



Field Test Report WiMAX Frequency Sharing with FSS Earth Stations February 2008



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Executive Summary

Several national administrations around the world have designated portions of the frequency band 3.4 – 4.2 GHz for use by terrestrial wireless applications such as WiMAX and future mobile services (“IMT advanced,” beyond 3G, 4G). However, this band, commonly referred to as the C-band, is already in use by satellite services, radar systems and domestic microwave links. C-band services cover large areas, facilitate intercontinental and global communications and provide a wide range of services in developing countries. The C-band provides a robust, reliable platform for such critical applications as distance learning, telemedicine, universal access, disaster recovery, and television transmission in many remote and tropical regions.

The sensitivity of C-band satellite receiving systems makes them particularly sensitive to disruptions by mobile terrestrial frequencies in immediately adjacent bands. Field tests by the Office of the Telecommunications Authority in Hong Kong concluded that use of frequencies for terrestrial wireless services in the Extended C- and Standard C-bands was not practical.

Early in 2007, the Global VSAT Forum (GVF) held an Emergency C-band Summit in Washington, D.C. during which it coordinated an effort to confirm whether WiMAX systems would cause severe interference to satellite systems operating in an adjacent frequency band. Subsequent discussions among the WiMAX Forum, GVF and the Satellite Users Interference Reduction Group (SUIRG), it was agreed on the need to conduct a side-by-side test in advance of the World Radio Communication Conference 2007 (WRC 07), which occurred in November. It was hoped that the test results would influence the decision-making process by the national administrations on the critical issue of WiMAX frequency sharing with FSS earth stations. This test plan was established in a transparent process involving full disclosure to the WiMAX Forum and coordinated with many satellite organizations and representative groups.

The primary objective of the plan was to measure the interference levels generated by fixed WiMAX transmissions into a Fixed Satellite Service (FSS) satellite receiving station. The method employed taking measurements of C/N (carrier/noise), I/N (interference/noise), BER (bit error rate), and spectrum plots of a satellite down link video channel. Testing was performed in 2 phases:

- Phase 1: The FSS antenna remained in a fixed location while a WiMAX base unit was moved to several locations operating at various angles and distances from the FSS antenna to simulate subscriber waveforms. This test modelled WiMAX subscribers in a nomadic deployment affecting FSS. Tests conducted within the immediate area (up to 1 km away) showed that the digital signal was rendered unacceptable for use.
- Phase 2: The WiMAX base antenna was fixed at a height of approximately 50 meters on top of a water tower. The FSS antenna was positioned at several different locations and at various angles and significantly greater distances from the WiMAX antenna (up to 12 km) than during Phase 1 testing. This was to model WiMAX base units being deployed on cellular towers.

The results of the testing showed that the WiMAX transmit signal could cause significant problems to a digital signal well in excess of 12 km away. At the extreme measurement distance, the video program was fully operational with the WiMAX carrier centred on the video carrier. However, the data BER was degraded from a nominal 10^{-8} to a BER of 10^{-4} . This is an unacceptable quality of service in the digital telecommunications industry.

Subsequent calculations based on the initial measured data, and scaling with ITU criteria for WiMAX output power along with additional path loss, resulted in a required separation distance of 278 km to

reduce the level of interference to meet the -10 dB specification. This analysis assumed that there is no blockage of the interference path due to buildings or other “clutter” near to either the WiMAX antenna or the FSS antenna. Further analysis was done on the measured data based on the actual location and the surrounding terrain, which indicated that a locus of about 50km was required to meet the -10 dB I/N criteria.

Combining the two analyses, from a flat non-blocking terrain to a wooded hilly terrain, results show that the criteria whereby FSS antennas cannot co-exist with WiMAX systems ranges from 50 to over 200 km dependent upon the local terrain and the WiMAX output levels.

The Problem:

Interference from Broadband Wireless Access (BWA) services have been reported in many parts of the world where administrations have opened portions of the C-band for WiMAX use, including Australia, Bolivia, Fiji, Hong Kong, Indonesia, Pakistan, Kazakhstan, and Sub-Saharan Africa. Other national administrations can, and should, avoid repeating this costly mistake. Alternative approaches to the sharing of C-band spectrum between satellite services and WiMAX are available through different frequencies or via new protection techniques being developed by SUIRG and other post WRC-07 meeting.

Importance of the C-band:

Use of the C-band for satellite communications is widespread throughout the world. It is particularly vital for many developing countries such as South and Central America, Asia, and equatorial Africa because of its resilience in the presence of heavy rain. C-band earth stations are also used extensively in many developed countries. C-band (“Standard C-band” and “Extended C band”¹) frequencies have been assigned for satellite downlinks since the industry was inaugurated more than 40 years ago.

C-band services cover large areas. They facilitate intercontinental and global communications, and provide a wide range of services in developing countries, including critical applications such as distance learning, telemedicine, universal access, disaster recovery, and television transmission in many tropical regions.

Technical Explanation:

Antennas that receive satellite downlink signals in the C-band frequency range are, by necessity, extremely sensitive devices. They are designed to receive a low-power signal emitted by small transmitters located in orbit 36,000 kilometers above the equator. In the C-band, satellite services have co-existed with domestic microwave and radar links for many years. This is because the latter systems operate via tightly focused beams from fixed points, and de-confliction can take place when necessary.

By contrast, terrestrial wireless applications are by definition ubiquitous and increasingly mobile/nomadic. Mobile and base stations for terrestrial wireless applications emit signals from many locations, in all directions, simultaneously. These signals are powerful enough to disrupt the sensitive C-band satellite receiving systems, causing a potential for total loss of service in the C-band. Recent operating experience in Australia, Fiji and Indonesia, and field trials in Hong Kong, have confirmed this interference. (In the Hong Kong experiments, television signals feeding 300,000 households throughout Asia were inadvertently knocked off the air.)

¹ The bands 3.4-3.7 GHz and 3.7-4.2 GHz are usually referred to as Extended C-Band and Standard C-Band, respectively.

The sensitivity of C-band satellite receiving systems also means that they may be disrupted by mobile terrestrial use of frequencies in immediately adjacent bands. Field tests by the Office of the Telecommunications Authority in Hong Kong concluded that use of frequencies for terrestrial wireless services in the Extended C- and Standard C-bands was not practical.

A Particular Problem for Developing Countries:

C-band services are especially important for developing countries since supporting equipment is relatively inexpensive and the signals easily cover large areas. Such services are well adapted to provide voice, data and internet connectivity in remote areas that are underserved by other communications means. They are an essential component in the ITU's push to bridge the "digital divide" between the developed and developing world.

Because the C-band covers wide areas with minimal susceptibility to rain fade, it has proven to be exceptionally useful for disaster recovery in tropical areas. For example, C-band based services were vital in facilitating clean up and recovery after the 2004 Asian tsunami disaster. Other growing applications in developing countries include distance learning and telemedicine.

History

Governments that assigned broadband wireless frequencies in the extended C-band assumed the problem could be limited by frequency segmentation. However, this has proven to be ineffective in real-world tests. Large-scale disruptions of services operating in non-overlapping frequency bands have occurred in several countries, and as a result, governments, intergovernmental bodies and the satellite industry – particularly in Asia, which is most dependent on these frequencies – have begun to recognize the threat that ill-considered assignment of standard C-band and extended C-band frequencies to terrestrial wireless services poses.

- Even in the case where BWA (which encompasses WiMAX systems) and satellite earth stations operate on different frequencies in the same portion of the C-band, considerable geographic separation is necessary. The Hong Kong Telecommunications Authority Working Group conducted an extensive series of field tests, with the following conclusion: "BWA equipment within an area of several kilometers around existing licensed earth stations operating in the same frequencies may cause interference to the latter ... protection by separation distance is only meaningful for fixed access but not for mobile access ... Based on the assessment in this paper, there are interference problems caused by the proposed allocation of BWA in the 3.4 – 3.6 GHz band to the reception of satellite signals by FSS systems in the 3.4 – 4.2 GHz band. For the coexistence of the two services in the same territory, some technical constraints must be observed. The technical constraints would imply significant costs to be incurred by both BWA operators and FSS users and they may make it difficult for a wide and cost-effective deployment of BWA systems in a dense urban environment."
- In South America, the Bolivian Superintendencia de Comunicaciones (SITTEL) approved the usage of the 3.4 to 3.8 GHz band for telecommunication as the primary allocation for usage for the WiFi industry. During the short testing period prior to the planned May 2006 rollout, satellite signals carrying television channels in Bolivia were severely interrupted and major interference was reported. This occurred during the World Cup games which led to extremely vocal complaints from this soccer-passionate country. SITTEL issued an administrative resolution mandating that wireless access system deployments in the 3.7 – 3.8 GHz band be suspended in the entire territory of Bolivia for a period of 90 days, so that SITTEL could adopt

measures to solve this matter. The resolution also instructed the spectrum planning department of SITTEL to propose a new norm for channels in the 3.4 – 3.8 GHz band. More recently, SITTEL indicated that it intends to accommodate the BWA operators in the band 3.4 – 3.5 GHz and had initiated the required procedures to finalize such arrangement.

- The Asia-Pacific Telecommunity (APT – a regional intergovernmental organization) in a report from the APT Wireless Forum (AWF) has warned: “... BWA systems within several kilometers of an FSS receive earth station operating in the same frequency band, but on a non-co-channel basis, would need to carefully conduct coordination on a case-by-case basis. Moreover, to avoid interference in non-overlapping frequency bands ... a minimum separation distance of 2 km needs to be ensured with respect to all FSS receivers, even where BWA and FSS operate on different non-overlapping frequencies. This distance can be reduced to about 0.5 km if an LNB band pass filter is fitted at all FSS receivers, the BWA base station has additional filtering of spurious emissions and outdoor BWA user terminals are prohibited. The effectiveness of any mitigation technique is dependent on its application to individual site situations and can be applied only when FSS earth stations are confined to a limited number of specific known locations.”
- In Europe, CEPT prepared a new ECC Report on *Compatibility Studies In The Band 3400 – 3800 MHz Between Broadband Wireless Access (BWA) Systems And Other Services* (ECC Report 100). The studies have shown that to meet all relevant interference criteria for a representative FSS earth station, the maximum distances required for BWA central stations are between 270 km and 320 km. These distances are referred to as “mitigation distances” in the report, to indicate that smaller distances may be achievable through coordination of each BWA central station. However, even with coordination it is clear that the necessary separation distances are at least tens of kilometres and may be hundreds of kilometres. The feasibility of the use of mitigation techniques by BWA systems to reduce the separation distances has not been demonstrated.
- The Asia-Pacific Broadcasting Union (ABU), a regional organization grouping government and non-government entities), has cautioned that “BWA is a promising technology. However, if implemented in the same frequency bands as the satellite downlinks, it will have an adverse impact ... and may make satellite operation in the entire C-band impracticable. These bands are by far the most important frequency bands for satellite communication in Asia.”
- Sharing studies conducted by ITU-R Working Party 8F have shown that a minimum distance separation of approximately 35 to 75 kilometers must be maintained between an IMT transmitter (a 4G mobile system) and an FSS receiver. There is no practical way to maintain such large separations between these two systems. Moreover, given the large number of FSS receive stations currently receiving in the 3.4 – 4.2 GHz, it is highly unlikely that the requisite separation can be maintained with respect to all of these stations.

It is important to understand that satellite transmissions in the 3.4 – 4.2 GHz band are received by a large number of earth stations worldwide. Many of these stations are “receive only,” and are therefore not registered at the ITU (or generally even with the local administrations) since such registration is not required. Co-frequency operation of BWA systems would severely disrupt reception of satellite transmissions.

Test Plan and Procedures

In order to conduct a valid, measurable, repeatable, quantitative, and realistic field test to assess the impact of WiMAX deployments on FSS reception, a planned attempt to simulate an actual deployment of both a nomadic WiMAX user and Base Station tower was conducted in two phases. These tests were also conducted in order to validate and demonstrate that the many studies submitted to ITU for BWA impacts on FSS receivers where in fact true.

Methodology

The test was conducted in two phases:

Phase 1 was done in Punta Gorda, Florida where the WiMAX transmitter was located on a mobile platform at a slightly elevated level of about 4 meters while the FSS antenna remained at a fixed location.

Phase 2 was completed in the Southern Maryland and Northern Virginia areas where the WiMAX antenna was mounted on a water tower at an elevation of 50 meters and the FSS antenna was positioned on a mobile platform then moved to various locations and at various angles from the WiMAX antenna.

The SES NewSkies owned satellite NSS 806 located at 319.5°E was used for both phases of the test with the baseline video signal being sent from a SES TT&C earth station in Manassas, Virginia.

The WiMAX test plan and procedures, including frequencies used during the test, are detailed in a separate document titled SUIRG WiMAX Test Plan & Procedures, available on the SUIRG web site at www.suirg.org. The C/N, BER and digital power of a video program channel were measured directly at the LNA output whereas the I/N level was read from the spectrum plots when the WiMAX signal was located away from the video center frequency.

Test Set-up

Figure 1 shows the fixed satellite earth station testing interconnection drawing identifying all components utilized in both Phase 1 and 2 testing.

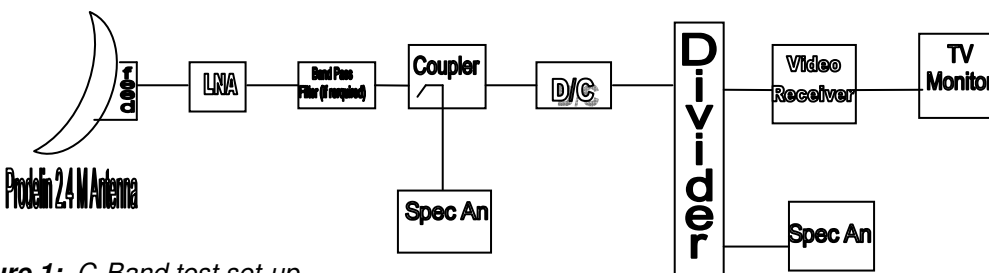


Figure 1: C-Band test set-up

Phase 1: Punta Gorda, Florida

Punta Gorda is a residential community of canals and single level homes. The geography of this community allowed the WiMAX system to be located at various distances and angles to the FSS antenna through the use of a boat and an automobile (see figure 2 for picture of FSS antenna test set-up location).

The Phase 1 testing process encompassed:

- A video carrier transmitted from the SES owned facility at Manassas, Virginia on satellite NSS 806, with the following operating parameters: Symbol Rate: 6532 Ksymbols, QPSK, FEC $\frac{3}{4}$
- The satellite FSS antenna was aligned to receive the video test transmission at 3,515 MHz
- The receive C/N of the test video carrier was approximately 10 dB
- The BER and digital power of the carrier were measured at the output of the Block Down Converter to establish a baseline measurement
- The WiMAX transmitter and omni-directional antenna were fixed to a mobile platform
- Various measurements were taken while the WiMAX transmitter was relocated to varying distances and angles relative to the satellite FSS antenna
- Both frequency and power level adjustments were made to the WiMAX transmitter
- Both C/N and BER values along with picture quality and spectrum analyser measurements were also taken at the output of the block down converter
- The final test during phase 1 utilized a directional WiMAX antenna with 18 dB gain



Figure 2: Phase 1 Test Location



Figure 3: Phase 2 Test Location-Long

Phase 2- Maryland and Virginia area

The Maryland and Virginia areas along the shores of the Potomac River allowed for longer distance testing while maintaining a direct line-of-sight between the WiMAX antenna and the FSS system (see figure 3 for picture of FSS antenna test set-up location and figure 4 for the water tower where the WiMAX hub antenna was installed.. Figure 5 provides an overview of the Phase 2 sites including the water tower and the 2 FSS test sites identified as short and long to distinguish the distances of 3.5 km and 12 km, respectively.



Figure 4: Phase 2 WiMAX antenna location



Figure 5: Phase 2 test locations

The Phase 2 testing process encompassed:

- A carrier transmitted from an SES owned facility in Manassas, Virginia on the NSS 806 satellite @ 319.5 East, with the following operating parameters: Symbol Rate: 6532 Ksymbols, QPSK, FEC $\frac{3}{4}$
- The WiMAX antenna and hub transmit equipment were located on a water tower (approximately 50 meters elevation) along the shores of the Potomac River in Northern Virginia
- The satellite FSS antenna was mounted onto a mobile platform and aligned at the various locations to receive the test carrier at 3,515 MHz
- The receive C/N of the test carrier was approximately 10 dB
- The BER and digital power of the carrier were measured at the output of the Block Down Converter to establish a baseline measurement
- The FSS antenna was relocated to varying distances and angles relative to the WiMAX antenna and a measurement was made at each location
- Both frequency and power level adjustments were made to the WiMAX transmitter
- Both C/N and BER values along with picture quality and spectrum analyser measurements were also taken at the output of the block down converter

Test Results

Phase 1

Figures 6 through 9 show the spectrum plots and the test signal from the NSS 806 satellite used during the Phase 1 local area Subscriber testing. A summary of the testing process and results are as follows:

- Tests were performed at 9 different remote WiMAX locations using an omni-directional antenna at ground level within a limited local area.
- Results identified significant problems within the immediate area of the FSS antenna at any WiMAX transmit level.
- Further distance testing identified significant problems at the max. (29 dBm EIRP) level and BER problems at the lower (3 dBm EIRP) level.
- The lowest I/N level recorded was +9 dB for a single subscriber unit; within the expected deployment of many units. The I/N level will definitely increase by each additional unit. Note the acceptable I/N level is -10dB which makes the interference level 19dB over the limit.

Baseline Video signal

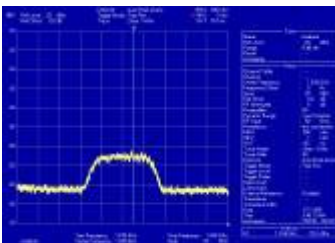
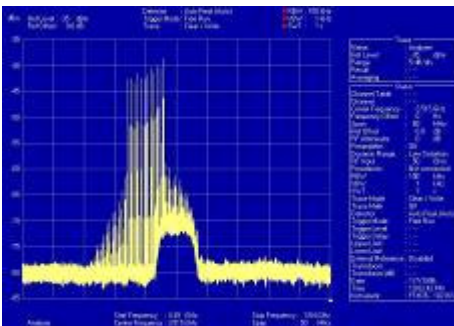


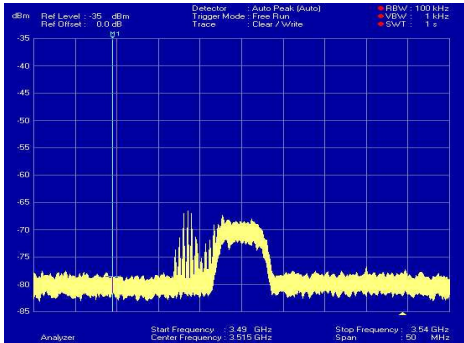
Figure 6 & 7: Baseline spectrum and video program



Phase 1 Measurement 3

- Distance: 0.14 km
- WiMax vs. FSS angle: 001°
- Video Carrier CF: 3,515 MHz
- WiMax CF: 3,510 MHz
- WiMax power: +29 dBm
- I/N: +42 dB
- BER: $<1 \times 10^{-4}$

Figure 8: Phase 1 Worst case Interference Measurement



Phase 1 Measurement 9

- Distance: 0.87 km
- WiMax vs. FSS angle: 187°
- Video Carrier CF: 3,515 MHz
- WiMax CF: 3,510 MHz
- WiMax power: +29 dBm
- I/N: + 20 dB
- BER: $<1 \times 10^{-5}$ when WiMax @ 3,515 MHz

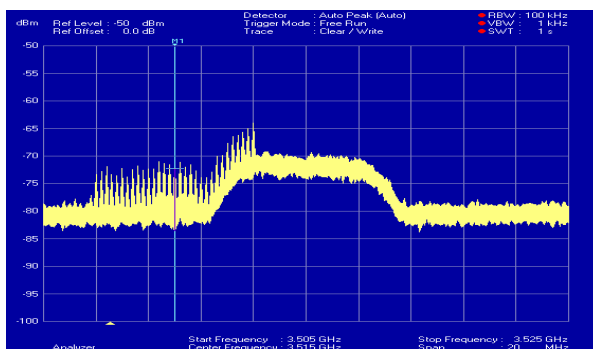
Figure 9: Phase 1 Best case Interference measurement

Phase 2

Phase 2 hub unit testing utilized the identical satellite carrier configuration as in Phase 1; however, the ground equipment was configured such that the WiMAX antenna was fixed on a water tower at 50 meters to simulate a WiMAX deployed Base Station cell tower, while the FSS antenna was mobile to enable distances up to 12 km with varying angles from the WiMAX antenna. A summary of the testing process and results are as follows:

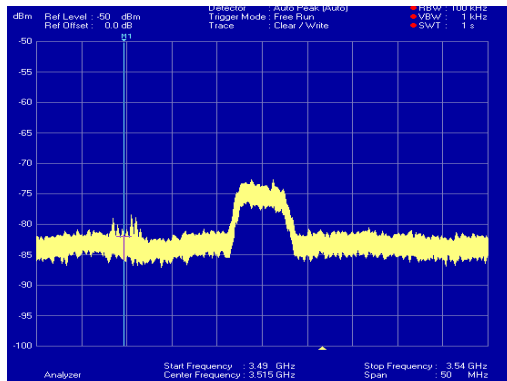
- Tests were performed at 2 different remote FSS locations using an 120° directional WiMAX antenna mounted on a water tower at around 50 meters to simulate a WiMAX deployed Base Station cell tower installation.
- Results identified problems within the test areas of significantly greater distances (6 to 12 km) away from the FSS antenna than Phase 1.
- The greater distance testing identified significant problems at the max. (34 dBm EIRP) WiMAX transmit level and BER problems at the lower (3 dBm EIRP) level.
- The I/N level ranged from +33 to +7 dB and, as stated in Phase 1 test results, the maximum acceptable I/N level is -10dB.

Figures 10 and 11 show the spectrum plot and test signal from the NSS 806 satellite used during the Phase 2 testing.



- WiMAX vs. FSS Angle: 16°
- Video Carrier CF: 3,515 MHz
- WiMAX CF: 3,510 MHz
- WiMAX power: +34 dBm EIRP
- Distance: 3 km
- I/N: + 8 dB
- BER: $<1 \times 10^{-5}$ when WiMAX

Figure 10: Phase 2 testing Local Area



- WiMAX vs. FSS Angle: 16°
- Video Carrier CF: 3515 MHz
- WiMAX CF: 3510 MHz
- WiMAX power: +34 dBm EIRP
- Distance: 12 km
- I/N: + 7 dB
- BER: $>1 \times 10^{-5}$ when WiMAX @ 3515 MHz

Figure 11: Phase 2 Testing Long Distance, Lowest I/N Measurement

The previous plot show the test results taken from a location not very far from the WiMAX antenna while the second plot is taken from a location at a maximum accessible distance from the WiMAX antenna. The Figure 10 plot was taken at a distance of 12 km with the WiMAX carrier offset to identify the signal level. The WiMAX signal level identified by the marker shows a +7 dB I/N level at a 34 dBm EIRP WiMAX output level. When the WiMAX carrier was within the test carrier it was visually undetectable; however, the BER degraded from 1×10^{-7} to $<1 \times 10^{-5}$

It should be noted that this testing was conducted using an LNA which had a 40K noise figure, vice 13K noise figure which most LNAs are currently designed to meet. In order to view and measure the actual C-Band spectrum for performance degradation an LNA had to be used along with a splitter that adds in additional attenuation (3dB) to the signal. Once the phase 2 tests with the LNA was over, an LNA was inserted in place, in order to assess the difference in lower noise figure of LNAs and without a splitter. The results with the LNA obtained a higher sensitivity to WiMAX interference with BER measurements dropping to 1×10^{-4} and the FSS video test pattern disappeared. Since there were no LNA DC block and splitters available, measurements of the down converted spectrum could not be taken.

Based on the ITU-R and CEPT studies concerning WRC-07 Agenda Item 1.4, contours have been calculated within which FSS protection criteria would be exceeded by WiMAX base stations. These contours were calculated for individual FSS earth stations located in various types of terrain. An example of the terrain calculation is reproduced in Figure 12 below.

Criteria established by the WiMAX Forum provides for an FSS long-term single-entry interference protection criterion for I/N not exceed -10 dB more than 20% of the time (i.e., the WiMAX signal should be at least 10 dB below the carrier noise floor). However, the field test results indicated significant interference where the lowest I/N level measured at the test FSS antenna was found to be 7 dB above the noise floor. In addition, the WiMAX base station and antenna used during Phase 2 had a maximum Equivalent Isotropic Radiated Power (EIRP) of 34 dBm. ITU studies and regulating bodies have used 44 dBm for the protection of FSS earth stations.

Calculations based solely on line of sight for defining the distance required between FSS and WiMAX systems indicate an exclusion zone of 280 km, which is greater than the direct line-of-sight earth curvature distance and assumed no terrestrial interference.

The following analysis, obtained from Phase 2, takes the actual test site terrain into account to calculate the exclusion zone:

- WiMAX base station type – Proxim Tsunami (3500-B00-AMD)
- WiMAX base station location – Latitude 38.329122°N, Longitude 77.206848°W
- Frequency – 3,505 MHz
- Channel bandwidth – 3.5 MHz
- Height of WiMAX antenna focus – 50 m
- Diameter of FSS earth station antenna – 2.4 m
- Height of FSS earth station antenna focus – 2 m
- Satellite to which FSS earth station is pointing – NSS 806
- FSS earth station receive system noise temperature - 100°K (from ITU-R studies)
- FSS long-term single-entry interference protection criterion – I/N not to exceed -10 dB for more than 20% of the time
- Overland path loss was calculated as in ITU-R Recommendation P.452 and P.526, using a terrain database

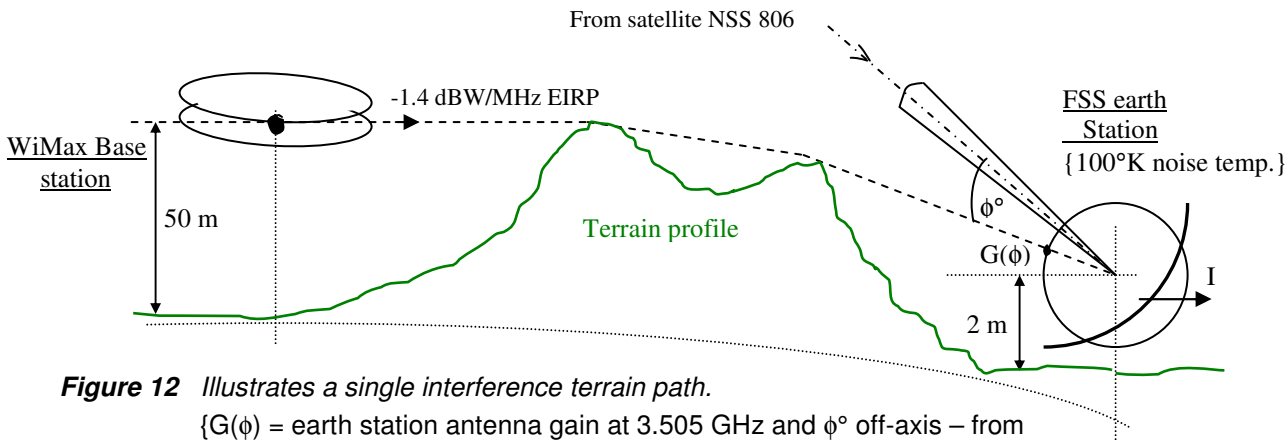


Figure 12 Illustrates a single interference terrain path.

{ $G(\phi)$ = earth station antenna gain at 3.505 GHz and ϕ° off-axis – from Rec.S.465}

A grid of points was set up at 2.5 km intervals over an area of 200 km x 200 km with the WiMAX base station at its centre. The value of path loss was computed between the base station and each point. The resulting locus is shown in Figure 13. For FSS earth stations sited outside the contour the long-term protection criterion would be met, but it would not be met for earth stations inside the contour.

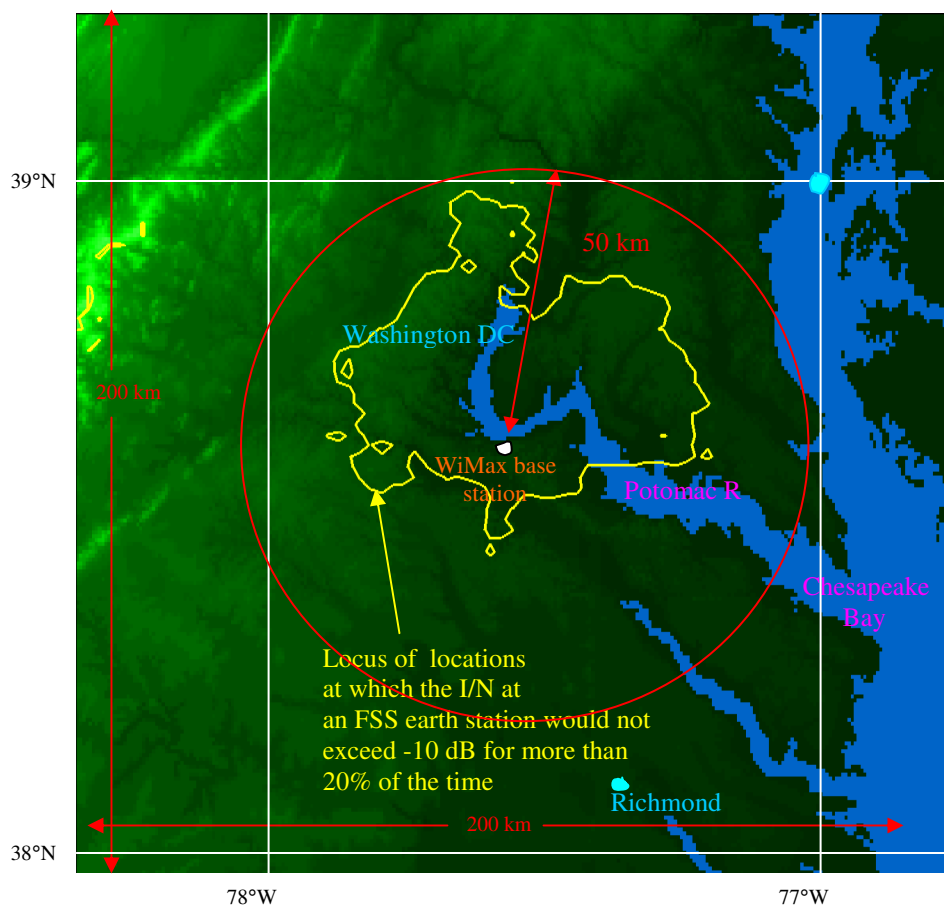


Figure 13: -10 dB I/N contour Locus

Field Test Conclusion

Phase 1 testing simulated a single mobile WiMAX subscriber unit by moving the WiMAX transmitter to various distances and angles to the FSS antenna system. The maximum distance utilized was 1 km, at which point the I/N level far exceeded the -10 dB criteria established by the WiMAX Forum. A typical implementation of a mobile subscriber network will include multiple transmitters thus compounding the interference into a local FSS system.

Phase 2 testing simulated a more typical WiMAX implementation with a Base station mounted to a height of 50 meters and a “mobile” 2.4-meter FSS antenna measuring the effects at different angles and distances from the WiMAX antenna. The results showed that there was significant interference at the 3 km distance for both low and high transmit levels. At the 12 km distance there was BER degradation to 10^{-5} with an I/N level of +7 dB, whereas, the industry specification requires the I/N for long term operation not to exceed -10 dB.

Initial calculations using only path loss indicated that a separation distance of 278 km was required to reduce the level of interference to meet the -10 dB specification. This analysis assumed that there was no blockage of the interference path due to buildings or other “clutter” near either the WiMAX antenna or the FSS antenna. A fairly accurate estimate of the path loss beyond line-of-sight can be obtained using the algorithms in Rec. ITU-R P.452 and its associated Recommendations.

Further analysis was done on the measured data based on the actual location and the surrounding terrain. The resulting estimation is that a locus of about 50 km was required to meet the -10 dB I/N criteria.

Taking into account the two test analyses, from a flat non-blocking terrain to a wooded hilly terrain, the results conclusively show that the criteria where FSS antennas cannot co-exist with WiMAX systems range from 50 to over 200 km dependent upon the local terrain.

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8. RSI/Vertex

NOTE: For technical details supporting the SUIRG WiMax Field Test Report, request a copy of the SUIRG WiMax Test Plan Procedures by emailing info@suig.org or visiting www.suig.org.