COMPATIBILITY OF SERVICES USING WiMAX TECHNOLOGY WITH SATELLITE SERVICES IN THE 2.3 - 2.7 GHz AND 3.3 - 3.8 GHz BANDS

Executive Summary

This document sets out a range of issues that may arise through sharing some spectrum with satellite services in two key candidate bands for WiMAX™ technology: 2.3-2.7 GHz and 3.3-3.8 GHz. The following areas are covered in this report:

- Information on frequency usage by satellite services in these bands is provided on a global and regional basis.
- Co-existence issues between the two services from two aspects:
  i. space-to-Earth where the downlink emissions from satellites may give rise to interference into WiMAX systems;
  ii. terrestrial sharing between the services (e.g. emissions from WiMAX technology into earth station receivers both in-band and out-of-band).
- The types of mitigation techniques that may be available to help promote a more favourable environment in which the services may be able to co-exist, particularly for those cases where sharing is likely to not be so straightforward.
- An indication of the relative ease of deployment of WiMAX systems in relation to existing and planned usage for satellite services.

The general conclusion drawn is that the ease of deployment of WiMAX systems in these bands is very much dependent on the extent to which satellite earth stations are already deployed in the country concerned and the amount of spectrum that they occupy and the situation in each country needs to be assessed on a case-by-case basis.

With regard to the 2.3-2.7 GHz frequency range, band segmentation or tighter power flux density limits are likely to be necessary to facilitate sharing between WiMAX technology and the satellite services. Furthermore, for countries which are using parts of the band 2.3-2.7 GHz for BSS, MSS or FSS satellite terminals, then sharing between WiMAX systems and satellite services on a co-channel basis in the same geographical area is likely to be difficult due to the interference potential between the terminals of each service.

For countries which have few gateway-type earth stations in the satellite downlink band 3.6-4.2 GHz then co-channel WiMAX technology deployment should be possible via coordination and use of mitigation techniques, possibly on a case-by-case basis with each earth station whose location is assumed to be known. Without mitigation, then there will be some geographical areas around the earth stations where deployments of WiMAX technology may be excluded from operation.

In some countries where earth stations are already ubiquitously deployed, and may well be unregistered, then mitigation techniques will be less beneficial. Even when the two services operate in separate, dedicated sub-bands (i.e. band segmentation), co-existence may prove difficult if the deployed earth stations use wideband front-end RF amplifiers that do not filter out the emissions from nearby terrestrial WiMAX base stations or terminals.

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1. INTRODUCTION

WiMAX system profiles currently consider use of the frequency bands 2.3 – 2.7 GHz and 3.3 – 3.8 GHz which also have ITU frequency allocations for satellite services. The Regulatory Working Group of the WiMAX Forum® set up a sub-team to address the compatibility of these services following recent activity in several national and international fora.

The purpose of this White paper is to provide the WiMAX Forum with the background to the satellite-related issues that relate to co-existence with wireless access services in the two bands and address the interference scenarios that can occur. The document provides examples of the regulatory framework by which coordination of the satellite services with terrestrial services is, or will be, effected in certain countries and the corresponding guidelines as to how wireless access systems and satellite services are able to co-exist and assessments of the methods by which co-existence can be more easily accomplished.

All of this is done from a worldwide perspective, drawing on information from global, regional and national sources.

In the 2.5-2.69 GHz portion of the lower of the two bands, much of the related work is currently underway in the ITU-R (Joint Task Group JTG 6-8-9 has finished its work and the next phase will be at the Conference Preparatory Meeting and World Radiocommunications Conference in 2007). This work has addressed co-existence between terrestrial wireless access systems and the satellite services which have allocations in the band and this report only provides a summary of the current status of this ongoing work. The interference that may arise into receiving earth stations in the 2500-2690 MHz band is not covered in this report. Sharing between WiMAX systems and satellite services on a co-channel basis in the same geographical area is likely to be difficult anywhere in the 2.3-2.7 GHz band and coordination of such services will be a national matter.

In the upper of the two bands being considered (3.3-3.8 GHz), work is in progress in several parts of the world to make WiMAX technology available for the deployment of broadband wireless access systems and this document concentrates in depth on the sharing with the Fixed Satellite Service which has frequency allocations in this band.

2. FREQUENCY ALLOCATIONS TO SATELLITE SERVICES IN WiMAX BANDS OF INTEREST

2.1. ITU Frequency Allocations

2.1.1. Service Allocations in 2.3 - 2.7 GHz Band

Figure 1 and Figure 2 illustrate the ITU primary frequency allocations in the 2.3 – 2.5 GHz and 2.5 - 2.7 GHz range, respectively. Note that the ITU Radio Regulations Article 5 Footnote **No. 5.393**[1] allocates the band 2310-2360 MHz to the Broadcasting Satellite Service (BSS sound) service in India, USA and Mexico. However, Malaysia also has satellite filings for this sub-band.

The fixed and mobile services have a global primary allocation from 2.3 to 2.69 GHz and, in some countries, band sharing may occur with various satellite services at frequencies above 2483.5 MHz (in addition to the BSS allocation by footnote described above).

[1] **5.393** *Additional allocation:* In the United States, India and Mexico, the band 2 310-2 360 MHz is also allocated to the broadcasting-satellite service (sound) and complementary terrestrial sound broadcasting service on a primary basis. Such use is limited to digital audio broadcasting and is subject to the provisions of Resolution **528 (WARC-92)**, with the exception of *resolves* 3 in regard to the limitation on broadcasting-satellite systems in the upper 25 MHz. (WRC-2000)

Figure 2 in particular is helpful in understanding the various frequency sharing issues that may arise between satellite and terrestrial systems and services that operate in various regions of the world in this band. The space-to-Earth sharing between the terrestrial and satellite services in this band is being dealt with under WRC-07 Agenda Item 1.9 (by Joint Task Group JTG6-8-9).

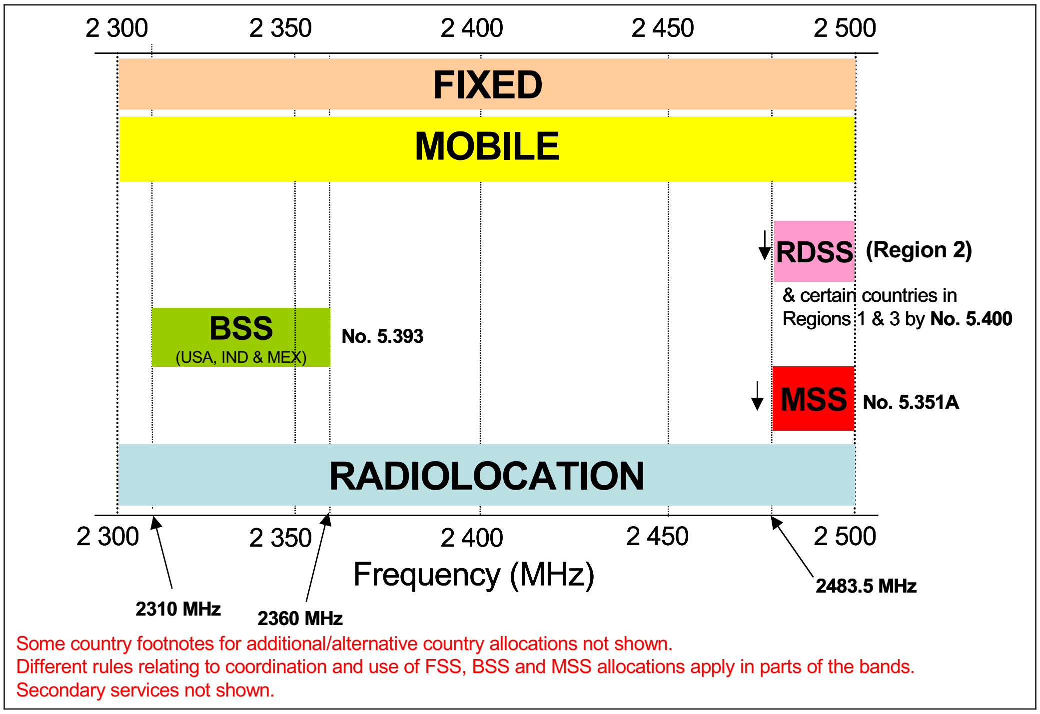

Figure 1. ITU Radio Regulations Article 5 frequency allocations on a primary basis in the band 2 300 – 2 500 MHz

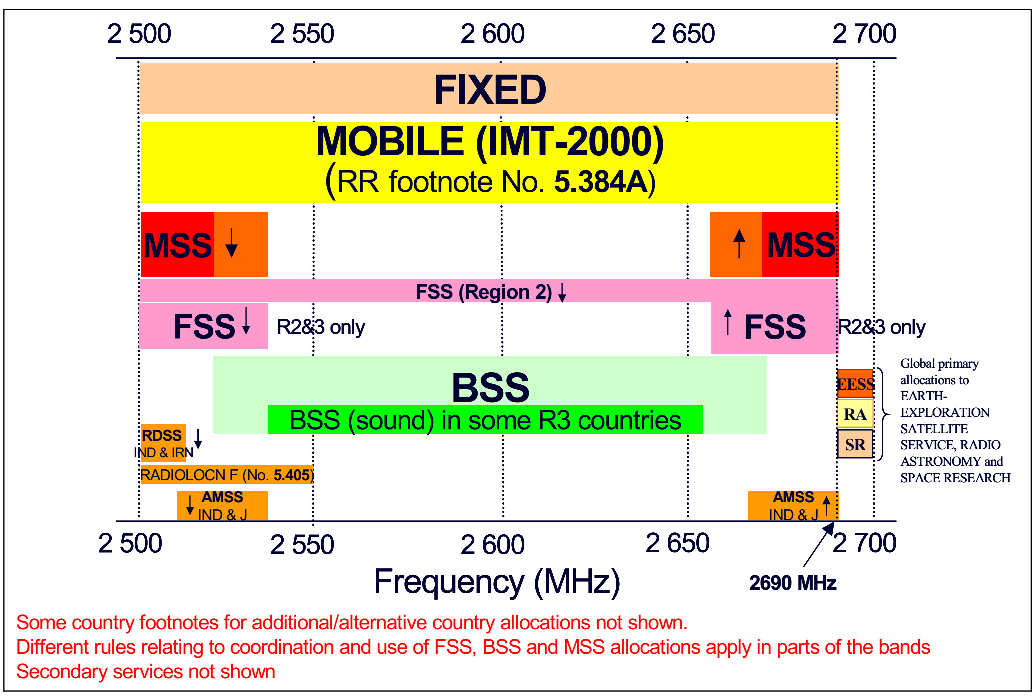

Figure 2. ITU Radio Regulations Article 5 frequency allocations on a primary basis in the band 2 500 – 2 690 MHz

2.1.2. Service Allocations in 3.3 - 3.8 GHz Band

Figure 3 shows the ITU frequency allocations in the 3.3-3.8 GHz band on a regional basis. The Fixed Service and the Fixed Satellite Service[2] have a global primary allocation from 3400 MHz upwards. Note that the mobile service has a primary allocation above 3500 MHz in Regions 2 and 3 but that there is only a secondary allocation to the mobile service in the band 3400-3800 in Region 1, and in the band 3400-3500 MHz in Regions 2 and 3.

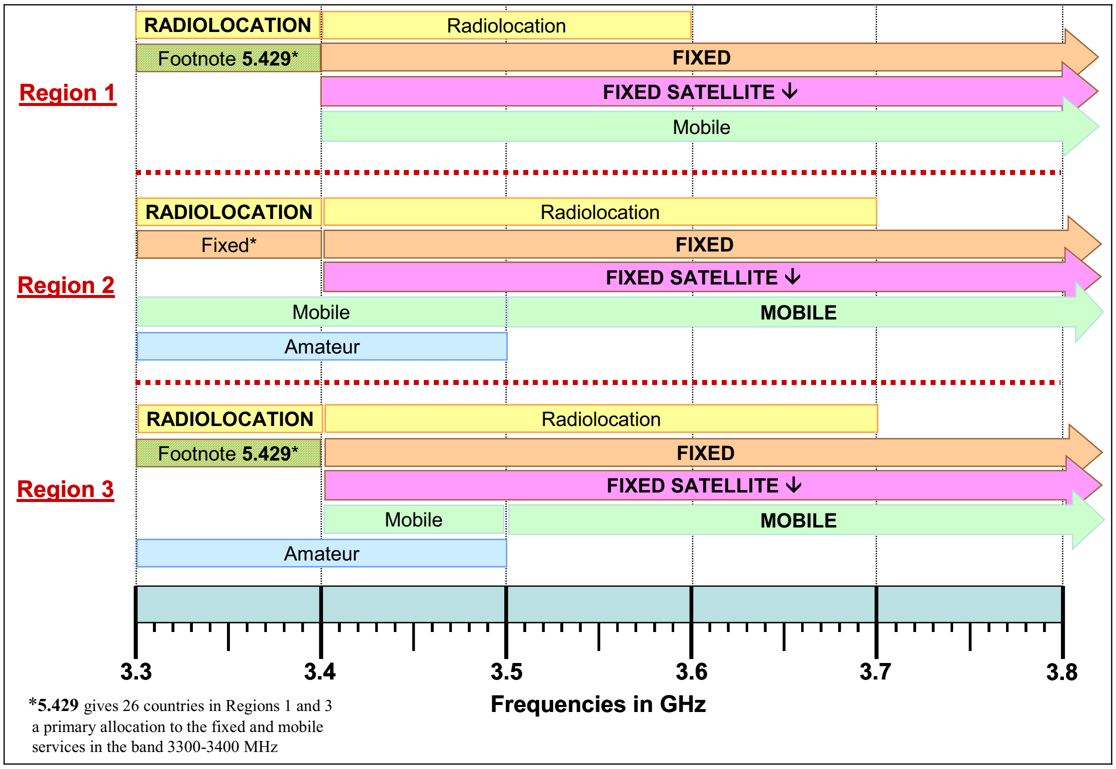

Figure 3. ITU-R Frequency Allocations in the 3.3 – 3.8 GHz band

Notes: 1) Services in upper case lettering (capitals) are PRIMARY allocations;
2) Services in lower case lettering are Secondary[3] allocations
3) Other allocations are made on a national basis by Article 5 footnotes

The following Article 5 footnote applies to this spectrum range:

5.429 *Additional allocation:* in Saudi Arabia, Bahrain, Bangladesh, Brunei Darussalam, China, the Congo, Korea (Rep. of), the United Arab Emirates, India, Indonesia, Iran (Islamic Republic of), Iraq, Israel, Japan, Jordan, Kenya, Kuwait, Lebanon, Libyan Arab Jamahiriya, Malaysia, Oman,

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[2] *ITU RR Article 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; the fixed-satellite service may also include *feeder links* for other *space radiocommunication services*.

[3] Stations of a *secondary* service:

a) shall not cause harmful interference to stations of primary services to which frequencies are already assigned or to which frequencies may be assigned at a later date;

b) cannot claim protection from harmful interference from stations of a primary service to which frequencies are already assigned or may be assigned at a later date;

c) can claim protection, however, from harmful interference from stations of the same or other secondary service(s) to which frequencies may be assigned at a later date.

Pakistan, Qatar, Syrian Arab Republic, Dem. People's Rep. of Korea and Yemen, the band 3 300-3 400 MHz is also allocated to the fixed and mobile services on a primary basis. The countries bordering the Mediterranean shall not claim protection for their fixed and mobile services from the radiolocation service. (WRC-03)

2.2. Regional and National Frequency Allocations

2.2.1. Africa

[Information not yet available]

2.2.2. Asia Pacific

In India the frequency band 2 500-2 690 MHz is being used for satellite based BSS and MSS systems.

In Japan, the bands 2 483.5-2 535 and 2 655-2 690 MHz are allocated to mobile satellite communications services. The band 2 605-2 655 MHz is allocated for satellite sound broadcasting.

In Japan, the band 3.6-4.2 GHz is currently used for the Fixed Satellite Service.

In Indonesia the band 2520 – 2670 MHz is used for the broadcasting satellite service.

In India, the band 3 400-4 200 MHz is used by Fixed Satellite Service.

In Vietnam, the band 3 400-4 200 MHz is allocated to fixed satellite service on a primary basis. This band will continue to be used extensively for FSS in the future.

In New Zealand, the band 3 600–4 200 MHz is allocated to the fixed-satellite services.

In Korea, the band 3400 – 3700 MHz is used for the fixed satellite service.

2.2.3. Europe

The latest revision to the European Common Allocation Table in ERC Report 25[4] indicates that the only (primary) satellite service allocation in the band 2.3-2.69 GHz is for the Mobile Satellite Service space-to-Earth allocation in the sub-band 2483.5-2500 MHz. The band above 2690 MHz is the same as for the ITU allocations shown in Figure 2.

Figure 4 shows the CEPT frequency allocations in the band 3.3-3.8 GHz according to the European Common Allocation Table: the allocation to the FSS and the allocation to FWA in the band 3410-3800 MHz.

[4] CEPT ERC Report 25: *The European table of frequency allocations and utilisations covering the frequency range 9 kHz to 275 GHz,* Copenhagen 2004

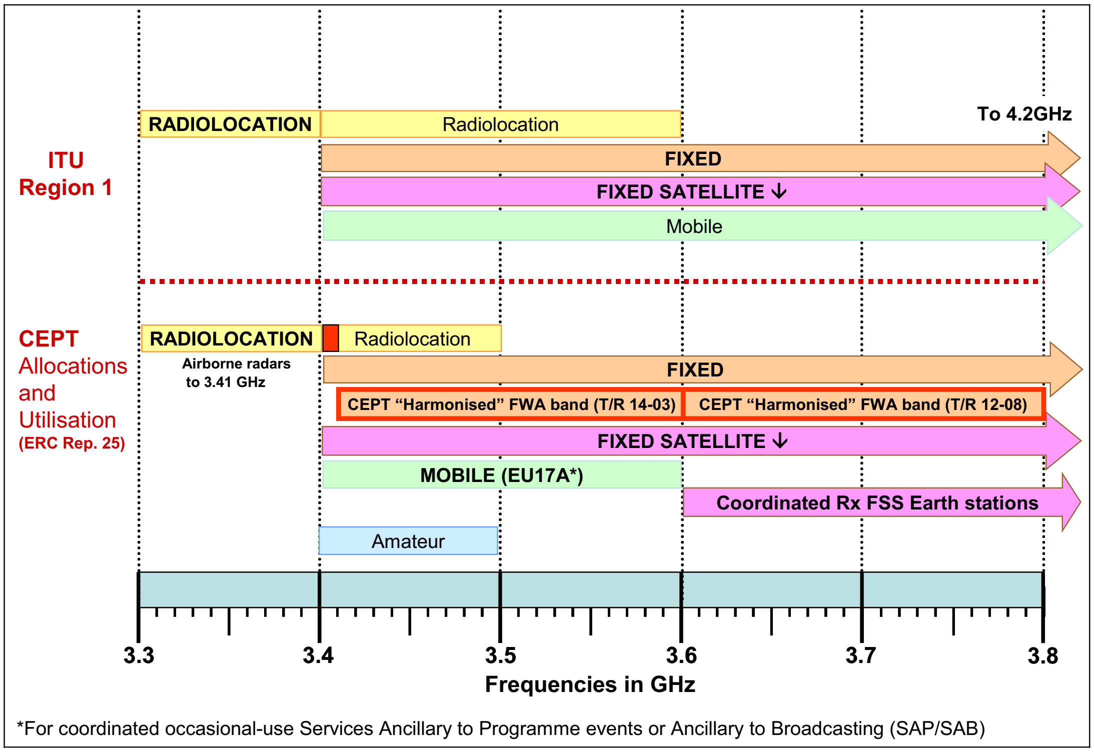

Figure 4. CEPT Frequency Allocations in the 3.3 – 3.8 GHz band

At the present time some CEPT countries use parts of the band for Fixed Wireless Access (FWA). CEPT ECC Spectrum Engineering Project Team (SE-19) has finalised a report that addresses inter-service sharing issues in the 3.4-3.8 GHz band with respect to the co-existence of BWA systems. Recently, the studies have been extended to address other Broadband Wireless Access (BWA) usage modes, such as nomadic (NWA) and mobile (MWA), as well as FWA. These results have been fed into the ECC Joint Project Team on Broadband Wireless Access who have produced an ECC Decision on the implementation of BWA in the 3.4-3.8 GHz band.[5]. As a result of this work, a primary mobile allocation for Broadband Wireless Access is now being considered for inclusion in the European Common Allocation Table.

2.2.4. Middle-East

[Information not yet available]

2.2.5. North America

The United States allocation for Wireless Communications Services (WCS) in the 2.3 GHz band is shown in Figure 5, the 2305-2320 MHz and 2345-2360 MHz bands are allocated on a primary basis to non-federal fixed and mobile services.[6] The 2310-2360 MHz band is allocated on a primary basis

[5] CEPT ECC/DEC/(06)[xx]: *Draft ECC Decision on the availability of frequency bands between 3400-3800 MHz for the Harmonised Implementation of Broadband Wireless Access systems (BWA)*

[6] US Footnote US338: In the 2305–2310 MHz band, space-to-Earth operations are prohibited. Additionally, in the 2305–2320 MHz band, all Wireless Communications Service (WCS) operations within 50 kilometers of 35°20" North Latitude and 116°53" West Longitude shall be coordinated through the Frequency Assignment Subcommittee of the Interdepartment Radio Advisory Committee in order to minimize harmful interference to NASA's Goldstone Deep Space facility.

to the broadcasting-satellite service (sound) and complementary terrestrial broadcasting service.[7] The 2360-2395 MHz band is allocation on a primary basis to the mobile services, use is limited to aeronautical telemetering and associated telecommand operations for flight testing.[8] The band 2300-2310 MHz is allocated on a secondary basis to Amateur operations.

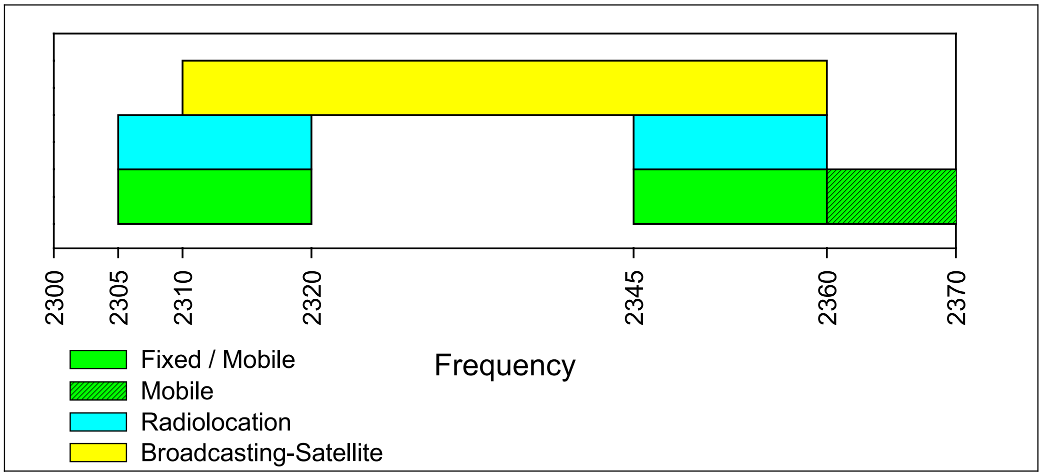

Figure 5. US Frequency Allocations in the 2300-2370 MHz band

The United States allocation for Broadband Radio Services (BRS) and Educational Broadband Services (EBS) in the 2.5 GHz band is shown in Figure 6, the 2495-2690 MHz band is allocated on a primary basis to non-federal fixed and mobile services. Overlapping and just below these services the 2483-2500 MHz band is allocated on a primary basis to the mobile satellite[9] and radiodetermination[10]. The band 2690-2700 MHz is allocated on a primary basis to the earth exploration-satellite, radio astronomy and space research services, in addition the 2655-2690 MHz band is used by radio astronomy[11].

In the United States, as shown in Figure 7, the 3650-4200 MHz band is allocated on a primary basis to the fixed service and the band 3650-3700 MHz is allocated on a primary basis to the mobile service[12]. The band 3300–3650 MHz is allocated on a primary basis to federal radiolocation

[7] Such use is limited via US Footnote US237 to digital audio broadcasting and is subject to the provisions of Resolution 528.

[8] US Footnote US276: Except as otherwise provided for herein, use of the band 2360–2395 MHz by the mobile service is limited to aeronautical telemetering and associated telecommand operations for flight testing of aircraft, missiles or major components thereof. The following three frequencies are shared on a co-equal basis by Federal and non-Federal stations for telemetering and associated telecommand operations of expendable and reusable launch vehicles, whether or not such operations involve flight testing: 2364.5 MHz, 2370.5 MHz, and 2382.5 MHz. All other mobile telemetering uses shall not cause harmful interference to, or claim protection from interference from, the above uses.

[9] US Footnote US391: In the band 2495–2500 MHz, the mobile-satellite service (space-to-Earth) shall not receive protection from non-Federal stations in the fixed and mobile except aeronautical mobile services operating in that band.

[10] US Footnote US41: In the band 2450–2500 MHz, the Federal radiolocation service is permitted on condition that harmful interference is not caused to non-Federal services.

[11] US Footnote US269: In the band 2655–2690 MHz, radio astronomy observations are performed at the locations listed in US311. Licensees are urged to coordinate their systems through the Electromagnetic Spectrum Management Unit, Division of Astronomical Sciences, National Science Foundation, Room 1030, 4201 Wilson Blvd., Arlington, VA 2230.

[12] US footnote US348: The band 3650–3700 MHz is also allocated to the Federal radiolocation service on a primary basis at the following sites: St. Inigoes, MD (38° 10' N, 76° 23' W); Pascagoula, MS (30° 22' N, 88° 29' W); and Pensacola, FL (30° 21' 28" N, 87° 16' 26" W). All fixed and fixed satellite operations within 80 kilometers of these sites shall be coordinated through the Frequency Assignment Subcommittee of the Interdepartmental Radio Advisory Committee on a case-by-case basis.

services and the band 3500-3650 MHz is allocated on a primary basis to the aeronautical radionavigation service. The band 3600-4200 MHz is allocated on a primary basis to the fixed-satellite (space-to-Earth) service[13].

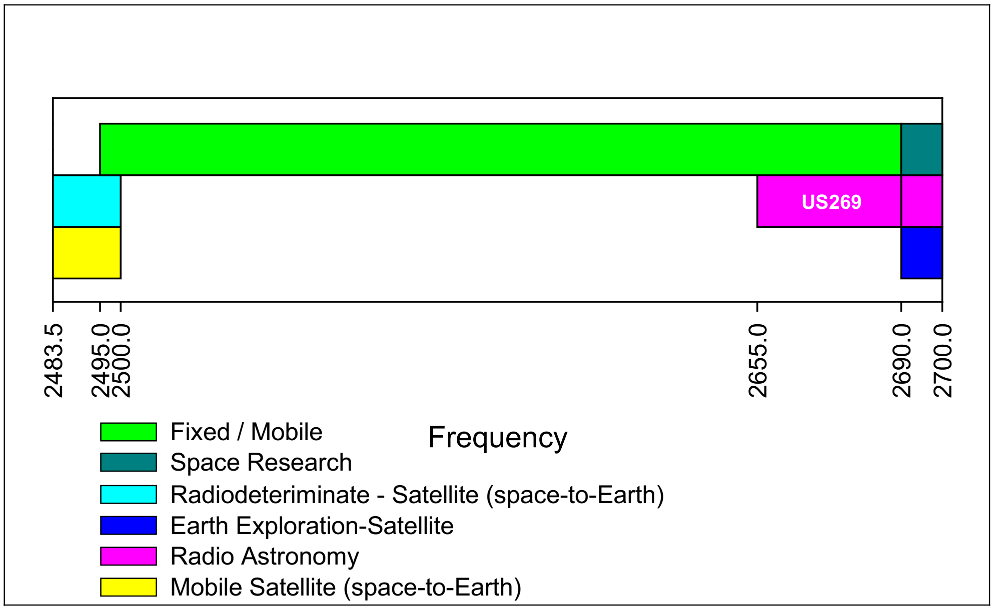

Figure 6. US Frequency Allocations in the 2483.5-2700 MHz band

US footnote US349: The band 3650–3700 MHz is also allocated to the Federal radiolocation service on a non-interference basis for use by ship stations located at least 44 nautical miles in off-shore ocean areas on the condition that harmful interference is not caused to non-Federal operations.

[13] US footnote US245: In the bands 3600–3650 MHz (space-to-Earth), 4500–4800 MHz (space-to-Earth), and 5850–5925 MHz (Earth-to-space), the use of the non-Federal fixed-satellite service is limited to international inter-continental systems and is subject to case-by-case electromagnetic compatibility analysis. The FCC's policy for these bands is codified at 47 CFR 2.108.
US footnote NG185 In the band 3650–3700 MHz, the use of the non-Federal fixed-satellite service (space-to-Earth) is limited to international inter-continental systems.
US footnote NG180 In the band 3700–4200 MHz (space-to-Earth) earth stations on vessels (ESVs) may be authorized to communicate with space stations of the fixed-satellite service and, while docked, may be coordinated for up to 180 days, renewable. ESVs in motion must operate on a secondary basis.

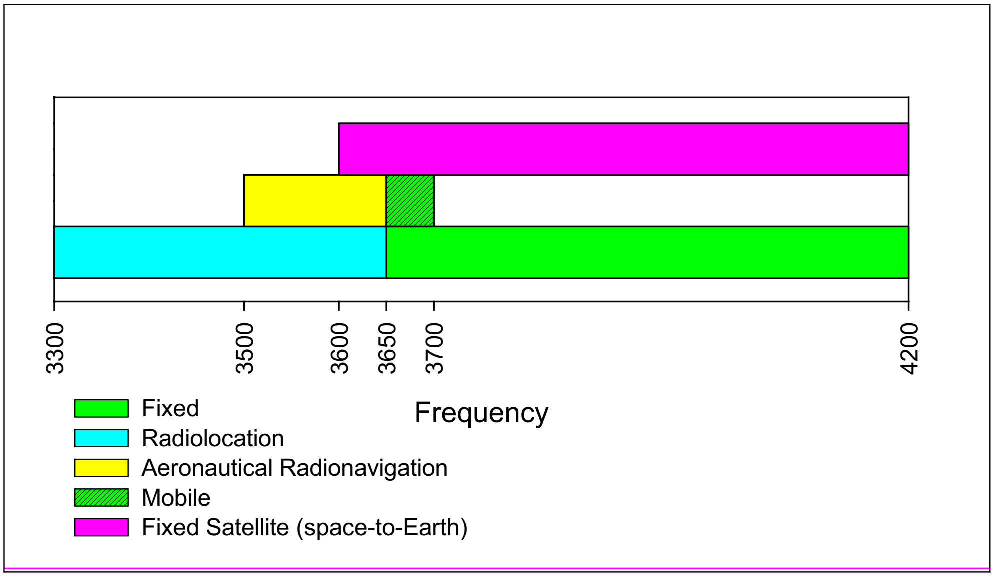

Figure 7. US Frequency Allocations in the 3.3-4.2 GHz band

In Canada, the band 3700-4200 MHz is heavily used by the fixed-satellite service in the space-to-Earth direction, with significant operations in both urban and rural areas. Satellite applications making use of this band include provision of communications services to remote communities. Also in Canada, there is currently an on-going consultation on the future use of the band 3650-3700 MHz, with a view to allow mobile services.

2.2.6. South & Central America

For the last 15 years, besides the band 3 700-4 200 MHz in the downlink, the Brazilian satellites also use an extended C-band 3 625-3 700 MHz as it is not shared in Brazil with the fixed service and is suited to applications with multiple terminals such as VSATs. Presently, there are more than 8,000 earth stations pointing to one of the Brazilian satellites in standard C-band and 12,000 earth stations pointing to one of the non-Brazilian satellites that cover the country plus an equal number of earth stations in the 75 MHz extended C-band and around 20 million TVRO terminals scattered around the country. Two new Brazilian satellites using C-band are presently under construction so this band will be extensively used for at least twenty years.

3. CHARACTERISTICS OF WiMAX SERVICES FOR USE IN SHARING STUDIES WITH SATELLITE SERVICES

3.1. WiMAX system characteristics in 2.5 – 2.69 GHz Band

Table 1 provides the characteristics of WiMAX systems required in sharing studies with the satellite services in the 2.5-2.69 GHz portion of the 2.3-2.7 GHz band. Only satellite to base station interference is considered in this report.

Table 1

WiMAX system characteristics 2.5-2.69 GHz used in sharing studies with satellite services[14]

Parameter	WiMAX Base Station	WiMAX Terminal Station
EIRP	54 dBm	7.5 dBm/MHz
Antenna gain (transmit and receive)	18 dBi (sectored)	
Receiver noise figure	3 dB	5 dB
Receiver thermal noise (including noise figure)	–109 dBm/MHz	–107 dBm/MHz
Antenna gain pattern	Recommendation ITU-R F.1336-1, *recommends* 2.1.2, *k* = 0.0	
Protection criteria (*I/N*) interference to individual Base or Terminal station	–10 dB	–10 dB
Antenna height above ground level (rural - urban)	15 - 30 metres	1.5 m
Antenna elevation (default)	-2 degrees	

3.2. WiMAX system characteristics in 3.4 – 3.8 GHz Band

Table 2 provides the characteristics of WiMAX systems required in sharing studies with the Fixed Satellite Service in the band 3.4-3.8 GHz. The sparcity of information for the terminal stations reflects the fact that all the sharing studies in this report are concerned with the WiMAX base station which is generally: i) located at a greater height above local ground level, ii) uses higher e.i.r.p., iii) transmits for a greater proportion of the time, iv) radiates as a virtual omni antenna (sectoral coverage in all directions).

Table 2. WiMAX system characteristics 3.4-3.8 GHz used in sharing studies with satellite services[15]

Parameter	WiMAX Base Station	WiMAX Terminal Station
EIRP density	46 dBm/MHz	7.5 dBm/MHz
Antenna gain (transmit and receive)	17 dBi (sectored)	-
Receive feeder loss	1 dB	-
Receiver noise figure	5 dB	7 dB
Receiver thermal noise (including noise figure)	–109 dBm/MHz	–107 dBm/MHz

[14] Parameters from ITU-R JTG6-8-9 Final Report (Section 1 of Annex 3 in R6-8-9/125,

[15] Parameters from ITU-R WP8F inputs by WiMAX Forum

Antenna gain pattern	Recommendation ITU-R F.1336-1, *recommends* 2.1.2, $k = 0.0$	-
Protection criteria (I/N) interference to individual Base or Terminal station	-6 dB (20% of time)	-6 dB
Antenna height above ground level (rural - urban)	15-30 metres	1.5 m
Antenna elevation (default)	-2 degrees	-

These parameters are used later in this report to address: a) interference into WiMAX receivers from satellite downlink transmissions; b) interference from WiMAX transmitters into earth station receivers.

4. CHARACTERISTICS OF SATELLITE SERVICES

4.1. Long-term and Short-term Interference thresholds

Before moving on to look at the potential impact of co-existence in the parts of the bands with allocation to satellite services, it is important to reflect on the interference criteria that apply, and the reasons for these.

Most high quality satellite systems have 2 interference criteria that are used for frequency co-ordination purposes. The first relates to the "normal" background interference, and specifies an interference level that must not be exceeded for more than (typically) 20% of the time. The need to quote a time percentage is because various factors (especially the weather) can cause interference levels to constantly vary. The criteria that must not be exceeded for more than 20% of time are known as the **"long-term"** criteria, and it is usually a very low level of interference so as to ensure an excellent background error rate over the satellite link.

However, there are certain anomalous weather conditions[16] that can result in atmospheric propagation mechanisms that give rise to significantly raised interference levels, albeit for short periods of time. High quality, high availability systems are therefore also protected by "**short-term**" interference criteria. These criteria recognise a higher level of interference that will bring the system to the point whereby it becomes out-of-service. However, such interference levels are only permitted for very small time percentages, typically for a total of between 0.001% and 0.01% of time in a year or worst month (depending on how the criteria are defined). These may well be linked to other criteria such as the tolerable number of Errored Seconds or Severely Errored Seconds.

It is worth noting that systems in the access network (and especially mobile systems) have traditionally only been concerned with long-term interference, and the short-term interference has not been of concern.

Reference is made to short-term and long-term interference criteria in the following sections.

4.2. System Characteristics for FSS Earth Stations

Receiving earth stations for satellite services use extremely sensitive receivers. The criterion for long-term interference into a major earth station is typically of the order of -160dB(W/MHz), so this requires significant isolation to protect the Earth station from transmissions from BWA systems

[16] e.g. i) low loss propagation via surface layer ducts or elevated ducts; ii) scattering due to rain in the common volume of the wanted and interfering antenna beams

(e.g. up to an e.i.r.p. of +14dBW/MHz in the UK in the band above 3.6 GHz). Despite the general use of highly directive antenna beams, the sensitivity is such that it is not just the main beam of the Earth station that is affected, but the antenna side-lobes all around the earth station antenna must also be considered.

Using Recommendation ITU-R S.1432[17] as a basis to develop long-term interference criteria, the maximum interference-to-noise ratio (I/N) is recommended to be 6% for co-primary services. This applies for 100% of the time. As discussed in the previous section, long-term interference levels are normally calculated by running the propagation models for 20% of time whence the I/N is –10 dB. Applicability of this interference criterion to either single or multiple WiMAX stations would depend on particular scenarios.

Recommendation ITU-R SF.1006[18] indicates how the long-term and short-term interference criteria are derived. The method to derive the short-term interference criterion is the same as the method used in Appendix 7 of the Radio Regulations (see §7.1 of this report).

Table 3 provides the system parameters for earth stations used in the sharing studies (smaller antenna sizes are used but this tables provides the parameters required for the worst-case sharing studies):

Table 3

Fixed Satellite Service system characteristics in the 3.4-3.8 GHz band[19]

Elevation angle	4° - 30°	
Antenna diameter (m)	8	32
Antenna Gain (dBi)	47.7	59.8
Antenna centre height a.g.l. (m)	5	25
Receiver Noise temperature (K)	82	70
Antenna diagram	Recommendation ITU-R S.465	
Long-term single-entry interference-to-noise ratio (dB)	-10 (20% of average year)	
Short-term interference-to-noise ratio (dB)	-1.3 (0.005% of average year – all entries)	

5. USAGE AND DEPLOYMENT SCENARIOS FOR EARTH STATIONS USED FOR SATELLITE SERVICES

5.1. Satellite usage in the band 2.3-2.7 GHz

The satellite usage below the band 2 500-2 690 MHz has been shown in Figure 1 and it seems that there are few sharing issues with satellite services below 2483.5 MHz.

[17] ITU-R Recommendation S.1432: *Apportionment of the allowable error performance degradations to fixed-satellite service (FSS) hypothetical reference digital paths arising from time invariant interference for systems operating below 30 GHz,* ITU-R WP4A, Geneva, 2006

[18] ITU-R Recommendation SF.1006: *Determination of the Interference Potential between Earth Stations of the Fixed-Satellite Service and stations in the Fixed Service,* ITU-R WP4-9S, Geneva, 2000

[19] Parameters from CEPT ECC Report 100 on sharing between FWA and other services 3.4-3.8 GHz

Many administrations have filed satellite networks (over 200 GSO satellite networks filed by about 25 administrations and more than 8 non-GSO networks) with the ITU/BR for operation in the 2 500-2 690 MHz band. These include the Mobile Satellite Service (MSS), the Broadcasting Satellite Service (BSS), both TV and sound broadcasting, and Fixed Satellite Service (FSS) networks.

There are seven operational systems in the world, namely, GSAT (India – BSS (sound)), INSAT (India – BSS(TV), MSS), INDOSTAR (Indonesia – BSS(TV)), NSTAR (Japan – LMSS, MMSS), ETS (Japan – LMSS, MMSS), MBSAT (Japan – BSS(sound)), and HANBYUL (Korea – BSS(sound)).

In the Region 3 countries listed in Radio Regulations Footnote No. **5.418** (Republic of Korea, India, Japan, Pakistan and Thailand) and **5.417A**, some BSS (sound) systems are already operating or planned to operate under these provisions

Korea has been using the band 2 630-2 655 MHz for BSS (sound) commercially from May 2005. The number of subscribers was near 400 000 at the end of 2005. The number of subscribers is expected to reach over 1.2 millions at the end of 2006.

In India the frequency band 2 500-2 690 MHz is being used for satellite based BSS and MSS systems. BSS is used in the band 2550-2630 MHz. There are MSS systems within India in the frequency band 2 500-2 520 MHz (space-to-Earth) and 2 670-2 690 MHz (Earth-to-space). Considering the emerging requirements for MSS, India is planning to use the extended MSS band 2 520-2 535 MHz (space-to-Earth) and 2 655-2 670 MHz (Earth-to-space) also in the very near future in accordance with the relevant provisions of the ITU Radio Regulations.

In Indonesia the band 2520 – 2670 MHz is used for the broadcasting satellite service.

In Japan, the bands 2 483.5-2 535 and 2 655-2 690 MHz are allocated to the MSS and the band 2 605-2 655 MHz is allocated for satellite sound broadcasting. Japan has an existing MSS system already operating under Nos. **5.403**, **5.414**, **5.419** and **5.420** of the Radio Regulations in the bands 2 500-2 535 MHz and 2 655-2 690 MHz. Currently there are more than 30,000 subscribers and it is required to continue this Mobile-satellite service in these bands on a long-term basis.

5.2. FSS usage in the band 3.4-3.8 GHz

As shown in §2.1.2, the whole of the band 3.4-4.2 GHz ("C-band") is allocated to the Fixed Satellite Service (FSS), space-to-Earth, on a worldwide basis by Article 5 of the ITU Radio Regulations. The top 500 MHz (3.7-4.2 GHz) is known as the "conventional" C-band and has been used by the FSS for more than 40 years. It is the most common and widely-used band for the FSS as it offers low propagation loss through rain compared with the higher frequency FSS bands. This band is used, amongst other applications, for program distribution to cable head-ends and radio/TV broadcast stations, broadband communications, VSATs, SNG, weather data distribution to airlines and pilots, and position location and status for trucking fleets. In areas of the world which experience high rainfall intensity (e.g. equatorial regions), the higher frequency FSS bands do not offer the high availability that many satellite services require and, as a consequence, these parts of the world may only be illuminated by C-band satellite beams. Furthermore, the geostationary orbit is fairly fully utilised in the top 500 MHz and use of the "extended C-band" spectrum down to 3625 MHz has increased in recent years. The whole band down to 3400 MHz is made use of in certain areas of the world (notably in the Russian Federation and parts of South-East Asia) although less than 10% of C-band satellite orbital slots have transponders in the range 3400-3600 MHz at the present time (many more are filed into the Radiocommunications Bureau of the ITU).

The C-band earth stations can be sorted into two main types in terms of their deployment:

1. Large gateway earth station complexes comprising a number of antennas typically with antenna diameters of 4 metres and greater (up to 32 metres). These are used for such services as inter-continental connectivity (telephony, internet, contribution TV), VSAT hub

stations (with VSAT outstation terminals on other continents). Typically, these antennas also transmit in the paired uplink band at 6 GHz (i.e. Earth-to-space). The larger complexes are usually found in rural areas, though smaller sites are found in suburban or even urban areas where they are frequently referred to as teleports. These types of earth station are generally registered for the purpose of coordination with other services (e.g. the terrestrial fixed service). In many countries there may be only a few such gateway or teleport sites.

2. Smaller earth stations deployed ubiquitously often without registration (e.g. program distribution to cable head-ends and radio/TV broadcast stations; VSAT terminals for corporate private networks; terminals for satellite news gathering). Antenna diameters range from 1.8 – 3.8 metres and are commonly deployed on the roofs of buildings or on the ground in urban, suburban or rural locations.

There are currently more than 160 geostationary satellites operating in these bands, without considering satellites operating feeder links or telemetry operations (Telemetry, Tracking and Command - TTC).

The band 3600-3625 MHz is used as the downlink FSS band for feeder links to satellites that are part of the Mobile Satellite Service (MSS) for aeronautical, land and maritime backhaul into the public networks, e.g. INMARSAT. Recently, these services are expanding to use the band 3550-3700 MHz. The land earth stations associated with these services are few in number (INMARSAT has about 10 worldwide) and tend to be located with other C-band terminals at major gateway earth stations.

In Europe, the band 3.4-3.625 GHz is used by few FSS networks and even the band up to 3.7 GHz is relatively lightly used in comparison with the band 3.7-4.2 GHz. The 3.625-4.2 GHz band is used in the majority of countries. In Europe, there is very little use of C-band for satellite services using small antennas (e.g. direct broadcasts to home, VSATs for corporate private networks). It should also be noted that the FSS earth station deployment scenario mentioned above does not include Receive Only Earth Stations. As a CEPT ERC Decision, ERC/DEC/(99)26, decided to exempt these from individual licensing, the locations are not available, but do need to be recognised in the sharing and compatibility studies between WiMAX technology and other services in the 3.4 – 3.8 GHz band.

In the Russian Federation the whole band 3 400-4 200 MHz is intensively used for FSS services, including VSAT networks, domestic and international telephony and other applications (internet, TV broadcasting, etc.). However, the band 3 400-3 450 and 3 500-3 550 MHz is also licensed for fixed wireless access.

Figure 8 shows some of the earth station in ITU Region 1 which are either on the ITU Radiocommunication Bureau's database or that of the operator, New Skies Satellites. There are other earth stations not shown which either work to different satellite operators, or are not registered with the ITU BR.

In South America, Brazil typifies the use of C-band for domestic satellite communications in this continent and makes extensive use of the band 3625-4200 MHz to cope with the severe rain fading experienced in the tropical climate. This band is used for applications such as: VSAT networks, point-to-point and point-to-multipoint links, satellite news gathering, TV broadcasting, DTH receivers using a mix of small, medium and large diameter earth station antennas. In remote areas there are no forms of communication other than satellite connections. Even in populated regions, satellite communications are extensively used.

In particular, the extended C-band 3 625-3 700 MHz is not shared with the fixed service in Brazil and so is particularly suited to applications with multiple terminals such as VSATs.

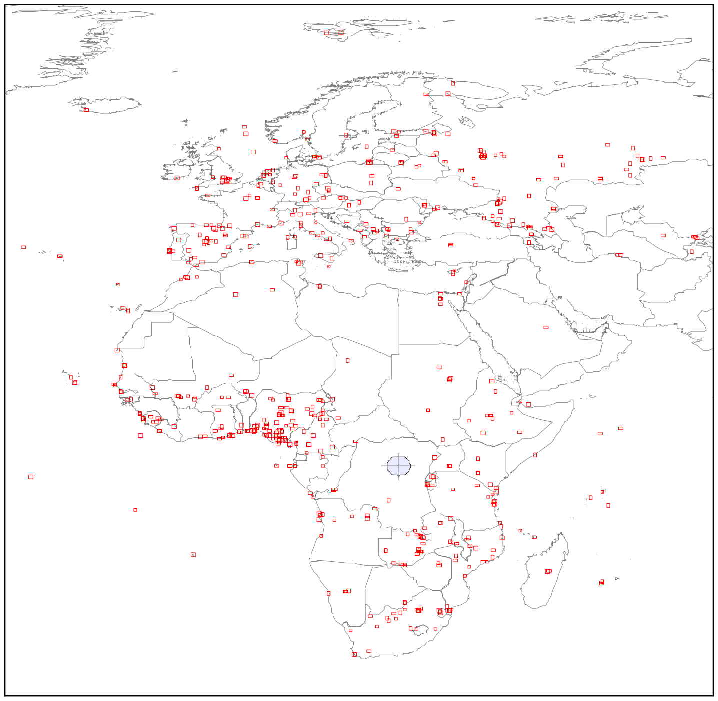

Figure 8. C-band Earth station sites on ITU and New Skies Satellites' databases in ITU Region 1

Note: The FSS Earth station deployment shown in the above plot relates only to information contained in the ITU database as well as those of New Skies and does not include governmental and military services and Receive-only Earth stations. Earth stations in Region 3 countries (e.g. Saudi Arabia, Pakistan etc. are not shown).

Source: Input document into August 2006 meeting of ITU-R WP8F in Denver (Doc. 8F/982)

Figure 9 shows a map of all the earth station sites in Brazil using the frequency band 3625-4200 MHz. Brazil has allocated the band 3400-3600 MHz for broadband wireless access services and other countries in South America do likewise (e.g. Venezuela).

In the USA there are FSS operations in the band 3600-4200 MHz[20]. In the 3650-3700 MHz portion of the band, the FCC "grandfathered" international earth station operations on an indefinite basis and disallowed any new deployments[21]. Only the band 3700-4200 MHz is used for ubiquitously deployed domestic services (VSATs, SMATV, DTH etc.). This is covered further in §7.3.

In Canada the band 3450-3650 MHz is allocated for FWA with most FSS use above 3700 MHz.

[20] Note that in the USA, there is an allocation in the 3 400-3 650 MHz band, on a primary basis, to the Federal Government for the radiolocation service which is used for high power airborne, shipboard and ground-based radars.

[21] FCC 05-56: *Report & Order and Memo & Order for Wireless Access Systems in the USA in the band 3650-3700 MHz,* USA, March 2005, (http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-05-56A1.pdf)

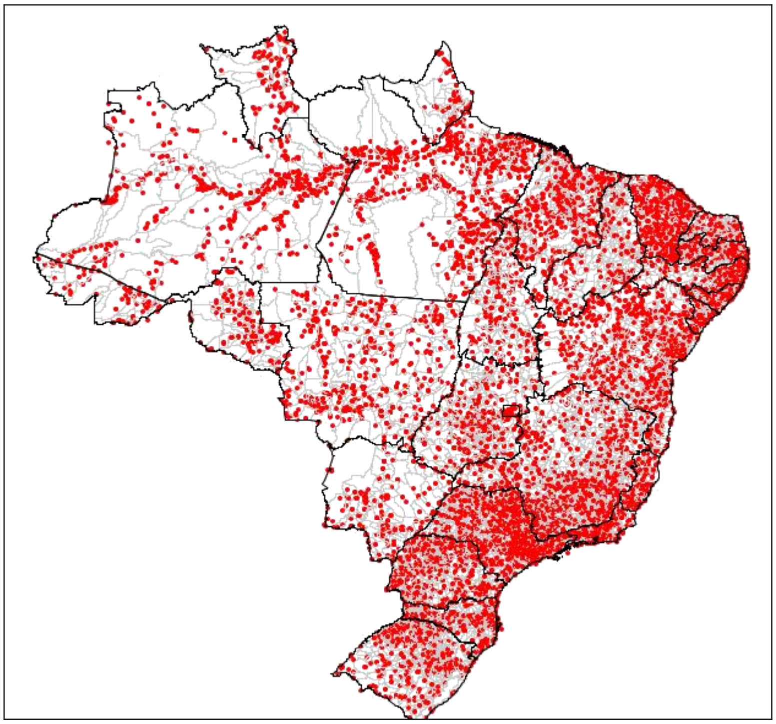

Figure 9. Earth station sites in Brazil using the frequency band 3625-4200 MHz

Note: Presently, there are more than 8,000 earth stations pointing to one of the Brazilian satellites in the band 3700-4200 MHz; 12,000 earth stations pointing to one of the international satellites with beams covering Brazil plus an equal number of earth stations in the 3625-3700 MHz extended C-band and around 20 million TV receive-only terminals scattered around the country.

Source: Input document into April 2006 meeting of ITU-R WP8F in Biarritz (Doc. 8F/780)

In many parts of Asia, satellites provide national and regional coverage over the whole band 3400-4200 MHz via a series of satellites such as INSAT, APSTAR, Thaicom, ST, Telstar, Palapa, Yamal, etc.

In Vietnam, the band 3 400-4 200 MHz is allocated to fixed satellite service on a primary basis. This band will continue to be used extensively for FSS in the future and broadband wireless access systems will not be allowed in this band.

In India, the band 3700-4200 MHz is used extensively for FSS for a number of applications. Hence spectrum for WiMAX technology will only be available in parts of the band 3300 – 3700 MHz (yet to be identified).

Some typical deployments of a variety of C-band earth stations are described in §9.2.

6. SPACE-TO-EARTH SHARING ISSUES

6.1. Potential interference from satellites to WiMAX systems in the 2.3 – 2.7 GHz Band

ITU-R Joint Task Group 6-8-9 is dealing with WRC-07 Agenda Item 1.9[22] to address whether any tightening of the mandatory power flux density limits[23] in Article 21 of the ITU Radio Regulations for the band 2500-2690 MHz is required in order to protect terrestrial wireless access systems (including WiMAX) from satellite interference. Figure 10 shows the current Article 21 limits together with the full range of tightened masks that have been proposed. The group completed its final meeting in July 2006 without consensus and these proposals will be debated further at the Conference Preparatory Meeting in February 2007 and the World Radiocommunications Conference in the autumn of that year (WRC-07). The current state-of-play in the ITU is that a suitable compromise may be close to the levels proposed by CEPT, USA, Australia and New Zealand.

The WiMAX Forum is of the view that tighter power flux density limits than those currently in Article 21 of the Radio Regulations are necessary to safeguard terrestrial interests from interference.

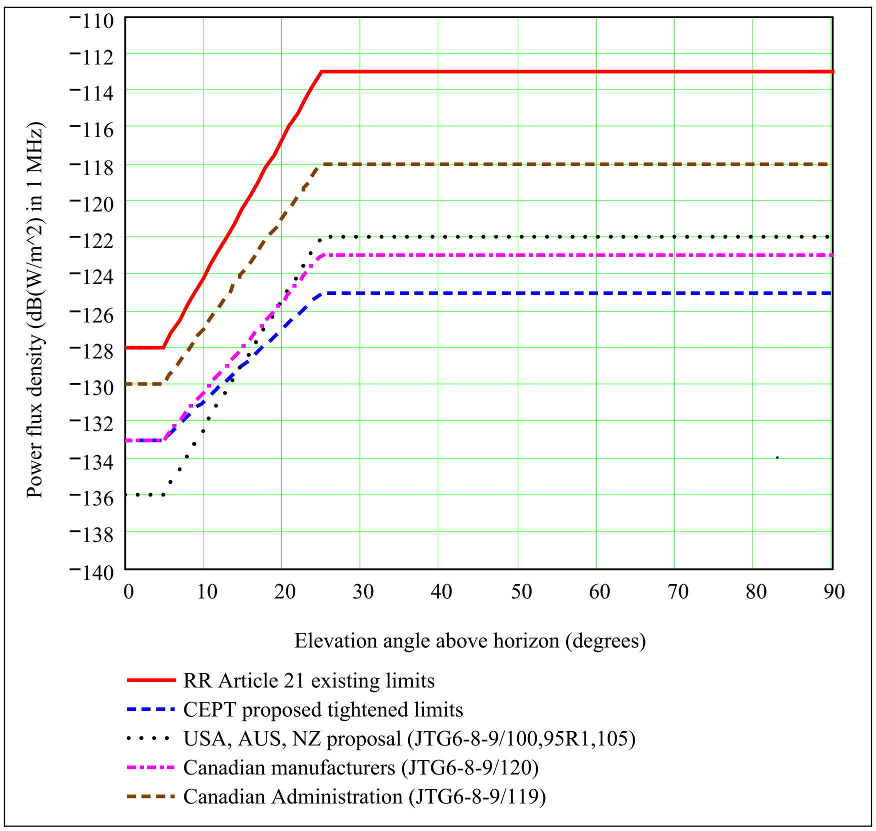

Figure 10. Range of proposals for tightening power flux density limits on the Earth's surface from geostationary satellites in the 2.5-2.69 GHz band

[22] WRC-07 Agenda Item 1.9: *To review the technical, operational and regulatory provisions applicable to the use of the band 2500-2690 MHz by space services in order to facilitate sharing with current and future terrestrial services without placing undue constraint on the services to which the band is allocated.*

[23] The limit relates to the power flux-density which would be obtained under assumed free-space propagation conditions and applies to emissions by a space station of the service indicated where the frequency bands are shared with equal rights with the fixed or mobile service, unless otherwise stated in footnotes to the ITU Radio Regulations.

6.2. Potential interference from FSS satellites to WiMAX systems in the 3.4 – 3.8 GHz Band

The power flux-density (pfd) limits for an FSS satellite operating in the band 3.4-3.8 GHz are given in Article 21 of the ITU Radio Regulations and the pfd limits for geostationary FSS satellites are shown in graphical form in Figure 11.

The interference-to-noise ratio (I/N) at the input to the base station receiver arising from a given pfd is calculated, for each satellite, by applying the following equation:-

$$\frac{I}{N} = pfd(\delta) \; + \; Gr(\theta,\phi) \; + \; 10\log\left(\frac{\lambda^2}{4\pi}\right) \; - FL \; - \; N \quad \text{dB} \qquad (1)$$

where:

pfd(δ): power flux density at surface of the Earth for angle of arrival, δ, above the horizontal plane in dB(W.m^{-2}) in reference bandwidth of 4 kHz;

Gr(θ,φ): base station sector antenna receive gain in direction of satellite (at off-axis angles θ,φ in elevation and azimuth plane, respectively);

λ: wavelength (metres);

FL: Feeder loss (dB);

N: Receiver noise in 4 kHz reference bandwidth (dBW).

As an example of the calculation, Table 4 shows the straightforward case of the derivation of the I/N due to a satellite positioned at an elevation angle of 0^{o} such that it lies at the beam centre of the base station sector antenna, i.e. where the base station antenna gain is at a maximum. The WiMAX base station system parameters are taken from Table 2. The frequency used is 3.6 GHz.

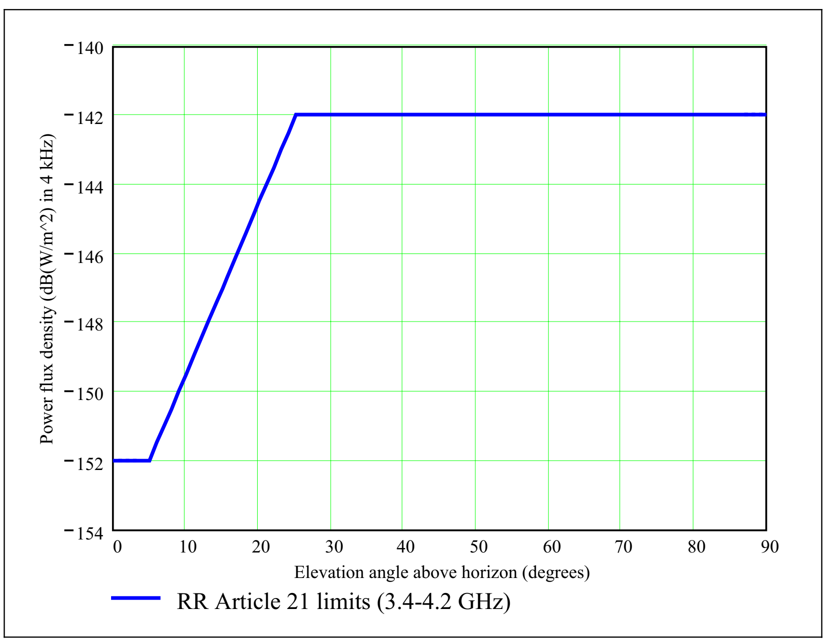

Figure 11. Power flux density limits on the Earth's surface from geostationary satellites in the 3.4-4.2 GHz band according to Article 21 of the ITU Radio Regulations

Table 4

Example of Interference calculation from a single GSO FSS satellite into a WiMAX base station receiver

Frequency: 3.6 GHz

Parameter	Value
Satellite power flux density in 4 kHz reference bandwidth (dBW/m^2) for base station antenna with 0^o downtilt	-152
WiMAX receiving base station maximum antenna gain (dBi)	17
Receiver feeder loss (dB)	1
10 log$(\lambda^2/4\pi)$ factor (dB)	-32.6
Interference in 4 kHz reference bandwidth (dBW)	-168.6
Noise figure (dB)	5
Receiver noise in 4 kHz reference bandwidth (dBW)	-163
I/N ratio (dB)	**-5.6**

The I/N of –5.6 dB arising from a single satellite located at beam centre would have the effect of degrading the carrier-to-noise ratio of the WiMAX link by about 1 dB.

In practice, some benefit from polarisation isolation may be achievable under certain situations but this would have to be assessed on a case-by-case basis. If the FSS space station uses a single circular polarisation (left-hand circular or right-hand circular polarisation), up to 3 dB reduction in interference can be expected when the WiMAX system uses linearly polarised signals. If the FSS space station uses linear polarisation, the isolation will depend on the angle between the polarisation of the FSS downlink emission at the WiMAX receiver location and the polarisation alignment of the WiMAX base station antenna. However, many satellites in this band use transmissions on both (orthogonal) polarisations to increase the spectrum efficiency. The calculations included here may therefore be considered as worst-case, and give an indication of the maximum interference from a single FSS satellite that the WiMAX operator should anticipate.

There is the possibility that satellites close to the horizon may be obstructed by local clutter. However, what is under study here is intended to represent the case where a base station antenna is mounted high enough to provide good radio coverage with minimal blockage.

The worst case situation is likely to occur when several geostationary satellites are close to the boresight direction of the WiMAX base station sector antenna and all are operating co-channel with the WiMAX system.

As an example, Figure 12 shows the FSS geostationary satellites close to the horizon for a WiMAX base station located at 54.6°N, 5.92°W with an azimuth pointing direction of 100° East of True North and elevation angle 0°. This is as viewed from the centre of the base station antenna looking towards the geostationary orbit. The six satellites shown all operate in the top 100 MHz of interest here (3700-3800 MHz) and some operate down to 3625 MHz. Others operating elsewhere in the 3.4-4.2 GHz band are not shown. The ellipse indicates the half-power beamwidth of the base station sector antenna which covers a 90 degree azimuth sector. Here, the downtilt of the base station sector antenna is set at 0° (the effect of beam downtilt is investigated further below).

The vertical pattern is derived from Recommendation ITU-R F.1336-1[24] using the base station maximum antenna gain of 17 dBi. Figure 13 shows the off-axis gain response of the base station sector antenna in the vertical plane. The wide-angle main-beam pattern in the azimuthal plane is not defined in Rec. F.1336-1 and has not been considered here due to its much slower roll-off with off-axis angle. Note that, in this example, all the satellites lie on the main beam of the antenna in both planes (i.e not the sidelobe envelope).

ITU-R WP4A have indicated in a liaison statement to WP8F (June 2006)[25] that, although many existing C-band FSS down-link carriers operate at EIRP spectral densities substantially below the values given in Figure 11, especially carriers received by large-dish earth stations, some approach them closely for operational reasons – e.g. telemetry carriers, MSS feeder down-link carriers, tracking beacons, etc. and there is a trend towards reception by smaller and smaller antennas on the ground which is driving the average level upwards. WP4A surveyed the ITU BR's SNS database and this revealed that the average spacing between co-frequency C-band satellites with overlapping coverages is of the order of 3 degrees (nearer 2 degrees in ITU-R Region 2 – the Americas), but the majority of the carriers involved do not operate at the maximum permitted EIRP density. Realistically therefore, it was concluded that interference from FSS space stations into WiMAX systems should be based simply on one GSO satellite every 10 degrees of longitude operating at the maximum permitted level.

In the example shown in Figure 12, this leads to a revised arrangement of equivalent satellites radiating at the full pfd level and this is shown in Figure 14. The values of maximum pfd and off-axis gain values have then been calculated for the indicated satellites (these are the main contributors affecting the level of interference) and then the contributions from each satellite summed, assuming each contributes the maximum pfd at the surface of the Earth at its elevation angle as viewed from the WiMAX base station.

The aggregate interference from all the satellites shown in Figure 14 leads to an aggregate I/N of – 4.5 dB compared with – 5.6 dB for the case of the single satellite at boresight as calculated in Table 4.

Other ameliorating factors have been considered: one such factor is the effect of base station antenna beam downtilt on the aggregate I/N into the base station receiver as some degree of downtilt will be usual. Figure 15 shows the effect of base station antenna downtilt on the aggregate I/N for the example set of satellites used in the above analysis. Clearly this does partially alleviate the interference and for an average downtilt angle of 2 degrees (see Table 2), the calculated I/N of about –5.8 dB corresponds to a degradation in wanted carrier-to-noise ratio in the WiMAX system of approximately 1 dB.

Apart from the likelihood that not all satellites will give rise to the maximum pfd co-channel due to varying transponder configurations, further improvement would come with the use of steerable beams by the WiMAX systems.

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[24] ITU-R Recommendation F.1336-1. *Reference radiation patterns of omni-directional, sectoral and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from 1GHz to about 70GHz*, ITU-R WP9D, Geneva, 2000

[25] ITU-R Working Party 4A Rapporteur Group on IMT-Advanced sharing with FSS: "*Frequency related matters for IMT-2000 and systems beyond IMT-2000 related to WRC-07 Agenda Item 1.4*"; Liaison statement to WP8F, 8F/901, 5th July 2006

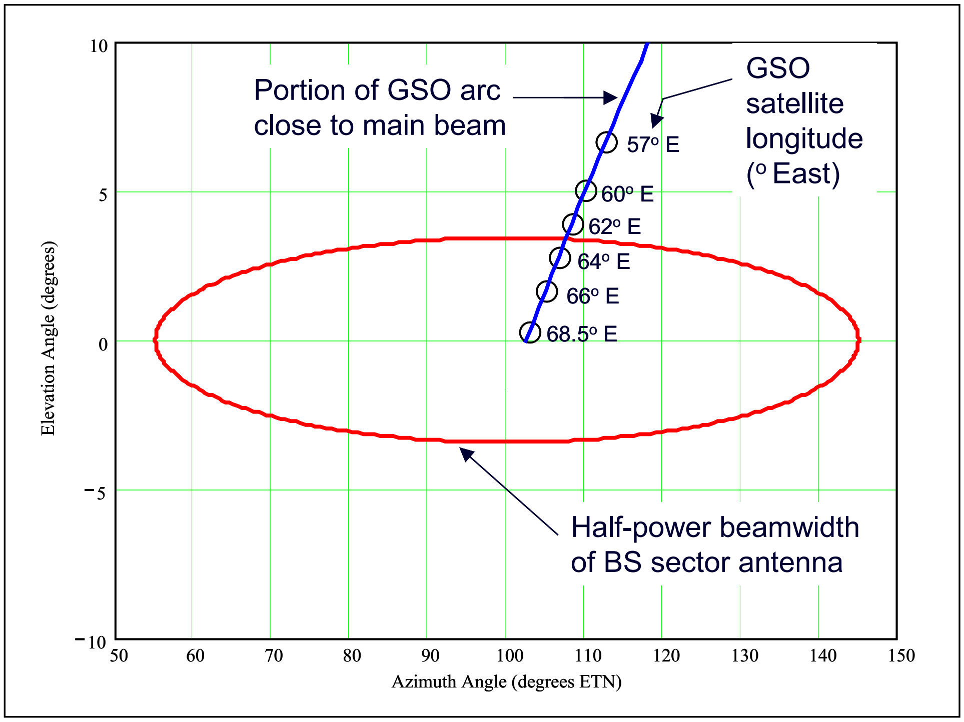

Figure 12. Location of satellites in geostationary orbit close to pointing direction of WiMAX base station antenna beam

(as viewed from the centre of the base station antenna beam looking towards the GSO)

Source: Rec. ITU-R F.1336-1
Base station latitude = 54° 36' North
Base station longitude = 5° 55' West
Base station pointing direction = 100° East of True North
Antenna beam downtilt = 0 degrees
Antenna beam sector azimuth coverage = 90 degrees
Half-power beamwidth of BS sector (elevation plane) = 6.9 degrees

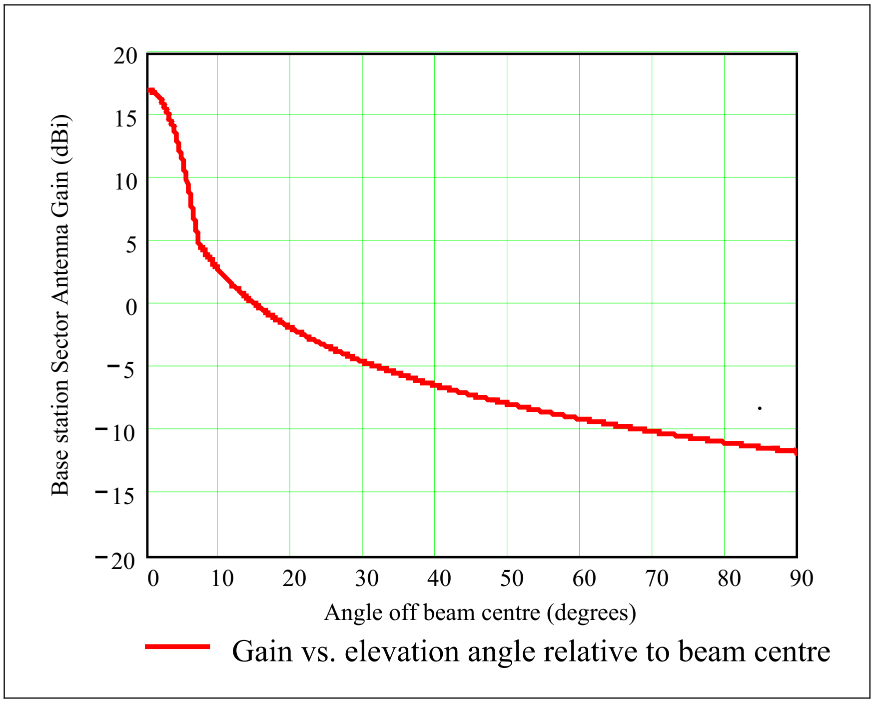

Figure 13. WiMAX Base station sector antenna pattern envelope in elevation plane

Source: Rec. ITU-R F.1336-1
Frequency = 3.6 GHz
Antenna gain at beam centre = 17 dBi
Antenna beam sector coverage = 90 degrees
Value of 'k' = 0.0 (from *recommends* **2.1.2** of Rec. ITU-R F.1336-1)

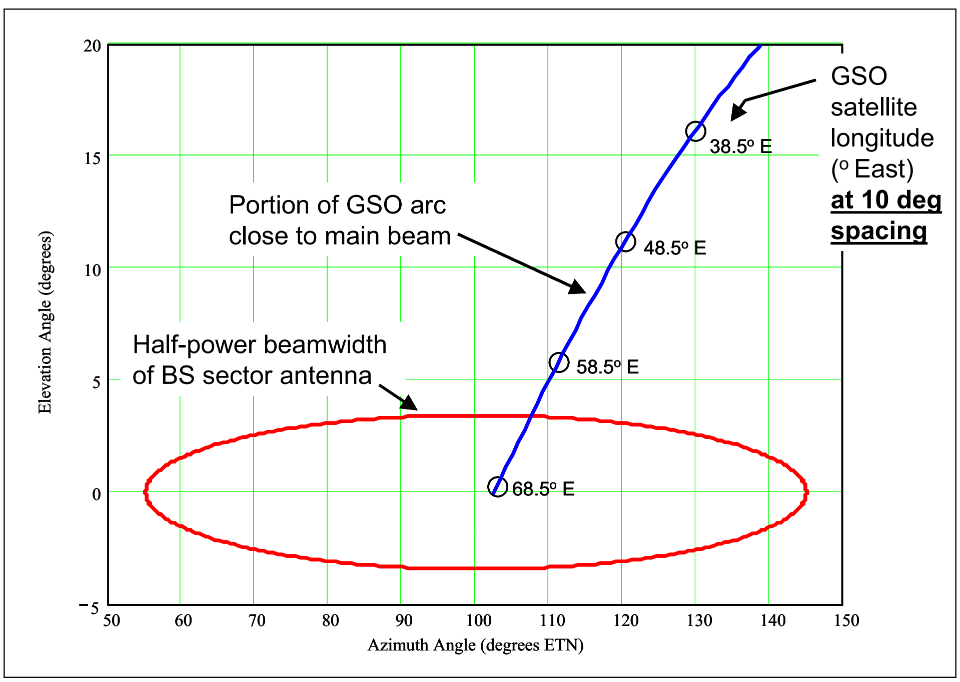

Figure 14. Location of 10-degree spaced satellites in geostationary orbit close to pointing direction of WiMAX base station antenna beam (from Figure 12)

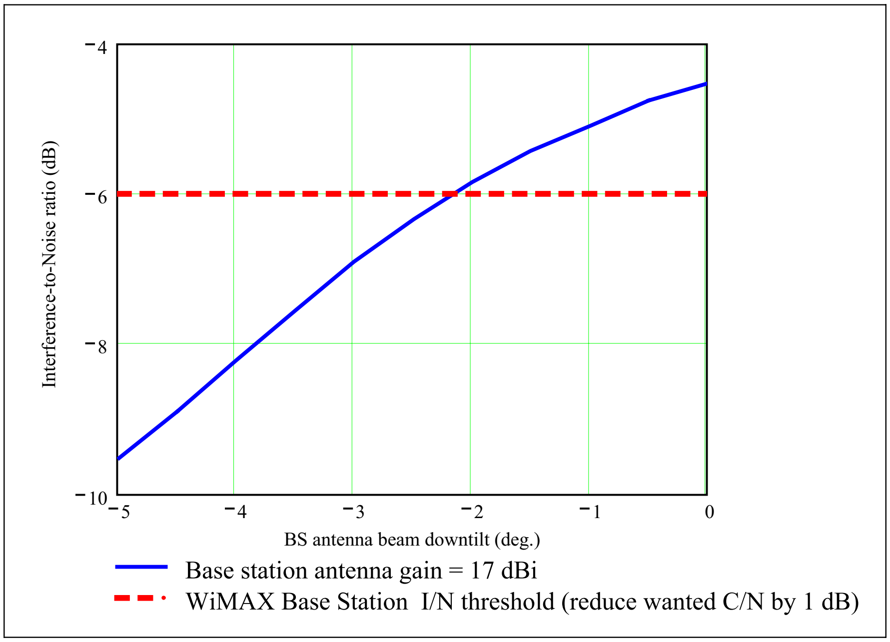

Figure 15. Effect of WiMAX base station antenna downtilt on the aggregate Interference-to-Noise ratio (I/N) due to emissions from GSO satellites close to main beam of WiMAX BS sector antenna (as shown in Figure 14)

Base station latitude = 54° 36' North
Base station longitude = 5° 55' West
Base station pointing direction = 100° East of True North

7. SUMMARY OF COORDINATION PROCEDURES, REGULATIONS & GUIDELINES (EXISTING AND PROPOSED) FOR TERRESTRIAL SHARING

All of the procedures in this section are for the case where the earth station locations are known and are used here for the case of **co-frequency** sharing. This section focuses on the 3.4 – 3.8 GHz band as co-frequency or co-channel sharing is unlikely to be feasible in the same geographic area in the 2.3-2.7 GHz band due to the characteristics of the antennas used for both services. Out-of-band and adjacent channel cases are dealt with in the next section.

Only base station transmitters are considered to represent the worst-case of interference and user terminals do not need to be considered. WiMAX technology user terminals are generally more benign than the base stations due to:

- User terminals operate at lower e.i.r.p.
- User terminals are generally lower in height above ground than base stations.
- User terminals are active for a lower percentage of time than base stations.
- Terminal stations may benefit from additional clutter loss, particularly in urban and suburban areas.

Hence, where coordination is an appropriate means of enabling co-existence, it may be feasible to coordinate terminal stations through coordination of the central station only assuming that central stations operate in the same frequency as terminal stations.

7.1. ITU Appendix 7 of the Radio Regulations

Appendix 7 of the ITU Radio Regulations provides a procedure for the determination of the *coordination area*[26] around a transmitting or receiving earth station that is sharing spectrum in frequency bands between 100 MHz and 105 GHz with terrestrial radiocommunication services. This procedure is usually carried out for large earth stations sharing the frequency band with terrestrial users and requiring protection from neighbouring countries. The procedure can be applied to ubiquitously deployed earth stations by means of a coordination contour around the "service area" in which the terminals operate.

For a receiving earth station (as is the case for the 3.4-3.8 GHz band example described here), the coordination area represents the area surrounding the earth station sharing the same frequency band with terrestrial stations within which the permissible level of interference may be exceeded and hence coordination is required. The coordination area is determined on the basis of known characteristics for the coordinating earth station and on conservative assumptions for the propagation path and for the system parameters for the "unknown" terrestrial stations (given in Table 8 of Appendix 7) that are sharing the same frequency band.

The procedure allows the determination of a distance in all azimuthal directions around the receiving earth station beyond which the predicted path loss would be expected to exceed a specified value for all but a specified percentage of the time. This distance is called the *coordination distance*. When the coordination distance is determined for each azimuth around the coordinating earth station it defines a distance contour, called the *coordination contour*, that encloses the coordination area.

It is important to note that, although the determination of the coordination area is based on technical criteria, it represents a regulatory concept. Its purpose is to identify the area within which detailed evaluations of the interference potential need to be performed in order to determine whether the coordinating earth station or any of the terrestrial stations, or in the case of a bidirectional allocation any of the receiving earth stations that are sharing the same frequency band, will experience unacceptable levels of interference. Hence, the coordination area is not an exclusion zone within which the sharing of frequencies between the earth station and terrestrial stations or other earth stations is prohibited, but a means for determining the area within which more detailed calculations need to be performed. In most cases a more detailed analysis will show that sharing within the coordination area is possible since the procedure for the determination of the coordination area is based on unfavourable assumptions with regard to the interference potential.

As an illustrative example, Figure 16 shows the coordination area around Burum Earth station in the Netherlands in the band 3.6-3.8 GHz. The terrestrial system chosen in this case is a BWA system with a maximum e.i.r.p. of 14 dB(W/MHz) which is the current upper limit for FWA systems in the UK in this band. Other parameters are taken from Table 8b of Appendix 7. The UK administration (Ofcom) is required by international treaty to protect this and all overseas earth stations from interference that may arise due to transmissions from such networks if the UK transmitters of the BWA network fall within the coordination area shown by the black line in the picture. As explained above, the presence of a BWA system within the coordination area does not imply that operation is impossible, merely that, having identified WiMAX base stations that could give rise to interference, more detailed bi-lateral coordination then follows to find a means of enabling sharing to take place.

In this example, the coordination area is determined largely by the "Mode 1" anomalous propagation mechanisms (ducting etc.) which enable the interfering signals to propagate well beyond the horizon, particularly over-water paths.

The coloured inner contours show the reduced area for a tightened e.i.r.p. The need to not coordinate at all with the UK only occurs when the e.i.r.p. is reduced by between 15 dB and 20 dB.

[26] Terms in *italics* are defined in Article 1 of the ITU Radio Regulations

An obvious mitigation technique could be to restrict the pointing of the base station sector antennas in the direction of the known earth stations (see §9).

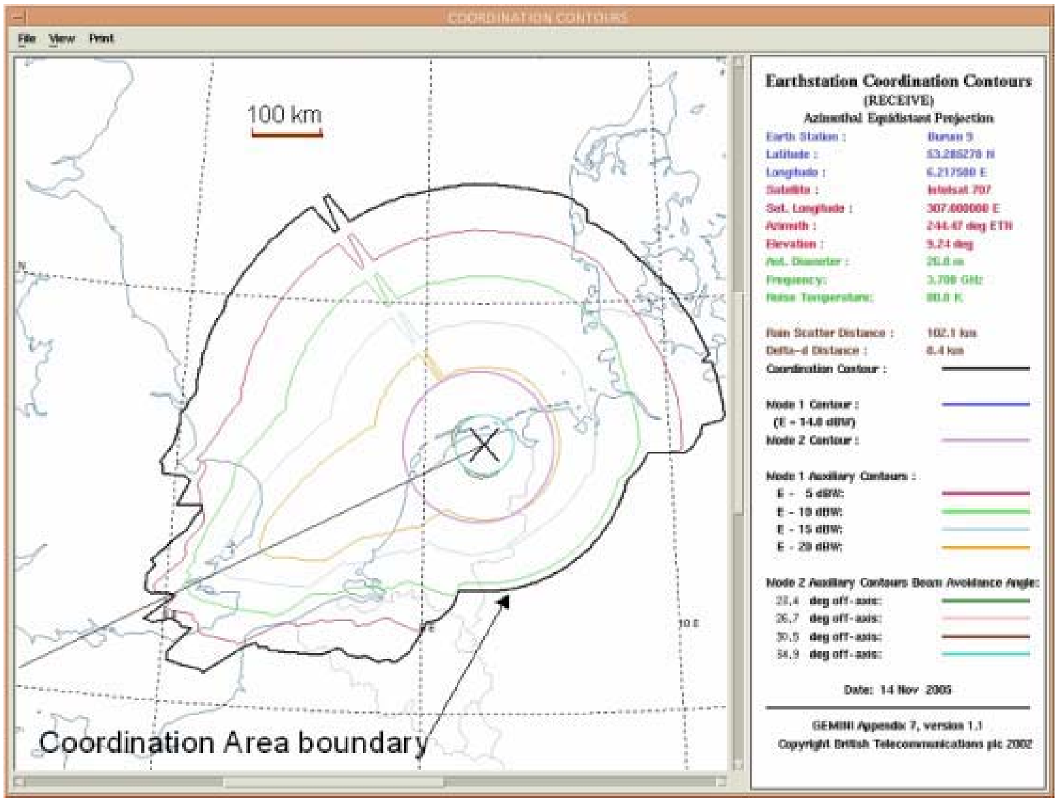

Figure 16. Coordination Area around Burum Earth station, Netherlands, for sharing with WiMAX systems in the 3.6 – 3.8 GHz band

Notes:
1) Outer black line is for WiMAX e.i.r.p. of 14 dB(W/MHz) which is UK upper limit in this band
2) As an idea of scale, the purple rain scatter circle ("Mode 2") is a radius of about 100 km.
3) Coordination with countries other than the UK would depend on the e.i.r.p. of the BWA systems in the countries concerned

7.2. Recommendation ITU-R SF.1486 (VSATs sharing with Fixed Wireless Access 3.4-3.7 GHz)

Ubiquitously deployed earth station terminals operating in the Fixed Satellite Service such as VSAT terminals tend to be deployed in "exclusive" bands where national administrations have taken steps to not deploy terrestrial networks[27]. Recommendation ITU-R SF.1486[28] provides a means of assessing the separation distance between in-band, co-channel FWA customer terminal stations (TS) with directional antennas and VSAT earth station terminals in a dense urban area. The FWA system considered is a specific narrow-band (307 kHz channel bandwidth) point-to-multipoint system. The VSAT system considered is for a carrier-to-interference ratio pertaining to a particular

[27] e.g. in the UK, the bands 14-14.25 GHz and 12.5-12.75 GHz are "satellite exclusive" bands

[28] ITU-R Recommendation SF.1486: *Sharing Methodology between Fixed Wireless Access Systems in the Fixed Service and Very Small Aperture Terminals in the Fixed-Satellite Service in the 3400-3700 MHz band*, ITU-R WP4-9S, Geneva, 2000

service and cannot be generally applied to all types of FSS service. Covering separation distances of up to a few tens of kilometres, it makes use of a free-space loss model with clutter at the TS end and varying amounts of shielding at the VSAT end (up to 40 dB). Importantly, the Earth's curvature is not included, so the larger separation distances that have been calculated (up to 90 km depending on the azimuthal separation angle between the TS and the VSAT) are questionable. Also, the central station (i.e. base station), CS is not considered. The assumption of shielding around the VSAT terminal of 20-40 dB is somewhat optimistic as the effects of shielding in urban areas tends to be diminished by scattering and reflection in the three-dimensional environment.

Mitigation techniques to facilitate co-frequency sharing provided in the recommendation are described as follows (note that these are specific to outdoor-mounted FWA terminal station antennas):

- VSATs, wherever possible, should be sited so as to maximize shielding from possible FWA interferers;
- VSATs and P-MP FWA stations should not be sited higher than is necessary for the application;
- where practicable, FWA TSs should generally be sited such as to reduce rear radiation, for example by mounting against walls, below roof lines, etc. and by avoiding reflections back in the direction of the VSAT;
- when deploying such FS and FSS systems, economical use should be made of available terrain, i.e. depressions, natural screening to increase obstructive/diffraction losses;
- if no natural screening exists use should be made of artificial obstructions such as judicious siting of systems amongst buildings, etc.;
- in some cases it may be possible to tailor the pattern of the VSAT antenna feeds to provide greater interference rejection;
- advantage may be taken in some cases by use of more directional FWA TS or CS antennas

Some of these techniques are considered in a later section on mitigation techniques (§9). Note that most of the techniques require knowledge of the location of both the FWA terminals and the VSAT terminals and this information may not be available in many countries.

As this is the only ITU Recommendation on sharing between wireless access services and satellite earth stations, many papers into recent ITU-R meetings (e.g. WP8F) have made use of it and attempted to apply it more widely (e.g. for mobile wireless access).

7.3. USA: FCC's Broadband Wireless Access allocation in 3650-3700 MHz band

In March 2004, the Federal Communications Commission published a Report and Order providing the basis on which the band 3650-3700 MHz[29] would be used by terrestrial wireless broadband access systems in the USA. This was introduced to allow adjacent band sharing with the domestic satellite networks in the band 3700-4200 MHz and grandfathered main international (inter-continental) fixed satellite earth stations at 86 sites and receiving within the same band as the wireless access networks.

The main features are:-

- BWA base stations and fixed terminals limited to a maximum e.i.r.p. of 25 Watts (in 25 MHz bandwidth) but power density cannot exceed 1 Watt/MHz.
- Mobile devices are limited to a peak e.i.r.p. of 1 Watt (in 25 MHz); maximum of 40 mW per MHz. Mobile and portable stations may only operate if they can positively receive and decode an enabling signal transmitted by a base station. This then permits mobile – mobile communications.

[29] FCC 05-56: *Report & Order and Memo & Order for Wireless Access Systems in the USA in the band 3650-3700 MHz,* USA, March 2005, (http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-05-56A1.pdf)

- Protection zones of 150 km around 86 international earth stations receiving in the 3650-3700 band (as well as the 2700-4200 MHz band); BWA operation within this is possible but by coordination with the earth station operator.
- Protection zones of 80 km around three radar (Radiolocation) sites operating in 3650-3700 MHz.
- Base station pointing constraints close to borders with Mexico and Canada.
- Licensing of both base stations and fixed subscriber terminals required
- Out-of-band emissions must be attenuated below transmitting power (P) by a factor at least 43 + 10 log(P) dBc where 'P' is the mean power in Watts supplied to the transmission line of the antenna.

The 86 existing earth stations sharing the band 3650-3700 MHz with the wireless access networks would be "grandfathered" and would have up to 150 km radius "protection" zones within which detailed coordination would have to be undertaken to permit wireless access systems to operate. Figure 17 is extracted from the Order and shows the earth stations where this procedure needs to be followed. These are not exclusion zones, merely where more detailed coordination must take place.

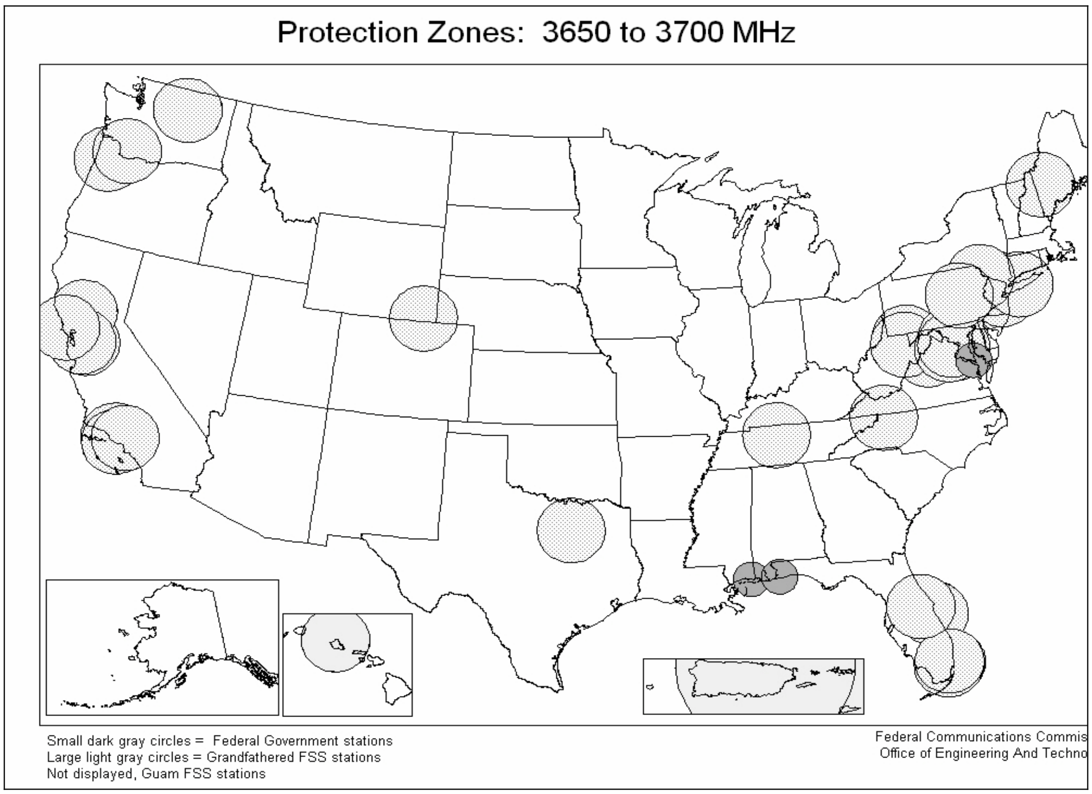

Figure 17. Protection Zones for Wireless Broadband Access Systems around USA FSS international gateway earth stations in the band 3650-3700 MHz

(Larger zone diameter ~300 km)

For the protection of earth station services operating in the adjacent band 3700-4200 MHz (where there is widespread deployment of earth station terminals), the Satellite Industry Association (SIA) and other organisations have submitted a petition[30] to the FCC demanding better protection for their services. The SIA's concerns relate to out-of-band emissions and possible saturation of the

[30] Satellite Industry Association submission to FCC: *Petition for partial reconsideration of the Satellite Industry Association on Wireless Access Systems in the USA in the band 3650-3700 MHz,* 10th June 2005.

wideband low noise amplifiers. As an example they state that the spurious and out-of-band emission limits using Appendix 3 of the ITU Radio Regulations (as decided by the FCC) are inadequate to protect the satellite services in the band above 3700 MHz and requested that these be tightened by almost 30 dB to 71.25 + 10 log(P) dBc[31] where *P* is the mean power in Watts supplied to the antenna.

The issues of adjacent band sharing are considered further in §7.5.

7.4. UK: Ofcom's Coordination Procedure for FWA sharing with FSS earth stations in the 3.6-4.2 GHz band

The 3.6-4.2 GHz band has been used in the UK by both receiving satellite earth stations (in the Fixed Satellite Service) and the Fixed Service for many years. In the last few years, the UK administration, Ofcom, has opened up the lower part of the band for point-to-multipoint Fixed Wireless Access (FWA) services using 3605-3689 MHz and a corresponding 'return' channel (for FDD) in the upper part of the band (3925-4009 MHz). This was achieved by tri-partite negotiation between existing earth station operators, the new FWA service providers and the UK regulator to ensure that the existing earth station services were able to be protected against interference. All FWA networks have to be coordinated with earth station operation. To help achieve successful co-existence, e.i.r.p. restrictions and other constraints have been placed on the FWA systems (usually 3 dBW/MHz but 14 dBW/MHz is allowed under certain circumstances). FWA operation is currently restricted to particular geographical areas.

Ofcom is currently revising a procedure[32] which describes the co-ordination process and criteria developed to facilitate the co-existence of Point-to-Multipoint fixed wireless access systems operating in the 3.6-4.2 GHz band with receiving satellite earth stations operating in the Fixed Satellite Service (space-to-Earth) within the UK.

Using this procedure, the results in this section are presented in the form of maps of the UK showing areas where WiMAX base stations could give rise to excessive interference into two such incumbent earth stations in the band 3625-3800 MHz (in fact the results are applicable up to 4200 MHz). For TDD operation, this scenario should cover the case of interference from customer terminals since the WiMAX uplink terminals will be located lower in height and use lower e.i.r.p.

For two examples of UK earth stations, the maps show the area around the receiving earth station within which a WiMAX base station could give rise to unacceptably high interference levels into the earth station receiver *assuming co-channel operation*. The analysis uses the propagation model in Recommendation ITU-R P.452[33] to evaluate the interference level at the earth station receiver input taking into account the terrain features, earth station antenna pattern etc. Interference levels are calculated for both long-term and short-term time percentages and any locations where a WiMAX base station would cause the earth station's interference protection limits to be exceeded can then be shown as shaded areas on the maps. Outside these "protection zones", interference is unlikely to occur. Within the zones, further mitigation techniques can be employed to facilitate sharing.

Only the Rec. 452 diffraction, multipath, ducting and troposcatter propagation models are considered. Rain scatter is not included in this analysis but may need to be considered when addressing short-term interference occurring via beam coupling.

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[31] dBc: *Decibels relative to the unmodulated carrier power of the emission. For carriers using digital modulation, the reference level equivalent to dBc is dB relative to the mean power, P.*

[32] Ofcom (UK): *Information Sheet describing the co-ordination process between Point-to-MultiPoint Systems, Point-to-Point Links, and Earth Stations in the Fixed Satellite Service, operating in the band 3.6 to 4.2 GHz*, UK OFW188, Sept 2004

[33] Recommendation ITU-R P.452-12. *Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above 0.7 GHz,* ITU-R WP3M, Geneva, 2005

Figure 18a indicates the area where WiMAX base stations with system characteristics as specified in Table 2 (frequency 3.7 GHz) could cause excessively high interference into an *inland* earth station on a long-term basis. For simplicity, the base station coverage is assumed to be omni-directional (achieved with sectoral antennas in practice) and hence the assumption that the maximum e.i.r.p. is always directed towards the earth station. The size of the protection zone is strongly influenced by two particular factors: a) the earth station in this case being in a rural location surrounded by hills and hence in a fairly sheltered location (in terms of interference); and b) there is no main beam coupling between the source and victim antennas. The larger red shaded areas are the locations where WiMAX base stations operating with a maximum e.i.r.p. of 14 dBW/MHz could cause the interference threshold in the earth station receiver to be exceeded, **if no other mitigation technique is employed**[34]. The smaller, yellow areas indicate the reduced size of the protection zone if the lower e.i.r.p. of 3 dBW/MHz is applied to the WiMAX base station transmissions.

It can be seen that the interference can be caused as far away as 60 km or so, depending on the intervening terrain and the height of the ground where the WiMAX base station is located.

Note that the effects of local clutter (trees, buildings etc.) along the path have not been included in the propagation calculations. These would be considered in detailed bi-lateral coordination. Indeed such features can be usefully exploited for WiMAX systems deployment.

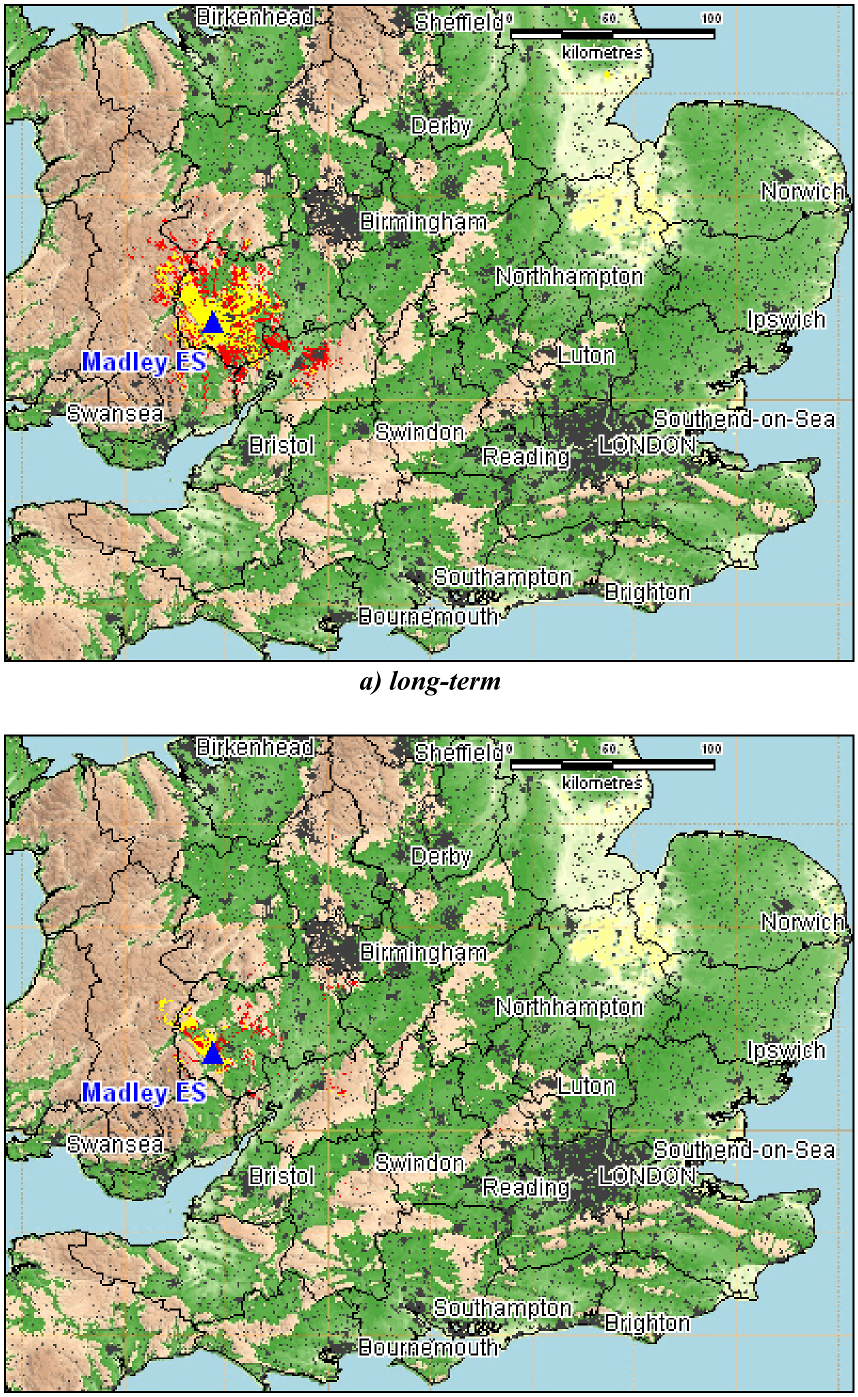
The long-term interference case represents "normal" weather conditions. However, as explained in §4.1, there are certain "anomalous" propagation conditions that can give rise to interfering signals travelling much further than normal. Figure 18b provides the results for the short-term case where anomalous propagation conditions occur – in this case the interference can be caused from WiMAX base stations located at greater ranges (> 200 km) from the earth station.

A contrasting case is shown in Figure 19. Here the earth station is located in flat, low-lying land near the coast. This leaves the earth station much more exposed and the interference protection zone is considerably larger, especially along over-water paths and particularly so for the short-term time percentage.

Note that in the case of short-term interference where the protection area is somewhat extended, we are looking at the **worst case** situation. Not all earth stations will have such stringent interference criteria for short time percentages, only those with very high availability targets.

Of course, these examples are just two such earth stations and there are several other such sites in the UK which will all need to be carefully coordinated with. Some sites are extensive in size and have large antennas pointing over a wide sector of the geostationary orbital arc. Hence certain mitigation techniques such as site shielding are not likely to prove beneficial in practice (see §9 on mitigation techniques).

[34] see §9

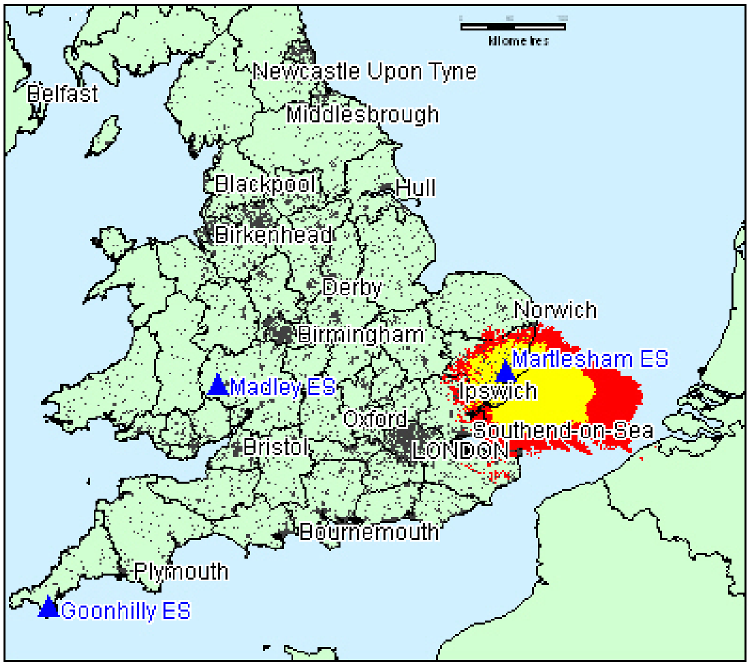


a) long-term

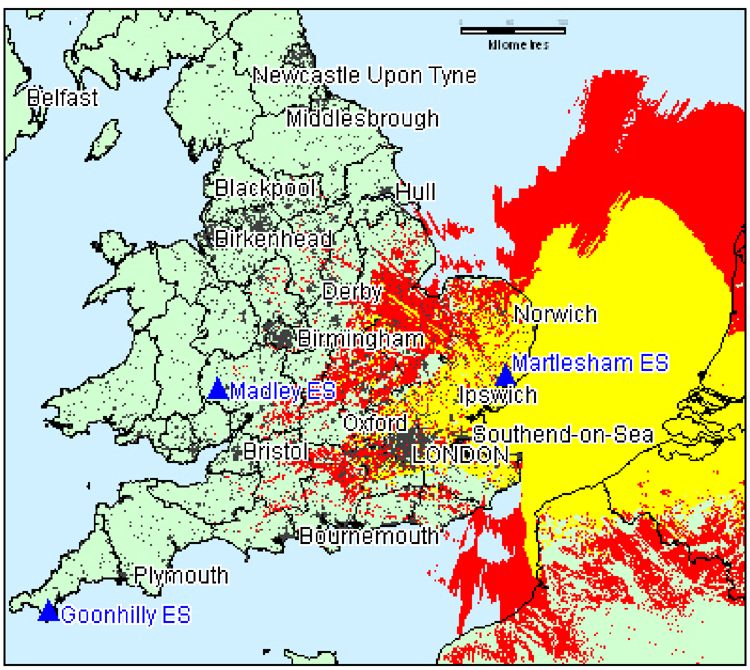
b) short-term

Figure 18. Areas where WiMAX base stations could cause the tolerable interference levels of a typical UK <u>inland</u> earth station to be exceeded

Notes: 1) frequency: 3.7 GHz
2) red area is for base station e.i.r.p. of 14 dBW/MHz
3) yellow area is for base station e.i.r.p. of 3 dBW/MHz
4) black shading represents built-up areas
5) time percentage: a) long-term (20% of average year); b) short-term (0.005% of average year)
6) assumed that base station antenna points towards earth station



a) long-term



b) short-term

Figure 19. Areas where WiMAX base stations could cause the tolerable interference levels of a typical UK coastal earth station to be exceeded

Notes:
1) frequency: 3.7 GHz
2) red and yellow areas are for base station e.i.r.p. of 14 dBW/MHz and 3 dBW/MHz respectively
3) black shading represents built-up areas
4) time percentage: a) long-term (20% of average year); b) short-term (0.005% of year)
5) assumed that base station antenna points towards earth station

7.5. CEPT ECC Report on Inter-service sharing with Broadband Wireless Access systems in the 3.4-3.8 GHz band

CEPT Project Team SE19 have recently completed ECC Report 100 on sharing[35] and arrived at the following conclusions arising from the compatibility studies between BWA and FSS:-

- In assessing the impact from BWA into FSS Earth Station, the studies in the ECC Report made use of the determination of a *mitigation zone or area*[36] which is defined as the geographical area delimited by the distance on a given azimuth and elevation from an earth station, sharing the same frequency band with terrestrial stations, within which there is a potential for the level of permissible interference to be exceeded and coordination is necessary to ensure successful operation between terrestrial stations and earth stations.
- The required mitigation distances with respect to FSS Earth stations naturally depend on the type and characteristics of the BWA station. Some examples of mitigation distances are provided based on generic calculations without terrain model and also for some realistic cases of FSS Earth Stations with consideration of terrain model.
- BWA operation at distances shorter than the required mitigation distance is often feasible due to the benefits gained from using actual terrain topography and clutter database information in propagation loss calculations.
- Operation of BWA central stations may be feasible within the mitigation zone, based on a detailed, case-by-case evaluation.
- BWA terminal stations are generally less impacting than the central stations. In addition, it is demonstrated that the coordination of the BWA base station will generally be sufficient to ensure the coexistence with BWA terminal stations. Furthermore, terminal stations may benefit from the additional clutter loss which is available in some environments, particularly urban environments.
- Studies show that ubiquitously deployed BWA systems and FSS, when the FSS is deployed in a ubiquitous manner and/or with no individual licensing of earth stations, cannot share in the same geographical area since no minimum separation can be guaranteed.
- In the case of BWA operating in adjacent frequency bands, there is a need for mitigation distance to avoid the low noise amplifiers of the satellite receivers being driven into non-linear operation, or even being saturated.
- Interference from FSS spacecraft transmitting with Article 21 limits into BWA may exceed the required interference criterion by few dB in few cases, however the probability of such cases is expected to be low.

8. OTHER EARTH STATION SHARING ISSUES

The previous section dealt with co-channel sharing between WiMAX services and earth stations for the situation where coordination between the two services is feasible. This section provides information about sharing between WiMAX systems and earth stations when not operating in a co-channel situation, i.e. the effect of out-of-band emissions and possible saturation of earth station low noise amplifiers from WiMAX systems. This requires consideration in countries where C-band earth stations are ubiquitously deployed and are unregistered, making coordination more difficult.

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[35] ECC Report 100. *Compatibility studies in the band 3400- 3800 MHz between Broadband Wireless Access (BWA) systems and other services,* CEPT ECC, 2007

[36] Existing provisions of the Radio Regulations relating to international coordination are unaffected by this definition, which is intended for national coordination purposes.

8.1. Spurious & Out-of-Band Emissions

Appendix 3 of the ITU Radio Regulations provides limits on spurious emissions for protection of services operating in adjacent bands. Figure 20 illustrates the way in which spurious emissions are defined for the case of a WiMAX emission operating close (in frequency) to a satellite receive carrier.

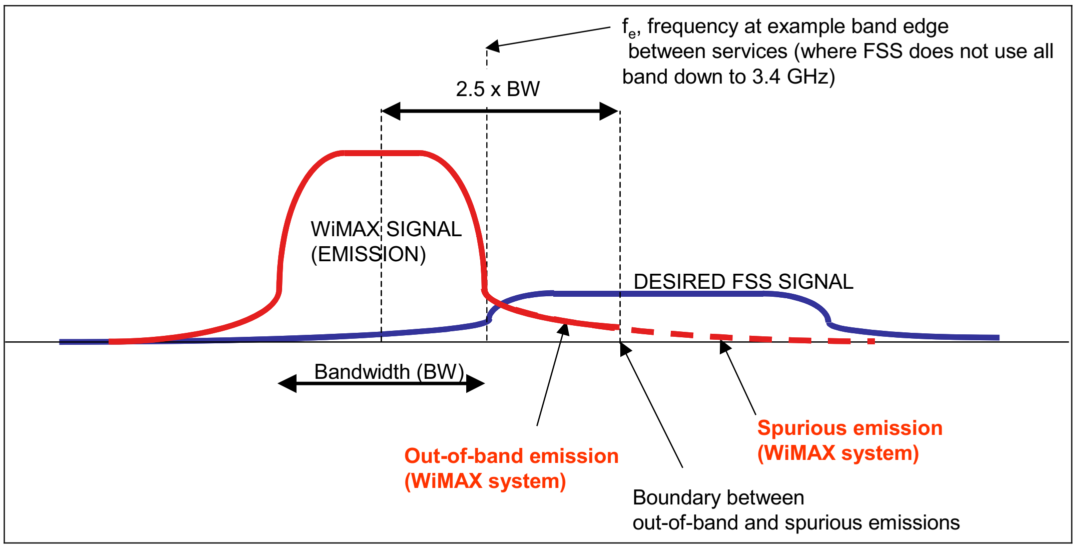


Figure 20. Illustration of the way in which interference due to out-of-band and spurious emissions may be caused from WiMAX systems into FSS earth station receivers in an adjacent band

Appendix 3 of the Radio Regulations requires that the spurious emissions from the WiMAX technology transmitting equipment are attenuated below the mean power supplied to the antenna transmission line by 43 + 10log(P) or 70 dBc, whichever is less stringent, measured in a 1 MHz bandwidth. Here, for a digital carrier, 'P' is the mean power in Watts supplied to the antenna. As an example, If P = 1 Watt, then the attenuation required for the spurious emissions is 43 dB below 1 Watt and this is less stringent than 70 dBc.

8.2. Example of the effect of Spurious & Out-of-Band Emissions in 3.3-3.8 GHz band

Using the 3650-3700 MHz band allocated in the USA for wireless access as an example where the maximum e.i.r.p. that would be radiated by a WiMAX base station is 1 Watt/MHz and using the FSS parameters provided in Table 3, Figure 21 illustrates the maximum range at which interference due to spurious emissions could occur into an earth station under line-of-sight conditions (i.e. free-space loss propagation). In practice, ground clutter is likely to make these distances much smaller, particularly in urban and suburban areas. However, where the locations of either the WiMAX systems or the earth stations are not known (e.g. in a licensing regime where registration is not required) then a wide deployment of both types of service in the same geographical area is likely to lead to sharing difficulties, particularly if the earth station antennas are operating at low elevation angles (as shown in Figure 21). For typical satellite elevation angles (> 20 degrees) the range at which interference occurs is reduced close to the minimum range shown in the Figure 21. For most domestic satellites which serve small dish services in low latitude countries, the elevation angle will usually be high enough to reduce the separation required to a few hundred metres. Reduced e.i.r.p. limits or tighter spurious emission limits reduce the maximum interference range still further. A change of 10 dB in Figure 21 alters the separation distance by a factor of three.

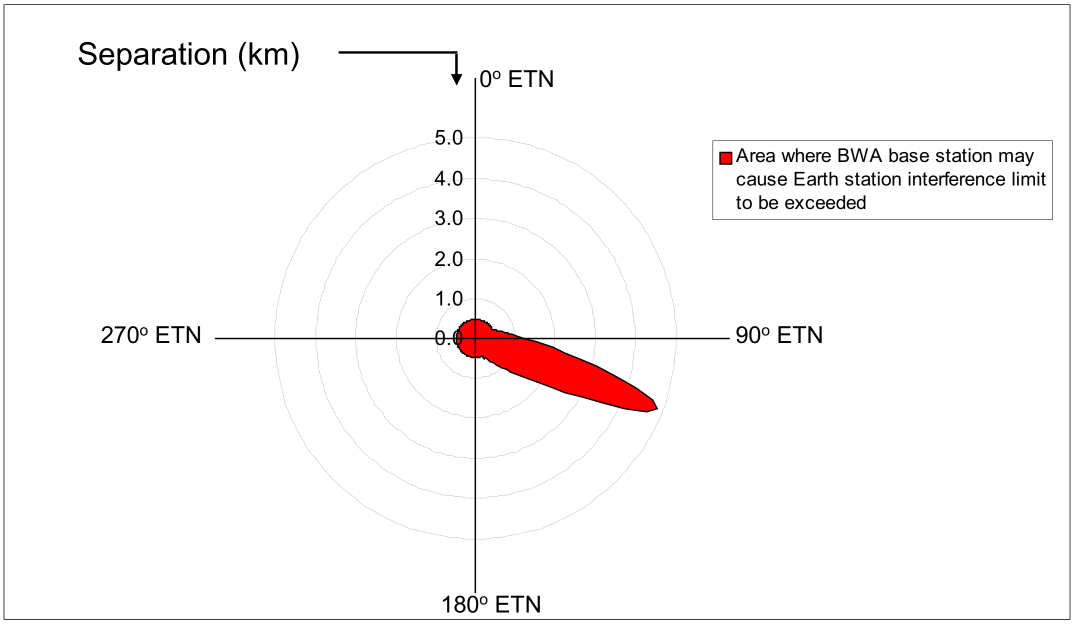


Figure 21. Area around earth station where spurious emissions of WiMAX base station may cause interference exceedance at FSS Earth Station

Notes:
1) earth station at centre of plot
2) earth station pointing: elevation angle = 7.6°; azimuth angle 112° East of True North
3) frequency: 3.7 GHz
4) line-of-sight propagation (free-space) assumed
5) WiMAX base station e.i.r.p. = 0 dB(W/MHz)
6) WiMAX base station peak gain = 17 dBi
7) base station and earth station assumed to be at same height above ground
8) Spurious attenuation limit: 43+10log(P) dBc
9) Earth station antenna pattern: Rec. ITU-R S.465

For a WiMAX system channel bandwidth of 5 MHz, the spurious emission boundary is reached 12.5 MHz away. It is not the intention to go into the effect of out-of-band emission limits – the ITU-R limits are provided in Recommendation ITU-R SM.1541[37]. If there is insufficient guard band between the two services for the country concerned then this will need to be addressed in further detail.

8.3. Spurious & Out-of-Band Emissions in 2.3-2.7 GHz band

Because of the antenna characteristics of satellite earth station terminals used for MSS, BSS and FSS services in the 2.3-2.7 GHz range of frequencies, it is unlikely that these terminals will be able to co-exist with WiMAX systems on a co-channel basis in the same geographical area. Hence, the options available for countries wishing to deploy both WiMAX systems and satellite services in this part of the spectrum are: i) geographic separation of the services; ii) band segmentation. Japan has been addressing the latter case and is allocating 70 MHz of spectrum in the band 2535-2605 MHz for Broadband Wireless Access services[38]. With downlink satellite services in the adjacent bands however, it has been necessary to examine the width of the guard band with regard to adjacent services.

[37] ITU-R Recommendation SM.1541-1: *Unwanted emissions in the out-of-band domain,* ITU-R SG1, Geneva, 2002

[38] Refer to KDDI presentation at San Diego meeting of WiMAX Forum Face-to-Face meeting, July 2006, on RWG web site.

8.4. Earth Station Low Noise Amplifier Saturation

At C-band, FSS earth stations use either a Low Noise Amplifier (LNA) at the front-end of the receiver or make use of Low Noise Block down-converters (LNB). Due to the very large range to a satellite in geostationary orbit and the resulting low signal-to-noise ratio of the carriers, these amplifiers feature very low noise figures and are often designed to operate over the full 800 MHz bandwidth allocated globally to the FSS (i.e. in the range 3.4-4.2 GHz). Figure 22 illustrates the case where the WiMAX channel lies within the passband of the LNA and where no front-end filtering is used in the earth station receive chain. This is obviously undesirable where the satellite services only operate above, say, 3625 MHz and where adequate filtering could promote terrestrial services in the adjacent band without leading to compression/saturation effects such as intermodulation. Consider an earth station LNA with a 15 dBm output power level corresponding to the 1 dB compression (saturation) point. For a typical LNA gain of 60 dB, this gives a 'saturation' level at the input of –45 dBm. An ideal design would aim for a composite signal input back-off (IBO) of 20 dB (typically -65 dBm) and practical designs would avoid hitting the input harder than 13dB IBO (approx 10 dB output back-off). Therefore the worst case acceptable composite power at the input of a typical LNA would be around -58 dBm. The worst case composite power flux density at the Earth's surface from the satellite (across 500MHz) is typically -115 dB(W/m^2) (dependent on spacecraft) and for a 13m diameter antenna with 68% efficiency, this would give a worst-case composite power (due to satellite) of -65.4 dBm at the LNA input (assuming negligible loss from antenna to LNA) i.e. very close to the ideal limit. When considering the additional impact of interference, a level no greater than about –65 dBm at the LNA input is recommended. Clearly there will be other LNAs and LNBs which are less sensitive in this respect.

Hence, the power level at the input of the LNA should be typically lower than about –65 dBm (from all transmitting channels across band) taking into account the fact that the amplifier receives all the transmitted channels from the satellite (not just the wanted ones).

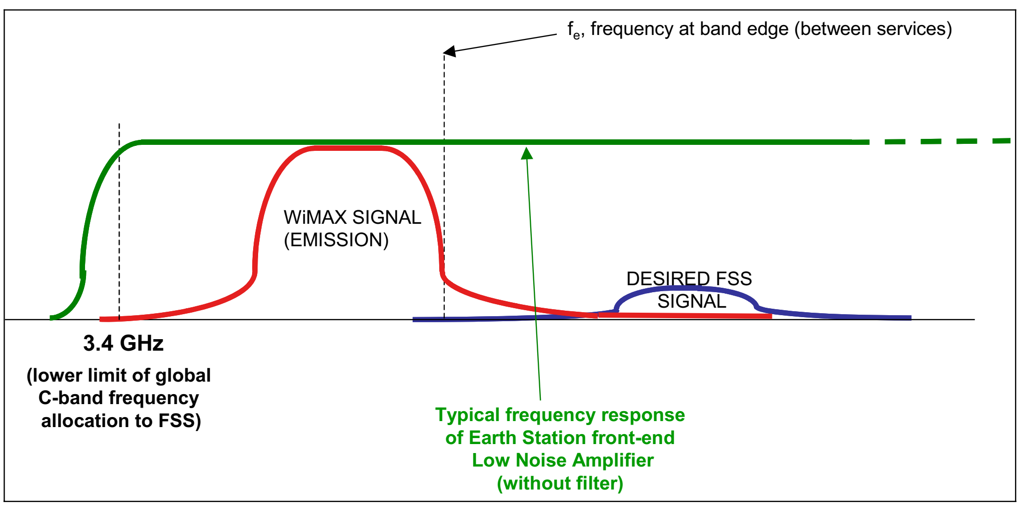


Figure 22. Illustration of the case where compression/saturation of an FSS earth station front-end amplifier can occur from a nearby WiMAX emission within the passband of the amplifier

Figure 23 shows the typical frequency response of an earth station LNA required for FSS receive operations in the band 3600-4200 MHz. The WiMAX technology band of interest is in green and the globally allocated FSS band is in blue. The frequency response of the LNA is seen to be 'flat' from about 3.1-4.3 GHz. There are radar allocations immediately above and below the FSS band (and in some countries up to 3.6 GHz) and these are shown in red. In regions where the radar systems operate, it is often necessary to fit earth station receivers with front-end waveguide filters to prevent compression and saturation effects occurring[39], so such filtering would also enable WiMAX systems to operate in an adjacent sub-band.

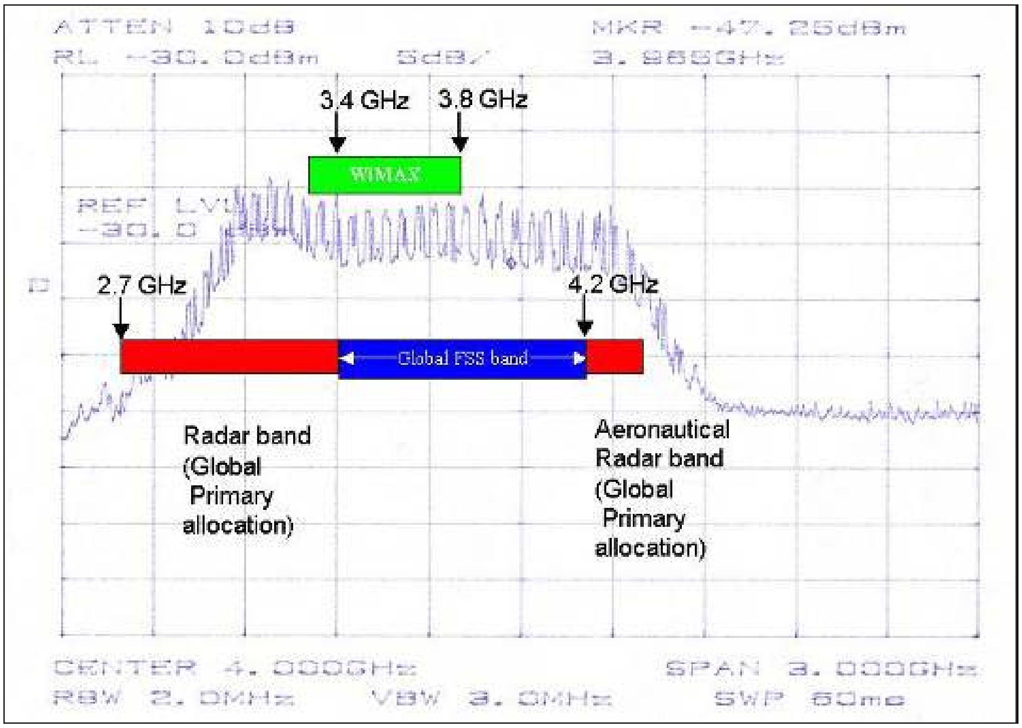


Figure 23. Typical frequency response of C-band earth station Low Noise Amplifier (without additional band-pass filtering in front of the LNA)

UK Martlesham Teleport MTP-10 13-metre antenna
Vertical scale: 5 dB/division
Horizontal scale: 300 MHz /division

Hence, where WiMAX systems and earth stations are deployed in a ubiquitous manner, a WiMAX system operating in, say, the 3.4-3.6 GHz band may affect operation of a nearby earth station operating in the 3.6-4.2 GHz band unless the earth station employs front-end filtering below 3.6 GHz.

Using the 3650-3700 MHz band allocated in the USA for wireless access as an example where the maximum e.i.r.p. that would be radiated by a WiMAX base station would be 1 Watt/MHz, Figure 24 illustrates the maximum range at which LNA compression effects may occur under line-of-sight conditions. As for the case with spurious emissions, the effect is enhanced close to the earth station antenna pointing direction particularly at low elevation angles.

[39] In fact, they may need to be fitted on earth station terminals a considerable distance away from the radar installations because of the high powers used by the radar transmitters.

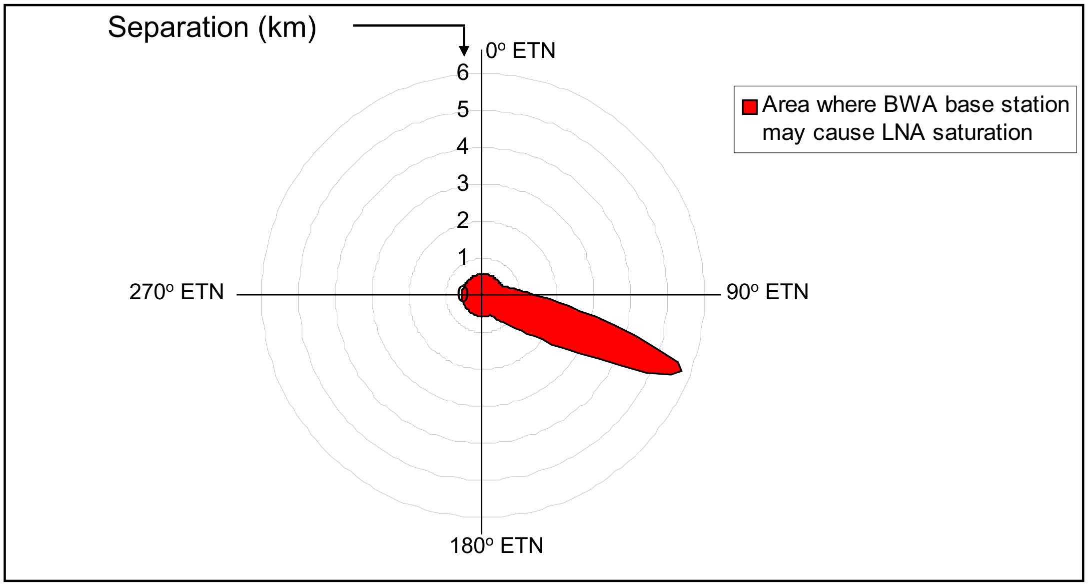


Figure 24. Area around FSS earth station where WiMAX base station could give rise to saturation/compression of Low Noise Amplifier of earth station (case with no filtering)

Assumptions:

1) earth station at centre of plot
2) earth station pointing: elevation angle = 7.6º; azimuth angle 112º East of True North
3) frequency 3.5 GHz
4) line-of-sight propagation (free-space) assumed
5) WiMAX base station e.i.r.p. = 0 dB(W/MHz)
6) WiMAX base station peak gain = 18 dBi
7) base station and earth station assumed to be at same height above ground
8) Maximum interference to avoid intermodulation and compression effects: -65 dBm (at input to earth station LNA); pass-band of LNA includes WiMAX channel(s)
9) Earth station antenna pattern: Rec. ITU-R S.465

Some filtering is commonly used even on quite small antennas at C-band because of the impact of radar interference near to coasts and airports. However, weight and loading limitations mean that only short, light-weight waveguide filters can be used on the widely deployed small front-fed antennas and hence the necessary rapid roll-off with frequency required for adjacent band working in the same geographical area is not easy to achieve. Figure 25 illustrates the case where the WiMAX channel is adjacent to the lowest edge of the FSS band in use. Here, a 'brick-wall' response is not possible and the roll-off slope is obviously key to how close together the two services can operate. For this reason (in the absence of a guard band) the satellite operators recommend restricting the e.i.r.p. in the top 25 MHz of the band 3650-3700 MHz in the USA to take into account the types of filter generally available. Note that, for this example, f_e = 3700 MHz in Figure 25.

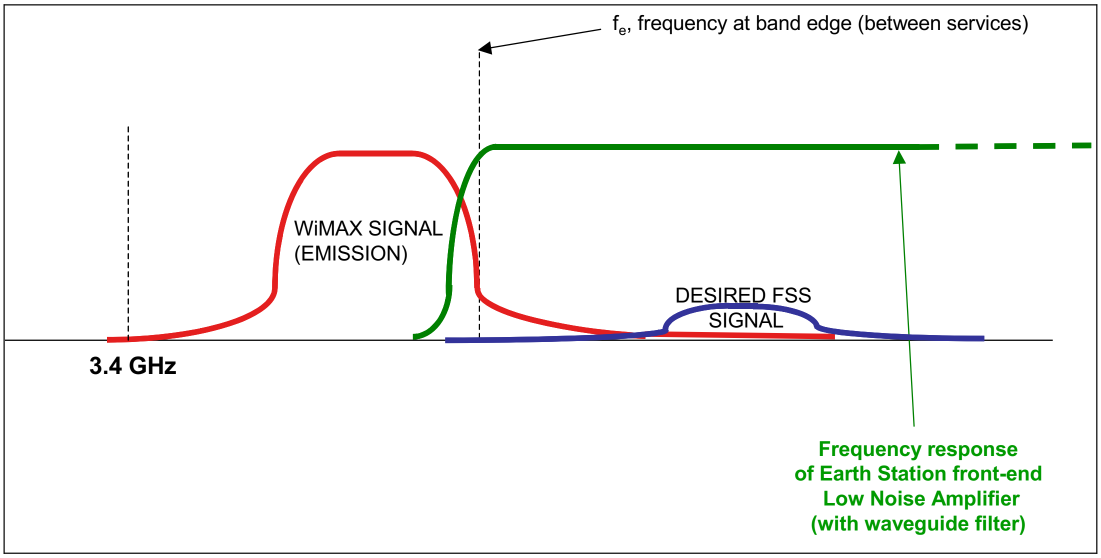


Figure 25. Adjacent band case where WiMAX signal is close to edge of passband of earth station LNA with no guard band

In January 2006, the Office of the Telecommunications Authority (OFTA) of Hong Kong commissioned some tests[40] to study the interference of BWA transmissions in the 3.4-3.6 GHz band into a satellite earth station receiver working in the 3.4-4.2 GHz band receiving television signals via an antenna with a diameter of 3 metres. Figure 26 illustrates the configuration used in one of the tests to investigate the effect of BWA base station antenna downtilt, earth station off-axis discrimination and the use of a 10 dB filter in front of the LNB. The BWA equipment used was pre-WiMAX technology. The earth station antenna received a digital TV channel at a centre frequency of 3725 MHz with a bandwidth of 6 MHz from the AsiaSat-3S satellite at a sub-satellite longitude of 105.5^{o} East (elevation angle 63 degrees). The BWA transmission was a 3.5 MHz bandwidth channel at 3550 MHz. At the separation shown (360 metres), with no downtilt of the BWA antenna, the TV picture quality was unaffected with an e.i.r.p. from the BWA antenna of 12 dBW (BWA antenna gain 14 dBi). The TV picture froze when the BWA antenna was downtilted at 10 degrees; the performance improved to marginal when the e.i.r.p. was reduced by 3 dB to 9 dBW; and the TV picture was free of interference when the e.i.r.p. was increased back to 12 dBW but a 10 dB bandpass filter (with low-end cut-off at 3.6 GHz) was introduced in front of the earth station LNB.

Obviously shielding by buildings will reduce the separation distances shown here.

The case of the aggregate effect of multiple BWA base stations and terminals was not considered.

[40] OFTA: *Assessment of Potential Interference between Broadband Wireless Access Systems in the 3.4 – 3.6 GHz Band and Fixed Satellite Services in the 3.4 – 4.2 GHz Band*, RSAC Paper 02/2006, Hong Kong, February 2006

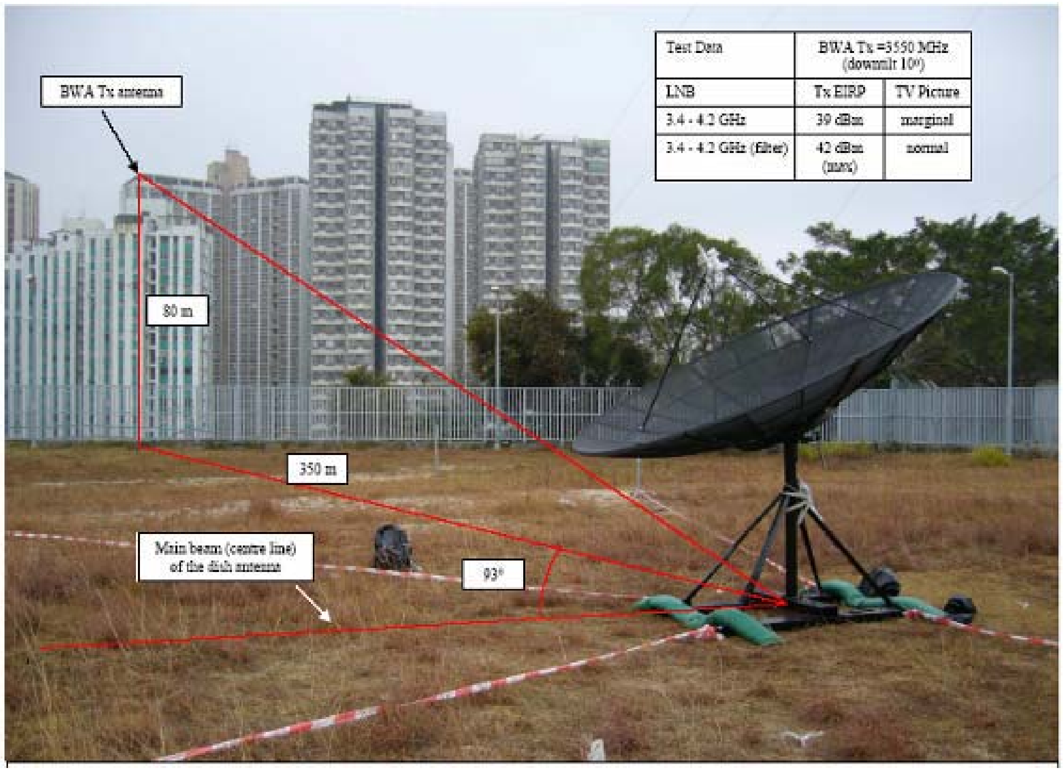


Figure 26. Measurements in Hong Kong to assess the effect of a C-band filter to mitigate against LNB compression/saturation effects

9. SOME MITIGATION TECHNIQUES TO FACILITATE CO-EXISTENCE BETWEEN WIMAX SYSTEMS AND SATELLITE SERVICES

This section provides a discussion on the types of mitigation techniques that may be available to promote a favourable sharing situation between WiMAX systems and satellite earth stations.

9.1. Mitigation techniques applicable to WiMAX Base Stations

- *Downtilting WiMAX base station antennas*: As shown in Figure 27, the effect of downtilt on WiMAX base station antennas is both beneficial for intra-service sharing and for sharing between base stations and earth stations but mainly when both are located on rooftop locations. Where the earth station terminal is positioned on the ground to gain extra shielding from distant interference sources by use of local clutter, the advantage is diminished.

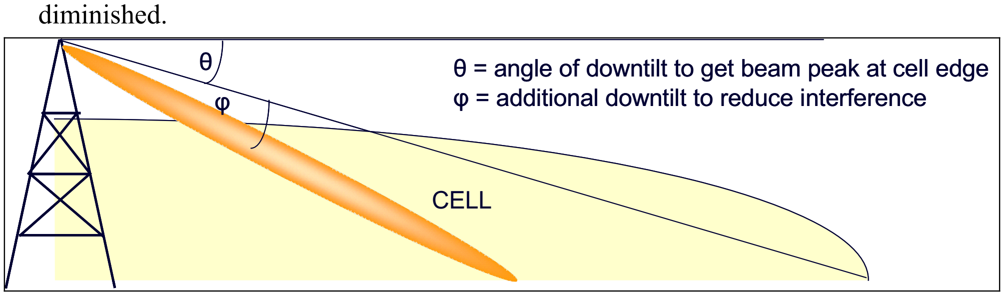


Figure 27. Interference reduction through the use of Downtilt on WiMAX base station antenna

- *Restricted coverage*: By not deploying full sectoral coverage at WiMAX base station sites, earth stations at known locations can be protected from WiMAX base station emissions. Care would need to be paid to the emissions of WiMAX technology user terminals in the active sectors as they may randomly point towards the earth station. This will of course increase the number of base stations required if significant coverage is required. Restrictions on e.i.r.p in particular directions (i.e. on certain sectors) is also a possibility.
- *Use of adaptive antennas on WiMAX base stations*: .As shown in Figure 28, use of beam-steering with adaptive antennas on WiMAX base stations can help to ensure that known directions of interference victims such as earth stations can be avoided. Of course this will only work if the earth stations are registered and the locations known.

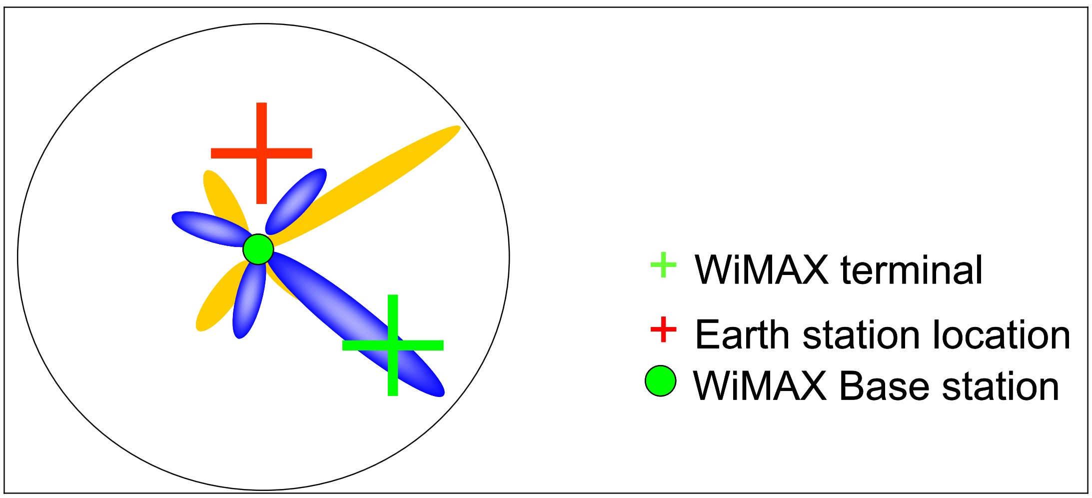


Figure 28. Interference reduction through the use of beam-steering on WiMAX base station antennas (plan view)

9.2. Mitigation techniques applicable to Satellite Earth Stations

- *Site Shielding*: C-band antennas at main gateway sites can be quite large (typical diameters are in the range 8 – 15 metres and may be as much as 32 metres in diameter). Hence artificial site shielding is generally impractical to provide as it would be prohibitively expensive and planning regulations may prevent its construction. Figure 29 and Figure 30 show examples of artificial C-band shielding in Caracas, Venezuela and in North America. These are to allow two-way protection from and to point-to-point links in the fixed service. A well designed screen such as that shown in the second picture is expensive and probably uneconomical to construct nowadays, especially for the protection of a single antenna. There is even less likelihood that this technique can be applied in the case of small antennas although some advantage can be taken of local ground cover or obstacles on roof-tops (see Figure 31) if the direction of the interference source is known. However, without all-round shielding the effectiveness tends to be poor owing to scattering and reflections in a three dimensional multipath environment in suburban and urban areas.
- *Use of front-end filtering where services are not operated over the full band:* Earth stations may have to receive anywhere in the allocated portion of the FSS band (e.g. 3625 – 4200 MHz in Brazil) as the assignment of carrier frequencies is carried out by the satellite operator, i.e. there is no means which allow the earth station operator to avoid particular frequency slots. Good front-end filtering in the earth station receive chain can help

WiMAX systems to be deployed in the lower part of the band, particularly where the earth stations are ubiquitously deployed and unregistered (i.e. locations not available to administration).

Figure 29. Mesh screening acting as interference shielding in Caracas

Figure 30. Optimised shielding screen in the USA

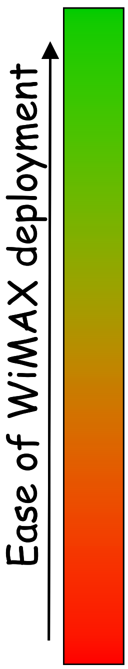
Figure 31. Local building clutter around C-band VSAT terminal in Harare, Zimbabwe

9.3. Other mitigation techniques

Operation in segmented bands: where countries have a large number of existing earth stations operating over part of the band (e.g. 3700-4200 MHz) this is likely to be the only solution, otherwise there may be fairly severe constraints on WiMAX systems deployment in the same geographical areas as the earth stations. This may need to be supplemented by the provision of front-end filters on the earth station receivers but this would be difficult if such earth station terminals were already deployed in large numbers.

10. DISCUSSION ON USE OF 3.4-3.8 GHz BAND FOR WiMAX SYSTEMS

One particular area of focus in this report has been the co-existence between WiMAX technology and satellite services in the 3.4-3.8 GHz band, part or all of which is used by many countries in the world for the Fixed Satellite Service. There in essence four main cases/scenarios that cover the use of the FSS in most countries of the world:



1) Countries with minimal use of the band for FSS where they only have to respect their international coordination obligations in accordance with the ITU Radio Regulations.
2) Countries with a few FSS earth station sites where national and international coordination should enable BWA systems such as WiMAX systems and the FSS earth stations to co-exist (e.g. France, UK). This may require considerable bi-lateral coordination if large geographical separations are to be avoided and there may be some impact on the future roll-out of both systems with appropriate restrictions where necessary.
3) Countries with existing large deployments of FSS earth stations, the smaller ones of which may well be unregistered and where only the top 500 or 600 MHz of the band may be used for downlink C-band services (e.g. 3625-4200 MHz in Brazil, 3700-4200 MHz in the USA). The issue then may be that many of the ubiquitously deployed earth station terminals will have wideband LNAs or LNBs operating in the range 3400-4200 MHz and amplifier non-linearity effects such as the generation of intermodulation products can occur as a result of compression/saturation by BWA and other terrestrial services even when the two services (WiMAX technology and FSS) are operating in different parts of the band. Under such conditions, interference may occur within a few hundred metres of the earth station terminal (under line-of-sight conditions).
4) Countries where the whole band 3400-4200 MHz is used for ubiquitous VSAT and/or TV reception. This is especially the case in some countries in South-East Asia such as Vietnam where no type of terrestrial wireless access service will be permitted anywhere in the band.

Figure 32 provides an illustration of the ease or difficulty with which WiMAX systems may be deployed in the 3.4-3.8 GHz band **with respect to FSS earth stations**, for the first three scenarios described above. Here, WiMAX systems deployment is expected to be fairly straightforward in the part of the band shaded green; at the other extreme, red means WiMAX systems deployment may be quite difficult and the orange and yellow colouring (rainbow colour order) indicate intermediate levels of sharing difficulty.

In practice, Scenario 3 is the most difficult case particularly with regard to existing FSS terminals where there may be many hundreds of thousands of such terminals deployed. This scenario has been further split into two to illustrate the case (3b) where the FSS earth station terminals may not have filtering at the lowest part of the FSS band used in the country concerned. In many countries where FSS operation is only used down to 3.7 GHz or 3.6 GHz, there may not have been the need up to now to include filters, as it would depend on how the band was used for other services (e.g. radar systems). Even where filtering is generally applied, adjacent band operation may be restricted due to the roll-off characteristics of the filter used. Although waveguide filters are widely available, weight and size constraints on small earth station terminals limit the protection available (particularly roll-off slope) and ideally a guard band may be advisable between the services. Where such filters have not been required it is unlikely that retrofitting a huge number of unregistered earth station terminals with appropriate filters is likely to be possible.

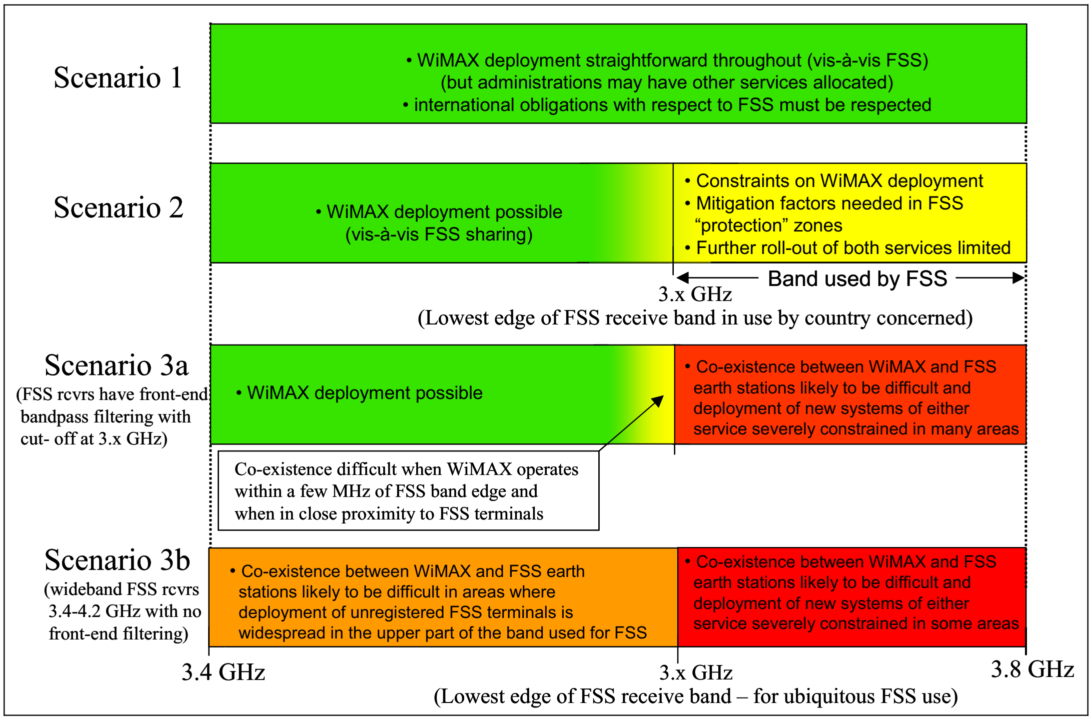


Figure 32. Ease of deployment of WiMAX systems in the band 3.4-3.8 GHz depending on the FSS usage within a country

Scenario 1: Countries where there is no or very little FSS earth station deployment
Scenario 2: Countries with several "gateway" earth stations in the upper part of the band
Scenario 3: Countries with existing large deployments of small FSS terminals operating in part of the band

11. CONCLUSIONS & STRATEGIC ACTIONS

11.1. Deployment of WiMAX systems in the band 2.3-2.7 GHz with respect to satellite services

In the band 2.5-2.69 GHz, ITU-R Joint Task Group JTG6-8-9 has addressed protection of WiMAX services from interference due to satellite services (space-to-Earth aspects only). There is a need to tighten up the power flux density masks in Article 21 of the Radio Regulations and the WiMAX Forum and the wireless access community needs to be continually engaged in the ongoing work in the ITU which will culminate at the World Radiocommunications Conference in late 2007 (WRC-07).

For countries which are using parts of the band 2.3-2.7 GHz for BSS, MSS or FSS, then geographical separation or band segmentation is likely to be necessary to permit the terrestrial systems such as WiMAX systems and satellite services to co-exist owing to the low directivity of the earth station terminal antennas used in this band.

11.2. Deployment of WiMAX systems in the band 3.3-3.8 GHz with respect to the Fixed Satellite Service

The general conclusion drawn is that the ease of deployment of WiMAX systems in the 3.3-3.8 GHz band is very much dependent on the extent to which satellite earth stations are already deployed in the country concerned, and the amount of spectrum that the Fixed Satellite Service is allocated in each country.

For co-frequency operation of WiMAX services and the earth stations operating in the Fixed Satellite Service, significant "protection" or "mitigation" zones may be required around registered FSS earth stations particularly if high availability requirements of the latter require that short-term interference criteria need to be met for the FSS service. This document has shown some examples of the size of these zones from some of the recognised procedures which can be used to determine them and it has been shown that these can be quite extensive in size (hundreds of kilometres under certain situations), even taking into account the effects of terrain. Within the protection zones, further mitigation techniques may be required to be applied and this may impose a considerable coordination burden on both services and the solution will be very much specific to each earth station location. As well as terrain, the shielding effects of additional clutter along the path towards the direction of interference needs to be assessed on a case-by-case basis specific to each earth station location (in three dimensions close to each end of the interference path). Mitigation techniques and associated financial costs will most likely fall on the new (incoming) service. New earth station sites may be required to demonstrate efficient use of the spectrum e.g. by the use of shielding enclosures (walls or pits) and/or providing waveguide filtering to enable terrestrial services using WiMAX technology to be deployed ubiquitously in other parts of the band where co-frequency operation is not possible.

A number of other mitigation techniques are available. The use of smart antennas on WiMAX base stations and beam steering will also be a way of protecting earth stations but only of course where their locations are made available by the administration concerned. Another technique may be to reduce, in the direction of the FSS Earth Station, the e.i.r.p. of WiMAX base stations that are close to the exclusion zone. Generally, WiMAX base stations will have three or more sector antennas so a further way of reducing the e.i.r.p. in a particular direction could be to avoid use of the sector that points towards the FSS earth station. This of course puts considerable constraints on WiMAX systems deployment. All of the above only works if registration of all WiMAX base stations as well as the earth stations is enforced.

Some inherent bias against wireless access sharing with earth stations services may need to be overcome by demonstrating to earth station operators (and administrations) that co-frequency operation may be possible.

There may be limited scope for interleaving the frequency channels between WiMAX systems and satellite services but the earth station carrier assignment is determined by the satellite operator and can change at short notice, and thus Earth stations will generally need to retain open access to much of the FSS band allocated in their country.

For the case where earth station deployment in this band is widespread and terminals are generally not registered with the administration concerned (e.g. for VSAT applications, TV cable-head end terminals etc.), coordination on a site-by-site basis is not feasible and co-frequency operation may be difficult without geographical separations between the services. However, with unregistered terminals a particular separation cannot be guaranteed. Even for the case where the earth station operates in a separate portion of the band to WiMAX systems, operations in the same area will be difficult because the widespread deployment of both services may lead to earth station receiver amplifier saturation/compression problems due to close proximity of a WiMAX base station or terminal to an earth station terminal. Whilst this can be overcome by the remedial action of fitting filters on the earth station, this would not be practical where thousands or millions of such terminals are already operating. Even where filtering is generally applied, adjacent band operation may be restricted due to the roll-off characteristics of the filter used. Although waveguide filters are widely available to protect earth station receivers from radar systems in adjacent bands to the FSS band (e.g. below 3.6 GHz and above 4.2 GHz), weight and size constraints on small earth station terminals limit the protection available (particularly the steepness of the filter's roll-off slope) and ideally a guard band may be required between the WiMAX system's spectrum and the FSS spectrum.

The difficulty with the different services in close geographic proximity is much alleviated if the earth stations are operating at high elevation angles and it is expected that this is the case for many countries with ubiquitously deployed earth station terminals for TV cable-head ends, VSATs etc.

This document has considered the state of FSS and wireless access systems in Brazil which is a good example of the case where there is intensive FSS use above 3625 MHz and the intention of the administration is to make further use of the 3400-3600 MHz band for broadband wireless access. Other countries in South America have adopted a similar approach (e.g. Venezuela).

In practice, the deployment of WiMAX in each country will need to be considered on a case-by-case basis.

ANNEX 1

SCOPE OF WORK ON SATELLITE-RELATED ISSUES

The scope of this work in the WiMAX Forum was as follows:-

- Capture global issues and provide analysis about co-existence between WiMAX technologies and satellite systems in the **2.3-2.7 GHz** band
    - space-to-Earth (receive wireless access systems co-existing with satellite downlinks)
- Capture global issues and provide analysis about co-existence between WiMAX technologies and satellite systems in the **3.3-3.8 GHz** band
    - space-to-Earth (receive wireless access systems co-existing with satellite downlinks)
    - terrestrial (transmitting wireless access systems co-existing with receiving earth stations)
- Identify existing international, regional and national regulations and guidelines concerning coordination / interference assessment and influence any new ones in preparation (via the relevant RWG TG as necessary).
- Address features that can be used to promote co-existence and minimise inter-service separation distances.
- Address frequency band regionalization for WiMAX systems where co-existence with satellite services deemed not possible.
- Provide a White Paper into the RWG on co-existence of WiMAX systems and satellite services and encapsulating formal WiMAX Forum policy. Deadline for approval of Issue 1: extended to end-August 2006.
- Ensure full interaction with RWG's regional and ITU Task Groups.
- As a parallel activity, agree strategy with RWG's regional and ITU Task Groups and provide expert comment where required (e.g. with regard to input papers into relevant groups such as ITU, CEPT, CITEL, APT, ASMG etc.). This includes monitoring inputs to all relevant fora on matters relating to the theme of the sub-team. Ensure WiMAX Forum representation and involvement at key meetings that are identified.

About the WiMAX Forum®

The WiMAX Forum is an industry-led, nonprofit corporation formed to help promote and certify the compatibility and interoperability of broadband wireless products using the IEEE 802.16 and ETSI HiperMAN wireless MAN specifications. The WiMAX Forum's goal is to accelerate the introduction of these devices into the marketplace. WiMAX Forum Certified™ products will be interoperable and support metropolitan broadband fixed, portable and mobile applications.

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