes a site that may include one or more stations.

FIGURE A6

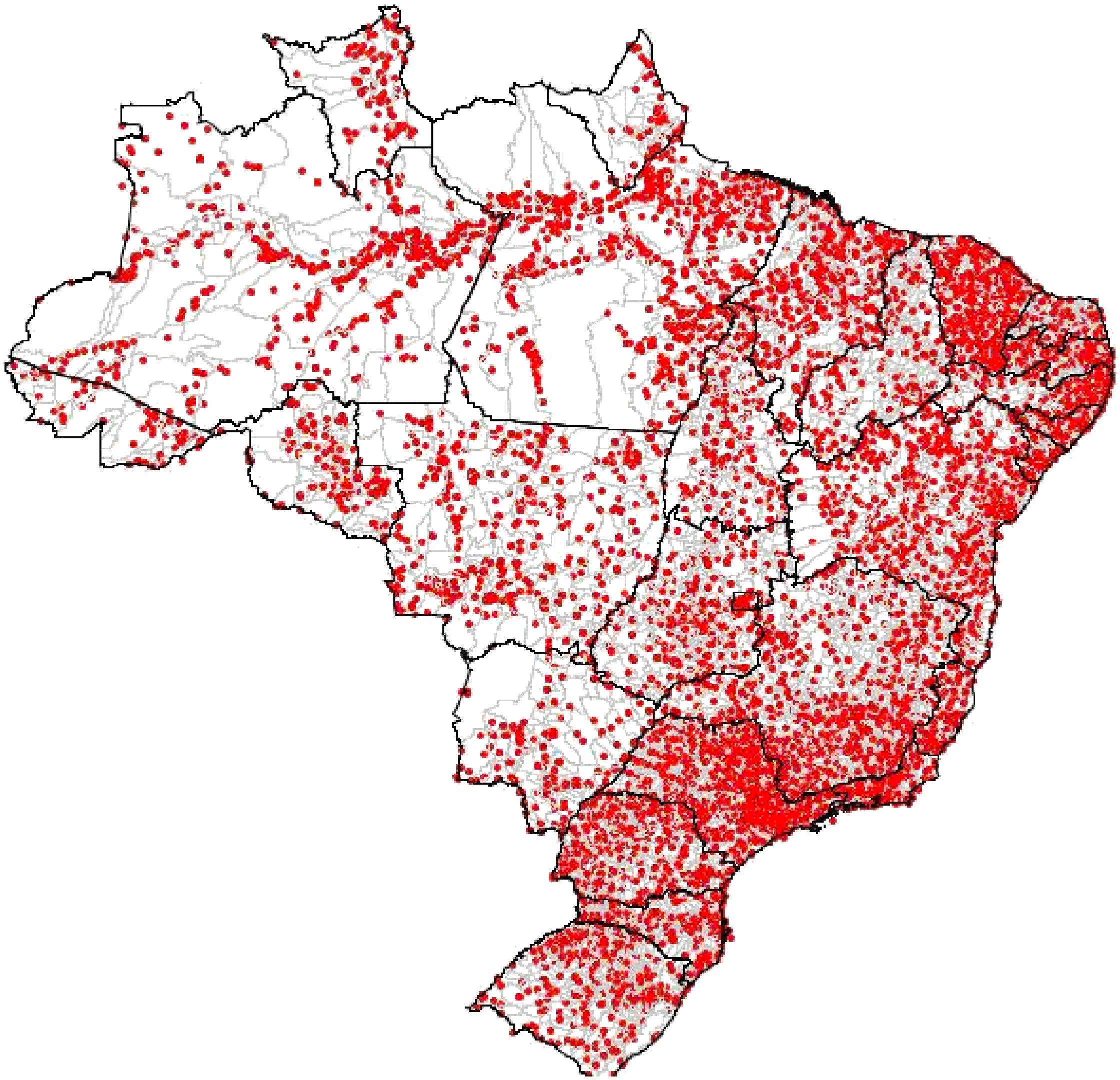
Locations of earth stations registered with several satellite operators and receiving in the 3 400-3 625 MHz band



✚ Denotes a site that may include one or more stations.

FIGURE A7

FSS earth stations in Brazil (sites using 3 625-4 200 MHz)



3 Locations and areas of coverage of 4/6 GHz FSS satellites

The longitudes and service areas of many, but not all, of the FSS satellites providing down-links in the 3 400-4 200 MHz band are given in Table A2.

TABLE A2

Some space stations operating in the 3 400-4 200 MHz band

Satellite Name	Orbital location (EL)	Service area
NSS 5	–177	East Asia /Australia / Western United States
AMC-8	–139.0	North America
AMC-7	–137.0	North America
AMC-10	–135.0	North America
Galaxy 15	–133.0	North America
AMC-11	–131.0	North America
Intelsat Americas 7	–129.0	North America
Galaxy 13	–127.0	North America
Galaxy 14	–125.0	North America
Galaxy 12	–125.0	North America
Galaxy 10R	–123.0	North America
Intelsat Americas 13	–121.0	North America
Anik F3	–118.7	North America
SATMEX-5	–116.9	North America
Solidaridad-2	–114.9	North America
SATMEX-6	–113.0	North America
Anik F2	–111.1	North America
Anik F1	–107.3	North America
Anik F1R	–107.3	South America
AMC-18	–105.0	North America
AMC-1	–103.0	North America
AMC-4	–101.0	North America
Galaxy 16	–99.0	North America
INMARSAT 3	–98.0	Global
Intelsat Americas 5	–97.0	North America
Galaxy 3C	–95.0	North America
Intelsat Americas 6	–93.0	North America
BRASILSAT B4	–92.0	Brazil
Galaxy 11	–91.0	North America
Intelsat Americas 8	–89.0	North America
AMC-3	–87.0	North America

Satellite Name	Orbital location (EL)	Service area
AMC-2	–85.0	North America
BRASILSAT B3	–84.0	Brazil
AMC-9	–83.0	North America
SATCOM-C3	–79.0	North America
Galaxy 4R	–76.8	North America
Galaxy 9	–74.0	North America
AMC-6	–72.0	North America
BRASILSAT B1	–70.0	Brazil
Venesat-1	–67.0	South America (under construction)
BRASILSAT B2	–65.0	Brazil
AMAZONAS	–61.0	North America / South America
PAS 9	–58.0	North America / South America / Europe
INTELSAT 805	–55.5	North America / South America / Europe
IS-805	–55.5	Global
IS-707	–53.0	Global
INMARSAT 4 F2	–53.0	Global
IS-706	–50.25	Global
PAS-1R	–45.0	Global
PAS-3R	–43.0	North America / South America/Africa/Europe
NSS 806	–40.5	North America / South America / Europe
INTELSAT 903	–34.5	North America / South America / Europe / Africa
INTELSAT 801	–31.5	North America / South America / Europe / Africa
INTELSAT 907	–27.5	North America / South America / Europe / Africa
INTELSAT 905	–24.5	North America / South America / Europe / Africa
NSS 7	–22.0	North America / South America / Europe / Africa
INTELSAT 603	–20.0	North America / South America / Europe / Africa
INTELSAT 901	–18.0	North America / South America / Europe / Africa
INMARSAT 3 F2	–15.0	Global
GORIZONT	–14.4	Beam 1: Global Beam 2: Northern Hemisphere
EXPRESS A4	–14.0	Europe / North Africa / Middle East / East United States
EXPRESS A3	–11.0	Europe / North Africa / Middle East / East United States
GORIZONT	–10.0	Beam 1: Global (Assumed) Beam 2: Northern Hemisphere (Assumed)
ATLANTIC BIRD 3	–5.0	Europe / Africa / Eastern United States / Northeast South America / Western Russia / Middle East
GORIZONT	–3.0	Beam 1: Global (Assumed) Beam 2: Northern Hemisphere (Assumed)
INTELSAT 10-02	–1.0	Global

Satellite Name	Orbital location (EL)	Service area
INMARSAT 3 F5	25.0	Global
PAS-5	26.25	Europe/Africa/Middle East
INTELSAT 802	33.0	Africa / Europe / India / East Asia
PAKSAT 1	38.0	Pakistan
EXPRESS AM1	40.0	Russia / Europe / Middle East
RADUGA	44.7	Assumed to be Russia
RADUGA	48.4	Assumed to be Russia
YAMAL 202	49.0	Europe / Asia
IS-706	50.25	Global
IS-702	54.85	Global
INSAT-3E	55.0	India (frequency plan is unknown)
GORIZONT	58.0	Beam 1: Global (Assumed) Beam 2: Northern Hemisphere (Assumed)
INTELSAT 904	60.0	Africa / Europe / Asia / India / Australia
INTELSAT 902	62.0	Africa / Europe / Asia / India / Australia
INTELSAT 906	64.0	Africa / Europe / Asia / India / Australia
INMARSAT 4 F1	64.0	Global
INMARSAT 2	64.0	Global
INTELSAT 601	64.25	Africa / Europe / Asia / India / Australia
IS-704	66.0	Global
PAS 7	68.5	Africa / Europe / India / Asia
RADUGA	68.8	Assumed to be Russia
RADUGA	70.0	Assumed to be Russia
PAS-4	72.0	Africa/Europe/Asia
EDUSAT	74.0	Assumed to be Russia
INSAT 3C	74.0	India
ABS	75.0	Central Asia
TELSTAR 10	76.5	Africa / Europe / Asia / Australia
THAICOM 5	78.5	India / China / Indochina
EXPRESS AM2	80.0	Russia / China / India / East Asia
INSAT 3B	83.0	India
INSAT 2E	83.0	India
RADUGA	84.6	Assumed to be Russia
IS-709	85.0	Global
ST-1	88.0	India / China / Indochina
YAMAL 101	89.8	Russia
YAMAL 201	90.0	Russia / Middle East / Northern China
ASIASAT 2	100.5	East Asia / Australia / India / Indochina / Indonesia

Satellite Name	Orbital location (EL)	Service area
EXPRESS 6	103.0	Russia (Assumed)
EXPRESS A2	103.0	China / Russia / Middle East / India / Japan
ASIASAT 3S	105.5	Asia / Australia / India
TELKOM 1	108.0	Indonesia / Indochina
TELSTAR 18	138.0	India / East Asia / Indochina / Australia and New Zealand
INMARSAT 3	109.0	Global
SINOSAT 1	110.5	China / Indochina / Indonesia / Philippines
GORIZONT	113.0	Beam 1: Global (Assumed) Beam 2: Northern Hemisphere (Assumed)
PALAPA C2	113.0	East Asia / Indonesia
TELKOM 2	118.0	Indonesia / Indochina
ASIASAT 4	122.3	India / China / Indochina /Indonesia / Philippines / Australia
RADUGA	126.0	Assumed to be Russia
GORIZONT	126.0	Beam 1: Global (Assumed) Beam 2: Northern Hemisphere (Assumed)
APSTAR 1A	130.0	India / East Asia / Indochina
APSTAR 6	134.0	India / East Asia / Indochina / Australia and New Zealand
TELSTAR 18	138.0	India / East Asia / Indochina / Australia and New Zealand
EXPRESS AM3	140.0	Beam 1: Northeast Asia Beam 2: Steerable Global
APSTAR 1	142.0	East Asia / Indochina / Indonesia
INMARSAT 2 F1	143.5	Global
GORIZONT	145.0	Beam 1: Global Beam 2: East Asia
AGILA 2	146.0	India / East Asia / Indochina
INTELSAT 602	150.5	East Asia / Australia/ India
GORIZONT	153.8	Beam 1: Global (Assumed) Beam 2: Northern Hemisphere (Assumed)
PAS-8	166	South East Asia/Australia/Indonesian region island
PAS-2	169	East Asia/ Australia/Indonesian region/Western U.S.
INTELSAT 605	174.0	East Asia / Australia/ India
INMARSAT 3 F3	178.0	Global
IS-701	180.0	Global

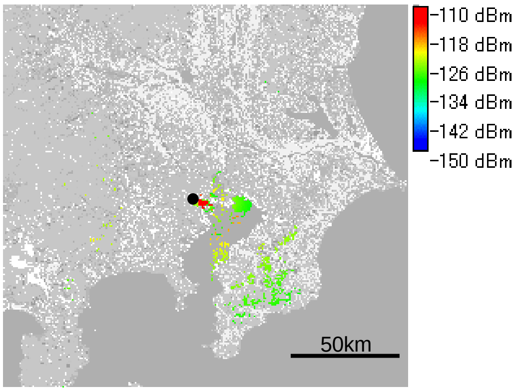
Annex B

Shape of protection zone for FSS earth station in a real environment

Figure B1 shows an example of the interference power level from the IMT-Advanced base station on the FSS earth station considering the shielding effect by terrain profile and clutter losses associated with artificial objects. In this figure, the deployment of IMT-Advanced base station is based on micro-cell using the antenna downtilt of seven degrees. The gradation of the colors white to red represents the lower to greater interference power from the IMT-Advanced base station.

FIGURE B1

Example of interference power level from the IMT-Advanced base station on FSS earth station considering terrain profile and clutter losses (Micro-cell deployment, antenna downtilt = 7°)



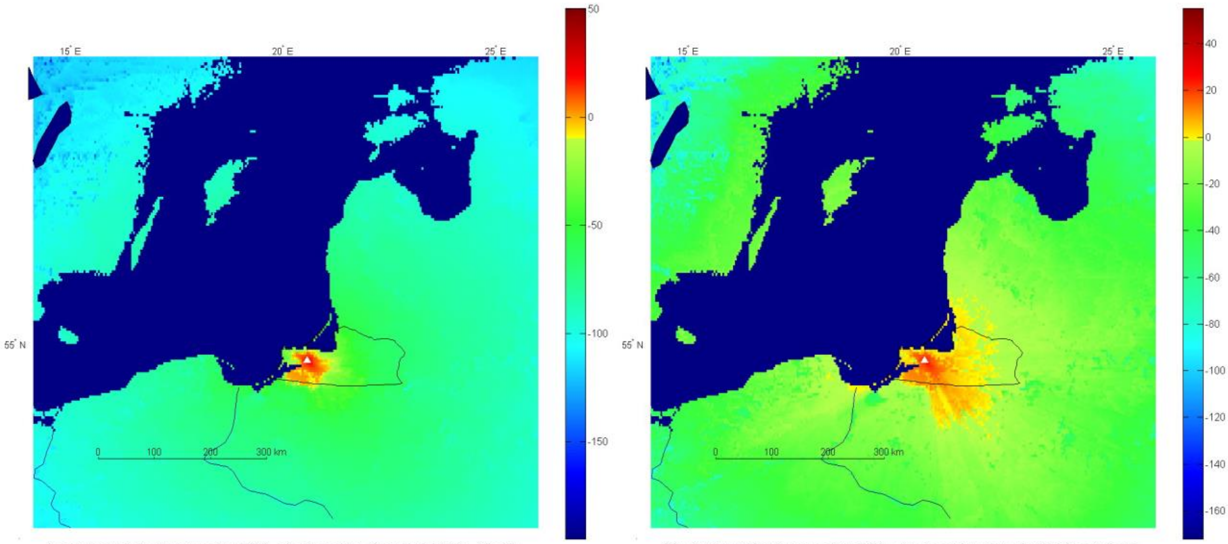
Below the case of multiple earth stations deployment is presented associated with the Study 11. For each channel arrangement exclusion zones for two earth stations are shown to highlight possible differences in the exclusion zones. And as a result the exclusion zone combined from nine considered earth stations is shown for two channel arrangement cases. In both cases even with dominating earth stations providing major area of exclusion zone other stations could extend it. The effect is more significant as more azimuth diversity exists corresponding to different satellites.

As shown in the figures, the interference power level is highly dependent on the locations over the 360° of area owing to the different degree of shielding effect by terrain profile and clutter losses.

These figures indicate that the required protection zones for FSS earth station will not be represented by the area of a circle. It should be also noted that the size of required protection distance depends on the deployment scenarios of IMT-Advanced systems, such as inter-site distance (i.e., micro- or macro- cell), antenna height, degree of antenna downtilt.

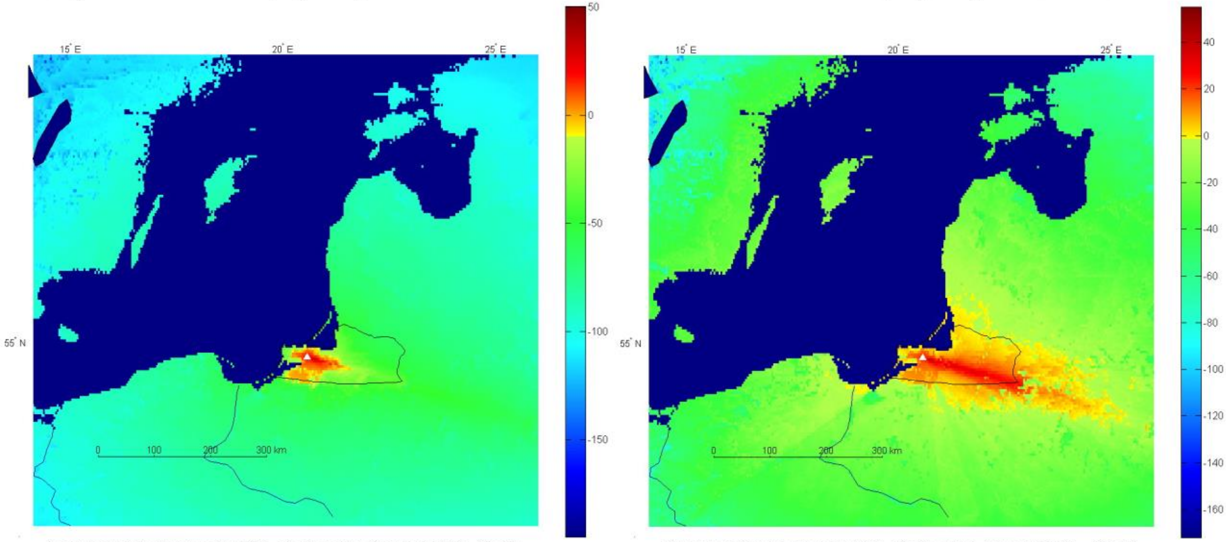
FIGURE B2

Example of interference power level from the IMT-Advanced base station on FSS earth station considering terrain profile and without clutter losses (Macro-cell deployment, antenna downtilt = 2°, 100 MHz channel arrangement)



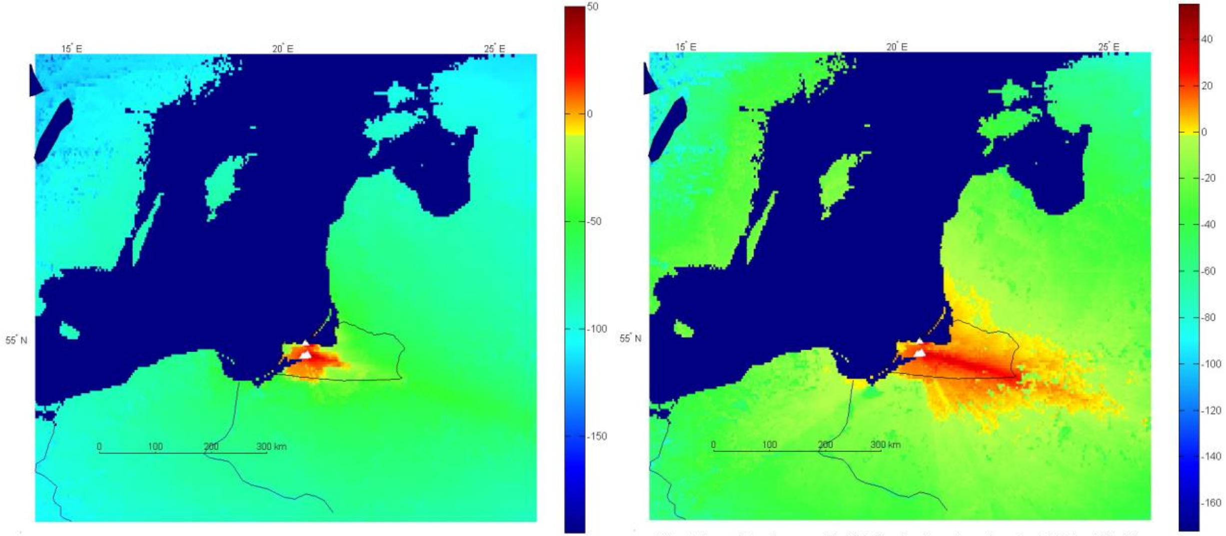
Long-term interference for ES3, single entry, threshold I/N=-10 dB

Short-term interference for ES3, single entry, threshold I/N=-1.3 dB



Long-term interference for ES4, single entry, threshold I/N=-10 dB

Short-term interference for ES4, single entry, threshold I/N=-1.3 dB

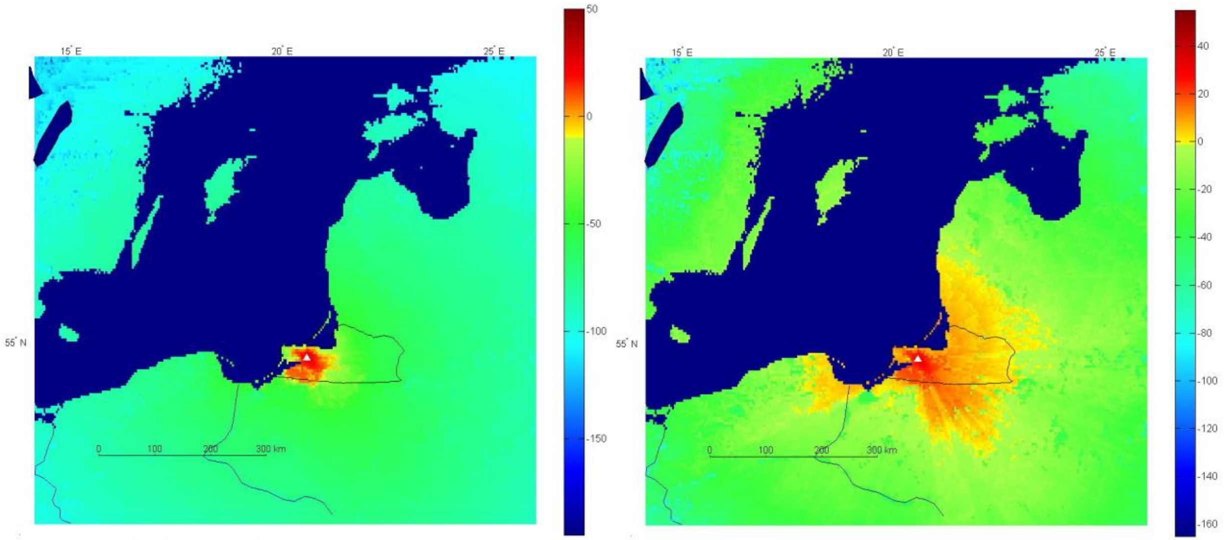


Long-term interference for 9 ES, single entry, threshold I/N=-10 dB

Short-term interference for 9 ES, single entry, threshold I/N=-1.3 dB

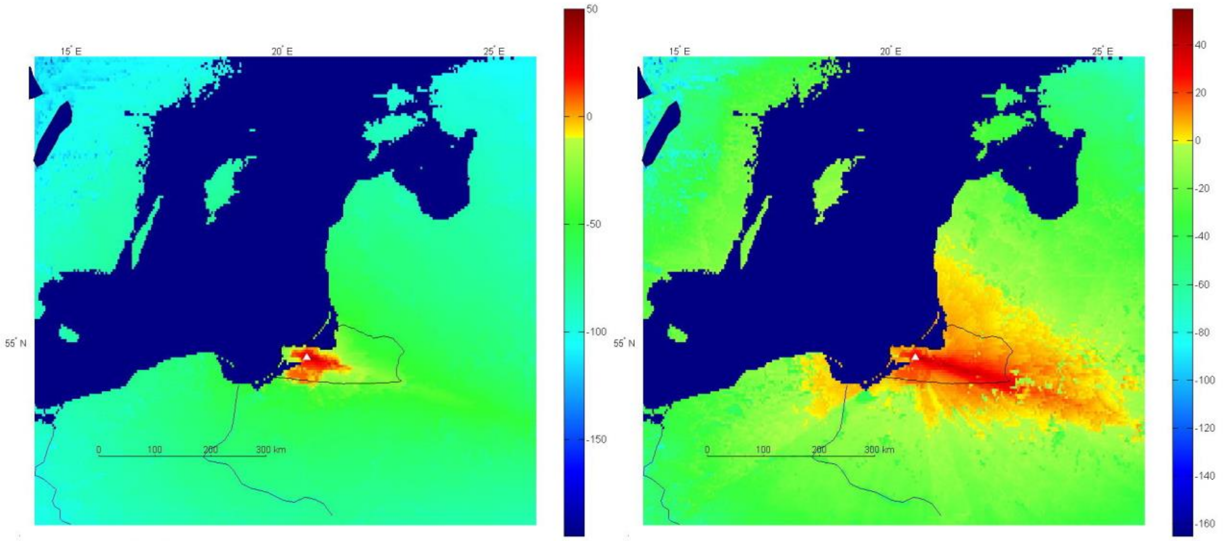
FIGURE B3

Example of interference power level from the IMT-Advanced base station on FSS earth station considering terrain profile and without clutter losses (Macro-cell deployment, antenna downtilt = 2°, five 20 MHz channels arrangement)



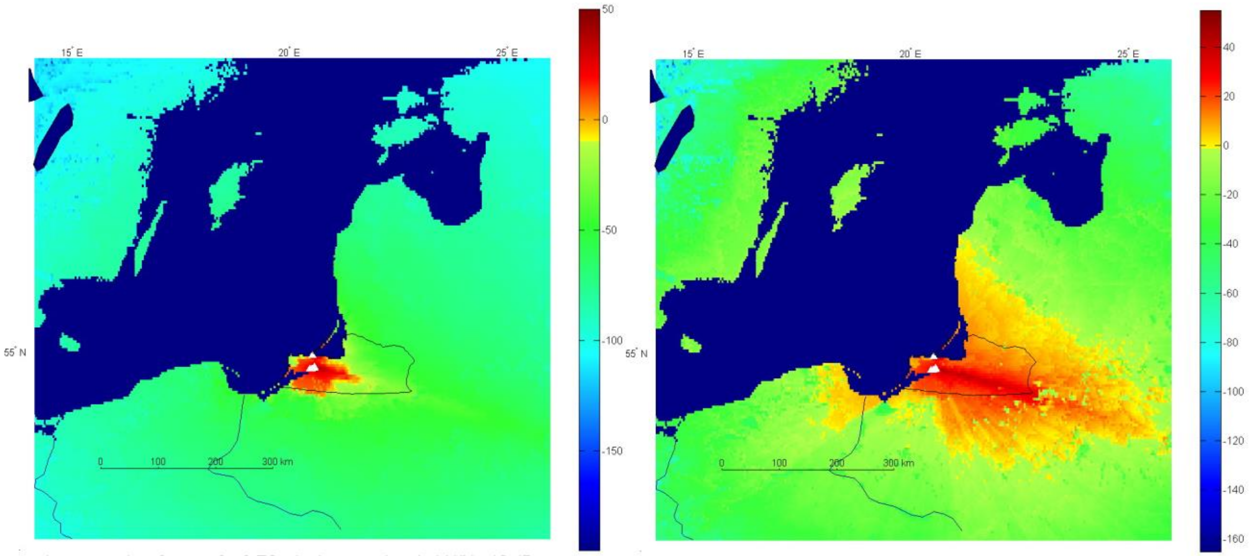
Long-term interference for ES3, single entry, threshold I/N=-10 dB

Short-term interference for ES3, single entry, threshold I/N=-1.3 dB



Long-term interference for ES4, single entry, threshold I/N=-10 dB

Short-term interference for ES4, single entry, threshold I/N=-1.3 dB



Long-term interference for 9 ES, single entry, threshold I/N=-10 dB

Short-term interference for 9 ES, single entry, threshold I/N=-1.3 dB

Annex C

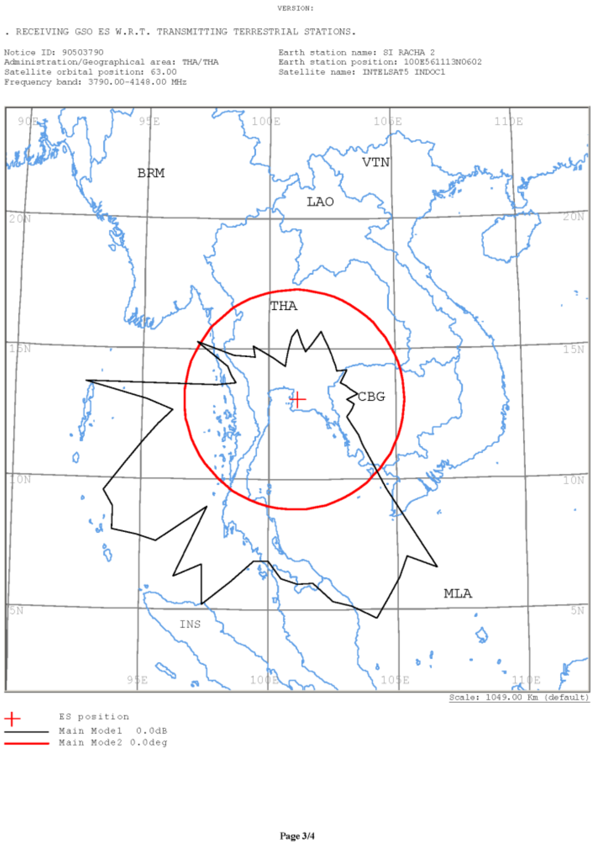
Examples of coordination contours

The figures below provide examples of coordination contours taken from the ITU Master Register for some earth stations around the world. These contours have been derived using the ITU-R Appendix 7 methodology and criteria. The example earth stations are:

	EARTH STATION INFORMATION			SATELLITE INFORMATION	
	NAME	LONGITUDE	LATITUDE	SATELLITE NAME	LONGITUDE (NOMINAL)
1	SI RACHA 2	100 E 56 11	13 N 06 02	INTELSAT5 INDOC1	63
2	AGARTALA	91 E 16 00	23 N 48 00	INSAT-1B	74

It should be noted that RR Appendix 7 states (see § 1.1 of RR Appendix 7) that “the coordination area is not an exclusion zone within which the sharing of frequencies between the earth station and terrestrial stations or other earth stations is prohibited, but a means for determining the area within which more detailed calculations need to be performed. In most cases a more detailed analysis will show that sharing within the coordination area is possible since the procedure for the determination of the coordination area is based on unfavourable assumptions with regard to the interference potential”.

FIGURE 1a



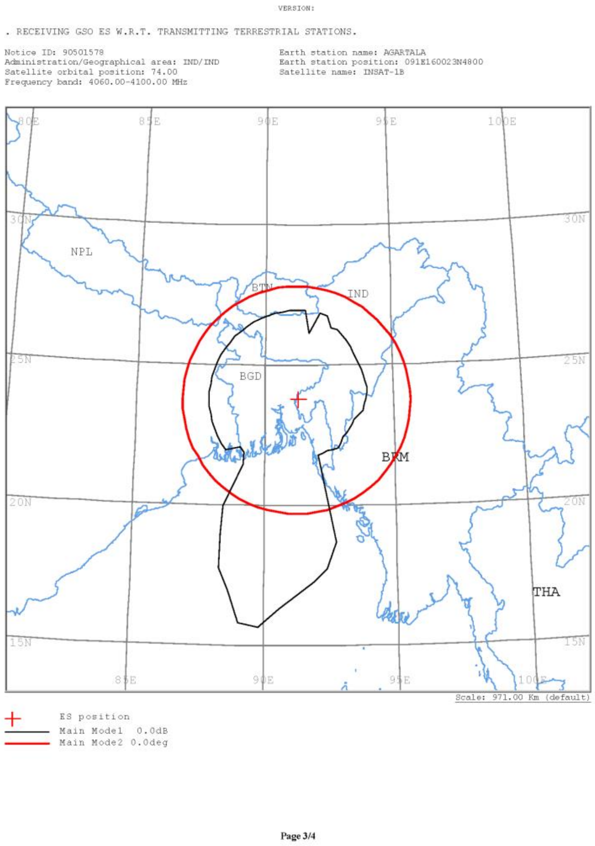
VERSION:

. RECEIVING GSO ES W.R.T. TRANSMITTING TERRESTRIAL STATIONS.

Notice ID: 90503790
Administration/Geographical area: THA/THA
Satellite orbital position: 63.00
Frequency band: 3790.00-4148.00 MHz

Earth station name: SI RACHA 2
Earth station position: 100E561113N0602
Satellite name: INTELSAT5 INDOC1

FIGURE 1b



VERSION:

. RECEIVING GSO ES W.R.T. TRANSMITTING TERRESTRIAL STATIONS.

Notice ID: 90501578
Administration/Geographical area: IND/IND
Satellite orbital position: 74.00
Frequency band: 4060.00-4100.00 MHz

Earth station name: AGARTALA
Earth station position: 091E160023N4800
Satellite name: INSAT-1B

Annex D

Sharing studies considering MIMO SDMA mitigation technique

In order to improve sharing conditions between IMT-Advanced and FSS, an interference mitigation technology such as MIMO SDMA can be utilized (see Report ITU-R M.2074 – Radio aspects for the terrestrial component of IMT-2000 and systems beyond IMT-2000 and Report ITU-R M.2038 – Technology trends). With such MIMO SDMA, IMT-Advanced base station can mitigate interference to a FSS earth station by generating null to the direction of the FSS earth station. The MIMO SDMA technique [Cheol Mun et *al.*, 2005] which is enabled by the pre-coded multiple transmit antennas utilizes the additional degrees of freedom in a spatial domain. As such, by adjusting the coefficient of each antenna, the MIMO SDMA technique can form the desired radiation pattern which consists of main lobe and nulls.

This contribution presents a method to calculate the interference at the FSS earth station based on the MIMO SDMA technique as described earlier when the IMT-Advanced base station uses a MIMO SDMA technique and shows improvement in sharing condition between IMT-Advanced base station and FSS earth station.

With the assumptions of co-channel frequency sharing condition and free space channel environment, the interference power from an IMT-Advanced base station to a FSS earth station can be reduced smaller than the maximum permissible interference level while the distance between IMT-Advanced base station and FSS earth station is more than 35 m. In case of an IMT-Advanced base station and 3 FSS receiving earth stations, the minimum separation distance increases up to 3.5 km under the same assumptions. Moreover, up to 22° of estimation error in the direction of earth station (DOE), the minimum separation distance is reduced further by a MIMO SDMA and at the DOE estimation error of 8°, the minimum separation distance can be reduced by at least 50% compared to the separation distance without any interference mitigation scheme of 44 km.

This sharing study results indicate that the high possibility of the sharing between the IMT-Advanced and multiple FSS systems.

System modelling and interference mitigation techniques

The basic concept of the mitigation scheme is to form nulls in the spatial domain to the direction of the victim FSS earth station. For convenience, ‘DOE’ denotes the direction angles of the victim FSS earth station in this contribution.

To enable the MIMO SDMA technology, the IMT-Advance base station has to obtain DOE information and perform null steering. DOE information can be obtained by adopting a popular spatial spectrum estimation direction finding method or from the database including information about the direction from the interfering IMT-Advanced base station to the victim FSS earth station. It is assumed that the IMT-Advanced base station is already aware of DOE information for the FSS earth station.

Fig. D1 shows the interference scenario of IMT-Advanced base station with proposed interference mitigation technique, where IMT-Advanced base station constructs nulls at DOE θ_1, θ_2, and θ_3. Fig. D2 illustrates the IMT-Advanced base station null-steering beamformer structures for suppressing the interference toward FSS earth stations.

FIGURE D1

Interference scenario of IMT-Advanced base station with interference mitigation technique

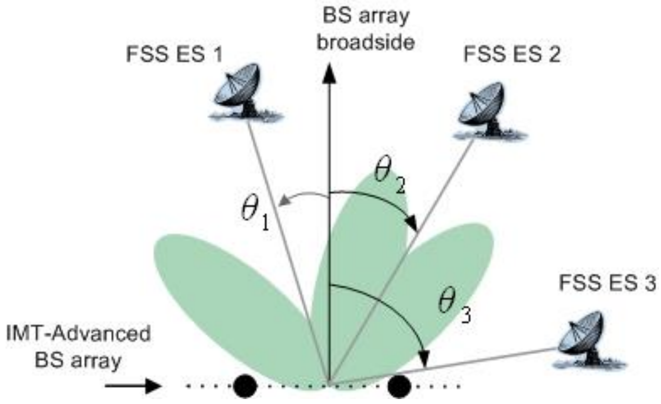
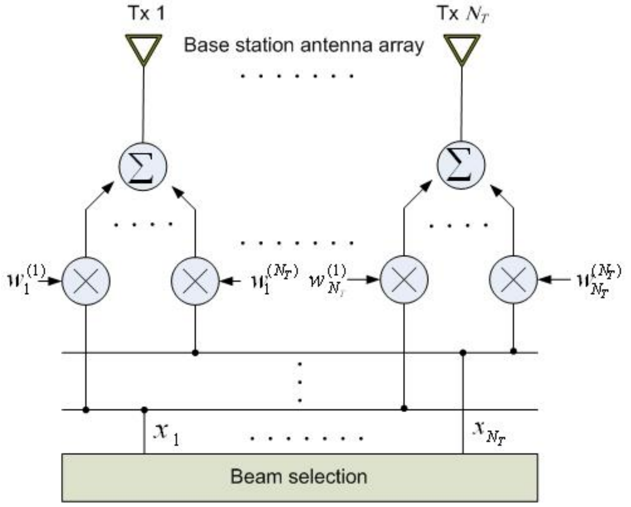


FIGURE D2

IMT-Advanced base station incorporating the interference mitigation technique based on null- steering for MIMO downlinks with uniform linear array



A linear array of N_T isotropic antenna elements with uniform spacing is considered. The data signals x_k , $k = 1,\cdots,N_T$ from the beam selector are direct multiplied by a set of weights $U = \{\mathbf{w}_1, \mathbf{w}_2, \cdots, \mathbf{w}_{N_T}\}$ to form a null at known DOE. $\mathbf{w}_m = \left[w_1^{(m)}, w_2^{(m)}, \cdots, w_{N_T}^{(m)}\right]$is the m-th weight vector in row vector and is given by the following set of equations:

$$\begin{aligned}&\mathbf{w}_m\mathbf{a}(\theta_d) = 1\\&\mathbf{w}_m\mathbf{a}(\theta_i) = 0; \quad i = 1,2,\cdots,N_T - 1\end{aligned}$$

where a(θ) is the array propagation vector at an angle θ with respect to the array broadside and is defined by:

$$\mathbf{a}(\theta) = \begin{bmatrix} 1 & \mathrm{e}^{j2\pi\frac{d}{\lambda}\sin\theta} & \cdots & \mathrm{e}^{j2\pi(N_T-1)\frac{d}{\lambda}\sin\theta}\end{bmatrix}^T$$

We can solve for the weight vector so that:

$$\mathbf{W}_m = \mathbf{A}^{-1}\begin{bmatrix}1\\0\\\vdots\\0\end{bmatrix}$$

where:

$$\mathbf{A} = \left[\mathbf{a}(\theta_d) \quad \mathbf{a}(\theta_1) \quad \mathbf{a}(\theta_2) \quad \cdots \quad \mathbf{a}(\theta_{N_T-1})\right]$$

Let us consider scenario where the spatial location of the desired user is at 0^{o} with respect to the array broadside. There are multiple FSS earth stations at -50^{o}, -20^{o}, and 40^{o}. IMT-Advanced base station is equipped with four antennas with half wavelength spacing between the antennas. Fig. D3 shows four mutually orthogonal overlapped beams generated by null-steering vectors

$\mathbf{W}_m, m = 0,\cdots,3$. $\mathbf{W}_0$ of four null-steering vectors constructs nulls at DOE -50°, -20°, and 40° as shown in Fig. D4 and thus is only used for IMT-Advance downlink service with the mitigation of interference to FSS earth station. Fig. D5 and D6 depict the IMT-Advanced base station radiation pattern regardless of whether the proposed algorithm is applied. The results confirm that, with the help of the proposed method, very little IMT-Advanced base station power is radiated to the FSS earth station.

FIGURE D3

Four mutually orthogonal overlapped beams generated by null-steering vectors

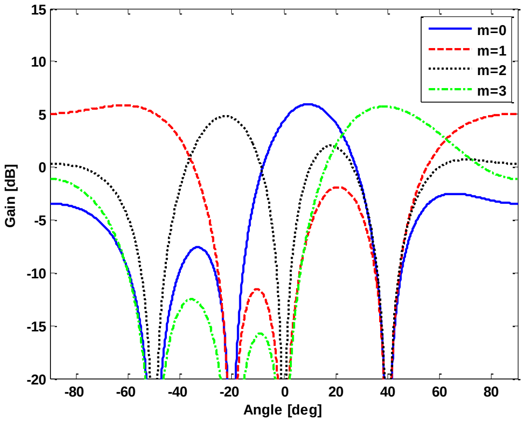


FIGURE D4

Single beam was selected from four overlapped beams, where constructed three nulls at DOE -50°, -20°, and 40°

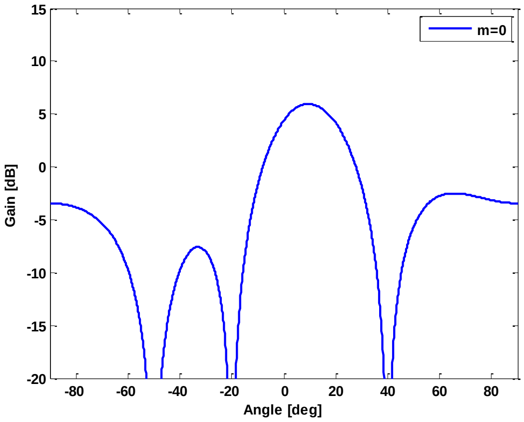


FIGURE D5

IMT-Advanced base station radiation patterns (Nt = 4, Nes = 3)

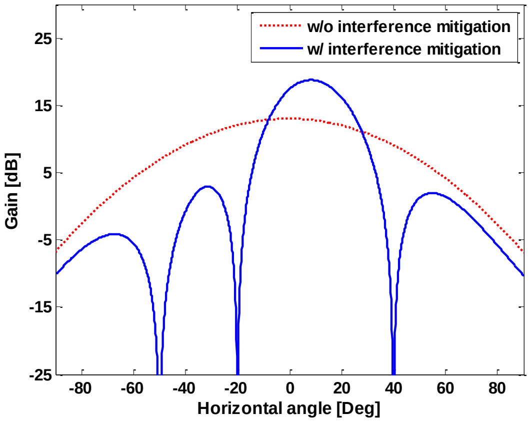
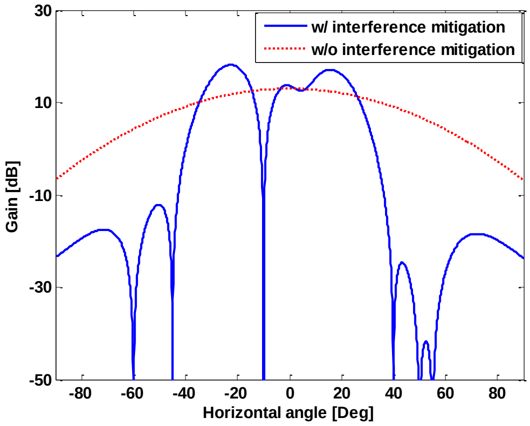


FIGURE D6

IMT-Advanced base station radiation patterns (Nt = 8, Nes = 6)



Results analysis

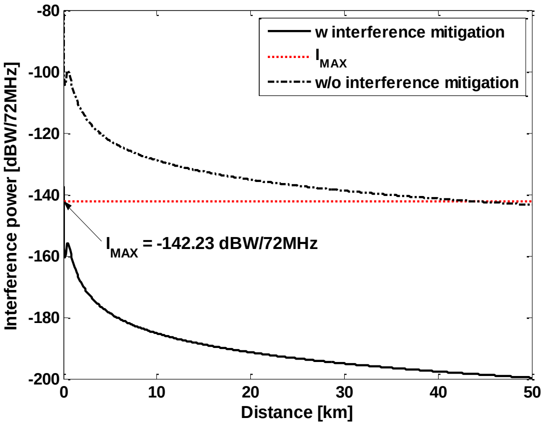
The interference received by the victim FSS earth station is depicted with various separation distances between single FSS earth station and IMT-Advanced base station in the Fig. D7. Nt and Nes denote the number of transmit antennas and FSS earth stations, respectively. The Fig. 7a) shows that the interference received by the victim FSS earth station almost approaches to the maximum permissible interference level, I_{max} without any interference mitigation schemes when the separation distance between the FSS earth station and IMT-Advanced base station is longer than 44 km. However, by using the MIMO SDMA, smaller windows are required to find the interference power that meets I_{max}, thus the interference becomes smaller than the maximum permissible interference power by the mitigation scheme at the separation distance of more than 35 m as shown in the Fig. 7b). Although the ideal case such that null beam to the FSS earth station can be formulated perfectly is assumed in the analysis, the results implies that the separation distance between IMT-Advanced and FSS earth station can be greatly reduced with the MIMO SDMA technique so that these two systems can co-exist in the same frequency with appropriate separation distance.

In addition, the imperfection in DOE estimation causes degradation in the improvement of the separation distance. The impact of the DOE estimation error to the gain of the interference mitigation technique is presented in the Fig. D8 and also in the Table D1. It is clear that the increase in the DOE estimation error causes the increase in the minimum separation distance between IMT-Advanced base station and FSS earth station. Even so, up to 22° of the DOE estimation error, the minimum separation distance with the MIMO SDMA can be still shorter than that without the interference mitigation scheme and at the DOE estimation error of 8°, the minimum separation distance can be half of the minimum distance without any interference mitigation schemes. It should be noted that the performance degradation of IMT-Advanced systems is expected when many users are around the direction of null beam of an IMT-Advanced base station.

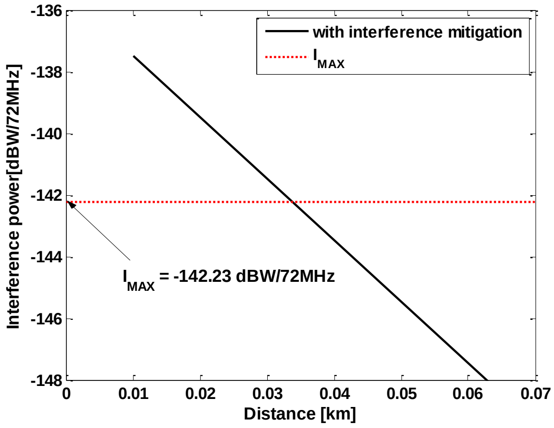
Table D2 presents the required minimum distances for multiple FSS earth stations when proposed mitigation technique is employed. It is observed that, using the mitigation scheme, the minimum separation distances can be reduced less than 3.5 km. Our results indicate that the proposed mitigation scheme is highly efficient in terms of reducing simultaneously the required distances between single IMT-Advance base station and multiple earth stations.

FIGURE D7

Interference power comparison of the proposed interference mitigation algorithm for the co-channel case (Nt = 4, Nes = 1)



a)



b)

FIGURE D8

Minimum separation difstance versus direction of earth station estimation error (Nt = 4, Nes = 1)

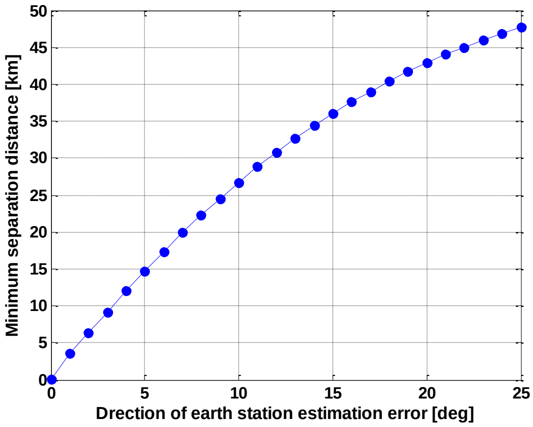


TABLE D1

Minimum required separation distance for different (Nt = 4, Nes = 1)

Simulation environments		Minimum separation distance (km)
With interference mitigation techniques	DOE estimation error: 0°	0.035
	DOE estimation error: 4°	12
	DOE estimation error: 8°	22
Without interference mitigation techniques		50

TABLE D2

Required minimum distance

a) Nt = 4, Nes = 3

	Minimum separation distance (km)	
	5° FSS earth station elevation angle	**48° FSS earth station elevation angle**
Victim earth station 1 (DOE: –0°)	1.4	1
Victim earth station 2 (DOE: –0°)	3.5	2.5
Victim earth station 3 (DOE: 40°)	3.3	2.3

b) Nt = 8, Nes = 6

	Minimum separation distance (km)	
	5° FSS earth station elevation angle	**48° FSS earth station elevation angle**
Victim earth station 1 (DOE: -60°)	0.7	0.5
Victim earth station 2 (DOE: -45°)	2.4	1.7
Victim earth station 3 (DOE: -10°)	14	10
Victim earth station 4 (DOE: 40°)	0.85	0.6
Victim earth station 5 (DOE: 50°)	0.05	0.05
Victim earth station 6 (DOE: 55°)	0.08	0.08

References

CHEOL MUN, *et al.* [15 December 2005] Space Division Multiplexing/Space Division Multiple Access Unitary Precoded MIMO. *Proc.* Of Wireless world research forum(WWRF).

Annex E

Assumptions and main results of Study 9

1 Assumptions

1.1 Line-of-sight

In line with equation (6) (and (5)) of Recommendation ITU-R P.452-12 for the effective radius of the earth and taking 60 as a representative annual average Δ*N*, the line-of-sight distance for the agreed antenna heights is calculated as follows:

TABLE E1

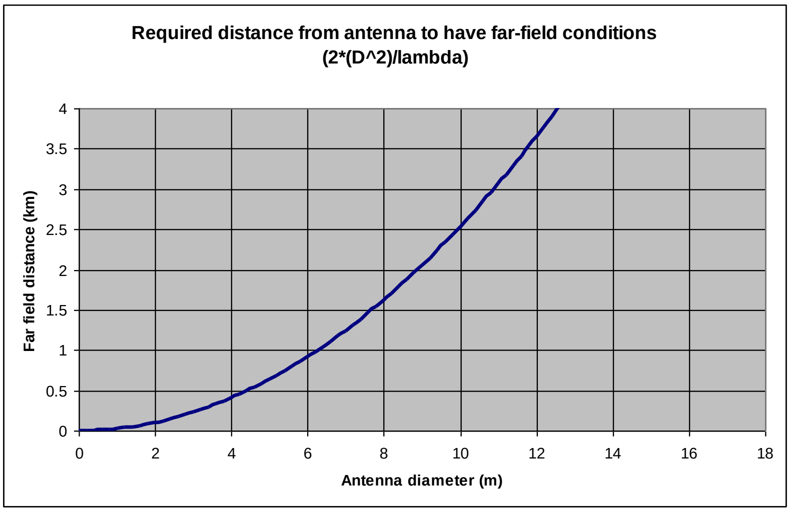
Line-of-sight distance (km)					
			Base station macro	Base station micro	User terminal
	FSS antenna height (m)	IMT-Advanced station height (m)	30	5	1.5
Urban	30				
Rural	3		**50**	**35**	**30**
			33	**18**	**13**

It can be seen that the depending on the types of IMT-Advanced and FSS stations, the line-of-sight distance will range from 50 to 13 km. Using other values of ΔN will change the line-of-sight distance, but not significantly.

1.2 Far-field

Close to the antenna, the radiation pattern of an antenna will be characterized by the "near-field" pattern. As the distances to the antenna increases, the "far-field" pattern will form. Using the customary assumption for far-field conditions (a point source giving a phase variation of 22.5° over the aperture of the antenna, i.e., $d = 2D^2/\lambda$, where D is the antenna diameter), the minimum distance to be in the far-field is shown in Fig. E1 ($f = 3.8$ GHz).

FIGURE E1



All calculations in this text are based upon the assumption of far-field antenna patterns of the FSS receive antenna. It can be seen that the required distance to be in the far-field ranges from some few hundred metres for small antennas to some few kilometres for large antennas. If the distance between the IMT-Advanced station and the FSS receive antenna is smaller than this, the assumed far-field antenna pattern may not give correct calculated interference levels.

1.3 Losses from local clutter

In cases where the direct line-of-sight is blocked by local obstructions, the propagation loss will increase. In the sensitivity analyses in this text, the impact of cases with such clutter losses have been addressed according to § 4.6 of Recommendation ITU-R P.452-12, using the two extreme cases; rural areas and dense urban areas. The calculated clutter losses for the different paths are shown in Table E2. It may be seen that the FSS receive antenna in many cases will stand up above the local clutter and no clutter loss will be encountered. The IMT-Advanced antennas will however in many cases be below the local clutter and clutter losses can occur. In the sensitivity analyses, clutter losses of 0 dB and 20 dB have been used as the two extreme cases. It may be noted that clutter losses in excess of about 3 dB is not predicted with respect to the base stations for this kind of rural terrain since the base stations will stand up above the local clutter. However, other types of rural surroundings, e.g. forests, could give higher losses and 20 dB has therefore been used as the upper extreme in all cases.

TABLE E2

Dense urban	30	30	5	1.5	25	0.02	**-0.3**	**-0.3**	**19.6**	**19.7**
Rural	3	30	5	1.5	4	0.1	**3.1**	**-0.3**	**-0.3**	**17.3**
	FSS antenna height (m)	Macro base station IMT-Advanced antenna height (m)	Micro base station IMT-Advanced antenna height (m)	User term IMT-Advanced antenna height (m)	Height of local clutter (m) (Rec. 452, Table 6)	Nominal distance from local clutter (km) (Rec. 452, Table 6)	Clutter loss FSS antenna (dB)	Clutter loss IMT-Advanced Macro base station antenna (dB)	Clutter loss IMT-Advanced Micro base station antenna (dB)	Clutter loss IMT-Advanced user terminal (dB)

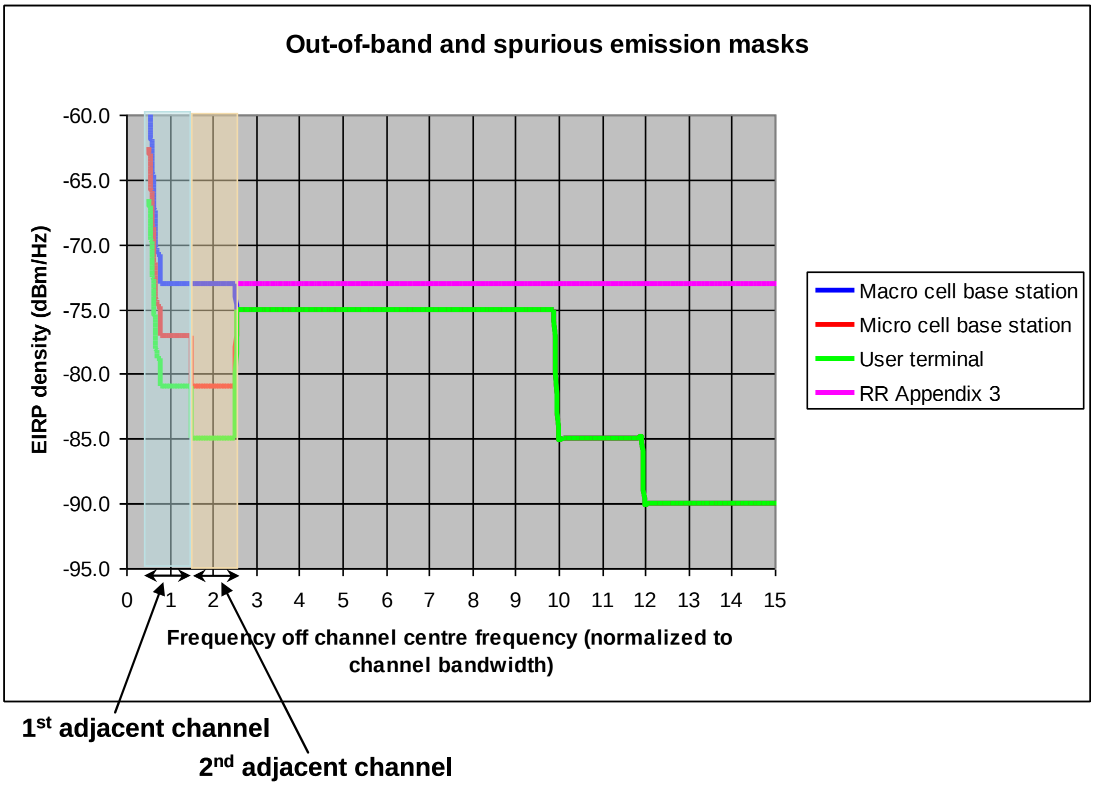
1.4 Unwanted emissions by IMT-Advanced equipment

The 3GPP TS 25.104 V7.5.0 (2006-12) standard for “band VII” (2.5 GHz) was used for determination of the expected levels of unwanted emissions from IMT-Advanced in 3 400-4 200 MHz.

This standard specifies the acceptable spurious emission levels outside the 2nd adjacent channel (Table 6.9E) and the acceptable out-of-band emission levels in the band of the 1st and 2nd adjacent channels (Tables 6.3, 6.5 and 6.6 Macro cell base station, Micro cell base station and User terminal respectively).

This 3GPP standard is based upon a 5 MHz channel bandwidth and specifies acceptable emission levels in different bandwidths for different off frequencies. Normalized to the channel bandwidth and emission levels per Hz, the requirements are as shown in Fig. E2.

FIGURE E2



It may be noted that in the spurious domain, the expected emission levels are the same for all types of stations.

2 Results

The total received RF power from one single IMT-Advanced station and the noise increase ($\Delta T/T$) due to unwanted emissions 50, 100 and 250 MHz off the edge of the last channels from one single IMT-Advanced station were calculated as a function of distance between the FSS receiver and the IMT-Advanced transmitter. The results are presented in the Figs. E3 and E4.

FIGURE E3

Overdrive of LNB

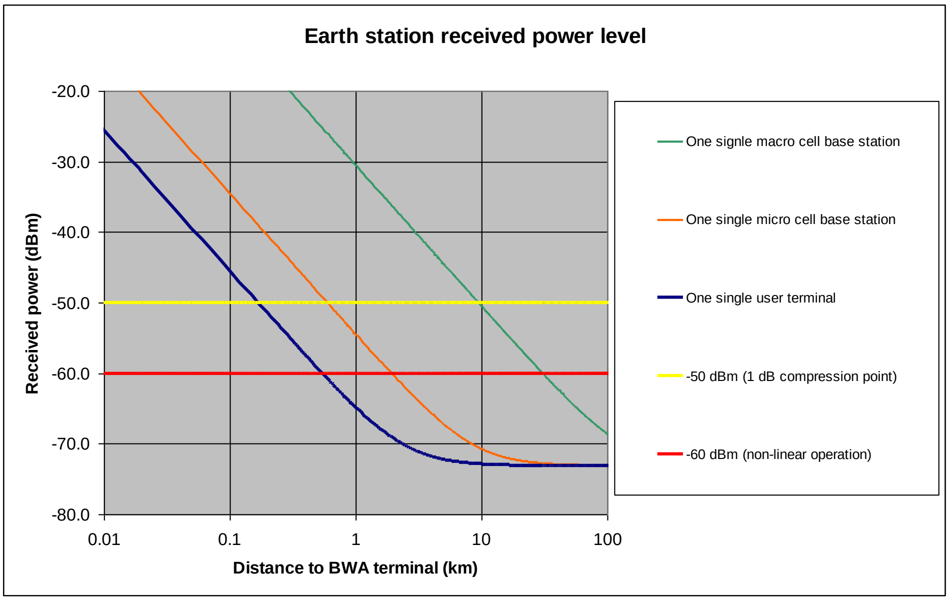
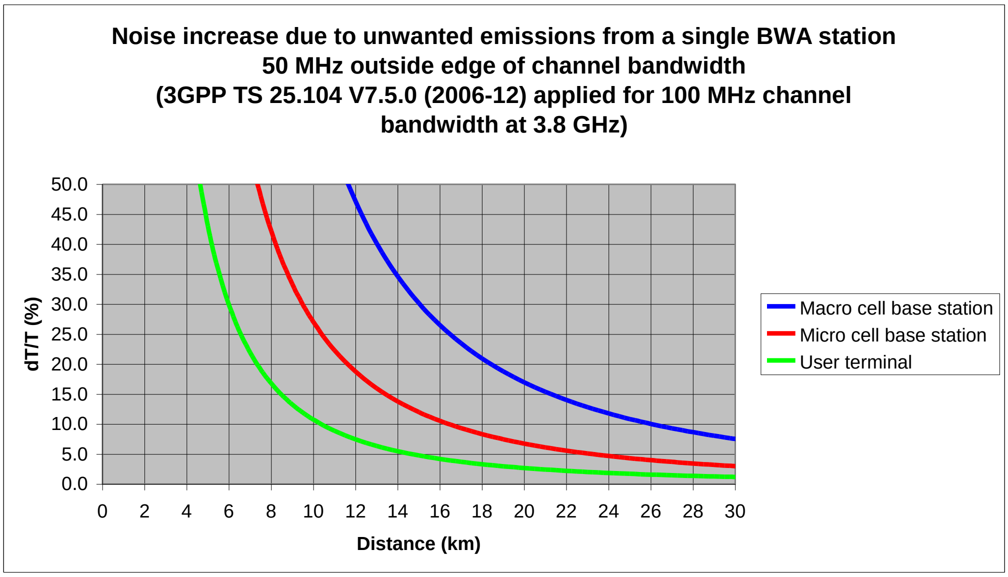
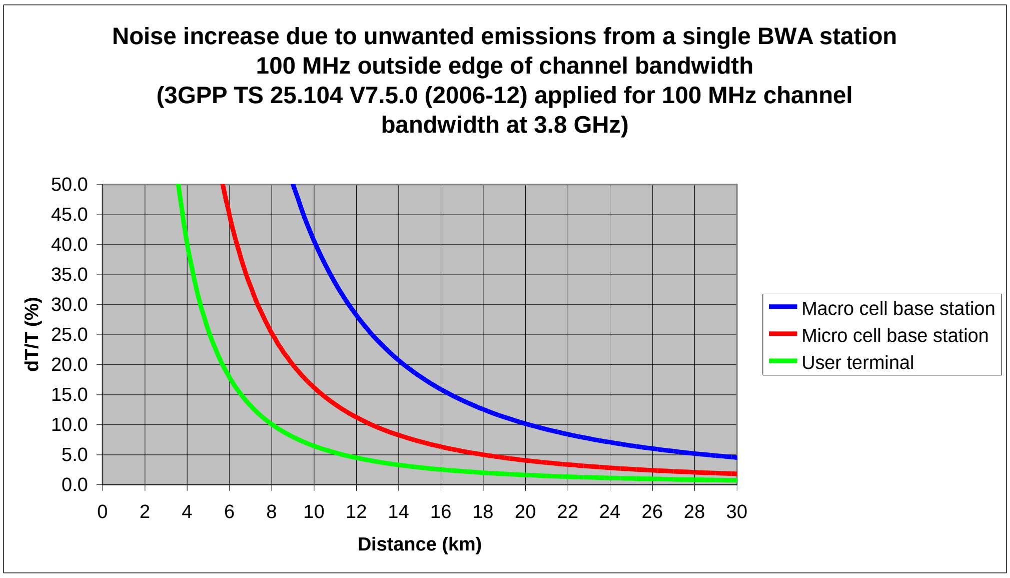
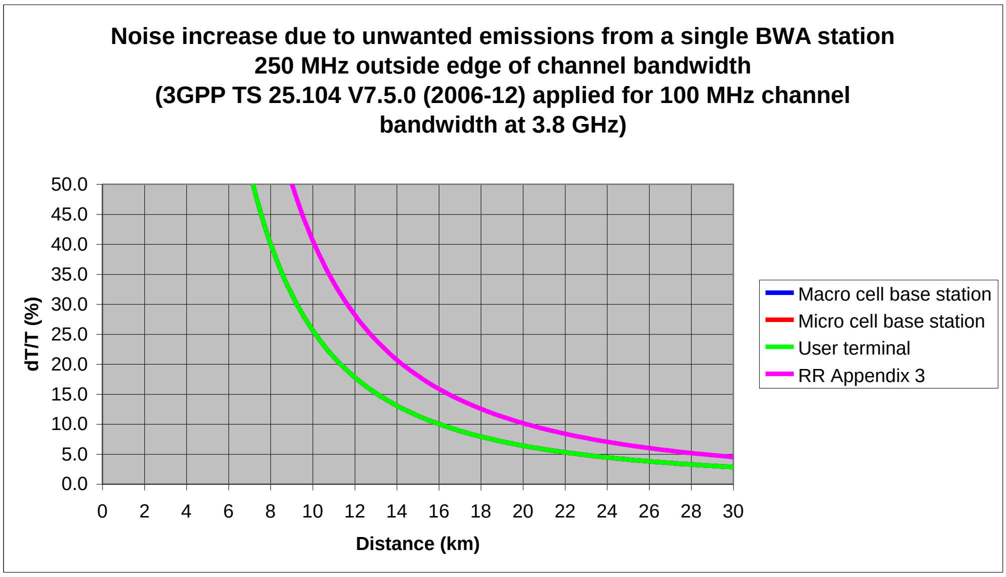


FIGURE E4

Unwanted emissions


Noise increase due to unwanted emissions from a single BWA station 50 MHz outside edge of channel bandwidth (3GPP TS 25.104 V7.5.0 (2006-12) applied for 100 MHz channel bandwidth at 3.8 GHz)


Noise increase due to unwanted emissions from a single BWA station 100 MHz outside edge of channel bandwidth (3GPP TS 25.104 V7.5.0 (2006-12) applied for 100 MHz channel bandwidth at 3.8 GHz)


Noise increase due to unwanted emissions from a single BWA station 250 MHz outside edge of channel bandwidth (3GPP TS 25.104 V7.5.0 (2006-12) applied for 100 MHz channel bandwidth at 3.8 GHz)

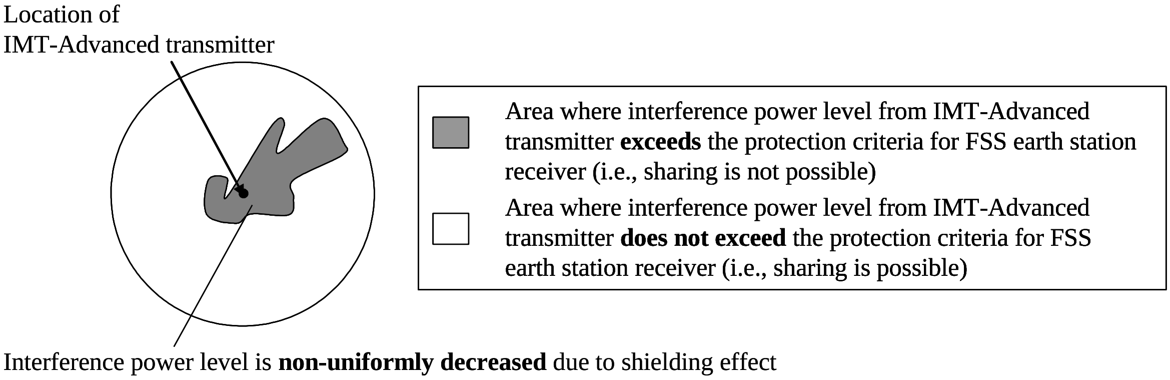
Annex F

Methodology “Interference Area Ratio” to be utilized with mitigation technique

Figure F1 shows the conceptual figure which indicates that the interference power level from an IMT-Advanced transmitter is non-uniformly decreased over the 360-degree area due to the shielding effect by terrain profile and clutter losses which may be observed in a real environment. Due to the feature of non-uniformly distributed interference power level over the 360-degree area, the required minimum separation distance can be reduced by using the additional mitigation technique based on directional-beam antenna.

FIGURE F1

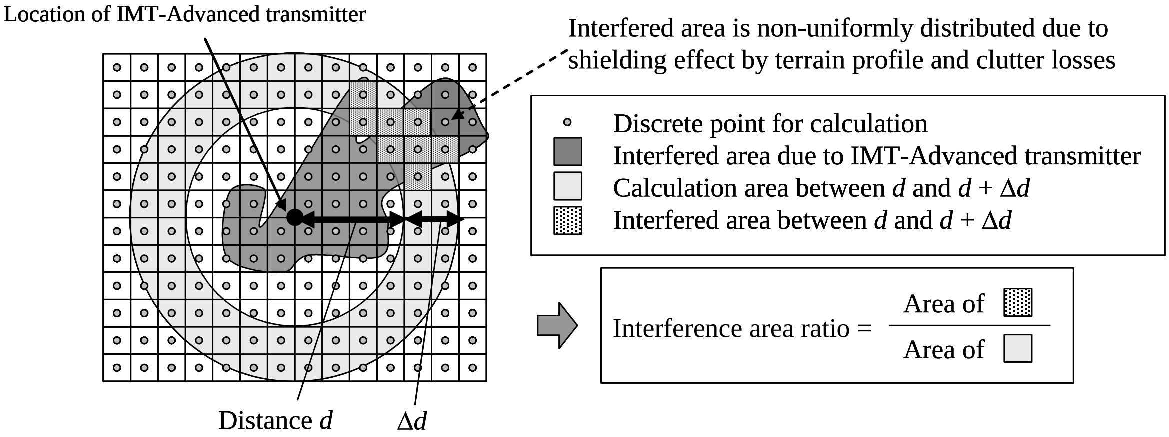
Shielding effect by terrain profile and clutter losses



In order to quantitatively evaluate this shileding effect, some studies use the methodology called “interference area ratio”. Figure F2 shows a conceptual figure to explain the definition of “interference area ratio”, where an IMT-Advanced transmitter is located at the center of the calculation area. When using the interference area ratio, at each grid of the calculation area, we calculate the interference power level caused by the IMT-Advanced transmitter and decide whether its interference power level exceeds the protection criteria of the FSS earth station based on Recommendation ITU-R SF.1006. If the interference power level exceeds the protection criteria, this grid is judged as the interfered area. Consequently, the interference area ratio as a function of distance, d, from the interferer, i.e., IMT-Advanced transmitter, is defined as the portion of the interfered area between the distance of d and $d + \Delta d$ from the interferer divided by the ring-shaped area between the distance of d and $d + \Delta d$ from the interferer. It should be noted that the analyses using the interference area ratio are also applicable to the aggregated interference case from multiple IMT-Advanced transmitters.

FIGURE F2

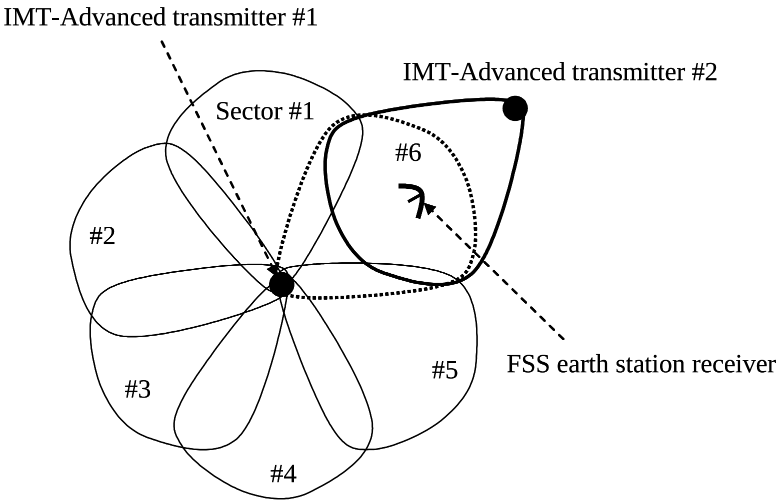
Definition of interference area ratio



When we derive the required separation distance for the interference area ratio of *x*%, we exclude the *x*% of area that has the larger separation distance over *d* + Δ*d*. Then, the required separation distance becomes *d* + Δ*d*. It should be noted that the additional mitigation technique based on directional-beam antenna, such as the sectorized-antenna and adaptive-beamforming antenna at the IMT-Advanced transmitters, is adopted in order to protect the FSS earth stations located in the *x*% of the area. Figure F3 shows an example employing sectorized-antenna as a mitigation technique. In this example, the transmission signal from the sector No. 6 of the IMT-Advanced transmitter No. 1 facing to the front direction of an FSS earth station antenna is stopped using a sectorized-antenna, while other base station No. 2, which is not facing to the front direction of an FSS earth station antenna, provides the services. It should be noted that the sectorized-antenna has been already implemented in the current cellular mobile communication technologies. Furthermore, the adaptive-beamforming has been also implemented in some cellular mobile communication systems. Therefore, these mitigation techniques can be applied to the IMT-Advanced systems.

FIGURE F3

Mitigation technique by utilizing sectorization



Annex G

Experimental evaluation on robustness against potential interference to TVRO terminal from IMT-Advanced transmitter in the 3 400-4 200 MHz band

1 Introduction

Among a variety of application deployed FSS earth stations in the 3 400-4 200 MHz band, TVRO is one of the applications in some parts of the world, although whether to protect these TVRO earth stations from the interference caused by other stations within the own territory is a matter of each administration. Thus, it would be useful to provide the information on the robustness of TVRO terminals against potential interference from other systems in a real environment.

The following sections provide a study on the robustness against interference to a TVRO terminal in the 3 400-4 200 MHz band, where the interference is caused by an IMT-Advanced transmitter, based on the field experiment performed in one country.

2 Specification of a TVRO terminal

A commercial TVRO terminal which is typically available is used in the experiment. Tables G1 to G3 summarize the overall specifications of the TVRO terminal, TVRO antenna and LNB, respectively. As shown in Table G3, two types of LNBs having the different specifications are employed in the experiment.

TABLE G1

Specification of TVRO terminal

System capabilities	Fully DVB compliant	
LNB tuner input	Connector	IEC 169-24 female
	Frequency range	950 MHz to 2 150 MHz
	Signal level	–65 dBm to –25 dBm
	LNB supply	14/ 18 V, Max 400 mA
	LNB switch control	22 KHz, 0/ 12 V
	DISEqC	Ver 1 2 and Ver 1.0 compatible
Demodulator	Frontend	QPSK
	Symbol rate	2 Msps to 45 Msps
	SCPC and MCPC capable	
	Spectral inversion	Auto conversion
Video decoder	MPEG 2	Main profile @ Main level
	Data rate	Up to 15M bits/s
	Resolution	720 x 576, 720 x 480
	Video format	NTSC, PAL
	Aspect ratio	4:3, 16:9
Teletext	DVB compliant	
MPEG audio	MPEG 1 layer 1 and 2	
	Type	Mono, Dual mono, Stereo, Joint stereo
	Sampling rate	32,441 and 48 kHz

TABLE G2

Specification of TVRO terminal antenna

Antenna size	2.4 m (96 in.)
Operating frequency	3 625 to 4 200 MHz
Midband gain	37.5 dBi (±0.2 dB)
3 dB beamwidth	2.1°
Antenna noise temperature	20° elevation 33K 30° elevation 31K
Feed interface	CPR 229F
Cross-polarization	>30 dB (on axis)
First sidelobe	–20 dB typical
Insertion loss	0.2 dB Max
VSWR	1.3:1 Max

TABLE G3

Specification of LNB

	LNB (Type A)	**LNB (Type B)**
Input frequency	3 400 to 4 200 MHz	3 400 to 4 200 MHz
Output frequency	950 to 1 750 MHz	950 to 1 750 MHz
Noise figure	17 K to 20 K @25°	30 K(Max)
Gain	65 dB typical	60 dB(Min) to 72 dB(Max) variation 6 dB(p-p)
Gain flatness	±1.5 dB Max	±1 dB/ 36 MHz
Image rejection	--	45 dB
RF band pass filter	Yes	
Output VSWR	2.0:1 Typical, 75 ohm	
1 dB compression point	+10 dBm Min	3 dBm
3rd order intercept point	+20 dBm Min	
L0 frequency	5 150 MHz	5 150 MHz
L0 frequency stability	±500 kHz Typical –40° C to +60° C	±500 kHz(25° C) ±1.5 MHz (–30° C to 60° C)
Phase noise	–73 dBc/Hz @ 1 kHz –95 dBc/Hz @ 10 kHz –110 dBc/Hz @ 100 kHz	–70 dBc/Hz @ 1 kHz –90 dBc/Hz @ 10 kHz –105 dBc/Hz @ 100 kHz
DC feed	+16 to +28 VDC	+12 to +20 VDC
Current	210 mA Max	150 mA Max
Operating temperature	–40° C to +60° C	–30° C to 60° C
Input interface	Flange, WR 229G	Flange, CPR-229G
Output interface	75 Ohm, Type “F” Female Gold plated	75 ohm Type “F” Female

3 Specification of an IMT-Advanced transmitter

Concrete specification of IMT-Advanced radio air-interference would be standardized after WRC-07 and is not available at the time of approval of this Report. Thus, in the experiment, the implemented transmitter having the specification shown in Table G4 is assumed to model a future envisaged IMT-Advanced transmitter.

TABLE G4

Specification of an IMT-Advanced transmitter used in experiment

Center frequency	3.9 GHz
Frequency bandwidth	100 MHz
Polarization	Vertical
Transmit power	40 dBm/100 MHz
Antenna gain	15 dBi
Antenna 3 dB width	60°
Antenna height	2.8 m
Modulation	OFDM
PAPR	12 dB

4 Evaluation methodologies

4.1 Scenarios

In the experimental evaluation, three TV channels having the different frequency ranges and coding rate of forward error correction (FEC) code are selected, which are summarized in Table G5. By employing these TV channels, the scenarios of co-channel and adjacent-channel interference on a TVRO terminal from an IMT-Advanced transmitter are investigated as shown in Fig. G1.

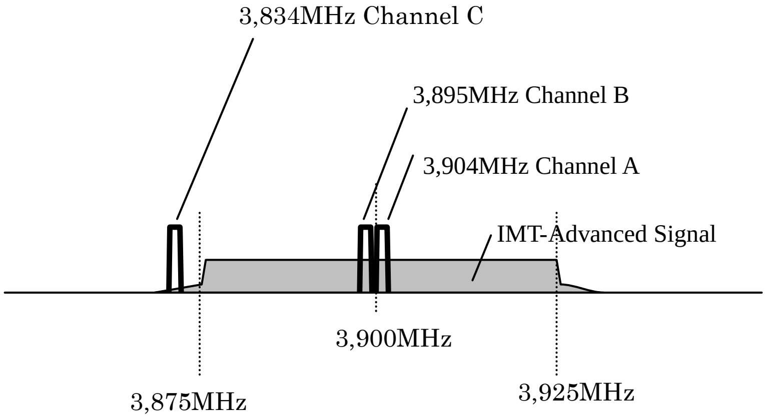
TABLE G5

Parameters of TV channels used in experiment

Channel name	Center frequency	Intermediate frequency	Polarization	Symbol rate	Coding rate	Channel bandwidth
TV channel A	3 904 MHz	1 246 MHz	Vertical	4.420	7/8	5.05 MHz
TV channel B	3 895 MHz	1 255 MHz	Vertical	6.813	3/4	9.08 MHz
TV channel C	3 834 MHz	1 316 MHz	Vertical	4.420	3/4	6 MHz

FIGURE G1

Frequency ranges of TV channels and interference signal from IMT-Advanced transmitter



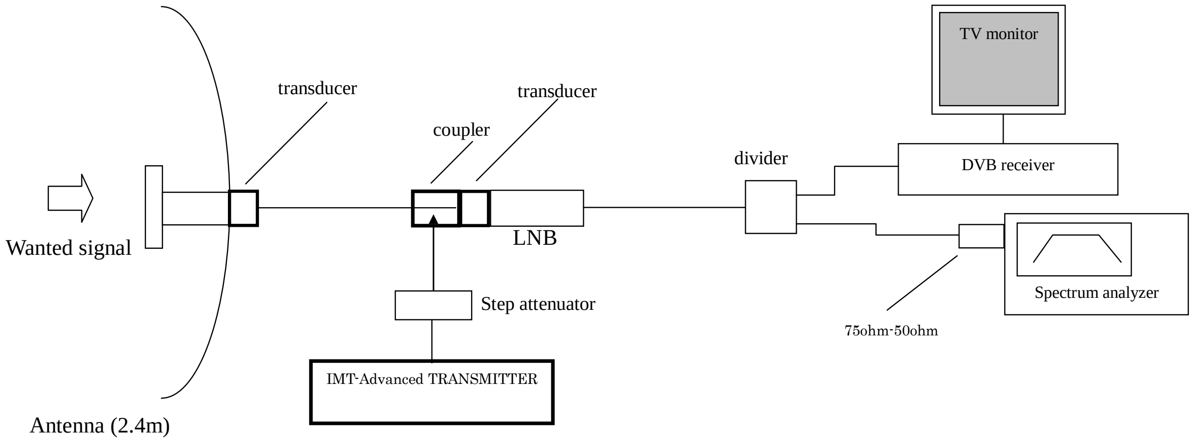
In the experiment, the following two test scenarios are set up for the evaluation.

Static test scenario

In this scenario, the TVRO terminal receives the radio signal of TV channels from the satellite through the TVRO antenna, while the interference signal from the IMT-Advanced transmitter is given to the LNB input via the cable connection as shown in Figure G2. In this scenario, the interference signal power level does not have temporal fluctuation, but is in static condition.

FIGURE G2

Configuration of static test scenario

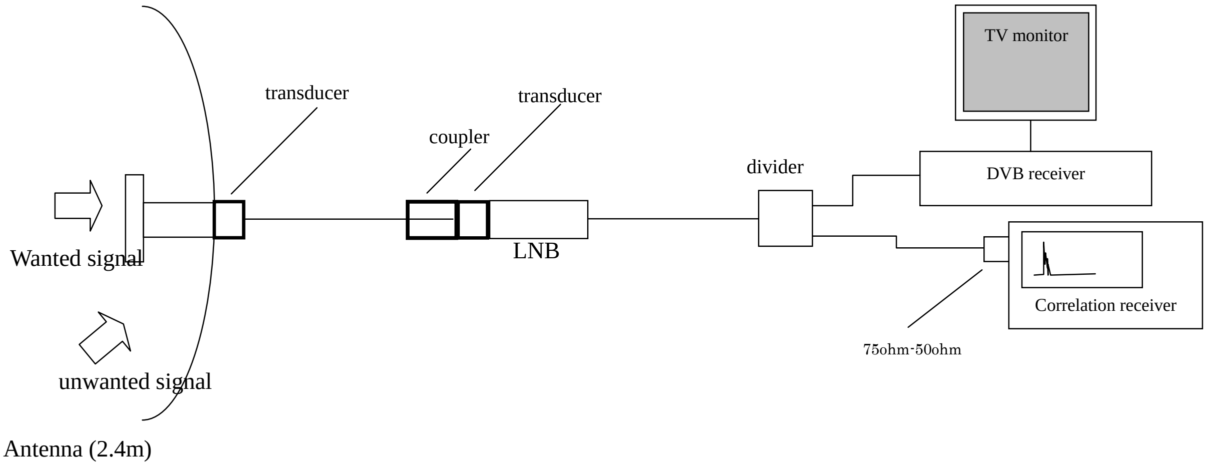


Dynamic test scenario

In this scenario, the TVRO terminal receives both the radio signal of TV channels from the satellite and the interference signal of the IMT-Advanced transmitter through the TVRO antenna as shown in Fig. G3. The power level of interfering signal is dynamically changed due to distance-dependent propagation loss, slow shadow-fading and fast fading phenomena caused in a real environment.

FIGURE G3

Configuration of dynamic test scenario



4.2 Evaluation criterion used in experiment

Although the employed TVRO terminal has a function to output the quality level in percentage, the technical details of this measure are not available. Meanwhile, subjective assessment methods are used to establish the performance of television systems using measurements that more directly anticipate the reactions of those who might view the systems tested. In Recommendation ITU-R BT.500-11 and ITU-T Recommendation P.800, there are similar subjective assessments so called Mean Opinion Score (MOS), which uses five-grade quality scale with Excellent (5), Good (4), Fair (3), Poor (2) and Bad (1). The numbers in the bracket represent the quality scale. This five-grade quality scale seems to be linear scale and it may be applicable for analogue and digital coding systems without bit-rate reduction. Therefore, in the experiment, the MOS quality grade having the quality grade of the received TV picture shown in Table G6 is employed.

TABLE G6

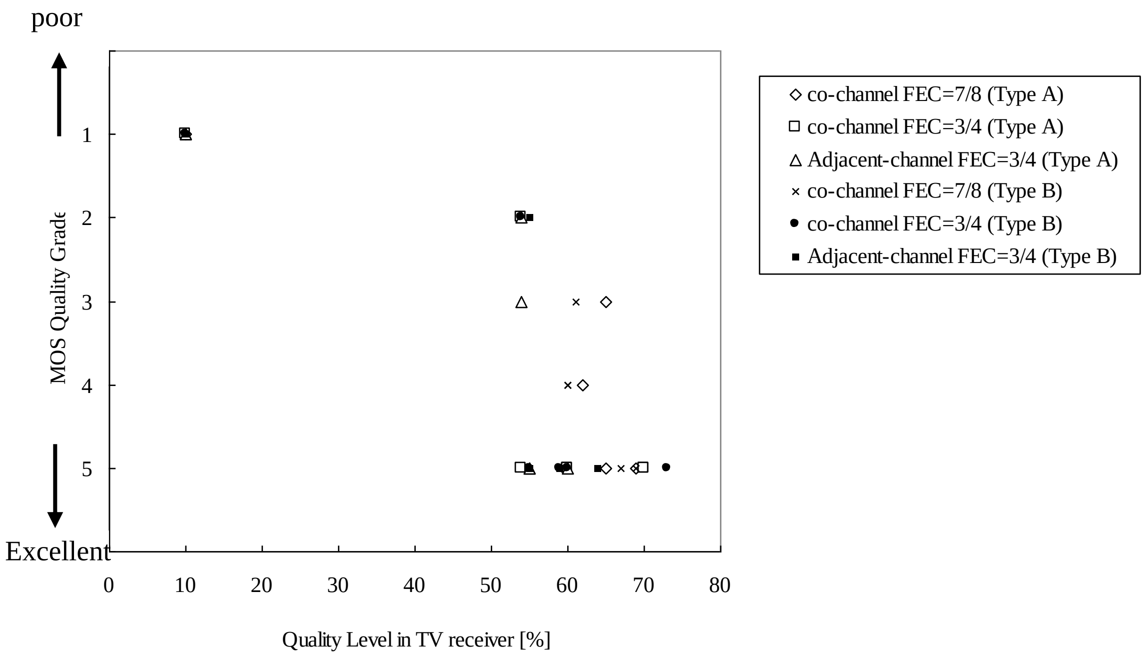
Definition of MOS quality grade in experiment

Quality grade of received TV picture	Conditions
5	No influence
4	Flickering or mosaic appeared once in a minute
3	Flickering or mosaic appeared once in twenty seconds
2	Flickering or mosaic appeared once in a second
1	No picture

Figure G4 shows the relationship between two measures, the quality level in percentage output from the TVRO terminal and the MOS quality grade, obtained by the experiment using the static test scenario. As shown in this figure, there is correlation between these two measures. Therefore, the following results are evaluated based on the MOS quality grade as an evaluation criterion.

FIGURE G4

Relationship between “quality level output from TVRO terminal” and “MOS quality grade”



5 Experimental results

5.1 Static test scenario

In this test scenario, the TVRO terminal with the antenna diameter of 2.4 m was placed at the location of E139.40.32/ N35.13.27. The experiment was conducted under the conditions as shown in Table G7.

TABLE G7

Test location of static test scenario

TVRO antenna location	Yokosuka, E139.40.32/ N35.13.27
Antenna height (a.m.s.l)	128.8 m
Weather	Shower

In the experiment, the measured LNB input channel power level, (*C*+*N*), was approximately –94.1 dBm/5 MHz using the LNB of Type A. In this case, the corresponding (*C*+*N*)/*N* value becomes approximately 17.5 dB assuming the noise temperature of 100 K.

Figures G5a) and b) show the quality of TV picture measured by the MOS quality grade as a function of the (*C*+*N*)/(*I*+*N*) for LNB Type A and Type B, respectively, where (*C*+*N*), *N*, and *I* represent the LNB input channel power level, thermal-noise power level, and interference power level from an IMT-Advanced transmitter, respectively. In this figure, the interference power level form an IMT-Advanced transmitter, *I*, is changed in the horizontal axis. As shown in the figure, the quality of TV picture is degraded in accordance with the increase in the interference power level. However, in order to maintain the same quality of TV picture, the FEC coding rate of 3/4 has more robustness against the interference power level by approximately 2 dB compared to that of 7/8.

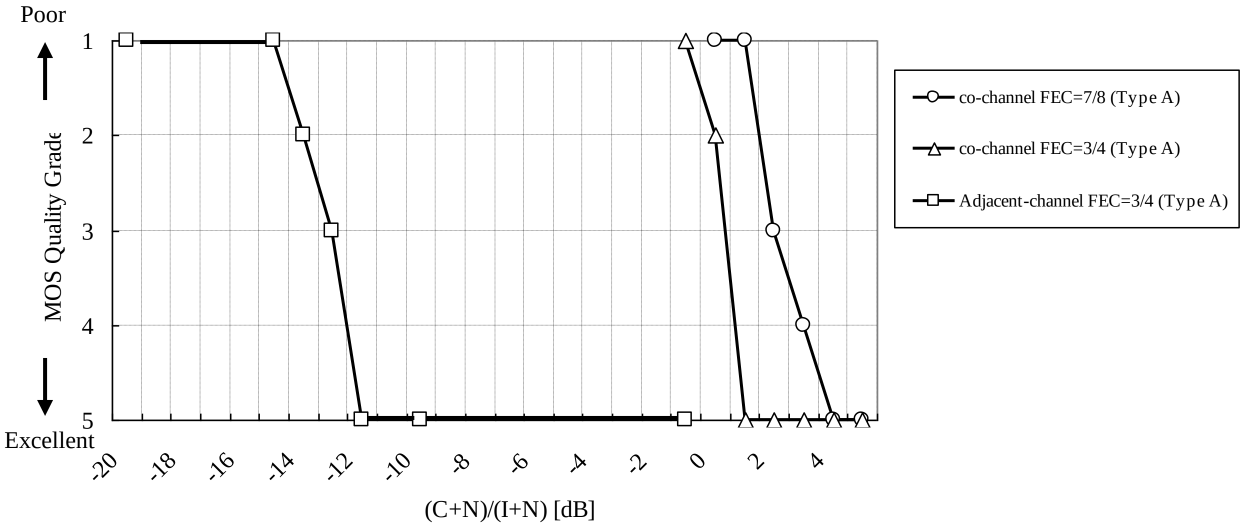
It should be noted that, according to the information on the TV channels provided by one satellite operator, among the fifty-seven TV channels, two, two, forty-seven, three, and five TV channels employ the FEC coding rate of 1/2, 2/3, 3/4, 5/6 and 7/8, respectively. Thus, in this case, approximately 80% of fifty-seven TV channels employ the FEC coding rate of 3/4.

Furthermore, when the co-channel and adjacent-channel interference scenarios are compared, the adjacent-channel interference scenario is more robust against the increase in the interference power level by approximately 14 dB, as shown in these figures.

FIGURE G5

Quality of TV picture measured by MOS quality grade as a function of (*C*+*N*)/(*I*+*N*)

a) LNB Type A



b) LNB Type B

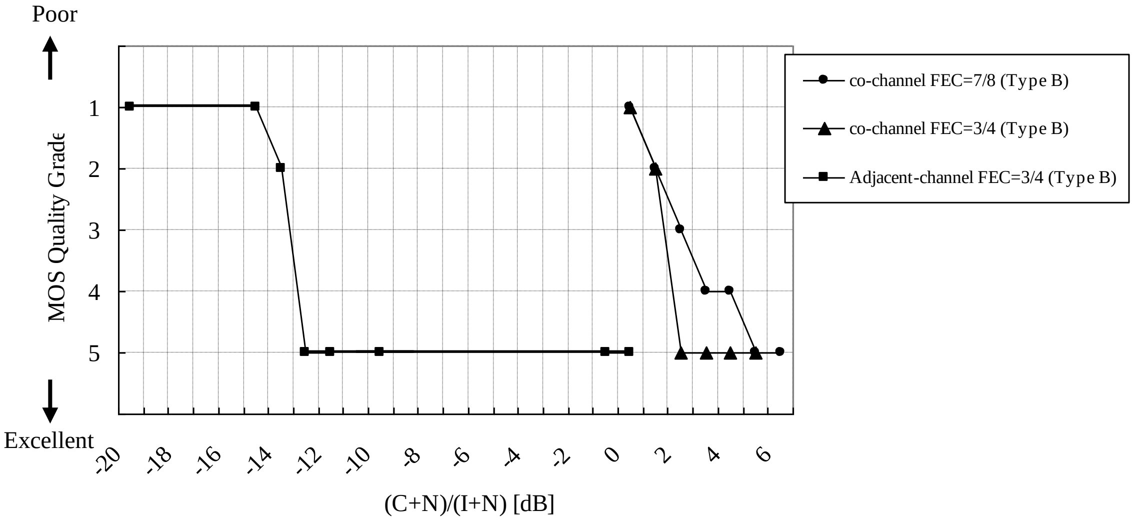


Table G8 summarizes the required (*C*+*N*)/(*I*+*N*) level in order to maintain the MOS quality grade of 5, i.e., no influence on TV picture. Furthermore, the corresponding *I*/*N* level is derived through the calculation. According to this table, in terms of *I*/*N* value, the margin of approximately 25 dB and 42 dB is observed for co-channel and adjacent-channel interference scenarios, respectively, compared to *I*/*N* = –12.2 dB corresponding to the aggregate interference from other systems having co-primary status for 100% of the time described in Recommendation ITU-R S.1432.

TABLE G8

Required (*C*+*N*)/(*I*+*N*) to maintain MOS quality grade of 5

Channel type, Coding rate	**Required (*C* + *N*)/(*I* + *N*)**		***I*/*N***	
	LNB Type A	**LNB Type B**	**LNB Type A**	**LNB Type B**
Co-channel, FEC = 7/8	4.5 dB	5.5 dB	13 dB	12 dB
Co-channel, FEC = 3/4	1.5 dB	2.5 dB	16 dB	15 dB
Adjacent-channel, FEC = 3/4	–11.5 dB	–12.5 dB	29 dB	30 dB

5.2 Dynamic test scenario

In this test scenario, the TVRO terminal with the antenna diameter of 2.4 m was placed at the rural location of E140.41.33.6/ N36.41.88.1 as shown in Table G9. The experiment was conducted under the weather condition of clear-sky.

TABLE G9

Test location of dynamic test scenario

TVRO antenna location	Ibaraki, E140.41.33.6/ N36.41.88.1
Topographical statistics	mean 83 m / standard deviation 109 m
Antenna height (a.m.s.l)	56 m
Antenna direction	33.7° (elev.) / 229.7°(hor)
Weather	Clear-sky

In the experiment, different 26 locations were selected in order to place the IMT-Advanced transmitter as an interferer, where each location of the IMT-Advanced transmitter is shown in Fig. G6. Furthermore, the location of the TVRO terminal is shown at the center of this figure, where the direction of the arrow indicates the antenna-direction of TVRO terminal to receive the signal from satellite. By changing the location of the IMT-Advanced transmitter, point-to-point interference measurement between the IMT-Advanced transmitter and TVRO terminal is conducted at each location. In the measurement, averaged interference power level, its standard deviation value and delay-spread are recorded in every one second during five minutes. The interference power level to be used for the calculation of I/N is derived by the averaged value over five minutes.

FIGURE G6

Location of TVRO terminal and IMT-Advanced transmitter in dynamic test scenario

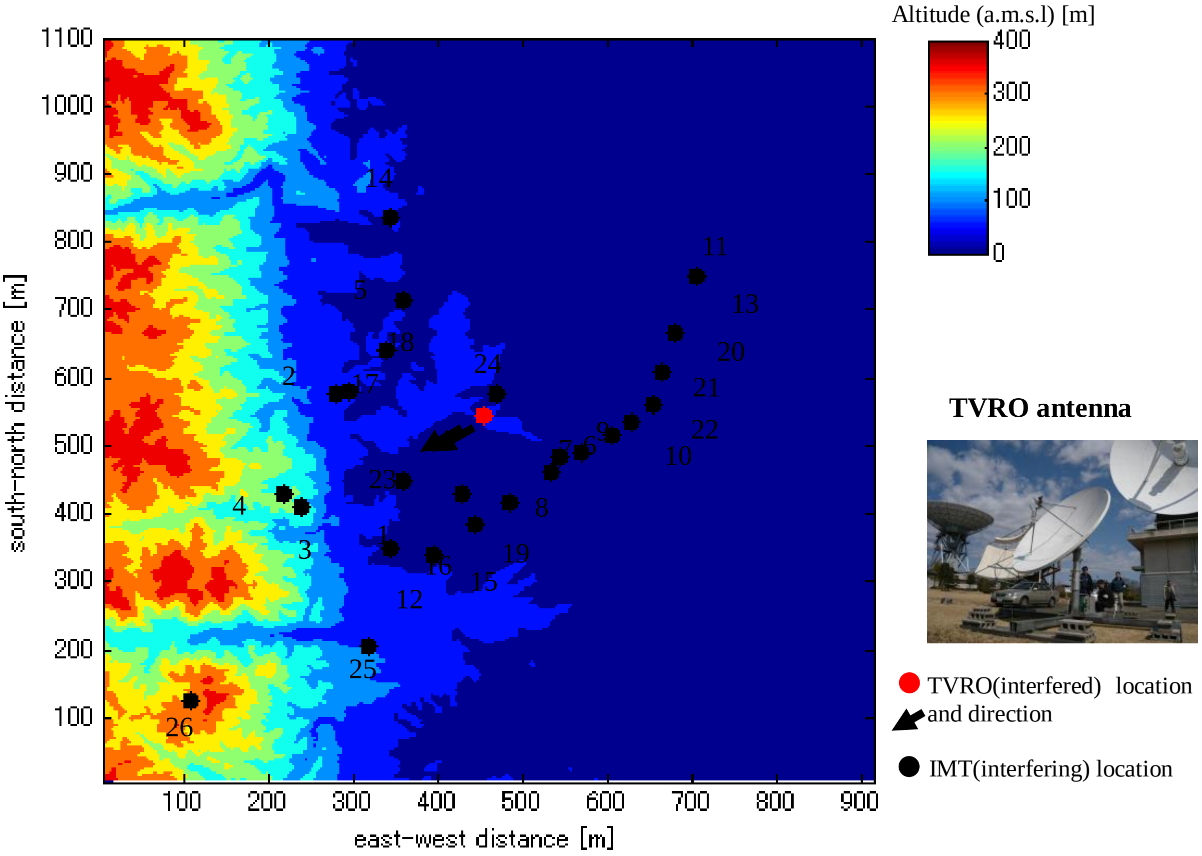


Table G10 summarizes the quality of TV picture measured by the MOS quality grade obtained by the measurement conducted at each location. As shown in the table, among 26 locations, the MOS quality grade of 5, i.e., no influence on the received TV quality, is observed at 25 and 24 locations in the case of co-channel interference scenarios with FEC coding rate of 3/4 and 7/8, respectively. Furthermore, in the case of adjacent-channel interference scenario, no influence on the received TV picture is observed at all the locations.

TABLE G10

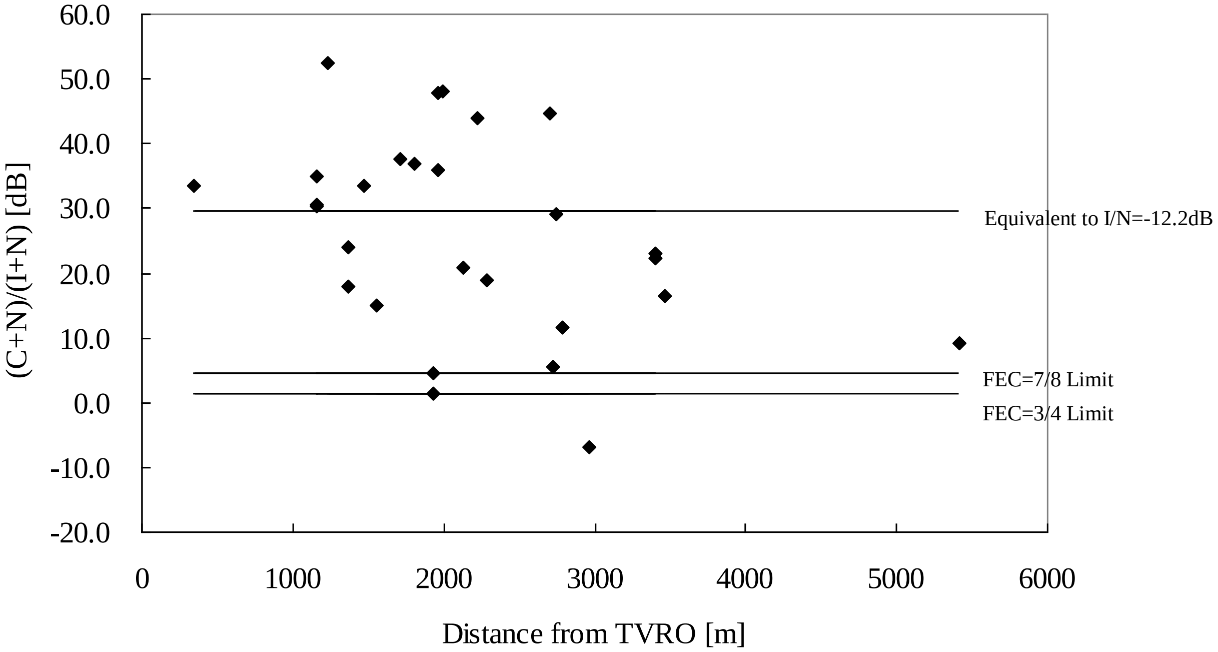
MOS quality grade at respective locations

Location of IMT-Advanced transmitter	**MOS quality grade**		
	Co-channel, FEC = 7/8	**Co-channel, FEC = 3/4**	**Adjacent-channel, FEC = 3/4**
1	5	5	5
2	5	5	5
3	5	5	5
4	5	5	5
5	1	5	5
6	5	5	5
7	5	5	5
8	5	5	5
9	5	5	5
10	5	5	5
11	5	5	5
12	5	5	5
13	5	5	5
14	1	1	5
15	5	5	5
16	5	5	5
17	5	5	5
18	5	5	5
19	5	5	5
20	5	5	5
21	5	5	5
22	5	5	5
23	5	5	5
24	5	5	5
25	5	5	5
26	5	5	5

Figure G8 summarizes the relationship of the $(C+N)/(I+N)$ value and distance between the TVRO terminal and IMT-Advanced transmitter. In the figure, the required $(C+N)/(I+N)$ levels to maintain the MOS quality grade of 5 that are obtained by the static test scenario are also depicted in the case of FEC coding rate of 3/4 and 7/8, respectively. Furthermore, the required $(C+N)/(I+N)$ level which corresponds to $I/N = -12.2$ dB is shown for reference.

FIGURE G8

Relationship of (*C+N*)/(*I+N*) value and distance between the TVRO terminal and IMT-Advanced transmitter

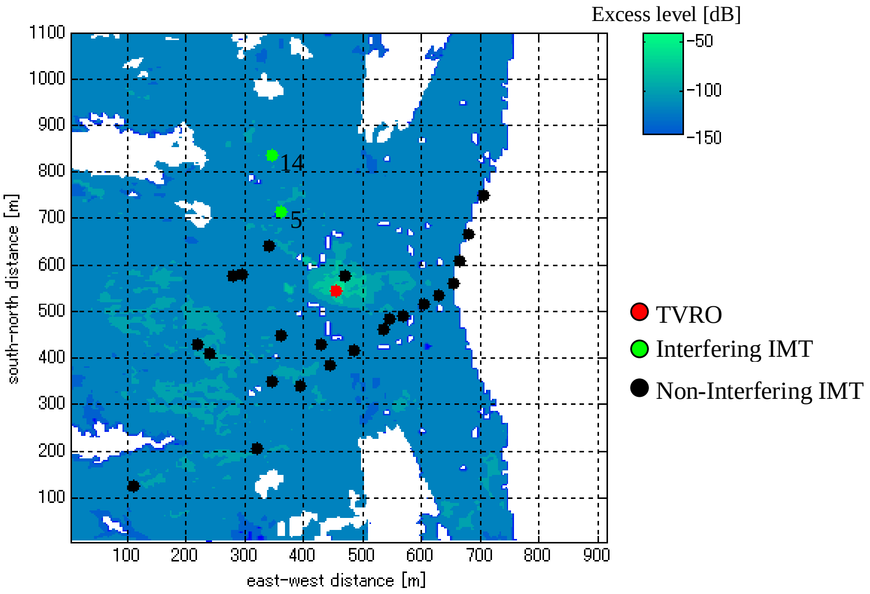


Finally, in Fig. G9, the experimental results and the results which are simulated by the required protection criteria and propagation model by Recommendation ITU-R P.452 are compared. In Fig. 9a) and b), the gradation color indicates the area where the received interference power level at TVRO terminal exceeds the required protection criteria, when assuming $I/N = –12.2$ dB (from ITU-R Recommendation for FSS systems carrying digital traffic) and +12 dB (from the experiment), respectively. In the figure, the white color indicates the area where the received interference power level at TVRO terminal does not exceed the protection criteria. The interference power level is calculated by assuming the propagation model shown in Recommendation ITU-R P.452 using the terrain data model and the additional clutter losses due to artificial objects. Furthermore, the location of the IMT-Advanced transmitter in the experiment is also shown in these figures, where the quality of the TV picture is damaged by the IMT-Advanced transmitter placed at the location 5 and 14 in the case of co-channel interference scenario with FEC coding rate of 7/8. As shown in Fig. 9a) assuming the criterion of $I/N = –12.2$ dB, most of locations of IMT-Advanced transmitter are expected to impact the quality of the TV picture in this area, however, this is not the case in the experiment in a real environment. Meanwhile, as shown in Fig. 9b) assuming the criterion of $I/N = +12$ dB, the location of the IMT-Advanced transmitter which is expected to impact the quality of TV picture is more accurately approximated compared with the area shown in Fig. 9a).

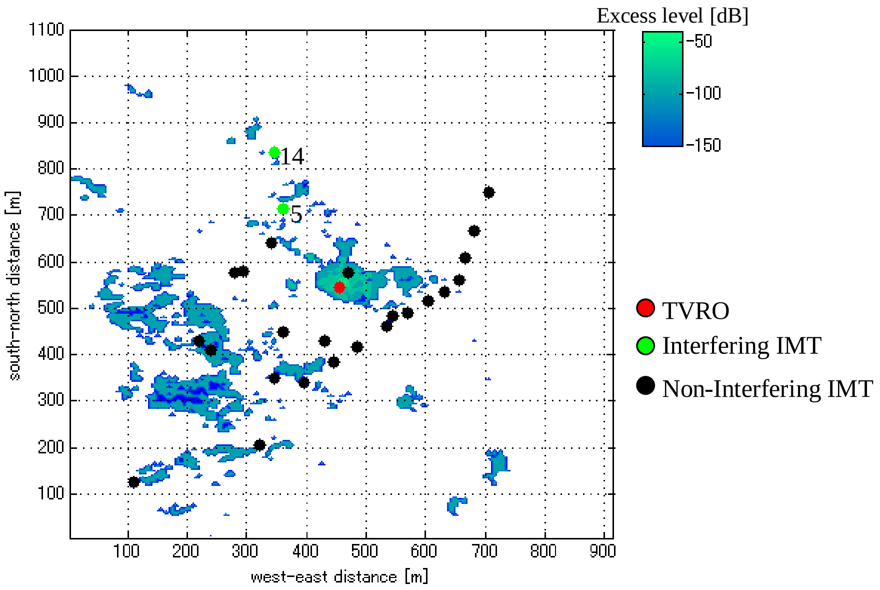
FIGURE 9

Comparison between experimental results and simulation results based on Recommendation ITU-R P.452 propagation model

a) *I*/*N* = –12.2 dB



b) *I*/*N* = +12 dB



6 Summary of study

The study on the robustness against interference to a TVRO terminal in the 3 400-4 200 MHz band, where the interference is caused by an IMT-Advanced transmitter, based on the field experiment performed in one country is summarized as follows:

a) When the distance between an IMT-Advanced transmitter and a TVRO terminal is ranged from 345 to 5,420 m comprising different 26 locations, no influence on the quality of the received TV picture is observed at 25 and 26 locations in the case of the co-channel and adjacent interference scenarios, respectively, with FEC coding rate of 3/4.

b) TV channel employing FEC coding rate of 3/4 has more robustness against the increase in the co-channel interference power level by approximately 2 dB compared to that of 7/8 in order to maintain the same quality of the received TV picture.

c) The influence on the quality of the received TV picture for adjacent-channel interference scenario is smaller compared to that for co-channel scenario. In order to maintain the same quality of the received TV picture, approximately 14 dB more power of an IMT-Advanced transmitter is permitted in the adjacent-channel interference scenario compared to the co-channel interference scenario.

Annex H

Adjacent band operations: Impact of the spurious emission of a Single IMT-Advanced transmitter into FSS receivers

In accordance with RR Appendix 3, it is assumed that the IMT-Advanced transmitters would be specified such that its spurious emission at frequency separation of 2.5*x* (Necessary Bandwidth) from the center frequency of the IMT-Advanced carrier, measured in bandwidth of 1 MHz, would be attenuated by 43 + 10 log(P) dB or 70 dBc, whichever is less stringent, below the transmitter power level P, where P is in watts.

The analyses presented here are based on the propagation models described in ITU-R P.452-12. Due to the generic nature of the analysis, for the long-term protection cases, the propagation is calculated over a smooth earth surface, utilizing the propagation model described in § 4.3 of ITU-R P.452-12. The models in ITU-R P.452-12 can include the effects of building losses and clutter where the topography of surrounding obstacles etc. is known. However, due to lack of information for these parameters, the building losses and clutter effects has been assumed to represent suburban environment in these analyses.

Furthermore, Recommendation ITU-R S.1432 contains the apportionment of the allowable error performance degradation to the FSS systems due to interference. This Recommendation states that for all sources of long-term interference that is neither from FSS systems, nor from systems having co-primary status, the allotted portion of the aggregate interference budget is 1%. This has been expressed in other forums as a required protection criterion of I/N = -20 dB (i.e. $\Delta T/T \leq 1\%$). The unwanted emissions interference contribution from an adjacent band would be considered as one of these “other sources of interference”. The analysis is based on:

Case A:

– The IMT-Advanced transmitter spurious emission limit of -43 dBW/MHz per RR Appendix **3**.

– For IMT-Advanced carrier bandwidths of 20 and 100 MHz, the above spurious emission limit must be met at frequency separation of 40 and 200 MHz away from the edge of the IMT-Advanced allocated band, respectively. In other words, these values represent the necessary frequency separation between these services for the computed separation distances.

– The FSS receiver antenna receives IMT-Advanced transmitter spurious emission at its 10º off-axis gain.

– The analysis is based on the impact of a single IMT-Advanced transmitter.

Figures H1 and H2 depict the required minimum separation distance for a Single IMT-Advanced transmitter from FSS receivers operating in an adjacent band to the IMT-Advanced system. The minimum separation distance resulting in $\Delta T/T$ increase of ≤ 1%, are 18 km and 300 m for IMT-Advanced Macro base station and mobile station, respectively. It should be noted that if the entire allowable 1% noise increase is used up by the spurious emission interference from a single IMT-Advanced transmitter, there would be no further allowances for any other sources of interference (in practice, there are many other sources of interference that their operation would compound and contribute to this 1% noise increase). Depending on the number of IMT-Advanced carriers and simultaneous IMT-Advanced transmissions, the required minimum separation distance due to aggregate impact of the spurious emission interference would be even larger. The ”▼“ markers in the figures point to the required minimum separation distances in relation to the $\Delta T/T$ increases of 1% and 0.5%.

FIGURE H1

Case A: Required minimum separation distance versus FSS earth station receiver $\Delta T/T$ due to spurious emission interference from a single IMT-Advanced macro base station transmitter (assuming LoS with diffraction path loss model)

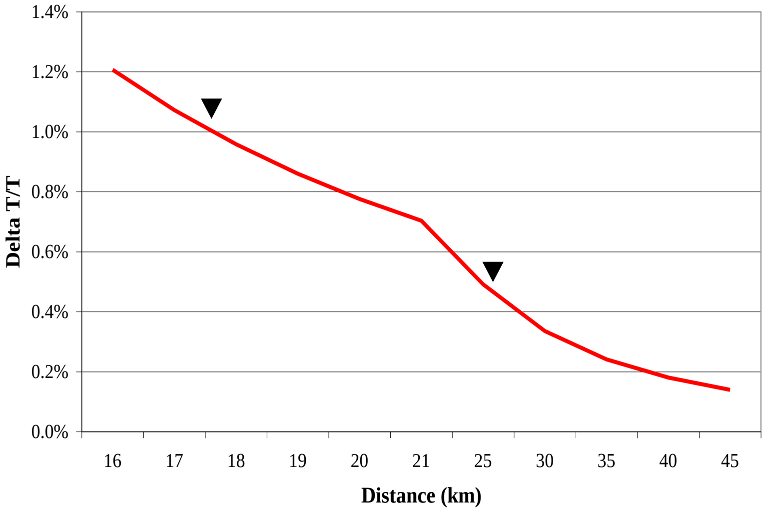
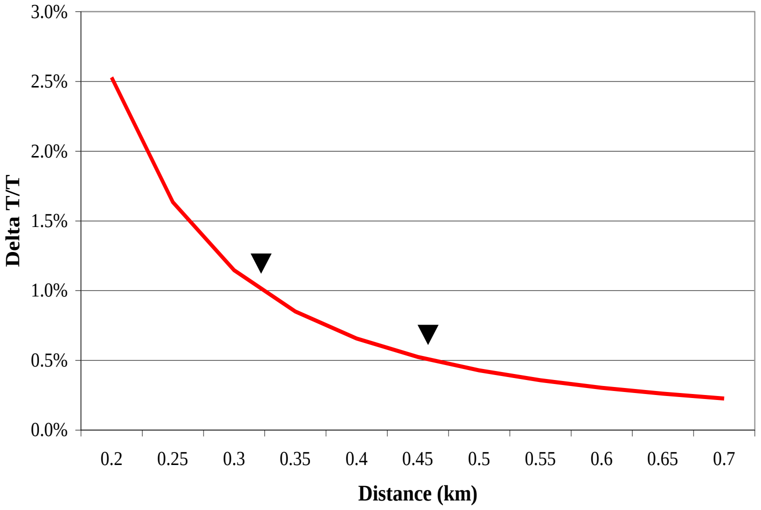


FIGURE H2

Case A: Required minimum separation distance versus FSS earth station receiver Δ*T*/*T* due to spurious emission interference from a single IMT-Advanced mobile station transmitter (assuming LoS with diffraction path loss model)



Case B:

- The IMT-Advanced transmitter spurious emission limit of -43 dBW/MHz per RR Appendix **3**.
- Assumed 10 dB additional reduction of IMT-Advanced transmitted spurious emission due to implementation of special band-edge filters, additional blocking losses, other mitigation techniques or a combination of them.
- For IMT-Advanced carrier bandwidths of 20 and 100 MHz, the above spurious emission limit must be met at frequency separation of 40 and 200 MHz away from the edge of the IMT-Advanced allocated band, respectively. In other words, these values represent the necessary frequency separation between these services for the computed separation distances.
- The FSS receiver antenna receives IMT-Advanced transmitter spurious emission at its 10° off-axis gain.
- The analysis is based on the impact of a single IMT-Advanced transmitter.

Figures H3 and H4 depict the required minimum separation distance for a single IMT-Advanced transmitter from FSS receivers operating in an adjacent band to the IMT-Advanced system. The minimum separation distance resulting in $\Delta T/T$ increase of $\leq 1.0\%$ assuming an additional 10 dB reduction of IMT-Advanced transmitted spurious emission, are 5 km and 100 m for IMT-Advanced Macro base station and mobile station, respectively. Depending on the number of IMT-Advanced carriers and simultaneous IMT-Advanced transmissions, the required minimum separation distance due to aggregate impact of the spurious emission interference would be even larger.

FIGURE H3

Case B: Required minimum separation distance versus FSS earth station receiver Δ*T*/*T* due to spurious emission interference from a single IMT-Advanced macro base station transmitter, where spurious level is reduced by an additional 10 dB (assuming LoS with diffraction path loss model)

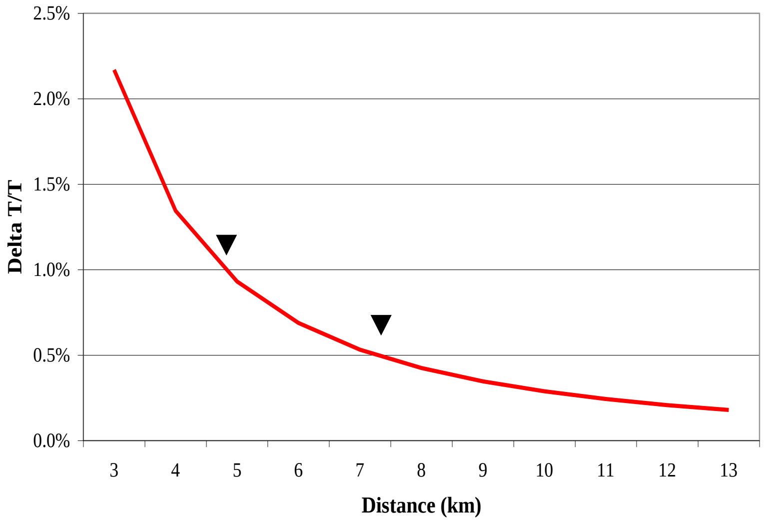
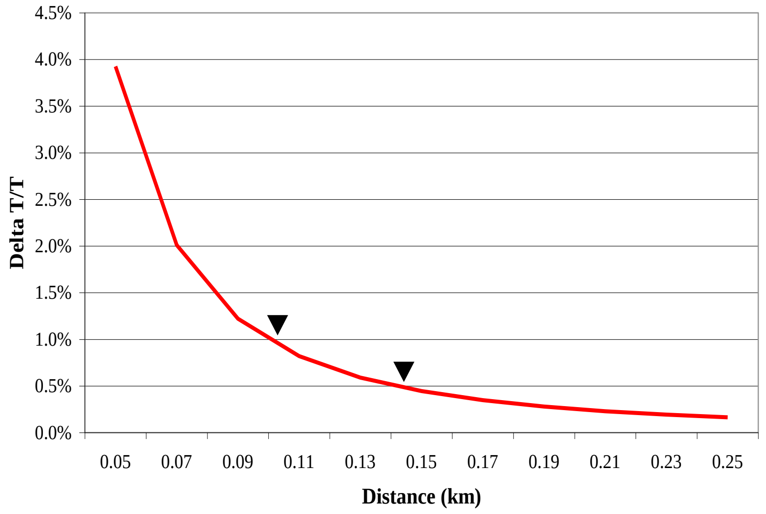


FIGURE H4

Case B: Required minimum separation distance versus FSS earth station receiver Δ*T*/*T* due to spurious emission interference from a single IMT-Advanced mobile station transmitter, where spurious level is reduced by an additional 10 dB (assuming LoS with diffraction path loss model)



Case C:

- The IMT-Advanced transmitter spurious emission limit of -43 dBW/MHz per RR Appendix **3**.
- Assumed 40 dB and 50 dB additional reduction of IMT-Advanced transmitted spurious emission due to implementation of special band-edge filters, additional blocking losses, other mitigation techniques or a combination of them.
- For IMT-Advanced carrier bandwidths of 20 and 100 MHz, the above spurious emission limit must be met at frequency separation of 40 and 200 MHz away from the edge of the IMT-Advanced allocated band, respectively. In other words, these values represent the necessary frequency separation between these services for the computed separation distances.
- The FSS receiver antenna receives IMT-Advanced transmitter spurious emission at its 10º off-axis gain.
- The analysis is based on the impact of a single IMT-Advanced transmitter.

Figures H5 and H6 depict the required minimum separation distance for a single IMT-Advanced transmitter from FSS receivers operating in an adjacent band to the IMT-Advanced system assuming the IMT-Advanced transmitter spurious emission level is reduced by an additional amount of 40 dB and 50 dB. The minimum separation distance resulting in $\Delta T/T$ increase of $\leq 1.0\%$ would be in the range of 115 m to 35 m for IMT-Advanced macro base station. It should be noted that depending on the number of IMT-Advanced carriers and simultaneous IMT-Advanced transmissions, the required minimum separation distance due to aggregate impact of the spurious emission interference would increase accordingly.

FIGURE H5

Case C: Required minimum separation distance versus FSS earth station receiver $\Delta T/T$ due to spurious emission interference from a single IMT-Advanced macro base station transmitter, where spurious level is reduced by an additional 40 dB (assuming LoS with diffraction path loss model)

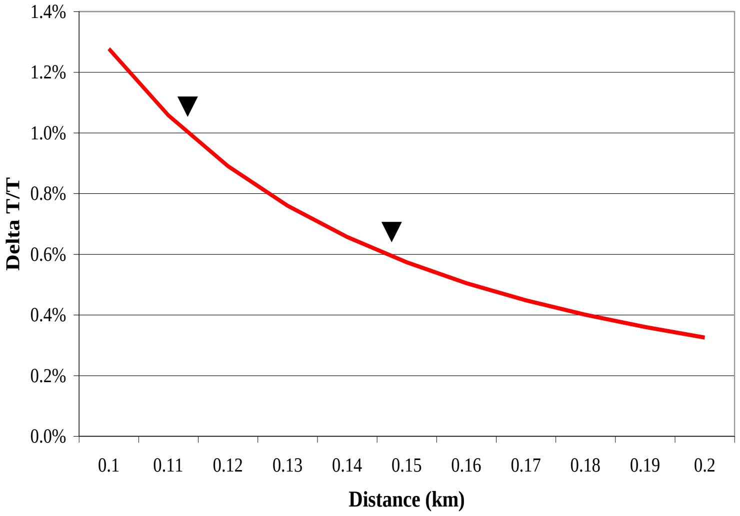


FIGURE H6

Case C: Required minimum separation distance versus FSS earth station receiver Δ*T*/*T* due to spurious emission interference from a single IMT-Advanced macro base station transmitter, where spurious level is reduced by an additional 50 dB (assuming LoS with diffraction path loss model)

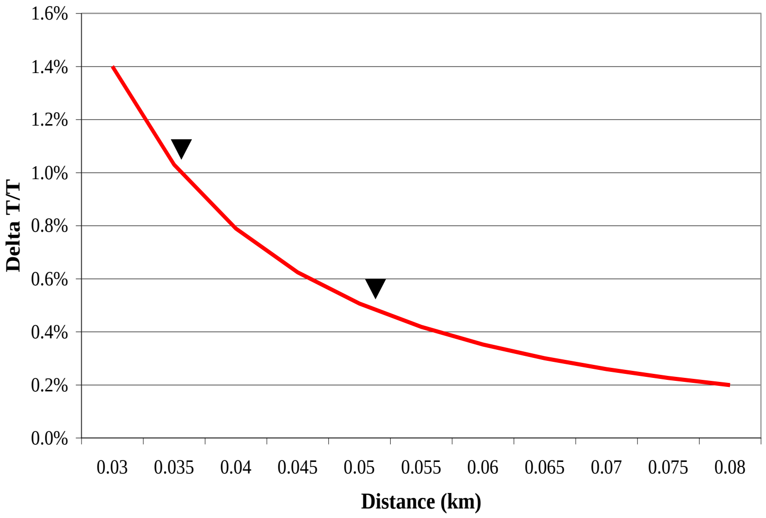


Table H1 depicts a summary of the derived required minimum separation distances to protect FSS earth stations receiver assuming Single-entry interference from IMT-Advanced transmitters operating in the adjacent band. The assumed values of 1.0%, 0.5% noise increase allotment and the 10 dB, 40 dB and 50 dB additional spurious emission levels reduction values are arbitrarily chosen and are used for illustration purposes.

TABLE H1

The minimum required separation distances to protect FSS receivers from single-entry interference of IMT-Advanced transmitter spurious emission operating in the adjacent band

a)

Percentage increase of FSS system noise	**1.0%**	**0.5%**		**1.0%**	**0.5%**
The assumed additional reduction of IMT-Advanced transmitter spurious emission level (dB)	**0**	**0**		**10**	**10**
IMT-Advanced macro base station	18 km	25 km		5 km	7.5 km
IMT-Advanced mobile station	300 m	450 m		100 m	140 m

b)

Percentage increase of FSS system noise	**1.0%**	**0.5%**		**1.0%**	**0.5%**
The assumed additional reduction of IMT-Advanced transmitter spurious emission level (dB)	**40**	**40**		**50**	**50**
IMT-Advanced macro base station	115 m	150 m		35 m	50 m

The results of this study show that operation of IMT-Advanced systems and the FSS in adjacent bands in the 4 GHz frequency range is very difficult and may not be feasible in the same geographical area if the IMT-Advanced transmitter spurious emission is defined in accordance with the limits specified in RR Appendix **3**. As depicted in Table H1a), large separation distances would be required to satisfy the long-term protection criterion of an FSS receiver from the spurious emission of a single IMT-Advanced transmission in the adjacent band at a given frequency separation. For example, the required minimum separation distance from FSS earth stations would be 18 km for the case of transmission from only one IMT-Advanced base station transmitter, assuming that the entire allowable FSS system noise increase due to other services is allocated to IMT-Advanced equipment spurious emission. Even if the IMT-Advanced spurious emission was reduced by an additional 10 dB from the specified limits of RR Appendix **3**, the required minimum separation distance from FSS earth stations would be 5 km for the case of transmission from only one IMT-Advanced base station transmitter, assuming that the entire allowable FSS system noise increase due to other services is allocated to IMT-Advanced systems. Depending on the number of IMT-Advanced carriers and simultaneous IMT-Advanced transmissions, aggregate interference from IMT-Advanced transmitters are expected to result in even larger required minimum separation distances from FSS earth stations.

However, as depicted in Table H1b), if the IMT-Advanced transmitter spurious emission level is reduced by an additional 40 to 50 dB from the specified limits in RR Appendix **3**, then the required separation distances due to interference from a single IMT-Advanced transmitter become very small and it would facilitate the operation of IMT-Advanced and FSS systems in adjacent bands in the 4 GHz frequency range. The exact value of the required additional reduction of the spurious emission level would depend on the expected aggregate interference from IMT-Advanced devices. Additional information on the IMT-Advanced network design (e.g., cell size, mobile unit distribution, access schemes, protocols, etc.) is required to be able to assess the expected aggregate interference from IMT-Advanced networks into FSS receivers operating in adjacent frequency bands.

International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Report ITU-R S.2199
(11/2010)

Studies on compatibility of broadband wireless access systems and fixed-satellite service networks in the 3 400-4 200 MHz band

S Series
Fixed satellite service

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2011

REPORT ITU-R S.2199

Studies on compatibility of broadband wireless access systems and fixed-satellite service networks in the 3 400-4 200 MHz band[1]

(2010)

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[1] The characteristics of BWA can be fixed, mobile or nomadic.

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Executive summary

The 3 400-4 200 MHz band or parts of the band, where implemented, can be heavily used by the fixed-satellite service (FSS) for space-to-Earth transmissions. In some geographical regions, many administrations are introducing broadband wireless access (BWA) systems in all or portions of this frequency band. As BWA is being introduced, harmful interference and loss of service for FSS receivers has been experienced. For these reasons, this Report examines the possibility of compatibility between BWA and FSS networks in the range 3 400-4 200 MHz for both co-channel and adjacent channel operations.

Appendix 7 of the Radio Regulations (RR) defines the methodology for calculating coordination contours around FSS receiving earth stations inside which coordination is required for terrestrial services. Such contours typically extend 400-1 000 km from the earth station. Implementation of BWA networks in a country will require international coordination with any country that has filed FSS earth stations whose coordination contour overlaps the service area of the BWA network.

Different types of FSS receive earth stations need to be considered in the compatibility studies. This includes earth stations deployed ubiquitously, earth stations without individual licensing or registration, individually-licensed[2] earth stations, telemetry earth stations, and feeder link earth stations for mobile-satellite systems.

Three possible types of interference have been identified and considered in this Report, namely:

1. co-frequency emissions from BWA causing in-band interference to FSS systems,
2. unwanted emissions from the BWA transmitters,
3. signals from nearby BWA transmitters causing overload to FSS earth station receivers operating in adjacent bands.

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[2] The terms “licensed” and “registered” are used throughout this Report to refer to stations for which location coordinates are known so their protection may be possible.

A set of parameters have been established that served as the basis for the compatibility studies. These are parameters concerning BWA base station and terminal station parameters, BWA and FSS antenna patterns, and FSS earth station parameters. Further a common set of propagation parameters to be used in the propagation model of Recommendation ITU-R P.452-13 have been set.

A summary of the compatibility studies that were done based on the above parameters are presented in this Report.

The results of these studies indicate that in order to provide protection to FSS earth station receivers, some separation distance between the stations of the BWA network and the FSS earth station receivers is required. The magnitude of the separation distance depends on the parameters of the networks, the protection criteria of concerned satellite networks and the deployment of the two services and whether the two services operate in the same or in adjacent frequency bands. With the assumptions used in the studies, it was observed that when no particular shielding with respect to the interfering signal could be guaranteed, and that when no other mitigation technique is applied by the BWA network, the required separation distances would be ranging from several tens to in excess of 100 km for the co-channel interference case, and in the order of a few kilometres for the adjacent channel case. However, for co-channel compatibility, mitigation techniques for BWA have not been studied in this Report.

Overall, from the studies reported in this text, it can be concluded that co-frequency operation of BWA systems and FSS receive earth stations in the same geographic area is not feasible. The implications are that BWA deployment would need to respect the above-mentioned separation distances to protect existing FSS earth stations, which may adversely affect the future deployment of BWA systems. In addition , when a BWA system is deployed, this creates an exclusion zone within which future deployments of FSS earth stations would not be possible. This limitation would adversely affect the future development in these zones of the infrastructure telecommunications/ICT of those countries which rely on the FSS in this band as the main backbone for this infrastructure .

Operation of BWA in a channel immediately adjacent to the band used by an FSS earth station may cause interference to receive earth stations through two different mechanisms:

i) Low Noise Block converter (LNB) saturation;

ii) unwanted emissions from BWA transmitters that fall within the band in which the FSS earth station operates.

In certain cases, particularly if the separation distances mentioned above are not met, the interference from BWA may block the reception of the earth station in the band in which it operates. Mitigation techniques may be employed to reduce the likelihood of LNB saturation, e.g. installation of a pass band filter at the front end of the FSS earth station and/or reduction of the BWA power. It has been verified that when a BWA system operates in a band immediately next to the band in which the FSS earth station operates, the effectiveness of the pass band filter is very limited.

Accordingly, higher power BWA signals should not be operated in channels adjacent to the edge of the operating FSS band, leaving the spectrum closer to that FSS band for use by BWA signals with lower power. The potential for interference caused by unwanted emissions generated by BWA transmitters could be reduced by limiting the level of such emissions.

To mitigate the LNB saturation interference, FSS earth stations could be also retrofitted with band pass filters at the LNB. This would improve the situation with regard to reducing the earth station’s susceptibility to interference. However, due to the large number of earth stations already deployed throughout the 3 400-4 200 MHz band, this would have cost and implementation implications which would also be significant. Introduction of band pass filters would introduce additional losses in the FSS earth station receive path. In addition, introduction of filters does not improve the sharing situation in the co-channel case. This would adversely affect the future development of these FSS systems in this band. This is in particular relevant for the developing countries for which the FSS forms the fundamental parts of their infrastructure for telecommunications/ICT networks.

When the FSS earth stations are individually licensed or registered such that the locations of the stations are known and the location of the BWA base stations and user terminals can be controlled, mitigation techniques to protect the FSS earth stations can be achieved by means of ensuring a minimum separation distance, taking into account specific site shielding and propagation conditions as a means to control and reduce the interference.

When the BWA stations and/or FSS earth stations are deployed in a ubiquitous manner and/or the locations of the stations are not known, no minimum separation distance can be guaranteed. In this case, compatibility of BWA networks operating within any part of the 3 400-4 200 MHz range and FSS networks operating in this same range is not likely feasible within the same geographical area.

1 Introduction

The 3 400-4 200 MHz band is allocated worldwide on a primary basis to the FSS. This band or parts of the band can be heavily used by the FSS for space-to-Earth transmissions. There are primary allocations to the mobile service and to the fixed service within the 3 400-4 200 MHz band. In various regions, many administrations are introducing BWA systems in all or portions of this frequency band.

This Report examines the possible compatibility between BWA and FSS networks in the range 3 400-4 200 MHz. In addition, the potential of the FSS receiving harmful levels of interference due to unwanted emissions from BWA systems is investigated.

2 Regulatory status of the services having allocations in the 3 400-4 200 MHz band

The ITU-R Radio Regulations define radiocommunication services and allocate different services to different frequency bands. Administrations are free to select a subset of these allocations for use in their own national spectrum allocations.

2.1 Definitions

Some selected definitions in Article 1 of the RR relevant for BWA and FSS applications include the following. The numbers correspond to their number in the RR:

“**1.20** *Fixed service:* A *radiocommunication service* between specified fixed points.

1.21 *Fixed-satellite service:* A *radiocommunication service* between *earth stations* at given positions, when one or more satellites are used; the given position may be a specified fixed point or any fixed point within specified areas; in some cases this service includes satellite-to-satellite links, which may also be operated in the *inter-satellite service*; the fixed-satellite service may also include *feeder links* for other *space radiocommunication services*.

1.24 *Mobile service:* A *radiocommunication service* between *mobile* and *land stations,* or between *mobile stations* (CV).

1.26 *Land mobile service:* A *mobile service* between *base stations* and *land mobile stations*, or between *land mobile stations*.

1.63 *Earth station:* A *station* located either on the Earth’s surface or within the major portion of the Earth’s atmosphere and intended for communication:

– with one or more space stations; or

– with one or more stations of the same kind by means of one or more reflecting satellites or other objects in space.

1.66 *Fixed station:* A station in the *fixed service*.

1.67 *Mobile stations:* A *station* in the *mobile service* intended to be used while in motion or during halts at unspecified points.

1.69 *Land station:* A station in the *mobile service* not intended to be used while in motion.

1.71 *Base stations:* A *land station* in the *land mobile service*.

1.73 *Land mobile station:* A *mobile station* in the *land mobile service* capable of surface movement within the geographical limits of a country or continent.

2.2 Table of frequency allocations

Table 1 is an excerpt of Article 5 of the RR that are relevant to the 3 400-4 200 MHz frequency band.

TABLE 1 (excerpt of ITU RR Article 5, 2008 Edition)

Allocation to services		
Region 1	**Region 2**	**Region 3**
3 400-3 600 FIXED FIXED-SATELLITE (space-to-Earth) Mobile 5.430A Radiolocation 5.431	**3 400-3 500** FIXED FIXED-SATELLITE (space-to-Earth) Amateur Mobile 5.431A Radiolocation 5.433 5.282 5.432	**3 400-3 500** FIXED FIXED-SATELLITE (space-to-Earth) Amateur Mobile ADD 5.432B ADD 5.432A Radiolocation 5.433 5.282 .432
	3 500-3 700 FIXED FIXED-SATELLITE (space-to-Earth) MOBILE except aeronautical mobile Radiolocation 5.433 5.435	**3 500-3 600** FIXED FIXED-SATELLITE (space-to-Earth) MOBILE except aeronautical mobile ADD 5.433A Radiolocation 5.433 5.435
3 600-4 200 FIXED FIXED-SATELLITE (space-to-Earth) Mobile		**3 600-3 700** FIXED FIXED-SATELLITE (space-to-Earth) MOBILE except aeronautical mobile Radiolocation 3 5.435
	3 700-4 200 FIXED FIXED-SATELLITE (space-to-Earth) MOBILE except aeronautical mobile	**3 700-4 200** FIXED FIXED-SATELLITE (space-to-Earth) MOBILE except aeronautical mobile

5.430A *Different category of service:* in Albania, Algeria, Germany, Andorra, Saudi Arabia, Austria, Azerbaijan, Bahrain, Belgium, Benin, Bosnia and Herzegovina, Botswana, Bulgaria, Burkina Faso, Cameroon, Cyprus, Vatican, Côte d'Ivoire, Croatia, Denmark, French Overseas Departments and Communities in Region 1, Egypt, Spain, Estonia, Finland, France, Gabon, Georgia, Greece, Guinea, Hungary, Ireland, Iceland, Israel, Italy, Jordan, Kuwait, Lesotho, Latvia, Macedonia, Liechtenstein, Lithuania, Malawi, Malta, Morocco, Mauritania, Moldova, Monaco, Mongolia, Montenegro, Mozambique, Namibia, Niger, Norway, Oman, Netherlands, Poland, Portugal, Qatar, Syria, Congo, Slovakia, Czech Rep., Romania, United Kingdom, San Marino, Senegal, Serbia, Sierra Leone, Slovenia, South Africa, Sweden, Switzerland, Swaziland, Togo, Chad, Tunisia, Turkey, Ukraine, Zambia and Zimbabwe**,** the band 3 400-3 600 MHz is allocated to the mobile, except aeronautical mobile, service on a primary basis subject to agreement obtained under No. 9.21 with other administrations and is identified for International Mobile Telecommunications (IMT). This identification does not preclude the use of this band by any application of the services to which it is allocated and does not establish priority in the Radio Regulations. At the stage of coordination the provisions of Nos. 9.17 and 9.18 also apply. Before an administration brings into use a (base or mobile) station of the mobile service in this band it shall ensure that the power flux-density (pfd) produced at 3 m above ground does not exceed –154.5 dBW/($m^2 \cdot$ 4 kHz) for more than 20% of time at the border of the territory of any other administration. This limit may be exceeded on the territory of any country whose administration has so agreed. In order to ensure that the pfd limit at the border of the territory of any other administration is met, the calculations and verification shall be made, taking into account all relevant information, with the mutual agreement of both administrations (the administration responsible for the terrestrial station and the administration responsible for the earth station), with the assistance of the Bureau if so requested. In case of disagreement, the calculation and verification of the pfd shall be made by the Bureau, taking into account the information referred to above. Stations of the mobile service in the band 3 400-3 600 MHz shall not claim more protection from space stations than that provided in Table 21-4 of the Radio Regulations (Edition of 2004).This allocation is effective from 17 November 2010. (WRC-07)

5.432A In Korea (Rep. of), Japan and Pakistan, the band 3 400-3 500 MHz is identified for International Mobile Telecommunications (IMT). This identification does not preclude the use of this band by any application of the services to which it is allocated and does not establish priority in the Radio Regulations. At the stage of coordination the provisions of Nos. 9.17 and 9.18 also apply. Before an administration brings into use a (base or mobile) station of the mobile service in this band it shall ensure that the power flux-density (pfd) produced at 3 m above ground does not exceed –154.5 dBW/($m^2 \cdot$ 4 kHz) for more than 20% of time at the border of the territory of any other administration. This limit may be exceeded on the territory of any country whose administration has so agreed. In order to ensure that the pfd limit at the border of the territory of any other administration is met, the calculations and verification shall be made, taking into account all relevant information, with the mutual agreement of both administrations (the administration responsible for the terrestrial station and the administration responsible for the earth station), with the assistance of the Bureau if so requested. In case of disagreement, the calculation and verification of the pfd shall be made by the Bureau, taking into account the information referred to above. Stations of the mobile service in the band 3 400-3 500 MHz shall not claim more protection from space stations than that provided in Table 21-4 of the Radio Regulations (Edition of 2004). (WRC-07)

5.432B *Different category of service:* in Bangladesh, China, India, Iran (Islamic Republic of), New Zealand, Singapore and French Overseas Communities in Region 3, the band 3 400-3 500 MHz is allocated to the mobile, except aeronautical mobile, service on a primary basis, subject to agreement obtained under No. 9.21 with other administrations and is identified for International Mobile Telecommunications (IMT). This identification does not preclude the use of this band by any application of the services to which it is allocated and does not establish priority in the Radio Regulations. At the stage of coordination the provisions of Nos. 9.17 and 9.18 also apply. Before an administration brings into use a station of the mobile service in this band it shall ensure that the power flux-density (pfd) produced at 3 m above ground does not exceed –154.5 dBW/($m^2 \cdot$ 4 kHz) for more than 20% of time at the border of the territory of any other administration. This limit may be exceeded on the territory of any country whose administration has so agreed. In order to ensure that the pfd limit at the border of the territory of any other administration is met, the calculations and verification shall be made, taking into account all relevant information, with the mutual agreement of both administrations (the administration responsible for the terrestrial station and the administration responsible for the earth station) with the assistance of the Bureau if so requested. In case of disagreement, the calculation and verification of the pfd shall be made by the Bureau, taking into account the information referred to above. Stations of the mobile service in the band 3 400-3 500 MHz shall not claim more protection from space stations than that provided in Table 21-4 of the Radio Regulations (2004 edition). This allocation is effective from 17 November 2010. (WRC-07)

5.433A In Bangladesh, China, Korea (Rep. of), India, Iran (Islamic Republic of), Japan, New Zealand, Pakistan and French Overseas Communities in Region 3, the band 3 500-3 600 MHz is identified for International Mobile Telecommunications (IMT). This identification does not preclude the use of this band by any application of the services to which it is allocated and does not establish priority in the Radio Regulations. At the stage of coordination the provisions of Nos. 9.17 and 9.18 also apply. Before an administration brings into use a station of the mobile service in this band it shall ensure that the power flux-density (pfd) produced at 3 m above ground does not exceed -154.5 dBW/($m^2 \cdot 4$ kHz) for more than 20% of time at the border of the territory of any other administration. This limit may be exceeded on the territory of any country whose administration has so agreed. In order to ensure that the pfd limit at the border of the territory of any other administration is met, the calculations and verification shall be made, taking into account all relevant information, with the mutual agreement of both administrations (the administration responsible for the terrestrial station and the administration responsible for the earth station), with the assistance of the Bureau if so requested. In case of disagreement, the calculation and verification of the pfd shall be made by the Bureau, taking into account the information referred to above. Stations of the mobile service in the band 3 500-3 600 MHz shall not claim more protection from space stations than that provided in Table 21-4 of the Radio Regulations (Edition of 2004). (WRC-07)

5.431A *Different category of service:* in Argentina, Brazil, Chile, Costa Rica, Cuba, Dominican Republic, El Salvador, Guatemala, Mexico, Paraguay, Suriname, Uruguay, Venezuela and French Overseas Departments and Communities in Region 2, the band 3 400-3 500 MHz is allocated to the mobile, except aeronautical mobile, service on a primary basis, subject to agreement obtained under No. 9.21. Stations of the mobile service in the band 3 400-3 500 MHz shall not claim more protection from space stations than that provided in Table 21-4 of the Radio Regulations (Edition of 2004). (WRC-07)

2.3 Coordination contours to protect FSS receive earth station

International protection of specific FSS earth stations and their coordination is governed by RR Nos. 9.17, 9.18, and in certain cases 9.21. The thresholds/conditions that trigger coordination are those specified in RR Appendix 5, together with the method of calculation for coordination contours completed in accordance with Appendix 7 of the RR.

These coordination contours may extend far into other countries. It is up to each administration to decide which stations within its own territory it wishes to protect in accordance with the RR. For example, if an administration wishes to ensure the protection of specific receiving FSS earth stations located within its territory from transmitting terrestrial stations located in the adjacent countries and within the coordination area of the earth station(s), those earth stations should be registered to ITU through the coordination and notification procedure under the provisions of RR Articles 9 and 11.

Particularly, as specified in RR No. 9.6, an administration intending to bring into use terrestrial services whose territory falls within the coordination contours of the earth stations under the coordination or notification procedure or notified under RR Articles 9 and 11, shall effect coordination with the administrations responsible for notifying these earth stations.

BWA networks in one country will need to be coordinated with all other countries having earth stations with coordination contours overlapping with the intended service area of the BWA network. Depending upon the specific terrain, BWA networks may need to be coordinated with FSS earth stations. Typically coordination distances range from 400 to 1 000 km.

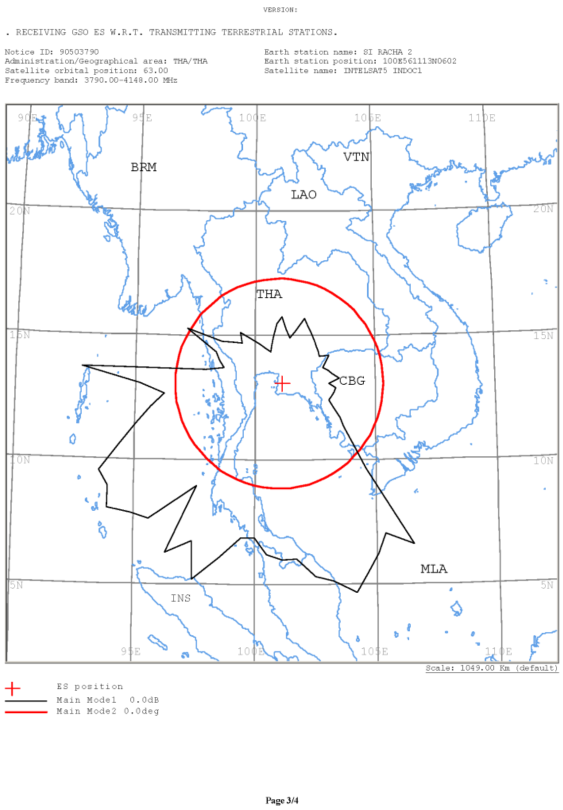
The coordination area is not an exclusion zone within which the sharing of frequencies between the earth station and terrestrial stations or other earth stations is prohibited, but rather a means for determining the area within which more detailed calculations need to be performed. A more detailed analysis may show that sharing within the coordination area is possible since the procedure for the determination of the coordination area is based on conservative assumptions with regard to the interference potential (see § 1.1 of Appendix 7 of the RR). Through the bilateral coordination process, it may be possible to identify one or more possible mechanisms to mitigate the interference to acceptable levels (e.g. site shielding, BWA antenna pointing or other considerations) resulting in smaller separation distances.

Calculation of a minimum coordination distance to protect an FSS earth station needs to take into account additional propagation effects (diffraction, building/terrain scattering etc.) not taken into account in the propagation model of RR Appendix 7. Minimum distances are usually in excess of 100 km depending on the latitude of the earth station. This means that regardless of the location of the earth station, the coordination contour will never be smaller than about 100 km in any direction.

Table 2 with the associated figures provides two examples of Appendix 7 mode 1 and mode 2 coordination contours around earth stations that are available using data from the ITU Master Register. These contours have been derived using the RR Appendix 7 methodology and criteria.

TABLE 2

	Earth station information			Satellite information	
	Name	**Longitude**	**Latitude**	**Satellite name**	**Longitude (nominal)**
1	SI RACHA 2	100 E 56 11	13 N 06 02	INTELSAT5 INDOC1	63
2	AGARTALA	91 E 16 00	23 N 48 00	INSAT-1B	74



VERSION:

. RECEIVING GSO ES W.R.T. TRANSMITTING TERRESTRIAL STATIONS.

Notice ID: 90503790
Administration/Geographical area: THA/THA
Satellite orbital position: 63.00
Frequency band: 3790.00-4148.00 MHz

Earth station name: SI RACHA 2
Earth station position: 100E561113N0602
Satellite name: INTELSAT5 INDOC1

Scale: 1049.00 Km (default)

ES position
Main Mode1 0.0dB
Main Mode2 0.0deg

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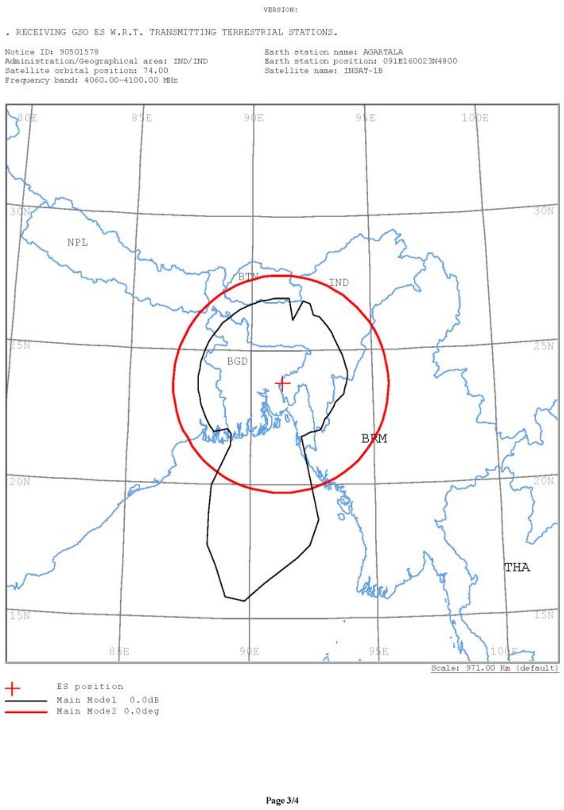

VERSION:

. RECEIVING GSO ES W.R.T. TRANSMITTING TERRESTRIAL STATIONS.

Notice ID: 90501578
Administration/Geographical area: IND/IND
Satellite orbital position: 74.00
Frequency band: 4060.00-4100.00 MHz

Earth station name: AGARTALA
Earth station position: 091E160023N4800
Satellite name: INSAT-1B

Scale: 971.00 Km (default)

ES position
Main Mode1 0.0dB
Main Mode2 0.0deg

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3 FSS systems in the 3 400-4 200 MHz band

Representative FSS technical characteristics for use in BWA/FSS compatibility studies are provided in Table 3 of Annex A to this Report.

The band 3 400-4 200 MHz has been used by the FSS for space-to-Earth links (downlinks) since the 1970’s. The technology is mature and equipment is available at low cost. This, together with the wide coverage beams possible in this band, has lead to satellites in this band being an important part of the telecommunications infrastructure in many developing countries. As of 2008 there are more than 160 geostationary satellites worldwide operating in all or part of the band 3 400-4 200 MHz. Most of these satellites operate in the 3 625-4 200 MHz band. Nearly two out of three of commercial satellites manufactured in 2006 used FSS allocations in this part of the spectrum. In addition, many satellites that operate in other bands have their telemetry operations (telemetry, tracking and ranging) in the 3 400-4 200 MHz range, especially for the purposes of Launch and Transfer Orbit Operations. This band, in particular the lower part of the band, is also used for feeder links to satellites in the mobile-satellite service.

The low gaseous atmospheric absorption combined with lower attenuation due to rain in bands below 7 GHz enables highly reliable space-to-Earth communication links with wide service area coverage, particularly in, but not limited to, geographical areas with severe rain fade conditions. As higher frequencies (i.e. 10-12 GHz or 19-20 GHz) are subject to severe rain fade conditions in many countries, the 3 400-4 200 MHz band is the only downlink band where FSS services can be provided efficiently with high availability and reliability. Also, for areas where the population is low and scattered (e.g. the islands in the Pacific) the wide coverage beams of satellites in this band may be one of the few options economically available. For these reasons, this band is the band of choice in many regions for a multitude of services, including very small aperture terminal (VSAT) networks, internet providers, point-to-multipoint links, satellite news gathering, TV and data broadcasting to satellite master antenna television (SMATV) and direct-to-home (DTH) receivers. In many countries receive only earth stations or VSAT terminals are not individually licensed and their number, location or detailed characteristics are not typically available. Due to their wide coverage characteristics, satellites operating in this band have been extensively employed for disaster relief operations.

3.1 Examples of FSS deployments

FSS earth stations are deployed, in varying degrees, all around the world in the band 3 400-4 200 MHz. Some examples of such deployment are provided below. Further details on earth station deployments can be found in Annexes A and C.

– Information obtained from Intelsat and SES New Skies in mid-2006 showed that in Europe there were approximately 830 earth stations operating to Intelsat satellites and 251 earth stations operating to SES New Skies satellites, for a total of 1 081 earth stations using the band 3 400-4 200 MHz. Updated information from the same sources showed that by late-2008 the total number had increased to 1 431, an increase of 350 registered earth stations in this band over the short two year period. Figure 20 of Annex C to this Report provides a map showing this 2008 census.

– One major satellite operator has more than 9 900 registered earth stations, in its data base, deployed across the globe operating in the 3 400-4 200 MHz band. The location of these earth stations is shown in Figs 20 through 23 of Annex C to this Report[3]. These figures do

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[3] Source: Report ITU-R M.2109 – Sharing studies between IMT Advanced systems and geostationary satellite networks in the fixed-satellite service in the 3 400-4 200 MHz and 4 500-4 800 MHz frequency bands.

not include receive only FSS earth stations such as Television Receive-Only (TVRO) terminals which may amount to several thousand more terminals.

- In Brazil, in the band 3 700-4 200 MHz there are more than 8 000 nationally registered earth stations pointing to one of the Brazilian satellites and 12 000 nationally registered earth stations pointing to one of the non-Brazilian satellites that cover the country, plus an equal number of earth stations in the 3 625-3 700 MHz band (see Fig. 24 of Annex C). There are also an estimated 20 million TVRO terminals deployed across the country.
- A provider of television programming in the United States of America delivers programming via satellite directly to the general public in areas that are outside the coverage area of its terrestrial television stations. As of December 2005, there were approximately 122 000 receive-only earth stations that received programming from that provider in that country.
- Members of one Broadcasting Association utilize more than 31 000 earth stations in North America to reach over 66 million cable television households.
- In the Russian Federation, there are approximately 6 000 nationally registered earth stations that receive transmissions in the 3 400-4 200 MHz band. These figures do not include TVRO earth stations that are deployed across the country.
- In the Russian Federation there are more than 20 satellite networks operating in the band 3 400-4 200 MHz with global and semi-global coverage. These are the EXPRESS, YAMAL and STATSIONAR networks.

3.2 Types of FSS receive earth stations

There are four different types of FSS receive earth stations:

a) Earth stations deployed ubiquitously and/or without individual licensing or registration
  - Where deployed, these earth stations are typically in large numbers and their specific locations are not known.

b) Individually licensed earth stations
  - The location of these earth stations is known so that site shielding and other mitigation techniques can possibly be implemented. International protection is provided to specific earth stations (i.e. at specific geographic locations) which are filed and coordinated pursuant to Article 9 of the RR.

c) Telemetry earth stations
  - These earth stations are part of the control system for the satellite and are responsible for its safe operation. This type of earth station can tolerate very little interference. However, there are very few earth stations of this type and just like other individually licensed earth stations, their specific location is known and can be taken into account to possibly mitigate the interference.

d) Feeder links for mobile-satellite systems
  - A number of mobile-satellite operators use a portion of the 3 400-4 200 MHz band for their feeder links. Because of the nature of the service, a very high degree of availability is required and very little interference can be tolerated. However, again these are a limited number of earth stations in known locations and case-by-case measures to reduce the interference can be implemented.

3.3 Unregistered earth stations

For earth station terminals that both transmit and receive, records of their key features such as antenna size and geographical location are kept by the operators of the satellites serving them, for example Intelsat and SES New Skies. Similar data is recorded by the licensing authorities of the countries in which the terminals are located. However in most countries licences are not required for terminals which receive but do not transmit, such as TVROs, and hence the great majority of such terminals are not included in either industrial or governmental data-bases. Thus it is not possible to state reliably the number of unregistered earth station terminals operating in Europe in 3 400-4 200 MHz.

It should be noted that in the United States of America and Canada, receive only earth stations are not required to obtain a license or register. However, unregistered receive stations do not receive protection from other services. Receive only earth stations may optionally seek protection on a licensed basis in the 3 700-4 200 MHz band.

Although the number of users that have acquired TVROs to take advantage of the extensive availability of 3 400-4 200 MHz-band TV carriers is unknown, it is likely to be a considerable number.

3.4 Conclusions on satellite system use of the 3 400-4 200 MHz band

Bearing in mind that the earth station data does not include non-registered terminals, such as TVROs, from the figures in Annex C it is reasonable to conclude that the use of the 3 400-4 200 MHz band by satellite services is extensive and exhibited an increase in the number of user terminals from 2006 to 2008 (see Fig. 20 of Annex C). However, Fig. 23 of Annex C indicates a much lower density of earth stations in several countries in the band 3 400-3 625 MHz, which could facilitate sharing between BWA applications and registered FSS earth stations in this sub-band. It should also be noted that some countries have even no registered earth stations in this band. This is likely reflective of national allocations decisions. At the technical level this still may not address the situation of non-registered stations.

In case of bilateral or multilateral coordination or sharing discussions, administrations are encouraged to make the most detailed information possible available concerning the FSS earth station usage on their territory.

4 Broadband wireless access systems in the 3 400-4 200 MHz band

Representative Broadband wireless access (BWA) technical characteristics for use in BWA/FSS compatibility studies are provided in Table 4 (Base station parameters) and Table 5 (Terminal station parameters) of Annex A to this Report. Further, the description of the BWA base station omnidirectional antenna is given in Fig. 1 of the same Annex. Figures 2 to 4 describe the BWA base station sector antenna.

In broad terms, wireless access is an end-user radio connection(s) to core networks. Broadband wireless access applications have connection capabilities that are higher than the primary rate – e.g. 1 544 kbit/s (T1) or 2 048 kbit/s (E1). Fixed wireless access (FWA) is an application in which the location of the end-user termination and the network access point to be connected to the end-user are fixed, whereas mobile wireless access is an application in which the location of the end-user termination is mobile. For nomadic wireless access (NWA), the location of the end-user termination may be in different places but it is stationary while in use. Although the exact locations of the mobile and nomadic terminals are in general unknown, they are restricted by the positions of their respective base stations and the maximum distance between base station and terminal.

A number of BWA systems and applications, based on different standards, are available and the suitability of each depends on usage (fixed, nomadic and/or mobile), and performance and geographic requirements, among others. These standards are found in Recommendations ITU-R F.1763 – Radio interface standards for broadband wireless access systems in the fixed service operating below 66 GHz and ITU-R M.1801 – Radio interface standards for broadband wireless access systems, including mobile and nomadic applications, in the mobile service operating below 6 GHz.

Both of these Recommendations cover nomadic applications, which can operate in either fixed or mobile service allocations. Moreover, advances in technologies have greatly enabled the convergence of broadband and mobile.

In countries where wired infrastructure is not well established, wireless systems like BWA or FSS can be more easily deployed to deliver services to population bases in dense urban environments as well as those in more remote areas. Some users may only require broadband Internet access for short ranges whereas others users may require broadband access over longer distances. Moreover, these same users may require that their BWA applications be nomadic, mobile, fixed or a combination of all three.

5 Possible types of interference to the FSS

Three possible types of interference have been identified as follows:

a) Co-frequency emissions from BWA

   – Due to the long distance to the satellite and the power limitations of the satellite, the incoming power flux density at the earth station location is very low. Terrestrial (e.g. BWA) equipment which is much closer to the earth station can produce significantly higher power levels at the input to the FSS receiver than the desired satellite signal.

b) Unwanted emissions (either out-of-band or spurious) from BWA

   – Due to the very low level of the incoming FSS signals and level of unwanted emissions that may be generated by the BWA transmitters BWA operation in one part of the band can create interference in other parts of the 3 400-4 200 MHz band used by the FSS. More stringent requirements for filtering of the BWA transmissions will reduce the impact on FSS reception, but will make BWA equipment more expensive.

c) Signals from nearby BWA transmitters causing FSS receiver overload to FSS earth station receivers operating in adjacent bands

   – FSS earth station Low Noise Amplifiers (LNAs) and Low Noise Block converters (LNBs) are optimized for the reception of very low level satellite signals, and hence have low noise figures and relatively low dynamic range. Typically, an LNA/LNB will be saturated with a total input power of around–50 dBm. Accordingly, the LNA/LNBs will start to show a non-linear behaviour, creating intermodulation products and suppression of carriers at a total incoming power about 10 dB below the 1 dB compression point at an input signal level of about –60 dBm.

     Typically LNAs and LNBs receive throughout the entire 3 400-4 200 MHz band. LNAs and LNBs specified for reception of only the 3 700-4 200 MHz band normally operate over the entire 3 400-4 200 MHz and have the bandwidth defining filtering only at Intermediate Frequency (IF). Therefore, terrestrial signals in any part of the 3 400-4 200 MHz band can be received by the LNA/LNB and affect the operating point of the LNA/LNB. Because of the potentially high signal power levels from BWA or other allocated services, such as high power radiolocation in the 3 400-3 600 MHz band, received by the FSS earth stations, the FSS receiver could be driven into their non-linear operating range, thus preventing FSS reception.

Bandpass filters that can be mounted between the FSS receive antenna and the LNA/LNB to filter out signals outside the wanted frequency band (e.g. 3 700-4 200 MHz) are available. Field trials have indicated that an out-of-band BWA signal can be reduced by about 10 dB. Such filters will however reduce the figure of merit (G/T) for the FSS earth station and may necessitate the use of a larger earth station antenna. Some earth stations, in particular smaller earth stations also commonly have the LNB and the feedhorn moulded together in one unit. In this case, insertion of a filter in between them is not possible. The cost of inserting filters also would add considerably to the cost of many antenna installations.

6 Sharing and compatibility studies and results

Annex A to this Report contains, apart from the BWA and FSS parameters to be used in the compatibility studies, also the parameters to be used in the propagation model of Recommendation ITU-R P.452-13.

Several sharing studies, based on the parameters contained in Annex A, have been conducted with regard to the interference potential of BWA systems into FSS networks operating in the 3 400-4 200 MHz band. Studies to this extent are summarized in Annex B.

To ensure protection of the FSS earth station, the studies documented in Annex B show that FSS receive earth stations in all cases of co-frequency interference need to be physically separated or shielded from BWA base stations and user terminals. Additionally, in some cases of adjacent channel interference there would also be a need for physical separation or shielding from BWA base stations and user terminals, which, when implemented, could have significant cost impact on the procurement and deployment of the FSS earth stations. The separation distance depends on the system parameters in the various scenarios. In particular this section considers BWA stations working in the 3 400-3 600 MHz band. Based on the sharing and compatibility studies, the worst-case separation between the BWA transmitters and FSS earth stations working in the 3 400-4 200 MHz band is summarized as follows:

6.1 Sharing between FSS and BWA (*Co-frequency emission problem*)

Interference may be caused by BWA operating in portions of the band 3 400-3 800 MHz to FSS systems receiving satellite signals in the same frequencies. The studies conducted indicate that separation distances of tens of kilometres, even in excess of 100 km in some cases, will be required if no shielding arrangement can be implemented at the earth stations, and if no other mitigation technique is applied to the BWA base station. However, for co-channel compatibility, mitigation techniques for BWA have not been investigated in this Report. It should be noted that these values reflect the long-term protection criterion only. In the co-frequency case, short-term protection criterion should also be considered. In this case the required separation distances will be much greater. The actual separation distance depends on the parameters of the stations and the actual scenario involved.

6.2 Compatibility of FSS with interference resulting from unwanted BWA emissions (*Unwanted emission problem*)

Unwanted emissions from BWA operating in portions of the 3 400-3 800 MHz band can affect FSS systems intending to receive signals in the adjacent frequency band of 3 800-4 200 MHz In the case where BWA equipment with out-of-band emissions conforming to European standards are deployed, separation distances of up to a few kilometres between BWA transmitters and FSS receiving stations would be required. If additional filtering can be implemented at the BWA base stations to reduce the levels of unwanted emissions the distance between the BWA base station and the FSS earth station may be shortened. It should be noted that it is important to have a sufficient separation distance between BWA terminal stations and FSS earth stations. For specific earth stations, clutter loss and shielding effects can also be taken into account to further reduce the separation distance.

6.3 FSS receiver overload (*FSS Receiver "saturation" problem*)

Signals from nearby BWA equipment transmitting in portions of the 3 400-3 800 MHz band can cause the overload of FSS receivers because their LNB typically receives over the entire 3 400-4 200 MHz range. Although there may be a number of technical solutions (e.g. BWA filtering, shielding, etc.) available in principle to minimize/overcome the problem, the most practical solution may be to add a bandpass filter in front of the FSS receiver (if possible, given the physical configuration of the earth station). However this will add to the cost of the FSS deployment. For those FSS systems not equipped with a band pass filter, separation distances of up to several kilometres would be required. Administrations may not have required separation or coordination distances for unwanted emissions.

7 Methods and techniques to enhance sharing and compatibility

7.1 Individually licensed/registered FSS earth stations at specific locations

Where FSS earth stations are individually licensed or registered such that the locations of the stations are known, coordination of the BWA network and FSS earth stations may be possible. This coordination can normally be facilitated by a combination of natural terrain features and local shielding at either or both ends of potential interference paths, along with frequency coordination and power reduction if necessary. According to the studies described, BWA systems within an area of several to over 100 km around existing licensed earth stations operating in the same frequencies may cause interference to the latter, indicating that careful coordination is necessary for co-frequency operation. If detailed data/knowledge is available on the clutter environment around the concerned BWA and FSS systems (e.g. in bilateral coordination), these can be taken into account, and may reduce the separation distances. However, the studies in Annex B assumed local clutter parameters, and the outcome was that "exclusion zones" still exist around earth stations where BWA services cannot be provided in the band.

7.2 BWA stations and/or FSS earth stations deployed in a ubiquitous manner and/or without individual licensing or registration

Protection by separation distance is only meaningful for fixed BWA stations or if locations of nomadic or mobile stations can be controlled. However, when the locations of the BWA stations are unknown no minimum separation distance can be guaranteed making compatibility between FSS and BWA quite difficult . If no practical solution can be identified to prevent the risk of interference by mobile BWA stations to FSS systems, it may be necessary to limit the operations of one service or introduce band segmentation.

7.3 Possible techniques to avoid LNB saturation

To overcome interference due to the saturation and unwanted emission problems which may potentially affect all FSS systems with LNA/LNBs operating in the 3 400-4 200 MHz range the following mitigation techniques may be considered:

– retrofit the interfered-with FSS earth station with an LNB band pass filter;

– ensure that the use of BWA stations is coordinated via a combination of e.i.r.p. limits and detailed coordination of BWA coverage areas.

7.4 Example of National Regulatory/Technical solutions

Annex D provides an example of a national implementation of BWA.

It provides details of the sharing arrangements between BWA and FSS in the 3 400-4 200 MHz band in Australia. In Australia, which does not share any national borders, the technical rules for sharing, including FSS Earth station and BWA base station filtering characteristics, are controlled by the Administration, which improves the sharing situation. This situation might not be true for other Administrations where additional measures may be required, such as cross-border coordination to protect the FSS in the 3 400-4 200 MHz band, although the technical compatibility criteria are applicable in other scenarios.

Furthermore, although the sharing arrangements can fully account for existing FSS systems at the time of deployment, it will limit the future deployment of FSS stations in locations where BWA is licensed.

The main licensing rules detailed in Example D-1 to ensure that BWA services in the 3 575-3 700 MHz band will be compatible with existing licensed FSS earth stations in the 3 600-4 200 MHz band may be summarized as follows:

– BWA is being licensed in regional and remote areas of Australia. Exclusion zones apply around defined areas, such as major cities, in order to preserve future planning options in these areas[4].

– Regional and remote BWA base station transmitters must meet a number of minimum performance characteristics; including an e.i.r.p. density mask above 3 700 MHz (see Table 42 and Fig. 25 of Annex D).

– Regional and remote BWA base station transmitters are not be licensed within 20 km of an existing licensed FSS earth station operating in the adjacent Standard C band (see Table 44 of Annex D).

– FSS earth station receivers are assumed to meet a number of minimum performance characteristics (in addition to their licence requirements) (see Table 43 of Annex D).

– Regional and remote BWA frequency assignments are being undertaken using additional coordination specific information (see Table 44 of Annex D).

8 Conclusions

Based on the studies that form the basis of this Report, the following conclusions are reached regarding the compatibility of BWA and FSS in the 3 400-4 200 MHz band:

a) BWA networks may operate within the fixed or mobile services depending on the type of technology and licensing regime adopted in individual administrations. BWA user terminals deployed at unknown locations (i.e. without individual licensing of fixed user terminals, ubiquitously deployed, nomadic or mobile) and the associated base stations would operate in the mobile service. BWA user terminals deployed at fixed, specified locations, and their associated gateway stations would operate in the fixed service.

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[4] Section 2 of the ACMA Spectrum Planning Discussion Paper 02/09 on the “Release of the 3.6 GHz band for Wireless Access Services (WAS)”, http://www.acma.gov.au/webwr/_assets/main/lib310829/spp2009-02_release_of_3.6ghz_band_for_was-disc_paper.pdf.

b) Appendix 7 of the RR defines the methodology for calculating coordination contours around FSS receive earth stations within which coordination is required for terrestrial services. Such contours typically extend 100-1 000 km from the earth station. Implementation of BWA networks in a country will require international coordination with any country that has filed FSS earth stations whose coordination contour overlaps the service area of the BWA network.

c) Sharing and compatibility studies and field trials referenced in this Report have been performed in relation to the co-existence of BWA networks being deployed in portions of the 3 400-3 800 MHz band and FSS networks in the bands 3 400-4 200 MHz. Three different types of interference were identified in these studies and tests:

- in-band interference – BWA interfering with FSS in overlapping frequency bands;
- unwanted emissions of BWA (out-of-band due to spectrum roll-off and spurious emissions) interfering with FSS in other parts of the 3 400-4 200 MHz band;
- FSS receiver saturation – BWA power levels affecting the operating point of the FSS receiver LNA or LNB so that it is driven into saturation or non-linear operation.

d) The studies indicate that to provide protection to FSS receive earth stations, some separation distance between the stations of the BWA network and the FSS receive earth stations is required. The magnitude of this separation distance depends on the parameters of the networks, the protection criteria of concerned satellite networks and the deployment of the two services and if the two services operate in the same or in adjacent frequency bands. With the assumptions used in the studies, it was shown that when no particular shielding or blocking with the respect to the interfering signal can be guaranteed, the approximate required separation distances would be as follows:

– co-frequency:	several tens to in excess of 100 km;
– out-of-band emissions:	a few km;
– FSS receiver saturation:	a few to several km.

e) When the FSS earth stations are individually licensed or registered such that the locations of the stations are known and the location of the BWA base stations and user terminals can be controlled, mitigation techniques to protect the FSS earth stations can be achieved by means of ensuring a minimum separation distance, taking into account specific site shielding and propagation conditions as a means to control and reduce the interference.

f) When the BWA stations and/or FSS earth stations are deployed in a ubiquitous manner and/or without individual licensing or registration, the locations of the stations are not known and hence, no minimum separation distance can be guaranteed. Compatibility of BWA networks operating within any part of the 3 400-4 200 MHz range and FSS networks operating in this same range is not feasible within the same geographical area.

g) The retrofit of FSS earth stations with band pass filters at the LNB could improve the situation with regard to reducing the earth station susceptibility to interference, however such measures may not be possible due to the specific design of the LNB/feed horn, would be costly and could reduce performance of the earth station, and in any case may be impractical due to the large number of earth stations already deployed in the 3 400-4 200 MHz band

h) Deployment of BWA in any portion of the 3 400-4 200 MHz band would likely pose limitations on future deployment of FSS earth stations in the entire 3 400-4 200 MHz band.

Annex A

FSS and BWA system parameters

TABLE 3

Representative FSS characteristics for use in BWA/FSS Compatibility studies in the 3 400-4 200 MHz band

FSS system parameters	
Frequency	3 400-4 200 MHz
Bandwidth	40 kHz-72 MHz
Earth station antenna radiation patterns	Appendix 8 of Radio Regulations Recommendation ITU-R S.465 Recommendation ITU-R BO.1213
Antenna diameters (m)	1.2, 1.8, 2.4, 3.0, 4.5, 8, 16, 32
Noise temperature (including the contributions of the antenna, feed and LNA/LNB referred to the input of the LNA/LNB receiver)	100 K for small antennas (1.2-3 m) 70 K for large antennas (4.5 m and above)
Antenna elevation angle	5-85°
Short-term and long-term max. permissible Interference level	Recommendations ITU-R S.1432-1, ITU-R SF.558 and ITU-R SF.1006

TABLE 4

Representative BWA characteristics for use in BWA/FSS Compatibility studies in the 3 400-4 200 MHz band – Base station parameters

	BWA BS		
	Case 1	**Case 2**	**Case 3**
Deployment scenario	Specific cellular deployment rural with expected nomadic BWA use	Typical cellular deployment rural	Typical cellular deployment urban
	System A	**System A**	**System A**
TX peak output power (dBm)	43	35	32
Channel bandwidth (MHz)	7(1)		
Feeder loss (dB)	3		
Power control (dB)	>10		
Peak antenna gain (dBi)	17	17	9
Antenna gain pattern	Recommendation ITU-R F.1336		
Antenna 3 dB beamwidth (degrees)	60 and 90 (sectorized)	60 and 90 (sectorized)	Omnidirectional

TABLE 4 (*end*)

	BWA BS		
	Case 1	**Case 2**	**Case 3**
Antenna downtilt (degrees)(3)	0-8 (1 degrees)	0-8 (2 degrees)	0-8 (4 degrees)
Antenna height a.g.l. (m)	50	30	15
e.i.r.p. (dBm)	57	49	38
Unwanted emissions	ACLR1 = 51 dB(4) ACLR2 = 87 dB(4) or ACLR1 = 37 dB(5) ACLR2 = 48 dB(5)		
Polarisation	Linear		

(1) Typical bandwidths are 5, 7 and 10 MHz. For these studies, 7 MHz is assumed as a representative value. Study of BWA/FSS compatibility for BWA systems of less than 5 MHz bandwidth is not addressed in this Report.

(2) Power control is used by BWA systems but has not been used in the studies in this Report in order to capture the worst-case scenario.

(3) A range of values is indicated, recognizing that the value for each situation depends on the actual deployment scenario taking into account the topology of the terrain. In parentheses, a typical value is given for use in the compatibility studies.

(4) Report ITU-R M.2116-1.

(5) WiMAX Forum Mobile Radio Specification, WMF-T23-005-R015v04 (2010-09-07).

TABLE 5

Representative BWA characteristics for use in BWA/FSS Compatibility studies in the 3 400-4 200 MHz band – Terminal station parameters

	BWA TS			
	Fixed-outdoor – System A	**Fixed-indoor – System A**	**Nomadic – System A**	**Mobile – System A**
TX peak output power (dBm)	26(1)	26(1)	22(1)	20(1)
Channel bandwidth (MHz)	7			
Feeder loss (dB)	1(2)			
Power control (dB)	0-45(3)			
Peak antenna gain (dBi)	17	5	5	0
Antenna gain pattern	Recommendation ITU-R F.1245	Omnidirectional		
Antenna 3 dB beamwidth (degrees)	24	N/A		

TABLE 5 (*end*)

	BWA TS			
	Fixed-outdoor – System A	**Fixed-indoor – System A**	**Nomadic – System A**	**Mobile – System A**
Antenna height a.g.l. (m)	10	1.5		
e.i.r.p. (dBm)	42	30	26	19
Unwanted emissions	ACLR1 = 33 dB(4) ACLR2 = 43 dB(4)			
Number of co-channel TSs per BS	10 users for uplink activity factor of 38% in a 5 ms frame(5)			

N/A: Not applicable.

(1) System A numbers for transmit peak output power are representative numbers, as this system covers a range of power classes.

(2) This value is the maximum feeder loss.

(3) The 45 dB is based on the minimum dynamic range requirements.

(4) Report ITU-R M.2116-1.

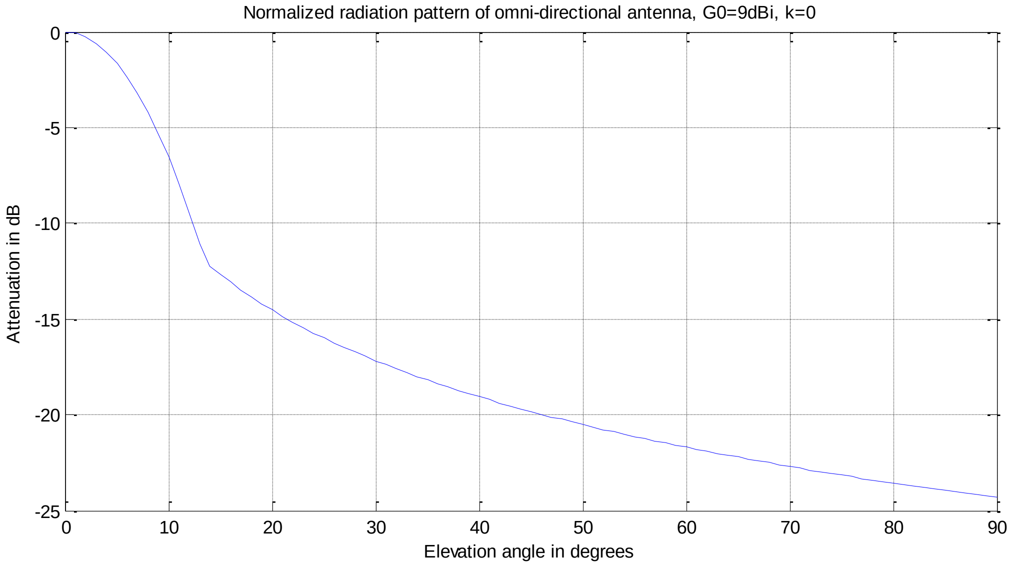
(5) Uplink activity factor for TDD mode is defined by the ratio of uplink subframe over the entire frame, that is uplink plus downlink subframes.

Antenna patterns for use with BWA

The detailed description of omnidirectional antenna pattern is in § 2.1 of Recommendation ITU-R F.1336-2. It is also considered that the antenna is with improved side-lobe performance. So, the parameter k is set to 0. Figure 1 shows the omnidirectional base station antenna pattern to be used.

FIGURE 1

Omnidirectional base station antenna pattern in the vertical plane



The detailed description of sectoral antenna pattern is in § 3.1 of Recommendation ITU-R F.1336-2. It is assumed that the antenna is with improved side-lobe performance. So, the parameter k is set to 0. Figure 2 shows the base station sectoral antenna vertical pattern at the horizontal boresight. Figure 3 shows the base station sectoral antenna vertical pattern at the horizontal 45° relative to the boresight. Figure 4 shows the base station sectoral antenna horizontal pattern at the vertical boresight.

FIGURE 2

Base station sectoral antenna vertical pattern at horizontal boresight

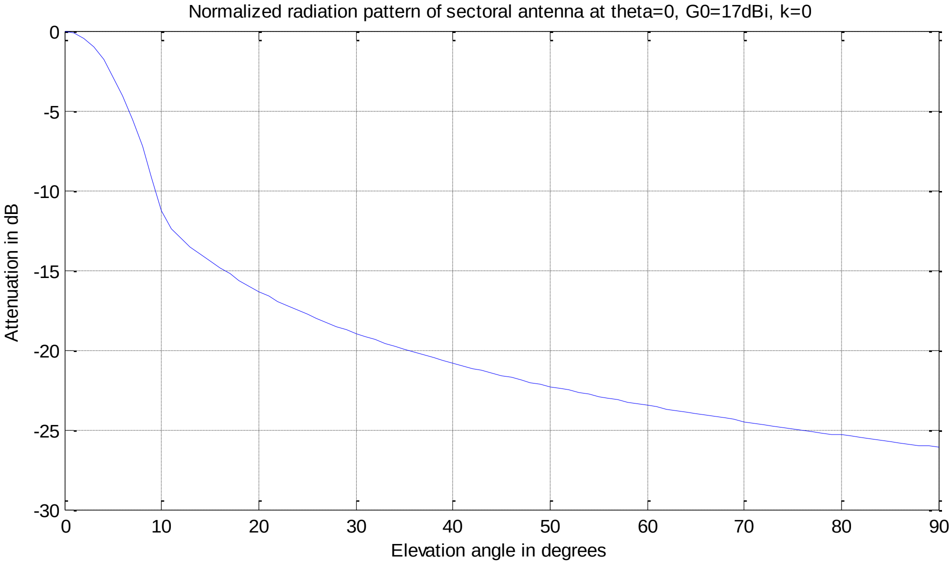


FIGURE 3

Base station sectoral antenna vertical pattern at horizontal 45° relative to the boresight

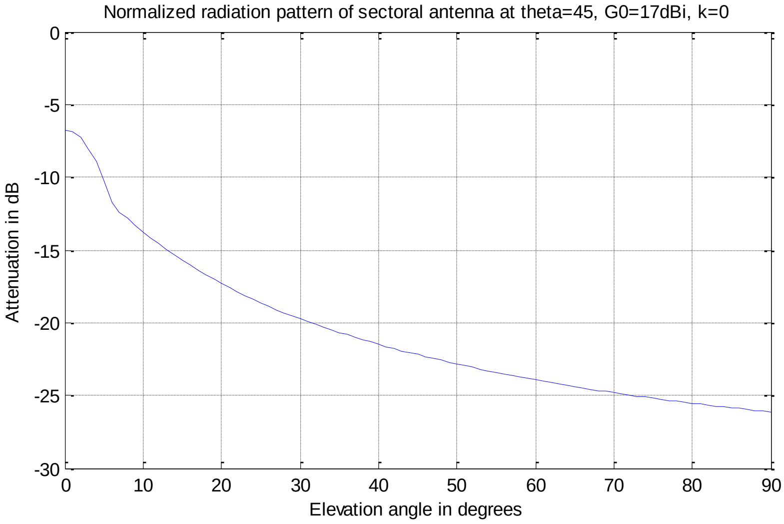
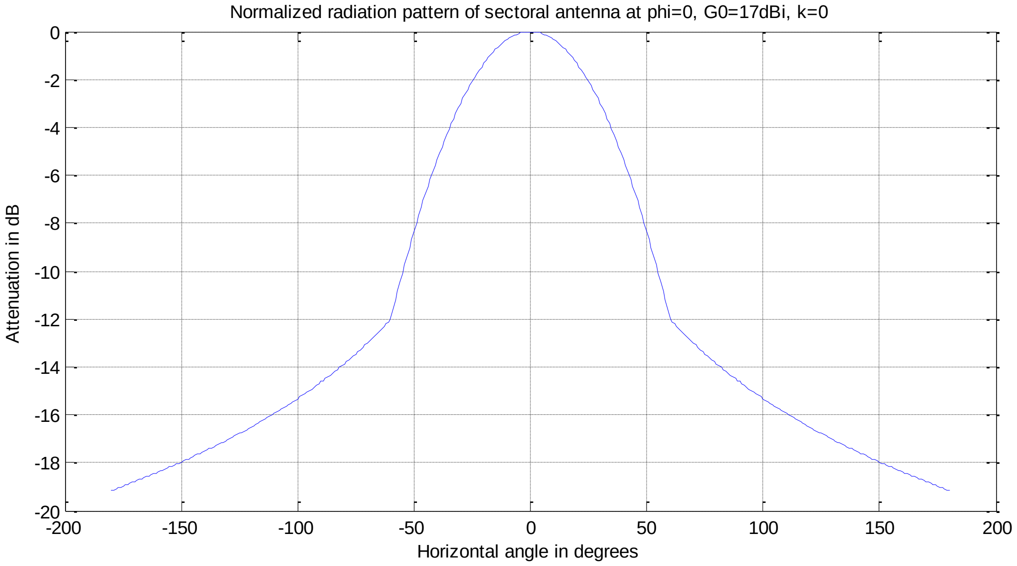


FIGURE 4

Base station sectoral antenna horizontal pattern at vertical boresight



Propagation model parameter for use in compatibility studies

TABLE 6

Values of parameters for the use of Recommendation ITU-R P.452-13

Parameter	Scenario	Value	Description
d_k (km)	Rural for BS	0.025	Distance from nominal clutter point to rural BS antenna; same distance for the interfered-with ES
	Urban for BS	0.02	Distance from nominal clutter point to urban BS antenna; same distance for the interfered-with ES
	Outdoor for TS	0.02	Distance from nominal clutter point to fixed-outdoor TS antenna; same distance for the interfered-with ES
	Indoor for TS	0.02	Distance from nominal clutter point to fixed-indoor TS antenna; same distance for the interfered-with ES
h_a (m)	Rural for BS	9	Nominal clutter height above local ground level for rural BS antenna
	Urban for BS	20	Nominal clutter height above local ground level for urban BS antenna
	Outdoor for TS	12	Nominal clutter height above local ground level for fixed-outdoor TS antenna
	Indoor for TS	12	Nominal clutter height above local ground level for fixed-indoor TS antenna
	Diameter = 32 m	30	Nominal clutter height above local ground level for 32 m ES antenna
	Diameter = 8 m	8	Nominal clutter height above local ground level for 8 m ES antenna
	Diameter = 1.2 m	8	Nominal clutter height above local ground level for 1.2 m ES antenna

TABLE 6 (*continued*)

Parameter	Scenario	Value	Description
L_P (dB)		8	Penetration loss, applied to fixed-indoor TS case
f (GHz)		3.6	Carrier frequency
p (%)		20	Required time percentage for which the calculated basic transmission loss is not exceeded
φ_t, φ_r (degrees)		40	Latitude of station
ψ_t, ψ_r (degrees)		–100	Longitude of station
h_g (m)		20	Smooth-Earth surface above sea level
h_m (m)		10	Terrain roughness parameter which is the maximum height of the terrain above the smooth-Earth surface in the section of the path
d_{tm} (km)		0.9d	Longest continuous land (inland and coastal) section of the great-circle path, d is the distance between TX and RX
d_{lm} (km)		0.8d	Longest continuous inland section of the great-circle path, d is the distance between TX and RX
d_{lt},d_{lr} (km)		0.25d	For a transhorizon path, distance from TX and RX to their respective horizons. For a LoS path, each is set to the distance from the terminal to the profile point identified as the principal edge in the diffraction method for 50% time, d is the distance between TX and RX. In this study, this parameter is set to 0.25d
θ_t, θ_r (mrad)		17.45	For a transhorizon path, transmit and receive horizon elevation angles respectively. For a LoS path, each is set to the elevation angle of the other terminal. In this study, these are set to +1°
θ (mrad)		$\theta_t + \theta_r + 10^3 d/\alpha_e$	Path angular distance. α_e is the median value of effective Earth radius
d_b (km)		0	Aggregate length of the path sections over water
$\gamma_o + \gamma_w(\rho)$ (dB/km)		0.008	Read from Fig. 5 in Recommendation ITU-R P.676-7 (for simplicity)
ΔN		50	Refractive index lapse-rate over the first 1 km of the atmosphere, read from Figs 11 and 12 in Recommendation ITU-R P.452-13
h_1 (m)		15	The first edge height above ground level
h_2 (m)		20	The second edge height above ground level
h_3 (m)		15	The third edge height above ground level
d_1 (km)		0.25d	Distance between TX and the first edge
d_2 (km)		0.5d	Distance between TX and the second edge
d_3 (km)		0.75d	Distance between TX and the third edge
N_0		310	Sea-level surface refractivity, read from Fig. 13 in Recommendation ITU-R P.452-13

TABLE 6 (*end*)

Parameter	**Scenario**	**Value**	**Description**
t (°C)		10	Annual average temperature
Pressure (hPa)		1 013.25	Standard pressure

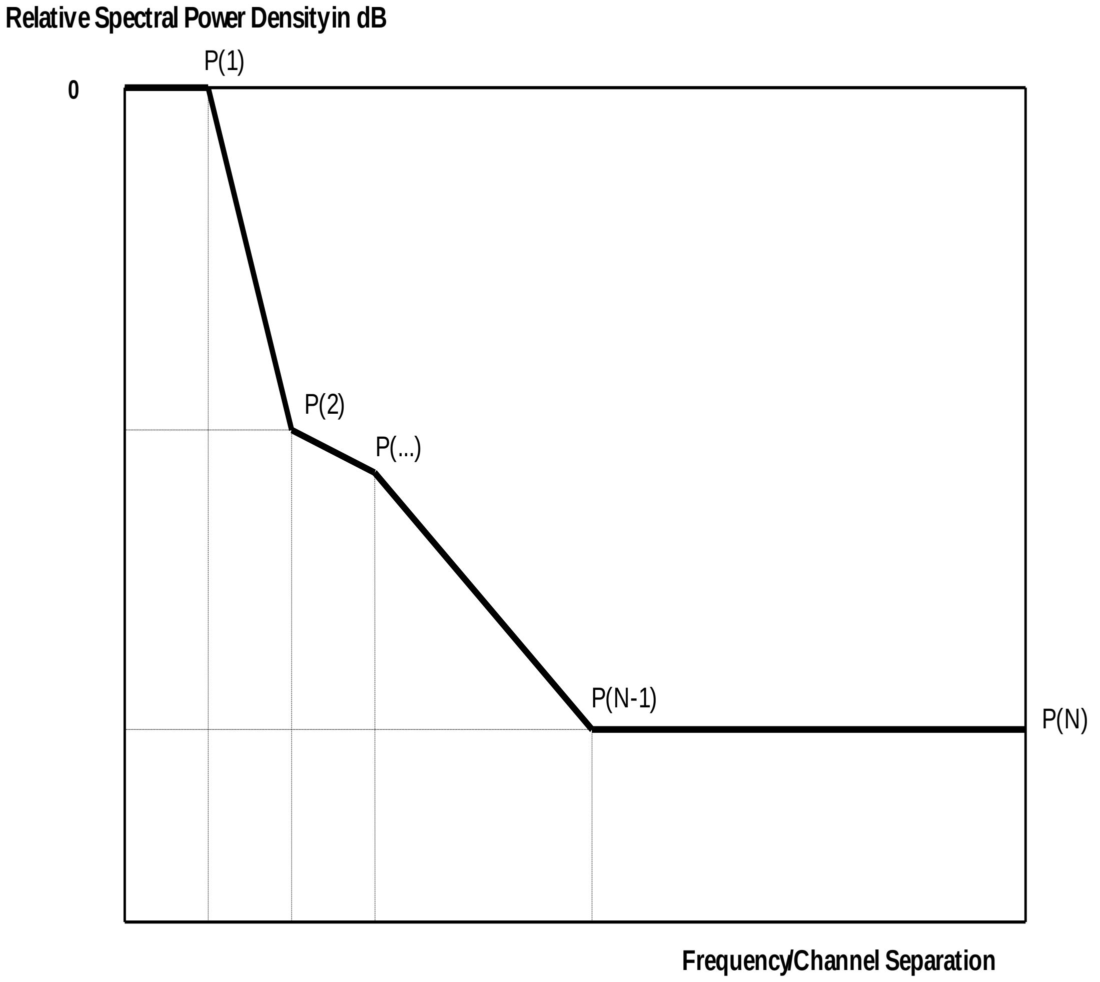
With respect to the clutter parameters referenced in Table 6, it should be noted that Recommendation ITU-R P.452-13 indicates that "*where there are doubts as to the certainty of the clutter environment, the additional loss should not be included*".

Further, the nominal clutter height for the 8 m and 1.2 m FSS earth Station antenna may not be reasonable to use when these antennas are operating at low elevation angles towards the spacecraft. Operations at low elevations require site surveys to make sure that there are no obstacles in the path between the spacecraft and the earth station. And therefore the nominal clutter height would logically be lower.

Attachment 1
to Annex A

Spectrum masks for BWA base stations

The spectrum mask shown in this Annex is an extract of EN 302 326-2 (Clause 5.3.4.1 Transmitter spectrum density masks).



Power spectrum reference points

Breakpoint from figure	P(0)		P(1)	P(2)	P(3)	P(4)	P(5)	P(6)
Frequency/Channel separation (F/Chs) ⇨	0		0.5	0.5	0.71	1.06	2	2.5
Attenuation(1) (dB)	0		0	–8	–32	–38	–50	–50

(1) The break points in the mask are for primary equipment type of OFDMA (EqC-PET = O) and equivalent modulation order of 6 (EqC-EMO = 6) in EN 302 326-2.

Attachment 2
to Annex A

Spectrum emission mask for terminal station equipment operating in the band 3 400-3 800 MHz

Emission mask for 7 MHz channel bandwidth

The spectrum emission mask of the terminal station applies to frequency offsets between 3.5 MHz and 17.5 MHz on both sides of the terminal station centre carrier frequency. The out-of-channel emission is specified as power level measured over the specified measurement bandwidth relative to the total mean power of the terminal station carrier measured in the 7 MHz channel.

1. The terminal station emission shall not exceed the levels specified in Table 7. Assuming specific power classes, relative requirements of Table 7 can be converted to absolute values for testing purposes.
2. In additions, for centre carrier frequencies within 3 650-3 700 MHz range, all emission levels shall not exceed –13 dBm/MHz.

TABLE 7

Spectrum emission mask requirement for 7 MHz channel bandwidth

Frequency offset Δf	Minimum requirement	Measurement bandwidth
3.5 MHz to 4.75 MHz	$\left\{-33.5-13.5\times\left(\frac{\Delta f}{\text{MHz}}-3.5\right)\right\}$ dBc	30 kHz
4.75 to 10.5 MHz	$\left\{-35.0-0.5\times\left(\frac{\Delta f}{\text{MHz}}-4.75\right)\right\}$ dBc	1 MHz
10.5 to 11.9 MHz	$\left\{-39.0-7\times\left(\frac{\Delta f}{\text{MHz}}-10.5\right)\right\}$ dBc	1 MHz
11.9 to 17.5 MHz	–49.0 dBc	1 MHz

NOTE 1 – Δf is the separation between the carrier frequency and the centre of the measuring filter.

NOTE 2 – The first measurement position with a 30 kHz filter is at Δf equals to 3.515 MHz; the last is at Δf equals to 4.735 MHz.

NOTE 3 – The first measurement position with a 1 MHz filter is at Δf equals to 5.25 MHz; the last is at Δf equals to 17 MHz. As a general rule, the resolution bandwidth of the measuring equipment should be equal to the measurement bandwidth. To improve measurement accuracy, sensitivity and efficiency, the resolution bandwidth can be different from the measurement bandwidth. When the resolution bandwidth is smaller than the measurement bandwidth, the result should be integrated over the measurement bandwidth in order to obtain the equivalent noise bandwidth of the measurement bandwidth.

NOTE 4 – Note that equivalent PSD type mask can be derived by applying 10*log ((7 MHz)/(30 kHz)) = 23.7 dB and 10*log((7 MHz)/(1 MHz)) = 8.5 dB scaling factor for 30 kHz and 1 MHz measurement bandwidth respectively.

Annex B

Description of studies

1 Introduction

This Annex contains a description of studies (Studies A, B, C and D) that have been provided to ITU-R , based on the BWA and FSS parameters as contained in Annex A. Further, these studies all took into account the propagation parameters as contained in that same Annex A. Where these studies have taken different assumptions, it will be reflected in the relevant summaries.

Attachment 1 contains a description of Study A.

Attachment 2 contains a description of Study B.

Attachment 3 contains a description of Study C.

Attachment 4 contains a description of Study D.

Attachment 1
to Annex B

Study A – Compatibility between BWA systems and FSS earth stations

1 Introduction

This study provides for a selection of these deployment scenarios based on the parameters available in Annex A of this Report.

The propagation models in Recommendation ITU-R P.452-13 are used in this study.

The assumptions on the parameters can be found in Annex A of this Report.

2 Compatibility study's methodology and assumptions

In the deterministic case, for each deployment scenario, the minimum separation distance between BWA BS/TS and FSS ES is derived according to the FSS ES receiver tolerance. The path loss has to meet the following equation:

$$PL(d) \geq TX + G_{TxMax} + AP_{TX}(d) - TX_{FL} + G_{RxMax} + AP_{RX}(d) - ACLR - L_p - I_{tolerance}$$

The separation distance, *d*, keeps increasing until the following equation is met,

$$PL(d) - AP_{TX}(d) - AP_{RX}(d) \geq TX + G_{TxMax} - TX_{FL} + G_{RxMax} - ACLR - L_p - I_{tolerance}$$

where:

$PL(d)$: Path loss between BWA BS/TS and FSS ES

$AP_{TX}(d)$: Normalized BWA BS/TS antenna pattern

$AP_{RX}(d)$: Normalized FSS ES antenna pattern

TX: BWA BS/TS TX power

G_{TxMax}: BWA BS/TS maximum antenna gain

TX_{FL}: BWA BS/TS transmitter feeder loss

G_{RxMax}: FSS ES maximum antenna gain

$ACLR$: BWA BS/TS adjacent channel leakage ratio; set to 0 for co-channel case

L_p: Penetration loss, only applied to fixed-indoor TS case

$I_{tolerance}$: Maximum interference FSS ES can tolerate.

2.1 FSS system parameters

The FSS system parameters used in this study are chosen from Table 3 in Annex A of this Report. Table 8 summarizes the FSS system parameters.

TABLE 8

FSS system parameters

Frequency	3 400-4 200 MHz (3 600 MHz is used in calculation)		
Bandwidth	40 kHz-72 MHz (7 MHz is used in calculation)		
Earth station antenna radiation patterns	Recommendation ITU-R S.465		
Antenna diameter (m)	1.2	8	32
Maximum antenna gain (dBi)	32.8	47.7	59.8
Antenna centre height (m)	5	5	25
Noise temperature (including the contributions of the antenna, feed and LNA/LNB referred to the input of the LNA/LNB receiver) (K)	100	70	70
Antenna elevation angle (degrees)	5 to 85		
Short-term and long-term maximum permissible Interference level	Recommendations ITU-R SF.1006		

2.2 FSS earth station maximum permissible interference

Recommendation ITU-R SF.1006 recommends a method to estimate the level of maximum permissible interference at the input of FSS earth station. The long-term (20% of the time) maximum permissible interference level is given by:

$$P_r(20\%) = 10 \log(kT_rB) + J - W \qquad \text{dBW}$$

where:

k: Boltzmann’s constant: 1.38×10^{-23} (J/K)

T_r: noise temperature of receiving system (K)

B: reference bandwidth (Hz) (bandwidth of concern to the FSS system over which the interference power can be averaged)

J: ratio (dB) of the permissible long-term interfering power from any one interfering source to the thermal noise power in the FSS system

W: a thermal noise equivalence factor (dB) for interfering emissions in the reference bandwidth.

In this contribution it is assumed that FSS systems use digital modulation, so *J* is –10 dB and *W* is 0 dB. Table 9 gives the levels of maximum permissible interference.

TABLE 9

Level of maximum permissible interference

k **(J/K)**	**T_r** **(K)**	**B** **(Hz)**	**J** **(dB)**	**W** **(dB)**	**M_s** **(dB)**	**N_L** **(dB)**	**P_r(20%)** **(dBm)**	**P_r(0.005%)** **(dBm)**
1.38×10^{-23}	100	7000000	–10	0	2	1	–120.2	–111.5
1.38×10^{-23}	70	7000000	–10	0	2	1	–121.7	–113.0

The interfering BWA system is assumed to have a bandwidth of 7 MHz.

2.3 FSS ES antenna pattern

The antenna pattern for FSS ES in this study is described in Recommendation ITU-R S.465-5.

2.4 BWA system parameters

A BWA system can be deployed in different scenarios. For the case of this study, Base Stations are categorized as specific cellular rural deployment, typical cellular rural deployment, or typical cellular urban deployment. Terminal Stations are used in fixed-outdoor, fixed-indoor, nomadic, or mobile deployments. Two tables in Annex A of this Report summarize the BWA system parameters. This study focuses on some of these scenarios. The BWA system parameters and scenarios related to this study are provided in Table 10.

TABLE 10

BWA system parameters

	Base station		**Terminal station**	
Deployment scenario	**Specific cellular deployment rural**	**Typical cellular deployment urban**	**Fixed-outdoor**	**Fixed-indoor**
TX peak output power (dBm)	43	32	26	26
Channel bandwidth (MHz)	7			
Feeder loss (dB)	3	3	1	1
Peak antenna gain (dBi)	17	9	17	5
Antenna gain pattern	Recommendation ITU-R F.1336	Recommendation ITU-R F.1336	Recommendation ITU-R F.1245	Omnidirectional

TABLE 10 (*end*)

	Base station		**Terminal station**	
Deployment scenario	**Specific cellular deployment rural**	**Typical cellular deployment urban**	**Fixed-outdoor**	**Fixed-indoor**
Antenna 3 dB beamwidth (degrees)	60 (sectorized)	Omnidirectional	24	N/A
Antenna downtilt (degrees)	1	4	N/A	
Antenna height a.g.l. (m)	50	15	10	1.5
e.i.r.p. (dBm)	57	38	42	30
Unwanted emissions	ACLR1 = 51 dB(1) ACLR2 = 87 dB(1) or ACLR1 = 37 dB(2) ACLR2 = 48 dB(2)		ACLR1 = 33 dB(3) ACLR2 = 43 dB(3)	

N/A: Not applicable.

(1) Report ITU-R M.2116-1.

(2) WiMAX Forum Mobile Radio Specification, WMF-T23-005-R015v04 (2010-09-07).

(3) Report ITU-R M.2116-1.

2.5 BWA base station antenna pattern

Two BWA base station antenna patterns are used in this study, which are described in Recommendation ITU-R F.1336-2. The antenna for specific cellular rural deployment is a sectoral antenna with 60° 3-dB beamwidth, while the antenna for typical cellular urban deployment is considered omnidirectional.

The Figures in Annex A of this Report provide the details of the antenna patterns used.

2.6 BWA terminal station antenna pattern

For fixed-outdoor terminal station, the antenna pattern described in Recommendation ITU-R F.1245 is assumed in this study. For fixed-indoor terminal station, the antenna is considered to be omnidirectional. Figure 5 shows the antenna pattern for fixed-out door terminal station.

2.7 BWA base station and terminal station out-of-band emission

Annex A of this Report has spectrum masks for BWA base station and terminal station. The following table gives the ACLR values for base station and terminal station, which are used in this study. ACLR1 and ACLR2 are for the first adjacent channel and the second adjacent channel respectively.

FIGURE 5

Fixed-outdoor terminal station sectoral antenna horizontal pattern

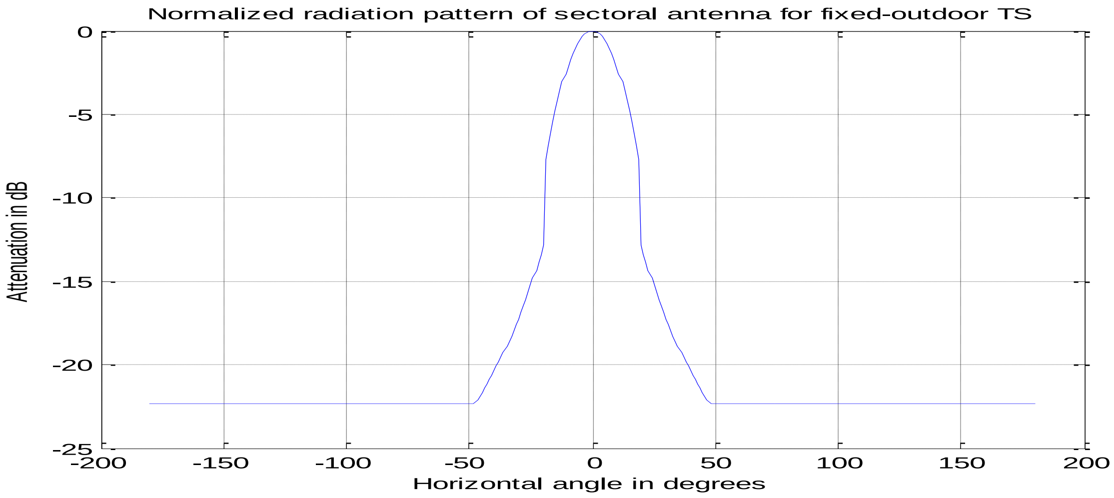


TABLE 11

BWA base station and terminal station ACLR values

		ACLR1 (dB)	ACLR2 (dB)
Base station	Scenario 1	51	87
	Scenario 2	37	48
Terminal station		33	43

Note that base station Scenario 1 assumes that the regulatory Block Edge mask is applied at the band edge channel rather than the system channel minimum requirements.

It should be noted that FSS systems operate a wide range of channel bandwidths. When the bandwidth of a channel used by an FSS system is wider than the 7 MHz bandwidth considered in this study for BWA systems, the impact of interference on the FSS system will be further reduced compared to the results presented in this Report. If the FSS system operates on a channel with a bandwidth narrower than 7 MHz the impact of interference is the same as if the FSS system channel bandwidth was 7 MHz.

2.8 Propagation models

The propagation models in Recommendation ITU-R P.452-13 are used in this study. These models are fairly complicated and use certain equations in Recommendation ITU-R P.676-7. For the sake of brevity, equestions are not reproduced in this contribution.

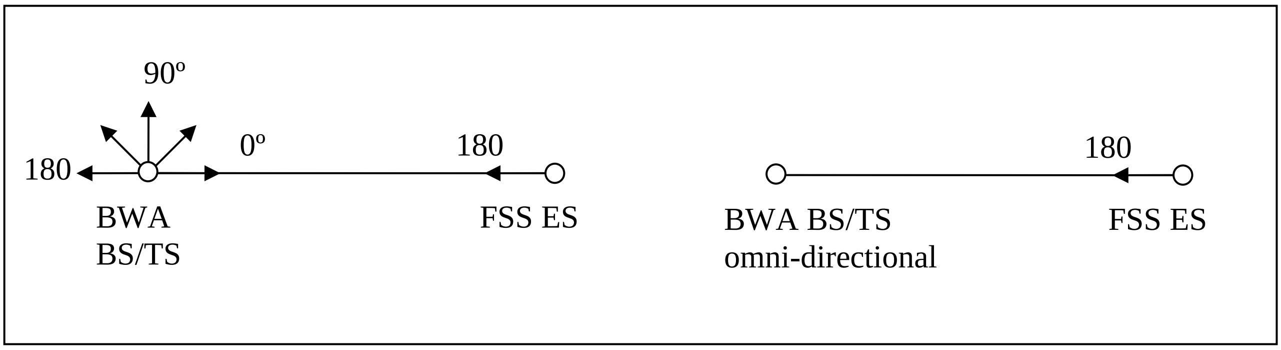
Table 6 in Annex A of this Report summarizes the values of the propagation model parameters used in this study.

3 Results

Figure 6 illustrates the assumption of horizontal locations and horizontal pointing directions of interfering and interfered-with systems.

FIGURE 6

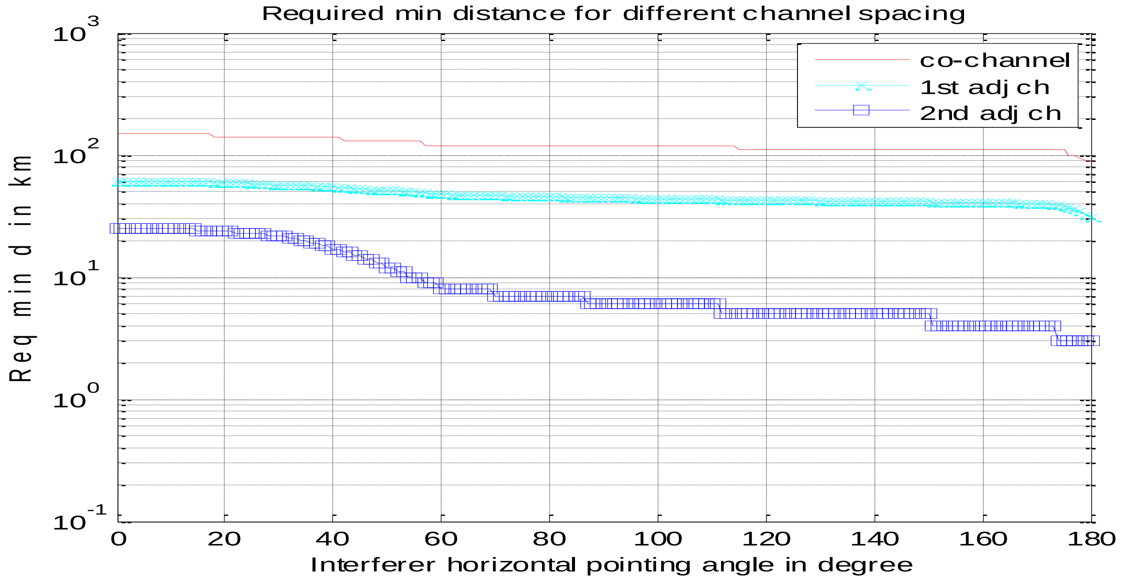
BWA BS/TS and FSS ES horizontal pointing positions

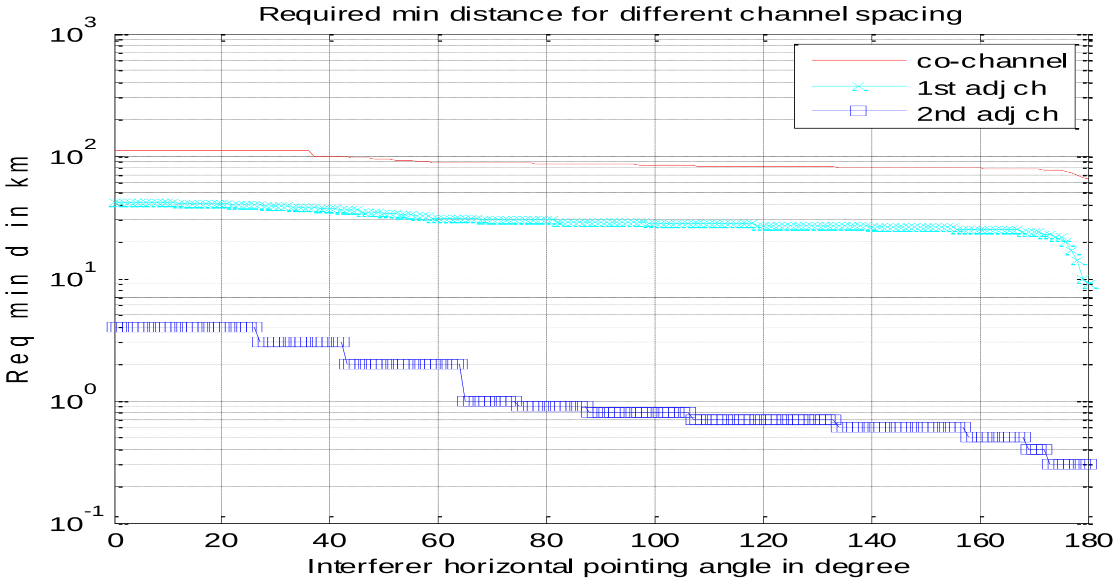


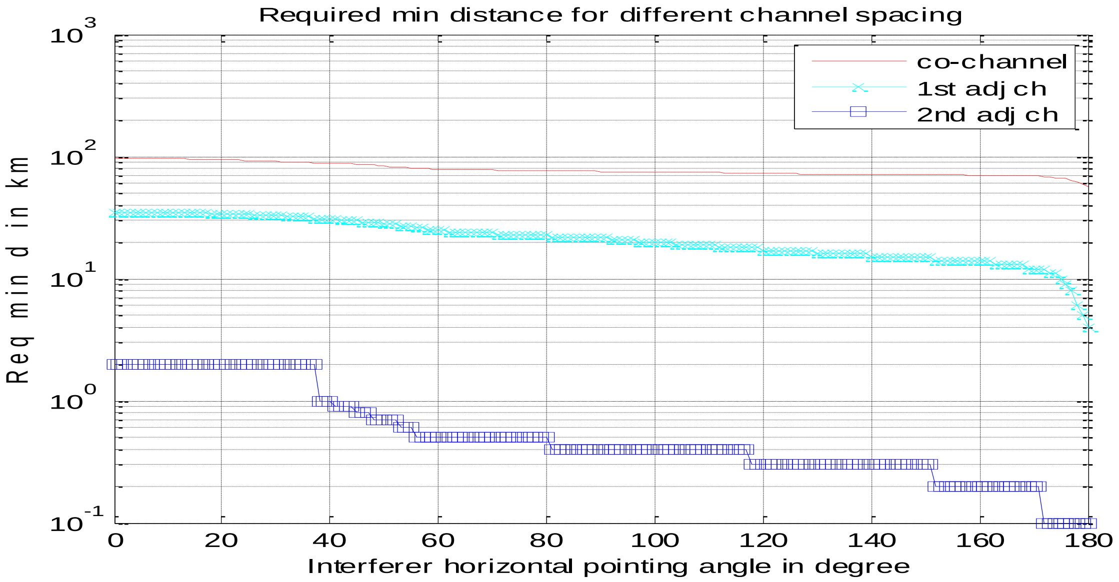
In each figure in this section, there are three curves; "co-channel" indicates two systems are deployed on the same channel, "1st adj ch" indicates two systems are deployed on the adjacent channels without any guardband, "2nd adj ch" indicates two systems are deployed with 7 MHz guardband.

3.1 BWA rural BS interfering with 32 m FSS ES

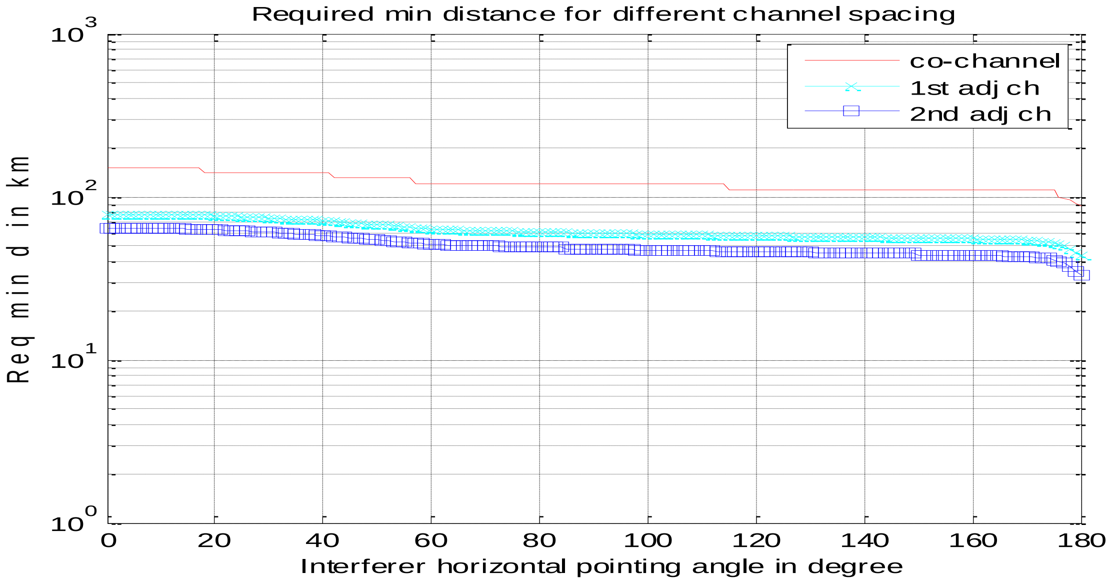
The following three figures show the minimum required distance in km between BWA rural BS with scenario 1 ACLR values and 32 m FSS ES with 5°, 25°, and 50° elevation pointing direction, respectively. The BS antenna horizontal pointing direction is from 0° to 180°.

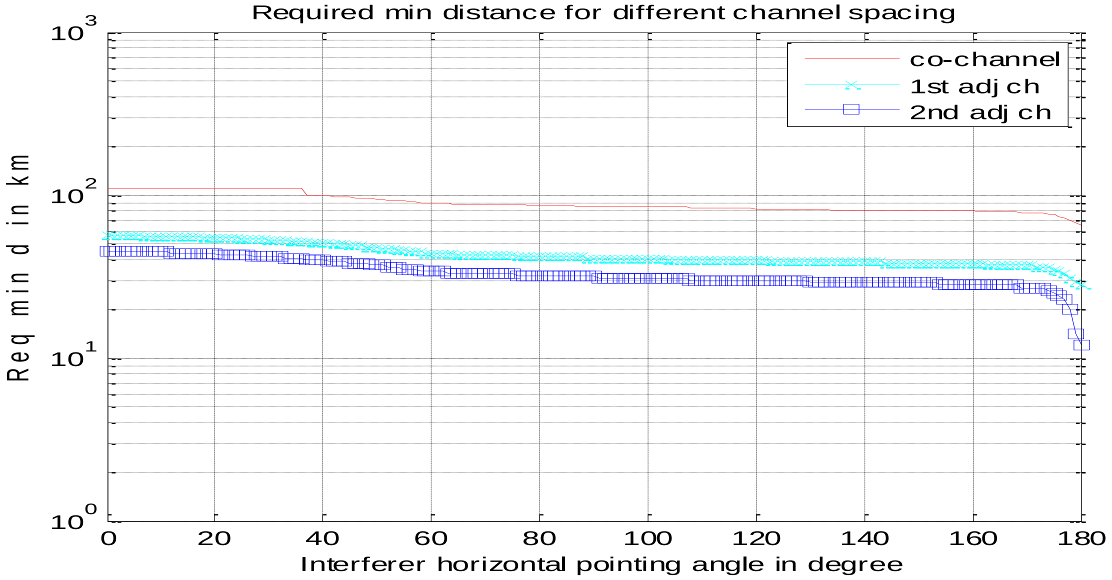


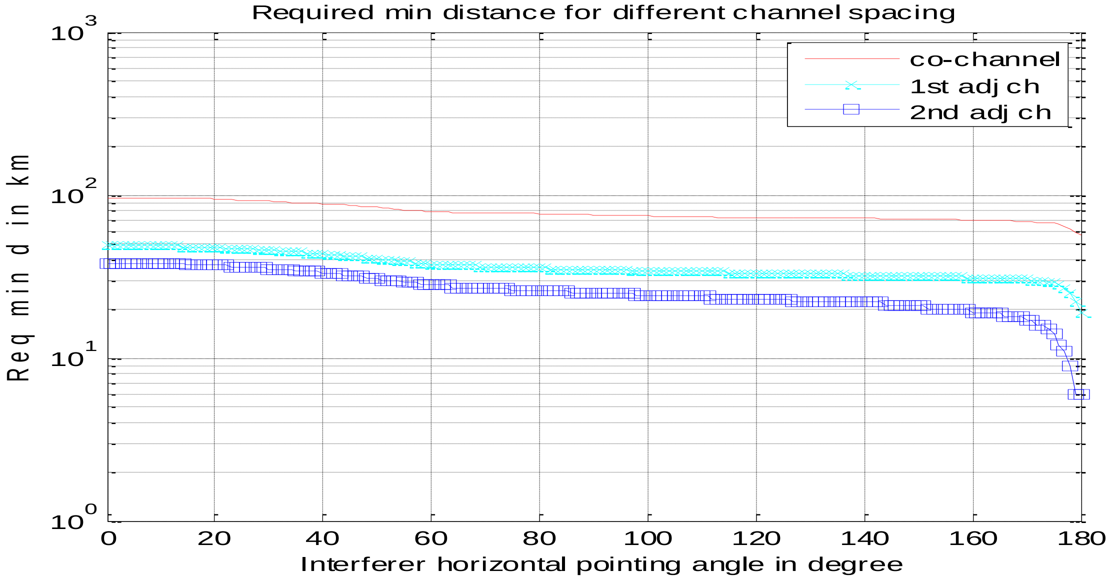




The following three figures show the minimum required distance in km between BWA rural BS with Scenario 2 ACLR values and 32 m FSS ES with 5º, 25º, and 50º elevation pointing direction, respectively. The BS antenna horizontal pointing direction is from 0º to 180º.

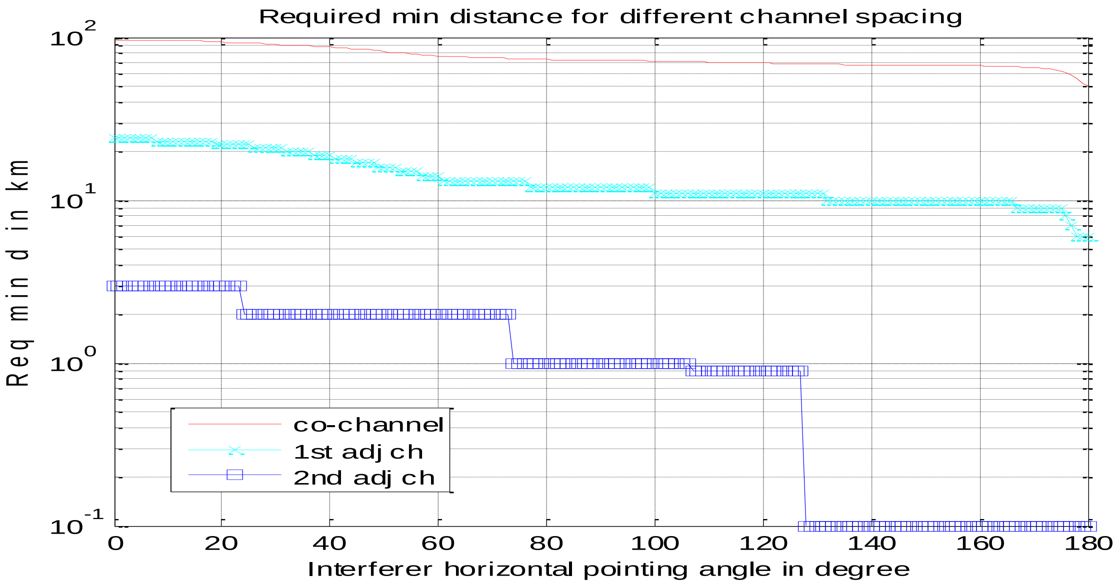

Required min distance for different channel spacing
co-channel
1st adj ch
2nd adj ch
Req min d in km
10^3
10^2
10^1
10^0
0
20
40
60
80
100
120
140
160
180
Interferer horizontal pointing angle in degree

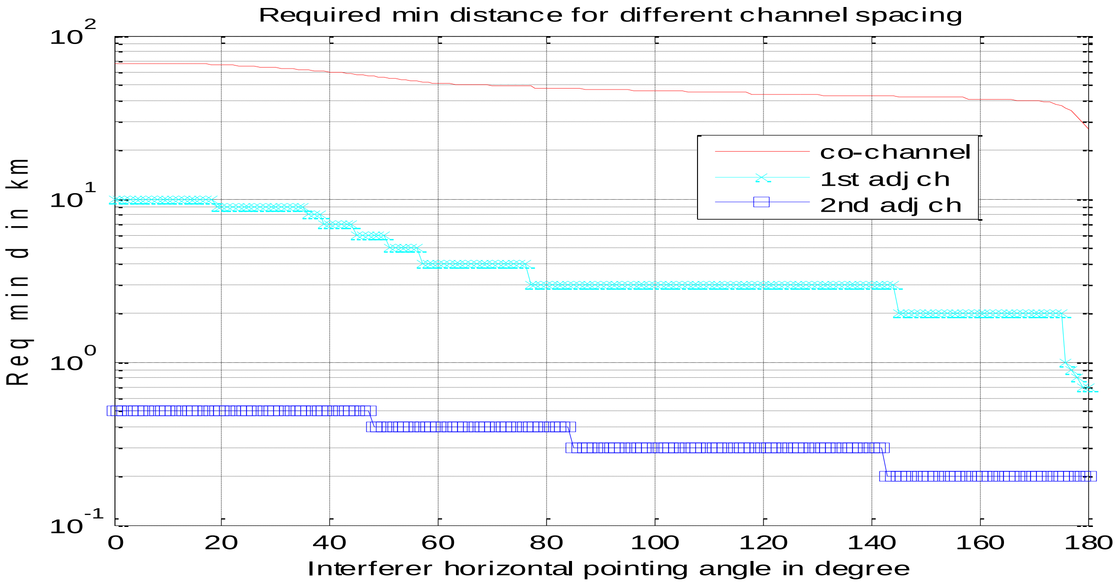

Required min distance for different channel spacing
co-channel
1st adj ch
2nd adj ch
Req min d in km
10^3
10^2
10^1
10^0
0
20
40
60
80
100
120
140
160
180
Interferer horizontal pointing angle in degree

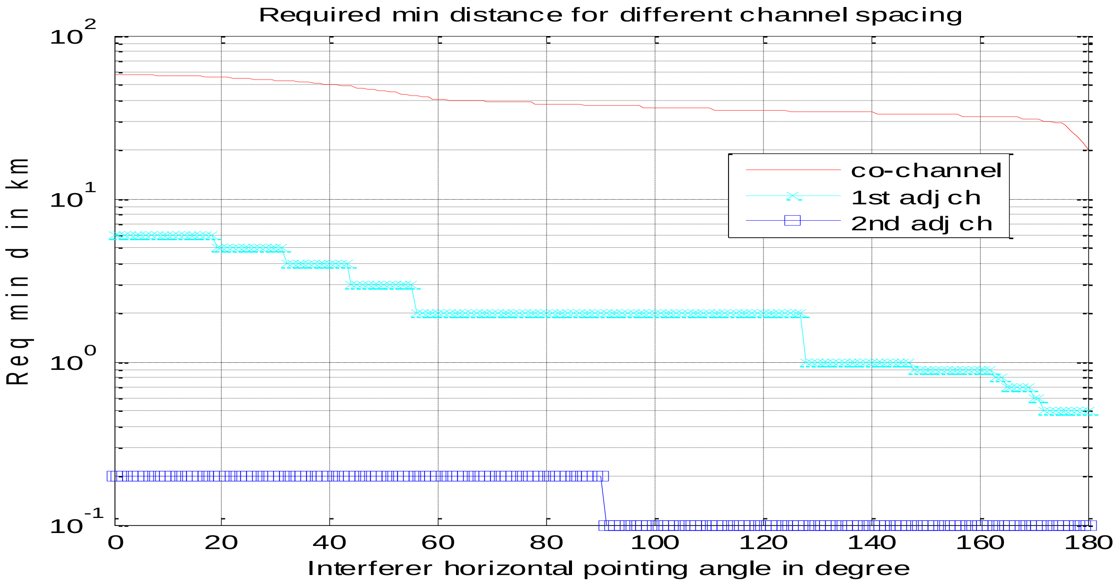

Required min distance for different channel spacing
co-channel
1st adj ch
2nd adj ch
Req min d in km
10^3
10^2
10^1
10^0
0
20
40
60
80
100
120
140
160
180
Interferer horizontal pointing angle in degree

3.2 BWA rural BS interfering with 8 m FSS ES

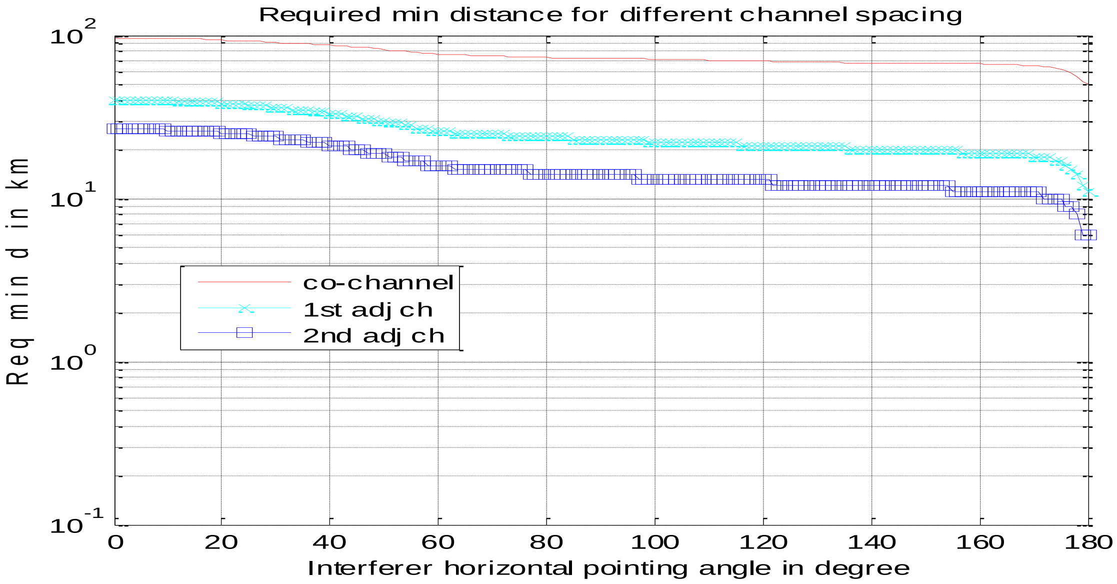
The following three figures show the minimum required distance in km between BWA rural BS with Scenario 1 ACLR values and 8 m FSS ES with 5º, 25º, and 50º elevation pointing direction, respectively. The BS antenna horizontal pointing direction is from 0º to 180º.

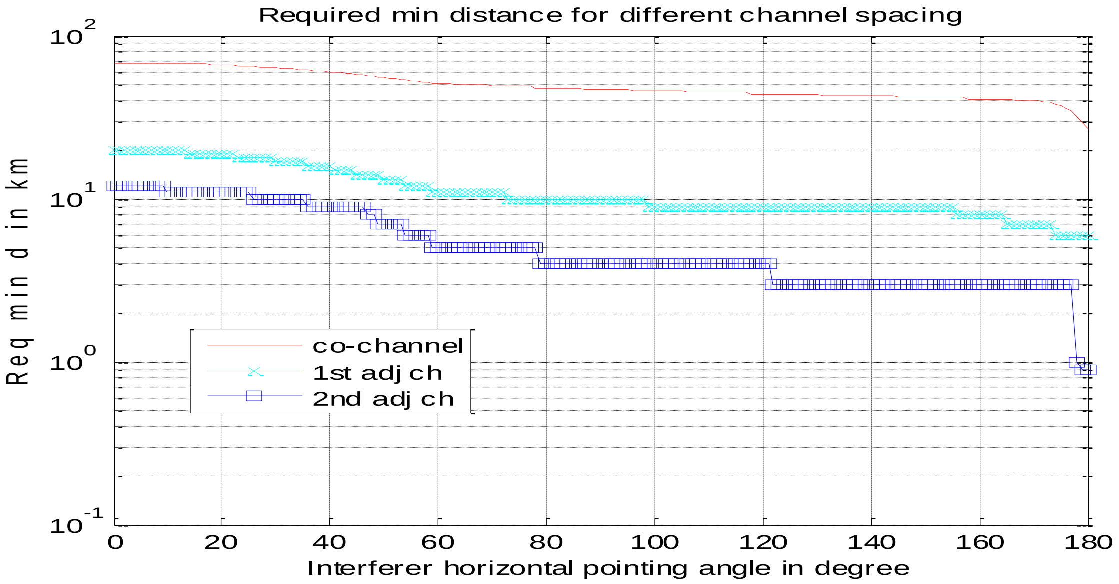


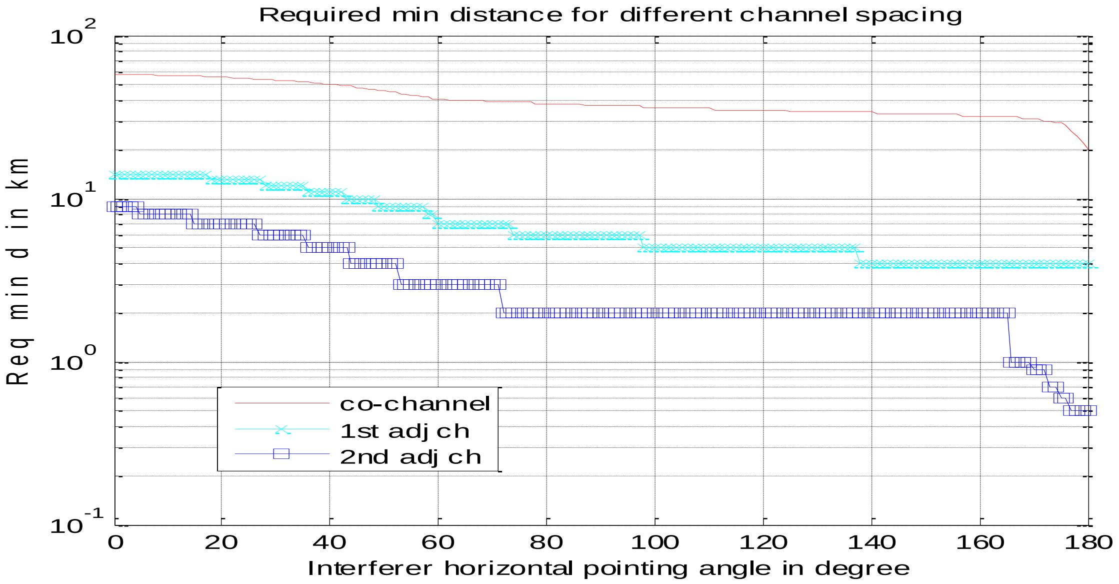




The following three figures show the minimum required distance in km between BWA rural BS with Scenario 2 ACLR values and 8 m FSS ES with 5º, 25º, and 50º elevation pointing direction, respectively. The BS antenna horizontal pointing direction is from 0º to 180º.

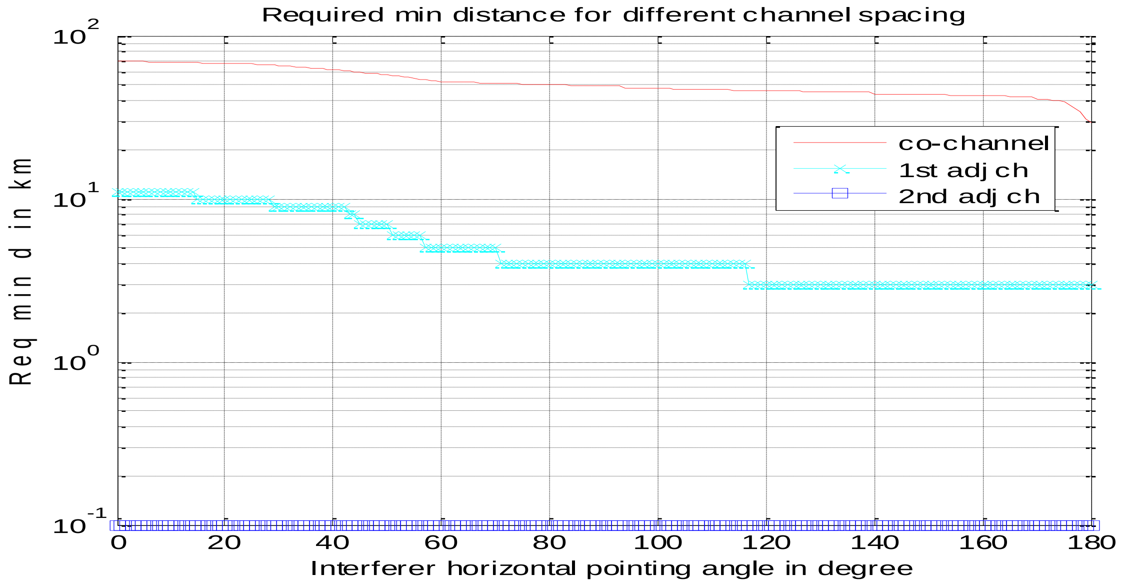


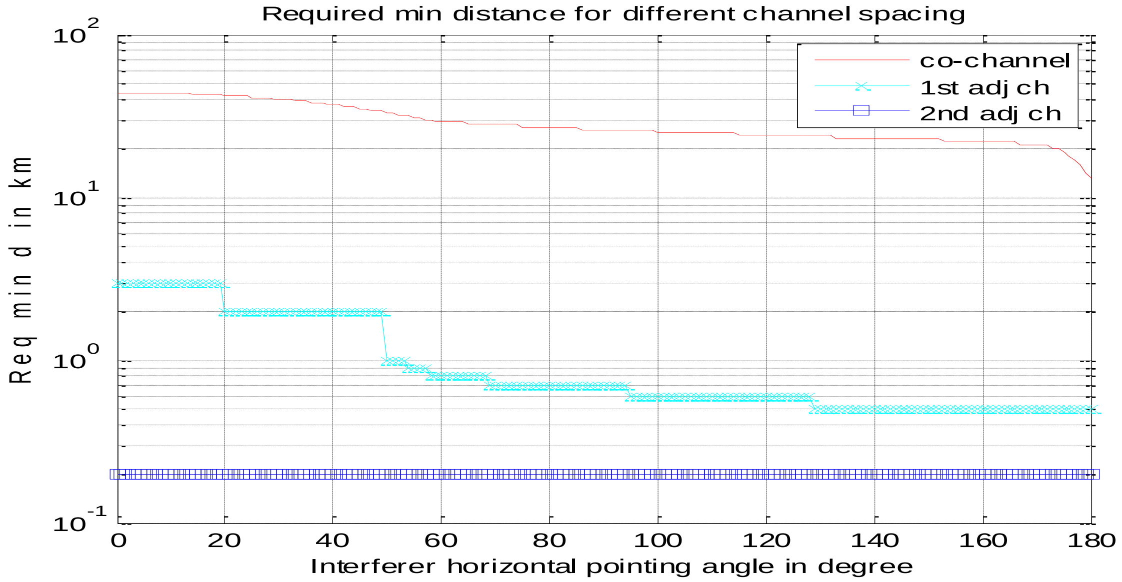


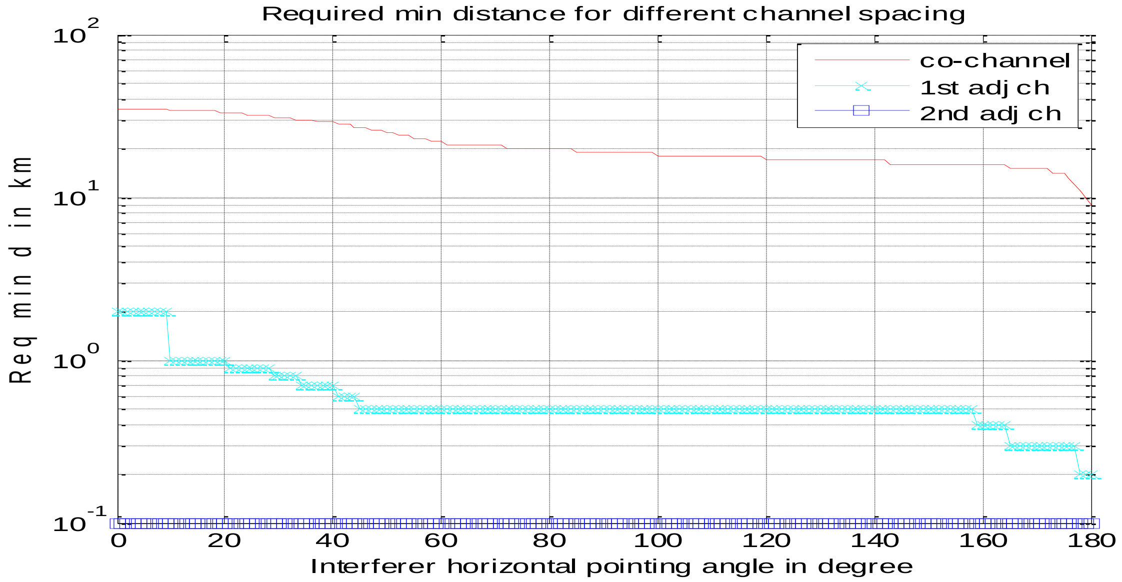


3.3 BWA rural BS interfering with 1.2 m FSS ES

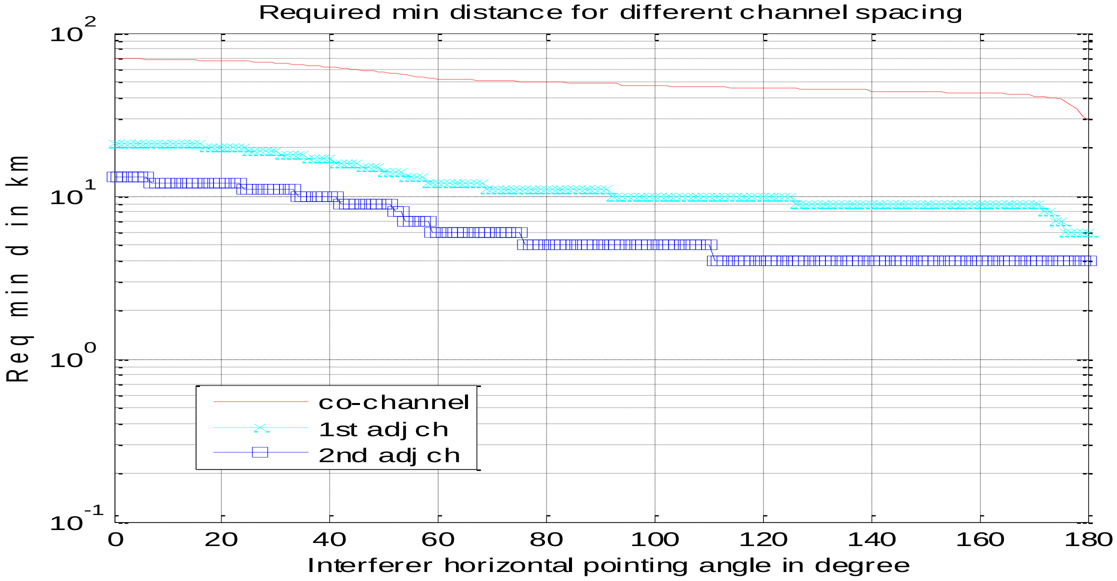
The following three figures show the minimum required distance in km between BWA rural BS with Scenario 1 ACLR values and 1.2 m FSS ES with 5º, 25º, and 50º elevation pointing direction, respectively. The BS antenna horizontal pointing direction is from 0º to 180º.

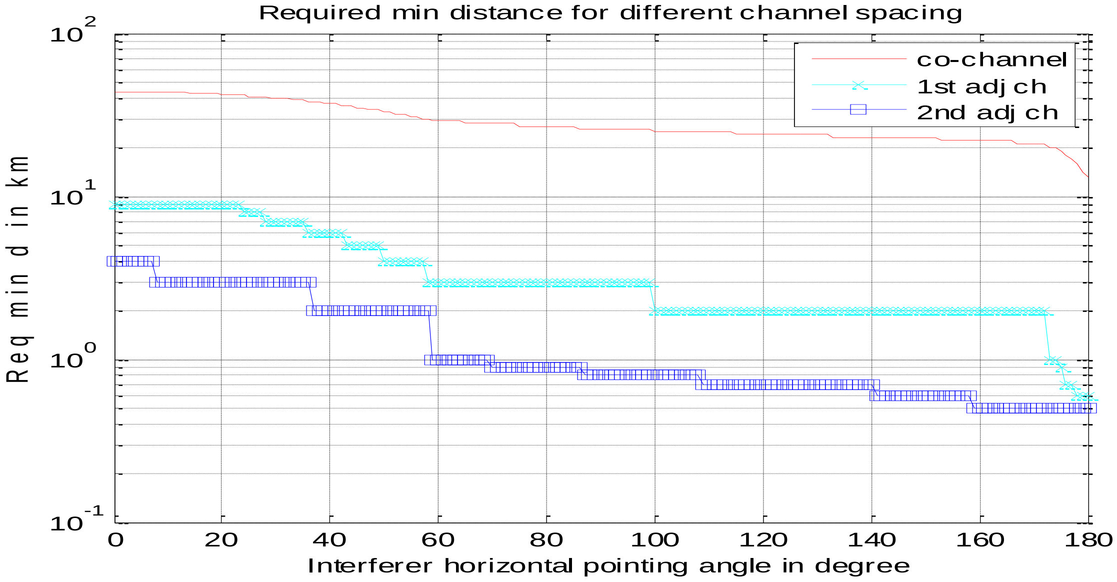

Required min distance for different channel spacing
10^2
10^1
10^0
10^{-1}
Req min d in km
0
20
40
60
80
100
120
140
160
180
Interferer horizontal pointing angle in degree
co-channel
1st adj ch
2nd adj ch

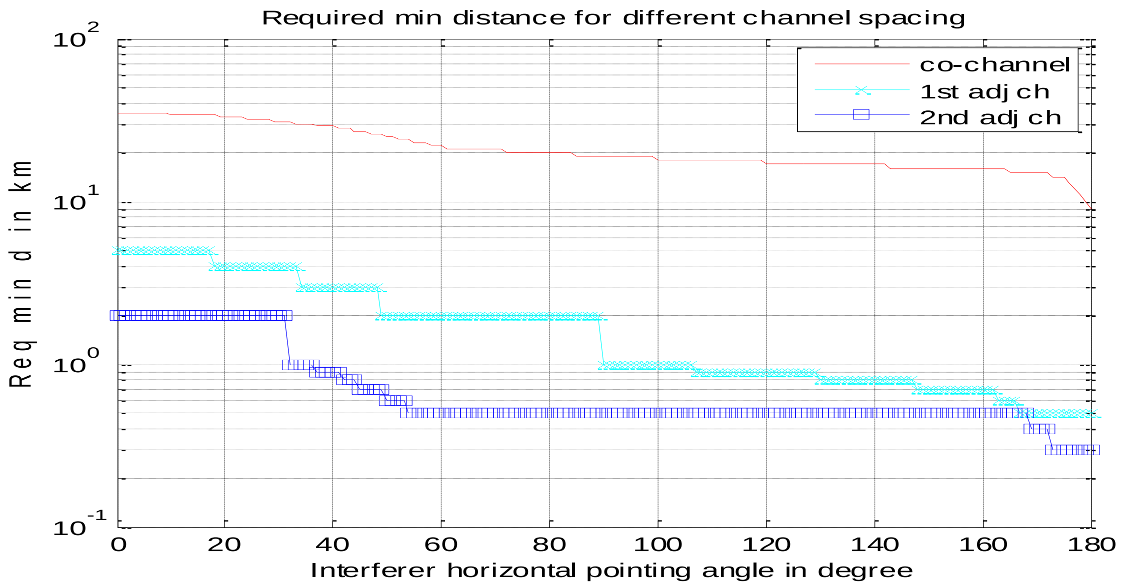

Required min distance for different channel spacing
10^2
10^1
10^0
10^{-1}
Req min d in km
0
20
40
60
80
100
120
140
160
180
Interferer horizontal pointing angle in degree
co-channel
1st adj ch
2nd adj ch


Required min distance for different channel spacing
10^2
10^1
10^0
10^{-1}
Req min d in km
0
20
40
60
80
100
120
140
160
180
Interferer horizontal pointing angle in degree
co-channel
1st adj ch
2nd adj ch

The following three figures show the minimum required distance in km between BWA rural BS with Scenario 2 ACLR values and 1.2 m FSS ES with 5º, 25º, and 50º elevation pointing direction, respectively. The BS antenna horizontal pointing direction is from 0º to 180º.

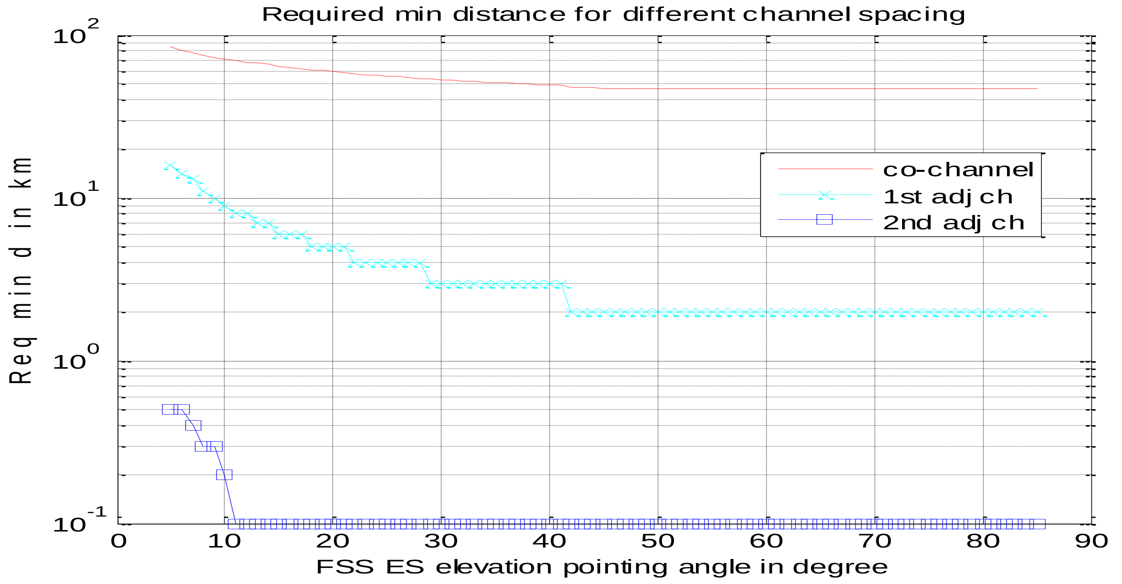




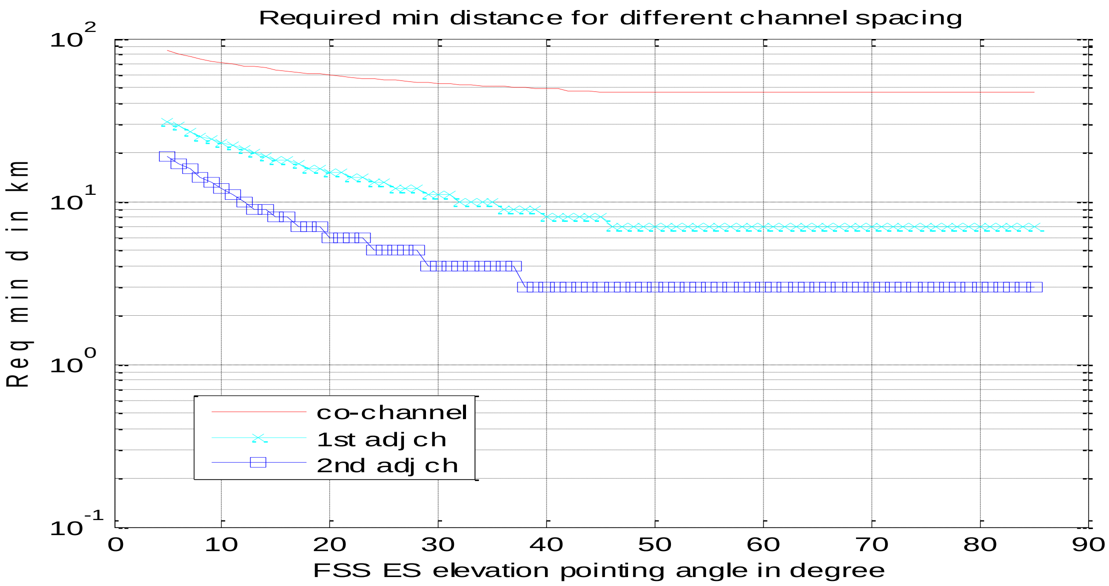


3.4 BWA urban BS interfering with 32 m FSS ES

The following figure shows the minimum required distance in km between BWA urban BS with Scenario 1 ACLR values and 32 m FSS ES with 5° to 85° elevation pointing direction.

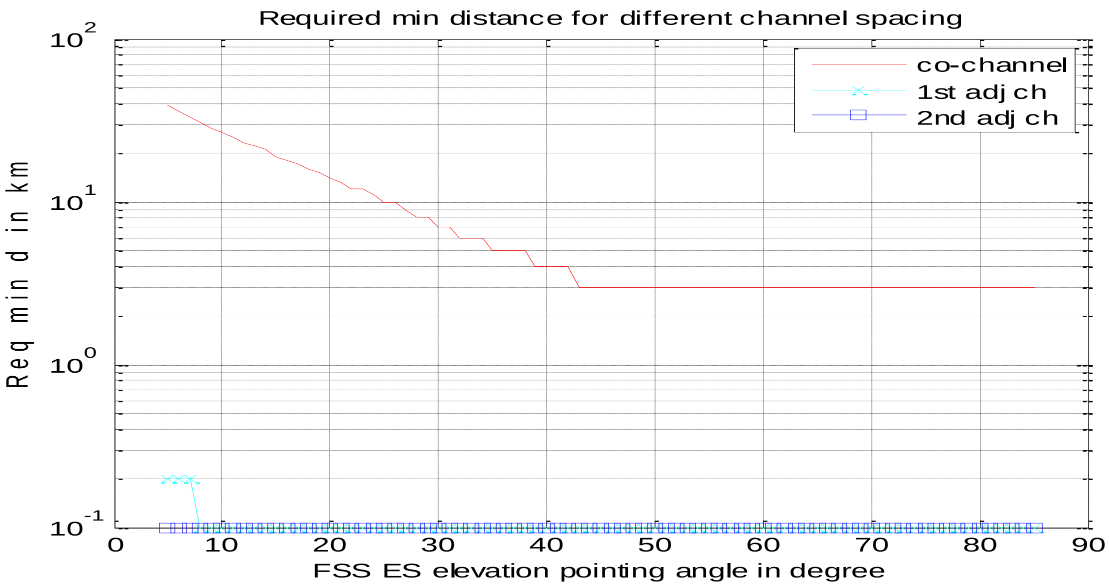


The following figure shows the minimum required distance in km between BWA urban BS with Scenario 2 ACLR values and 32 m FSS ES with 5° to 85° elevation pointing direction.

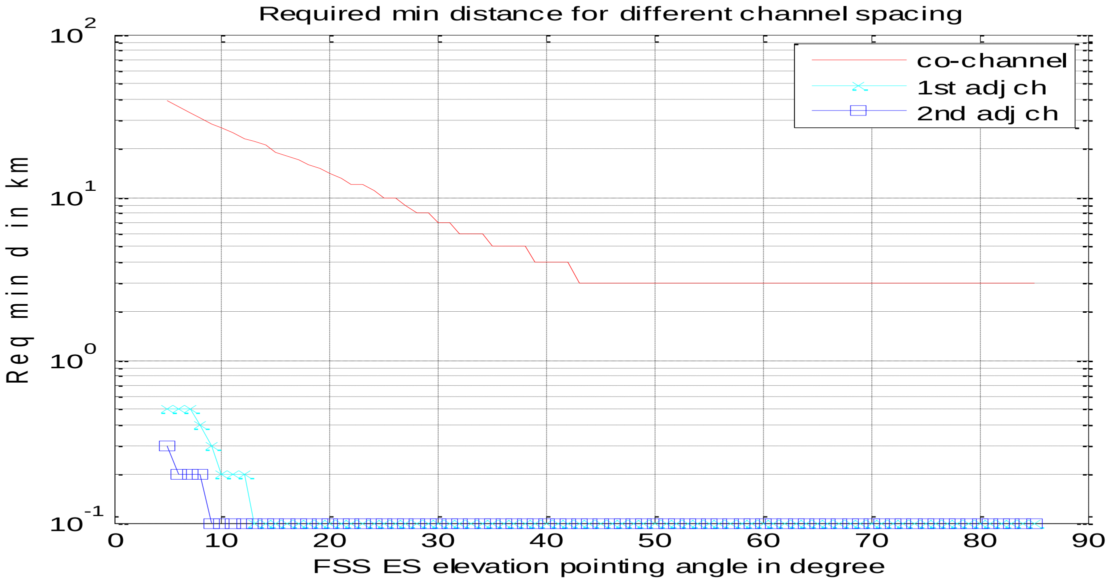


3.5 BWA urban BS interfering with 8 m FSS ES

The following figure shows the minimum required distance in km between BWA urban BS with Scenario 1 ACLR values and 8 m FSS ES with 5° to 85° elevation pointing direction.



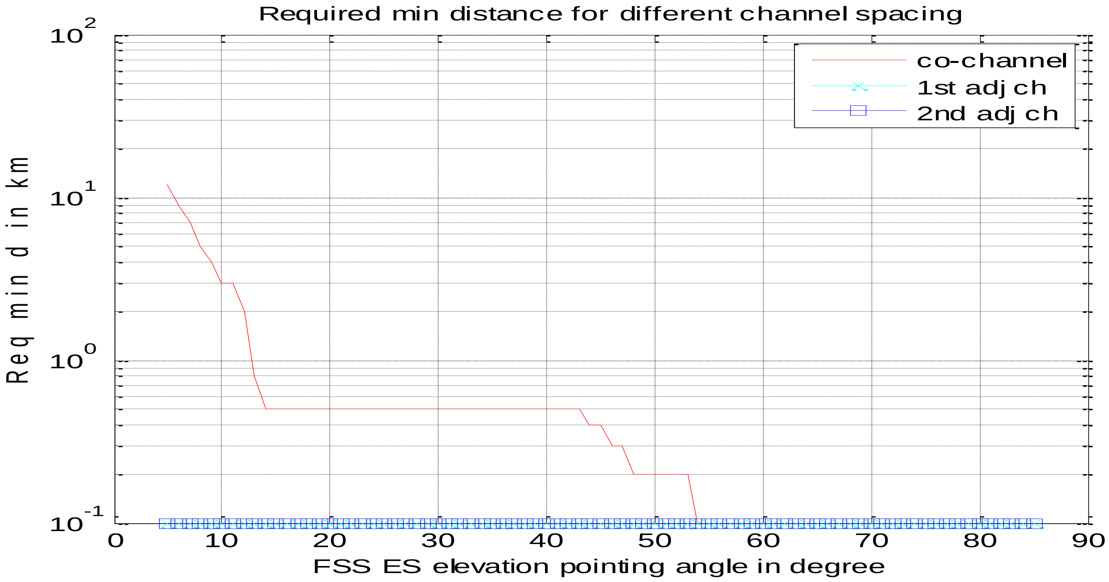
The following figure shows the minimum required distance in km between BWA urban BS with Scenario 2 ACLR values and 8 m FSS ES with 5° to 85° elevation pointing direction.



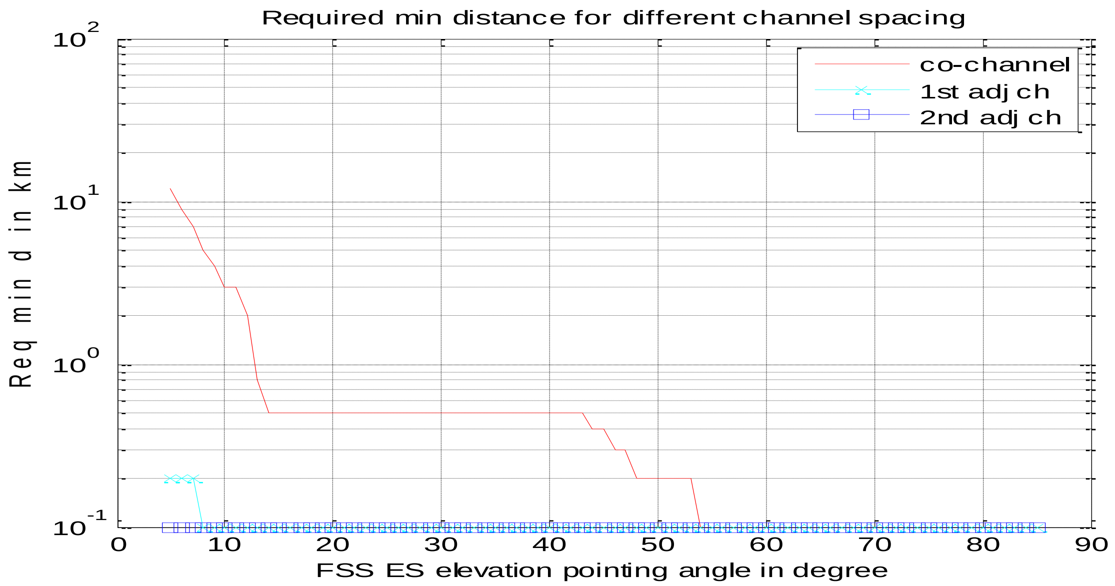
Note that distances below 100 m are not considered in the calculation of required separation distances.

3.6 BWA urban BS interfering with 1.2 m FSS ES

The following figure shows the minimum required distance in km between BWA urban BS with Scenario 1 ACLR values and 1.2 m FSS ES with 5° to 85° elevation pointing direction.



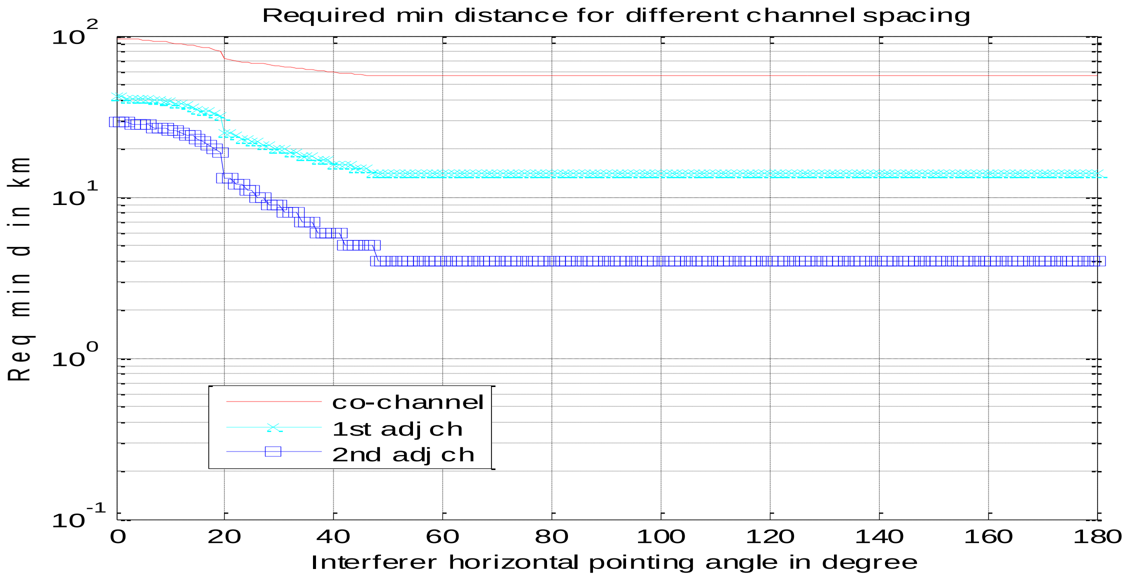
The following figure shows the minimum required distance in km between BWA urban BS with Scenario 2 ACLR values and 1.2 m FSS ES with 5° to 85° elevation pointing direction.

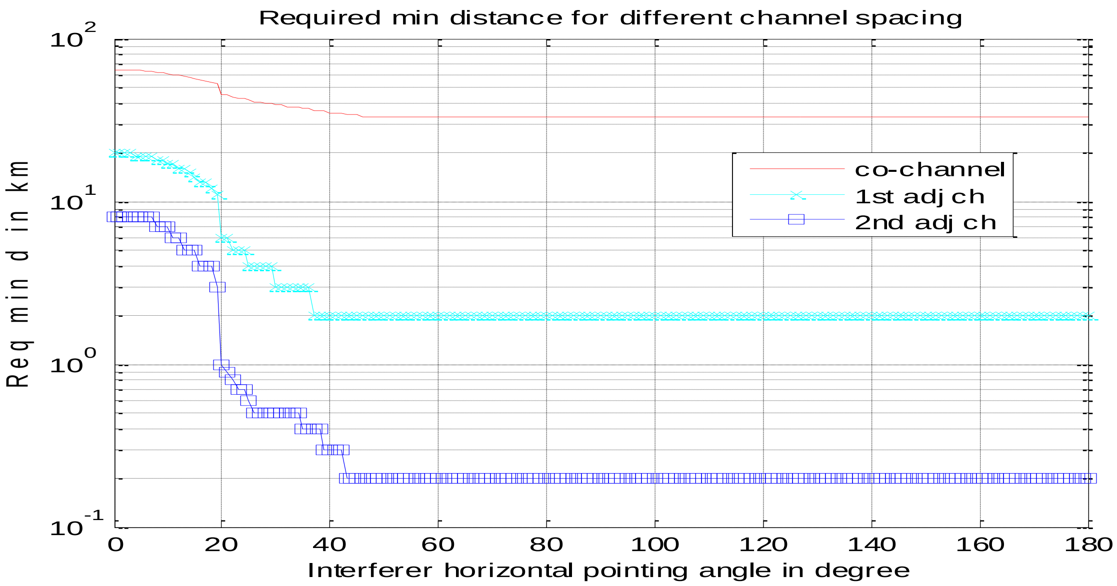


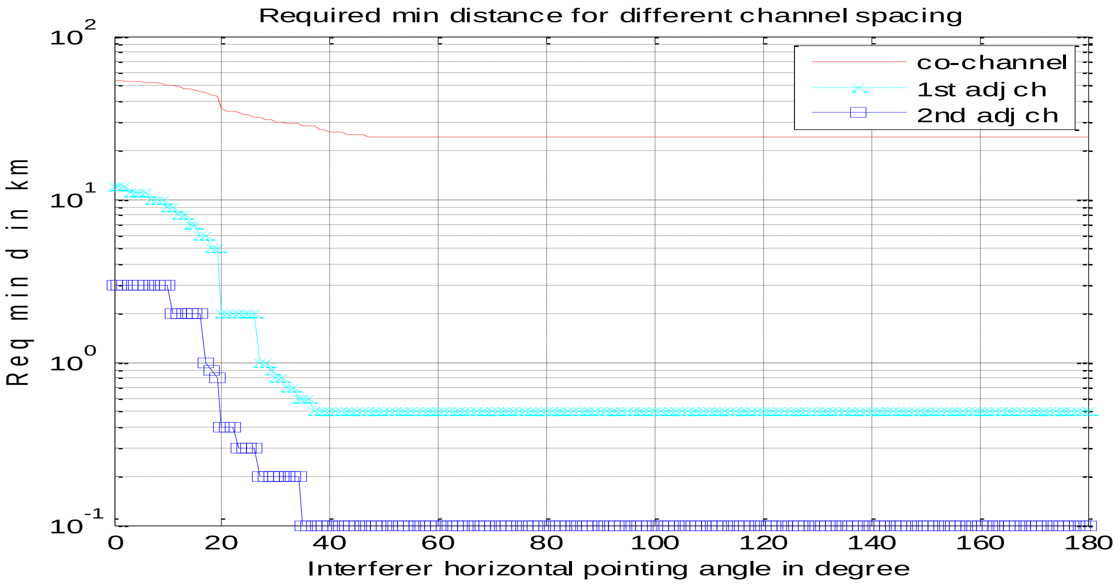
Note that distances below 100 m are not considered in the calculation of required separation distances.

3.7 BWA fixed-outdoor TS interfering with 32 m FSS ES

The following three figures show the minimum required distance in km between BWA fixed-outdoor TS and 32 m FSS ES with 5º, 25º, and 50º elevation pointing direction, respectively. The TS antenna horizontal pointing direction is from 0º to 180º.



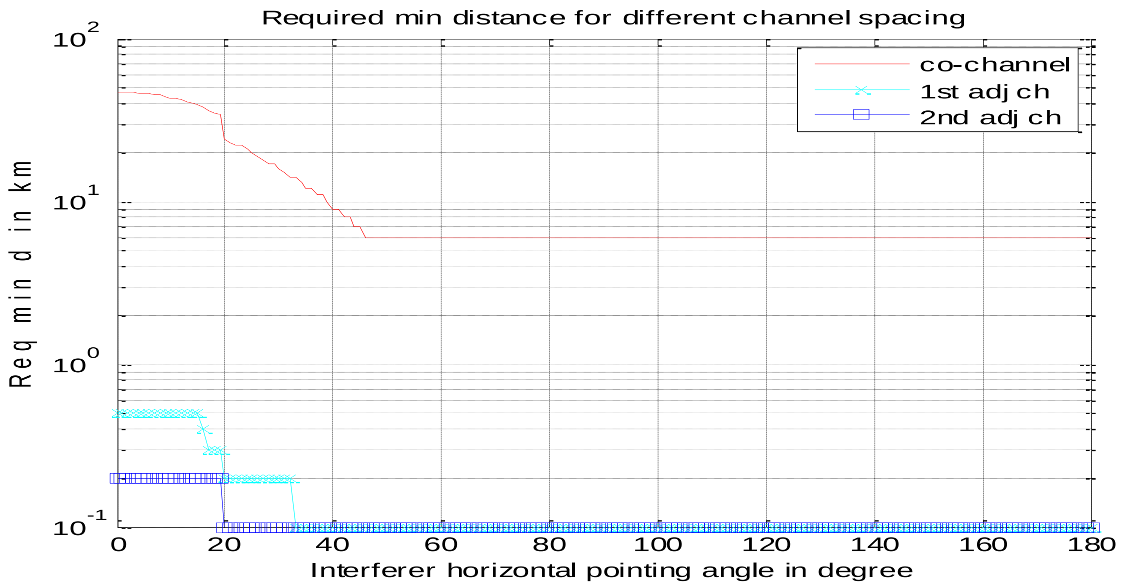


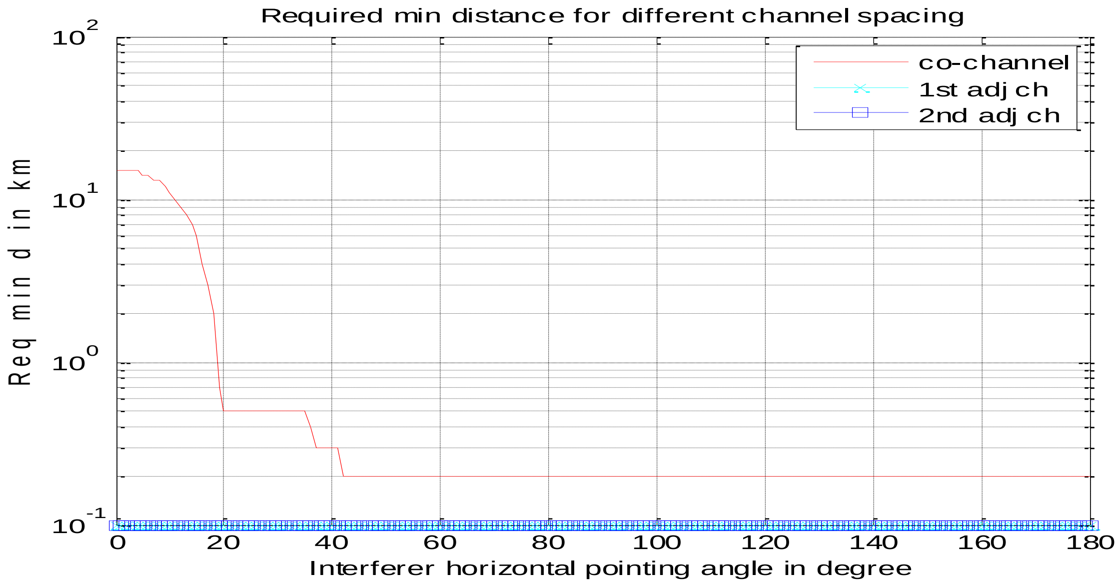


Note that distances below 100 m are not considered in the calculation of required separation distances.

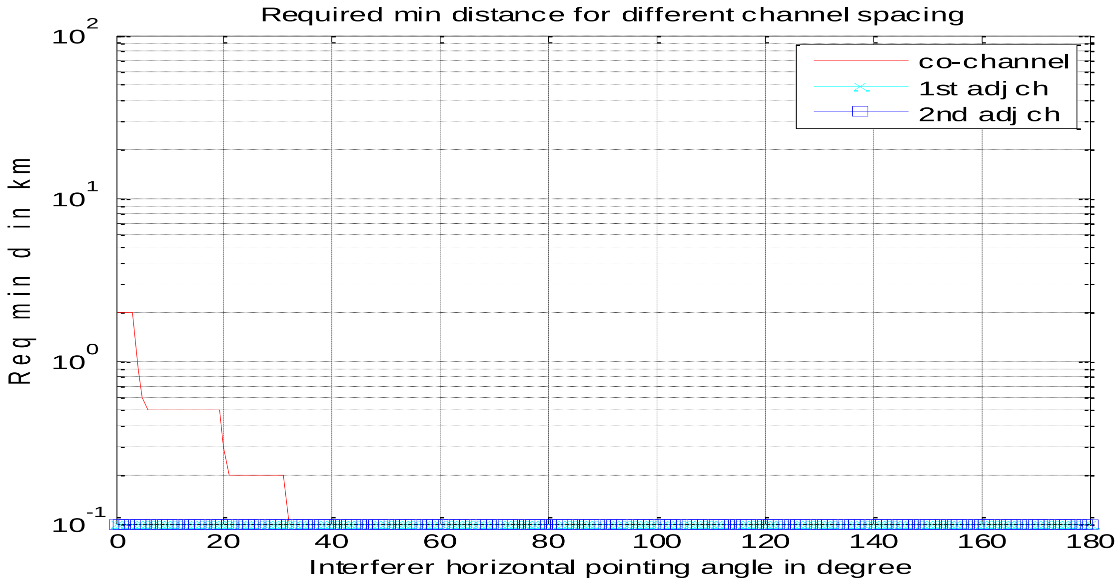
3.8 BWA fixed-outdoor TS interfering with 8 m FSS ES

The following three figures show the minimum required distance in km between BWA fixed-outdoor TS and 8 m FSS ES with 5°, 25°, and 50° elevation pointing direction, respectively. The TS antenna horizontal pointing direction is from 0° to 180°.


Required min distance for different channel spacing
Req min d in km
Interferer horizontal pointing angle in degree
co-channel
1st adj ch
2nd adj ch
10^2
10^1
10^0
10^{-1}
0
20
40
60
80
100
120
140
160
180


Required min distance for different channel spacing
Req min d in km
Interferer horizontal pointing angle in degree
co-channel
1st adj ch
2nd adj ch
10^2
10^1
10^0
10^{-1}
0
20
40
60
80
100
120
140
160
180

f

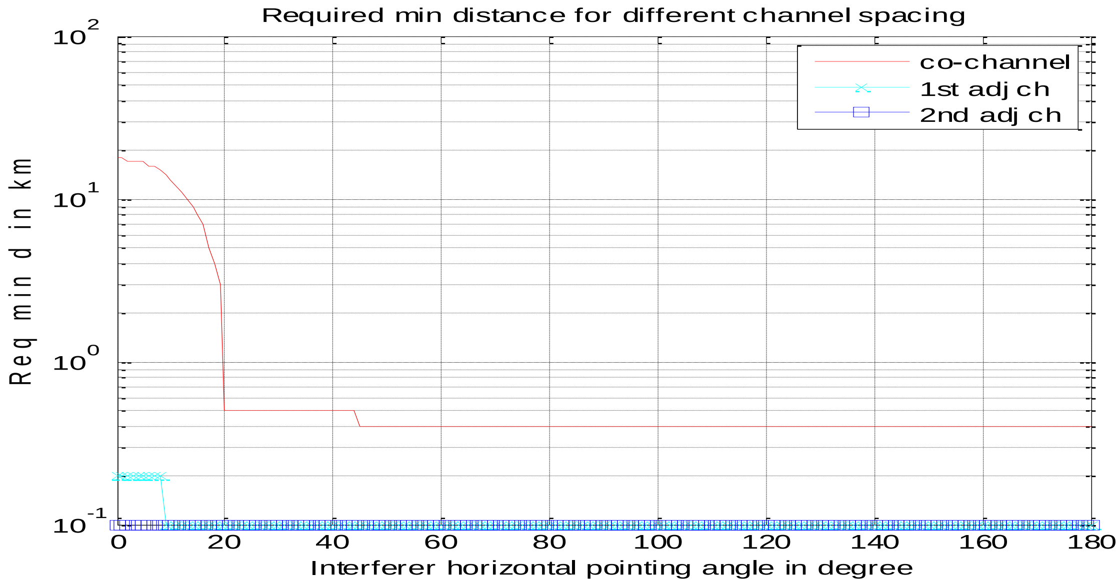

Required min distance for different channel spacing
Req min d in km
Interferer horizontal pointing angle in degree
co-channel
1st adj ch
2nd adj ch
10^2
10^1
10^0
10^{-1}
0
20
40
60
80
100
120
140
160
180

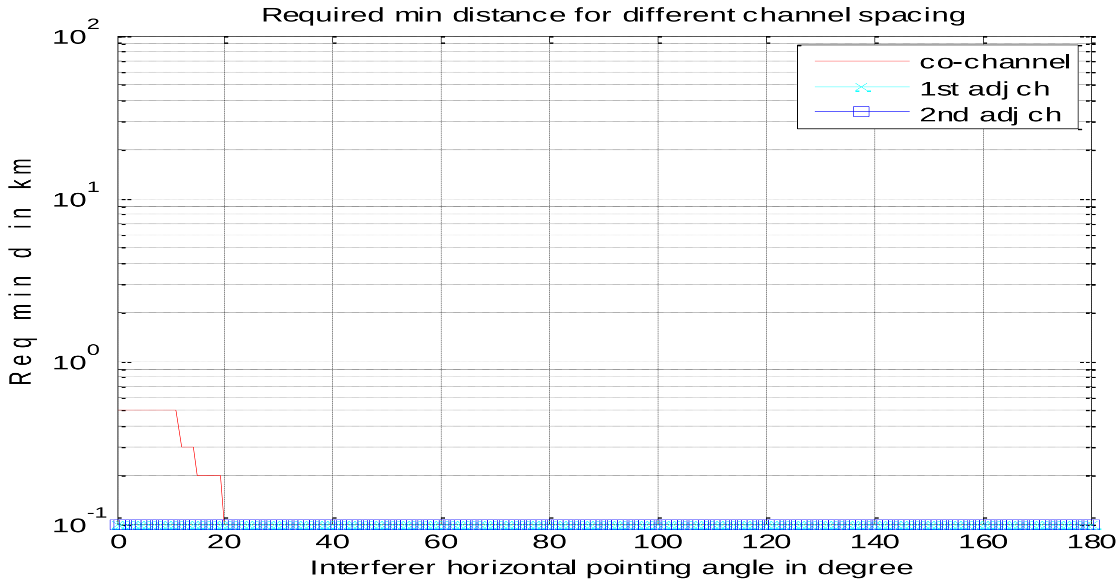
f

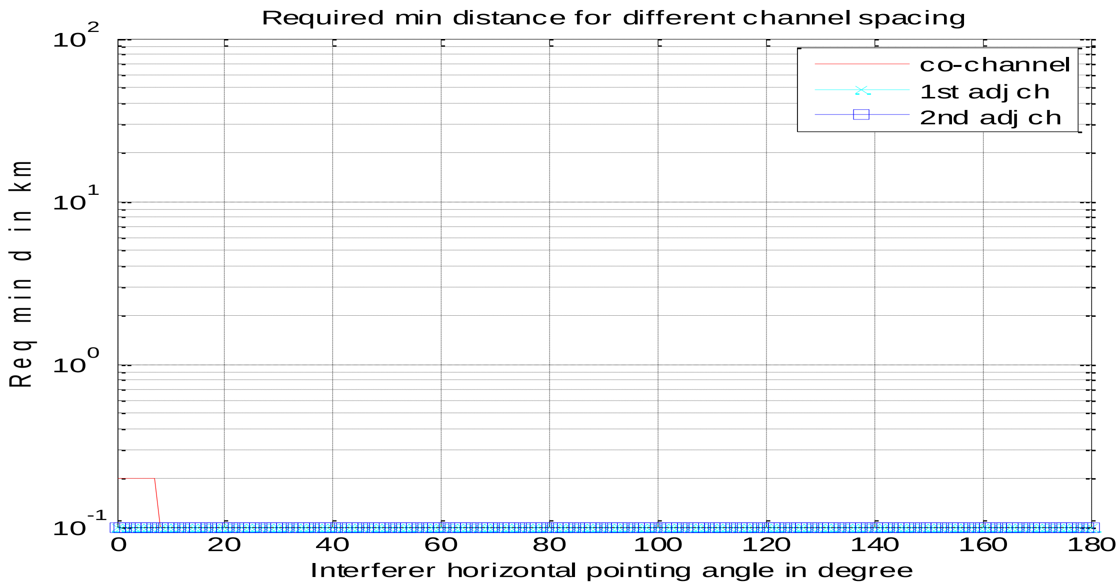
Note that distances below 100 m are not considered in the calculation of required separation distances.

3.9 BWA fixed-outdoor TS interfering with 1.2 m FSS ES

The following three figures show the minimum required distance in km between BWA fixed-outdoor TS and 1.2 m FSS ES with 5º, 25º, and 50º elevation pointing direction, respectively. The TS antenna horizontal pointing direction is from 0º to 180º.



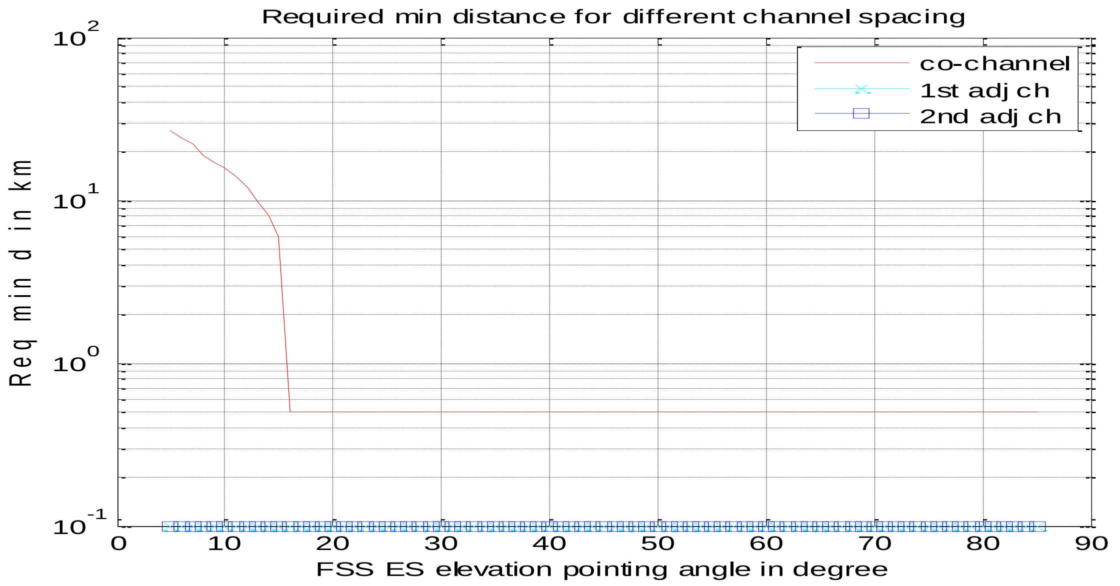




Note that distances below 100 m are not considered in the calculation of required separation distances.

3.10 BWA fixed-indoor TS interfering with 32 m FSS ES

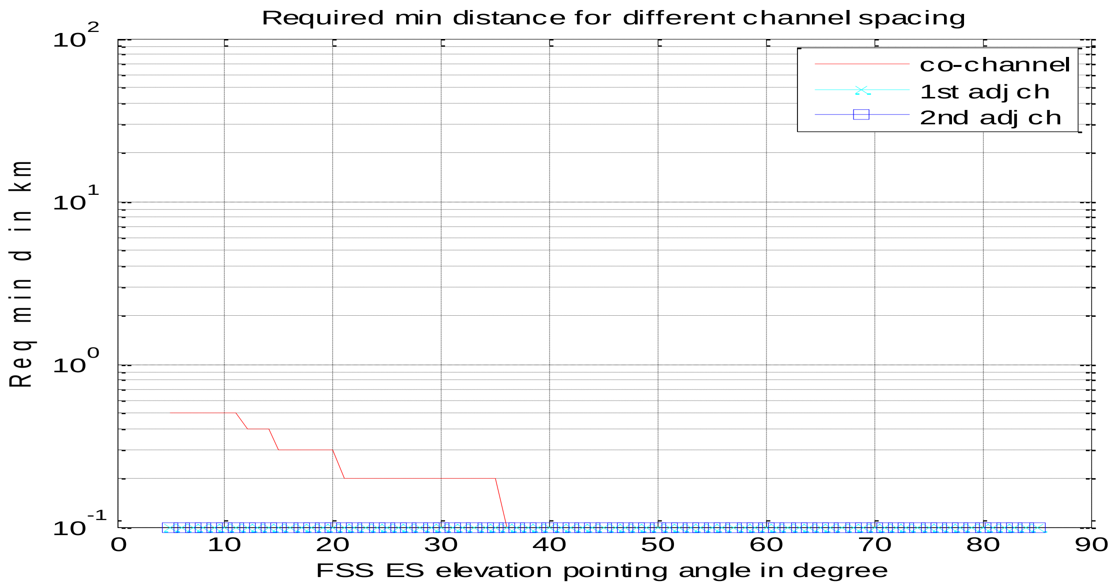
The following figure shows the minimum required distance in km between BWA fixed-indoor TS and 32 m FSS ES with 5º to 85º elevation pointing direction.



Note that distances below 100 m are not considered in the calculation of required separation distances.

3.11 BWA fixed-indoor TS interfering with 8 m FSS ES

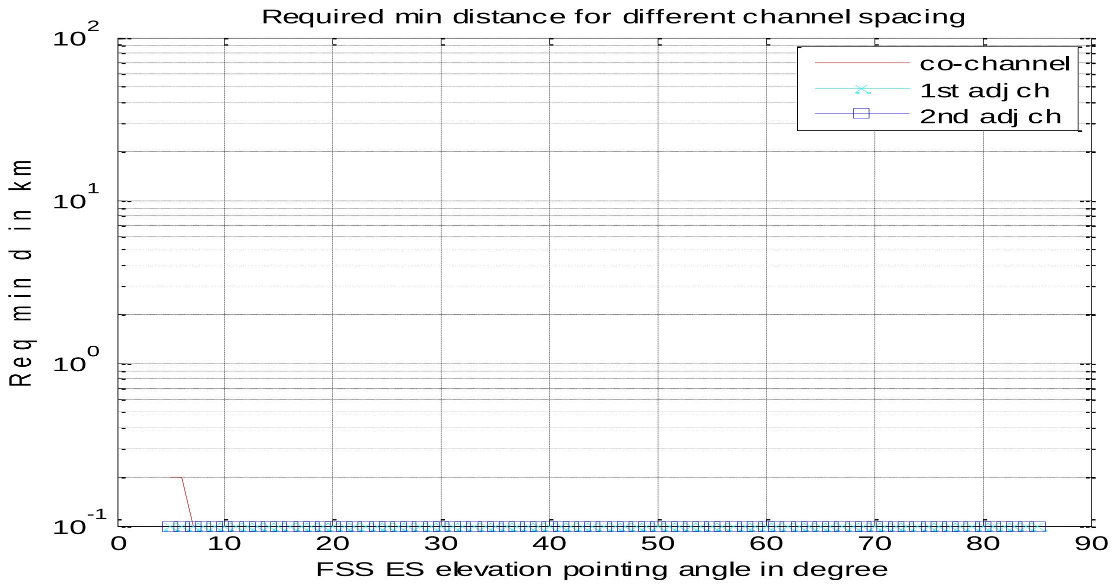
The following figure shows the minimum required distance in km between BWA fixed-indoor TS and 8 m FSS ES with 5º to 85º elevation pointing direction.



Note that distances below 100 m are not considered in the calculation of required separation distances.

3.12 BWA fixed-indoor TS interfering with 1.2 m FSS ES

The following figure shows the minimum required distance in km between BWA fixed-indoor TS and 1.2 m FSS ES with 5° to 85° elevation pointing direction.



Note that distances below 100 m are not considered in the calculation of required separation distances.

4 Conclusions

Successful coexistence of BWA systems and FSS systems in the 3 400-4 200 MHz band depends on their channel allocations and their deployment scenarios, as well as on the propagation environments. The results in this study highlight the cases where they can coexist versus the cases that other measures need to be taken to facilitate coexistence.

BWA rural BS interfering with 32 m FSS ES For co-channel allocation the minimum required distance can be as large as 150 km when their antennas point to each other horizontally and the FSS ES antenna elevation angle is only 5º. This is the worst scenario in this study. The minimum required distance reduces, as the gap between their channel allocations becomes larger or as the FSS ES antenna elevation angle increases or as the BS antenna points away from the FSS ES. The minimum required distance can smaller than 100 m, when the BS antenna points 180º away from FSS ES and the FSS ES elevation angle is higher than 48º with 7 MHz channel allocation gap.

BWA rural BS interfering with 8 m FSS ES For co-channel allocation the minimum required distance can be as large as 96 km when their antennas point to each other horizontally and the FSS ES antenna elevation angle is only 5º. The minimum required distance reduces, as the gap between their channel allocations becomes larger or as the FSS ES antenna elevation angle increases or as the BS antenna points away from the FSS ES. The minimum required distance can be smaller than 100 m.

BWA rural BS interfering with 1.2 m FSS ES For co-channel allocation the minimum required distance can be as large as 70 km when their antennas point to each other horizontally and the FSS ES antenna elevation angle is only 5º. The minimum required distance reduces, as the gap between their channel allocations becomes larger or as the FSS ES antenna elevation angle increases or as the BS antenna points away from the FSS ES. The minimum required distance can be smaller than 100 m.

BWA urban BS interfering with 32 m FSS ES For co-channel allocation the minimum required distance can be as large as 84 km when the FSS ES antenna elevation angle is only 5º. The minimum required distance reduces, as the gap between their channel allocations becomes larger or as the FSS ES antenna elevation angle increases. The minimum required distance can smaller than 100 m.

BWA urban BS interfering with 8 m FSS ES For co-channel allocation the minimum required distance can be as large as 39 km when the FSS ES antenna elevation angle is only 5º. The minimum required distance reduces, as the gap between their channel allocations becomes larger or as the FSS ES antenna elevation angle increases. The minimum required distance can smaller than 100 m.

BWA urban BS interfering with 1.2 m FSS ES The minimum required distance is 12 km when these two systems are deployed co-channel and when the FSS ES antenna elevation angle is only 5º. The minimum required distance can be smaller than 100 m.

BWA fixed-outdoor TS interfering with 32 m FSS ES For co-channel allocation the minimum required distance can be as large as 95 km when their antennas point to each other horizontally and the FSS ES antenna elevation angle is only 5º. The minimum required distance reduces, as the gap between their channel allocations becomes larger or as the FSS ES antenna elevation angle increases or as the BS antenna points away from the FSS ES. The minimum required distance can be less than100 m for some cases.

BWA fixed-outdoor TS interfering with 8 m FSS ES For co-channel allocation the minimum required distance can be as large as 47 km when their antennas point to each other horizontally and the FSS ES antenna elevation angle is only 5º. The minimum required distance reduces, as the gap between their channel allocations becomes larger or as the FSS ES antenna elevation angle increases or as the BS antenna points away from the FSS ES. The minimum required distance can be less than 1 km for most cases and it is less than 100 m for some cases.

BWA fixed-outdoor TS interfering with 1.2 m FSS ES For co-channel allocation the minimum required distance can be as large as 18 km when their antennas point to each other horizontally and the FSS ES antenna elevation angle is only 5º. For most of the other cases, the minimum required distance can be less than 1 km and it is less than 100 m for some cases.

BWA fixed-indoor TS interfering with 32 m FSS ES For co-channel allocation the minimum required distance can be as large as 27 km when the FSS ES antenna elevation angle is only 5º. The minimum required distance reduces, as the gap between their channel allocations becomes larger or as the FSS ES antenna elevation angle increases. The minimum required distance can be less than 100 m for most cases.

BWA fixed-indoor TS interfering with 8 m FSS ES For co-channel allocation the minimum required distance can be as large as 500 m when the FSS ES antenna elevation angle is very small. For most of the other cases the minimum required distance is less than 100 m.

BWA fixed-indoor TS interfering with 1.2 m FSS ES The minimum required distance is 200 m when these two systems are deployed co-channel and when the FSS ES antenna elevation angle is only 5º or 6º. For all other cases the minimum required distance is less than 100 m.

Attachment 2
to Annex B

Description of Study B

Evaluation of Study A with BWA antenna patterns and propagation model parameters

1 Introduction

This Report evaluates the results from the study in Attachment 1 of Annex B[5] by comparing them with results from simulations performed with a commercial off-the-shelf (COTS) software tool that has the capability for implementing all of the BWA and FSS characteristics, as well as the BWA base station antenna patterns and Recommendation ITU-R P.452-13.

2 Evaluation of parameters used in Recommendation ITU-R P.452-13

The software tool used for the simulations in this document has an implementation of Recommendation ITU-R P.452-13. Most of the parameters that are used for this Recommendation can be manually configured. However, as the software tool makes use of actual terrain data, when available, not all the parameters related to a number of parameters can be manually configured. Table 12 details for every parameter, as contained in Table 6 of Annex A of this Report, whether the implementation of the Recommendation ITU-R P.452-13 allowed for manual configuration of this parameter. In the case it was not possible, additional explanatory comments will be given.

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[5] The comparison referenced in this study is based on a comparison with the study A results based on certain assumed ACLR values. It should be noted that, since this comparative study was made, the ACLR values that were used in Study A have been revised as reflected in Tables 4 and 5 of Annex A to this Report.

TABLE 12

Overview of configurable parameters for Recommendation ITU-R P.452-13

Parameter	Scenario	Value	Configurable	Comment
d_k (km)	Rural for BS	0.025	Yes	
	Urban for BS	0.02	Yes	
	Outdoor for TS	0.02	Yes	
	Indoor for TS	0.02	Yes	
h_a (m)	Rural for BS	9	Yes	
	Urban for BS	20	Yes	
	Outdoor for TS	12	Yes	
	Indoor for TS	12	Yes	
	Diameter = 32 m	30	Yes	
	Diameter = 8 m	8	Yes	
	Diameter = 1.2 m	8	Yes	
L_P (dB)		8	Yes	
L_P (dB)		8	Yes	
f (GHz)		3.6	Yes	Configurable independent of Recommendation ITU-R P.452-13 implementation
p (%)		20	Yes	
φ_t, φ_r (degrees)		40	Yes	Configurable independent of Recommendation ITU-R P.452-13 implementation
ψ_t, ψ_r (degrees)		–100	Yes	Configurable independent of Recommendation ITU-R P.452-13 implementation
h_g (m)		20	No	The software has a standard implementation of the smooth earth model. If terrain data is available, the height information from the terrain data will be used
h_m (m)		10	No	The software will either use smooth earth, or, terrain data, when available
d_{tm} (km)		0.9d	No	Automatically determined by the software based on available terrain data
d_{lm} (km)		0.8d	No	Automatically determined by the software based on available terrain data
d_{lt},d_{lr} (km)		0.25d	No	Automatically determined by the software based on available terrain data
θ_t, θ_r (mrad)		17.45	No	Automatically determined by the software based on available terrain data and resulting geometry

TABLE 12 (*end*)

Parameter	Scenario	Value	Configurable	Comment
θ (mrad)		$\theta_t + \theta_r$ $+10^3 d/\alpha_e$	No	Automatically determined by the software based on available terrain data and resulting geometry
d_b (km)		0	No	Automatically determined by the software based on available terrain data
$\gamma_{o+}\gamma_w(\rho)$ (dB/km)		0.008	No	Automatically derived by software based on carrier frequency
ΔN		50	Yes	
h_1 (m)		15	No	Automatically determined by the software based on available terrain data
h_2 (m)		20	No	Automatically determined by the software based on available terrain data
h_3 (m)		15	No	Automatically determined by the software based on available terrain data
d_1 (km)		0.25d	No	Automatically determined by the software based on available terrain data
d_2 (km)		0.5d	No	Automatically determined by the software based on available terrain data
d_3 (km)		0.75d	No	Automatically determined by the software based on available terrain data
N_0		310	Yes	
t (°C)		10	Yes	
Pressure (hPa)		1 013.25	Yes	

In summary, it can be stated that the software tool allows for configuration of all parameters except those related to the terrain, as they are directly derived from available terrain data. If terrain data is not available, the software will assume a smooth earth.

3 Set-up of simulations

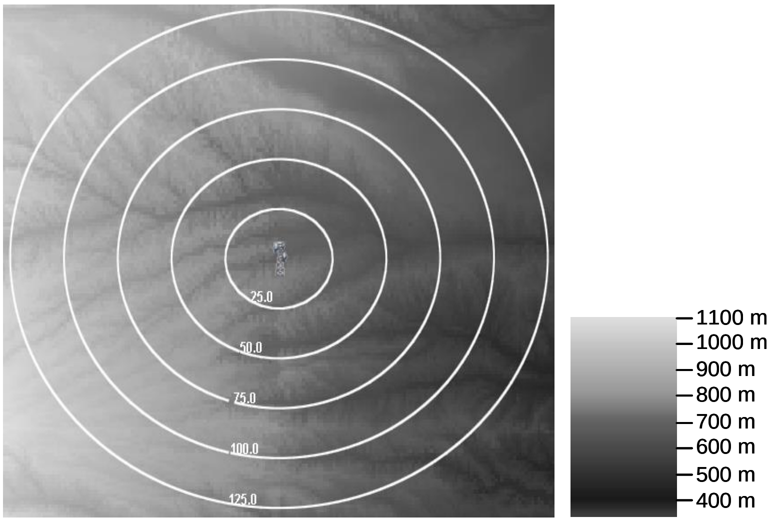
As the software tool will not enable manual determination of certain aspects of Recommendation ITU-R P.452-13, simulations have been set up for the BWA base station scenarios as was done in Study A, with the difference that 2 different cases will be studied. One case is assuming smooth earth, and the other case is assuming the use of actual terrain data.

It is recognized that there is a large variety of different terrain types available. As one example, the terrain data around the proposed geographical point of 100W longitude and 40N latitude will be taken. The terrain database used has a resolution of 1 m vertically and 1 km horizontally. For the simulation a grid of FSS earth stations is assumed around the BWA base station at 1 km intervals.

Figure 7 depicts the details of the type of terrain that was used, together with contours indicating the distance from the BWA base station in the centre of the plots, in 25 km intervals, from 25 km up to 125 km distance. The plots contained in the analysis results will not show the actual terrain in order to make those plots more readable.

FIGURE 7

Details of terrain characteristics assumed in simulations



Simulations are run based on the scenarios identified in Table 13, assuming the parameters as identified in Table 14 and Table 15. It should be noted that this study takes into account the BWA base stations, but not the BWA terminal stations. Further, it is important to note that this study is only considering the long term protection criteria as reflected in Recommendation ITU-R SF.1006.

The results from Study A are derived from the plots as depicted in their study, where distances derived have been rounded to the nearest 5 km. Those results are then compared the results from the simulations performed in this study.

TABLE 13

Overview of simulation scenarios

Scenario	BWA antenna	FSS antenna	Terrain
1a	Specific rural sectoral	32 m	Smooth Earth
1b		8 m	
1c		1.2 m	
2a	Specific rural sectoral	32 m	Actual terrain
2b		8 m	
2c		1.2 m	
3a	Typical urban omnidirectional	32 m	Smooth Earth
3b		8 m	
3c		1.2 m	
4a	Typical urban omnidirectional	32 m	Actual terrain
4b		8 m	
4c		1.2 m	

TABLE 14

FSS system parameters

Frequency	3 400-4 200 MHz (3 600 MHz is used in calculation)		
Bandwidth	40 kHz-72 MHz (7 MHz is used in calculation)		
Earth station antenna radiation patterns	Recommendation ITU-R S.465		
Antenna diameter (m)	1.2	8	32
Maximum antenna gain (dBi)	31.2	47.7	59.8
Antenna centre height (m)	5	5	25
Noise temperature (including the contributions of the antenna, feed and LNA/LNB referred to the input of the LNA/LNB receiver) (K)	100	70	70
Antenna elevation angle (degrees)	5 to 85		
Short-term and long-term maximum permissible Interference level	Recommendations ITU-R SF.1006 (this study only considers the long-term levels)		

TABLE 15

BWA base station system parameters

	Base station	
Deployment scenario	**Specific cellular deployment rural**	**Typical cellular deployment urban**
TX peak output power (dBm)	43	32
Channel bandwidth (MHz)	7	7
Feeder loss (dB)	3	3
Peak antenna gain (dBi)	17	9
Antenna gain pattern	Recommendation ITU-R F.1336	Recommendation ITU-R F.1336
Antenna 3 dB beamwidth (degrees)	60 (sectorized)	Omnidirectional
Antenna downtilt (degrees)	1	4
Antenna height a.g.l. (m)	50	15
e.i.r.p. (dBm)	57	38
Unwanted emissions	TBD	TBD

The adjacent channel leakage ratio (ACLR) values used in this study are depicted in the table below It should be noted that the study contained in Attachment 1 to Annex B of this Report uses more recent ACLR values.

BWA base station ACLR values used in this study

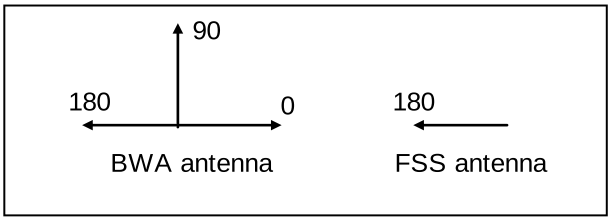
	ACLR1 (dB)	**ACLR2 (dB)**	**ACLR3 (dB)**
BWA base station	22.0	47.8	50.0

Due to the small difference between the values for the second and third adjacent channels, this study will only take into account the results for the first and second adjacent channels.

Further, in this study, for the BWA specific rural sectoral antenna case (Scenarios 1 and 2), not all azimuth angles between 0° and 180° were studied, as was done in Study A, but a subset of this range. The azimuth angles studied were 0°, 90° and 180°. It is believed that these values allow for adequate comparison with the results obtained in Study A. Figure 8 depicts the geometrical scenarios studied under Scenarios 1 and 2.

FIGURE 8

Geometric azimuth configurations studied under Scenarios 1 and 2



As for Scenarios 3 and 4, for the BWA typical urban omnidirectional antenna, where the azimuth aspect of the antennas is not relevant, not all elevation angles for the FSS earth stations are studied, but the same subset of elevation angles that were used in Scenarios 1 and 2, i.e. 5°, 25° and 50° elevation.

4 Results of simulation

This section contains the results of the simulations and a comparison with the results from Study A. Except for the values of ACLR1, the same assumed set of parameters was used to enable a comparison of the results of the two studies. If the values of ACLR1 used in study A were used the results would improve. However, § 5 contains a discussion on some of the parameters that were assumed in this study.

4.1 Scenario 1 (BWA sectoral antenna, smooth earth)

Tables 16 to 18 in this section show the comparison of the results from Study A with the results of the simulation done for this particular contribution, when a smooth earth is assumed. The tables also show the difference between the two results. All distances are in kilometres. The results are generally rounded to the nearest 5 km point, except for the cases when the separation distance was about 1 km. When the distance was below 1 km, a separation distance of 0 km is indicated.

TABLE 16

Comparison of result for separation distances for Scenario 1a

		Scenario 1a: BWA sectoral antenna, FSS 32 m antenna								
	Elevation	5			25			50		
	Azimuth	0	90	180	0	90	180	0	90	180
Study A	Co-channel	150	130	90	110	85	65	95	75	60
	1st adjacent	110	80	60	75	60	40	65	50	35
	2nd adjacent	60	50	35	45	30	15	40	20	5
Study B	Co-channel	100	75	65	75	60	50	70	55	40
	1st adjacent	70	55	45	55	40	20	50	30	10
	2nd adjacent	50	25	5	20	5	1	10	1	0
Delta	Co-channel	–50	–55	–25	–35	–25	–15	–25	–20	–20
	1st adjacent	–40	–25	–15	–20	–20	–20	–15	–20	–25
	2nd adjacent	–10	–25	–30	–25	–25	–14	–30	–19	–5

TABLE 17

Comparison of result for separation distances for Scenario 1b

		Scenario 1b: BWA sectoral antenna, FSS 8 m antenna								
	Elevation	5			25			50		
	Azimuth	0	90	180	0	90	180	0	90	180
Study A	Co-channel	95	70	50	70	50	25	60	40	20
	1st adjacent	60	40	25	40	20	10	30	15	5
	2nd adjacent	30	15	5	10	5	1	10	1	0
Study B	Co-channel	75	60	45	55	40	30	50	35	20
	1st adjacent	50	35	25	35	20	5	30	10	5
	2nd adjacent	30	10	5	5	1	0	5	1	0
Delta	Co-channel	–20	–10	–5	–15	–10	5	–10	–5	0
	1st adjacent	–10	–5	0	–5	0	–5	0	–5	0
	2nd adjacent	0	–5	0	–5	–4	–1	–5	0	0

TABLE 18

Comparison of result for separation distances Scenario 1c

		Scenario 1c: BWA sectoral antenna, FSS 1.2 m antenna								
	Elevation	5			25			50		
	Azimuth	0	90	180	0	90	180	0	90	180
Study A	Co-channel	70	50	30	45	35	15	35	20	10
	1st adjacent	40	20	10	20	10	5	15	5	1
	2nd adjacent	15	5	5	5	1	1	10	1	0
Study B	Co-channel	75	55	40	55	40	25	45	35	20
	1st adjacent	50	35	25	35	20	5	30	10	5
	2nd adjacent	25	10	5	5	1	0	5	1	0
Delta	Co-channel	5	5	10	10	5	10	10	15	10
	1st adjacent	10	15	15	15	10	0	15	5	4
	2nd adjacent	10	5	0	0	0	–1	–5	0	0

Generally speaking it can be observed that the separation distances calculated are of the same order of magnitude.

However, when comparing the three scenarios in more detail, it seems that the results for Scenario 1b (FSS earth station size of 8 m) are most similar to the results from Study A. Results from Scenario 1a (FSS earth station size of 32 m) differ in the sense that the separation distances as calculated in Study A are larger, and the separation distances for Scenario 1c (FSS earth station size of 1.2 m) are lower.

4.2 Scenario 2 (BWA sectoral antenna, actual terrain data)

As indicated in § 3, in order to show an example of the impact of terrain on the simulation results, it was decided to assume the terrain data available at the proposed geographical coordinates in the WP 5A liaison statement. It is realised that this will entail one example out of the many, but it was believed to be a valuable addition to this study, also taking into account that the terrain around the chosen coordinates is relatively smooth.

In this simulation, a grid of earth stations, 300 m apart, was created around the BWA base station. From every location, the earth station's azimuth was pointing towards the BWA base station, but the elevation was fixed at predetermined values. Also the pointing of the BWA sectoral antenna was configurable, so that it could be pointed at all times towards the FSS earth station, 90° and 180° away from the FSS earth station. This set of simulations will then give an indication of variations of separation distances around a BWA base station. The results of the simulations are shown in Fig. 9 for Scenario 2a, Fig. 10 for Scenario 2b and Fig. 11 for Scenario 2c. Each figure contains three contours. The black contour corresponds to the co-channel case, the blue contour corresponds to the 1st adjacent channel case and the dark red contour corresponds to the 2nd adjacent channel case. Further, on the figure a scale for the distance with respect to the BWA base station is reflected. Lines are drawn in 25 km intervals, from 25 km to 125 km separation distance.

FIGURE 9

Results for Scenario 2a: 32 m FSS earth station

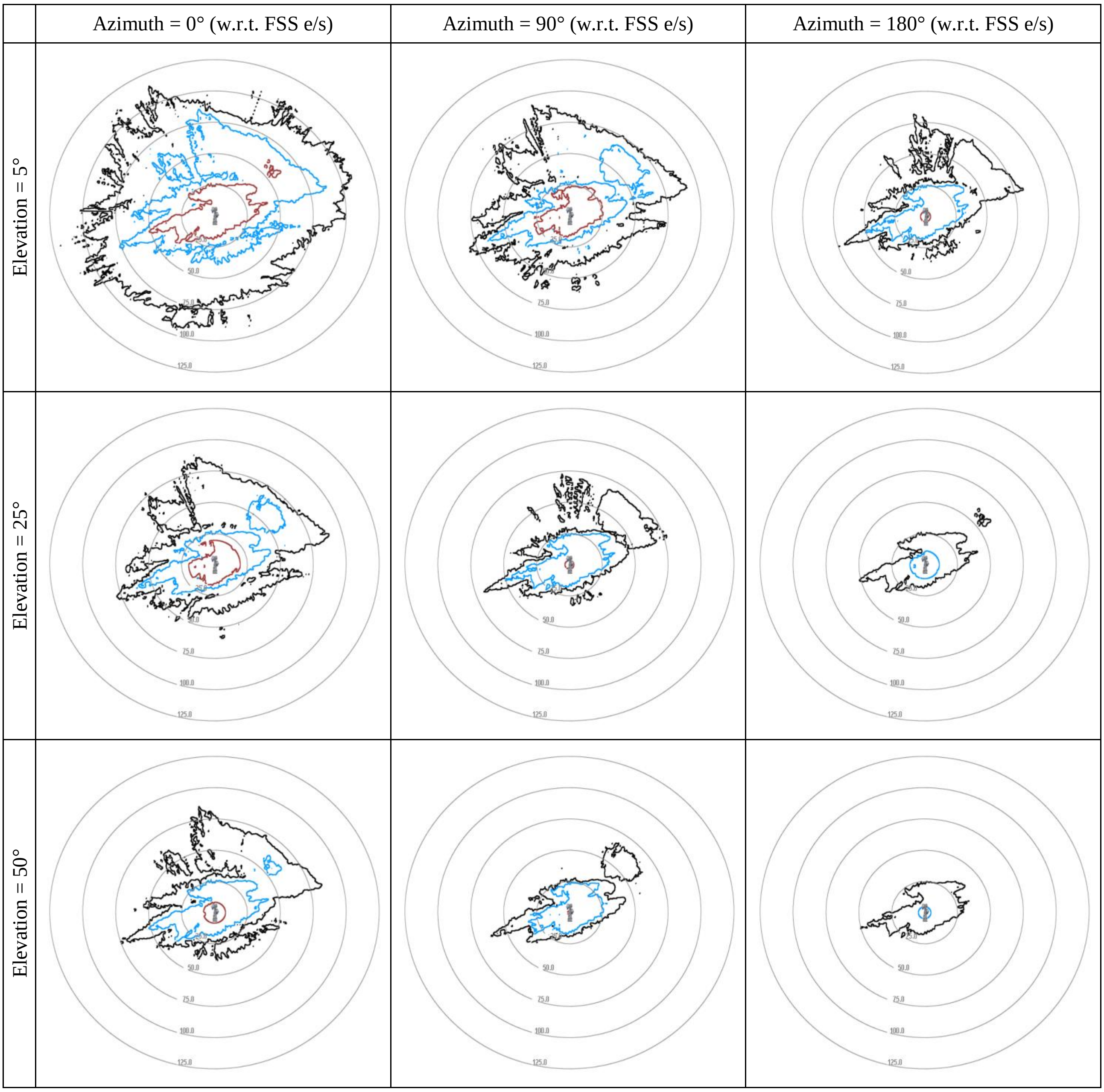


FIGURE 10

Results for Scenario 2b: 8 m FSS earth station

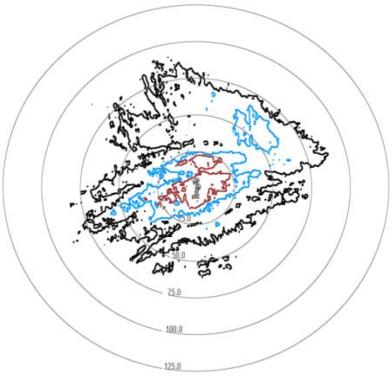
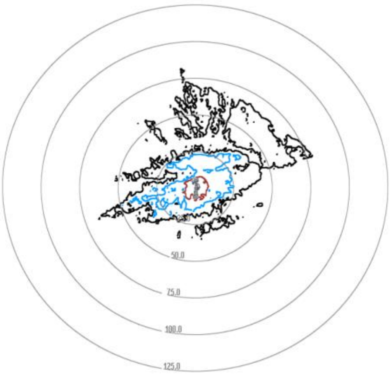
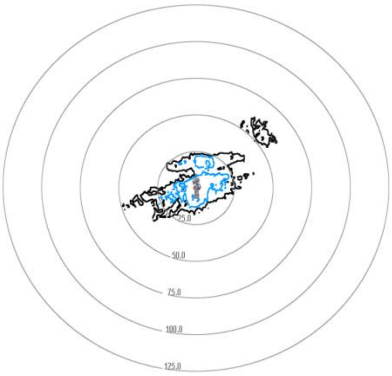
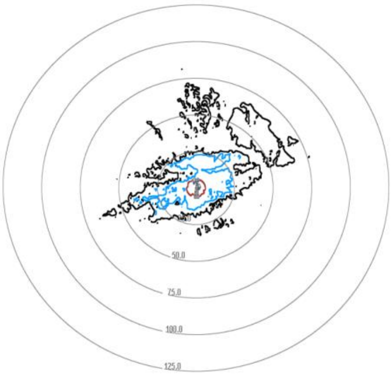
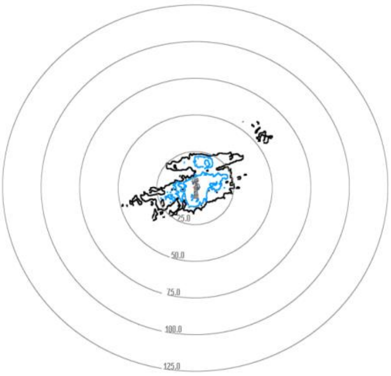
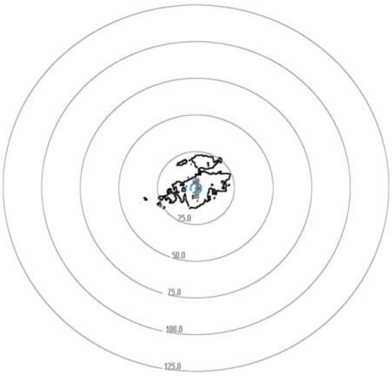
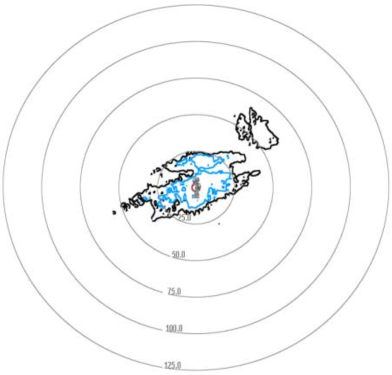
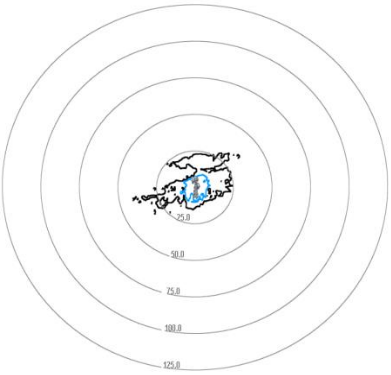
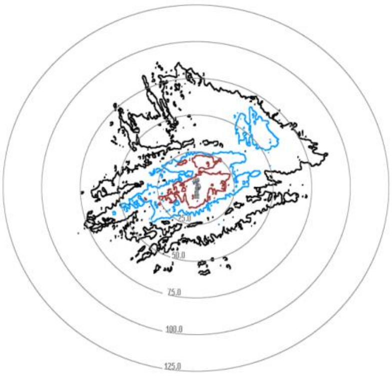
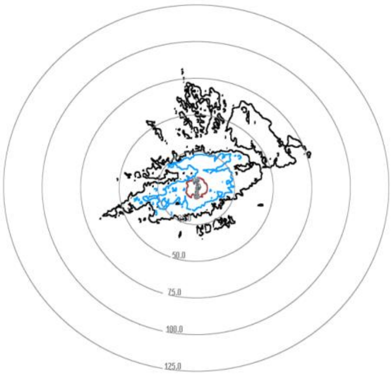
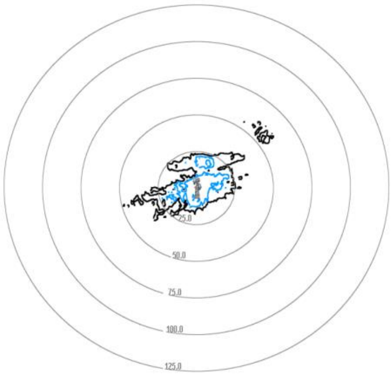
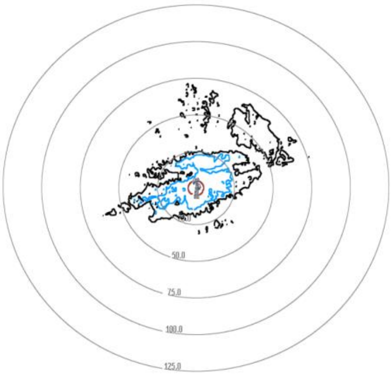
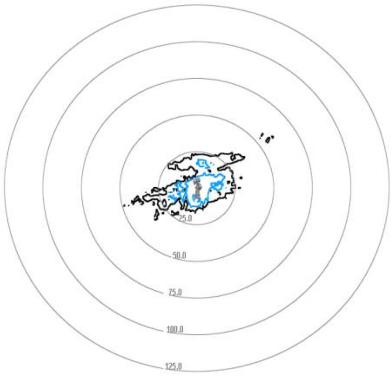
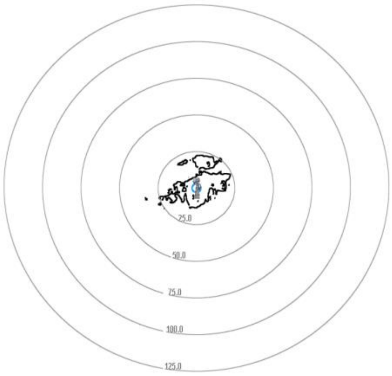
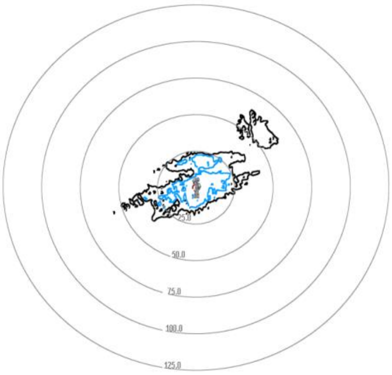
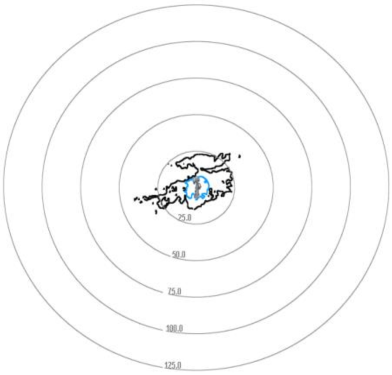
	Azimuth = 0° (w.r.t. FSS e/s)	Azimuth = 90° (w.r.t. FSS e/s)	Azimuth = 180° (w.r.t. FSS e/s)
Elevation = 5°			
Elevation = 25°			
Elevation = 50°			

FIGURE 11

Results for Scenario 2c: 1.2 m FSS earth station

	Azimuth = 0° (w.r.t. FSS e/s)	Azimuth = 90° (w.r.t. FSS e/s)	Azimuth = 180° (w.r.t. FSS e/s)
Elevation = 5°			
Elevation = 25°			
Elevation = 50°			

It is difficult to draw clear conclusions from the results with an example of real terrain data. However, comparing the variation of separation distances due to the terrain, with the separation distances calculated based on the smooth earth model (i.e. comparing Scenario 1 with Scenario 2), it can be concluded that the results from Scenario 1 do not seem overly conservative nor too optimistic.

4.3 Scenario 3 (BWA omnidirectional antenna, smooth earth)

With respect to the use of the omnidirectional urban base station antenna, Tables 19 to 21 depict the comparison of the results of the studies for Scenarios 3a, 3b and 3c.

TABLE 19

Comparison of result for separation distances Scenario 3a

		Scenario 3a: BWA omnidirectional antenna, FSS 32 m antenna		
	Elevation	5	25	50
Study A	Co-channel	85	60	50
	1st adjacent	50	30	20
	2nd adjacent	20	5	1
Study B	Co-channel	55	40	35
	1st adjacent	35	25	10
	2nd adjacent	10	1	0
Delta	Co-channel	–30	–20	–15
	1st adjacent	–15	–5	–10
	2nd adjacent	–10	–4	–1

TABLE 20

Comparison of result for separation distances Scenario 3b

		Scenario 3b: BWA omnidirectional antenna, FSS 8 m antenna		
	Elevation	5	25	50
Study A	Co-channel	40	10	5
	1st adjacent	5	1	0
	2nd adjacent	0	0	0
Study B	Co-channel	35	20	15
	1st adjacent	20	10	5
	2nd adjacent	5	1	0
Delta	Co-channel	–5	10	10
	1st adjacent	15	9	5
	2nd adjacent	5	1	0

TABLE 21

Comparison of result for separation distances Scenario 3c

		Scenario 3c: BWA omnidirectional antenna, FSS 1.2 m antenna		
	Elevation	5	25	50
Study A	Co-channel	10	1	0
	1st adjacent	1	0	0
	2nd adjacent	0	0	0
Study B	Co-channel	35	20	15
	1st adjacent	15	5	5
	2nd adjacent	5	1	0
Delta	Co-channel	25	19	15
	1st adjacent	14	5	5
	2nd adjacent	5	1	0

Comparison of results for Scenario 3 shows a similar conclusion w.r.t. comparison of results for Scenario 1, i.e. the case with the 8 m FSS earth station is the case for which the results of this study with those of Study A show the most commonalities. For the 32 m FSS earth station case, the separation distances calculated in this contribution are lower, and for the 1.2 m FSS earth station case they are higher.

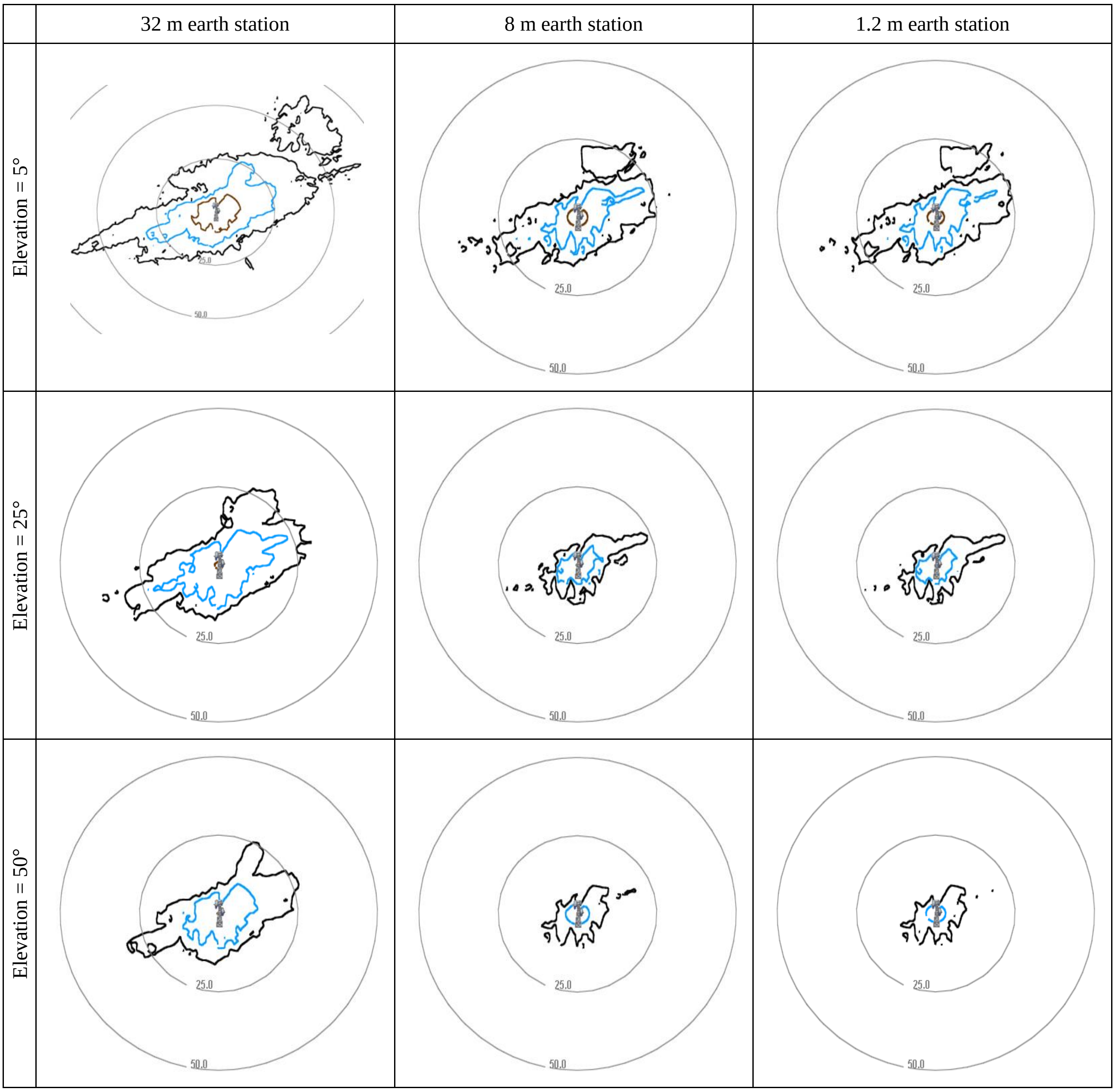
It is interesting to note though, that for the 8 m and 1.2 m FSS earth station case, for 50° elevation, the results of the simulation in this study clearly show that the separation distances are not negligible for the co-channel case and 1st adjacent channel case, when comparing with the results from Study A.

4.4 Scenario 4 (BWA omnidirectional antenna, actual terrain data)

For the simulations based on actual terrain data for Scenario 4, a similar approach was taken as for Scenario 2. However, as in this case the BWA base station antenna is omnidirectional, it was not necessary to make separate plots for different azimuth angles. The results for the simulations can be found in Fig. 12.

FIGURE 12

Results for Scenario 4



As was the case for Scenario 2, no clear conclusions can be drawn from the results with one example of real terrain data. However, comparing the variation of separation distances due to the terrain, with the separation distances calculated based on the smooth earth model (i.e. comparing Scenario 3 with Scenario 4), it can be concluded that the results from Scenario 3 do not seem overly conservative nor too optimistic.

5 Discussion of assumptions

This section will provide a discussion on a number of assumed parameters, such as the clutter parameters, sectoral antenna use, and aggregate interference scenarios, together with potential impacts that they have on the simulation results.

5.1 Clutter parameters

The model for calculating the clutter loss is described in § 4.5 of Recommendation ITU-R P.452-13. It is indicated that clutter losses can be calculated at both the transmitting and receiving end of an (un)wanted link in situations where the clutter scenario is known. The calculation predicts a maximum additional loss of 20 dB at either end of the path. The Recommendation goes on to say that "*where there are doubts as to the certainty of the clutter environment, the additional loss should not be included*".

The expression to calculate the loss due to protection from local clutter is[6]:

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

where:

A_h: loss due to clutter (dB)

d_k : 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.

Table 22 shows the results of the calculated clutter losses, based on the above expression, for the parameters as contained in Table 6 of Annex A of this Report.

TABLE 22

Results for clutter loss calculations

	Antenna	***h* (m)**	**h_a (m)**	**d_k (km)**	**A_h (dB)**
Scenario 1+2	BWA specific rural sectoral	50	9	0.025	–0.3
	FSS earth station 32 m	25	30	0.025	1.2
	FSS earth station 8 m	5	8	0.025	9.7
	FSS earth station 1.2 m	5	8	0.025	9.7
Scenario 3+4	BWA typical urban omnidirectional	15	20	0.020	3.3
	FSS earth station 32 m	25	30	0.020	1.2
	FSS earth station 8 m	5	8	0.020	9.7
	FSS earth station 1.2 m	5	8	0.020	9.7

---

[6] This expression is reproduced from expression (47) in § 4.5.3 in Recommendation ITU-R P.452-13.

If the above assumed clutter parameters are compared with the Table[7] on nominal clutter heights and distances as depicted in Recommendation ITU-R P.452-13, it seems that the specific rural sectoral antenna is assuming a suburban clutter category and the typical urban omnidirectional antenna is assuming an urban clutter category.

The nominal clutter height of 30 m assumed for the 32 m FSS earth station seems not to correspond to any of the nominal clutter categories. The maximum nominal clutter height amongst the nominal categories is 25 m, which corresponds to a dense urban category. Based on this it would be more reasonable to assume a clutter height of 9 m, as was the case for the specific rural sectoral antenna. The impact is that A_h would be about 1.5 dB less for this case.

The nominal clutter height for the 8 m and 1.2 m FSS Earth Station antenna seem not reasonable to use when these antennas are operating at low elevation angles towards the spacecraft. Operations at low elevations require site surveys to make sure that there are no obstacles in the path between the spacecraft and the earth station. Therefore, it is proposed to use a nominal clutter height that is equal to the antenna height for elevations up to 20° elevation. The impact of this would be that A_h would be about 10 dB less for these cases.

Simulations have been done studying the impact of the above on the separation distances in the low elevation scenarios. The results show that the separation distances would be about 10 km more in this case.

5.2 Use of sectorized antennas

The studies in Scenarios 1 and 2 have assumed the use of a BWA sectoral antenna, with azimuth angles (w.r.t. the FSS earth station) ranging from 0° to 180° (see Fig. 8). Unfortunately, in the BWA parameters provided so far by WP 5A, there is no information on the frequency reuse factors or patterns.

For the sectorized antennas with a beamwidth of 60°, as used in this study, it is reasonable to assume that the frequency could be reused at 0°, 120°, and 240° azimuth angles. This would mean that the conclusions of the analysis, based on the case of an azimuth angle of 180° are not relevant, and that the maximum elevation angle studied should be 120°.

A further important aspect is that frequency reuse in sector antennas leads to an aggregation of the interference environment, and will lead to larger separation distances than in the case of a single sector antenna per BWA base station.

In order to quantify this effect one simulation has been reproduced, employing three sectoral antennas on one base station. For the example, the FSS earth station size of 8 m was chosen, together with a smooth earth assumption (basically Scenario 1b). Table 23 shows the results for the nominal case (these numbers can also be found in Table 17 and the case where the base station is deploying 3 sector antennas, 120° apart in azimuth, operating co-frequency. As reference the 8 m FSS earth station antenna was chosen as those results seemed to match best those of Study A.

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[7] This Table is Table 4 in § 4.5.3 in Recommendation ITU-R P.452-13.

TABLE 23

Results of effect of multiple sector antennas

		Scenario 1b: BWA sectoral antenna, FSS 8 m antenna								
		Sensitivity w.r.t. multi sector antennas								
	Elevation	5			25			50		
	Az. Sector 1	0	90	180	0	90	180	0	90	180
	Az. Sector 2	–120	–30	60	–120	–30	60	–120	–30	60
	Az. Sector 3	120	–150	–60	120	–150	–60	120	–150	–60
Single Sector	Co-channel	75	60	45	55	40	30	50	35	20
	1st adjacent	50	35	25	35	20	5	30	10	5
	2nd adjacent	30	10	5	5	1	0	5	1	0
Multi Sector	Co-channel	75	70	65	55	55	45	50	45	40
	1st adjacent	50	45	40	35	30	25	30	25	20
	2nd adjacent	30	20	15	5	5	1	5	5	1
Delta	Co-channel	0	10	20	0	15	15	0	10	20
	1st adjacent	0	10	15	0	10	20	0	15	15
	2nd adjacent	0	10	10	0	4	1	0	4	1

From the results it can be seen that for the 0° azimuth angle case there is no impact on the separation distance as the antenna pointing directly towards the FSS earth station is the dominating interferer compared to the other two sector antennas. However, for the other azimuth cases there is a clear impact on the separation distances needed. For the co-channel and 1st adjacent channel cases, the impact ranges from 10 to 20 km. For the 2nd adjacent channel the impact is in between 1 and 10 km.

As the impact of the aggregation of the sectoral antennas on one base station is significant, it would be important to understand the exact nature of the frequency reuse patterns that are planned for BWA systems in the band 3 400-4 200 MHz.

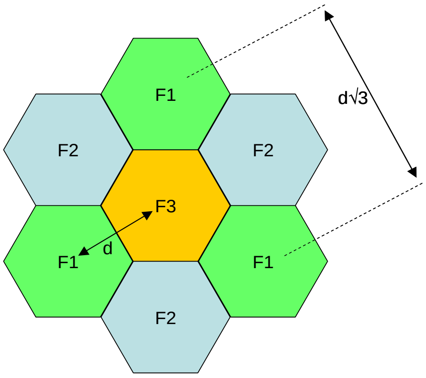
5.3 Aggregate effect from multiple cells

Urban BWA deployment is typically done in a cell like structure where it is of interest to the BWA operator to reuse its assigned frequencies to the maximum extent possible. In the case of an urban BWA deployment with omnidirectional antennas, such as the ones studied under Scenarios 3 and 4 under this study, frequency reuse will most likely be achieved by reusing the same frequencies in difference cells. It is important to assess the impact of the aggregate effect on the required separation distances with respect to FSS earth stations where multiple BWA base stations reuse the same frequency in an urban environment.

Figure 13 depicts a cell shaped frequency reuse scenarios, where three frequencies, F1, F2 and F3 are reused throughout the network. The distance d is the distance between the base stations in the network. From this the distance between two co-frequency base stations can be defined as being $d\sqrt{3}$.

FIGURE 13

Typical frequency reuse pattern in cell structure



In order to determine whether there would be any impact due to the aggregate interference, it is important to understand the typical value for d, i.e. what is the typical distance between BWA bases stations in an urban environment, and what kind of frequency reuse pattern should be assumed.

6 Conclusions

The aim of this study was to evaluate the results from Study A by comparing them with results from simulations performed with a COTS software tool that has the capability for implementing all of the BWA and FSS characteristics, as well as the BWA base station antenna patterns and Recommendation ITU-R P.452-13, by assuming the same assumptions, as far as was possible. This study is only considering the long term protection criteria as reflected in Recommendation ITU-R SF.1006. Short term effects might need to be evaluated separately.

Exact comparison is not straightforward as different assumptions with respect to the terrain have been taken, however, generally speaking, it seems that results obtained in both studies achieve results for needed separation distances that are within same order of magnitudes.

This study also discussed some of the assumptions more in detail, such as the assumed clutter parameters and possible impact of aggregation of multiple co-frequency sector antennas on one base station, and aggregate interference due to frequency re-use in different cells.

From the above it became clear that it is not obvious to assume general parameters for clutter, as different geometrical scenarios might require different parameters. Also, Recommendation ITU-R P.452-13 states clearly that "*where there are doubts as to the certainty of the clutter environment, the additional loss should not be included*". Studies have indicated that impact of clutter can be significant.

Also, it was shown that the aggregate effect of multiple co-frequency sector antennas per BWA base station can be significant (addition required separation distances of 20 km have been calculated), and that this effect would also not allow to study azimuth angles of up to 180°.

Attachment 3
to Annex B

Description of Study C

Simulations for interference from a BWA system to FSS in The Netherlands

1 Assumptions for simulation

During a measurement campaign that took place in the Netherlands in 2009, a DVB test carrier was put up on the SES WORLD SKIES NSS-806 satellite, located at 40.5°W, at a centre downlink frequency of 3 533.5 MHz. Table 24 details the specifics of this carrier.

TABLE 24

Carrier details of satellite signal used in measurement campaign

Item	Value
Carrier frequency (MHz)	6 558.5/3 533.5
Carrier polarisation	LHCP/RHCP
Data rate (Mbit/s)	6 144
Symbol rate (msym/s)	4 445
Modulation	QPSK
FEC	3/4
RS	188/204
Required E_b/N_0 (dB)	5.5

The receive equipment consisted of a 2.4 m fly-away antenna (Gigasat FA240), which was equipped with a Norsat LNB (3.4-4.2 GHz, LO 5 150 MHz) and C-band circular feed. The LNB was connected to a DVB MPEG-2 decoder and a Rhode & Schwarz spectrum analyzer.

The satellite receive antenna was set up at different distances from Amsterdam, The Netherlands, in order to assess a BWA signal and the effect it had on the test signal from the satellite. The BWA system deployed in Amsterdam is based on the WiMAX standard.

A theoretical model was set up to simulate the interference environment for a satellite earth station operating around a WiMAX transmitter which is set up in the Amsterdam area. An analysis has been made of the required separation distances assuming two different BWA base station types. These BWA base station types, and their assumed parameters, are depicted in Table 25.

TABLE 25

BWA base station parameters assumptions for use in study

	Base station	
Deployment scenario	**Specific cellular deployment rural**	**Typical cellular deployment urban**
TX peak output power (dBm)	43	32
Channel bandwidth (MHz)	7	7
Feeder loss (dB)	3	3
Peak antenna gain (dBi)	17	9
Antenna gain pattern	Recommendation ITU-R F.1336	Recommendation ITU-R F.1336
Antenna 3 dB beamwidth (degrees)	60 (sectorized)	Omnidirectional
Antenna downtilt (degrees)	1	4
Antenna height a.g.l. (m)	50	15
e.i.r.p. (dBm)	57	38
Azimuth Angle (degrees)	0, 90, 180, 270	N/A
Unwanted emissions	Not studied	Not studied

N/A: Not applicable.

The assumption for the detailed antenna pattern parameters are those as indicated Figs 1 to 4 of Annex A of this Report. For the BWA base station employing a sectoral antenna, different pointing directions in terms of azimuth will be assumed. The azimuth angles are 0°, 90°, 180° and 270° respectively.

The assumption for the FSS earth station are based on the parameters actual used during the measurements in terms of antenna height above ground level, antenna size, and elevation towards the actual satellite it was operating to.

Table 26 repeats the assumptions used in this study.

TABLE 26

FSS system parameters

Frequency	3 600 MHz is used in calculation
Bandwidth	7 MHz is used in calculation
Earth station antenna radiation patterns	Recommendation ITU-R S.465
Antenna diameter (m)	2.4
Maximum antenna gain (dBi)	37.8
Antenna centre height (m)	2
Noise temperature (including the contributions of the antenna, feed and LNA/LNB referred to the input of the LNA/LNB receiver) (K)	100
Antenna elevation angle (degrees)	17.1
Short-term and long-term maximum permissible Interference level	Recommendations ITU-R SF.1006 (in this study only the long-term protection level is taken into account)

The satellite earth station was modelled to be a 2.4 m antenna complying with antenna pattern Recommendation ITU-R S.465, with a noise temperature of 100 K at an elevation and azimuth corresponding to pointing to a satellite at 40.5W (i.e. 17.1°). The height above ground was assumed to be 2 m.

The exact parameters within used in the propagation model are assumed as far as possible to be the same as those indicated in Table 6 of Annex A of this Report, including the clutter parameters, based on Recommendation ITU-R P.452-13. However, as the simulation software is implementing this recommendation based on actual terrain data, the terrain characteristics cannot be modelled manually.

The simulation software is using a terrain database having a resolution of 1 m vertically and 1 km horizontally, and assumes the WiMAX base station to be at a fixed location, and the satellite earth station simulated at 1 km intervals. As indicated, path loss is derived by the algorithms in Recommendation ITU-R P.452-13.

The interference can be modelled as follows:

$$\mathrm{I} = \mathrm{e.i.r.p.}_{\mathrm{WIMAX}}(\varphi_1) - \mathrm{L} + \mathrm{G}(\varphi_2) \text{ (dBW/MHz)}$$

where:

I = Interference (dBW/MHz)

$\mathrm{e.i.r.p.}_{\mathrm{WIMAX}}(\varphi_1)$ = e.i.r.p. in direction of horizon of WiMAX base station (dBW/MHz)

L = Path loss (dB)

$\mathrm{G}(\varphi_2)$ = Satellite earth station antenna gain in direction of the WiMAX transmitter (dBi).

The protection criterion for the long term interference to be observed is for the *I*/*N* ratio not to exceed –10 dB for more than 20% of the time.

2 Simulation results

Figure 14 to Fig. 17 show the results for the case of a BWA specific cellular deployment rural case, for azimuth pointings of 0°, 90°, 180° and 270° respectively. Note that only the contours for *I*/*N* of –10 dB are indicated. These contours are represented by the purple line on the map. The source of all maps used in this text is Google Maps.

FIGURE 14

Simulation results BWA rural sectoral antenna (azimuth : 0°)

FIGURE 15

Simulation results BWA rural sectoral antenna (azimuth : 90°)

FIGURE 16

Simulation results BWA rural sectoral antenna (azimuth : 180°)

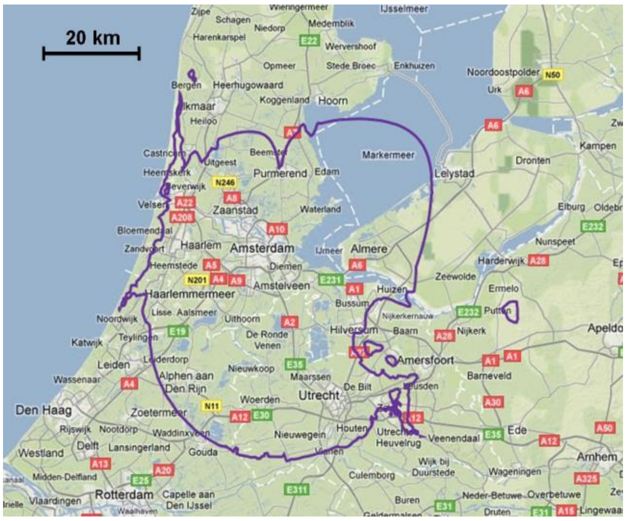


FIGURE 17

Simulation results BWA rural sectoral antenna (azimuth : 270°)

These results were found to be in line with the results from the actual measurements done during the measurement campaign, i.e. covering the cases where clear interference was observed.

Figure 18 shows the result for the case of a BWA typical cellular deployment urban case.

FIGURE 18

Simulation results BWA urban omnidirectional antenna

As expected, the contours related to the BWA omnidirectional antenna, used as a typical urban case, show shorter separation distances than in the case of the BWA sector antennas used in the specific rural case.

3 Conclusions

A measurement campaign was set-up in order to make use of the presence of this operational WiMAX system, and to analyze the potential impact it can have on FSS signal reception in the same operating band.

In this study, the theoretical part of the analysis was updated based on the latest BWA base station and antenna parameters, as well as propagation model parameters as contained in Annex A of this Report.

Based on the results, it would seem that the WiMAX system that was deployed in Amsterdam, was using BWA base station parameters that were more in line with the parameters based on a specific rural cellular case than with the parameters based on a typical urban cellular case.

Attachment 4
to Annex B

Description of Study D

Study of required separation distances in order to avoid LNB saturation or non-linear behaviour

1 Introduction

This Attachment provides a study of the adjacent band interference that could lead to saturation or non-linear operation of the Low Noise Blockconverter (LNB) of the FSS earth station, taking into account the agreed BWA and FSS parameters.

2 LNB operational range

For the reception of satellite signals, FSS earth stations use LNBs, that have two main functions. The first one is to amplify the satellite signal coming from the receive antenna, and the second function is to down convert the satellite signal to an intermediary frequency (IF) in order to facilitate the further transport of the signal by co-axial cable.

As LNBs are designed for the reception of very low level satellite signals, the dynamic range is designed accordingly. In order to illustrate this, one can assume a 36 MHz satellite transponder operating in the band 3 400-4 200 MHz, transmitting a fully saturated signal with a downlink e.i.r.p. of 40 dBW. With a 3.7 m receive antenna, having a gain of 41 dBi, and a free space loss in this band of about 196 dB, the signal level at the input of the LNB is (40-196 + 41) = –115 dBW = –85 dBm. Even if the entire band 3 400-4 200 MHz would have transponders transmitting this e.i.r.p., the total power at the input of the LNB would not exceed –72 dBm.

The 1 dB compression point for LNBs is typically at total incoming power of around –50 dBm. This means that non-linear behaviour, intermodulation products, and suppression of total incoming power starts to occur already below that level, at about –60 dBm (in Annex D to this Report, concerning examples of National implementations, a value of –65 dBm is assumed, as indicated in Table 2 of that Annex). Taking into account the example calculation above, this means that in normal circumstances, LNBs always operate in linear mode.

LNB non-linear operations could occur when nearby BWA base stations or terminal stations transmit in a portion of the band that lies within the receive band of an LNB.

Typically LNBs receive over the entire 3 400-4 200 MHz range. Therefore, even if there would not be a co-frequency operation between the frequencies at which an FSS earth station received a certain satellite, and the frequency at which a BWA station operates, due to the wide band of the LNB receiver there is a potential for non-linear behaviour.

3 Set-up of simulations

The goal is to calculate the separation distance between a BWA station or terminal, and an FSS earth station, at which the non-linear behaviour of the LNB, as described in the previous section, would not occur.

The propagation model that will be taken into account is the free space loss propagation as defined in Recommendation ITU-R P.525-2. It is believed that for the analysis considered here this propagation model is sufficient since line-of-sight can be assumed between the transmitting BWA station or terminal, and the FSS earth station. The free-space basic transmission loss is described in this Recommendation as:

$$L_{bf} = 32.4 + 20 \log f + 20 \log d \qquad \text{dB} \tag{1}$$

where:

L_{bf} : free-space basic transmission loss (dB)
f : frequency (MHz)
d : distance (km).

In order to meet the saturation level at the LNB the following expression is valid:

$$BWA_{eirp} - L_{bf} + G_{es} = LNB_{sat} \qquad \text{dBm} \tag{2}$$

where:

BWA_{eirp} : e.i.r.p. from BWA station in the direction of the FSS earth station (dBm)
G_{es} : gain of FSS earth station in the direction of the BWA station (dBi)
LNB_{sat} : saturation point of the LNB (dBm).

Expression (1) and (2) can be combined in order to calculate d with the following result:

$$d = 10^{\left(\frac{BWA_{eirp} + G_{es} - LNB_{sat} - 32.4 - 20 \log f}{20}\right)} \qquad \text{km} \tag{3}$$

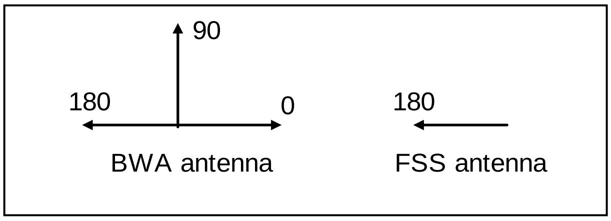
For the LNB value, two different assumptions will be studied. One is assuming the LNB to be at the 1 dB compression point due to transmissions from a BWA station, i.e. a level of –50 dBm, which would prevent the LNB from working at all. The second option is to assume a level of –60 dBm, which is the level needed to avoid non-linear behaviour in the LNB.

For the gain of the FSS earth station in the direction of the BWA transmit station, Recommendation ITU-R S.465 is used. Further, three different antenna sizes (1.2 m, 8 m and 32 m) at three different elevation angles (5°, 25° and 50°) will be studied. These parameters are in line with those in Table 3 in Annex A of this Report.

The assumptions for the BWA stations are taken from Tables 4 and 5 in Annex A of this Report. For the BWA transmit stations, a distinction is made between antennas with a directional antenna (such as the sector antennas) and omnidirectional antennas. For the directional antennas, different azimuth angles between the BWA station and the FSS earth station are studied as depicted in Fig. 19.

FIGURE 19

Geometric azimuth configurations assumed with directional BWA antennas



The assumptions on the e.i.r.p. levels in the direction of the FSS earth station are depicted in Table 27. They take into account the e.i.r.p. and the down tilting of the antenna. For this study it is assumed that the FSS earth station would be located at 0° elevation as seen from the BWA transmitting station. The maximum e.i.r.p. and down tilting angle assumptions are taken from Tables 4 and 5 in Annex A of this Report.

TABLE 27

BWA station e.i.r.p. levels in the direction of the FSS earth station

Type of BWA station	**Type of antenna**	**Max. e.i.r.p. (dBm)**	**Downtilt (degrees)**	**e.i.r.p. in direction of FSS$_{es}$ (dBm)**
BS Specific rural – System A	Directional	57.0	1	56.90
BS Specific rural – System B	Directional	59.0	1	58.90
BS Typical rural – System A	Directional	49.0	2	48.50
BS Typical rural – System B	Directional	51.0	2	50.50
BS Typical urban – System A	Omnidirectional	38.0	4	37.00
BS Typical urban – System B	Directional	40.0	4	40.00
TS Fixed-outdoor – System A	Directional	42.0	N/A	42.00
TS Fixed-outdoor – System B	Directional	42.0	N/A	42.00
TS Nomadic – System A	Omnidirectional	26.0	N/A	26.00
TS Nomadic – System B	Omnidirectional	23.0	N/A	23.00
TS Mobile – System A	Omnidirectional	19.0	N/A	19.00
TS Mobile – System B	Omnidirectional	23.0	N/A	23.00

N/A: Not applicable.

4 Results of analysis

Table 28 to Table 30 show the calculated separation distances for the BWA directional stations, assuming an the 1 dB compression point of the LNB of –50 dBm, for FSS earth station antenna sizes of 32 m, 8 m and 1.2 m respectively.

TABLE 28

Separation distances for BWA directional stations (LNB: –50 dBm, FSS antenna size: 32 m)

Elevation (degrees)	5			25			50		
Azimuth (degrees)	0	90	180	0	90	180	0	90	180
Off-axis gain (dBi)	14.5	–10.0	–10.0	–2.9	–10.0	–10.0	–10.0	–10.0	–10.0
Separation distances (FSS antenna size : 32 m, LNB sat level : –50 dBm)									
Specific rural (A) (km)	7.85	0.47	0.47	1.05	0.47	0.47	0.47	0.47	0.47
Specific rural (B) (km)	9.89	0.59	0.59	1.32	0.59	0.59	0.59	0.59	0.59
Typical rural (A) (km)	2.99	0.18	0.18	0.40	0.18	0.18	0.18	0.18	0.18
Typical rural (B) (km)	3.76	0.22	0.22	0.50	0.22	0.22	0.22	0.22	0.22
Typical urban (B) (km)	1.12	0.07	0.07	0.15	0.07	0.07	0.07	0.07	0.07
Fixed-outdoor (A) (km)	1.41	0.08	0.08	0.19	0.08	0.08	0.08	0.08	0.08
Fixed-outdoor (B) (km)	1.41	0.08	0.08	0.19	0.08	0.08	0.08	0.08	0.08

TABLE 29

Separation distances for BWA directional stations (LNB : –50 dBm, FSS antenna size: 8 m)

Elevation (degrees)	5			25			50		
Azimuth (degrees)	0	90	180	0	90	180	0	90	180
Off-axis gain (dBi)	14.7	–9.8	–9.8	–2.8	–9.8	–9.8	–9.8	–9.8	–9.8
Separation distances (FSS antenna size : 8 m, LNB sat level : –50 dBm)									
Specific rural (A) (km)	8.01	0.48	0.48	1.07	0.48	0.48	0.48	0.48	0.48
Specific rural (B) (km)	10.09	0.60	0.60	1.35	0.60	0.60	0.60	0.60	0.60
Typical rural (A) (km)	3.05	0.18	0.18	0.41	0.18	0.18	0.18	0.18	0.18
Typical rural (B) (km)	3.84	0.23	0.23	0.51	0.23	0.23	0.23	0.23	0.23
Typical urban (B) (km)	1.15	0.07	0.07	0.15	0.07	0.07	0.07	0.07	0.07
Fixed-outdoor (A) (km)	1.44	0.09	0.09	0.19	0.09	0.09	0.09	0.09	0.09
Fixed-outdoor (B) (km)	1.44	0.09	0.09	0.19	0.09	0.09	0.09	0.09	0.09

TABLE 30

Separation distances for BWA directional stations (LNB: –50 dBm, FSS antenna size: 1.2 m)

Elevation (degrees)	5			25			50		
Azimuth (degrees)	0	90	180	0	90	180	0	90	180
Off-axis gain (dBi)	19.4	–1.6	–1.6	5.5	–1.6	–1.6	–1.6	–1.6	–1.6
Separation distances (FSS antenna size : 1.2 m, LNB sat level : –50 dBm)									
Specific rural (A) (km)	13.72	1.23	1.23	2.77	1.23	1.23	1.23	1.23	1.23
Specific rural (B) (km)	17.28	1.55	1.55	3.48	1.55	1.55	1.55	1.55	1.55
Typical rural (A) (km)	5.22	0.47	0.47	1.05	0.47	0.47	0.47	0.47	0.47
Typical rural (B) (km)	6.57	0.59	0.59	1.32	0.59	0.59	0.59	0.59	0.59
Typical urban (B) (km)	1.96	0.18	0.18	0.40	0.18	0.18	0.18	0.18	0.18
Fixed-outdoor (A) (km)	2.47	0.22	0.22	0.50	0.22	0.22	0.22	0.22	0.22
Fixed-outdoor (B) (km)	2.47	0.22	0.22	0.50	0.22	0.22	0.22	0.22	0.22

Table 31 to Table 33 show the calculated separation distances for the BWA directional stations, assuming an LNB level of –60 dBm, for FSS earth station antenna sizes of 32 m, 8 m and 1.2 m respectively.

TABLE 31

Separation distances for BWA directional stations
(LNB: –60 dBm, FSS antenna size: 32 m)

Elevation (degrees)	5			25			50		
Azimuth (degrees)	0	90	180	0	90	180	0	90	180
Off-axis gain (dBi)	14.5	–10.0	–10.0	–2.9	–10.0	–10.0	–10.0	–10.0	–10.0
Separation distances (FSS antenna size : 32 m, LNB sat level : –60 dBm)									
Specific rural (A) (km)	24.83	1.47	1.47	3.32	1.47	1.47	1.47	1.47	1.47
Specific rural (B) (km)	31.26	1.86	1.86	4.18	1.86	1.86	1.86	1.86	1.86
Typical rural (A) (km)	9.44	0.56	0.56	1.26	0.56	0.56	0.56	0.56	0.56
Typical rural (B) (km)	11.88	0.71	0.71	1.59	0.71	0.71	0.71	0.71	0.71
Typical urban (B) (km)	3.55	0.21	0.21	0.47	0.21	0.21	0.21	0.21	0.21
Fixed-outdoor (A) (km)	4.47	0.27	0.27	0.60	0.27	0.27	0.27	0.27	0.27
Fixed-outdoor (B) (km)	4.47	0.27	0.27	0.60	0.27	0.27	0.27	0.27	0.27

TABLE 32

Separation distances for BWA directional stations
(LNB: –60 dBm, FSS antenna size: 8 m)

Elevation (degrees)	5			25			50		
Azimuth (degrees)	0	90	180	0	90	180	0	90	180
Off-axis gain (dBi)	14.7	–9.8	–9.8	–2.8	–9.8	–9.8	–9.8	–9.8	–9.8
Separation distances (FSS antenna size : 8 m, LNB sat level : –60 dBm)									
Specific rural (A) (km)	25.34	1.51	1.51	3.39	1.51	1.51	1.51	1.51	1.51
Specific rural (B) (km)	31.90	1.89	1.89	4.27	1.89	1.89	1.89	1.89	1.89
Typical rural (A) (km)	9.63	0.57	0.57	1.29	0.57	0.57	0.57	0.57	0.57
Typical rural (B) (km)	12.13	0.72	0.72	1.62	0.72	0.72	0.72	0.72	0.72
Typical urban (B) (km)	3.62	0.22	0.22	0.48	0.22	0.22	0.22	0.22	0.22
Fixed-outdoor (A) (km)	4.56	0.27	0.27	0.61	0.27	0.27	0.27	0.27	0.27
Fixed-outdoor (B) (km)	4.56	0.27	0.27	0.61	0.27	0.27	0.27	0.27	0.27

TABLE 33

Separation distances for BWA directional stations
(LNB: –60 dBm, FSS antenna size: 1.2 m)

Elevation (degrees)	5			25			50		
Azimuth (degrees)	0	90	180	0	90	180	0	90	180
Off-axis gain (dBi)	19.4	–1.6	–1.6	5.5	–1.6	–1.6	–1.6	–1.6	–1.6
Separation distances (FSS antenna size : 1.2 m, LNB sat level : –60 dBm)									
Specific rural (A) (km)	43.40	3.89	3.89	8.75	3.89	3.89	3.89	3.89	3.89
Specific rural (B) (km)	54.63	4.89	4.89	11.02	4.89	4.89	4.89	4.89	4.89
Typical rural (A) (km)	16.50	1.48	1.48	3.33	1.48	1.48	1.48	1.48	1.48
Typical rural (B) (km)	20.77	1.86	1.86	4.19	1.86	1.86	1.86	1.86	1.86
Typical urban (B) (km)	6.20	0.56	0.56	1.25	0.56	0.56	0.56	0.56	0.56
Fixed-outdoor (A) (km)	7.81	0.70	0.70	1.57	0.70	0.70	0.70	0.70	0.70
Fixed-outdoor (B) (km)	7.81	0.70	0.70	1.57	0.70	0.70	0.70	0.70	0.70

Tables 34 and 35 show the calculated separation distances for the BWA omnidirectional stations, assuming an LNB level of –50 dBm and –60 dBm respectively, for FSS earth station antenna sizes of 1.2 m, 8 m and 32 m.

TABLE 34

Separation distances for BWA omnidirectional stations
(LNB: –50 dBm)

Antenna size (m)	1.2			8			32		
Gain (dBi)	31.2			47.7			59.8		
Elevation (degrees)	5	25	50	5	25	50	5	25	50
Off-axis gain (dBi)	19.4	5.5	–1.6	14.7	–2.8	–9.8	14.5	–2.9	–10.0
Separation distances (LNB sat level : –50 dBm)									
Typical urban (A) (km)	1.39	0.28	0.12	0.81	0.11	0.05	0.79	0.11	0.05
Nomadic (A) (km)	0.39	0.08	0.04	0.23	0.03	0.01	0.22	0.03	0.01
Nomadic (B) (km)	0.28	0.06	0.02	0.16	0.02	0.01	0.16	0.02	0.01
Mobile (A) (km)	0.17	0.04	0.02	0.10	0.01	0.01	0.10	0.01	0.01
Mobile (B) (km)	0.28	0.06	0.02	0.16	0.02	0.01	0.16	0.02	0.01

TABLE 35

Separation distances for BWA omnidirectional stations
(LNB: –60 dBm)

Antenna size (m)	1.2			8			32		
Gain (dBi)	31.2			47.7			59.8		
Elevation (degrees)	5	25	50	5	25	50	5	25	50
Off-axis gain (dBi)	19.4	5.5	–1.6	14.7	–2.8	–9.8	14.5	–2.9	–10.0
Separation distances (LNB sat level : –60 dBm)									
Typical urban (A) (km)	4.39	0.89	0.39	2.56	0.34	0.15	2.51	0.34	0.15
Nomadic (A) (km)	1.24	0.25	0.11	0.72	0.10	0.04	0.71	0.09	0.04
Nomadic (B) (km)	0.88	0.18	0.08	0.51	0.07	0.03	0.50	0.07	0.03
Mobile (A) (km)	0.55	0.11	0.05	0.32	0.04	0.02	0.32	0.04	0.02
Mobile (B) (km)	0.88	0.18	0.08	0.51	0.07	0.03	0.50	0.07	0.03

5 Discussion of results

Tables 36 to 39 provides an overview of the different separation distances calculated for the cases studied. For each FSS earth station antenna size and LNB value, the minimum, maximum and average separation distances are calculated. The average number is calculated by excluding the maximum and minimum distance values.

TABLE 36

Separation distances for BWA directional antennas
and LNB value of -50 dBm

Antenna size (m)	1.2	8	32
Maximum (km)	17.28	10.09	9.89
Minimum (km)	0.18	0.07	0.07
Average (km)	1.20	0.57	0.55

TABLE 37

Separation distances for BWA directional antennas
and LNB value of –60 dBm

Antenna size (m)	1.2	8	32
Maximum (km)	54.63	31.90	31.26
Minimum (km)	0.56	0.22	0.21
Average (km)	3.80	1.80	1.76

TABLE 38

Separation distances for BWA omnidirectional antennas and LNB value of –50 dBm

Antenna size (m)	1.2	8	32
Maximum (km)	1.39	0.81	0.79
Minimum (km)	0.02	0.01	0.01
Average (km)	0.14	0.07	0.07

TABLE 39

Separation distances for BWA omnidirectional antennas and LNB value of –60 dBm

Antenna size (m)	1.2	8	32
Maximum (km)	4.39	2.56	2.51
Minimum (km)	0.05	0.02	0.02
Average (km)	0.45	0.23	0.22

The results indicate that separation distances of several kilometres distance are needed in order to prevent the LNBs to have non-linear behaviour.

6 Aggregate effects

The results in this study are based on calculation the separation distance assuming a BWA station is transmitting one single channel within the receive band of the LNB. Especially for BWA base stations it is reasonable to assume that multiple channels will be transmitted at any given time. The aggregation of these channels would lead to separation distances that would be considerably higher than in the cases studied in § 4. For example, let’s assume that a base station (BS Typical Urban – System A) would be transmitting 4 × 7 MHz channels in an overlapping band with an FSS earth station LNB, then the aggregate e.i.r.p. level transmitted would be 37 + 10 log(4) = 43 dBm. Tables 40 and 41 show the impact of this aggregate effect with respect to the baseline scenario.

TABLE 40

Aggregate impact for one BWA omnidirectional station (LNB: –50 dBm)

Antenna size (m)	1.2			8			32		
Elevation (degrees)	5	25	50	5	25	50	5	25	50
Off-axis gain (dBi)	19.4	5.5	–1.6	14.7	–2.8	–9.8	14.5	–2.9	–10.0
Typical Urban (A) – Separation distances (LNB sat level: –50 dBm)									
Baseline (e.i.r.p.: 37 dBm) (km)	1.39	0.28	0.12	0.81	0.11	0.05	0.79	0.11	0.05
Aggregate (e.i.r.p.: 43 dBm) (km)	2.77	0.56	0.25	1.62	0.22	0.10	1.58	0.21	0.09

TABLE 41

Aggregate impact for one BWA omnidirectional station
(LNB: –60 dBm)

Antenna size (m)	1.2			8			32		
Elevation (degrees)	5	25	50	5	25	50	5	25	50
Off-axis gain (dBi)	19.4	5.5	–1.6	14.7	–2.8	–9.8	14.5	–2.9	–10.0
Typical Urban (A) – Separation distances (LNB sat level: –60 dBm)									
Baseline (e.i.r.p.: 37 dBm) (km)	4.39	0.89	0.39	2.56	0.34	0.15	2.51	0.34	0.15
Aggregate (e.i.r.p.: 43 dBm) (km)	8.76	1.77	0.78	5.12	0.68	0.30	5.01	0.67	0.30

As can be seen (and expected from the 6 dB higher aggregate level), the required separation distances would double.

7 Band-pass filters on LNBs

One mitigation technique that could improve (i.e. reduce) the separation distances to avoid LNB saturation could be to add a bandpass filter in front of the FSS receiver. However, it is not always possible to retrofit an FSS earth station with a band-pass filter. Further, there could be economical implications associated with the cost of such installations.

8 Conclusions

The aim of this study was to calculate the separation distances that are needed between BWA stations and FSS earth stations in order to avoid saturation or non-linear behaviour of the LNB installed on the FSS earth stations.

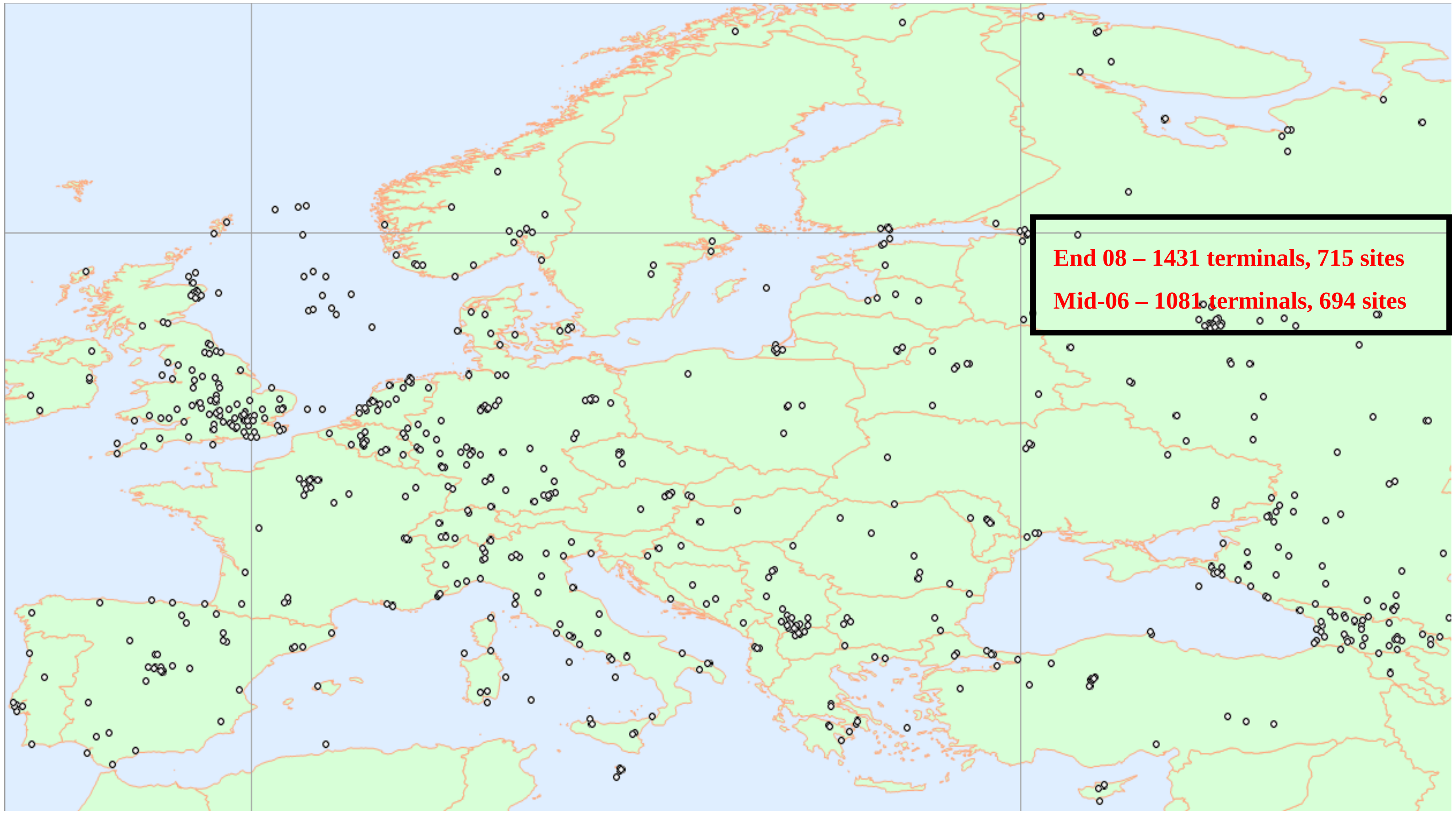
All types of BWA stations (both base stations and terminal stations) have been considered in this study, as well as a range of FSS earth station sizes and elevations that are within the agreed study parameters in this Report.

The results show that separation distances of up to several kilometres are needed in to avoid saturation or non-linear behaviour of the LNB. Further, the risk is highlighted associated with the aggregate effect of multiple carriers operating from a BWA station.

Annex C

FIGURE 20

Earth stations[8] in Europe operating to satellites of Intelsat and SES New Skies in the band 3 400-4 200 MHz at the end of 2008



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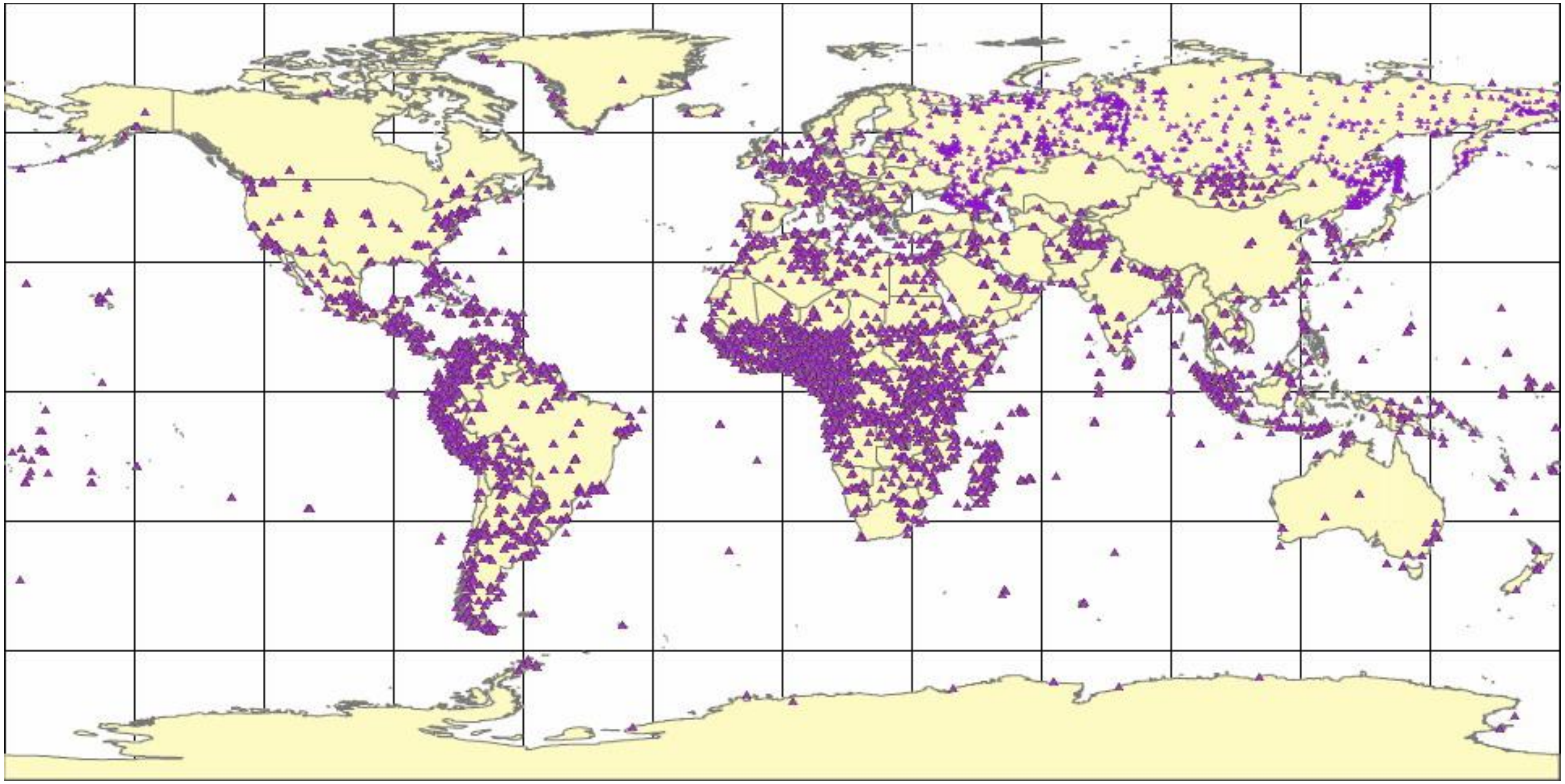
[8] The sites shown are those registered by Intelsat and SES New Skies. Additionally many TVRO earth stations exist but are unrecorded and thus unable to be shown here. Furthermore, the map does not show earth stations served in this band by other satellite operators.

FIGURE 21

Locations of earth stations[9] registered with several satellite operators and receiving in the 3 700-4 200 MHz band



▲ Denotes a site that may include one or more stations.

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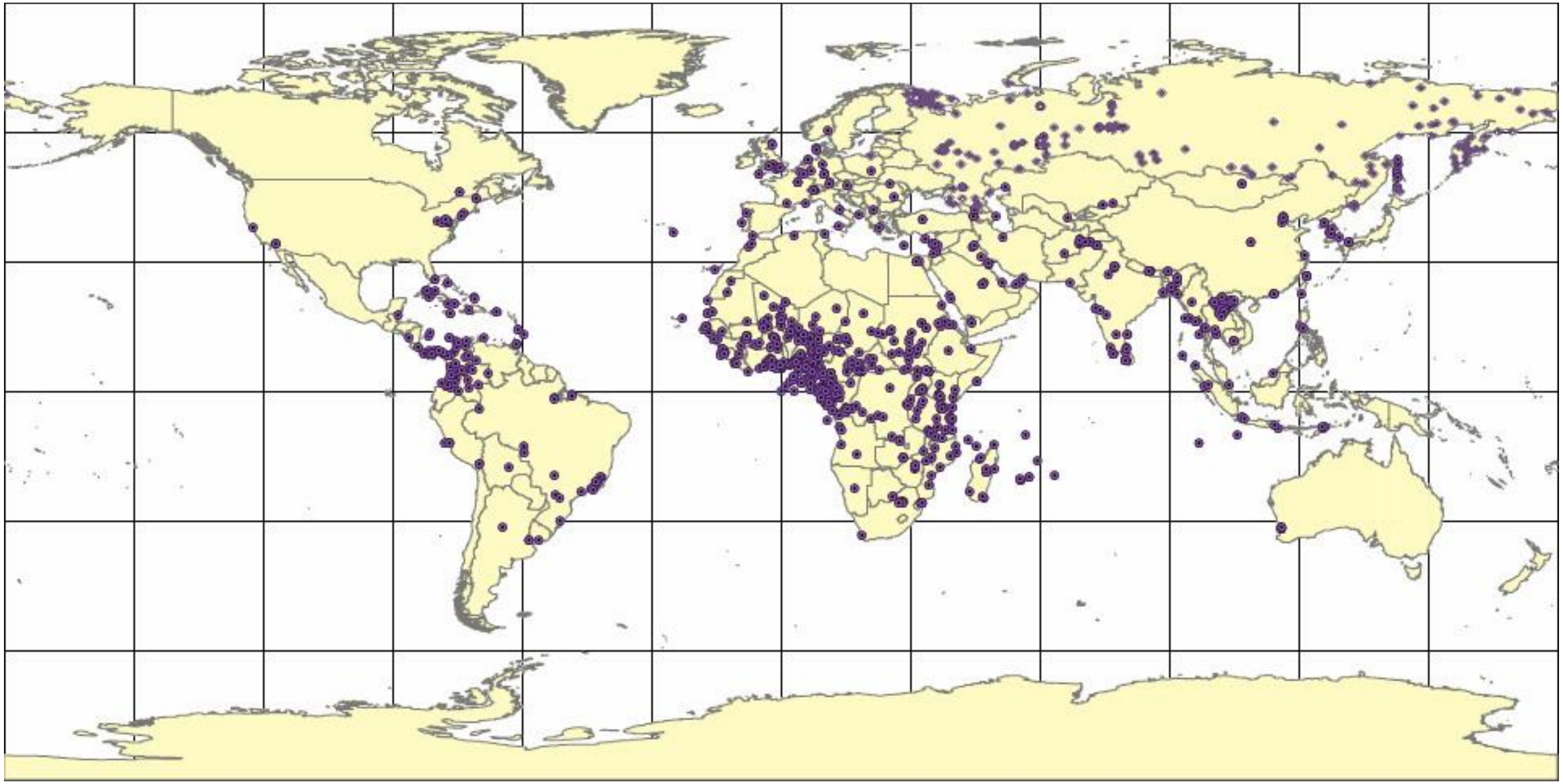
[9] Many TVRO earth stations exist but are unrecorded and thus unable to be shown here.

FIGURE 22

Locations of earth stations[10] registered with several satellite operators and receiving in the 3 625-3 700 MHz band



● Denotes a site that may include one or more stations.

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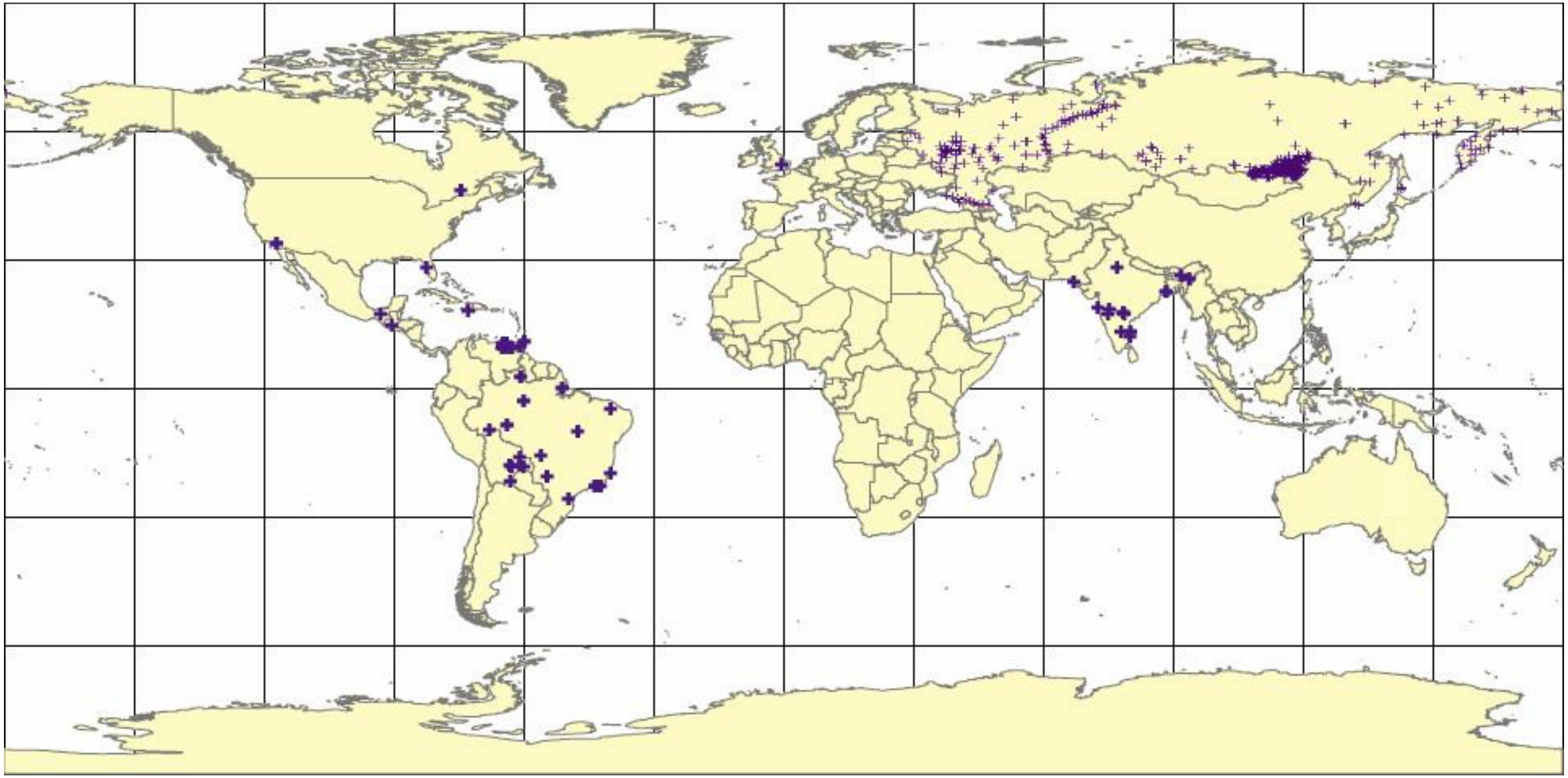
[10] Many TVRO earth stations exist but are unrecorded and thus unable to be shown here.

FIGURE 23

Locations of earth stations[11] registered with several satellite operators and receiving in the 3 400-3 625 MHz band



✚ Denotes a site that may include one or more stations.

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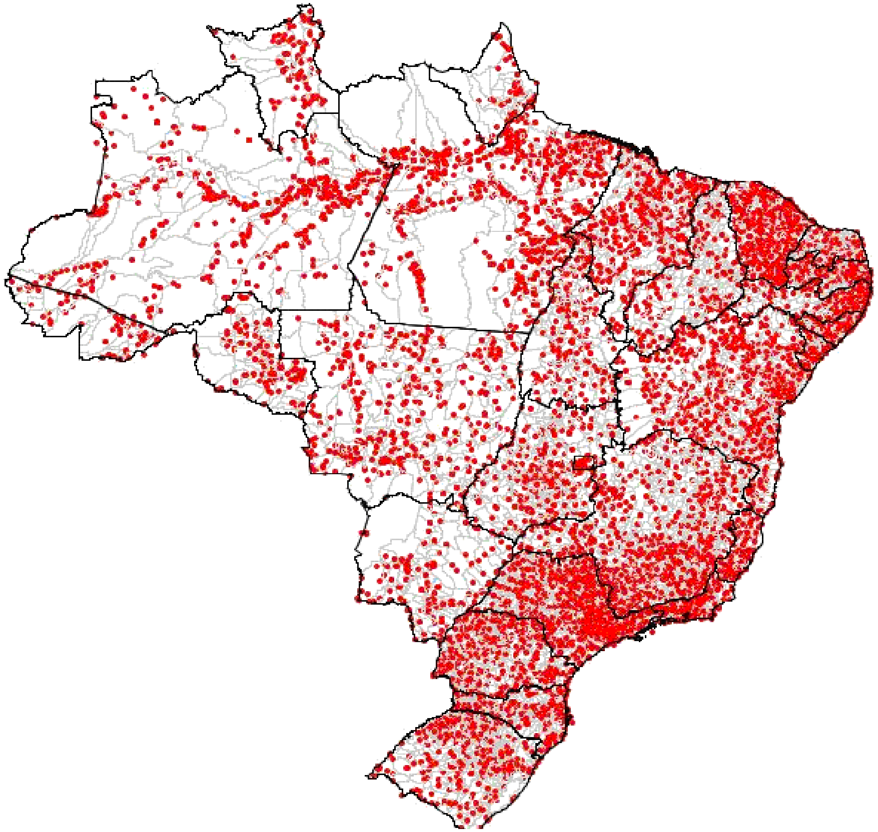
[11] Many TVRO earth stations exist but are unrecorded and thus unable to be shown here.

FIGURE 24

FSS earth stations[12] registered in Brazil (sites using 3 625-4 200 MHz)



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[12] Many TVRO earth stations exist but are unrecorded and thus unable to be shown here.

Annex D

Example of a national implementation

FSS/BWA sharing arrangements in the 3 400-4 200 MHz band in Australia

This example provides details of the sharing arrangements between BWA and FSS in the 3 400-4 200 MHz band in Australia. In Australia, which does not share any national borders, the technical rules for sharing, including FSS earth station and BWA base station filtering characteristics, are controlled by the Administration, which improves the sharing situation. This situation might not be true for other Administrations where additional measures may be required to protect the FSS in the 3 400-4 200 MHz band.

The arrangements detailed in this example may be appropriate for a nation with no national borders but may not be reflective of the more general or common case where national cross-border coordination is required. Furthermore, although the sharing arrangements can fully account for existing FSS systems at the time of deployment, it will likely limit the future deployment of FSS stations in locations where BWA is licensed due to the quasi omnidirectional nature of the BWA base station emissions.

1 Introduction

In early 2010 Australia introduced terrestrial BWA services to the 3 575-3 700 MHz part of the *Extended-C* band. BWA is being licensed to operate in regional and remote areas of Australia. To ensure protection of urban based FSS earth stations the major capital cities have been specifically excluded.

This decision follows a long period of careful analysis into whether BWA could harmoniously share with other co-frequency and adjacent frequency national services, particularly FSS space-to-Earth (s-to-E) downlinks in the 3 400-4 200 MHz band. As Australia does not share any national borders this is essentially a domestic licensing issue.

In this Annex Australia wishes to advise the ITU-R of the arrangements that apply to ensure compatible sharing in this important frequency band. Minimum performance characteristics of the new BWA services and of incumbent FSS downlinks in the *Extended-C* and *Standard-C* bands are included, together with a short summary of the main sharing criteria. Further details can be obtained at: http://www.acma.gov.au/WEB/STANDARD/pc=PC_100424.

2 Summary of the main sharing rules

To ensure that BWA services in the 3 575-3 700 MHz band will be compatible with licensed FSS earth stations in the 3 600-4 200 MHz band a defined frequency coordination process, together with BWA deployment restrictions will apply.

In summary, the main licensing rules are:

- BWA is being licensed in regional and remote areas of Australia. *Exclusion zones* apply around defined areas, such as major cities, in order to preserve future planning options in these areas[13].
- Regional and remote BWA base station transmitters must meet a number of minimum performance characteristics; including an e.i.r.p. density mask above 3 700 MHz (see Table 42 and Fig. 25).
- Regional and remote BWA base station transmitters are not being licensed within 20 km of an existing licensed FSS earth station operating in the adjacent *Standard C* band (see Table 44).
- FSS earth station receivers are assumed to meet a number of minimum performance characteristics (in addition to their licence requirements) (see Table 43).
- Regional and remote BWA frequency assignments are being undertaken using additional coordination specific information (see Table 44).

TABLE 42

BWA base station transmitter characteristics and deployment constraints

Parameter	Explanatory comments	Requirement
Duplex mode		TDD
Smart antenna gain		Coordinate to highest achievable antenna gain
Antenna polarisation discrimination	Potential losses due to polarisation discrimination can be taken into account in cases of main beam coupling. Mixed polarisation refers to the use of two orthogonally polarised signals.	***BWA Tx → ES Rx: dB loss*** Mixed → Circular: 0 dB Mixed → Linear: 3 dB Linear → Circular: 3 dB Linear → Linear (Co-polar): 0 dB Linear → Linear (Cross-polar): As specified by antenna data.
e.i.r.p. density limits (dBm/MHz)	Lower limits apply > 3 670 MHz to reduce out-of-band (OoB) emissions into the 3 700-4 200 MHz band and offer greater protection to earth stations against saturation.	3 575-3 670 MHz = 51 dBm/MHz 3 670-3 700 MHz = 30 dBm/MHz

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[13] Section 2 of the ACMA Spectrum Planning Discussion Paper 02/09 on the “Release of the 3.6 GHz band for Wireless Access Services (WAS)”, http://www.acma.gov.au/webwr/_assets/main/lib310829/spp2009-02_release_of_3.6ghz_band_for_was-disc_paper.pdf.

TABLE 42 (*end*)

Parameter	Explanatory comments	Requirement
Emission masks	A band edge mask at the 3 700 MHz frequency boundary is needed to reduce OoB emissions into the 3 700-4 200 MHz band.	– All transmitters are to adhere to relevant emission masks stated in ETSI EN 302 326. – At, and above, the 3 700 MHz boundary, base stations must meet the mask of Fig. 25.
Main deployment constraints(1)	Deployment constraints are proposed in addition to coordination criteria. These are created to reduce the chance of interference from base stations (and user terminals) into earth stations operating in the 3 700-4 200 MHz band.	– No transmitters may be placed inside exclusion areas. – No user terminal transmitters are to be deployed within a 2 km radius of an earth station operating in the 3 700-4 200 MHz band–unless agreement can be reached with the earth station licensee.

(1) Additional deployment constraints can be found at: http://www.acma.gov.au/webwr/_assets/main/lib310829/rali_fx19_draft_update.pdf.

FIGURE 25

Band edge emission limits for BWA services

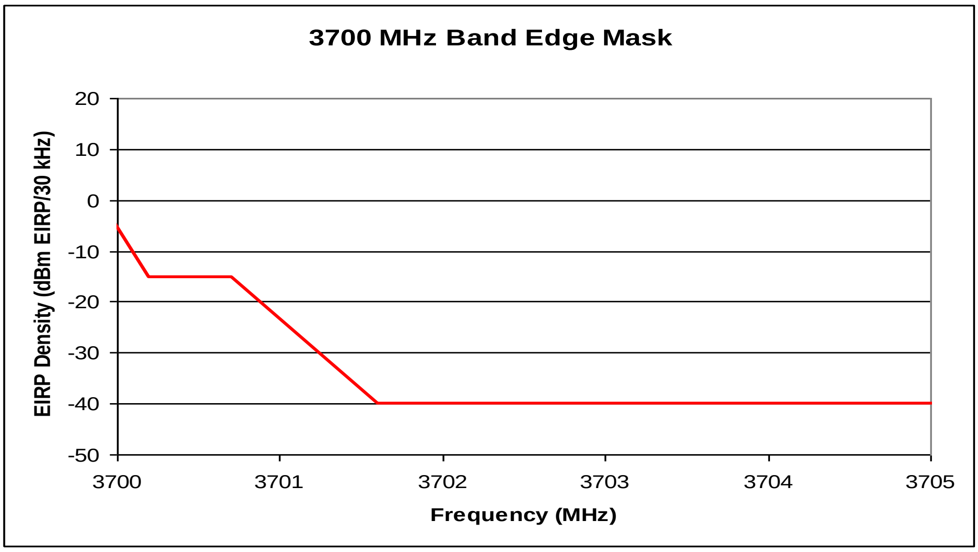

TABLE 43

FSS earth station receiver characteristics

Parameter	Explanatory comments	Value
Reference bandwidth (MHz)	To allow for per MHz coordination.	1
Antenna gain (dBi)	Value to be taken from licence.	–
Antenna pattern (dBi)	Recommendation ITU-R S.465.	–
Antenna feeder losses (dB)	Follows review of existing licensee's data.	0
Antenna height (m)	Value to be taken from licence.	–
Minimum elevation angle (degrees)	Follows review of existing licensee's data.	5
System temperature (K)	Follows review of existing licensee's data.	70
Noise floor (dBW/MHz)	Calculation.	–150.1
Protection criteria (*I*/*N*) (dB)	Based on Recommendations ITU-R S.1432 and ITU-R SF.1006: – ST = Short term (0.0017% time) – LT = Long Term (20% time).	ST = –1.3 LT = –10
Onset of non-linear operation level (dBm)	Follows review of existing licensee's data.	–65 (single entry)
Assumed filter (band pass or notch) attenuation (dB)	Protection requirements have been developed assuming specific filter performance as mentioned here. The fitting of filters is not mandatory; however, earth stations operating in the 3 700-4 200 MHz band are not afforded protection from harmful interference occurring from BWA stations operating in the 3 575-3 700 GHz band.	3 670-3 700 MHz → 0 < 3 670 MHz → 15

TABLE 44

Frequency coordination requirements[14]

Parameter	Explanatory comments	Requirement
Co-channel cull distance	This is the minimum BWA-FSS separation distance for which coordination is required (to protect earth stations in regional and remote areas).	150 km – BWA in 3 670-3 700 MHz 200 km – BWA in 3 600-3 670 MHz
Frequency cull range	This is the frequency range for which co-channel and adjacent channel coordination is required.	Co-channel: 3 600-3 700 MHz Adjacent channel*: 3 575-3 700 MHz *refers to FSS in the 3 700-4 200 MHz band

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[14] Additional frequency coordination requirements can be found at: http://www.acma.gov.au/webwr/_assets/main/lib310829/rali_fx19_draft_update.pdf.

TABLE 44 (*end*)

Parameter	Explanatory comments	Requirement
Adjacent channel separation distance	This is the separation distance required between BWA base stations and FSS earth stations in order to affect adjacent channel coordination. **Note that a minimum 20 km separation distance applies in all adjacent band sharing cases.**	**Note that a minimum 20 km separation distance applies in all adjacent band sharing cases.** ***Case 1*: Interference into 3 700-4 200 MHz** – Guardband < 10 MHz: A BWA base station wishing to deploy within 100 km of an earth station operating in the 3 700-4 200 MHz band is required to undergo adjacent channel coordination, assuming a net filter discrimination (NFD) of 20 dB and a minimum allowable separation distance of 20 km. – Guardband ≥ 10 MHz: a minimum 20 km separation is required. ***Case 2*: Interference into 3 600-3 700 MHz** – Guardband ≥ 10 MHz: Coordination not required as exclusion zones will provide enough protection. – Guardband < 10 MHz: A BWA base station wishing to deploy within 150 km of an earth station operating in the 3 600-3 700 MHz band is required to undergo coordination. Both adjacent channel interference (assuming NFD of 20 dB) and protection against the onset of non-linear operations (assuming 20 MHz channel and no additional filtering losses) analysis is required.
Propagation model		Recommendation ITU-R P.452 – clear sky conditions.
Assignment priority		BWA assignments to be made from lowest available frequency up.

3 Summary and conclusion

Australia has introduced BWA services to the 3 575-3 700 MHz part of the *Extended-C* band. The new BWA services are permitted to operate outside *Exclusion Zones*, typically defined around major cities in Australia, and only where it can be demonstrated that compatibility will exist with licensed FSS earth stations in the area.

In addition BWA base stations are not licensed within 20 km of an existing licensed FSS earth station using the *Standard-C* frequency band. Other frequency coordination requirements also apply.

APPENDIX-B

RECOMMENDATION 724 (WRC-07)

Use by civil aviation of frequency allocations on a primary basis to the fixed-satellite service

The World Radiocommunication Conference (Geneva, 2007),

considering

a) that remote and rural areas often still lack a terrestrial communication infrastructure that meets the evolving requirements of modern civil aviation;

b) that the cost of providing and maintaining such an infrastructure could be expensive, particularly in remote regions;

c) that satellite communication systems operating in the fixed-satellite service (FSS) may be the only medium to satisfy the requirements of the International Civil Aviation Organization's (ICAO) communication, navigation, surveillance and air traffic management (CNS/ATM) systems, where an adequate terrestrial communication infrastructure is not available;

d) that the use of VSAT systems, operating in the FSS and being deployed on a large scale in aeronautical communications, has the potential to significantly enhance communications between air traffic control centres as well as with remote aeronautical stations;

e) that establishing and utilizing satellite communication systems for civil aviation would also bring benefits for developing countries and countries with remote and rural areas by enabling the use of VSAT systems for non-aeronautical communications;

f) that in the cases identified in *considering e)* it is necessary to draw attention to the importance of aeronautical communications as opposed to non-aeronautical communications,

noting

a) that the FSS is not a safety service;

b) that Resolution **20 (Rev.WRC-03)** *resolves to instruct the Secretary-General* "to encourage ICAO to continue its assistance to developing countries which are endeavouring to improve their aeronautical telecommunications ...",

recommends

1 that administrations, in particular in developing countries and in countries with remote and rural areas, recognize the importance of VSAT operations to the modernization of civil aviation telecommunications systems and encourage the implementation of VSAT systems that could support both aeronautical and other communication requirements;

2 that administrations in developing countries be encouraged, to the maximum extent possible and as necessary, to expedite the authorization process to enable aeronautical communications using VSAT technology;

3 that arrangements should be made to provide for urgent service restoration or alternative routing in case of a disruption of a VSAT link associated with the aeronautical communications;

4 that administrations implementing VSAT systems in accordance with *recommends* 1 to 3 should do so in satellite networks operating in frequency bands with a primary allocation to the satellite services;

5 to invite ICAO, noting Resolution **20 (Rev.WRC-03)**, to continue its assistance to developing countries to improve their aeronautical telecommunications, including interoperability of VSAT networks, and provide guidance to developing countries on how they could best use VSAT technology for this purpose,

requests the Secretary-General

to bring this Recommendation to the attention of ICAO.

APPENDIX- C

RESOLUTION 154 –(COM6/24)-WRC-12

Consideration of technical and regulatory actions in order to support existing and future operation of fixed-satellite service earth stations within the band 3 400-4 200 MHz, as an aid to the safe operation of aircraft and reliable distribution of meteorological information in some countries in Region 1

The World Radiocommunication Conference (Geneva, 2012),

considering

a) that remote and rural areas often still lack a terrestrial communication infrastructure that meets the evolving requirements of modern civil aviation;

b) that the cost of providing and maintaining such an infrastructure could be expensive, particularly in remote regions;

c) where an adequate terrestrial communication infrastructure is not available, fixed-satellite service (FSS) earth stations are the only viable option to augment the communication infrastructure in order to satisfy the overall communications infrastructure requirements of the International Civil Aviation Organization (ICAO) and to ensure distribution of meteorological information under the auspices of the World Meteorological Organization (WMO);

d) that the use of FSS earth stations deployed in some countries in Region 1 for aeronautical communications has the potential to significantly enhance communications between air traffic control centres as well as with remote aeronautical stations,

noting

a) that the FSS is not a safety service;

b) that, by its Resolution **20 (Rev.WRC-03)**, WRC resolved to instruct the Secretary-General "to encourage ICAO to continue its assistance to developing countries which are endeavouring to improve their aeronautical telecommunications ...";

c) Recommendation ITU-R SF.1486 on sharing methodology between fixed wireless access systems in the fixed service (FS) and very small aperture terminals (VSATs) in the FSS in the 3 400-3 700 MHz band;

d) Report ITU-R S.2199 on studies on compatibility of broadband wireless access systems and FSS networks in the 3 400-4 200 MHz band;

e) Report ITU-R M.2109 on sharing studies between International Mobile Telecommunications-Advanced (IMT-Advanced) systems and geostationary-satellite networks in the fixed-satellite service in the 3 400-4 200 MHz and 4 500-4 800 MHz frequency bands,

resolves to invite ITU-R

to study possible technical and regulatory measures in some countries in Region 1 to support the existing and future FSS earth stations in the 3 400-4 200 MHz band used for satellite communications related to safe operation of aircraft and reliable distribution of meteorological information referred to in *considering c)*,

invites

all members of the Radiocommunication Sector, ICAO and WMO to contribute to these studies,

instructs the Director of the Radiocommunication Bureau

to include the results of these studies in his Report to WRC-15 for the purposes of considering adequate actions in response to *resolves to invite ITU-R* above,

instructs the Secretary-General

to bring this Resolution to the attention of ICAO and WMO.