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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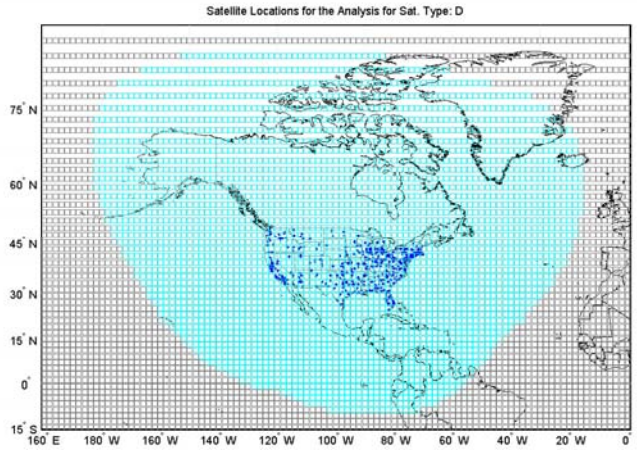
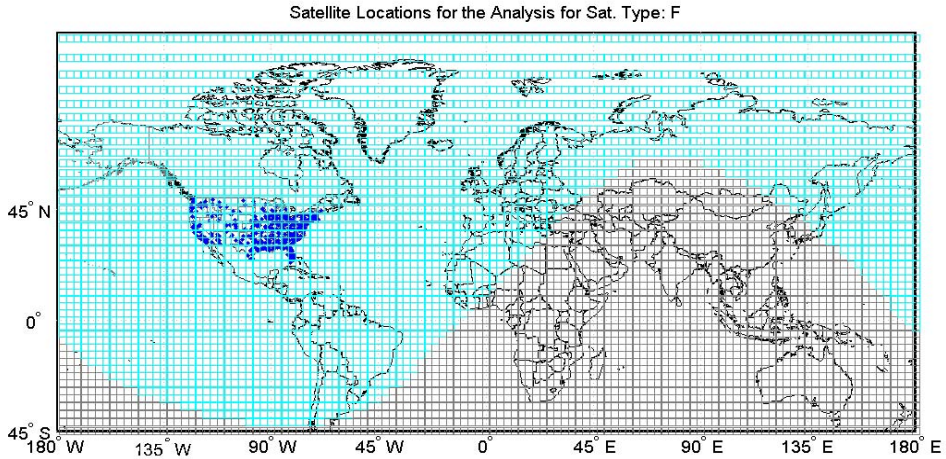
# Subsatellite Locations Relevant to Analysis

## LEO-D




## LEO-F



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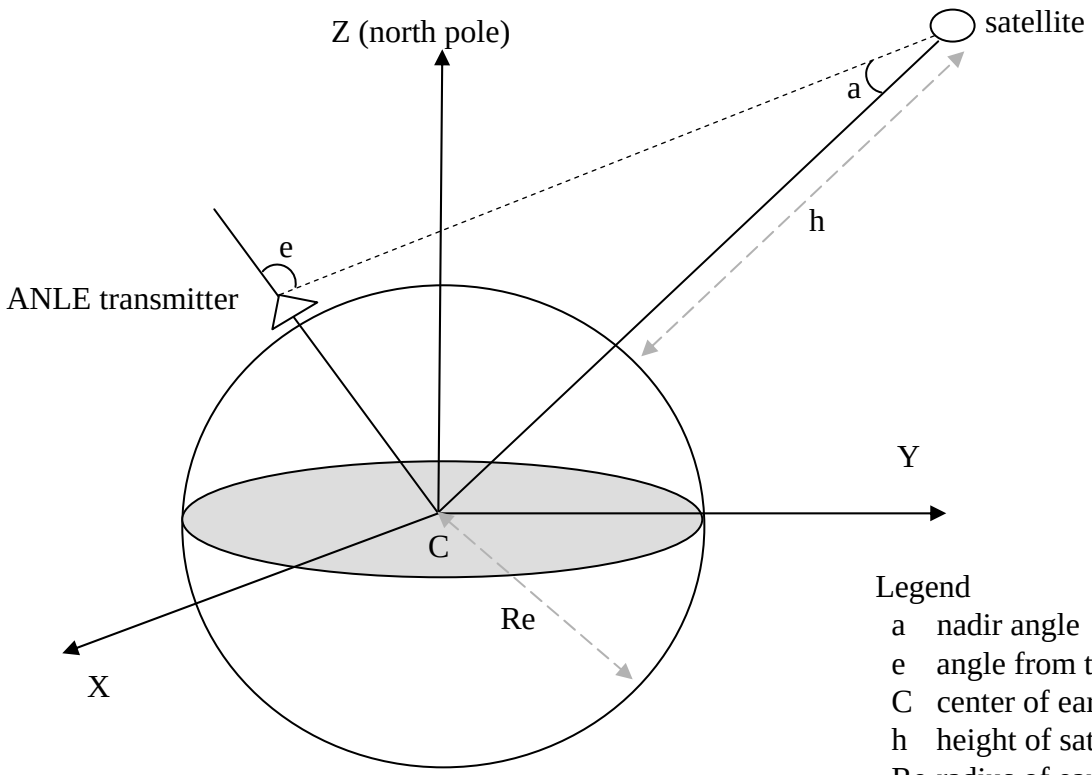
# Interference-Computation Procedure (1 of 2)

- **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**

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

Legend

| | |
|---|---|
| $P_r$ | 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 |
| $\beta_f$ | bandwidth factor |

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



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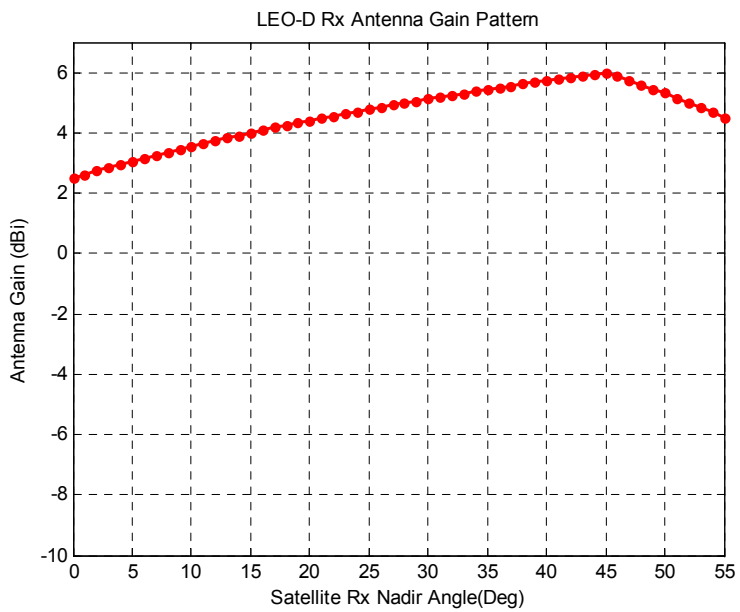
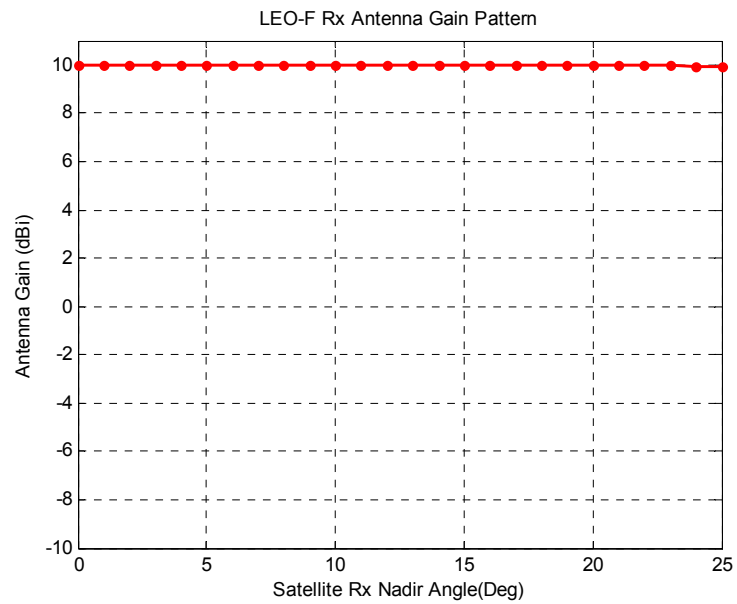
# Characteristics of LEO (1 of 2)

- **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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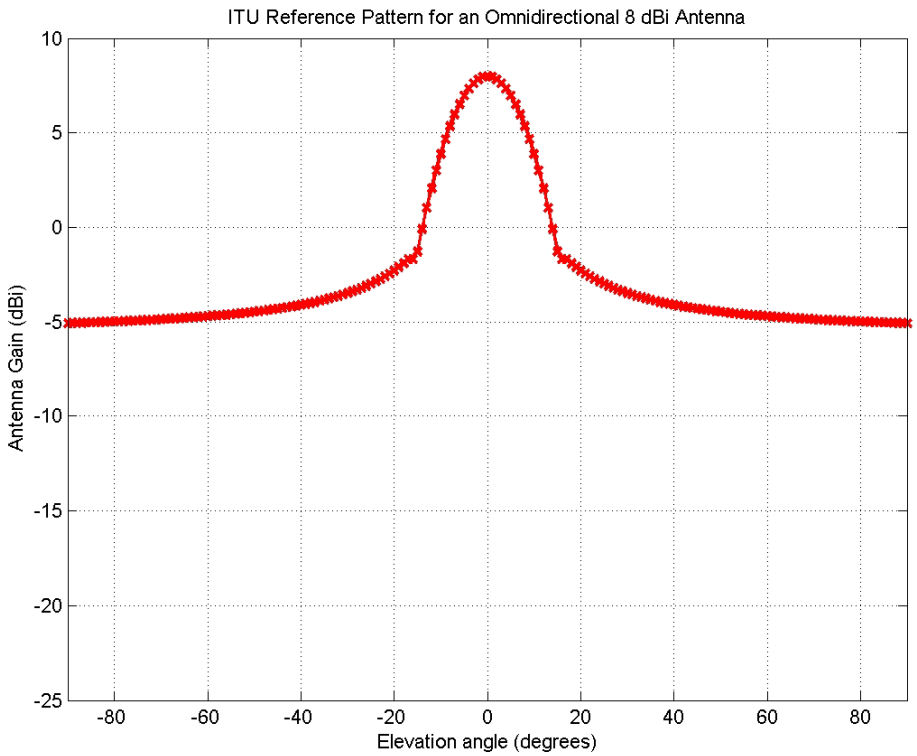
# Characteristics of ANLE (1 of 3)

- **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**

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

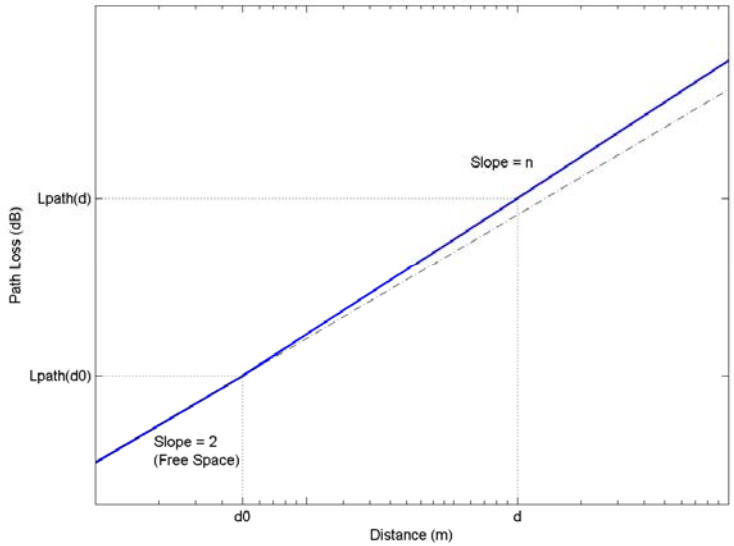
**where:**

***$L_{free}$*** **= 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 $\beta_f$ 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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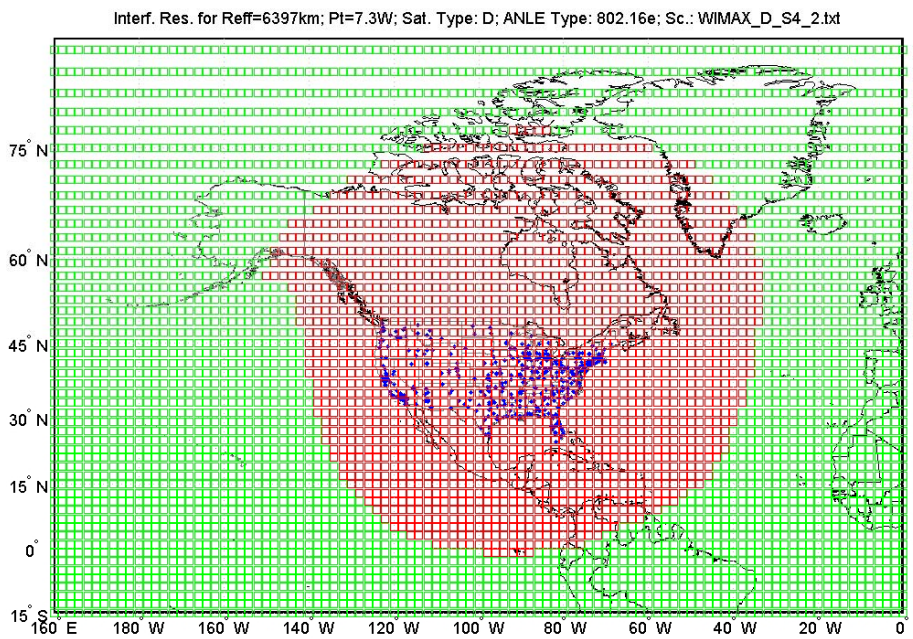
# Examples of Computation Results (1 of 2)

- **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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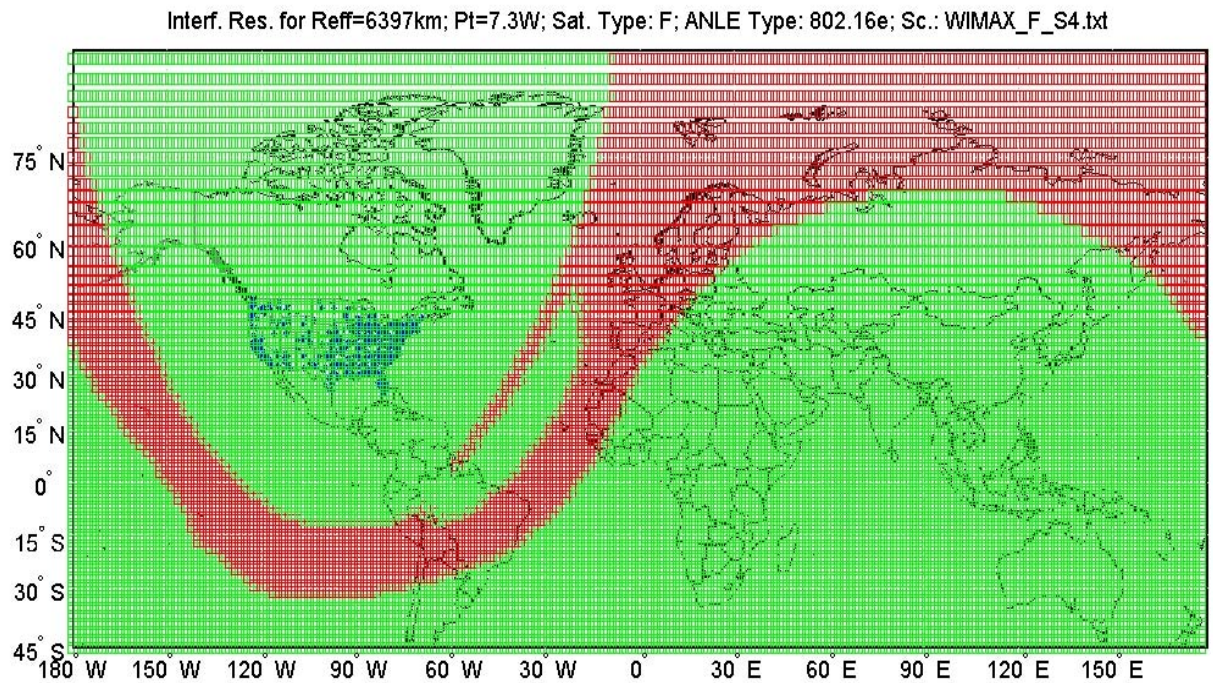
# Examples of Computation Results (2 of 2)

- **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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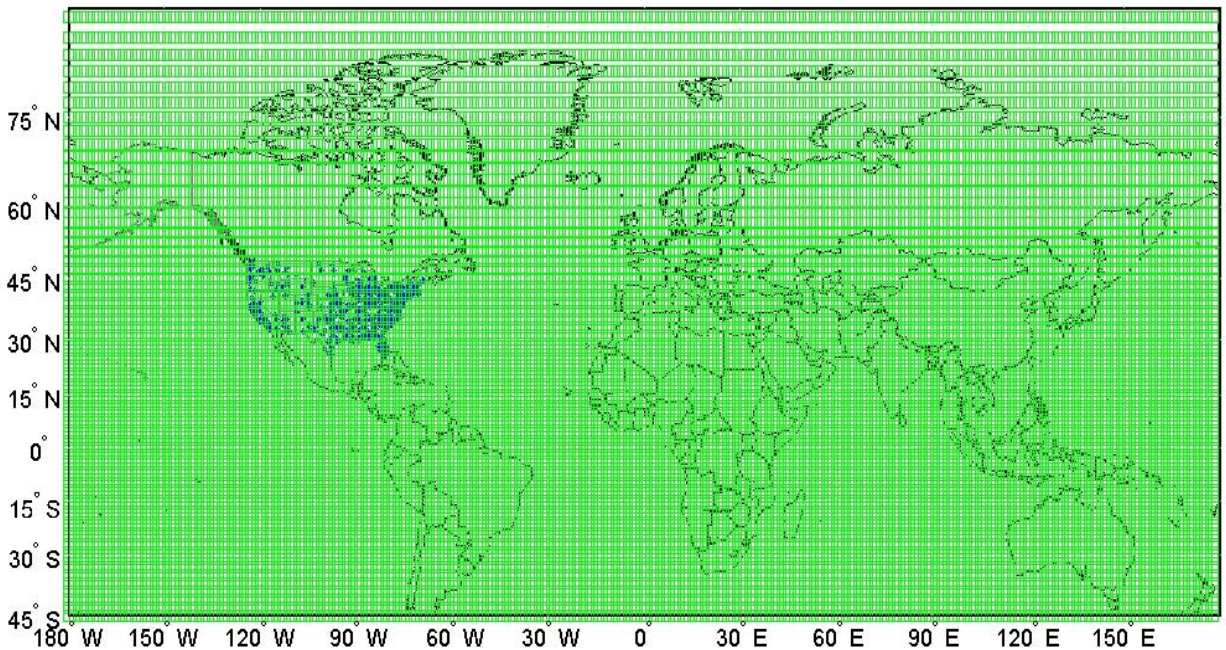
# Interference-Free Operation Achieved Using Appropriate Mitigation Methods

- **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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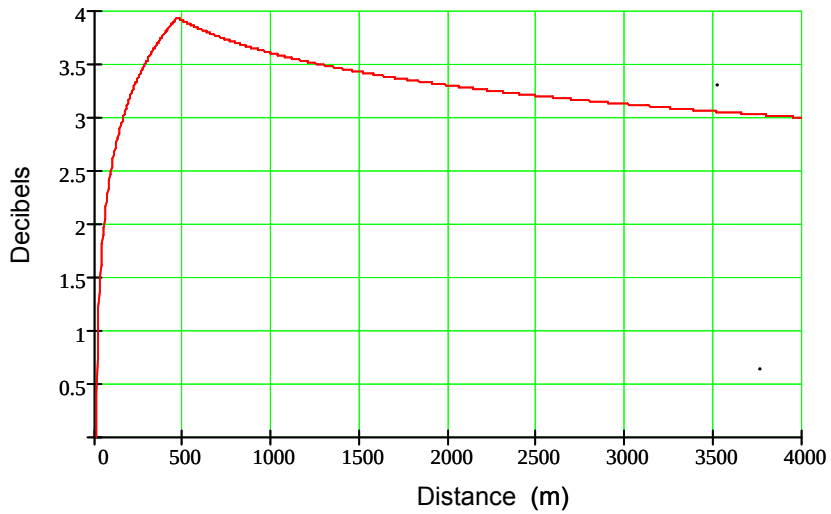
# Review of Recent 5-GHz Test Results

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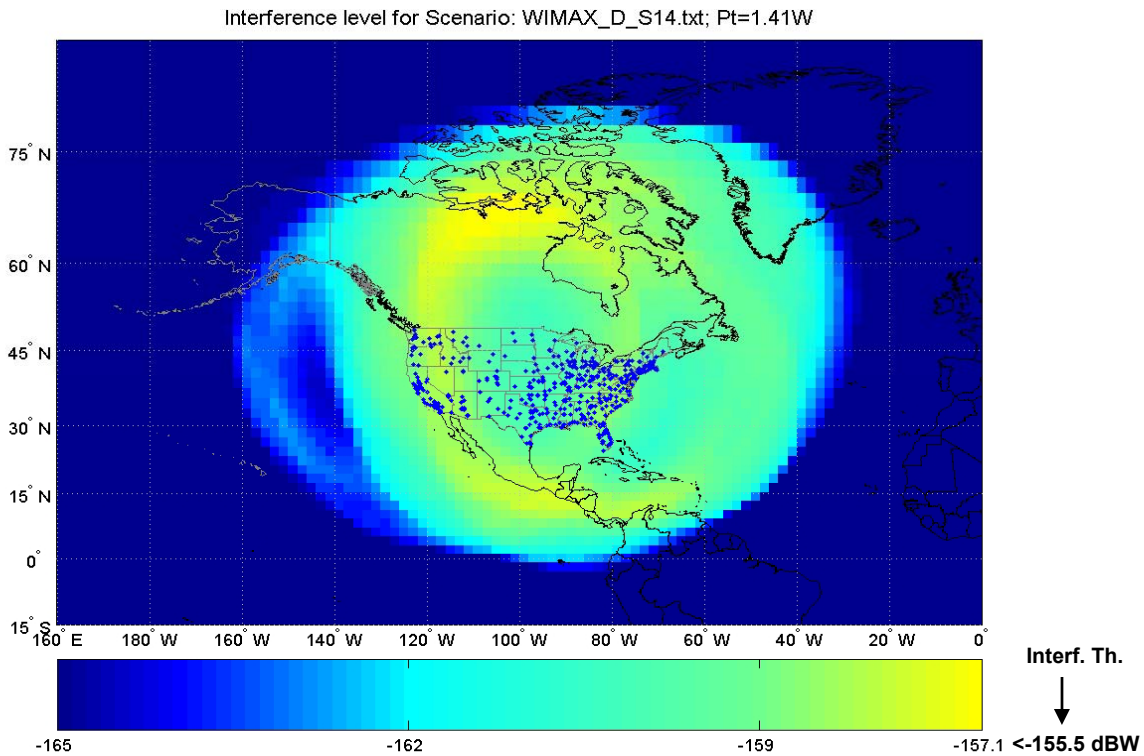
# Fine-Scale Map of Aggregate Power Results (1 of 2)

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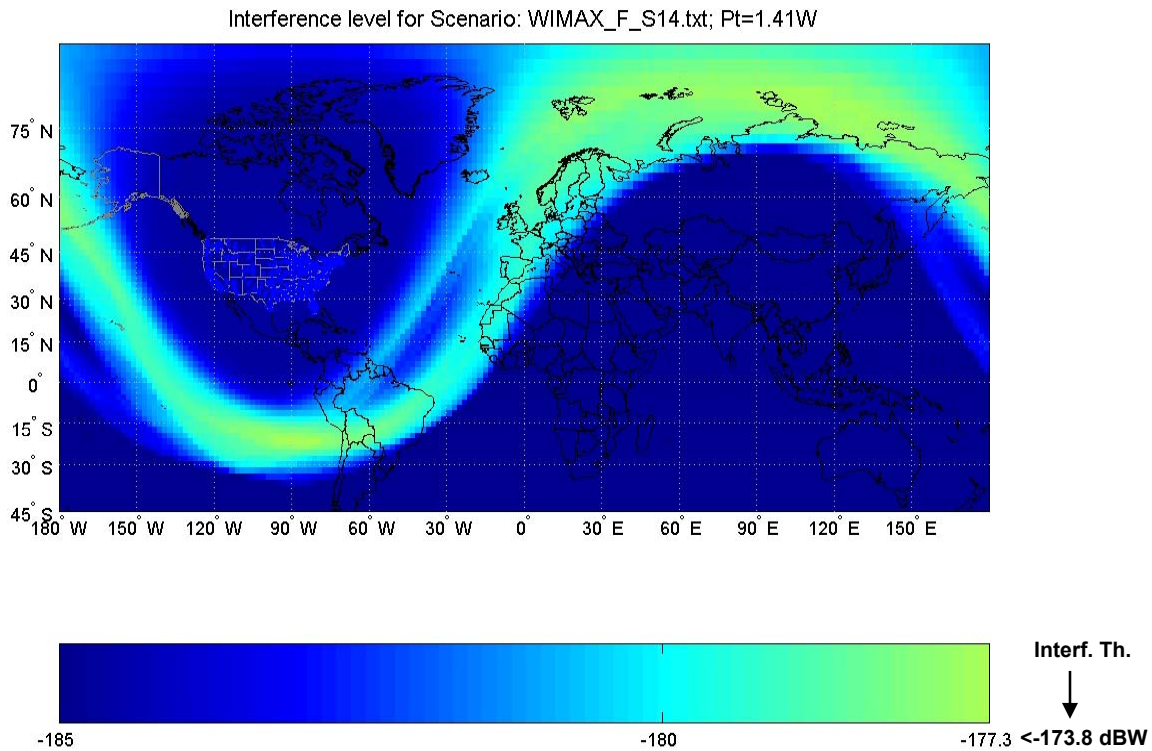
# Fine-Scale Map of Aggregate Power Results (2 of 2)

- **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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