CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

Compatibility Analysis of Airport Wireless Local Area Networks and Satellite Feeder Links in the 5091-5150 MHz Band

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Introduction

- The 5000-5250 MHz frequency band is allocated to aeronautical radionavigation
  - WRC-07 offers an opportunity for new aeronautical mobile (R) allocations (safety communications) to share the band
- As part of the WRC-07 efforts, the FAA is considering the use of the 5091-5150 MHz subband for a future airport Local Area Network (LAN) system
  - Notional system termed Airport Network and Location Equipment (ANLE)
- The same subband has also been allocated, on a co-primary basis, to the fixed-satellite service (FSS) for use by non-geostationary (non-GSO) mobile-satellite service (MSS) feeder uplinks
- This briefing presents results of MITRE's 2005 compatibility analysis
- The impact of recent (2006) NASA/Ohio University propagation measurement results is also discussed

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Background

- The coverage area of an ANLE network is assumed to be a circle of up to about 3 km radius
- Two protocols in the IEEE 802 family of standards have been considered as potential candidates for ANLE implementation for the analysis
  - IEEE 802.11a
  - IEEE 802.16e
- Due to the mobility features of IEEE 802.16e, the remainder of the presentation focuses on this protocol

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IEEE 802.16 Standards Overview

- IEEE 802.16-2004
  - Specifies the air interface for fixed broadband wireless access (BWA) systems in the 2-66 GHz frequency range
  - Includes medium access control (MAC) layer and multiple physical layer specifications
  - Supports non-line-of-sight (NLOS) communications
    - 2-11 GHz frequency range
- IEEE 802.16e-2005
  - Expands IEEE 802.16-2004 to allow for mobile subscriber stations moving at ground vehicular speeds
- The results in this presentation are based on IEEE 802.16-2004 and IEEE 802.16e/D5

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Problem Statement and Analysis Approach

- **Problem statement**
  - If ANLE transmitters using IEEE 802.16e are eventually deployed at all 497 towered airports in CONUS, can they interfere with LEO-D and LEO-F satellites sharing the same subband?
- **Analysis approach**
  - Evaluate cochannel interference power level at the receiver input of victim satellites for ANLE transmissions implementing IEEE 802.16e
    - ANLE transmitting antennas are assumed to be omnidirectional
    - Aggregate interference received by satellite passing over each relevant cell area of 2°(latitude) × 2°(longitude)
  - Identify mitigation methods

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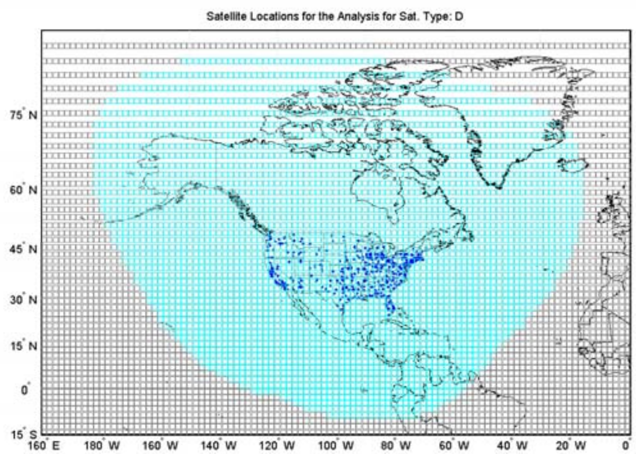
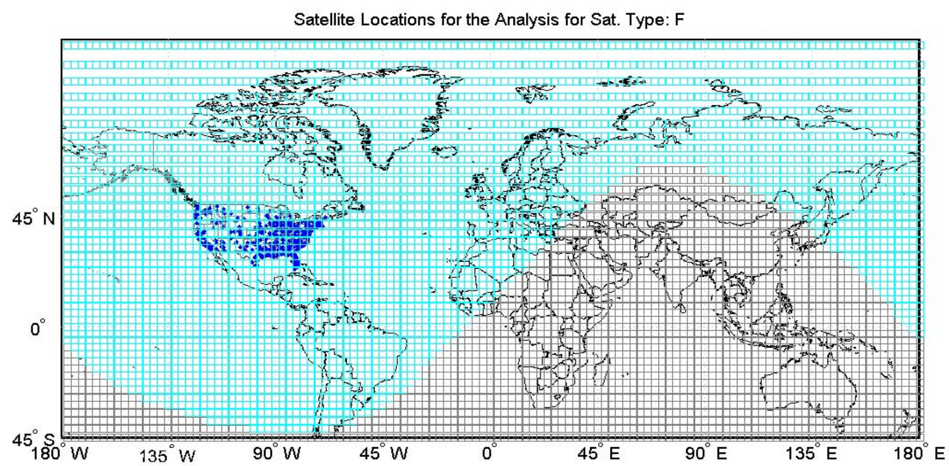
Subsatellite Locations Relevant to Analysis

LEO-D



LEO-F



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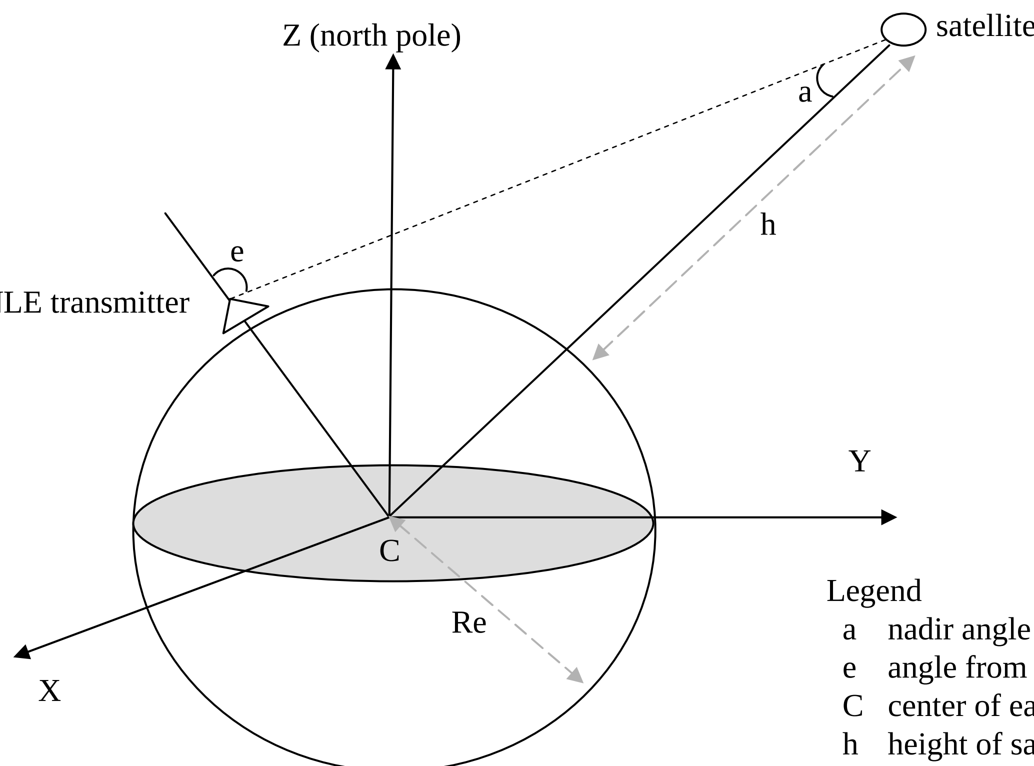
Interference-Computation Procedure (1 of 2)

- **Geometrical configuration**



Legend
a nadir angle
e angle from tx zenith
C center of earth
h height of satellite above mean sea level
Re radius of earth (6397 km)

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Interference-Computation Procedure (2 of 2)

- **Computations performed at frequency 5120 MHz**
- **Interference power, P_r, at receiver is calculated as**

$$P_r(dBm) = P_t(dBm) + G_t(dBi) + G_r(dBi) - L_{pfs}(dB) - L_{feed}(dB) - L_c(dB) - L_p(dB) + \beta_f(dB)$$

<u>Legend</u>

P_r	received power
P_t	transmitted power
G_t	ANLE antenna gain toward satellite
G_r	satellite antenna gain toward ANLE
L_{pfs}	free-space path loss
L_{feed}	feed loss
L_p	polarization discrimination
L_c	cable loss
β_f	bandwidth factor

- **If $P_r \geq$ ITU-defined threshold, interference results**

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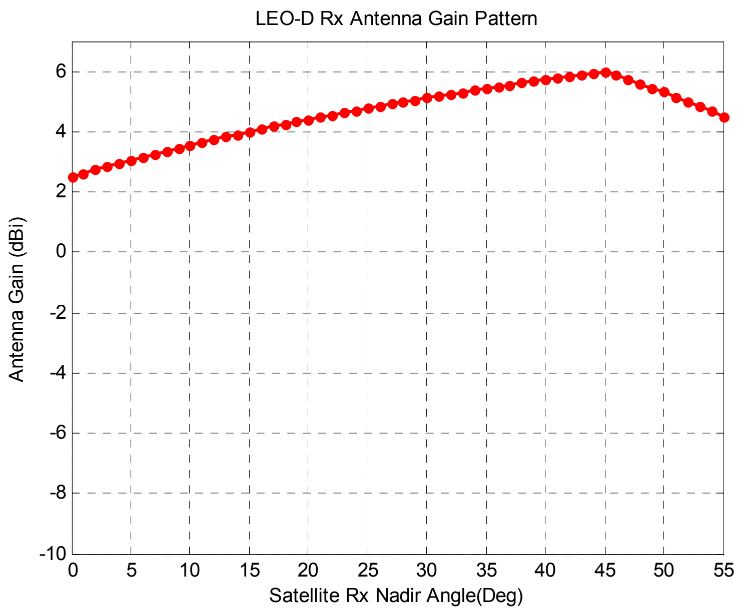
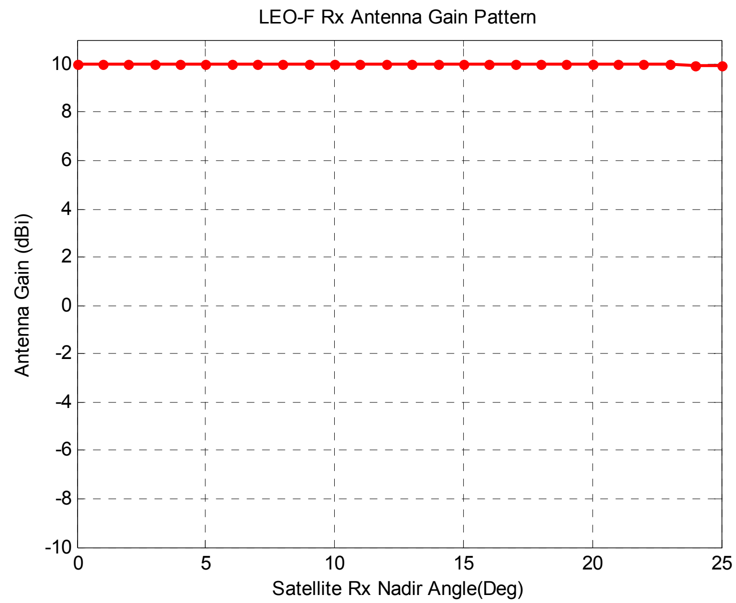
Characteristics of LEO (1 of 2)

- **Receiver antenna gain patterns**





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Characteristics of LEO (2 of 2)

- **Parameter values are based on ITU-R recommendation M.1454**

Parameter	LEO-D	LEO-F
Satellite orbit altitude (km)	1414	10390
Satellite receiver noise temperature (K)	550	400
Criterion	3%*	3%*
Interference threshold (dBW)	-155.5	-173.8
Polarization discrimination (dB)	1	1
Feed loss (dB)	2.9	0
Satellite receiver bandwidth (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 (km) between subsatellite point and ANLE transmitter visible from satellite	3921	7558

*We adopt the interference criterion of 3% increase of the satellite receiver's noise temperature as specified in ITU-R recommendation S.1427

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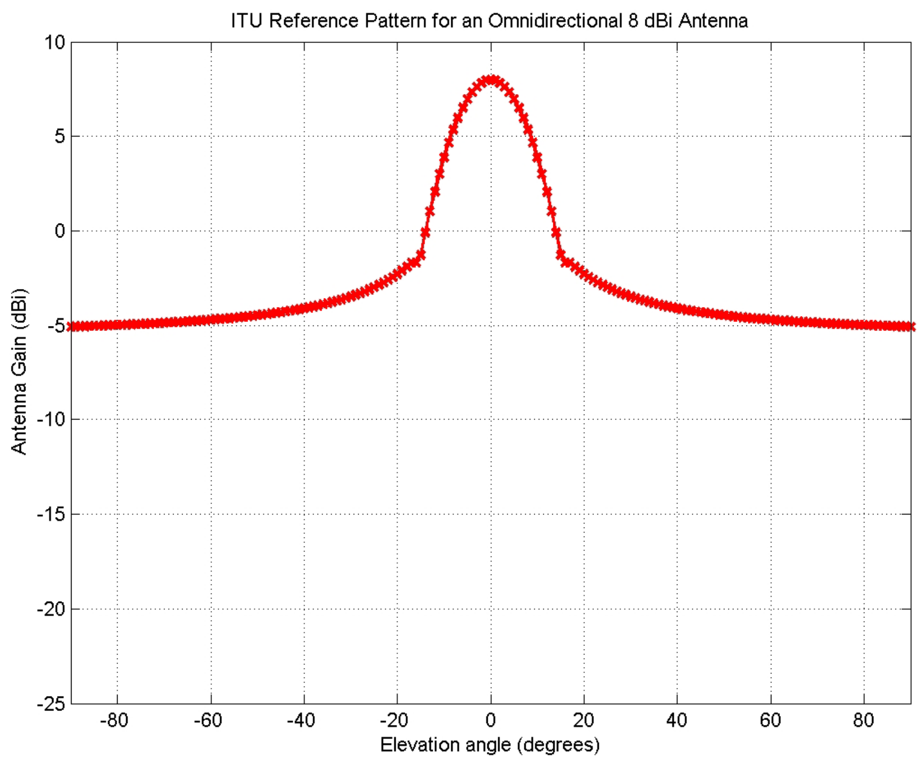
Characteristics of ANLE (1 of 3)

- **ANLE transmitter antenna pattern**

  - According to ITU recommendation ITU-R F.1336-1



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Characteristics of ANLE (2 of 3)

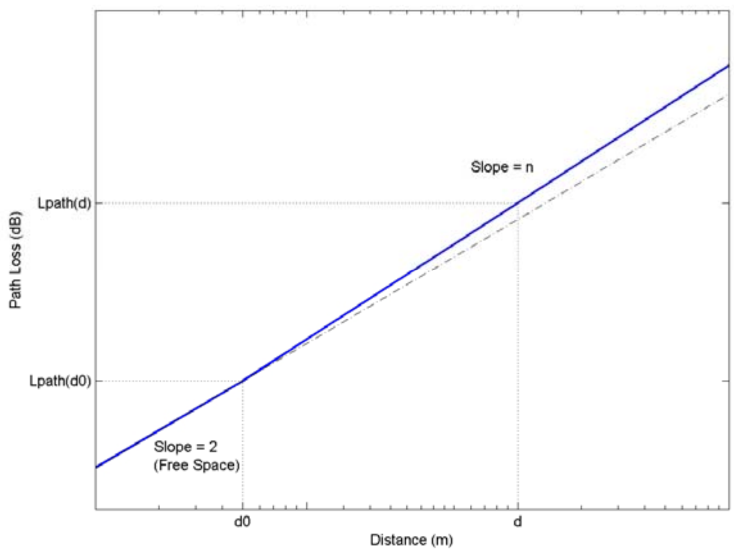
- **Path loss equation**

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

where:

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

$$L_{free}(d_0) = 32.44 + 20\log_{10}(f_{MHz}) + 20\log_{10}\left(\frac{d_0}{1000}\right)$$



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Characteristics of ANLE (3 of 3)

Parameter	IEEE 802.16e
Emission bandwidth (MHz)	20
Receiver sensitivity (dBm)	-80.1[a]
Transmitter antenna gain (dBi)	8.0
Receiver antenna gain (dBi)	6.0
Assumed link margin (dB) [b]	11.0
Assumed path-loss exponent n [c]	2.2
Assumed distance d_0 (m) [c]	5
Transmitter power required [d]	38.6 dBm (7.3 W)

Notes:

a. Calculated minimum receiver performance based on IEEE 802.16 standard
b. Value estimated from indirect data
c. Different values of n and d_0 were obtained in the NASA/Ohio University measurement program after we published our initial results (2005)
d. Transmitter power required to communicate to nodes 3 km away

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Impact of Recent 5-GHz Test Results

- **Recent NASA/Ohio University measurements show that n = 2.3 and d_0 = 462 meters, based on a curve fitting with a standard deviation of 9 dB**
- **The path loss used in MITRE’s study of ANLE/MSS feeder link band-sharing is larger (thus more conservative) than the path loss obtained using the subsequent measurement results**
- **The difference between the calculated path losses is less than 4 dB (3.1 dB at 3 km), much less than the curve-fitting standard deviation (9 dB)**
- **Thus our initial results are essentially consistent with the new propagation measurements**

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Bandwidth Factor

- Bandwidth factor $\beta_f = B_{LEO}/B_{ANLE}$ determines amount of ANLE interfering power falling into victim's 'filtered' bandwidth
  - B_{LEO} : victim LEO satellite receiver bandwidth
  - B_{ANLE} : interfering ANLE transmitter bandwidth
- The values of β_f are:

	IEEE 802.16e
LEO-D	-12.1 dB
LEO-F	-29.0 dB

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Analysis for 802.16e ANLE System

- **Aggregate interference power computation results**
  - **Worst-case ANLE transmitter power level = 38.6 dBm (7.3 W)**

	Interference threshold (dBW)	Aggregate interference power at hottest 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

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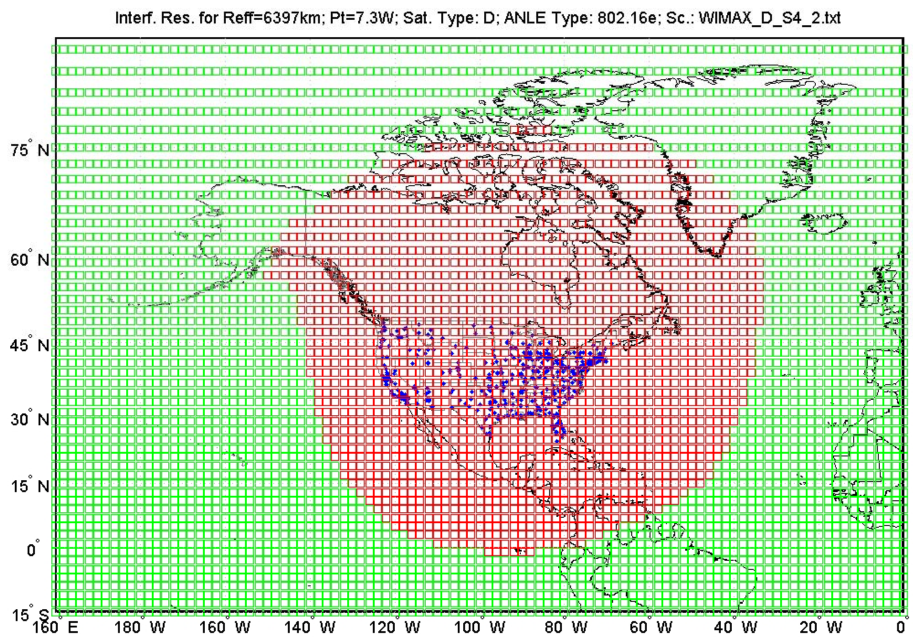
Examples of Computation Results (1 of 2)

- **Victim: LEO-D**
- **Interferer: ANLE 802.16e transmitting at 7.3 W (38.6 dBm)**
  - **Red: interference level >= threshold**
  - **Green: interference level < threshold**
  - **Worst-case assumptions (including 100% duty cycle)**



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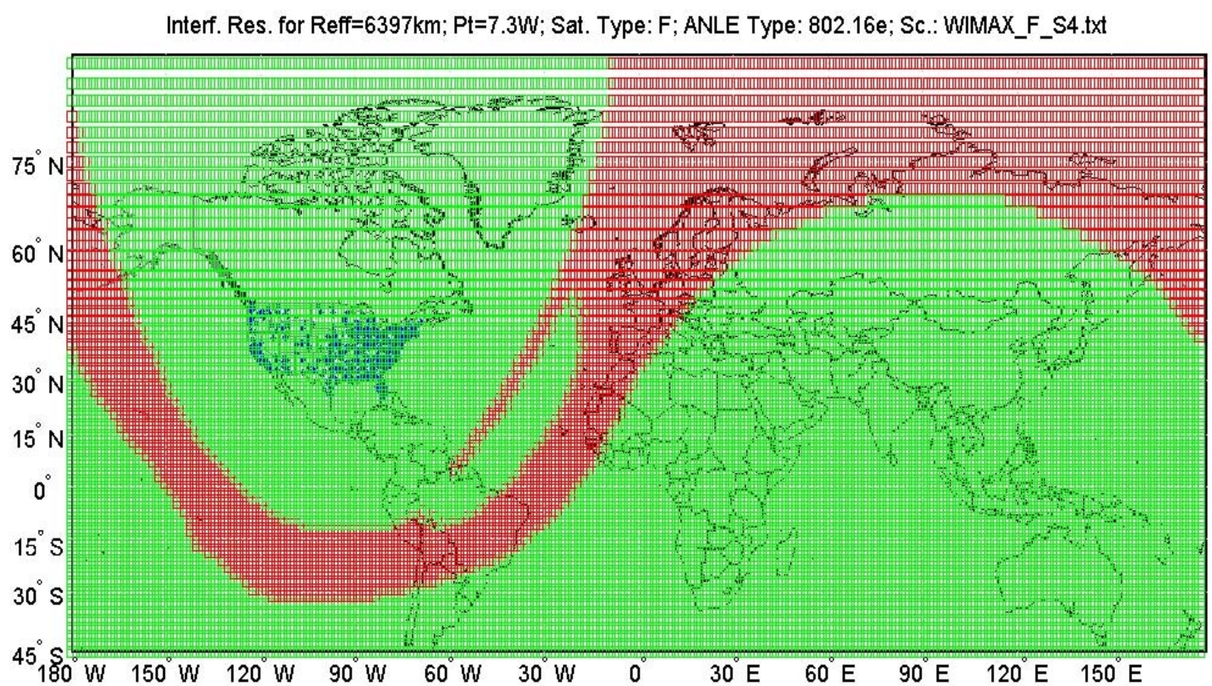
Examples of Computation Results (2 of 2)

- **Victim: LEO-F**
- **Interferer: ANLE 802.16e transmitting at 7.3 W (38.6 dBm)**
  - **Red: interference level >= threshold**
  - **Green: interference level < threshold**
  - **Worst-case assumptions (including 100% duty cycle)**



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Mitigation Methods and Expected Results (1 of 2)

- **Three mitigation methods are considered**
  - **(1) Use more-sensitive ANLE receivers**

	Value used in present study	Possible value for more-sensitive receiver	Resultant interference power reduction
802.16e	-80.1 dBm	-84.1 dBm (1)	**4 dB**
(1) IEEE 802.16 Standard and IEEE C802.16-04/14			

  - **(2) Ensure ANLE transmissions do not exceed 50% duty cycle**
    - **ANLE duty cycle of 50% considered conservative enough while still being reasonably realistic**
    - **Compared to 100% duty cycle, this translates to 3 dB reduction in ANLE aggregate transmitter power**

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Mitigation Methods and Expected Results (2 of 2)

- (3) Use 3 ANLE subnetworks per airport to reduce cochannel interfering power
  - Each subnetwork uses a different frequency channel
  - If three 20-MHz frequency channels are used, the effective interfering power drops ~4 dB

- **Total reduction (in dB) of interfering power upon employing all 3 mitigation methods is 11 dB**
  - Compared to 5.5 dB reduction required to eliminate interference from ANLE networks using 802.16e

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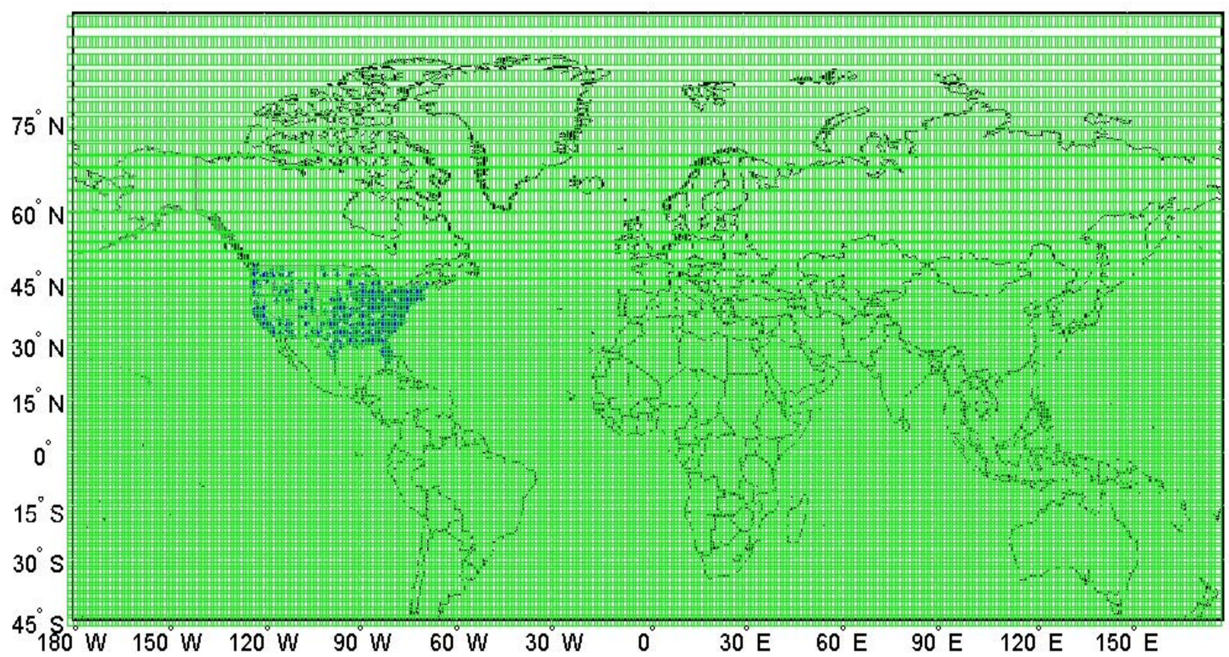
Interference-Free Operation Achieved Using Appropriate Mitigation Methods

- **Interference–free operations of LEO-D and LEO-F in the presence of ANLE system using an appropriate combination of the 3 mitigation methods**



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Conclusions and Future Work

- It seems feasible for ANLE systems (based on IEEE 802.16e) to share the 5091-5150 MHz band with MSS feeder uplinks for LEO-D and LEO-F satellites provided that:
  - The 3% interference criterion applies (as in ITU S.1427)
  - An appropriate combination of the following interference mitigation approaches is employed
    - Use more-sensitive ANLE receivers
    - Ensure ANLE transmitters do not exceed duty cycle of 50%
    - Use a 3-frequency channel allocation strategy for ANLE networks
- The recent measurements tend to support the findings of our 2005 band-sharing analysis
- Future work
  - Identify applicable duty cycle values for an ANLE network based on given application scenarios for such a network
  - Perform analyses for scenarios using the recently approved IEEE 802.16e scalable OFDMA physical layer implementation

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BACKUP SLIDES

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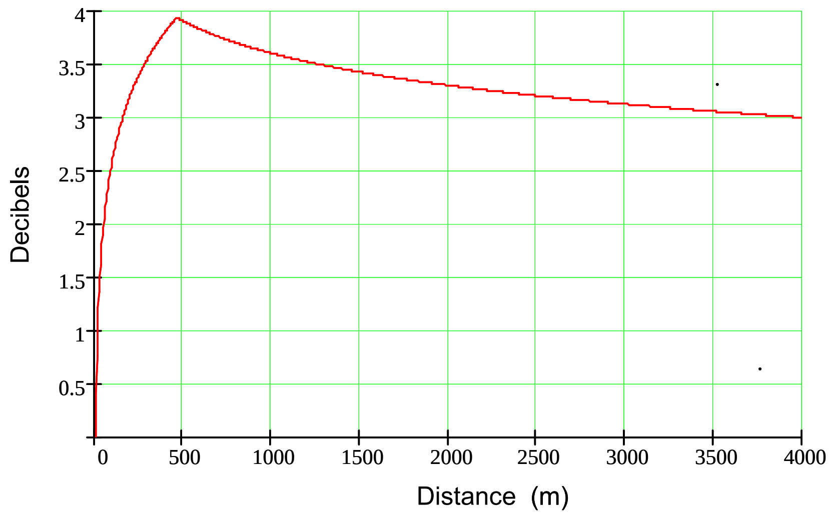
Review of Recent 5-GHz Test Results

Parameter	Values Assumed in 2005 MITRE Study	Values Obtained from 2006 Measurement Results
Path loss exponent *n*	2.2	2.3
Distance d_0 (m)	5	462

- **Notation:**
  - **–M(d) = path loss obtained using the 2005 MITRE assumptions**
  - **–N(d) = path loss obtained using the new (2006) measurement results from NASA/Ohio University 5-GHz field tests**
  - **–Difference M(d)-N(d) is plotted**



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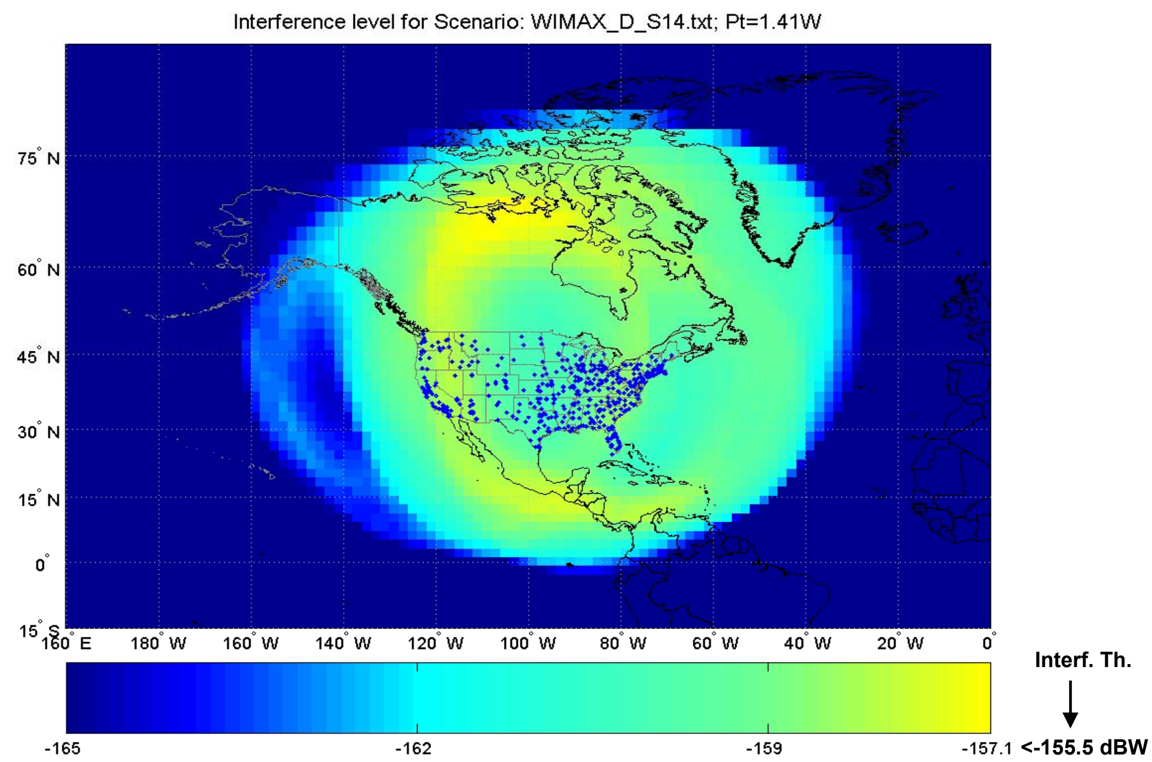
Fine-Scale Map of Aggregate Power Results (1 of 2)

- **Fine-scale aggregate power computational results**
  - **Victim: LEO-D**
  - **Interferer: ANLE 802.16e power of 1.41 W (31.5 dBm), using:**
    - **New path loss parameters**
    - **Receiver sensitivity of -84.1 dBm**



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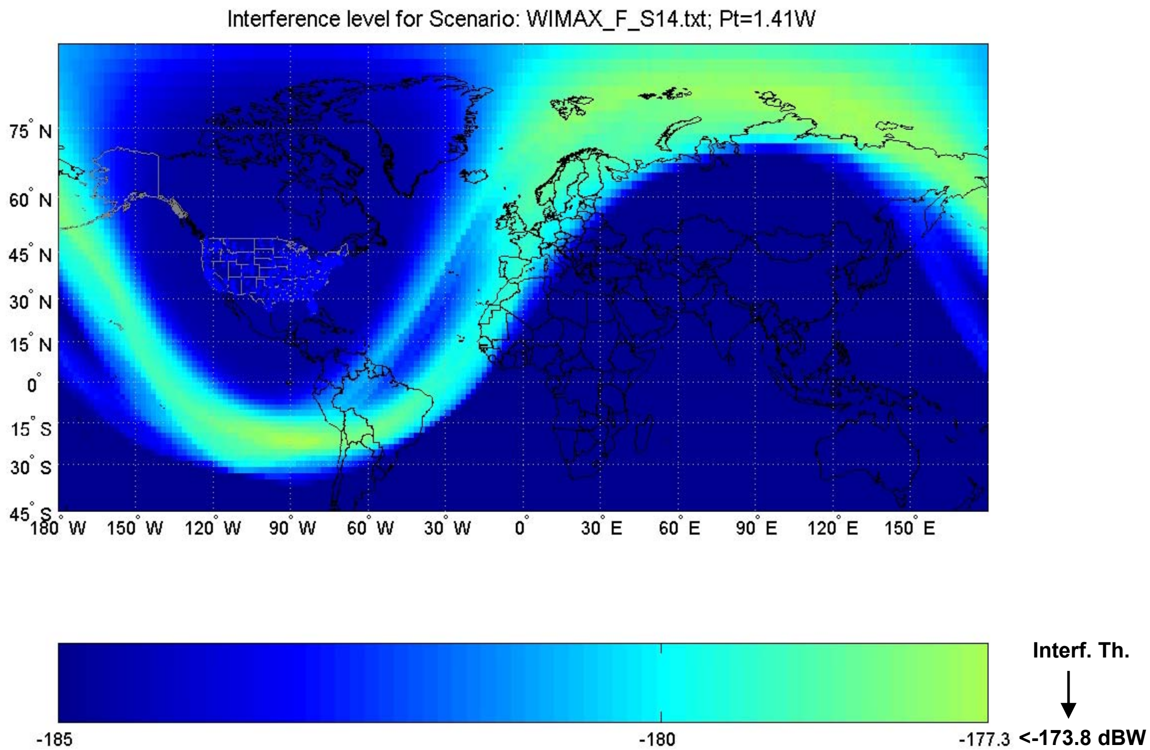
Fine-Scale Map of Aggregate Power Results (2 of 2)

- **Fine-scale aggregate power computational results**
  - **Victim: LEO-F**
  - **Interferer: ANLE 802.16e power of 1.41 W (31.5 dBm), using:**
    - **New path loss parameters**
    - **Receiver sensitivity of -84.1 dBm**



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