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Sharing studies between International Mobile Telecommunication-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 in the WRC study cycle leading to WRC-15

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REPORT ITU-R S.2368-0

Sharing studies between International Mobile Telecommunication-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 in the WRC study cycle leading to WRC-15

(2015)

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Scope

This Report describes 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.

1 Introduction

This Report provides a summary of the sharing studies between International Mobile Telecommunication (IMT)-Advanced systems and geostationary satellite networks in the fixed-satellite service (FSS) in the 3 400-4 200 MHz and 4 500-4 800 MHz frequency bands.

This Report supplements but does not replace other existing Reports on similar subject matters, for example Report ITU-R M.2109-0 – 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, and 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.

2 FSS parameters and deployment information

FSS receiving earth stations operate in the space-to-Earth direction in the 3 400-4 200 MHz frequency band. These earth stations can generally be grouped into four categories: earth stations deployed ubiquitously and/or without individual licensing or registration; individually licensed earth stations; telemetry earth stations; and earth stations that are feeder links for mobile-satellite systems.

The 3 400-4 200 MHz frequency band has been used by the FSS since the 1970's. The technology is mature and equipment is available at low cost. The low gaseous atmospheric absorption combined with lower attenuation due to rain enables highly reliable space-to-Earth communication links. This, together with the wide coverage beams possible in this band, has led to satellites in this band being an important part of the telecommunications infrastructure in many countries. This band is the band of choice 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), direct-to-home (DTH) receivers, and disaster relief. 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. This band is also used by governments in conjunction with international commitments, for example, WMO uses this band to distribute meteorological data through commercial satellite systems.

Further information on FSS space stations and earth stations deployment in the 3 400-4 200 MHz and 4 500-4 800 MHz frequency bands are detailed in § 4 of Report ITU-R M.2109-0.

Typical downlink fixed-satellite service parameters are provided in Tables 1 and 2 below:

TABLE 1

Typical space-to-Earth FSS parameters in the 3 400-4 200 MHz and 4 500-4 800 MHz frequency bands

Parameter	Typical value
Range of operating frequencies	3 400-4 200 MHz, 4 500-4 800 MHz
Antenna diameters (m)	1.2, 1.8, 2.4, 3.0, 4.5, 8, 16, 32
Antenna reference pattern	Recommendation ITU-R S.465
Range of emission bandwidths	40 kHz – 72 MHz
Receiving system noise temperature	100 K for small antennas (1.2-3 m) 70 K for large antennas (4.5 metres and above)
Earth station deployment	All regions, in all locations (rural, semi-urban, urban)[1]
Power flux-density at the Earth's surface produced by emissions from a space station	In accordance with RR No. **21.16**, Table **21-4**

1 FSS antennas in this band may be deployed in a variety of environments. Smaller antennas (1.8-3.8 metres) 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.

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

TABLE 2

Typical MSS feeder link receiving earth station parameters in the 3 GHz bands

Parameter	Units	System-1 Feeder link earth station	System-2 Feeder link earth station
Range of operating frequencies	MHz	3 550-3 700	3 550-3 700
Antenna reference pattern		RR Appendix **7**	RR Appendix **7**
System noise temperature (T_S)	K	71	52.5
IF bandwidth (B_{IF})	MHz	40	40

System-1 satellites are currently used to provide different types of services in land, maritime and aeronautical environments.

System-2 satellites will be used in the near future to continue the existing and evolved services in land, maritime and aeronautical environments. In addition, these satellites will be used for enhanced data services up to 432 kbit/s from small portable Mobile Earth Station (MES) terminals.

3 IMT-Advanced parameters

Deployment-related parameters for terrestrial IMT-Advanced systems between 3 and 6 GHz are provided in Table 3 below.

TABLE 3

Deployment-related parameters for IMT-Advanced systems between 3 and 6 GHz bands

	Macro suburban	Macro urban	Small cell outdoor	Small cell indoor
Base station characteristics / Cell structure				
Cell radius / Deployment density	0.3-2 km (typical figure to be used in sharing studies 0.6 km)	0.15-0.6 km (typical figure to be used in sharing studies 0.3 km)	1-3 per urban macro cell[1] <1 per suburban macro site	depending on indoor coverage/capacity demand
Antenna height	25 m	20 m	6 m	3 m
Sectorization	3-sectors	3-sectors	single sector	single sector
Downtilt	6 degrees	10 degrees	N/A	N/A
Frequency reuse[2]	1	1	1	1

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[1] Outdoor small cells would typically be deployed in very limited areas in order to provide local capacity enhancement. Within these areas, the outdoor small cells would not need to provide contiguous coverage since there would typically be an overlaying macro network present.

[2] If the IMT-Advanced network consists of three cell layers – macro cells, small outdoor cells and small indoor cells – they will not all use the same carrier. Two layers may use the same carrier, although separate carriers in the same or different bands are also possible.

TABLE 3 (*cont.*)

	Macro suburban	**Macro urban**	**Small cell outdoor**	**Small cell indoor**
Antenna pattern	Recommendation ITU-R F.1336 (*recommends* 3.1) – k_a = 0.7 – k_p = 0.7 – k_h = 0.7 – k_v = 0.3 Horizontal 3 dB beamwidth: 65 degrees Vertical 3 dB beamwidth: determined from the horizontal beamwidth by equations in Recommendation ITU-R F.1336. Vertical beamwidths of actual antennas may also be used when available.		Recommendation ITU-R F.1336 omni	
Antenna polarization	linear / ±45 degrees	linear / ±45 degrees	linear	linear
Indoor base station deployment	N/A	N/A	N/A	100%
Indoor base station penetration loss	N/A	N/A	N/A	20 dB (3-5 GHz) 25 dB (5-6 GHz) (horizontal direction) P.1238, Table 3 (vertical direction)
Below rooftop base station antenna deployment	0%	50%	100%	N/A
Feeder loss	3 dB	3 dB	n.a	n.a
Maximum base station output power (5/10/20 MHz)	43/46/46 dBm	43/46/46 dBm	24 dBm	24 dBm
Maximum base station antenna gain	18 dBi	18 dBi	5 dBi	0 dBi
Maximum base station output power/sector (e.i.r.p.)	58/61/61 dBm	58/61/61 dBm	29 dBm	24 dBm
Average base station activity	50%	50%	50%	50%
Average base station power/sector taking into account activity factor	55/58/58 dBm	55/58/58 dBm	26 dBm	21 dBm

TABLE 3 (*end*)

	Macro suburban	**Macro urban**	**Small cell outdoor**	**Small cell indoor**
UE characteristics				
Indoor UE usage	70%	70%	70%	100%
Indoor UE penetration loss	20 dB	20 dB	20 dB	20 dB (3-5 GHz) 25 dB (5-6 GHz) (horizontal direction) P.1238, Table 3 (vertical direction)
UE density in active mode to be used in sharing studies	2.16 / 5 MHz/km^2	3 / 5 MHz/km^2	3 / 5 MHz/km^2	depending on indoor coverage/capacity demand
Maximum UE output power	23 dBm	23 dBm	23 dBm	23 dBm
Average UE output power	–9 dBm	–9 dBm	–9 dBm	–9 dBm
Typical antenna gain for UE	–4 dBi	–4 dBi	–4 dBi	–4 dBi
Body loss	4 dB	4 dB	4 dB	4 dB

3.1 Adjacent channel leakage power ratio[3]

Adjacent channel leakage power ratio (ACLR) is the ratio of the filtered mean power centred on the assigned channel frequency to the filtered mean power centred on an adjacent channel frequency.

The requirements shall apply whatever the type of transmitter considered (single-carrier or multi-carrier). It applies for all transmission modes foreseen by the manufacturer's specification. For a multi-carrier base station, the requirement applies for the adjacent channel frequencies below the lowest carrier frequency transmitted by the base station and above the highest carrier frequency transmitted by the base station for each supported multi-carrier transmission configuration or carrier aggregation configurations.

Minimum requirement

The ACLR is defined with a square filter of bandwidth equal to the transmission bandwidth configuration of the transmitted signal (BWConfig) centred on the assigned channel frequency and a filter centred on the adjacent channel frequency according to the tables below.

For Category A Wide Area base station, either the ACLR limits in the tables below or the absolute limit of –13 dBm/MHz apply, whichever is less stringent.

For Category B Wide Area base station, either the ACLR limits in the tables below or the absolute limit of –15 dBm/MHz apply, whichever is less stringent.

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[3] The information in this section is extracted from section 6.6.2 from the 3GPP Document TS 36.104 v.11.2.0.

For Local Area base station, either the ACLR limits in the tables below or the absolute limit of –32 dBm/MHz shall apply, whichever is less stringent.

For Home base station, either the ACLR limits in Tables 4 and 5 below or the absolute limit of –50 dBm/MHz apply, whichever is less stringent.

TABLE 4

Base station ACLR in paired spectrum

Channel bandwidth of E-UTRA lowest (highest) carrier transmitted $BW_{Channel}$ (MHz)	**BS adjacent channel centre frequency offset below the lowest or above the highest carrier centre frequency transmitted**	**Assumed adjacent channel carrier (informative)**	**Filter on the adjacent channel frequency and corresponding filter bandwidth**	**ACLR limit**
1.4, 3.0, 5, 10, 15, 20	$BW_{Channel}$	E-UTRA of same BW	Square (BW_{Config})	45 dB
	2 x $BW_{Channel}$	E-UTRA of same BW	Square (BW_{Config})	45 dB
	$BW_{Channel}$/2 + 2.5 MHz	3.84 Mcps UTRA	RRC (3.84 Mcps)	45 dB
	$BW_{Channel}$/2 + 7.5 MHz	3.84 Mcps UTRA	RRC (3.84 Mcps)	45 dB

NOTE 1 – BWChannel y BWConfig are the channel bandwidth and transmission bandwidth configuration of the E-UTRA lowest (highest) carrier transmitted on the assigned channel frequency.

NOTE 2 – The RRC filter shall be equivalent to the transmit pulse shape filter defined in TS 25.104, with a chip rate as defined in this Table.

TABLE 5

Base station ACLR in unpaired spectrum with synchronized operation

Channel bandwidth of E-UTRA lowest (highest) carrier transmitted $BW_{Channel}$ (MHz)	**BS adjacent channel centre frequency offset below the lowest or above the highest carrier centre frequency transmitted**	**Assumed adjacent channel carrier (informative)**	**Filter on the adjacent channel frequency and corresponding filter bandwidth**	**ACLR limit**
1.4, 3	$BW_{Channel}$	E-UTRA of same BW	Square (BW_{Config})	45 dB
	2 x $BW_{Channel}$	E-UTRA of same BW	Square (BW_{Config})	45 dB
	$BW_{Channel}$/2 + 0.8 MHz	1.28 Mcps UTRA	RRC (1.28 Mcps)	45 dB
	$BW_{Channel}$/2 + 2.4 MHz	1.28 Mcps UTRA	RRC (1.28 Mcps)	45 dB

TABLE 5 (*end*)

Channel bandwidth of E-UTRA lowest (highest) carrier transmitted $BW_{Channel}$ (MHz)	BS adjacent channel centre frequency offset below the lowest or above the highest carrier centre frequency transmitted	Assumed adjacent channel carrier (informative)	Filter on the adjacent channel frequency and corresponding filter bandwidth	ACLR limit
5, 10, 15, 20	$BW_{Channel}$	E-UTRA of same BW	Square (BW_{Config})	45 dB
	2 x $BW_{Channel}$	E-UTRA of same BW	Square (BW_{Config})	45 dB
	$BW_{Channel}$/2 + 0.8 MHz	1.28 Mcps UTRA	RRC (1.28 Mcps)	45 dB
	$BW_{Channel}$/2 + 2.4 MHz	1.28 Mcps UTRA	RRC (1.28 Mcps)	45 dB
	$BW_{Channel}$/2 + 2.5 MHz	3.84 Mcps UTRA	RRC (3.84 Mcps)	45 dB
	$BW_{Channel}$/2 + 7.5 MHz	3.84 Mcps UTRA	RRC (3.84 Mcps)	45 dB
	$BW_{Channel}$/2 + 5 MHz	7.68 Mcps UTRA	RRC (7.68 Mcps)	45 dB
	$BW_{Channel}$/2 + 15 MHz	7.68 Mcps UTRA	RRC (7.68 Mcps)	45 dB

NOTE 1 – BWChannel y BWConfig are the channel bandwidth and transmission bandwidth configuration of the E-UTRA lowest (highest) carrier transmitted on the assigned channel frequency.

NOTE 2 – The RRC filter shall be equivalent to the transmit pulse shape filter defined in TS 25.105 [7], with a chip rate as defined in this table.

4 Propagation Models

The propagation model defined in Recommendation ITU-R P.452 is used in the sharing studies.

5 FSS Interference Information

There are four known interference mechanisms from IMT-Advanced into FSS. These are as follows:

a) **Interference from in-band IMT-Advanced emissions:** Due to the long distance to the satellite and the power limitations of the satellite, the incoming FSS signal's power flux density at the earth station location is very low. IMT-Advanced 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) **Interference from adjacent band IMT-Advanced emissions (or IMT-Advanced unwanted emissions):** Due to the very low power level of the incoming FSS signals, unwanted emissions generated by IMT-Advanced base stations or UE operating in an adjacent frequency band, can create interference to FSS;

c) **LNA/LNB overdrive:** Earth station low-noise amplifiers (LNAs) and low-noise block down-converters (LNBs) are optimized for reception of the very low power level of the incoming satellite signal and, hence, have a very high sensitivity. Incoming

IMT-Advanced signals at much higher power levels can severely affect the operating point of the LNA/LNB and drive it out of its dynamic range to where it exhibits a non-linear behaviour. This results in the creation of intermodulation products and gain compression (within the device) that in turn result in distortion of the FSS signal. Typically LNAs and LNBs are wideband devices with a low noise figure and flat frequency response over the wanted frequency range. FSS receivers have the bandwidth defining filtering only at intermediate frequency (IF) stage, not at the LNA/LNB; and

d) **LNA/LNB Intermodulation (IM):** A non-linear device, such as an amplifier, can self-generate intermodulation products. There are input levels that would cause the LNA/LNB to exhibit non-linear behaviour. IM is analysed based on the entry into the non-linear device of two or more interfering signals that exceed the IM input level threshold, the third-order intercept point, and the fact that the input/output response slope for the desired RF input is 1, while the slope for 3rd order IM is 3. The onset of IM translated to the 3rd order results in an IM threshold.

5.1 Interference Criteria

Two interference criteria are identified for use when assessing the interference mechanisms of "In-band emissions" and "Adjacent band emission (out-of-band or spurious emission)" from IMT-Advanced to FSS as discussed below.

Long-term interference criterion

– Based on Recommendation ITU-R S.1432

– 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.

– 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.

Short-term interference criterion

– Based on Recommendation ITU-R SF.1006.

– In-band sharing studies: I/N = –1.3 dB that may be exceed by up to 0.001667% time (single entry).

Apportionment of interference allowance

In the absence of specific recommendations on how to apportion these allowances among the competing potential sources of interference, it is suggested that the long-term interference from any individual secondary or unallocated service as well as interference into adjacent frequency bands (unwanted emissions) should be limited to half of the total noise interference allowance into an FSS link, and from any individual primary service it should be limited to half of the afore mentioned values of 6% or 10% of the total noise, as appropriate.

LNA/LNB overdrive

The gain compression threshold at the LNB input is determined by subtracting a typical LNB gain of 63 dB from a gain compression level of 2 dBm at the LNB output. The resulting input threshold level for gain compression is –61 dBm.

The LNB 1 dB compression point is –50 dBm at the LNB input. The LNB would typically start to show non-linear behaviour at an input level of approximately 10 dB below the 1 dB compression point. Therefore, the LNB would start to show non-linear behaviour at an LNB input level equal to –60 dBm.

Based on the above, for the purpose of the sharing studies, a value of –61/–60 dBm should be used.

Intermodulation

An LNB would start to show non-linear behaviour at an input level approximately 10 dB below the gain compression level, at which point the onset of intermodulation will occur. Considering a gain compression level of 2 dBm, the onset of intermodulation occurs at a level of –8 dBm at the output of the LNB. The equivalent level at the LNB input is –71 dBm, as determined by subtracting the LNB gain of 63 dB from the –8 dBm LNB output level. Third-order intermodulation interference is based on the third-order intercept point, and the fact that the input/output response slope for the desired RF input is 1, while the slope for third-order intermodulation interference is 3. The onset of intermodulation translates to a third-order intermodulation threshold at the LNB input of –55.7 dBm.

Based on the above, for the purpose of the sharing studies, a value of –55.7 dBm should be used.

6 Technical studies

A number of studies were conducted that investigated the impact of potential IMT-Advanced transmissions on receiving FSS earth stations.

Short descriptions of the individual technical studies are addressed in the sub-sections below. It should be noted that the details of each technical study are contained in the corresponding Annex of this Report. Reference to adjacent channel in the Annexes to this Report is understood to refer to compatibility between IMT-Advanced systems in the bands or parts of the bands 3 300-3 400 MHz / 4 400-4 500 MHz / 4 800-4 990 MHz and FSS systems in the bands 3 400-4 200 MHz / 4 500-4 800 MHz.

When the below studies refer to IMT-Advanced parameters, these parameters are according to Report ITU-R M.2292 (these are also provided in Table 3).

6.1 Study #1 in Annex 1

This study considered non-site specific conditions using a smooth earth surface model (i.e. not using any specific terrain information) in the sharing studies. Similar studies to Report ITU-R M.2109 were conducted. This study considers additional deployment scenarios of IMT-Advanced systems which are provided in Report ITU-R M.2292.

6.2 Study #2 in Annex 2

This study considered non-site specific conditions both in-band and adjacent-band cases including short and long-term interference criteria were evaluated, as well as non-linear effects, such as the FSS earth station front end receiver saturation. Macro cell and outdoor / indoor small cell IMT-Advanced deployment scenarios were analysed in the urban, suburban and rural environments.

One of the aims of this study is to assess how much the feasibility of sharing between IMT-Advanced systems and FSS earth stations has changed since Report ITU-R M.2109 was developed. In particular, with reference to the propagation model, the more recently updated Recommendation ITU-R P.452-14 is adopted which allows adding terrain or cluttering factors to the smooth earth model by defining the diffraction loss part in detail. Most sharing studies that contributed to the Report ITU-R M.2109 referred to Recommendation ITU-R P.452-12 (now superseded) utilizing the smooth earth propagation model simplification.

6.3 Study #3 in Annex 3

This study considered the interference caused by IMT-Advanced into FSS earth station taking into account specific deployment scenarios, with specific conditions and parameters to the scenarios, for the FSS earth station and the IMT-Advanced base station, including geographical and terrain conditions.

6.4 Study #4 in Annex 4

This sharing study analysed the potential interference caused by IMT-Advanced into the Fixed Satellite Service (FSS) (According to Table 1) space-to-Earth downlink receivers in the frequencies from 3 400-4 200 MHz. Both in-band and adjacent-band cases including short and long-term interference criteria were evaluated, as well as non-linear effects, such as gain compression, Low noise block down-converter (LNB) overload, and intermodulation. Both macro cell and small cell IMT-Advanced deployment scenarios were analysed. An investigation into the utilization of an RF front end filter was performed. An aggregate adjacent band analysis was performed to investigate the effects of varying the size of a guard band between IMT-Advanced and FSS on the required protection distance.

6.5 Study #5 in Annex 5

This study provides in-band and adjacent band compatibility studies to assess the technical feasibility of deploying IMT-Advanced systems in the 3 400-4 200 MHz band based on IMT-Advanced parameters in Report ITU-R M.2292.

6.6 Study #6 in Annex 6

This study examines the potential for coexistence between IMT-Advanced and FSS in the band 3 400-4 200 MHz for an example sharing scenario. The study considers co-channel interference from an IMT-Advanced network into an FSS earth station. Protection contours are calculated for short- and long-term *I/N* criteria both with and without the effects of terrain. Results obtained using Recommendation ITU-R P.452-14 are also compared with those using Recommendation ITU-R P.452-12.

6.7 Study #7 in Annex 7

The study provided adjacent band compatibility analysis between FSS in the frequency band 3 400-4 200 MHz and 4 500-4 800 MHz, and IMT-Advanced in the frequency bands 3 300-3 400 MHz, 4 400-4 500 MHz and 4 800-4 990 MHz. The key FSS parameters and interference criteria refer to Report ITU-R M.2109. Recommendation ITU-R P.452-15 was used as propagation model. IMT-Advanced macro cell/small cell/small cell indoor scenario were evaluated.

6.8 Study #8 in Annex 8

This study provides information related to the potential use of all or parts of the band 3 400-4 200 MHz by IMT-Advanced systems.

One of the aims of this study to assess how the feasibility of sharing between IMT-Advanced systems and FSS earth stations might have changed since Report ITU-R M.2109 was developed. In particular, it is known that the Recommendation ITU-R P.452 propagation model has been updated since Report ITU-R M.2109 was developed, and some of the IMT-Advanced parameter values have been revised.

Another aim of this study to examine how the size of the separation zone for new proposed IMT-Advanced systems varies as a consequence of different terrain around the earth station. To this end, two example earth station locations in the UK have been examined: one surrounded by high hills and the other less well protected by the natural terrain. The former earth station ("Madley"), is also examined in Study #4. Furthermore, example plots are provided for the Yamaguchi earth station in Japan which is a naturally well shielded site, and which is also examined in Study #3.

6.9 Study #9 in Annex 9

This compatibility study analysed the potential interference caused by IMT-Advanced-macros and outdoor small cell outdoor networks into ubiquitously deployed small FSS earth stations. The study looked at aggregate interference from IMT-Advanced in an adjacent band and used guard band between the two services as a study parameter.

One of the aims of the study was to characterise out of band transmit performance of the IMT-Advanced base stations and the FSS receiver sensitivity in a way that allows a net filter discrimination to be calculated as a function of guard band size between the two services. Using this method, the study then aimed to determine the minimum required frequency guard band between the IMT-Advanced and the FSS, in conjunction with the minimum physical separation that is inherent in the high-rise urban scenario.

6.10 Study #10 in Annex 10

This study examined the non-site specific geographic and frequency separation that would be necessary to permit compatible operation between IMT-Advanced and FSS earth stations. The study investigated in-band and adjacent band compatibility with the FSS allocation.

6.11 Study #11 in Annex 11

This study considered the additional required attenuation levels between interfering transmit IMT base stations and interfering IMT fixed UE and a satellite receive earth station. Characterization of IMT base stations and UE was based on actual parameter values taken from deployed broadband wireless access (BWA) networks in Brazil. Interfering signal level limits were not calculated but rather set from levels actually measured in typical LNAs/LNBs under controlled conditions. Earth station antenna performance was referred to ITU Recommendations based on actual data taken from antenna patterns submitted by certified labs.

7 Summary of results

7.1 Major assumptions and evaluated interference mechanisms in individual technical studies

Table 6 is a comparison table regarding major assumptions and evaluated interference mechanisms in the individual technical studies detailed in the corresponding Annexes of this Report.

TABLE 6

Summary of major assumptions and evaluated interference mechanisms in individual technical studies

Study #	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**	**#11**
Parameter settings of IMT-Advanced and FSS earth stations											
Use of the FSS parameters in § 2	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES (B.0)
Use of the IMT-Advanced parameters in § 3	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES (B.0)
Propagation model											
Use of Recommendation ITU-R P.452 14	YES	YES	YES	YES	YES	YES	NO (P.452-15)	YES	YES	YES	YES (B.1)
Use of actual terrain profile	NO	NO (generic)	YES	YES	YES	NO	NO	YES	NO	NO	NO
Evaluated interference mechanisms											
In-band emissions evaluation using interference criteria in § 5	YES	YES	YES	YES	YES	NO	NO	YES	NO	YES	NO
Adjacent band emissions evaluation using interference criteria in § 5	NO	YES	YES	YES	YES	YES	YES	NO	YES	YES	NO
LNA/LNB overdrive evaluation using interference criteria in § 5	NO	NO	YES	YES	NO	NO	NO	NO	NO	NO	NO
Intermodulation evaluation using interference criteria in § 5	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO

NOTE B.0 – Partial use of parameters, derived from actual networks installed in Brazil.

NOTE B.1 – Free Space and Free Space with a penalty.

Further details of the assumptions used in the individual technical studies are contained in the embedded file below.

Study assumptions
and results v1.xlsx

7.2 Summary of results in individual technical studies

Tables 7 to 9 summarize the required separation distances presented in the individual technical studies to protect FSS earth stations for the respective interference mechanisms, in-band emissions, adjacent band emissions, and LNA/LNB overdrive, respectively.

TABLE 7

Required separation distances to protect FSS earth stations associated with in-band emissions

Study #	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**	**#11**
Scenario			**IMT-Advanced networks using suburban macro-cell deployment**								
Long-term interference	61-84 km (FSS antenna elevation angle of 5°)	56-61 km (FSS antenna elevation angle from 48° to 5°)	30-40 km / 10-20 km (FSS antenna elevation angle of 6.5/36º with mountain terrain profile)	**Single entry:** 58.1 km **Aggregate:** 63.0 km (FSS antenna elevation angle of 5°)	57.1-87.1 km (FSS antenna elevation angle of 5°)	N/A	N/A	About 100 km (FSS antenna elevation angle of 9.4º)	N/A	27-50 km (FSS antenna elevation angle of 5°)	N/A
Short-term interference	486-628 km (FSS antenna elevation angle of 5°)	44-224 km, main lobe 2-62.7 km, side lobe (FSS antenna elevation angle from 48° to 5°)	30-70 km/ 10-26 km (FSS antenna elevation angle of 6.5/36º with mountain terrain profile)	525 km (FSS antenna elevation angle of 5°)	312.2-487.6 km (FSS antenna elevation angle of 5°)	N/A	N/A	About 450 km on partly over-sea path; about 300 km on overland path (FSS antenna elevation angle of 9.4°)	N/A	N/A	N/A

TABLE 7 (*cont.*)

Study #	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**	**#11**
Scenario			**IMT-Advanced networks using urban macro-cell deployment**								
Long-term interference	46-62 km (FSS antenna elevation angle of 5°)	67-72 km (FSS antenna elevation angle from 48° to 5°)	N/A	**Single entry:** 51.2 km **Aggregate**: 53 km (FSS antenna elevation angle of 5°)	45.5-93.0 km (FSS antenna elevation angle of 5°)	N/A	N/A	About 100 km (FSS antenna elevation angle of 9.4°)	N/A	28-48 km (FSS antenna elevation angle of 5°)	N/A
Short-term interference	364-510 km (FSS antenna elevation angle of 5°)	250-450 km, main lobe 110-280 km, side lobe (FSS antenna elevation angle from 48° to 5°)	N/A	477 km (FSS antenna elevation angle of 5°)	266.4-467.3 km (FSS antenna elevation angle of 5°)	N/A	N/A	About 420 km on partly over-sea path, about 250 km on overland path (FSS antenna elevation angle of 9.4°)	N/A	N/A	N/A

TABLE 7 (*cont.*)

Study #	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
Scenario	**IMT-Advanced networks using small-cell outdoor deployment**										
Long-term interference	25 km (FSS antenna elevation angle of 5°)	0.5-5 km (FSS antenna elevation angle from 48° to 5°)	15-25 km (FSS antenna elevation angle of 6.5/36° with mountain terrain profile)	**Single entry**: 20.3 km **Aggregate**: 20.3 km (FSS antenna elevation angle of 5°)	4.9-35.1 km (FSS antenna elevation angle of 5°)	N/A	N/A	80 km	N/A	3-16 km (FSS antenna elevation angle of 5°)	N/A
Short-term interference	26 km (FSS antenna elevation angle of 5°)	3 km or less (FSS antenna elevation angle from 48° to 5°)	15-25 km (FSS antenna elevation angle of 6.5/36° with mountain terrain profile)	225 km (FSS antenna elevation angle of 5°)	up to 262.7 km (FSS antenna elevation angle of 5°)	N/A	N/A	120 km for an overland path; 350 km for a partly oversea path	N/A	N/A	N/A (FSS antenna elevation greater than 48°)

TABLE 7 (*end*)

Study #	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
Scenario	**IMT-Advanced networks using small-cell indoor deployment**										
Long-term interference	< 5 km to 16 km when penetration loss = 20 to 0 dB (FSS antenna elevation angle of 5°)	0.5-4 km, 20 dB indoor loss 1.5-5 km, 10 dB indoor loss (FSS antenna elevation angle from 48° to 5°)	N/A	**Single entry**: 4.1 to 8.4 km when building penetration loss = 20 to 5 dB **Aggregate**: 4.1 to 8.4 km when building penetration loss = 20 to 5 dB (FSS antenna elevation angle of 5°)	N/A	N/A	N/A	60 km	N/A	< 1 km when penetration loss = 20 (FSS antenna elevation angle of 5°)	N/A (FSS antenna elevation greater than 48°)
Short-term interference	< 5 km to 16 km when penetration loss = 20 to 0 dB (FSS antenna elevation angle of 5°)	10 and 20 dB indoor loss: *I/N* criterion met provided the presence of a 20 m (40 m) high obstacle at 200 m (100 m) distance from FSS ES	N/A	3.8 to 8.3 km when building penetration loss = 20 to 5 dB (FSS antenna elevation angle of 5°)	N/A	N/A	N/A	120 km for an overland path; 300 km for a partly oversea path	N/A	N/A	N/A (FSS antenna elevation greater than 48°)

TABLE 8

Required separation distances to protect FSS earth stations associated with adjacent band emissions

Study #	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**	#11
	IMT-Advanced networks using suburban macro-cell deployment										
Long-term interference	N/A	< 0.6-1.4 km, 0 MHz GB < 0.6-1.3 km, 5 MHz GB (FSS antenna elevation angle from 48° to 5°)	10-15 km (FSS antenna elevation angle of 6.5/36º with mountain terrain profile)	**Single entry:** 13.8 km or 13.4 km with RF filter **Aggregate**: 19.0 km or 18.0 km with RF filter (FSS antenna elevation angle of 5°)	13.6-33.6 km (FSS antenna elevation angle of 5°)	N/A	1.4 km (FSS antenna elevation angle of 5°)	N/A	N/A	~30 km (FSS antenna elevation angle of 5°)	N/A
Scenario	**IMT-Advanced networks using urban macro-cell deployment**										
Long-term interference	N/A	39-49 km, 0-10 MHz GB (FSS antenna elevation angle from 48° to 5°)	N/A	**Single entry**: 9.3 km both with and without RF filter **Aggregate**: 12.0 km both with and without RF filter (FSS antenna elevation angle of 5°)	11.0-40.2 km (FSS antenna elevation angle of 5°)	N/A	N/A	N/A	N/A	~30 km (FSS antenna elevation angle of 5°)	N/A

Scenario	**IMT-Advanced networks using small-cell outdoor deployment**										
Long-term interference	N/A	< 0.3, 0 MHz GB (FSS antenna elevation angle from 48° to 5°)	5-10 km/ less than 2 km (FSS antenna elevation angle of 6.5/36° with mountain terrain profile)	**Single entry**: 3.8 km both with and without RF filter **Aggregate**: 3.8 km both with and without RF filter (FSS antenna elevation angle of 5°)	4.7 km (FSS antenna elevation angle of 5°)	N/A	50 m (FSS antenna elevation angle of 5°)	N/A	Related to frequency separation and assumptions about filtering and OOB emissions. Some cases show co-existence in same geographic area is possible	~5 km (FSS antenna elevation angle of 5°)	N/A
Scenario	**IMT-Advanced networks using small-cell indoor deployment**										
Long-term interference	N/A	< 0.3, 0 MHz GB, 20 dB indoor loss; < 0.4, 0 MHz GB, 10 dB indoor loss (FSS antenna elevation angle from 48° to 5°)	N/A	Single entry and aggregate: 0.5 to 1.5 km when building penetration loss = 20 to 5 dB (FSS antenna elevation angle of 5°)	N/A	N/A	60 m (FSS antenna elevation angle of 5°)	N/A	N/A	< 5 km (FSS antenna elevation angle of 5°)	N/A

TABLE 9

Required separation distances to protect FSS earth stations associated with LNA/LNB overdrive

Study #	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**	#11
Scenario	**IMT-Advanced networks using suburban macro-cell deployment**										
IF filter	N/A	N/A	N/A since aggregate case	9.0 km (FSS antenna elevation angle of 5°)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IF and RF filter	N/A	N/A	N/A since aggregate case	8.8 km (FSS antenna elevation angle of 5°)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Scenario	**IMT-Advanced networks using urban macro-cell deployment**										
IF filter	N/A	N/A	N/A	8.7 km (FSS antenna elevation angle of 5°)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IF and RF filter	N/A	N/A	N/A	8.5 km (FSS antenna elevation angle of 5°)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Scenario	**IMT-Advanced networks using small-cell outdoor deployment**										
IF filter	N/A	N/A	N/A	1.1 km (FSS antenna elevation angle of 5°)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IF and RF filter	N/A	N/A	N/A	0.9 km (FSS antenna elevation angle of 5°)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Only one of the studies (Study #4) determined the required separation distance to protect FSS earth station receivers from intermodulation interference from IMT-Advanced. The required separation distances are:

– In the case of an IMT-Advanced suburban macro-cell deployment, the required separation distance is 8.5 km. If an RF front-end filter is installed on the FSS earth station receiver, the required separation distance is 8.4 km.

– In the case of an IMT-Advanced urban macro-cell deployment, the required separation distance is 8.0 km. If an RF front-end filter is installed on the FSS earth station receiver, the required separation distance is 7.9 km.

– In the case of an IMT-Advanced small cell outdoor deployment, the required separation distance is 0.6 km. If an RF front-end filter is installed on the FSS earth station receiver, the required separation distance is 0.5 km.

8 Real interference cases[4]

8.1 Interference from WiMAX systems to FSS earth stations in Bangladesh

8.1.1 Introduction

This section contains information about interference from WiMAX systems to FSS earth stations operating in Bangladesh.

8.1.2 Summary

Bangladesh is one of many developing countries in Asia where WiMAX is widely deployed by ISPs as a cheap alternative to ADSL. A field test was carried out by a regional FSS operator in 20-22 March 2012 in Dhaka, after it had received a number of serious quality degradation complaints from cable operators who receive TV channels from satellite.

The test found out the problem was caused by transmissions from WiMAX repeaters being deployed throughout the city. It mainly examined and proved the “saturation effect” of WiMAX interference into FSS, i.e. the powerful influx of WiMAX transmission making the satellite receiving system working in saturation mode, since these WiMAX transmitters are located in distances ranging from 50 metres to a few hundred metres and all the transmitters are visible from the test sites. The WiMAX transmitter power is limited to 4 W. The test result was compared with the values benchmarked in Hong Kong, where no WIMAX interference existed, and with those derived by theoretical calculations.

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[4] Information on whether the WiMAX systems discussed in this section are in line with IEEE 802.16d or IEEE 802.16e is yet to be provided.

8.1.3 Test Plots

FIGURE 1

Satellite Dish and a nearby WiMAX Transmitter

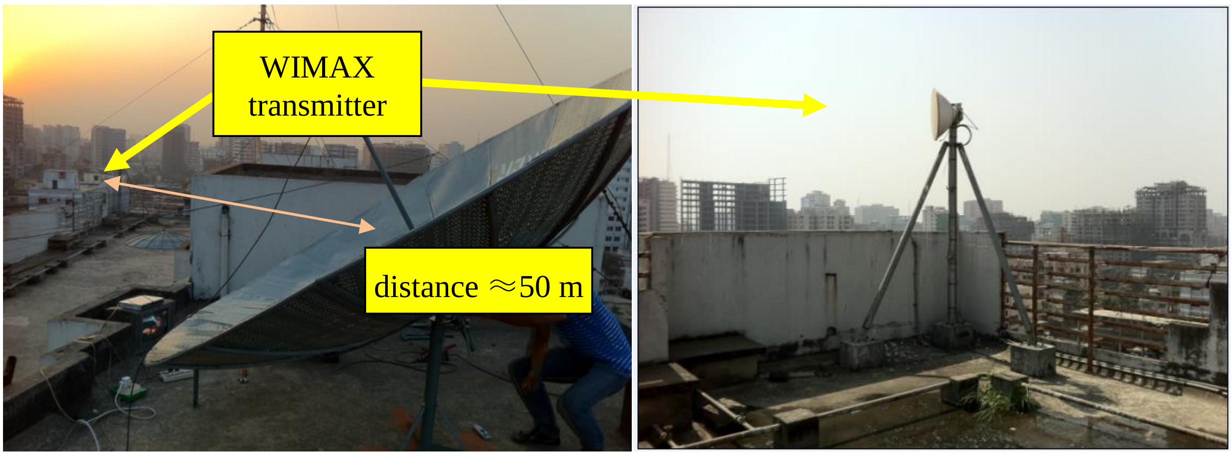


FIGURE 2

WiMAX everywhere in Dhaka

FIGURE 3

Plot of WiMAX Signals side by side with FSS signals

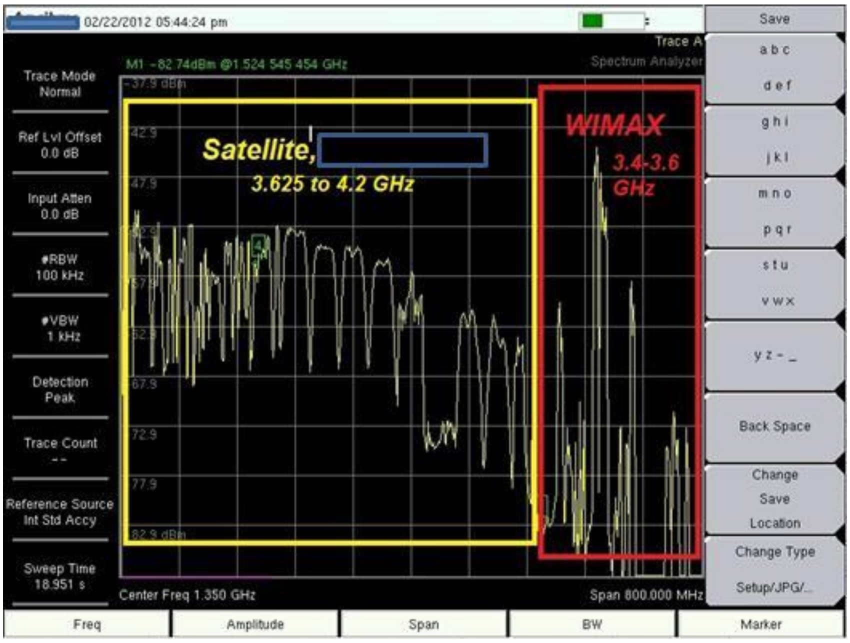
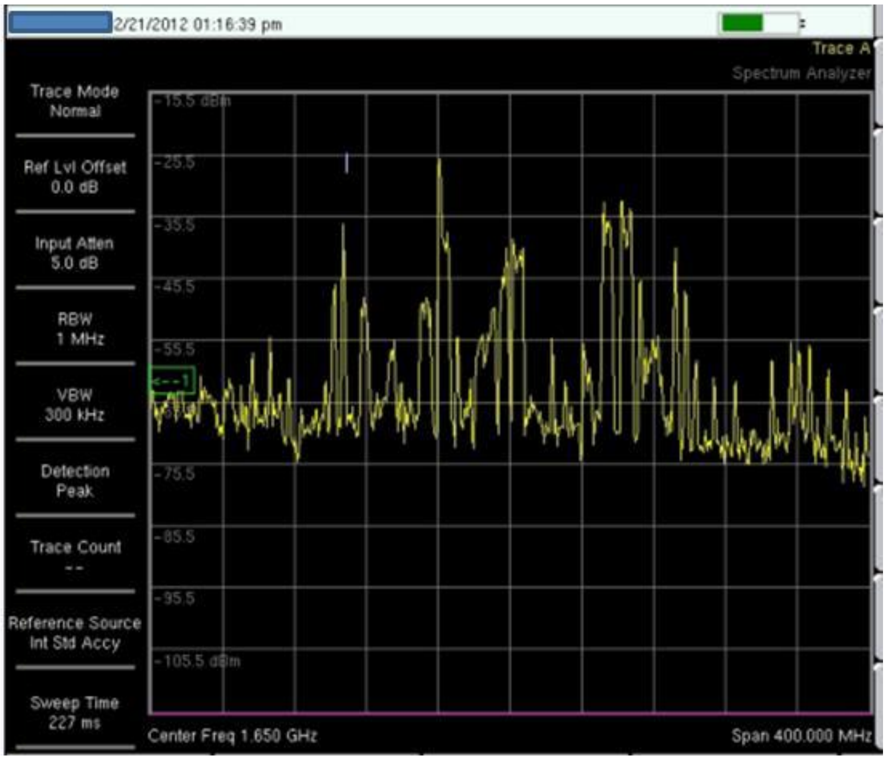


FIGURE 4

Plot of WiMAX Signals



Figures 3 and 4 are the plots of the WiMAX signal and its interference caused to satellite spectrum. The WiMAX transmitters are located in various distances ranging from 50 metres to a few hundred metres. All transmitters are visible from the test sites. The plots show the WiMAX interference has seriously distorted the noise floor of the satellite receiving system, due to compression of LNB performance, and consequently causes degradation on the G/T performance and inferior TV reception qualities.

8.1.4 Test Data

TABLE 10

G/T degradation in Dhaka as compared to Hong Kong

Parameter	**Mesh 3 metre @HK**	**Solid 3 metre @HK**	**Solid 3.7 metre @BGD***
C/N	*41.0*	*43.0*	*38.0*
CW e.i.r.p.	*19.8*	*19.8*	*18.8*
Path Loss	*196.1*	*196.1*	*196.1*
C/No	*69.3*	*71.3*	*66.3*
Experimental G/T	*17.0*	*19.0*	*15.0*
Theoretical G/T	*17.4 (40% efficiency)*	*19.5*	*21.3*
Reason for inconsistency	*Within error range*	*Within error range*	*LNB compression due to WiMAX influx*

TABLE 11

Margin loss in Dhaka as compared to Hong Kong

	Downlink H-pol						**Downlink V-pol**			
TV Channels	TV-1		TV-2		TV-3		TV-4		TV-5	
Freq	3 787 MHz		3 920 MHz		4 163 MHz		3 747 MHz		3 993 MHz	
Readings	Eb/No	Margin	Eb/No	Margin	Eb/No	Margin	Eb/No	Margin	Eb/No	Margin
Satellite TV Margin@HK	*10.5*	*5.4*	*10.4*	*4.3*	*10.4*	*4.9*	*10.5*	*5.0*	*13.4*	*7.9*
Satellite TV Margin@Dhaka	*7.6*	*2.6*	*8.3*	*2.3*	*10.8*	*5.3*	*7.8*	*2.3*	*11.6*	*6.1*

8.1.5 Conclusions

This report has presented the experimental analysis of interference impacts on the C-band satellite TV receiving station caused by the WiMAX. It was found that, although WiMAX operates in extended C-band, i.e. 3 400 to 3 700 MHz, it did cause systematic degradation on the performance of the satellite links operating in standard C-band, i.e. 3 700 to 4 200 MHz, due to the "saturation effect". The deterioration on the TV reception quality varied from **2 to 6 dB** depending on the interfering scenarios. More WiMAX transmitters in close proximity also cause more interference because of the aggregated effect.

8.2 Interference case from Brazil

In early 2007/2008, the first BWA technology equipment began to be installed in Brazil by a national telecommunications operator. At that time, several cases of harmful interference in C-Band satellite systems (Cable TV head-end or Local TV Signals and VSAT networks) operating in the range of 3 600-4 200 MHz started to pop-up in the country, due to the large difference in power flux densities between the BWA transmitters and the receiving C-Band antennas.

During that period, the total number of BWA stations was approximately 400 and the number of reported interference cases reached percentages as high as 15% of the installed stations.

Taking into account those reported interference cases, a number of field interference tests were performed that validate the interference model described previously. One of testes is described as follows.

8.2.1 Test results

Tests were performed during September, 2009.

Main test data were as follows:

a) Satellite station
   - C-band (and extended C-band) digital receiver
   - 2.6 meter antenna
   - Receiving frequencies
     - 3 628 MHz – Extended C-Band
     - 3 955 MHz – Standard C-Band
   - LNBs used in the tests
     - Regular – 3 400 to 4 200 MHz
     - Greatek non-professional – 3 700 to 4 200 MHz
     - Norsat professional – 3 700 to 4 200 MHz

b) BWA station
   - Maximum output power of 1 W
   - Transmitting frequency – 3 550 MHz

c) Distance between BWA stations and earth station
   - 100 meters.

Tests were performed for the following situations:

- Satellite station with unfiltered low noise block downconverter feedhorn (LNBF) operating in extended C-Band
- Satellite station with unfiltered LNBF operating in standard C-Band
- Satellite station with filtered Greatek LNBF operating in standard C-Band
- Satellite station with filtered Norsat LNBF filter operating in standard C-Band.

The tests results are shown in the table below, noting that both extended and standard C-band are susceptible to harmful interference.

TABLE 12

Minimum distance without interference (m)

	Minimum distance without interference			
	Transmitted power – BWA			
Type of filter	**1 W**	**2 W**	**30 W**	**C-Band**
Without filter	1 600	3 000	12 350	Extended
Without filter	900	1 700	6 950	Standard
Greatek Filter	350	650	2 700	Standard
Norsat Filter	200	375	1 550	Standard

8.2.2 Registered interference cases

The following table provides a list of actual interference cases registered by large TVRO user groups, TV broadcast headends with satellite receive stations and VSAT operators in Brazil during the 2008-2009 time period, with the initial deployment by one national operator of a WiMax fixed access network operating at 3 550 MHz.

TABLE 13

Actual registered interference cases

Locality	Date	User
Joinville – SC	Dec 2008	TVRO
Blumenau – SC	Nov 2008	TVRO
Camboriú – SC	Nov 2008	TVRO
Florianópolis – SC	Oct 2008	Corporate Data Network
Criciúma – SC	Oct 2008	TVRO
Curitiba – PR	Aug 2008	TV Network
Chapecó – SC	Sep 2008	Corporate Data Network
Cascavel – PR	Oct 2008	TVRO
Bagé – RS	Oct 2009	TVRO
Telêmaco Borba – PR	Nov 2009	TVRO
Cornélio Procópio – PR	Nov 2009	TVRO
Vacaria – RS	Nov 2009	TVRO
Caçador – SC	Nov 2009	TVRO
Lajeado – RS	Aug 2008	TV Network – Cable
Caxias do Sul – RS	May 2009	TV Network

TABLE 13 (*end*)

Locality	Date	User
Porto Alegre – RS	Jun 2009	TV Network
Cornélio Procópio – PR	Nov 2009	Corporate Data Network
Umuarama – PR	Jan 2009	Corporate Data Network
São Luiz – MA	Oct 2008	TV Network
São Luiz – MA	Oct 2008	TV Network
Caruaru – PE	Oct 2008	TV Network
Recife – PE	Oct 2008	TV Network
Salvador – BA	Aug 2008	TV Network
Belo Horizonte – MG	Sep 2009	Private Data Network
Belo Horizonte – MG	Aug 2009	TVRO
Contagem – MG	Nov 2008	TVRO
Divinópolis – MG	Jul 2009	TV Network
Divinópolis – MG	Jul 2009	Private Data Network
Divinópolis – MG	Jul 2009	TVRO
Governador Valadares – MG	Aug 2008	Private Data Network
Sete Lagoas – MG	Aug 2008	TVRO
Sete Lagoas – MG	Aug 2008	Private Data Network
Barbacena – MG	Nov 2009	TVRO
Vila Velha Jaburuna – MG	Nov 2008	Satellite Radio
Itabuna – BA	Apr 2009	TV Network
Juazeiro – BA	Jun 2009	TV Network
Araçatuba – SP	Jul 2008	Corporate Data Network
Taquacequetuba – SP	May 2008	TVRO
Nova Friburgo – RJ	Aug 2008	Private Data Network
Nova Friburgo – RJ	Oct 2009	Private Data Network
Campos – RJ	Jun 2008	TVRO
Imperatriz – MA	Jun 2009	TV Network
Imperatriz – MA	Jun 2009	TV Network
Imperatriz – MA	Jul 2009	TV Network

9 Summary

This Report has assessed technical feasibility of deploying IMT-Advanced networks considering sharing and compatibility with geostationary satellite networks in the FSS in the 3 400-4 200 MHz and 4 500-4 800 MHz frequency bands.

The required separation distances to protect FSS receiving earth stations are summarized as follows with respect to the following different interference mechanisms.

(1) In-band emissions

In the case of IMT-Advanced suburban/urban macro-cell deployment scenarios:

> For the long-term interference criterion, the required separation distances are at least in the tens of km. For the short-term interference criterion, the required separation distances, including when the effects of terrain are taken into account, exceed 100 km for most of the cases. Both the long-term and short-term interference criteria would have to be met.
>
> In some cases, the required separation distances are larger, up to 525 km. In other cases, the required separation distances could be reduced by taking into account additional effects of natural and artificial shielding. However these effects are site specific.

In the case of IMT-Advanced small-cell outdoor deployment scenarios:

> For the long-term interference criterion, the required separation distances are in the tens of km. For the short-term interference criterion, the required separation distances, including when the effects of terrain and clutter are taken into account, are around 30 km in typical IMT-Advanced small-cell deployment using low antenna height in urban environment. In some cases the required separation distances were found to exceed 100 km. Both the long-term and short-term interference criteria would have to be met.

In the case of IMT-Advanced small-cell indoor deployment scenarios:

> The required protection distance for an indoor small cell deployment was smaller relative to small cell outdoor due to the fact that some degree of building attenuation was assumed, as well as lower base station e.i.r.p. and antenna height.
>
> For the long-term interference criterion, the required separation distances vary from about 5 km to tens of km. For the short-term interference criterion, the required separation distances vary from about 5 km to tens of km, and in some instances up to 120 km. Both the long-term and short-term interference criteria would have to be met.
>
> The wide range of distances is a consequence of earth stations in a variety of terrain conditions, assumed clutter loss, and different assumptions for the building penetration loss (0 to 20 dB).

The above mentioned separation distances were derived assuming an IMT Advanced deployment limited to indoor. If a percentage of IMT-Advanced UE are used outdoors, the required separation distances would normally be larger.

FSS earth station receivers that are deployed with low elevation angles require a path between space and earth to and from the satellite that is clear of ground clutter. For this reason, it should not be assumed that clutter is available to attenuate emissions from an IMT-Advanced device that is located in the azimuth of the main beam of the FSS earth station receiver, especially those that have been installed with low elevation angles.

(2) Adjacent band emissions

Adjacent band compatibility between IMT-Advanced systems in the bands or parts of the bands 3 300-3 400 MHz / 4 400-4 500 MHz / 4 800-4 990 MHz and FSS systems in the bands 3 400-4 200 MHz / 4 500-4 800 MHz have been studied.

– Using the long-term interference criteria, the required separation distance is from 5 km up to tens of km for IMT-Advanced macro-cell and from 900 m to less than 5 km for IMT-Advanced small-cell outdoor deployments, respectively, with no guard band.
– In the case of IMT-Advanced deployment in the adjacent band, the separation distance between IMT Advanced base stations and a single FSS receiver earth station could be reduced by employing a guard band between the edge of the IMT-Advanced emission and FSS allocation.
– For a specific macro-cell deployment scenario studied, the required separation distances from the edge of the IMT-Advanced deployment area are in the range of 30 km to 20 km with an associated guard band of 2 MHz to 80 MHz respectively. Likewise, for a specific small-cell deployment studied, the required separation distances from the edge of the IMT-Advanced deployment area are in the range of 20 kilometres to 5 km with an associated guard band of 1 MHz to 2 MHz respectively.

One study shows that the use of a common representative FSS receive LNA/LNB front-end RF filter provides an insignificant decrease in the required separation distance to protect the FSS earth station receiver from adjacent band emissions. Moreover, inclusion of an RF filter provides little additional rejection of adjacent band emissions over what is already provided by the IF selectivity of the tuner.

(3) LNA/LNB overdrive

The results show that emissions from one IMT-Advanced station can overdrive the FSS receiver LNA, or bring it into non-linear operation, if a macro cell deployment is closer than a required protection distance that ranges from 4 km to 9 km to an earth station in the band 3 400-4 200 MHz and 4 500-4 800 MHz. The required protection distance to prevent overdrive of the FSS receiver by IMT-Advanced emissions ranges from one hundred metres to 900 m for the case of small cell deployments.

(4) Intermodulation

The required protection distance to prevent intermodulation interference produced in the receiver of the FSS earth station from being caused by multiple IMT-Advanced stations ranges from 2 km to 8 km in the case of macro cell deployments. The required protection distance in the small cell deployment scenario to limit the possibility of intermodulation interference being caused into the earth station receivers in the band 3 400-4 200 MHz and 4 500-4 800 MHz is at least 100 metres to as high as half a kilometre.

Conclusions

The sharing between IMT-Advanced and FSS is feasible only when FSS earth stations are at known, specific locations, and deployment of IMT-Advanced is limited to the areas outside of the minimum required separation distances for each azimuth to protect these specific FSS earth stations. In this case, the FSS protection criteria should be used to determine the necessary separation distances to ensure protection of the existing and planned FSS earth stations.

When FSS earth stations are deployed in a typical ubiquitous manner or with no individual licensing, sharing between IMT-Advanced and FSS is not feasible in the same geographical area since no minimum separation distance can be guaranteed.

Deployment of IMT-Advanced would constrain future FSS earth stations from being deployed in the same area in the bands 3 400-4 200 MHz and 4 500-4 800 MHz as shown by the studies.

Annex 1

Study #1

1 Introduction

This study considered non-site specific conditions using smooth earth surface (i.e. not using any specific terrain information) in the sharing studies. This study employs the latest considerations on possible deployment scenarios of IMT-Advanced systems which are not fully taken into account in the similar studies in Report ITU-R M.2109.

As already indicated in Report ITU-R M.2109, in the case of calculations using short-term criterion, distances derived using a smooth earth surface are provided to assess the maximum range of distances 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.

2 Technical characteristics used in sharing studies

The parameters employed in the sharing study are summarized below, which are compliant with those defined in the main body of this Report.

TABLE A1-1

FSS earth stations parameters

Parameter	Value used in the study
Range of operating frequencies	3 400-4 200 MHz and 4 500-4 800 MHz
Antenna diameters	2.4 m and 16 m
Antenna reference pattern	Recommendation ITU-R S.465
Antenna elevation angle	5º and 48º
Antenna height	3 m and 30 m
Receiving system noise temperature	100 K for 2.4 m antenna and 70 K for 16 m antenna

TABLE A1-2

IMT-Advanced base stations parameters

Cell structure	Macro suburban	Macro urban	Small cell outdoor	Small cell indoor
Antenna height	25 m	20 m	6 m	3 m
Downtilt	6 degrees	10 degrees	N/A	N/A
Antenna pattern	Recommendation ITU-R F.1336 (*recommends* 3.1) – k_a = 0.7 – k_p = 0.7 – k_h = 0.7 – k_v = 0.3 Horizontal 3 dB beamwidth: 65 degrees Vertical 3 dB beamwidth: determined from the horizontal beamwidth by equations in Recommendation ITU-R F.1336. Vertical beamwidths of actual antennas may also be used when available.		Recommendation ITU-R F.1336 omni	
Antenna polarization	±45 degrees	±45 degrees	linear	linear
Indoor base station penetration loss	N/A	N/A	N/A	20 dB
Maximum base station output power/sector (e.i.r.p.)	61 dBm/20 MHz	61 dBm/20 MHz	29 dBm/20 MHz	24 dBm/20 MHz

The propagation model defined in Recommendation ITU-R P.452-14 is employed in the sharing study. In order to evaluate non-site specific conditions, any specific terrain information is not assumed, but smooth earth surface model is assumed. Furthermore, in the studies, impact of additional clutter losses defined in § 4.5 of Recommendation ITU-R P.452-14 is evaluated.

Two interference criteria are used to assess the interference mechanisms of "In-band emissions" from an IMT-Advanced base station to an FSS earth station.

Long-term interference criterion:

– In-band sharing studies: I/N = –10 dB ($\Delta T/T$ = 10%) corresponding to the aggregate interference from co-primary allocation for 20% of any month.

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

In the absence of specific recommendations on how to apportion these allowances among the competing potential sources of interference, the long-term interference from any individual secondary or unallocated service as well as interference into adjacent frequency bands (unwanted emissions) should be limited to half of the total noise interference allowance into an FSS link, and from any individual primary service it should be limited to half of the afore mentioned values of 10% of the total noise. This 50% apportionment of interference is applicable to the case where two other allocated services (e.g. fixed and mobile) are contributing the same level of interference in the same geographical area and this results in a reduction of 3 dB in the *I/N* value above (*I/N* = –13 dB).

Short-term interference criterion:

– In-band sharing studies: *I/N* = –1.3 dB that may be exceeded by up to 0.001667% of the time (single entry).

3 Evaluation methodology

In order to assess interference from an IMT-Advanced base station to an FSS earth station, the following equation is used to calculate the interference power level at the input to the FSS earth station, $I_{interference}$,

$$I_{interference} = P_{IMT\_e.i.r.p.} + G_t - PL + G_r,$$

where $P_{IMT\_e.i.r.p.}$, G_t, PL, and G_r represent e.i.r.p of IMT base station, off-axis antenna gain of the IMT base station, propagation path loss and off-axis antenna gain of the FSS earth station, respectively. The required separation distance is calculated in order to meet the interference criteria described in § 2 above.

4 Results of studies

4.1 In-band emissions

The calculated results of required separation distance in the two operating frequency bands 3 400-4 200 MHz and 4 500-4 800 MHz are summarized in Tables A1-3 and A1-4, respectively. As the required separation distances for the bands between 3 400-4 200 MHz and 4 500-4 800 MHz are almost the same, the band 3 400-4 200 MHz is mainly investigated by changing the simulation parameters.

It should be also noted that Table A1-3(c) contains the results of studies when the local clutter losses at both IMT-Advanced base station and FSS earth station sides are not available. However, the results in this Table A1-3(c) should not be default to define an exclusion zone around an FSS earth station, since they are derived using a smooth earth surface model without any clutter losses which is not representative of all areas around the world.

TABLE A1-3

Required separation distance to meet interference criteria for 3 400-4 200 MHz

(a) Local clutter losses at both IMT-Advanced base station and earth station sides

IMT-Advanced base station		**Scenario**	**Macro suburban**		**Macro urban**		**Small cell outdoor**	**Small cell indoor**
		Clutter category	**Suburban**		**Urban**		**Urban**	**Urban**
earth station		Antenna height	3 m		3 m		30 m	30 m
		Antenna size	2.4 m	16 m	2.4 m	16 m	2.4 m	2.4 m
		Clutter category	Village centre	Village centre	Village centre	Village centre	Urban	Urban
earth station elevation angle = 5°	Required separation distance	Long-term interference	61 km	63 km	46 km	48 km	25 km	< 5 km
		Short-term interference	486 km	504 km	364 km	383 km	26 km	< 5 km
earth station elevation angle = 48°		Long-term interference	35 km	36 km	20 km	22 km	6 km	< 5 km
		Short-term interference	199 km	221 km	74 km	89 km	< 5 km	< 5 km

(b) Local clutter losses at IMT-Advanced base station side only

IMT-Advanced base station		**Scenario**	**Macro suburban**		**Macro urban**		**Small cell outdoor**	**Small cell indoor**
		Clutter category	**Suburban**		**Urban**		**Urban**	**Urban**
earth station		Antenna height	3 m		3 m		30 m	30 m
		Antenna size	2.4 m	16 m	2.4 m	16 m	2.4 m	2.4 m
		Clutter category	N/A	N/A	N/A	N/A	N/A	N/A
earth station elevation angle = 5°	Required separation distance	Long-term interference	78 km	84 km	59 km	62 km	25 km	< 5 km
		Short-term interference	610 km	628 km	491 km	510 km	26 km	< 5 km
earth station elevation angle = 48°		Long-term interference	46 km	48 km	33 km	35 km	6 km	< 5 km
		Short-term interference	337 km	356 km	205 km	227 km	< 5 km	< 5 km

(c) No local clutter loss neither at IMT-Advanced base station nor earth station side

IMT-Advanced base station		**Scenario**	**Macro suburban**		**Macro urban**		**Small cell outdoor**	**Small cell indoor**
		Clutter category	**N/A**		**N/A**		**N/A**	**N/A**
earth station		Antenna height	3 m		3 m		30 m	30 m
		Antenna size	2.4 m	16 m	2.4 m	16 m	2.4 m	2.4 m
		Clutter category	N/A	N/A	N/A	N/A	N/A	N/A
earth station elevation angle = 5°	Required separation distance	Long-term interference	78 km	84 km	59 km	62 km	42 km	17 km
		Short-term interference	610 km	628 km	491 km	510 km	233 km	15 km
earth station elevation angle = 48°		Long-term interference	46 km	48 km	33 km	35 km	24 km	< 5 km
		Short-term interference	337 km	356 km	205 km	227 km	26 km	< 5 km

NOTE – Propagation loss is calculated at 3 600 MHz.

TABLE A1-4

Required separation distance to meet interference criteria for 4 500-4 800 MHz

(a) Local clutter losses at both IMT-Advanced base station and earth station sides

IMT-Advance base station		**Scenario**	**Macro suburban**		**Macro urban**		**Small cell outdoor**	**Small cell indoor**
		Clutter category	**Suburban**		**Urban**		**Urban**	**Urban**
earth station		Antenna height	3 m		3 m		30 m	30 m
		Antenna size	2.4 m	16 m	2.4 m	16 m	2.4 m	2.4 m
		Clutter category	Village centre	Village centre	Village centre	Village centre	Urban	Urban
earth station elevation angle = 5°	Required separation distance	Long-term interference	57 km	59 km	43 km	45 km	25 km	< 5 km
		Short-term interference	431 km	448 km	318 km	336 km	27 km	< 5 km
earth station elevation angle = 48°		Long-term interference	31 km	34 km	20 km	21 km	6 km	< 5 km
		Short-term interference	165 km	185 km	55 km	69 km	< 5 km	< 5 km

NOTE – Propagation loss is calculated at 4 500 MHz.

Based on the Tables A1-3 and A1-4 above, the results of studies for interference scenario from an IMT-Advanced macro cell base station into an FSS earth station are summarized as follows:

– for the long-term interference criterion, the required separation distance is tens of kilometres;

– for the short-term interference criterion, the required separation distance exceeds one hundred kilometres except for some cases. However, it should be also noted that these separation distance values should not be applied by default to define an exclusion zone around an FSS earth station, since the results are derived using a smooth earth surface model which is not representative of all areas around the world.

Meanwhile, the results of studies for the interference scenarios from an IMT-Advanced small cell base station into an FSS earth station are summarized as follows:

– for both the long-term and short-term interference criteria, the required separation distance is about less than 30 kilometres in the outdoor IMT-Advanced small cell base station scenario when the effect of local clutter losses at IMT-Advanced base station side is available. When such clutter losses are not available, the required separation distance reaches two hundred kilometres for the short-term interference criterion as shown in Table A1-3(c). However, such a scenario is not realistic for IMT-Advanced small cell base stations, since they are deployed using low antenna height in dense urban environment surrounded by tall buildings;

– for both the long-term and short-term interference criteria, the required separation distance is less than 5 kilometres in the indoor IMT-Advanced small cell base station scenario.

In order to assess improved sharing possibilities between an IMT-Advanced macro base station and an FSS earth station, Table A1-5 investigates the required separation distance considering the effect of additional losses. These additional losses can be obtained through taking into account local terrain information as well as clutter losses by artificial shielding effect at an FSS earth station. Effect and example values for these additional losses could be found in the Study #2 of this Report (for shielding effect by local terrain) as well as in the past ITU-R studies, such as in Recommendation ITU-R SF.1486 (for shielding effect at an FSS earth station), Report ITU-R M.2109 (for shielding effect by local terrain).

TABLE A1-5

Required separation distance for IMT-Advanced macro cell base station considering additional loss to meet interference criteria for 3 400-4 200 MHz

(a) Local clutter losses at both IMT-Advanced base station and earth station sides

IMT-Advanced base station type (Clutter category)			**Macro urban (Urban)**				
Additional loss			**0 dB**	**10 dB**	**20 dB**	**30 dB**	**35 dB**
earth station		Antenna height	3 m				
		Antenna size	2.4 m				
		Clutter category	Village centre				
earth station elevation angle = 5°	Required separation distance	Long-term interference	46 km	35 km	22 km	17 km	14 km
		Short-term interference	364 km	233 km	99 km	15 km	13 km

(b) Local clutter losses at IMT-Advanced base station side only

IMT-Advanced base station type (Clutter category)			**Macro urban (Urban)**				
Additional loss			**0 dB**	**10 dB**	**20 dB**	**30 dB**	**35 dB**
earth station		Antenna height	3 m				
		Antenna size	2.4 m				
		Clutter category	None				
earth station elevation angle = 5°	Required separation distance	Long-term interference	59 km	47 km	36 km	25 km	19 km
		Short-term interference	491 km	372 km	243 km	106 km	58 km

Impact of employing different values of indoor bases station penetration loss is investigated for IMT-Advanced small-cell indoor deployment scenarios as shown in Table A1-6.

TABLE A1-6

Required separation distance when employing different level of penetration loss for IMT-Advanced small-cell indoor base station in 3 400-4 200 MHz

<table>
<tr><td rowspan="3" colspan="2">IMT-Advanced base station</td><td>Scenario</td><td colspan="3">Small cell indoor</td></tr>
<tr><td>Clutter category</td><td colspan="3">Urban</td></tr>
<tr><td>Penetration loss</td><td>20 dB</td><td>10 dB</td><td>0 dB</td></tr>
<tr><td rowspan="3" colspan="2">earth station</td><td>Antenna height</td><td colspan="3">30 m</td></tr>
<tr><td>Antenna size</td><td colspan="3">2.4 m</td></tr>
<tr><td>Clutter category</td><td colspan="3">N/A</td></tr>
<tr><td rowspan="2">earth station elevation angle = 5°</td><td rowspan="2">Required separation distance</td><td>Long-term interference</td><td>< 5 km</td><td>7 km</td><td>16 km</td></tr>
<tr><td>Short-term interference</td><td>< 5 km</td><td>< 5 km</td><td>16 km</td></tr>
</table>

Annex 2

Study #2

1 Introduction

The 3 400-4 200 MHz frequency provides large contiguous spectrum for mobile broadband services and applications using IMT macro and small cell rollout scenarios forming parts of new advanced Heterogeneous Networks (HetNet).

The 3 400-4 200 MHz frequency range was part of the candidate bands for IMT services taken into considerations for the WRC-07 Conference. Report ITU-R M.2109-0 contains the summary of technical studies which were based on assumptions on FSS and IMT systems available in 2007. Report ITU-R M.2109 provides conclusions on terrestrial service (IMT systems) and satellite service (FSS systems) that are based on worst case assumptions which may not always lead to the most efficient spectrum utilization. Building upon studies from 2007, there is a need to update the sharing studies in order to account for updated methodologies, parameters and assumptions for both FSS and IMT systems.

2 Background (References)

The following Recommendations, Reports, Specifications, Submissions are used in the analysis:

Report ITU-R M.2109-0 (2007) – 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

3GPP TR 36.814 "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects (Release 9)"

Recommendation ITU-R S.1323-2 (09/2002) – Maximum permissible levels of interference in a satellite network (GSO/FSS; non-GSO/FSS; non-GSO/MSS feeder links) in the fixed-satellite service caused by other co-directional FSS networks below 30 GHz

Recommendation ITU-R S.1432-1 (01/2006) – Apportionment of the allowable error performance degradations to fixed-satellite service (FSS) hypothetical reference digital paths arising from time invariant interference for systems operating below 30 GHz

Recommendation ITU-R P.452-12 (03/2005) – Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz

Recommendation ITU-R P.452-14 (10/2009) – Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz

Recommendation ITU-R P.1238-7 (02/2012) – Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 900 MHz to 100 GHz

Recommendation ITU-R P.526-12 (02/2012) – Propagation by diffraction

Recommendation ITU-R S.465-6 (01/2010) – Reference radiation pattern for earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz

Report ITU-R M.2135-0 (10/2008) – Guidelines for evaluation of radio interface technologies for IMT-Advanced

Recommendation ITU-R P.1546-4 (09/2010) – Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz

3 Technical characteristics

3.1 Methodology

3.1.1 IMT interference calculation

Assuming one base station or an indoor IMT small cell system interferes with an FSS earth station, the received interference power level at the earth station is calculated according to the following equation:

$$I_{IMT} = P_{IMT} + G_{IMT} + G_{FFS}(\varphi) - L(f,d) - FDR(\Delta f)$$

I_{IMT}: Received interference power level in 1 MHz bandwidth at the earth station receiver caused by the transmission from the IMT system (dBm)

P_{IMT}: IMT system transmission power in 1 MHz bandwidth (dBm)

G_{IMT}: IMT system antenna gain (dB)

$G_{Es}(\varphi)$: ES reception antenna gain (dB)

Φ: ES antenna elevation angle

$L(f, d)$: Path loss (dB).

Adjacent channel interference

The following parameters are specifically used for the IMT interference calculation for the adjacent channel interference analysis:

FDR: Frequency dependent rejection (dB)[5]

Δf: Frequency offset (Hz).

The following tables provide the IMT transmission power suppression at the first adjacent frequency based on the 3GPP 36.104 v.11.2.0, section 6.6.2 specifications.

Furthermore, ACLR shall be no less than 45 dB.

For Wide Area BS, either the ACLR limits or the absolute limit of –15 dBm/MHz apply, whichever is less stringent.

For Local Area BS, either the ACLR limits or the absolute limit of –32 dBm/MHz shall apply, whichever is less stringent.

If the band is larger than the ACLR region, the operating band unwanted emission limits will refer to the following tables from 3GPP 36.104 v.11.2.0, section 6.6.3:

TABLE A2-1

IMT Wide area base station operating band unwanted emission limits for 5, 10, 15 and 20 MHz channel bandwidths (Table 6.6.3.2.1-6 in 3GPP 36.104 v.11.2.0)

Frequency offset of measurement filter –3 dB point, Δf	Frequency offset of measurement filter centre frequency, f_offset	Minimum requirement	Measurement bandwidth
0 MHz ≤ Δf < 5 MHz	0.05 MHz ≤ f_offset < 5.05 MHz	$-7dBm-\frac{7}{5}\cdot\left(\frac{f\_offset}{MHz}-0.05\right)dB$	100 kHz
5 MHz ≤ Δf < min(10 MHz, Δf_{max})	5.05 MHz ≤ f_offset < min(10.05 MHz, f_offset_{max})	–14 dBm	100 kHz
10 MHz ≤ Δf ≤ Δf_{max}	10.5 MHz ≤ f_offset < f_offset_{max}	–15 dBm (Note 5)	1 MHz

TABLE A2-2

IMT Local area base station operating band unwanted emission limits for 5, 10, 15 and 20 MHz channel bandwidths (Table 6.6.3.2a-3 in 3GPP 36.104 v.11.2.0)

Frequency offset of measurement filter –3 dB point, Δf	Frequency offset of measurement filter centre frequency, f_offset	Minimum requirement	Measurement bandwidth
0 MHz ≤ Δf < 5 MHz	0.05 MHz ≤ f_offset < 5.05 MHz	$-30dBm-\frac{7}{5}\left(\frac{f\_offset}{MHz}-0.05\right)dB$	100 kHz
5 MHz ≤ Δf < min(10 MHz, Δf_{max})	5.05 MHz ≤ f_offset < min (10.05 MHz, f_offset_{max})	–37 dBm	100 kHz
10 MHz ≤ Δf ≤ Δf_{max}	10.05 MHz ≤ f_offset < f_offset_{max}	–37 dBm (Note 5)	100 kHz

[5] FDR = 0 dB for co-channel analysis.

3.1.2 Interference criteria (from Report ITU-R M.2109)

The following methodology is adopted in Report ITU-R M.2109-0 to evaluate the earth station tolerable long-term and short-terms interference from other systems.

3.1.2.1 Co-channel sharing studies – long term criterion

The following long-term interference criterion is identified for use when assessing the interference mechanisms within in-band sharing studies and adjacent band sharing studies (out-of-band or spurious emission) from IMT-Advanced to FSS as discussed below.[6,7]

$$I/N = -10 \text{ dB } (\Delta T/T = 10\%)$$

Corresponding to the aggregate interference from co-primary allocation for 20% of any month.[8]

3.1.2.2 Co-channel sharing studies – short term 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**:

$$I/N = -1.3 \text{ dB}$$

Which may be exceeded 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.

3.1.2.3 Adjacent channel sharing studies – long term criterion

$$I/N = -20 \text{ dB } (\Delta T/T = 1\%)$$

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.

3.1.3 Apportionment of interference allowance

Fifty percent of the apportionment of the allowable interference is assumed among the competing potential sources of interference.

Long-term interference from any individual secondary or unallocated service as well as interference into adjacent frequency bands (unwanted emissions) is considered to be limited to half of the total noise interference allowance into an FSS link, and from any individual primary service it is considered to be limited to half of the afore mentioned values of 6% or 10% of the total noise, as appropriate.

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[6] Based on Recommendation ITU-R S.1432-1.

[7] This criterion was adopted in 2007 by Report ITU-R M.2109.

[8] For typical BER vs. C/N characteristics of PSK/FEC demodulators, the two criteria are effectively the same: if one is met the other will be met).

3.2 Sharing Scenarios and Topologies

This sharing and compatibility report focuses on the simultaneous operation of the FSS and IMT systems within the 3 400-4 200 MHz frequency range.

Three main scenarios are assessed for the IMT systems:

– IMT macro cells scenario in the suburban and urban environments;

– Outdoor IMT small cells scenario in the urban environment;

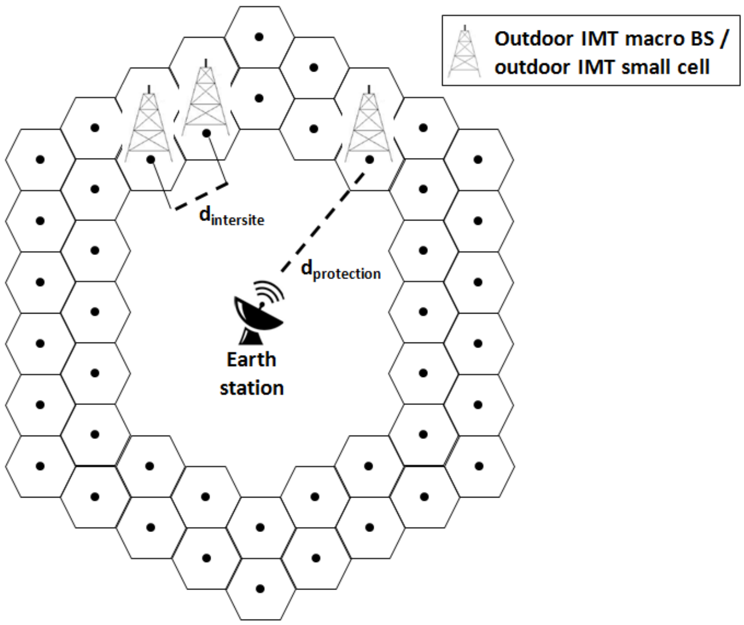
– Indoor IMT small cells scenario in the urban environment.

3.2.1 Topology for IMT macro and outdoor IMT small cell scenarios

Report ITU-R M.2109-0 is taken as reference. The adopted topology is described below.[9]

FIGURE A2-1

IMT macro and outdoor IMT small cell scenarios' topology



d(i): The radius of the *i*-th ring:

$$d(i) = d_{protection} + (i–1) * d_{intersite}$$

N(i): The number of IMT base stations located on the *i*-th ring. It is assessed based on the corresponding distance d(i) and the base station inter-site distance range:

$$N(i) = pi / (arc\ sin\ (d_{intersite} / (2*d(i))))$$

In order to avoid the case in which the earth station antenna main lobe is directed between the cells, thus providing an optimistic result, 1 000 snapshots are performed and for each snapshot the FSS earth station antenna's bore sight is randomly simulated.

Two rings of interfering IMT base stations are considered for this scenario, in line with the topology adopted by Report ITU-R M.2109-0.

9 The topology considered in this proposal is consistent with Report ITU-R M.2109-0, and it is the most conservative (elevation only off-set) topology. However in a significant number of practical cases less conservative situations will happen involving elevation as well as azimuth off-set.

NOTE – The uniform distribution of outdoor IMT small cells represents a conservative assumption. Outdoor small cells would typically be deployed in very limited areas in order to provide local capacity enhancement. Within these areas, the outdoor small cells would not need to provide contiguous coverage since there would typically be an overlaying macro network present.

3.2.2 Topology for indoor IMT small cell scenario

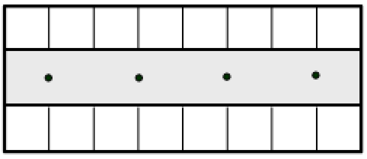
Multiple buildings are distributed in a ring-shaped topology around the FSS earth station. Each building contains an indoor IMT small cell system comprising multiple IMT small cells.

The spacing between the terrestrial IMT and the satellite FSS systems corresponds to the distance between the FSS earth station and the nearest IMT small cell base station within an identified building.

An indoor IMT small cell system topology considered for the sharing scenario is distributed in buildings of six floors. The topology of each floor is based on Fig. 2.1.1.5-1 from the 3GPP specification 3GPP TR 36.814.

FIGURE A2-2

IMT small cell indoor system building: floor topology.



As shown in the Figure above:

– the size of the building where IMT small cell indoor system is located: 120 m x 50 m, including rooms and corridor;

– number of rooms in the building: 16;

– room size: 15 m × 15 m;

– corridor size: 120 m × 20 m;

– 4 indoor IMT small cell base stations on each floor[10];

– all terminals are deployed in the rooms;

– the IMT indoor base stations are deployed in 4 floors randomly selected among the six available floors in the building (i.e. 16 IMT small cell base stations are considered in each building);

– height of each floor: 3 m;

– building penetration loss:

  – building penetration loss (horizontal): 20 dB / wall;

  NOTE 1 – Sensitivity analysis performed for: 12 and 15 dB is performed in § 8.4.1.

  – building penetration loss (vertical): 18 dB / floor (Recommendation ITU-R P.1238, Table 3).

NOTE 2 – This value is only used when the protection distance becomes very small. For larger protection distances, the interference is considered in the horizontal direction only (no vertical penetration loss applies). As described in the diagram below, at short enough distances, the radio signal will pass through the floor in addition to the wall.

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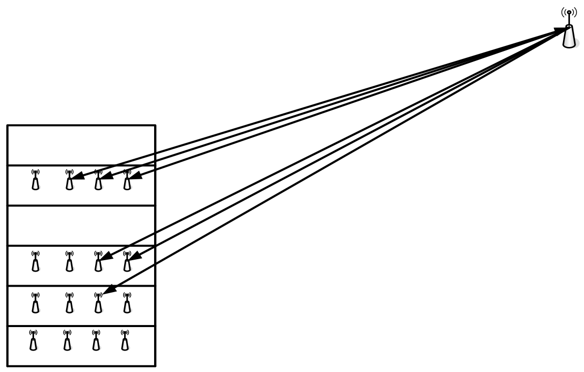
[10] Four small cells are considered in each floor instead of 2 the cells per floor considered in 3GPP TR 36.814.

FIGURE A2-3

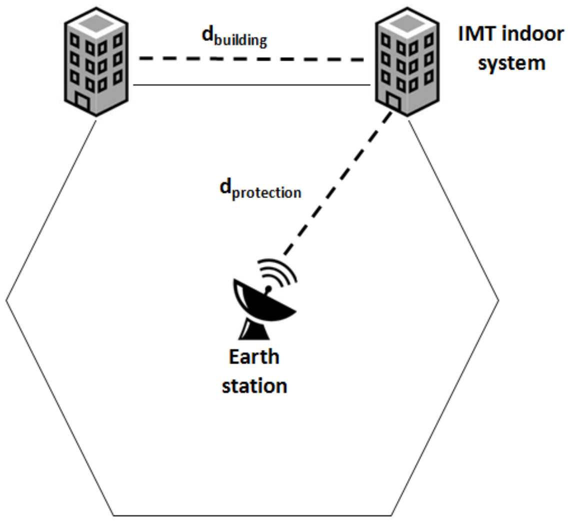
Building penetration loss (horizontal and vertical)



The buildings are uniformly distributed around the FSS earth station as described in the diagram below (the topology given in Report ITU-R M.2109 is considered).

FIGURE A2-4

Indoor IMT small cell scenario topology



where:

$d_{protection}$: Protection distance, between the FSS earth station and the central position of IMT small cell indoor system

$d_{building}$: Distance between two IMT small cell indoor systems.

As shown in Fig. A2-4 above, the number of indoor IMT small cell systems (i.e. number of buildings) is:

$$\mathrm{N}_{Build} = (2\pi \times d_{protection}) / d_{building}$$

The system-level compatibility simulation assumes $d_{building}$ = 300 m.

The number of buildings is calculated by taking into account the buildings containing one of the IMT small cell indoor systems, the distance between buildings is calculated according to the average distribution.

In order to avoid the case in which the earth station antenna main lobe is directed between the buildings, thus providing an optimistic result, 1 000 snapshots are performed and for each snapshot the FSS earth station antenna's bore sight is randomly simulated.

NOTE 3 – The uniform distribution of the buildings containing indoor IMT small cells represents a conservative assumption. Outdoor small cells would typically be deployed in very limited areas in order to provide local capacity enhancement. Within these areas, the outdoor small cells would not need to provide contiguous coverage since there would typically be an overlaying macro network present.

3.3 Propagation model

Most sharing studies that contributed to the Report ITU-R M.2109-0 refer to Recommendation ITU-R P.452-12 (now superseded) utilizing the smooth earth propagation model. This assumption treats the propagation path as smooth earth which does not seem to be a realistic assumption.

This contribution adopts the more recently updated Recommendation ITU-R P.452-14 which allows adding terrain or local clutter factors to the smooth earth model by defining the diffraction loss part in detail.

Recommendation ITU-R P.452-14 requires the terrain information as input for diffraction loss. The proposal below uses the typical terrain information contained in the Table 4 of Recommendation ITU-R P.452-14.

TABLE A2-3

Nominal clutter heights and distances according to the Table 4 of Recommendation ITU-R P.452-14

Clutter (ground-cover) category	Nominal height h_a (m)	Nominal distance d_k (km)
High crop fields Park land Irregularly spaced sparse trees Orchard (regularly spaced) Sparse houses	4	0.1
Village centre	5	0.07
Deciduous trees (irregularly spaced) Deciduous trees (regularly spaced) Mixed tree forest	15	0.05
Coniferous trees (irregularly spaced) Coniferous trees (regularly spaced)	20	0.05
Tropical rain forest	20	0.03
Suburban	9	0.025
Dense suburban	12	0.02
Urban	20	0.02
Dense urban	25	0.02
High-rise urban	35	0.02
Industrial zone	20	0.05

h_a: Nominal clutter height (m) above local ground level.

d_k: Distance (km) from nominal clutter point to the antenna.

For transmitter and receiver side, the terrain info is selected according to the above table. The concrete value is based on which specific scenario the node is located.

It is assumed that the path includes transmit terrain, receive terrain and dense suburban terrain in the middle path; the propagation estimation is based on Recommendation ITU-R P.452 employing a smooth earth model merged with a 12 metre obstacle in the middle of the path for a diffraction loss estimation with additional losses introduced due to clutters, at the locations of a receiving station in the FSS and transmitting station in the MS, to acquire the separation distance.

If the transmitter or receiver side terrain is lower than 12 metres, the minimum value among the transmitter and receiver is chosen for the middle path terrain's height.

For the indoor IMT small cell scenario, additional penetration loss will be considered as follows:

– Building penetration loss:
  – Building penetration loss (horizontal): 20 dB / wall;

  NOTE 1 – Sensitivity analysis performed for: 12 and 15 dB is performed in § 8.4.1.

  – Building penetration loss (vertical): 18 dB / floor (Recommendation ITU-R P.1238, Table 3).

NOTE 2 – This value is only used when the protection distance becomes very small. For larger protection distances, the interference is considered in the horizontal direction only (no vertical penetration loss applies). As described in the diagram below, at short enough distances, the radio signal will pass through the floor in addition to the wall.

3.4 FSS earth stations and IMT base stations parameters

The following Tables summarize the parameters that have been adopted for the various scenarios.

3.4.1 IMT macro cell scenario – Suburban, urban environments

TABLE A2-4

FSS earth station and IMT base station parameters for IMT macro cell scenario – Suburban environment

IMT macro cell scenario – Suburban environment	(*) According to Report ITU-R M.2292 – Table D
FSS antenna diameter (m)	10 m
FSS antenna pattern	Recommendation ITU-R S.465-6
FSS antenna height (m)	7 m
FSS antenna elevation angle (degrees)	5°, 15°, 48°
FSS receiving system noise temperature (K)	100 K
FSS bandwidth (MHz)	36 MHz
FSS filter characteristics	IMT filter
IMT interference model / deployment	Aggregate for long term analysis Single entry for short term analysis NOTE – Continuous, homogeneous IMT base stations coverage around the FSS ES. Hexagonal pattern. Consistent with Report ITU-R M.2109.
Number of cells	N/A NOTE – # cells depends on the calculated protection distance from FSS ES
Number of sectors per cells	3 (*)

TABLE A2-4 *(end)*

IMT macro cell scenario – Suburban environment	**(*) According to Report ITU-R M.2292 – Table D**
Cell radius (km) IMT base station antenna height (m)	0.6 kilometres (*) 25 metres (*)
IMT base station antenna gain (dBi)	18 dBi
IMT base station antenna pattern	Recommendation ITU-R F.1336 (*recommends* 3.1) (*)
IMT downtilt (degrees)	6° (*)
IMT bandwidth (MHz)	20 MHz
IMT base station max power output (dBm)Average base station activity: 50% (***) (i.e. –3 dB from max pwr)	46 dBm
IMT feeder loss (dB)	3 dB
Max IMT base station e.i.r.p. (dBm)	61 (max. e.i.r.p. value used for the single entry interference analysis, avg. value (i.e. 50%) for aggregate interference analysis)
IMT base station filter characteristics / ACLR	3GPP TS 36.104 v.11.2.0, § 6.6.2
Terrain model	Statistical model, based on Table 4 in par. 4.5.3 of Recommendation ITU-R P.452-14
Terrain profile	Base station side: suburban (avg. height: 9 m) earth station side: suburban (avg. height: 9 m) Middle path: dense suburban terrain (12 metres terrain's height) If the terrain on the tx. or rx. side is < 12 m, the minimum value among the tx. and rx. is chosen for the middle path terrain’s height.
Clutter category	Base station side: suburban earth station side: suburban Based on Table 4 in par. 4.5.3 of Recommendation ITU-R P.452-14
Nominal height (m)	Base station side: 9 m earth station side: 9 m Based on Table 4 in par. 4.5.3 of Recommendation ITU-R P.452-14
Nominal distance (km)	Base station side: 0.025 km earth station side: 0.025 km Based on Table 4 in par. 4.5.3 of Recommendation ITU-R P.452-14
Building penetration loss (dB)	0 dB outdoor

TABLE A2-5

FSS earth station and IMT base station parameters for IMT macro cell scenario – Urban environment

IMT macro cell scenario – Urban environment	(*) According to Report ITU-R M.2292 – Table D
FSS antenna diameter (m)	2.4 m
FSS antenna pattern	Recommendation ITU-R S.465-6
FSS antenna height (m)	30 m
FSS antenna elevation angle (degrees)	5°, 15°, 48°
FSS receiving system noise temperature (K)	100 K
FSS bandwidth (MHz)	36 MHz
FSS filter characteristics	IMT filter
IMT interference model / deployment	Aggregate for long term analysis Single entry for short term analysis NOTE – Continuous, homogeneous IMT base stations coverage around the FSS ES. Hexagonal pattern. Consistent with Report ITU-R M.2109.
Number of cells	N/A NOTE – # cells depends on the calculated protection distance from FSS ES
Number of sectors per cells	3 (*)
Cell radius (km)	0.3 kilometres (*) NOTE – Different ISD for different scenarios
IMT base station antenna height (m)	20 metres (*)
IMT base station antenna gain (dBi)	18 dBi
IMT base station antenna pattern	Recommendation ITU-R F.1336 (*recommends* 3.1) (*)
IMT downtilt (degrees)	10° (*)
IMT bandwidth (MHz)	20 MHz
IMT base station max power output (dBm)Average base station activity: 50% (***) (i.e. –3 dB from max pwr)	46 dBm
IMT feeder loss (dB)	3 dB
Max IMT base station e.i.r.p. (dBm)	61 (max. e.i.r.p. value used for the single entry interference analysis, avg. value (i.e. 50%) for aggregate interference analysis)
IMT base station filter characteristics / ACLR	3GPP TS 36.104 v.11.2.0, § 6.6.2
Terrain model	Statistical model, based on Table 4 in par. 4.5.3 of Recommendation ITU-R P.452-14
Terrain profile	Base station side: suburban (avg. height: 9 m) earth station side: suburban (avg. height: 9 m) Middle path: dense suburban terrain is used in the middle path: 12 m terrain's height, If the terrain on the tx. or rx. side is < 12 m, the minimum value among the tx. and rx. is chosen for the middle path terrain's height.

TABLE A2-5 (*end*)

IMT macro cell scenario – Urban environment	**(*) According to Report ITU-R M.2292 – Table D**
Clutter category	Base station side: urban earth station side: urban Based on Table 4 in § 4.5.3 of Recommendation ITU-R P.452-14
Nominal height (m)	Base station side: 20 m earth station side: 20 m Based on Table 4 in § 4.5.3 of Recommendation ITU-R P.452-14
Nominal distance (km)	Base station side: 0.02 km earth station side: 0.02 km Based on Table 4 in § 4.5.3 of Recommendation ITU-R P.452-14
Building penetration loss (dB)	0 dB outdoor

3.4.2 Outdoor IMT small cell scenario – Urban environment

TABLE A2-6

FSS earth station and IMT base station parameters for Outdoor IMT small cell scenario – Urban environment

Outdoor IMT small cell scenario – Urban environment	**(*) According to Report ITU-R M.2292 – Table D**
FSS antenna diameter (m)	2.4 m
FSS antenna pattern	Recommendation ITU-R S.465-6
FSS antenna height (m)	30 m
FSS antenna elevation angle (degrees)	5°, 15°, 48°
FSS receiving system noise temperature (K)	100 K
FSS bandwidth (MHz)	36 MHz
FSS filter characteristics	IMT filter
IMT interference model / deployment	Aggregate for long term analysis Single entry for short term analysis NOTE – Continuous, homogeneous IMT base stations coverage around the FSS ES. Hexagonal pattern. Consistent with Report ITU-R M.2109.
Number of cells	N/A NOTE – # cells depends on the calculated protection distance from FSS ES
Number of sectors per cells	1 (omnidirectional antenna) (*)
Cell radius (km)	N/A (*)
IMT base station antenna height (m)	6 metres (*)
IMT base station antenna gain (dBi)	5 dBi
IMT base station antenna pattern	Recommendation ITU-R F.1336 omni (*)
IMT downtilt (degrees)	N/A (***)

TABLE A2-6 (*end*)

Outdoor IMT small cell scenario – Urban environment	**(*) According to Report ITU-R M.2292 – Table D**
IMT bandwidth (MHz)	20 MHz
IMT base station max power output (dBm)Average base station activity: 50% (***) (i.e. –3 dB from max pwr)	24 dBm
IMT feeder loss (dB)	0 dB
Max IMT base station e.i.r.p. (dBm)	29 dBm (max. e.i.r.p. value used for the single entry interference analysis, avg. value (i.e. 50%) for aggregate interference analysis)
IMT base station filter characteristics / ACLR	3GPP TS 36.104 v.11.2.0, § 6.6.2
Terrain model	Statistical model, based on Table 4 in § 4.5.3 of Recommendation ITU-R P.452-14
Terrain profile	N/A
Clutter category	Base station side: urban earth station side: urban Based on Table 4 in § 4.5.3 of Recommendation ITU-R P.452-14
Nominal height (m)	Base station side: 20 m earth station side: 20 m Based on Table 4 in § 4.5.3 of Recommendation ITU-R P.452-14
Nominal distance (km)	Base station side: 0.02 km earth station side: 0.02 km Based on Table 4 in § 4.5.3 of Recommendation ITU-R P.452-14
Building penetration loss (dB)	0 dB outdoor

3.4.3 Indoor IMT small cell scenario – Urban environment

TABLE A2-7

FSS earth station and IMT base station parameters for the Indoor IMT small cell scenario – Urban environment

Indoor IMT small cell scenario – urban environment	**(*) According to Report ITU-R M.2292 – Table D**
FSS antenna diameter (m)	2.4 m
FSS antenna pattern	Recommendation ITU-R S.465-6
FSS antenna height (m)	30 m
FSS antenna elevation angle (degrees)	5°, 15°, 48°
FSS receiving system noise temperature (K)	100 K
FSS bandwidth (MHz)	36 MHz
FSS filter characteristics	IMT filter
IMT interference model / deployment	Aggregate

TABLE A2-7 (*end*)

Indoor IMT small cell scenario – urban environment	**(*) According to Report ITU-R M.2292 – Table D**
Number of cells	N/A 16 IMT small cell BSs are always considered in each building. The number of buildings depends on the calculated protection distance from FSS ES.
Number of sectors per cells	1 (omnidirectional antenna) (*)
Cell radius (km)	According to the indoor building topology.
IMT base station antenna height (m)	3 metres above the floor (*)
IMT base station antenna gain (dBi)	0
IMT base station antenna pattern	Recommendation ITU-R F.1336 omni (*)
IMT downtilt (degrees)	N/A (*)
IMT bandwidth (MHz)	20 MHz
IMT base station max power output (dBm) Average base station activity: 50% (***) (i.e. –3 dB from max pwr)	24 dBm
IMT feeder loss (dB)	0 dB
Max IMT base station e.i.r.p. (dBm)	24 dBm (max. e.i.r.p. value used for the single entry interference analysis, avg. value (i.e. 50%) for aggregate interference analysis)
IMT base station filter characteristics / ACLR	3GPP TS 36.104 v.11.2.0, § 6.6.2
Terrain model	Statistical model, based on Table 4 in § 4.5.3 of Recommendation ITU-R P.452-14
Terrain profile	N/A
Clutter category	Base station side: urban earth station side: urban Based on the Table 4 in § 4.5.3 of Recommendation ITU-R P.452-14
Nominal height (m)	Base station side: 20 m earth station side: 20 m Based on Table 4 in § 4.5.3 of Recommendation ITU-R P.452-14
Nominal distance (km)	Base station side: 0.02 km earth station side: 0.02 km Based on Table 4 in § 4.5.3 of Recommendation ITU-R P.452-14
Building penetration loss (dB)	Building penetration loss (horizontal): 20 dB / wall (***) (NOTE – Sensitivity analysis for: 10 dB, 12 dB and 15 dB) Building penetration loss (vertical): 18 dB / floor (Recommendation ITU-R P.1238, Table 3) (*)

NOTE – The assumed FSS antenna height is in line with what was considered in Report ITU-R M.2109. However with respect to the receiving FSS earth station antenna, the assumed antenna height may not sufficiently represent the typical FSS earth station located in the given operational environment.

4 Analysis

4.1 Co-channel interference analysis

4.1.1 Long term analysis

4.1.1.1 IMT macro cell scenario – suburban and urban

The Monte Carlo statistical method provides the following results:

TABLE A2-8

Minimum protection distance for IMT macro cell scenario – suburban and urban environments, co-channel, long term criterion

I/N criterion (dB)	FSS elevation angle	Min. protection distance (km)	
		Suburban	Urban
–13 (incl. –3 dB for 50% interference apportionment)	5°	60.5	72
	15°	58.2	69
	48°	55.6	67

4.1.1.2 Outdoor IMT small cell scenario – urban

The Monte Carlo statistical method provides the following results:

TABLE A2-9

Minimum protection distance for Outdoor IMT small cell scenario – urban environment, co-channel, long term criterion.

I/N criterion (dB)	FSS elevation angle	Min. protection distance (km)
–13 (incl. –3 dB for 50% interference apportionment)	5°	5
	15°	1.2
	48°	0.53

4.1.1.3 Indoor IMT small cell scenario – urban

The Monte Carlo statistical method provides the following results:

TABLE A2-10

Minimum protection distance for Indoor IMT small cell scenario – urban environment, co-channel, long term criterion, building penetration loss (horizontal): 10 dB and 20 dB

I/N criterion (dB)	Building penetration loss (dB)	FSS elevation angle	Min. protection distance (km)
–13 (incl. –3 dB for 50% interference apportionment)	20	5°	4
	20	15°	1
	20	48°	0.55
	10	5°	5
	10	15°	3
	10	48°	1.5

4.1.2 Deterministic calculation for long-term analysis

This paragraph provides a deterministic calculation to assess the worst case for the single entry interference. While earth station and the IMT base station parameters listed in § 3.4 apply, the main difference from the aggregated analysis lies in the fact that the antenna directions, elevation angle and down-tilt are selected in order to determine the maximum interference towards the earth station.

The following table provides the results for such worst case analysis.

TABLE A2-11

Worst case analysis (deterministic calculation for single entry interference)

I/N criterion (dB)	Elevation angle	Min. protection distance (km)			
		Macro cell		Outdoor small cell urban	Indoor small cell urban
		Urban	Suburban		
–13 (incl. –3 dB for 50% interference apportionment)	5°	67.5	56.5	2.8	1.45
	10°	62.5	51.4	1.2	< 1
	20°	57.5	46	< 1	< 1
	48°	42	28.6	< 1	< 1

4.1.3 Short term interference analysis with deterministic calculation

Larger protection distances apply compared to the long term interference when applying the short term criterion as described in § 3.1.2.2. Such increase is determined by the combination of the following two factors:

– The level of interference that can be tolerated for short periods is higher and given by: I/N = –1.3 dB.

– The percentage of time to be used in the propagation models is smaller: 0.0017%.

While the first factor would determine smaller protection distances, the first factor will dominate leading to an actual increase of the protection distance.

4.1.3.1 IMT macro cell scenario – suburban and urban

TABLE A2-12

Minimum protection distance for IMT macro cell scenario – suburban and urban environments, co-channel, short term criterion

***I/N* criterion (dB)**	**IMT main lobe / side lobe**	**FSS elevation angle**	**Min. protection distance (km)**		
			Suburban	**Urban**	**Urban 1**
–1.3	Main lobe	5°	223.8	450	55
		10°	157	390	40
		20°	90.9	330	35
		48°	44.3	250	3
	Side lobe (20 dB front-to-back ratio)	5°	62.7	280	5
		10°	42.5	220	2.5
		20°	21.6	170	< 2
		48°	2	110	< 2

The "Urban" scenario assumes 30 metres earth station antenna height while the "Urban 1" scenario assumes 3 metres earth station antenna height.

Although the co-existence will be difficult for the macro scenario in general terms, when feasible, the proper antennae setting (e.g. lower antenna height and higher antenna elevation angle) can mitigate the impact on the protection distances.

4.1.3.2 Outdoor IMT small cell scenario – urban

TABLE A2-13

Minimum protection distance for outdoor IMT small cell scenario – urban environment, co-channel, short term criterion

***I/N* criterion (dB)**	**FSS elevation angle**	**Min. protection distance (km)**
–1.3	5°	3
	10°	< 2
	20°	< 2
	48°	< 2

According to the results in the table above, coexistence is still feasible for outdoor IMT small cell scenario in urban environment.

4.1.3.3 Indoor IMT small cell scenario – urban

TABLE A2-14

Minimum protection distance for indoor IMT small cell scenario – urban environment, co-channel, short term criterion, building penetration loss (horizontal): 10 dB and 20 dB

I/N criterion (dB)	Building penetration loss (dB)	FSS elevation angle	Required outdoor propagation loss (dB)
–1.3	20	5°	125.8
	20	10°	118.3
	20	20°	110.8
	20	48°	101.3
	10	5°	135.8
	10	10°	128.3
	10	20°	120.8
	10	48°	111.3

If the indoor IMT small cell is located on the first floor (which is 3 metres high), the required propagation loss (see table above for both 10 dB and 20 dB building penetration loss) would be achieved by only one 20 metres high obstacle at less than 200 metres distance from the base station.

If the indoor IMT small cell is located on the sixth floor (which is 18 metres high), the required propagation loss (see table above for both 10 dB and 20 dB building penetration loss) would be achieved by only one 40 metres high obstacle at less than 100 metres distance from the base station.

The coexistence is therefore still feasible for the indoor IMT small cell scenario in urban environment.

4.2 Adjacent channel interference analysis

In simple terms, the interference in the adjacent channel case is made up of two components as shown in the diagram below:

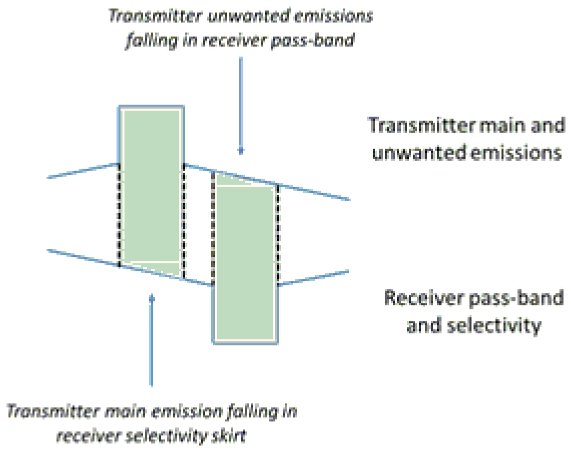
– the transmitter unwanted emissions falling within the receiver pass-band;

– the transmitter main emission falling in the receiver selectivity skirt.

The total impact is in fact a convolution of the interfering transmitter emission mask (its in-band and out-of-band characteristic combined) and the victim receiver selectivity (its in-band and out-of-band characteristic combined). Another factor to be accounted for (for ground path interference) is overload of the earth station receiver front-end which is often wideband.

FIGURE A2-5

Adjacent channel interference components.



The total received interference from IMT base station is derived as follows:

$$IMT\_Tx\_power*10^\wedge(-0.1*ACS_{FSS}) + IMT\_Tx\_power*10^\wedge(-0.1*ACLR_{IMT})$$

The 36 MHz ACLR is calculated as follows:

ACLR = in band power of IMT (46 dBm) / adjacent 36 MHz emission power (which will slightly differ according to the different guard band values between IMT and FSS).

The emission power will be calculated based on § 3.4.

4.2.1 IMT macro cell scenario – suburban and urban

The Monte Carlo statistical analysis provides the following results:

4.2.1.1 Adjacent frequencies (0 MHz guard band)

TABLE A2-15

Minimum protection distance for IMT macro cell scenario – suburban and urban environments, adjacent frequencies

***I/N* criterion (dB)**	**FSS elevation angle**	**Min. protection distance (km)**	
		Suburban	**Urban**
–23 (incl. –3 dB for 50% interference apportionment)	5°	1.4	49
	15°	< 0.6	43.5
	48°	< 0.6	39

4.2.1.2 5 MHz frequency protection (guard band)

TABLE A2-16

Minimum protection distance for IMT macro cell scenario – suburban and urban environments, 5 MHz frequency protection

***I/N* criterion (dB)**	**FSS elevation angle**	**Min. protection distance (km)**	
		Suburban	**Urban**
–23 (incl. –3 dB for 50% interference apportionment)	5°	1.3	49
	15°	< 0.6	43
	48°	< 0.6	39

4.2.1.3 10 MHz frequency protection (guard band)

TABLE A2-17

Minimum protection distance for IMT macro cell scenario – suburban and urban environments, 10 MHz frequency protection

***I/N* criterion (dB)**	**FSS elevation angle**	**Min. protection distance (km)**	
		Suburban	**Urban**
–23 (incl. –3 dB for 50% interference apportionment)	5°	1.3	49
	15°	< 0.6	43
	48°	< 0.6	38.5

4.2.2 Outdoor IMT small cell scenario – urban

4.2.2.1 Adjacent frequencies (0 MHz guard band)

TABLE A2-18

Minimum protection distance for outdoor IMT small cell scenario – urban environment, adjacent frequencies

***I/N* criterion (dB)**	**FSS elevation angle**	**Min. protection distance (km)**
–23 (incl. –3 dB for 50% interference apportionment)	5°	<0.3
	15°	<0.3
	48°	<0.3

4.2.3 Indoor IMT small cell scenario – urban

4.2.3.1 Adjacent frequencies (0 MHz guard band)

TABLE A2-19

Minimum protection distance for indoor IMT small cell scenario – urban environment, adjacent frequencies

***I/N* criterion (dB)**	**Building penetration loss (dB)**	**FSS elevation angle**	**Min. protection distance (km)**
–23 (incl. –3 dB for 50% interference apportionment)	20	5°	< 0.3
	20	15°	< 0.3
	20	48°	< 0.3
	10	5°	< 0.4
	10	15°	< 0.4
	10	48°	< 0.4

4.3 Front-end saturation

This paragraph presents some considerations on the impact of FSS earth station receiver intermediation LNA/LNB overdrive and inter-modulation (large signal analysis).

The LNBs employed by satellite earth stations are wideband and tend to receive standardised frequency bands e.g. 3 400-4 200 MHz, 3 600-4 200 MHz and 3 700-4 200 MHz. As such these devices receive signals from any system, terrestrial included, operating anywhere in the frequency band even if later parts of the receive chain target much smaller amounts of bandwidth.

Signal levels that give rise to front-end saturation are described variously and with different levels. These levels generally fall in the range of –60 to –50 dBm. For the purpose of analysis a level of –55 dBm might reasonably be assumed.

No meaningful interference impact is therefore expected as the above described criterion is looser than the criteria which have already been considered in previous paragraphs.

5 Summary

Coexistence criteria and parameters

The *I/N* criteria defined within Report ITU-R M.2109 are adopted together with the specified parameters for both FSS systems and IMT systems.

Updated propagation model

As for the propagation model, the more recently updated Recommendation ITU-R P.452-14 is adopted which allows adding terrain or cluttering factors to the smooth earth model by defining the diffraction loss part in detail. Most sharing studies that contributed to the Report ITU-R M.2109 referred to Recommendation ITU-R P.452-12 (now superseded) utilizing the smooth earth propagation model simplification.

Updated scenarios

Both indoor and outdoor small cells are addressed in addition to the outdoor macro base stations, small cells represent a clear trend in the ongoing evolution of mobile broadband networks. The following scenarios and environments have been analysed in detail:

– outdoor IMT macro cell scenario in suburban and urban environments;

– outdoor IMT small cell scenario in urban environment;

– indoor IMT small cell scenario in urban environment.

This study is based on Monte Carlo statistical analysis to obtain stable and accurate results while accounting for the randomness in the FSS antenna horizontal bore sight and in the small cells location.

The above scenarios have been assessed in the following two cases:

– co-channel interference analysis;

– adjacent channel interference analysis.

Summary of results

The required protection distance is in the range of 50 km in a suburban environment and in the range of 70 kilometres in an urban environment in the case of an IMT macro cell system interfering (long term analysis) an earth station operating in the same frequency channel.

The required protection distance is in the range from 500 metres to 5 kilometres (depending on the FSS earth station antenna elevation angle) in the case of an outdoor IMT small cell system interfering (long term analysis) an earth station in an urban environment operating in the same frequency channel.

The required protection distance is in the range from 550 metres to 4 km (depending on the FSS earth station antenna elevation angle) in the case of an indoor IMT small cell system interfering (long term analysis) an earth station in an urban environment operating in the same frequency channel. It is noted that, for the indoor IMT small cell scenario in the urban environment, the assumed FSS antenna height is in line with what was considered in Report ITU-R M.2109. However with respect to the receiving FSS earth station antenna, the assumed antenna height may not sufficiently represent the typical FSS earth station located in the given operational environment.

Significantly lower protection distances are reached (long term analysis) in case of IMT and FSS systems operating in adjacent channels: from 49 km, for an IMT macro base station operating in an adjacent frequency channel with the FSS earth station operating channel (0 MHz guard band) in an urban environment, to less than 300 metres for an outdoor IMT small cell always operating in an adjacent frequency channel with the FSS earth station operating channel (0 MHz guard band) in an urban environment.

In case of outdoor IMT small cells, the short term analysis determines protection distances smaller than 3 kilometres in the urban environment.

With respect to the studies performed in the context of the WRC-07, this sharing study therefore provides somewhat reduced protection distances compared to those of Report ITU-R M.2109.

TABLE A2-20

Summary of sharing study results

			IMT vs. FSS sharing study results (protection distance – km) (Ranges depend on ES elev. angle)
Co-channel	**Long term**	**Macro suburban**	56 to 61
		Macro urban	67 to 72
		Outdoor small cell	0.5 to 5
		Indoor small cell	0.5-4, 20 dB indoor loss 1.5-5, 10 dB indoor loss
	Short term	**Macro suburban**	Separation distances would range from 80 km for interference within the main lobe of a 20º elevation antenna in the suburban environment to hundreds of kilometres
		Macro urban	
		Outdoor small cell	< 3
		Indoor small cell	10 dB and 20 dB indoor loss: 20 m (40 m) high obstacle at 200 m (100 m) distance from ES provides required outdoor propag. loss
Adjacent ch.	**Long term**	**Macro suburban**	< 0.6-1.4, 0 MHz GB < 0.6-1.3, 5 MHz GB
		Macro urban	39 to 49, 0 MHz and 10 MHz GB
		Outdoor small cell	< 3
		Indoor small cell	< 0.3, 0 MHz GB, 20 dB indoor loss; < 0.4, 0 MHz GB, 10 dB indoor loss

Annex 3

Study #3

1 Introduction

The sharing study was performed in the frequency band 3 400-4 200 MHz between IMT-Advanced base station and FSS earth station (ES) taking into account the actual conditions and parameters, including but not limited to geographical and terrain conditions.

2 Background

The following Recommendations and Reports are used in the analysis:

– Recommendation ITU-R P.452-14
– Report ITU-R M.2109-0
– Recommendation ITU-R SF.1486
– Report ITU-R S.2199
– Recommendation ITU-R S.465-6
– Recommendation ITU-R S.1432
– Recommendation ITU-R SF.1006.

3 Technical characteristics

The systems used in the sharing study are as follows:

IMT-Advanced base station

Following parameters were used in accessing the interference from IMT system to the earth station receiver.

TABLE A3-1

IMT base station parameters (typical)

Parameter	**Values in the evaluations**	
	Macro cell (suburban)	**Small cell (outdoor)**
Maximum base station output power	33 dBm/MHz	17 dBm/MHz
Maximum base station antenna gain	18 dBi	5 dBi
Average base station activity	50%	50%
Downtilt	6 degrees	0 degree
Antenna height	25 m	6 m
Feeder loss	3 dB	0 dB
Adjacent channel leakage power ratio	–45 dB	–45 dB

TABLE A3-2

FSS earth station (ES)

Downlink FSS parameters to be used in calculation

Parameter	Values
Operating frequencies	3 400-4 200 MHz
Satellite Orbital location	60°, 166° E
FSS earth station elevation angle	6.5°, 36°
Antenna pattern	Recommendation ITU-R S.465-6
Antenna gain	56 dBi
Antenna size	18 m in diameter
Antenna height	12 m in centre of the antenna
System noise temperature	91.2 K

4 Analysis

Following assumptions and methodologies are used for the simulation.

1) Interference criteria for FSS ES

Long-term interference criterion

- Recommendation ITU-R S.1432
- Recommendation ITU-R SF.1006.

Short-term interference criterion

- Recommendation ITU-R SF.1006
- Annex 7 of RR Appendix **7**

2) Propagation condition.

- Recommendation ITU-R P.452-14.

3) Actual system parameters of FSS ES and IMT-Advanced base station are used as indicated in Technical characteristics above.

The results are shown in the Attachment, which proves that there is a case that the sharing between FSS ES and IMT base station could be achieved with separation distance acceptable for both IMT-Advanced system and FSS system, and it was recognized that it is effective to include following conditions into consideration. In particular, geographical conditions have substantial effects on the propagation characteristics in the frequency band over 1 GHz. It is worth noting that sufficient measures to exchange these conditions among concerned parties are important.

– Geographical conditions around earth stations:
  - surrounded by mountains with appropriate height so as to be shielded from the terrestrial radio systems;
  - use of shielding wall, such as effect of shielding isolation in a range about 30 dB as explained in Recommendation ITU-R SF.1486, whose effect should be considered with the location of each ES;
  - location of the earth station and beam direction for satellites (e.g. an earth station is located near the sea shore and its beams for satellite are directed to the sea).

– Conditions of IMT systems:
  – frequency separation between IMT and FSS;
  – use of filters suitable for individual interference scenario;
  – use of small cell whose parameters are as indicated in Table A3-4 of the Attachment;
  – distance between IMT and FSS stations in co-channel case, and so on.

5 Summary

1) In order to pursue possibilities to share the spectrum between FSS and IMT with acceptable separation distance, the contribution proposes that sharing studies should be conducted using typical parameters of FSS and IMT together with some practical assumptions (geographic data, etc., if available). The results of such studies should be used to assess the sharing possibilities between FSS and IMT related to WRC-15 agenda item 1.1.

2) This study also proposes for the parameters to take into account of the methodology shown above in carrying out the sharing studies.

Attachment to Annex 3

Sharing studies between IMT systems and fixed satellite service networks in the 3 400-4 200 MHz frequency band

1 Introduction

The 3 400-4 200 MHz frequency band is allocated to FSS and to the mobile service. This band is used worldwide by the FSS for space-to-Earth transmissions. The 3 400-3 600 MHz frequency band is identified for use by IMT in a number of countries in Regions 1 and 3. In these regions, many administrations are introducing IMT systems in all or portions of this frequency band.

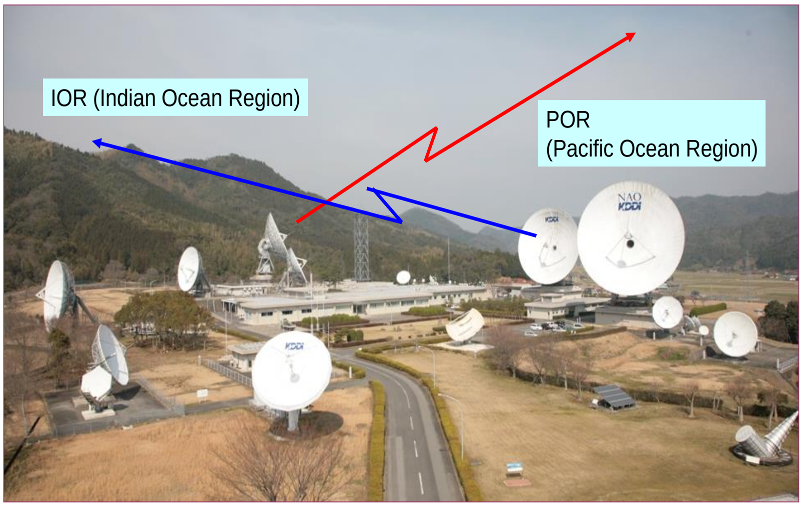
2 Scope of the Attachment

This Attachment presents the results of the sharing studies performed between the particular FSS earth station using the geostationary satellite orbit (GSO) and IMT systems. The FSS earth station evaluated in this Attachment is located in Yamaguchi prefecture, western part of Japan (called Yamaguchi earth station). The earth station is surrounded by mid-altitude hills on three sides and used for satellites in the IOR (Indian Ocean Region) and POR (Pacific Ocean Region) as shown in Fig. A3-1. With its unique characteristics of the terrain, the earth station has been taking advantage of natural screening to increase obstructive/ diffraction losses in sharing between the fixed service (FS) and FSS as described in some ITU-R Recommendations (e.g. Recommendation ITU-R SF.1486).

The sharing studies were performed based on the current band usage of the Yamaguchi earth station as well as the associated technical and geographic characteristics, and the assumptions on the characteristics and future deployment of IMT system.

FIGURE A3-1

Yamaguchi earth station, Japan



3 FSS parameters including the interference criteria

The parameters listed in § 3.1 provide key FSS parameters to be used in the evaluation of interference into receivers of the earth station. Section 3.2 provides the interference criteria for FSS.

3.1 System parameters

TABLE A3-3

Downlink FSS parameters to be used in calculation

Parameter	Values
Operating frequencies	3 400-4 200 MHz
Satellite Orbital location	60°, 166° E
FSS Earth Station Elevation Angle	6.5°, 36°
Antenna pattern	Recommendation ITU-R S.465-6
Antenna gain	56 dBi
Antenna size	18 m in diameter
Antenna height	12 m in centre of the antenna
System noise temperature	91.2 K

3.2 FSS interference criteria

Based on the descriptions in § 6.2 of Report ITU-R M.2109 and Annex B of Report ITU-R S.2199, the following interference criteria were used when accessing the interference from IMT system to the earth station.

3.2.1 Long-term interference criterion

As described in the Recommendations ITU-R S.1432 and SF.1006, the long-term interference should be less than $I/N = -10$ dB ($\Delta T/T = 10\%$) corresponding to the interference from co-primary allocation (IMT) for 20% of any month, where N is the clear-sky satellite earth station system noise as described in Recommendation ITU-R S.1432.

3.2.2 Short-term interference criterion

This criterion is referred to Recommendation ITU-R SF.1006 and Annex 7 (in both text and Table 8b) of RR Appendix **7**: $I/N = -1.3$ dB which may be exceeded by up to 0.001667% of any month.

3.2.3 Apportionment of interference allowance

Regarding apportionment of interference allowance; it is recommended that the long-term interference from any individual secondary or unallocated service as well as interference into adjacent frequency bands (unwanted emissions) should be limited to half of the total noise interference allowance into an FSS link, and from any individual primary service it should be limited to half of the afore mentioned values of 6% or 10% of the total noise, as appropriate.

3.2.4 Low Noise Amplifiers saturation

As LNAs and LNBs of FSS earth stations are optimized for the reception of very low level satellite signals, the dynamic range is also designed accordingly. Typically, an LNA/LNB will be saturated with a total input power of around –50 to –60 dBm. This value is considered as the saturation criterion in the evaluation.

4 IMT parameters

The following typical parameters were used when accessing the interference from IMT system to the earth station receiver.

TABLE A3-4

IMT base station parameters (typical)

Parameter	Values in the evaluations	
	Macro cell (suburban)	**Small cell (outdoor)**
Maximum base station output power	33 dBm/MHz	17 dBm/MHz
Maximum base station antenna gain	18 dBi	5 dBi
Average base station activity	50%	50%
Downtilt	6 degrees	0 degree
Antenna height	25 m	6 m
Feeder loss	3 dB	0 dB
Adjacent channel leakage power ratio	–45 dB	–45 dB

5 Propagation Models

The propagation model Recommendation ITU-R P.452 is used in the sharing between IMT-Advanced systems and geostationary satellite networks in the fixed-satellite service in the 3 400-4 200 MHz frequency band.

6 Sharing methodology

The method in the following sections or a combination of these methods can be used for determining whether an IMT base station proposed to operate in the 3 400-4 200 MHz frequency band would meet the interference criteria.

6.1 Method 1

Method 1 is simple but admittedly conservative. This method produces the protection distance using a smooth Earth model.

An IMT base station deployed at a distance greater than or equal to the minimum separation distance is assumed to meet the sharing criterion. No further analyses are required. Note that deployment in areas excluded by this method is still possible provided a potential site can be shown to meet the sharing criterion through application of an adapted form of Method 2.

In order to calculate the value of the distance, some basic assumptions and propagation models are required. Those in Recommendation ITU-R P.452 have been used in many similar sharing situations and would appear to be the most appropriate to be used here.

6.2 Method 2

The basis of this method is to perform a case-specific analysis for each IMT base station to be deployed. Deployment may go forward if the analysis shows that the interference does not exceed the interference criteria. The analysis is accomplished by using digital terrain data in conjunction with the IMT base station parameters, appropriate propagation models and any other mitigation techniques that may be used (e.g. sector disabling or multiple input, multiple output). It is expected that this method will only be employed when a potential deployment site cannot be shown to be compliant with the interference criteria using either the Method 1.

The description of the method is as follows:

1) Digital terrain data that includes the IMT base station site and surrounding area is required. The data should encompass a sufficient area to reasonably perform the interference analysis.

2) The parameters of the IMT base station to be deployed will be required for the analysis. This includes the peak gains, beamwidths and pointing angles of the base station’s antenna beam in the horizontal and vertical planes, the height of the antenna above terrain, and the IMT carrier spectral density. The appropriate reference earth station radiation pattern for this method could be the one provided by the earth station operator or the one found in the relevant ITU-R Recommendation (e.g. Recommendation ITU-R F.1336).

3) As with the Method 1, the propagation model best suited to the site-specific analysis is Recommendation ITU-R P.452.

4) The IMT base station parameters, digital terrain data, and propagation models enable calculation of the path loss in all directions around the potential site. This in turn yields the interference level at the input of FSS earth station receivers. If the interference criteria are met, then deployment may proceed. Otherwise, additional interference mitigation techniques may need to be applied.

6.3 Calculation of interference from IMT stations into FSS earth stations

The interference power is given by subtracting the path loss, the feeder loss, the isolation from the site shielding and the centre frequency offset factor from the sum of the e.i.r.p. of the base station in the direction of the earth station and the receive antenna gain of the earth station in the direction of the base station. Therefore:

$$I = P_{t,basestation} + G_{t,basestation} - L_b(d, p_s) + G_{r,FSS} - FL - R - F \qquad (1)$$

where:

$P_{t,\,base\,station}$: maximum transmit power at the base station's antenna input flange (dBW)

$G_{t,\,base\,station}$: transmission antenna gain of the base station in the direction of the earth station (dBi)

$L_b\,(d,\,p_s)$: path loss (dB)

d: distance between the base station and the FSS earth station

p_s: percentages of the time during which the interference may exceed the permissible level.

Recommendation ITU-R P.452 defines the clear-air propagation models for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz considering all the factors associated the terrain profile such as diffraction, tropospheric scattering, ducting/layer reflection and clutter losses.

$G_{r,FSS}$: receive antenna gain of the earth station in the direction of the base station (dBi)

F: earth station antenna feeder loss (dB)

R: the isolation from the site shielding

F: centre frequency offset factor.

Depending upon the mobile system frequency plan, it may be possible to select a centre frequency of an FSS carrier which is completely outside of the assigned bandwidth of an interfering carrier. In this example, we assume 0 dB frequency offset improvement factor, the worst case.

6.4 Required separation distance

When the interference criteria of *I/N* is given, the maximum permissible interference power is given by:

$$I_{\max} = (I / N)_{th} + 10\log_{10}(kT_{sys}B) \qquad \text{dBW} \qquad (2)$$

where:

$(I/N)_{th}$: interference to thermal noise power ratio defined in interference criterion (dB)

k: Boltzman's constant (W/(K-Hz))

T_{sys}: system noise temperature of earth station receiver (K)

B: bandwidth of earth station receiver (Hz).

The required separation distance, *d*, can be found by combining Equations (1) and (2) with $I = I_{max}$.

7 Sharing study results

The studies presented in this Attachment have considered both co-frequency and adjacent interference case. The studies examined effects of single entry interference from IMT base stations, incorporating site specific conditions and terrain profile surrounding the earth station site using Method 2.

It is noted that the aggregated interference should be also evaluated with appropriate calculation conditions, taking account of location of base station, terrain geographical features between base station and ES, architectures building conditions between base station and ES, and other required conditions, as an earth station receives interference from multiple IMT base stations.

The saturation of the low noise amplifier (LNA) of the earth station is also studies.

7.1 Single-entry interference analysis

In order to evaluate the interference from the IMT base station with using the specific terrain profile information, in each trial of the calculation, it is assumed that the IMT base station is located within a particular mesh (with the resolution of 250 metres × 250 metres) in the area of 160 kilometres × 110 kilometres around the earth station, and then the interference into the earth station is computed. This computation is repeated by changing the location of the IMT base station over the above mentioned area.

The result plots for a co-frequency condition in a macro suburban deployment are given in Figs. A3-2 and A3-3 for the elevation angle of 6.5 and 36 degrees, respectively. In each Figure, the protection areas for the long-term and short-term interference criteria are depicted as a contour plot (red colour) and a block plot (blue colour), respectively. Thus it is shown that, although terrain causes some irregularity in area shapes, the long-term protection areas are up to 20 kilometres in radius, and the short-term protection areas spreads larger than the long-term one in specific directions, i.e. westward directions. If the macro-cell outdoor deployment is employed (Figs. A3-4 and A3-5), both the long-term and short-term protection areas shrink up to 15 kilometres in radius.

The result plots for an adjacent frequency condition are given in Figs. A3-6, A3-7, A3-8 and A3-9. The protection areas are limited up to approximately 15 kilometres in radius for the macro suburban deployment, while only nearby areas to the earth station may cause interference in a case of the small-cell outdoor deployment.

Thus, the terrain profile around the Yamaguchi earth station provides great benefit for the sharing.

FIGURE A3-2

Areas that exceeds long-term and short-term interference criteria
(macro suburban deployment, co-frequency, elevation angel of 6.5 degrees, 3.4 GHz)

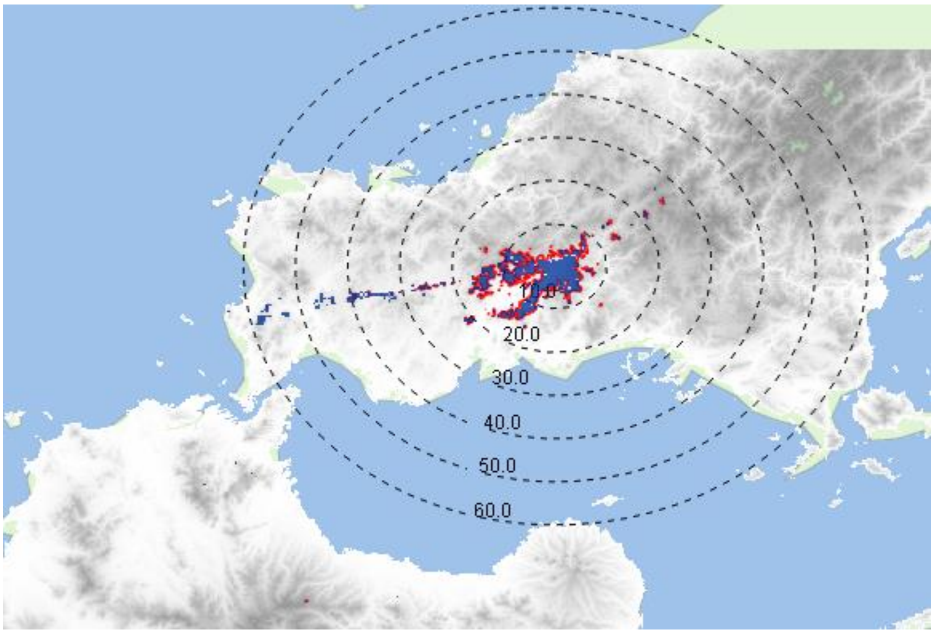


FIGURE A3-3

Areas that exceeds long-term and short-term interference criteria
(macro suburban deployment, co-frequency, elevation angel of 36 degrees, 3.4 GHz)

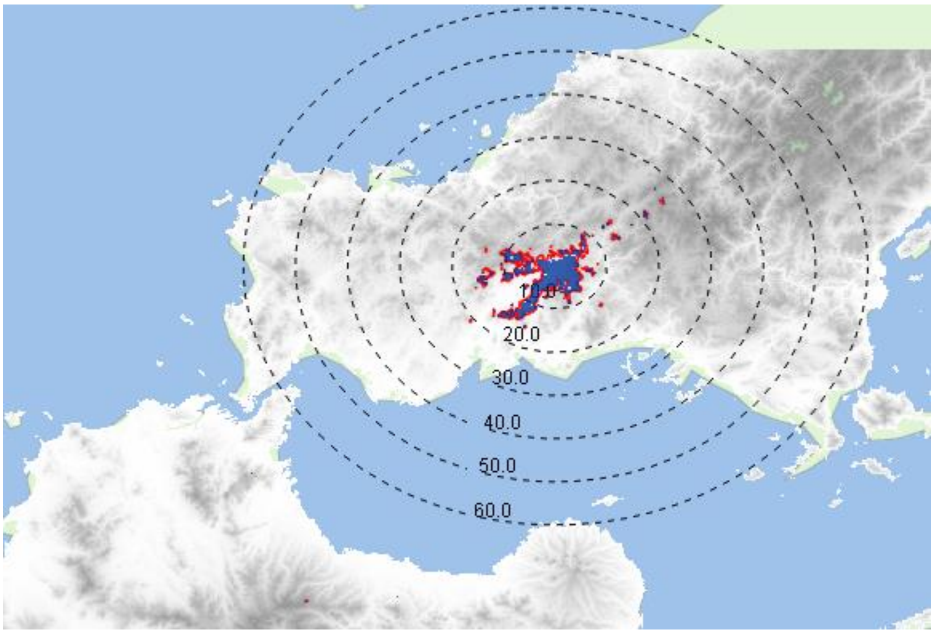


FIGURE A3-4

Areas that exceeds long-term and short-term interference criteria
(small-cell outdoor deployment, co-frequency, elevation angle of 6.5 degrees)

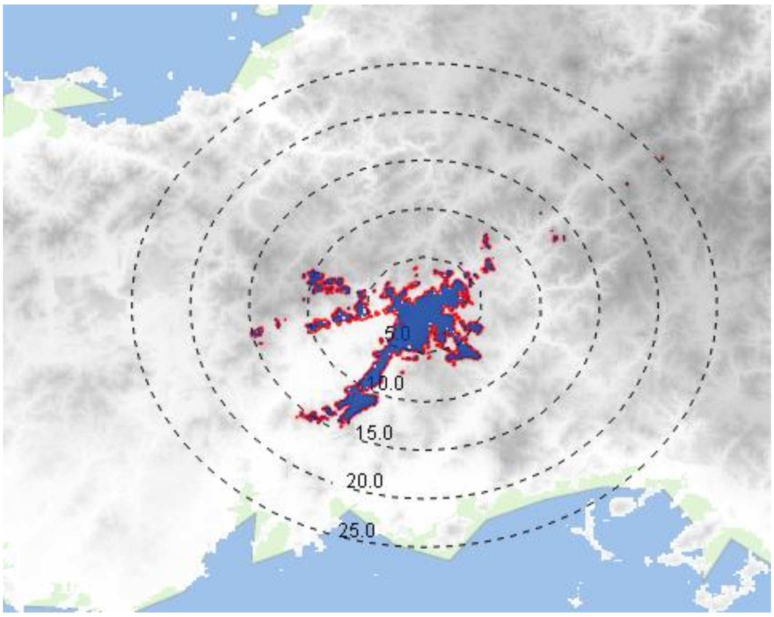


FIGURE A3-5

Areas that exceeds long-term and short-term interference criteria (small-cell outdoor deployment, co-frequency, elevation angle of 36 degrees)

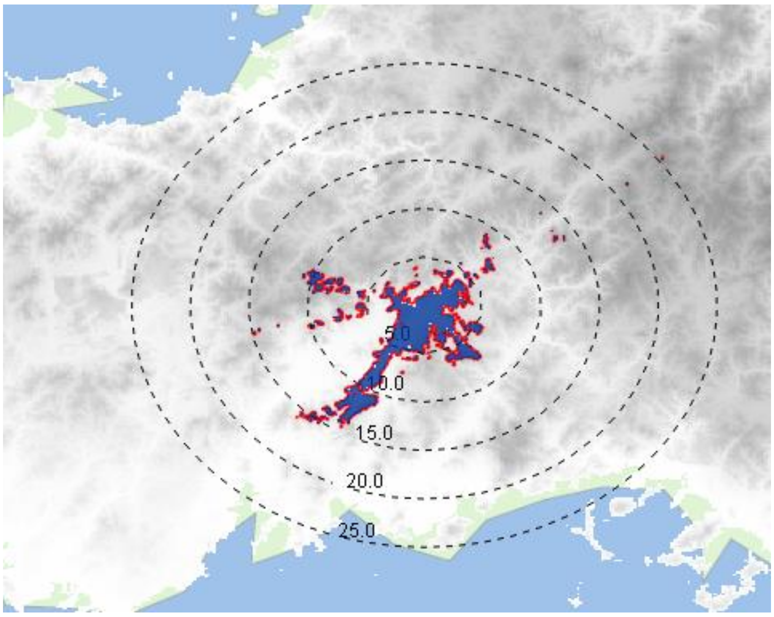


FIGURE A3-6

Areas that exceeds long-term and short-term interference criteria (macro suburban deployment, adjacent-frequency, elevation angle of 6.5 degrees)

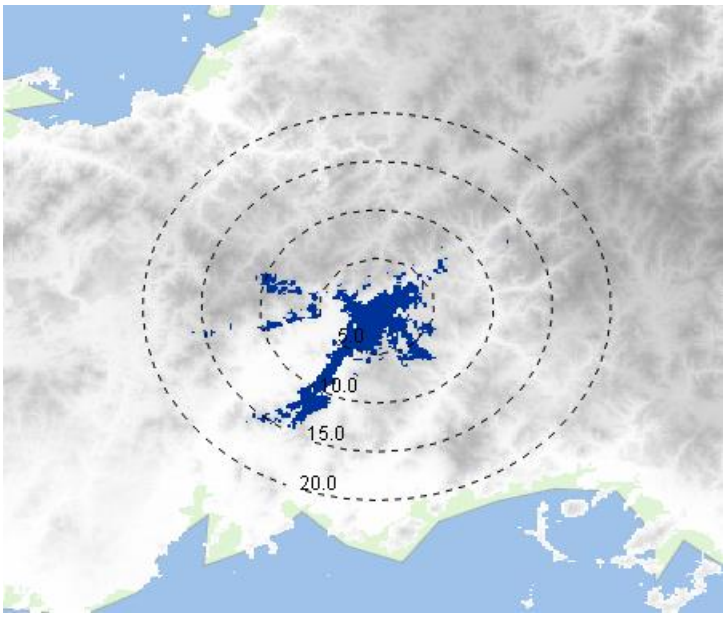


FIGURE A3-7

Areas that exceeds long-term and short-term interference criteria
(macro suburban deployment, adjacent-frequency, elevation angle of 36 degrees)

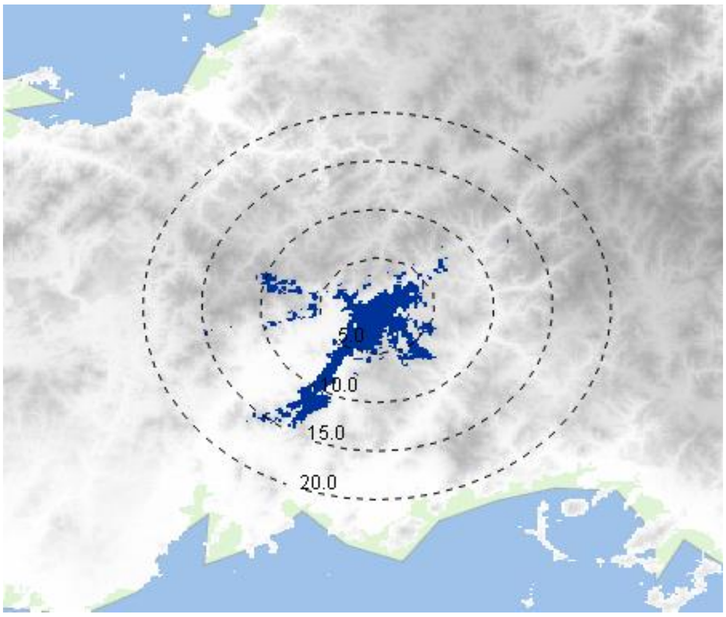


FIGURE A3-8

Areas that exceeds long-term and short-term interference criteria
(small-cell outdoor deployment, adjacent-frequency, elevation angle of 6.5 degrees)

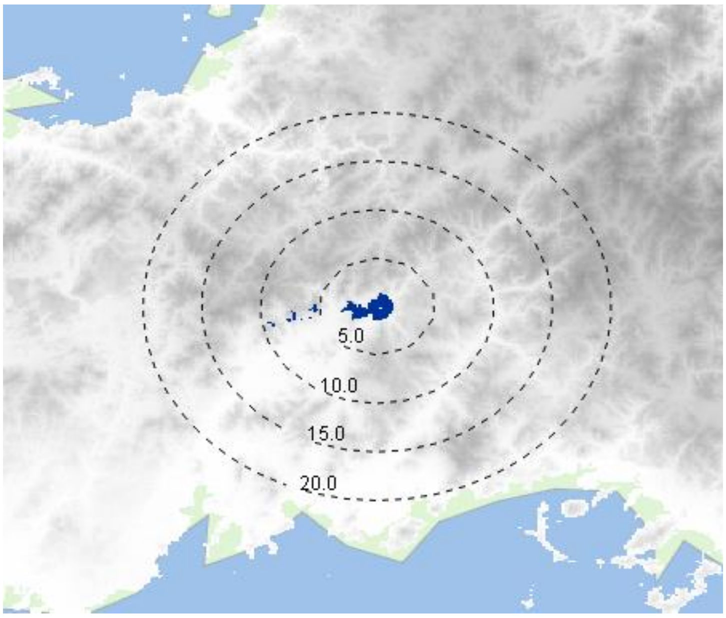
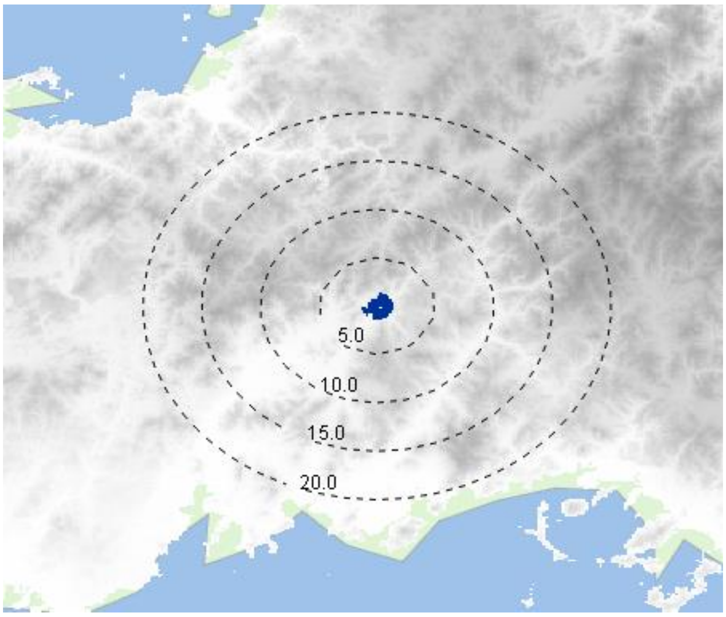


FIGURE A3-9

Areas that exceeds long-term and short-term interference criteria (small-cell outdoor deployment, adjacent-frequency, elevation angle of 36 degrees)



7.2 LNAs saturation

Typical LNAs and LNBs receive over the entire 3 400-4 200 MHz range or more. Therefore, even if IMT base stations operate in portions of 3 400-3 600 MHz range, due to the characteristics of the wide band of the LNA/LNB receiver, there is a potential saturation for earth stations operating in 3 600-4 200 MHz range.

In evaluating the LNA saturation, it is assumed that RF carriers from IMT base stations are transmitted uniformly over the 3 400-3 600 MHz range as an example.

The input power to LNA is summed up from multiple IMT BSs in cities A to G in Yamaguchi prefecture, Japan as shown in Fig. A3-10. It should be noted that the number of IMT BSs depends on an area of each city; approximately 20 and 80 stations for thickly-populated and thinly-populated city, respectively. Although power from base stations in totally 7 cities is aggregated in the result, power from BSs in the remaining cities and towns should be aggregated actually.

Table A3-5 shows the input power to LNA in a condition that the aggregated interference from multiple IMT base stations exists across the bandwidth of 3 400-3 600 MHz (200 MHz band). The result shows the input power both including and excluding City G, the closest city to the earth station.

It should be noted that the receiving signal power from satellites are also aggregated to the input power. Although the input power including City G may saturate the LNA, the input power excluding City G is lower than the saturation level when comparing with the value indicated in § 3.2.3 of this Attachment.

It is noted that the saturation characteristics should be evaluated using actual LNA/LNB devices.

FIGURE A3-10

Cities in Yamaguchi Prefecture for LNA saturation analysis

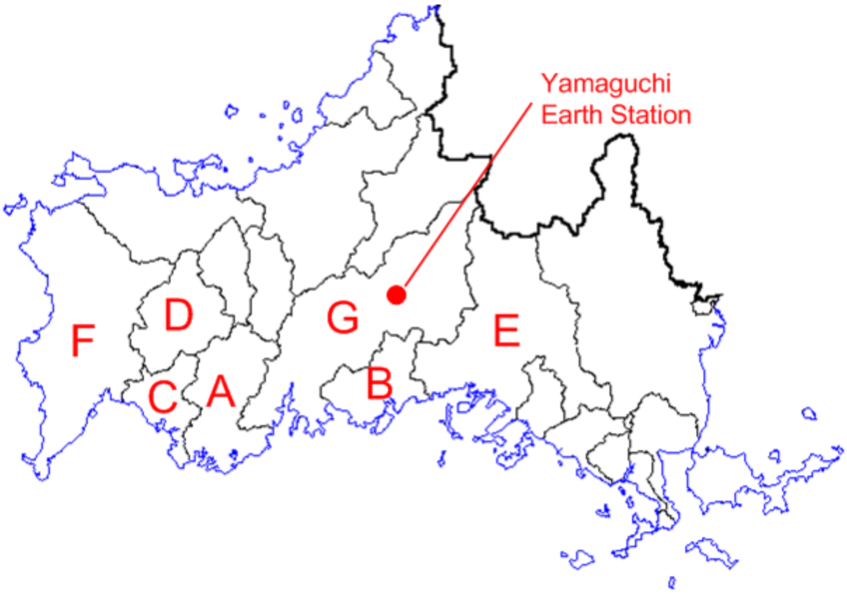


TABLE A3-5

LNA saturation (macro-cell deployment)

	Aggregate Interference Level (dBW/MHz)	
Tx location	**Long-term (20%)**	**Short-term (0.005%)**
City A	–157.9	–143.3
City B	–170.7	–163.4
City C	–175.2	–156.7
City D	–129.6	–120.7
City E	–175.4	–166.2
City F	–166.7	–148.6
City G	–107.7	–103.4

Input power to LNA including City G	–107.6 dBW/MHz	–103.3 dBW/MHz
	–54.6 dBm/200 MHz	–50.3 dBm/200 MHz

Input power to LNA excluding City G	–129.6 dBW/MHz	–120.6 dBW/MHz
	–76.6 dBm/200 MHz	–67.6 dBm/200 MHz

8 Summary

This Attachment presents the result of the sharing studies between IMT systems and the Yamaguchi earth station in the 3 400-4 200 MHz frequency band. The Yamaguchi earth station is surrounded by mid-altitude hills on three sides that provide great benefit for the sharing.

Although each earth station has its own operating characteristics and terrain profile conditions, the result shows that sharing between an IMT base station and an FSS earth station is possibly feasible under practical sharing conditions with the minimum required separation distances.

Some practical possible mitigation techniques as required should be taken into consideration for further sharing study between IMT systems and earth stations.

Annex 4

Study #4

1 Requirement

This sharing study analysed the potential interference caused by IMT-Advanced (IMT-A) into the FSS space-to-Earth downlink receivers in the frequencies from 3 400-4 200 MHz. Both in-band and adjacent-band cases including short and long-term interference criteria were evaluated, as well as non-linear effects, such as gain compression, LNB overload, and intermodulation. Both macro cell and small cell IMT-A deployment scenarios were analysed.

1.1 Study elements

The objective of this analysis was to perform a sharing study of IMT-A systems operating in-band and adjacent band to FSS earth stations in the 3 400-4 200 MHz band FSS primary allocation.

2 Background

In North America, the band is used for satellite downlink of video and television broadcasts of programming materials and other data.

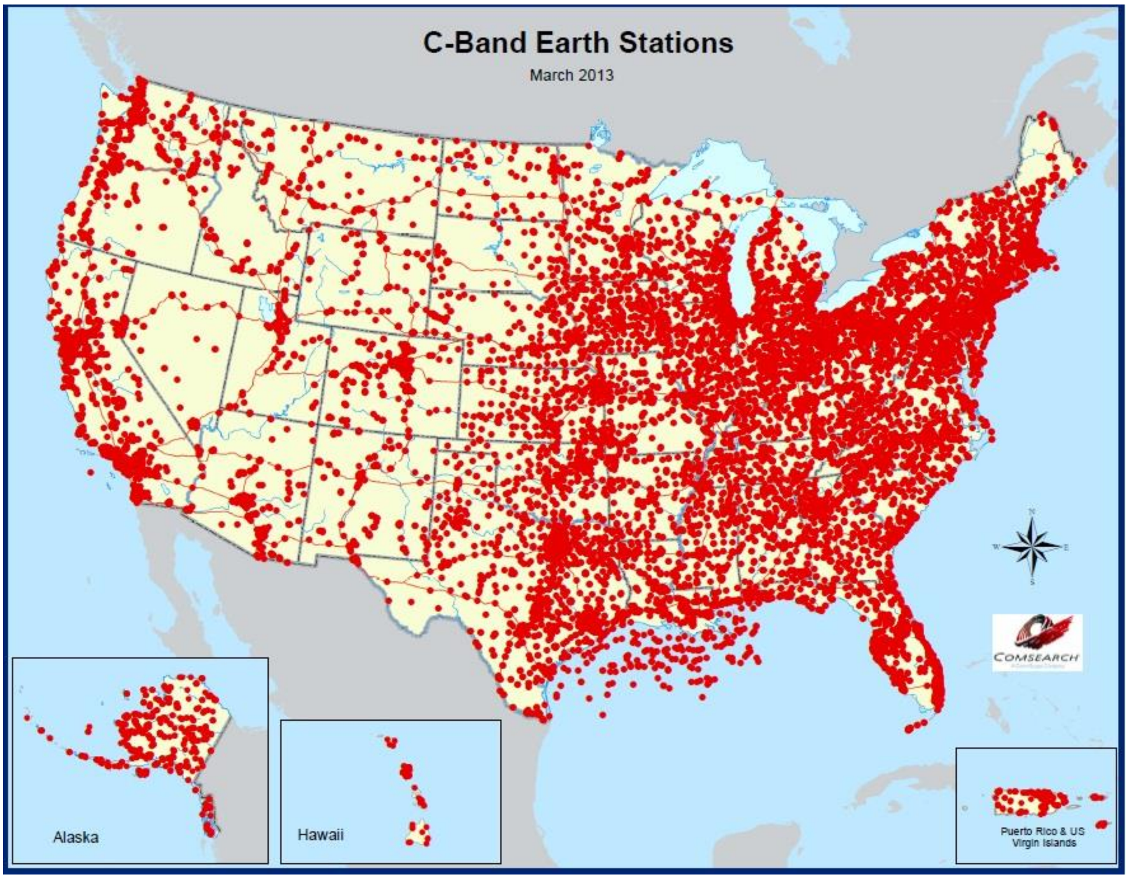
A search of United States Federal Communications Commission (FCC) database records indicated that approximately 5 000 earth stations are licensed in the 3 700-4 200 MHz band[11] in the United States. Since receive-only systems are not required to be licensed, there are additional, but largely unknown, numbers of unlicensed earth stations. For example, as of December 2005, there were approximately 122 000 receive-only earth stations that received programming from the Public Broadcasting System (PBS)[12], a provider of public television programming in the United States, on the 3 700-4 200 MHz band. There are more than 1 300 earth stations that are registered for this band in the Industry Canada database. In addition to these, there are currently over 1 700 unregistered cable head-ends operating in Canada. Figure A4-1 shows the deployment of FSS earth stations in the band 3 700-4 200 MHz in the United States.

[11] http://fjallfoss.fcc.gov/General_Menu_Reports/engineering_search.cfm?accessible=NO, Frequency select performed from Federal Communications Commission (FCC) International Bureau website, 28 March 2013.

[12] This information is provided by the Public Broadcasting Systems in USA.

FIGURE A4-1

Receiving FSS earth stations in the band 3 700-4 200 MHz in the United States



This band has been in use for this service for many decades and such earth stations are ubiquitous.

3 Technical characteristics

3.1 FSS earth stations

This study used the technical characteristics for FSS earth stations as specified in this Report.

3.2 International mobile telecommunications-advanced system technical characteristics

The technical characteristics are the same as those, provided Report ITU-R M.2292.

4 Analysis

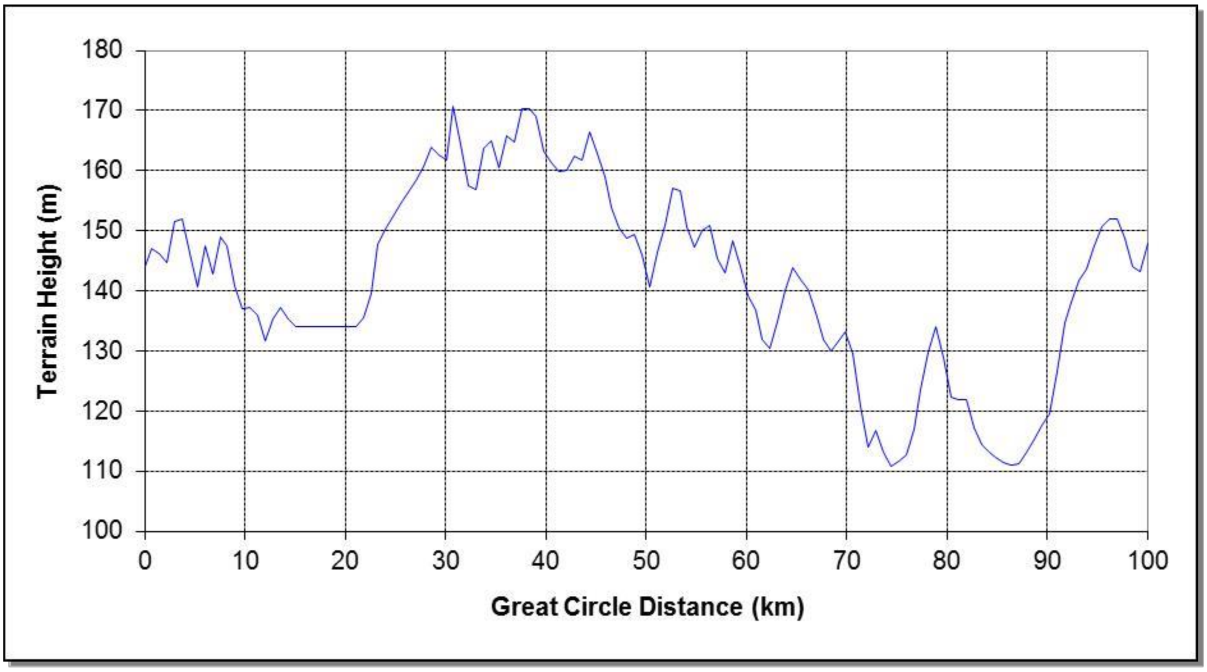
This analysis consisted of performing a sharing study to evaluate the potential interference caused by IMT-A systems operating in-band and adjacent band to FSS earth stations operating in the 3 400-4 200 MHz band FSS primary allocation.

4.1 Assumptions

The study considered single entry and aggregate interference effects of suburban and urban macro cell and urban small cell broadband IMT-A base station deployments in the frequency range 3 400-4 200 MHz to FSS users. In-band and adjacent-band interactions from outdoor and indoor deployment scenarios were examined. The current version of propagation model Recommendation ITU-R P.452-14 was incorporated into the analysis model for this study. Since this propagation model includes the effects of terrain, a representative location with moderate terrain characteristics was used for this analysis. Figure A4-2 shows the terrain profile for the single-entry path of the base station relative to the FSS earth station.

FIGURE A4-2

Terrain profile for single-entry analysis



For this analysis, only base stations were modelled.

4.2 Methodology with formulas

4.2.1 Mutual coupling characterization

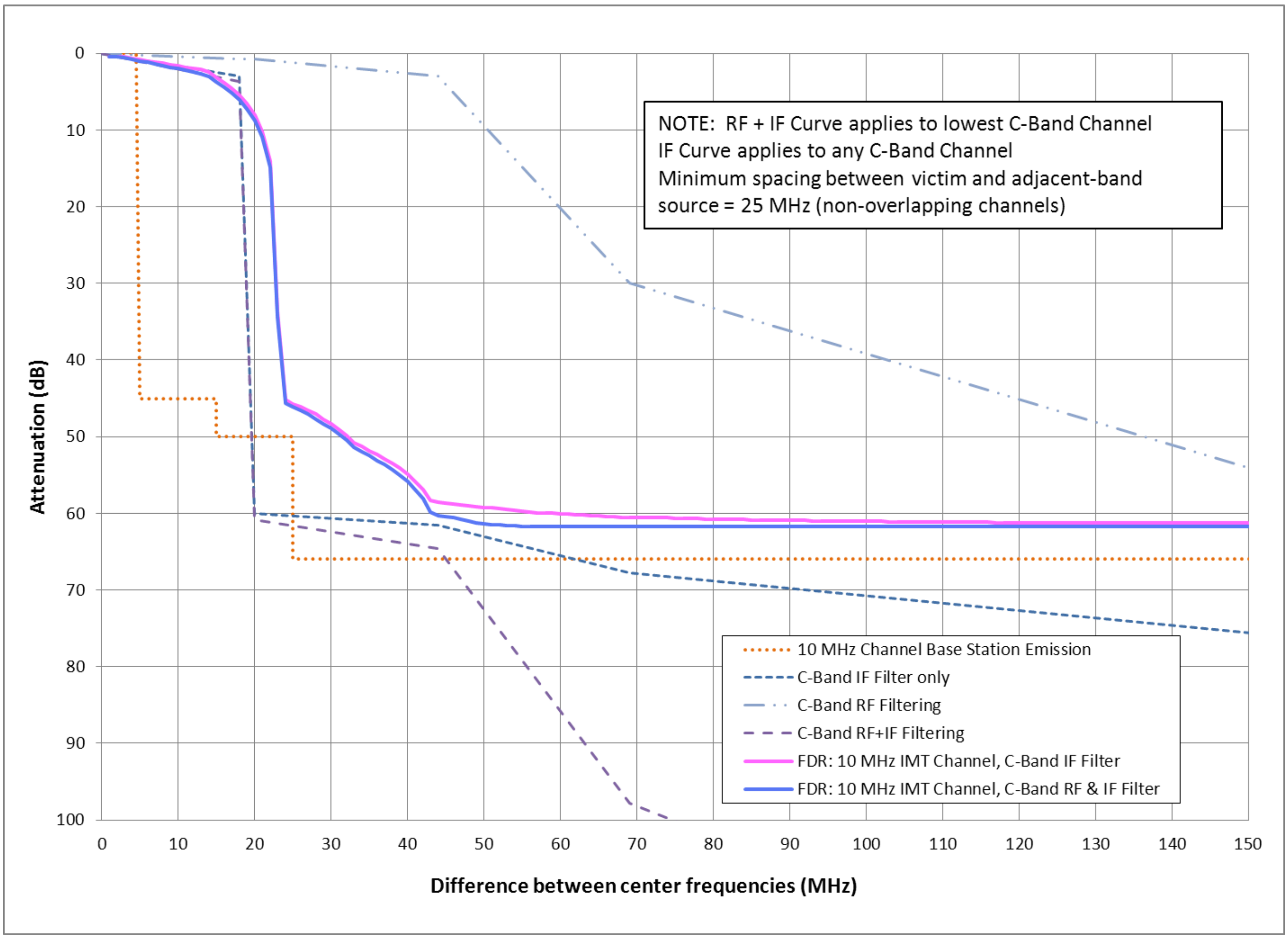
Frequency-dependent rejection (FDR) is used in the computation of received interference levels. More information on FDR can be obtained from Recommendation ITU-R SM.337-6 (current version).

IMT-A transmitter emissions were modelled using the ACLR specification documented in Report ITU-R M.2109. The FSS earth station receiver intermediate frequency (IF) selectivity characteristic was assumed.

The calculated FDR curves that were used in this analysis are shown in Fig. A4-3.

FIGURE A4-3

Input data and mutual coupling results



4.2.2 Interference criteria

The analysis used ITU-R-defined protection criteria as specified in Recommendations ITU-R S.1432 and ITU-R SF.1006.

4.2.3 Apportionment of interference

The apportionment was assumed for this study that 50% of the interference to the FSS earth station receiver was allocated to IMT-A systems for which the long-term interference criteria applied. For the cases in which the short-term interference criteria were applicable, and also the large-signal analysis, 100% of the interference was allocated to IMT-A systems.

4.3 Calculations

4.3.1 Small signal analysis (in-band and out-of-band emissions)

For the single-entry analysis, a single IMT-A base station was placed along a path relative to the earth station location, aligned with the antenna azimuth. For the adjacent-band cases, it was assumed that the IMT-A base station was tuned to the closest adjacent-band channel to the lowest FSS earth station receiver channel. For the in-band cases, it was assumed that the IMT-A base station was co-channel with the FSS earth station receiver. The IMT-A base station was moved along this path and a protection distance was determined based on the separation distance necessary to reduce the interference level below the interference threshold.

For the aggregate analysis, the frequency for each IMT-A base station was randomly selected for each model iteration from the available pool of frequencies. For the three-sector base stations, each sector was assigned a random channel. The model incrementally increases the protection distance relative to the FSS earth station receiver and calculates the received aggregate interference power. IMT-A base stations are shut off within this protection distance. For the minimum protection distance, if the calculated aggregate interference at a FSS earth station receiver remained below the interference threshold for a minimum of 100 model iterations, this result was reported. For each deployment scenario, the base stations were spaced in a grid with the FSS earth station receiver in the centre. The aggregate scenario includes the single-entry base station. It is positioned at the inner radius of the grid scenario and along the azimuth axis of the earth station antenna. The IMT-A system bandwidth was assumed to be 10 MHz, so the channels were spaced at 10-MHz intervals. IMT-A base stations were modelled using three-sector or omnidirectional antennas, depending on the type of scenario.

4.3.1.1 Outdoor deployments

For the outdoor deployments, both macro and small cell IMT-A base station scenarios were analysed. Each simulation was performed for FSS earth station antenna elevation angles of 5°, 10°, 20°, and 30°.

An adjacent-band aggregate analysis was also performed to investigate the use of a guard band adjacent to the 3 400-4 200 MHz band. The guard band was made up of the difference in frequency between the high frequency channel edge of the adjacent-band base stations tuned closest to the FSS earth station receiver channel and the low frequency channel edge of the FSS earth station receiver. The size of guard band was varied parametrically and protection distances were determined.

4.3.1.2 Indoor deployments

For the indoor deployment portion of the analysis, only small cell IMT base stations were considered. Simulations were performed for FSS earth station elevation angles of 5° and 30°. Scenarios were examined using building attenuation values equal to 5, 10, 15, and 20 dB.

The indoor deployments were analysed for in-band and adjacent band both for single-entry (long-term and short-term interference) and aggregate (long-term interference only).

4.3.2 Large Signal Analysis (LNB Overdrive, and Intermodulation)

Large-signal interactions were also analysed. These interactions include gain compression and receiver intermodulation (IM). FSS earth station systems with and without RF filters were considered. For interfering signals in the adjacent frequency band, RF filter attenuation will reduce the potential for degradation. No IF attenuation was considered for this analysis because gain compression and IM products occur prior to the IF filtering.

Distances to mitigate potential gain compression were determined. This is referred to as LNB overdrive. These calculations were performed using the Recommendation ITU-R P.452-14 propagation model.

Intermodulation interference effect on the earth station LNA/LNB from IMT operation was also analysed. For the LNB under analysis, the onset of IM occurs at 10 dB below the gain compression level of 2 dBm, or –8 dBm at the LNB output. The onset of IM at the input of the LNB was determined by subtracting the LNB gain of 63 dB from the –8 dBm output level resulting in –71 dBm at the LNB input.

IM was analysed based on the third-order intercept point, and the fact that the input/output response slope for the desired RF input is 1, while the slope for 3rd order IM is 3. The onset of IM translated to the 3rd order results in an IM threshold at the LNB input of –55.7 dBm.

4.4 Results

4.4.1 Small signal results (in-band and out-of-band emissions)

4.4.1.1 Outdoor deployments

Results for the in-band, long-term interference threshold case with IF filtering only are presented in Table A4-1.

TABLE A4-1

In-band, long-term interference threshold protection distances from IMT-Advanced base stations to FSS earth stations, with IF filtering only

Receiver antenna elevation angle, degrees	Single-entry protection distance, on azimuth, km	Aggregate protection distance, km
Macro Cell Suburban		
5	58.1	63.0
10	50.5	55.0
20	45.7	53.0
30	44.6	52.0
Macro Cell Urban		
5	51.2	53.0
10	45.2	48.0
20	40.0	45.0
30	35.7	44.0
Small Cell Urban		
5	20.3	20.3
10	9.0	10.0
20	8.3	9.0
30	6.2	9.0

Results for the adjacent-band, long-term interference threshold case with IF filtering only are presented in Table A4-2.

TABLE A4-2

Adjacent-band, long-term interference threshold protection distances from IMT-Advanced base stations to FSS earth stations, with IF filtering only

Receiver antenna elevation angle, degrees	Single-entry protection distance, on azimuth, km	Aggregate protection distance, km
Macro cell suburban		
5	13.8	19.0
10	9.4	18.0
20	8.7	17.0
30	8.2	17.0
Macro cell urban		
5	9.3	12.0
10	8.5	10.0
20	6.4	9.0
30	5.1	9.0
Small cell urban		
5	3.8	3.8
10	2.8	2.8
20	1.5	1.5
30	0.90	0.90

Results for the adjacent-band, long-term interference threshold case with IF and RF filtering are presented in Table A4-3.

TABLE A4-3

Adjacent-band, long-term interference threshold protection distances from IMT-Advanced base stations to FSS earth stations, with IF and RF filtering

Receiver antenna elevation angle, degrees	Single-entry protection distance, on azimuth, km	Aggregate protection distance, km
Macro cell suburban		
5	13.4	18.0
10	9.4	17.0
20	8.6	17.0
30	8.2	15.0
Macro cell urban		
5	9.3	12.0
10	8.4	10.0
20	6.4	9.0
30	5.0	9.0
Small cell urban		
5	3.8	3.8
10	2.8	2.8
20	1.4	1.4
30	0.90	0.90

The results can be seen to be comparable to those presented in Table A4-2. This is due to the similarity of the FDR curves in these two cases.

Results for the in-band, short-term interference threshold case with IF filtering only are presented in Table A4-4.

TABLE A4-4

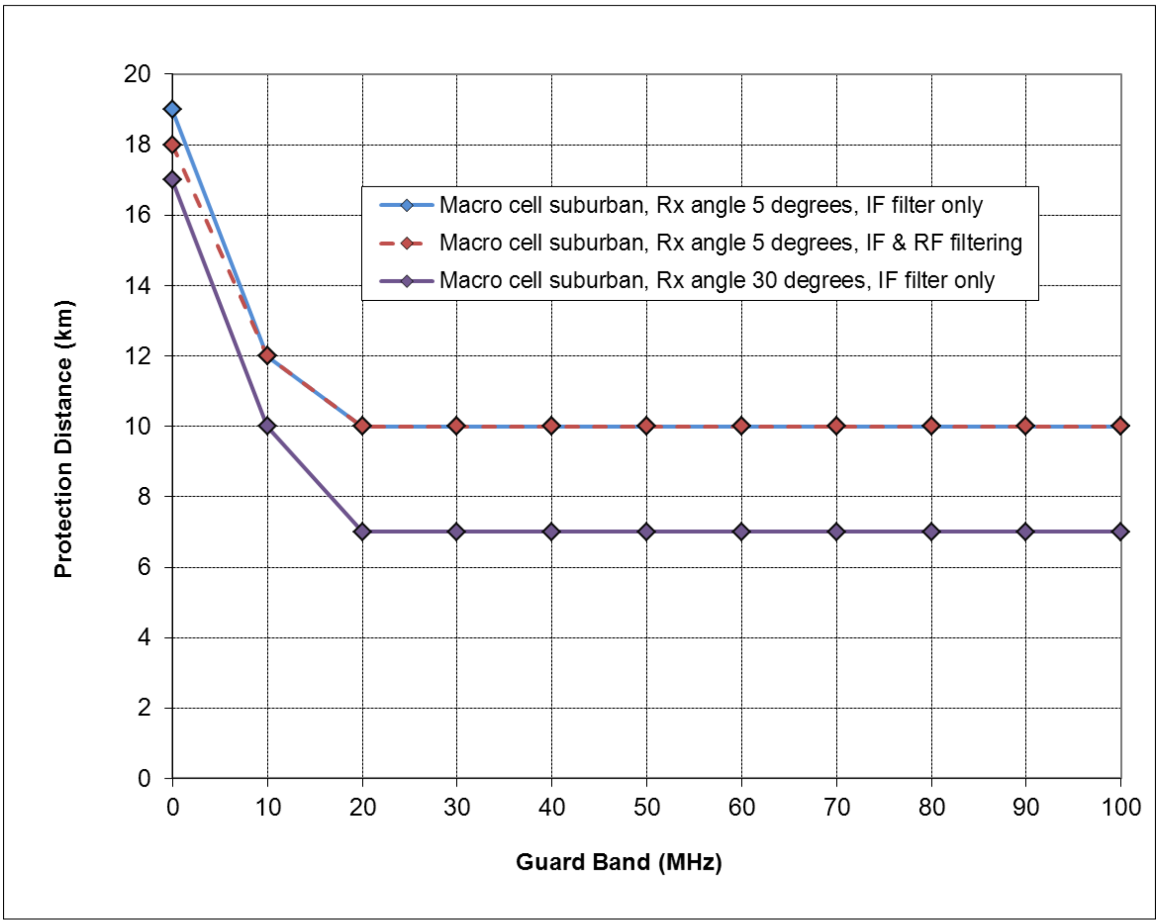
In-band, short-term interference threshold protection distances from IMT-Advanced base stations to FSS earth stations, with IF filtering only

Receiver antenna elevation angle, degrees	Single-entry protection distance, on Azimuth, km
Macro cell suburban	
5	525
10	498
20	393
30	312
Macro cell urban	
5	477
10	393
20	311
30	262
Small cell urban	
5	225
10	119
20	54.1
30	5.1

Results for the guard band aggregate analysis performed to investigate the use of a guard band adjacent to the 3 400-4 200 MHz band are presented in Fig. A4-4. The results show the required protection distance as the guard band size is increased. The guard band size was increased by parametrically eliminating the base station 10 MHz transmit channels closest to the earth station receive channel. There is an initial decrease in the required separation distance as the guard band increases from 0 to 10 MHz, however, as the guard band increases to 20 MHz and beyond, the separation distance does not continue to decrease. The reason for this plateau in the required protection distance from 20 MHz and beyond is due to the fact that the ACLR emissions specification does not continue to “roll-off” with additional frequency separation. It can be concluded from Fig. A4-4 that increasing the size of the guard band beyond 20 MHz has no effect on reducing the separation distance required to protect the FSS receiving earth station, i.e. for example if the guard band were to increase from 20 to 100 MHz, the same separation distance would still be required to ensure protect the FSS receiving earth station from harmful interference from IMT-A systems.

FIGURE A4-4

Aggregate protection distance versus guard band size



4.4.1.2 Indoor deployments

Small cell urban indoor deployment results for the in-band, long-term interference threshold case with IF filtering only are presented in Table A4-5.

TABLE A4-5

Small cell indoor urban in-band, long-term interference threshold protection distances from IMT-Advanced base stations to FSS earth stations, with IF filtering only

Receiver antenna elevation angle, degrees	Building attenuation, dB	Single-entry protection distance, on Azimuth, km	Aggregate protection distance, km
5	5	8.4	8.4
30		3.9	4.0
5	10	8.1	8.1
30		3.8	3.8
5	15	4.2	4.2
30		3.0	3.0
5	20	4.1	4.1
30		1.5	1.5

Small cell urban indoor deployment results for the adjacent-band, long-term interference threshold case with IF filtering only are presented in Table A4-6.

TABLE A4-6

Small cell indoor urban adjacent-band, long-term interference threshold protection distances from IMT-Advanced base stations to FSS earth stations, with IF filtering only

Receiver antenna elevation angle, degrees	Building attenuation, dB	Single-entry protection distance, on Azimuth, km	Aggregate protection distance, km
5	5	1.5	1.5
30		0.4	0.4
5	10	1.4	1.4
30		0.2	0.2
5	15	1.1	1.1
30		0.2	0.2
5	20	0.5	0.5
30		< 0.1	< 0.1

Small cell urban indoor deployment results for the in-band, short-term interference threshold case with IF filtering only are presented in Table A4-7.

TABLE A4-7

Small cell indoor urban in-band, short-term interference threshold protection distances from IMT-Advanced base stations to FSS earth stations, with IF filtering only

Receiver antenna elevation angle, degrees	Building attenuation, dB	Single-entry protection distance, on Azimuth, km
5	5	8.3
30		3.7
5	10	4.2
30		1.5
5	15	4.0
30		1.4
5	20	3.8
30		1

4.4.2 Large signal results (LNB overdrive, and intermodulation)

Table A4-8 presents the results for gain compression and onset of non-linear interactions for co-channel interference.

TABLE A4-8

Large-signal protection distances for FSS earth station without RF filtering

E/S Antenna		Gain compression computation (LNA Input Threshold = -61 dBm)
Off-Axis Angle, degrees	**Gain, dBi**	**Required distance to mitigate, km***
Macro cell suburban		
5	14.5	9.0
10	7.0	8.3
20	–0.5	6.2
30	–4.9	4.8
Macro cell urban		
5	14.5	8.7
10	7.0	7.9
20	–0.5	4.9
30	–4.9	4.4
Small cell urban		
5	14.5	1.1
10	7.0	0.5
20	–0.5	0.2
30	–4.9	0.1

* For distances less than 1 km, free-space propagation loss was used.

Table A4-9 presents the results for FSS earth systems with RF filtering and assuming immediately adjacent-channel interference (0 MHz separation between edges of channels).

TABLE A4-9

Large-signal protection distances for FSS earth stations, with RF filtering

E/S Antenna		Gain compression computation (LNA Input Threshold = –61 dBm)
Off-Axis Angle, degrees	**Antenna gain, dBi**	**Required distance to mitigate, km***
Macro cell suburban		
5	14.5	8.8
10	7.0	8.1
20	–0.5	5.1
30	–4.9	4.1
Macro cell urban		
5	14.5	8.5
10	7.0	6.4
20	–0.5	4.8
30	–4.9	4.1
Small cell urban		
5	14.5	0.9
10	7.0	0.4
20	–0.5	0.2
30	–4.9	0.1

* For distances less than 1 km, free-space propagation loss was used.

Tables A4-10 and A4-11 present the results for the IM protection distances required. It is assumed that the IM source signals are not co-channel with the desired signal, but operating within the pass-band of the LNB.

TABLE A4-10

Intermodulation protection distances for FSS earth stations, without RF filtering

Earth station system		**IM protection zone (LNA Input Threshold = –55.7 dBm)**
Off-Axis Angle, degrees	**Antenna gain, dBi**	**Required distance to mitigate, km***
Macro cell suburban		
5	14.5	8.5
10	7.0	6.4
20	–0.5	4.3
30	–4.9	2.6
Macro cell urban		
5	14.5	8.0
10	7.0	5.8
20	–0.5	4.3
30	–4.9	2.6
Small cell urban		
5	14.5	0.6
10	7.0	0.2
20	–0.5	0.1
30	–4.9	0.1

* For distances less than 1 km, free-space propagation loss was used.

TABLE A4-11

Intermodulation protection distances for FSS earth stations, with RF filtering

earth station system (1.4 dB RF filter attenuation)		**IM protection zone (LNA Input Threshold = –55.7 dBm)**
Off-Axis Angle, degrees	**Antenna gain, dBi**	**Required distance to mitigate, km***
Macro cell suburban		
5	14.5	8.4
10	7.0	6.3
20	-0.5	3.7
30	–4.9	2.2
Macro cell urban		
5	14.5	7.9
10	7.0	5
20	–0.5	3.6
30	–4.9	2.2
Small cell urban		
5	14.5	0.5
10	7.0	0.2
20	–0.5	0.1
30	–4.9	0.1

* For distances less than 1 km, free-space propagation loss was used.

5 Summary

This sharing study determined the protection distances that are required to prevent interference from IMT-A devices and ensure compliance with the requisite protection criteria at FSS space-to-Earth downlink receivers operating in the 3 700-4 200 MHz band. The range of required protection distances provided in this summary section is dependent on the FSS earth station receiver elevation angle.

In order to mitigate long term interference:

The required protection distance for IMT-A operating in-band with the FSS earth stations for both the single entry case and aggregate case, were found to be at least tens of kilometres for the macro cell cases considered in this study. The required protection distance for the small cell urban outdoor deployment in-band cases ranged from several kilometres to over twenty kilometres. Depending on the amount of building attenuation assumed, the required protection distance for the small cell urban indoor deployment in-band cases ranged from over one kilometre to over several kilometres. Similarly, the required protection distance for IMT-A operating in the band adjacent to the FSS earth stations for both the single entry case and aggregate case, were found to be at least several kilometres for the macro cell cases considered in this study. The required protection distance for the small cell urban outdoor deployment adjacent band cases ranged from approximately one kilometre to over several kilometres. Depending on the amount of building attenuation assumed, the required protection distance for the small cell urban indoor deployment adjacent-band cases ranged from less than one hundred metres to several kilometres.

Moreover, since the required protection distance for IMT-A operating in the band adjacent to the FSS earth stations with RF filters were found to be in the same order of magnitude of those without RF filters, it can be concluded that RF filters would not have an appreciable effect in mitigating interference received from IMT-Advanced systems into FSS receiver earth stations.

In order to mitigate short term interference:

The required protection distance for IMT-A operating in-band with the FSS earth stations for both the single entry case and aggregate case, were found to be at least several hundred kilometres for the macro cell cases considered in this study. The required protection distance for the small cell urban outdoor deployment in-band cases ranged from several kilometres to several hundred kilometres. Depending on the amount of building attenuation assumed, the required protection distance for the small cell urban indoor deployment in-band cases ranged from one kilometre to over several kilometres.

6 Conclusions

The results of the study showed that the required protection distances were dependent on the type of base station scenario with the macro cell cases requiring the largest exclusion zones.

For the in-band case, the required protection distance for a macro cell deployment regardless of environment (i.e. in both a suburban and urban environment) was found to be several hundred kilometres. The required protection distance for an outdoor small cell deployment in an urban environment ranges were found to be several kilometres and extend up to hundreds of kilometres. The required protection distance for an indoor small cell deployment was not as extensive due to the fact that some degree of building attenuation was assumed. However, the required protection distance was found to be more than several kilometres in cases where an indoor small cell might be operating close to a window where building attenuation is significantly reduced.

For the adjacent band case, the deployment of IMT-A systems will create unacceptable restrictions to avoid RF interference or large-signal interactions with FSS earth stations for macro cell base station scenarios. For the small cell scenario, the size of the exclusion zones was smaller due to the fact that they have been specified to be installed lower to the ground and limited in transmit power. However, the required protection distances would still prevent small cell urban deployments over a protection area centred about a FSS earth station receiver ranging from 2.5 to over 45 square kilometres –a result which makes sharing not feasible. The protection distance required to avoid RF interference to FSS earth stations from small cell indoor deployments was found to range from one kilometre to several kilometres, even with up to 15 dB of building attenuation assumed, for the lower receiver elevation angles.

The results show that an IMT implementation of any deployment scenario sterilizes large geographical areas preventing future deployment of satellite earth stations, e.g. VSATs.

The results also show that the use of a common representative front-end RF filter provides an insignificant decrease in the required separation distance. Moreover, inclusion of an RF filter provides little additional rejection over what is already provided by the IF selectivity of the tuner.

The conclusion of this study is that sharing the band from 3 400-4 200 MHz is not feasible due to the size of the needed exclusion zones, up to an area of over 865 000 square km, and the large number of FSS earth stations that would need to be protected. Prior ITU studies, as are summarized in Report ITU-R M.2109, drew the same conclusions.

Annex 5

Study #5

1 Introduction

This study provides in-band and adjacent band compatibility studies between IMT-Advanced systems and FSS receive earth stations operating in the 3 400-4 200 MHz and 4 500-4 800 MHz bands. The analysis is based on the latest IMT-Advanced and FSS parameters as provided (and referenced in Tables A5-1 and A5-2 of this Annex), and provides an assessment of the impact of IMT-Advanced system transmissions into the receiving systems of the FSS under agenda item 1.1.

2 FSS earth stations parameters

The parameters listed below have been used in assessing the interference into FSS receive earth stations for the purpose of the studies in this Annex. These values have been extracted from Report ITU-R M.2109 (and also contained in §§ 2 and 5 of this Report) and typical downlink parameters for FSS earth stations.

TABLE A5-1

Downlink FSS earth station parameters

Parameter	Value
Range of operating frequencies	3 400-4 200 MHz, 4 500-4 800 MHz
FSS earth station sample location	Orlando, Florida
Satellite Orbital location	155.24° W, 127.87° W
FSS earth station Elevation Angle	5°, 30°
FSS Antenna reference pattern	Recommendation ITU-R S.465 (up to 85°)
Range of emission bandwidths	40 kHz – 72 MHz
FSS Receiving system noise temperature	100 K
FSS earth station antenna diameter	2.4 m
FSS earth station antenna height	3 m (rural deployment case), 30 m (urban deployment case)
FSS earth station receiver filter	Assumed to be ideal
earth station deployment	All regions, in all locations (rural, semi-urban, urban)[1]

[1] FSS antennas in this band may be deployed in a variety of environments. Smaller antennas (1.8 - 3.8 metres) 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.

3 FSS parameters and interference criteria

Both long term and short term interference criteria are considered when assessing the interference from IMT-Advanced systems into FSS receiver earth stations.

For long-term interference, two cases can be considered depending on the type of the scenarios studied based on Recommendation ITU-R S.1432:

– 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;

– 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.

For short-term interference, Recommendation ITU-R SF.1006 is used. This criterion also appears in Annex 7 (see both text and Table 8b) of RR Appendix **7**:

0 $I/N = -1.3$ dB which may be exceed by up to 0.001667% time (single entry)

Apportionment of interference allowance

In the absence of specific ITU-R recommendations on how to apportion these allowances among the competing potential sources of interference, ITU-R recommended that the long-term interference from any individual secondary or unallocated service as well as interference into adjacent frequency bands (unwanted emissions) should be limited to half of the total noise interference allowance into an FSS link, and from any individual primary service it should be limited to half of the afore mentioned values of 6% or 10% of the total noise, as appropriate.

This 50% apportionment of interference is applicable to the case where two other allocated services (e.g. fixed and mobile) are contributing the same level of interference in the same geographical area and this results in a reduction of 3 dB in the I/N values.

4 IMT Advanced systems parameters

Table A5-2 contains the IMT-Advanced systems parameters, extracted from Table D of Report ITU-R M.2292. The scenario for small cell base station indoor was not studied.

TABLE A5-2

Technical and operational characteristics of IMT- Advanced base stations

IMT-Advanced base station type	**Macro cell base station suburban**	**Macro cell base station urban**	**Small cell base station outdoor**
Antenna height	25 m	20 m	6 m
Maximum base station antenna gain	18 dBi	18 dBi	5 dBi
Sectorization	3-sectors	3-sectors	single sector
Downtilt	6 degrees	10 degrees	N/A
Antenna pattern	Recommendation ITU-R F.1336 (*recommends* 3.1) k_a = 0.7 k_p = 0.7 k_h = 0.7 k_v = 0.3 Horizontal 3 dB beamwidth: 65 degrees Vertical 3 dB beamwidth: determined from the horizontal beamwidth by equations in Recommendation ITU-R F.1336. Vertical beamwidths of actual antennas may also be used when available.		Recommendation ITU-R F.1336 omni
Building penetration loss	0 dB	0 dB	0 dB
Base station bandwidth	10 MHz	10 MHz	10 MHz
Maximum base station output power	46 dBm	46 dBm	24 dBm
Feeder Loss	3 dB	3 dB	N/A
Maximum base station output power (e.i.r.p.)	61 dBm	61 dBm	29 dBm
Adjacent-Channel Leakage Power Ratio (ACLR)	3GPP Document TS 36.104 v.11.2.0, § 6.6.2.	3GPP Document TS 36.104 v.11.2.0, § 6.6.2.	3GPP Document TS 36.104 v.11.2.0, § 6.6.2.

5 Methodology for sharing studies

For the purpose of this compatibility study, the macro suburban, macro urban, and small cell outdoor, for the single entry case, were modelled in Visualyse[13] using the parameters for the FSS receive earth stations and the IMT-Advanced base station from §§ 2 and 4 respectively. In all cases, the IMT-Advanced base station antenna was assumed to be pointed towards the FSS receiving earth station and down-tilted below the horizon by the amount specified in Table A5-2. Terrain information was

[13] Visualyse Professional Version 7.710 (Transfinite Systems Ltd).

taken into account and an example location was considered with an FSS earth station location in Orlando, Florida corresponding to a flat terrain profile.

For both the macro suburban and macro urban deployment the effect of clutter was considered with the following characteristics in accordance with Recommendation ITU-R P.452[14].

– for the suburban deployment case, a nominal clutter distance of 25 m and a nominal clutter height of 9 m were used;

– for the urban deployment case, a nominal clutter distance of 20 m and a nominal clutter height of 20 m were used

For the small cell outdoor scenario, the Shuttle Radar Topography Mission (SRTM) database was used, which includes in addition to terrain information, building or vegetation heights. The SRTM is a surface database taken by radar measurements from a Space Shuttle mission and contains measurements of where the radar waves are reflected off the surface of the earth.

The simulation was performed with two elevation angles for the FSS earth station: 5 degrees and 30 degrees.

Through the "Area Analysis" tool in Visualyse, the location of the IMT-Advanced base station was placed within a pre-defined area around the FSS receive earth station. At each point, the elevation angle (at the IMT-Advanced base station antenna's boresight height) towards the FSS earth station was determined, from which the off-axis angle of the IMT-Advanced base station antenna, relative to its maximum gain lobe, was determined. The e.i.r.p. level of the IMT-Advanced base station towards the earth station was then calculated using the aforementioned off-axis gain of the IMT-Advanced base station antenna. Taking into account the propagation loss between the IMT-Advanced base station and FSS earth station, the I/N level at the FSS earth station location was computed. Contour lines were then drawn through those (IMT-Advanced base station) points/locations where the computed I/N value at the FSS earth station was the minimum required level. Accordingly, an IMT-Advanced base station operating in accordance with the parameters specified in Table A5-2 (as appropriate for the specific scenario under consideration) at any point within the bounded contour area would result in an I/N level at the FSS earth station that did not meet the minimum required level.

6 Sharing study results

For each elevation angle (5° and 30°) of the FSS receiving earth station, the following cases were examined:

– a macro suburban scenario;

– a macro urban scenario;

– a suburban small cell outdoor scenario.

The results of the study are provided in Figs. A5-2 through A5-19 of Appendix A and the following observations can be made:

a) For the case of an IMT-Advanced macro cell base station deployed in a suburban environment

[14] A brief description of the various propagation modes that are considered in Recommendation ITU-R P.452 for the determination of short-term and long-term propagation losses is provided in the appendix to this document.

In order to mitigate long term interference and ensure that the FSS receiving earth station is not subjected to excessive levels of in-band interference from the transmitting IMT-Advanced base station:

– a distance separation of 57.1 to 87.1 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 5 degrees;

– a distance separation of 51.8 to 58.6 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 30 degrees.

In order to mitigate short term interference and ensure that the FSS receiving earth station is not subjected to excessive levels of in-band interference from the transmitting IMT-Advanced base station:

– a distance separation of 312.2 to 487.6 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 5 degrees;

– a distance separation of 312.2 to 368.3 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 30 degrees.

Similarly, in order to ensure that the FSS receiving earth station is not subjected to excessive levels of out-of-band emissions from the transmitting IMT-Advanced base station:

– a distance separation of 13.6 to 33.6 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 5 degrees;

– a distance separation of 13.6 to 16.5 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 30 degrees.

b) For the case of an IMT-Advanced macro cell base station deployed in an urban environment

In order to mitigate long term interference and ensure that the FSS receiving earth station is not subjected to excessive levels of in-band interference from the transmitting IMT-Advanced base station:

– a distance separation of 45.5 to 93.0 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 5 degrees;

– a distance separation of 45.4 to 52.9 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 30 degrees.

In order to mitigate short term interference and ensure that the FSS receiving earth station is not subjected to excessive levels of in-band interference from the transmitting IMT-Advanced base station:

– a distance separation of 266.4 to 467.3 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 5 degrees;

– a distance separation of 266.4 to 318.9 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 30 degrees.

Similarly, in order to ensure that the FSS receiving earth station is not subjected to excessive levels of out-of-band emissions from the transmitting IMT-Advanced base station:

– a distance separation of 11.0 to 40.2 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 5 degrees;

– a distance separation of 10.9 to 20.0 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 30 degrees.

c) For the case of an IMT-Advanced small cell outdoor base station deployed in Orlando, Florida

In order to mitigate long term interference and ensure that the FSS receiving earth station is not subjected to excessive levels of in-band interference from the transmitting IMT-Advanced base station:

– a distance separation of 4.9 to 35.1 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 5 degrees;

– a distance separation of 3.4 to 15.8 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 30 degrees.

In order to mitigate short term interference and ensure that the FSS receiving earth station is not subjected to excessive levels of in-band interference from the transmitting IMT-Advanced base station:

– a distance separation of up to 262.7 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 5 degrees;

– a distance separation of up to 72.7 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 30 degrees.

Similarly, in order to ensure that the FSS receiving earth station is not subjected to excessive levels of out-of-band emissions from the transmitting IMT-Advanced base station:

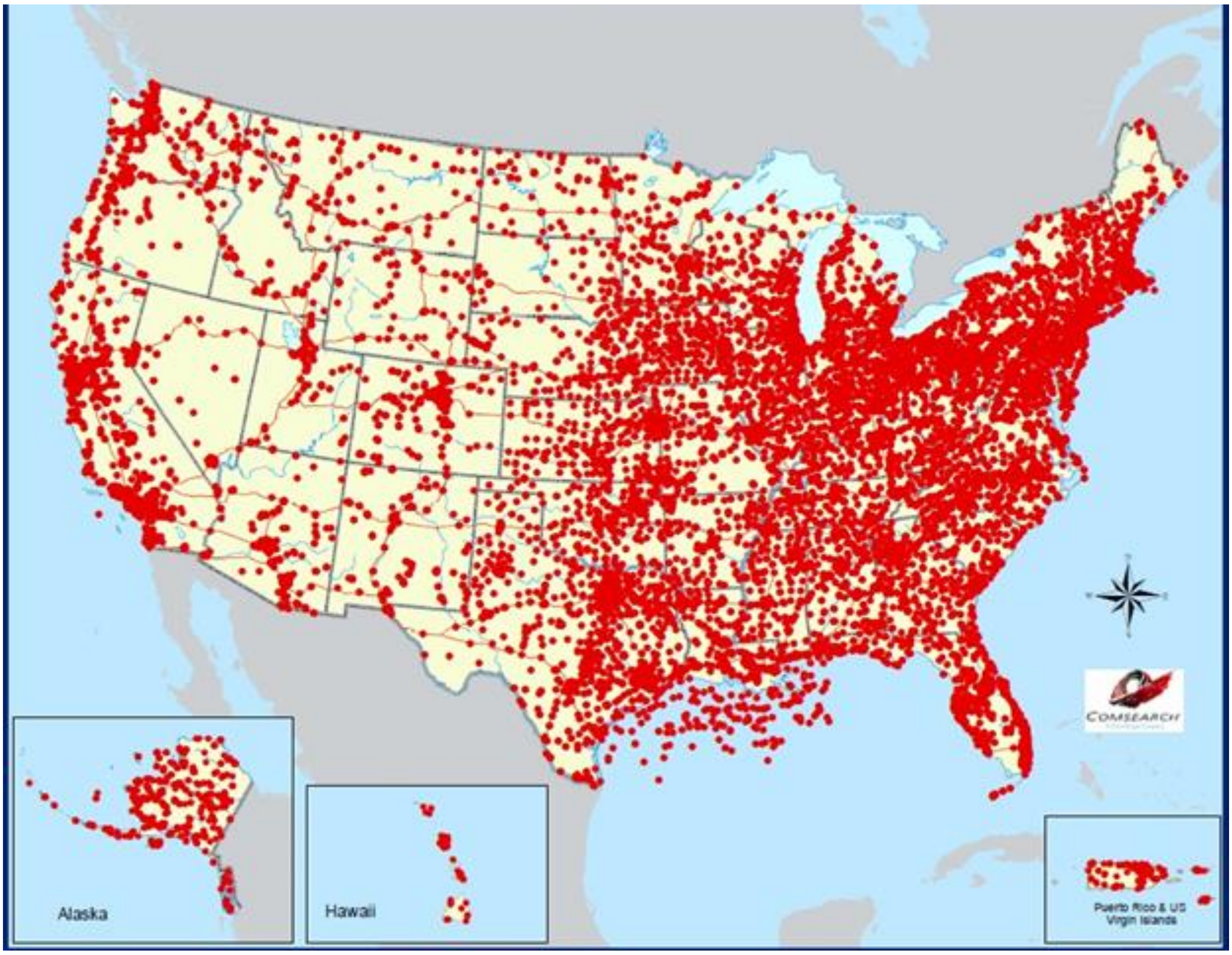
– a distance separation of up to 4.7 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 5 degrees;

– a distance separation of up to 1.8 kilometres, depending on direction, should be maintained between the transmitting IMT-Advanced base station and the receiving FSS earth station operating at an elevation angle of 30 degrees.

7 FSS Deployment in the US

FIGURE A5-1

C-Band Earth Stations – March 2013



The Figure above depicts the FSS earth stations in the USA in the 3 400-4 200 MHz and 4 500-4 800 MHz bands. These FSS earth stations are primarily deployed in the 3 700-4 200 MHz frequency range.

8 Conclusion

Sharing studies have been performed to assess the technical feasibility of deploying IMT-Advanced systems using the characteristics in Tables 1-5 of this Report. To provide protection of the FSS receive earth stations operating in the 3 400-4 200 MHz and 4 500-4 800 MHz bands, required separation distances were derived relative to the IMT-Advanced base station location. As can be seen from the results found in § 6, the magnitude of those required separation distances to protect the FSS receive earth stations depend on the topography, parameters of the networks and the deployment of the two services. The results found in this study show that:

– for in-band, co-channel operations, the minimum separation distances associated with long-term interference criterion have been found to be at least several kilometres for the small cell outdoor scenario and at least in the tens of kilometres for the macro cell scenario. The minimum separation distances associated with short term interference criterion have been found to be at least tens of kilometres and extend up to several hundred kilometres in the considered cases with similar assumptions as the ones used for the long term;

– for adjacent-band operations, in order to ensure that the FSS receiving earth station is not subjected to excessive levels of out-of-band emissions from the transmitting IMT-Advanced base station, the minimum separation distances have been found to be at least several kilometres for the small cell outdoor scenario and at least in the tens of kilometres for the macro cell scenario.

It may be concluded that macro urban, macro suburban and small cell outdoor IMT deployments in this band would likely face sharing problems for the scenarios studied.

Attachment A
to Annex 5

Contours obtained for the case of an IMT-Advanced macro cell base station deployed in a suburban environment

FIGURE A5-2

Contour in order to mitigate long term interference for the receiving FSS earth station operating at an elevation angle of 5 degrees, showing a distance separation of 57.1 to 87.1 kilometres depending on direction

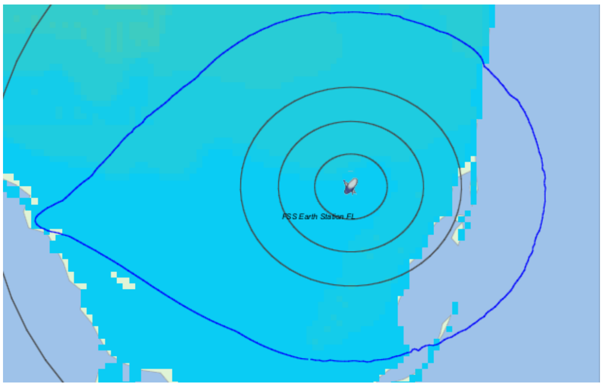


FIGURE A5-3

Contour in order to mitigate long term interference for the receiving FSS earth station operating at an elevation angle of 30 degrees, showing a distance separation of 51.8 to 58.6 kilometres depending on direction

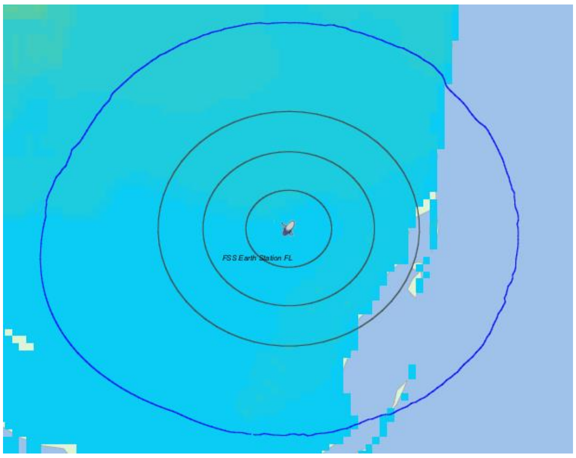


FIGURE A5-4

Contour in order to mitigate short term interference for the receiving FSS earth station operating at an elevation angle of 5 degrees, showing a distance separation of 312.2 to 487.6 kilometres depending on direction

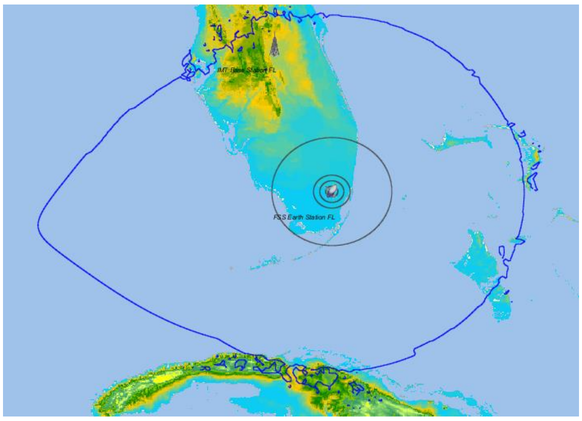


FIGURE A5-5

Contour in order to mitigate short term interference for the receiving FSS earth station operating at an elevation angle of 30 degrees, showing a distance separation of 312.2 to 368.3 kilometres depending on direction

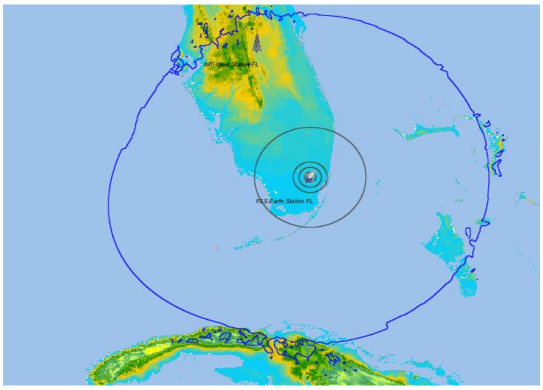


FIGURE A5-6

Contour in order to protect from out-of-band emissions for the receiving FSS earth station operating at an elevation angle of 5 degrees, showing a distance separation of 13.6 to 33.6 kilometres depending on direction

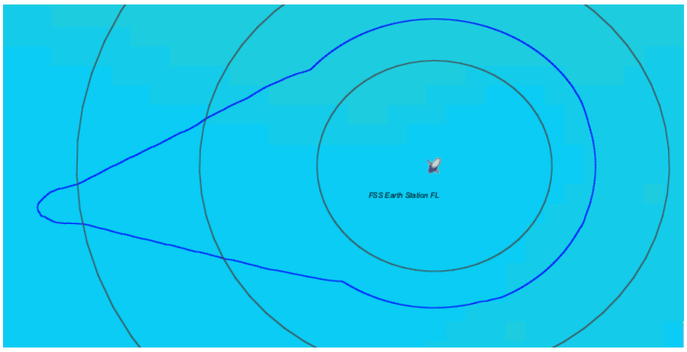
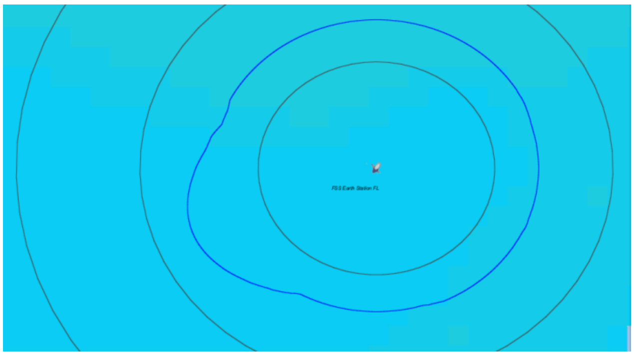


FIGURE A5-7

Contour in order to protect from out-of-band emissions for the receiving FSS earth station operating at an elevation angle of 30 degrees, showing a distance separation of 13.6 to 16.5 kilometres depending on direction



Contours obtained for the case of an IMT-Advanced macro cell base station deployed in an urban environment:

FIGURE A5-8

Contour in order to mitigate long term interference for the receiving FSS earth station operating at an elevation angle of 5 degrees, showing a distance separation of 45.5 to 93.0 kilometres depending on direction

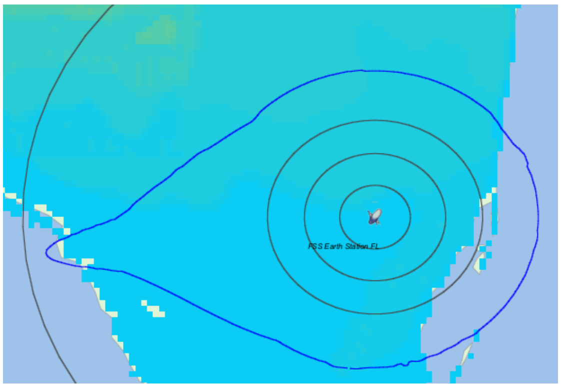


FIGURE A5-9

Contour in order to mitigate long term interference for the receiving FSS earth station operating at an elevation angle of 30 degrees, showing a distance separation of 45.4 to 52.9 kilometres depending on direction

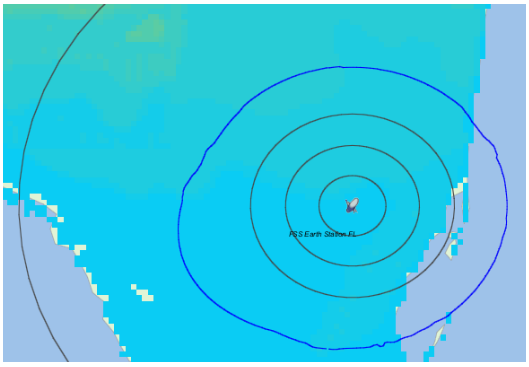


FIGURE A5-10

Contour in order to mitigate short term interference for the receiving FSS earth station operating at an elevation angle of 5 degrees, showing a distance separation of 266.4 to 467.3 kilometres depending on direction

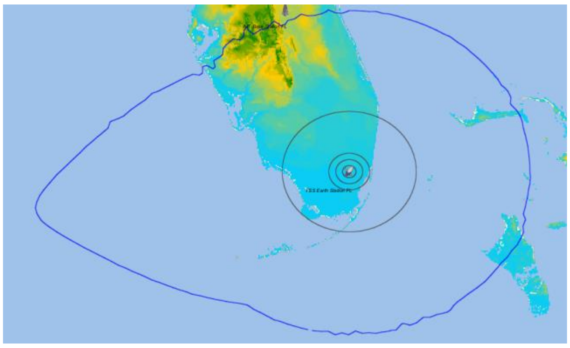


FIGURE A5-11

Contour in order to mitigate short term interference for the receiving FSS earth station operating at an elevation angle of 30 degrees, showing a distance separation of 266.4 to 318.9 kilometres depending on direction

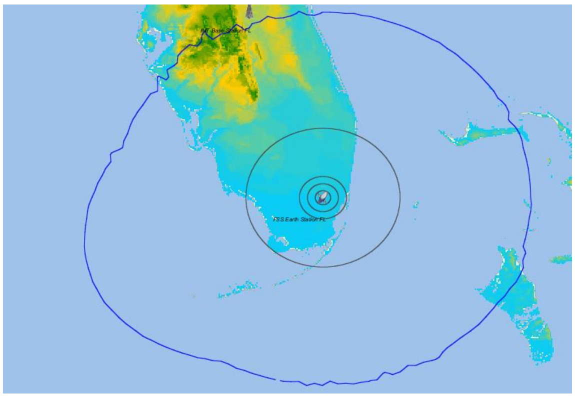


FIGURE A5-12

Contour in order to protect from out-of-band emissions for the receiving FSS earth station operating at an elevation angle of 5 degrees, showing a distance separation of 11.0 to 40.2 kilometres depending on direction

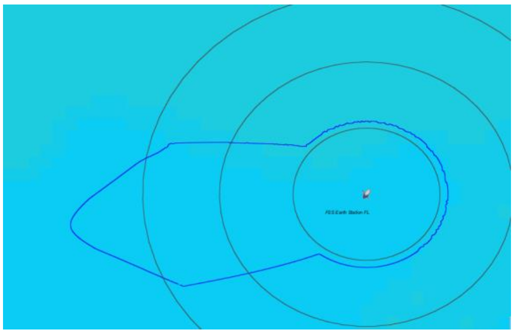
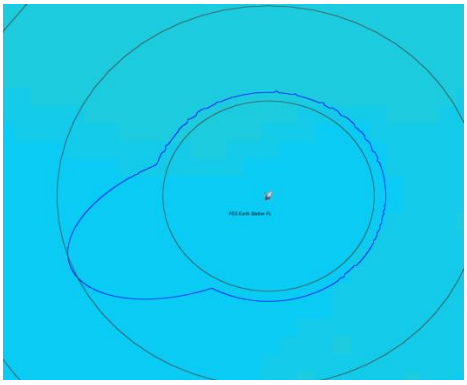


FIGURE A5-13

Contour in order to protect from out-of-band emissions for the receiving FSS earth station operating at an elevation angle of 30 degrees, showing a distance separation of 10.9 to 20.0 kilometres depending on direction



Contours obtained for the case of an IMT-Advanced small cell outdoor base station deployed in Orlando, Florida:

FIGURE A5-14

Contour in order to mitigate long term interference for the receiving FSS earth station operating at an elevation angle of 5 degrees, showing a distance separation of 4.9 to 35.1 kilometres depending on direction

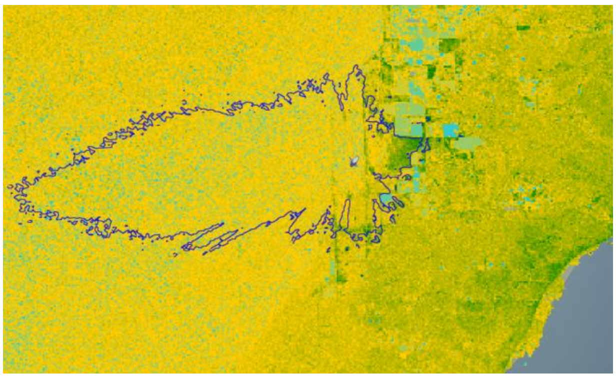


FIGURE A5-15

Contour in order to mitigate long term interference for the receiving FSS earth station operating at an elevation angle of 30 degrees, showing a distance separation of 3.4 to 15.8 kilometres depending on direction

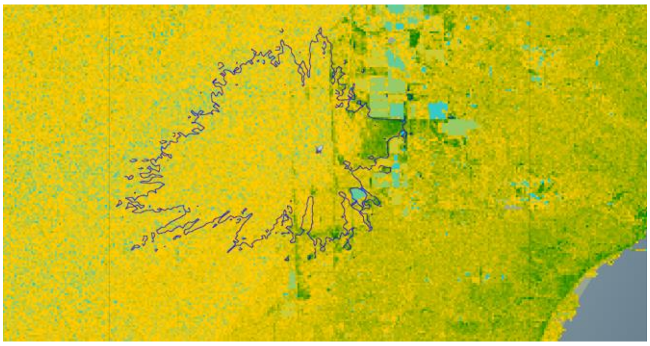


FIGURE A5-16

Contour in order to mitigate short term interference for the receiving FSS earth station operating at an elevation angle of 5 degrees, showing a distance separation of up to 262.7 kilometres depending on direction

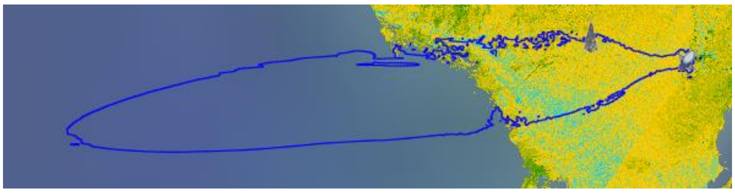


FIGURE A5-17

Contour in order to mitigate short term interference for the receiving FSS earth station operating at an elevation angle of 30 degrees, showing a distance separation of up to 72.7 kilometres, depending on direction

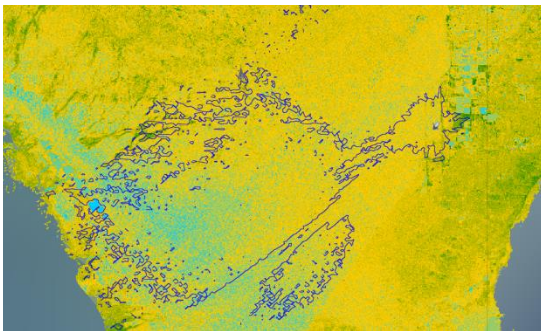


FIGURE A5-18

Contour in order to protect from out-of-band emissions for the receiving FSS earth station operating at an elevation angle of 5 degrees, showing a distance separation of up to 4.7 kilometres depending on direction

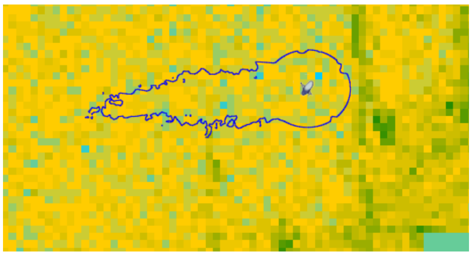
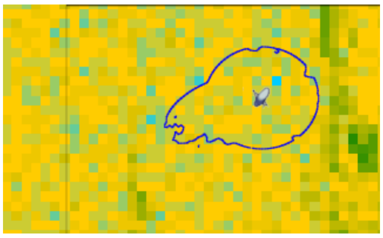


FIGURE A5-19

Contour in order to protect from out-of-band emissions for the receiving FSS earth station operating at an elevation angle of 30 degrees, showing a distance separation of up to 1.8 kilometres depending on direction



Attachment B
to Annex 5

Additional explanatory material from Recommendation ITU-R P.452-14 related to interference propagation mechanisms

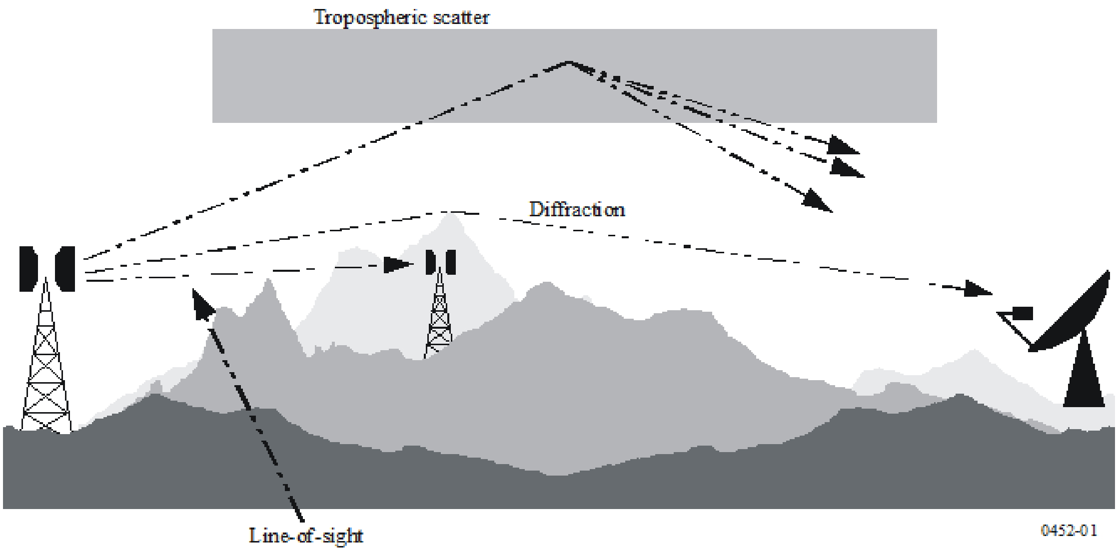
Interference may arise through a range of propagation mechanisms whose individual dominance depends on climate, radio frequency, time percentage of interest, distance and path topography. At any one time a single mechanism or more than one may be present. The principal interference propagation mechanisms are as follows:

Long term interference

In the case of long term interference, the principal interference propagation mechanisms are: line of sight, diffraction and tropospheric scatter. The Figure below depicts the propagation mechanisms that are involved in the long term interference case:

FIGURE A5-20

Long-term interference propagation mechanisms



– *Line-of-sight* (Fig. A5-20): The most straightforward interference propagation situation is when a line-of-sight trans-mission path exists under normal (i.e. well-mixed) atmospheric conditions. However, an additional complexity can come into play when subpath diffraction causes a slight increase in signal level above that normally expected. Also, on all but the shortest paths (i.e. paths longer than about 5 kilometres) signal levels can often be significantly enhanced for short periods of time by multipath and focusing effects resulting from atmospheric stratification (see Fig. A5-21).

– *Diffraction* (Fig. A5-20): Beyond line-of-sight (LoS) and under normal conditions, diffraction effects generally dominate wherever significant signal levels are to be found. For services where anomalous short-term problems are not important, the accuracy to which diffraction can be modelled generally determines the density of systems that can be achieved. The diffraction prediction capability must have sufficient utility to cover smooth-earth, discrete obstacle and irregular (unstructured) terrain situations.

– *Tropospheric scatter* (Fig. A5-20): This mechanism defines the "background" interference level for longer paths (e.g. more than 100-150 km) where the diffraction field becomes very weak. However, except for a few special cases involving sensitive earth stations or very high power interferers (e.g. radar systems), interference via troposcatter will be at too low a level to be significant.

Short term interference

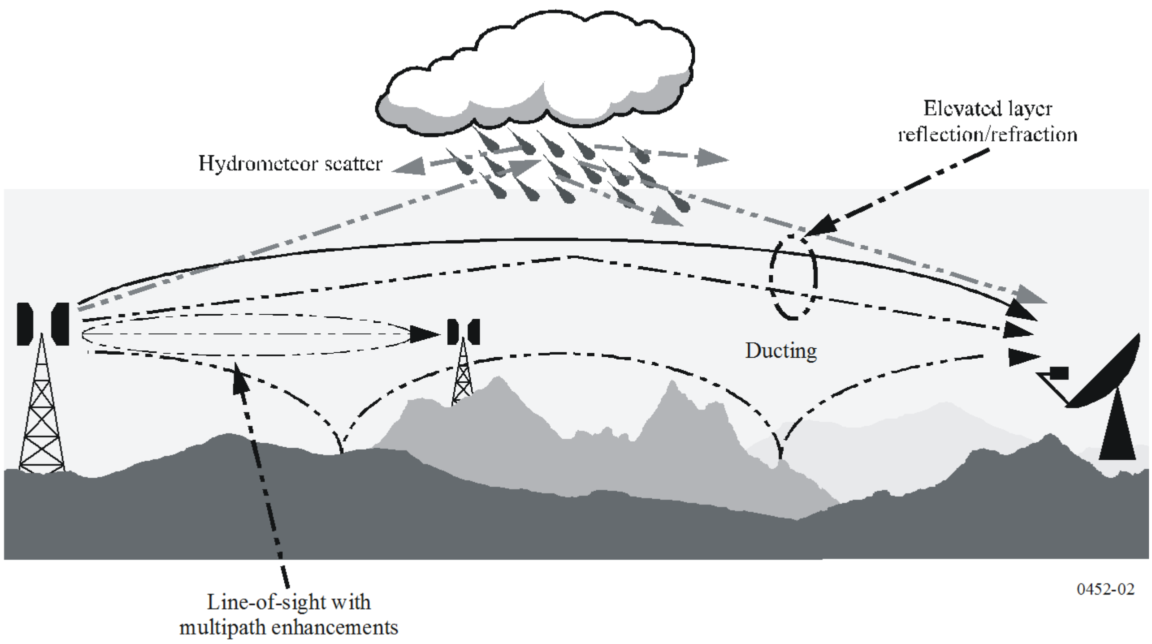
In the case of short term interference, surface ducting is the most important short term interference mechanism over water and in flat coastal land areas, and can give rise to high signal levels over long distances (more than 500 kilometres over the sea). Such signals can exceed the equivalent "free-space" level under certain conditions.

In addition, in the case of elevated terrain, the treatment of reflection and refraction from layers at heights up to a few hundred metres is of major importance as these mechanisms enable signals to overcome the diffraction loss of the terrain very effectively under favourable path geometry situations. Again the impact can be significant over quite long distances (up to 250-300 kilometres).

The Figure below depicts the propagation mechanisms that are involved in the short term interference case:

FIGURE A5-21

Anomalous (short-term) interference propagation mechanisms



– Surface ducting (Fig. A5-21): This is the most important short-term interference mechanism over water and in flat coastal land areas, and can give rise to high signal levels over long distances (more than 500 km over the sea). Such signals can exceed the equivalent "free-space" level under certain conditions.

– Elevated layer reflection and refraction (Fig. A5-21): The treatment of reflection and/or refraction from layers at heights up to a few hundred metres is of major importance as these mechanisms enable signals to overcome the diffraction loss of the terrain very effectively under favourable path geometry situations. Again the impact can be significant over quite long distances (up to 250-300 km).

– *Hydrometeor scatter* (Fig. A5-21): Hydrometeor scatter can be a potential source of interference between terrestrial link transmitters and earth stations because it may act virtually omnidirectionally, and can therefore have an impact off the great-circle interference path. However, the interfering signal levels are quite low and do not usually represent a significant problem.

Therefore in the case of short term interference, because of these specific propagation mechanisms, one can expect the interfering signals to propagate farther within the medium and therefore one can expect longer separation distances or protection zones around the FSS receive earth station.

Annex 6

Study #6

1 Introduction

This Annex presents an example sharing study using a realistic sharing scenario in order to demonstrate the range of results that can be seen under a variety of propagation assumptions. The study uses an example scenario where a small cell IMT network intended to enhance capacity in urban areas would like to coexist with a nearby licensed FSS site.

The FSS site chosen for the study, Madley in the UK, is a BT owned teleport between Madley and Kingstone in Herefordshire. It has a number of assignments in the Master International Frequency Register (MIFR) which allow us to extract a range of operational parameters.

Two links have been chosen, both operating to Intelsat satellites, one at 60° E and one at 27.5° W. This provides a variation in both elevation angle and FSS antenna azimuth. The higher elevation link has an elevation angle of 26.2° whilst the lower has an elevation angle of 7.69°.

The analysis in this study is in terms of short– and long-term *I/N* thresholds that could be considered as coordination triggers.

As will become clear later, local clutter and obstacles are important and so the picture below of the Madley site is useful to show that the antennas are generally above the local foliage.

FIGURE A6-1

Photograph of the Madley teleport site

2 Technical characteristics

IMT parameters

This study looks at the type of IMT network that would be used in urban locations to enhance capacity of an existing network. This type of network would typically be deployed in populated urban areas, out of town shopping areas, sports stadia, etc.

The Table below shows the relevant parameters for the IMT system that have been used in the analysis. These parameters are taken from Table D of Report ITU-R M.2292.

TABLE A6-1

IMT small cell outdoor base station parameters

Parameter	Value	Unit	
e.i.r.p. density (maximum)	19	dBm/MHz	
e.i.r.p. density (maximum)	−11	dBW/MHz	
Tx antenna gain	5	dBi	
Antenna pattern	Recommendation ITU-R F.1336		
Downtilt	0	degrees	
Antenna height	6	metres	
Frequency reuse	all cells use same frequency		

FSS parameters

The following parameters are used to represent the Madley site. They are derived from entries in the MIFR.

Location – 52.0194° N, 2.8466° W

Operating satellite locations 60° E and 27.5° W

Calculated Link angles

Link to 60° E – elevation = 7.69°, azimuth = 112°

Link to 27.5° W – elevation = elevation 26.2°, azimuth = −149.8°

Antenna performance

Recommendation ITU-R S.465

Peak gain = 53.1 dBi

Beamwidth = 0.44°

Link temperature = 100 K

Trigger levels

A reference *I/N* value of –15.2 dB for long-term sharing has been used. This is a conservative value and assumes 50% of apportionment to IMT.

For short-term interference, a reference value of –1.3 dB has been used.

3 Analysis

3.1 Methodology

Coordination zones

In the analysis, the area around Madley has been studied within which an IMT station may cause interference. This approach is based on an *I/N* calculation and the specification of a maximum acceptable *I/N* value as discussed above. If the value is exceeded this indicates that interference is possible and further analysis is needed.

In the first part of the analysis a smooth earth model is used. In this case the monotonic increase in path loss with range allows to consider the concept of a coordination contour. In each azimuth around the earth station, the distance at which the *I/N* is exceeded is calculated and anywhere closer than this is considered as requiring closer attention or detailed coordination.

This is not an exclusion zone but a coordination area and it is an important distinction to make. There are very many cases where FSS earth stations coexist with high power fixed links that theoretically exceed the *I/N* trigger level and lie within the zone.

Auxiliary contours

It is also useful for the presentation of the results to draw an analogy with Auxiliary Contours –which like coordination contours are also familiar from earth station coordination.

The coordination zone is plotted under worst-case assumptions and smooth earth by drawing a contour at the trigger *I/N* level. On the same map, contours at higher *I/N* levels are also plotted –in this document, it is chosen to show steps of 5 dB.

To know what the coordination contour would look like if there was an extra 10 dB local clutter loss this can be seen by looking at the higher value contour.

The motivation for this is that the reader can then see on one plot the potential effect of various mitigation techniques or additional propagation losses.

3.2 Results

Comparison of Recommendation ITU-R P.452 revisions and smooth earth contours

The following two figures show long-term *I/N* contours using Revision 14 of Recommendation ITU-R P.452 without terrain data, and Revision 12 using the smooth earth model from Recommendation ITU-R P.526.

As discussed earlier, the Revision 14 does not leave the user with any decision to make with respect of Recommendation ITU-R P.526 whereas Revision 12 was more relaxed in this respect.

In both cases the red contour is −15.2 dB and the others increase in 5 dB steps.

FIGURE A6-2

Smooth earth *I/N* contours derived using Recommendation ITU-R P.452-14

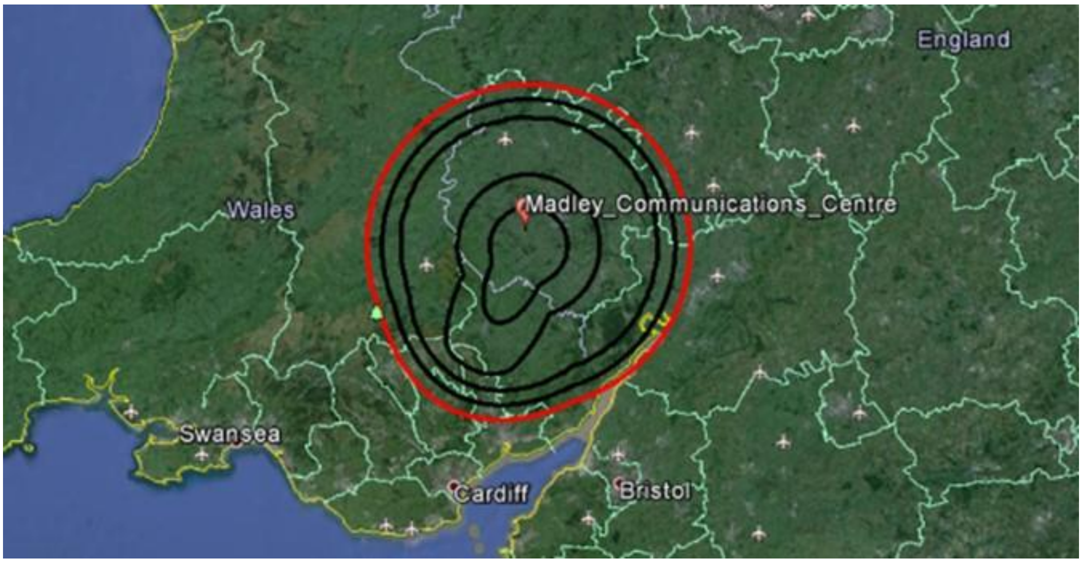
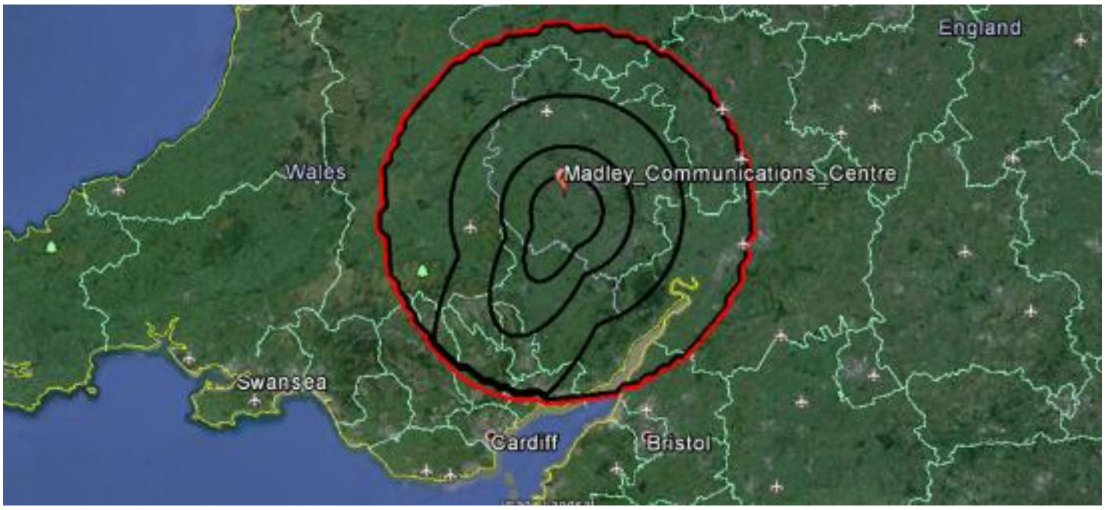


FIGURE A6-3

Smooth earth *I/N* contours derived using Recommendation ITU-R P.452-12

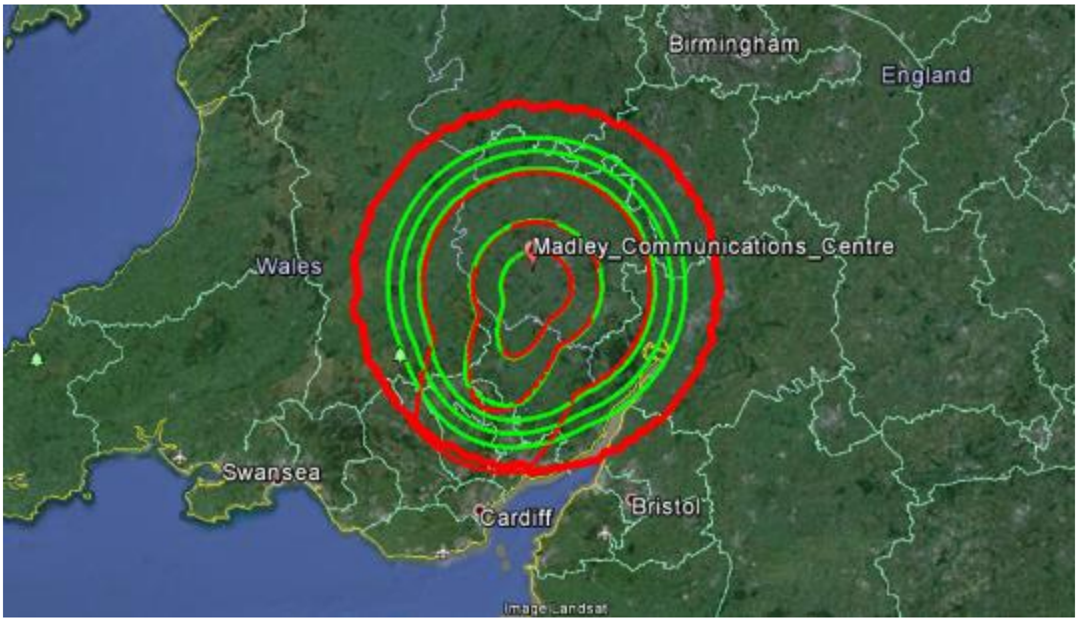


There are some significant differences in the contours – especially along the azimuth of the FSS antenna main lobe.

The following two Figures place both sets of contours on the same map and show long and short-term contours for the link operating to 27.5° W. Red contours are for Revision 12 and green for Revision 14.

FIGURE A6-4

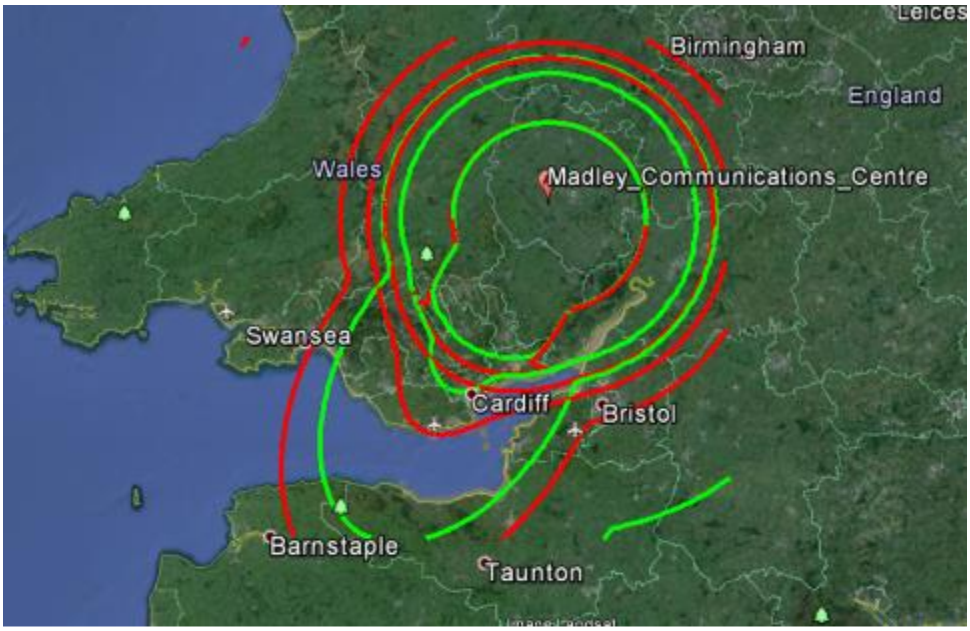
Long-term interference contours for link operating to 27.5º W at −15.3 dB and 5 dB intervals. 20% time. Red contours use Recommendation ITU-R P.452-12, green use Recommendation ITU-R P.452-14



Differences are also seen in the short-term case. The following Figure shows the Revision 12 contours in red and the smaller Revision 14 contours in green.

FIGURE A6-5

Short-term interference contours for link operating to 27.5º W at −1.3 dB and 5 dB intervals. 0.001667% time. Red contours use Recommendation ITU-R P.452-12, green use Recommendation ITU-R P.452-14



From the Figures above, it is concluded that changing the version of the recommended propagation model reduces the size of the coordination zone in this case. It does this significantly in the limiting direction along the azimuth of the FSS antenna boresight.

For the lower elevation link, operating to the satellite at 60° E the same data are shown on the two following Figures.

FIGURE A6-6

Long-term interference contours for link operating to 60° E at −15.3 dB and 5 dB intervals. 20% time. Red contours use Recommendation ITU-R P.452-12, green use Recommendation ITU-R P.452-14

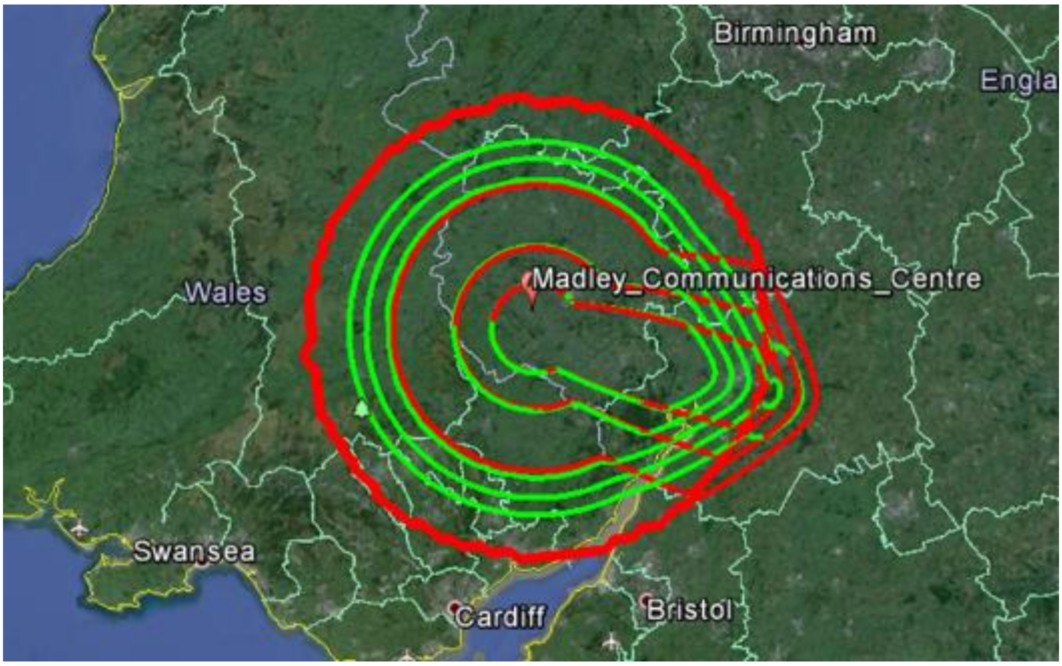
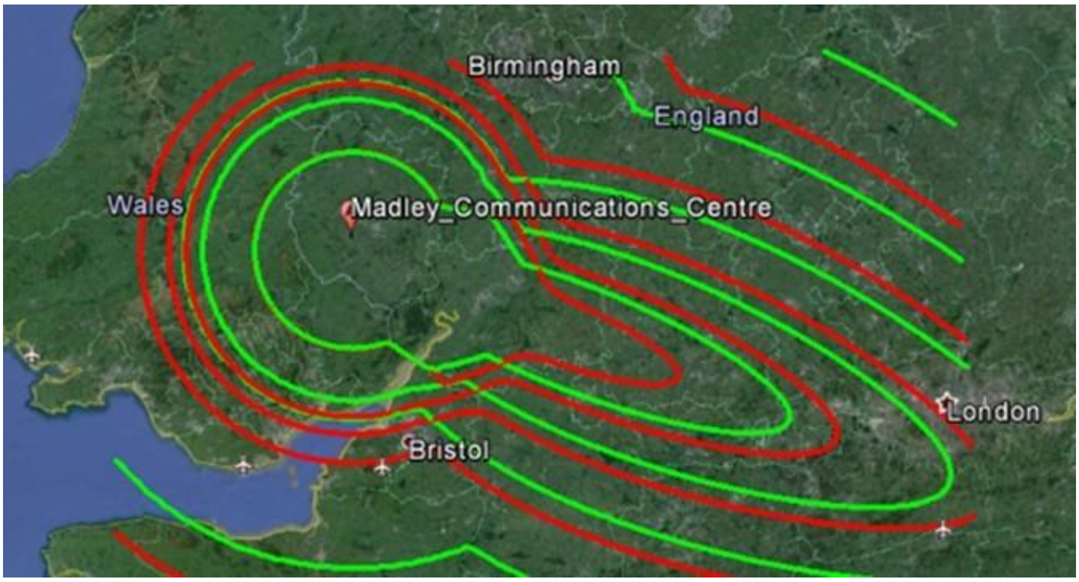


FIGURE A6-7

Short-term interference contours for link operating to 60° E at −15.3 dB and 5 dB intervals. 0.001667% time. Red contours use Recommendation ITU-R P.452-12, green use Recommendation ITU-R P.452-14



For the lower elevation link in the two Figures above, Revision 14 of Recommendation ITU-R P.452 results in smaller long-term contours but slightly larger short-term contours. This is consistent with the results in Figs A6-2 and A6-3.

Having shown that the lower elevation link has a fairly large contour under both assumptions it is important now to consider the additional factors of terrain and clutter.

Terrain and clutter in Recommendation ITU-R P.452 Revision 14

Results in this section are all based on Recommendation ITU-R P.452 Revision 14 and concentrate on the low elevation link towards the satellite at 60° E which is the limiting case, as we have seen in Fig. A6-7.

The effect of the addition of terrain data and the use of that data in diffraction loss modelling has a major effect on potential interference. If the victim receiver is shielded interference levels are generally reduced. If the victim is located on low ground interference will be lower still. On the other hand, if the interferer is on high ground potential interference levels at long range may be enhanced.

In order to show the effect of adding terrain data and local clutter loss, the following figures show colour-coded plots of *I/N* where the dark red areas are at or above the relevant trigger level. Other colours show decreasing *I/N* levels.

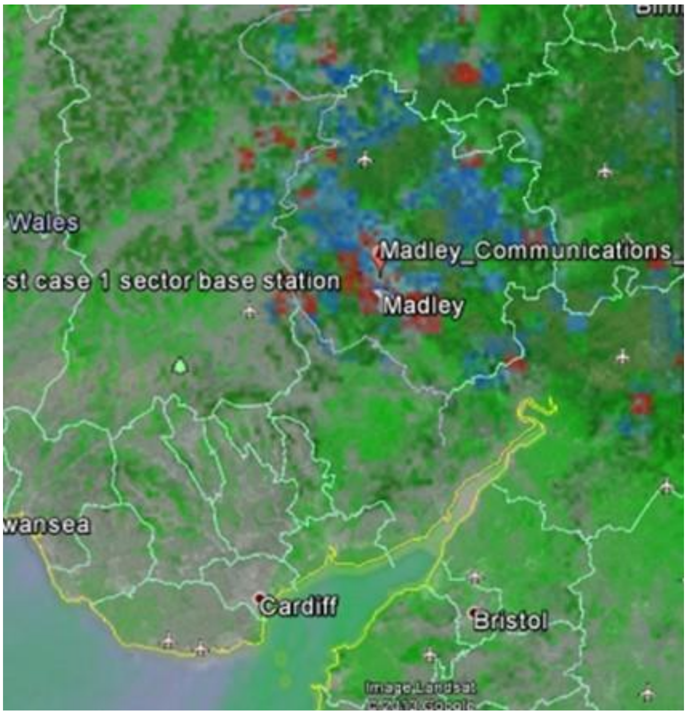
The following Figures show the effect of added high resolution terrain on the short- and long-term *I/N* levels.

FIGURE A6-8

Red pixels show where *I/N* is −15.2 dB or higher for 20% of time when high resolution terrain is taken into account. Red areas are where the long-term *I/N* criterion is exceeded

FIGURE A6-9

Red pixels show where *I/N* is −1.3 dB or higher for 0.00167% of time when high resolution terrain is taken into account. Red areas are where the long-term *I/N* criterion is exceeded



Adding the terrain has taken into account the local geography around Madley – the mountains and the bowl in which the teleport is set. This has had a dramatic effect on the area in which coordination would actually be needed.

In fact no population centres seem to be affected, although there is a possibility that some small areas of high ground around Gloucester (South East of Madley) may violate the short-term *I/N*. This could occur if a much higher resolution was looked at.

However, what is missing from the two figures above is any account for local clutter. The terrain database used is not a surface database and a path independent value for local terminal loss can be added.

The simplest way to do this is to consider the actual deployments it is attempted to simulate.

As shown in Fig. A6-1 the LNBs and substantial parts of most of the dishes at Madley are above the level of the local foliage. With this in mind no additional clutter losses at the receive site should be assumed.

For the IMT system nodes are considered that would be deployed on the sides of buildings or perhaps on street furniture such as lamp posts. These nodes would be close to and below the local clutter. In Recommendation ITU-R P.452, two parameters can be added – local clutter height and distance to local clutter. If conservatively assuming the clutter 2 metres above the base stations and at a distance of 5 metres it can be seen that all the red pixels disappear.

In practice, it would be expected that most locations would have a larger clutter loss than this implies and using the value of 15 dB as used in some Report ITU-R M.2109 studies, this is more than sufficient to remove all *I/N* excesses.

4 Summary

The smooth earth contours indicate, for the example scenario, that:

1) Sharing with a link with elevation angle above 26°, operating to a satellite at 27.5° W may not be problematic. Only one populated area falls with the worst-case *I/N* contour and then only slightly.

2) The lower elevation link (7.6° operating to 60° E) requires more analysis – the worst-case contour extends significantly over several population areas.

For the high elevation link, the worst-case contour for both short and long-term propagation conditions encompass only one populated area (Newport) where a micro network is likely to be employed. The same contours indicate that a small improvement of less than 5 dB in the results would put Newport outside the contour.

For the low elevation link, the contour is much larger, but the addition of terrain and the use of Recommendation ITU-R P.452-14 is found to reduce the affected areas significantly. The addition of a very conservative clutter loss value that might apply to the IMT network under consideration eliminates any residual issues.

Annex 7

Study #7

1 Introduction

1.1 Scope and objective

Fixed-satellite service (space-to-Earth) is the primary allocation in the frequency bands 3 400-4 200 MHz and 4 500-4 800 MHz which are the adjacent bands with the frequency bands 3 300-3 400 MHz, 4 400-4 500 MHz and 4 800-4 990 MHz. This Report provides the detailed studies of adjacent band compatibility between IMT system and FSS system in the bands respectively.

2 Characteristics and parameters

2.1 IMT parameters

IMT Base station parameters are taken from Table 3 in the main document.

2.2 FSS parameters

The Table below provides the key FSS parameters to be used for these studies[15].

[15] From Report ITU-R M.2109-0 (2007) – 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.

TABLE A7-1

Typical downlink FSS parameters in the 4 GHz frequency 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 metres and 11 metres (feeder link).

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

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

FSS filter characteristics is referring to IMT filter, 45 dB ACS is assumed.

3 Methodologies and propagation models

3.1 Possible types of interference to the FSS

The possible types of interference from IMT system has been identified to impact FSS system:

a) Unwanted emissions from IMT base station to FSS earth station in adjacent channels

Interference from unwanted emissions generated by IMT base station to FSS earth station in adjacent channels is studied.

b) Unwanted emissions from IMT UE to FSS earth station in adjacent channels

Interference from unwanted emissions generated by IMT UE to FSS earth station in adjacent channels is not evaluated because it can be referred to the studies on IMT base station with larger Maximum output power, especially when taking into consideration the lower average UE output power in IMT system[16].

3.2 FSS interference criteria

The following methodology is adopted in Report ITU-R M.2109 to evaluate the ES tolerable long-term interference from other IMT systems.

---

[16] See § 2.1.

In line with ITU-R S.1432-1, the Report utilizes the following *I/N* value for the long term interference criterion[17]:

$$I/N = -20.0 \text{ dB } (\Delta T/T = 1\%)$$

The aggregate interference from all other sources of interference is considered for 100% of the time where *N* is the clear-sky satellite system noise as described in Recommendation ITU-R S.1432.

Apportionment of interference allowance

50% apportionment of the allowable interference is assumed among the competing potential sources of interference.

Long-term interference from any individual secondary or unallocated service as well as interference into adjacent frequency bands (unwanted emissions) is considered to be limited to half of the total noise interference allowance into an FSS link, and from any individual primary service it is considered to be limited to half of the afore mentioned values of 6% or 10% of the total noise, as appropriate.

3.3 Methodologies

Assuming one IMT macro cell base station interfere FSS receiver, the received interference power level at the FS receiver is calculated according to the equation:

$$I_r = P_{IMT} + G_{IMT} + G_{FSS}(\theta) - L(f,d) - S - F$$

I_{IMT}: the received interference power level in 1 MHz bandwidth at the FS receiver (dBm)

P_{IMT}: transmission power per MHz bandwidth of IMT system (dBm)

G_{IMT}: antenna gain of IMT system (dB)

$G_{FSS}(\theta)$: reception antenna gain of FSS system (dB)

$L(f,d)$: the path loss (dB).

Adjacent channel interference

The following parameters are specifically used for the IMT interference calculation for the adjacent channel interference analysis.

FDR: Frequency dependent rejection (dB)[18]

Δf: Frequency offset (Hz).

Based on the 3GPP 36.104 v.11.2.0, § 6.6.2 specifications.

At first, ACLR shall be no less than 45 dB.

In addition,

– For wide area base station, either the ACLR limits or the absolute limit of –15 dBm/MHz apply, whichever is less stringent.

– For local area base station, either the ACLR limits or the absolute limit of –32 dBm/MHz shall apply, whichever is less stringent.

If the band is larger than the ACLR region, the operating band unwanted emission limits will refer to the following tables from 3GPP TS 36.104 v.11.2.0 § 6.6.3:

---

[17] Adjacent interference criterion is used.

[18] FDR = 0 dB for co-channel analysis.

TABLE A7-2

Macro base station operating band unwanted emission limits for 5, 10, 15 and 20 MHz channel bandwidth

Frequency offset of measurement filter –3 dB point, Δf	**Frequency offset of measurement filter centre frequency, f_offset**	**Minimum requirement**	**Measurement bandwidth**
0 MHz ≤ Δ*f* < 5 MHz	0.05 MHz ≤ f_offset < 5.05 MHz	$-7dBm-\frac{7}{5}\cdot\left(\frac{f\_offset}{MHz}-0.05\right)dB$	100 kHz
5 MHz ≤ Δ*f* < min(10 MHz, Δf_{max})	5.05 MHz ≤ f_offset < min(10.05 MHz, f_offset_{max})	–14 dBm	100 kHz
10 MHz ≤ Δ*f* ≤ Δf_{max}	10.5 MHz ≤ f_offset < f_offset_{max}	–15 dBm (Note 5)	1 MHz

TABLE A7-3

Local Area base station operating band unwanted emission limits for 5, 10, 15 and 20 MHz channel bandwidth

Frequency offset of measurement filter –3 dB point, Δf	**Frequency offset of measurement filter centre frequency, f_offset**	**Minimum requirement**	**Measurement bandwidth**
0 MHz ≤ Δ*f* < 5 MHz	0.05 MHz ≤ f_offset < 5.05 MHz	$-30dBm-\frac{7}{5}\left(\frac{f\_offset}{MHz}-0.05\right)dB$	100 kHz
5 MHz ≤ Δ*f* < min(10 MHz, Δf_{max})	5.05 MHz ≤ f_offset < min(10.05 MHz, f_offset_{max})	–37 dBm	100 kHz
10 MHz ≤ Δf ≤ Δf_{max}	10.05 MHz ≤ f_offset < f_offset_{max}	–37 dBm (Note 5)	100 kHz

In simple terms, the interference in the adjacent channel case is made up of two components as shown in the diagram below:

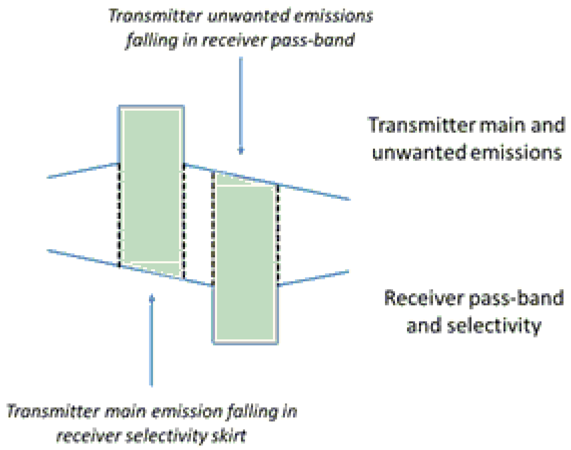
– the transmitter unwanted emissions falling within the receiver pass-band;

– the transmitter main emission falling in the receiver selectivity skirt.

The total impact is in fact a convolution of the interfering transmitter emission mask (its in-band and out-of-band characteristic combined) and the victim receiver selectivity (its in-band and out-of-band characteristic combined). Another factor to be accounted for (for ground path interference) is overload of the earth station receiver front-end which is often wideband.

FIGURE A7-1

Adjacent channel interference components



The total received interference from IMT base station is derived as follows:

$$IMT\_Tx\_power*10\text{^}(-0.1*ACS_{FSS}) + IMT\_Tx\_power*10\text{^}(-0.1*ACLR_{IMT})$$

The 36 MHz ACLR is calculated as follows:

ACLR = in band power of IMT (46 dBm) / adjacent 36 MHz emission power (which will slightly differ according to the different guard band values between IMT and FSS).

3.4 IMT network topology

3.4.1 Indoor IMT small cell scenario topology

Multiple buildings are distributed in a ring-shaped topology around the FSS earth station. Each building contains an IMT small cell indoor system comprising multiple IMT small cells. The spacing between the terrestrial IMT and the FSS systems corresponds to the separation distance between the FSS earth station and the nearest IMT small cell base station within an identified building.

The IMT small cell indoor system topology is distributed in buildings of 6 floors, the topology of each floor is based on the below figure from the 3GPP specification 3GPP TR 36.814. As shown in figure below:

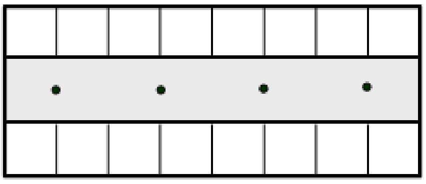
– IMT small cell indoor system buildings size: 120 metres × 50 metres, including rooms and corridor;
– number of rooms in the building (per floor): 16;
– room size: 15 metres × 15 metres;
– corridor size: 120 metres × 20 metres;
– 4 indoor IMT small cell BSs in each floor[19];
– all terminals are deployed in the rooms;
– 6 floors in each building, the IMT indoor base station are deployed in 4 floors randomly selected among the 6 available floors in the building (i.e. 16 IMT small cell BSs are always considered in each building);
– height of each floor: 3 m;

[19] Four small cell base stations are considered in each floor instead of the two base stations per floor considered in 3GPP TR 36.814.

– external wall loss: 20 dB;
– floor penetration loss: 18 dB for each floor (in line with Recommendation ITU-R P.1238, Table 3).

FIGURE A7-2

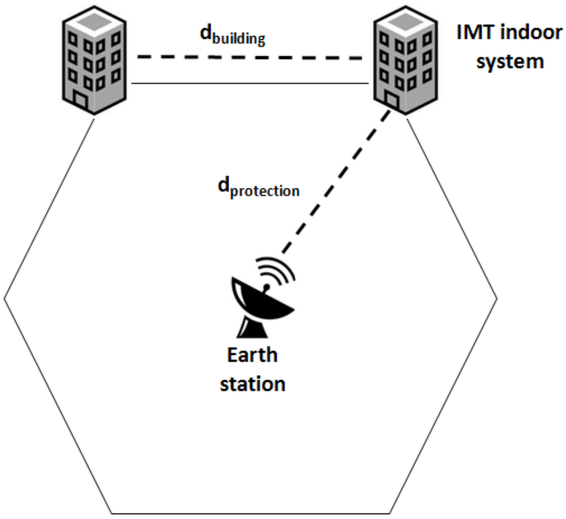
IMT small cell indoor system building: floor topology



The buildings are uniformly distributed around the FSS earth station as described in the diagram below (same topology adopted as in Report ITU-R M.2109).

FIGURE A7-3

IMT small cell indoor scenario topology



where:

$d_{\text{protection}}$: Protection distance: the distance between the FSS earth station and the central position of IMT small cell indoor system;

d_{building}: Distance between two IMT small cell indoor systems.

As shown in the figure above, the number of IMT small cell indoor systems (i.e. number of buildings) is:

$$\text{N}_{Build} = (2\pi \times d_{protection}) / d_{building}$$

The system-level compatibility simulation assumes $d_{building}$ = 300 metres.

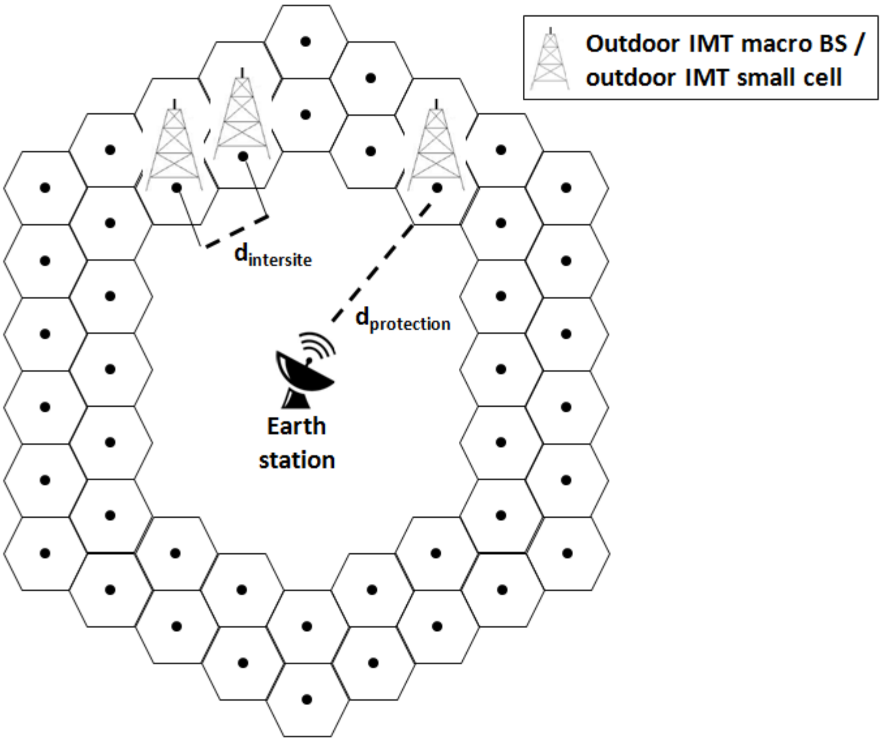
The number of buildings containing one of the IMT small cell indoor systems is calculated, the distance between buildings is calculated according to the average distribution.

3.4.2 IMT macro cell / IMT small cell outdoor scenarios topology

Report ITU-R M.2109 is taken as reference with few exceptions. The adopted topology is described below[20].

FIGURE A7-4

IMT macro cell / IMT small cell outdoor scenarios topology



$d(i)$ The radius of the i-th ring:

$$d(i) = d_{protection} + (i-1) * d_{intersite}$$

$N(i)$ The number of IMT base stations located on the i-th ring. It is assessed based on the corresponding distance $d(i)$ and the base station inter-site distance range:

$$N(i) = pi / (\arcsin (d_{intersite} / (2*d(i))))$$

3.5 Propagation models

The propagation model is from Recommendation ITU-R P.452-15.

Basic transmission loss is from Recommendation ITU-R P.452-15 as follows:

$$L = 92.5 + 20 \log f + 20 \log d + A_g + L_{d50} + A_{ht} + A_{hr} \quad \text{dB}$$

where:

L: transmission loss due to free-space propagation and attenuation by diffraction loss (dB)

f: frequency (GHz)

[20] The topology considered in this document, consistently with Report ITU-R M.2109, is the most conservative (elevation only off-set). However in a significant number of practical cases less conservative situations will happen to involve elevation as well as azimuth off-set.

d : path length (km)

L_{d50}: the median diffraction loss (dB):

$$L_{d50} = L_{m50} + \left(1 - e^{-\frac{L_{m50}}{6}}\right)\left(L_{t50} + L_{r50} + 10 + 0.04d\right) \quad \text{for } \nu_{m50} > -0.78$$

$$= 0 \quad \text{otherwise}$$

where:

L_{m50}: the median knife-edge diffraction loss for the main edge (dB)

L_{t50}: the median knife-edge diffraction loss for the transmitter-side secondary edge (dB)

L_{r50}: the median knife-edge diffraction loss for the receiver-side secondary edge (dB)

ν_{m50}: the diffraction parameter of the main edge (dB)

$A_{ht,hr}$: additional losses to account for clutter shielding the transmitter and receiver.

Recommendation ITU-R P.452-15 requires the terrain information as input for diffraction loss. The proposal below uses the typical terrain information contained in the Table 4 of Recommendation ITU-R P.452-15 and the method of applying height-gain correction in the Fig. 3 of Recommendation ITU-R P.452-15.

TABLE A7-4

Nominal clutter heights and distances

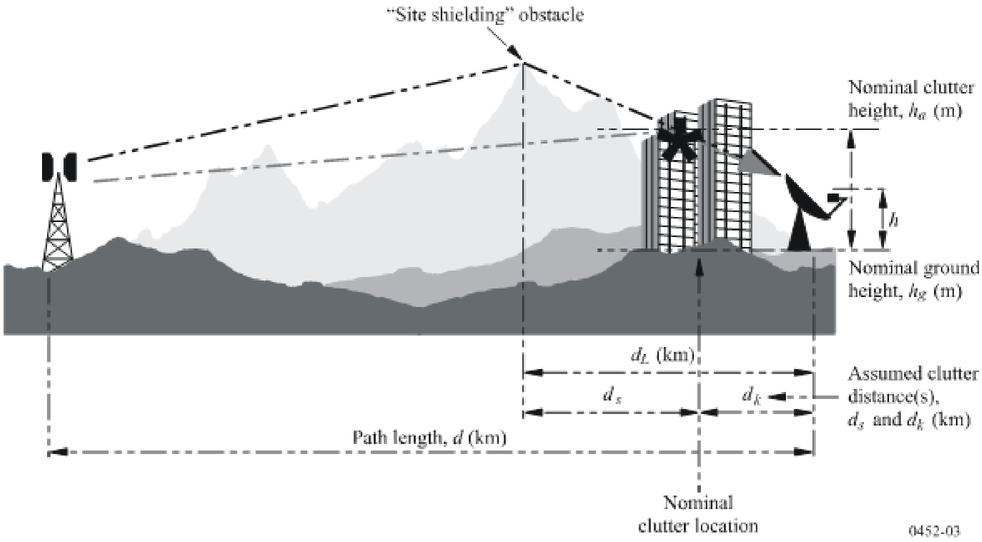
Clutter (ground-cover) category	Nominal height h_a (m)	Nominal distance d_k (km)
High crop fields Park land Irregularly spaced sparse trees Orchard (regularly spaced) Sparse houses	4	0.1
Village centre	5	0.07
Deciduous trees (irregularly spaced) Deciduous trees (regularly spaced) Mixed tree forest	15	0.05
Coniferous trees (irregularly spaced) Coniferous trees (regularly spaced)	20	0.05
Tropical rain forest	20	0.03
Suburban	9	0.025
Dense suburban	12	0.02
Urban	20	0.02
Dense urban	25	0.02
High-rise urban	35	0.02
Industrial zone	20	0.05

h_a: Nominal clutter height (m) above local ground level.

d_k: Distance (km) from nominal clutter point to the antenna.

FIGURE A7-5

Method of applying height-gain correction



For transmitter and receiver side, the terrain info is according to the above table. The concrete value is based on which scenario the node is located. It is assumed that the path includes transmit terrain, receive terrain and dense suburban terrain in the middle path; the 12 metres high terrain that characterizes the dense suburban is chosen as default for the dense urban middle path. If the transmitter or receiver side terrain is lower than 12 metres, the minimum value among the transmitter and receiver is chosen for the middle path terrain's height.

4 Studies and results of compatibility

The statistical method provides the following average value statistics for minimum separation distance between IMT base stations for macro cell deployment in suburban and rural area in the bands 3 300-3 400/4 400-4 500/4 800-4 990 MHz and FSS earth station in the adjacent bands 3 400-4 200/4 500-4 800 MHz.

	IMT macro cell deployment in suburban and rural area				
IMT antenna height (m)	**FSS antenna height (m)**	***I/N* criterion (dB)**	**FSS elevation angle**	**Min. separation distance (m)**	**Isolation (dB)**
25	3 m for suburban	–23.0 (incl. –3 dB for 50% interference apportionment)	5°	1 400	146
			15°	467	135
			48°	315	131

The statistical method provides the following average value statistics for min. separation distance between IMT base stations for small cell outdoor deployment in urban area in the bands 3 300-3 400/4 400-4 500/4 800-4 990 MHz and FSS earth station in the adjacent bands 3 400-4 200/4 500-4 800 MHz.

	IMT small cell outdoor deployment in urban area				
IMT antenna height (m)	**FSS antenna height (m)**	***I/N* criterion (dB)**	**FSS elevation angle**	**Min. separation distance (m)**	**Isolation (dB)**
6	30 m for urban	–23.0 (incl. –3 dB for 50% interference apportionment)	5°	50[21]	124
			15°	50	120
			48°	50	118

The statistical method provides the following average value statistics for Min. separation distance between IMT base stations for small cell indoor deployment in urban area in the bands 3 300-3 400/4 400-4 500/4 800-4 990 MHz and FSS earth station in the adjacent bands 3 400-4 200/4 500-4 800 MHz.

	IMT small cell indoor deployment in urban area				
IMT antenna height (m)	**FSS antenna height (m)**	***I/N* criterion (dB)**	**FSS elevation angle**	**Min. separation distance (m)**	**Isolation (dB)**
3 m above each floor	30 m for urban	–23.0 (incl. –3 dB for 50% interference apportionment)	5°	60[22]	120
			15°	60	116
			48°	60	115

5 Summary

With regard to the results in this report, they were directed to protect FSS system in the bands 3 400-4 200/4 500-4 800 MHz from IMT system in the bands 3 300-3 400/4 400-4 500/ 4 800-4 990 MHz. The following observations may be reached:

– It may be possible to deploy IMT system in the area with the Min. separation distance of about 1400 metres (for IMT macro cell deployment in suburban and rural area) or 50 metres (for IMT small cell outdoor deployment in urban area) or 60 metres (for IMT small cell indoor deployment in urban area).

Annex 8

Study #8

1 Introduction

This document provides information related to the potential use of all or parts of the frequency band 3 400-4 200 MHz.

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[21] Note that: the Min. separation distance is limited by the scenario of the Recommendation ITU-R P.452 model.

[22] Note that the minimum separation distance is limited by the building model.

One of the aims of this contribution is to assess how the feasibility of sharing between IMT-Advanced systems and FSS earth stations might have changed since Report ITU-R M.2019 was developed. In particular, it is known that the Recommendation ITU-R P.452 propagation model has been updated since Report ITU-R M.2109 was developed, and some of the IMT-Advanced parameter values have been revised.

Another aim of this contribution is the examine how the size of the separation zone for new proposed IMT-Advanced systems varies as a consequence of different terrain around the earth station. To this end, two example earth station locations in the UK have been examined: one surrounded by high hills and the other less well protected by the natural terrain. Furthermore, example plots are provided for the Yamaguchi earth station in Japan which is a naturally well shielded site, and which is also examined in Study #3.

These studies also examine the impact of the IMT-Advanced macro base station antenna downtilt angle.

2 Background

The frequency band 3 400-4 200 MHz has been suggested as a potential band for use by IMT-Advanced applications. This band is widely used by the FSS, with receiving earth stations deployed throughout the world.

The potential use of this band for IMT-Advanced systems has been analysed in Report ITU-R M.2109, which was prepared in response to WRC-07 agenda item 1.4.

3 Technical characteristics

The technical characteristics of FSS earth stations and IMT-Advanced systems contained in §§ 2 and 3 of the main body of this Report have been used. Specific example FSS earth stations are considered, and hence where possible, specific characteristics of those earth stations have been used.

Regarding the interference criteria for FSS earth stations, the following values are used:

TABLE A8-1

FSS earth station interference criteria

Long term	I/N = –13 dB, which may be exceeded for up to 20% of the time
Short term	I/N = –1.3 dB that may be exceed by up to 0.001667% time

The above criteria are applicable for the aggregate interference from all IMT-Advanced stations and hence when considering interference from a single IMT-Advanced base station, a further accommodation might be required to account for interference from other co-frequency base stations. For the time being, no such accommodation is included, but this might be reviewed in a future contribution.

4 Analysis

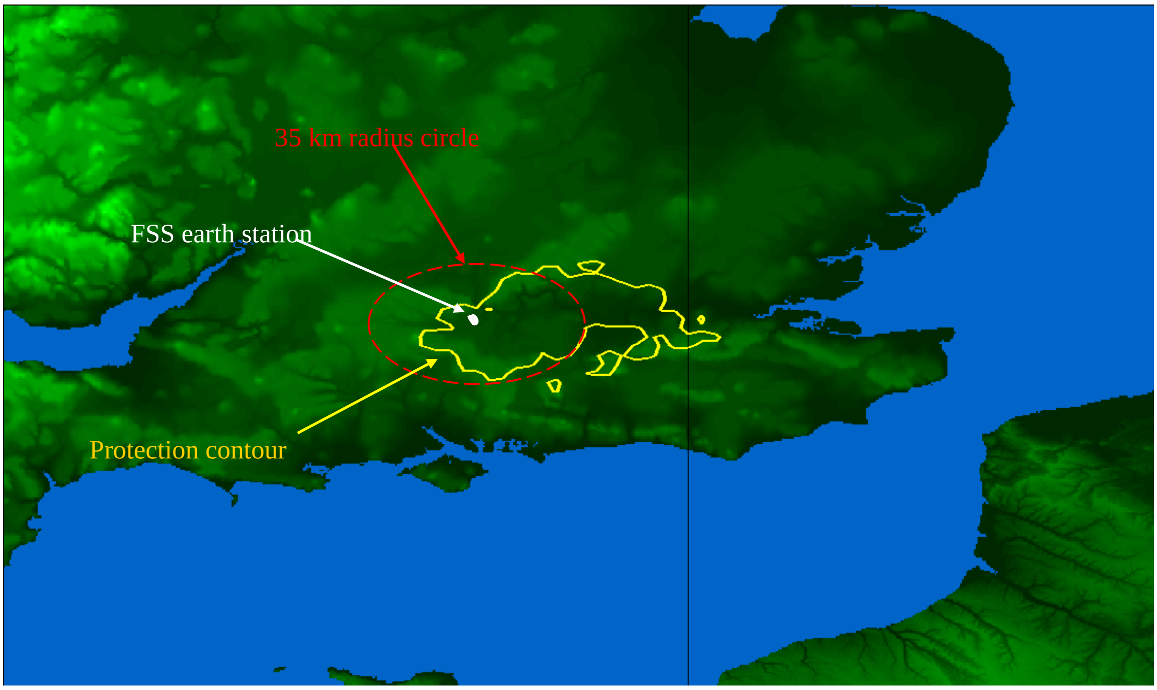
Two types of analysis are provided. The first provides a comparison of the results in Report ITU-R M.2109. The second analysis shows the required minimum.

4.1 Assessment of applicability of results in Report ITU-R M.2109

The analysis in this section makes a comparison of the results contained in Report ITU-R M.2109 with those derived with the latest propagation model and the latest IMT-Advanced characteristics. As a reference, example earth station contours contained in Report ITU-R M.2019 were used. Figures A1 and A2 from Report ITU-R M.2109 are reproduced below.

FIGURE A8-1

Example of zone for long-term interference protection* in moderately hilly area (Fig. A1 in Report ITU-R M.2109)

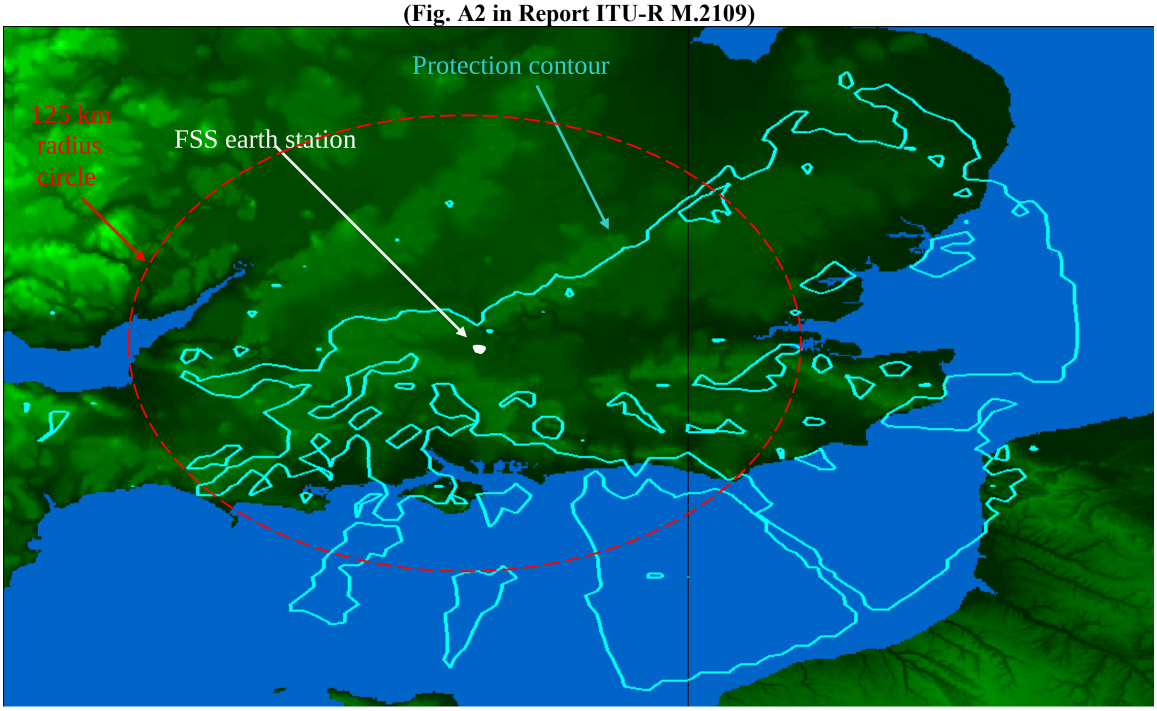


* *I*/*N* not to exceed –10.0 dB for more than 20% of the time.

The maximum separation distance in Fig. A8-1 is about 75 km.

FIGURE A8-2

Example of zone for short-term interference protection* in moderately hilly area (Fig. A2 in Report ITU-R M.2109)



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

The maximum separation distance in Fig. A8-2 is about 225 km.

Table A8-2 below shows the parameter values use to developed the figures in Report ITU-R M.2109, which were based on assumed parameters for IMT-Advanced macro base stations at that time. The new parameter values are also shown, based on for IMT-Advanced macro base stations, following the most recent parameters.

TABLE A8-2

Comparison of study parameter values

Parameter	**Original value**	**New value**
Maximum IMT base station e.i.r.p.	16 dBW/MHz	28 dBW in 5 MHz (= 21 dBW/MHz)
IMT base station antenna height a.g.l.	30 m	25 m
FSS earth station antenna pattern	Recommendation ITU-R S. 465	Recommendation ITU-R S. 465
Earth station antenna height a.g.l.	2 m	2 m
Earth station receiver temperature	100 K	100 K
Long term criterion	*I/N* = –10 dB, which may be exceeded for 20% of the time	*I/N* = –10 dB, which may be exceeded for 20% of the time
Short term criterion	*I/N*= –1.3 dB, which may be exceeded for 0.001667% of the time	*I/N*= –1.3 dB, which may be exceeded for 0.001667% of the time
Propagation model	Recommendation ITU-R P.452 (version not specified)	Recommendation ITU-R P.452-14
Terrain data	Not specified	Aster

Figures A8-3 and A8-4 below show the results for the same earth station, using the new parameter values shown in the table above.

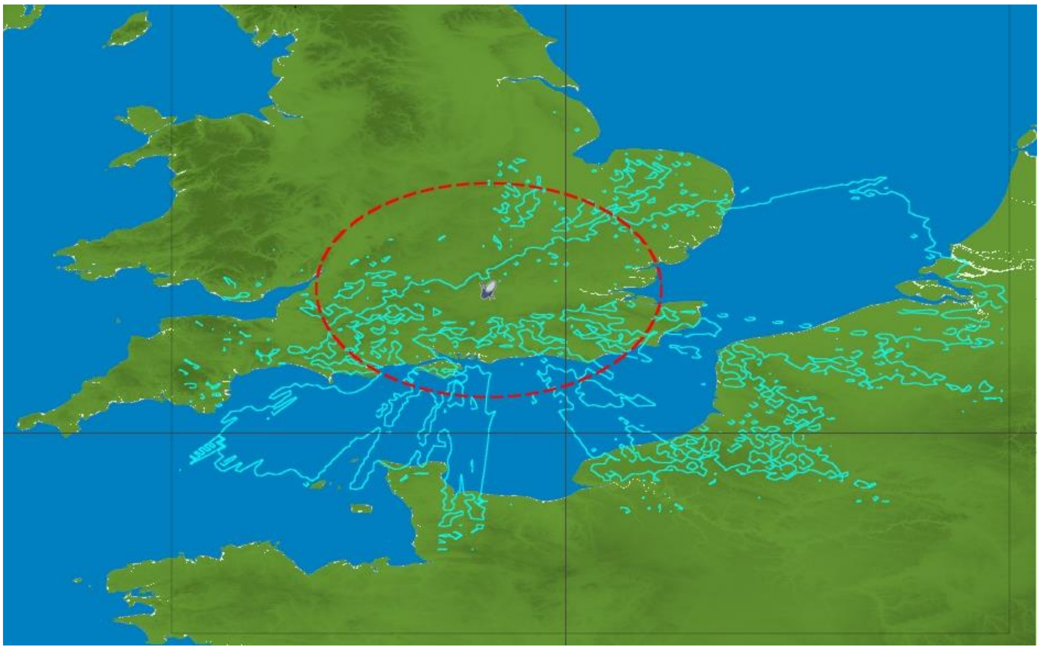
FIGURE A8-3

Zone for protection based on long-term interference criterion

The red dotted circle has a radius of 35 kilometres. The maximum separation distance, is about 85 km.

FIGURE A8-4

Zone for protection based on short-term interference criterion



The red dotted circle is radius 125 kilometres. The maximum separation distance is about 400 km from the earth station.

Comparing Fig. A8-3 with Fig. A8-1, shows that when using the latest propagation model and the latest IMT-Advanced macro cell characteristics, the protection area derived by considering the long-term protection criterion is slightly increased. Considering the long term criterion only, the maximum separation distance is increased from about 75 to 85 km.

Comparing Fig. A8-4 with Fig. A8-2, shows that when using the latest propagation model and the latest IMT-Advanced macro cell characteristics, the protection area derived by considering the short-term criterion is increased. Considering the short-term criterion, the maximum separation distance is increased from about 225 km to about 400 km.

4.2 Example separation areas for FSS earth stations

As examples of the required separation distances, plots are developed for three example FSS earth stations. Brookmans Park is a teleport to the north of London in the UK, at a site with little natural site shielding. Madley as a teleport near the Wales/England border in the UK, in an area with a high level of natural shielding from surrounding hills. This earth station is also examined in Study #5. It should be noted that the band 3 400-3 600 MHz is not allocated to the FSS in the UK but this study has used these two stations as examples with respect to the potential deployment of IMT. The third earth station examined is the Yamaguchi earth station in Japan, which operates as a land earth station for the Inmarsat network. This earth station was examined in Study #2. The interference criteria indicated in § 5.1 in the main body of this Report are used. In all figures, Recommendation ITU-R P.452-14 is used, along with the "Aster" terrain data (see http://www.jspacesystems.or.jp/ersdac/GDEM/E/index.html).

TABLE A8-3

FSS earth station parameters used in the figures below

	Brookmans Park (UK)	Madley (UK)	Yamaguchi (Japan)
Location	N51:43:44, W0:10:39	52.0194° N, 2.8466° W	34.214° N, 131.558° E
Antenna height a.g.l.	5 m	12 m	12 m
Antenna elevation and azimuth	9.4° elevation, 114.2° azimuth (Satellite at 60° E)	7.7 ° elevation, 112.0 ° azimuth (satellite at 60º E)	6.5° elevation, –100.6° azimuth (satellite at 60º E
Reference antenna pattern	Recommendation ITU-R S.465	Recommendation ITU-R S.465	Recommendation ITU-R S.465
Receiver temperature	70 K	70 K	91 K
Interference criteria (long term)	I/N = –13 dB, which may be exceeded for up to 20% time	I/N = –13 dB, which may be exceeded for up to 20% time	I/N = –13 dB, which may be exceeded for up to 20% time
Interference criteria (short term)	I/N = –1.3 dB, which may be exceeded for up to 0.001667% time	I/N = –1.3 dB, which may be exceeded for up to 0.001667% time	I/N = –1.3 dB, which may be exceeded for up to 0.001667% time

Example plots are presented for IMT Macro stations with the parameters shown in Table A8-4. For the "macro suburban" base station, two examples are used: one assuming no antenna downtilt ("Macro suburban (1)") and the other assuming 6° downtilt ("Macro suburban (2)"). Similarly, two examples are used for the "macro urban" base station: one assuming no antenna downtilt ("Macro urban (1)") and the other assuming 10° downtilt ("Macro urban (2)"). In a future update of these studies the IMT-Advanced "small cell" might also be used.

TABLE A8-4

IMT Macro station parameters used in the figures below

	Macro suburban (1)	**Macro suburban (2)**	**Macro urban (1)**	**Macro urban (2)**
Antenna height a.g.l.	25 m	25 m	20 m	20 m
Downtilt	0 degrees	6 degrees	0 degrees	10 degrees
Antenna pattern	Rec. ITU-R F.1336	Rec. ITU-R F.1336	Rec. ITU-R F.1336	Rec. ITU-R F.1336
Feeder loss	3 dB	3 dB	3 dB	3 dB
base station output power 5 MHz	43 dBm	43 dBm	43 dBm	43 dBm
Maximum base station antenna gain	18 dBi	18 dBi	18 dBi	18 dBi
Maximum base station output power (e.i.r.p.)	58 dBm	58 dBm	58 dBm	58 dBm

Example plots are also presented for IMT Small Cells, with the parameters shown in Table A4-5. For the indoor Small Cell case, three difference values of building penetration loss have been considered: 0 dB, 10 dB and 20 dB.

TABLE A8-5

IMT Small cell parameters used in the figures below

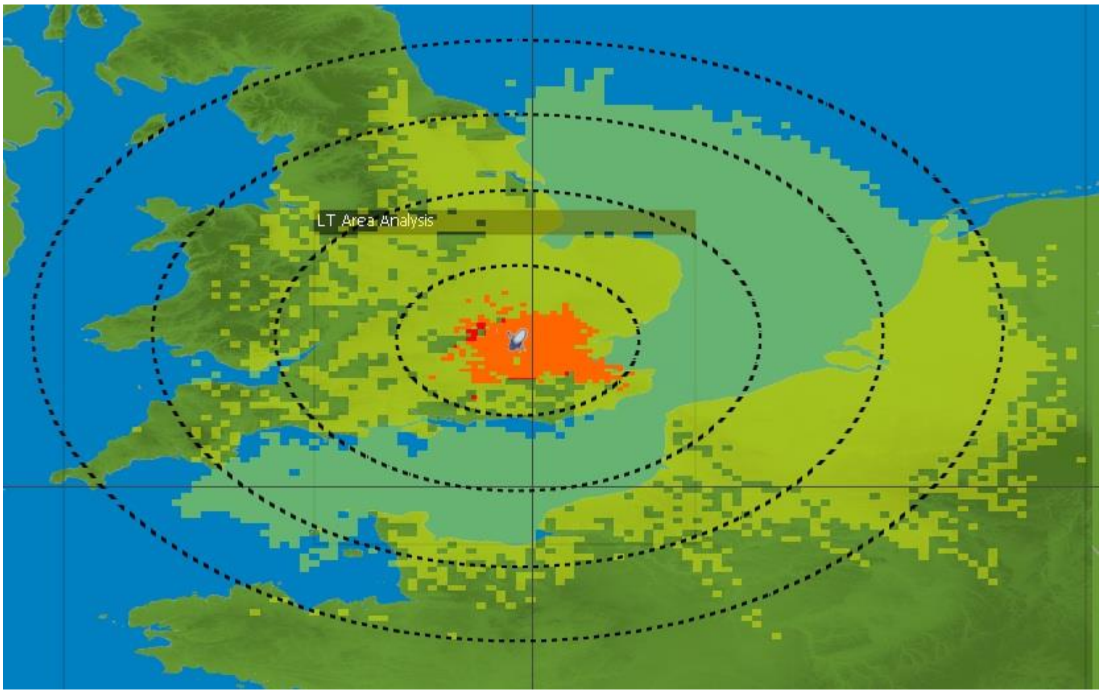
	Small cell outdoor	**Small cell indoor (1)**	**Small cell indoor (2)**	**Small cell indoor (3)**
Building penetration loss (dB)	0 dB	0 dB	10 dB	20 dB
Antenna height a.g.l.	6 m	3 m		
Downtilt	N/A	N/A		
Antenna pattern	omni	omni		
Feeder loss	N/A	N/A		
base station output power 5 MHz	24 dBm	24 dBm		
Maximum base station antenna gain	5 dBi	0 dBi		
Maximum base station output power (e.i.r.p)	29 dBm	24 dBm		

In the Figures below the red pixels show where the long-term interference criterion would be exceeded and the yellow pixels show where the short-term interference criterion would be exceeded.

4.3 Results for Brookmans Park earth station

FIGURE A8-5

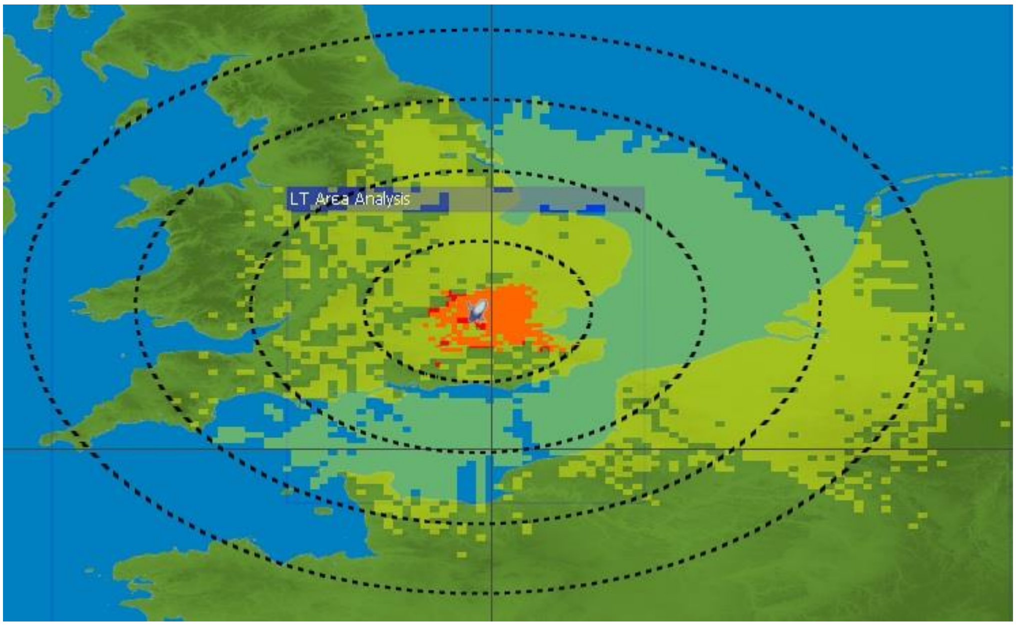
Protection zone for Brookmans Park earth station with respect to Macro Suburban (1)



NOTE – The black dotted circles are radius 100, 200, 300 and 400 km.

FIGURE A8-6

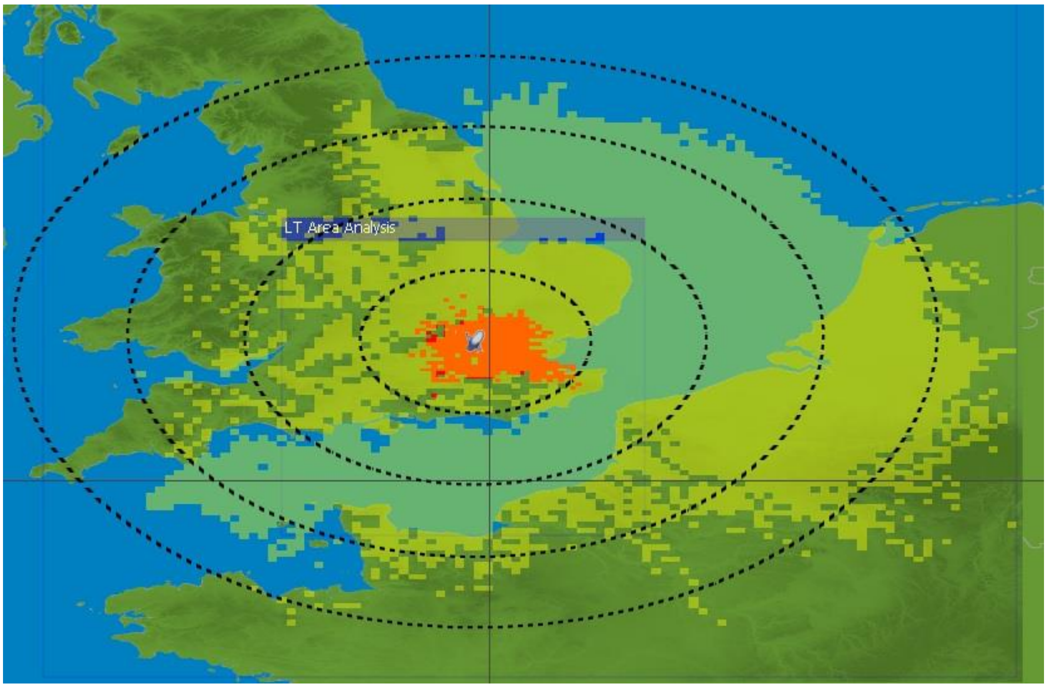
Protection zone for Brookmans Park earth station with respect to Macro Suburban (2)



NOTE – The black dotted circles are radius 100, 200, 300 and 400 km.

FIGURE A8-7

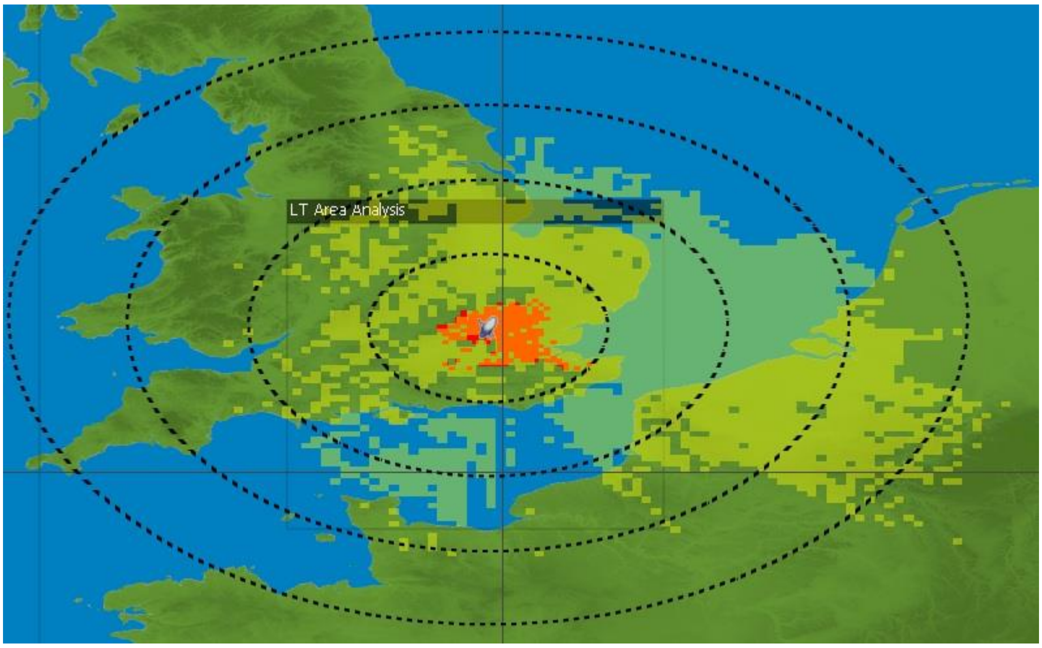
Protection zone for Brookmans Park earth station with respect to Macro Urban (1)



NOTE – The black dotted circles are radius 100, 200, 300 and 400 km.

FIGURE A8-8

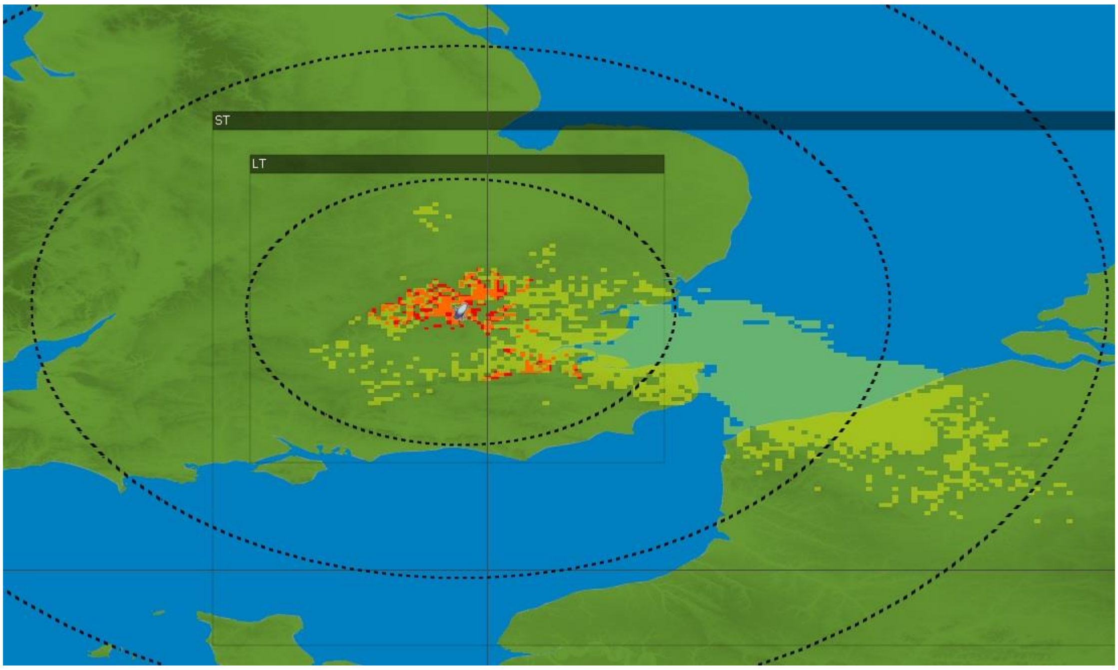
Protection zone for Brookmans Park earth station with respect to Macro Urban (2)



NOTE – The black dotted circles are radius 100, 200, 300 and 400 km.

FIGURE A8-9

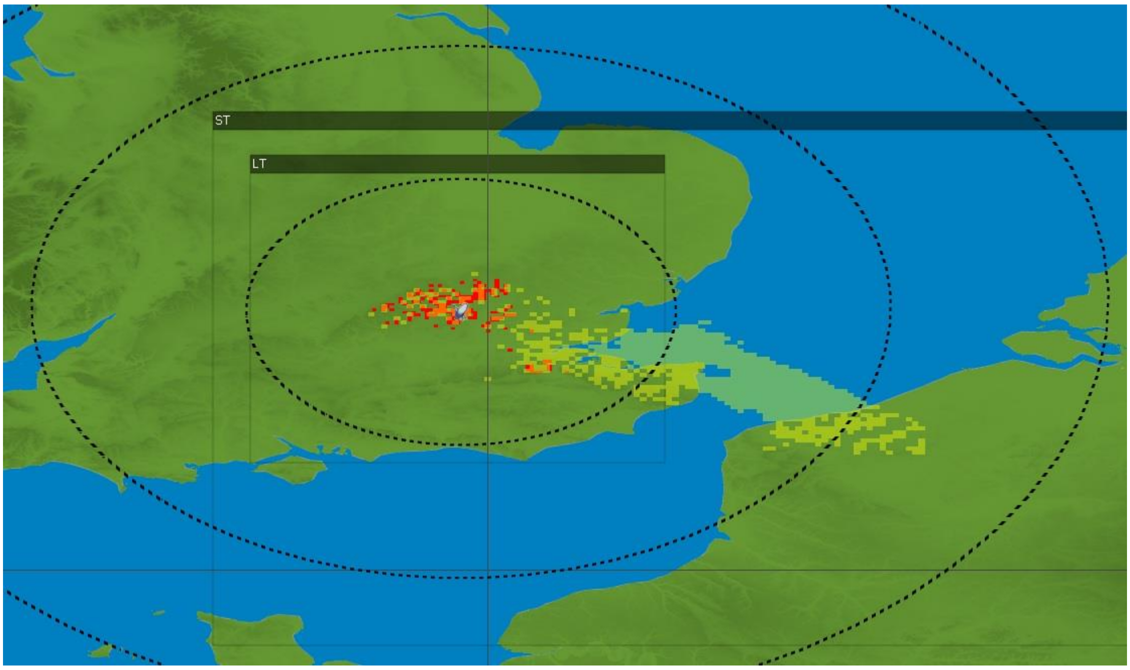
Protection zone for Brookmans Park earth station with respect to Small Cell Outdoor



NOTE – The black dotted circles are radius 100, 200 and 300 km.

FIGURE A8-10

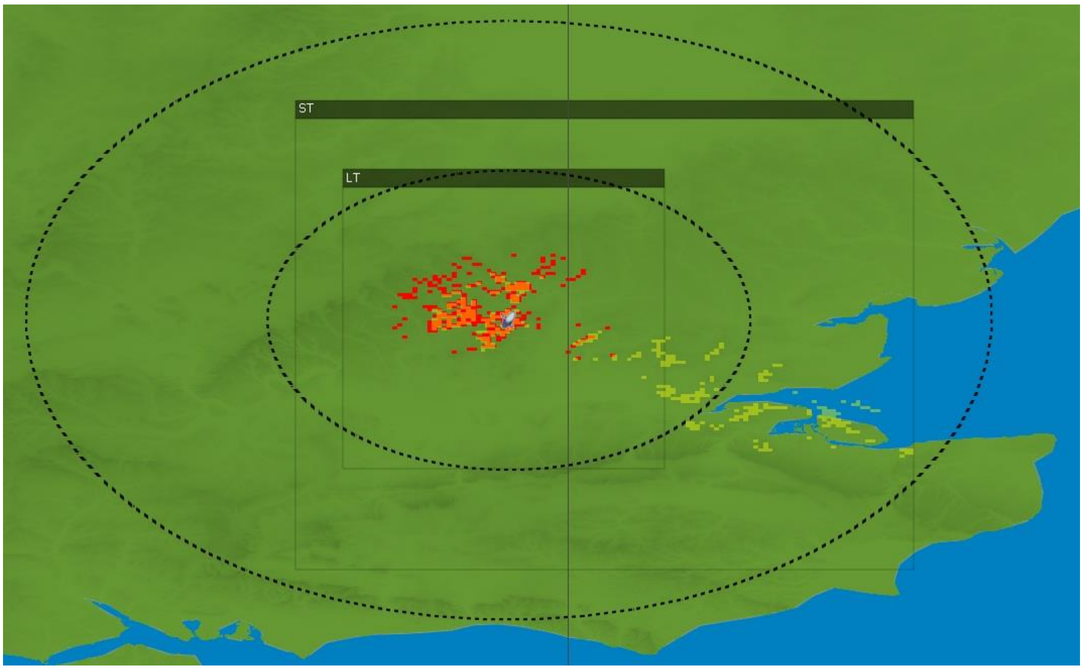
Protection zone for Brookmans Park earth station with respect to Small Cell Indoor (1)



NOTE – The black dotted circles are radius 100, 200 and 300 km.

FIGURE A8-11

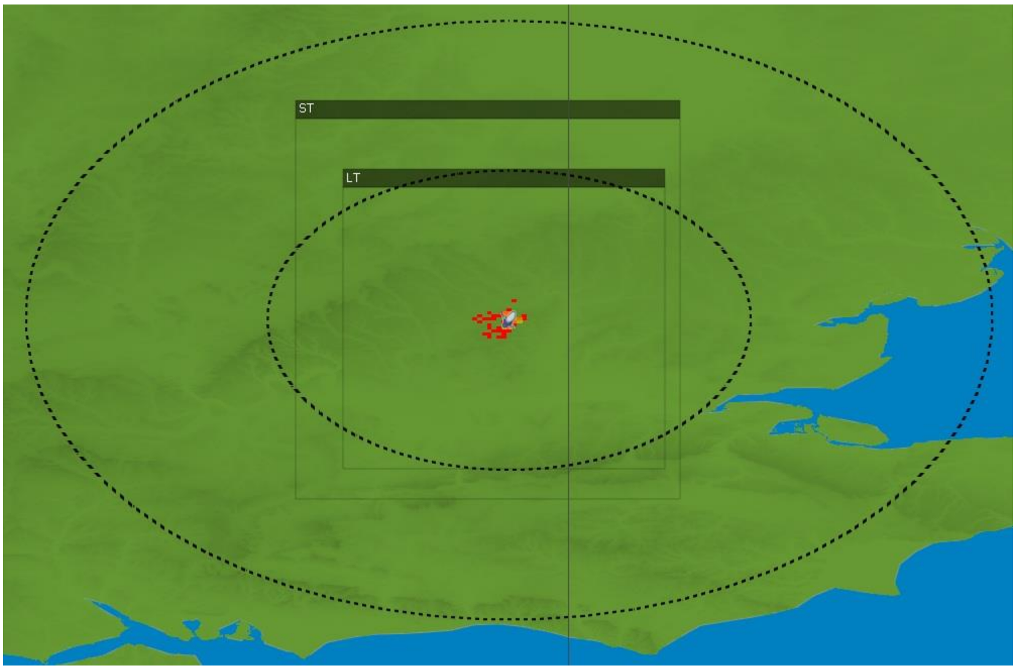
Protection zone for Brookmans Park earth station with respect to Small Cell Indoor (2)



NOTE – The black dotted circles are radius 50 and 100 km.

FIGURE A8-12

Protection zone for Brookmans Park earth station with respect to Small Cell Indoor (3)

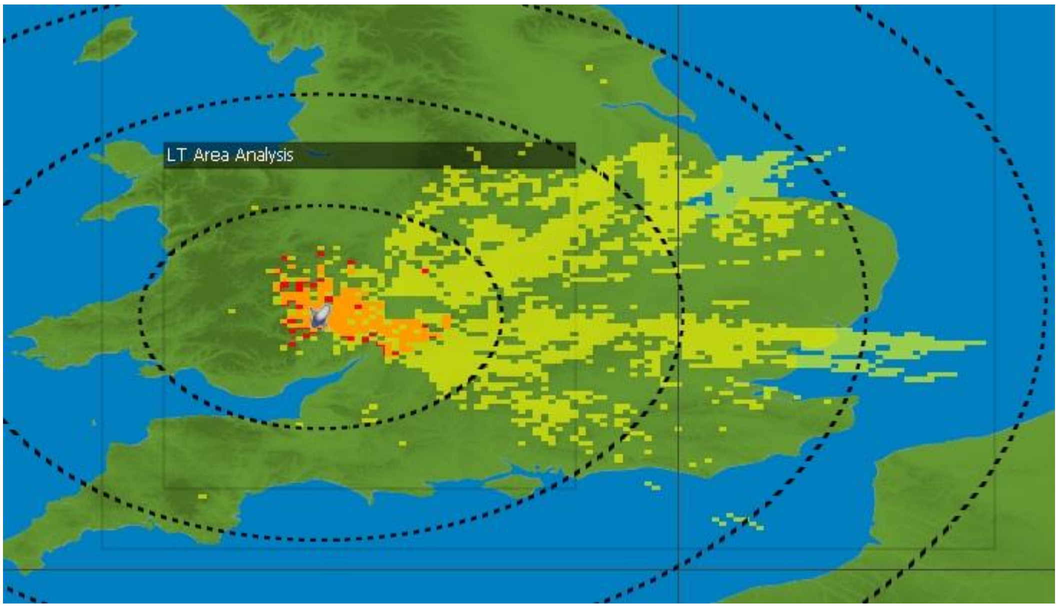


NOTE – The black dotted circles are radius 50 and 100 km.

4.4 Results for the Madley earth station

FIGURE A8-13

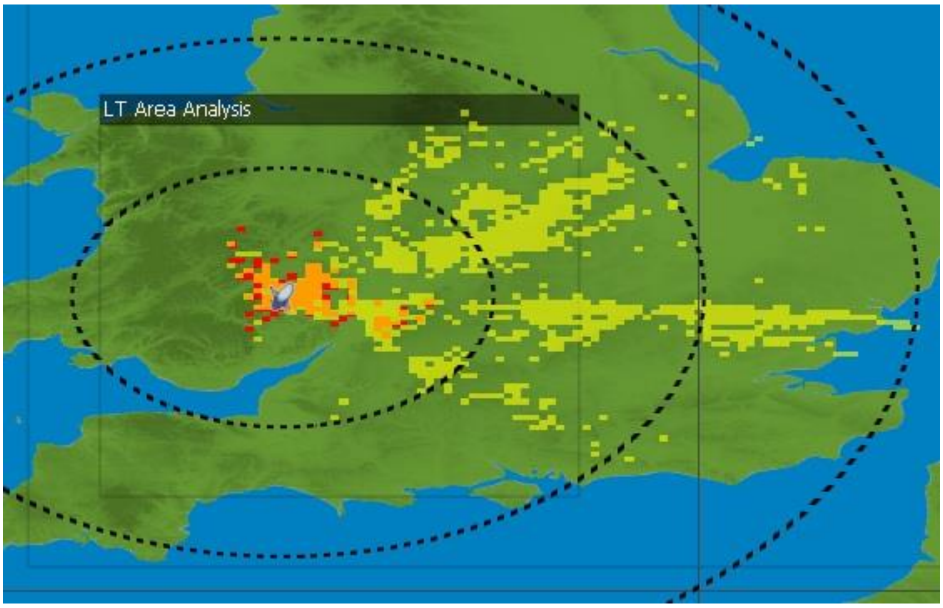
Protection zone for Madley earth station with respect to Macro Suburban (1)



NOTE – The black dotted circles are radius 100, 200, 300 and 400 km.

FIGURE A8-14

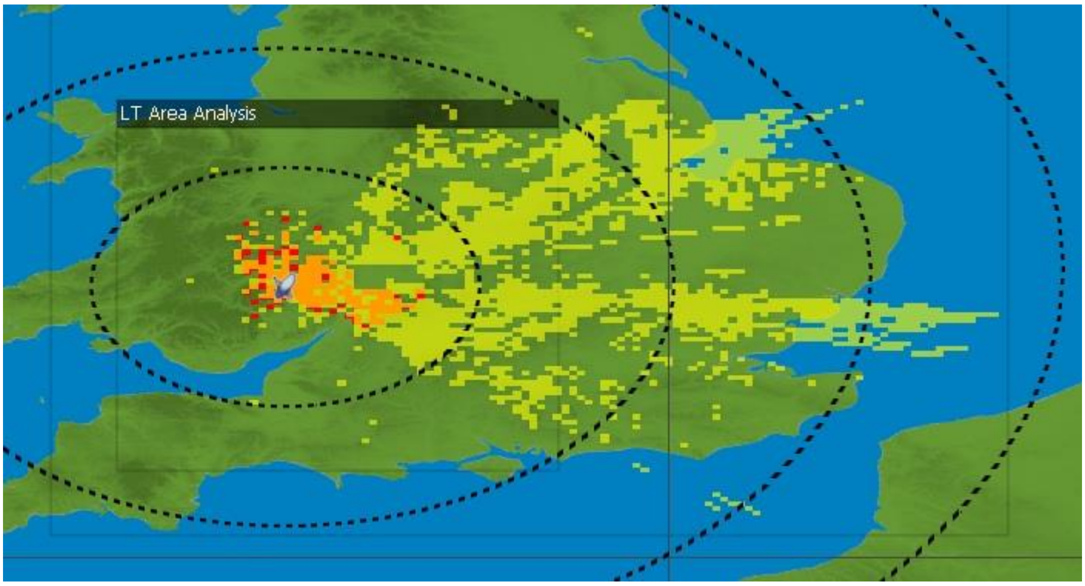
Protection zone for Madley earth station with respect to Macro Suburban (2)



NOTE – The black dotted circles are radius 100, 200 and 300 km.

FIGURE A8-15

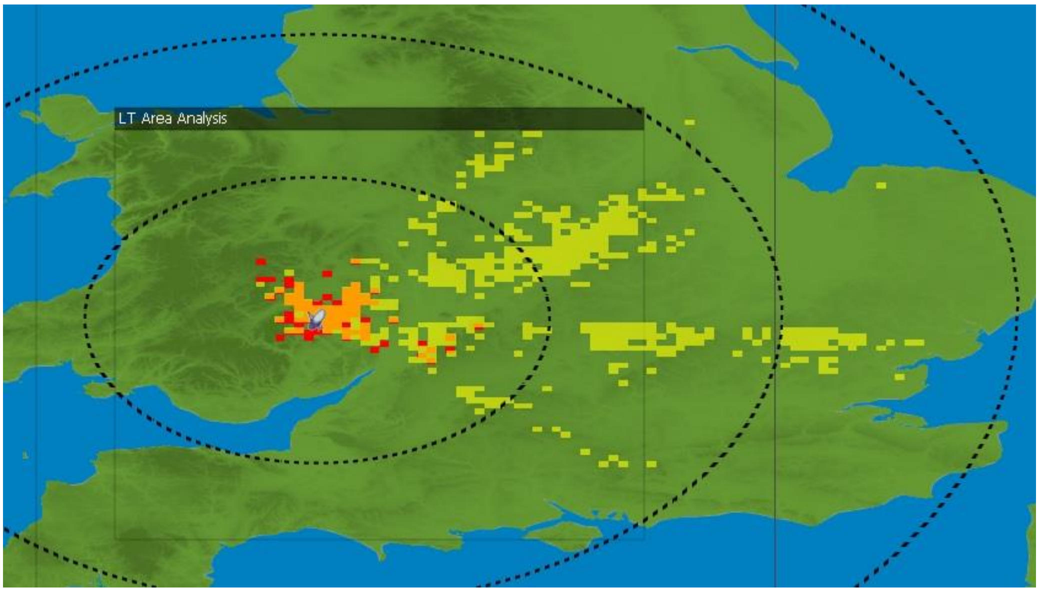
Protection zone for Madley earth station with respect to Macro Urban (1)



NOTE – The black dotted circles are radius 100, 200, 300 and 400 km.

FIGURE A8-16

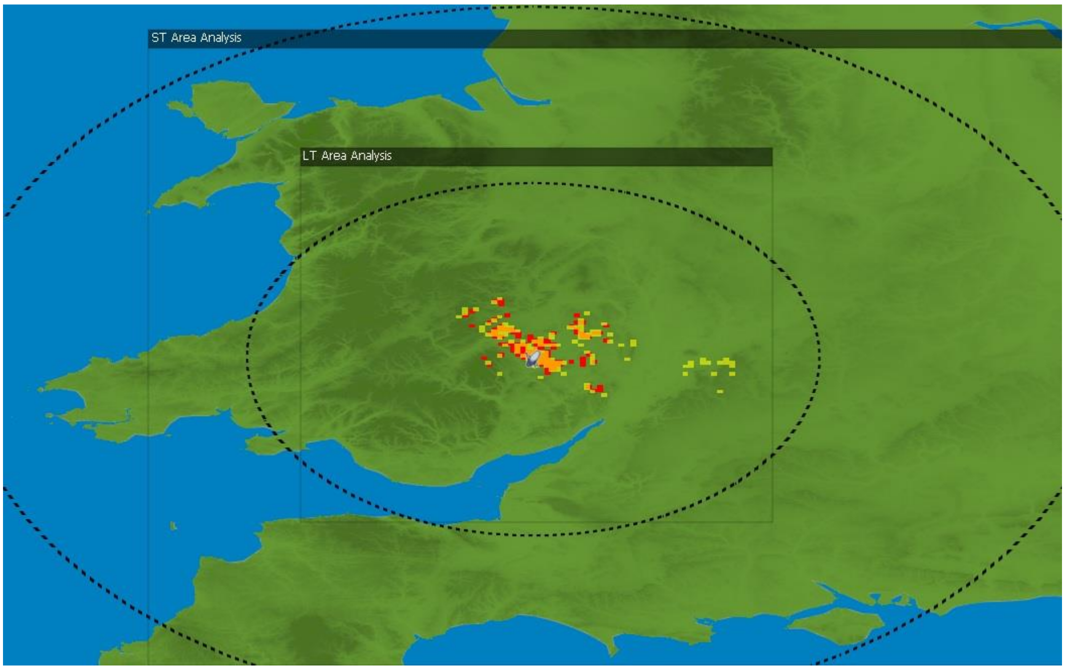
Protection zone for Madley earth station with respect to Macro Urban (2)



NOTE – The black dotted circles are radius 100, 200 and 300 km.

FIGURE A8-17

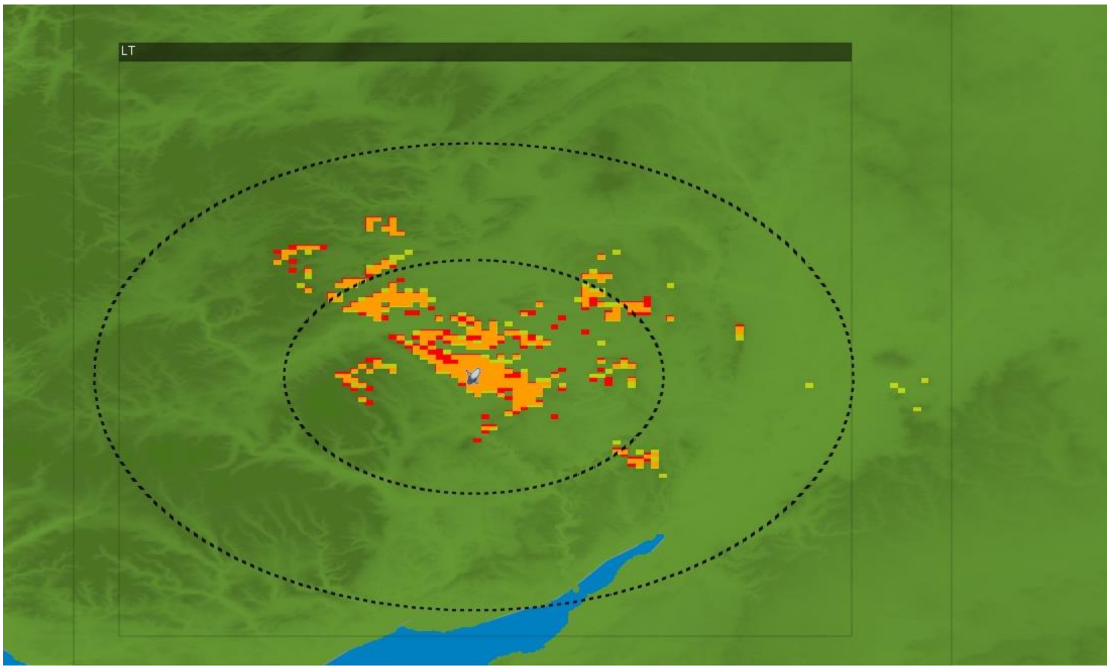
Protection zone for Madley earth station with respect to Small Cell Outdoor



NOTE – The black dotted circles are radius 100 and 200 km.

FIGURE A8-18

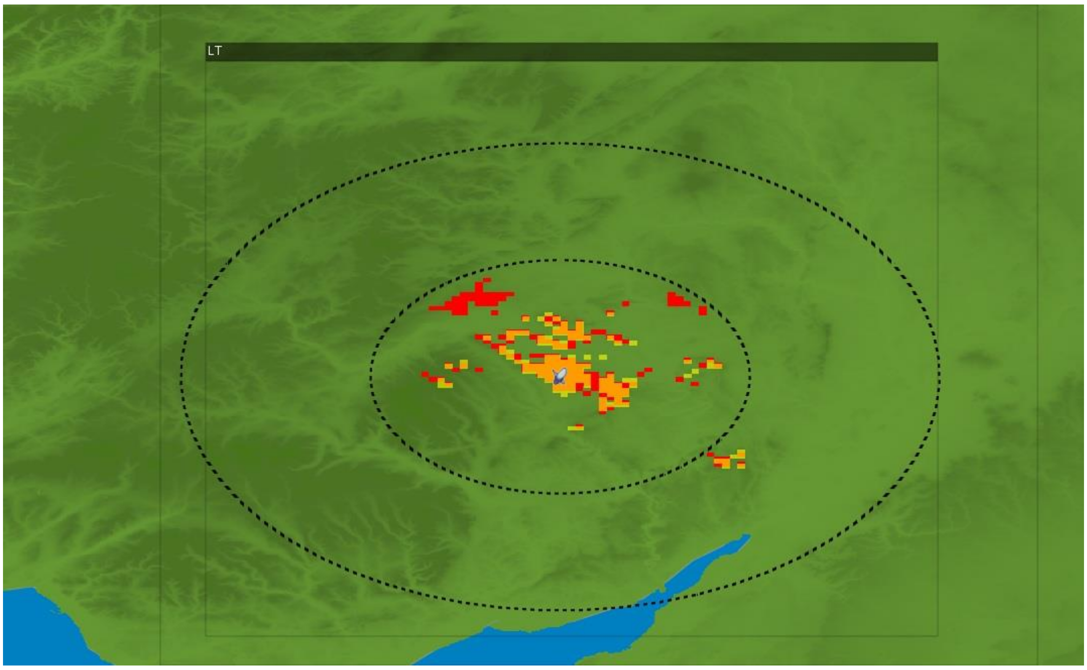
Protection zone for Madley earth station with respect to Small Cell Indoor (1)



NOTE – The black dotted circles are radius 25 and 50 km.

FIGURE A8-19

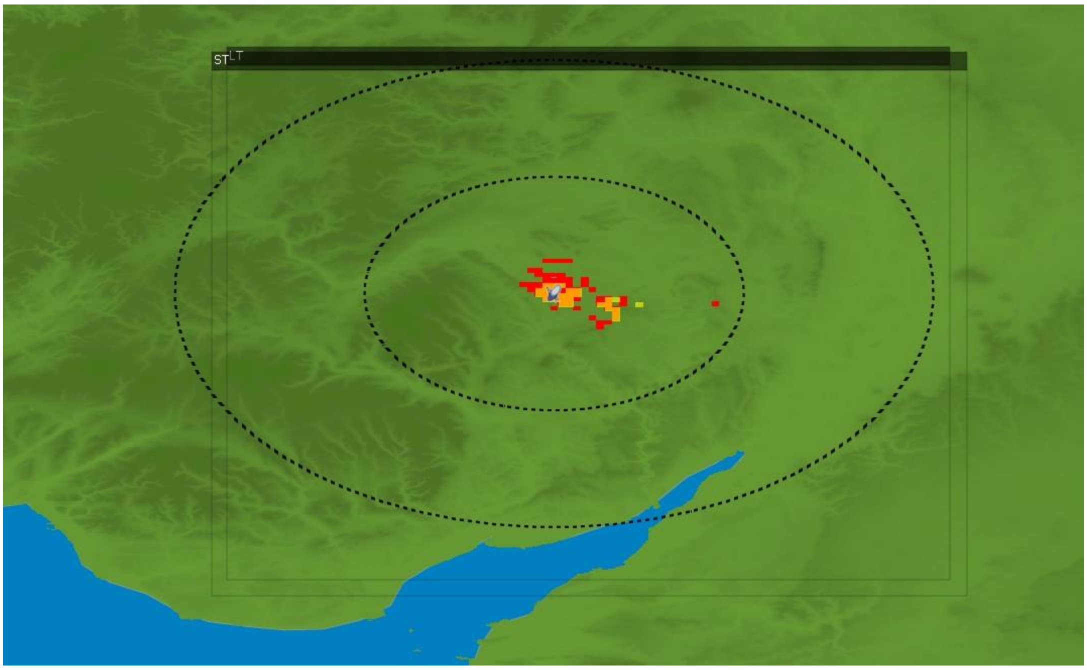
Protection zone for Madley earth station with respect to Small Cell Indoor (2)



NOTE – The black dotted circles are radius 25 and 50 km.

FIGURE A8-20

Protection zone for Madley earth station with respect to Small Cell Outdoor (3)

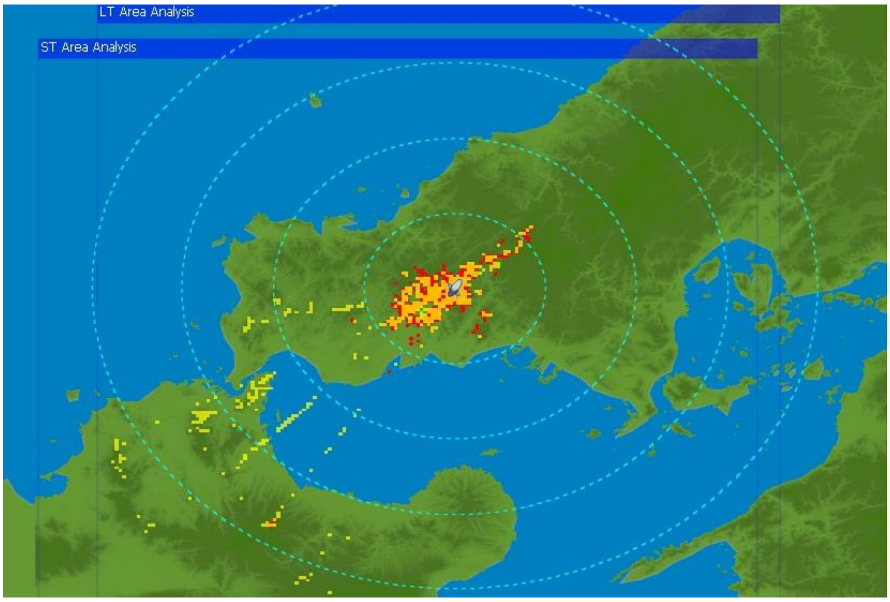


NOTE – The black dotted circles are radius 25 and 50 km.

4.5 Results for the Yamaguchi earth station

FIGURE A8-21

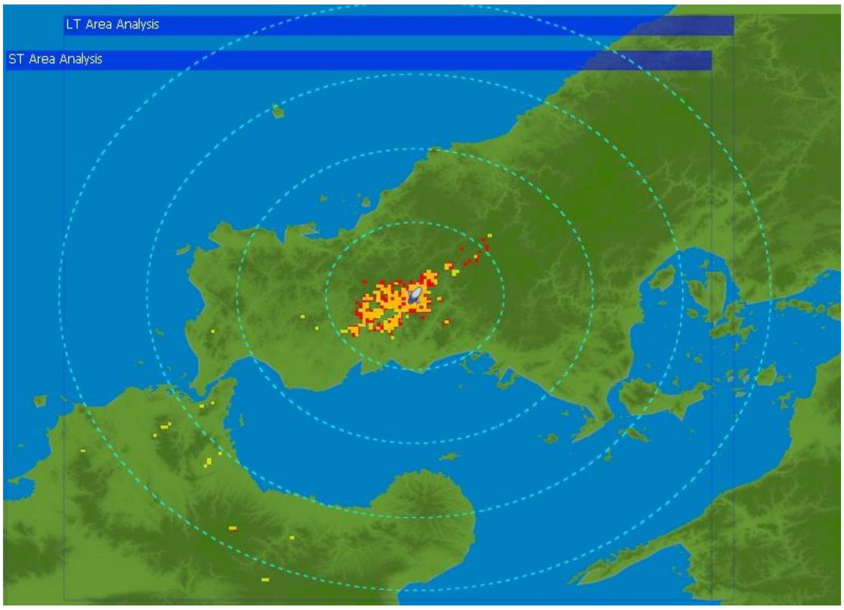
Protection zone for Yamaguchi earth station with respect to Macro Suburban (1)



NOTE – The blue dotted circles are radius 25, 50, 75 and 100 km.

FIGURE A8-22

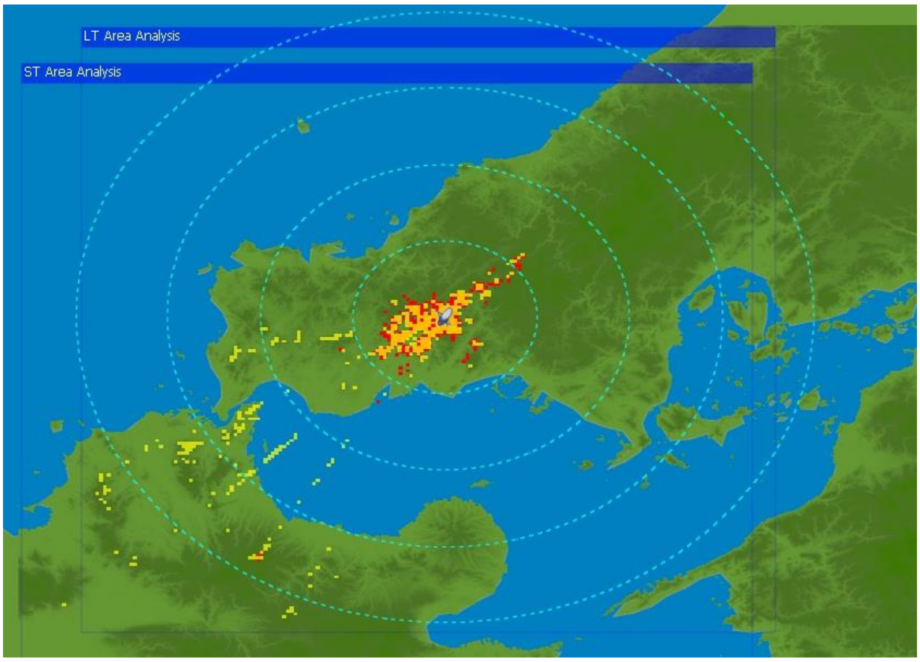
Protection zone for Yamaguchi earth station with respect to Macro Suburban (2)



NOTE – The blue dotted circles are radius 25, 50, 75 and 100 km.

FIGURE A8-23

Protection zone for Yamaguchi earth station with respect to Macro Urban (1)



NOTE – The blue dotted circles are radius 25, 50, 75 and 100 km.

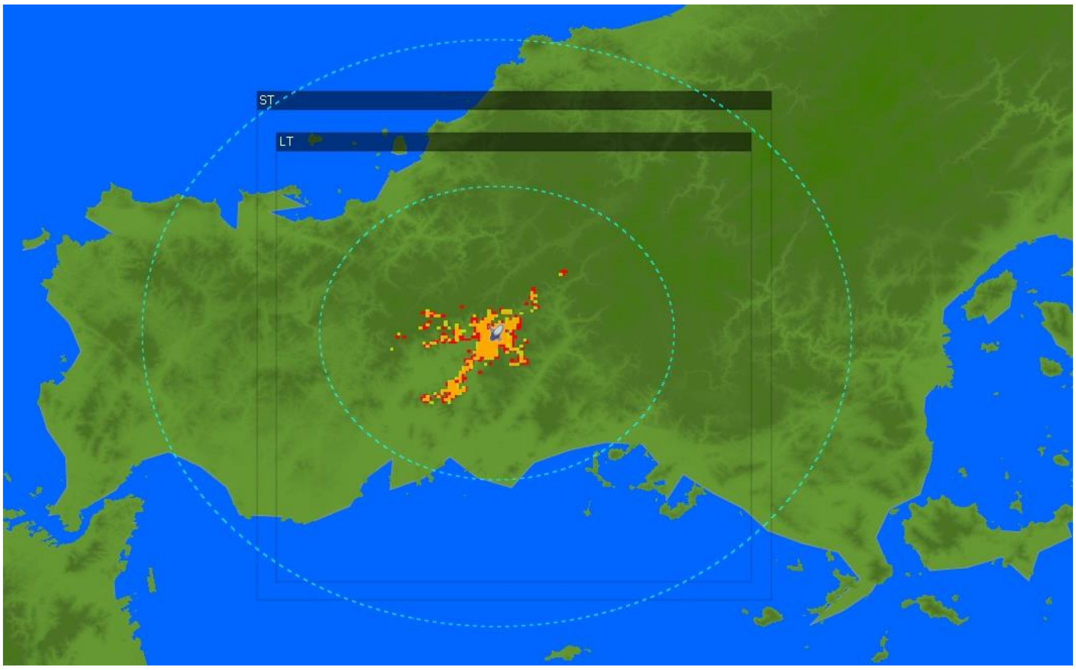
FIGURE A8-24

Protection zone for Yamaguchi earth station with respect to Macro Urban (2)

NOTE – The blue dotted circles are radius 25, 50, 75 and 100 km.

FIGURE A8-25

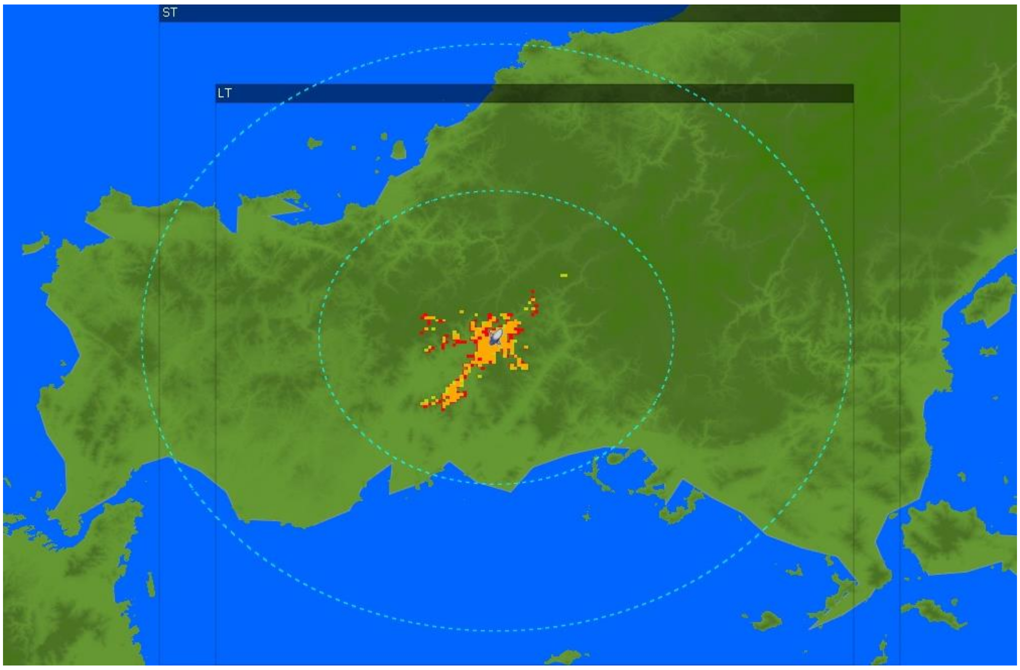
Protection zone for Yamaguchi earth station with respect to Small Cell Outdoor



NOTE – The blue dotted circles are radius 25 and 50 km.

FIGURE A8-26

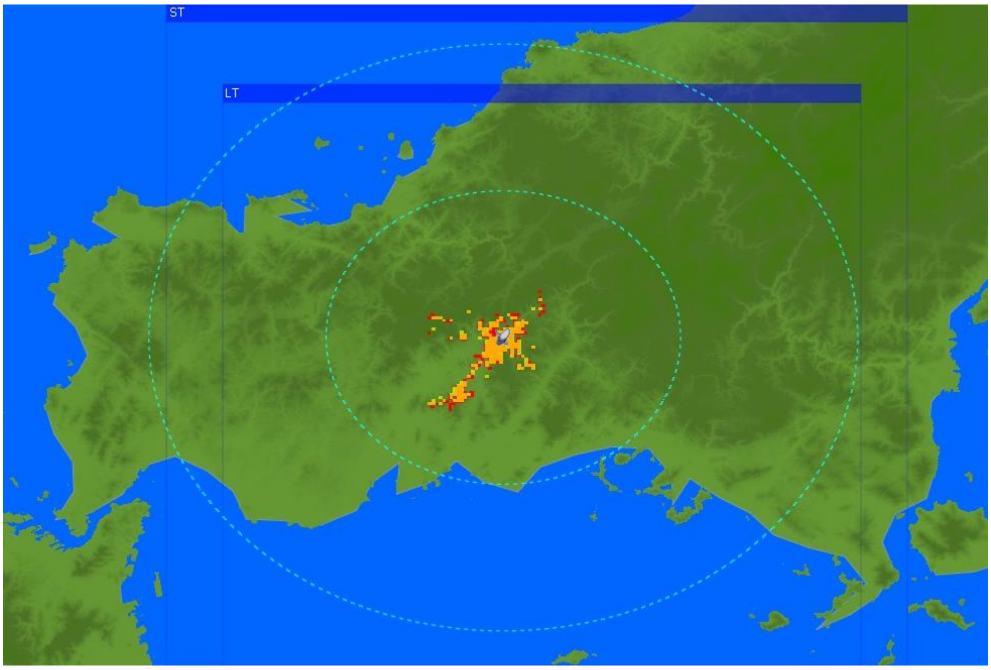
Protection zone for Yamaguchi earth station with respect to Small Cell Indoor (1)



NOTE – The blue dotted circles are radius 25 and 50 km.

FIGURE A8-27

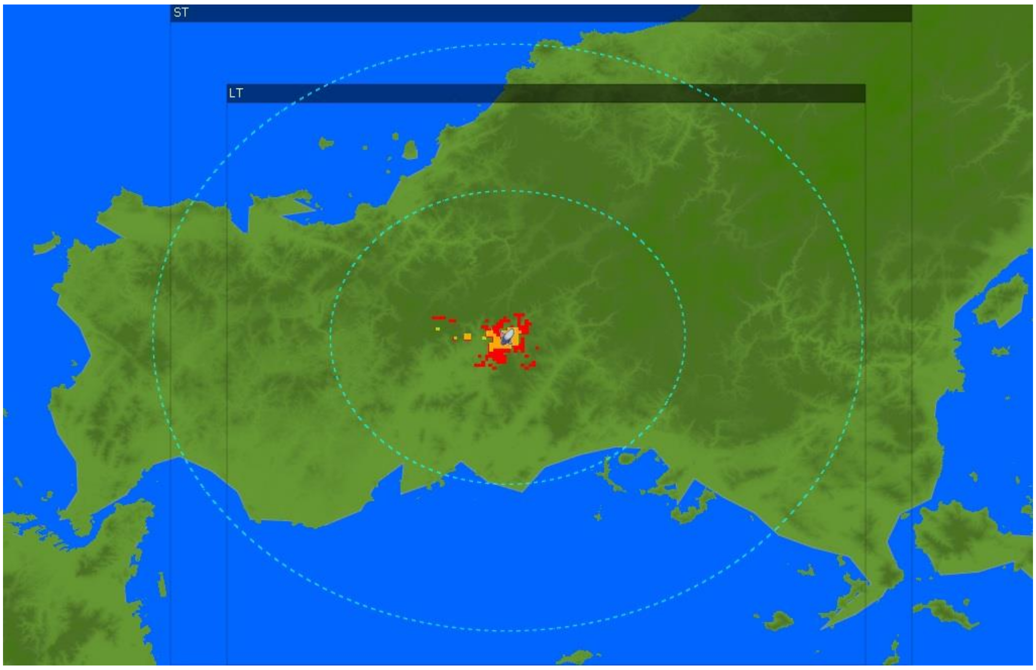
Protection zone for Yamaguchi earth station with respect to Small Cell Indoor (2)



NOTE – The blue dotted circles are radius 25 and 50 km.

FIGURE A8-28

Protection zone for Yamaguchi earth station with respect to Small Cell Indoor (3)



NOTE – The blue dotted circles are radius 25 and 50 km.

5 Summary

The results in § 4.1 indicate that in comparison with the assumptions used in Report ITU-R M.2109, the use of the new IMT-Advanced system characteristics and the use of the latest version of propagation model Recommendation ITU-R P.452 lead to larger separation distances.

The results for the three example earth stations shown in § 4.2 are summarised in the following table.

IMT-Advanced station	Brookmans Park	Madley	Yamaguchi
Macro suburban (1)	Maximum separation distance = about 450 km on partly over-sea path, about 350 km on overland path	Maximum separation distance = about 350 km on partly over-sea path, about 300 km on overland path	Maximum separation distance = about 110 km on partly over-sea path, about 60 km on overland path. Almost all locations > 25 km from the earth station are acceptable.
Macro suburban (2)	Maximum separation distance = about 450 km on partly over-sea path, about 300 km on overland path	Maximum separation distance = about 300 km on partly over-sea path, about 270 km on overland path	Maximum separation distance = about 110 km on partly over-sea path, about 60 km on overland path. Almost all locations > 25 km from the earth station are acceptable.
Macro urban (1)	Maximum separation distance = about 450 km on partly over-sea path, about 350 km on overland path	Maximum separation distance = about 350 km on partly over-sea path, about 300 km on overland path	Maximum separation distance = about 125 km on partly over-sea path, about 60 km on overland path. Almost all locations > 25 km from the earth station are acceptable.
Macro urban (2)	Maximum separation distance = about 420 km on partly over-sea path, about 250 km on overland path	Maximum separation distance = about 250 km (on overland path)	Maximum separation distance = about 90 km on partly over-sea path, about 25 km on overland path. Almost all locations > 25 km from the earth station are acceptable.
Small cell outdoor	Maximum separation distance = about 300 km on a partly over-sea path, about 120 km on an overland path	Maximum separation distance = about 70 km (on overland path)	Maximum separation distance = about 15 km
Small cell indoor (1)	Maximum separation distance = about 240 km on a partly over-sea path, about 120 km on an overland path	Maximum separation distance = about 55 km (on overland path)	Maximum separation distance = about 15 km

IMT-Advanced station	Brookmans Park	Madley	Yamaguchi
Small cell indoor (2)	Maximum separation distance = about 90 km on an overland path	Maximum separation distance = about 30 km (on overland path)	Maximum separation distance = about 15 km
Small cell indoor (3)	Maximum separation distance = about 7 km, on an overland path	Maximum separation distance = about 20 km (on overland path)	Maximum separation distance = about 10 km

These example earth stations have very different levels of natural shielding which lead to quite different results. Considering macro IMT base stations, in the best case of these examples, a maximum separation distance of more than 100 km may be required and in the worst case of these examples, a maximum separation distance of more than 450 km may be required. Considering small cell IMT base stations, in the best case of these examples, the maximum separation distances is about 7 km. In the worst case of these examples, the maximum separation distances is about 300 km for a partly oversea path, and is about 120 km for a fully overland path.

The operation of IMT base stations at closer distances is feasible in many cases as a consequence of additional terrain shielding. In principle, it might be possible to coordinate IMT macro cell base stations with FSS earth stations. However in practice, large holes would have to exist in the IMT coverage as a consequence of the exclusion areas around each earth station. If earth stations are located within a few hundred kilometres of one-another, the exclusion areas would join up, creating even larger exclusion areas.

IMT small cells require smaller separation distances than macro cells, but the maximum separation distances are still tens and sometimes hundreds of kilometers. It is not clear whether coordination of IMT small cell base stations is a viable proposition considering: a) the very large number (potentially millions) of base stations that would be required to achieve good coverage; and b) that IMT small cells might be installed in individual homes and offices by the home owners and office workers – not by specialist radio engineers.

These distances also demonstrate the difficulties that could be faced for the deployment of new FSS earth stations in or near to countries which have deployed IMT systems in this band. If IMT base stations were to be deployed in this band, new earth stations would need to be separated by the same distances of tens or hundreds of kilometers.

6 Conclusions

The study in § 4 has shown that when comparing with the studies contained in Report ITU-R M.2109, the new analysis leads to larger separation distances. This is most likely due to the higher e.i.r.p. spectral density now assumed for the IMT-Advanced base station.

Based on results presented for IMT-Advanced macro cell and small cell base stations, and considering the widespread deployment of FSS earth stations throughout the world, the band 3 400-4 200 MHz is not a practical band for identification for IMT.

Annex 9

Study #9

1 Introduction

This document looks at interference from IMT base stations into a small FSS dish that may be ubiquitously deployed in some urban areas for the delivery of VSAT services.

The study considers IMT stations operating in part of the band adjacent to the band used by the FSS. An earth station location have been arbitrarily selected and two satellite locations have been looked at that give low and typical elevation angles.

The aim of the study is to quantify the size of guard band needed to reduce the calculated interference level to below the coordination trigger level. The adjacent band advantage from a convolution of an IMT transmit emission mask and an FSS receiver sensitivity mask has been calculated. The convolution is a function of the frequency separation or guard band.

This convolution gives a number called Net Filter Discrimination (NFD), and the calculation of the NFD is explained briefly in § 3.4. This number is fixed for each pair of masks and each value of frequency separation.

This preliminary study considers a small set of variables which are considered parametric and useful for further study and sensitivity analysis:

– Minimum centre frequency separation (or alternatively, size of guard band);
– IMT transmit emissions mask;
– FSS receive mask;
– FSS carrier bandwidth;
– IMT carrier bandwidth.

2 Technical characteristics

Scenario description

The scenario modelled is high rise urban case in which a single test point FSS small dish is placed at the centre of a deployment of IMT base stations that extends to a radius of 3 km.

The IMT networks considered include a macro network and a network of outdoor small cells. Each is modelled separately.

Each IMT macro base station is assumed to have 3 sectors with one antenna pointing directly on an azimuth towards the FSS station, with a downtilt angle of 10° (for the macro base station). This is a pessimistic assumption.

The outdoor small cell base stations are assumed to have omnidirectional antennas with 5 dB gain.

Each IMT station has a transmit carrier in a 10 MHz channel with a given separation from a 36 MHz FSS channel.

The aggregate interference into the FSS receiver on a co-channel basis is calculated and then an adjustment based on the pre-calculated NFD for each pair of transmit and receive masks and for each value of guard band is applied.

The calculation is compared to a long-term I/N threshold of −20 dB.

2.1 FSS earth station, satellite and link

The following parameters are used to represent a typical small dish in a high rise urban environment. Two operational satellite locations have been considered – one gives a very low elevation angle of 5° and the other a more typical angle of 27.5°.

Location – 25.73° S, 28.22° E (Pretoria, South Africa)

Operating satellite locations – 100.5° E and 22° W

Antenna height – 35 metres above terrain

Calculated link angles

Link to 100.5° E – elevation = 5°, azimuth = 84.17°

Link to 22° W – elevation = 27.5°, azimuth = −70.12°

Antenna performance

Recommendation ITU-R S.465*

Dish Size = 1.8 m

Efficiency = 65%

Link temperature = 100 K

2.1.1 FSS receive sensitivity mask

Two options for modelling the FSS receive channel have been considered –both are very conservative and are used in the absence of better information.

The first option is based on Reference [1][23], a study reported by IDA Singapore. In that study a 36 MHz channel is simulated and the receive filter mask is derived by superimposing an rf bandpass filter on an assumed IF surface acoustic wave filter.

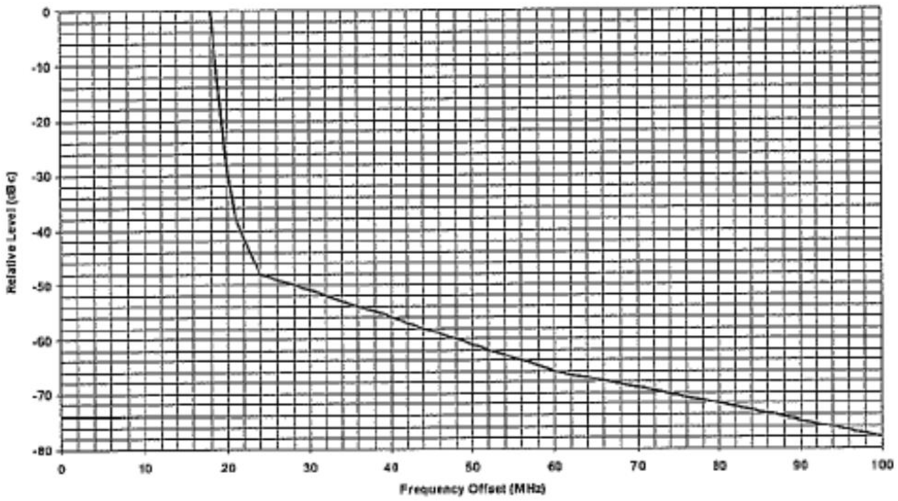
The Figure below shows the relative mask (dBc) as a function of offset from the centre frequency – which is assumed to be symmetric.

This mask has a reasonably fast roll off at the channel edge but is defined over a range of frequencies approximately 5 times the nominal bandwidth.

[23] [1] “Project WIFSS, Test Report of Potential Interference of WBA on FSS in Singapore”, R-J6375-TR002.

FIGURE A9-1

36 MHz channel FSS receive mask sourced from the study in Reference 1



The following table gives the values that are used in the calculations:

TABLE A9-1

FSS receive filter mask from Reference 1

Frequency offset (MHz)	Relative sensitivity (dBc)
0	0
18	0
19	−15
20	−30
24	−48
50	−61
100	−78

Another approach that may be applied to different bandwidth channels is to assume a Gaussian roll off with a −30 dB point at twice the channel bandwidth. This mask is given for a 36 MHz channel in the table below:

TABLE A9-2

FSS receive filter mask based on a Gaussian filter

Frequency offset (MHz)	Relative sensitivity (dBc)
0	0
2.4	0.13
4.8	−0.51
7.2	−1.16
9.6	−2.06
12	−3.22
14.4	−4.63
16.6	−6.31
19	−8.24
21.4	−10.42
23.8	−12.87
26.2	−15.57
28.6	−18.53
31	−21.75
33.4	−25.22
36	−28.95

2.2 IMT parameters

For this study, the base station macro and micro parameters summarized in the table below is used. These parameters are taken from Table D of Report ITU-R M.2292.

TABLE A9-3

IMT base station parameters

Base station characteristics	Macro urban	Small cell outdoor
Cell radius	0.3 km	1 per macro site
Antenna height	20 m	6 m
Antenna pattern	Recommendation ITU-R F.1336 k_a = 0.7	Recommendation ITU-R F.1336 omni
Sectorization	3-sectors	single sector
Downtilt	10 degrees	N/A
Frequency reuse	1	1
Antenna polarization	linear /±45 degrees	Linear
Below rooftop base station antenna deployment	50%	100%
Maximum base station output power (10 MHz)	46 dBm	24 dBm

TABLE A9-3 (*end*)

Base station characteristics	Macro urban	Small cell outdoor
Maximum base station antenna gain	18 dBi	5 dBi
Average base station activity	50%	50%
Average base station e.i.r.p. (to be used in sharing studies)	58 dBm	26 dBm

2.2.1 Unwanted emissions from IMT base stations

In this study, the unwanted emissions are modelled through the use of transmit emission masks. The baseline mask is defined in a 3GPP Standard (3GPP TS 36 104).

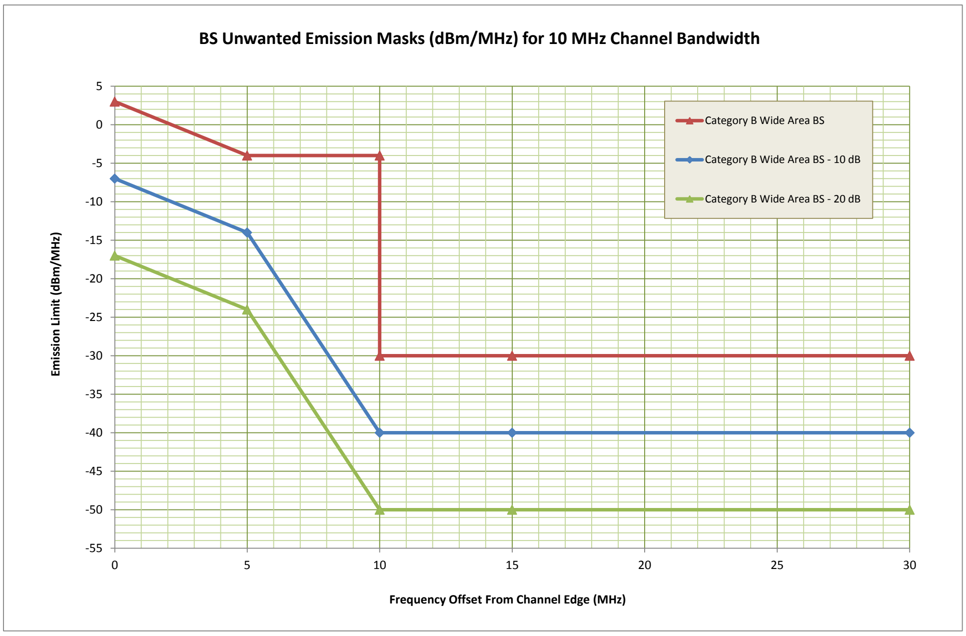
This mask is considered conservative and actual equipment will be better than this. Consequently, the following mask is used and the far out of band unwanted emissions level are treated as a study parameter.

In order to consider the implications of practical unwanted emissions from IMT BS, additional masks have been generated by suppressing the 3GPP masks by 10 and 20 dB. These masks have also been used in the analysis.

The Figure below shows these masks as dBm/MHz from the –3 dB point of the main lobe of the mask. A flat main lobe is considered and these masks are applied from the nominal carrier bandwidth.

FIGURE A9-2

3GPP mask and modified masks used for IMT base stations



The table below give the relative mask values as a function of offset from the centre frequency, for the 10 MHz carrier we are using in our study:

TABLE A9-4

IMT base station transmit emission masks

	Macro base stations			Outdoor small cells		
Frequency off-set	**3GPP**	**3GPP − 10 dB**	**3GPP − 20 dB**	**3GPP**	**3GPP − 10 dB**	**3GPP − 20 dB**
−50	−81	−91	−101	−49	−59	−69
−30	−81	−91	−101	−49	−59	−69
−15.1	−81	−91	−101	−49	−59	−69
−15	−55	−65	−75	−23	−33	−43
−10	−55	−65	−75	−23	−33	−43
−5.1	−55	0	0	−23	0	0
−5	−48	0	0	−16	0	0
−4.99	0	0	0	0	0	0
0	0	0	0	0	0	0
4.99	0	0	0	0	0	0
5	−48	0	0	−16	0	0
5.1	−55	0	0	−23	0	0
10	−55	−65	−75	−23	−33	−43
15	−55	−65	−75	−23	−33	−43
15.1	−81	−91	−101	−49	−59	−69
30	−81	−91	−101	−49	−59	−69
50	−81	−91	−101	−49	−59	−69

3 Analysis – Method

A deployment of IMT base stations around a single FSS test point earth station have been simulated. The aggregate interference level from these base stations is calculated under various combinations of assumptions and parameter variations.

The baseline case assumes FSS and IMT operate in different but adjacent parts of the band and that the IMT carrier is at top end of its sub-band and the FSS carrier at the bottom of its sub-band, i.e. the guard band is zero.

This baseline case also uses the 3GPP mask for the IMT base station.

The FSS elevation angle is a parameter in the study and the base line case uses values of 27.5° and 5°.

The IMT base stations are deployed on a hexagonal grid. All are assumed initially to be co-frequency in order to calculate a reference baseline *I/N*.

3.1 Propagation

Recommendation ITU-R P.452-14 without terrain is used. No detailed clutter database is available, but the scenario is a dense urban location and so a single figure for local clutter loss based on the high rise urban parameters in the table below, which is taken from Recommendation ITU-R P.452-14, is included.

TABLE A9-5

Nominal clutter heights and distances from Recommendation ITU-R P.452-14

Clutter (ground-cover) category	Nominal height, h_a (m)	Nominal distance, d_k (km)
High crop fields Park land Irregularly spaced sparse trees Orchard (regularly spaced) Sparse houses	4	0.1
Village centre	5	0.07
Deciduous trees (irregularly spaced) Deciduous trees (regularly spaced) Mixed tree forest	15	0.05
Coniferous trees (irregularly spaced) Coniferous trees (regularly spaced)	20	0.05
Tropical rain forest	20	0.03
Suburban	9	0.025
Dense suburban	12	0.02
Urban	20	0.02
Dense urban	25	0.02
High-rise urban	35	0.02
Industrial zone	20	0.05

Whilst Recommendation ITU-R P.452 is a good propagation model for longer paths, it is known that for shorter paths it may not be appropriate. At this stage there are some other Recommendations in development and these could be investigated for future work.

Recommendation ITU-R P.1546 for instance includes a correction for short urban paths, and currently has some significant changes pending approval for the next revision. These changes address the range of applicability of the model, including distances below 1 km and scenarios where transmit and receive antenna heights are very different.

3.2 Interference thresholds

This study is based on an I/N threshold that would trigger the need for detailed coordination. Following Recommendation ITU-R M.2109 we are considering a long-term value of $I/N = -20$ dB.

Recommendation ITU-R S.1432 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”.

3.3 Study outputs

Two parameters are calculated:

1) the interference level at the output of the FSS antenna;

2) the minimum separation size which would result in no interference above the defined *I/N* threshold.

Each of these is derived as a function of guard band size.

3.4 Net filter discrimination calculation method

The coexistence problem in an adjacent band/channel may occur due to interference associated with transmitter filtering (unwanted emissions) and victim receiver selectivity beyond the edge of its nominal band/channel.

This can generally be modelled in two ways:

1) use continuous masks for transmit spectrum and receiver sensitivity;

2) using single figures for adjacent channel performance —adjacent channel leakage ratio and adjacent channel sensitivity respectively for transmitter and receiver.

In the analysis, the continuous masks are used and in this way, it is possible to consider the guard band to be a continuous variable – rather than consider only discreet ‘channels’.

3GPP TS 36.104 provides the specification for the emission masks that any IMT transmitter should be able to satisfy. Figure A9-2 summarizes the specification values.

The approach used to assess the effect of increasing guard band is to calculate the NFD based on a convolution of the transmit and receive masks defined above.

NFD allows to parameterize the guard band size as a continuous variable. For a fixed value of frequency separation the NFD is a single figure and is calculated in our software implementation in the following way:

1) the transmit mask is defined as the relative power density compared to in-band: in other words as a table it would be defined in dB while in the integration the units would be an absolute ratio;

2) the receive mask is defined as the relative attenuation of the receive signal compared to in-band: in other words as a table it would be defined in dB while in the integration the units would be an absolute ratio.

Both the transmit and receive masks are defined using tables with linear interpolation in dB between each point and hence can be modelled as a set of straight lines with equation (in dBs):

$$y_{tx} = a_{tx} + b_{tx} f$$

$$y_{rx} = a_{rx} + b_{rx} f$$

In which case the NFD is:

$$NFD = \sum_{f_{\min}}^{f_{\max}} NFD[f_1, f_2]$$

where:

$$NFD[f_1, f_2] = \frac{10^P}{Q'}\left(e^{Q'f_2} - e^{Q'f_1}\right)$$

and:

$$P = (a_{tx} + a_{rx})/10$$

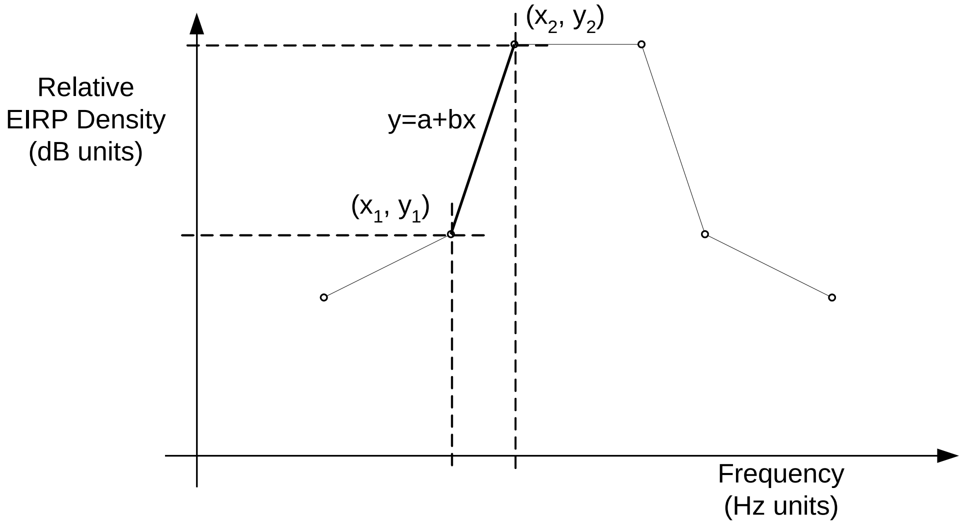
$$Q = (b_{tx} + b_{rx})/10$$

$$Q' = \ln(10).(b_{tx} + b_{rx})/10$$

Note that in general the values of *a* and *b* are not user-entered but are derived from a set of values at specific points, as in the Figure below, and as given in Tables A9-1, A9-2 and A9-4 above.

FIGURE A9-3

Example mask with interpolation



The integration technique is not unique and there are three widely used formats that are available in the software we have used:

Integrate masks (Classic): Transmit and receive masks integrated and then divided by the transmit bandwidth. This is the correct approach if the TX spectrum mask is referenced to the mean in-band density i.e. 0 dB is when the power density = TX power / occupied bandwidth.

Integrate masks (NFD): Transmit and receive masks integrated and then divided by the integration of the transmit mask. This is the correct approach if the TX spectrum mask 0 dBi point is referenced to the peak power density.

Integrate masks (ETSI): Transmit and receive masks are integrated for the specified frequency offset and then divided by the integral of the TX and RX masks when co-frequency. This is the correct approach to be consistent with the methodology in ETSI TR 101 854 and is sometimes called the Frequency Dependent Rejection or FDR. To adjust for different bandwidth carriers the carrier overlap calculation is included in the adjustment.

In our definitions the masks are relative to the peak power density.

4 Analysis – Results

4.1 Co-frequency baseline results

The *I/N* calculation was first performed assuming co-frequency interference based on a single IMT carrier within the FSS channel. This gives the reference value from which the expected value can then be extrapolated for a range of guard band separations.

TABLE A9-6

Baseline co-frequency single entry and aggregate *I/N* calculated from the outdoor small cell network to the two links that have been analysed

Baseline case	Aggregate interference *I/N*	Worst single entry interference *I/N*
FSS link to 22° W	12.12 dB	3.9 dB
FSS link to 100.5° E	18.77 dB	15.62 dB

TABLE A9-7

Baseline co-frequency single entry and aggregate *I/N* from the macro network calculated to the two links that have been analysed

Baseline case	Aggregate interference *I/N*	Worst single entry interference *I/N*
FSS link to 22° W	46.92 dB	38.72 dB
FSS link to 100.5° E	54.14 dB	51.25 dB

It is interesting to note that in the case of the higher elevation link the difference between the single entry and aggregate *I/N* is larger than in the lower elevation case.

4.2 Net filter discrimination results

The following table shows the net filter discrimination for each pair of masks (2 FSS vs. 3 IMT) as a function of guard band, for the macro base station case. The centre frequency separation is equal to the guard band plus half the bandwidth of each carrier, i.e. guard band plus 23 MHz.

TABLE A9-8

Net filter discrimination calculation for macro base station

	Net filter discrimination (dB)					
Guard band size (MHz)	**Gaussian FSS vs. 3GPP**	**Gaussian FSS vs. 3GPP minus 10 dB**	**Gaussian FSS vs. 3GPP minus 20 dB**	**IDA Study FSS mask vs. 3GPP**	**IDA Study FSS mask vs. 3GPP minus 10 dB**	**IDA Study FSS mask vs. 3GPP minus 20 dB**
0	−16.36	−16.15	−16.17	−48.75	−48.59	−48.75
2	−18.76	−18.52	−18.55	−50.24	−50.66	−50.71
4	−21.32	−21.04	−21.07	−51.48	−51.69	−51.72
6	−23.91	−23.59	−23.63	−52.74	−52.72	−52.72
8	−26.32	−26.00	−26.04	−53.73	−53.72	−53.72
10	−28.18	−27.93	−27.96	−54.73	−54.71	−54.72
12	−29.16	−29.05	−29.07	−55.72	−55.71	−55.72
14	−29.39	−29.39	−29.39	−56.70	−56.71	−56.72
16	−29.54	−29.55	−29.55	−57.69	−57.71	−57.72
18	−30.11	−30.25	−30.24	−58.67	−58.70	−58.71
20	−31.28	−31.37	−31.36	−59.60	−59.66	−59.67
22	−32.82	−32.80	−32.81	−60.48	−60.56	−60.58
24	−35.12	−34.88	−34.90	−61.30	−61.41	−61.43
26	−39.99	−38.75	−38.86	−62.03	−62.19	−62.21
28	−76.40	−57.12	−59.55	−62.69	−62.89	−62.91
30	−76.54	−82.02	−89.34	−63.33	−63.56	−63.59
32	−76.68	−87.05	−97.01	−63.96	−64.24	−64.27
34	−76.82	−87.19	−97.15	−64.59	−64.91	−64.95
36	−76.96	−87.32	−97.29	−65.21	−65.59	−65.63
38	−77.03	−87.39	−97.36	−65.82	−66.26	−66.31
40	−77.03	−87.39	−97.36	−66.42	−66.93	−66.99

The following Table shows the net filter discrimination for each pair of masks (2 FSS vs. 3 IMT) as a function of guard band, for the outdoor small cell base station case.

TABLE A9-9

Net filter discrimination calculation for outdoor small cell base station

	Net filter discrimination (dB)					
Guard band size (MHz)	**Gaussian FSS vs. 3GPP**	**Gaussian FSS vs. 3GPP minus 10 dB**	**Gaussian FSS vs. 3GPP minus 20 dB**	**IDA Study FSS mask vs. 3GPP**	**IDA Study FSS mask vs. 3GPP minus 10 dB**	**IDA Study FSS mask vs. 3GPP minus 20 dB**
0	−16.2024	−15.954	−16.0551	−25.7074	−35.8178	−43.8583
2	−18.5614	−18.2912	−18.4102	−27.7144	−38.0498	−46.233
4	−21.0655	−20.7668	−20.9073	−31.5503	−41.698	−48.8551
6	−23.5969	−23.2887	−23.4476	−42.5131	−50.0627	−52.3413
8	−25.9524	−25.6885	−25.8528	−43.0084	−50.8035	−53.2952
10	−27.8066	−27.6676	−27.8091	−43.0963	−51.2979	−54.1986
12	−28.8535	−28.9045	−28.9911	−43.1585	−51.7296	−55.0786
14	−29.1814	−29.3578	−29.3846	−43.2082	−52.1057	−55.9321
16	−29.3884	−29.5813	−29.5694	−43.248	−52.4293	−56.7542
18	−29.9691	−30.3286	−30.3005	−43.2798	−52.702	−57.5326
20	−31.1043	−31.4002	−31.3921	−43.3045	−52.9251	−58.2459
22	−32.5645	−32.7674	−32.7947	−43.3234	−53.1047	−58.8862
24	−34.6686	−34.687	−34.7894	−43.3378	−53.2476	−59.4489
26	−38.6677	−38.0303	−38.3862	−43.3488	−53.3599	−59.9323
28	−44.4485	−47.6976	−51.226	−43.3571	−53.4474	−60.34
30	−44.5884	−54.4791	−63.6735	−43.3641	−53.5199	−60.7046
32	−44.728	−55.2947	−65.1783	−43.3701	−53.5827	−61.0422
34	−44.8673	−55.434	−65.3176	−43.3753	−53.637	−61.3532
36	−45.0062	−55.5729	−65.4565	−43.3797	−53.684	−61.6381
38	−45.0766	−55.6434	−65.527	−43.3834	−53.7246	−61.8974
40	−45.0766	−55.6434	−65.527	−43.3866	−53.7597	−62.1321

4.3 IMT 3GPP mask vs. Gaussian FSS mask

The following Table shows the aggregate and worst single entry interference that the FSS earth station will see for a range of guard band sizes. This table shows results considering the 3GPP mask for the IMT base station and the Gaussian FSS mask.

TABLE A9-10

Interference to the FSS earth station as a function of guard band – 3GPP IMT mask vs. Gaussian FSS mask

	outdoor small cells		macro network	
Guard band (MHz)	**Aggregate *I/N* long term to FSS link to 22º E (dB)**	**Aggregate *I/N* long term to FSS link to 100.5º W (dB)**	**Aggregate *I/N* long term to FSS link to 22º E (dB)**	**Aggregate *I/N* long term to FSS link to 100.5º W (dB)**
0	−4.17	2.56	30.56	37.78
2	−6.45	0.21	28.16	0.01
4	−8.95	−2.30	25.60	−2.55
6	−11.48	−4.82	23.01	−5.14
8	−13.83	−7.18	20.60	−7.55
10	−15.69	−9.04	18.74	−9.41
12	−16.73	−10.09	17.76	−10.39
14	−17.06	−10.41	17.53	−10.62
16	−17.26	−10.61	17.38	−10.77
18	−17.93	−11.20	16.81	−11.34
20	−19.20	−12.33	15.64	−12.51
22	−20.45	−13.79	14.10	−14.05
24	−22.54	−15.90	11.80	−16.35
26	−26.54	−19.89	6.93	−21.22
28	−62.30	−25.68	−29.48	−57.63
30	−32.47	−25.82	−29.62	−57.77
32	−32.80	−25.96	−29.76	−57.91
34	−32.94	−26.10	−29.90	−58.05
36	−33.08	−26.24	−30.04	−58.19
38	−33.15	−26.31	−30.11	−58.26
40	−33.15	−26.31	−30.11	−58.26

4.4 IMT 3GPP mask vs. IDA FSS mask

The following Table shows the aggregate and worst single entry interference that the FSS earth station will see for a range of guard band sizes. This table shows results considering the 3GPP mask for the IMT base station and the IDA FSS mask.

TABLE A9-11

Interference to the FSS earth station as a function of guard band – 3GPP IMT mask vs. IDA study FSS mask

	Outdoor small cells		Macro network	
Guard band (MHz)	**Aggregate *I/N* long term to FSS link to 22º E (dB)**	**Aggregate *I/N* long term to FSS link to 100.5º W (dB)**	**Aggregate *I/N* long term to FSS link to 22º E (dB)**	**Aggregate *I/N* long term to FSS link to 100.5º W (dB)**
0	−15.51	2.56	−1.83	5.39
2	−17.49	0.21	−3.32	3.90
4	−21.29	−2.30	−4.56	2.66
6	−32.03	−4.82	−5.82	1.40
8	−32.53	−7.18	−6.81	0.41
10	−32.66	−9.04	−7.81	−0.59
12	−32.78	−10.09	−8.80	−1.58
14	−32.88	−10.41	−9.78	−2.56
16	−32.97	−10.61	−10.77	−3.55
18	−33.03	−11.20	−11.75	−4.53
20	−33.04	−12.33	−12.68	−5.46
22	−33.04	−13.79	−13.56	−6.34
24	−33.00	−15.90	−14.38	−7.16
26	−32.74	−19.89	−15.11	−7.89
28	−31.21	−25.68	−15.77	−8.55
30	−31.22	−25.82	−16.41	−9.19
32	−31.23	−25.96	−17.04	−9.82
34	−31.24	−26.10	−17.67	−10.45
36	−31.25	−26.24	−18.29	−11.07
38	−31.25	−26.31	−18.90	−11.68
40	−31.26	−26.31	−19.50	−12.28

4.5 Effect of suppressed 3GPP masks

By reference to Table A9-8, the difference that the 10 dB and 20 dB improved IMT transmission mask could make can be seen. The effect is not as pronounced as might be expected and does not influence the conclusions of the analysis.

The convolution is dominated by the performance of the FSS masks that have been used in the analysis.

If the FSS mask was improved, the effect of improving the IMT performance would be more relevant.

5 Conclusions

This study demonstrates a method of calculating the potential interference from an IMT network into an FSS earth station which is in an adjacent band and separated by a guard band, which is a parameter in the study.

The method requires that the unwanted emissions of the interferer be represented by a transmission mask and the out of band sensitivity of the victim also be represented by a mask.

The mask used for the IMT base station, taken from a 3GPP standard, is conservative. Little information about FSS receive masks has been found and some conservative assumptions also there have been made.

In the case of small cell outdoor networks, it has been found that a guard band of less than 4 MHz is required in order to meet the *I/N* threshold.

The macro network case is less straightforward. Nevertheless it is found that for a guard band greater than 26 MHz the *I/N* threshold is met for all of the cases analysed, even when assuming a Gaussian mask for the FSS receiver.

The limiting factor in the NFD calculation, in the analysis, is the performance of the FSS receiver at the edge of the band. The results show little benefit from improvements to the IMT emissions mask, which implies that the assumptions about the FSS sensitivity are too cautious.

The guard band size could be decreased by relaxing some of the assumptions or by modelling some aspects in more detail. For further studies, the following could be considered:

– use of a better mask for the FSS earth station;

– detailed definition of the IMT mask based on actual achievable filtering;

– more detailed and accurate modelling of short path propagation in the urban environment;

– consideration of placing narrower bandwidth carriers close to edge of the band.

Future work is also likely to include use of Monte Carlo modelling, for example to investigate potential interference from IMT user equipment, as well as for consideration of statistical aspects associated with scenarios studied in this paper.

Annex 10

Study #10

1 Introduction

WRC-15 agenda item 1.1 considers additional spectrum allocations to the mobile service on a primary basis and identification of additional frequency bands for IMT and related regulatory provisions, to facilitate the development of terrestrial mobile broadband applications, in accordance with Resolution **233 (WRC-12)**.

Resolution **233 (WRC-12)** invites the ITU-R to conduct sharing and compatibility studies with services already having allocations in the potential candidate bands and in adjacent bands, as appropriate, taking into account the current and planned use of these bands by the existing services, as well as the applicable studies already performed in ITU-R.

This analysis examined the compatibility between IMT and FSS systems operating in the 3 400-4 200 MHz frequency range. Two interference scenarios were considered: IMT base station into FSS earth station and IMT user equipment (UE) into FSS earth station. Four deployment environments were considered: macro suburban, macro urban, small cell outdoor, and small cell indoor.

Methodologies were developed to determine the interference level as a function of separation distance for the two scenarios. Then the frequency dependent rejection was calculated based on the interfering signal and FSS receive filter characteristics.

For the macro deployment scenarios, the required separation distance from the edge of the IMT deployment area is on the order of tens of kilometres when the frequency separation is about 25 MHz. For the small cell outdoor deployment scenario, the separation distance is on the order of a few kilometres when the frequency separation is about 25 MHz. For the small cell indoor deployment scenarios, the separation distance is on the order of a few kilometres when the frequency separation is about 5 MHz. These frequency separations are defined as the difference between the centre frequency of the IMT signal and the centre frequency of the FSS receiver filter.

The separation distance around an IMT station where the PFD produced at 3 metres above ground does not exceed –154.5 dB(W/m^2 4 kHz) for more than 20% of the time varies from less than 1 kilometre to as much as about 40 km, depending on station type, deployment environment, and in the case of the IMT base station, the antenna orientation.

The required geographic and frequency separations are significantly reduced for the small cell base station deployment scenarios

It should be noted that certain assumptions (e.g. FSS earth station placement and direction, use of propagation model, etc.) overestimate interference from the IMT network.

2 Technical characteristics used in sharing studies

The following Tables summarize the IMT and FSS characteristics considered for this analysis. Detailed FSS and IMT system characteristics are provided in §§ 2 and 3 of the main body of this Report respectively. Note that the FSS material does not address adjacent channel selectivity, and values similar to those for the IMT base station are assumed for this analysis.

TABLE A10-1

IMT base station characteristics

Parameter	Macro suburban	Macro urban	Small cell outdoor	Small cell indoor
Deployment				
Number of cells	19	19	19	19
Number of sectors per cell	3	3	1	1
Cell radius	0.6 km	0.3 km	0.3 km	0.3 km
Percent indoor	0%	0%	0%	100%
Base station				
Antenna				
Height	25 m	20 m	6 m	3 m
Frequency range	3 400-4 200 MHz	3 400-4 200 MHz	3 400-4 200 MHz	3 400-4 200 MHz
Peak gain	18 dBi	18 dBi	5 dBi	0 dBi
Gain pattern	F.1336 Annex 10	F.1336 Annex 10	F.1336	F.1336
k_a	0.7	0.7	N/A	N/A
k_p	0.7	0.7	N/A	N/A
k_h	0.7	0.7	N/A	N/A
k_v	0.3	0.3	N/A	N/A
k	N/A	N/A	0.7	0.7
Horizontal beamwidth	65 degrees	65 degrees	N/A	N/A
Downtilt	–6 degrees	–10 degrees	0 degrees	0 degrees
Transmitter				
Power	16 dBW	16 dBW	–6 dBW	–6 dBW
Activity factor	3 dB	3 dB	3 dB	3 dB
Signal bandwidth	10.0 MHz	10.0 MHz	10.0 MHz	10.0 MHz
Channel spacing	10.0 MHz	10.0 MHz	10.0 MHz	10.0 MHz
Feeder loss	3 dB	3 dB	3 dB	3 dB
ACLR				
1st adjacent	45 dB	45 dB	45 dB	45 dB
2nd adjacent	45 dB	45 dB	45 dB	45 dB
Spurious	54 dB	54 dB	54 dB	54 dB

For the Small Cell Indoor case, it is assumed that the IMT device would operate under a license requiring indoor use, so 100% of the IMT base stations are assumed to be located indoors for this deployment environment.

TABLE A10-2

IMT UE characteristics

Parameter	Macro suburban	Macro urban	Small cell outdoor	Small cell indoor
Deployment				
Percent indoor	70%	70%	70%	100%
UE				
Antenna				
Height	1.5 m	1.5 m	1.5 m	1.5 m
Frequency range	3 400-4 200 MHz	3 400-4 200 MHz	3 400-4 200 MHz	3 400-4 200 MHz
Peak gain	–4 dBi	–4 dBi	–4 dBi	–4 dBi
Gain pattern	ND	ND	ND	ND
Transmitter				
Maximum power	–7 dBW	–7 dBW	–7 dBW	–7 dBW
Minimum power	–70 dBW	–70 dBW	–70 dBW	–70 dBW
Signal bandwidth	10.0 MHz	10.0 MHz	10.0 MHz	10.0 MHz
Channel spacing	10.0 MHz	10.0 MHz	10.0 MHz	10.0 MHz
Feeder loss	0 dB	0 dB	0 dB	0 dB
Power control				
Handover margin	3 dB	3 dB	3 dB	3 dB
Balancing factor (gamma)	1.0	1.0	1.0	1.0
Percent at maximum power	10%	10%	10%	10%
ACLR				
1st adjacent	30 dB	30 dB	30 dB	30 dB
2nd adjacent	33 dB	33 dB	33 dB	33 dB
Spurious	53 dB	53 dB	53 dB	53 dB

TABLE A10-3

Fixed-satellite service station characteristics

Parameter	Value
FSS earth station	
Antenna	
Height	3 m
Diameter	3 m
Gain pattern	S.465
Receiver	
Signal bandwidth	36 MHz
Channel spacing	40 MHz
Noise temperature	100 K
I/N requirement	
Co-channel	–13 dB
Adjacent channel	–23 dB
ACS	
1st adjacent	45 dB
2nd adjacent	50 dB
> 2nd adjacent	55 dB

Propagation loss is based on Recommendation ITU-R P.452-14. This recommendation has been used in past studies in the 3 400-4 200 MHz band. The analysis in this study takes a conservative approach by assuming a smooth Earth terrain profile, which may result in the overestimation of the interference into a receiving FSS earth station for environments other than flat plain regions. Other ITU-R propagation models that were utilized in the IMT-Advanced evaluation process (i.e. Report ITU-R M.2135) may provide a more realistic match to measured data. The propagation characteristics used in this analysis are shown in Table A10-4.

TABLE A10-4

Propagation characteristics

Parameter	Macro suburban	Macro urban	Small cell outdoor	Small cell indoor
Propagation				
Model	P.452-14	P.452-14	P.452-14	P.452-14
Percentage of time basic loss is not exceeded	20%	20%	20%	20%
Average radio-refractive index lapse rate	45 N-units/km	45 N-units/km	45 N-units/km	45 N-units/km
Sea-level surface refractivity	330 N-units	330 N-units	330 N-units	330 N-units
Path centre latitude	40 N	40 N	40 N	40 N
Clutter height	9 m	20 m	9 m	9 m
Clutter distance	0.025 km	0.02 km	0.025 km	0.025 km
Polarization discrimination				
IMT base station	3 dB	3 dB	3 dB	3 dB
IMT UE	0 dB	0 dB	0 dB	0 dB
Other propagation effects				
Building penetration loss (indoor stations only)	20 dB	20 dB	20 dB	20 dB
IMT UE body loss	4 dB	4 dB	4 dB	4 dB

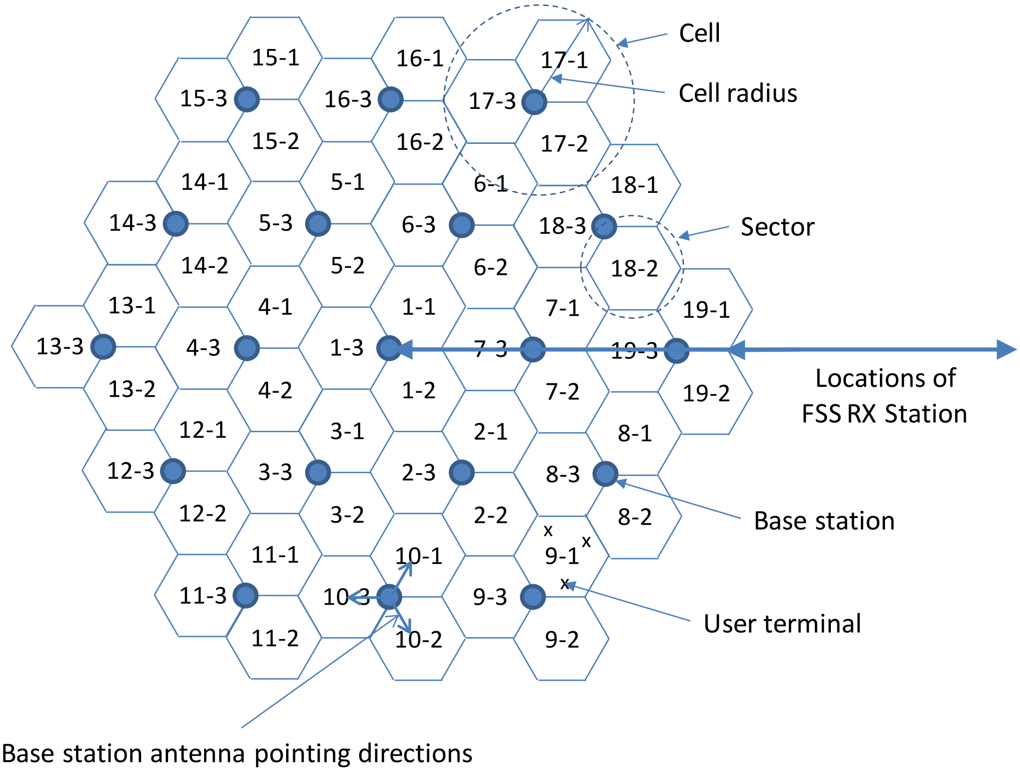
3 Evaluation methodology

This analysis examined the required frequency rejection as a function of separation distance for compatible operation of IMT and FSS systems. Two interference scenarios are considered: IMT base station into FSS earth station and IMT mobile station into FSS earth station. Four deployment environments are considered: macro suburban, macro urban, small cell outdoor, and small cell indoor. Propagation loss is calculated using Recommendation ITU-R P.452-14.

The IMT network layout is illustrated in Fig. A10-1. Nineteen cells are arranged in a hexagonal pattern with each cell consisting of three sectors. An IMT base station is located at the centre of each cell and operates with a 3-sector antenna. Each antenna serves a single sector covering 120 degrees of the cell. For the small cell deployment scenarios, the base station antenna is omni-directional in azimuth and the cell contains only one sector.

FIGURE A10-1

IMT Network Layout



The interference calculation methodology used depends on the interference scenario considered:

IMT Base Station into FSS Earth Station

Both co-channel and adjacent channel scenarios are addressed.

For the co-channel scenario, the interference from a single IMT base or mobile station pointing in azimuth toward the FS receive station is computed over a range of azimuths and distances. The result is presented as a plot of the required separation distance around the FSS earth station.

For the adjacent channel scenario, the FSS earth station is positioned adjacent to the IMT network base stations. The aggregate interference into the FSS station is computed assuming varying separation distances. At each distance the required rejection is determined based on a specified protection requirement. The result is presented as a plot of the required rejection as a function of separation distance. The required frequency separation between the two systems is then determined based on the out-of-band emission characteristics of the IMT base station signal and the adjacent channel selectivity of the FSS receiver.

IMT UE into FSS Earth Station

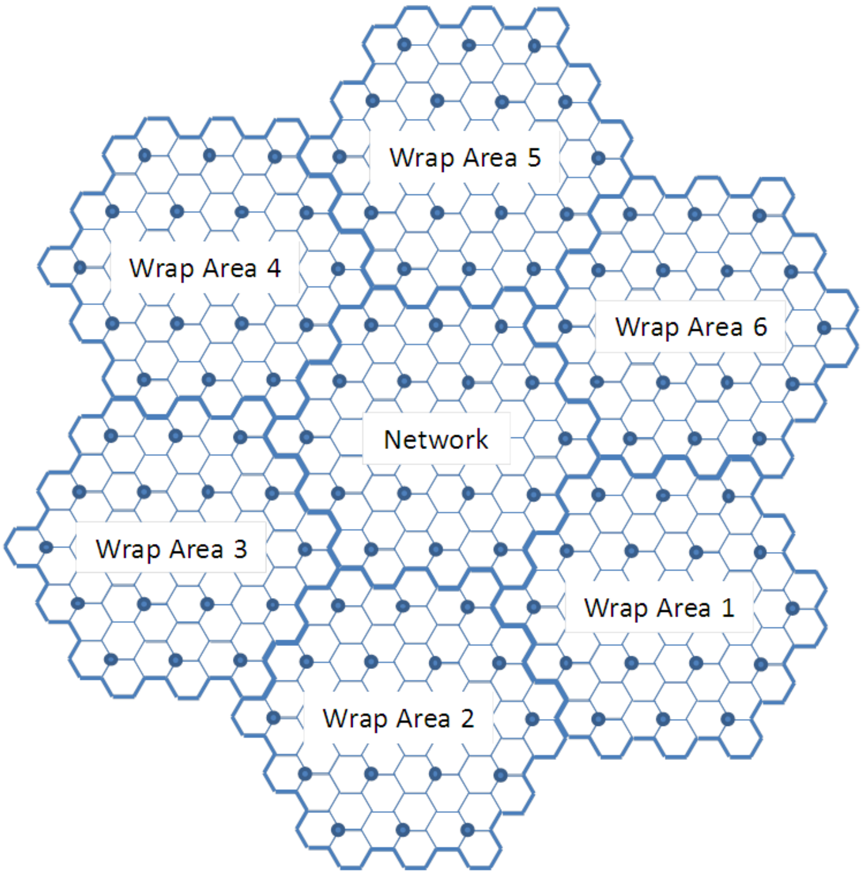
Aggregate interference from IMT UE is modelled based on the Monte Carlo methodology. The methodology consists of 1) randomly positioning IMT UE throughout the IMT network area, 2) randomly assigning these UE to an IMT base station based on the propagation loss and a specified “handover margin”, 3) randomly locating the UE either indoors or outdoors based on a specified percentage of indoor devices, and 4) applying a power control algorithm to the mobile stations based on their path loss distribution.

The calculations are repeated for a number of “snapshots”, from which statistics are extracted. Elements from the methodology pertinent to this analysis are presented below:

The network region relevant for simulations is the cluster of 19 cells illustrated in Fig. A10-1. Additional clusters of 19 cells are repeated around this central cluster based on a "wrap-around" technique employed to avoid the network deployment edge effects as shown in Fig. A10-2.

FIGURE A10-2

IMT network layout with "wrap-around" clusters



The simulation of interference on the IMT uplink is structured as follows:

For i = 1:number of snapshots:

1 Distribute sufficiently many UE randomly throughout the system area such that to each cell within the HO margin of 3 dB the same number K_{UL} of users is allocated as active UE:

– calculate the pathloss from each UE to all cells and find the smallest pathloss;

– link the UE randomly to a cell to which the pathloss is within the smallest pathloss plus the HO margin of 3 dB;

– select K_{UL} UE randomly from all the UE linked to one cell as active UE. These K_{UL} active UE will be scheduled during this snapshot.

2 Perform UL power control:

– Set UE transmit power to $P_t = P_{max} \times \min\left\{1, \max\left[R_{min}, \left(\frac{PL}{PL_{x-ile}}\right)^{\gamma}\right]\right\}$

where P_t is the transmit power of the UE, P_{max} is the maximum transmit power, R_{min} is the ratio of UE minimum and maximum transmit powers *Pmin* / *Pmax* and determines the minimum power reduction ratio to prevent UE with good channel conditions to transmit at very low power level. *PL* is the path-loss for the UE from its serving base station and $PL_{x\text{-}ile}$

is the x-percentile path-loss (plus shadowing) value. With this power control scheme, the 1-x percent of UE that have a path-loss larger than $P_{Lx\text{-}ile}$ will transmit at P_{max}. Finally, $0 < \gamma < = 1$ is the balancing factor for UE with bad channel and UE with good channel.

The analysis assumes that there are a sufficient number of IMT UE in each sector to fully occupy the bandwidth of the FSS earth station receiver. The number of "snapshots" used for the Monte Carlo simulation is set to 50.

Again, both co-channel and adjacent channel scenarios are addressed.

Interference levels are calculated as follows:

$$I_0 = PD_{tx} - FL_{tx} - HL_{tx} + G_{tx}(\theta_{tx}) - BL_{tx} - PL - BL_{rx} + G_{rx}(\theta_{rx}) - FL_{rx} - HL_{rx} - PD$$

where:

I_0 = Interference power density, dBW/Hz

PD_{tx} = Transmit station signal power density, dBW/Hz

FL_{tx} = Transmit station feeder loss, dB

HL_{tx} = Transmit station head loss (applicable only to hand-held mobile stations), dB

$G_{tx}(\theta_{tx})$ = Transmit station antenna gain in direction of receive station, dBi

BL_{tx} = Building penetration loss (applicable only to indoor transmit stations), dB

PL = Propagation loss, dB

BL_{rx} = Building penetration loss (applicable only to indoor receive stations), dB

$G_{rx}(\theta_{rx})$ = Receive station antenna gain in direction of transmit station, dBi

FL_{rx} = Receive station feeder loss, dB

HL_{rx} = Receive station head loss (applicable only to hand-held mobile stations), dB

PD = Polarization discrimination, dB.

The required rejection is determined from the interference level as follows:

$$I / N = I_0 - N_0$$

$$R = I / N - I / N_{reqt}$$

where:

N_0 = Receive station noise power density, dBW/Hz

R = Rejection needed to meet protection requirement, dB

I/N_{reqt} = I/N protection requirement, dB.

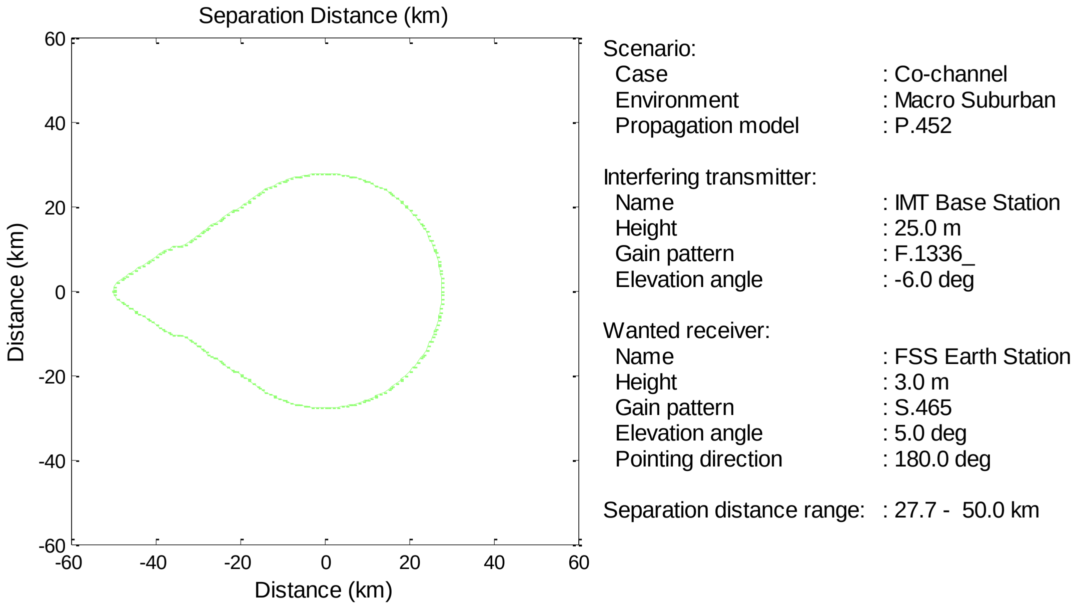
4 Results of studies

Co-channel

The interference from a single IMT base or mobile station pointing in azimuth toward the FSS earth station is computed over a range of azimuths and distances. From this data, a contour is drawn at the locations around the FSS earth station that meet interference protection requirement.

FIGURE A10-3

Separation distance IMT base station into FSS earth station



Applying this methodology to the interference scenarios and deployment environments shown in the tables above gives the following results:

TABLE A10-5

Co-channel separation distance

Scenario	Environment	Separation distance
IMT base station into FSS earth station	Macro suburban	27.7-50.0 km
	Macro urban	28.3-48.0 km
	Small cell outdoor	2.8-16.0 km
	Small cell indoor	< 1.0 km
IMT UE into FSS earth station	Macro suburban	< 1.0 km
	Macro urban	< 2.0 km
	Small cell outdoor	< 1.0 km
	Small cell indoor	< 1.0 km

Adjacent channel

Nineteen IMT base stations are positioned over the network area as illustrated in Fig. A10-1. The FSS receive station is initially positioned at the centre of the IMT network area. The pointing angle of the FSS receive antenna is along the –x axis toward the array of IMT base stations. (The pointing angles in the following figures are measured counter clockwise from the x-axis.) This positioning creates the worst case scenario for receiving interference from the IMT network. However, these pointing scenarios should be avoidable in practice, and as such, it could be expected that in reality interference is somewhat lower due to varying pointing direction of FSS earth station with respect to IMT network. Next, the aggregate interference from the IMT base stations into the FSS receive station is computed. Then the FSS receive station position is moved incrementally along the x-axis and the aggregate interference is recomputed at each of these positions. This aggregate interference is compared with the FSS protection requirement to determine the additional rejection needed to meet the protection requirement as a function of separation distance. The results are illustrated in the following figures:

FIGURE A10-4A

Required rejection IMT base station into FSS earth station FSS earth station located within IMT deployment area

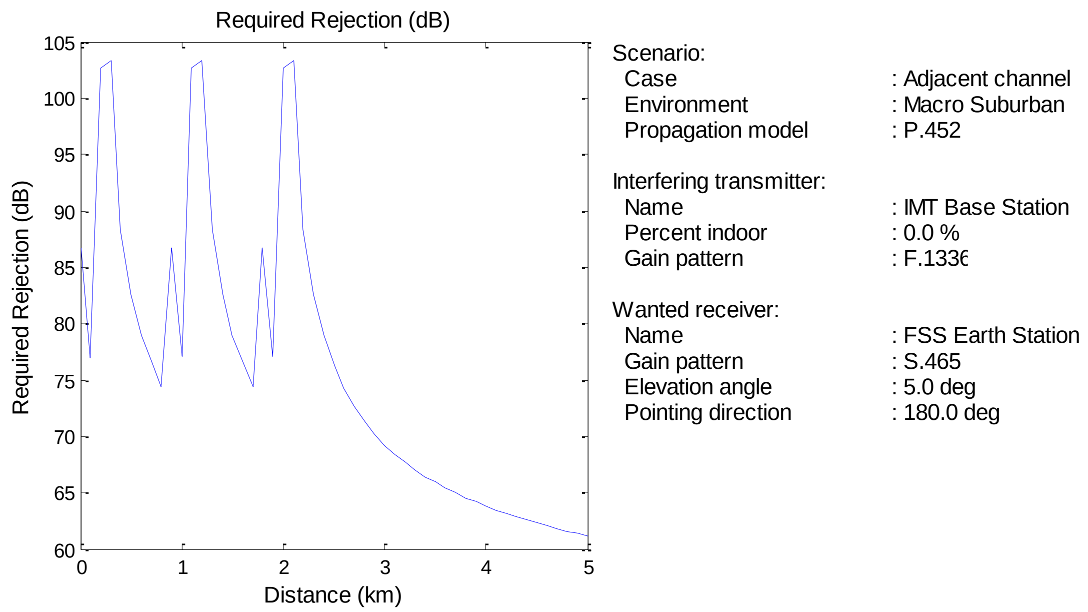
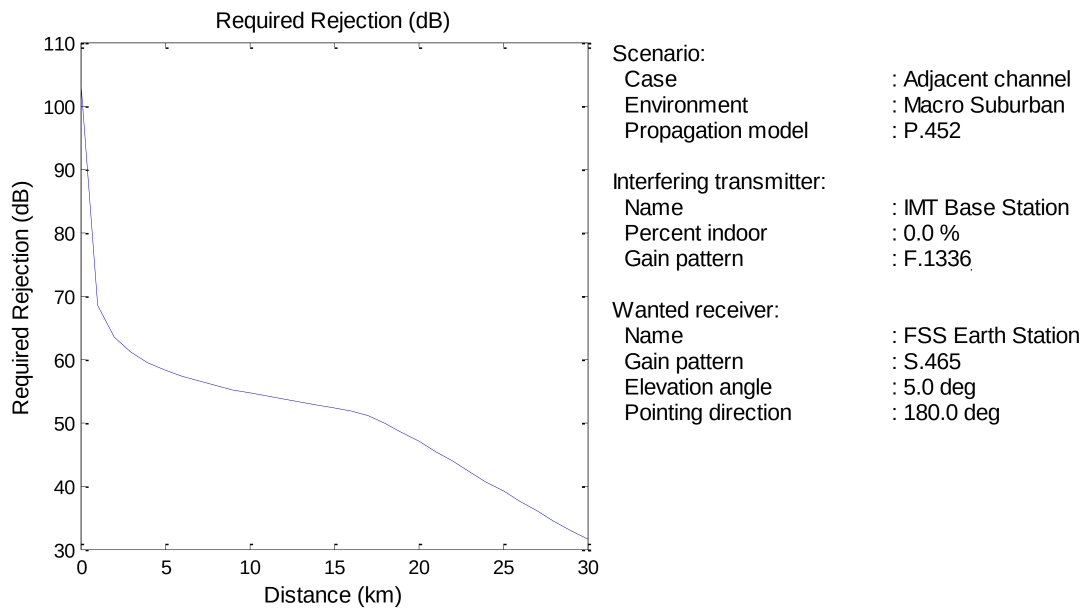


FIGURE A10-4B

Required rejection IMT base station into FSS receive station FSS receive station located adjacent to IMT deployment area



For the scenario of aggregate interference from IMT UE, a Monte Carlo simulation to determine the interference into the FSS earth station receiver. The IMT UE are randomly positioned over each sector in sufficient numbers to ensure that the entire bandwidth of the FSS earth station receiver is fully occupied by interfering signals. A specified percentage of the IMT terminals are assumed to be located indoors.

As described above, a power control algorithm is applied to assign path loss and transmit power levels to each of the UE. Again, the FSS receive station is initially positioned just to the right of the IMT network area and its antenna is pointed along the –x axis, or directly toward the IMT service area. The aggregate interference is computed for a range of separation distances and compared with the FSS protection requirement to derive the needed rejection as a function of distance. This calculation is repeated 50 times.

These methodologies are applied to the deployment environments shown in the tables above, but, for brevity, plots of these results are not included here.

4.1 Frequency dependent rejection calculations

Frequency dependent rejection (FDR) is dependent on the characteristics of the interfering signal and the wanted receiver filter. FDR is calculated from the following equation:

$$FDR(\Delta f) = 10\log_{10}\left[\frac{\int_{-\infty}^{+\infty} S(f)df}{\int_{-\infty}^{+\infty} S(f)F(f+\Delta f)df}\right]$$

where:

FDR	= Frequency dependent rejection, dB
S	= Power spectral density of the interfering signal, W/Hz
F	= Frequency response of the wanted receiver, relative power fraction
f	= Frequency, Hz
Δf	= Frequency offset, Hz.

The interfering signal, *S*, is modelled as a flat spectrum within the signal bandwidth and a specified ACLR curve outside the signal bandwidth. Similarly, the wanted receiver filter response, *F*, is modelled as a flat response within the receive signal bandwidth and a specified ACS curve outside the signal bandwidth. The following figures show the interfering signal, FSS receiver frequency response, and resulting FDR for each interference scenario considered here.

FIGURE A10-5

Frequency dependent rejection IMT base station into FSS earth station

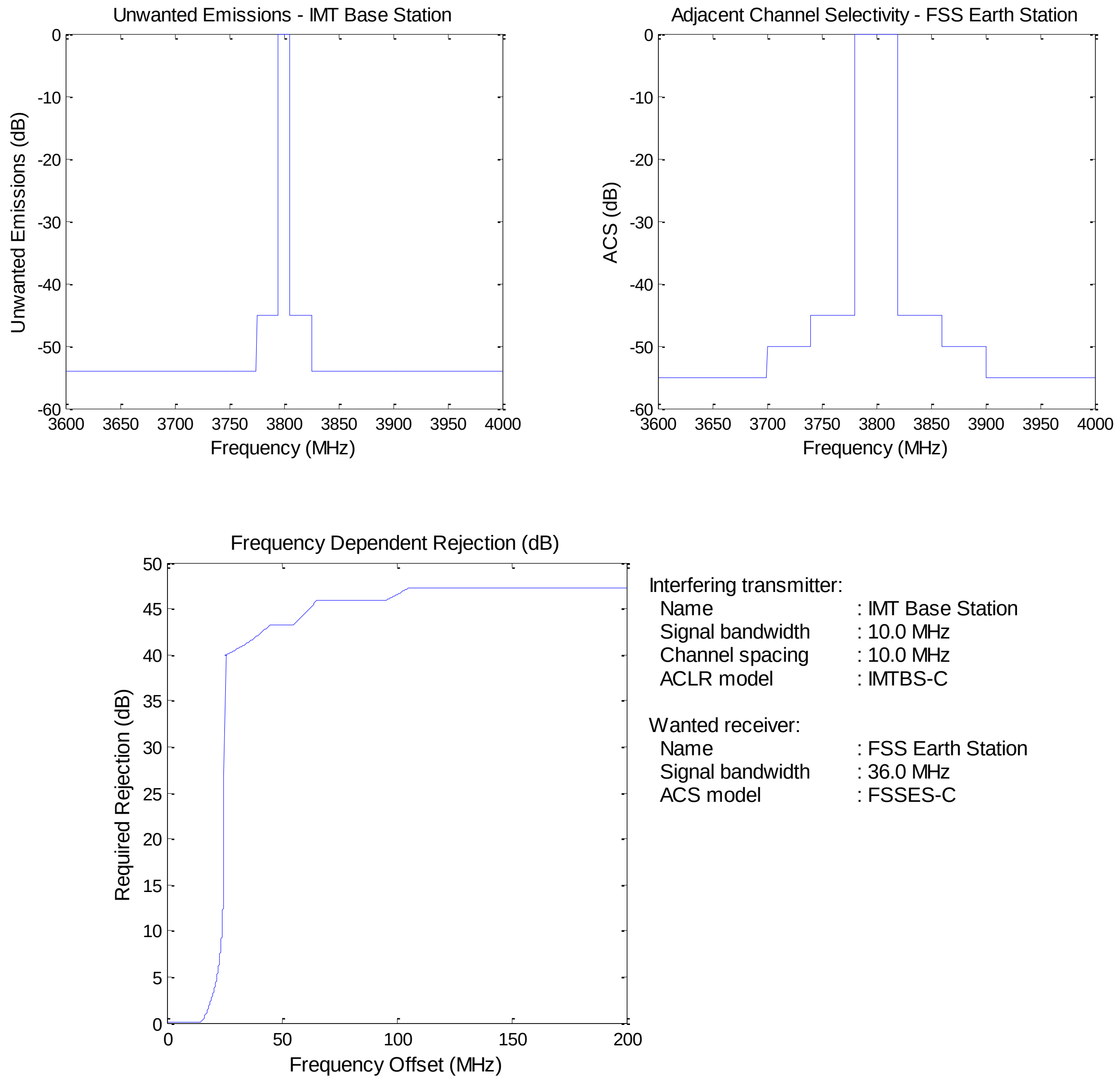
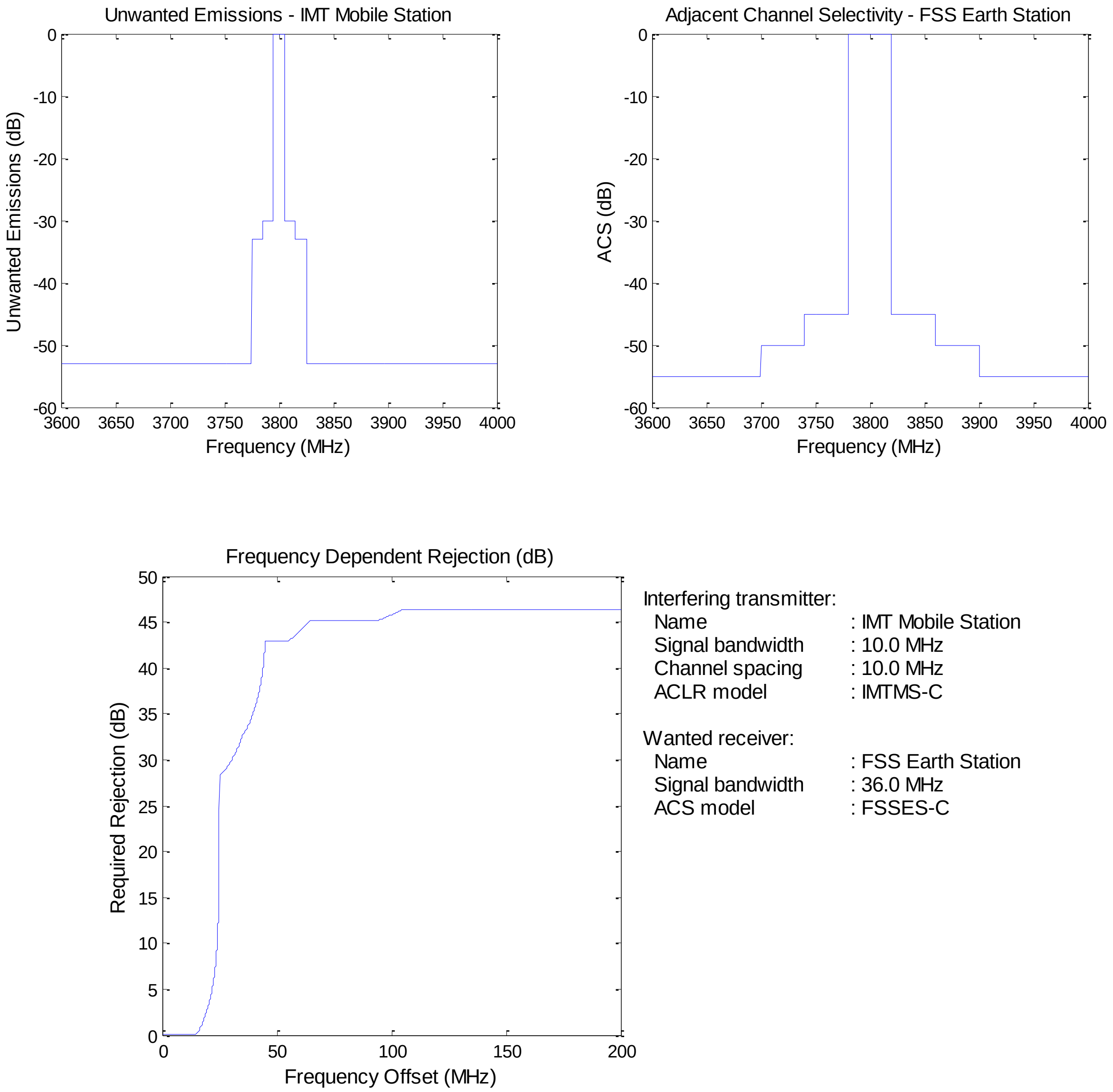


FIGURE A10-6

Frequency dependent rejection IMT mobile station into FSS earth station



The adjacent channel interference levels and FDR curves computed above are combined to derive the frequency separation (centre-to-centre) necessary to meet the stated protection requirement at various separation distances. Table A10-6 provides results for selected separation distances for the various interference scenarios and deployment environments considered here.

TABLE A10-6

Adjacent channel frequency/distance separation IMT signal bandwidth = 10.0 MHz, FSS signal bandwidth = 36.0 MHz

Scenario	Environment	FSS earth station elevation angle	Frequency separation				
			1.0 km	5.0 km	10.0 km	20.0 km	30.0 km
IMT base station into FSS earth station	Macro suburban	5 deg	–	–	–	103.3 MHz	25.0 MHz
		30 deg	–	39.8 MHz	25.0 MHz	25.0 MHz	24.5 MHz
	Macro urban	5 deg	–	–	–	98.7 MHz	25.0 MHz
		30 deg	–	25.0 MHz	25.0 MHz	25.0 MHz	24.7 MHz
	Small cell outdoor	5 deg	40.0 MHz	25.0 MHz	25.0 MHz	24.3 MHz	16.3 MHz
		30 deg	25.0 MHz	24.8 MHz	24.1 MHz	5.0 MHz	5.0 MHz
	Small cell indoor	5 deg	22.0 MHz	5.0 MHz	5.0 MHz	5.0 MHz	4.8 MHz
		30 deg	4.8 MHz	4.8 MHz	4.8 MHz	4.6 MHz	4.6 MHz
IMT UE into FSS earth station	Macro suburban	5 deg	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz
		30 deg	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz
	Macro urban	5 deg	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz
		30 deg	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz
	Small cell outdoor	5 deg	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz
		30 deg	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz
	Small cell indoor	5 deg	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz
		30 deg	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz	0.0 MHz

4.2 Results of power flux density calculations

The power flux density (PFD) produced at varying azimuths and ranges around an IMT base station is calculated using the following equation:

$$PFD = PD_{tx} - FL_{tx} - HL_{tx} + G_{tx}(\theta_{tx}) - BL_{tx} - PL + 10\log_{10}(4\pi/\lambda^2) + 10\log_{10}(BW_{ref})$$

where:

PFD = Power flux density, dB(W/ m^2 • 4 kHz)

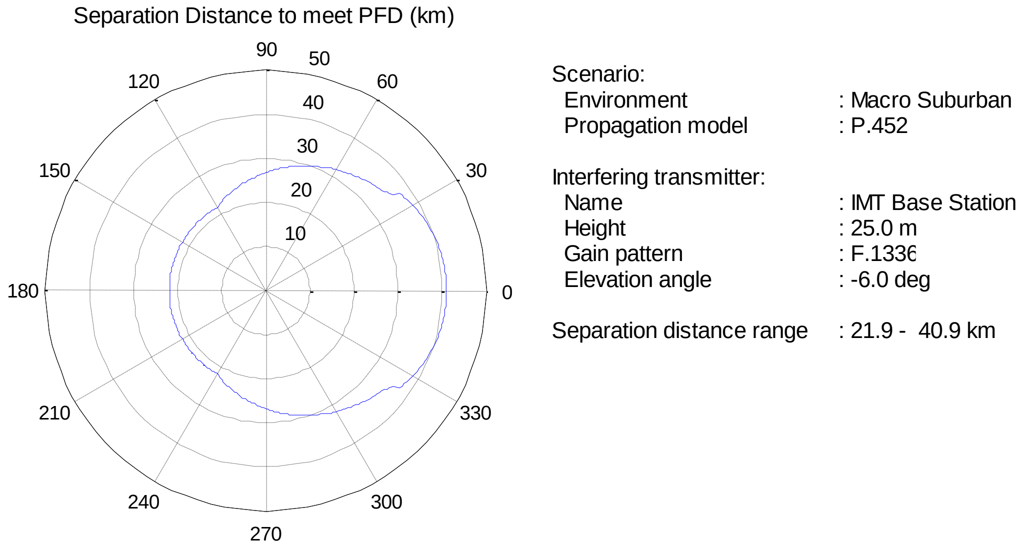
λ = Wavelength, m

BW_{ref} = Reference bandwidth (4 kHz).

From the results of this calculation a contour is drawn around the IMT base station at distances where the PFD produced at 3 metres above ground does not exceed –154.5 dB(W/m^2 4 kHz) for more than 20% of the time. This PFD level is the same as is found in several footnotes in Article **5** of the Radio Regulations related to the 3 400-3 600 MHz band.

FIGURE A10-7

Separation distance based on PFD level IMT base station



Applying this methodology to the station types and deployment environments shown in the tables above gives the following results:

TABLE A10-7

Separation Distance based on PFD Level

Station	Environment	Separation distance
IMT base station	Macro suburban	21.9-40.9 km
	Macro urban	17.9-37.9 km
	Small cell outdoor	< 11.4 km
	Small cell indoor	< 0.3 km
IMT UE	Macro suburban	< 0.7 km
	Macro urban	< 0.7 km
	Small cell outdoor	< 0.7 km
	Small cell indoor	< 0.1 km

4.3 Overall results

The co-frequency channel results show that the required separation distance can range from very short to nearly 50 km, depending on the interference scenario and deployment environment.

The adjacent channel results show that in the scenarios (FSS earth station at 5 degrees elevation and pointing in azimuth generally in the direction toward a macro deployment of IMT base stations), a combination of geographic separation and frequency separation is needed to protect the FSS earth station. For the macro deployment scenarios, the required separation distance from the edge of the cluster of IMT base stations is on the order of tens of kilometres when the frequency separation is about 25 MHz. (The frequency separation is defined as the difference between the centre frequency of the IMT signal and the centre frequency of the FSS receiver filter.) It should be noted that operators decide where to deploy IMT base stations based on a variety of factors including minimizing interference near international borders in accordance with regulations.

The required geographic and frequency separations are significantly reduced for the small cell indoor base station deployment scenario to about one kilometre coupled with a frequency separation of about 5 MHz.

It should be noted that certain assumptions such as FSS earth station placement and direction, use of propagation model, etc. overestimate interference from the IMT network.

These results also show that the aggregate interference from the IMT UE is low. The interference level meets the protection criteria for geographic separations of less than 1 kilometre.

The separation distance around an IMT station where the PFD produced at 3 metres above ground does not exceed –154.5 dB(W/m^2 4 kHz) for more than 20% of the time varies from less than 1 kilometre to as much as about 40 km, depending on station type, deployment environment, and in the case of the IMT base station, the antenna orientation.

Annex 11

Study #11

1 Introduction

This Annex provides studies regarding the co-existence of wireless terrestrial services, in the 3 400-3 600 MHz band with fixed satellite service operating in the 3 600-4 200 MHz band.

It should be noted that the compatibility studies have not considered LTE systems. The implementation of LTE technology or others in these bands will lead us to a completely new scenario that will demand new studies due to the mobility and ubiquity aspects, and also due to the new network topologies that are being developed for these technologies.

Even though the performed studies were made taking into account the effects of BWA services at 3 400 to 3 600 MHz in the FSS at 3 600 to 4 200 MHz, it is important to note that the same methodology can be applied to any wireless service provided that the appropriate parameters are taken into consideration.

The study analysed three types of interference:

– saturation of the TV receiver at intermediate frequency (L band);

– interference on the local oscillator;

– LNBF saturation.

2 Technical characteristics

2.1 BWA system characteristics

The characterization of broadband wireless access networks was the most realistic possible, taking into account the characteristics of BWA networks in operation (national and regional), and taking into consideration three types of environments: urban, suburban and rural. For the urban environment, the study considered the number of 4 BWA operators in the market. For the suburban and rural environment, a total number of 2 operators were considered.

2.2 Satellite receive systems characteristics

The characterization of the receiving antenna took into account the regulator´s specifications, which establishes the general and specific minimum technical requirements of transmission antennas used in earth stations operating with geostationary satellites and is applicable to earth station antennas. As a typical LNBF, it was used a device equivalent to the best available in the market. Nevertheless, these devices do not provide the appropriate protection against interference signals higher than –60 dBm.

The –60 dBm value for the interfering signal is within the minimum (–67 dBm) and maximum (–51 dBm) LNBF input levels of the tested devices, and less than 25% of total measured levels exceed that value.

3 Interference analysis

Once the types of interference were identified and the networks were characterized, the following step was to evaluate the effect of aggregate interference by means of models based on the following BWA reference networks:

– urban region with population greater than 500 thousand inhabitants (e.g. Curitiba/PR);
– urban region with population less than 500 thousand inhabitants (e.g. Imperatriz/MA);
– urban “dense” region (e.g. Salvador/BA);
– suburban region;
– rural region.

In the interference aggregate calculation, 2 or 4 operators acting in the areas were considered, with 32 customer premises equipment (CPE) per cell. Three scenarios were studied, as follows:

TABLE A11-1

Studied scenarios

Parameter	Scenario 1	Scenario 2	Scenario 3
Antenna gain in direction >= 48 degrees	0 dBi	–4 dBi	–10 dBi
LNBF oscillator interference limit	–60 dBm	–60 dBm	–47 dBm
CPE gain	12 dBi	14 dBi	14 dBi
CPE antenna front/back ratio	–19 dB	–22 dB	–22 dB

3.1 Interference models

BWA network base stations and customer premises stations were assumed geographically uniformly distributed. The satellite receive station was at first considered located at the same distance from the nearest base stations. These initial assumptions lead to a general expression for the aggregate interference received from the closest 4 base stations (distance D0) and the next 8 closest base stations (distance D1) that in terms of distance can be related just to the separation distance between base stations. The contributions of stations at greater distances can be considered irrelevant, as power decays at least with distance squared. Refer to the following figures for a graphical representation of the previous assumptions.

FIGURE A11-1

Dense urban scenario

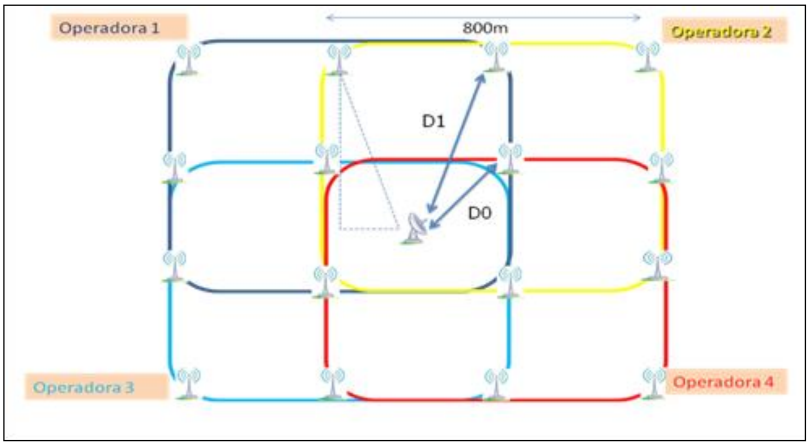


FIGURE A11-2

Suburban and rural scenario

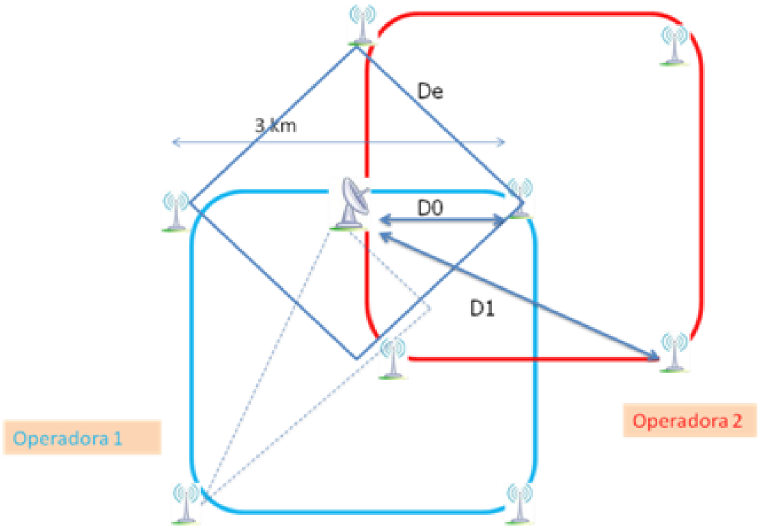
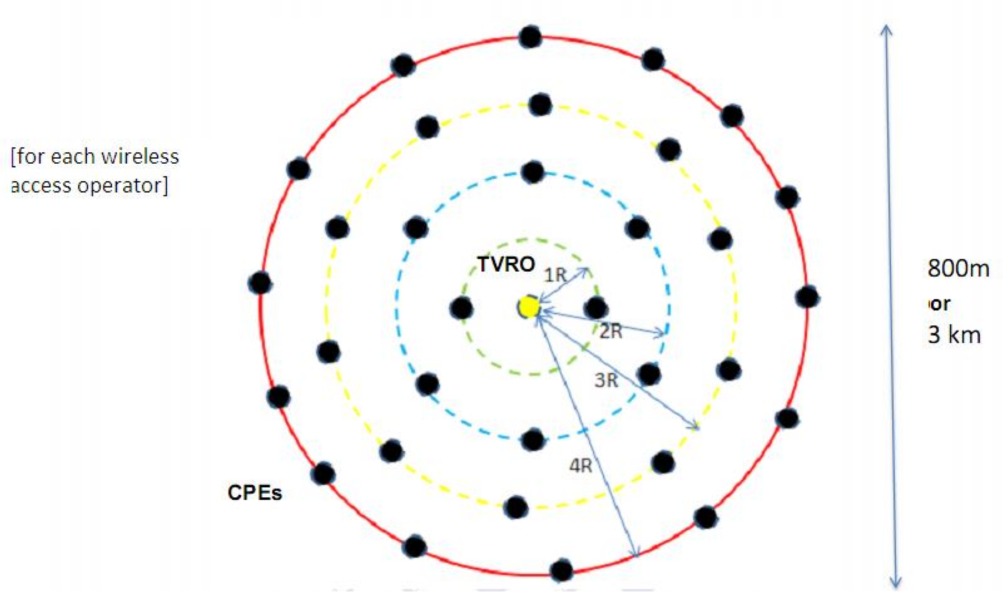


FIGURE A11-3

Customer stations distribution scenario



The following factors are taken into account in order to calculate each interference entry:

1 base station, customer premise and satellite receive station antenna heights, used to determine incidence angles and corresponding antenna gains based on typical transmit and receive patterns (refer to Figs. A11-1 and A11-2);

2 base station antenna tilt optimized for area coverage (3 dB vertical beam width limit positioned at edge of area coverage);

3 propagation loss (free space for short distances—LOS, +16 dB additional loss for greater distances—NLOS; based on field testing published data);[24]

4 operating power levels for BWA stations.

4 Conclusions

Table A11-2 shows the aggregate interference caused by BWA operating with transmission power of 2 W, equivalent to 80 W e.i.r.p. (base station), and a UE with a 2 W e.i.r.p.

It should be noted that the results presented in the Table below reflect the premises, technical parameters and designed scenarios adopted for this study.

The negative protection ratio indicates that the protection against interference is not sufficient, i.e. the interference potential is considerably high not allowing the co-existence. Positive values indicate conceivably acceptable interference conditions.

[24] Radio wave propagation mechanisms and empirical models for fixed wireless access systems.

TABLE A11-2

Aggregate interference

Area	Necessary protection relation for co-existence		
	Scenario 1	Scenario 2	Scenario 3
Urban	–25.2 dB	–21.2 dB	+1.77 dB
Suburban	–20.7 dB	–16.7 dB	+6.0 dB
Rural	–19.3 dB	–15.3 dB	+7.6 dB

The compatibility in scenarios 1 and 2 is not possible – without mitigation techniques – in the full 3 400-3 600 MHz band, demonstrating the need to establish technical conditions to guarantee the compatibility of both systems operating in adjacent bands.