

MP 05W0000083

MITRE PRODUCT

Feasibility Analysis of 5091-5150 MHz Band Sharing by ANLE and MSS Feeder Links

March 2005

Yan-Shek Hoh
Izabela L. Gheorghisor
Frank Box

© 2005 The MITRE Corporation. All Rights Reserved.

MITRE

Center for Advanced Aviation System Development
McLean, Virginia



MP 05W0000083

MITRE PRODUCT

Feasibility Analysis of 5091-5150 MHz Band Sharing by ANLE and MSS Feeder Links

March 2005

Yan-Shek Hoh
Izabela L. Gheorghisor
Frank Box

Sponsor: Federal Aviation Administration
Dept. No.: F043

Contract No.: DTFA01-01-C-00001
Project No.: 0205F202-WL

This is the copyright work of The MITRE Corporation and was produced for the U.S. Government under Contract Number DTFA01-01-C-00001 and is subject to Federal Aviation Administration Acquisition Management System Clause 3.5-13, Rights In Data-General, Alt. III and Alt. IV (Oct., 1996). No other use other than that granted to the U.S. Government, or to those acting on behalf of the U.S. Government, under that Clause is authorized without the express written permission of The MITRE Corporation. For further information, please contact The MITRE Corporation, Contracts Office, 7515 Colshire Drive, McLean, VA 22102, (703) 883-6000.

Approved for public release; distribution unlimited.

©2005 The MITRE Corporation. All Rights Reserved.

MITRE
Center for Advanced Aviation System Development
McLean, Virginia

MITRE Department Approval:

Lisandro del Cid

Program Manager

MITRE Project Approval:

Frank W. Buck

Outcome Leader

Abstract

The Federal Aviation Administration plans to use the 5091-5150 megahertz band for the future Airport Network and Location Equipment (ANLE) system, which will provide an enhanced surveillance capability for airport surface environments. The same band has also been allocated on a co-primary basis to non-geostationary mobile-satellite-service (MSS) feeder uplinks, which must be protected against potential interference from ANLE transmissions. Our analysis demonstrates that if ANLE is based on the IEEE 802.11a or 802.16e standard, then compatibility with co-frequency MSS feeder links appears feasible by controlling the output power of ANLE transmitters, limiting their duty cycles, and distributing their frequency assignments among the three channels available in the band. Our results are contingent on the accuracy of our assumptions (which still need to be validated through field testing outside the scope of the present study) about the fading margins and path-loss exponents that apply to airport surface environments in the frequency band of interest.

Table of Contents

Section	Page
1. Introduction	1-1
2. System Characteristics	2-1
2.1 Relevant Features of IEEE 802 Family of Standards	2-1
2.2 LEO-D and LEO-F Satellites	2-2
3. Methodology and Parameters Used in Analysis	3-1
3.1 ANLE Characteristics	3-1
3.2 LEO-D and LEO-F Characteristics	3-4
3.3 Bandwidth Factor	3-6
4. Interference Prediction and Mitigation	4-1
4.1 Baseline Calculations	4-1
4.1.1 Aggregate Interference and Hot Points	4-1
4.1.2 Illustrations of Computation Results	4-2
4.2 Interference-Mitigation Methods and Expected Results	4-4
5. Concluding Remarks	5-1
List of References	RE-1
Appendix. Examples of Fine-Scale Aggregate Power Results	A-1
Glossary	GL-1

List of Figures

Figure	Page
2-1. Illustration of LEO Satellite and ANLE Transmitter	2-2
2-2. Cells Considered in Analysis	2-3
3-1. Potential ANLE 802.11a Transmitter Antenna Pattern	3-1
3-2. Potential ANLE 802.16e Transmitter Antenna Pattern	3-2
3-3. Illustration of LEO-D Receiving Antenna Gain in FOV	3-5
4-1. Region of Potential 802.11a ANLE Interference to LEO-D, Using Worst-Case Assumptions (Including 100% Duty Cycle)	4-3
4-2. Region of Potential 802.11a ANLE Interference to LEO-F, Using Worst-Case Assumptions (Including 100% Duty Cycle)	4-3
4-3. Region of Potential 802.16e ANLE Interference to LEO-D, Using Worst-Case Assumptions (Including 100% Duty Cycle)	4-4
4-4. Region of Potential 802.16e ANLE Interference to LEO-F, Using Worst-Case Assumptions (Including 100% Duty Cycle)	4-4
4-5. Interference-Free Operation of LEO-D and LEO-F in the Presence of ANLE System Using Appropriate Mitigation Methods	4-6
A-1. Fine-Scale Map of Aggregate Power from 2.25 W 802.11a ANLE Transmissions to LEO-D	A-1
A-2. Fine-Scale Map of Aggregate Power from 2.25 W 802.11a ANLE Transmissions to LEO-F	A-2

A-3. Fine-Scale Map of Aggregate Power from 2 W 802.16e ANLE Transmissions to LEO-D	A-3
A-4. Fine-Scale Map of Aggregate Power from 2 W 802.16e ANLE Transmissions to LEO-F	A-4

List of Tables

Table	Page
3-1. Estimated ANLE Transmitter Power Needed for 3-km Range	3-4
3-2. Parameter Values Used in Satellite Interference Calculations	3-6
3-3. Bandwidth Factors (dB)	3-6
4-1. Aggregate Interference from ANLE 802.11a	4-2
4-2. Aggregate Interference from ANLE 802.16e	4-2
4-3. Better ANLE Receiver Sensitivity and Interference Power Reduction	4-5

Section 1

Introduction

The 5000-5250 megahertz (MHz) frequency band is allocated to the aeronautical radionavigation service (ARNS) on an international basis. The 5030-5090 MHz portion is in use for Microwave Landing System (MLS) applications. The aviation community is exploring other applications in the 5091-5150 MHz band to support aeronautical applications. One candidate aeronautical application is the Airport Network and Location Equipment (ANLE) system. ANLE is visualized as a high-integrity, safety-rated wireless local area network (LAN) for the airport area, combined with a connected grid of multilateration sensors. Simple transmitters would be added to surface-moving vehicles, allowing for the development of a high-fidelity complete picture of the airport surface environment. The typical coverage area of the ANLE network will be a circle up to about 3 km in radius.

However, the 5091-5150 MHz band has also been allocated, on a co-primary basis, to non-geostationary (non-GSO) mobile-satellite-service (MSS) Earth-to-space feeder uplinks under footnote S5.444A to the International Allocation Tables and Resolution 114 of the 1995 World Radiocommunication Conference (WRC-95). The FAA/ATO-W Spectrum Office has requested the MITRE Corporation's Center for Advanced Aviation System Development (CAASD) to investigate whether measures may be needed to protect the MSS feeder uplinks from potential cochannel interference due to ANLE transmissions. This report presents the results of the effort.

Section 2

System Characteristics

This section briefly introduces the relevant features of the systems to be considered in the present analysis. More detailed discussions of the systems can be found in their respective standards documents.

2.1 Relevant Features of IEEE 802 Family of Standards

There are several protocols in the Institute of Electrical and Electronics Engineers (IEEE) 802 family of standards that are potential candidates for the ANLE implementation; namely, IEEE 802.11a [1], 802.16e [2], [3], and 802.20. IEEE 802.20, however, is in a very early development stage.

IEEE 802.11a

IEEE 802.11a currently operates in the 5-GHz Unlicensed National Information Infrastructure (U-NII) band and uses the Orthogonal Frequency Division Multiplexing (OFDM) modulation scheme. The U-NII band, whose lower limit is 5150 MHz, is split into three subbands, each of which has four channels. Each channel is 20 MHz wide.

IEEE 802.16e

The IEEE 802.16 standard supports non-line-of-sight (NLOS) communications in the 2-11 GHz band. In the bands below 6 GHz, operations suitable for fixed or mobile use can occupy various channel bandwidths. The 20-MHz channelization scheme has been defined to be compatible with the IEEE 802.11a-1999 standard [2, p. 630] and is thus the bandwidth to be considered in the present analysis. The IEEE 802.16e standard [3] allows for networking between carriers' fixed base stations and mobile users moving at speeds up to 150 km/hour. The frequency channel plan and transmission mask of IEEE 802.16e are still in the development stage, but are expected to be similar to those of existing 802.16.

IEEE 802.20

On 11 December 2002, the IEEE Standards Board approved the establishment of IEEE 802.20, the Mobile Broadband Wireless Access Working Group. The IEEE 802.20 system will operate in licensed bands below 3.5 GHz and will be more adapted to the mobile environment as it supports various vehicular mobility classes up to 250 km per hour. However, its standard is still in the early development stage. Therefore, no investigation of the IEEE 802.20 standard will be included in the present analysis.

2.2 LEO-D and LEO-F Satellites

The interference victims to be considered in the analysis are the low-earth-orbit (LEO) satellites LEO-D and LEO-F. Figure 2-1 illustrates the geometrical concept.

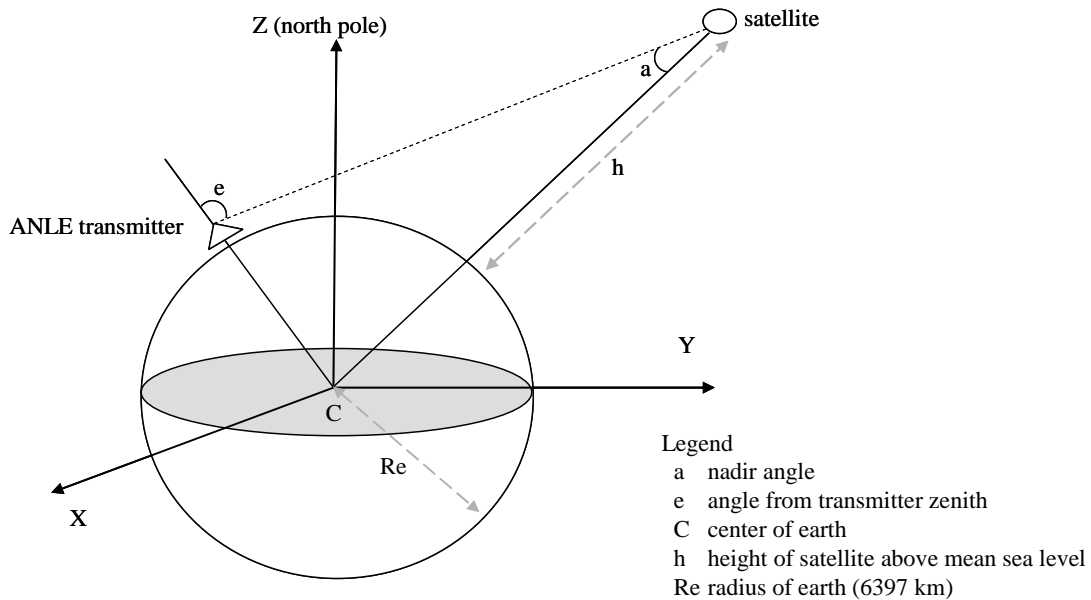
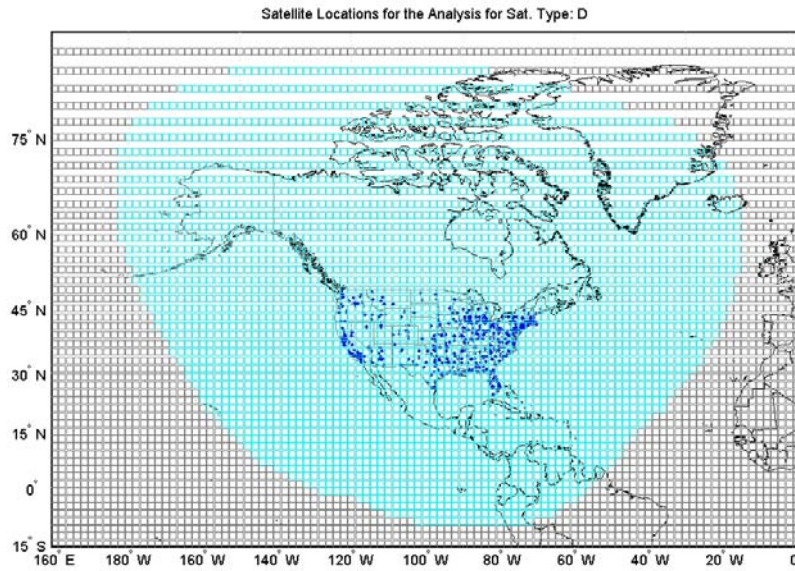
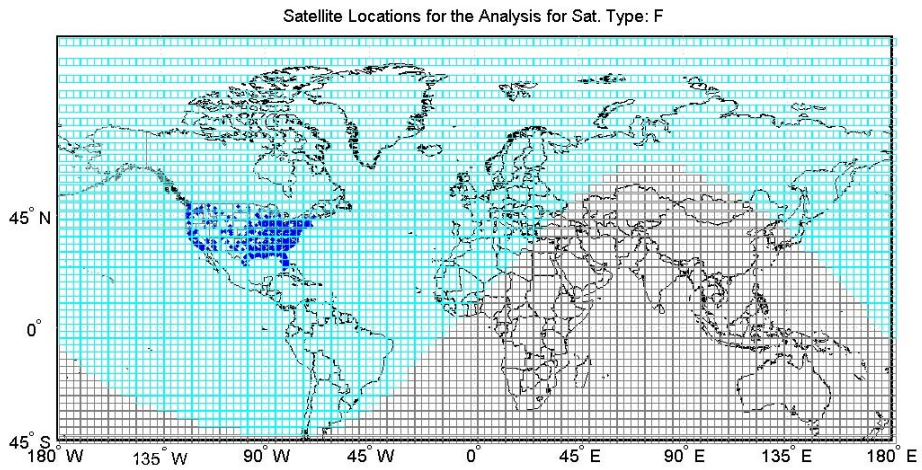


Figure 2-1. Illustration of LEO Satellite and ANLE Transmitter

The height of the satellite orbit is 1414 km for LEO-D and 10390 km for LEO-F. We identified 497 towered airports in the contiguous United States (CONUS) that are expected to be the primary candidates for ANLE system installations. Figure 2-2 shows (in light blue), for both LEO-D and LEO-F, the full set of “relevant” $2^\circ \times 2^\circ$ latitude/longitude cells such that a satellite directly above the center of a given cell would be in view of at least one of the 497 towered CONUS airports (shown in dark blue in the figure).



(a) Relevant Cells for LEO-D



(b) Relevant Cells for LEO-F

Figure 2-2. Cells Considered in Analysis

Section 3

Methodology and Parameters Used in Analysis

This section outlines the technical approach of the analysis and the system parameters used in the interference calculation.

3.1 ANLE Characteristics

We identified two potential ANLE transmitter antenna gain patterns for use in the analysis. Both are omnidirectional in the horizontal plane. The pattern for 802.11a is adopted from International Telecommunication Union (ITU) Radiocommunication Sector (ITU-R) recommendation M.1652 for wireless access systems including radio local area networks (RLANs) in the 5-GHz band [4]. Figure 3-1 illustrates the 802.11a antenna pattern assumed in this analysis. For 802.16e, the antenna pattern is adopted from ITU-R F.1336-1 [5]. Figure 3-2 illustrates the 802.16e pattern assumed in this analysis. (In practice, many if not most installed ANLE antennas are likely to have sectoral rather than omnidirectional patterns. Sectoral antennas would allow ANLE transmitters to operate at lower power, thereby enhancing compatibility with MSS and reducing overall interference levels below the values estimated in this report.)

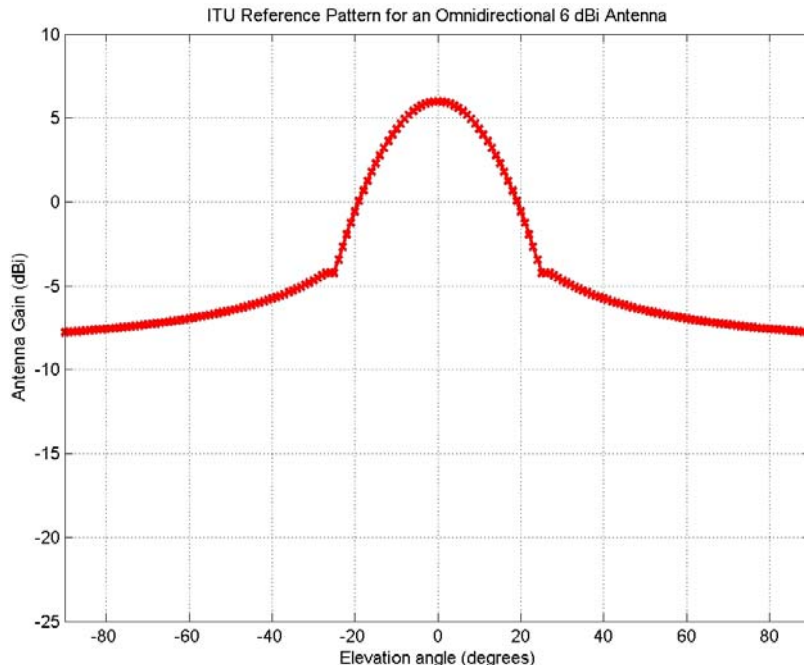


Figure 3-1. Potential ANLE 802.11a Transmitter Antenna Pattern

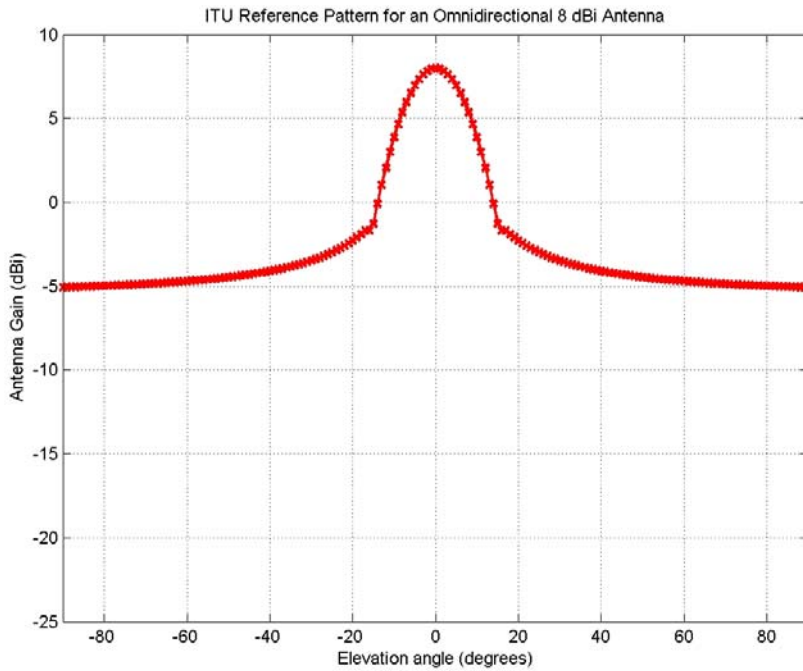


Figure 3-2. Potential ANLE 802.16e Transmitter Antenna Pattern

The ANLE transmitter power required to cover a cell 3 km in radius can be estimated on the basis of a set of nominal parameter values. For a worst-case consideration, we use a sensitivity value of -79.0 dBm for 802.11a receivers; this is based on the receiver minimum performance requirement from the standard [1]. For 802.16e receivers, we adopt a calculated value of -80.1 dBm, based on the 806.16 standard [2]. (Receivers with better sensitivity are available on the open market [6] for 802.11a and appear technically feasible [7] for 802.16e, and so will be considered in the latter part of the paper when interference mitigations are discussed.)

The path loss is a function of the path distance d . For an ANLE system the propagation path loss is evaluated on the airport surface where the path loss characteristics could be different from the free-space path loss. The path loss exponent n , defined in [8, 9], is used to characterize the environment. The path loss equation is defined as:

$$L_{path}(d) = L_{free}(d_0) + 10n \log_{10}(d / d_0) \quad (3-1)$$

where:

- L_{free} = free-space path loss,
- d_0 = distance up to which path loss can be modeled using the free-space equation,
- n = path loss exponent,

and

$$L_{free}(d_0) = 32.44 + 20\log_{10}(f_{MHz}) + 20\log_{10}(d_{0km}) \quad (3-2)$$

with

f_{MHz} = operating frequency (in MHz), and
 d_{0km} = propagation distance (in kilometers) up to which path loss can be described by free-space loss.

Note that if $n = 2$, Eq. 3-1 reduces to the case where the entire path distance is treated as a free-space path. In the present analysis, we adopt the values of 2.2 for n and 5 meters for d_0 as discussed in [9]. (The assumption that $n = 2.2$ is more conservative than a free-space loss assumption, because it results in higher estimated values of necessary ANLE transmitter power.) In regard to the link margin L_m for the ANLE-like system, the available information is very sketchy and indirect. In the present analysis, a value of 11 decibels (dB) is estimated from some indirect data to account for fading plus line loss. It is thus important to have the values of the path-loss exponent and the link margin validated by field tests (which are beyond the scope of the present study). The required ANLE transmitter power P_t , in dB referred to one milliwatt (dBm), is computed using the following expression:

$$P_t = R_{xs} + L_{path}(d) + L_m - G_t - G_r \quad (3-3)$$

where:

R_{xs} = receiver sensitivity in dBm,

$d = 3$ km,

G_t = transmitter antenna gain in dB referred to lossless isotropic gain (dBi), and

G_r = receiver antenna gain in dBi.

The ANLE transmitter power levels required to establish a 3-km direct link in the system as determined using Eq. 3-3 are 41.7 dBm (14.9W) for 802.11a and 38.6 dBm (7.3W) for 802.16e. Table 3-1 summarizes the ANLE system parameters and the transmitter power required.

Table 3-1. Estimated ANLE Transmitter Power Needed for 3-km Range

Parameter	IEEE 802.11a	IEEE 802.16e
Receiver sensitivity R_{xs} (dBm)	-79.0 ⁽¹⁾	-80.1 ⁽²⁾
Transmitter antenna gain G_t (dBi)	6.0	8.0
Receiver antenna gain G_r (dBi)	6.0	6.0
Assumed link margin L_m (dB) ⁽³⁾	11.0	11.0
Assumed path-loss exponent n	2.2	2.2
Transmitter power required P_t ⁽⁴⁾	41.7 dBm (14.9 W)	38.6 dBm (7.3 W)

Notes:

- (1) Receiver minimum performance requirement based on standard [1].
- (2) Calculated receiver performance based on standard [2].
- (3) Available information for determining link margin is very sketchy and indirect. The value estimated here must be verified by tests. This value also includes an allowance of 1 dB for line loss.
- (4) Transmitter power required to communicate to nodes 3 km away outdoors.

The present analysis assumes a worst-case scenario in which the duty cycle of each ANLE transmission is 100%, i.e., continuous transmission in all ANLE airports. In a real-world situation, however, the duty cycle values are expected to be less than 100%. A range of values from 1% to 15% was proposed by different parties in a HIPERLAN study and a compromise value of 5% was suggested [10]. Detailed design studies (beyond the scope of the present study) will be needed to ascertain a reasonable duty-cycle value for an ANLE transmitter.

3.2 LEO-D and LEO-F Characteristics

The LEO-D satellite has a 109.9° field of view (FOV) covering approximately 9% of the Earth's surface. Its receiving antenna gain in the FOV, shown in Figure 3-3, is rotationally symmetrical around the nadir.

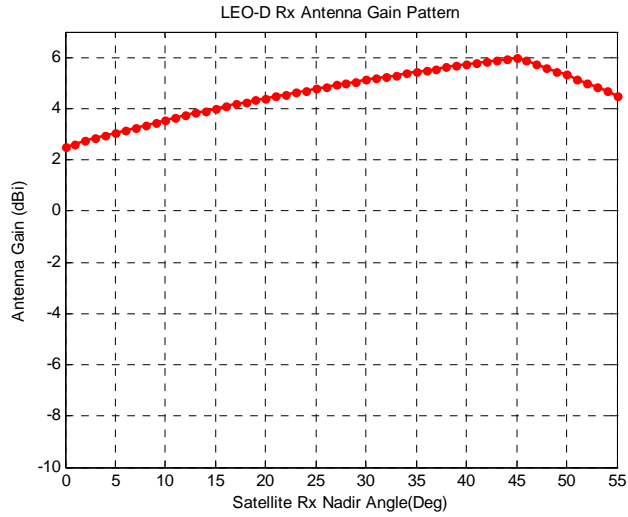


Figure 3-3. Illustration of LEO-D Receiving Antenna Gain in FOV

The LEO-F satellite has a 44.8° FOV covering approximately 31% of the Earth’s surface. For interference-calculation purposes, its receiving-antenna gain is assumed to be 10 dBi throughout the FOV.

We adopt the interference criterion of a 3% increase of the satellite receiver’s noise temperature, which has been used in similar studies of the adjacent 5150-5250 MHz band [11]. This criterion can be translated into an interference threshold, H , that must not be exceeded at the satellite receiver by the aggregation of power received from all transmitting ANLE devices in view of the victim receiver. The interference threshold, in dB referred to one watt (dBW), is determined according to the following expression:

$$H = 10\log_{10}(kBTC) \tag{3-4}$$

where

- k = Boltzmann’s constant = 1.38×10^{-23} joules/K
- B = bandwidth of the receiver (hertz)
- T = noise temperature of the receiver (K), and
- C = 3%.

Table 3-2 shows the values of key LEO-D and LEO-F parameters. The threshold values as determined using Eq. 3-4 are seen to be -155.5 dBW for LEO-D and -173.8 dBW for LEO-F. Much of the data presented here can be found in [12].

Table 3-2. Parameter Values Used in Satellite Interference Calculations

Parameter	LEO-D	LEO-F
Satellite orbit altitude h (km)	1414	10390
Satellite receiver noise temperature T (K)	550	400
Criterion C	3%	3%
Interference threshold H (dBW)	-155.5	-173.8
Polarization discrimination L_p (dB)	1	1
Feed loss L_{feed} (dB)	2.9	0
Satellite receiver bandwidth B (MHz)	1.23	0.025
Width of field of view (degrees)	109.9	44.8
ANLE transmitter height (feet)	30	30
Maximum great circle distance between subsatellite point and ANLE transmitter visible from satellite (km)	3921	7558

3.3 Bandwidth Factor

The bandwidth factor, B_f , is the ratio of the victim satellite receiver bandwidth (B_{LEO}) to the interfering ANLE transmitter bandwidth (B_{ANLE}), if $B_{LEO} < B_{ANLE}$; otherwise, $B_f = 1$. It determines the amount of interfering power falling into the victim’s “filtered” bandwidth. As discussed in Section 2, the channel bandwidths for both 802.11a and 802.16e are 20 MHz. This value is larger than the receiver bandwidth of either LEO-D or LEO-F. Therefore, the bandwidth factor is much less than unity for both types of LEO receivers. Since adjacent-channel interference is ignored in the present analysis, we thus only need to consider the situation where, in each of the 497 towered airports, one ANLE transmitter is transmitting at a given time into the victim passband. Table 3-3 lists the computed bandwidth factors.

Table 3-3. Bandwidth Factors (dB)

	IEEE 802.11a	IEEE 802.16e
LEO-D	-12.1	-12.1
LEO-F	-29.0	-29.0

Section 4

Interference Prediction and Mitigation

This section presents the interference computation results based on the parameters discussed in Section 3. Mitigation methods identified for eliminating the interference at the satellites and the expected results of employing these mitigation methods are also presented.

4.1 Baseline Calculations

The interference power P_r , in dBm, at the input of the satellite receiver is determined from the following expression:

$$P_r = P_t + (G_t - L_c) + G_r - L_{free}(d) - L_{feed} - L_p + \beta_f \quad (4-1)$$

where:

- P_t = transmitter power (dBm)
- G_t = ANLE antenna gain (dBi) toward satellite
- L_c = cable/line loss in ANLE transmission system (assumed to be 1 dB)
- G_r = satellite antenna gain (dBi) toward ANLE
- L_{free} = free-space path loss (dB)
- L_{feed} = feed loss (dB)
- L_p = polarization discrimination (dB)
- β_f = bandwidth factor (dB)
- d = distance (km) between ANLE transmitter and satellite receiver.

4.1.1 Aggregate Interference and Hot Points

For a given combination of ANLE system and satellite type, the aggregate interference power assumes a maximum value for a certain subsatellite point (the “hot point”). On the basis of the assumed worst-case ANLE transmitter power (14.9 W for 802.11a and 7.3 W for 802.16e), the hot points associated with all ANLE/LEO combinations are determined (to 2° accuracy in latitude and longitude) from the interference power computation results at the relevant cells. The aggregate interference power reduction required to eliminate the interference can thus be determined from the difference between the hot point’s interference power level and the interference threshold value. The results are listed in the following tables.

Table 4-1. Aggregate Interference from ANLE 802.11a

Satellite	Interference threshold (dBW)	Aggregate interference power at hot point (dBW)	Aggregate interference power reduction required to eliminate interference (dB)
LEO-D	-155.5	-147.5 at 63°N 100°W	$(-147.5)-(-155.5)=8.0$
LEO-F	-173.8	-168.0 at 23°S 92°W	5.8

Table 4-2. Aggregate Interference from ANLE 802.16e

Satellite	Interference threshold (dBW)	Aggregate interference power at hot point (dBW)	Aggregate interference power reduction required to eliminate interference (dB)
LEO-D	-155.5	-150.0 at 67°N 104°W	$(-150.0)-(-155.5)=5.5$
LEO-F	-173.8	-170.2 at 23°S 92°W	3.6

The above tables show that, in order to eliminate interference to the satellites under the noted worst-case assumptions, the required reduction in aggregate interference power is about 8 dB for ANLE 802.11a and about 5.5 dB for ANLE 802.16e. Section 4.2 offers several methods for achieving the necessary reduction in aggregate power.

4.1.2 Illustrations of Computation Results

Figures 4-1 through 4-4 illustrate the results for all four ANLE/LEO combinations with the ANLE transmitters operating with 100% duty cycles and omnidirectional antennas at the worst-case power levels (14.9 W for 802.11a, and 7.3 W for 802.16e) we have assumed to be required for establishing an ANLE network 3 km in radius. The prominent red areas shown in all four plots indicate the regions of the earth above which the satellites could experience ANLE interference above the threshold. All other regions are shown in green. The thin red stripes appearing in some plots result from the convergence of the relatively high-gain portions of numerous ANLE transmitting antenna beams in certain narrow sections of the LEO-F orbits.

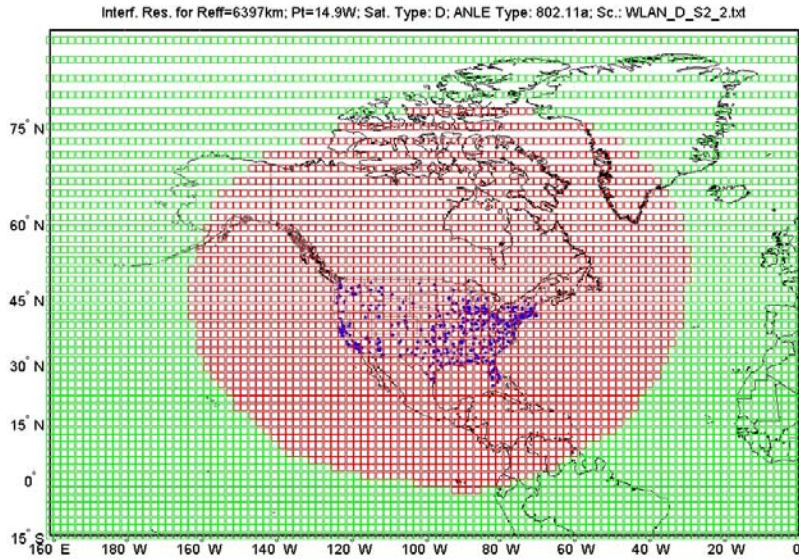


Figure 4-1. Region of Potential 802.11a ANLE Interference to LEO-D, Using Worst-Case Assumptions (Including 100% Duty Cycle)

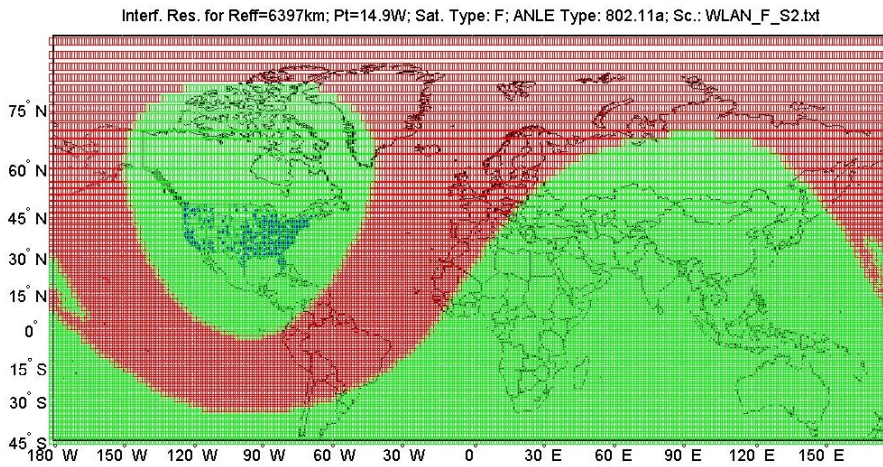


Figure 4-2. Region of Potential 802.11a ANLE Interference to LEO-F, Using Worst-Case Assumptions (Including 100% Duty Cycle)

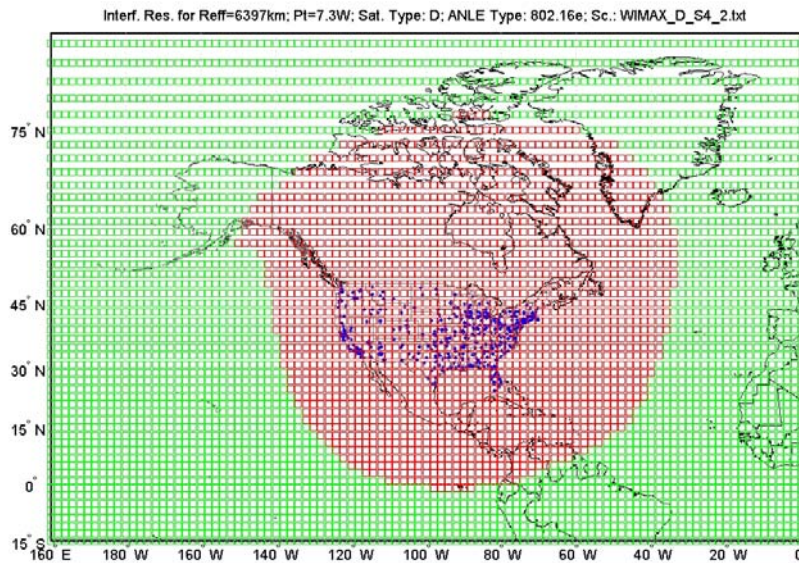


Figure 4-3. Region of Potential 802.16e ANLE Interference to LEO-D, Using Worst-Case Assumptions (Including 100% Duty Cycle)

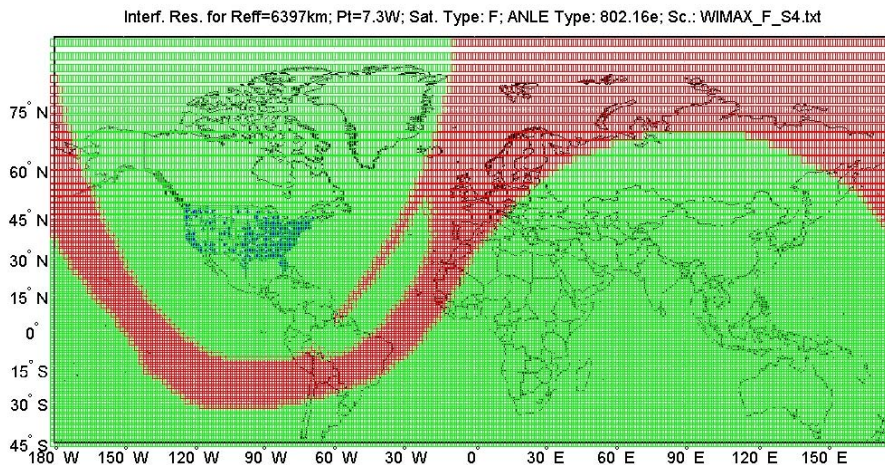


Figure 4-4. Region of Potential 802.16e ANLE Interference to LEO-F, Using Worst-Case Assumptions (Including 100% Duty Cycle)

4.2 Interference-Mitigation Methods and Expected Results

In this section three interference-mitigation methods are identified and the expected effects of employing these methods are discussed.

1. *Use ANLE receivers of better sensitivity.* The benefits of this measure are shown in Table 4-3. The lower interference power results from the reduction in the ANLE transmitter power needed to communicate with the more sensitive receivers that are commercially available for 802.11a [6] and technically feasible for 802.16e if noise figures and implementation losses cited in [7] are used.

Table 4-3. Better ANLE Receiver Sensitivity and Interference Power Reduction

System	Value used in preceding calculations	Possible value for better receiver	Interference power reduction resulting from better receiver sensitivity
802.11a	-79.0 dBm	-83.0 dBm [6]	4 dB
802.16e	-80.1 dBm	-84.1 dBm [7]	4 dB

2. *Ensure ANLE transmissions do not exceed 50% duty cycle.* We consider an ANLE transmitter duty cycle of 50% to be conservative enough while still being reasonably realistic. (It should be noted that the duty cycles under consideration for sharing studies in the adjacent 5150-5250 MHz band range from 1% to 15%.) Compared to the 100% value used in our prior calculations, this translates to a 3-dB reduction in the ANLE aggregate transmitter power, and hence a 3-dB reduction in the interference power level at the satellite receivers.
3. *Use three ANLE subnetworks per airport to reduce the cochannel interference.* Since each subnetwork will use a different frequency channel, only about 1/3 of the ANLE transmitters will be operating cochannel with the satellite, and the effective interference power falling into the victim receiver's filtered bandwidth will drop by a factor of three. In practice, however, the average achievable value is slightly less and the reduction is about 4 dB.

Thus the total reduction of interference power upon employing all three mitigation methods is $4 + 3 + 4 = 11$ dB for both 802.11a and 802.16e. These values compare favorably to the required interference reduction values determined in Section 4.1.1, where Tables 4-1 and 4-2 showed the required reduction to be about 8 dB for the 802.11a ANLE system and 5.5 dB for the 802.16e ANLE system. Thus the three methods together seem to be capable of providing sufficient interference mitigation to meet the band-sharing requirement (i.e., no interference to the MSS feeder uplinks) for both versions of the ANLE system. Figure 4-5 depicts the interference-free situation that can be achieved through an appropriate combination of the three methods.

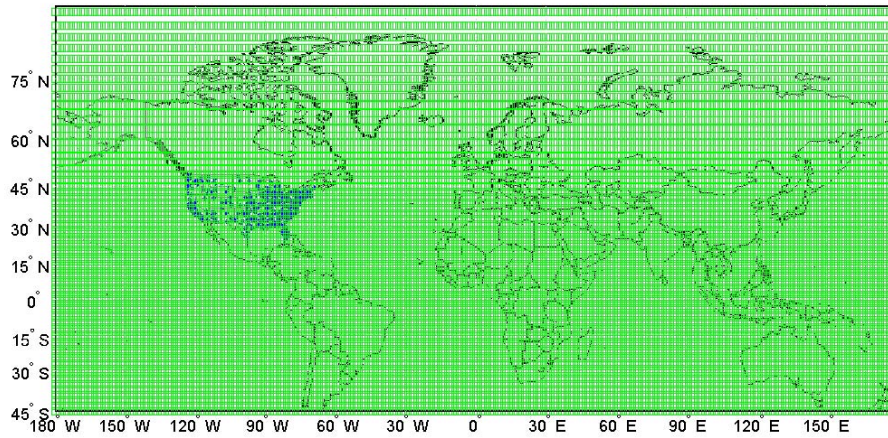


Figure 4-5. Interference-Free Operation of LEO-D and LEO-F in the Presence of ANLE System Using Appropriate Mitigation Methods

Section 5

Concluding Remarks

It seems feasible for an ANLE system based on either 802.11a or 802.16e to share the 5091-5150 MHz band with non-GSO MSS feeder uplinks for LEO-D and LEO-F satellites, provided that:

- The 3% interference criterion applies (as in ITU-R S.1427), and
- An appropriate combination of the following interference-mitigation approaches is employed:
 - (1) Use ANLE receivers that are more sensitive than the least sensitive receivers allowed in current IEEE standards.
 - (2) Ensure ANLE networks do not exceed an average duty cycle of 50%.
 - (3) Implement a three-channel allocation strategy for the ANLE networks.

In the course of the analysis, we used assumed values for two critical ANLE parameters:

- 11 dB for the link margin (which includes 1 dB of line loss)
- 2.2 for the path-loss exponent

These assumed values must be validated by field tests that are outside the scope of the present study.

List of References

1. IEEE Std 802.11a-1999, *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 1: High-speed Physical Layer in the 5 GHz band*, International Standard ISO/IEC 8802-11:1999/Amd 1:2000(E).
2. IEEE Std 802.16-2004 Revision D, *Standard for Local and Metropolitan Area Networks, Part 16: Air Interface for Fixed Broadband Wireless Access Systems*, International Standard ISO/IEC.
3. IEEE P802.16e/D5, *Draft IEEE Standard for Local and Metropolitan Area Networks, Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems, Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands*, September 2004.
4. ITU-R, *Dynamic frequency selection (DFS) in wireless access systems including radio local area networks for the purpose of protecting the radiodetermination service in the 5 GHz band*, ITU-R M.1652 (2003 version).
5. ITU-R, *Reference Radiation Patterns of Omnidirectional, Sectoral and Other Antennas in Point-to-Multipoint Systems for Use in Sharing Studies in the Frequency Range from 1 GHz to above 70 GHz*, ITU-R F.1336-1 (1997-2000 version).
6. <http://www.cisco.com/en/US/products/hw/wireless/>
7. IEEE 802.16 Broadband Wireless Access Working Group, *Interference scenarios in 2.4 GHz and 5.8 GHz UNII bands – reviewed document*, IEEE C802.16-04/14, June 28, 2004.
8. Parsons, D., 1994, *The Mobile Radio Propagation Channel*, Halsted Press: a division of John Wiley & Sons, New York/Toronto.
9. Prasad, N. R., 2000, *IEEE 802.11 System Design*, IEEE ICPWC.
10. European Radiocommunications Committee (ERC), *Study of the Frequency Sharing between HIPERLANs and MSS feeder links in the 5 GHz band*, ERC Report 67, February 1999, Marbella, European Conference of Postal and Telecommunications Administrations (CEPT).
11. ITU-R, *Methodology and criterion to assess interference from radio local area network (RLAN) transmitters to non-GSO MSS feeder links in the band 5150-5250 MHz*, ITU-R S.1427 (2000 version), International Telecommunication Union.

12. ITU-R, *e.i.r.p. Density Limit and Operational Restrictions for RLANs or Other Wireless Access Transmitters in Order to Ensure the Protection of Feeder Links of Non-Geostationary Systems in the Mobile-Satellite Service in the Frequency Band 5150-5250 MHz*, ITU-R M.1454 (2000 version), International Telecommunication Union.

Appendix

Examples of Fine-Scale Aggregate Power Results

The following examples illustrate the fine-scale aggregate power computation results, assuming that ANLE power levels have been reduced by factors that would be just sufficient to prevent interference even without other mitigation measures. The “warm” regions can easily be identified by referring to the color index scale shown beneath each map. An arrow is placed above the interference threshold value. Although the aggregate interference power level is below the threshold value at all locations for all of these plots, the relative exposure of different satellite locations is clearly shown in each plot.

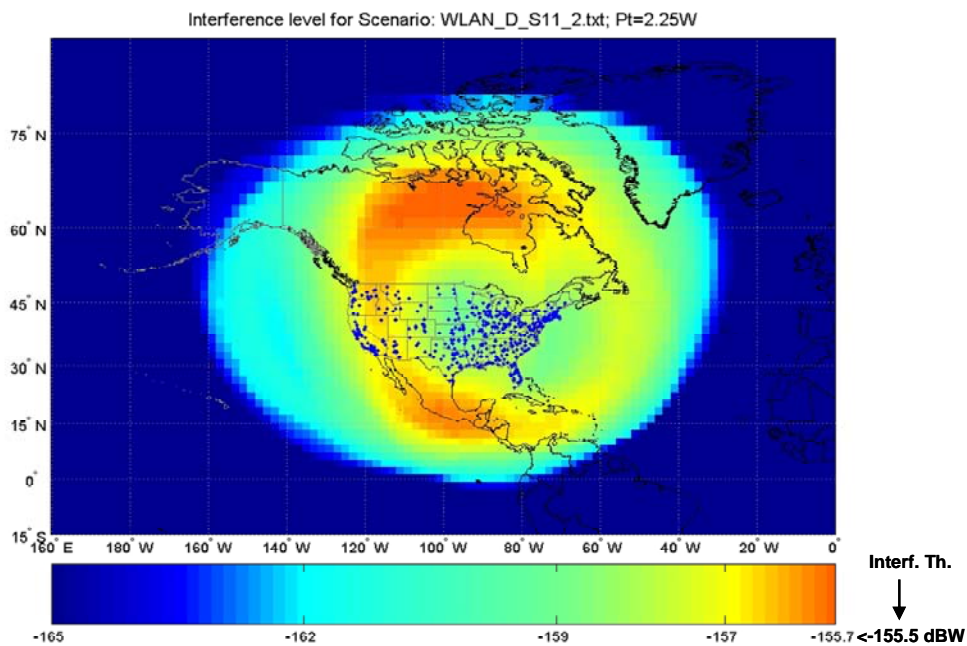


Figure A-1. Fine-Scale Map of Aggregate Power from 2.25 W 802.11a ANLE Transmissions to LEO-D

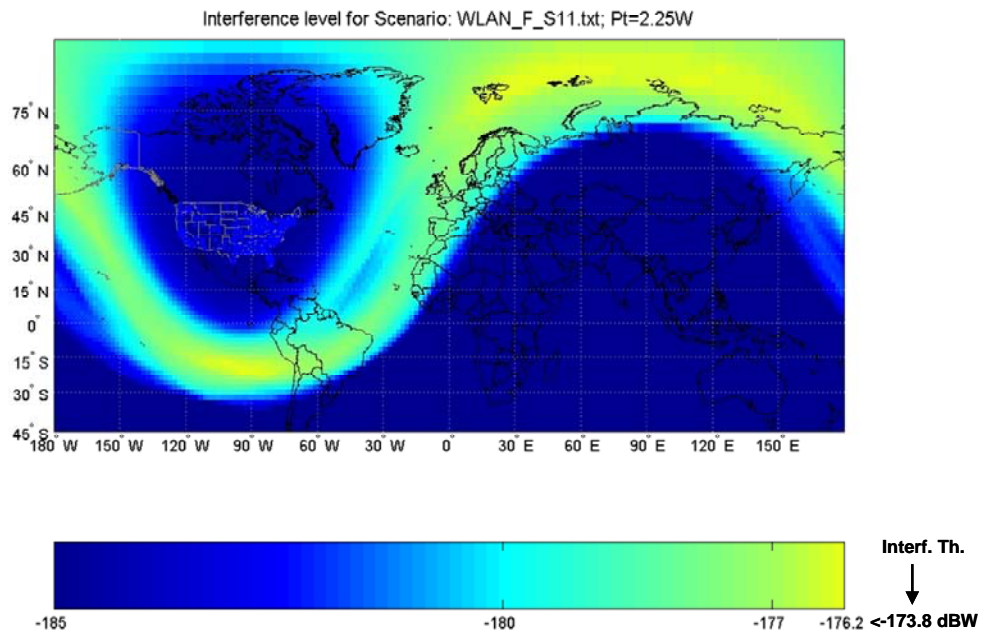


Figure A-2. Fine-Scale Map of Aggregate Power from 2.25 W 802.11a ANLE Transmissions to LEO-F

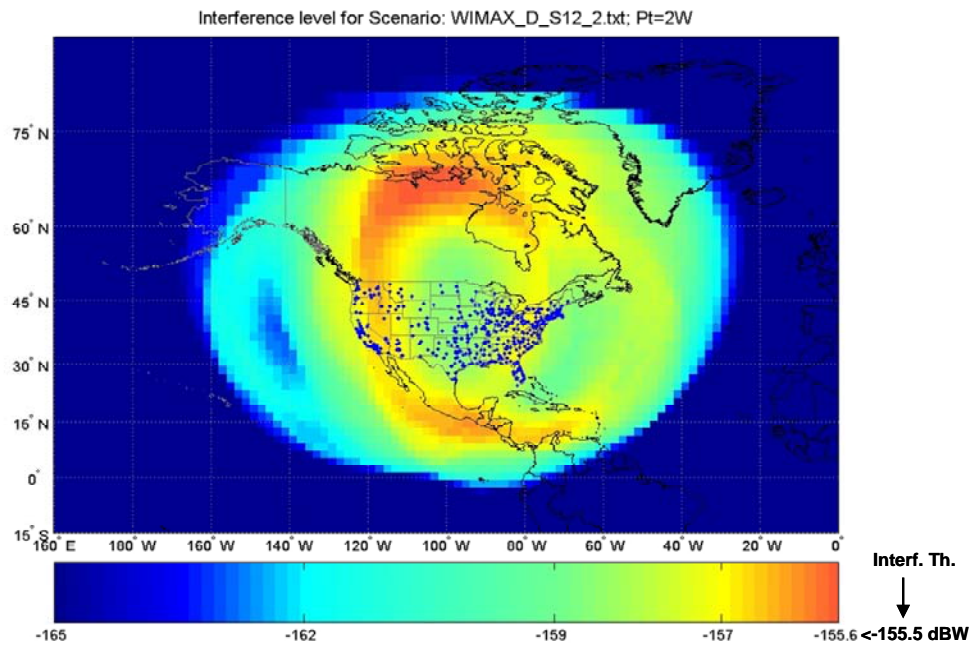


Figure A-3. Fine-Scale Map of Aggregate Power from 2 W 802.16e ANLE Transmissions to LEO-D

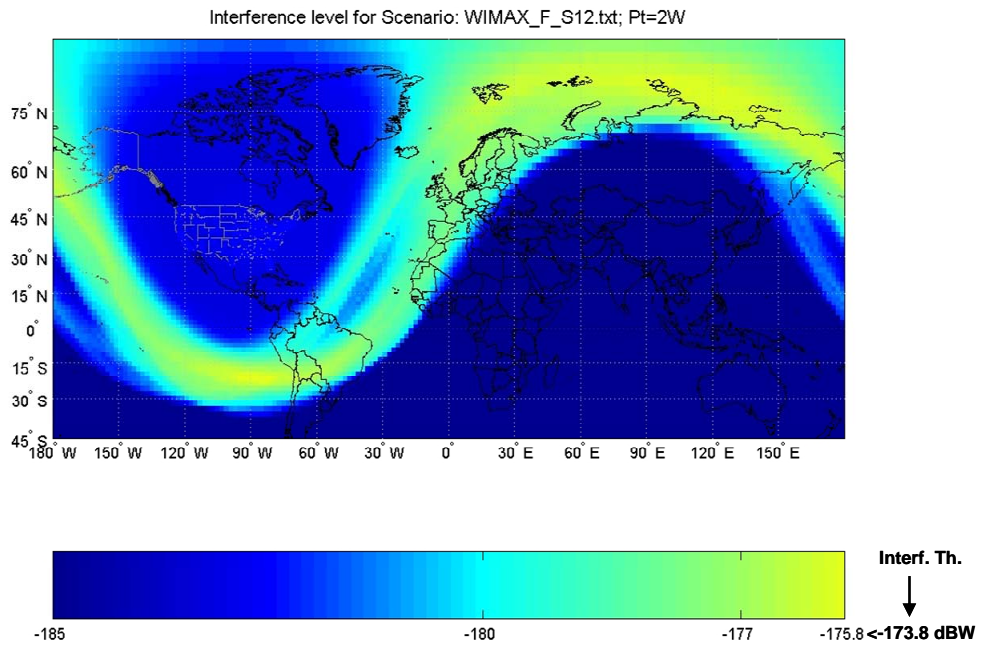


Figure A-4. Fine-Scale Map of Aggregate Power from 2 W 802.16e ANLE Transmissions to LEO-F

Glossary

ANLE	Airport Network and Location Equipment
ARNS	aeronautical radionavigation service
CAASD	Center for Advanced Aviation System Development
CONUS	contiguous United States
dB	decibel
dB_i	dB referred to lossless isotropic gain
dB_m	dB referred to one milliwatt
dBW	dB referred to one watt
FAA	Federal Aviation Administration
FOV	field of view
GHz	gigahertz
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
km	kilometer
LAN	local area network
LEO	low-earth-orbit
MHz	megahertz
MLS	Microwave Landing System
MSS	mobile-satellite service
NLOS	non-line-of-sight
non-GSO	non-geostationary
OFDM	Orthogonal Frequency Division Multiplexing
RLAN	radio local area network
U-NII	Unlicensed National Information Infrastructure
WRC	World Radiocommunication Conference