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

S Series

Fixed satellite service

International Telecommunication Union

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REPORT ITU-R S.2199

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

(2010)

TABLE OF CONTENTS

Page

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

Executive summary

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

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

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

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

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

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

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

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

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

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

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

i) Low Noise Block converter (LNB) saturation;

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

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

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

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

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

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

1 Introduction

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

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

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

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

2.1 Definitions

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

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

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

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

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

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

– with one or more space stations; or

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

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

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

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

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

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

2.2 Table of frequency allocations

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

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

<table>
<tr><th colspan="3">Allocation to services</th></tr>
<tr><th>Region 1</th><th>Region 2</th><th>Region 3</th></tr>
<tr><td rowspan="2">3 400-3 600
FIXED
FIXED-SATELLITE (space-to-Earth)
Mobile 5.430A
Radiolocation
5.431</td><td>3 400-3 500
FIXED
FIXED-SATELLITE (space-to-Earth)
Amateur
Mobile 5.431A Radiolocation 5.433
5.282 5.432</td><td>3 400-3 500
FIXED
FIXED-SATELLITE (space-to-Earth)
Amateur
Mobile ADD 5.432B ADD 5.432A
Radiolocation 5.433
5.282 .432</td></tr>
<tr><td rowspan="2">3 500-3 700
FIXED
FIXED-SATELLITE (space-to-Earth)
MOBILE except aeronautical mobile
Radiolocation 5.433
5.435</td><td>3 500-3 600
FIXED
FIXED-SATELLITE (space-to-Earth)
MOBILE except aeronautical mobile ADD 5.433A
Radiolocation 5.433
5.435</td></tr>
<tr><td rowspan="2">3 600-4 200
FIXED
FIXED-SATELLITE (space-to-Earth)
Mobile</td><td>3 600-3 700
FIXED
FIXED-SATELLITE (space-to-Earth)
MOBILE except aeronautical mobile
Radiolocation 3
5.435</td></tr>
<tr><td>3 700-4 200
FIXED
FIXED-SATELLITE (space-to-Earth)
MOBILE except aeronautical mobile</td><td>3 700-4 200
FIXED
FIXED-SATELLITE (space-to-Earth)
MOBILE except aeronautical mobile</td></tr>
</table>

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

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

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

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

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

2.3 Coordination contours to protect FSS receive earth station

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

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

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

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

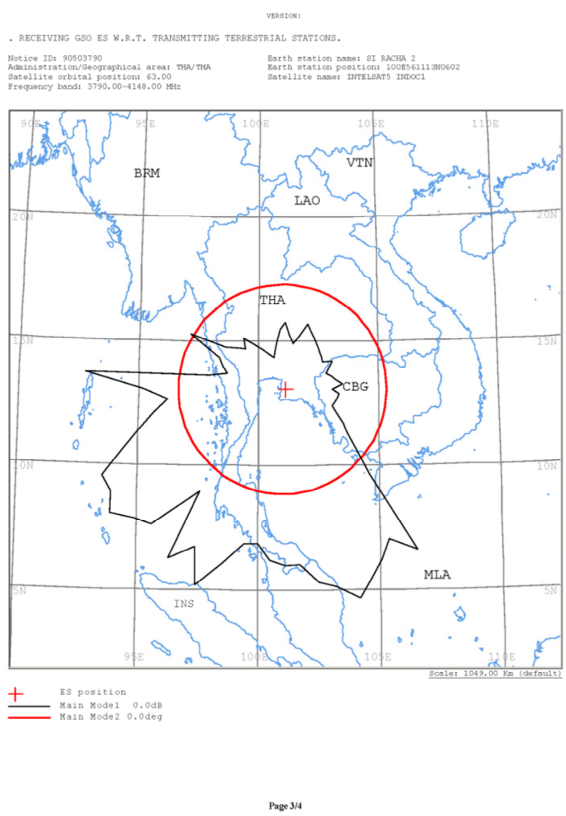
The coordination area is not an exclusion zone within which the sharing of frequencies between the earth station and terrestrial stations or other earth stations is prohibited, but rather a means for determining the area within which more detailed calculations need to be performed. A more detailed analysis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

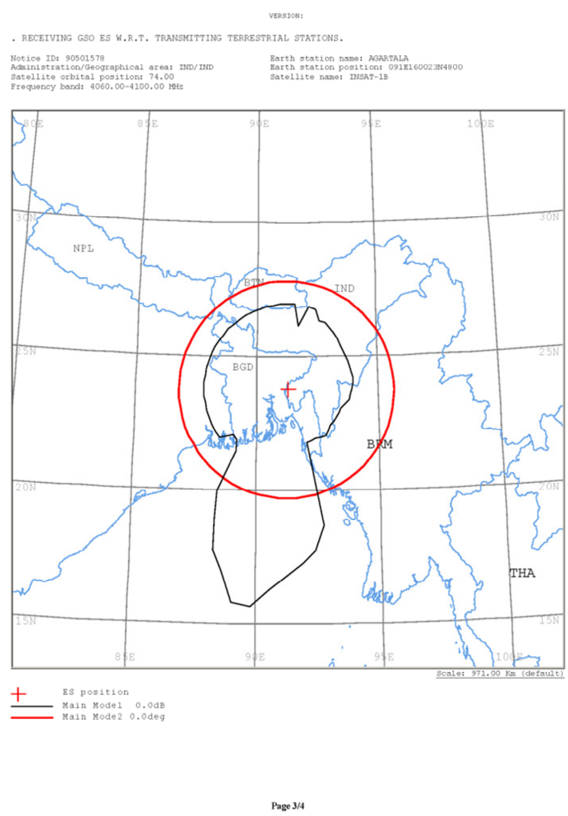
Calculation of a minimum coordination distance to protect an FSS earth station needs to take into account additional propagation effects (diffraction, building/terrain scattering etc.) not taken into account in the propagation model of RR Appendix 7. Minimum distances are usually in excess of 100 km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

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

TABLE 2

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





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

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

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

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

3.1 Examples of FSS deployments

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

– Information obtained from Intelsat and SES New Skies in mid-2006 showed that in Europe there were approximately 830 earth stations operating to Intelsat satellites and 251 earth stations operating to SES New Skies satellites, for a total of 1 081 earth stations using the band 3 400-4 200 MHz. Updated information from the same sources showed that by late-2008 the total number had increased to 1 431, an increase of 350 registered earth stations in this band over the short two year period. Figure 20 of Annex C to this Report provides a map showing this 2008 census.
– One major satellite operator has more than 9 900 registered earth stations, in its data base, deployed across the globe operating in the 3 400-4 200 MHz band. The location of these earth stations is shown in Figs 20 through 23 of Annex C to this Report[3]. These figures do

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

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

– In Brazil, in the band 3 700-4 200 MHz there are more than 8 000 nationally registered earth stations pointing to one of the Brazilian satellites and 12 000 nationally registered earth stations pointing to one of the non-Brazilian satellites that cover the country, plus an equal number of earth stations in the 3 625-3 700 MHz band (see Fig. 24 of Annex C). There are also an estimated 20 million TVRO terminals deployed across the country.

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

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

– In the Russian Federation, there are approximately 6 000 nationally registered earth stations that receive transmissions in the 3 400-4 200 MHz band. These figures do not include TVRO earth stations that are deployed across the country.

– In the Russian Federation there are more than 20 satellite networks operating in the band 3 400-4 200 MHz with global and semi-global coverage. These are the EXPRESS, YAMAL and STATSIONAR networks.

3.2 Types of FSS receive earth stations

There are four different types of FSS receive earth stations:

a) Earth stations deployed ubiquitously and/or without individual licensing or registration

   – Where deployed, these earth stations are typically in large numbers and their specific locations are not known.

b) Individually licensed earth stations

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

c) Telemetry earth stations

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

d) Feeder links for mobile-satellite systems

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

3.3 Unregistered earth stations

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

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

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

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

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

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

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

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

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

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

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

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

5 Possible types of interference to the FSS

Three possible types of interference have been identified as follows:

a) Co-frequency emissions from BWA

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

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

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

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

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

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

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

6 Sharing and compatibility studies and results

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

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

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

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

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

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

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

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

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

7 Methods and techniques to enhance sharing and compatibility

7.1 Individually licensed/registered FSS earth stations at specific locations

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

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

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

7.3 Possible techniques to avoid LNB saturation

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

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

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

7.4 Example of National Regulatory/Technical solutions

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

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

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

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

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

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

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

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

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

8 Conclusions

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

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

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

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

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

– in-band interference – BWA interfering with FSS in overlapping frequency bands;

– unwanted emissions of BWA (out-of-band due to spectrum roll-off and spurious emissions) interfering with FSS in other parts of the 3 400-4 200 MHz band;

– FSS receiver saturation – BWA power levels affecting the operating point of the FSS receiver LNA or LNB so that it is driven into saturation or non-linear operation.

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

– co-frequency: several tens to in excess of 100 km;

– out-of-band emissions: a few km;

– FSS receiver saturation: a few to several km.

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

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

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

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

Annex A

FSS and BWA system parameters

TABLE 3

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

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

TABLE 4

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

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

TABLE 4 (*end*)

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

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

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

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

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

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

TABLE 5

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

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

TABLE 5 (*end*)

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

N/A: Not applicable.

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

(2) This value is the maximum feeder loss.

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

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

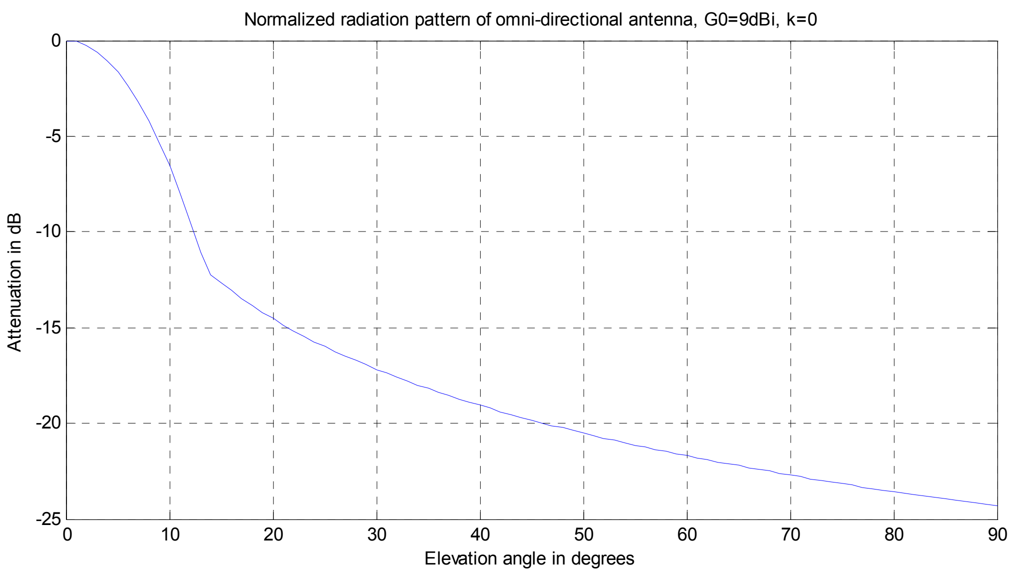
(5) Uplink activity factor for TDD mode is defined by the ratio of uplink subframe over the entire frame, that is uplink plus downlink subframes.

Antenna patterns for use with BWA

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

FIGURE 1

Omnidirectional base station antenna pattern in the vertical plane



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

FIGURE 2

Base station sectoral antenna vertical pattern at horizontal boresight

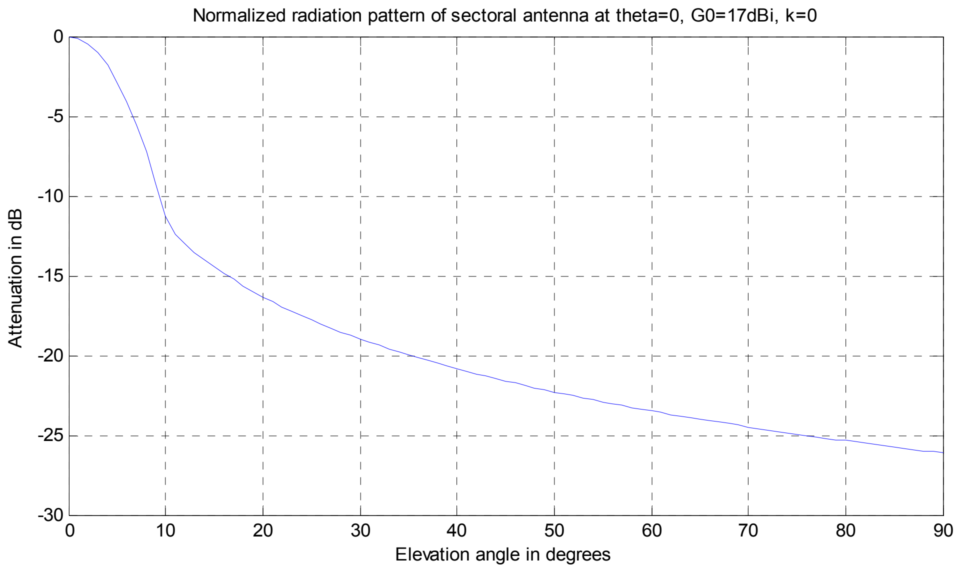


FIGURE 3

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

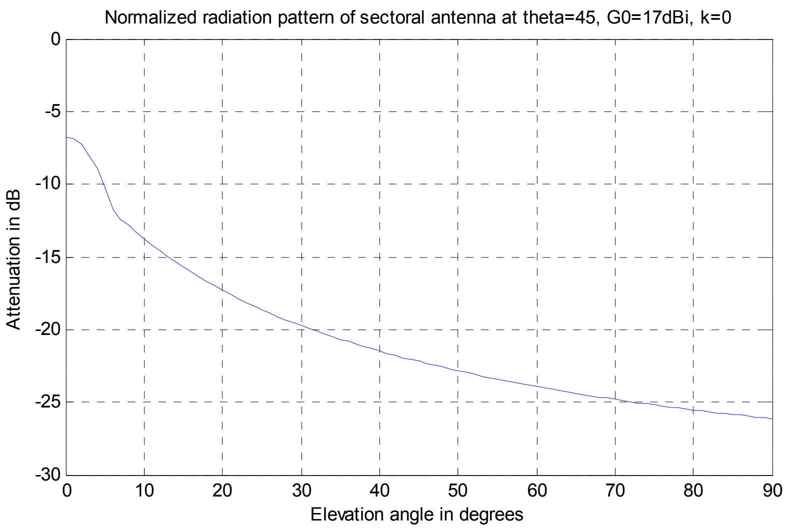
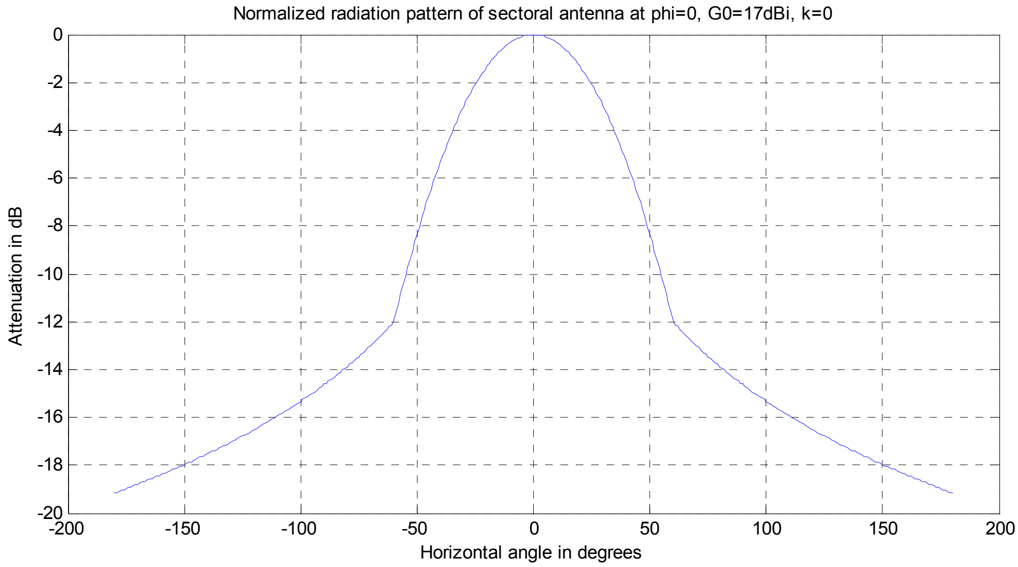


FIGURE 4

Base station sectoral antenna horizontal pattern at vertical boresight



Propagation model parameter for use in compatibility studies

TABLE 6

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

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

TABLE 6 (*continued*)

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

TABLE 6 (*end*)

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

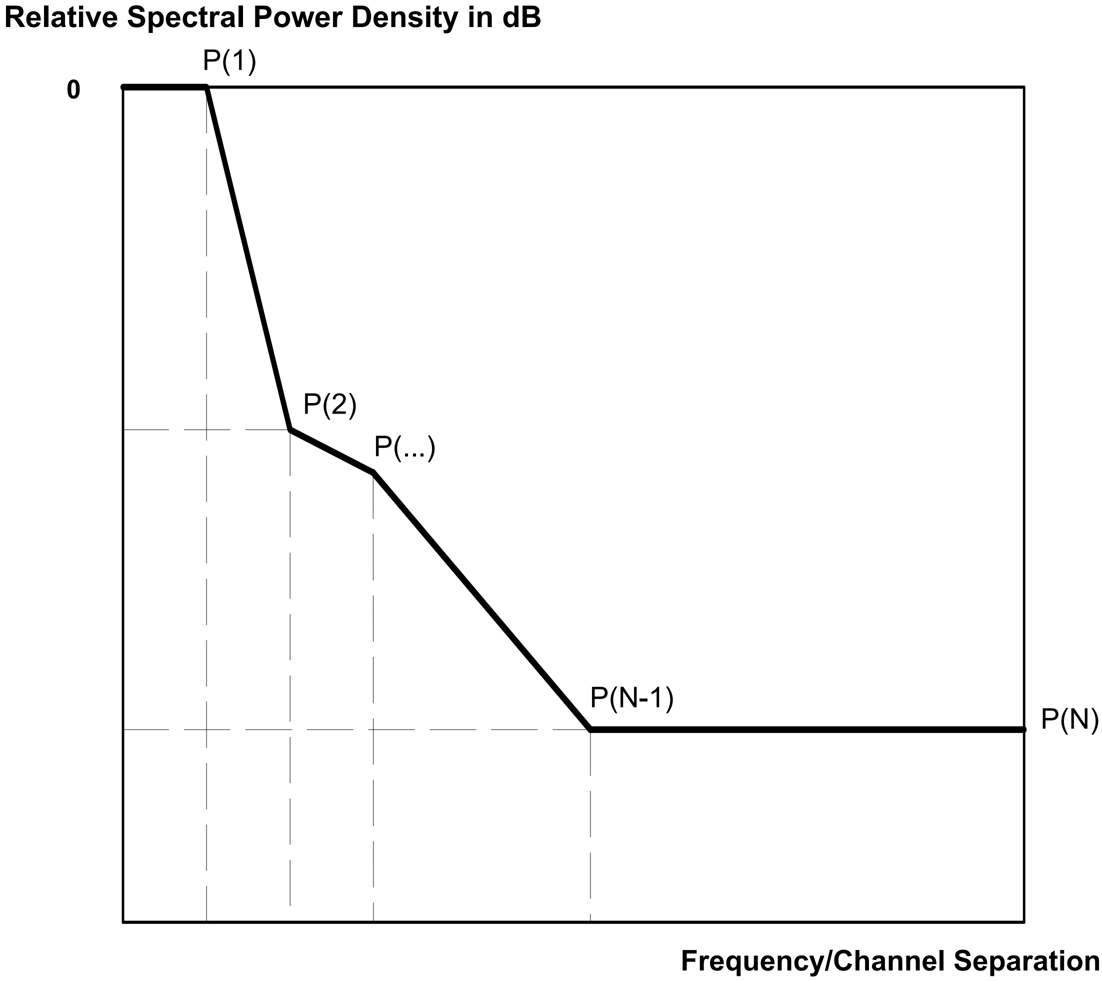
With respect to the clutter parameters referenced in Table 6, it should be noted that Recommendation ITU-R P.452-13 indicates that "*where there are doubts as to the certainty of the clutter environment, the additional loss should not be included*".

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

Attachment 1
to Annex A

Spectrum masks for BWA base stations

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



Power spectrum reference points

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

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

Attachment 2 to Annex A

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

Emission mask for 7 MHz channel bandwidth

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

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

TABLE 7

Spectrum emission mask requirement for 7 MHz channel bandwidth

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

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

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

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

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

Annex B

Description of studies

1 Introduction

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

Attachment 1 contains a description of Study A.

Attachment 2 contains a description of Study B.

Attachment 3 contains a description of Study C.

Attachment 4 contains a description of Study D.

Attachment 1 to Annex B

Study A – Compatibility between BWA systems and FSS earth stations

1 Introduction

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

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

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

2 Compatibility study's methodology and assumptions

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

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

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

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

where:

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

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

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

TX: BWA BS/TS TX power

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

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

G_{RxMax}: FSS ES maximum antenna gain

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

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

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

2.1 FSS system parameters

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

TABLE 8

FSS system parameters

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

2.2 FSS earth station maximum permissible interference

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

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

where:

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

T_r: noise temperature of receiving system (K)

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

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

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

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

TABLE 9

Level of maximum permissible interference

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

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

2.3 FSS ES antenna pattern

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

2.4 BWA system parameters

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

TABLE 10

BWA system parameters

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

TABLE 10 (*end*)

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

N/A: Not applicable.

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

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

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

2.5 BWA base station antenna pattern

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

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

2.6 BWA terminal station antenna pattern

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

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

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

FIGURE 5

Fixed-outdoor terminal station sectoral antenna horizontal pattern

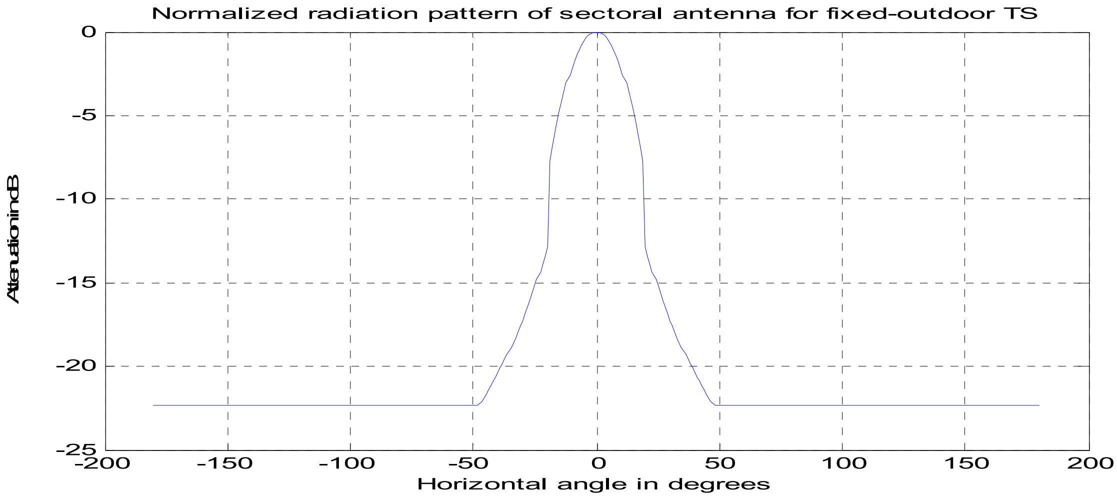


TABLE 11

BWA base station and terminal station ACLR values

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

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

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

2.8 Propagation models

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

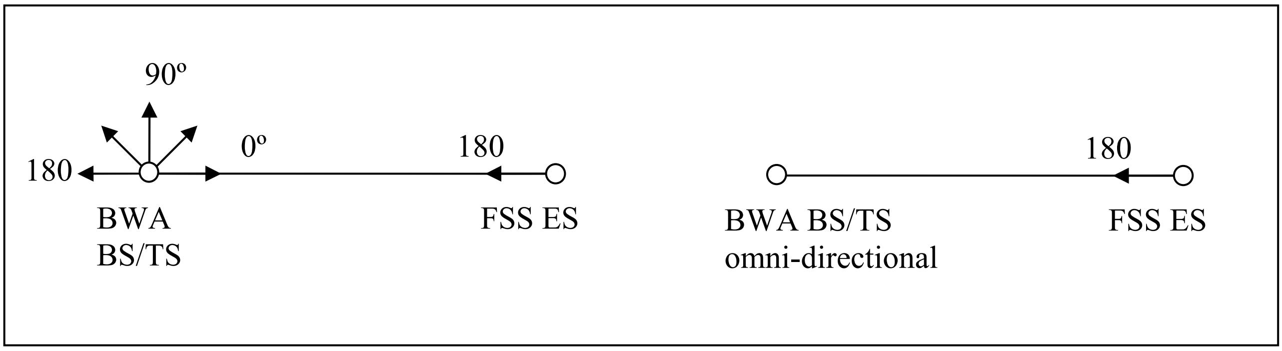
Table 6 in Annex A of this Report summarizes the values of the propagation model parameters used in this study.

3 Results

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

FIGURE 6

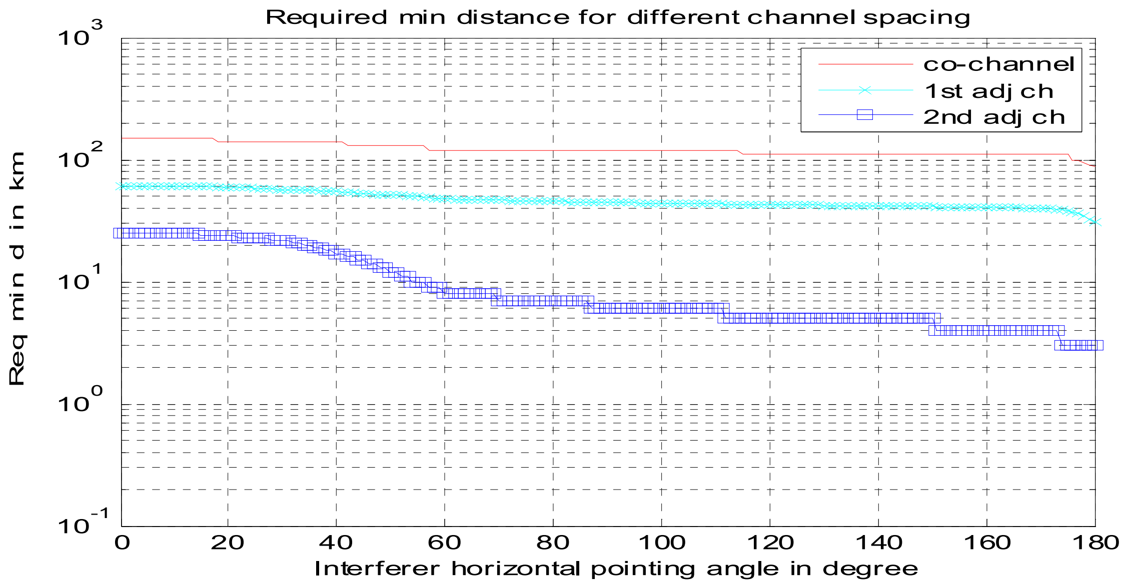
BWA BS/TS and FSS ES horizontal pointing positions

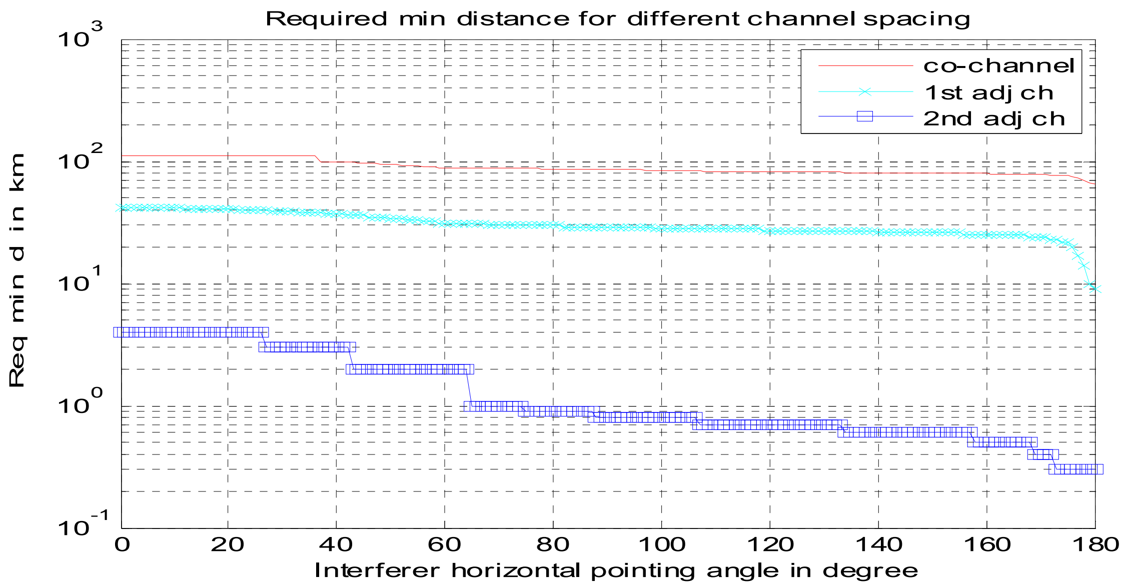


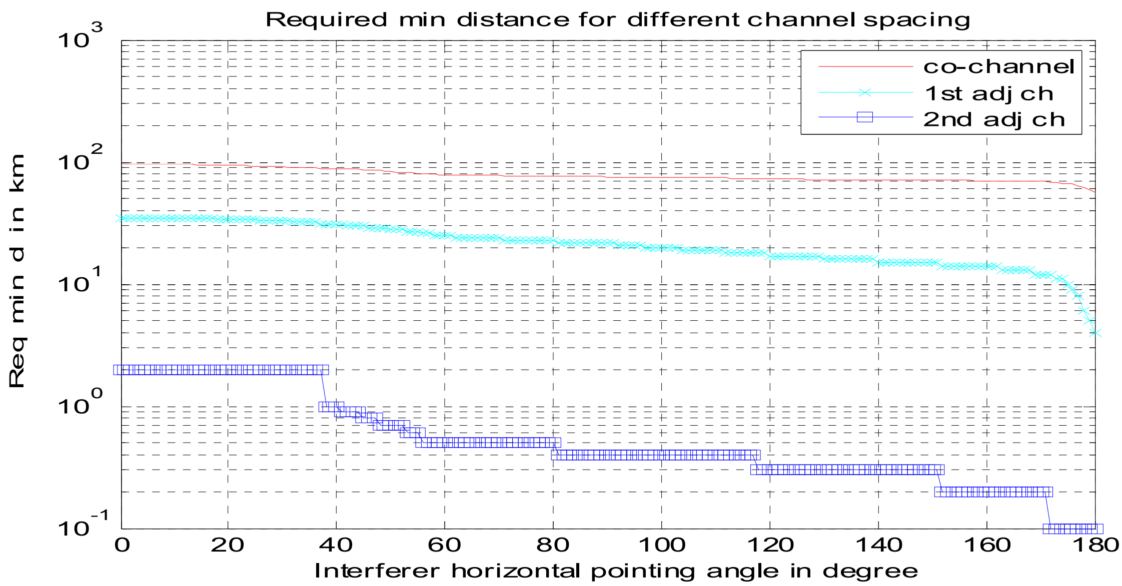
In each figure in this section, there are three curves; "co-channel" indicates two systems are deployed on the same channel, "1st adj ch" indicates two systems are deployed on the adjacent channels without any guardband, "2nd adj ch" indicates two systems are deployed with 7 MHz guardband.

3.1 BWA rural BS interfering with 32 m FSS ES

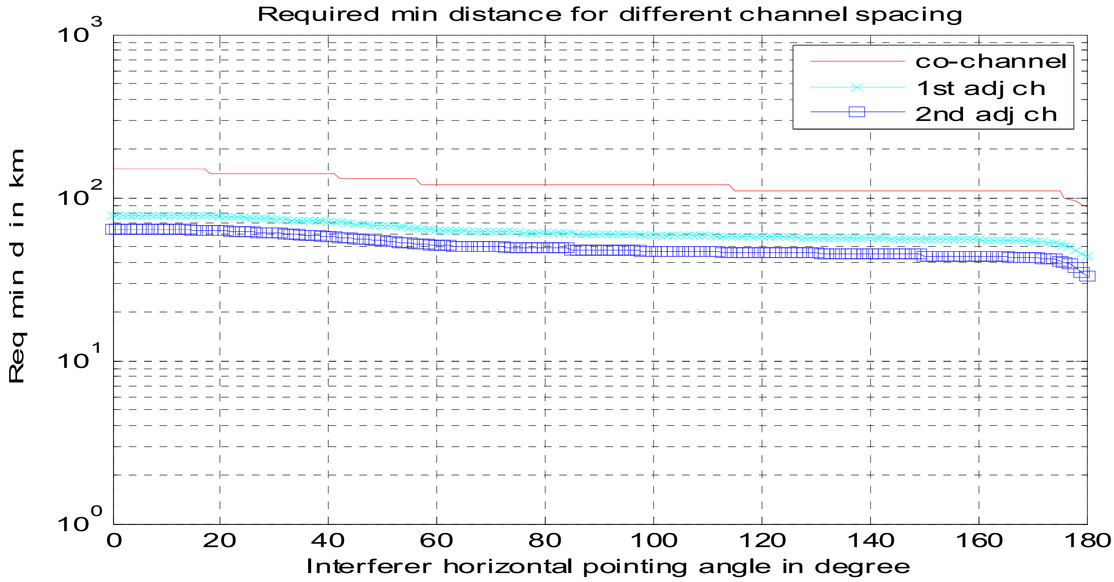
The following three figures show the minimum required distance in km between BWA rural BS with scenario 1 ACLR values and 32 m FSS ES with 5º, 25º, and 50º elevation pointing direction, respectively. The BS antenna horizontal pointing direction is from 0º to 180º.

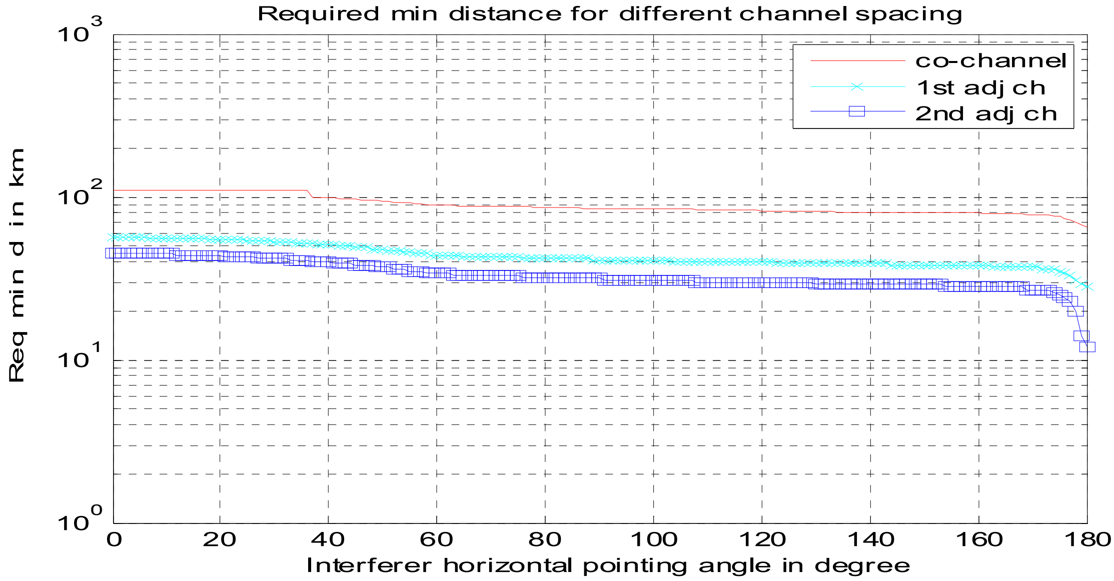


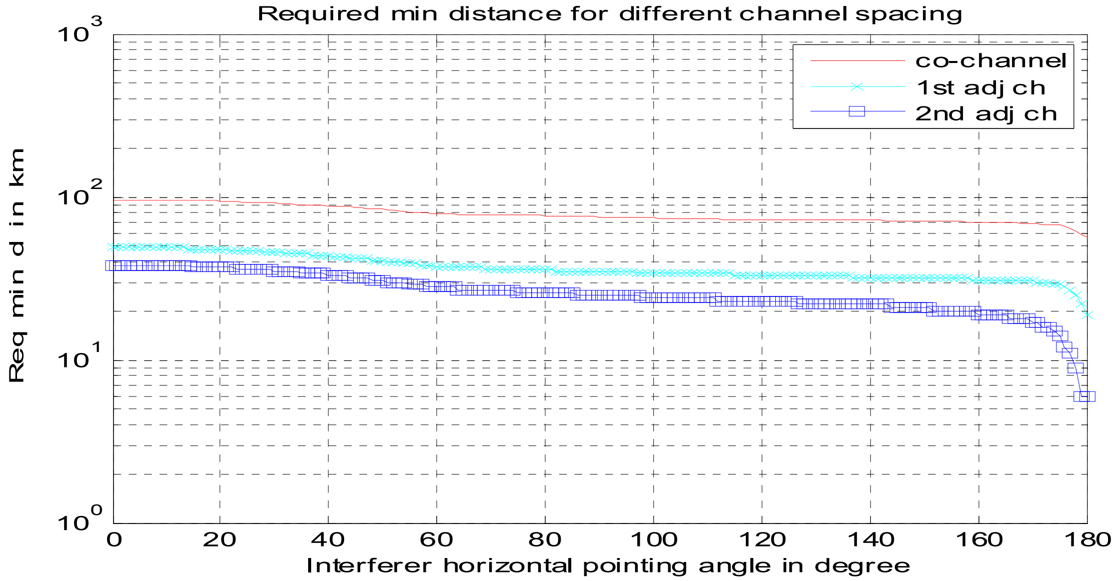




The following three figures show the minimum required distance in km between BWA rural BS with Scenario 2 ACLR values and 32 m FSS ES with 5º, 25º, and 50º elevation pointing direction, respectively. The BS antenna horizontal pointing direction is from 0º to 180º.

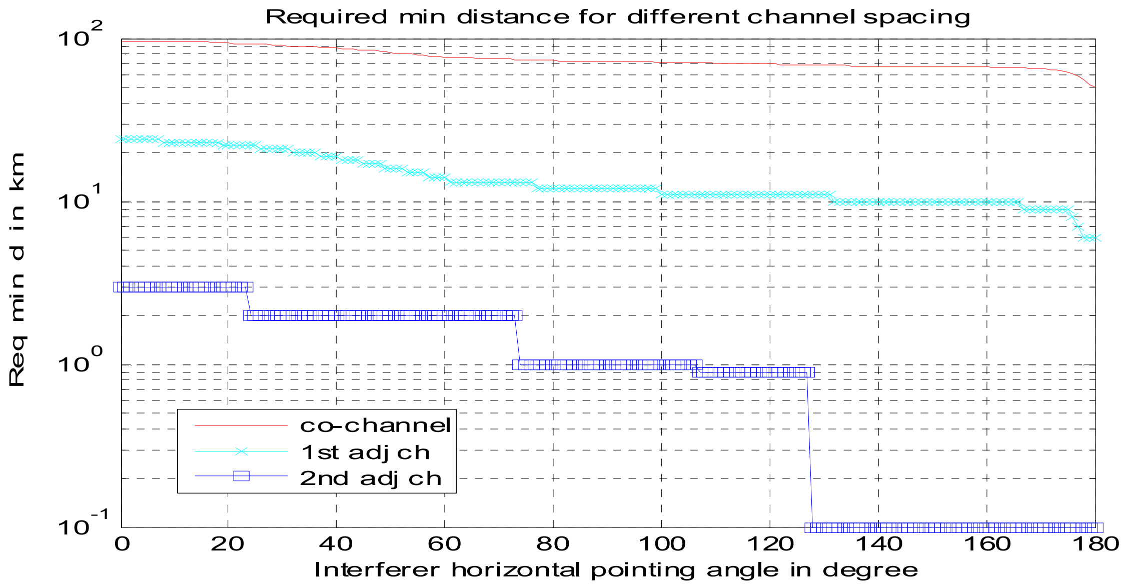

Required min distance for different channel spacing
co-channel
1st adj ch
2nd adj ch
Req min d in km
Interferer horizontal pointing angle in degree
10^3
10^2
10^1
10^0
0 20 40 60 80 100 120 140 160 180

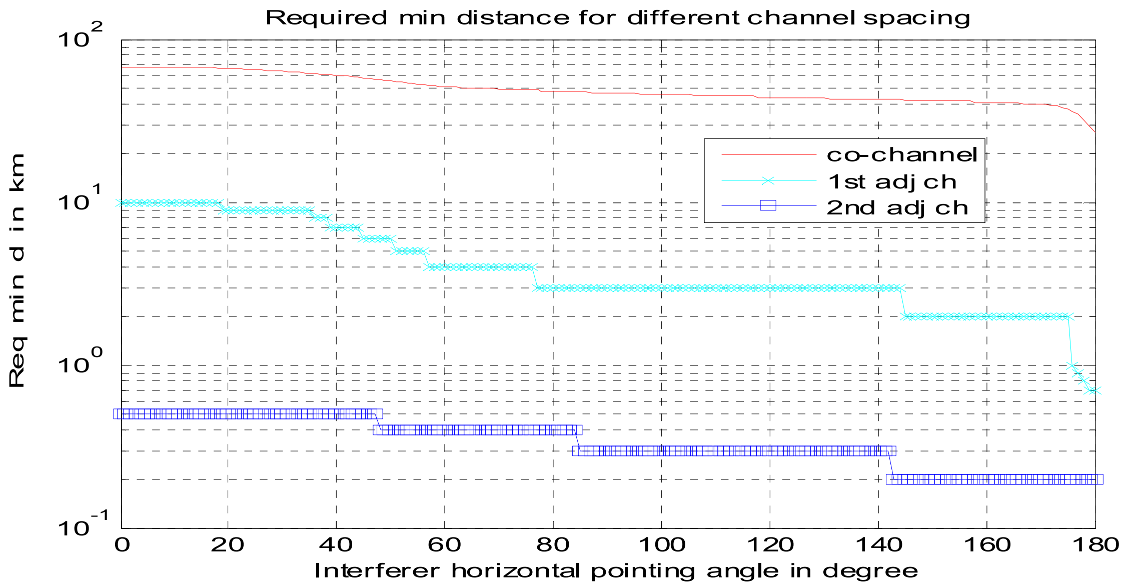

Required min distance for different channel spacing
co-channel
1st adj ch
2nd adj ch
Req min d in km
Interferer horizontal pointing angle in degree
10^3
10^2
10^1
10^0
0 20 40 60 80 100 120 140 160 180

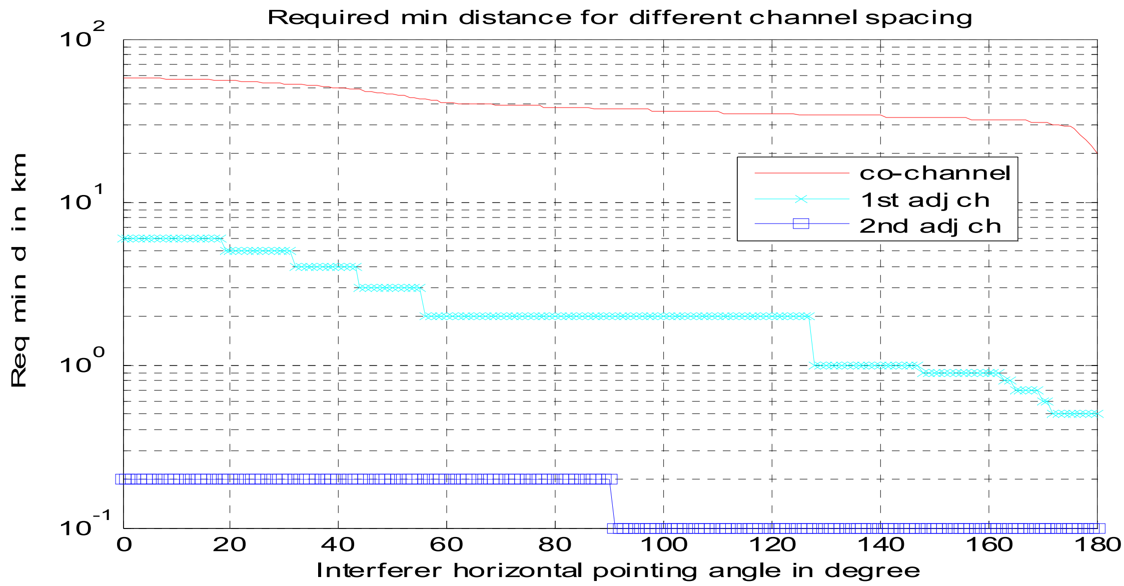

Required min distance for different channel spacing
co-channel
1st adj ch
2nd adj ch
Req min d in km
Interferer horizontal pointing angle in degree
10^3
10^2
10^1
10^0
0 20 40 60 80 100 120 140 160 180

3.2 BWA rural BS interfering with 8 m FSS ES

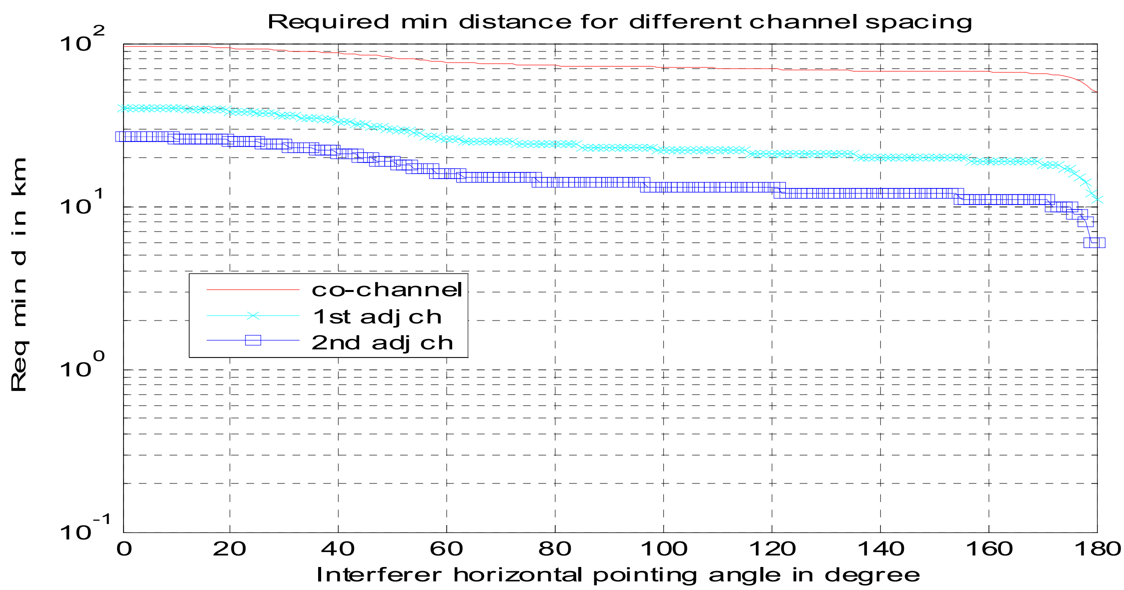
The following three figures show the minimum required distance in km between BWA rural BS with Scenario 1 ACLR values and 8 m FSS ES with 5º, 25º, and 50º elevation pointing direction, respectively. The BS antenna horizontal pointing direction is from 0º to 180º.

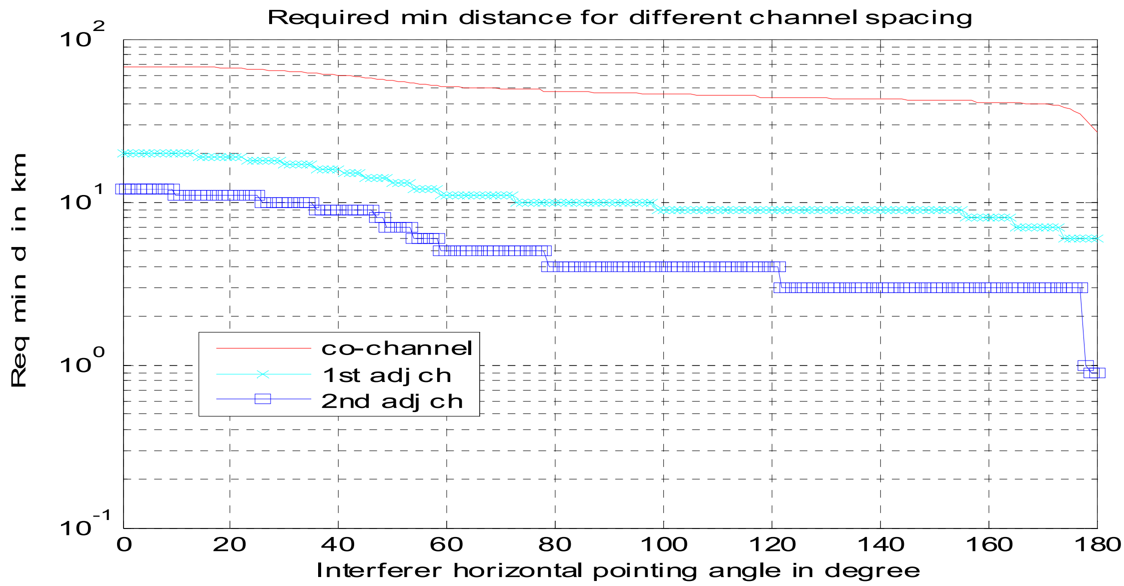


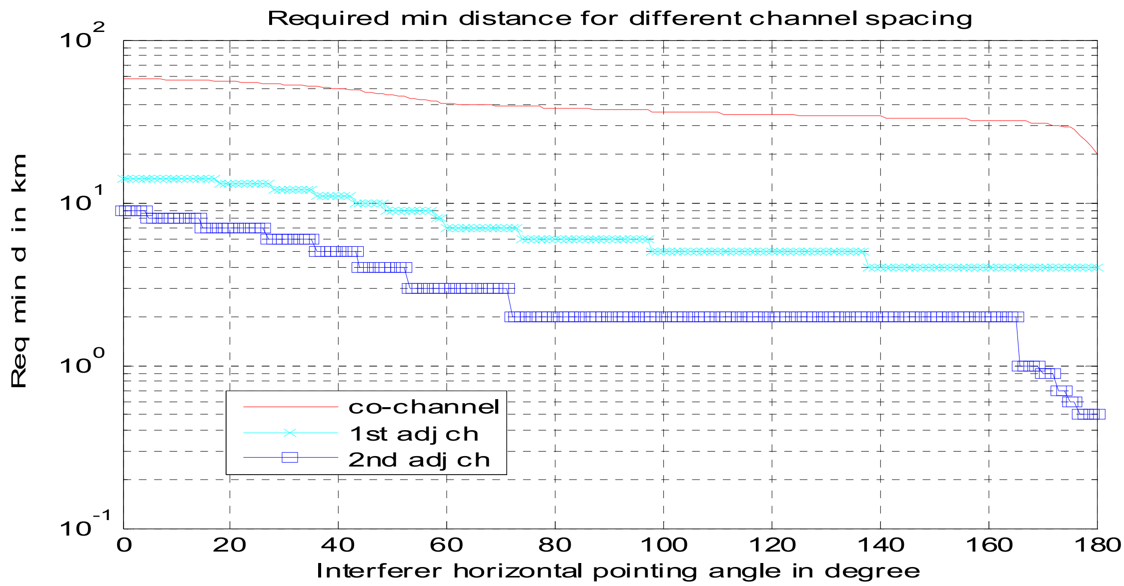




The following three figures show the minimum required distance in km between BWA rural BS with Scenario 2 ACLR values and 8 m FSS ES with 5º, 25º, and 50º elevation pointing direction, respectively. The BS antenna horizontal pointing direction is from 0º to 180º.

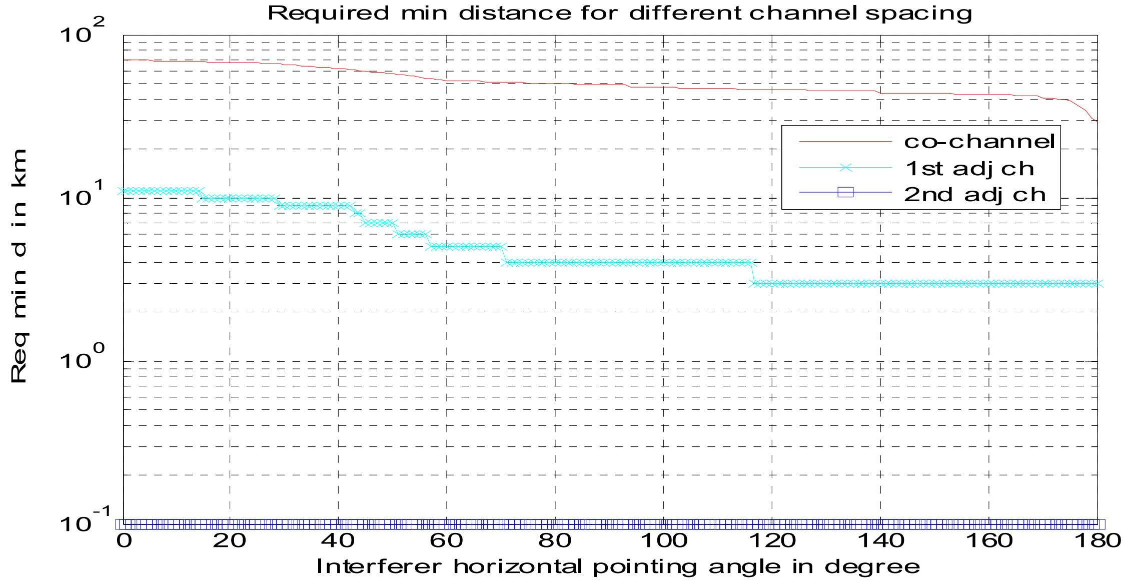


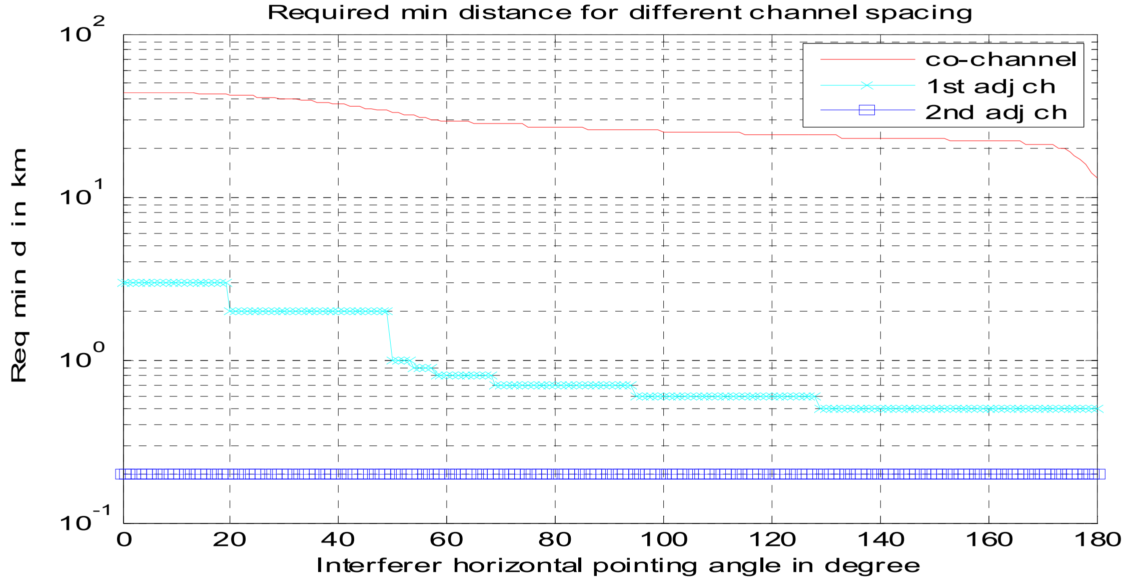


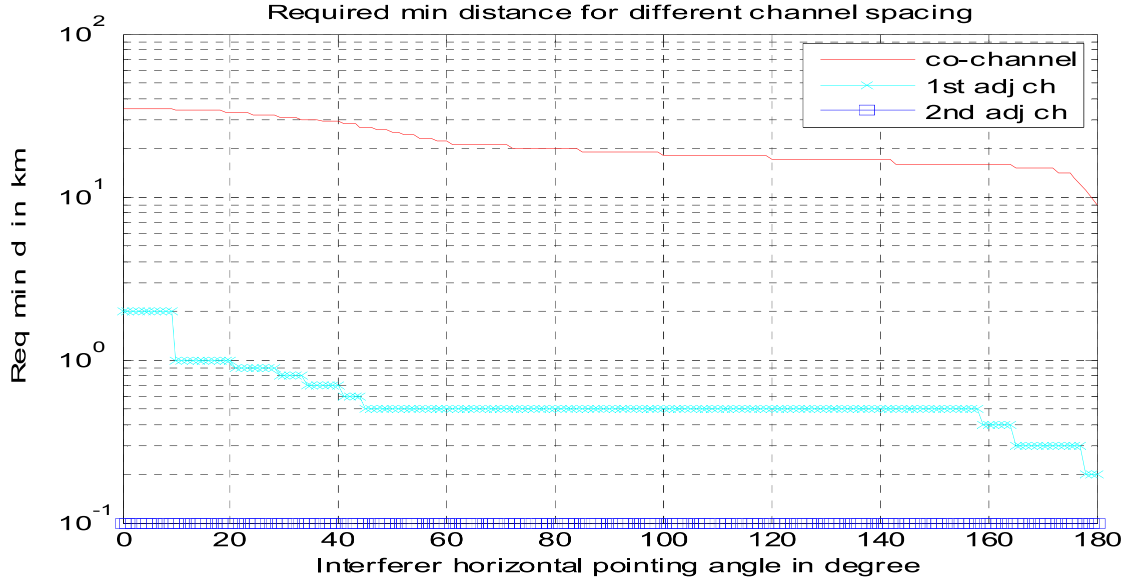


3.3 BWA rural BS interfering with 1.2 m FSS ES

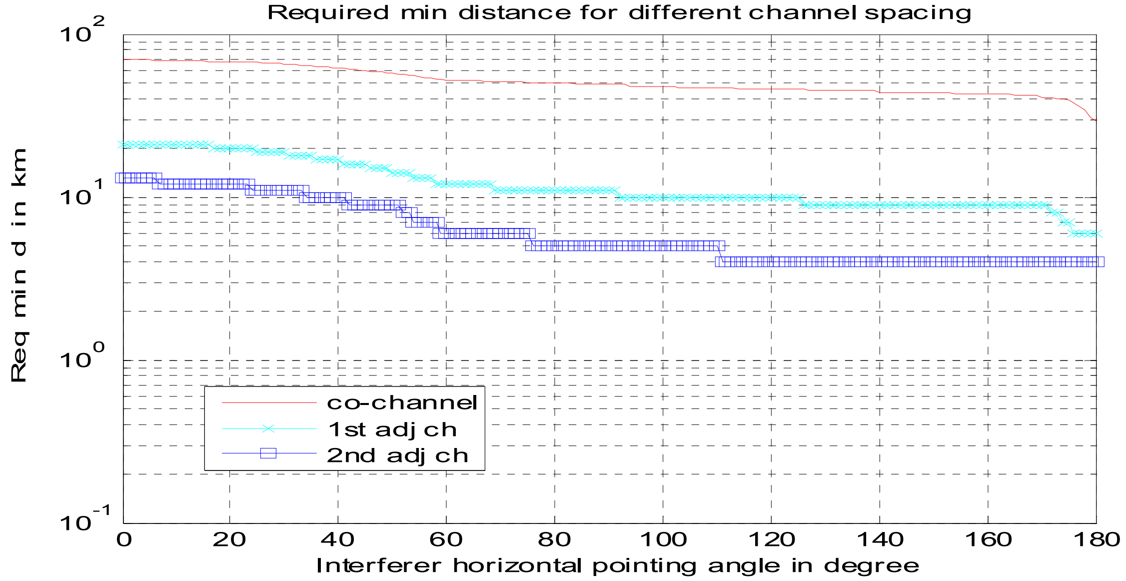
The following three figures show the minimum required distance in km between BWA rural BS with Scenario 1 ACLR values and 1.2 m FSS ES with 5º, 25º, and 50º elevation pointing direction, respectively. The BS antenna horizontal pointing direction is from 0º to 180º.

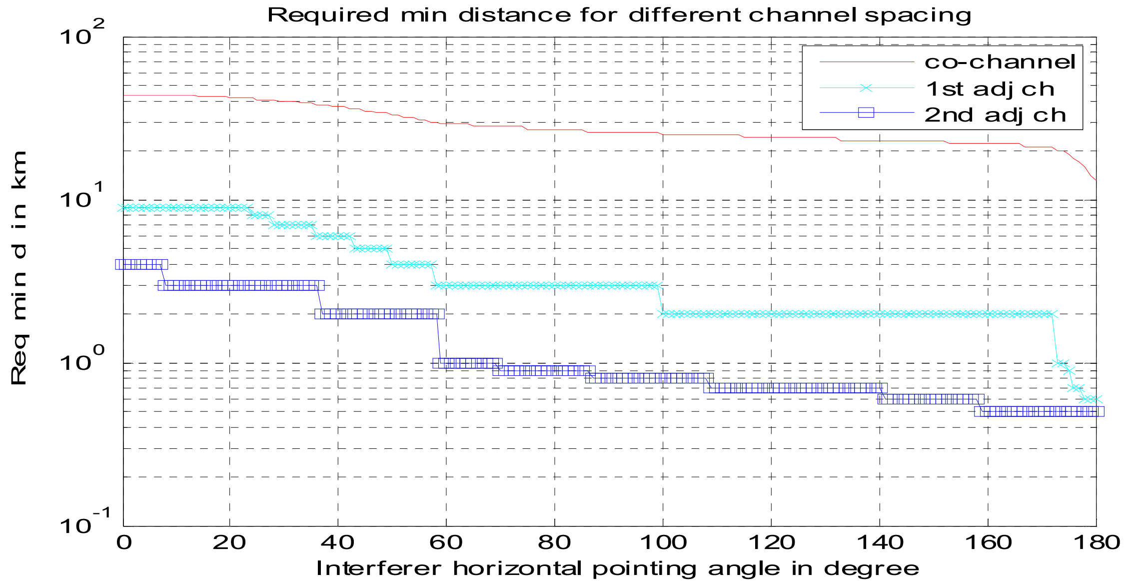

Required min distance for different channel spacing
Req min d in km
Interferer horizontal pointing angle in degree
co-channel
1st adj ch
2nd adj ch
10^2
10^1
10^0
10^-1
0
20
40
60
80
100
120
140
160
180

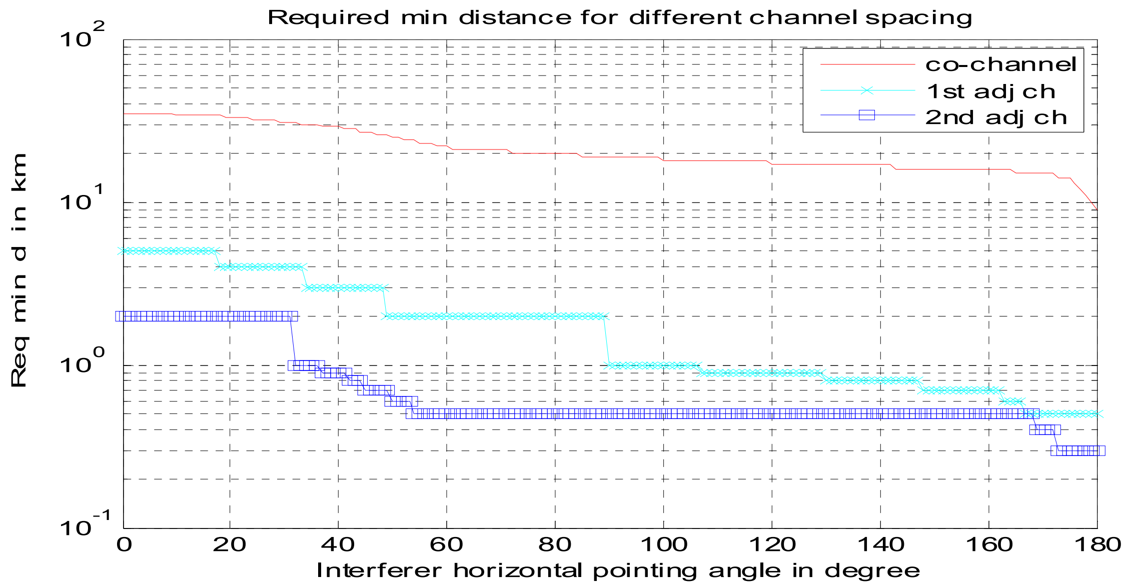

Required min distance for different channel spacing
Req min d in km
Interferer horizontal pointing angle in degree
co-channel
1st adj ch
2nd adj ch
10^2
10^1
10^0
10^-1
0
20
40
60
80
100
120
140
160
180


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

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

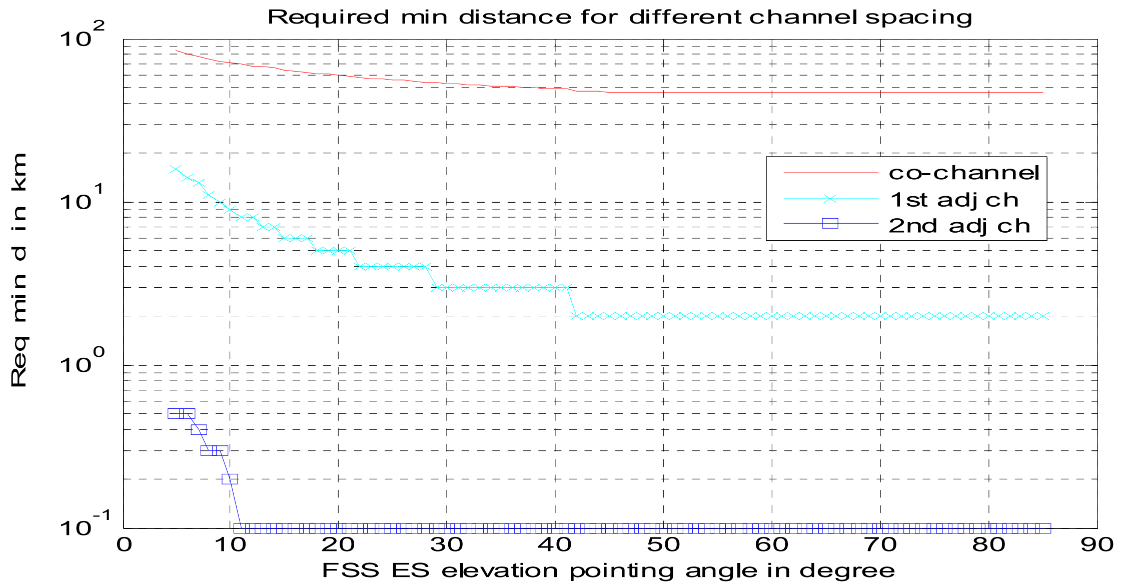




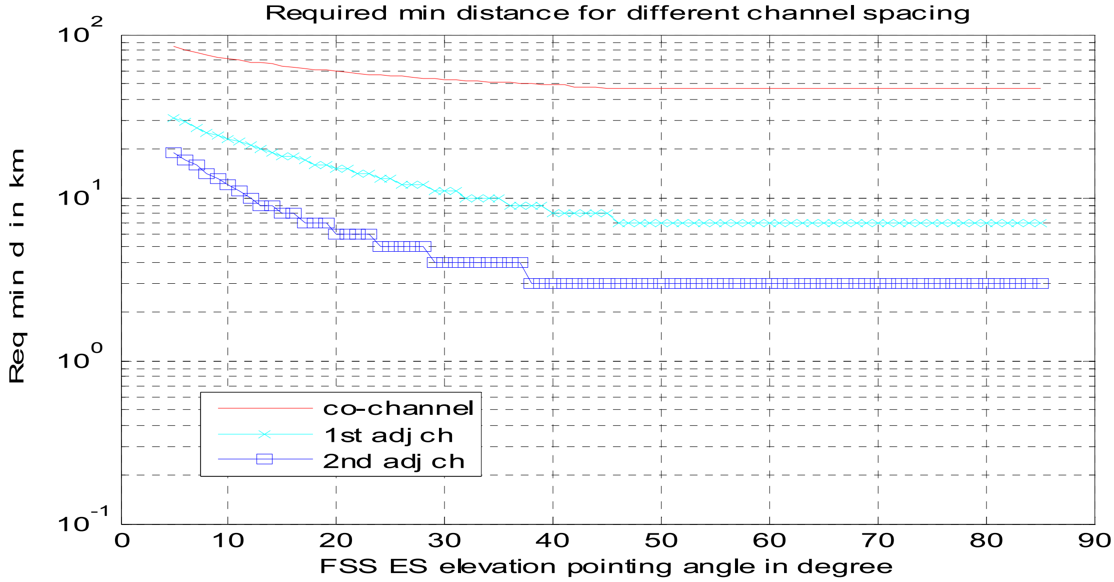


3.4 BWA urban BS interfering with 32 m FSS ES

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

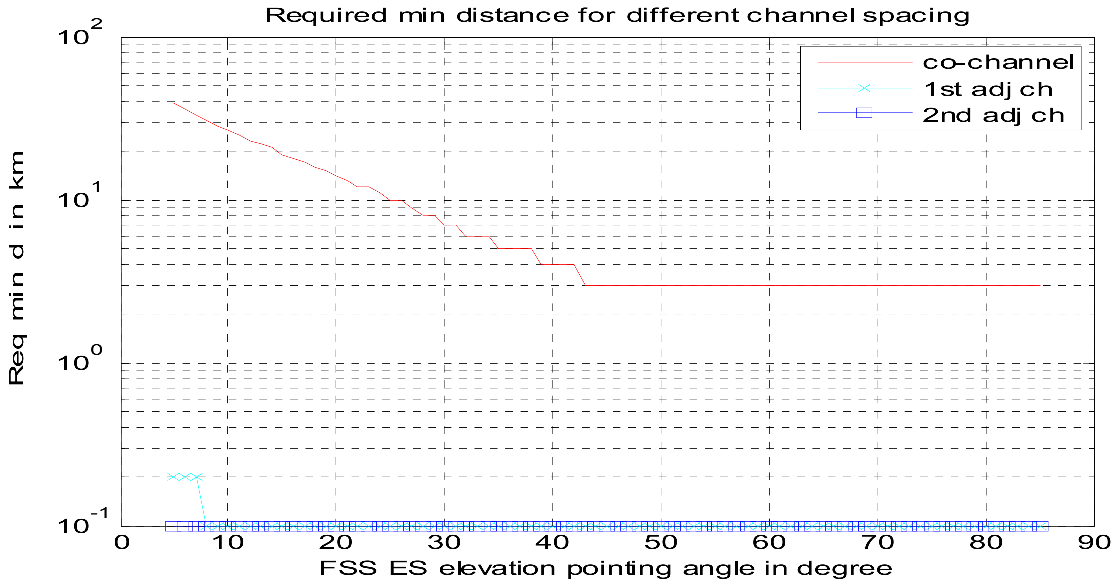


The following figure shows the minimum required distance in km between BWA urban BS with Scenario 2 ACLR values and 32 m FSS ES with 5° to 85° elevation pointing direction.

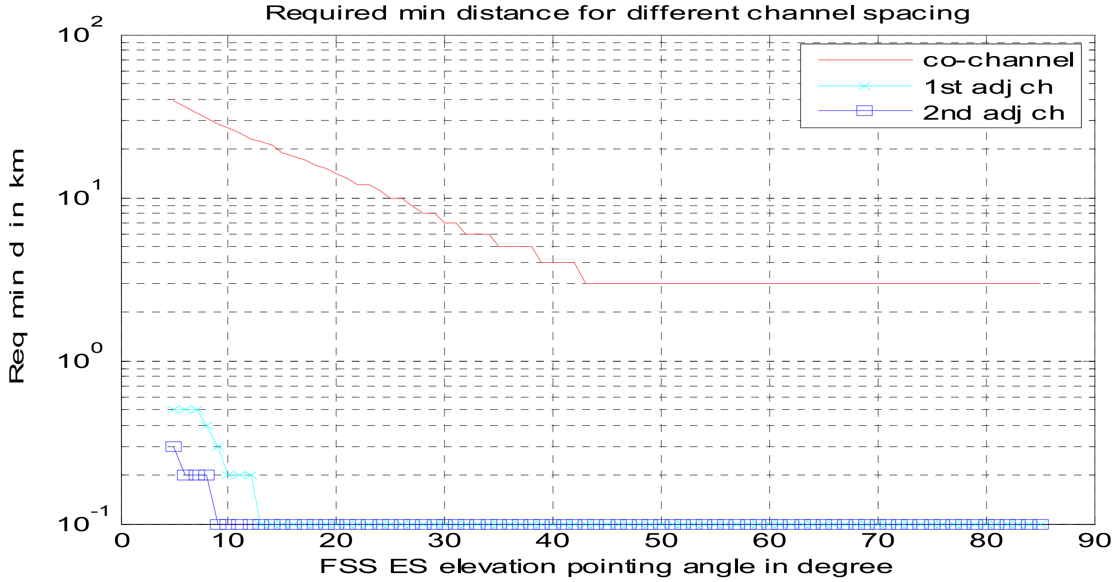


3.5 BWA urban BS interfering with 8 m FSS ES

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



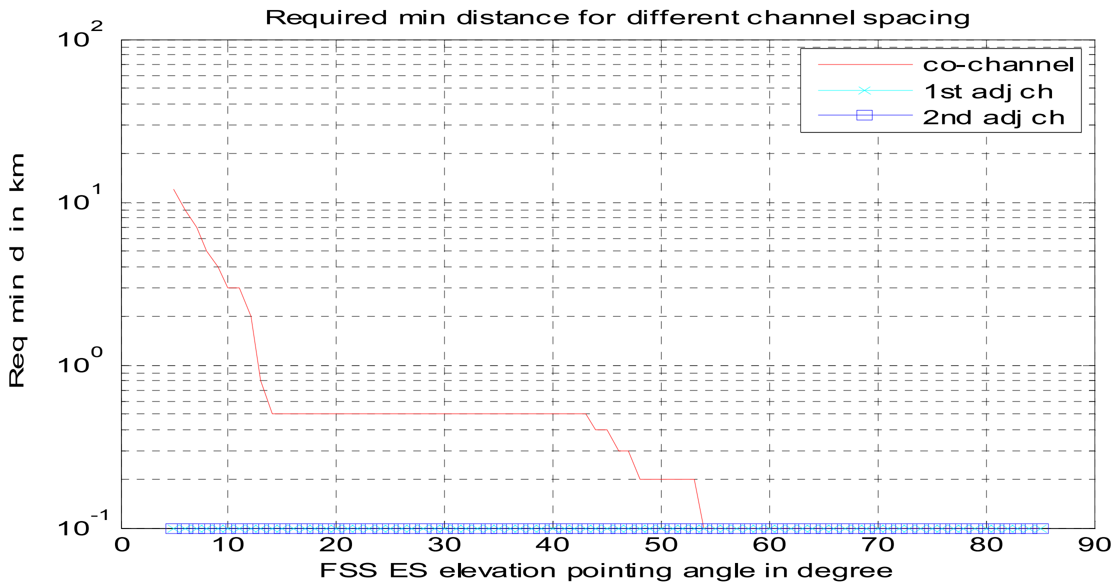
The following figure shows the minimum required distance in km between BWA urban BS with Scenario 2 ACLR values and 8 m FSS ES with 5º to 85º elevation pointing direction.



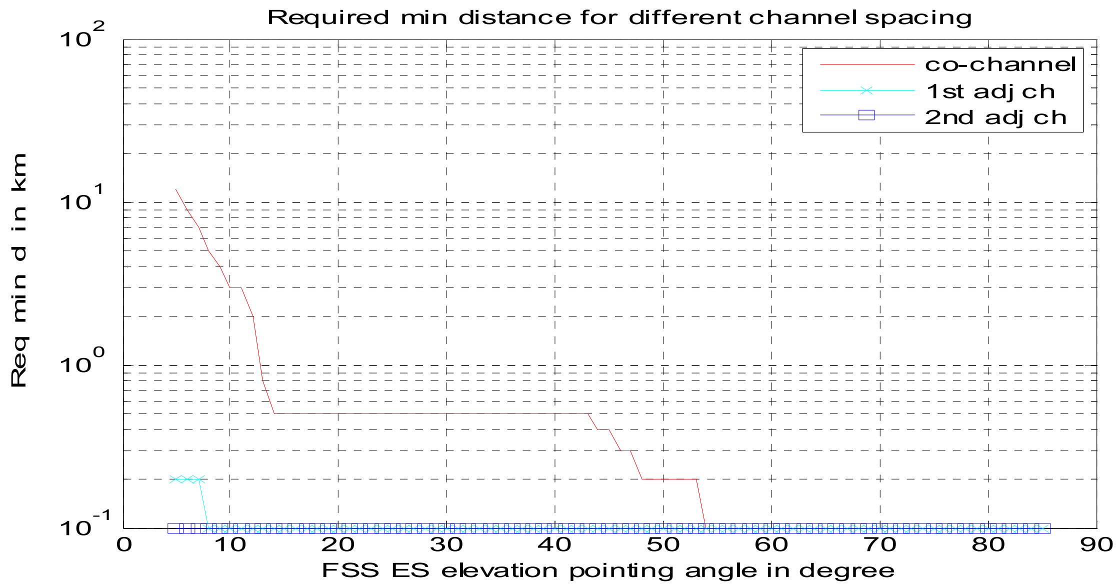
Note that distances below 100 m are not considered in the calculation of required separation distances.

3.6 BWA urban BS interfering with 1.2 m FSS ES

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



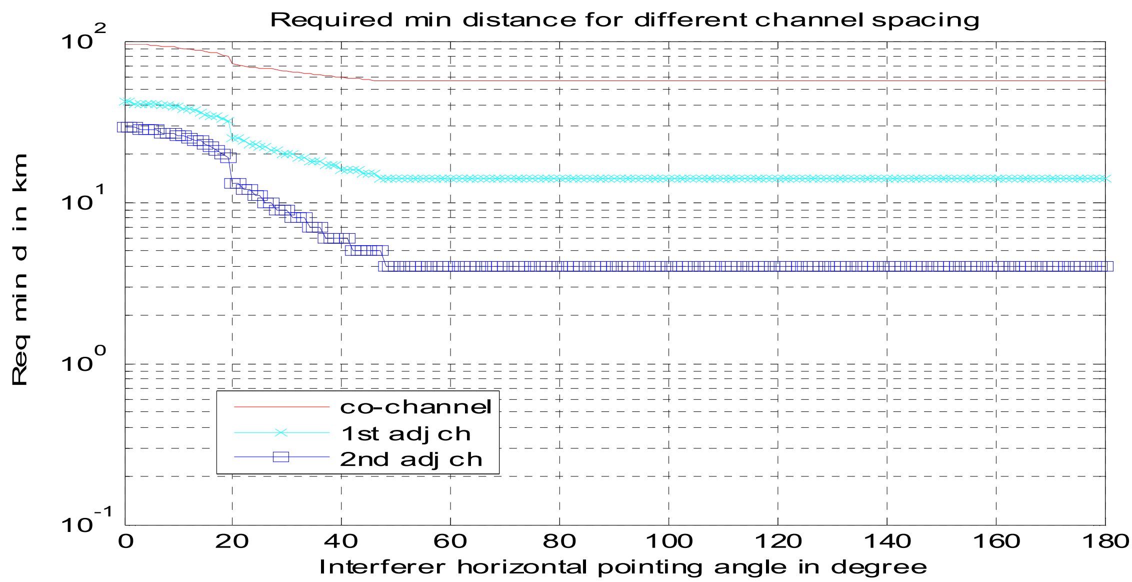
The following figure shows the minimum required distance in km between BWA urban BS with Scenario 2 ACLR values and 1.2 m FSS ES with 5º to 85º elevation pointing direction.

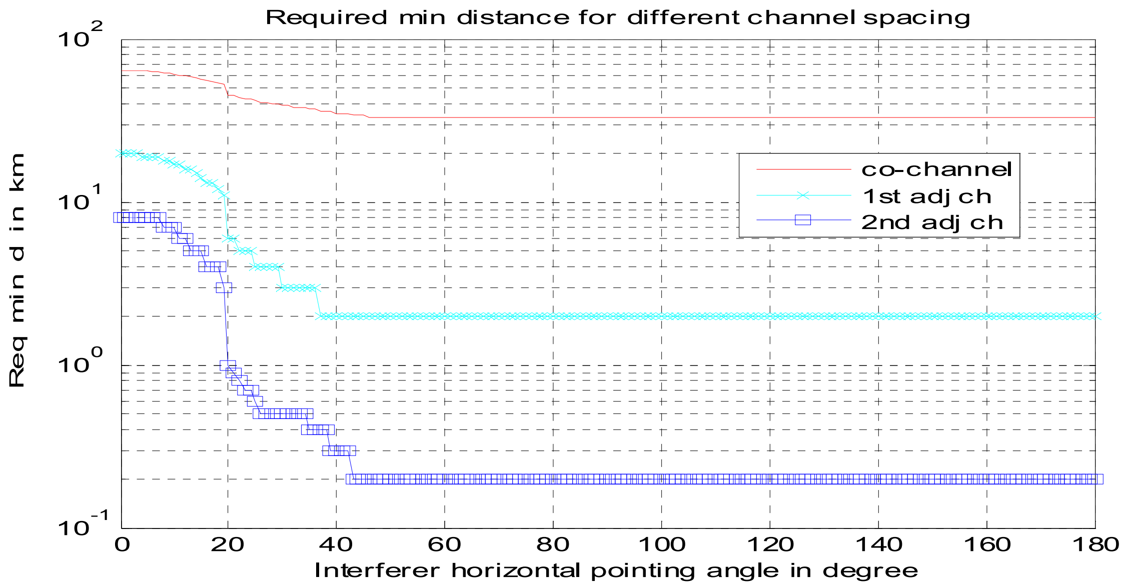


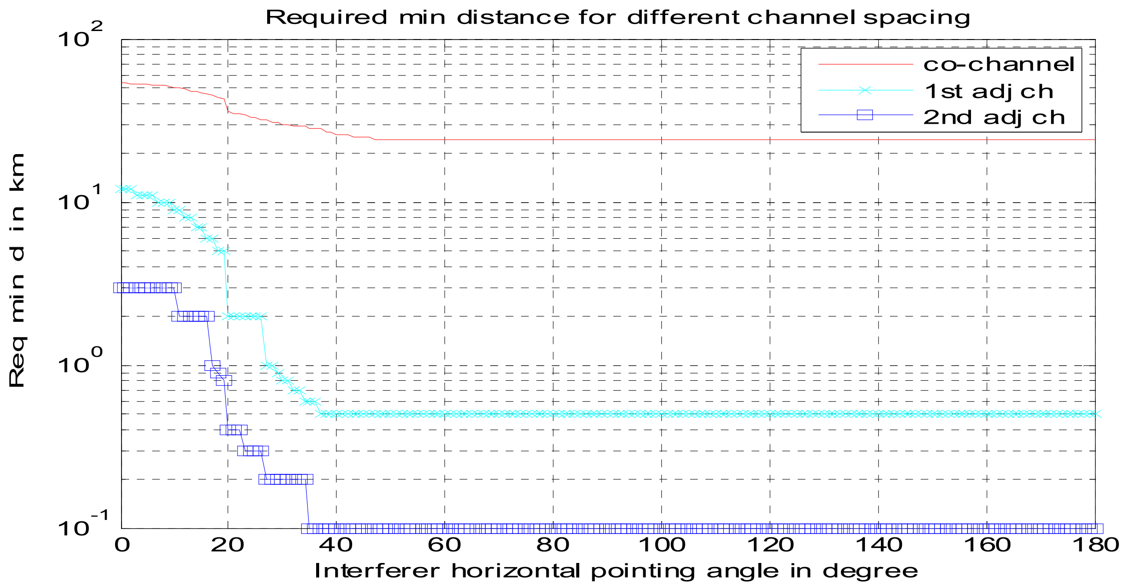
Note that distances below 100 m are not considered in the calculation of required separation distances.

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

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



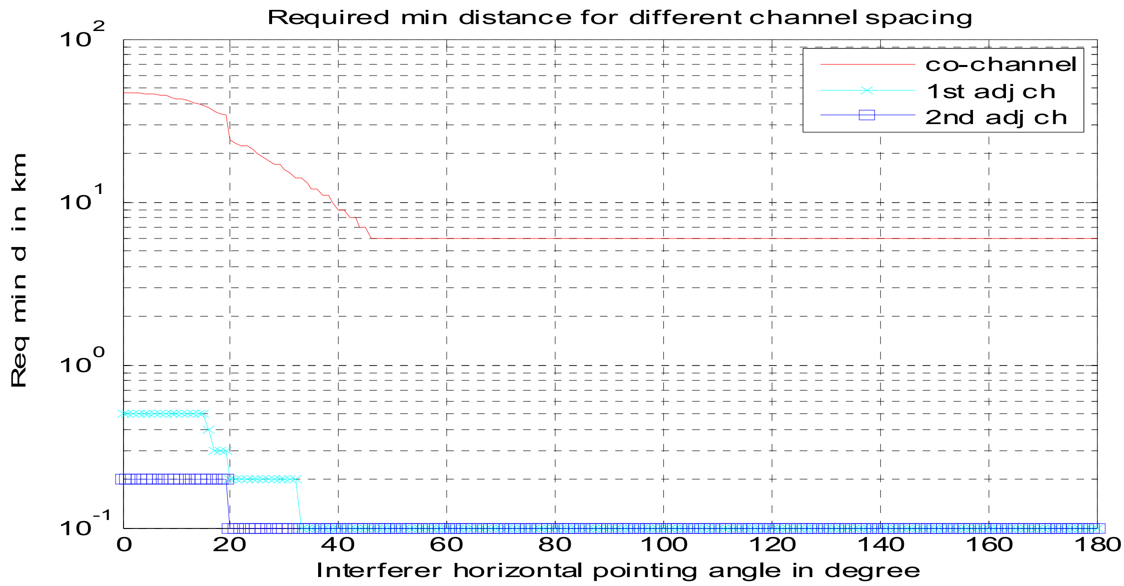


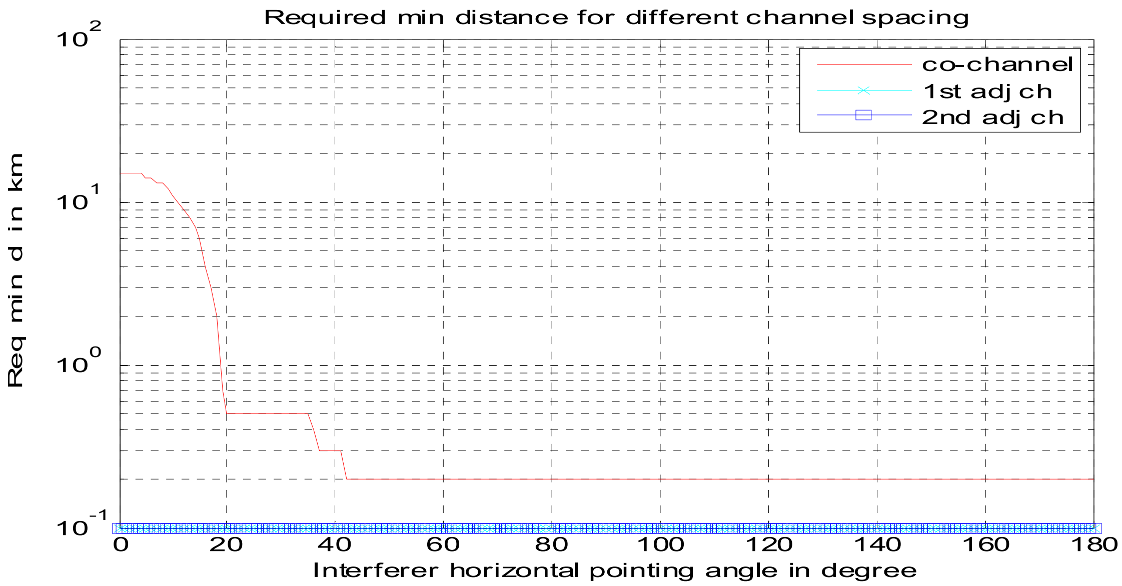


Note that distances below 100 m are not considered in the calculation of required separation distances.

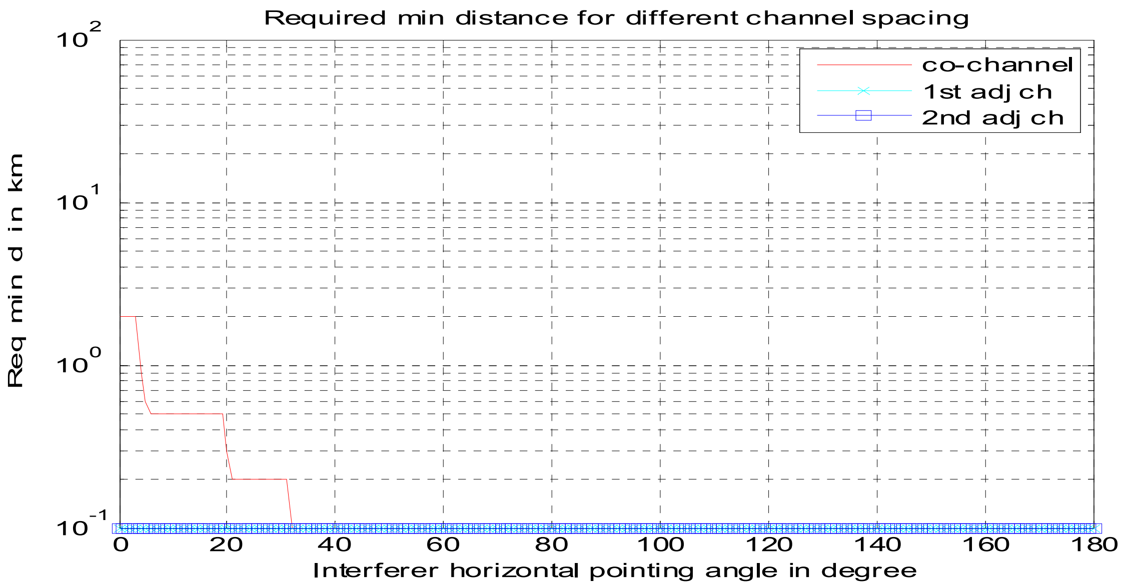
3.8 BWA fixed-outdoor TS interfering with 8 m FSS ES

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


Required min distance for different channel spacing
co-channel
1st adj ch
2nd adj ch
Req min d in km
Interferer horizontal pointing angle in degree


Required min distance for different channel spacing
co-channel
1st adj ch
2nd adj ch
Req min d in km
Interferer horizontal pointing angle in degree

f

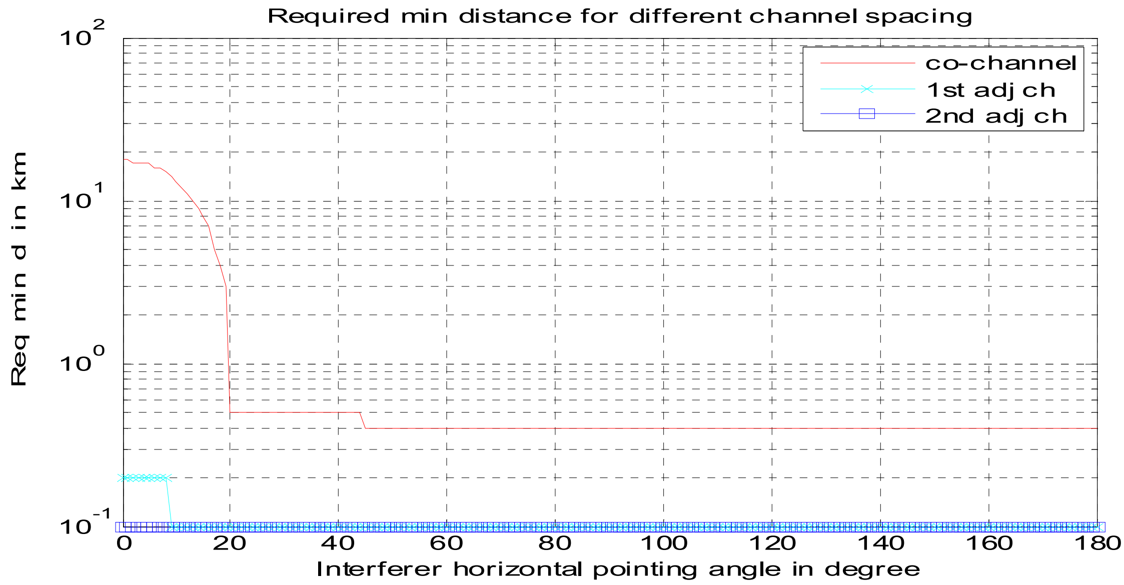

Required min distance for different channel spacing
co-channel
1st adj ch
2nd adj ch
Req min d in km
Interferer horizontal pointing angle in degree

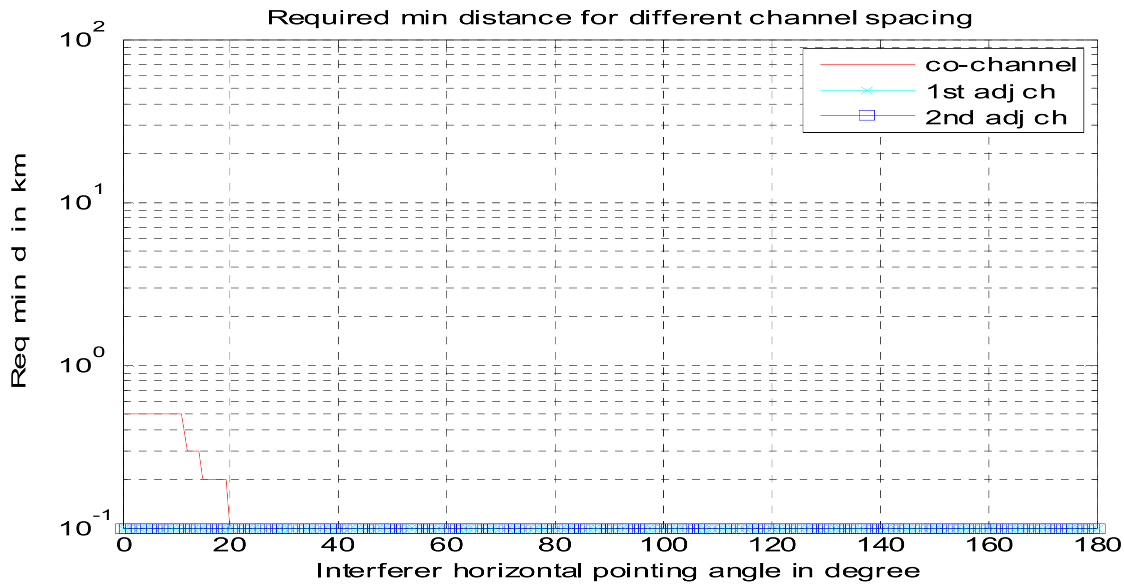
f

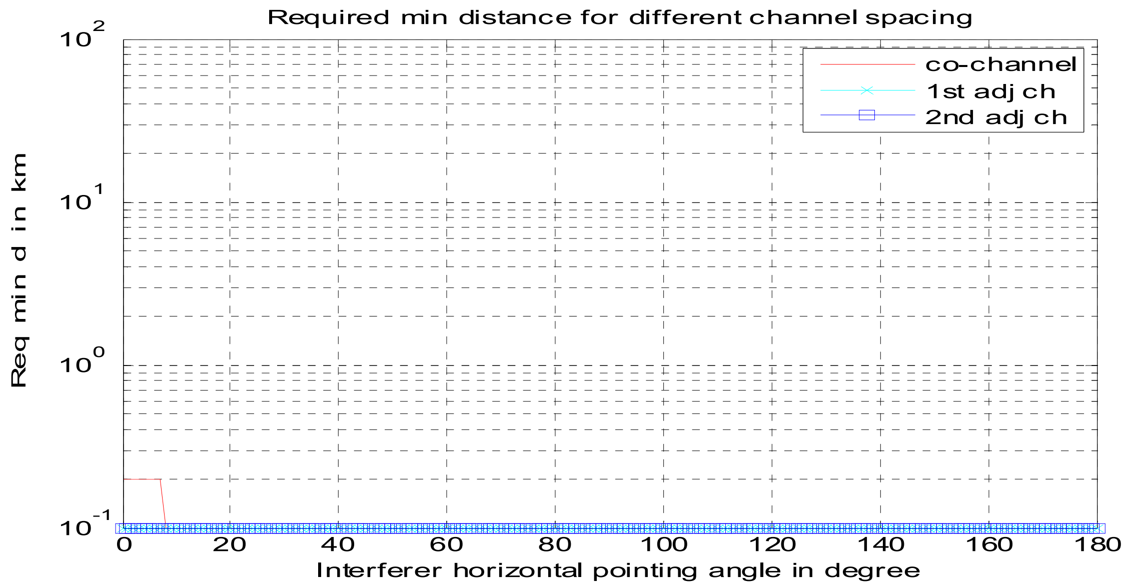
Note that distances below 100 m are not considered in the calculation of required separation distances.

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

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



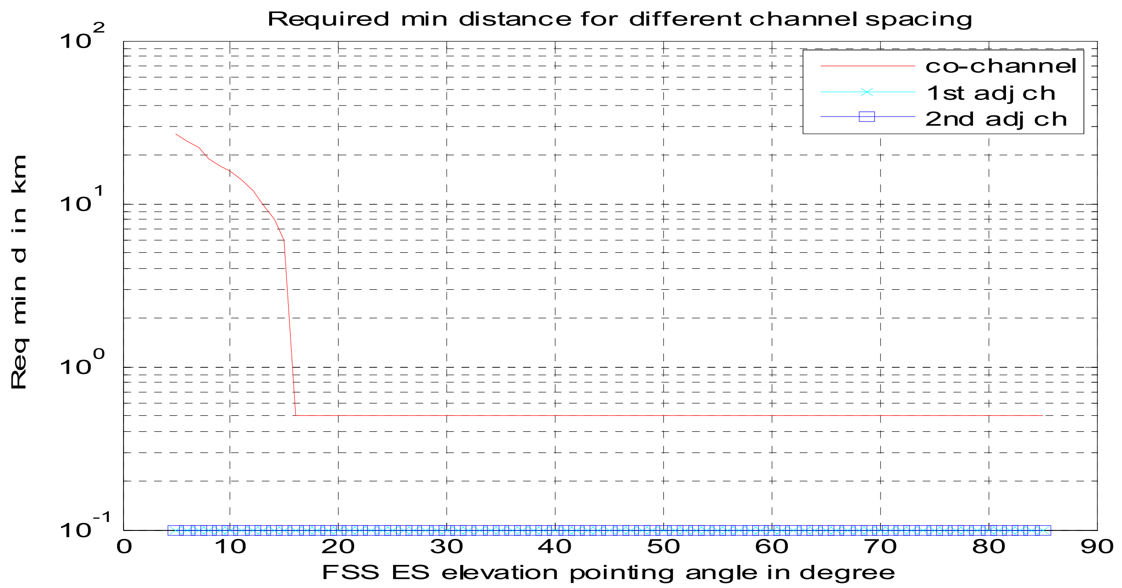




Note that distances below 100 m are not considered in the calculation of required separation distances.

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

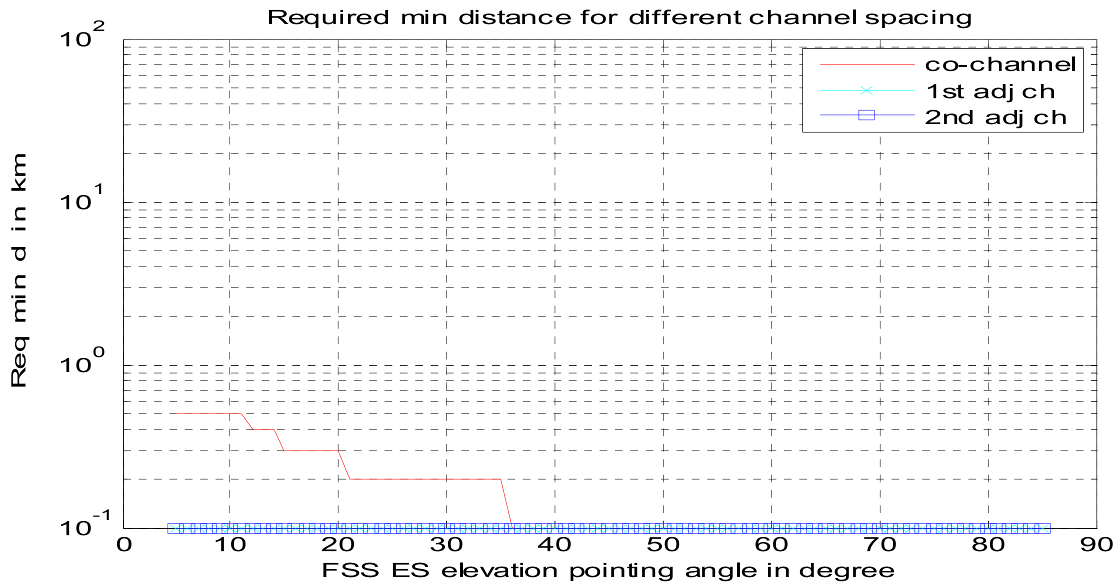
The following figure shows the minimum required distance in km between BWA fixed-indoor TS and 32 m FSS ES with 5º to 85º elevation pointing direction.



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

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

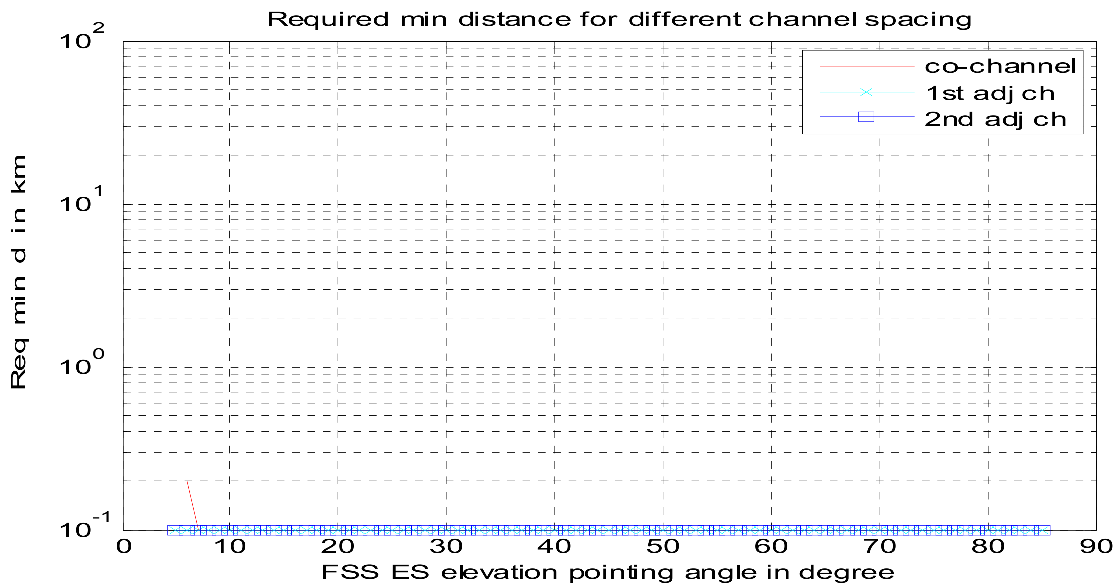
The following figure shows the minimum required distance in km between BWA fixed-indoor TS and 8 m FSS ES with 5º to 85º elevation pointing direction.



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

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

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



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

4 Conclusions

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

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

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

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

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

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

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

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

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

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

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

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

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

Attachment 2 to Annex B

Description of Study B

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

1 Introduction

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

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

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

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

TABLE 12

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

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

TABLE 12 (*end*)

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

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

3 Set-up of simulations

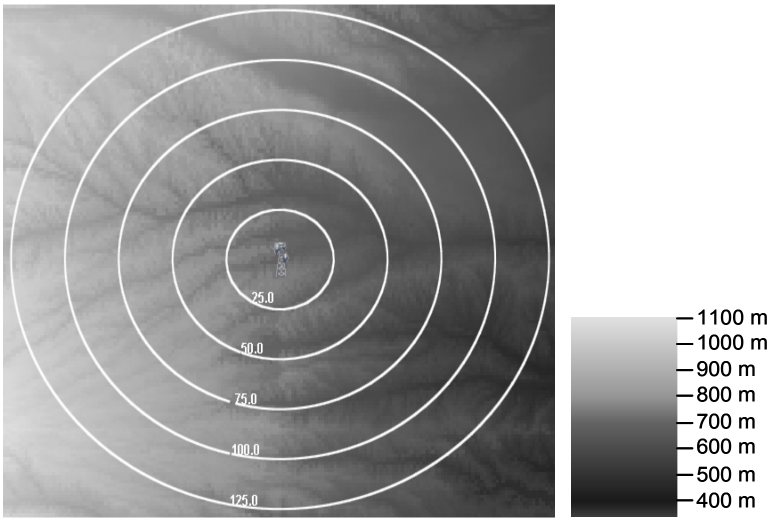
As the software tool will not enable manual determination of certain aspects of Recommendation ITU-R P.452-13, simulations have been set up for the BWA base station scenarios as was done in Study A, with the difference that 2 different cases will be studied. One case is assuming smooth earth, and the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

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

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

FIGURE 7

Details of terrain characteristics assumed in simulations



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

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

TABLE 13

Overview of simulation scenarios

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

TABLE 14

FSS system parameters

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

TABLE 15

BWA base station system parameters

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

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

BWA base station ACLR values used in this study

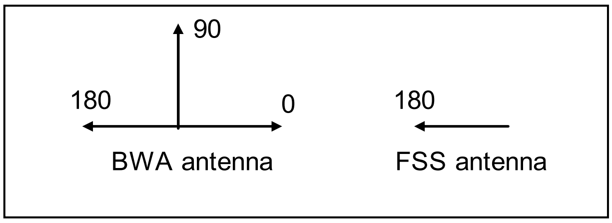
	ACLR1 (dB)	**ACLR2 (dB)**	**ACLR3 (dB)**
BWA base station	22.0	47.8	50.0

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

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

FIGURE 8

Geometric azimuth configurations studied under Scenarios 1 and 2



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

4 Results of simulation

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

4.1 Scenario 1 (BWA sectoral antenna, smooth earth)

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

TABLE 16

Comparison of result for separation distances for Scenario 1a

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

TABLE 17

Comparison of result for separation distances for Scenario 1b

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

TABLE 18

Comparison of result for separation distances Scenario 1c

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

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

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

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

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

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

FIGURE 9

Results for Scenario 2a: 32 m FSS earth station

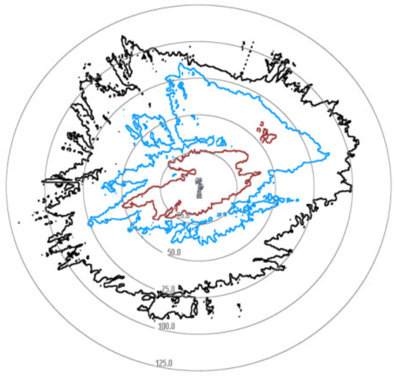
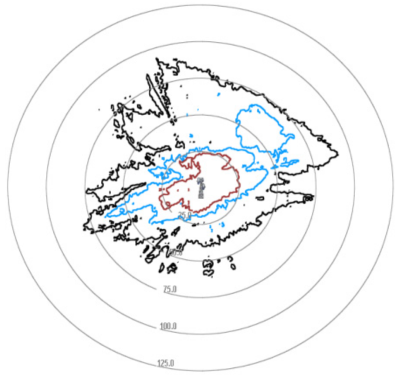
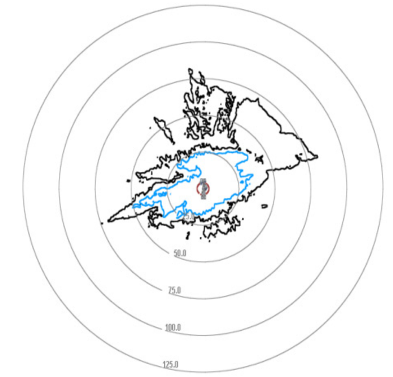
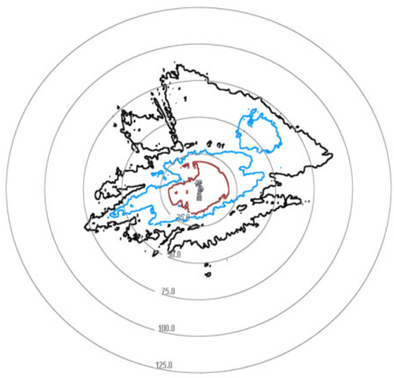
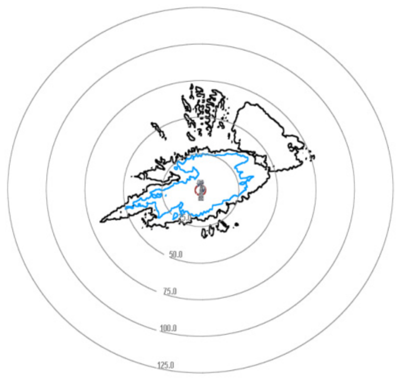
	Azimuth = 0° (w.r.t. FSS e/s)	Azimuth = 90° (w.r.t. FSS e/s)	Azimuth = 180° (w.r.t. FSS e/s)
Elevation = 5°			
Elevation = 25°			
Elevation = 50°			

FIGURE 10

Results for Scenario 2b: 8 m FSS earth station

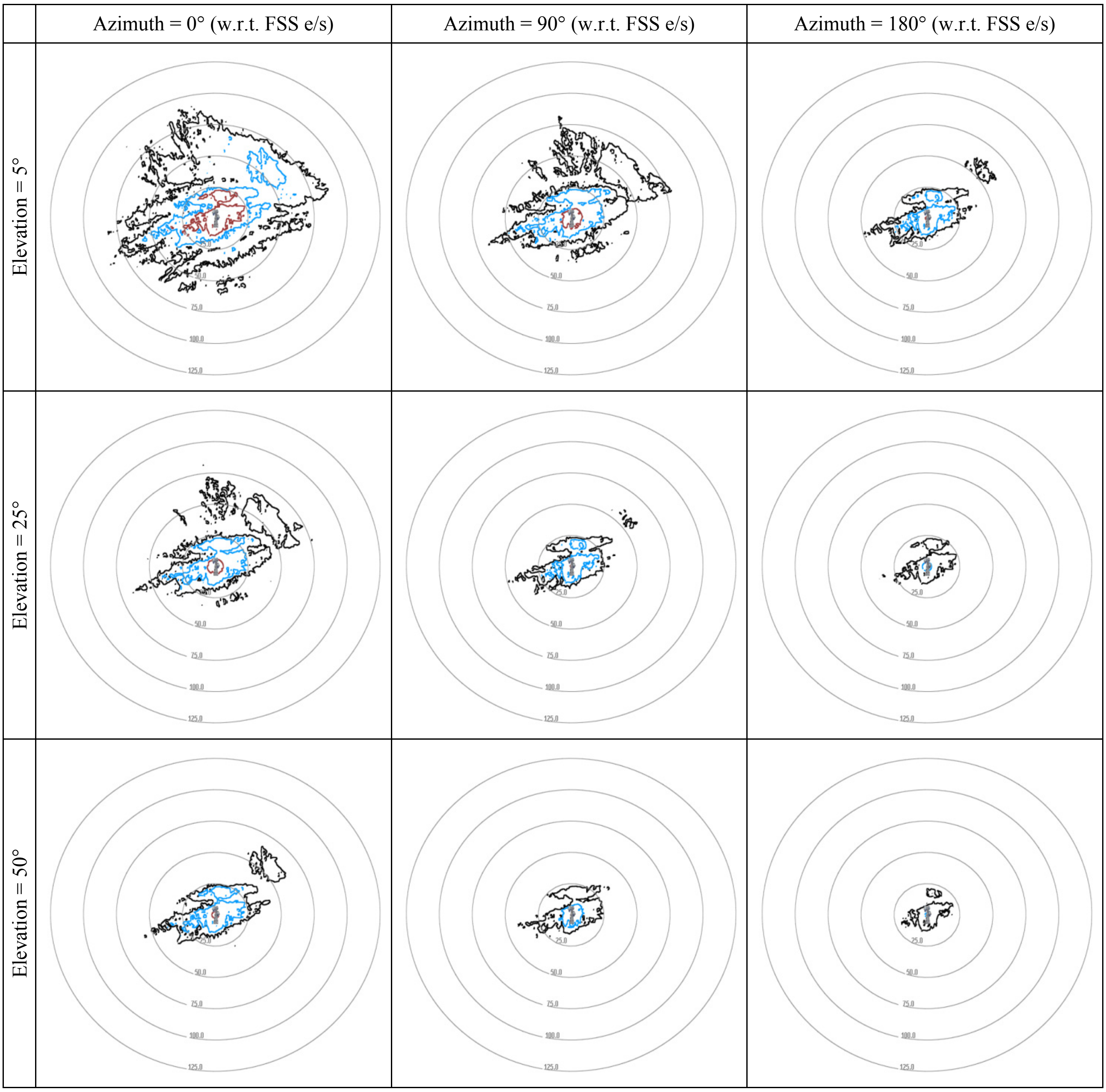
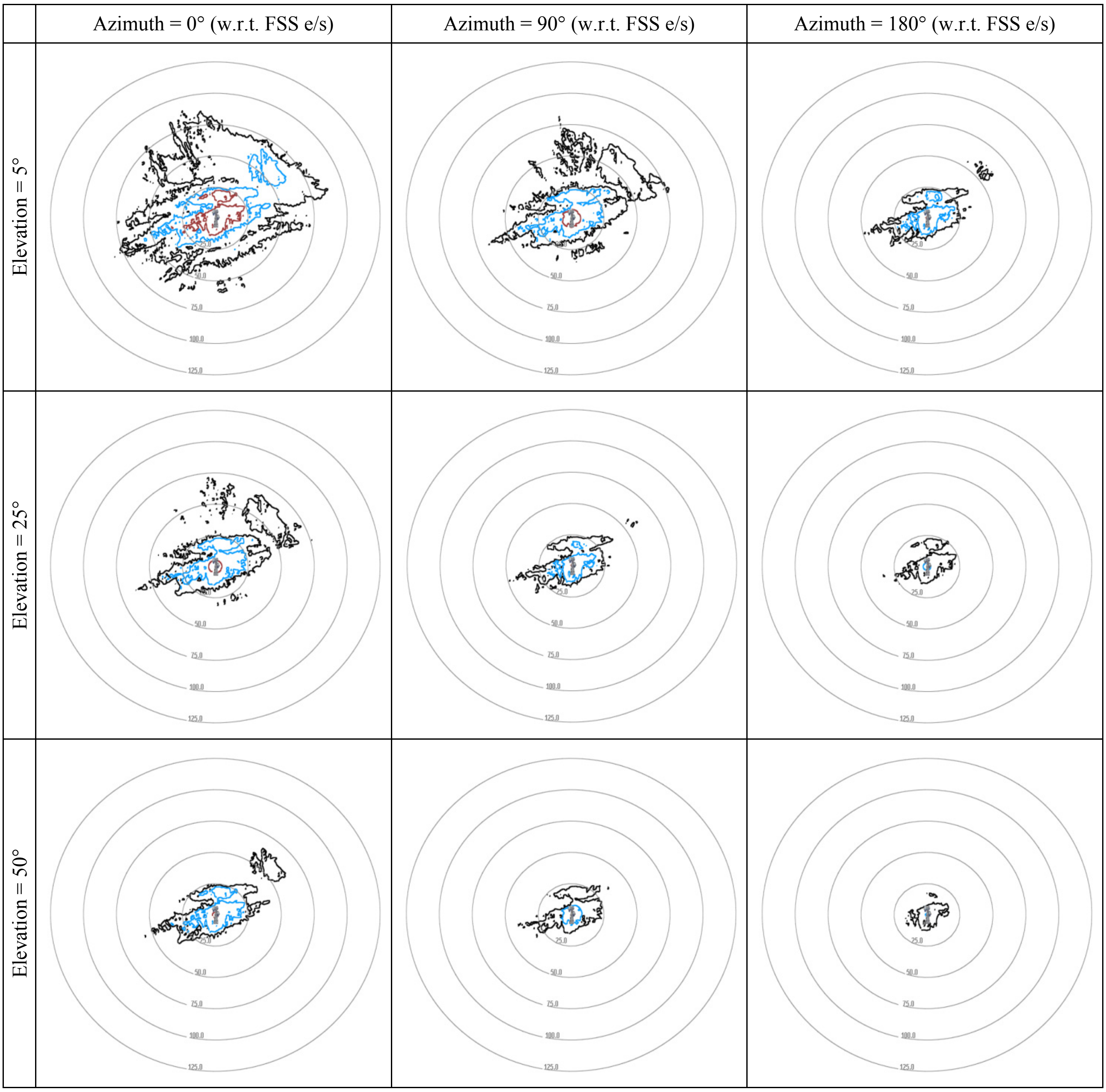


FIGURE 11

Results for Scenario 2c: 1.2 m FSS earth station



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

4.3 Scenario 3 (BWA omnidirectional antenna, smooth earth)

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

TABLE 19

Comparison of result for separation distances Scenario 3a

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

TABLE 20

Comparison of result for separation distances Scenario 3b

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

TABLE 21

Comparison of result for separation distances Scenario 3c

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

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

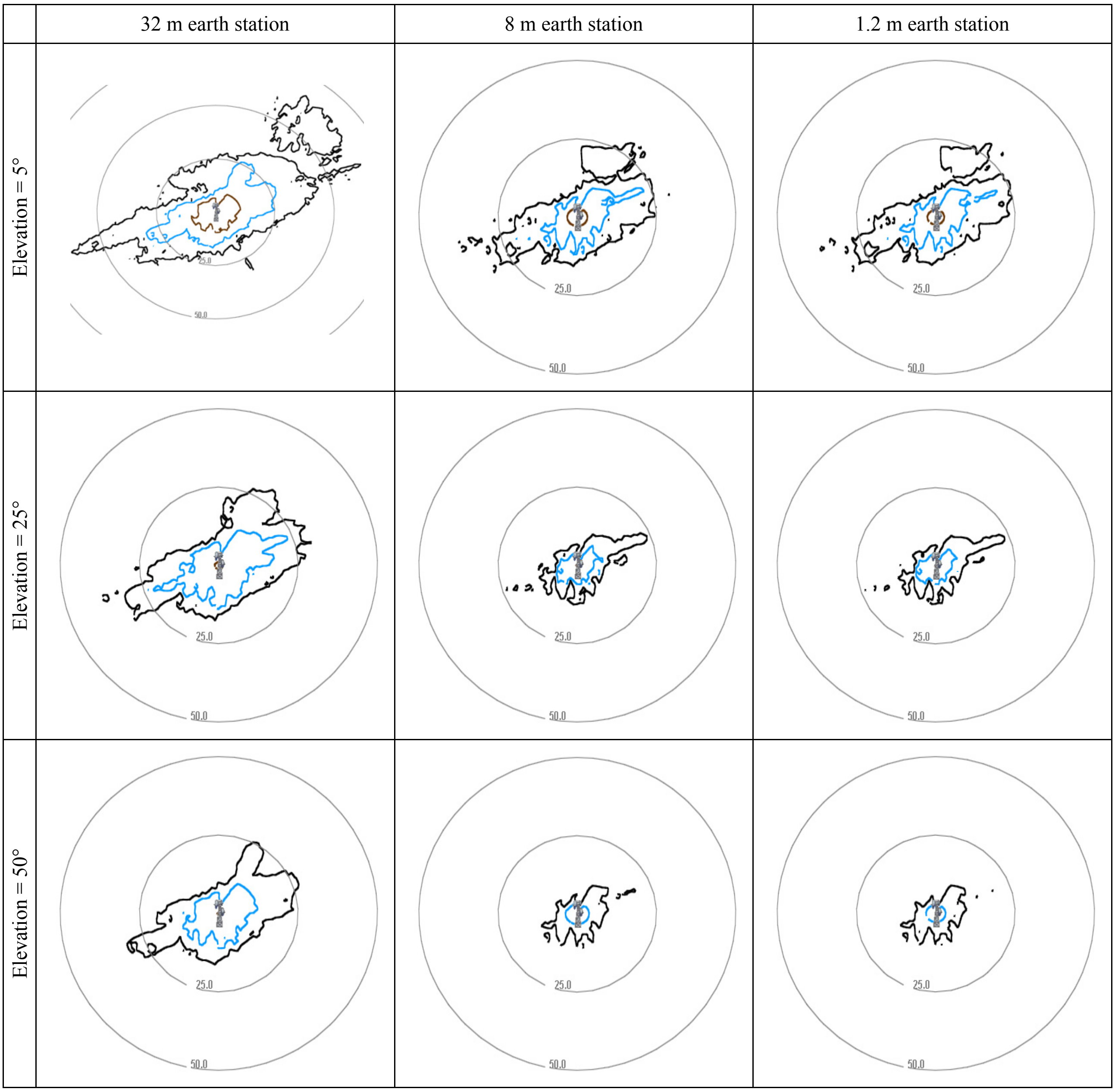
It is interesting to note though, that for the 8 m and 1.2 m FSS earth station case, for 50° elevation, the results of the simulation in this study clearly show that the separation distances are not negligible for the co-channel case and 1st adjacent channel case, when comparing with the results from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

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

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

FIGURE 12

Results for Scenario 4



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

5 Discussion of assumptions

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

5.1 Clutter parameters

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

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

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

where:

A_h: loss due to clutter (dB)

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

h: antenna height (m) above local ground level

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

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

TABLE 22

Results for clutter loss calculations

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

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

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

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

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

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

5.2 Use of sectorized antennas

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

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

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

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

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

TABLE 23

Results of effect of multiple sector antennas

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

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

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

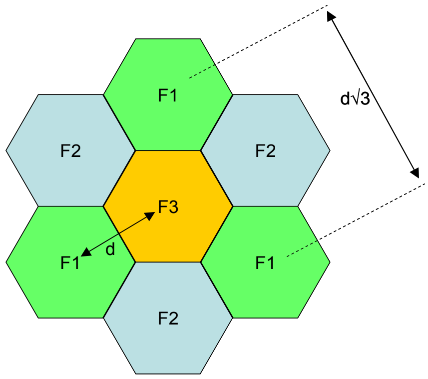
5.3 Aggregate effect from multiple cells

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

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

FIGURE 13

Typical frequency reuse pattern in cell structure



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

6 Conclusions

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

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

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

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

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

Attachment 3
to Annex B

Description of Study C

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

1 Assumptions for simulation

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

TABLE 24

Carrier details of satellite signal used in measurement campaign

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

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

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

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

TABLE 25

BWA base station parameters assumptions for use in study

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

N/A: Not applicable.

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

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

Table 26 repeats the assumptions used in this study.

TABLE 26

FSS system parameters

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

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

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

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

The interference can be modelled as follows:

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

where:

I =	Interference (dBW/MHz)
$e.i.r.p._{WIMAX}(\varphi_1)$ =	e.i.r.p. in direction of horizon of WiMAX base station (dBW/MHz)
L =	Path loss (dB)
$G(\varphi_2)$ =	Satellite earth station antenna gain in direction of the WiMAX transmitter (dBi).

The protection criterion for the long term interference to be observed is for the *I*/*N* ratio not to exceed –10 dB for more than 20% of the time.

2 Simulation results

Figure 14 to Fig. 17 show the results for the case of a BWA specific cellular deployment rural case, for azimuth pointings of 0°, 90°, 180° and 270° respectively. Note that only the contours for *I*/*N* of –10 dB are indicated. These contours are represented by the purple line on the map. The source of all maps used in this text is Google Maps.

FIGURE 14

Simulation results BWA rural sectoral antenna (azimuth : 0°)

FIGURE 15

Simulation results BWA rural sectoral antenna (azimuth : 90°)

FIGURE 16

Simulation results BWA rural sectoral antenna (azimuth : 180°)

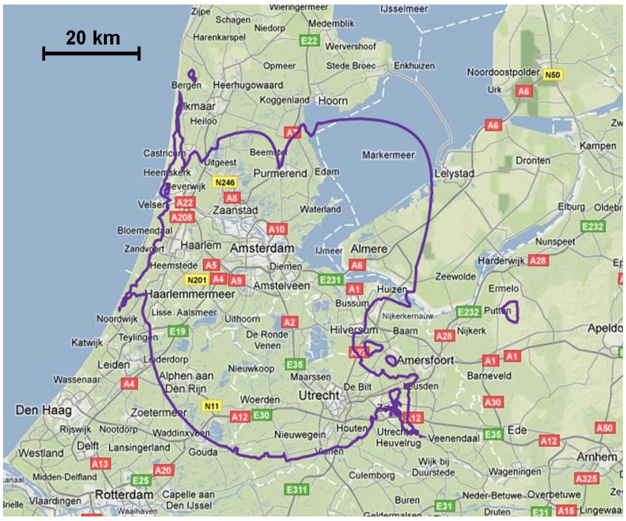
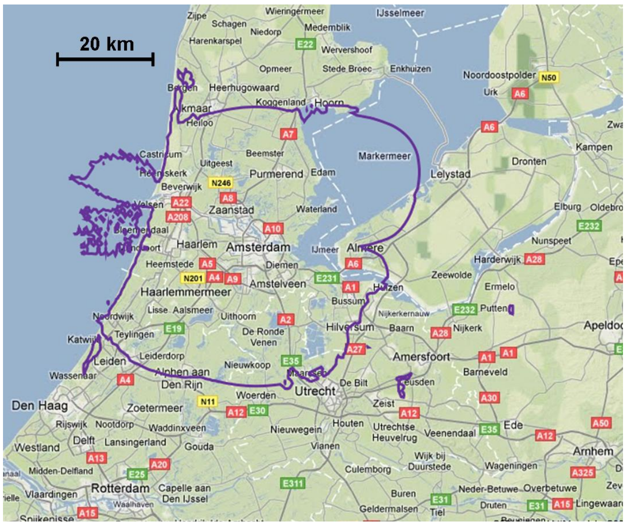


FIGURE 17

Simulation results BWA rural sectoral antenna (azimuth : 270°)



These results were found to be in line with the results from the actual measurements done during the measurement campaign, i.e. covering the cases where clear interference was observed.

Figure 18 shows the result for the case of a BWA typical cellular deployment urban case.

FIGURE 18

Simulation results BWA urban omnidirectional antenna

As expected, the contours related to the BWA omnidirectional antenna, used as a typical urban case, show shorter separation distances than in the case of the BWA sector antennas used in the specific rural case.

3 Conclusions

A measurement campaign was set-up in order to make use of the presence of this operational WiMAX system, and to analyze the potential impact it can have on FSS signal reception in the same operating band.

In this study, the theoretical part of the analysis was updated based on the latest BWA base station and antenna parameters, as well as propagation model parameters as contained in Annex A of this Report.

Based on the results, it would seem that the WiMAX system that was deployed in Amsterdam, was using BWA base station parameters that were more in line with the parameters based on a specific rural cellular case than with the parameters based on a typical urban cellular case.

Attachment 4
to Annex B

Description of Study D

Study of required separation distances in order to avoid LNB saturation or non-linear behaviour

1 Introduction

This Attachment provides a study of the adjacent band interference that could lead to saturation or non-linear operation of the Low Noise Blockconverter (LNB) of the FSS earth station, taking into account the agreed BWA and FSS parameters.

2 LNB operational range

For the reception of satellite signals, FSS earth stations use LNBs, that have two main functions. The first one is to amplify the satellite signal coming from the receive antenna, and the second function is to down convert the satellite signal to an intermediary frequency (IF) in order to facilitate the further transport of the signal by co-axial cable.

As LNBs are designed for the reception of very low level satellite signals, the dynamic range is designed accordingly. In order to illustrate this, one can assume a 36 MHz satellite transponder operating in the band 3 400-4 200 MHz, transmitting a fully saturated signal with a downlink e.i.r.p. of 40 dBW. With a 3.7 m receive antenna, having a gain of 41 dBi, and a free space loss in this band of about 196 dB, the signal level at the input of the LNB is (40-196 + 41) = –115 dBW = –85 dBm. Even if the entire band 3 400-4 200 MHz would have transponders transmitting this e.i.r.p., the total power at the input of the LNB would not exceed –72 dBm.

The 1 dB compression point for LNBs is typically at total incoming power of around –50 dBm. This means that non-linear behaviour, intermodulation products, and suppression of total incoming power starts to occur already below that level, at about –60 dBm (in Annex D to this Report, concerning examples of National implementations, a value of –65 dBm is assumed, as indicated in Table 2 of that Annex). Taking into account the example calculation above, this means that in normal circumstances, LNBs always operate in linear mode.

LNB non-linear operations could occur when nearby BWA base stations or terminal stations transmit in a portion of the band that lies within the receive band of an LNB.

Typically LNBs receive over the entire 3 400-4 200 MHz range. Therefore, even if there would not be a co-frequency operation between the frequencies at which an FSS earth station received a certain satellite, and the frequency at which a BWA station operates, due to the wide band of the LNB receiver there is a potential for non-linear behaviour.

3 Set-up of simulations

The goal is to calculate the separation distance between a BWA station or terminal, and an FSS earth station, at which the non-linear behaviour of the LNB, as described in the previous section, would not occur.

The propagation model that will be taken into account is the free space loss propagation as defined in Recommendation ITU-R P.525-2. It is believed that for the analysis considered here this propagation model is sufficient since line-of-sight can be assumed between the transmitting BWA station or terminal, and the FSS earth station. The free-space basic transmission loss is described in this Recommendation as:

$$L_{bf} = 32.4 + 20 \log f + 20 \log d \qquad \text{dB} \qquad (1)$$

where:

L_{bf} : free-space basic transmission loss (dB)

f : frequency (MHz)

d : distance (km).

In order to meet the saturation level at the LNB the following expression is valid:

$$BWA_{eirp} - L_{bf} + G_{es} = LNB_{sat} \qquad \text{dBm} \qquad (2)$$

where:

BWA_{eirp} : e.i.r.p. from BWA station in the direction of the FSS earth station (dBm)

G_{es} : gain of FSS earth station in the direction of the BWA station (dBi)

LNB_{sat} : saturation point of the LNB (dBm).

Expression (1) and (2) can be combined in order to calculate d with the following result:

$$d = 10^{\left(\frac{BWA_{eirp} + G_{es} - LNB_{sat} - 32.4 - 20 \log f}{20}\right)} \qquad \text{km} \qquad (3)$$

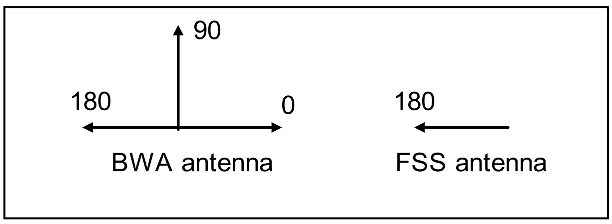
For the LNB value, two different assumptions will be studied. One is assuming the LNB to be at the 1 dB compression point due to transmissions from a BWA station, i.e. a level of –50 dBm, which would prevent the LNB from working at all. The second option is to assume a level of –60 dBm, which is the level needed to avoid non-linear behaviour in the LNB.

For the gain of the FSS earth station in the direction of the BWA transmit station, Recommendation ITU-R S.465 is used. Further, three different antenna sizes (1.2 m, 8 m and 32 m) at three different elevation angles (5°, 25° and 50°) will be studied. These parameters are in line with those in Table 3 in Annex A of this Report.

The assumptions for the BWA stations are taken from Tables 4 and 5 in Annex A of this Report. For the BWA transmit stations, a distinction is made between antennas with a directional antenna (such as the sector antennas) and omnidirectional antennas. For the directional antennas, different azimuth angles between the BWA station and the FSS earth station are studied as depicted in Fig. 19.

FIGURE 19

Geometric azimuth configurations assumed with directional BWA antennas



The assumptions on the e.i.r.p. levels in the direction of the FSS earth station are depicted in Table 27. They take into account the e.i.r.p. and the down tilting of the antenna. For this study it is assumed that the FSS earth station would be located at 0° elevation as seen from the BWA transmitting station. The maximum e.i.r.p. and down tilting angle assumptions are taken from Tables 4 and 5 in Annex A of this Report.

TABLE 27

BWA station e.i.r.p. levels in the direction of the FSS earth station

Type of BWA station	Type of antenna	Max. e.i.r.p. (dBm)	Downtilt (degrees)	e.i.r.p. in direction of FSS_{es} (dBm)
BS Specific rural – System A	Directional	57.0	1	56.90
BS Specific rural – System B	Directional	59.0	1	58.90
BS Typical rural – System A	Directional	49.0	2	48.50
BS Typical rural – System B	Directional	51.0	2	50.50
BS Typical urban – System A	Omnidirectional	38.0	4	37.00
BS Typical urban – System B	Directional	40.0	4	40.00
TS Fixed-outdoor – System A	Directional	42.0	N/A	42.00
TS Fixed-outdoor – System B	Directional	42.0	N/A	42.00
TS Nomadic – System A	Omnidirectional	26.0	N/A	26.00
TS Nomadic – System B	Omnidirectional	23.0	N/A	23.00
TS Mobile – System A	Omnidirectional	19.0	N/A	19.00
TS Mobile – System B	Omnidirectional	23.0	N/A	23.00

N/A: Not applicable.

4 Results of analysis

Table 28 to Table 30 show the calculated separation distances for the BWA directional stations, assuming an the 1 dB compression point of the LNB of –50 dBm, for FSS earth station antenna sizes of 32 m, 8 m and 1.2 m respectively.

TABLE 28

Separation distances for BWA directional stations (LNB: –50 dBm, FSS antenna size: 32 m)

Elevation (degrees)	5			25			50		
Azimuth (degrees)	0	90	180	0	90	180	0	90	180
Off-axis gain (dBi)	14.5	–10.0	–10.0	–2.9	–10.0	–10.0	–10.0	–10.0	–10.0
Separation distances (FSS antenna size : 32 m, LNB sat level : –50 dBm)									
Specific rural (A) (km)	7.85	0.47	0.47	1.05	0.47	0.47	0.47	0.47	0.47
Specific rural (B) (km)	9.89	0.59	0.59	1.32	0.59	0.59	0.59	0.59	0.59
Typical rural (A) (km)	2.99	0.18	0.18	0.40	0.18	0.18	0.18	0.18	0.18
Typical rural (B) (km)	3.76	0.22	0.22	0.50	0.22	0.22	0.22	0.22	0.22
Typical urban (B) (km)	1.12	0.07	0.07	0.15	0.07	0.07	0.07	0.07	0.07
Fixed-outdoor (A) (km)	1.41	0.08	0.08	0.19	0.08	0.08	0.08	0.08	0.08
Fixed-outdoor (B) (km)	1.41	0.08	0.08	0.19	0.08	0.08	0.08	0.08	0.08

TABLE 29

Separation distances for BWA directional stations
(LNB : –50 dBm, FSS antenna size: 8 m)

Elevation (degrees)	5			25			50		
Azimuth (degrees)	0	90	180	0	90	180	0	90	180
Off-axis gain (dBi)	14.7	–9.8	–9.8	–2.8	–9.8	–9.8	–9.8	–9.8	–9.8
Separation distances (FSS antenna size : 8 m, LNB sat level : –50 dBm)									
Specific rural (A) (km)	8.01	0.48	0.48	1.07	0.48	0.48	0.48	0.48	0.48
Specific rural (B) (km)	10.09	0.60	0.60	1.35	0.60	0.60	0.60	0.60	0.60
Typical rural (A) (km)	3.05	0.18	0.18	0.41	0.18	0.18	0.18	0.18	0.18
Typical rural (B) (km)	3.84	0.23	0.23	0.51	0.23	0.23	0.23	0.23	0.23
Typical urban (B) (km)	1.15	0.07	0.07	0.15	0.07	0.07	0.07	0.07	0.07
Fixed-outdoor (A) (km)	1.44	0.09	0.09	0.19	0.09	0.09	0.09	0.09	0.09
Fixed-outdoor (B) (km)	1.44	0.09	0.09	0.19	0.09	0.09	0.09	0.09	0.09

TABLE 30

Separation distances for BWA directional stations
(LNB: –50 dBm, FSS antenna size: 1.2 m)

Elevation (degrees)	5			25			50		
Azimuth (degrees)	0	90	180	0	90	180	0	90	180
Off-axis gain (dBi)	19.4	–1.6	–1.6	5.5	–1.6	–1.6	–1.6	–1.6	–1.6
Separation distances (FSS antenna size : 1.2 m, LNB sat level : –50 dBm)									
Specific rural (A) (km)	13.72	1.23	1.23	2.77	1.23	1.23	1.23	1.23	1.23
Specific rural (B) (km)	17.28	1.55	1.55	3.48	1.55	1.55	1.55	1.55	1.55
Typical rural (A) (km)	5.22	0.47	0.47	1.05	0.47	0.47	0.47	0.47	0.47
Typical rural (B) (km)	6.57	0.59	0.59	1.32	0.59	0.59	0.59	0.59	0.59
Typical urban (B) (km)	1.96	0.18	0.18	0.40	0.18	0.18	0.18	0.18	0.18
Fixed-outdoor (A) (km)	2.47	0.22	0.22	0.50	0.22	0.22	0.22	0.22	0.22
Fixed-outdoor (B) (km)	2.47	0.22	0.22	0.50	0.22	0.22	0.22	0.22	0.22

Table 31 to Table 33 show the calculated separation distances for the BWA directional stations, assuming an LNB level of –60 dBm, for FSS earth station antenna sizes of 32 m, 8 m and 1.2 m respectively.

TABLE 31

Separation distances for BWA directional stations (LNB: –60 dBm, FSS antenna size: 32 m)

Elevation (degrees)	5			25			50		
Azimuth (degrees)	0	90	180	0	90	180	0	90	180
Off-axis gain (dBi)	14.5	–10.0	–10.0	–2.9	–10.0	–10.0	–10.0	–10.0	–10.0
Separation distances (FSS antenna size : 32 m, LNB sat level : –60 dBm)									
Specific rural (A) (km)	24.83	1.47	1.47	3.32	1.47	1.47	1.47	1.47	1.47
Specific rural (B) (km)	31.26	1.86	1.86	4.18	1.86	1.86	1.86	1.86	1.86
Typical rural (A) (km)	9.44	0.56	0.56	1.26	0.56	0.56	0.56	0.56	0.56
Typical rural (B) (km)	11.88	0.71	0.71	1.59	0.71	0.71	0.71	0.71	0.71
Typical urban (B) (km)	3.55	0.21	0.21	0.47	0.21	0.21	0.21	0.21	0.21
Fixed-outdoor (A) (km)	4.47	0.27	0.27	0.60	0.27	0.27	0.27	0.27	0.27
Fixed-outdoor (B) (km)	4.47	0.27	0.27	0.60	0.27	0.27	0.27	0.27	0.27

TABLE 32

Separation distances for BWA directional stations (LNB: –60 dBm, FSS antenna size: 8 m)

Elevation (degrees)	5			25			50		
Azimuth (degrees)	0	90	180	0	90	180	0	90	180
Off-axis gain (dBi)	14.7	–9.8	–9.8	–2.8	–9.8	–9.8	–9.8	–9.8	–9.8
Separation distances (FSS antenna size : 8 m, LNB sat level : –60 dBm)									
Specific rural (A) (km)	25.34	1.51	1.51	3.39	1.51	1.51	1.51	1.51	1.51
Specific rural (B) (km)	31.90	1.89	1.89	4.27	1.89	1.89	1.89	1.89	1.89
Typical rural (A) (km)	9.63	0.57	0.57	1.29	0.57	0.57	0.57	0.57	0.57
Typical rural (B) (km)	12.13	0.72	0.72	1.62	0.72	0.72	0.72	0.72	0.72
Typical urban (B) (km)	3.62	0.22	0.22	0.48	0.22	0.22	0.22	0.22	0.22
Fixed-outdoor (A) (km)	4.56	0.27	0.27	0.61	0.27	0.27	0.27	0.27	0.27
Fixed-outdoor (B) (km)	4.56	0.27	0.27	0.61	0.27	0.27	0.27	0.27	0.27

TABLE 33

Separation distances for BWA directional stations
(LNB: –60 dBm, FSS antenna size: 1.2 m)

Elevation (degrees)	5			25			50		
Azimuth (degrees)	0	90	180	0	90	180	0	90	180
Off-axis gain (dBi)	19.4	–1.6	–1.6	5.5	–1.6	–1.6	–1.6	–1.6	–1.6
Separation distances (FSS antenna size : 1.2 m, LNB sat level : –60 dBm)									
Specific rural (A) (km)	43.40	3.89	3.89	8.75	3.89	3.89	3.89	3.89	3.89
Specific rural (B) (km)	54.63	4.89	4.89	11.02	4.89	4.89	4.89	4.89	4.89
Typical rural (A) (km)	16.50	1.48	1.48	3.33	1.48	1.48	1.48	1.48	1.48
Typical rural (B) (km)	20.77	1.86	1.86	4.19	1.86	1.86	1.86	1.86	1.86
Typical urban (B) (km)	6.20	0.56	0.56	1.25	0.56	0.56	0.56	0.56	0.56
Fixed-outdoor (A) (km)	7.81	0.70	0.70	1.57	0.70	0.70	0.70	0.70	0.70
Fixed-outdoor (B) (km)	7.81	0.70	0.70	1.57	0.70	0.70	0.70	0.70	0.70

Tables 34 and 35 show the calculated separation distances for the BWA omnidirectional stations, assuming an LNB level of –50 dBm and –60 dBm respectively, for FSS earth station antenna sizes of 1.2 m, 8 m and 32 m.

TABLE 34

Separation distances for BWA omnidirectional stations
(LNB: –50 dBm)

Antenna size (m)	1.2			8			32		
Gain (dBi)	31.2			47.7			59.8		
Elevation (degrees)	5	25	50	5	25	50	5	25	50
Off-axis gain (dBi)	19.4	5.5	–1.6	14.7	–2.8	–9.8	14.5	–2.9	–10.0
Separation distances (LNB sat level : –50 dBm)									
Typical urban (A) (km)	1.39	0.28	0.12	0.81	0.11	0.05	0.79	0.11	0.05
Nomadic (A) (km)	0.39	0.08	0.04	0.23	0.03	0.01	0.22	0.03	0.01
Nomadic (B) (km)	0.28	0.06	0.02	0.16	0.02	0.01	0.16	0.02	0.01
Mobile (A) (km)	0.17	0.04	0.02	0.10	0.01	0.01	0.10	0.01	0.01
Mobile (B) (km)	0.28	0.06	0.02	0.16	0.02	0.01	0.16	0.02	0.01

TABLE 35

Separation distances for BWA omnidirectional stations (LNB: –60 dBm)

Antenna size (m)	1.2			8			32		
Gain (dBi)	31.2			47.7			59.8		
Elevation (degrees)	5	25	50	5	25	50	5	25	50
Off-axis gain (dBi)	19.4	5.5	–1.6	14.7	–2.8	–9.8	14.5	–2.9	–10.0
Separation distances (LNB sat level : –60 dBm)									
Typical urban (A) (km)	4.39	0.89	0.39	2.56	0.34	0.15	2.51	0.34	0.15
Nomadic (A) (km)	1.24	0.25	0.11	0.72	0.10	0.04	0.71	0.09	0.04
Nomadic (B) (km)	0.88	0.18	0.08	0.51	0.07	0.03	0.50	0.07	0.03
Mobile (A) (km)	0.55	0.11	0.05	0.32	0.04	0.02	0.32	0.04	0.02
Mobile (B) (km)	0.88	0.18	0.08	0.51	0.07	0.03	0.50	0.07	0.03

5 Discussion of results

Tables 36 to 39 provides an overview of the different separation distances calculated for the cases studied. For each FSS earth station antenna size and LNB value, the minimum, maximum and average separation distances are calculated. The average number is calculated by excluding the maximum and minimum distance values.

TABLE 36

Separation distances for BWA directional antennas and LNB value of -50 dBm

Antenna size (m)	1.2	8	32
Maximum (km)	17.28	10.09	9.89
Minimum (km)	0.18	0.07	0.07
Average (km)	1.20	0.57	0.55

TABLE 37

Separation distances for BWA directional antennas and LNB value of –60 dBm

Antenna size (m)	1.2	8	32
Maximum (km)	54.63	31.90	31.26
Minimum (km)	0.56	0.22	0.21
Average (km)	3.80	1.80	1.76

TABLE 38

Separation distances for BWA omnidirectional antennas and LNB value of –50 dBm

Antenna size (m)	1.2	8	32
Maximum (km)	1.39	0.81	0.79
Minimum (km)	0.02	0.01	0.01
Average (km)	0.14	0.07	0.07

TABLE 39

Separation distances for BWA omnidirectional antennas and LNB value of –60 dBm

Antenna size (m)	1.2	8	32
Maximum (km)	4.39	2.56	2.51
Minimum (km)	0.05	0.02	0.02
Average (km)	0.45	0.23	0.22

The results indicate that separation distances of several kilometres distance are needed in order to prevent the LNBs to have non-linear behaviour.

6 Aggregate effects

The results in this study are based on calculation the separation distance assuming a BWA station is transmitting one single channel within the receive band of the LNB. Especially for BWA base stations it is reasonable to assume that multiple channels will be transmitted at any given time. The aggregation of these channels would lead to separation distances that would be considerably higher than in the cases studied in § 4. For example, let's assume that a base station (BS Typical Urban – System A) would be transmitting 4 × 7 MHz channels in an overlapping band with an FSS earth station LNB, then the aggregate e.i.r.p. level transmitted would be 37 + 10 log(4) = 43 dBm. Tables 40 and 41 show the impact of this aggregate effect with respect to the baseline scenario.

TABLE 40

Aggregate impact for one BWA omnidirectional station (LNB: –50 dBm)

Antenna size (m)	1.2			8			32		
Elevation (degrees)	5	25	50	5	25	50	5	25	50
Off-axis gain (dBi)	19.4	5.5	–1.6	14.7	–2.8	–9.8	14.5	–2.9	–10.0
Typical Urban (A) – Separation distances (LNB sat level: –50 dBm)									
Baseline (e.i.r.p.: 37 dBm) (km)	1.39	0.28	0.12	0.81	0.11	0.05	0.79	0.11	0.05
Aggregate (e.i.r.p.: 43 dBm) (km)	2.77	0.56	0.25	1.62	0.22	0.10	1.58	0.21	0.09

TABLE 41

Aggregate impact for one BWA omnidirectional station (LNB: –60 dBm)

Antenna size (m)	1.2			8			32		
Elevation (degrees)	5	25	50	5	25	50	5	25	50
Off-axis gain (dBi)	19.4	5.5	–1.6	14.7	–2.8	–9.8	14.5	–2.9	–10.0
Typical Urban (A) – Separation distances (LNB sat level: –60 dBm)									
Baseline (e.i.r.p.: 37 dBm) (km)	4.39	0.89	0.39	2.56	0.34	0.15	2.51	0.34	0.15
Aggregate (e.i.r.p.: 43 dBm) (km)	8.76	1.77	0.78	5.12	0.68	0.30	5.01	0.67	0.30

As can be seen (and expected from the 6 dB higher aggregate level), the required separation distances would double.

7 Band-pass filters on LNBs

One mitigation technique that could improve (i.e. reduce) the separation distances to avoid LNB saturation could be to add a bandpass filter in front of the FSS receiver. However, it is not always possible to retrofit an FSS earth station with a band-pass filter. Further, there could be economical implications associated with the cost of such installations.

8 Conclusions

The aim of this study was to calculate the separation distances that are needed between BWA stations and FSS earth stations in order to avoid saturation or non-linear behaviour of the LNB installed on the FSS earth stations.

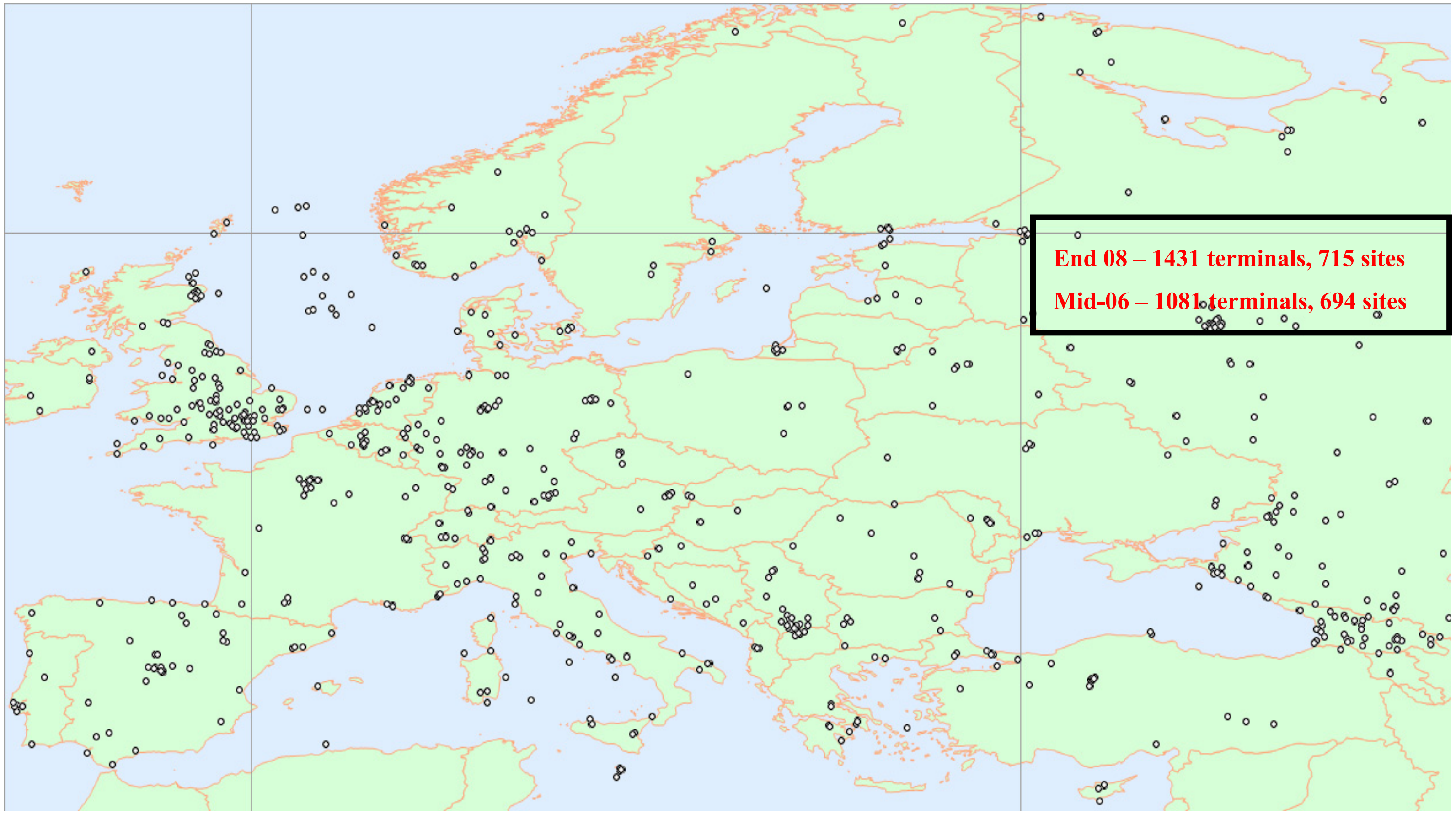
All types of BWA stations (both base stations and terminal stations) have been considered in this study, as well as a range of FSS earth station sizes and elevations that are within the agreed study parameters in this Report.

The results show that separation distances of up to several kilometres are needed in to avoid saturation or non-linear behaviour of the LNB. Further, the risk is highlighted associated with the aggregate effect of multiple carriers operating from a BWA station.

Annex C

FIGURE 20

Earth stations[8] in Europe operating to satellites of Intelsat and SES New Skies in the band 3 400-4 200 MHz at the end of 2008



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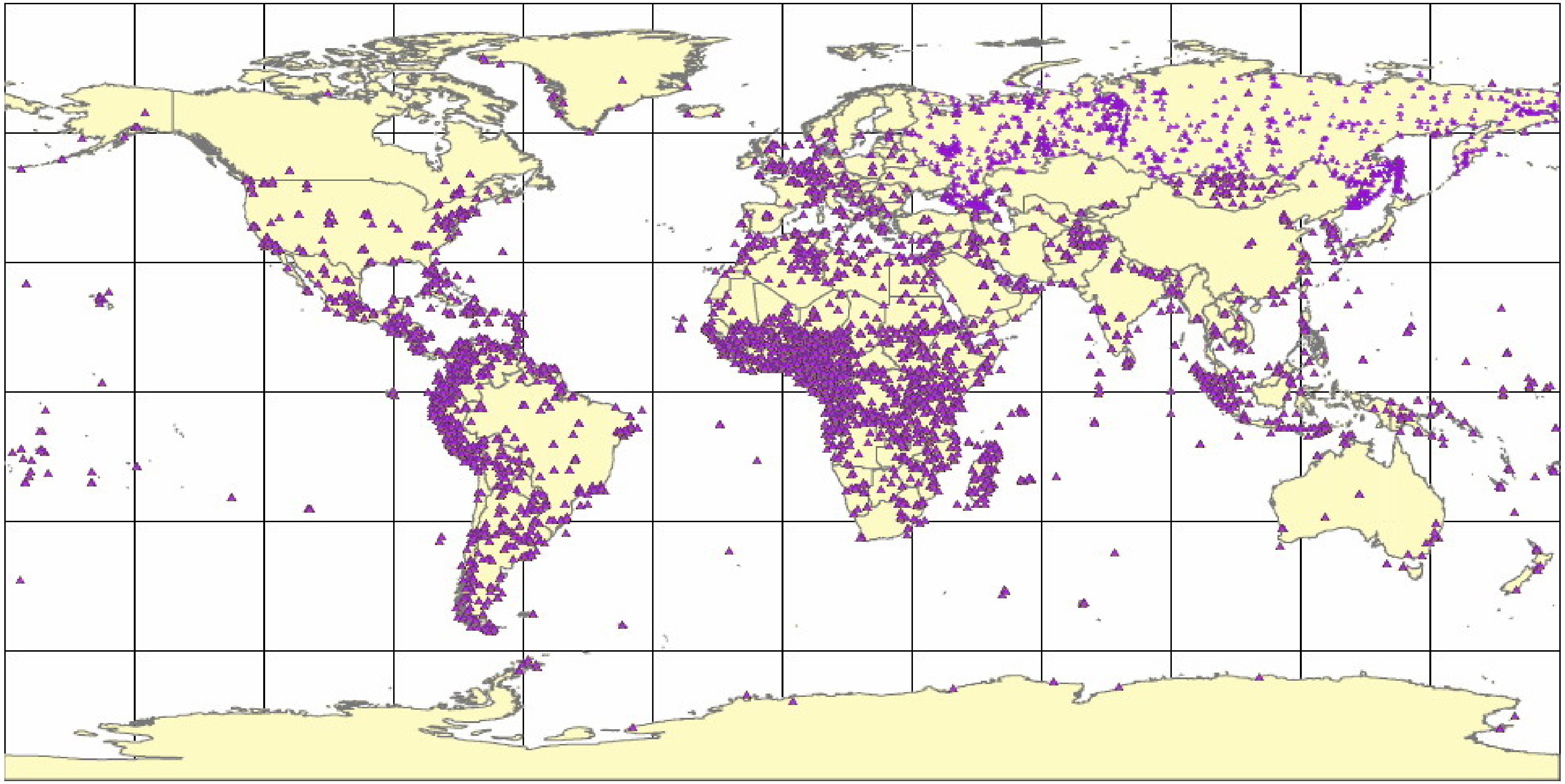
8 The sites shown are those registered by Intelsat and SES New Skies. Additionally many TVRO earth stations exist but are unrecorded and thus unable to be shown here. Furthermore, the map does not show earth stations served in this band by other satellite operators.

FIGURE 21

Locations of earth stations[9] registered with several satellite operators and receiving in the 3 700-4 200 MHz band

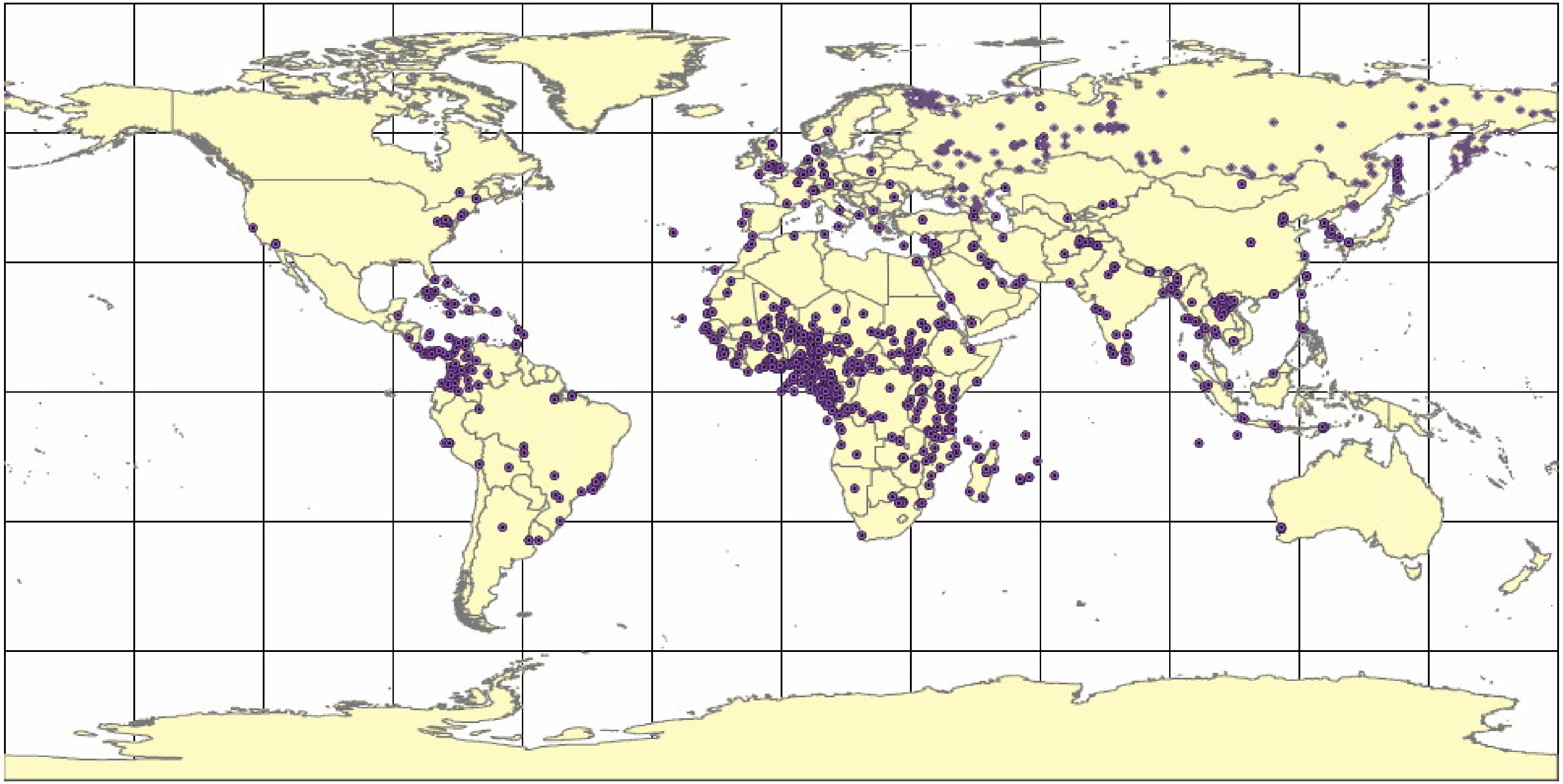


▲ Denotes a site that may include one or more stations.

[9] Many TVRO earth stations exist but are unrecorded and thus unable to be shown here.

FIGURE 22

Locations of earth stations[10] registered with several satellite operators and receiving in the 3 625-3 700 MHz band

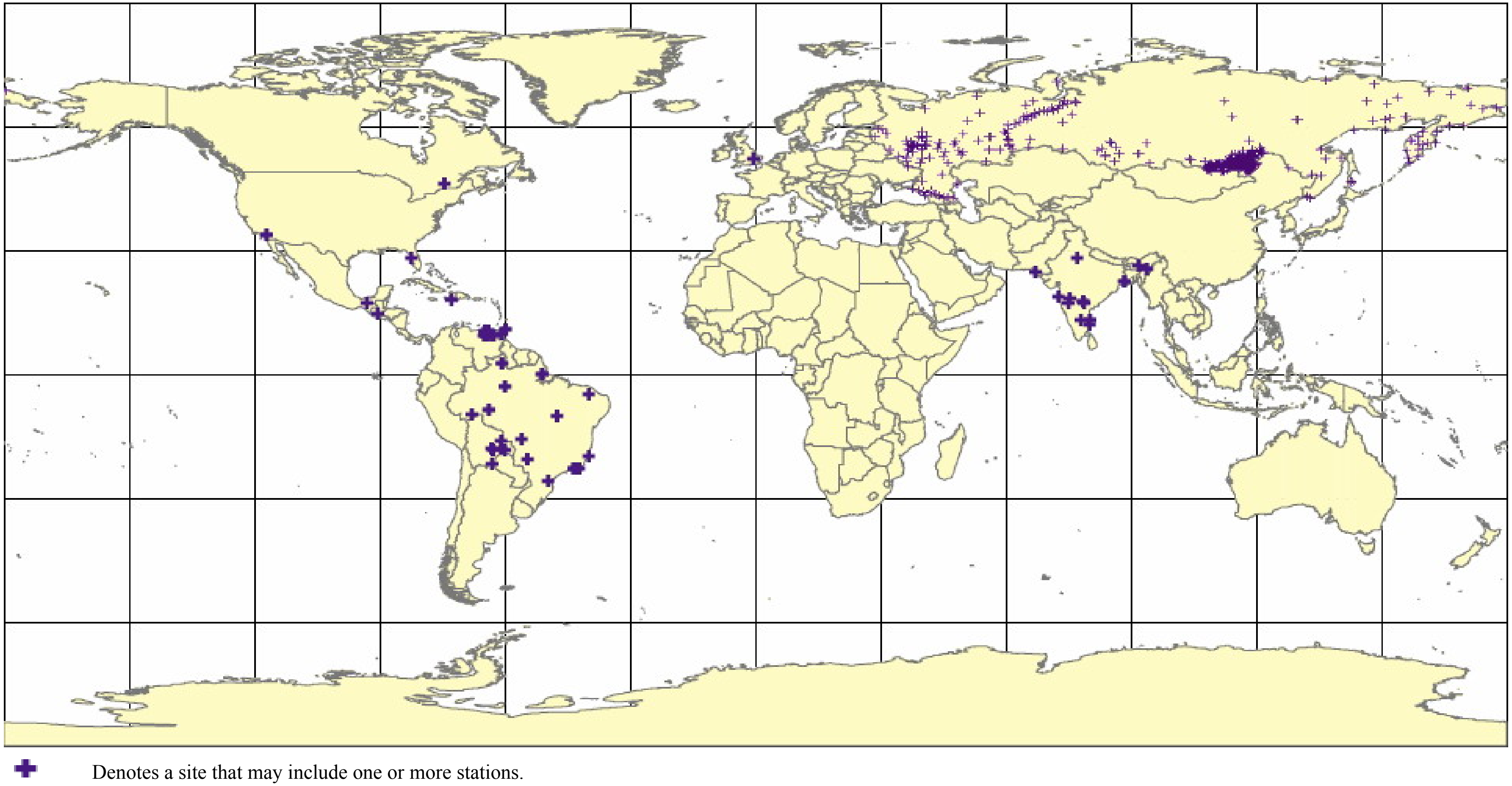


Denotes a site that may include one or more stations.

[10] Many TVRO earth stations exist but are unrecorded and thus unable to be shown here.

FIGURE 23

Locations of earth stations[11] registered with several satellite operators and receiving in the 3 400-3 625 MHz band

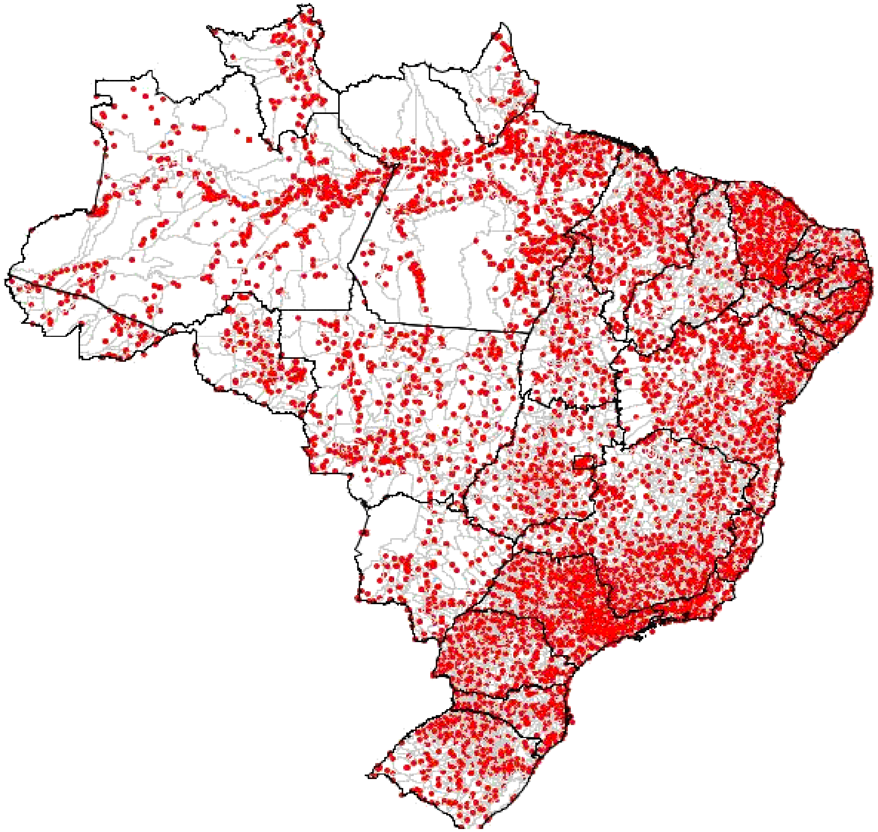


Denotes a site that may include one or more stations.

[11] Many TVRO earth stations exist but are unrecorded and thus unable to be shown here.

FIGURE 24

FSS earth stations[12] registered in Brazil (sites using 3 625-4 200 MHz)



[12] Many TVRO earth stations exist but are unrecorded and thus unable to be shown here.

Annex D

Example of a national implementation

FSS/BWA sharing arrangements in the 3 400-4 200 MHz band in Australia

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

The arrangements detailed in this example may be appropriate for a nation with no national borders but may not be reflective of the more general or common case where national cross-border coordination is required. Furthermore, although the sharing arrangements can fully account for existing FSS systems at the time of deployment, it will likely limit the future deployment of FSS stations in locations where BWA is licensed due to the quasi omnidirectional nature of the BWA base station emissions.

1 Introduction

In early 2010 Australia introduced terrestrial BWA services to the 3 575-3 700 MHz part of the *Extended-C* band. BWA is being licensed to operate in regional and remote areas of Australia. To ensure protection of urban based FSS earth stations the major capital cities have been specifically excluded.

This decision follows a long period of careful analysis into whether BWA could harmoniously share with other co-frequency and adjacent frequency national services, particularly FSS space-to-Earth (s-to-E) downlinks in the 3 400-4 200 MHz band. As Australia does not share any national borders this is essentially a domestic licensing issue.

In this Annex Australia wishes to advise the ITU-R of the arrangements that apply to ensure compatible sharing in this important frequency band. Minimum performance characteristics of the new BWA services and of incumbent FSS downlinks in the *Extended-C* and *Standard-C* bands are included, together with a short summary of the main sharing criteria. Further details can be obtained at: http://www.acma.gov.au/WEB/STANDARD/pc=PC_100424.

2 Summary of the main sharing rules

To ensure that BWA services in the 3 575-3 700 MHz band will be compatible with licensed FSS earth stations in the 3 600-4 200 MHz band a defined frequency coordination process, together with BWA deployment restrictions will apply.

In summary, the main licensing rules are:

– BWA is being licensed in regional and remote areas of Australia. *Exclusion zones* apply around defined areas, such as major cities, in order to preserve future planning options in these areas[13].

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

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

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

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

TABLE 42

BWA base station transmitter characteristics and deployment constraints

Parameter	Explanatory comments	Requirement
Duplex mode		TDD
Smart antenna gain		Coordinate to highest achievable antenna gain
Antenna polarisation discrimination	Potential losses due to polarisation discrimination can be taken into account in cases of main beam coupling. Mixed polarisation refers to the use of two orthogonally polarised signals.	***BWA Tx → ES Rx: dB loss*** Mixed → Circular: 0 dB Mixed → Linear: 3 dB Linear → Circular: 3 dB Linear → Linear (Co-polar): 0 dB Linear → Linear (Cross-polar): As specified by antenna data.
e.i.r.p. density limits (dBm/MHz)	Lower limits apply > 3 670 MHz to reduce out-of-band (OoB) emissions into the 3 700-4 200 MHz band and offer greater protection to earth stations against saturation.	3 575-3 670 MHz = 51 dBm/MHz 3 670-3 700 MHz = 30 dBm/MHz

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

TABLE 42 (*end*)

Parameter	Explanatory comments	Requirement
Emission masks	A band edge mask at the 3 700 MHz frequency boundary is needed to reduce OoB emissions into the 3 700-4 200 MHz band.	– All transmitters are to adhere to relevant emission masks stated in ETSI EN 302 326. – At, and above, the 3 700 MHz boundary, base stations must meet the mask of Fig. 25.
Main deployment constraints(1)	Deployment constraints are proposed in addition to coordination criteria. These are created to reduce the chance of interference from base stations (and user terminals) into earth stations operating in the 3 700-4 200 MHz band.	– No transmitters may be placed inside exclusion areas. – No user terminal transmitters are to be deployed within a 2 km radius of an earth station operating in the 3 700-4 200 MHz band–unless agreement can be reached with the earth station licensee.

(1) Additional deployment constraints can be found at: http://www.acma.gov.au/webwr/_assets/main/lib310829/rali_fx19_draft_update.pdf.

FIGURE 25

Band edge emission limits for BWA services

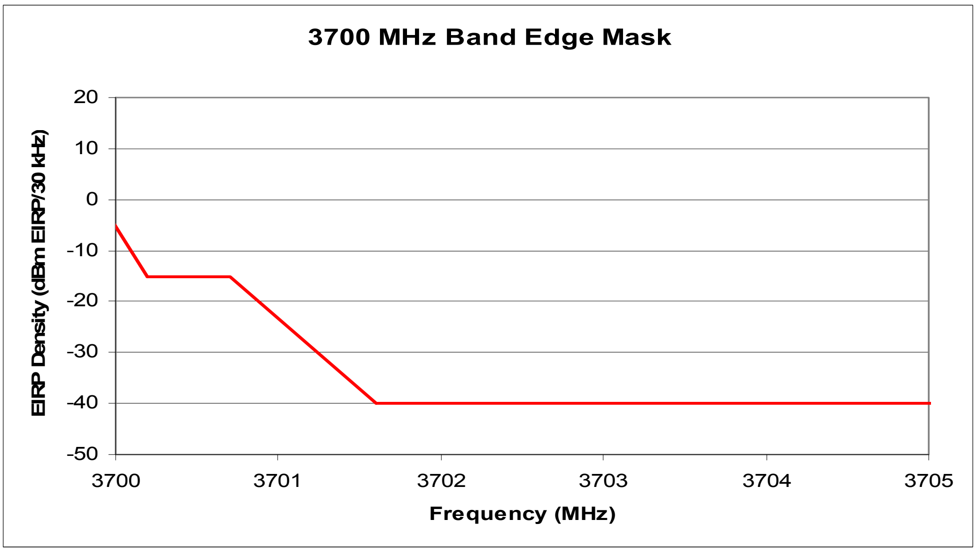


TABLE 43

FSS earth station receiver characteristics

Parameter	Explanatory comments	Value
Reference bandwidth (MHz)	To allow for per MHz coordination.	1
Antenna gain (dBi)	Value to be taken from licence.	–
Antenna pattern (dBi)	Recommendation ITU-R S.465.	–
Antenna feeder losses (dB)	Follows review of existing licensee's data.	0
Antenna height (m)	Value to be taken from licence.	–
Minimum elevation angle (degrees)	Follows review of existing licensee's data.	5
System temperature (K)	Follows review of existing licensee's data.	70
Noise floor (dBW/MHz)	Calculation.	–150.1
Protection criteria (*I*/*N*) (dB)	Based on Recommendations ITU-R S.1432 and ITU-R SF.1006: – ST = Short term (0.0017% time) – LT = Long Term (20% time).	ST = –1.3 LT = –10
Onset of non-linear operation level (dBm)	Follows review of existing licensee's data.	–65 (single entry)
Assumed filter (band pass or notch) attenuation (dB)	Protection requirements have been developed assuming specific filter performance as mentioned here. The fitting of filters is not mandatory; however, earth stations operating in the 3 700-4 200 MHz band are not afforded protection from harmful interference occurring from BWA stations operating in the 3 575-3 700 GHz band.	3 670-3 700 MHz → 0 < 3 670 MHz → 15

TABLE 44

Frequency coordination requirements[14]

Parameter	Explanatory comments	Requirement
Co-channel cull distance	This is the minimum BWA-FSS separation distance for which coordination is required (to protect earth stations in regional and remote areas).	150 km – BWA in 3 670-3 700 MHz 200 km – BWA in 3 600-3 670 MHz
Frequency cull range	This is the frequency range for which co-channel and adjacent channel coordination is required.	Co-channel: 3 600-3 700 MHz Adjacent channel*: 3 575-3 700 MHz *refers to FSS in the 3 700-4 200 MHz band

[14] Additional frequency coordination requirements can be found at: http://www.acma.gov.au/webwr/_assets/main/lib310829/rali_fx19_draft_update.pdf.

TABLE 44 (*end*)

Parameter	Explanatory comments	Requirement
Adjacent channel separation distance	This is the separation distance required between BWA base stations and FSS earth stations in order to affect adjacent channel coordination. **Note that a minimum 20 km separation distance applies in all adjacent band sharing cases.**	**Note that a minimum 20 km separation distance applies in all adjacent band sharing cases.** ***Case 1*: Interference into 3 700-4 200 MHz** – Guardband < 10 MHz: A BWA base station wishing to deploy within 100 km of an earth station operating in the 3 700-4 200 MHz band is required to undergo adjacent channel coordination, assuming a net filter discrimination (NFD) of 20 dB and a minimum allowable separation distance of 20 km. – Guardband ≥ 10 MHz: a minimum 20 km separation is required. ***Case 2*: Interference into 3 600-3 700 MHz** – Guardband ≥ 10 MHz: Coordination not required as exclusion zones will provide enough protection. – Guardband < 10 MHz: A BWA base station wishing to deploy within 150 km of an earth station operating in the 3 600-3 700 MHz band is required to undergo coordination. Both adjacent channel interference (assuming NFD of 20 dB) and protection against the onset of non-linear operations (assuming 20 MHz channel and no additional filtering losses) analysis is required.
Propagation model		Recommendation ITU-R P.452 – clear sky conditions.
Assignment priority		BWA assignments to be made from lowest available frequency up.

3 Summary and conclusion

Australia has introduced BWA services to the 3 575-3 700 MHz part of the *Extended-C* band. The new BWA services are permitted to operate outside *Exclusion Zones*, typically defined around major cities in Australia, and only where it can be demonstrated that compatibility will exist with licensed FSS earth stations in the area.

In addition BWA base stations are not licensed within 20 km of an existing licensed FSS earth station using the *Standard-C* frequency band. Other frequency coordination requirements also apply.