Commerce Spectrum Management Advisory Committee (CSMAC)

Working Group 3 (WG 3) Report on

1755-1850 MHz Satellite Control and Electronic Warfare

Contents

1 Introduction

CSMAC WG 3 developed the following mission statement to guide its work:

Mission Statement

> CSMAC WG 3 will focus on recommendations to optimize industry access to the 1755-1850 MHz band while protecting federal operations. This work shall consider the entire 1755-1850 MHz band while taking into account the industry priority to access to 1755-1780 MHz first. Deliverables include recommendations regarding definition and specification for sharing techniques with satellite operations (including any interference acceptance rules and coordination zones) and improved coordination rules and procedures for electronic warfare.

1.1 Executive Summary of Working Group Findings

CSMAC WG 3 was responsible to study the sharing between satellite control systems and Long Term Evolution (LTE) (LTE is a standard for wireless mobile communication standardized by 3GPP) as well as LTE and Electronic Warfare in the 1755-1850 MHz band. Three interference scenarios were identified and the following conclusions were reached.

With respect to potential harmful interference caused by LTE devices to satellite control systems (SATOPS), working group analysis found negligible interference predicted to all satellite programs except possibly a few experimental spacecraft based upon current deployment and operational assumptions. A power flux density of -179 dBW/Hz/m^2 was determined to be a safe interference level for satellites in geostationary orbit. Specifying the protection level for geostationary orbit also protects satellites at other altitudes.

With respect to potential harmful interference by SATOPS ground stations to LTE base stations, analysis showed that the SATOPS ground stations only radiate a relatively small percentage of the time: 8-13% of the time in the lower portions of the band (1761-1780 MHz), with higher radiating percentages in the upper (1780-1842 MHz) portions of the band. Analysis found that when the SATOPS ground stations radiate, they only use a small fraction of the overall band (typically 0.2 to 4 MHz of the 1761-1842 MHz band) at any one time. The group identified a number of technologies and techniques with significant potential to mitigate harmful interference when it does occur. It therefore concluded that LTE operations can effectively share the 1761-1842 MHz band with satellite operations.

With respect to Electronic Warfare, the group recommended continuing Electronic Warfare (EW) Research, Development, Test and Evaluation (RDT&E), training and Large Force Exercise (LFE) operations in the band, on DoD ranges and within associated airspace, on a Non-Interference Basis (NIB) using existing national coordination procedures.

In summary, CSMAC WG 3 concluded that satellite control systems and Electronic Warfare operation can co-exist with LTE operations in the 1755-1850 MHz band.

1.2 Summary of WG 3 Recommendations for Presentation to CSMAC

Below are all the recommendations from CSMAC WG 3. The recommendations number is a reference to the section of the report from which they originate.

Recommendation 3.2.1-1: The CSMAC recommends that NTIA allow the federal agencies to continue to conduct EW RDT&E, training and LFE operations on DoD ranges and within associated airspace on a NIB with commercial wireless operations, if introduced to the band.

Recommendation 3.2.1-2: The CSMAC recommends that NTIA and FCC evaluate current simulation and modeling tools, techniques and management processes used to coordinate EW RDT&E, training and LFE operations to ensure they are robust enough to allow timely and effective deconfliction with potential commercial wireless operations in the band.

Recommendation 3.2.1-3: The CSMAC recommends that NTIA, FCC and DoD assess the usefulness of establishing a formal coordination process between DoD and commercial wireless service providers to assist with spectrum sharing issues on a localized basis.

Recommendation 3.2.1-4: The CSMAC recommends that NTIA add additional information concerning the procedures for performing EA in the United States to section 7.14, Use of Frequencies for the Performance of Electronic Attack Test, Training and Exercise Operations, of the NTIA Manual. (see section 3.2.3)

Recommendation 4.2.3-1: NTIA should direct federal earth station operators to document in their transition plans publicly releasable information to allow prospective licensees to understand the potential impact to any base station receivers from SATOPS uplinks. Detailed information to be provided by the federal users should include:

- Contours within which radiated power levels from federal earth stations is likely to exceed the -137.4 dBW LTE interference threshold (1 dB desense) assuming worst case conditions of maximum transmit power at minimum elevation angle.
- Contours within which radiated power levels from federal earth stations is likely to remain below the -137.4 dBW LTE interference threshold (1 dB desense) as calculated at 100%, 99%, and 95% of the time assuming nominal operating conditions, based on recent historical use. Usage of federal earth stations can and will change with time, and is not limited by the information provided.

Recommendation 4.2.3-2: NTIA should recommend that the FCC, in consultation with the NTIA, consider methods to allow government agencies to share with commercial licensees information relevant to spectrum sharing in the vicinity of federal earth stations, subject to appropriate non-disclosure or other agreements, consistent with US law and government policies.

Recommendation 4.2.3-3: The space operation service (Earth-to-space) remains a primary service in the 1761 – 1842 MHz band, as defined in Government footnote G42.

Recommendation 4.2.3-4: NTIA should recommend the FCC require that commercial licensees accept interference from federal SATOPS earth stations operating in the 1761-1842 MHz band.

Recommendation 4.2.3-5: NTIA should direct federal earth station operators to identify and document in their transition plans the cost and schedule required to accelerate and/or expand the transition of all federal earth stations to radiate a narrower bandwidth signal.

Recommendation 4.2.4-1: NTIA should recommend establishment of rules/regulations with built in flexibility for future SATOPS growth and change, including satellite network and ground station locations/configurations. New federal earth station locations must be determined in coordination with commercial licensees. For existing federal earth stations, federal users must notify commercial licensees of significant changes such as additional antenna or extended anomaly support.

Recommendation 4.2.4-2: NTIA should recommend all federal costs related to planning, sharing and continued compatibility activities for satellite sharing should be part of the federal agencies’ cost estimate and fundable through the Spectrum Relocation Fund (SRF). Agencies should remain eligible for SRF funds as long as federal agencies operate and incur costs related to sharing satellite operations with commercial operation in the 1761-1842 MHz band.

Recommendation 4.2.4-3: NTIA should recommend that the FCC, in consultation with NTIA and relevant federal agencies, develop methods for licensees in the 1761-1842 MHz band to demonstrate technologies or techniques that ensure commercial operations can accept interference from the satellite operations when operating within the zones where the nominal SATOPS power is expected to exceed the LTE interference threshold (a 1 dB desense), prior to deployment of base stations in the zones.

Recommendation 4.2.6-1: CSMAC recommends that the FCC propose in their rulemaking a requirement on licensees which overlap any of the 1761-1842 MHz band that specifies a technical showing of compatibility with satellite uplinks.

- The aggregate for all licensees on the same frequency is a compliance level, in terms of power flux density at the geostationary orbit (GSO), not to exceed -179 $dBW/Hz/m^2$.
- The initial showing shall be provided no later than 2 years after the issuance of the license and must contain technical data supporting the current deployment and an projected estimate of the deployment for 5 years in the future.
- The showing shall be updated on a periodic basis to be determined by the FCC.
- Due to the nature of such a showing, all data shall be proprietary between the licensee, FCC and NTIA (including government earth station operators).

Draft Recommendation 4.2.6-2: CSMAC recommends the FCC consider in its rulemaking methods to ensure that the following conditions be met to ensure the aggregate commercial wireless mobile broadband emissions will not exceed the acceptable threshold power level, including:

- Method to aggregate the individual showings into a single value expected at the GSO arc from all licensees.
- The actions to be taken by the FCC to reduce the projected aggregate emissions if it is projected to exceed the threshold.
- The actions to be taken by the FCC to eliminate harmful interference if it does occur, to include potential cessation of operations by the commercial licensee(s) on the affected frequency until interference is resolved.

Recommendation 4.2.6-3: CSMAC recommends the NTIA investigate measures that can be implemented in its NTIA manual to enhance future spectrum sharing with mobile broadband networks. One approach could be to specify power radiated at the horizon from new SATOPS terminals similar to that found in the NTIA manual at Section 8.2.35.

1.3 Next Steps/Path Forward

This report was developed by CSMAC Working Group 3 so that its recommendations could be taken into consideration by NTIA when coordinating with the FCC on any steps related to an auction and reallocation of these bands. The efforts documented here should also inform any resulting development of transition plans related to auction, reallocation and/or sharing of these bands.

Electronic Warfare - Continue EW RDT&E, training and LFE operations in the 1755-1850 MHz band on DoD ranges and within associated airspace on a NIB using the existing national level procedures to coordinate EA operations between federal agencies and the FCC. Additionally, NTIA, FCC and DoD assess that existing simulation and modeling tools and management processes are adequate to provide timely and effective deconfliction between current and future mobile wireless networks and federal EW systems to ensure continued EW RDT&E, training and LFE operations without disruption of commercial wireless services. Finally, implement guidance, processes and mechanisms through the NTIA Manual and FCC Rules to allow for the creation of a formal coordination process between DoD and commercial wireless service providers on a localized basis in the event that interference thresholds could be exceeded or in the event of other unusual circumstances that may arise.

2 Organization and Functioning of the Working Group

2.1 Organization of WG 3

The working group is composed of approximately 90 members from DoD and Industry. The full list of the membership can be found in Section 5 of this report. The chairs, CSMAC member participants, CSMAC liaisons and the FCC/NTIA points of contact for the group are:

CSMAC Working Group 3		
Co-Chairs	Alexander Gerdenitsch	COL Harold Martin
	Robert Kubik	
CSMAC Member Liaison	Rick Reaser	Charlie Rush
CSMAC Member Participants	Thomas Dombrowsky Jr	Janice Obuchowski
NTIA POC	Rob Haines	
FCC	Peter Giorgio	John Kennedy

2.2 Work Plan

The efforts of the group were pursued in four main areas, and were heavily influenced by the availability of publically released or releasable technical and operational details regarding satellite operations. An initial “Phase 1 Analysis of Interference into LTE Base Station Receivers” effort was based on publically available information regarding SATOPS. The government (or federal) facilitated this effort by clearing for public release a “Government Satellite Control Overview” briefing with updates to previously released information such as the “Department of Defense Investigation of the Feasibility of Accommodating the International Mobile Telecommunications (IMT) 2000 Within the 1755-1850 MHz Band” (DoD IMT-2000 Assessment) report.

A “CSMAC WG 3 Phase 2 Study Summary” effort further refined the analysis of potential SATOPS interference with LTE base stations by drawing on additional information regarding SATOPS operational details that were not publically releasable for security reasons. These details allowed the Phase 2 Study to describe not only the contours of SATOPS antenna power for locations around the SATOPS site, but to also model with higher fidelity the probability of an LTE threshold being exceeded by interference from the SATOPS antenna as it varies by location.

A third major effort of study resulted in an “Analysis of Potential Aggregate Long-term Evolution (LTE) Radio Frequency Interference (RFI) to Space-Borne Satellite Operations in 1755-1850 MHz Final Brief” that analyzed the potential impact to satellite operations from LTE sharing of the band. Due to the sensitivity of satellite operations design and operations details, the study was based on information not publically releasable, but resulted in overall conclusions that were cleared for public release documented in this report.

A fourth major effort of the study analyzed and assessed issues related to sharing of the band by LTE with Electronic Warfare activities

2.3 Functioning of WG 3

Working group 3 first met on July 17, 2012 and continued to meet on a recurring 2 week basis. During this time we held three face-to-face meetings and 23 meetings via teleconference. Starting November 28 we initiated a technical sub-working group to discuss modeling methodologies on SATOPS uplink stations into base station receivers. This sub-working group met 8 times. CSMAC WG 3 would like to thank the Telecommunications Industry Association for providing teleconference facilities, and Wiley Rein for providing meeting facilities.

3 Working Group Report

The sections below summarize efforts and recommendations related to sharing of the 1755-1850 MHz Band by LTE with both Satellite Control and Electronic Warfare Operations. The Satellite Control section analyzes both interference to satellite control systems (receivers on board orbiting spacecraft) and interference to mobile broadband (LTE) systems. The analysis of interference to LTE systems includes both the initial efforts based on publically releasable information, and subsequent efforts that accounted for additional information not publically releasable.

3.1 Satellite Control

Two paths of interference were evaluated by the Working Group, the first path is interference to Satellite space-borne receivers from an aggregate of transmitting LTE mobile devices. The second is interference from transmitting satellite earth terminal to an LTE receiving base station.

3.1.1 Interference to Satellite Control Systems

The working group examined aggregate LTE interference to satellite operations (SATOPS) on-board orbiting spacecraft in the 1755-1850 MHz band. The analysis can be found in Section 4.2.6 of this report, analysis was based on CSMAC Working Group 1 (WG 1) assumptions about LTE parameters (November 2012 revision). CSMAC WG 3 concluded that there is low risk of harmful interference from aggregate LTE to SATOPS based on current assumptions.

Most major Air Force and Navy programs were analyzed. An interference level of -205 dBW/Hz into a SATOPS receiver, assuming a 0 dBi antenna and no other losses, (equivalent to a power flux density of -179 dBW/Hz/m^2) was determined to be a safe interference level at geostationary orbit for most programs. This level was derived from requirements documented for all programs. It also ensures a safe level of RFI for most low earth orbit programs. Satellite receiver designs/technology are not expected to change significantly in the future.

Analysis indicated that aggregate mean interference was estimated to be -212.6 dBW/Hz (7.6 dB below the safe level). However, a few experimental programs may not be protected by this level. Therefore additional consideration is needed for the experimental programs, e.g., during transition planning. Analysis also found insignificant interference variation due to LTE power control ($\sigma = 0.12$ dB).

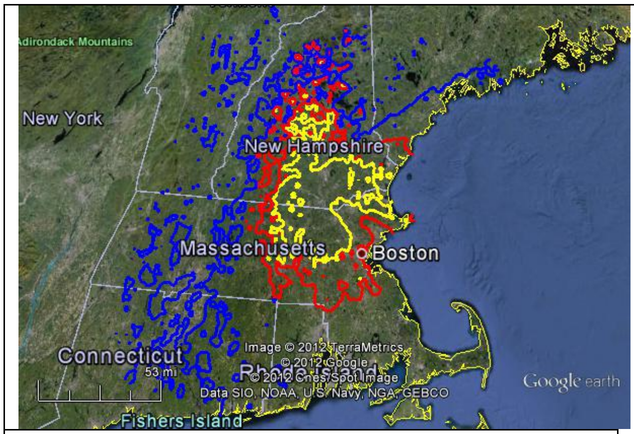
In conclusion, analysis found negligible interference predicted to all programs except possibly a few experimental spacecraft

3.1.2 Interference to Mobile Broadband Systems

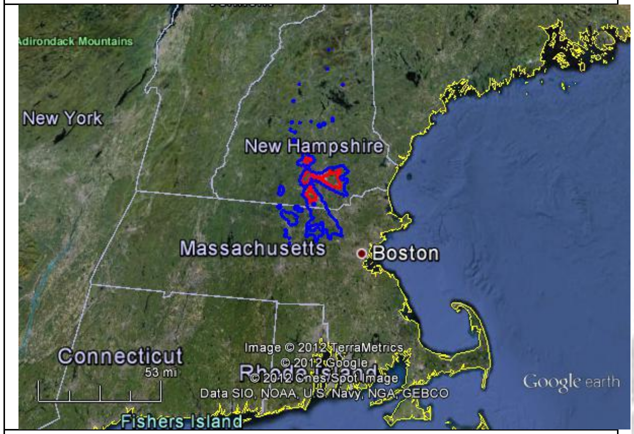
The team developed results to describe SATOPS transmitting earth terminal interference into LTE base station receive operations. The analysis can be found in Sections 4.2.3 and 4.2.4 of this report. The study developed contours outside which interference is below a specified level into LTE operations is predicted. Due to the time varying nature of SATOPS earth terminal operation there would be increasing probability of interference (temporal) to LTE with proximity to SATOPS ground station. Potential mitigation techniques were identified for further evaluation and implementation by licensees that may reduce interference impacts from SATOPS to LTE.

This work was performed in two phases, the initial “Phase 1 Analysis of Interference into LTE Base Station Receivers” effort was based on publically available information regarding SATOPS and is found in Section 4.2.3. A “CSMAC WG 3 Phase 2 Study Summary” effort further refined the analysis of potential SATOPS interference with LTE base stations by drawing on additional information regarding SATOPS operational details that were not publically releasable for security reasons, this effort is described in Section 4.2.4.

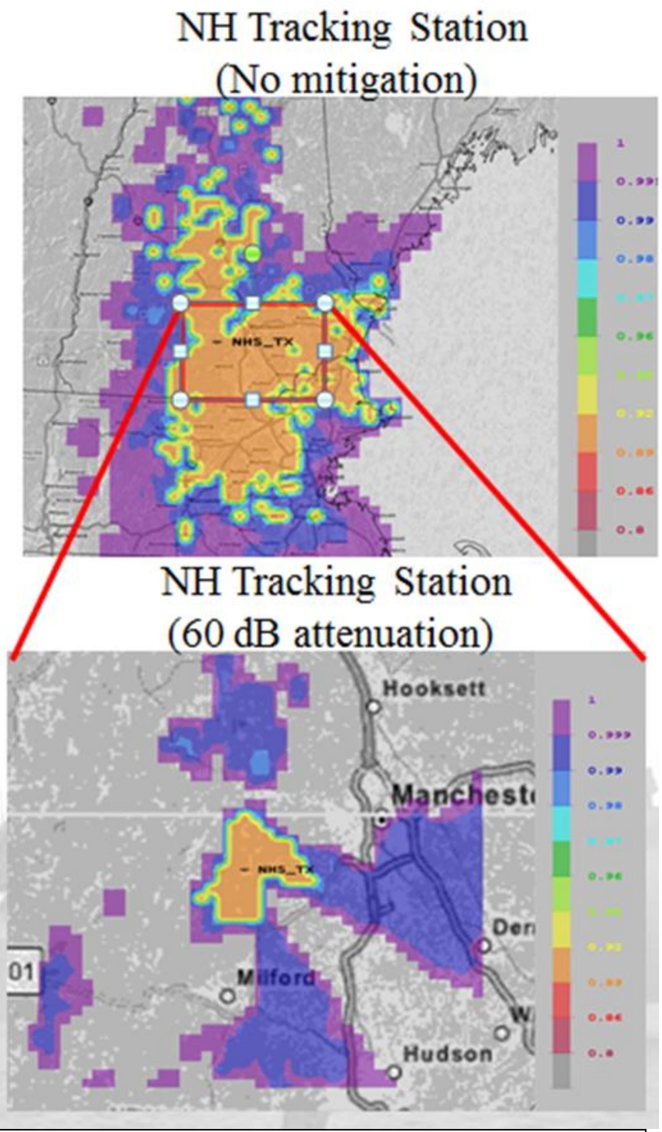
Figure 3.1.2-1 shows example results of both phases of study when interference mitigation techniques are applied. Both phase of studies show a very significant reduction in the distance at which an LTE base station receiver would be interfered with. The Phase 1 studies provide the zones in which a base station would receive interference in excess of a 1 dB desense threshold. The Phase 2 studies shows a similar result with the added detail about how often that level may be exceeded. The two figures are not exactly the same as the Phase 2 studies was performed with a different set of parameters that are not part of the public domain. Even with this difference, the two phases of study are in general agreement.



Amount of Mitigation:
Blue = 0 dB, Red = 20 dB, Yellow = 40 dB



Amount of Mitigation:
Blue = 60 dB, Red = 80 dB



Phase 1 Studies showing 0 to 80 dB Mitigation	Phase 2 studies showing 60 dB Mitigation

Figure 3.1.2-1: Reduction of interference zones based on various levels of mitigation.

The team concluded that SATOPS uplinks will not interfere with LTE base stations outside the contours identified.

3.2 Electronic Warfare (EW)

The Department of Defense's (DoD) ability to conduct research, development, test and evaluation (RDT&E) of electronic warfare (EW) systems and provide realistic EW training, to include large force employment exercises (LFEs), with fielded EW systems to U.S. forces, are essential to countering existing and emerging threat systems within the 1755-1850 MHz band.

Relocation of EW systems from the 1755-1850 MHz band would leave U.S. forces unprotected and vulnerable from threats operating in this band and is therefore not a viable option. Currently, the 1755-1850 MHz band is designated for exclusive federal use only, where EW operations are conducted on a non-interfere basis (NIB) with other federal agencies operating in the band using national level coordination procedures. Electronic attack (EA) RDT&E, training and LFE coordination is limited to the effected federal agencies. Sharing the 1755-1850 MHz band with commercial wireless carriers will complicate this process enormously. Enhancements to existing procedures must take place to enable commercial wireless broadband service while maintaining EW RDT&E, training and LFE capabilities in and around approved federal test and training ranges and operating areas.

3.2.1 Summary of Electronic Warfare Recommendations

Recommendation 3.2.1-1: The CSMAC recommends that NTIA allow the federal agencies to continue to conduct EW RDT&E, training and LFE operations on DoD ranges and within associated airspace on a NIB with commercial wireless operations, if introduced to the band.

Recommendation 3.2.1-2: The CSMAC recommends that NTIA and FCC evaluate current simulation and modeling tools, techniques and management processes used to coordinate EW RDT&E, training and LFE operations to ensure they are robust enough to allow timely and effective deconfliction with potential commercial wireless operations in the band.

Recommendation 3.2.1-3: The CSMAC recommends that NTIA, FCC and DoD assess the usefulness of establishing a formal coordination process between DoD and commercial wireless service providers to assist with spectrum sharing issues on a localized basis.

Recommendation 3.2.1-4: The CSMAC recommends that NTIA add additional information concerning the procedures for performing EA in the United States to section 7.14, Use of Frequencies for the Performance of Electronic Attack Test, Training and Exercise Operations, of the NTIA Manual.

3.2.2 Report

EW consists of military actions involving the use of electromagnetic (EM) energy and directed energy (DE) to control the electromagnetic spectrum (EMS). Successful military operations require unfettered access to, and use of, the EMS. All modern forces rely on spectrum dependent systems (SDS) for communications; command and control (C2); intelligence, reconnaissance and surveillance (ISR); position, navigation and timing (PNT); radar; and precision weapons employment. EW is essential for the protection of these operations for friendly forces, while denying their use to an adversary. The value of EW has been clearly demonstrated in current operations in Iraq and Afghanistan, where U.S. forces have successfully countered radio controlled improvised explosive devices (RCIEDs), saving countless lives and protecting vital operations.

To ensure continued successful military operations, robust RDT&E, training and LFE operations, driven by existing and emerging threat systems, must be maintained. In the 1755-1850 MHz band, the threat is propelled by the explosion of commercial wireless systems being employed in nontraditional ways against U.S. forces. To ensure the continued protection of U.S. operations, forces must be equipped with cutting edge EW equipment and thoroughly trained in the most current employment tactics, techniques and procedures (TTPs). Additionally, effective EW RDT&E, training and LFE operations must be conducted against realistic threat systems and simulations. Therefore it is a requirement to maintain the ability to field and operate realistic training threat systems on DoD test and training ranges.

Currently, EA, a division of EW involving the use of EM, DE or anti-radiation weapons to attack an adversary with the intent to degrade, neutralize or destroy its combat capabilities, is not recognized by the NTIA, or FCC as an authorized service outside DoD test and training ranges. However, with proper coordination, as defined by national and DoD regulations, EA may be performed under the condition that harmful interference will not affect authorized services. Coordination is conducted at the national level and based on the desired EA frequency band, geographical area, time and duration of EA operations. EA clearances are requested and processed through the applicable Military Department (MILDEPS) Spectrum Management Offices (SMOs), who then coordinate the request with applicable federal agencies and the FCC. Though this process is effective, it is a cumbersome and time consuming process that offers very little flexibility.

If the 1755-1850 MHz band is reallocated for commercial use, it is still possible to continue EW RDT&E, training and LFEs operations in the band, but additional enhancements to existing EA coordination procedures and threat system assignment processes will be required. Enhancements to coordination include increasing the time EA clearances are authorized; reduce the EA clearance processing times; acquire improved EA modeling and management tools; and implement procedures to allow EA coordination to take place at the local levels. These enhancements will increase the flexibility and responsiveness of the EA clearance process; add stability to EW RDT&E, training and LFE operations; and enable more effective coordination between commercial industry and federal agencies.

3.2.3 Draft Text for NTIA Manual of Regulations and Procedures

The below is recommended draft text for Federal Radio Frequency Management/Rules and proposed Coordination Procedures for DoD Area Frequency Coordinator, or Fleet Area Control and Surveillance Facility, Range Managers and Commercial Wireless Service Providers for the 1755-1850 MHz Band.

> EW operations within the US&P should continue to be conducted in accordance with the NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management, IRAC Document 34279/1, Joint Chiefs of Staff Manual CJCSM 3212.02B, dated October 15, 2003, titled Performing Electronic Attack in the United States and Canada for Tests, Training and Exercises. This manual contains details concerning Agency and organizational responsibilities regarding radio frequency (RF) clearance coordination for the performance of EA in the United States. Due to restrictions that limit the release of CJCSM 3212.02B to DoD components and other federal agencies only, combined with the increased coordination requirements that will be generated between the federal

agencies and the commercial wireless service providers, the following paragraphs should be added to section 7.14, Use of Frequencies for the Performance of Electronic Attack Test, Training and Exercise Operations, of the NTIA Manual.

The Administrator, NTIA, discharges radio communication and frequency management functions for the federal government with the advice of the Interdepartmental Radio Advisory Committee (IRAC). The IRAC consists of representatives from key government departments and agencies, including each Military Department. The United States Table of Frequency Allocations, published in the Federal Register, is the source document listing authorized federal government and nonfederal government RF spectrum allocations for the United States. This table defines frequency allocations as primary and secondary services. Authorized users have the right to operate in their respective services free from harmful interference. Outside of DOD EW test and training ranges, EA is not recognized by the NTIA or the FCC as an authorized service. With the proper coordination, however, EA may be performed under the condition that harmful interference will not affect authorized services.

EA coordination minimizes the likelihood of EA harmful interference to authorized RF spectrum users. In an increasingly crowded and dynamic RF spectrum, proper EA coordination serves to protect the portions of the spectrum currently available for EA from restrictions caused by occurrences of unintentional harmful interference. EA coordination is required when a user desires to conduct EA in a frequency band where authorized users of primary or secondary services are assigned. National-level coordination involves submitting an EA clearance request through the applicable federal agency SMOs in order to obtain an EA clearance. The coordination requirements for EA in the United States are based on the desired EA frequency band, the geographical area, proposed duration and time of the EA operation.

NTIA and FCC will support the establishment of local EA coordination working groups that will be convened as required to provide subject matter expertise and support to develop recommendations for resolving local EA clearance restrictions; facilitate expedited EA clearance coordination for short-notice, high priority EA test and training events; and identify possible sharing technologies, procedures and process that could be implemented to allow EA test and training without disrupting authorized use of the band. Local EA coordination working groups should be tailored to meet the necessary tasks, and as required, consist of representatives from the NTIA, FCC, DoD area frequency coordinator (AFC) or fleet area coordination and surveillance facility (FACSFAC), DoD range managers and frequency managers, DoD event coordinators, the Range Commander Council Frequency Management Group (RCC-FMG), applicable federal agencies and commercial wireless carriers. These local working groups will be tasked by, and report to the federal regulators (FCC and NTIA) and federal agency coordination authority (e.g. MILDEP SMOs, FAA National HQ, and NASA). Each local EA coordination working group will be chaired by the corresponding AFC/FACSFAC representative. All recommendations from a local EA coordination working group must be approved by National Level Coordination Authorities and/or Federal Regulators before being implemented. In order to share information and best practices, all local EA coordination working group members will meet as a whole once a year in conjunction with RCC-FMG meetings.

4 Technical Appendices

4.1 Overview of Technical Appendices

The technical appendices are organized to reflect the CSMAC WG 3 assigned study items. Section 4.2 address the studies for sharing between satellite control systems and LTE, subsections provide details about parameters for LTE and Satellite operations, evaluation of satellite orbital statistics, phase 1 and 2 interference analysis from SATOPS earth terminals to LTE base station receivers, mitigation concepts to reduce interference to LTE base station receivers and analysis of interference from LTE mobile transmitters to space-borne satellite receivers. Section 4.3 addresses evaluation of LTE and Electronic Warfare in the 1755-1850 MHz band. Section 4.4 provides government cleared submissions to CSMAC WG 3 process.

4.2 Satellite Control Technical Appendices

4.2.1 Parameters of LTE and Satellite Operations

4.2.1.1 Satellite Operations

The locations for evaluation of sharing between SATOPS earth terminal and mobile broadband systems should be based on the Table 4.2.1-1 through 4.2.1-3. These tables are based on information provided in the NTIA Special publication 01-46 and on data provided by DOD.[1]

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[1] NTIA Special Publication 01-46, “The Potential for Accommodating Third Generation Mobile Systems in The 1710-1850 MHz Band: Federal Operations, Relocation Costs, and Operational Impacts”.

Table 4.2.1-1: Government Tracking Sites

Site	Abbreviation	Facility
Annapolis, Maryland	AN, MD	Other
Buckley AFB, Colorado	BAFB	Other
Blossom Point, Maryland	BP, MD	Navy
Cape GA, CCAFB, Florida	CAPEG	Other
Camp Parks, California	CP, CA	Other
Colorado Tracking Station, Schriever AFB, Colorado	CTS	AFSCN
Diego Garcia Tracking Station, British Indian Ocean Territory, Diego Garcia	DGS	AFSCN
Eastern Vehicle Checkout Facility, Cape Canaveral AFS, Florida (Launch support only)	EVCF	AFSCN
Fairbanks (NOAA), Alaska	FB, AK	Other
Ft Bragg, NC	FB, NC	Other
Fort Belvoir, Virginia	FB, VA	Other
Ft Hood, TX	FH, TX	Other
NAVSOC Det. Charlie (Navy)	GNS	Navy
Guam Tracking Station, Andersen AFB, Guam	GTS	AFSCN
Huntington Beach , CA	HB, CA	Other
Hawaii Tracking Station, Kaena Point, Oahu, Hawaii	HTS	AFSCN
Joint Base Lewis-McChord, WA	JB, WA	Other
Kirtland AFB, New Mexico	KAFB	Other
JIATF-S, Key West, FL	KW, FL	Other
Laguna Peak, California (Navy)	LP, CA	Navy
Monterey, California	MO, CA	Other
New Hampshire Tracking Station, New Boston AFS, New Hampshire	NHS	AFSCN
Prospect Harbor, Maine (Navy)	PH, ME	Navy
Patuxent River NAS, MD	PR, MD	Other
Sacramento, CA	SAC, CA	Other
Oakhanger Telemetry and Command Station, Borden, Hampshire, England	TCS	AFSCN
Thule Tracking Station, Thule Air Base, Greenland	TTS	AFSCN
Vandenberg Tracking Station, Vandenberg AFB, California	VTS	AFSCN

Table 4.2.1-2: Locations and Transmit Information for SATOPS Sites

SATOP Site	Latitude	Longitude	Elevation above MSL (m)	Max Transmit Power (dBW)[2]	Max Antenna Gain (dB)	Auth Spectrum Use (MHz)
AN,MD	38-59-26.93N	76-29-24.74W	24	14.8	36	81
BAFB	39-42-55N	104-46-29W	1726	32	43	81
BP, MD	38-25-53.5N	77-05-06.4W	19	25	46	81
CAPEG	28-29-03N	80-34-21W	6	24	40	81
CP, CA	37-43-51N	121-52-50W	300	30	42	81
CTS	38-48-21.6N	104-31-40.8W	1910	31.2	45	81
EVCF	28-29-09N	080-34-33W	2	23	28	81
FB, AK	64-58-26N	212-29-39E	385	25	43	81
FB, NC	35-09-04N	78-59-13W	89	24	26.8	81
FB, VA	38-44-04N	077-09-12.5W	61	25	40	81
FH, TX	31-08-57N	97-46-12W	300	24	26.8	81
GNS	13-34-57.6	144-50-31.6E	208	15	40	81
GTS	13-36-54N	144-51-21.6E	218	37.1	45.1	81
HB,CA	33-44-49.89N	118-2-3.84W	11	24	26.8	81
HTS	21-33-43.2N	158-14-31.2W	430	32.1	45.4	81
JB,WA	47-06-11N	122-33-11W	86	24	26.8	81
KAFB	34-59-46N	106-30-28W	1600	28	38.4	81
KW, FL	24-32-36N	81-48-17W	2	24	26.8	81
LP, CA	34-06-31N	119-03-53W	439	31	43	81
MO,CA	36-35-42N	121-52-28W	102	14.8	36	81
NHS	42-56-45.6N	71-37-44.4W	200	38.6	45	81
PH, ME	44-24-16N	068-00-46W	6	31	38	81
PR, MD	38-16-28N	76-24-45W	6	24	26.8	81
SAC,CA	38-39-59N	121-23-33W	23	24	26.8	81
VTS	34-49-22.8N	120-30-7.2W	269	37.1	45	81

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[2] The maximum radiated power show in this table is the maximum transmit power supplied to the antenna.

Table 4.2.1-3: Locations and Operational Information for SATOPS Sites

SATOP Site	**Radiation Time (%)**	**Instantaneous Spectrum Use Max (MHz)**	**Percent of Spacecraft** in **1755-1780 MHz Sub-Band**	**% GEO Support**
AN, MD	4	2	100	0
BAFB	18	2	0	100
BP, MD	45	5	100	0
CAPEG	46	2	0	0
CP, CA	Not currently operational	-	-	-
CTS	30	4	17	40
EVCF	< 1	4	17	40
FB, AK	11	2	0	0
FB, NC	2	1	0	0
FB, VA	20	4	0	50
FH, TX	2	1	0	0
GNS	9	2	0	100
GTS	100	20	17	40
HB,CA	2	1	0	0
HTS	70	5	17	40
JB,WA	2	1	0	0
KAFB	0.6	2	67	0
KW, FL	2	1	0	0
LP, CA	9	3	0	100
MO,CA	4	2	100	0
NHS	60	6	17	40
PH, ME	3	3	0	100
PR, MD	2	1	0	0
SAC,CA	2	1	0	0
VTS	65	6	17	40

Table Notes:

Percent Radiation Time – Percent of time site is transmitting estimated over a one year period.

Instantaneous Spectrum Use - The maximum spectrum amount in use at site at any single point in time.

Percent Spacecraft in Sub-Band - The percentage of spacecraft using the indicated sub-band estimated over a 1 year period.

Percent GEO Support - The percentage of spacecraft using the site that have a GSO orbit.

Shown in Figure 4.2.1-1 is the computed 13 meter reflector antenna pattern, the redline on the figure indicates the NTIA antenna pattern for a peak gain of 47.38 dBi at a frequency of 1795 MHz based on NTIA models for electromagnetic compatibility[3]. For this analysis the antenna pattern for the SATOPS uplinks will be assumed to follow the recommended model as shown in Figure 4.2.1-1 and Figure 4.2.1-2.

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[3] See NTIA Publication TM-13-489, "Antenna Models for Electromagnetic Compatibility Analysis," at section 6.3.1.3 for an NGSO system earth station antenna co-polarized radiation performance standard. NTIA recommends the side lobe radiation performance standard from the FCC and the main beam pattern from ITU-R S.1428-1.

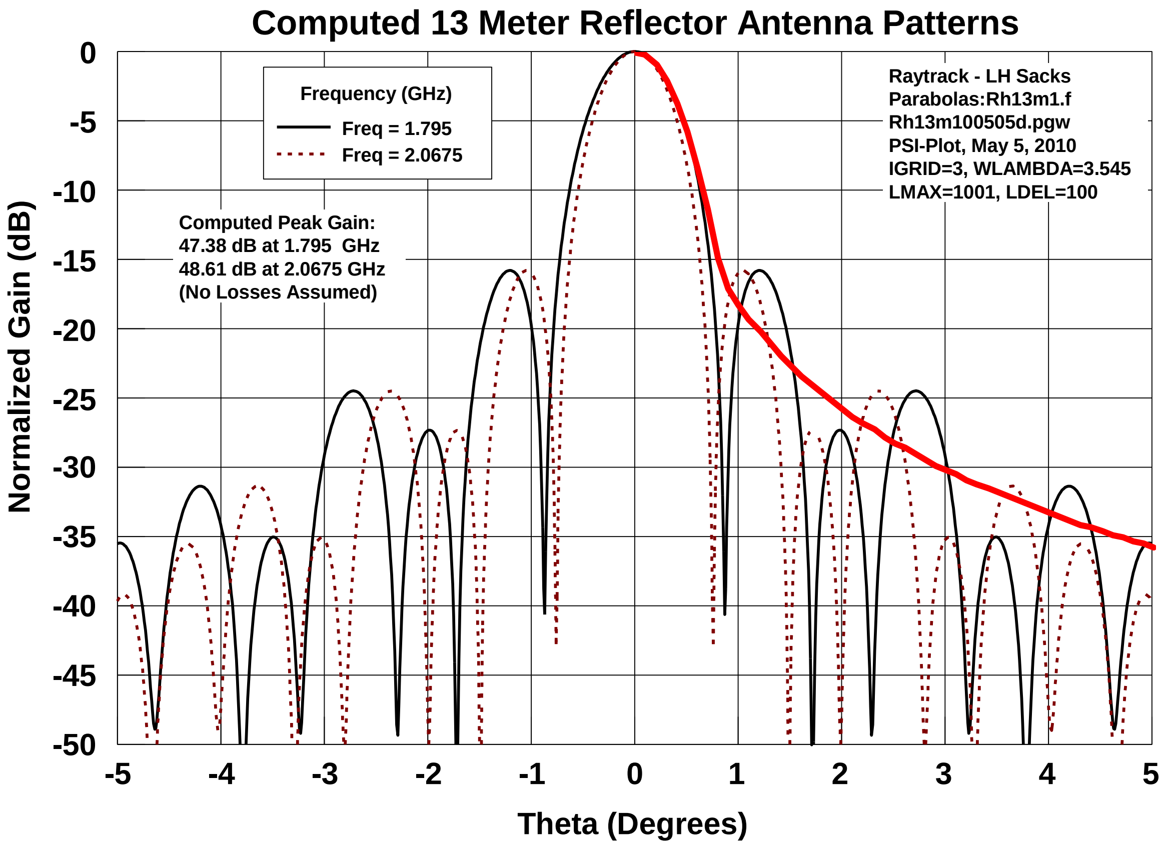


Figure 4.2.1-1: Typical AFSCN Antenna Pattern

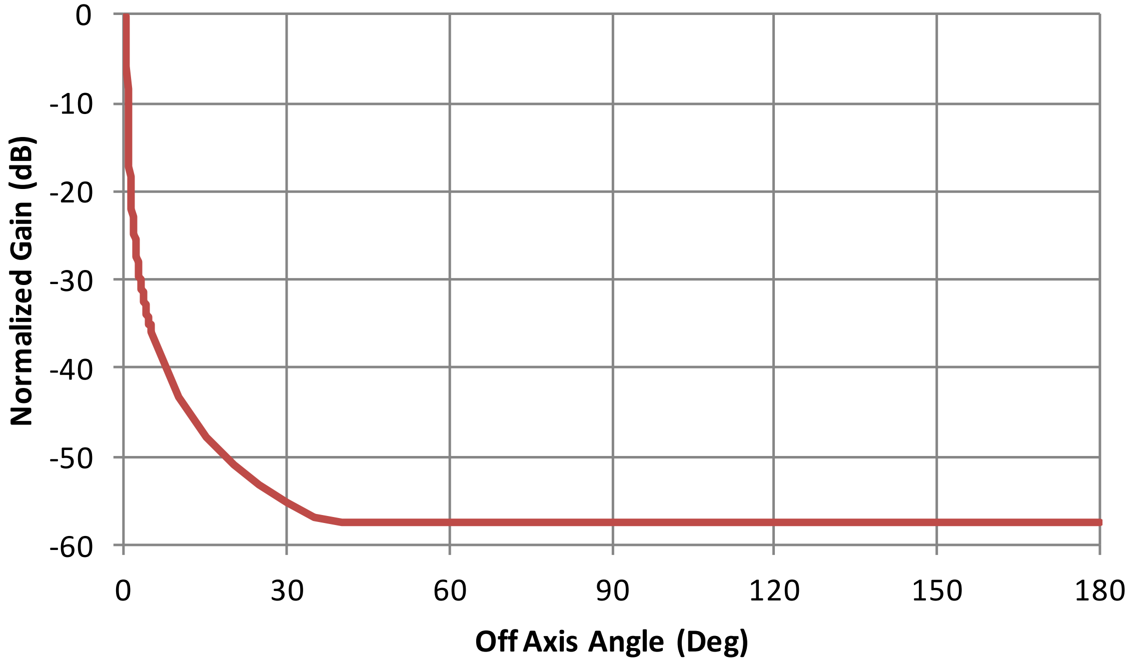
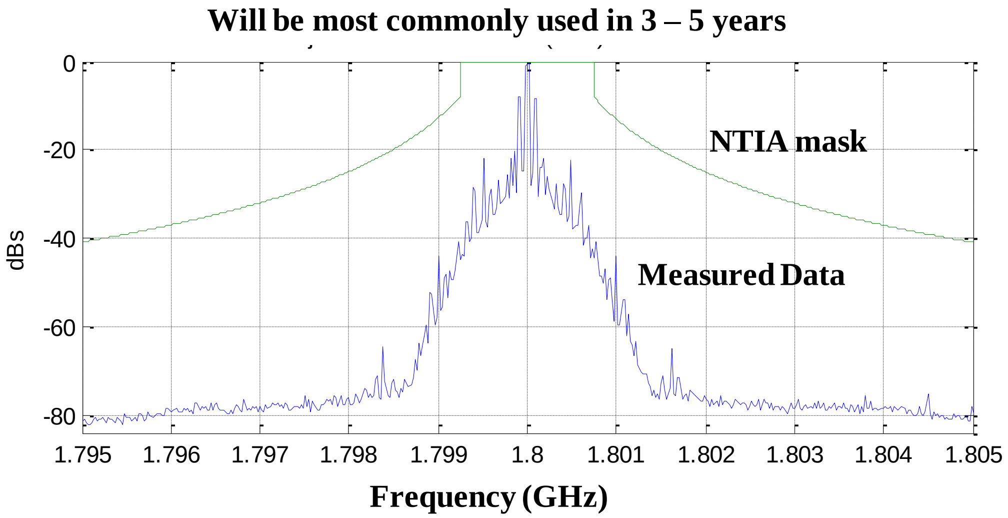


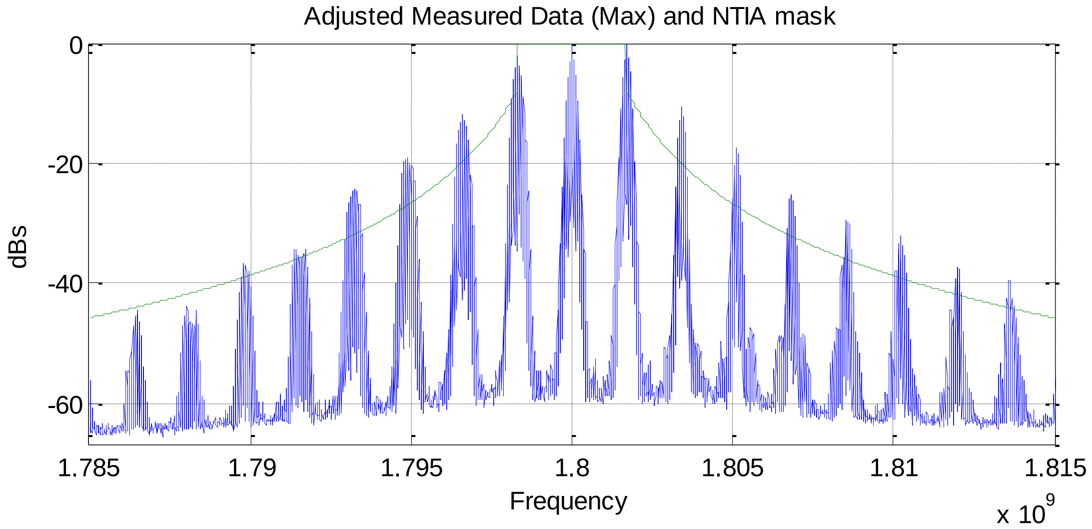
Figure 4.2.1-2: NTIA Recommended Antenna Pattern.



AFSCN RBC Spectral Emissions for 2 kbps SGLS command and 1 Mcps ranging 1795-1805 MHz span

225 kHz bandwidth within -20 dB from peak power

Figure 4.2.1-3: Typical AFSCN Uplink Emission for future operations.



AFSCN ARTS Spectral Emissions for 1.7 MHz Subcarrier Commanding 1785-1815MHz span

4 MHz bandwidth within -20 dB from peak power

Figure 4.2.1-4: Typical AFSCN Uplink Emission for legacy operations.

4.2.1.1.1 Satellite Coordination Data from ITU Space Networks Database

The International Telecommunications Union (ITU) Space Services Department is responsible for coordination and recording procedures for space systems and earth stations. The Department handles capture, processing and publication of data and carries out examination of frequency assignment notices submitted by administrations for inclusion in the formal coordination procedures or recording in the Master International Frequency Register. This department provides data in the form of a Space Networks Systems Database which contains coordination data of more than 10600 geostationary (GSO) satellite filings, 1070 non-geostationary (NGSO) satellite filings and 7900 earth station filings.[4]

This section summarizes satellite data associated with the US Administration for satellites operating in 1761-1842 MHz for each of the 20 channels associated with the SGLS telemetry system.[5] This data is to be seen as representative of the characteristics of operating satellite systems on a channel-by-channel basis. However, it is noted that in addition there may be several classified satellite systems which are not included in this section.

Figure 4.2.1-5 indicates how many NGSO systems have the ability to operate in each of the 20 SGLS channels. Figure 4.2.1-6 indicates how many GSO systems have the ability to operate in each of the 20 SGLS channels.

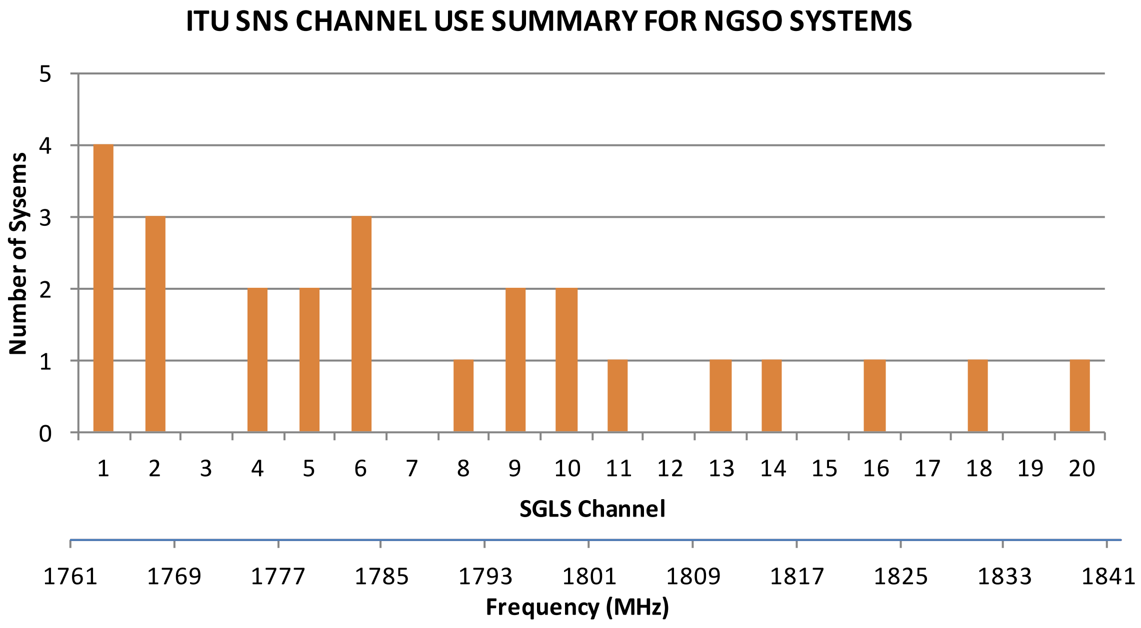


Figure 4.2.1-5: ITU SNS Channel use summary for NGSO Systems.

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[4] See http://www.itu.int/sns/, visited 11 September 2012.

[5] Data as of 10 August 2012.

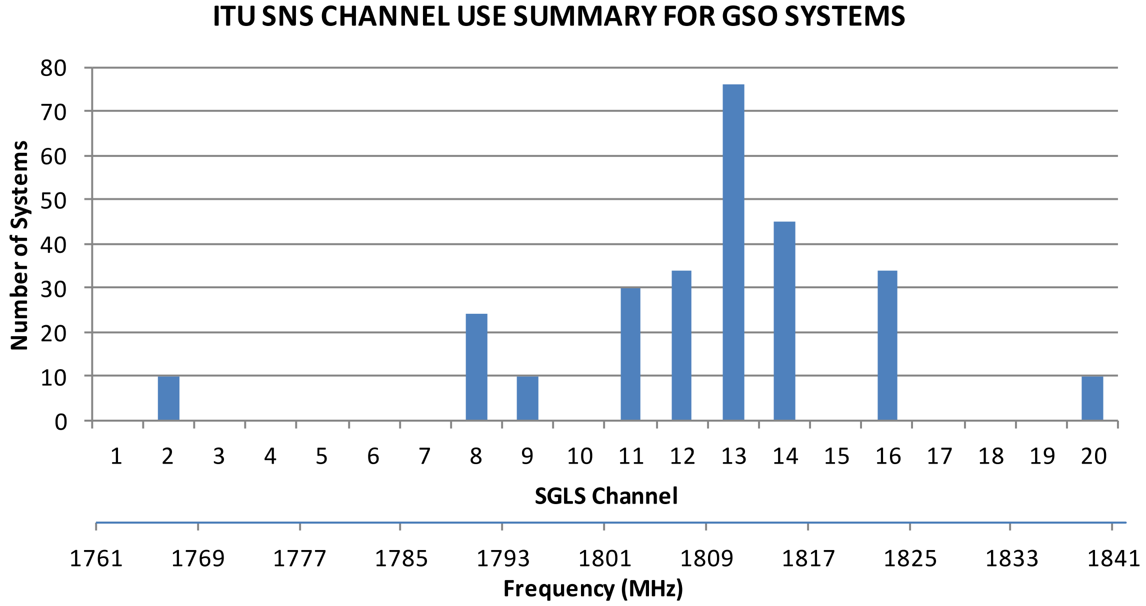

Figure 4.2.1-6: ITU SNS Channel use summary for GSO Systems.

Noting both the 1755-1850 MHz report findings and the industry priority to get access to the 1755-1780 MHz band, approaches should be considered that make that lower band available first, while also dealing with the rest of band up to 1850 MHz to meet agency concerns. To help foster this approach Table 4.2.1-4 and Table 4.2.1-5 provides detailed information on satellite characteristics for the 1755-1780 MHz band (SGLS channels in 1761-1780 MHz) while Table 4.2.1-6 and Table 4.2.1-7 provides similar data for the 1780-1850 MHz band (SGLS channels in 1780-1842 MHz). It should be noted that in the tables for NGSO systems, the convention used is if there is a single orbital plane that the satellite orbits, there will be only one number listed which indicates the number of satellites in that orbital plane. If the satellite constellate is made up of multiple satellites in multiple orbit planes, the convention used is "*a* x *b*" where *a* is the number of orbital planes and *b* is the number of satellites in each orbital plane.

479 Table 4.2.1-4: NGSO System data for 1761-1780 MHz.

ITU Designation	SGLS Channel(s)	Number of Satellites	Inclination (deg)	Apogee (km)	Perigee (km)	C/N (dB)	Noise Temp (K)	Max Gain (dBi)	Emission Designation
USKW	1	1	98	630	630	15	288	6	4M00G9D
USPOJOAQUE	1	1	40	600	600	15	290	2	2M00G1D
USYV	1	1	99	900	900	15	630	3	4M00G9D
L-92	1, 5, 14, 16	12	55	1300	650	15	5000	0	4M00G7W
MIDSTAR-1	2	1	46	492	492	15	350	2	93K0G1D
P-197-1	2	9	62	39000	470	15	1045	11.5	4M00G7W
USNFR	2	1	49.4	495	495	15	627	4	4M00G9D
ALEXIS	4	1	90	835	740	N/A	438	2	10K0G1D
SPACE SHUTTLE	4, 18	1	57	300	300	N/A	5360	1.5	4M00G2D
CRRES	5	1	28.5	35800	350	N/A	500	5.5	4M00G7W
Adjacent channel									
NAVSTAR GPS	6	3 x 6	55	20200	20200	N/A	1500	4	4M00FXX
USRSR	6	6 x 6	55	20200	20200	10.7	627	13.2	4M00G2D
USKL	6	5 x 2	65	40000	465	15	2250	11	4M00G9D

480 Table 4.2.1-5: GSO System data for 1761-1780 MHz.

ITU Designation	SGLS Channel(s)	GSO Location (deg)	C/N (dB)	Noise Temp (K)	Max Gain (dBi)	Emission Designation
P-197-2	2	-144	15	1045	11.5	4M00G7W
P-197-3	2	-141	15	1045	11.5	4M00G7W
P-197-4	2	-13	15	1045	11.5	4M00G7W
P-197-5	2	-10	15	1045	11.5	4M00G7W
P-197-6	2	-30.4	15	1045	11.5	4M00G7W
P-197-7	2	92	15	1045	11.5	4M00G7W
P-197-8	2	110	15	1045	11.5	4M00G7W
USNN-3	2, 9, 20	-127	15	5000	-3, 11	4M00G7W
USNN-4	2, 9, 20	100	15	5000	-3, 11	4M00G7W
USNN-5	2, 9, 20	170	15	5000	-3, 11	4M00G7W

481 Table 4.2.1-6: NGSO System data for 1780-1842 MHz.

ITU Designation	SGLS Channel(s)	Number of Satellites	Inclination (deg)	Apogee (km)	Perigee (km)	C/N (dB)	Noise Temp (K)	Max Gain (dBi)	Emission Designation
L-92	1, 5, 14, 16	12	55	1300	650	15	5000	0	4M00G7W
SPACE SHUTTLE	4, 18	1	57	300	300	N/A	5360	1.5	4M00G2D
NAVSTAR GPS	6	3 x 6	55	20200	20200	N/A	1500	4	4M00FXX
USRSR	6	6 x 6	55	20200	20200	10.7	627	13.2	4M00G2D
USKL	6	5 x 2	65	40000	465	15	2250	11	4M00G9D
BLOCK 5D-3	8	5	81.3	833	833	N/A	870	4	4M00G7W
P92-1	9	5	70	1200	300	N/A	5000	0	4M00G7W
P92-2	9, 20	10	65	40000	465	15	2500, 5000	0, 11	4M00G7W
ORBITAL TEST FLIGHT	10, 13	2	70	550	350	N/A	600	4	4M00G7W
USCP	10	2	58	1350	1350	15	1200	1.5	4M00G9D
USSTP-1	11	1	35.2	560	560	15	627	5	4M00G9D

Table 4.2.1-7: GSO System data for 1780-1842 MHz.

ITU Designation	SGLS Channel(s)	GSO Location (deg)	C/N (dB)	Noise Temp (K)	Max Gain (dBi)	Emission Designation
USNN-3	2, 9, 20	-127	15	5000	-3, 11	4M00G7W
USNN-4	2, 9, 20	100	15	5000	-3, 11	4M00G7W
USNN-5	2, 9, 20	170	15	5000	-3, 11	4M00G7W
USOBO-1A	8	-159.4	15	1463	2	4M00G9D
USOBO-1R	8	-159.4	15	1463	2	4M00G9D
USOBO-2	8	-96.8	15	1463	2	4M00G9D
USOBO-2A	8	-96.8	15	1463	2	4M00G9D
USOBO-2R	8	-96.8	15	1463	2	4M00G9D
USOBO-3	8	-49.4	15	1463	2	4M00G9D
USOBO-3A	8	-49.4	15	1463	2	4M00G9D
USOBO-3R	8	-49.4	15	1463	2	4M00G9D
USOBO-4A	8	-21.2	15	1463	2	4M00G9D
USOBO-4R	8	-21.2	15	1463	2	4M00G9D
USOBO-5A	8	20.6	15	1463	2	4M00G9D
USOBO-5R	8	20.6	15	1463	2	4M00G9D
USOBO-6A	8	66	15	1463	2	4M00G9D
USOBO-6R	8	66	15	1463	2	4M00G9D
USOBO-7A	8	73	15	1463	2	4M00G9D
USOBO-7R	8	73	15	1463	2	4M00G9D
USOBO-8A	8	87.5	15	1463	2	4M00G9D
USOBO-8R	8	87.5	15	1463	2	4M00G9D
USOBO-9A	8	94	15	1463	2	4M00G9D
USOBO-9R	8	94	15	1463	2	4M00G9D
USOBO-10A	8	130.6	15	1463	2	4M00G9D
USOBO-10R	8	130.6	15	1463	2	4M00G9D
USOBO-11A	8	139	15	1463	2	4M00G9D
USOBO-11R	8	139	15	1463	2	4M00G9D
P92-3	9, 20	-10		5000	-3, 11	4M00G7W
P92-4	9, 20	-13		5000	-3, 12	4M00G7W
P92-5	9, 20	-141		5000	-3, 13	4M00G7W
P92-6	9, 20	-144		5000	-3, 14	4M00G7W
P92-7	9, 20	-30.4	15	5000	-3, 15	4M00G7W
P92-8	9, 20	92	15	5000	-3, 16	4M00G7W
P92-9	9, 20	110	15	5000	-3, 17	4M00G7W
FLTSATCOM-C E ATL-2	11, 13	-15.5		630	-4	4M00W9D
FLTSATCOM-C E PAC-1	11, 13	-105		630	-4	4M00W9D
FLTSATCOM-C E PAC-2	11, 13	-100		630	-4	4M00W9D
FLTSATCOM-C INDOC-1	11, 13	29		630	-4	4M00W9D
FLTSATCOM-C INDOC-2	11, 13	72		630	-4	4M00W9D
FLTSATCOM-C INDOC-3	11, 13	75		630	-4	4M00W9D
FLTSATCOM-C W PAC-1	11, 13	172		630	-4	4M00W9D
FLTSATCOM-C W PAC-2	11, 13	-177		630	-4	4M00W9D
IRIS-10A	11, 13	29	20	630	-4	4M00W9D
IRIS-11A	11, 13	125	20	630	-4	4M00W9D
IRIS-1A	11, 13	-105	20	630	-4	4M00W9D
IRIS-2A	11, 13	-100	20	630	-4	4M00W9D
IRIS-3A	11, 13	-22.5	20	630	-4	4M00W9D
IRIS-4A	11, 13	-15.5	20	630	-4	4M00W9D
IRIS-5A	11, 13	72	20	630	-4	4M00W9D
IRIS-6A	11, 13	75	20	630	-4	4M00W9D
IRIS-7A	11, 13	172	20	630	-4	4M00W9D

ITU Designation	SGLS Channel(s)	GSO Location (deg)	C/N (dB)	Noise Temp (K)	Max Gain (dBi)	Emission Designation
IRIS-8A	11, 13	-177	20	630	-4	4M00W9D
IRIS-9A	11, 13	-145	20	630	-4	4M00W9D
USGCSS PH3 E PAC-2	12, 16	-130		877	-4.5	4M00G2D
USGCSS PH3 INDOC	12, 16	60		877	-4.5	4M00G2D
USGCSS PH3 INDOC-2	12, 16	57		877	-4.5	4M00G2D
USGCSS PH3 MID-ATL	12, 16	-42.5		877	-4.5	4M00G2D
USGCSS PH3 W PAC	12, 16	175		877	-4.5	4M00G2D
USGCSS PH3 W PAC-2	12, 16	180		877	-4.5	4M00G2D
USGCSS PH3B ATL	12, 16	-12	15	877	-4.5	4M00G2D
USGCSS PH3B E PAC	12, 16	-135	15	877	-4.5	4M00G2D
USGCSS PH3B E PAC-2	12, 16	-130	15	877	-4.5	4M00G2D
USGCSS PH3B INDOC	12, 16	60	15	877	-4.5	4M00G2D
USGCSS PH3B INDOC-2	12, 16	57	15	877	-4.5	4M00G2D
USGCSS PH3B MID-ATL	12, 16	-42.5	15	877	-4.5	4M00G2D
USGCSS PH3B W ATL	12, 16	-52.5	15	877	-4.5	4M00G2D
USGCSS PH3B W PAC	12, 16	175	15	877	-4.5	4M00G2D
USGCSS PH3B W PAC-2	12, 16	180	15	877	-4.5	4M00G2D
USGCSS PH3B W PAC-3	12, 16	150	15	877	-4.5	4M00G2D
USGOVSAT-10	12, 16	60	20	800	-4.5	4M00G2D
USGOVSAT-11R	12, 16	150	20	630	-4	4M00G2D
USGOVSAT-12	12, 16	175	20	630	-4	4M00G2D
USGOVSAT-13R	12, 16	-121.9	20	630	-4	4M00G2D
USGOVSAT-14R	12, 16	-77	20	630	-4	4M00G2D
USGOVSAT-16R	12, 16	24	20	630	-4	4M00G2D
USGOVSAT-18R	12, 16	78.5	20	630	-4	4M00G2D
USGOVSAT-19R	12, 16	86	20	630	-4	4M00G2D
USGOVSAT-1R	12, 16	180	20	630	-4	4M00G2D
USGOVSAT-20R	12, 16	134	20	630	-4	4M00G2D
USGOVSAT-2R	12, 16	-151	20	800	-4.5	4M00G2D
USGOVSAT-3R	12, 16	-135	20	800	-4.5	4M00G2D
USGOVSAT-4R	12, 16	-130	20	800	-4.5	4M00G2D
USGOVSAT-5R	12, 16	-112	20	800	-4.5	4M00G2D
USGOVSAT-6R	12, 16	-52.5	20	800	-4.5	4M00G2D
USGOVSAT-7R	12, 16	-42.5	20	800	-4.5	4M00G2D
USGOVSAT-8	12, 16	-12	20	800	-4.5	4M00G2D
USGOVSAT-9R	12, 16	57	20	800	-4.5	4M00G2D
FLTSATCOM-C E ATL-1	13	-22.5		630	-4	4M00W9D
MILSTAR 1	13, 14	-90		630	-4	4M00G2D
MILSTAR 13	13, 14	4		630	-4	4M00G2D
MILSTAR 14	13, 14	177.5		630	-4	4M00G2D
MILSTAR 4	13, 14	55		630	-4	4M00G2D
MILSTAR 5	13, 14	90		630	-4	4M00G2D
MILSTAR 6	13, 14	-120		630	-4	4M00G2D
MILSTAR 8	13, 14	-68		630	-4	4M00G2D
USGAE-1	13, 14	-90	20		-4	2M90G2D
USGAE-10	13, 14	-150	20	630	-4	2M90G2D
USGAE-10R	13, 14	-150	20	630	-4	2M90G2D
USGAE-11	13, 14	93	20	630	-4	2M90G2D
USGAE-11M	13, 14	93	20	630	-4	2M90G2D
USGAE-12	13, 14	111	20	630	-4	4M00G2D
USGAE-12M	13, 14	111	20	630	-4	4M00G2D
USGAE-13	13, 14	96	20	630	-4	4M00G2D
USGAE-13M	13, 14	96	20	630	-4	4M00G2D

ITU Designation	SGLS Channel(s)	GSO Location (deg)	C/N (dB)	Noise Temp (K)	Max Gain (dBi)	Emission Designation
USGAE-14	13, 14	-16.5	20	630	-4	4M00G2D
USGAE-14M	13, 14	-16.5	20	630	-4	4M00G2D
USGAE-15	13, 14	-31.5	20	630	-4	4M00G2D
USGAE-15M	13, 14	-31.5	20	630	-4	4M00G2D
USGAE-16	13, 14	30	20	630	-4	4M00G2D
USGAE-16R	13, 14	30	20	630	-4	4M00G2D
USGAE-17	13, 14	-39	20	630	-4	4M00G2D
USGAE-17R	13, 14	-39	20	630	-4	4M00G2D
USGAE-18	13, 14	-155	20	630	-4	4M00G2D
USGAE-18M	13, 14	-155	20	630	-4	4M00G2D
USGAE-19	13, 14	150	20	630	-4	4M00G2D
USGAE-2	13, 14	4	20	630	-4	2M90G2D
USGAE-20	13, 14	155	20	630	-4	4M00G2D
USGAE-21	13, 14	175	20	630	-4	4M00G2D
USGAE-22	13, 14	180	20	630	-4	4M00G2D
USGAE-23M	13, 14	19	20	630	-4	4M00G2D
USGAE-3	13, 14	90	20	630	-4	2M90G2D
USGAE-3M	13, 14	90	20	630	-4	2M90G2D
USGAE-4	13, 14	177.5	20	630	-4	2M90G2D
USGAE-5	13, 14	55	20	630	-4	2M90G2D
USGAE-5M	13, 14	55	20	630	-4	2M90G2D
USGAE-6	13, 14	-120	20	630	-4	2M90G2D
USGAE-6M	13, 14	-120	20	630	-4	2M90G2D
USGAE-7	13, 14	-68	20	630	-4	2M90G2D
USGAE-7M	13, 14	-68	20	630	-4	2M90G2D
USGAE-8	13, 14	-9	20	630	-4	2M90G2D
USGAE-8M	13, 14	-9	20	630	-4	2M90G2D
USGAE-9	13, 14	152	20	630	-4	2M90G2D
USGAE-9R	13, 14	152	20	630	-4	2M90G2D

4.2.1.2 LTE System Parameters

The information in this section is taken from the CSMAC Working Group 1 report regarding LTE System parameters[6], relevant details are included in this report.

The information regarding LTE Uplink Characteristics is intended for use in general analysis of the potential for harmful interference between commercial LTE operations and Federal Government operations in the 1755-1850 MHz band. The information represents a collaborative effort between industry and government representative experts to agree on LTE parameters that are closer to realistic operational parameters than have been used in past analysis. However, because these parameters will be used in general analysis, it is not possible to fully capture the parameters that will be observed in an actual deployment, which will vary by carrier implementation and site specific geography. In order to provide a uniform set of information to

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[6] Commerce Spectrum Management Advisory Committee, Final Report, Working Group 1- 1695-1710 MHz Meteorological-Satellite, dated 1/22/2013, downloaded from: http://www.ntia.doc.gov/other-publication/2013/csmac-wg-1-final-report-v2.

apply in a wide variety of analysis, a number of simplifying assumptions have been made that may continue to result in analysis showing a greater level of interference that would actually occur. These include, but are not limited to, the assumptions being based on 100% loading rather than a more realistic loading level and use of propagation curves that may result in higher calculated power. In addition, because the transmit power and interference potential of a UE device is highly dependent on the UE distance to a base station, developing and applying UE information that is uncorrelated to interfering path is likely to overestimate the amount of interference. None-the-less, given the difficulty of developing and running a fully correlated model, it was agreed that it is reasonable to proceed with uncorrelated values in order to develop a general understanding of the interference potential given limited time and resources. Analysis based on this information will serve as useful guidance in understanding the potential for systems to coexist and the potential for harmful interference. However, site specific coordination will be necessary to maximize efficient use of the spectrum.

4.2.1.2.1 User Equipment (UE) Transmit Characteristics

4.2.1.2.1.1 Cumulative Distribution Function (CDF) of Total EIRP per Scheduled User Equipment

Assumptions for generation of CDF data:

- LTE Frequency Division Duplex (FDD) system
- 10 MHz LTE Bandwidth
- 100% system loading at LTE Base Station (eNodeB)
    - All Physical Resource Blocks (PRB) are occupied at all times
- 100% outdoor UE distribution
- P_0 = -90 dBm and alpha = 0.8 for UL Power Control (urban/suburban/rural)
- Proportional fair algorithm for LTE Scheduler
- Full-buffer traffic model (i.e. All UEs have data in their Radio Link Control (RLC) layer buffer at all times)

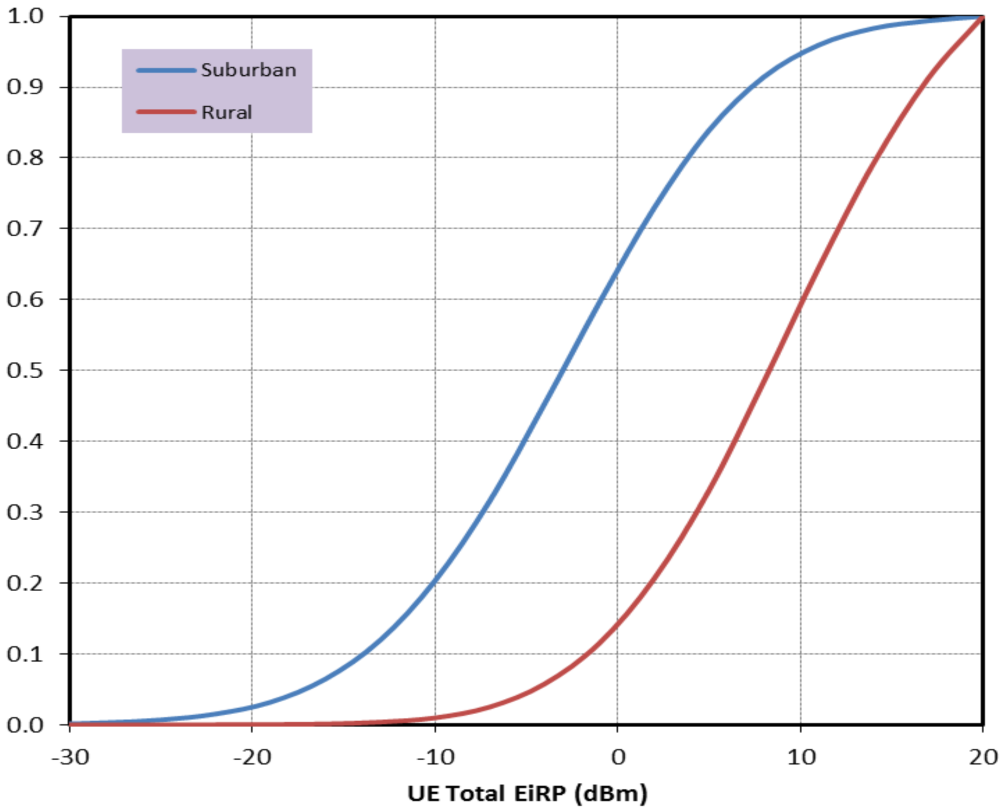

Figure 4.2.1-7: UE EIRP Cumulative Distribution Function.

Table 4.2.1-8: Tabulated UE EIRP Cumulative Distribution Function.

	Urban/Suburban (1.732 Km ISD) (6 UE scheduled/TTI/sector)		Rural (7 Km ISD) (6 UE scheduled/TTI/sector)	
UE EiRP (dBm)	PDF	CDF	PDF	CDF
-40	0.0000	0.0000	0.0000	0.0000
-37	0.0001	0.0001	0.0000	0.0000
-34	0.0002	0.0003	0.0000	0.0000
-31	0.0008	0.0011	0.0000	0.0000
-28	0.0020	0.0031	0.0000	0.0000
-25	0.0040	0.0071	0.0000	0.0000
-22	0.0083	0.0154	0.0002	0.0002
-19	0.0166	0.0320	0.0004	0.0006
-16	0.0327	0.0647	0.0007	0.0013
-13	0.0547	0.1194	0.0026	0.0039
-10	0.0839	0.2033	0.0060	0.0099
-7	0.1128	0.3160	0.0153	0.0252
-4	0.1370	0.4530	0.0325	0.0577
-1	0.1429	0.5959	0.0575	0.1152
2	0.1338	0.7297	0.0911	0.2062
5	0.1094	0.8390	0.1245	0.3307
8	0.0753	0.9143	0.1536	0.4843
11	0.0450	0.9594	0.1605	0.6448
14	0.0236	0.9830	0.1473	0.7920
17	0.0106	0.9936	0.1203	0.9123
20	0.0064	1.0000	0.0877	1.0000

4.2.1.2.1.2 Assumed Number of Scheduled (transmitting) UE per Sector

- Assume Physical Downlink Control Channel (PDCCH) = 6 is typical for a 10 MHz LTE Channel
  - PDCCH contains Downlink Control Information (DCI) blocks, which provide downlink and uplink resource allocations, and power control commands for UEs
  - Use UEs per sector (i.e. the number of simultaneously transmitting UEs is 6 per sector or 18 per eNodeB, for a 10 MHz Channel)
  - 100 % of uplink resources (PRBs) are equally distributed among transmitting UEs in each sector
- Randomly assign power in accordance with UE power CDF for each independent Monte-Carlo analysis trial
- The PDCCH value and corresponding number of UE should be adjusted based on the LTE channel bandwidth:

Table 4.2.1-9: PDCCH Value.

PDCCH Value / Channel Bandwidth			
5 MHz	10 MHz	15 MHz	20 MHz
PDCCH = 3	PDCCH = 6	PDCCH = 9	PDCCH = 12

4.2.1.2.1.3 Requirements for Unwanted Emissions

LTE specification defines requirements for two separate kinds of unwanted emissions, with those for spurious emissions being the more stringent. In addition to these minimum requirements, additional spectrum emission requirements defined in the 3GPP standard must be fulfilled for a specific deployment scenario such as intra-band contiguous Carrier Aggregation, cell handover, UL-MIMO, etc.

4.2.1.2.1.4 RF Spectrum Emissions

4.2.1.2.1.4.1 Out-of-Band Emissions - Spectrum Emissions Mask (SEM)

Out-of-band (OOB) specification is defined with respect to the edge of the occupied bandwidth and it is absolute value.

The 3GPP defines standard identifies two resolution measurement bandwidths (30 kHz and 1 MHz). For example, -15 dBm/30 kHz for Δf_{OOB} ± 0-1 in 5 MHz can be converted to 1 MHz bandwidth resolution results in a limit of 0.23 dBm/1MHz.

For frequencies greater than (Δf_{OOB}) as specified in Table below for Band Class 4, the spurious emissions requirements are applicable.

Table 4.2.1-10: Spectrum Emission Limit (dBm)/ Channel Bandwidth

Δf_{OOB} (MHz)	1.4 MHz	3.0 MHz	5 MHz	10 MHz	15 MHz	20 MHz	Measurement Bandwidth
± 0-1	-10 (5.23)	-13 (2.23)	-15 (0.23)	-18 (-2.77)	-20 (-4.77)	-21 (-5.77)	30 kHz (1 MHz)
± 1-2.5	-13	-13	-13	-13	-13	-13	1 MHz
± 2.5-2.8	-25	-13	-13	-13	-13	-13	1 MHz
± 2.8-5		-13	-13	-13	-13	-13	1 MHz
± 5-6		-25	-13	-13	-13	-13	1 MHz
± 6-10			-25	-13	-13	-13	1 MHz
± 10-15				-25	-13	-13	1 MHz
± 15-20					-25	-13	1 MHz
± 20-25						-25	1 MHz

4.2.1.2.1.4.2 Adjacent Channel Leakage Ratio (ACLR)

ACLR is the ratio of the filtered mean power centered on the assigned channel frequency to the filtered mean power centered on an adjacent channel frequency at nominal channel spacing.

Defines ACLR requirements for two scenarios for an adjacent LTE (Evolved Universal Terrestrial Radio Access (E-UTRA)) channels and/or UMTS channels.

Table 4.2.1-11: The minimum requirement of ACLR for LTE.

	Channel bandwidth / E-UTRA$_{ACLR1}$ / Measurement Bandwidth					
	1.4 MHz	3.0 MHz	5 MHz	10 MHz	15 MHz	20 MHz
E-UTRA$_{ACLR1}$	30 dB	30 dB	30 dB	30 dB	30 dB	30 dB
E-UTRA channel Measurement bandwidth	1.08 MHz	2.7 MHz	4.5 MHz	9.0 MHz	13.5 MHz	18 MHz
Adjacent channel center frequency offset (in MHz)	+1.4 / -1.4	+3.0 / -3.0	+5 / -5	+10 / -10	+15 / -15	+20 / -20

4.2.1.2.1.4.3 Spurious Emissions

Spurious emissions are emissions which occur well outside the bandwidth necessary for transmission and may arise from a large variety of unwanted transmitter effects such as harmonic emission, parasitic emissions, intermodulation products and frequency conversion products, but exclude OOB emissions unless otherwise stated.

This value would be used outside the defined SEM mask.

Table 4.2.1-12: Spurious Emissions.

Frequency Range	Maximum Level	Measurement Bandwidth	Notes
9 kHz ≤ f < 150 kHz	-36 dBm (-6 dBm)	1 kHz (1 MHz)	
150 kHz ≤ f < 30 MHz	-36 dBm (-16 dBm)	10 kHz (1 MHz)	
30 MHz ≤ f < 1000 MHz	-36 dBm (-26 dBm)	100 kHz (1 MHz)	
1 GHz ≤ f < 12.75 GHz	-30 dBm	1 MHz	
12.75 GHz ≤ f < 19 GHz	-30 dBm	1 MHz	Note 1
Note 1: Applies for Band 22, Band 42 and Band 43			

4.2.1.2.2 LTE Base Station Receive Characteristics

This table endeavors herein to provide an overview of Base Station Receiver characteristics established by international standards. While the characteristics can be used in a preliminary analysis of the potential for harmful interference from Government operations to commercial operations there are numerous implementation specific methods that a carrier can deploy to significantly impact the potential for harmful interference. Examples include, but are not limited to antenna down tilt, antenna orientation, power control to improve link margin, temporal use of specific channels to avoid using channels during periods when harmful interference is likely, and use of natural terrain to provide shielding. Section 4.2.1.2.3provides a more detailed discussion of the potential impact of antenna down tilt and orientation. Because these features are implementation specific it is difficult to include them as part of a general analysis and specific features should not be included as part of final rules. While a general analysis may be useful in determining the overall viability as to whether some form of sharing is possible, rules should not include a defined exclusion or coordination zone that precludes commercial deployments in a given area based on the potential for harmful interference to the commercial operation. Instead, as much information as possible regarding the government operations should be provided, thus allowing the commercial licensee to determine the most effective method to mitigate harmful interference.

Table 4.2.1-13: LTE (FDD) Base Station Receiver Characteristics

Parameter	Base Station	
Receiver Channel Bandwidth (MHz)	1.4, 3, 5, 10, 15 and 20 With signal bandwidths of 1.08, 2.7, 4.5, 9, 13.5 and 18 MHz	
Adjacent Channel Selectivity (ACS)	Channel BW Wide Area BS	Wide Area BS Wanted Signal Mean Power (dBm)
	1.4 MHz	-95.8 ($P_{REFSENS}$ + 11dB)
	3 MHz	-95.0 ($P_{REFSENS}$ + 8dB)
	5 MHz	-95.5 ($P_{REFSENS}$ + 6dB)
	10 MHz	-95.5 ($P_{REFSENS}$ + 6dB)
	15 MHz	-95.5 ($P_{REFSENS}$ + 6dB)
	20 MHz	-95.5 $P_{REFSENS}$ + 6dB
	Reference TS 36.104 Table 7.5.1-3	Interfering signal mean power: -52 dBm [7]
	Channel BW Local Area BS	Local Area BS Wanted Signal Mean Power (dBm)
	1.4 MHz	-87.8 ($P_{REFSENS}$ + 11dB)
	3 MHz	-87.0 ($P_{REFSENS}$ + 8dB)
	5 MHz	-87.5 ($P_{REFSENS}$ + 6dB)
	10 MHz	-87.5 ($P_{REFSENS}$ + 6dB)
	15 MHz	-87.5 ($P_{REFSENS}$ + 6dB)
	20 MHz	-87.5 ($P_{REFSENS}$ + 6dB)
	Reference TS 36.104 Table 7.5.1-4	Interfering signal mean power: -44 dBm [8]
Noise Figure (dB)	5	
Reference Sensitivity (dBm) $P_{REFSENS}$ for Wide Area BS [9]	1.4 MHz	-106.8
	3 MHz	-103.0

Notes:

[7] This interfering signal mean power is for a wanted signal mean power at P_REFSENS + xdB (where x=6dB for 3-20MHz channels and 11dB for 1.4MHz channel). One way to interpret this spec is that this is the maximum interference level for xdB desense criterion. For instance, if 1dB desense is used in the coexistence studies, a conversion can be done to adjust for the lower desense criterion. For example, if adjacent channel selectivity is specified as -52dBm and wanted signal mean power is P_REFSENS + 6dB, the level can be adjusted by 11dB for the smaller sensitivity degradation allowed giving -52-11= -63dBm:

- 1 dB desense: maximum interference = Noise floor - 5.87 dB

[8] Same as in footnote i, interfering signal mean power can be adjusted for 1dB desense if this criterion is used in the coexistence studies. For example, in the case of wanted signal mean power at P_REFSENS + 6dB, the level can be adjusted by 11dB for the smaller sensitivity degradation allowed giving -44-11=-55dBm.

[9] See 3GPP TS 36.104, §7.2. $P_{REFSENS}$ is the power level of a single instance of the reference measurement channel. This requirement shall be met for each consecutive application of a single instance of FRC A1-3 mapped to disjoint frequency ranges with a width of 25 resource blocks each.

Parameter	Base Station	
	5 MHz	-101.5
	10 MHz	-101.5
	15 MHz	-101.5
	20 MHz	-101.5
Reference Sensitivity (dBm) $P_{REFSENS}$ for Local Area BS	1.4 MHz	-98.8
	3 MHz	-95.0
	5 MHz	-93.5
	10 MHz	-93.5
	15 MHz	-93.5
	20 MHz	-93.5
Antenna Gain (Mainbeam) (dBi) [10, 11, 12]	18	
Azimuth Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	ITU-R Recommendation F.1336-3 with an elevation 3 dB beamwidth of 10 degrees, k=0.2 and the equations in Section 3.2[vi]	
Elevation Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	ITU-R Recommendation F.1336-3 with an elevation 3 dB beamwidth of 10 degrees, k=0.2 and the equations in Section 3.2[vi]	
Antenna Polarization	Linear	
Antenna Height (meters) [1]	30 (Urban/Suburban) 15 to 60 (Rural)	
Antenna Azimuth 3 dB Beamwidth (degrees) [2]	70	
Antenna Down Tilt Angle (degrees)	3	
Cable, Insertion, or Other Losses (dB)	2	
Interference Criterion	1dB desense. This translates into a maximum interference = Noise floor - 5.87 dB (I/N= ~ -6dB).	

Note 1: For single entry analysis the maximum antenna height of 45 meters for base stations will be used for rural. For aggregate analysis antenna heights will be varied between the minimum and maximum values shown in the table.

Note 2: A base station typically has three sectors each 120 degrees wide.

4.2.1.2.2.1 Assumed Inter-Site Distance (ISD) for Generic LTE eNodeB Deployment

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[10] Base station antennas, both receive and transmit, typically have strongly angle-dependent gain characteristics characterized by a horizontal and vertical beamwidth. The gain value listed here corresponds to the maximum gain corresponding to the main lobe of the antenna.

[11] Assuming full bore-sight gain of the LTE BS receive antenna (18dBi) may not reflect interference mitigation techniques as would be naturally deployed. Significant interference mitigation can be achieved via several factors, which are standard in the industry: e.g., antenna downtilts (point below the horizon, achieved by either mechanical and/or electrical means), antenna azimuth orientation (orient away from the interferer), and use of available terrain (where it exists) for additional refraction loss, etc. This needs to be taken into account when doing interference studies. The antenna techniques are further discussed in the Annex.

[6] See Annex 8 of ITU-R Recommendation F.1336-3, which observes that the recommended equations for antenna gains often do not accurately reflect the gains of actual antennas – particularly with regard to the side lobes, as indicated in Figs 24 to 27 in Annex 8. This should be taken account when considering interference in directions far from the main antenna lobe.

Use concentric circles centered around metropolitan area unless other site specific assumptions are agreed upon.

Urban/suburban area assumed to be 30 km radius with rural area covering outer circle up to 100 km, unless other site specific assumptions are mutually agreed upon.

Surrounding rural deployment may be adjusted by mutual agreement if and when there is more than one urban/suburban area within 100 km of the site being analyzed.

Table 4.2.1-14: LTE (FDD) Base Station Receiver Characteristics

Deployment	ISD	eNodeB Antenna Height	UE Antenna Height
Urban/Suburban (r <= 30 km)	1.732 km	30 m	1.5 m
Rural (U/S Edge < r <= 100 km)	7 km	45 m	1.5 m

4.2.1.2.3 Annex Example: Interference Mitigation via Antenna Downtilting and Antenna Azimuth Orientation

Commercial cellular deployments do regularly take into account interference considerations. Even inter-cell interference within the same service provider network typically results in finite antenna downtilt, particularly for systems with full spectral reuse (i.e., 3G, 4G). Also in the commercial cellular world there exist numerous instances where adjacent band and other interference scenarios have been successfully mitigated via proper RF design (e.g., between service providers in adjacent spectrum, etc).

To illustrate the potentially significant impact of these antenna techniques on the interference issues, we evaluate two representative commercial base station antennas from CommScope/Andrew in the discussion below. Depending on the Federal Government systems involved, different assumptions might be appropriate.

- Andrew HBX-6516DS-T0M: 18 dBi max gain (along the main beam or “bore sight” direction), 65° horizontal beamwidth, 0° electrical downtilt, 7.1° vertical beamwidth.
- Andrew HBX-9016DS-T0M: 18.3 dBi max gain, 90° horizontal beamwidth, 0° electrical downtilt, 4.8° vertical beamwidth.

Using these antennas, and orienting them with a 60° azimuthal offset from the Federal Government system direction, the gain reductions for various reasonable antenna downtilts are calculated (in the table, the gain reductions listed below are with respect to the max ~18dBi gain of these antennas). The displayed gain reductions as a function of the downtilt angles are for the case of an interferer at the horizon. Note that an interference source like JTRS may be at an elevation (e.g., the WG-5 draft calculation assumed 10,000 feet), which would result in higher gain reductions.

Table 4.2.1-15: Gain reduction examples.

Antenna	Gain reduction from 60° azimuthal orientation	Gain reduction from 4° vertical downtilt [Total reduction from azimuth + downtilt]	Gain reduction from 6° vertical downtilt [Total reduction from azimuth + downtilt]	Gain reduction from 8° vertical downtilt [Total reduction from azimuth + downtilt]
Andrew HBX-6516DS-T0M	8.6 dB	2.8 dB [11.4 dB]	7.4 dB [16.0 dB]	16.3 db [24.9 dB]
Andrew HBX-9016DS-T0M	6.3 dB	8.7 dB [15.0 dB]	26.9 dB [33.2 dB]	24.1 dB [30.4 dB]

As can be seen, total gain reductions (summing the reductions due to azimuthal orientation plus those from vertical downtilt) can be very large, anywhere from 11.4 to 30.4 dB – assuming the Federal Government interfering transmitter is at the horizon in our example.

4.2.2 Satellite Orbital Statistics Evaluation

Satellite systems will schedule operations based on need to communicate with each satellite system and on the time that a particular satellite is in view of the earth terminal. In the evaluation of sharing between mobile broadband and Satellite earth terminal transmissions this section evaluates the time that a satellite may be able to receive TT&C commands, we note that procedures in DoD Instruction 3100.2 indicate that routine satellite TT&C is to be performed on the same channels as mission data operations, therefore it can be expected that for some systems the need to use the SGLS channels may be reduced.[13]

This satellite orbital statistical analysis indicates that, based on data in the ITU SNS Database, there will be a significant amount of time slots where there will not be any satellite earth terminal transmissions on particular channels.

Some observations from this analysis indicate the follow aspects relevant in sharing:

If a satellite has a near polar orbit then there will be significant periods of time that the satellite will be at low elevations and the satellite will be at all azimuth angle from the satellite earth terminal.

Duration of any satellite pass[14], can be on the order of minutes for satellites at low altitudes. For satellites at high altitudes, the duration of communication is longer.

4.2.2.1 Modeling Method

The mathematical model for prediction of satellite position and velocity using NORAD “two-line elements” is based on the SGP – C Library. This orbital model was used to evaluate the time that

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[13] DoD Instruction Number 3100.12, Subject: Space Support, September 14, 2000.

[14] A satellite pass is contiguous time of which the satellite is above the minimum elevation angle for communications.

a satellite is above a minimum elevation angle recommend for this evaluation for this section. Based on SGLS operational parameters the minimum elevation angle is 3 degrees.

By simulating the satellite system and recording the elevation angle and azimuth angle, along with the time period when the satellite is above the minimum elevation can provide an indication of when it is possible to communicate with a satellite. This will provide an upper limit to how often a channel issued but not provide a complete analysis as it is unusual for TT&C operations to occur at every SGLS uplink location for every satellite pass.

The orbital model used in this analysis considered a satellite in a spherical orbit over a spherical earth and does not consider other factors such as drag of the atmosphere or other similar effects that are used in more accurate orbital models.

4.2.2.2 Model Results

Each system was evaluated over a 1 year time frame and sampled at 1 second increments in time. Shown in Figure 4.2.2-1 is the results for pointing direction of the earth terminal during a simulation of each individual system on channel 1 at the Ft. Belvoir, VA location (38.7411N, -77.3726E) for satellite listed in Table 4.2.2-1.[15] The data is aggregated in 1 degree increments for elevation and azimuth from the location of the earth terminal and the vertical axis is the number of 1 second increment at which the satellite is at the particular azimuth / elevation angle. The convention is that due north is zero degree azimuth with due east being 90 degrees azimuth.

Table 4.2.2-1: NGSO System data for SGLS Channel 1.

ITU Designation	SGLS Channel	Number of Satellites	Inclination (deg)	Apogee (km)	Perigee (km)	C/N (dB)	Noise Temp (K)	Max Gain (dBi)	Emission Designation
USKW	1	1	98	630	630	15	288	6	4M00G9D
USPOJOAQUE	1	1	40	600	600	15	290	2	2M00G1D
USYV	1	1	99	900	900	15	630	3	4M00G9D

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[15] Note that one of the satellite systems, L-92, has an option of operating on any of 4 channels in the SGLS band and is not evaluated here, consideration should be given if this system can operate in band not being used by mobile broadband systems.

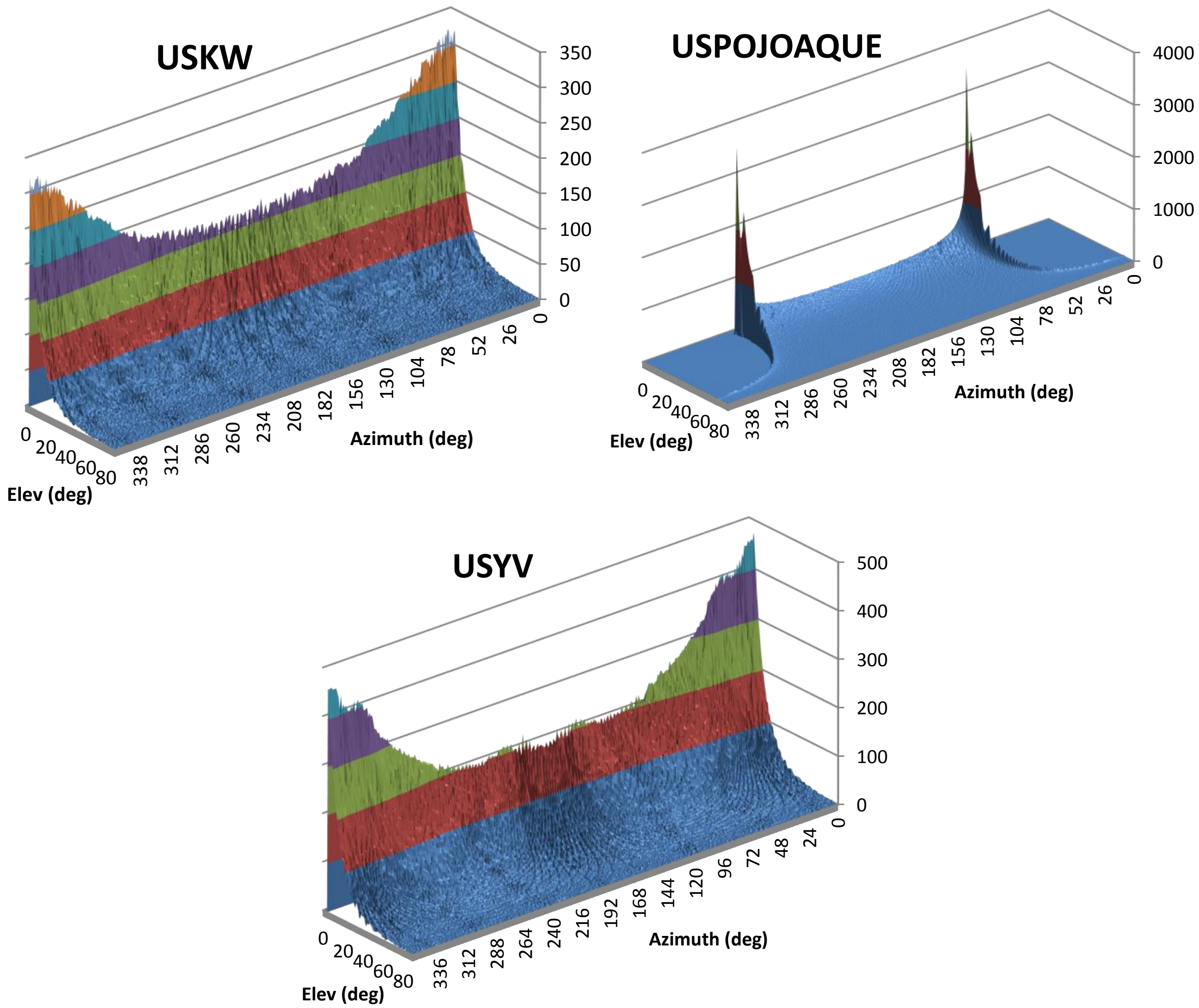

Figure 4.2.2-1: Ft. Belvoir channel 1 Azimuth / Elevation histogram.

Shown in Figure 4.2.2-2 is the histogram of how long a satellite is continuously above the minimum elevation angle (i.e. length of a satellite pass) and the histogram between satellite passes for each of the constellations. As these are low earth orbiting satellites the length of a satellite pass is relative short, while the time between passes can be relatively long. It should be noted that actual TT&C operations will be driven jointly by all satellites that can potentially use a channel and the need to perform TT&C operations to that satellite.

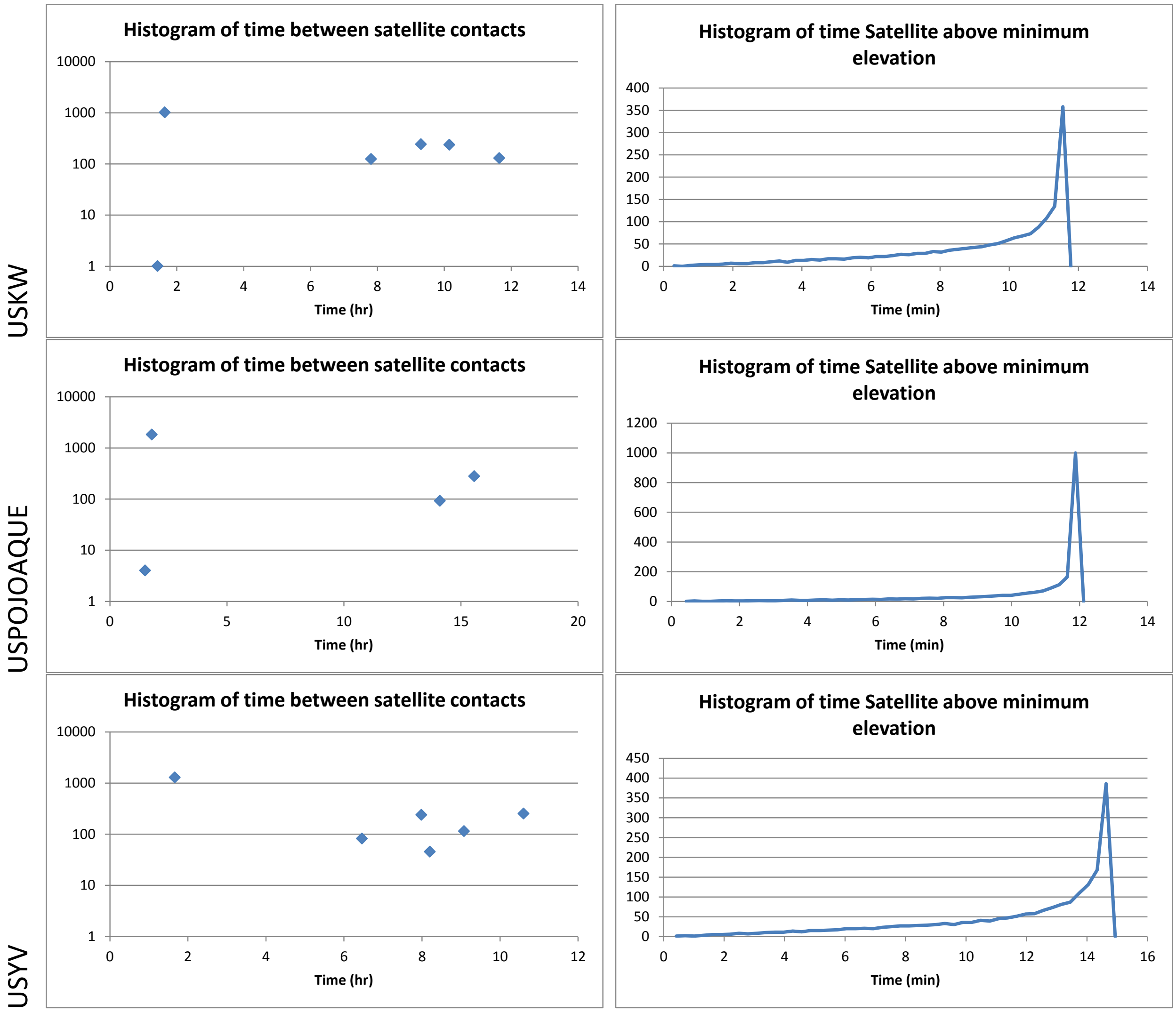

Figure 4.2.2-2: Ft. Belvoir channel 1 satellite pass information.

To Illustrate how location can impact this data, shown in Figure 4.2.2-3 is the results for pointing direction of the earth terminal during a simulation of each individual system on channel 1 at the Prospect Harbor, ME location (44.4067N, -68.0128E) for satellites listed in Table 4.2.2-1.[16] While the near polar orbit satellites (USKW and USYV, with high inclination angels) have very similar charts, the USPOJOAQUE chart indicates the earth terminal will be pointing south during contacts, this is due to the inclination of the satellite being lower.

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[16] Note that one of the satellite systems, L-92, has an option of operating on any of 4 channels in the SGLS band and is not evaluated here, consideration should be given if this system can operate in band not being used by mobile broadband systems.

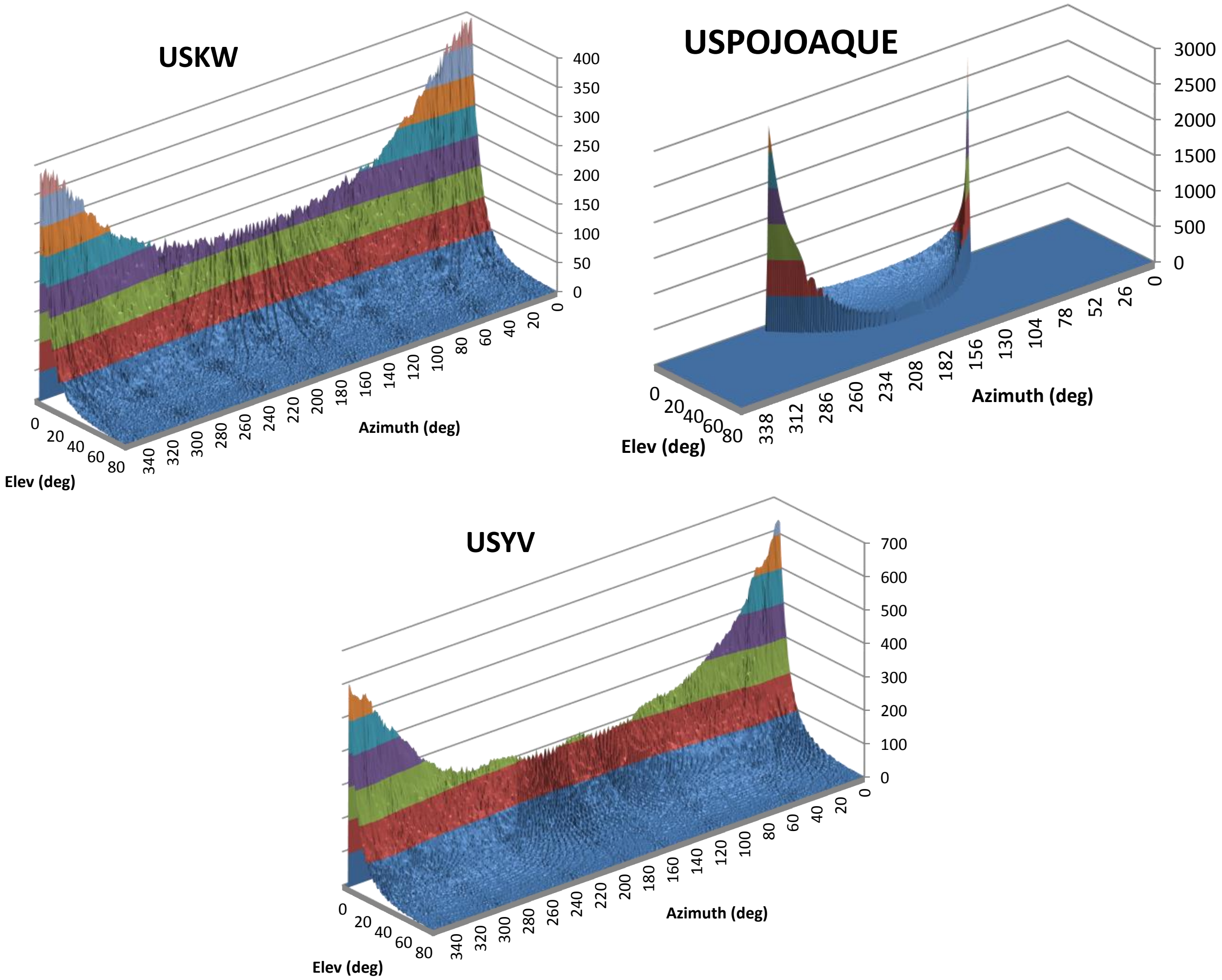

Figure 4.2.2-3: Prospect Harbor channel 1 Azimuth / Elevation histogram.

Shown in Figure 4.2.2-4 is the histogram of how long a satellite is continuously above the minimum elevation angle (i.e. length of a satellite pass) and the histogram between satellite passes for each of the constellations. There is little difference due to the location of the earth terminal.

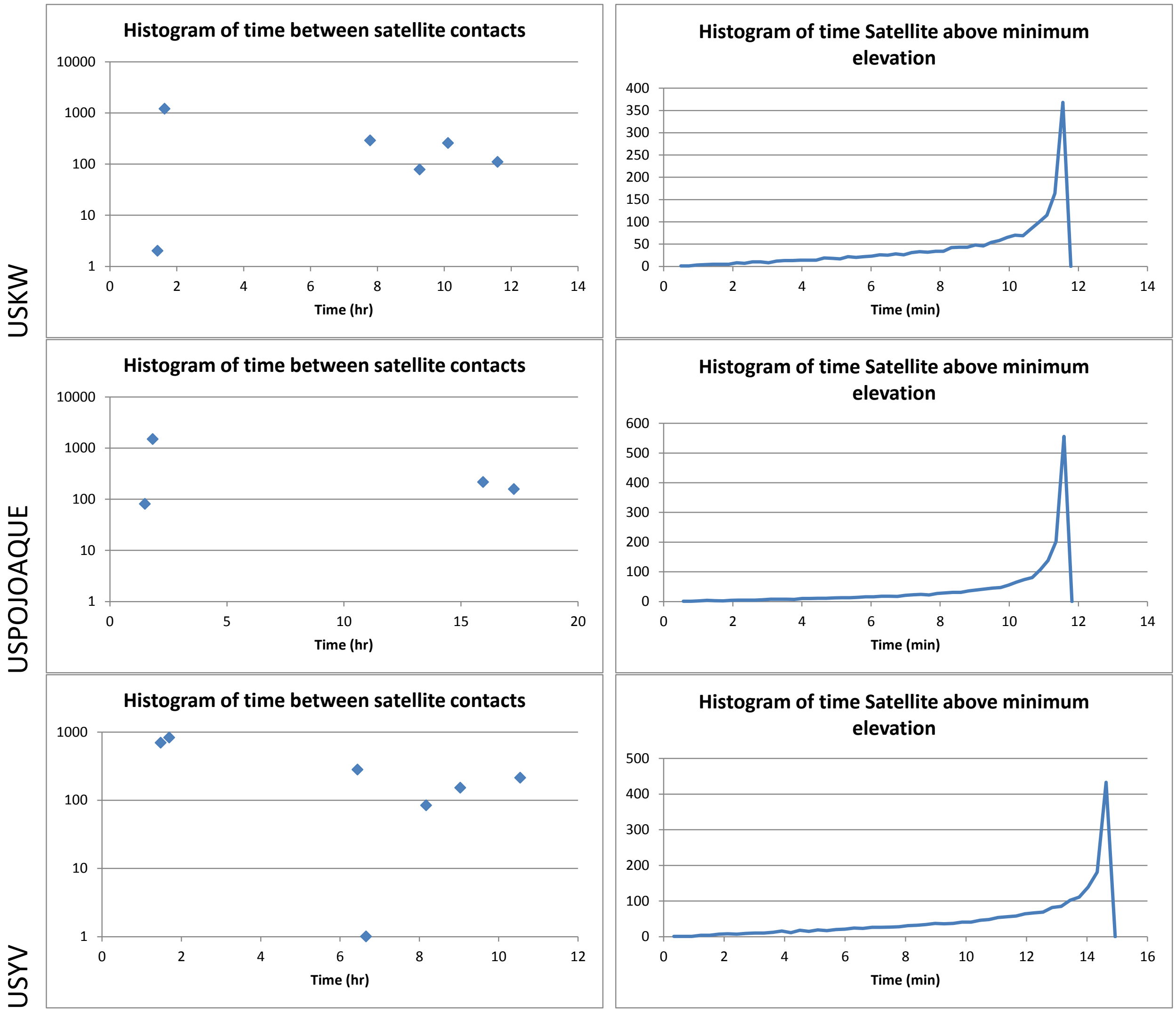

Figure 4.2.2-4: Prospect Harbor channel 1 satellite pass information.

4.2.3 Phase 1 Analysis of interference into LTE Base Station Receivers

4.2.3.1 Introduction / Summary

Operational factors such as the percentage of time Satellite Operation (SATOPS) antennas spend at low elevations, the exact channel usage statistics, the use of power control and other various operational factors will impact the level of interference received by LTE base stations (BS). Phase 1 of this analysis will use assumptions based on information that can be provided in a public form, along with assumptions based the ITU registration data of the satellite systems, to provide representative guidance on the level of interference around a SATOPS uplink that may be received by a LTE base station. The key assumptions made in this document are listed in Table 4.2.3-1. Phase 2 of this study will present results based on the same methodology but will be based on confidential operational parameters that will not be made public as part of this report. The results of phase 2 can be found in section 4.2.4.

Section 4.2.3.2 provides a full description of the interference analysis methodology, key assumptions and results. Section 4.2.5 discusses mitigation methods and other associated factors that can be implemented to reduce the impact of harmful interference from SATOPS into base station receivers.

Based on the analysis presented in Phase 1 of this analysis, the CSMAC WG 3 proposes the following recommendations be adopted by the full CSMAC.

Recommendation 4.2.3-1: NTIA should direct federal earth station operators to document in their transition plans publicly releasable information to allow prospective licensees to understand the potential impact to any base station receivers from SATOPS uplinks. Detailed information to be provided by the federal users should include:

- Contours within which radiated power levels from federal earth stations is likely to exceed the -137.4 dBW LTE interference threshold (1 dB desense) assuming worst case conditions of maximum transmit power at minimum elevation angle.
- Contours within which radiated power levels from federal earth stations is likely to remain below the -137.4 dBW LTE interference threshold (1 dB desense) as calculated at 100%, 99%, and 95% of the time assuming nominal operating conditions, based on recent historical use. Usage of federal earth stations can and will change with time, and is not limited by the information provided.

Recommendation 4.2.3-2: NTIA should recommend that the FCC, in consultation with the NTIA, consider methods to allow government agencies to share with commercial licensees information relevant to spectrum sharing in the vicinity of federal earth stations, subject to appropriate non-disclosure or other agreements, consistent with US law and government policies.

Recommendation 4.2.3-3: The space operations service (Earth-to-space) remains a primary service in the 1761 – 1842 MHz band, as defined in Government footnote G42.

Recommendation 4.2.3-4: NTIA should recommend the FCC require that commercial licensees accept interference from federal SATOPS earth stations operating in the 1761-1842 MHz band.

Recommendation 4.2.3-5: NTIA should direct federal earth station operators to identify and document in their transition plans the cost and schedule required to accelerate and/or expand the transition of all federal earth stations to radiate a narrower bandwidth signal.

4.2.3.2 Interference Assessment

SATOPS model data given in Table C-4 of the interim report indicates that the SATOPS ground stations are capable of emitting very high EIRP at low elevation angles. When these ground stations are located in a geographic area containing LTE systems the high EIRP can cause harmful interference to LTE base stations. The percentage of time that these emissions take place is based on the methods described in this section.

4.2.3.2.1 Key Assumptions

The evaluation in this document makes several assumptions regarding the operational parameters of SATOPS and deployment parameters of LTE systems. The key assumptions used in the evaluation are shown in Table 4.2.3-1.

Table 4.2.3-1: Interference Impact Assumptions

SATOPS Assumptions
Distribution of pointing angles, down to minimum elevation of 3 degrees
Distribution of SATOPS channel usage
Parameters listed in Section 4.2.3.2.2.2.1
Spherical symmetry of antenna patterns
No more than 2 uplinks occur at any one time
4.004 MHz emission bandwidth
SATOPS operate at a range of power levels, both maximum and minimum power levels will be evaluated
LTE Assumptions
Minimum channel use of 2x5 MHz, band of use will be Base Station receive
Parameter of operation as listed in Section 4.2.3.2.2.2.2

More complete information could provide a more accurate analysis of SATOPS interference impact on LTE could include data on:

- Distribution of SATOPS elevation angles
- Distribution of SATOPS channel usage
- Distribution of SATOPS EIRP in time taking into account the use of power control

4.2.3.2.2 Evaluation

4.2.3.2.2.1 Interference Computation

The interference power levels at the BS system receiver are calculated using the equation below for each SATOPS uplink being considered in the analysis:

$$I = EIRP + G_R - L_T - L_R - L_P - L_L - FDR$$

where:

I: Received interference power at the output of the BS receiver antenna (dBm)
EIRP: Equivalent isotropically radiated power (EIRP) of the SATOPS uplink station (dBm)
G_R: Antenna gain of the BS receiver in the direction of the SATOPS uplink station (dBi)
L_R: BS insertion loss (dB)
L_P: Propagation loss between BS and SATOPS uplink station (dB)
L_L: Building and non-specific terrain losses (dB)
FDR: Frequency dependent rejection (dB)

The FDR will be applied for two cases, one in which the BS channel overlaps with the SATOPS channel (co-channel case). The other case is an adjacent channel, for this situation it is assumed that the SATOPS channel begins at the edge of the BS channel, the FDR for adjacent channel operation is derived below in section 4.2.3.2.2.4.

Using the equation above, the values of interference power level are calculated for each SATOPS uplink transmitters being considered in the analysis. These individual interference power levels are then used in the calculation of the aggregate interference to the BS system receivers using the equation below:[17]

$$I_{AGG} = 10 \log \left[\sum_{j=1}^{N} I_j \right] + 30$$

where:

I_{AGG}: Aggregate interference to the BS system receiver from the SATOPS transmitters (dBm)
N: Number of SATOPS transmitters
I_j: Interference power level at the input of the base station receiver from the jth SATOP transmitter (Watts)

4.2.3.2.2.2 Input Parameters

4.2.3.2.2.2.1 SATOPS

The input parameters for satellite terminals used in this analysis are found in section 4.2.1.1 of this report.

4.2.3.2.2.2.2 Base Station

The base station characteristics are found in section 4.2.1.2 of this report.

4.2.3.2.2.2.3 Propagation Model

For this analysis two models are evaluated, the modified Hata-Model and the ITM model used in point-to-point mode.

4.2.3.2.2.2.4 Modified Hata-Model

This is a radio propagation model that extends the urban Hata Model (which in turn is based on the Okumura Model) to cover a more elaborated range of frequencies.[18]

The modified Hata-Model is formulated for 1 500 MHz < $f \leq$ 2 000 MHz as[19],

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[17] The interference power calculated from each SGLS uplink must be converted from dBm to Watts before calculating the aggregate interference seen by the BS system receiver.

[18] Final report for COST Action 231, Chapter 4

Case 1: $d \leq 0.04$ km

$$L = 32.4 + 20\log(f) + 10\log\left(d^2 + \frac{(H_b + H_m)^2}{10^6}\right)$$

Case 2: $d \geq 0.1$ km

Sub-Case 1: Urban

$$\begin{aligned} L = {} & 46.3 + 33.9\log(f) - 13.82\log(\max\{30, H_b\}) + \\ & [44.9 - 6.55\log(\max\{30, H_b\})]\log(d)^{\alpha} - a(H_m) - b(H_b) \end{aligned}$$

Sub-case 2: *Suburban*

$$L = L(urban) - 2\{log[(f/28)]\}^2 - 5.4$$

Sub-case 3: *Open area*

$$L = L(urban) - 4.78\{log[(f)]\}^2 + 18.33\ log(f) - 40.94$$

Case 3: 0.04 km < d < 0.1 km

$$L = L(0.04) + \frac{[\log(d) - \log(0.04)]}{[\log(0.1) - \log(0.04)]}\ [L(0.1) - L(0.04)]$$

---

[19] Report ITU-R SM.2028-1.

When L is below the free space attenuation for the same distance, the free space attenuation should be used instead

where

L = Median path loss. (dB)
f= Frequency of Transmission. (MHz)
H_B = Base Station Antenna effective height. (m)
d = Link distance. (km)
H_m = Mobile Station Antenna effective height. (m)
$a(H_m)$= Mobile station Antenna height correction factor as described in the Hata Model for Urban Areas.

$$a(H_m) = (1.1 \log(f) - 0.7) \min\{10, H_m\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_m / 10)\}$$

$$b(H_b) = \min\{0, 20 \log(H_b / 30)\}$$

Note that for short range devices in the case of low base station antenna height, H_b, $b(H_b) = \min\{0, 20 \log(H_b / 30)\}$ is replaced by:

$$b(H_b) = (1.1\, log(f) - 0.7) min\{10, H_b\} - (1.56 \log(f) - 0.8)$$

$$+ max\big(0, 20\, log(H_b/10)\big)$$

$$\propto = \begin{cases} 1 & d \le 20\ km \\ 1 + (0.14 + 1.87x10^{-4} f + 0.00107 H_b)\left(\log\left(\frac{d}{20}\right)\right)^{0.8} & 20\ km < d\ \le 100\ km \end{cases}$$

4.2.3.2.2.2.5 ITM Model

The ITS model of radio propagation for frequencies between 20 MHz and 20 GHz (the Longley-Rice model) (named for Anita Longley & Phil Rice, 1968) is a general purpose model that can be applied to a large variety of engineering problems. The model, which is based on electromagnetic theory and on statistical analyses of both terrain features and radio measurements, predicts the median attenuation of a radio signal as a function of distance and the variability of the signal in time and in space.[20]

This analysis will use the ITM model in point-to-point mode with the parameters shown below in Table 4.2.3-2.

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[20] See http://www.its.bldrdoc.gov/resources/radio-propagation-software/itm/itm.aspx

Table 4.2.3-2: ITM Parameters.

Parameter	Selected	Options
Polarization	Vertical	Vertical Horizontal
Radio climate	Contental subtropical	Equatorial Contental subtropical Maritime tropical Desert Contental Temperate Maritime temperate, over land Maritime temperate, over sea
Dielectric constant of ground	15 – Average Ground	4- Poor ground 15 - Average ground 25 - Good ground 81 - Fresh/sea water
Conductivity of ground	0.005 - Average ground	0.001 - Poor ground 0.005 - Average ground 0.02 - Good ground 0.01 - Fresh water 5.00 - Sea water
Reliability statistic values	50%	Greater than zero, less than 100%
Confidence statistic values	50%	Greater than zero, less than 100%
Surface Refractivity	301 - Contental Temperate (Use for Avg. Atmospheric Conditions)	280 - Desert (Sahara) 301 - Contental Temperate (Use for Avg. Atmospheric Conditions) 320 - Continental Subtropical (Sudan) / Maritime Temperate, Over Land (UK and Contenital West Coast) 350 - Maritime Temperate, Over Sea 360 - Equatorial (Congo) 370 - Maritime Subtropical (West Coast of Africa)
Terrain Database	GLOBE – 30 Second[21]	

4.2.3.2.2.3 Interference Criteria

The interference criteria for the BS is found in Section 4.2.3.2.2.2.2, for this analysis results will be shown for a 1 dB desense level and for a 3 dB desense level to provide a representative for cases in which licenses would be willing to accept more interference from SATOPS operations than the baseline interference criteria.

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[21] The GLOBE 30 second terrain data can be downloaded from the following website http://www.ngdc.noaa.gov/mgg/topo/gltiles.html.

A wide area BS has a reference sensitivity of -101.5 dBm. A 1 dB desense interference criteria occurs at an interference level of -101.5-5.87 = 107.37 dBm. A 3 dB desense interference occurs at an interference level of -101.5 dBm.

4.2.3.2.2.4 Adjacent channel FDR

In order to consider adjacent channel interference there are two interference mechanisms to be considered: interfering transmitter unwanted emission and receiver filtering imperfection.[22]

To analyze the combined effect of these two interference mechanism, we adopt the analytical methodology that is widely used by ITU-R[23] and 3GPP[24]. First, the two interference mechanisms are modeled by the following two parameters:

- Adjacent Channel Leakage Ratio (ACLR) (transmitter unwanted emission mechanism) is the portion of interfering Tx power which leaks into the victim Rx channel (integrated over the Rx channel bandwidth). ACLR is thus a measure of the transmitter performance. Power received by the victim receiver due to unwanted emission can be represented by P/ACLR, where P is the transmitted power.
- Adjacent Channel Selectivity (ACS) (receiver filtering mechanism) is the portion of Tx power which is picked up from the interferer Tx by the overlap of the victim receiver filter with the Tx bandwidth. ACS is thus a measure of the receiver performance. Power received by the victim receiver due to receiver filtering imperfection can be represented by P/ACS.

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[22] Inter-System MWA MS to MWA MS Coexistence analysis in 3.5 GHz Band for Unsynchronized TDD systems or TDD adjacent to FDD systems, Annex 5, Doc. SE19(06)70, Source: Motorola, 17 November 2006.

[23] Coexistence between IMT-2000 time division duplex and frequency division duplex terrestrial radio interface technologies around 2 600 MHz operating in adjacent bands and in the same geographical area. http://www.itu.int/itudoc/itu-r/publica/rep/m/2030.html.

[24] WiMAX Forum, “Sharing studies in the 2 500-2 690 MHz band between IMT-2000 and broadband wireless access (BWA) systems,” ITU-R WP8F/597, October 2005.

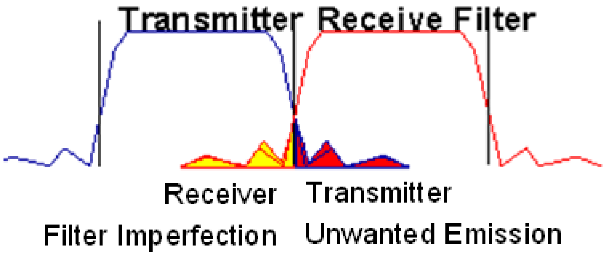

Figure 4.2.3-1: Adjacent channel interference mechanisms.

The combined interference power of these two mechanisms, *I*, can be written as

$$I = \frac{P}{ACLR} + \frac{P}{ACS} = P\left(\frac{1}{ACLR} + \frac{1}{ACS}\right)$$

Therefore,

$$\frac{P}{I} = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}}$$

This ratio is termed Adjacent Channel Interference Ratio (ACIR) and can be ex*press*ed as:

$$ACIR = \frac{1}{\frac{1}{ACS} + \frac{1}{ACLR}}$$

ACIR is therefore defined as the ratio of the transmission power to the interference power measured after a receiver filter in the victim channels. It should be emphasized that when one of the two factors is much smaller than the other, *ACIR* will be dominated by the smaller one. In such case, the larger factor can be omitted.

Sections 4.2.3.2.2.4.1 and 4.2.3.2.2.4.2 compute the ACLR for the transmitting SATOPS terminals using a spectrum mask that is commonly expected to be used with-in 3-5 years and the legacy mask that is currently in common use.

The adjacent/alternate channel rejection performance is typically measured using the following procedure. First, the BER performance is measured at receiver sensitivity without any interference. Then the desired signal strength is raised 6 dB above the rate dependent receiver sensitivity, and power level of the interfering signal is raised until the same BER is obtained. The power difference between the interfering signal and the desired channel is the corresponding adjacent/alternate channel rejection depending on the frequency location of the interference signal. In other words, we want to obtain same performance (e.g., BER, FER) when operating at Sensitivity without interference, and when operating at Sensitivity+6dB in presence of interference. Therefore, the following Equation holds.

$$SNR_{\min} = \frac{Sensitivity}{N} = \frac{\left[Sensitivity + 6dB\right]}{N + \dfrac{P}{ACS}} = \frac{2 \bullet Sensitivity}{N + \dfrac{P}{ACS}}$$

where P = interference power and N is the noise power.

Based on the above Equation, ACS can be expressed as:

$$\begin{aligned} ACS &= \frac{P}{N} \\ &= SNR_{\min} + 6dB + Adjacent\ /\ Alternate\ Channel\ Rejection \end{aligned}$$

The relationship between ACS, SNR_{min} (or $P_{REFSENS}$), and Adjacent/alternate channel rejection are illustrated in the following figure.

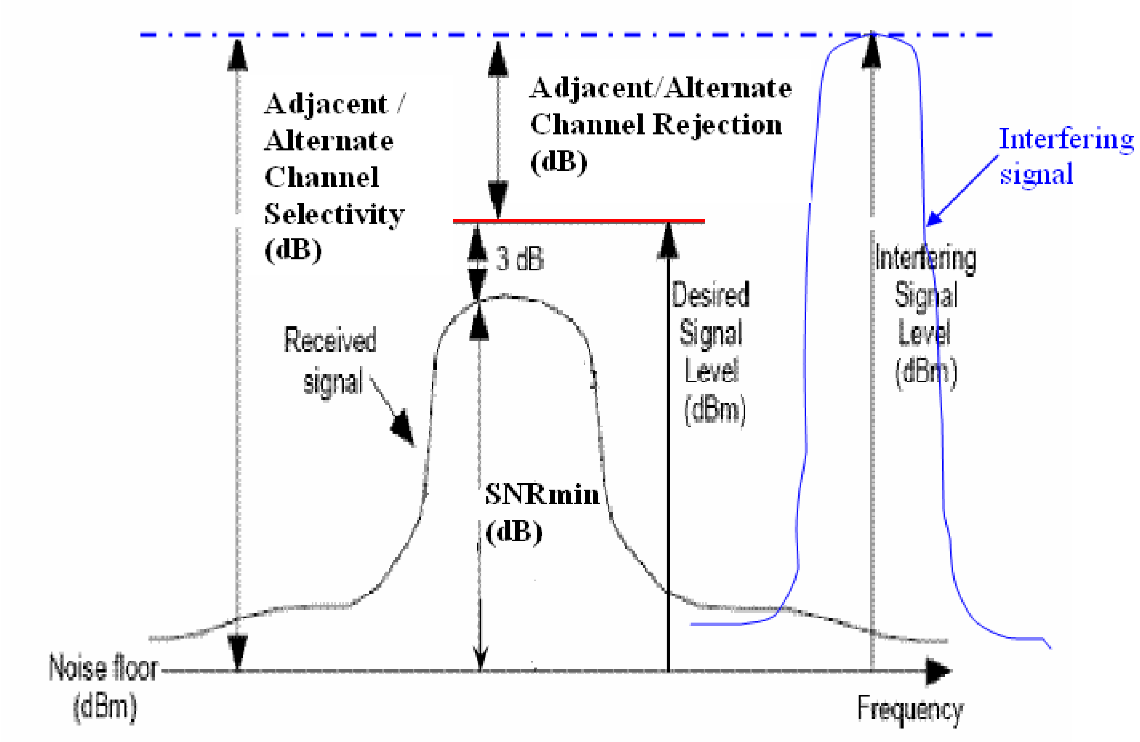

Figure 4.2.3-2: Illustration of ACS, SNRmin and Adjacent/Alternate channel rejection.

Using the Parameters provided for the LTE BS in section 4.2.1.2 the ACS for a 5 or 10 MHz channel is computed to be $ACS = -95.5 + (-95.5 - (-52)) = 52$ dB.

4.2.3.2.2.4.1 Spectrum Mask Commonly used in the Future

For the analysis of the interference from SATOPs into LTE base stations in an adjacent channel the measured data shown in Figure 4.2.1-3 is used. It is the understanding that these new 225 kHz width AFSCN signals will be commonly used within 3 to 5 years. The signals will use 440 channels with a 160 kHz separation. To study the scenario of adjacent channel interference it is assumed that the LTE system can be directly adjacent to the AFSCN uplink signal in the frequency space (0 MHz offset) or at larger offsets.

For the calculation of the attenuation in the adjacent spectrum, the measured AFSCN signal is approximated by the following reference spectrum mask.

Table 4.2.3-3: Reference mask to calculate attenuation in adjacent channel.

Distance from channel edge	Attenuation [dB]
Channel edge	-8
1 MHz	-46
2 MHz	-77
5 MHz	-80

Figure 4.2.3-3 shows the defined reference spectrum mask in red. This mask will be used to calculate the attenuation in the adjacent 5 and 10 MHz. With defining this reference spectrum mask, it is guaranteed that the measured signal is below the mask all the time.

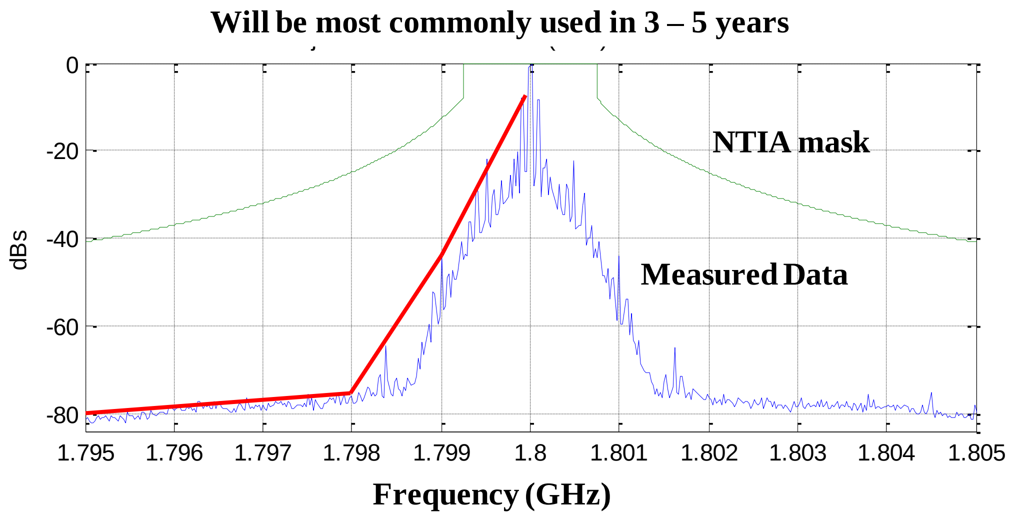

Figure 4.2.3-3: Reference mask to calculate attenuation in adjacent channel.

The attenuation in the adjacent channel is now calculated integration of the transmitter mask over the 5 MHz and 10 MHz LTE victim receive channel. The results for 0 MHz, 1 MHz and 2 MHz offset from channel edge are shown in Table 4.2.3-4, other offsets are shown in Figure 4.2.3-4.

Table 4.2.3-4: ACLR for typical AFSCN emissions.

Offset	**5 MHz LTE channel**	**10 MHz LTE channel**
0 MHz	15.7 dB	15.7 dB
1 MHz	53.0 dB	53.0 dB
2 MHz	71.9 dB	69.4 dB

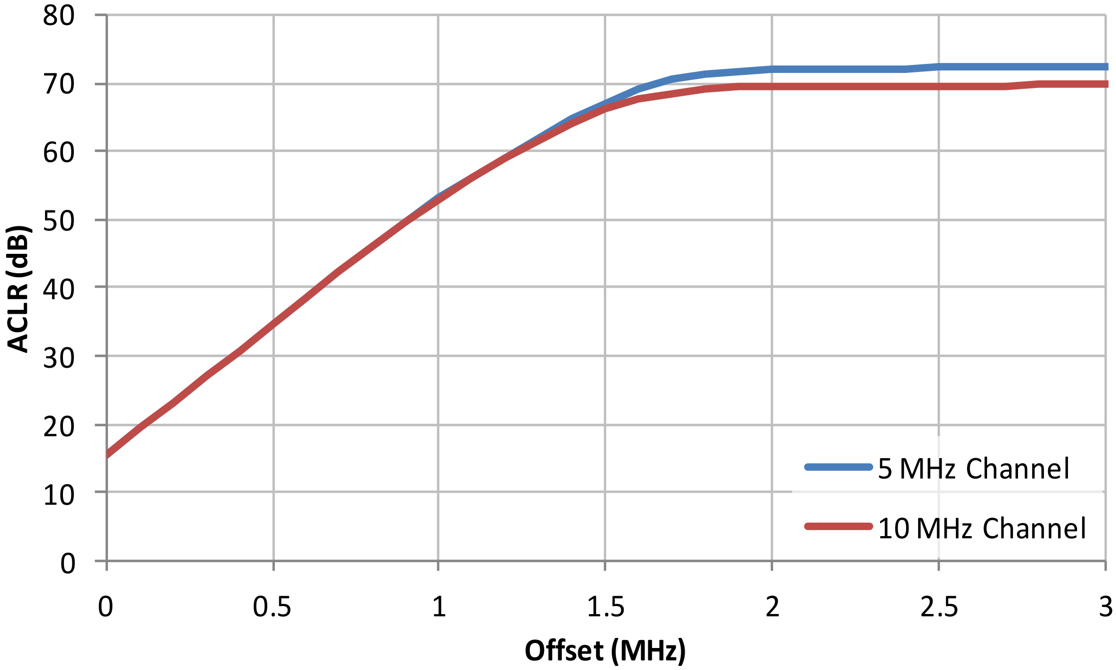

Figure 4.2.3-4: ACLR for Typical AFSCN emissions.

Based on the above results, the ACIR values are found in Table 4.2.3-5 and Figure 4.2.3-5.

Table 4.2.3-5: ACIR for typical AFSCN emissions.

Offset	**5 MHz LTE channel**	**10 MHz LTE channel**
0 MHz	15.7 dB	15.7 dB
1 MHz	49.5 dB	49.5 dB
2 MHz	52 dB	51.9 dB

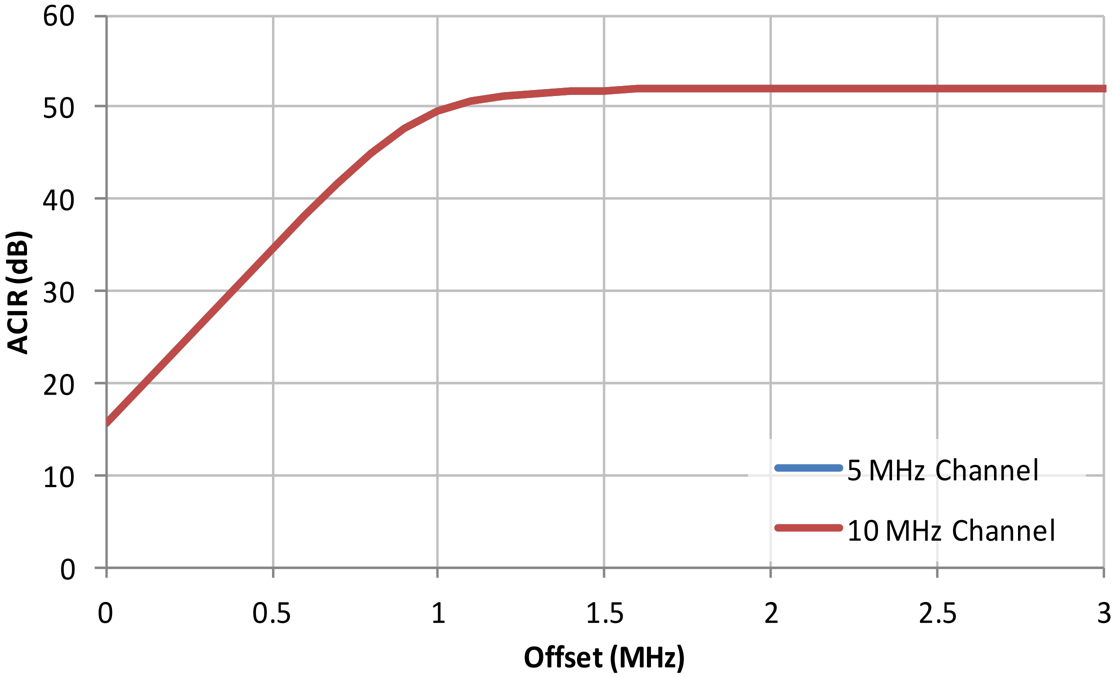

Figure 4.2.3-5: ACIR for Typical AFSCN emissions.

4.2.3.2.2.4.2 Legacy Spectrum Mask

Additionally, the legacy spectrum mask, which is currently used in current AFSCN terminals, is also considered in this adjacent channel analysis. This mask is to be understood as a worst case scenario and is shown in Figure 4.2.1-4.

As for the previous spectrum mask, the mask is approximated by a reference spectrum mask over the frequency range of 1785-1800 MHz by the maximum of $[SF * f_a(x)]$ and $[SF * f_b(x)]$. In which:

$$f_a(x) = (x - 1800) * \sum_{i=-8}^{8} f_2(x - 1800 + 1.6878i)$$

$$f_b(x) = 5.05e - 8 * x + 1.615e - 6$$

Where

x – Frequency in MHz

$f_1(y)$ – Mask represented by Table 4.2.3-6

$f_2(y)$ – Mask represented by Table 4.2.3-7

SF – Scale factor to ensure total power in mask is equal to 1, computed by $\int max\big(f_a(x), f_b(x)\big)dx$

Table 4.2.3-6: Mask $f_1(y)$ to calculate attenuation in adjacent channel.

y (MHz)	Attenuation [dB]
0	0
-1.6878	0
-3.3756	-12
-5.0634	-19
-6.7512	-23
-8.439	-33
-10.1268	-37
-11.8146	-41
-13.5024	-43
-16	-45

Table 4.2.3-7: Mask $f_2(y)$ to calculate attenuation in adjacent channel.

y (MHz)	Attenuation [dB]
-30	-85
-0.6	-85
-0.4	-20
-0.2	-5
0	0
0.2	-5
0.4	-20
0.6	-85
30	-85

Figure 4.2.3-6 shows the defined reference legacy spectrum mask in red. This mask will be used to calculate the attenuation in the adjacent 5 and 10 MHz starting at the channel edge at an offset of 2.002 MHz from the center frequency.

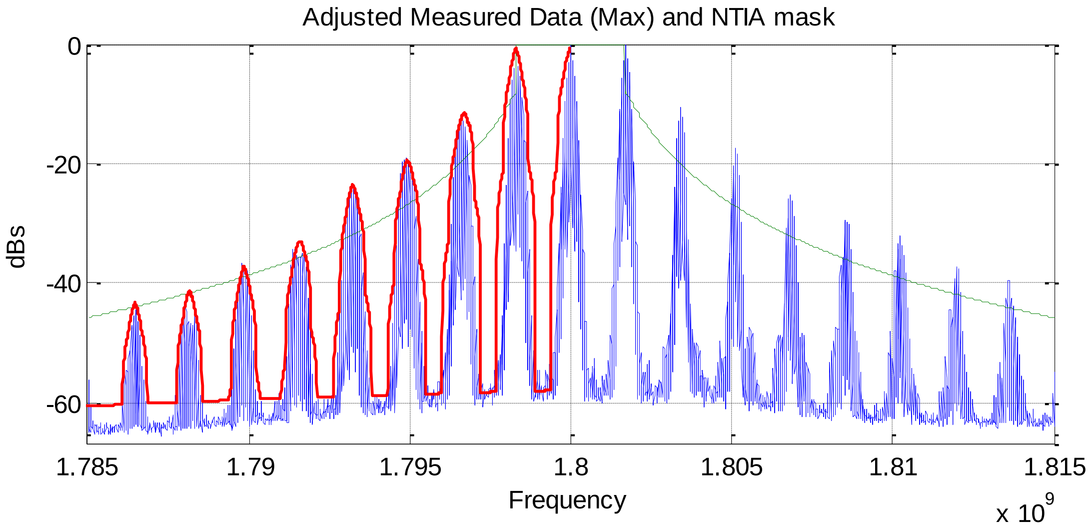

Figure 4.2.3-6: Reference mask to calculate attenuation in adjacent channel.

The attenuation in the adjacent channel is now calculated by integrating the mask over the 5 MHz and 10 MHz LTE victim receive channel. The results for 0 MHz, 1 MHz, 2 MHz and 3 MHz offset are shown in Table 4.2.3-8, other offsets are show in Figure 4.2.3-7.

Table 4.2.3-8: ACLR for Legacy Mask.

Offset	**5 MHz LTE channel**	**10 MHz LTE channel**
0 MHz	13.7 dB	13.7 dB
1 MHz	14.5 dB	14.4 dB
2 MHz	22.0 dB	21.9 dB
3 MHz	23.5 dB	23.4 dB

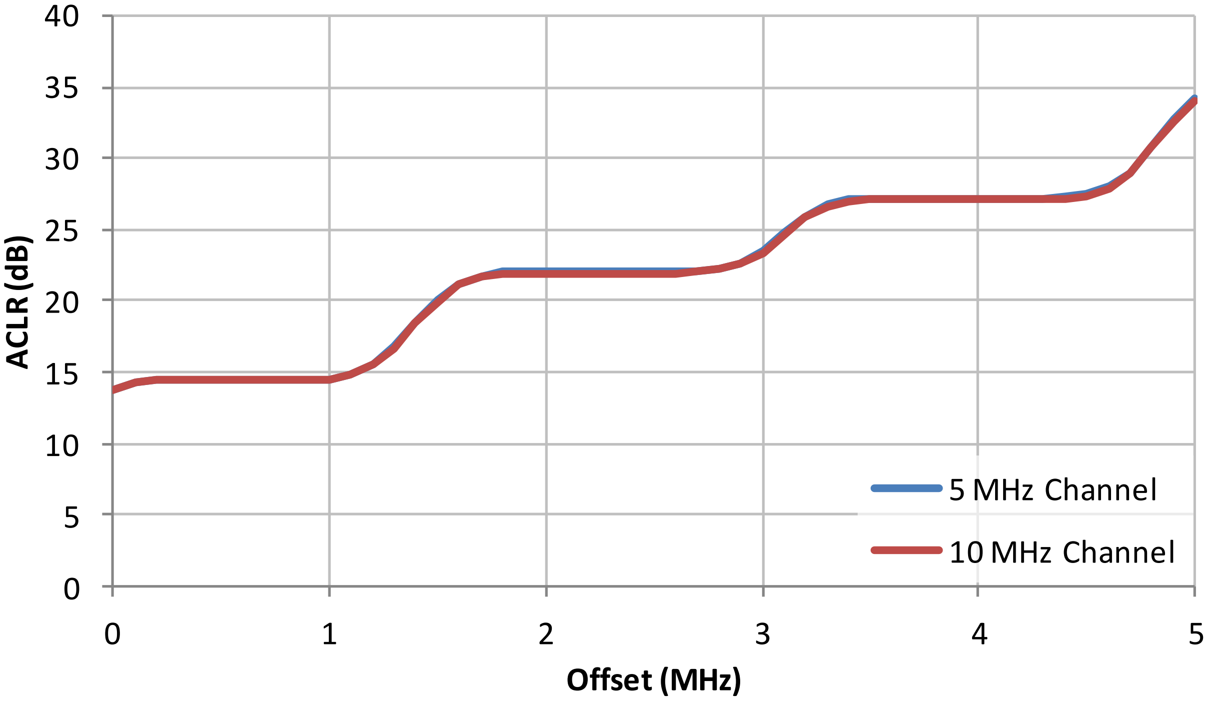

Figure 4.2.3-7: Legacy AFSCN ACLR.

Based on the above results the ACIR values are below in Table 4.2.3-9 and Figure 4.2.3-8.

Table 4.2.3-9: ACIR for Legacy Mask.

Offset	**5 MHz LTE channel**	**10 MHz LTE channel**
0 MHz	13.7 dB	13.7 dB
1 MHz	14.5 dB	14.4 dB
2 MHz	22.0 dB	21.9 dB
3 MHz	23.5 dB	23.4 dB

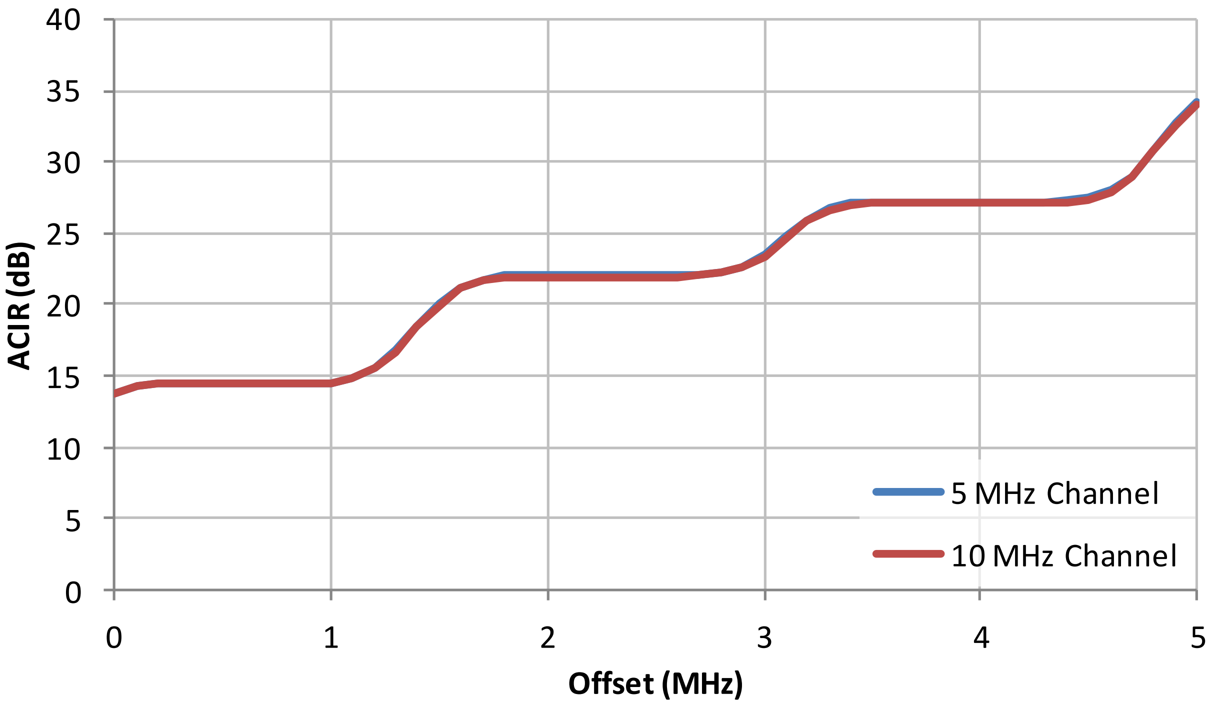

Figure 4.2.3-8: Legacy AFSCN ACIR.

4.2.3.2.2.5 Consideration of BS pointing angles

This analysis will consider three options for the base station pointing angle, one in which the base station is pointed in the direction of the SATOPS transmitter with 3 degrees downtilt using the ITU-R antenna masks (baseline) and the two others in which the base station is pointed 60 degrees away from a vector from the BS to the SATOPS transmitter with either the ITU-R pattern or a representative antenna pattern.

Table 4.2.3-10: BS Scenarios considered in this analysis.

Scenario	Pointing direction	BS Antenna Pattern	Note
Baseline	Directly at SATOPS transmitter	ITU-R F.1336-3 18 dBi max gain 70° azimuth 3 dB beamwidth 10° elevation 3 dB beamwidth 3° downtilt	All the figures will show the baseline case by a blue line
Opt 1	60 degrees away from vector between BS and SATOPS transmitter	ITU-R F.1336-3 18 dBi max gain 70° azimuth 3 dB beamwidth 10° elevation 3 dB beamwidth 3° downtilt	All the figures will show the Opt 1 case by a yellow line
Opt 2	60 degrees away from vector between BS and SATOPS transmitter	Andrew HBX-9016DS-T0M 18.3 dBi max gain 90° azimuth 3 dB beamwidth 4.8° elevation 3 dB beamwidth 8° downtilt	All the figures will show the Opt 2 case by a red lie

4.2.3.2.2.6 Satellite Assumptions

4.2.3.2.2.6.1 Satellite Orbit Model

The mathematical model for prediction of satellite position and velocity using NORAD "two-line elements" is based on the SGP – C Library.[25] This library implements five mathematical models: SGP, SGP4, SDP4, SGP8 and SDP8 and are described in the Spacetrack report No. 3.[26] For this analysis the SGP model will be used.

4.2.3.2.2.6.2 SATOPS Pointing Angles

The analysis will consider the below scenarios in Table 4.2.3-11 for the SATOPS pointing angle.

Table 4.2.3-11: SATOPS Antenna Pointing Scenarios considered in this analysis.

Scenario	**Comment**
A – Assume SATOPS antenna is always pointing at minimum elevation angle	This is worst case scenario and is not representative of the time varying factors, nor is this representative of the actual point angles for some satellite systems (see section 4.2.2 on satellite pointing angles).
B – Assume SATOPS antenna is always pointing at selected satellite	Will need to consider statistical representation of interference expected to be received.

4.2.3.2.3 Results

4.2.3.2.3.1 Case A – Minimum Elevation Angles

The below in Table 4.2.3-12 are the results for the NHS Location using Modified Hata Propagation. Note that for the Baseline the 3 degree of down tilt does not significantly reduce the antenna gain towards the horizon.

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[25] http://www.brodo.de/space/sgp/.

[26] Spacetrack Report No. 3 - Models for Propagation of NORAD Element Sets. Felix R. Hoots, Ronald L. Roehrich, TS Kelso. December 1988. Available at http://www.celestrak.com

Table 4.2.3-12: Modified Hata Propagation model for NHS location.

SATOPS Parameters	**Baseline**	**Opt 1**	**Opt 2**
Tx Frequency (MHz)	1762	1762	1762
Tx Power (dBm)	68.6	68.6	68.6
Peak Antenna Gain (dBi)	45	45	45
Antenna Gain @ Horizon (dBi) (3 deg elev)	16	16	16
EIRP @ Horizion (dBm)	84.6	84.6	84.6
Antenna Height (m)	30	30	30
BS Parameters			
Antenna Height (m)	30	30	30
Down tilt (deg)	3	3	8
3dB Beamwidth (elevation) (deg)	10	10	4.8
Off Azimuth direction (deg)	0	60	60
3dB Beamwidth (azimuth) (deg)	70	70	90
Insertion Loss (dB)	2	2	2
Peak Antenna Gain (dBi)	18	18	18.2
Gain at Horizon (dBi)	18.0	6.5	-12.4
Ref Sen (dBm)	-101.50	-101.50	-101.50
Interference @ 1 dB desense (dBm)	-107.37	-107.37	-107.37
Interference @ 3 dB desense (dBm)	-101.50	-101.50	-101.50
Loss Required for			
1 dB desense (dB)	207.94	196.51	177.54
3 dB desense (dB)	202.07	190.64	171.67
Modified Hata Model separation distance			
Urban case distance (1 dB desense) (km)	102.3	82.7	54.1
Suburban case distance(1 dB desense) (km)	124.4	103.1	71.4
Open area case distance (1 dB desense) (km)	165.6	141.4	104.8
Urban case distance (3 dB desense) (km)	92.0	73.3	46.2
Suburban case distance(3 dB desense) (km)	113.3	92.8	62.6
Open area case distance (3 dB desense) (km)	153.0	129.6	94.4

Figure 4.2.3-10 shows the distances at which a BS would receive interference at a prescribed level, in this case 1 dB desense, when located in the area around the earth terminal. For this figure the ITM model in point-to-point mode and the Modified Hata Model is used to compute loss. The contours are computed by distributing BS within a distance of 200 km around the Satellite uplink terminal in a hexagonal grid with inter-site distance between BS of 7 km, see Figure 4.2.3-9, each red marker is a location of a BS at which the interference level is computed. In Figure 4.2.3-10 the blue line is for the Baseline case, the yellow line is for the Opt 1 case and the red line is for the Opt 2 case. The circles are the corresponding 1 dB desense curves for the Modfied Hata model as computed above in Table 4.2.3-12.

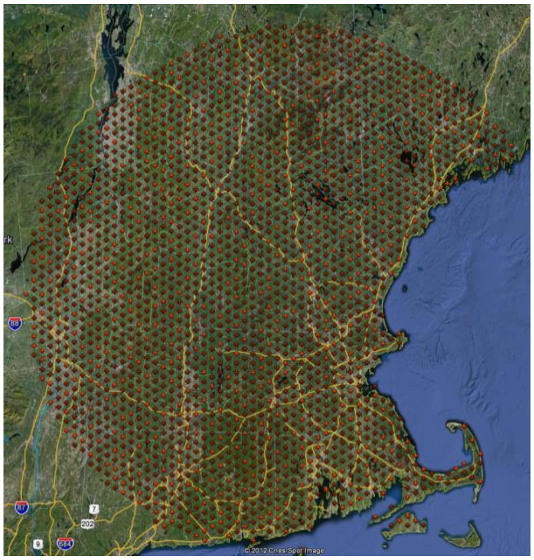
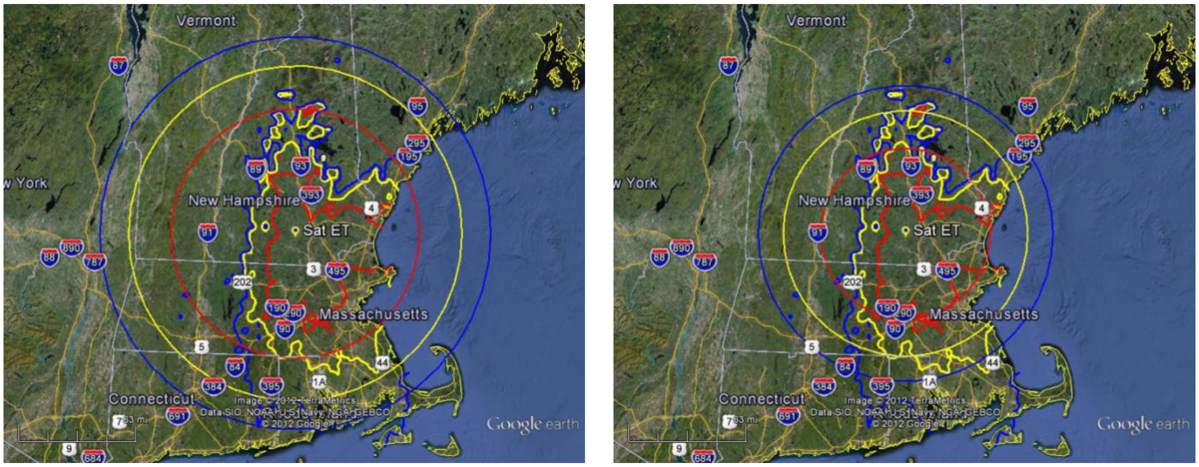


Figure 4.2.3-9: Distribution of BS with 7 km spacing around NHS site (2281 locations).



ITM Model and modified Hata for Open Area Case

ITM Model and modified Hata for Surburban Case

Figure 4.2.3-10: NHS Site 1 dB desense curves.

As can be seen in the figures the impact of terrain around the SATOPS site will have a significant impact regarding the distance at which a BS will receive harmful interference. For that reason the remainder of the analysis will be based on the ITM model.

4.2.3.2.3.1.1 Co Channel Operations

When considering co-channel operations the specific band plan will indicate which channels are co-frequency and which channels are adjacent. Shown in Figure 4.2.3-11 is the representation of 5 MHz blocks with the SGLS channels being the numbered channels and the commercial channels being the lettered channels.

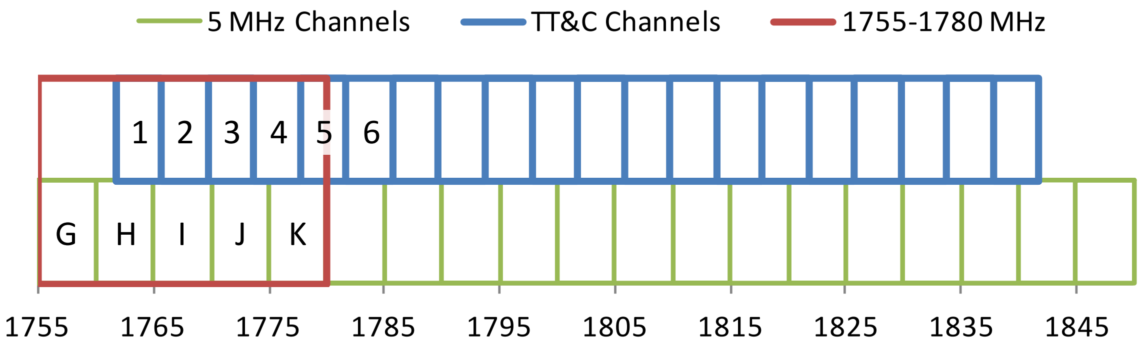


Figure 4.2.3-11: Channel overlap between SGLS channels and Commercial Channels.

Due to this channelization not all of the emissions from a SGLS channel may fall with-in the commercial channel. The amount will depend on the spectral mask in use by the SGLS station. If the SGLS station is using the typical emission mask as indicated in Figure 4.2.1-3 then no reduction will needed due to the narrow operating frequency of the emissions under the assumption that the SGLS terminal will tune to all frequencies with-in the selected channel indicated in the above figure. If the SGLS terminal is operating using the legacy emission mask as indicated in Figure 4.2.1-4 then only a portion of the would impact any selected AWS channel that would overlap the selected channel.

An indication of the amount of reduction in operating power can be found by integrating the legacy emissions over the receiver bandwidth that overlaps and is representative by the Frequency Dependent Rejection (FDR) term in Section 4.2.3.2.2.1, the results are indicated in the below table. As an example if a SGLS station is using channel 2 then all power is with-in AWS channel I and no other AWS channels are co-channel. If a SGLS station is using channel 3, then AWS channel I is co-channel and would see a reduced power of 8.1 dB relative to full power operations, also AWS channel J is co-channel and would see power at a 0.9 dB reduced level relative to full power operations.

Table 4.2.3-13: Reduction of on-channel power for legacy emissions masks.

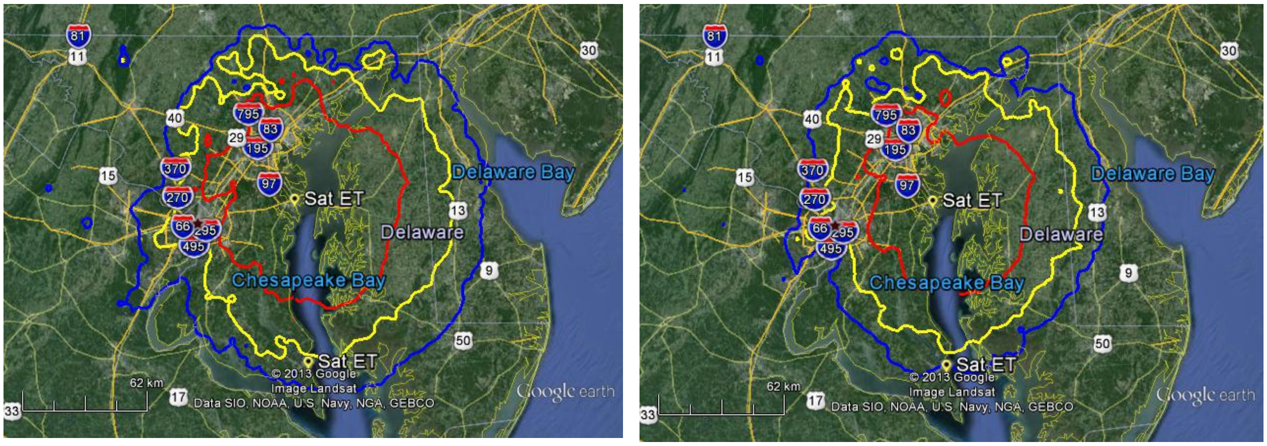
AWS Channel	**SGLS Co-Channels**	**Overlap (%)**	**FDR (dB)**
G			
H	1	81.90%	1.9
I	1, 2, 3	18.1%, 100%, 6.8%	4.7, 0.0, 8.1
J	3, 4	93.2%, 31.7%	0.9, 4.7
K	4, 5	68.3%, 56.6%	1.9, 2.0

Shown in Table 4.2.3-14 is a summary of the figures in this section to the specific site locations listed. All co-channel computations are performed under the assumption that the SGLS channel is fully with-in the receiver channel of an LTE Base station. To relate these results to a specific channel when the SGLS station is using the legacy emission mask, the factors discussed above in Table 4.2.3-13 need to be applied to the results.

The convention in the remainder of this Phase 1 analysis for the figures is that the blue line is for the Baseline case, the yellow line is for the Opt 1 case and the red line is for the Opt 2 case listed in Table 4.2.3-10. The data is computed by use of the ITM propagation model in point-to-point mode when distributing BS within a distance of 200 km around the Satellite uplink terminal in a hexagonal grid with inter-site distance between BS of 7 km.

Table 4.2.3-14: Summary Table

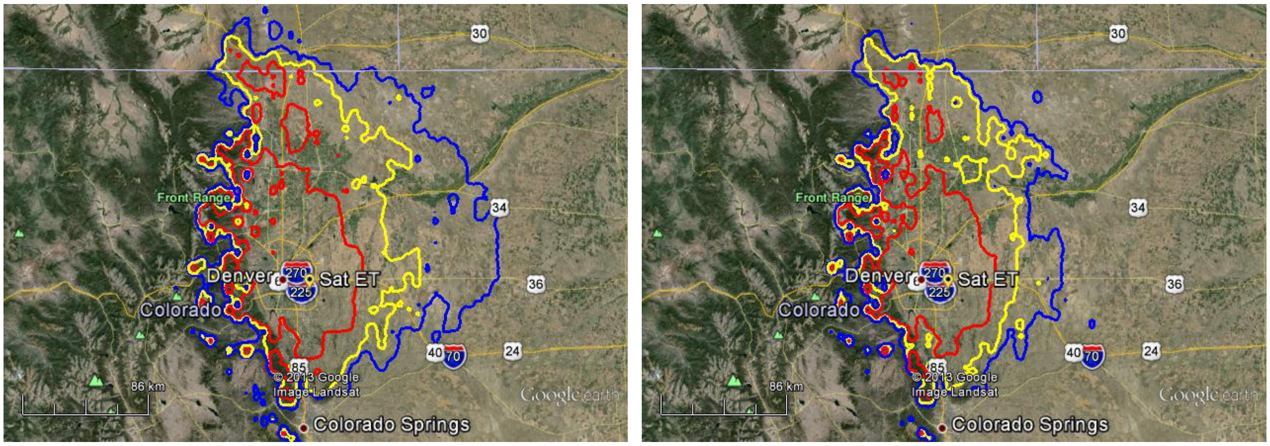
SATOPS Sites	Figure	Note
AN, MD	Figure 4.2.3-12	
BAFB	Figure 4.2.3-13	
BP, MD	Figure 4.2.3-14	
CAPEG	Figure 4.2.3-15	
CP, CA	Figure 4.2.3-16	Not Currently Operational
CTS	Figure 4.2.3-17	
EVCF	Figure 4.2.3-18	
FB, AK	Figure 4.2.3-19	
FB, NC	Figure 4.2.3-20	
FB, VA	Figure 4.2.3-21	
FH, TX	Figure 4.2.3-22	
GNS	Figure 4.2.3-23	
GTS	Figure 4.2.3-24	
HB, CA	Figure 4.2.3-25	
HTS	Figure 4.2.3-26	
JB, WA	Figure 4.2.3-27	
KAFB	Figure 4.2.3-28	
KW, FL	Figure 4.2.3-29	
LP, CA	Figure 4.2.3-30	
MO, CA	Figure 4.2.3-31	
NHS	Figure 4.2.3-32	
PH, ME	Figure 4.2.3-33	
PR, MD	Figure 4.2.3-34	
SAC, CA	Figure 4.2.3-35	
VTS	Figure 4.2.3-36	



1 dB Desense

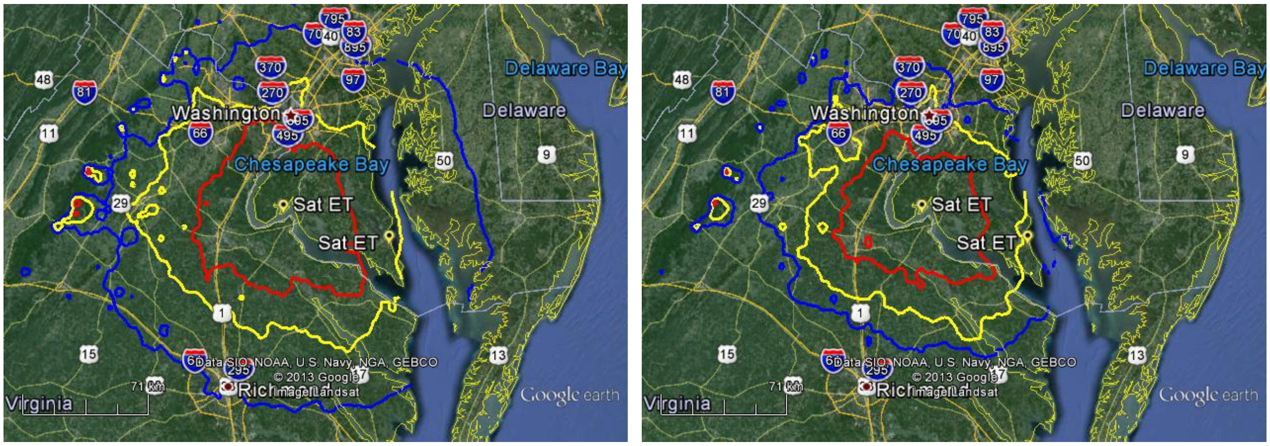
3 dB Desense

Figure 4.2.3-12: AN, MD Site.



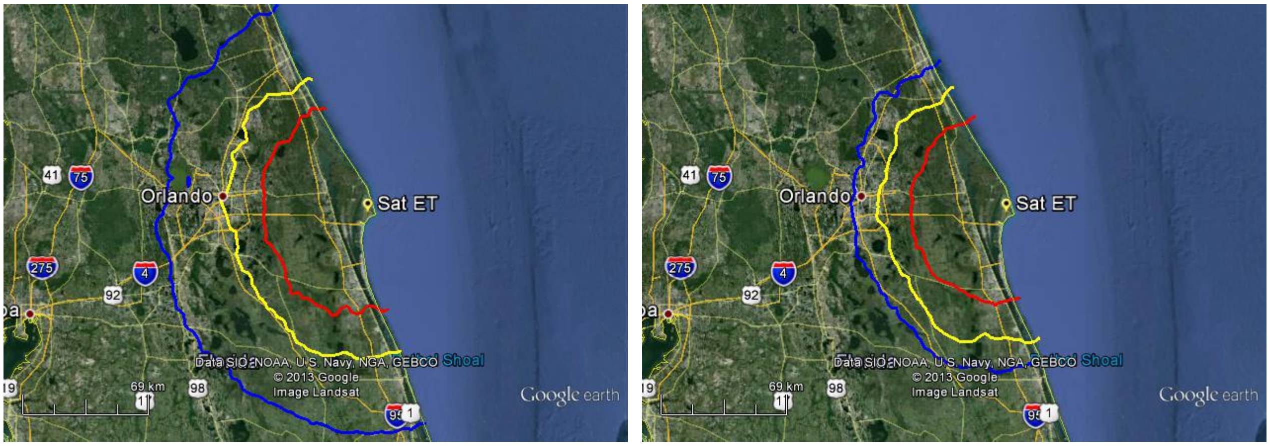
1 dB Desense 3 dB Desense

Figure 4.2.3-13: BAFB Site.



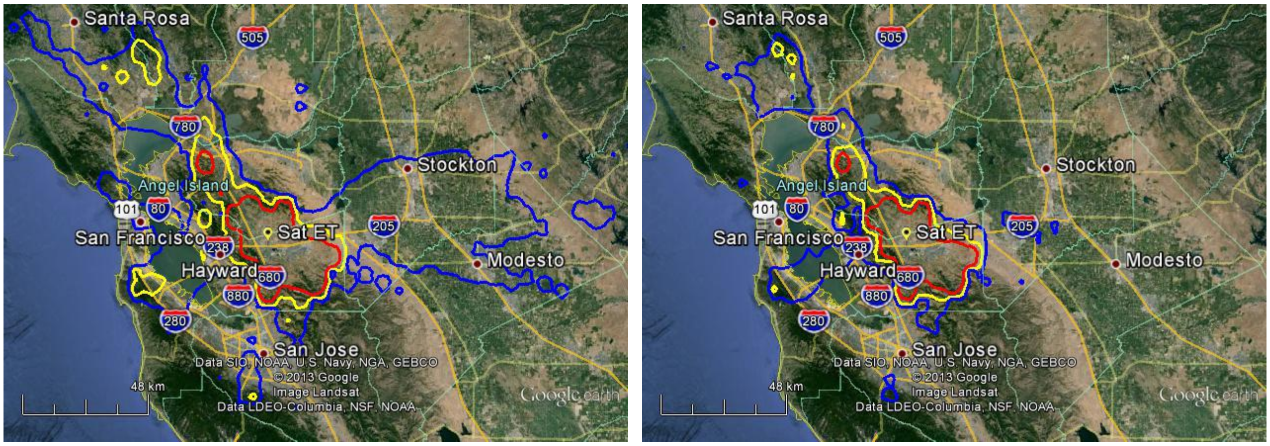
1 dB Desense 3 dB Desense

Figure 4.2.3-14: BP, MD Site.



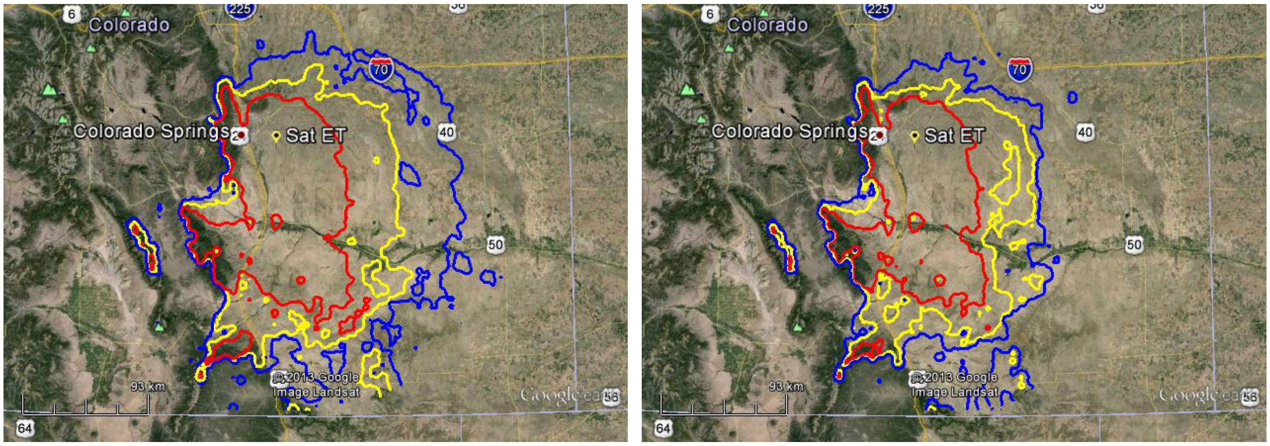
1 dB Desense 3 dB Desense

Figure 4.2.3-15: CAPEG Site.



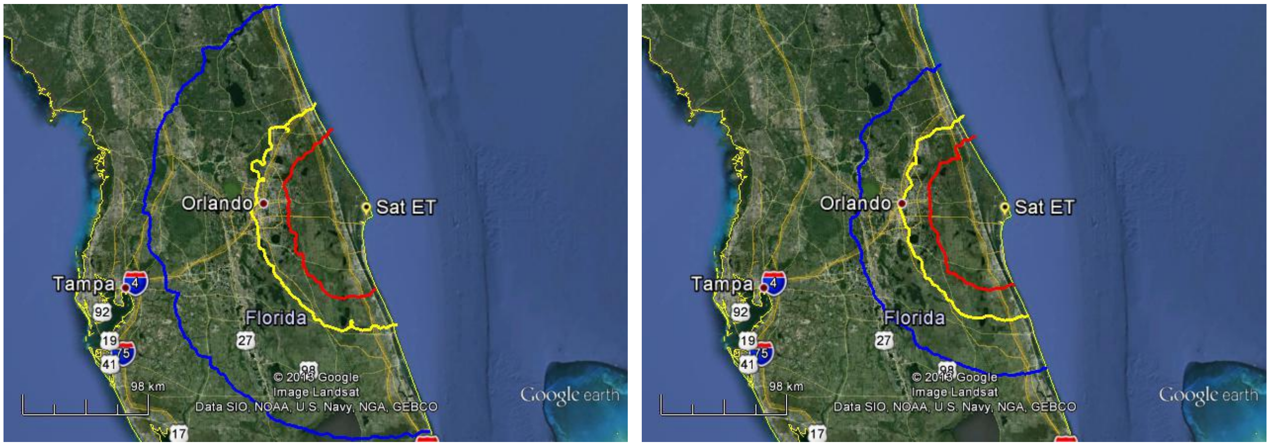
1 dB Desense 3 dB Desense

Figure 4.2.3-16: CP, CA Site.



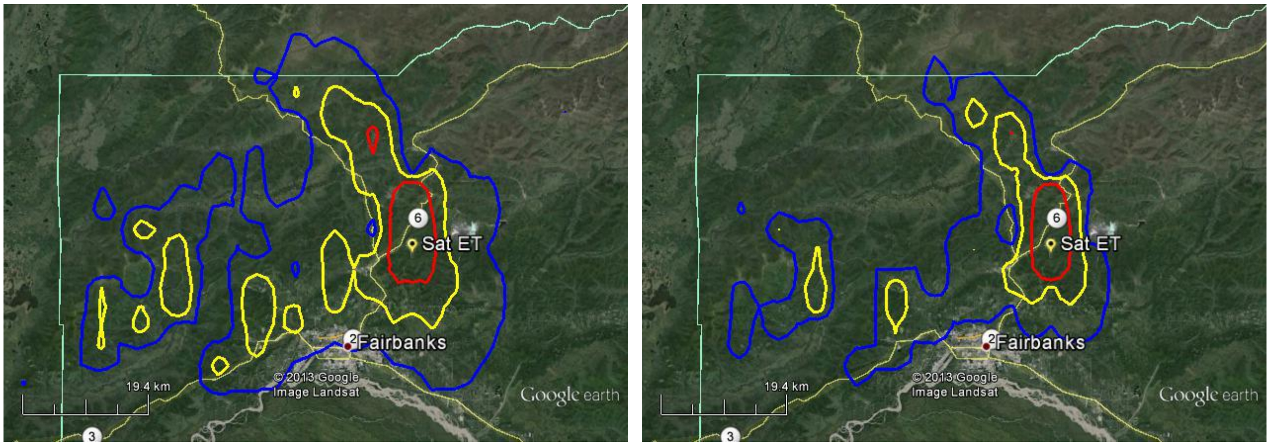
1 dB Desense 3 dB Desense

Figure 4.2.3-17: CTS Site.



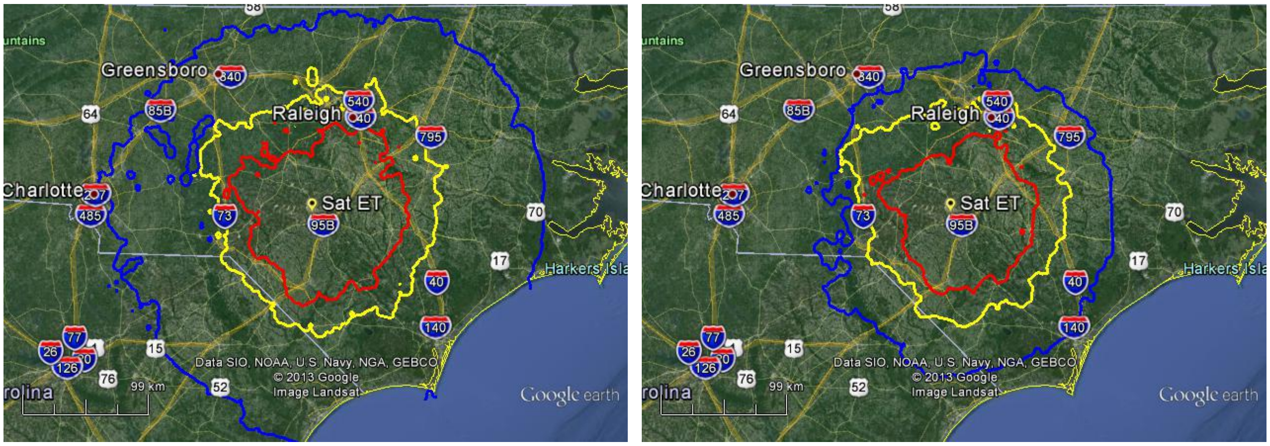
1 dB Desense 3 dB Desense

Figure 4.2.3-18: EVCF Site.



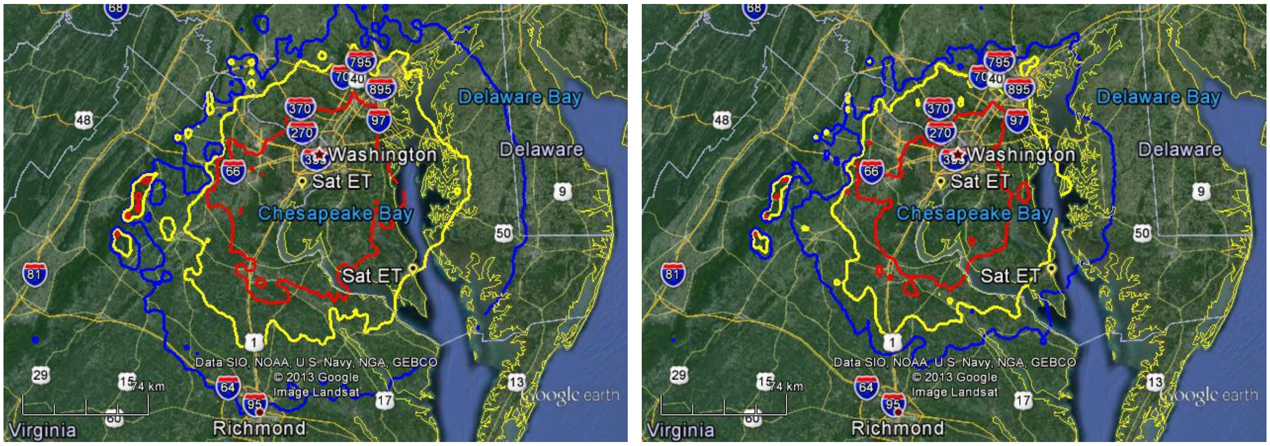
1 dB Desense 3 dB Desense

Figure 4.2.3-19: FB, AK Site.



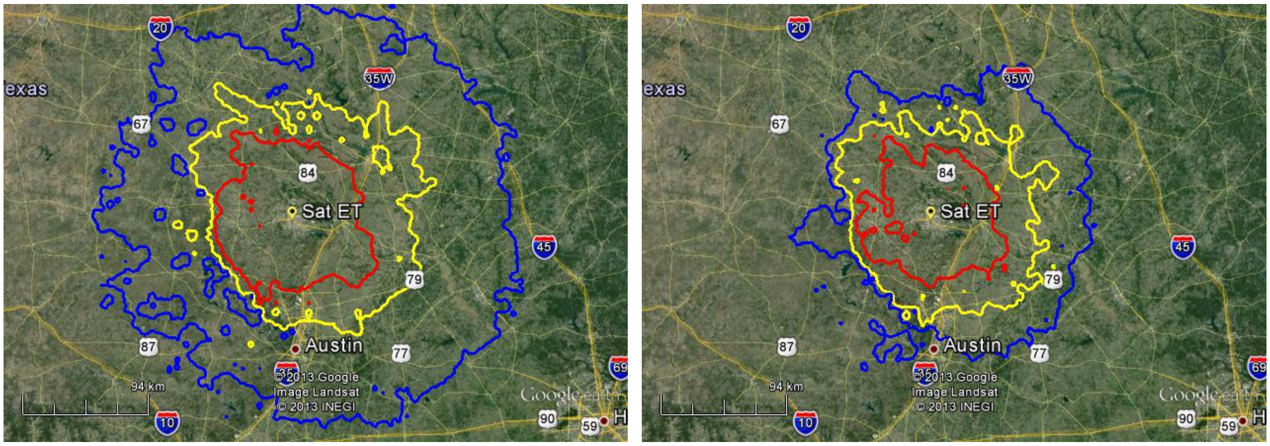
1 dB Desense 3 dB Desense

Figure 4.2.3-20: FB, NC Site.



1 dB Desense 3 dB Desense

Figure 4.2.3-21: FB, VA Site.



1 dB Desense

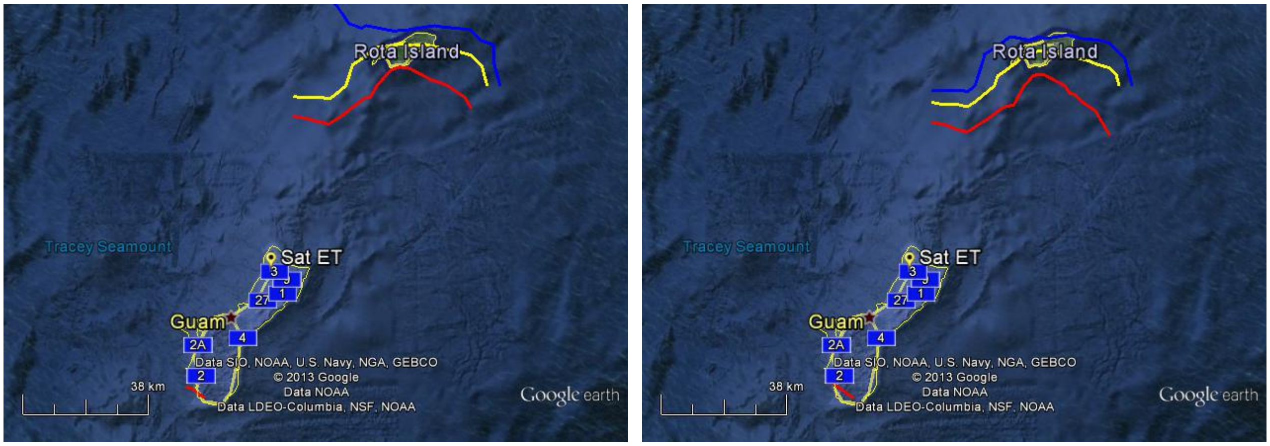
3 dB Desense

Figure 4.2.3-22: FH, TX Site.

1 dB Desense

3 dB Desense

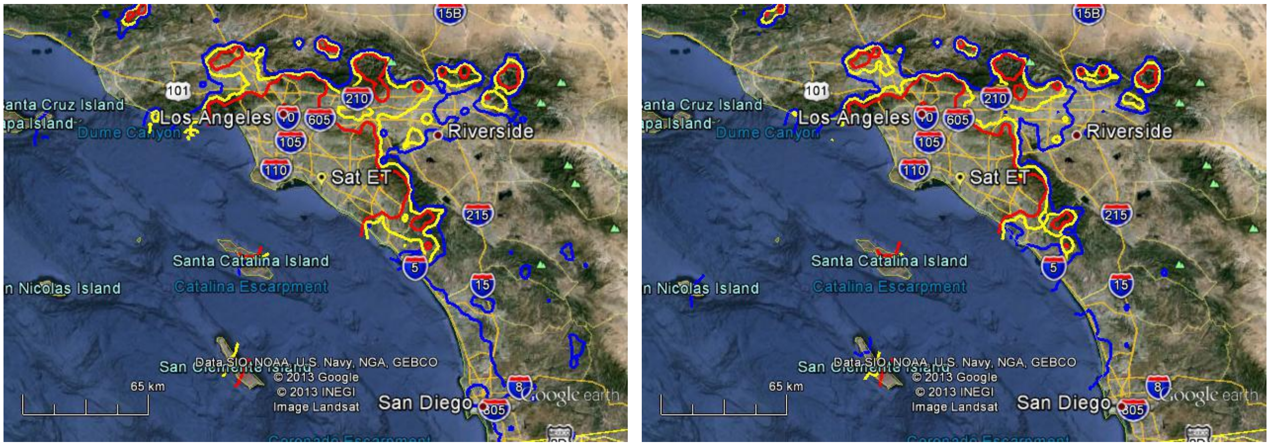
Figure 4.2.3-23: GNS Site.



1 dB Desense

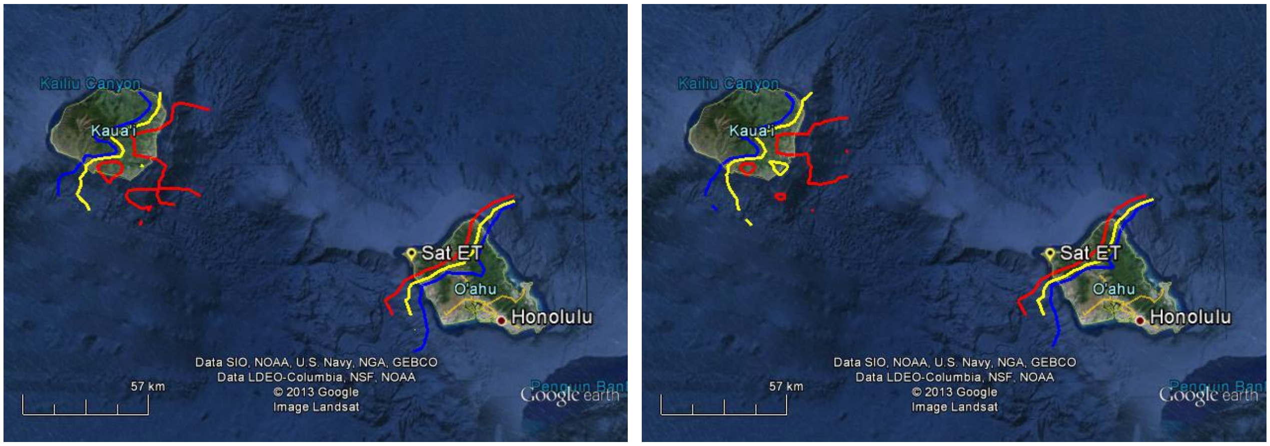
3 dB Desense

Figure 4.2.3-24: GTS Site.



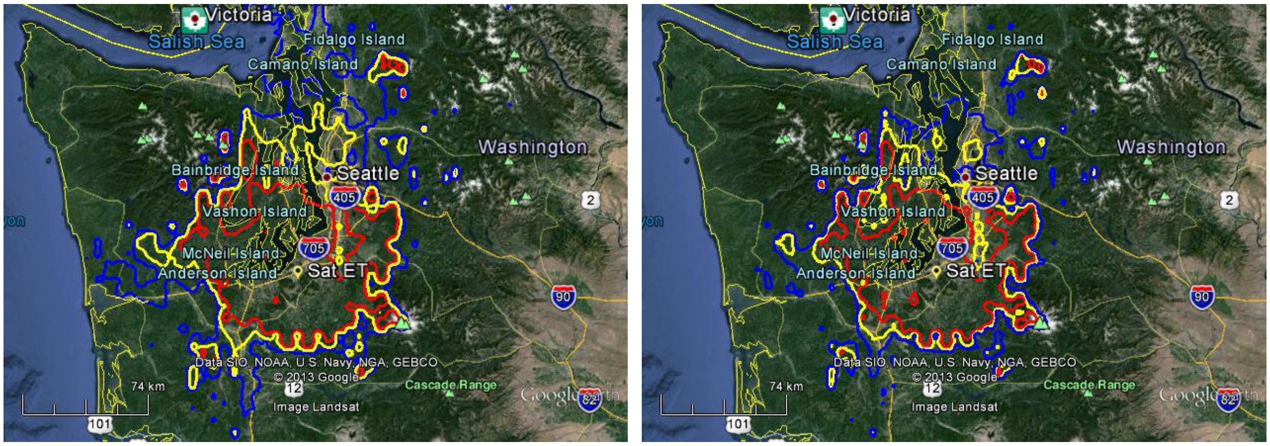
1 dB Desense 3 dB Desense

Figure 4.2.3-25: HB, CA Site.



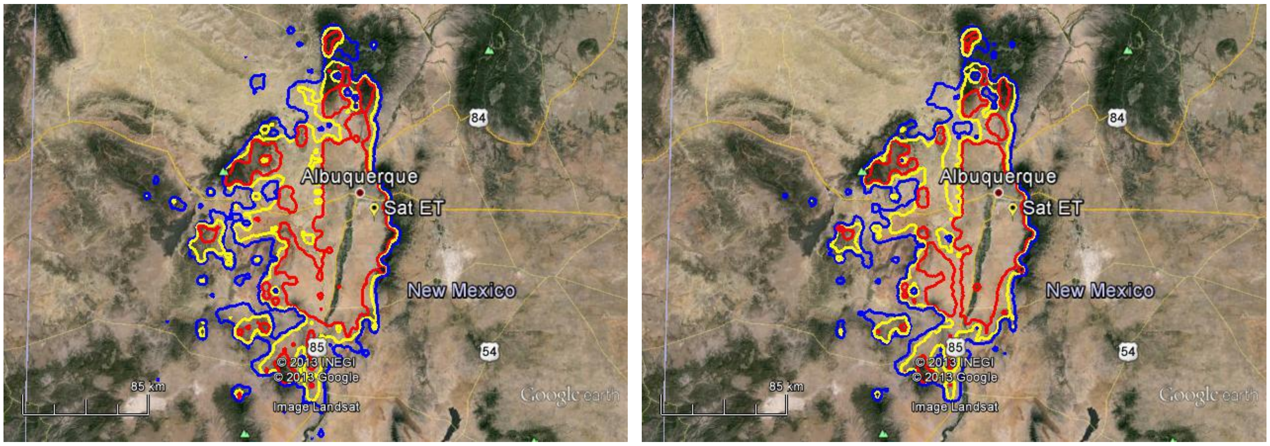
1 dB Desense 3 dB Desense

Figure 4.2.3-26: HTS Site.



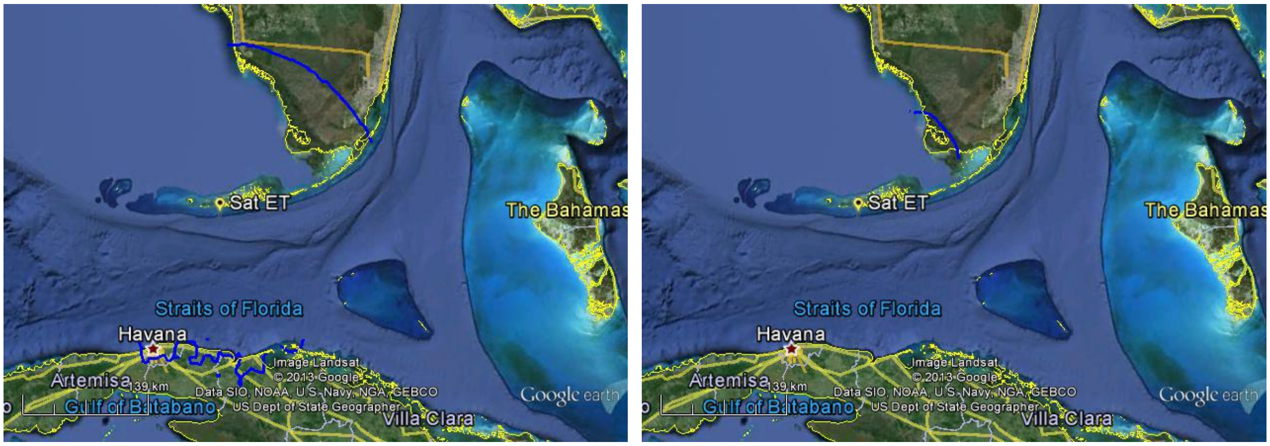
1 dB Desense 3 dB Desense

Figure 4.2.3-27: JB, WA Site.



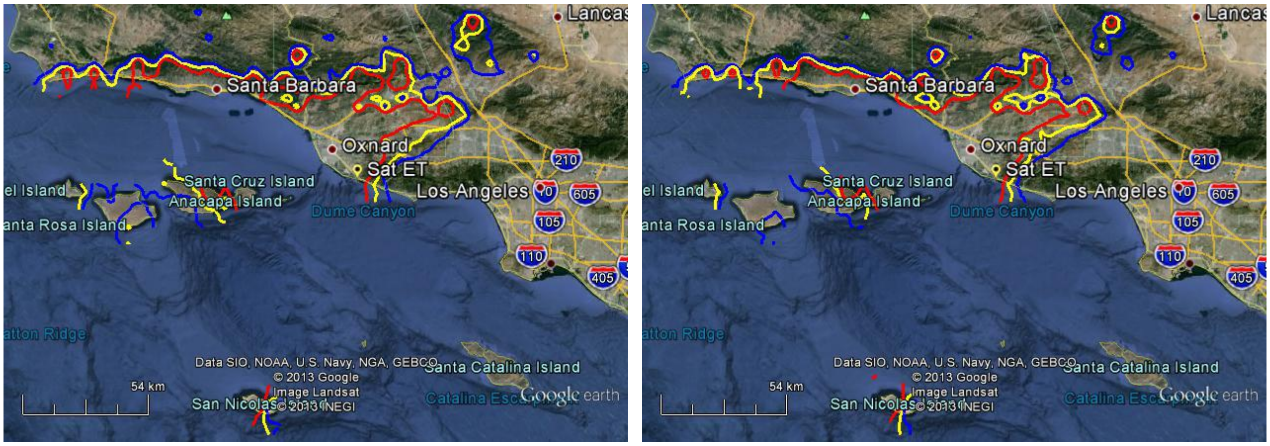
1 dB Desense 3 dB Desense

Figure 4.2.3-28: KAFB Site.



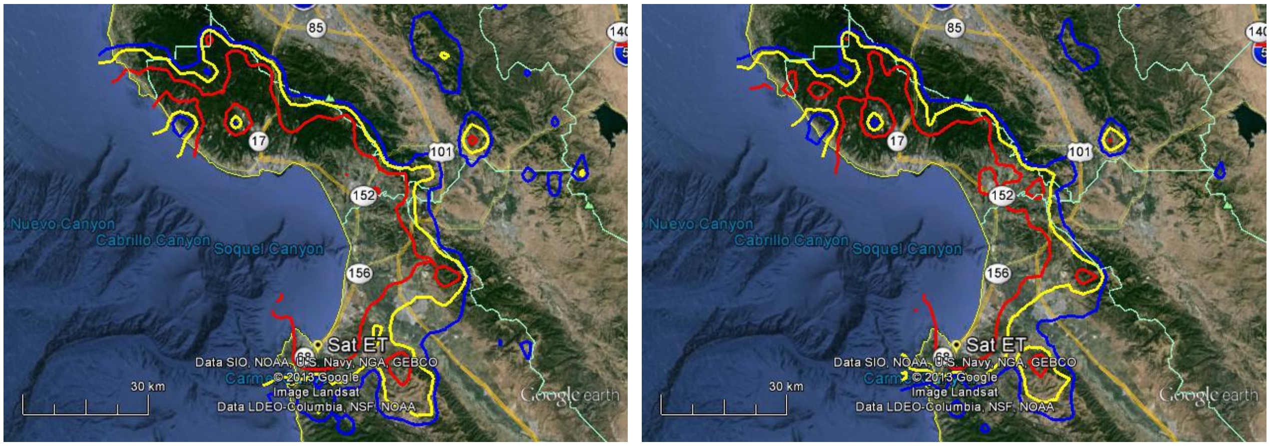
1 dB Desense 3 dB Desense

Figure 4.2.3-29: KW, FL Site.



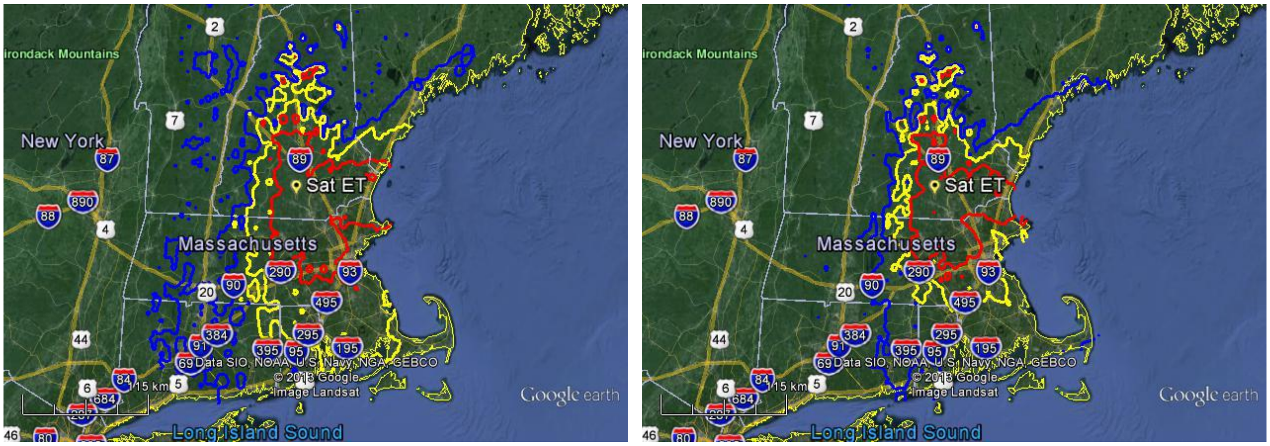
1 dB Desense 3 dB Desense

Figure 4.2.3-30: LP, CA Site.



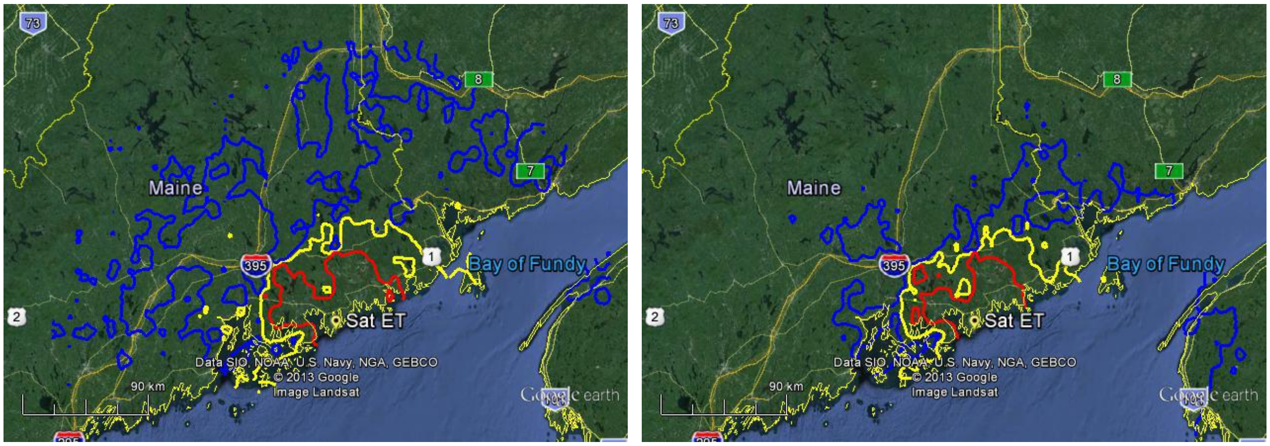
1 dB Desense 3 dB Desense

Figure 4.2.3-31: MO, CA Site.



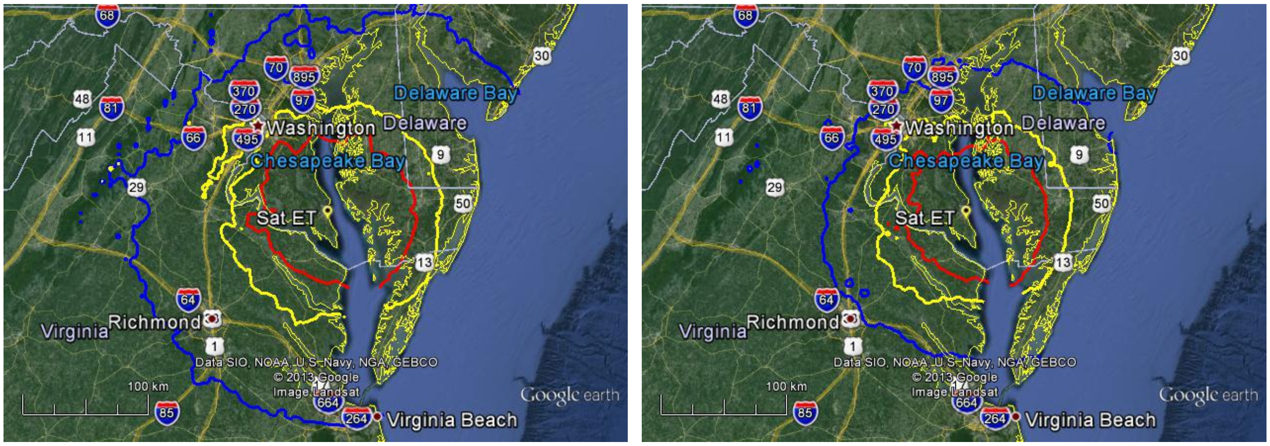
1 dB Desense 3 dB Desense

Figure 4.2.3-32: NHS Site.



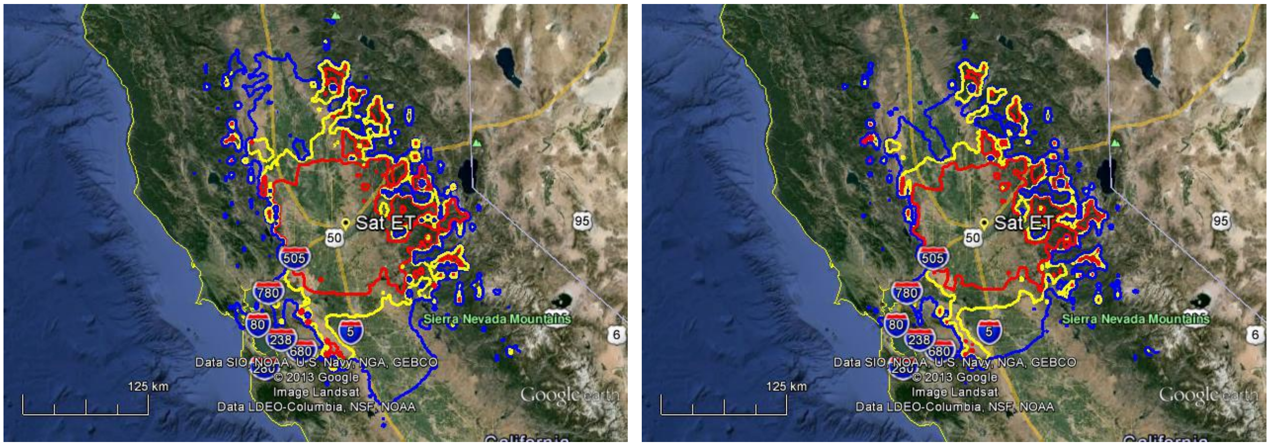
1 dB Desense 3 dB Desense

Figure 4.2.3-33: PH, ME Site.



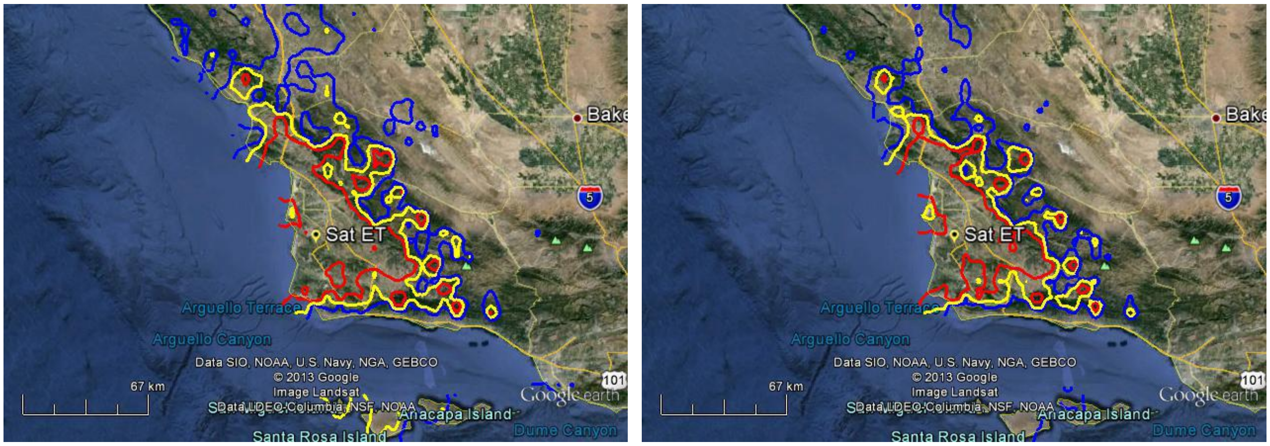
1 dB Desense 3 dB Desense

Figure 4.2.3-34: PR, MD Site.



1 dB Desense 3 dB Desense

Figure 4.2.3-35: SAC, CA Site.



1 dB Desense 3 dB Desense

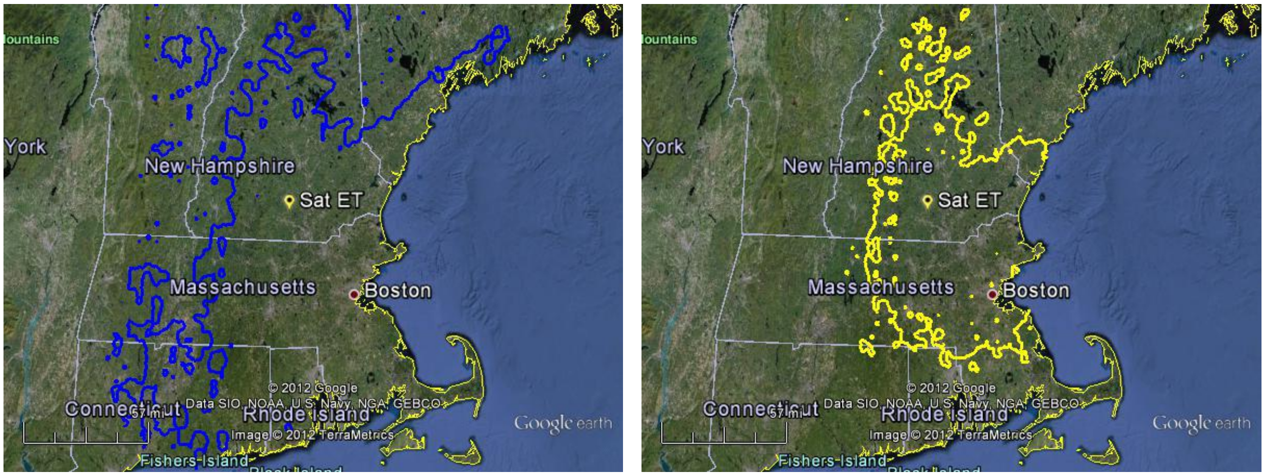
Figure 4.2.3-36: VTS Site.

4.2.3.2.3.1.2 Adjacent Channel Operations

When considering the adjacent channel operations the specific channelization of both the SGLS operation and the commercial base stations, along with the emission mask of the SGLS terminal, will determine the amount of interference present.

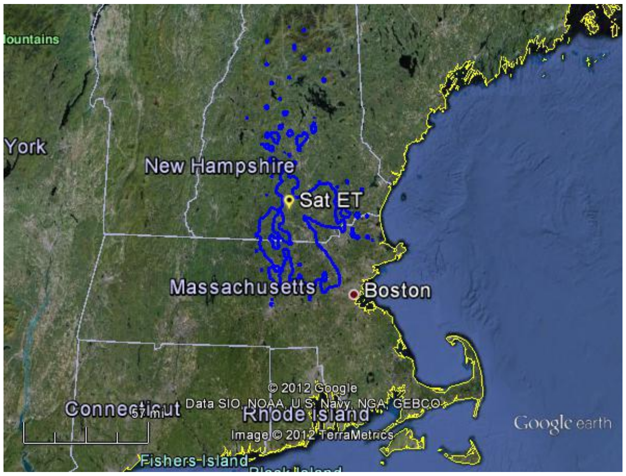
4.2.3.2.3.1.2.1 Future Mask

For the case of the future mask as found in Figure 4.2.1-3 the adjacent channel offset will be as small as 0 MHz depending on the exact frequency the SGLS terminal is tuned to for operation. For this analysis results will be shown for a 0 MHz offset and a 1 MHz offset. Based on the results found in Table 4.2.3-5 the ACIR is 15.7 dB and 49.5 dB, respectively.



Co-Channel

0 MHz Offset (ACIR = 15.7 dB)



1 MHz Offset (ACIR = 49.5 dB)

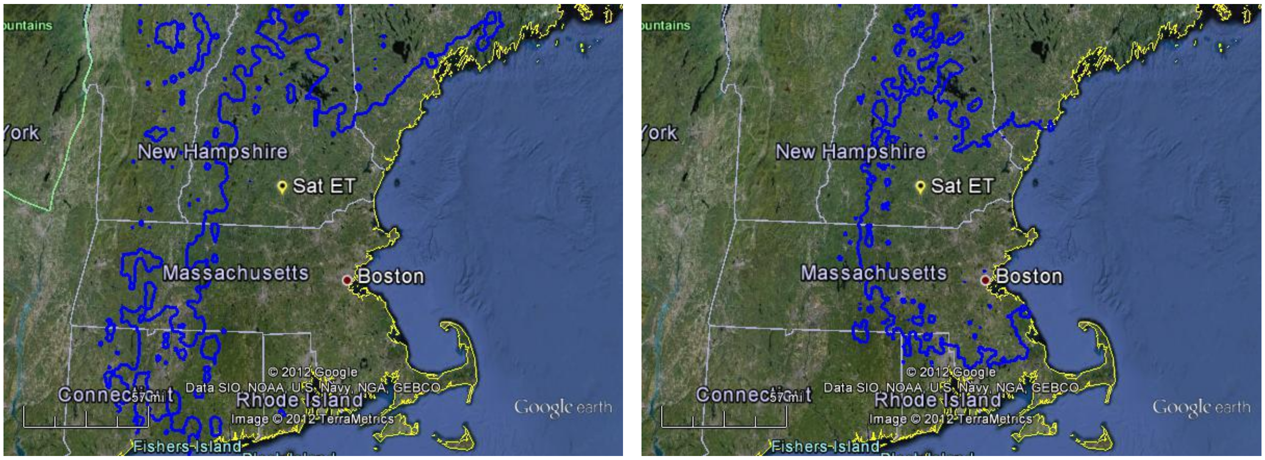
Figure 4.2.3-37: NHS Site adjacent channel offset 1 dB desense curves.

4.2.3.2.3.1.2.2 Legacy Mask

For the case of the Legacy mask as found in Figure 4.2.1-4 the adjacent channel offset will be between 0.27 and 3.73 MHz based on the 5 MHz base station channelization. The results in this section are found in Figure 4.2.3-38.

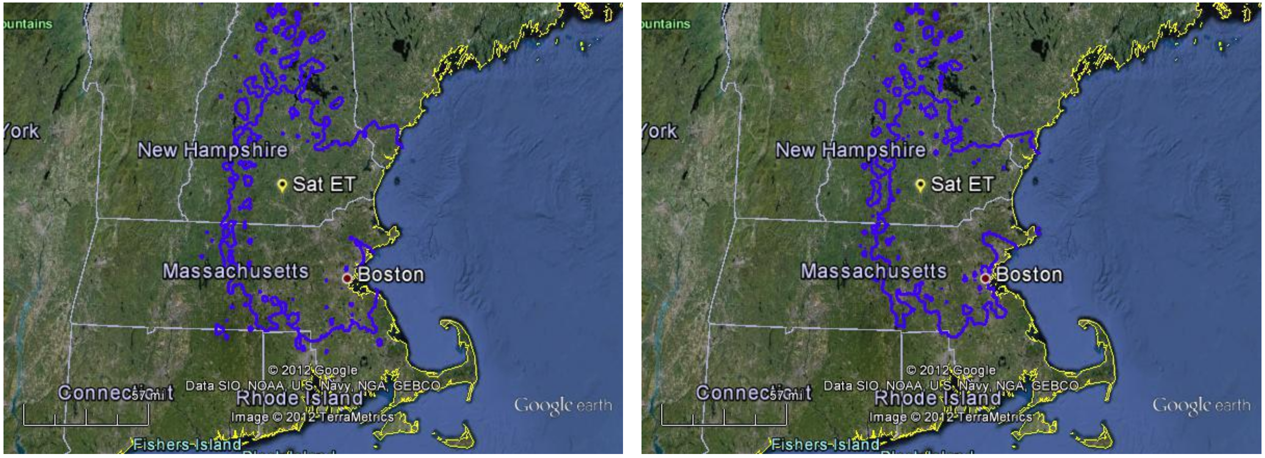
Table 4.2.3-15. ACIR for Legacy Mask.

AWS Channel	SGLS Adj-Channels	Minimum Offset (MHz)	ACIR (dB)
G	1	1.72	21.9
H	2	0.72	14.4
I	4	3.73	27.2
J	2, 5	0.27, 2.74	14.4, 22.2
K	3, 6	1.27, 1.74	16.4, 21.9



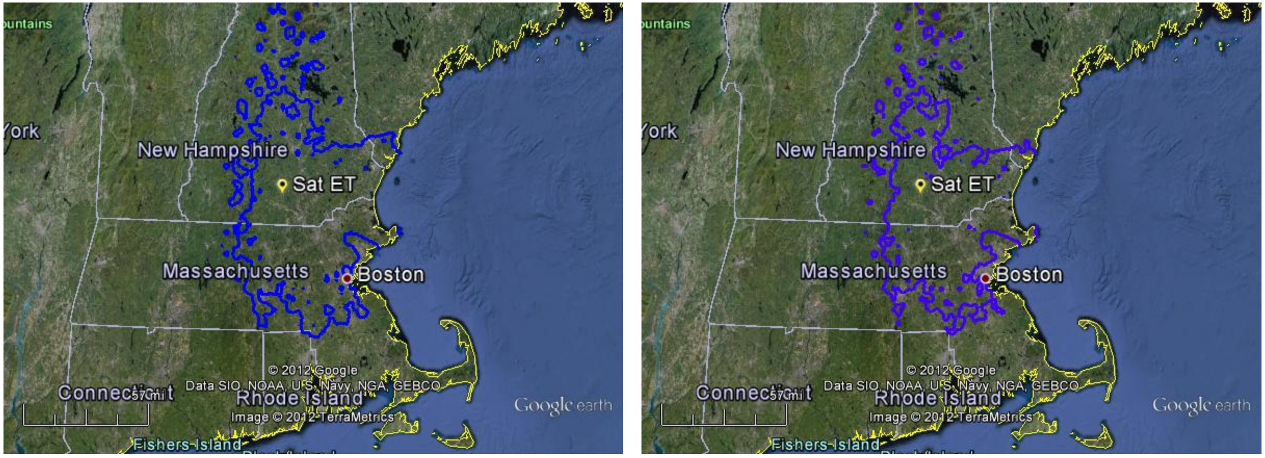
Co-Channel

0.27 MHz and 0.72 MHz Offset (ACIR = 14.4 dB)



1.27 MHz Offset (ACIR = 16.4 dB)

1.72 MHz and 1.74 MHz Offset (ACIR =21.9 dB)



2.74 MHz Offset (ACIR = 22.2 dB)

3.73 MHz Offset (ACIR = 27.2 dB)

Figure 4.2.3-38: NHS Site adjacent channel offset 1 dB desense curves.

4.2.3.2.3.2 Case B – Statistical Interference Levels

Case B is based on the assumption that the SATOPS antenna is always pointing at a selected satellite. When the SATOPS station is communicating with a GSO satellite there is no time variation of the pointing angle. When the SATOPS station is communicating with an NGSO satellite the pointing angle will change with time and the interference level at any BS receiver will also vary with time. For case B the same method of finding the interference level as described in Section 4.2.3.2.3.1.1 is used, but in this case a histogram of the interference level will be captured.

Analysis in this section will be based on one year of simulation time with a sample increments of one second.

Shown in Figure 4.2.3-40 is the simulation results based on the assumption that the satellite being tracked is that of USKW and the tracking station is located at the NHS location. This satellite uses SGLS channel 1 (see Section 4.2.1.1.1), and is a near polar orbiting satellite with an inclination angle of 98 degrees operates at an altitude of 630 km. The percentages listed in the figure is a conditional percentage of the interference level, the condition is that the SATOPS terminal is transmitting on the specific channel of interest. As an example of the below data, if the SATOPS terminal is communicating on channel 1 every time the USKW satellite passes, the maximum time that the satellite USKW is above the minimum elevation angle of 3 degrees would be 3.22% of the year. This would mean that given a conditional interference level at 75% of time, the total probability that the interference is at or above this level would be 0.805%.[27] Note that this may not be representative of actual SGLS channel use, actual use will take into account all the satellite systems to be contacted over all the SGLS channels potentially in use. The 0.805% of the time in this case would represent an upper bound of the time in operation if only the USKW satellite system is operational in channel 1.

An example of the interference at one particular simulated base station is shown in Figure 4.2.3-39. This result is for a base station located at 42.63N 72.22W, about 60 km from the Satellite uplink terminal. The percentages indicate the probability of the interference at or below the level indicated in the figure.

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[27] This is computed by

$P(I \geq Io) = 1 - P(I<Io) = 1-[P(I<Io|Ton)*P(Ton)+P(I<Io|Toff)*P(Toff)]$

Where

$P(I \geq Io)$ = Probability that Interference is at or above Io
$P(I<Io)$ = Probability that interference is below Io
$P(I<Io|Ton)$ = Conditional probability that interference is below Io given that the SGLS transmitter is on
$P(I<Io|Toff)$ = Conditional probability that the interference is below Io given the SGLS transmitter is off
$P(Ton)$ = Probability that the SGLS transmitter is on
$P(Toff)$ = Probability that the SGLS transmitter is off

For the example given here:

$P(I<Io|Ton)$ = 75%
$P(I<Io|Toff)$ = 100%
$P(Ton)$ = 3.22%, assumes the SGLS transmitter is always on when the satellite is above the minimum elevation angle
$P(Toff)$ = 96.78%

$P(I \geq Io) = 1-[0.0322 * 0.75 + 1.00*0.9678]= 0.805\%$.

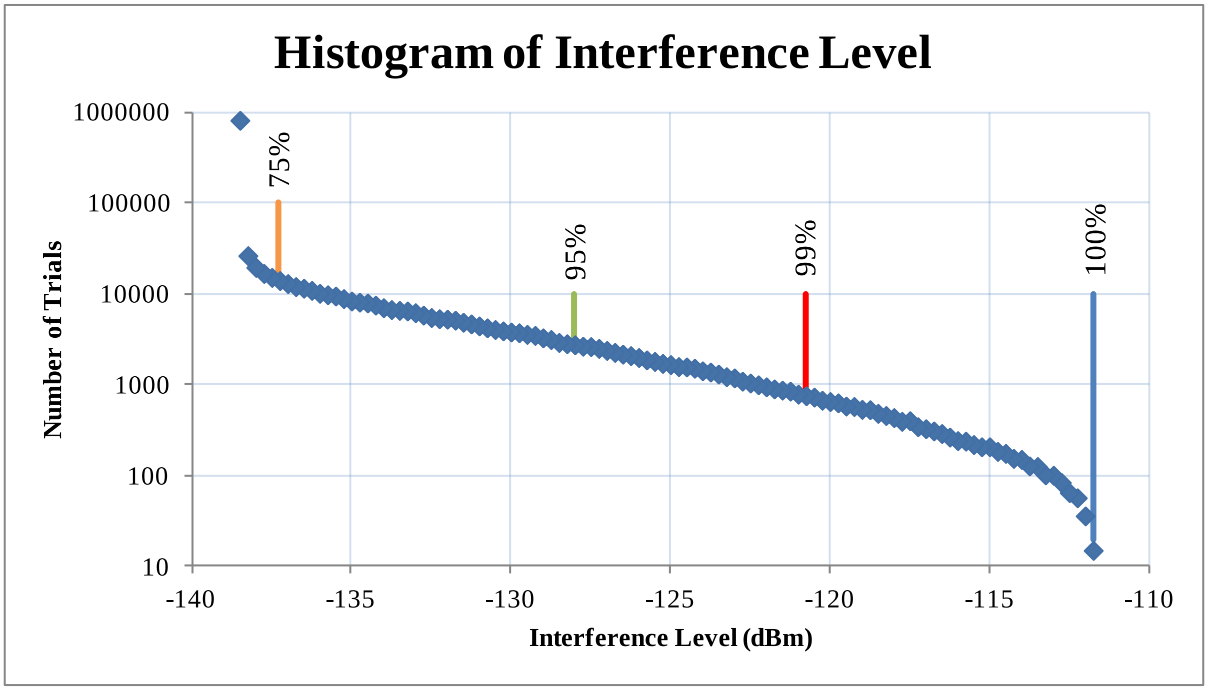
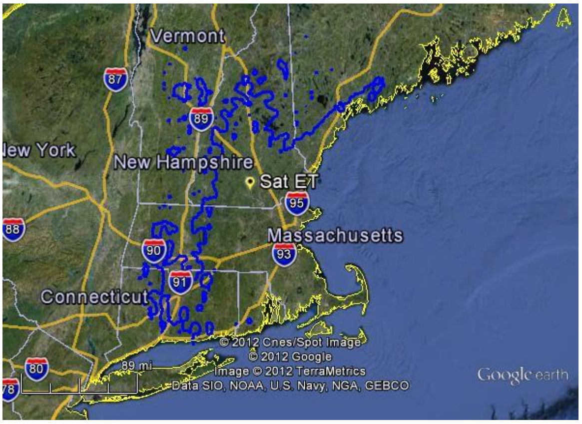


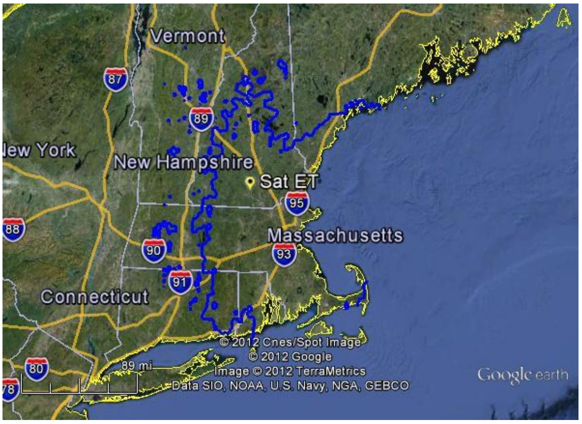
Figure 4.2.3-39. Histogram of interference level from satellite simulation.

Shown in Figure 4.2.3-41 is the simulation results based on the assumption that the satellite being tracked is that of USPOJOAQUE which uses SGLS channel 1 (see Section 4.2.1.1.1), this satellite has inclination angle of 40 degrees at operates at an altitude of 600 km.

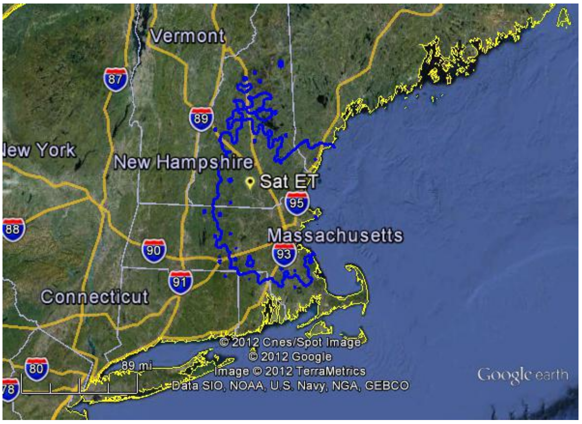
It should be noted that all these figures in this section are for the conditional probability that the interference is below the 1 dB desense level given the condition that the transmitter is on.



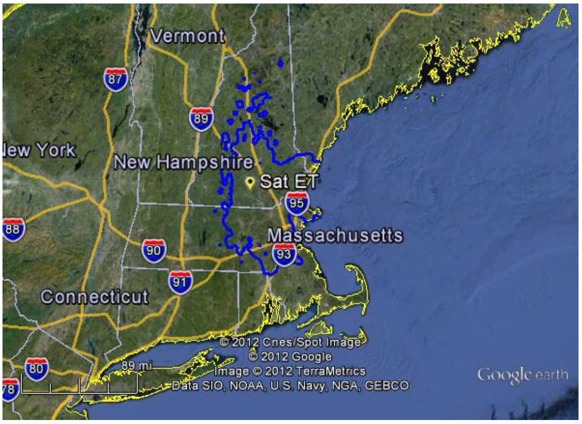
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).



Interference at or below 1 dB desense for 100% of the time.



Interference at or below 1 dB desense for 99% of the time.



Interference at or below 1 dB desense for 95% of the time.

Interference at or below 1 dB desense for 75% of the time.

Figure 4.2.3-40. 1 dB Desense for NHS baseline scenario at various percentages of time, Satellite Inclination of 98 degrees.

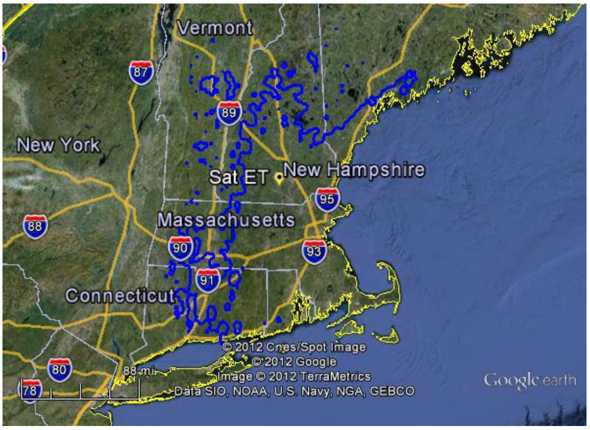
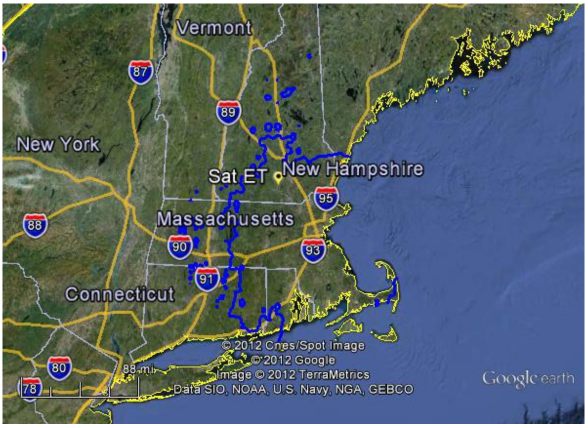
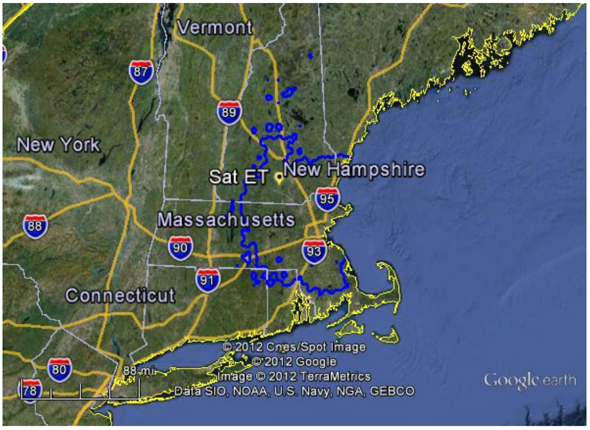
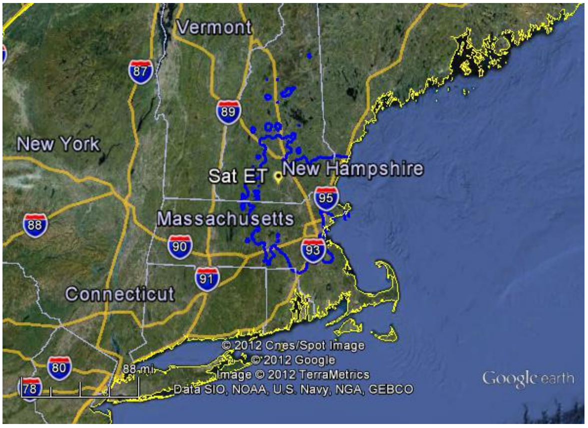
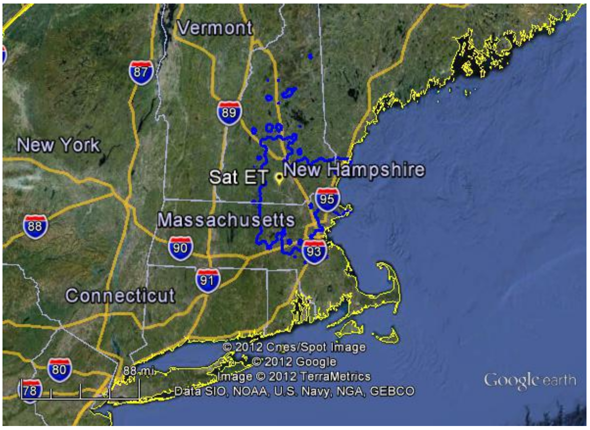
	
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).	Interference at or below 1 dB desense for 100% of the time.
	
Interference at or below 1 dB desense for 99% of the time.	Interference at or below 1 dB desense for 95% of the time.
	
Interference at or below 1 dB desense for 75% of the time.	

Figure 4.2.3-41. 1 dB Desense for NHS baseline scenario at various percentages of time, Satellite Inclination of 40 degrees.

4.2.3.2.3.2.1 Co-Channel Operations

To perform analysis of co-channel operations it is assumed that the systems operating in the specific channels are based on ITU database information as indicated in Section 4.2.1.1.1. Figure 4.2.3-42 shows the graphic representation of SGLS channels in relation to 5 MHz channels. To reduce the amount of data collected and presented the 4 key tracking stations of New Hampshire (NHS), Vandenberg (VTS), Guam (GTS) and Hawaii (HTS) are presented. It should be noted that when relating the interference in a particular SGLS channel to the interference into a AWS channel, the discussion and factors in Section 4.2.3.2.3.1.1 should be considered.

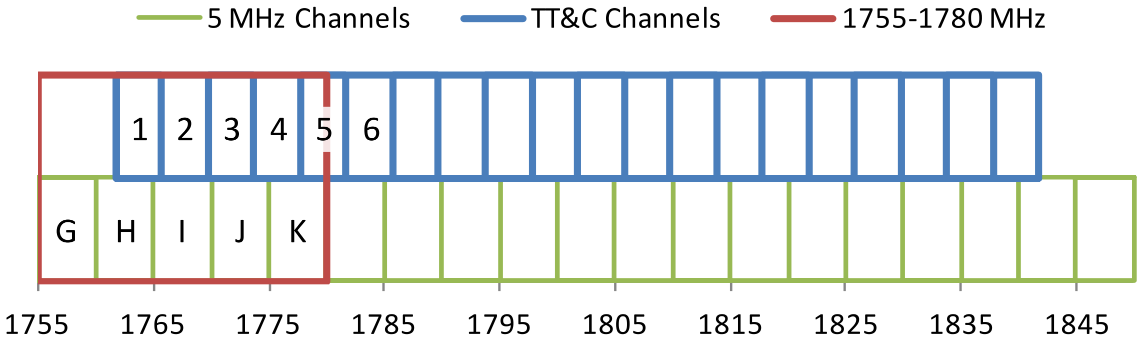


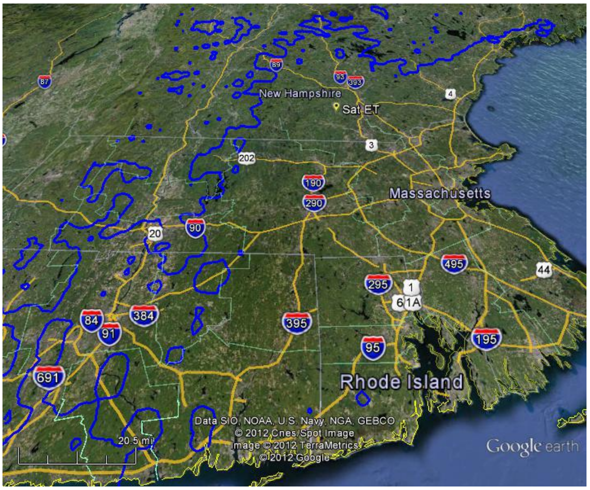
Figure 4.2.3-42. SGLS Channels

4.2.3.2.3.2.1.1 SGLS Channel 1

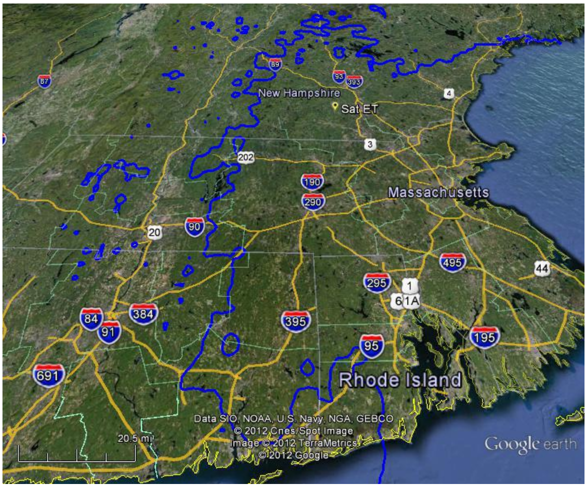
Table 4.2.3-16. ITU NGSO System data for Channel 1.

ITU Designation	Number of Satellites	Inclination (deg)	Apogee (km)	Perigee (km)	C/N (dB)	Noise Temp (K)	Max Gain (dBi)	Emission Designation
USKW	1	98	630	630	15	288	6	4M00G9D
USPOJOAQUE	1	40	600	600	15	290	2	2M00G1D
USYV	1	99	900	900	15	630	3	4M00G9D
L-92	12	55	1300	650	15	5000	0	4M00G7W

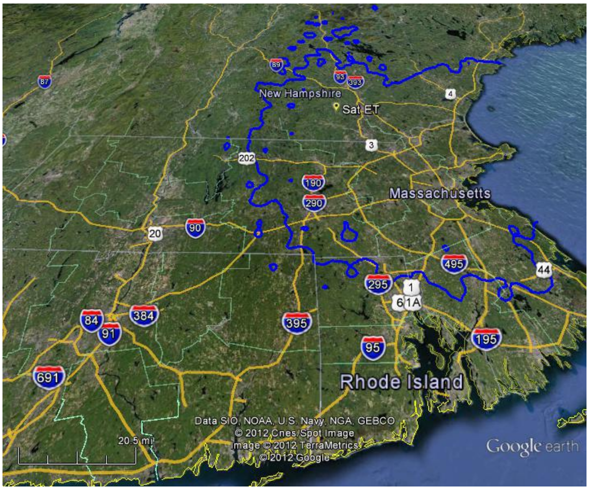
No GSO systems are listed in the ITU database for channel 1.



Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).

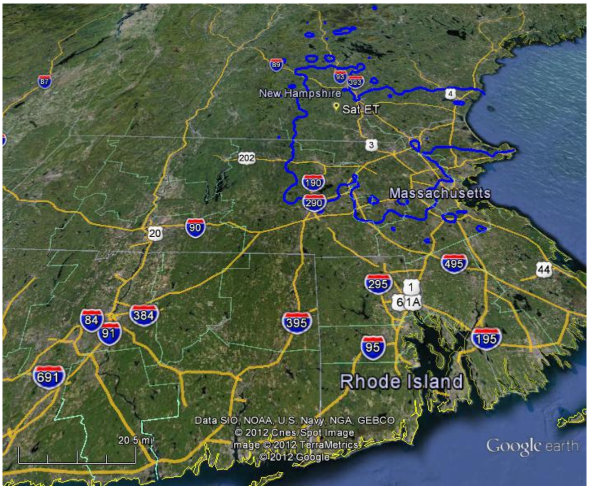


Interference at or below 1 dB desense for 100% of the time.



Interference at or below 1 dB desense for 99% of the time.

Interference at or below 1 dB desense for 95% of the time.



Interference at or below 1 dB desense for 75% of the time.

Figure 4.2.3-43. 1 dB Desense for NHS, baseline scenario at various percentages of time, Channel 1.

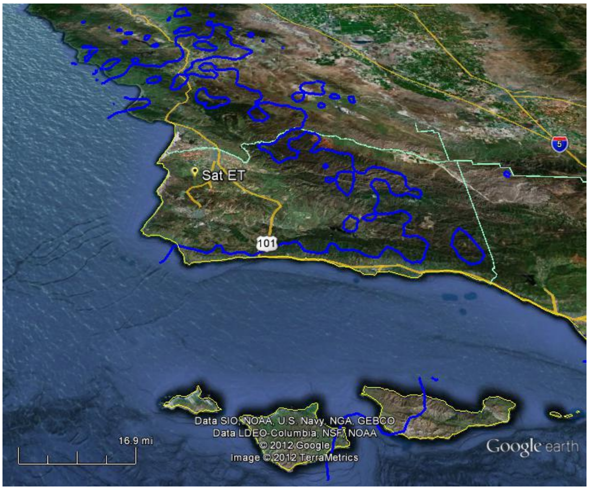
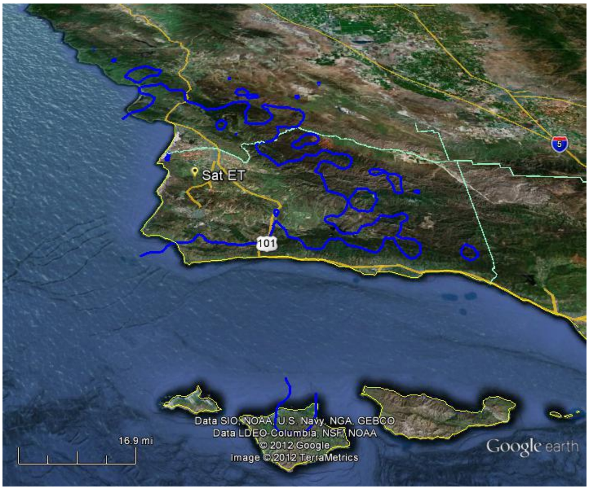
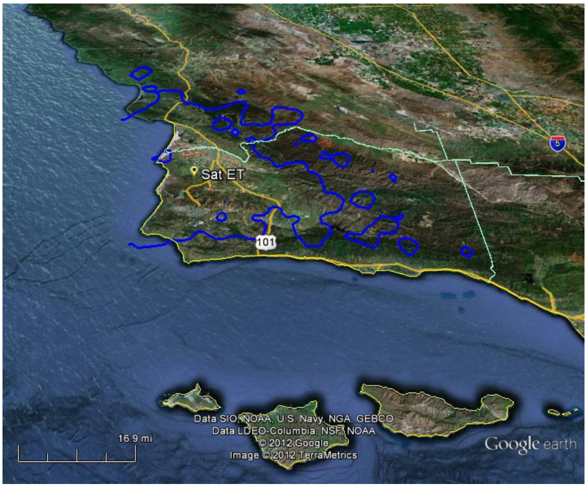
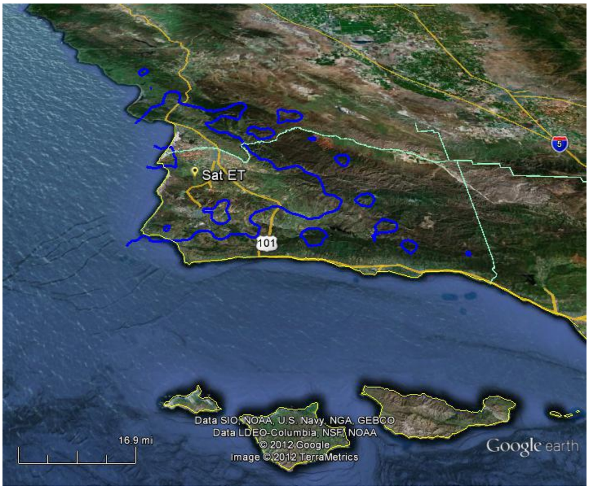
	
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).	Interference at or below 1 dB desense for 100% of the time.
	
Interference at or below 1 dB desense for 99% of the time.	Interference at or below 1 dB desense for 95% of the time.
	
Interference at or below 1 dB desense for 75% of the time.	

Figure 4.2.3-44. 1 dB Desense for VTS, baseline scenario at various percentages of time, Channel 1.

<table>
<tr>
<td>
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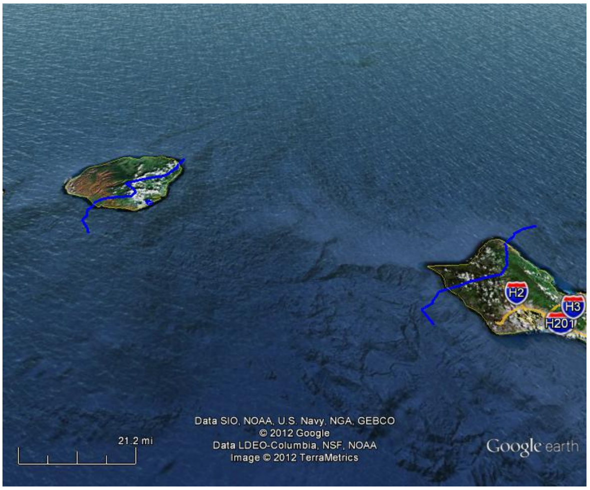
<tr>
<td>Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).</td>
<td>Interference at or below 1 dB desense for 100% of the time.</td>
</tr>
<tr>
<td>
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<td>
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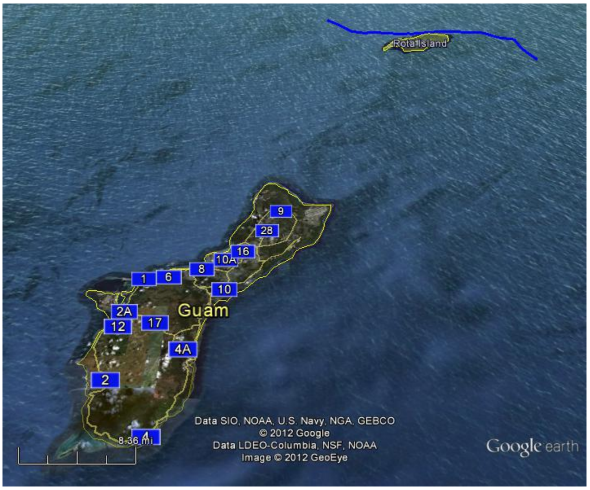
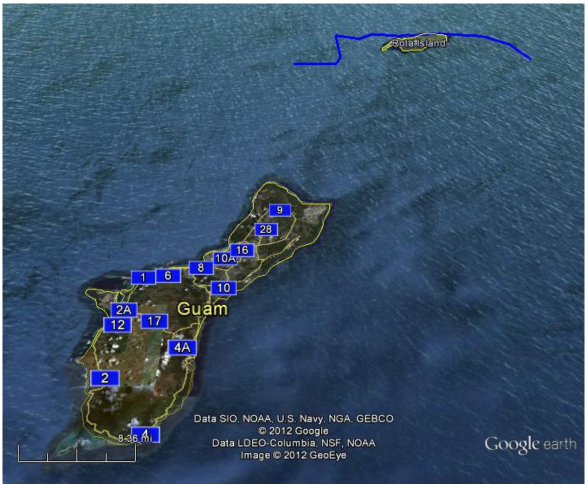
<tr>
<td>Interference at or below 1 dB desense for 99% of the time.</td>
<td>Interference at or below 1 dB desense for 95% of the time.</td>
</tr>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>Interference at or below 1 dB desense for 75% of the time.</td>
<td></td>
</tr>
</table>

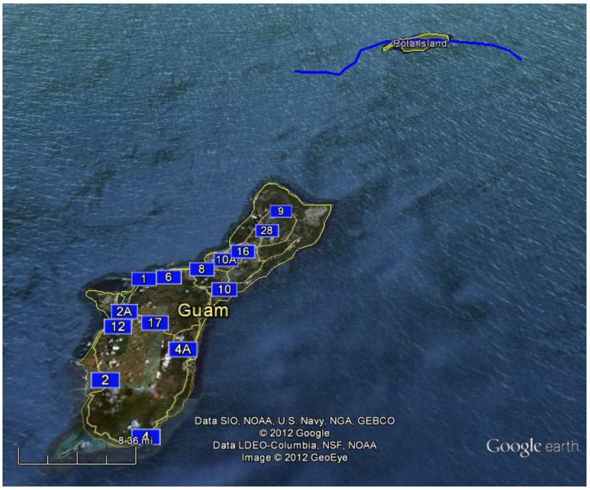
Figure 4.2.3-45. 1 dB Desense for HTS, baseline scenario at various percentages of time, Channel 1.



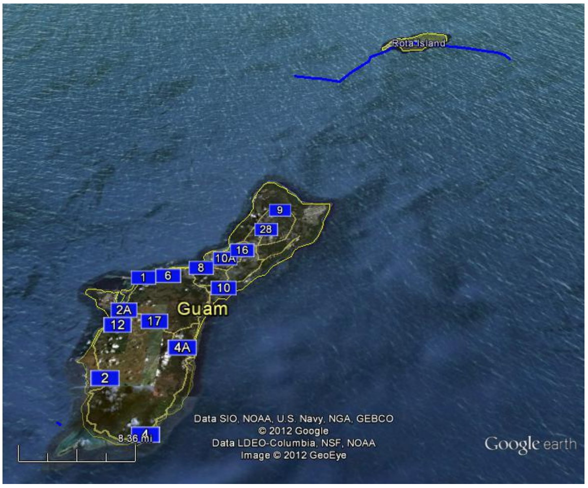
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).



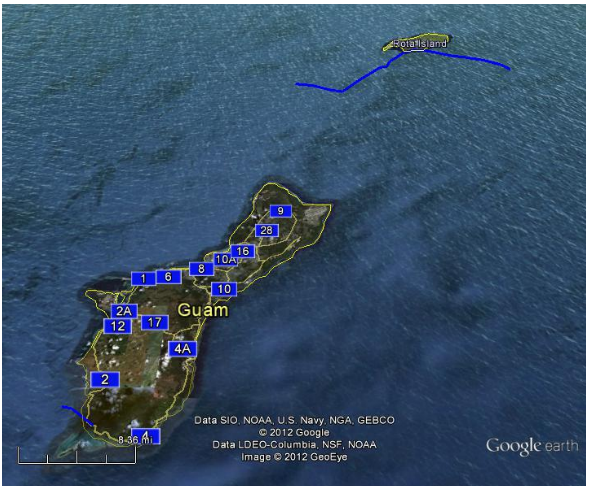
Interference at or below 1 dB desense for 100% of the time.



Interference at or below 1 dB desense for 99% of the time.



Interference at or below 1 dB desense for 95% of the time.



Interference at or below 1 dB desense for 75% of the time.

Figure 4.2.3-46. 1 dB Desense for GTS, baseline scenario at various percentages of time, Channel 1.

4.2.3.2.3.2.1.2 SGLS Channel 2

Table 4.2.3-17. ITU NGSO System data for Channel 2.

ITU Designation	**Number of Satellites**	**Inclination (deg)**	**Apogee (km)**	**Perigee (km)**	**C/N (dB)**	**Noise Temp (K)**	**Max Gain (dBi)**	**Emission Designation**
MIDSTAR-1	1	46	492	492	15	350	2	93K0G1D
P-197-1	9	62	39000	470	15	1045	11.5	4M00G7W
USNFR	1	49.4	495	495	15	627	4	4M00G9D

Table 4.2.3-18. ITU GSO System data for channel 2.

ITU Designation	**GSO Location (deg)**	**C/N (dB)**	**Noise Temp (K)**	**Max Gain (dBi)**	**Emission Designation**
P-197-2	-144	15	1045	11.5	4M00G7W
P-197-3	-141	15	1045	11.5	4M00G7W
P-197-4	-13	15	1045	11.5	4M00G7W
P-197-5	-10	15	1045	11.5	4M00G7W
P-197-6	-30.4	15	1045	11.5	4M00G7W
P-197-7	92	15	1045	11.5	4M00G7W
P-197-8	110	15	1045	11.5	4M00G7W
USNN-3	-127	15	5000	-3, 11	4M00G7W
USNN-4	100	15	5000	-3, 11	4M00G7W
USNN-5	170	15	5000	-3, 11	4M00G7W

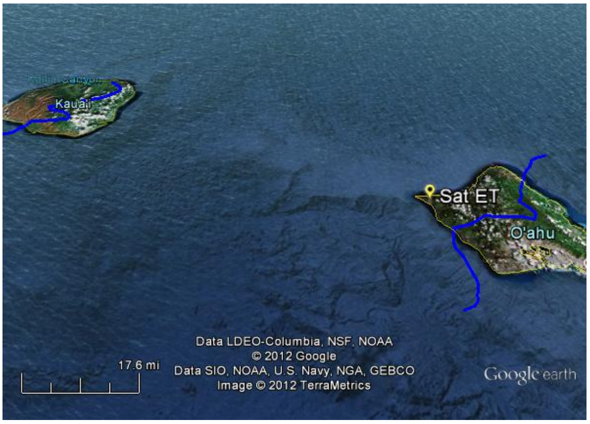
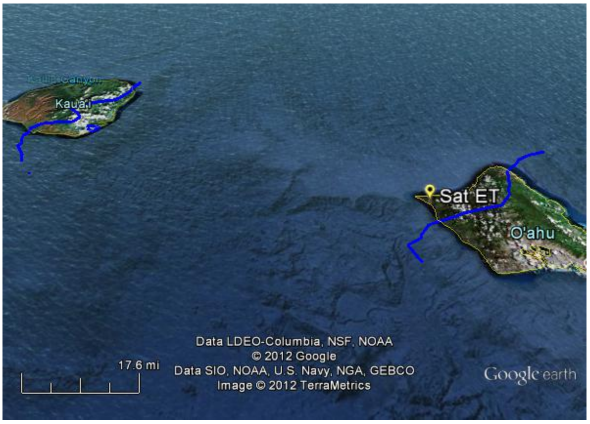
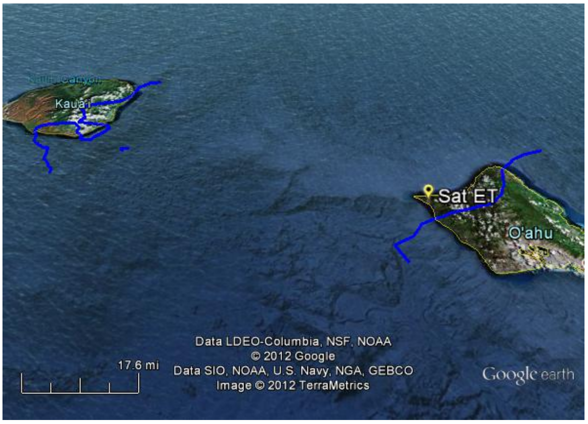
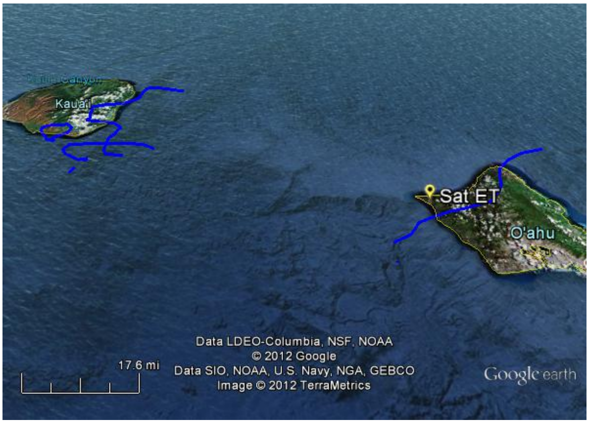
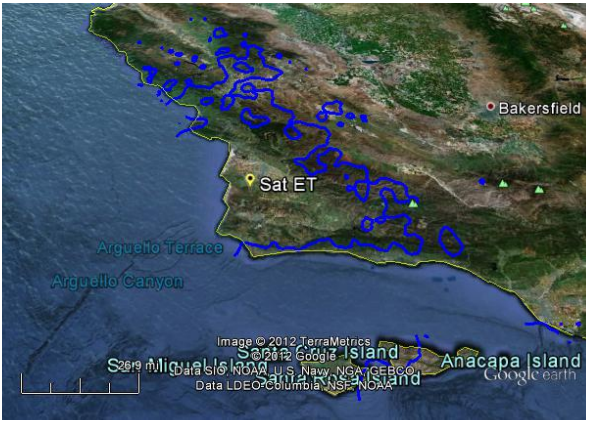
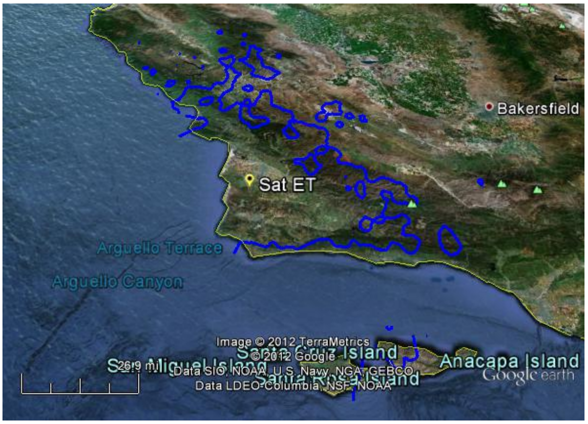
	
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).	Interference at or below 1 dB desense for 100% of the time.
	
Interference at or below 1 dB desense for 99% of the time.	Interference at or below 1 dB desense for 95% of the time.
	
Interference at or below 1 dB desense for 75% of the time.	

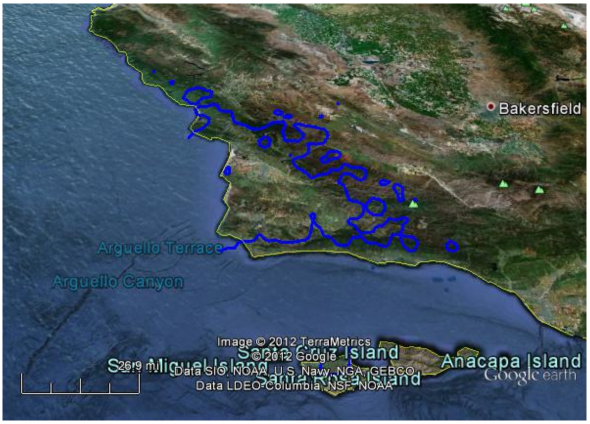
Figure 4.2.3-47. 1 dB Desense for NHS, baseline scenario at various percentages of time, Channel 2.



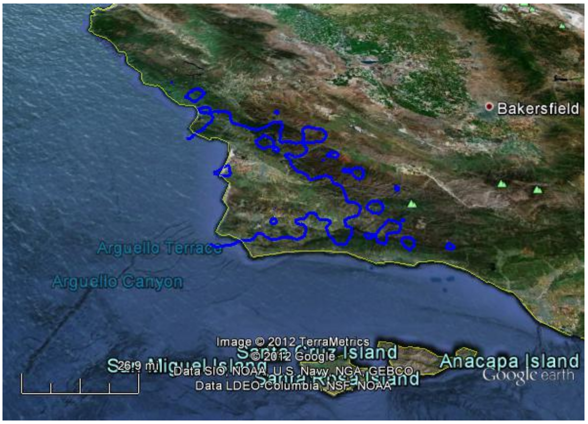
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).



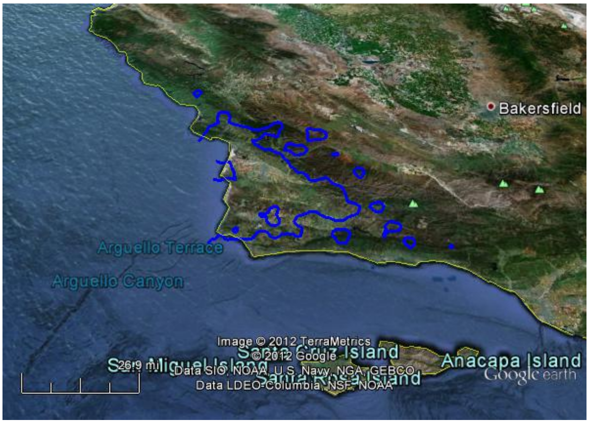
Interference at or below 1 dB desense for 100% of the time.



Interference at or below 1 dB desense for 99% of the time.



Interference at or below 1 dB desense for 95% of the time.



Interference at or below 1 dB desense for 75% of the time.

Figure 4.2.3-48. 1 dB Desense for VTS, baseline scenario at various percentages of time, Channel 2.

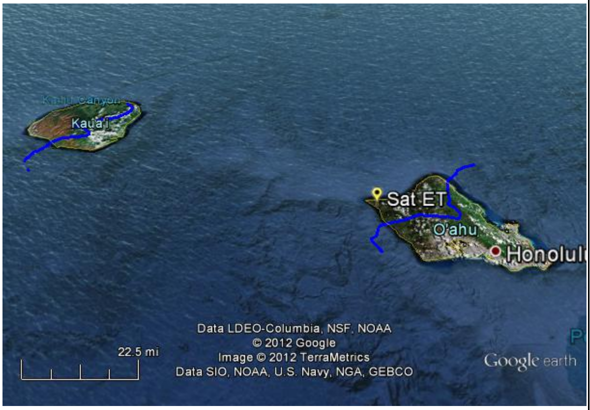
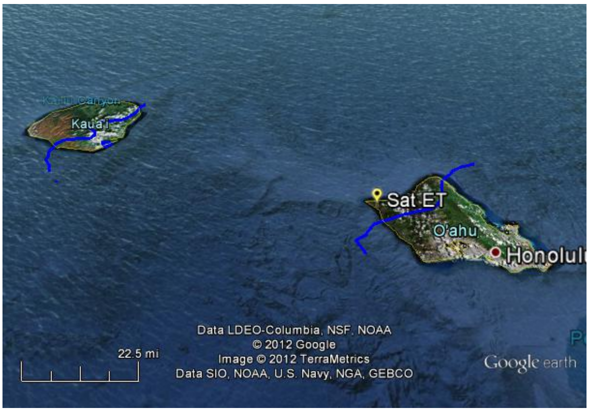
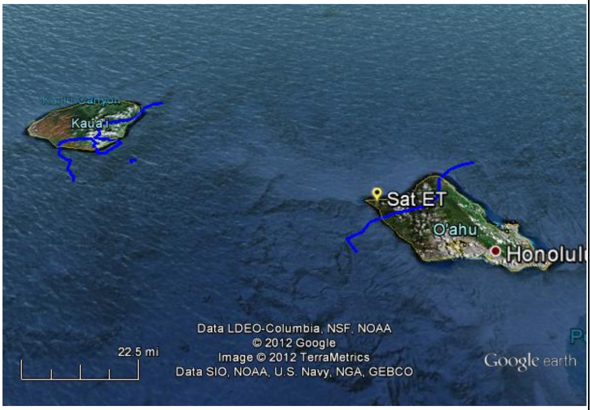
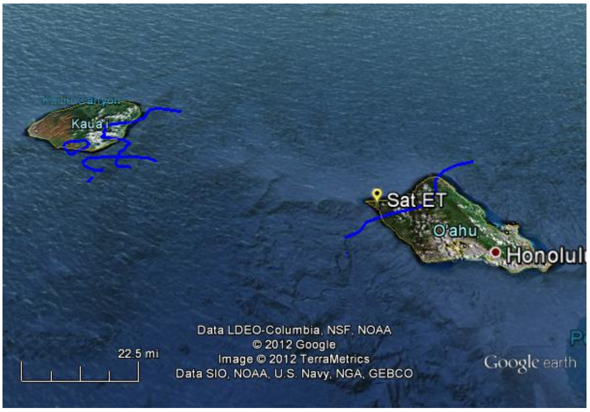
	
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).	Interference at or below 1 dB desense for 100% of the time.
	
Interference at or below 1 dB desense for 99% of the time.	Interference at or below 1 dB desense for 95% of the time.
	
Interference at or below 1 dB desense for 75% of the time.	

Figure 4.2.3-49. 1 dB Desense for HTS, baseline scenario at various percentages of time, Channel 2.

	
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).	Interference at or below 1 dB desense for 100% of the time.
	
Interference at or below 1 dB desense for 99% of the time.	Interference at or below 1 dB desense for 95% of the time.
	
Interference at or below 1 dB desense for 75% of the time.	

Figure 4.2.3-50. 1 dB Desense for GTS, baseline scenario at various percentages of time, Channel 2.

4.2.3.2.3.2.1.3 SGLS Channel 3

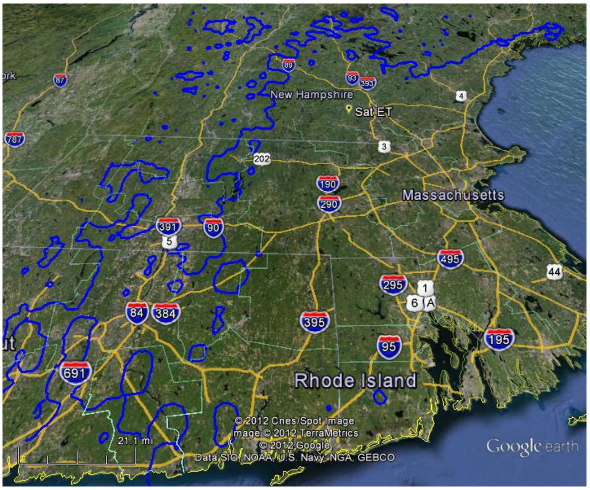
No GSO or NGSO systems are listed in the ITU database for channel 3.

4.2.3.2.3.2.1.4 SGLS Channel 4

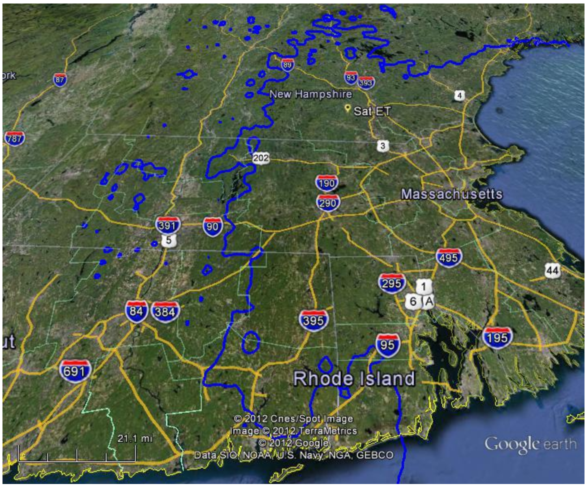
Table 4.2.3-19. ITU NGSO System data for Channel 4.

ITU Designation	Number of Satellites	Inclination (deg)	Apogee (km)	Perigee (km)	C/N (dB)	Noise Temp (K)	Max Gain (dBi)	Emission Designation
ALEXIS	1	90	835	740	N/A	438	2	10K0G1D
SPACE SHUTTLE	1	57	300	300	N/A	5360	1.5	4M00G2D

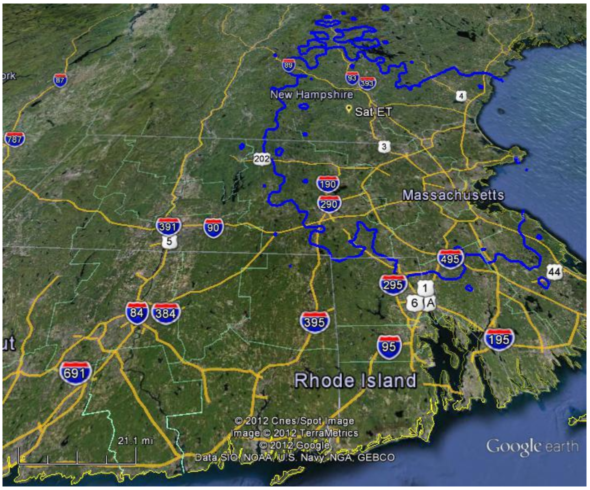
Since the Space Shuttle program has been retired, this analysis will not consider this system. No GSO systems are listed in the ITU database for channel 4.



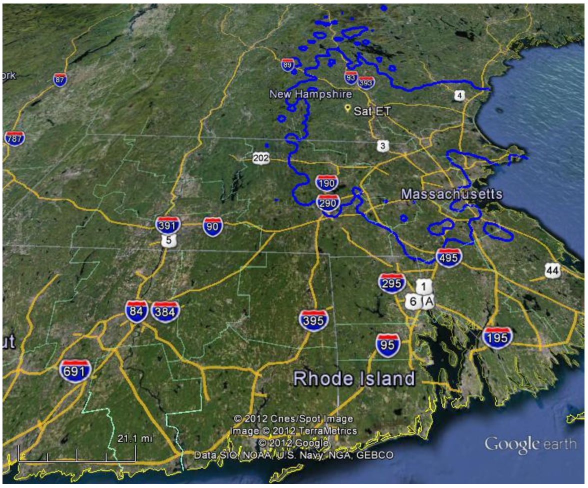
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).



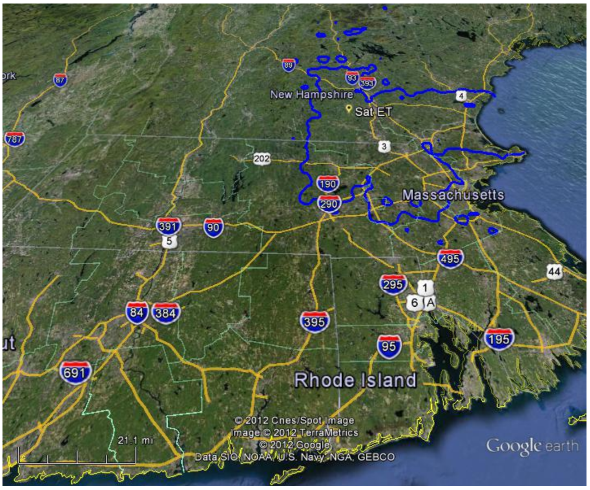
Interference at or below 1 dB desense for 100% of the time.



Interference at or below 1 dB desense for 99% of the time.



Interference at or below 1 dB desense for 95% of the time.



Interference at or below 1 dB desense for 75% of the time.

Figure 4.2.3-51. 1 dB Desense for NHS, baseline scenario at various percentages of time, Channel 4.

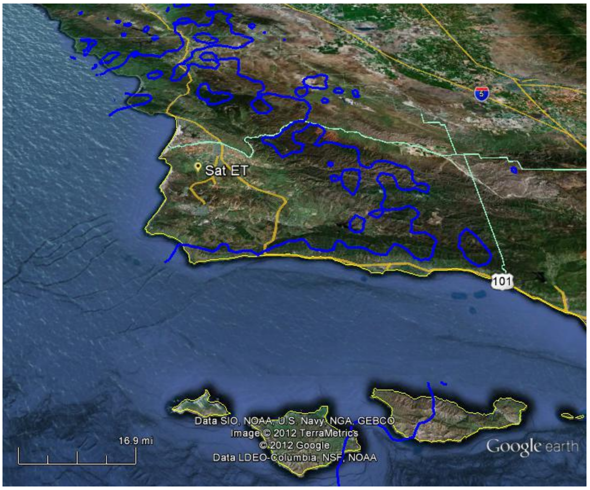
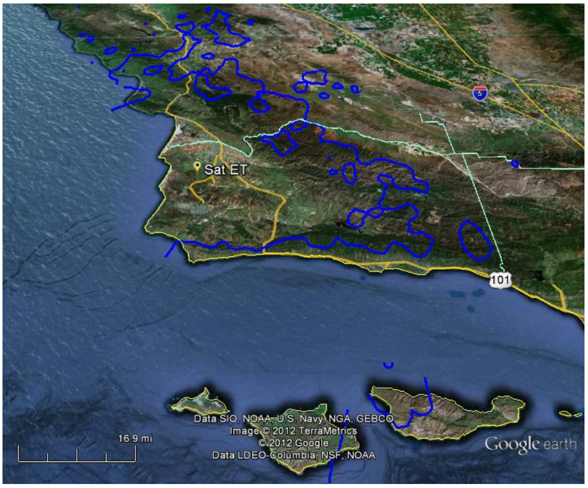
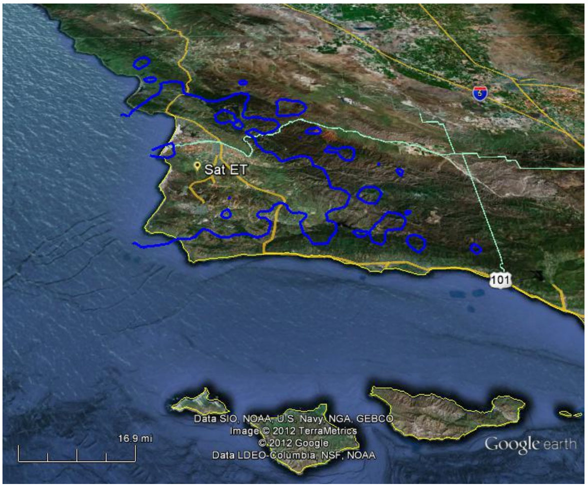
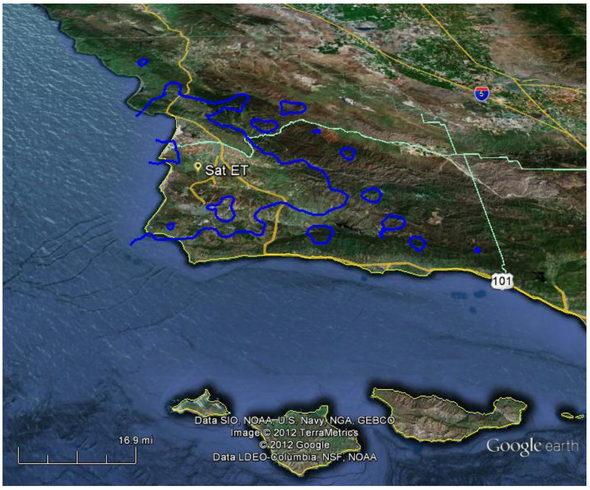
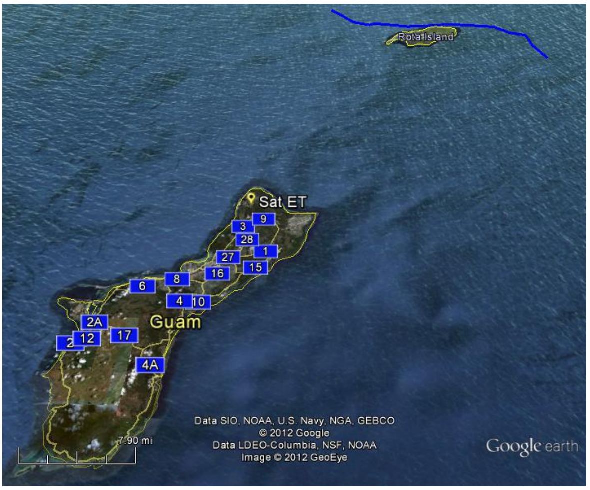
	
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).	Interference at or below 1 dB desense for 100% of the time.
	
Interference at or below 1 dB desense for 99% of the time.	Interference at or below 1 dB desense for 95% of the time.
	
Interference at or below 1 dB desense for 75% of the time.	

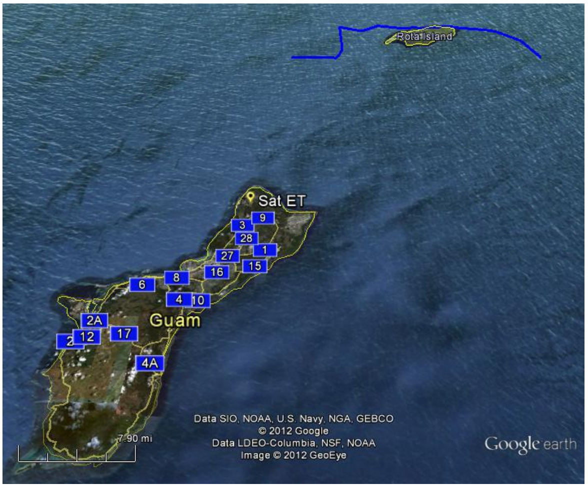
Figure 4.2.3-52. 1 dB Desense for VTS baseline scenario at various percentages of time, Channel 4.

	
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).	Interference at or below 1 dB desense for 100% of the time.
	
Interference at or below 1 dB desense for 99% of the time.	Interference at or below 1 dB desense for 95% of the time.
	
Interference at or below 1 dB desense for 75% of the time.	

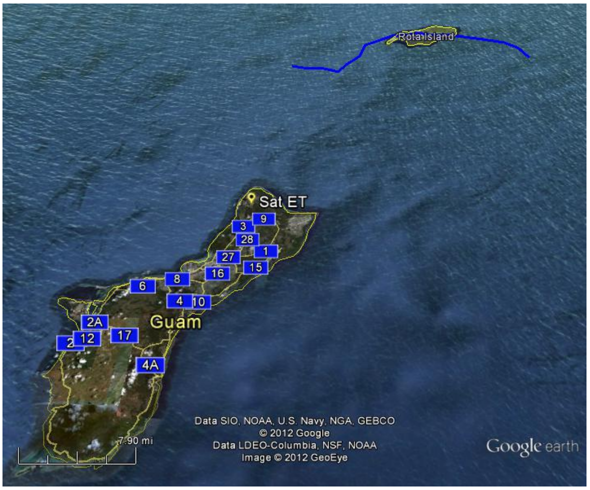
Figure 4.2.3-53. 1 dB Desense for HTS, baseline scenario at various percentages of time, Channel 4.



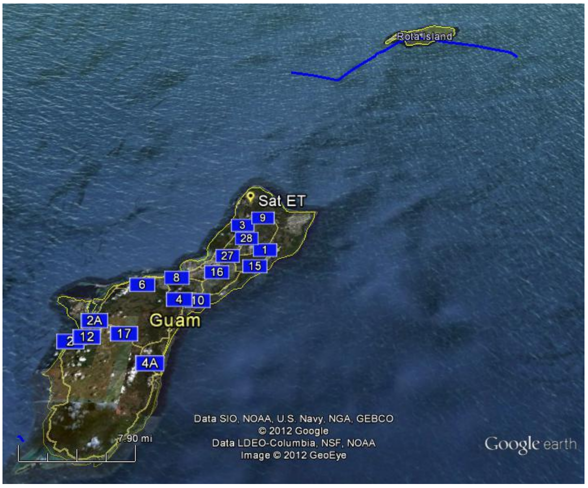
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).



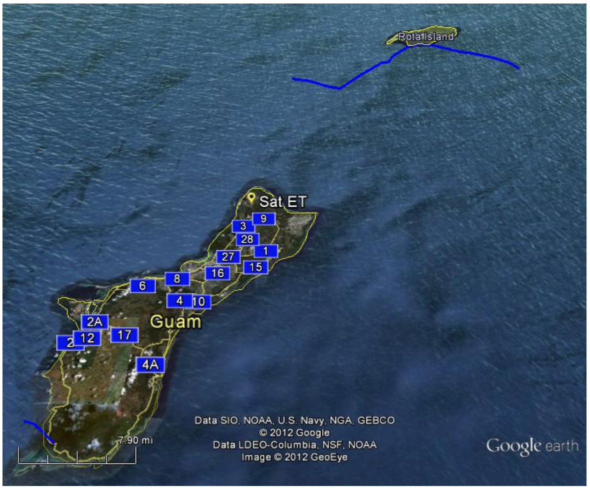
Interference at or below 1 dB desense for 100% of the time.



Interference at or below 1 dB desense for 99% of the time.



Interference at or below 1 dB desense for 95% of the time.



Interference at or below 1 dB desense for 75% of the time.

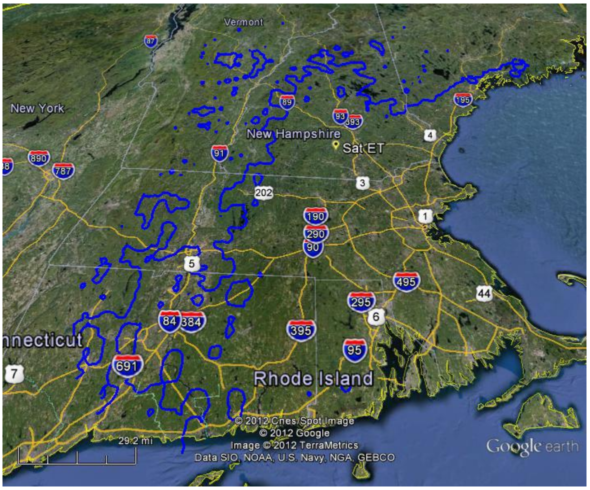
Figure 4.2.3-54. 1 dB Desense for GTS, baseline scenario at various percentages of time, Channel 4.

4.2.3.2.3.2.1.5 SGLS Channel 5

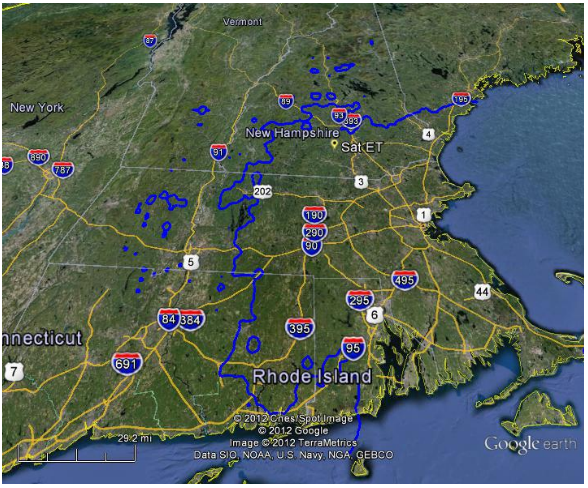
Table 4.2.3-20. ITU NGSO System data for Channel 5.

ITU Designation	**Number of Satellites**	**Inclination (deg)**	**Apogee (km)**	**Perigee (km)**	**C/N (dB)**	**Noise Temp (K)**	**Max Gain (dBi)**	**Emission Designation**
CRRES	1	28.5	35800	350	N/A	500	5.5	4M00G7W

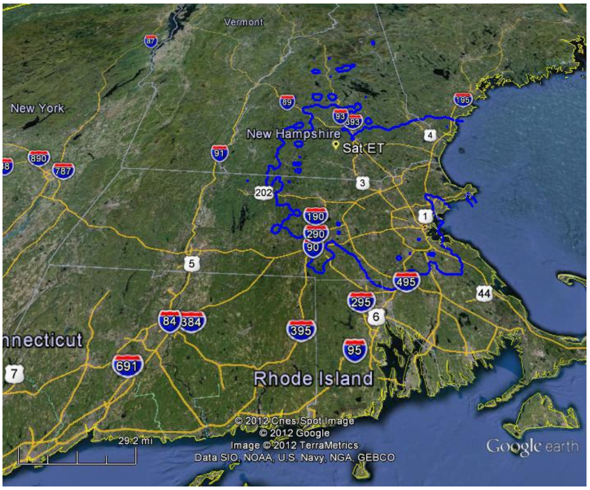
No GSO systems are listed in the ITU database for channel 5.



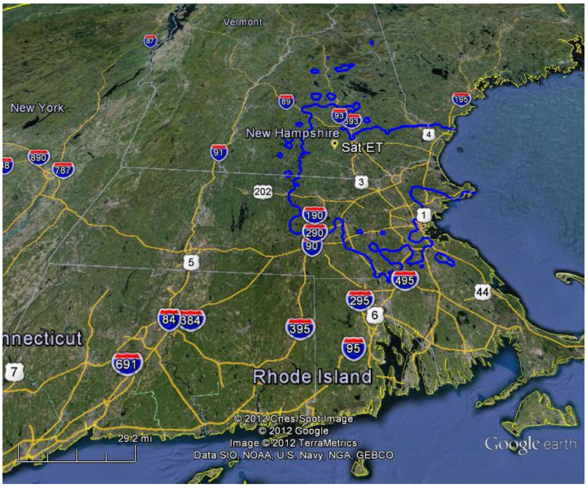
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).



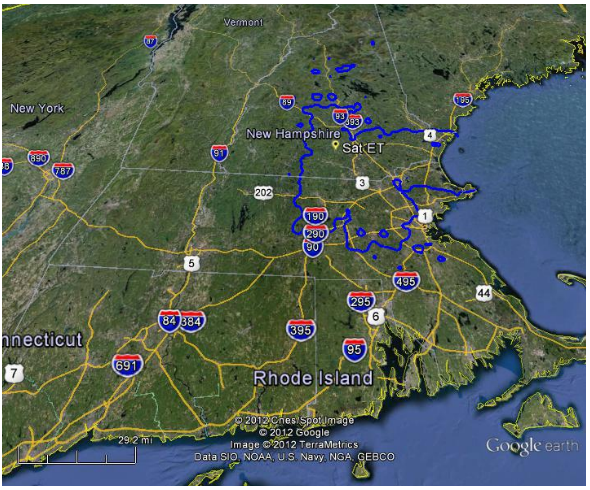
Interference at or below 1 dB desense for 100% of the time.



Interference at or below 1 dB desense for 99% of the time.



Interference at or below 1 dB desense for 95% of the time.



Interference at or below 1 dB desense for 75% of the time.

Figure 4.2.3-55. 1 dB Desense for NHS, baseline scenario at various percentages of time, Channel 5.

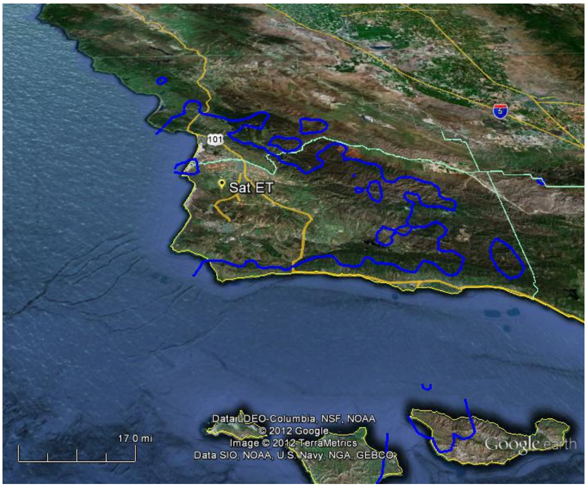
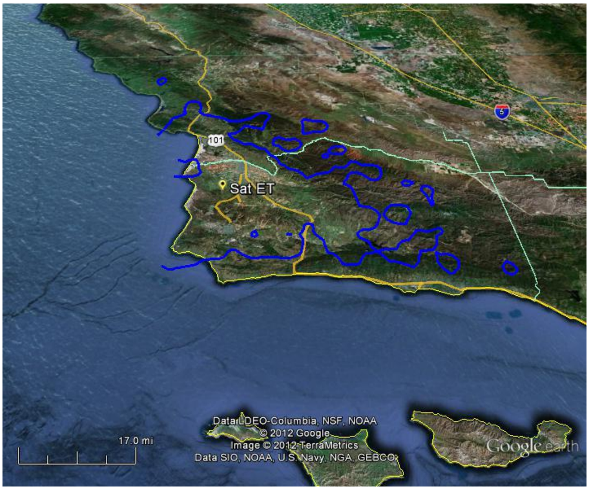
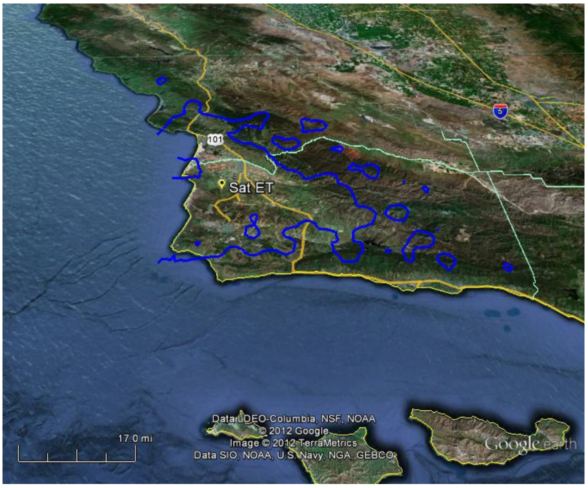
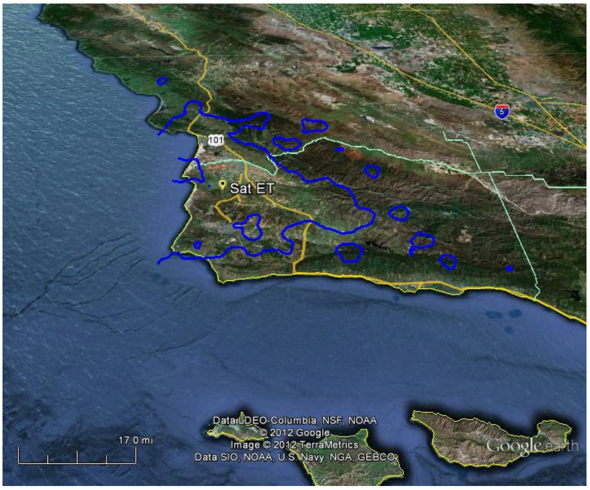
	
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).	Interference at or below 1 dB desense for 100% of the time.
	
Interference at or below 1 dB desense for 99% of the time.	Interference at or below 1 dB desense for 95% of the time.
	
Interference at or below 1 dB desense for 75% of the time.	

Figure 4.2.3-56. 1 dB Desense for VTS, baseline scenario at various percentages of time, Channel 5.

Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).

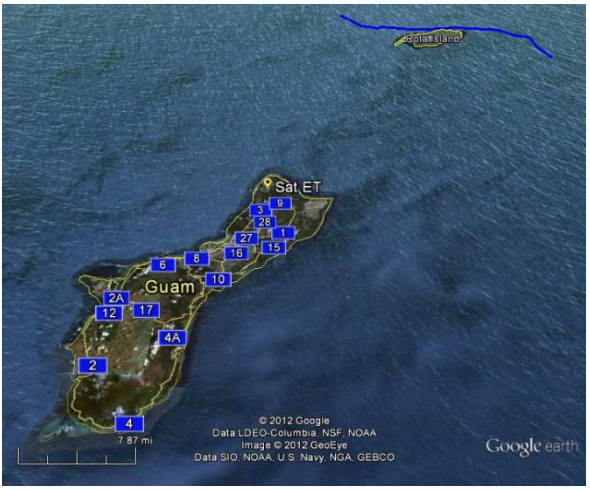
Interference at or below 1 dB desense for 100% of the time.

Interference at or below 1 dB desense for 99% of the time.

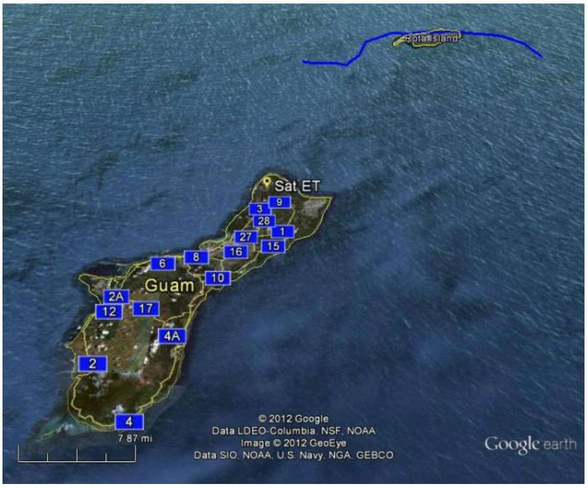
Interference at or below 1 dB desense for 95% of the time.

Interference at or below 1 dB desense for 75% of the time.

Figure 4.2.3-57. 1 dB Desense for HTS, baseline scenario at various percentages of time, Channel 5.

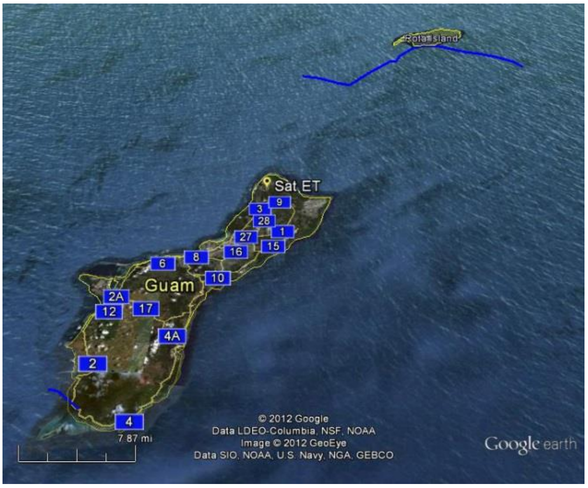


Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking).



Interference at or below 1 dB desense for 100% of the time.

Interference at or below 1 dB desense for 99% of the time.



Interference at or below 1 dB desense for 95% of the time.

Interference at or below 1 dB desense for 75% of the time.

Figure 4.2.3-58. 1 dB Desense for GTS, baseline scenario at various percentages of time, Channel 5.

4.2.3.2.3.2.2 Adjacent Channel Operations

Adjacent channel operations will seem the same relative reduction in levels as indicated in Section 4.2.3.2.3.1.2.

4.2.4 Phase 2 Analysis of interference into LTE Base Station Receivers

4.2.4.1 Introduction/Summary

The concepts and analysis provided in this report are intended for Government and Commerce Spectrum Management Advisory Committee (CSMAC) discussion purposes only. This information is provided for use in developing estimates only and is not intended to be exactly representative of actual ground site operating parameters in the future. Government operational information for each sub band studied in this report has been summarized and enveloped to avoid presenting individual program or ground site information.

Since additional information regarding SATOPS operational details were not publically releasable for security reasons, a follow-on study was conducted to refine initial analysis. This "CSMAC WG 3 Phase 2 Study Summary" followed a similar methodology as used in the Phase 1 study, but included consideration of additional information not publically releasable. These details allowed the Phase 2 Study to describe not only the contours of SATOPS antenna power for locations around the SATOPS site, but also to model with higher fidelity the probability of an LTE threshold being exceeded by harmful interference from the SATOPS antenna as it varies by location.

Government uplink emissions were analyzed from three Air Force Satellite Control Network sites (New Hampshire Tracking Station, Vandenberg Tracking Station, and Hawaii Tracking Station), two Navy sites (Blossom Point Tracking Facility and Laguna Peak Tracking Station) and the NOAA Fairbanks Alaska site. The analyses made use of NTIA's Irregular Terrain Model (ITM) and the NOAA/NGDC GLOBE terrain database for propagation prediction in conjunction with historical SATOPS information. The results are presented on maps in the vicinity of the selected SATOPS locations to display, as a function of distance and azimuth from the SATOPS sites, contours of two parameters: 1) the predicted peak received power levels (for median value of path loss), and 2) the probability over time that the received power does not exceed the selected LTE interference threshold (for median values of path loss).

The results of modeling transmitted radiation as a function of distance from each site, with various attenuation scenarios are presented. Potential exceedance of the standard LTE threshold is also presented for each case. In addition, estimates of site usage based on satellite contact parameters are provided. Uncertainties associated with each of the models used (mission astrodynamics, power, path loss, terrain, and probabilities) are described, including propagation variability and modeling simplifications. The data should not be construed to be actual power levels of the AFSCN or other SATOPS sites.

In summary, this study provides estimates of the areas potentially impacted by Government radio emissions from selected ground facilities. The information is provided for estimating purposes only and is not intended to be representative of actual ground site operating parameters in the future.

Based on the continuing need for SATOPS operation and growth the below recommendations are provided to help foster compatibility with SATOPS.

Recommendation 4.2.4-1: NTIA should recommend establishment of rules/regulations with built in flexibility for future SATOPS growth and change, including satellite network and ground station locations/configurations. New federal earth station locations must be determined in coordination with commercial licensees. For existing federal earth stations, federal users must notify commercial licensees of significant changes such as additional antenna or extended anomaly support.

Recommendation 4.2.4-2: NTIA should recommend all federal costs related to planning, sharing and continued compatibility activities for satellite sharing should be part of the federal agencies' cost estimate and fundable through the Spectrum Relocation Fund (SRF). Agencies should remain eligible for SRF funds as long as federal agencies operate and incur costs related to sharing satellite operations with commercial operation in the 1761-1842 MHz band.

Recommendation 4.2.4-3: NTIA should recommend that the FCC, in consultation with NTIA and relevant federal agencies, develop methods for licensees in the 1761-1842 MHz band to demonstrate technologies or techniques that ensure commercial operations can accept interference from the satellite operations when operating within the zones where the nominal SATOPS power is expected to exceed the LTE interference threshold (a 1 dB desense), prior to deployment of base stations in the zones.

4.2.4.2 Interference Assessment

4.2.4.2.1 Methodology

4.2.4.2.1.1 Overview

The Power Model used is an application of the Aerospace SOAP Model[28] that computes Radio Frequency Interference (RFI) power received by a cellular base station (receiver) when a SATOPS antenna is pointed in each Azimuth/Elevation (Az/El) cell, driven by an input value of propagation path loss.

The Path Loss Model computes RFI path loss (attenuation) at a cellular base station (receiver) as input to the Power Model. This computation uses the NTIA Irregular Terrain Model[29] with the

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[28] Satellite Orbit Analysis Program (SOAP), The Aerospace Corporation, OTR-2013 0314155423, 2013.

[29] "Integrated Terrain Model" by NTIA/ITS, see: http://www.its.bldrdoc.gov/resources/radiopropagation-software/itm/itm.aspx.

GLOBE Terrain Data Base[30]. Each path loss is the median value loss. No single propagation model is best suited for all purposes. Some models are conservative regarding predicting interference (i.e., lead to predicting more interference than would really occur). Other models are conservative towards identifying low signal levels (i.e., lead to predicting lower received power than would really occur). Various models also have varying degrees of accuracy. While there are varying degrees of uncertainty associated with any model, these types of models are typically applied in spectrum management studies

The Aerospace Astrodynamics Mission Model computes, for each SATOPS site, the transmit minutes per year (average) in each Az/El cell. The minutes of radiate time is the sum of the contributions of all satellites in the “Mission Model” that operate in the band of interest, distributed over all Az/El cells above minimum allowable elevation angle. Radiate time amounts to a fraction of the total contact time. Contact start and end times are derived from recorded experience. Radiate time was assumed to be uniformly distributed over contact time. Contact time is based on statistical records averaged for one year for the AFSCN sites and estimated for non-AFSCN sites. Actual radiation time is less than visibility time as depicted in the figure below. Note that publicly available ITU registration data may be used to estimate visibility time, but does not indicate actual radiation time. While there is sometimes flexibility in contact time scheduling; many times there is no such flexibility.

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[30] The Global Land One-km Base Elevation Project (GLOBE) Elevation Database, National Geophysical Data Center, NOAA; available online at: http://www.ngdc.noaa.gov/mgg/topo/globe.html.

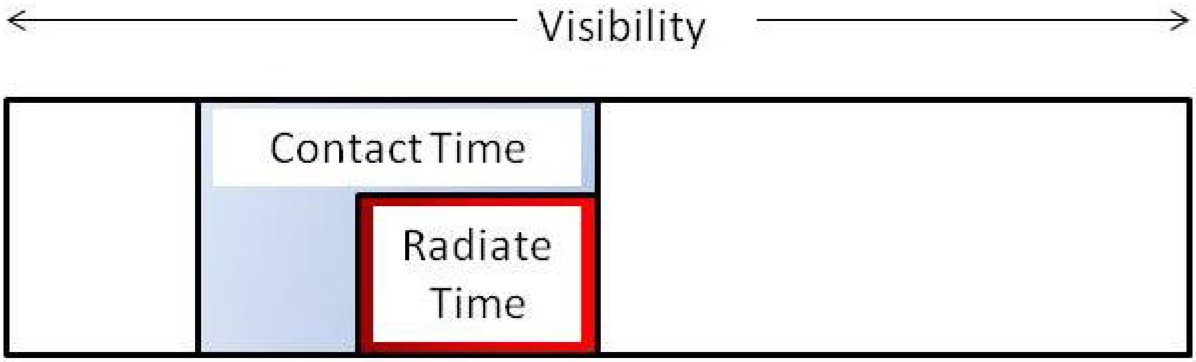

Figure 4.2.4-1. Relationship between Satellite visibility, contact time and radiation time.

The EXCEL Combiner Model computes, for a SATOPS site and a cellular base station (receiver), an RFI power histogram and the "probability” of RFI power not exceeding the receiver threshold of harmful interference. Each probability in a histogram is the sum of the “Mission Model” Az/El cell values (which are the annual transmit minutes for each Az/El) divided by yearly minutes for all the Az/El cells corresponding to the received power level. The probability that the RFI doesn’t exceed threshold power level, assuming that the path loss is, in fact, the median value, is the complement of the sum of probabilities for received power levels exceeding the threshold level. The “LTE Threshold” is assumed to be -137.37 dBW or (-107.37 dBm) using CSMAC WG-1 documented values (See Section 4.2.1.2). For sites with 2 or more antennas, “probability” of RFI power not exceeding the receiver threshold of harmful interference is defined as the percent time (all site antennas) below threshold RFI level, less percent time of overlap (i.e. simultaneous radiation).

The accompanying chart shows the four major computer tools used in this study, and the data flows between them.

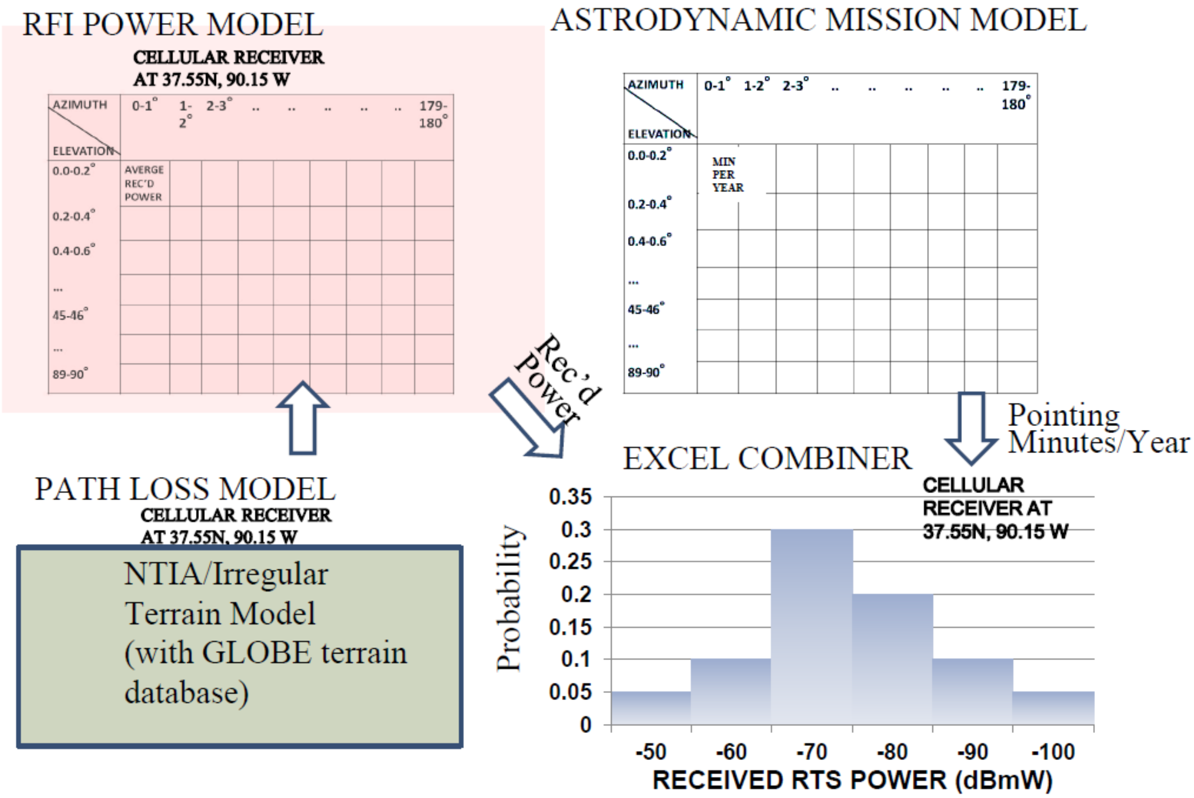

Figure 4.2.4-2. Methodology - Calculating Base Station Received Interference (resulting from given Government SATOPS antenna).

4.2.4.2.1.2 Model Uncertainties

Uncertainties arising from the use of the ITM model for path loss calculations translate into uncertainties in the predicted SATOPS RFI levels that constitute the principal quantitative outputs of this study. ITM model uncertainties include uncertain applicability to urban propagation and unknown effect of variations in the ITM input variables on output values. Input variables include propagation path electrical parameters (soil conductivity/dielectric constant and surface refraction) and regional characteristics (climate types and terrain types). These input variables were made common for all SATOPS sites, despite their actual differences. The net impact (over-or underestimation of RFI levels) is unknown. Other input variables whose effects on SATOPS RFI were not assessed include path loss "reliability" (temporal variability) and "confidence" (variations with LTE base station receiver site location), although both are known to significantly affect path losses. The ITM model was employed without accounting for site-specific vegetation and man-made features (e.g. buildings), the impacts of which are unknown. There also may be electromagnetic environment parameters to which ITM is not sensitive (e.g. soil permeability).

Three modeling simplifications resulted in under- or overestimation of SATOPS RFI levels to an unknown degree. The propagation path elevation angle to the first path obstruction was not taken into account, which results in underestimating the base station elevation angle and underestimating SATOPS RFI levels. The use of an envelope of the SATOPS transmitter antenna gain pattern, rather than the actual pattern, results in overestimation of SATOPS RFI levels. The assumed uniform distribution of radiate time over the contact periods, while the actual radiation is more likely biased toward the beginning of the contact period (at lower elevation angles) may have resulted in underestimation of SATOPS RFI levels and durations.

4.2.4.2.1.3 Visibility Time as a Function of Ground Antenna Pointing Angles

Figure 4.2.4-3 represents an example of SATOPS site visibility for a single non-geostationary satellite with one frequency uplink accumulated over one year in 1^o x 1^o Az/El cells. The calculations include the number of minutes per year that a given antenna points in a given azimuth and elevation in supporting one single non-geostationary satellite. It is illustrative of the type of data that is combined for multiple satellites in arriving at a composite profile for the earth station's radiation over the year. Note the antenna only points in any given direction a small percentage of the time.

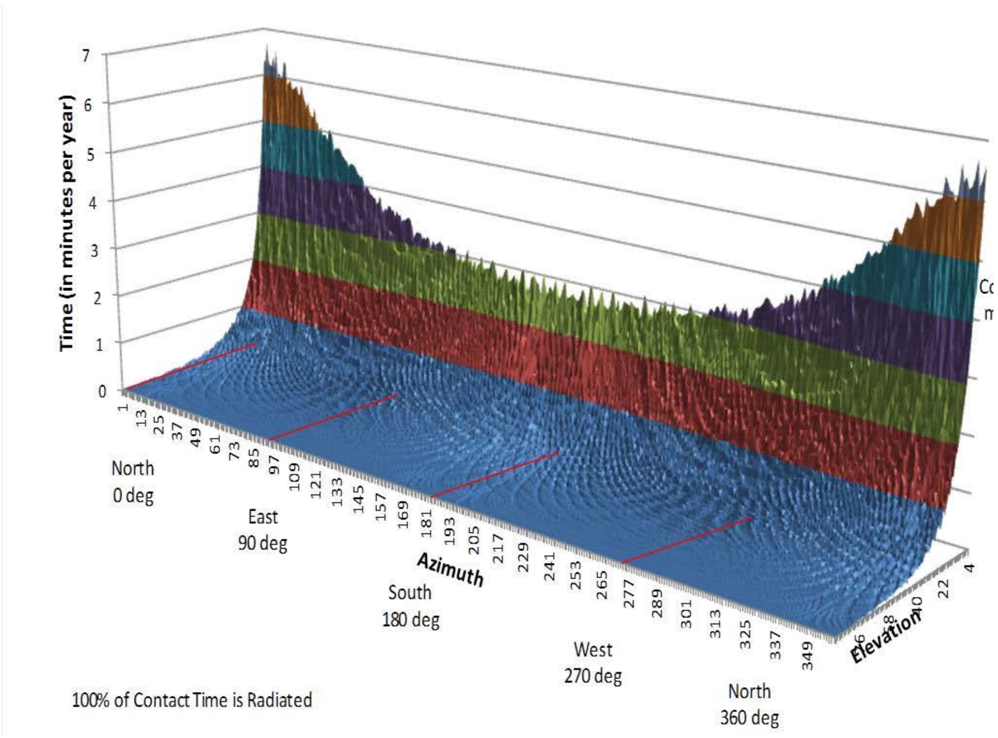

Figure 4.2.4-3. Example visibility of single non-geostationary satellite.

4.2.4.2.1.4 Power Contour Plots

Power radiated from each of the Government sites along with other computational details are presented in Section 4.2.4.4.

These calculations use 1 kW transmitter power for AFSCN sites for the analysis. The AFSCN power actually varies from 500 W to ~ 7kW, within the US. A few maximum power cases are included for comparison.

The contours are calculated using the NTIA Irregular Terrain Model (ITM) with the GLOBE Terrain Data Base for propagation loss and are accurate to 1 and 5 km grid spacing as labeled. 1 or 5 km grid spacing, as limited by the GLOBE data base, adds considerable uncertainty because natural terrain features can be greatly varied over these distances.

This model does not take into account vegetation or artificial structures so a 20 dB attenuation factor on the radiated signal was also added to some of the analyses cases.

4.2.4.2.1.5 Mobile Wireless Long Term Evolution (LTE) System Threshold Exceedance

The received power level was calculated and compared to the LTE threshold of -137.4 dBW (1dB desense level) for each potential LTE base station site and at each antenna pointing angle. The percentage non-exceedance time is that which the LTE base stations can operate without RFI given the stated LTE threshold. A 1 dB desense level is used as the interference criterion for the LTE receiver; it is the level at which the apparent receiver noise floor is increased by 1 dB, thereby reducing the effective sensitivity by 1 dB. The center color of the plot(s) (i.e. nearest to the ground station) represents the minimum value of threshold non-exceedance which is the complement of the site radiation percentage time. This study uses aggregated statistics of radiation to spacecraft over a given band for the past year.

Note that the probability of non-exceedance describes the probability that the antenna is not radiating in ANY frequency portion of the sub band portrayed in the plot, at a level above the receiver threshold. When that threshold is exceeded (1 - the probability of non-exceedance), antenna radiation would be expected to interfere with a LTE base station at that location operating in at least SOME frequency portion of the sub band. However, that LTE base station may still be able to operate without significant harmful interference at OTHER frequencies in the sub band. The SATOPS antennas traditionally only operated in a 4 MHz-wide sections of the band at a time, and newer waveforms now are being programmed to operate in only 160 KHz sections of the band at a time. The transmitting frequency of the SATOPS terminal is determined by the satellite being supported at that time.

4.2.4.2.2 Study Results

Using data characterizing typical SATOPS at the selected sites, and applying propagation modeling as described, contour plots in Section 4.2.4.3 were generated. These Power Contour Plots show SATOPS antenna power in the relative vicinity of the sites as a function of azimuth and distance. For each point, the power plots provide the power level assuming the SATOPS antenna were pointing in that direction in Azimuth. Threshold exceedance plots indicate the probability that the predicted SATOPS signal level at various points of azimuth and distance does not exceed the threshold interference criterion, given median path loss values. The results are subject to uncertainties of the modeling process further elaborated in Section 4.2.4.4.

4.2.4.2.3 Summary

SATOPS information was requested by the CSMAC WG 3 to assess Government and commercial sharing of the 1755-1850 MHz band the information provided for analysis in section 4.4. A methodology for estimating power contours over geographic areas is presented. Limitations of models to simulate power profiles are described. Results are based on general usage but are not actual operational scenarios for Government SATOPS ground sites.

Note that this study is not intended to support any derivation of requirements. Impacts to future commercial operations can only be estimated at this time. There is still a need to assess actual ground site parameters for potential impacts. Regulatory provisions should allow for potential changes in Government mission requirements including the possibility of greater satellite contact times, higher power levels at existing sites and the addition of new sites.

4.2.4.3 Study Results.

Various power plots and threshold non-exceedance plots are presented as indicated in the table below, which refers to Figures 4.2.4-4 through 4.2.4-58.

Table 4.2.4-1. Summary Chart of Phase 2 Results.

Type of Plot[31]	**Grid (km)**	**Site**					
		NHS	VTS	HTS	BP,MD	FB,AK	LP, CA
Power Contour	5	4-5	18-19	30-31, 34	42-43	51	53-54
Power Contour	1					50	
Power Contour with 20 dB Attenuation	5	6-7	20-21	32-33, 35	44-45	51	55-56
LTE Threshold Exceedance 1755-1780 MHz	5	8	24	36	46, 48		
LTE Threshold Exceedance 1755-1780 MHz	1					52	
LTE Threshold Exceedance 1755-1780 MHz, with 20 dB Attenuation	1	9	25	37	47,49	52	
LTE Threshold Exceedance 1780-1805 MHz	5	10	26	38			57
LTE Threshold Exceedance 1780-1805 MHz	1						58
LTE Threshold Exceedance 1780-1805 MHz, with 20 dB Attenuation	1	11	27	39			
LTE Threshold Exceedance 1805-1850 MHz	5	12	28	40			
LTE Threshold Exceedance 1805-1850 MHz	1		29				
LTE Threshold Exceedance 1805-1850 MHz, with 20 dB Attenuation	1	13		41			
Power Contour (Radiating at 5.02 kW)	5		22				
Power Contour (Radiating at 5.02 kW), with 20 dB Attenuation	5		23				
Power Contour (Radiating at 7.244 kW)	5	14					
Power Contour (Radiating at 7.244 kW), with 20 dB Attenuation	5	15					
LTE Threshold Exceedance 1755-1780 MHz (Radiating at 7.244 kW)	5	16					
LTE Threshold Exceedance 1755-1780 MHz (with 10 dB standard deviation applied to propagation loss)	5	17					

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[31] Unless otherwise stated in the table, charts reflect transmit power of 1 kW except for BP, MD which uses a power of 300 W.

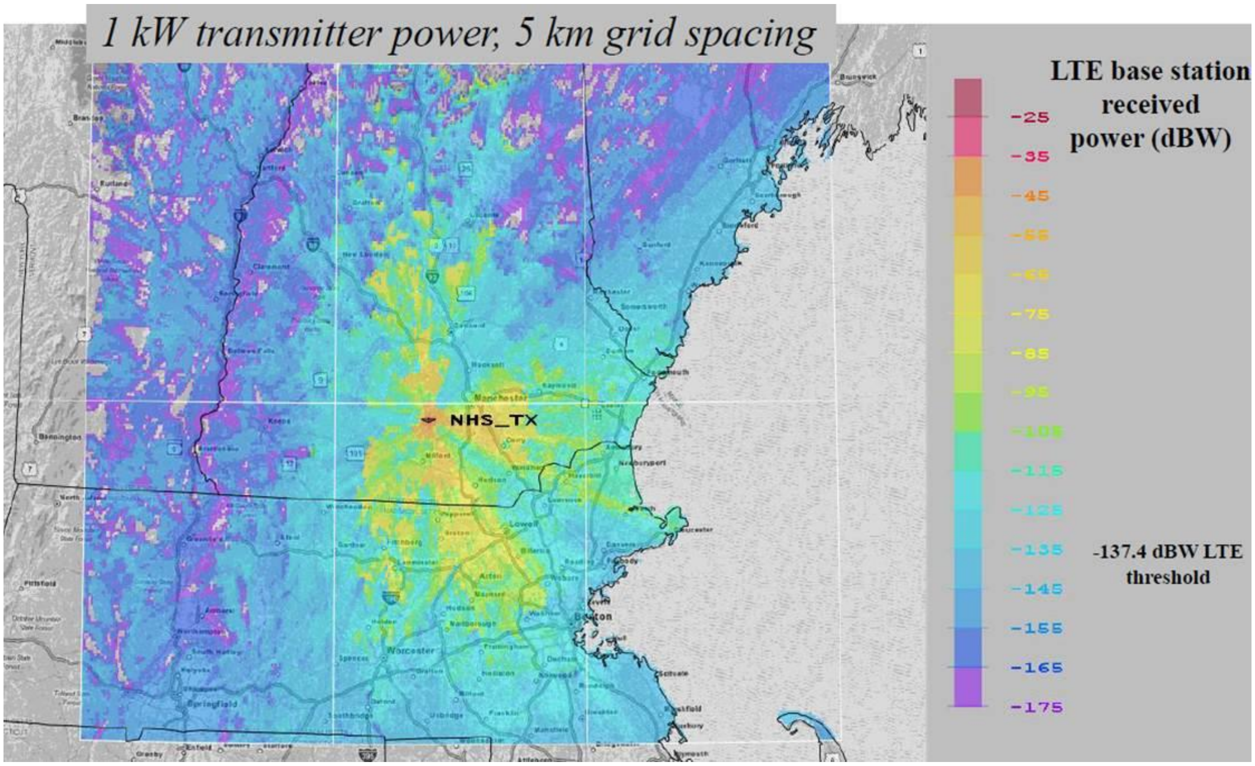


Figure 4.2.4-4 NHS Power Contours

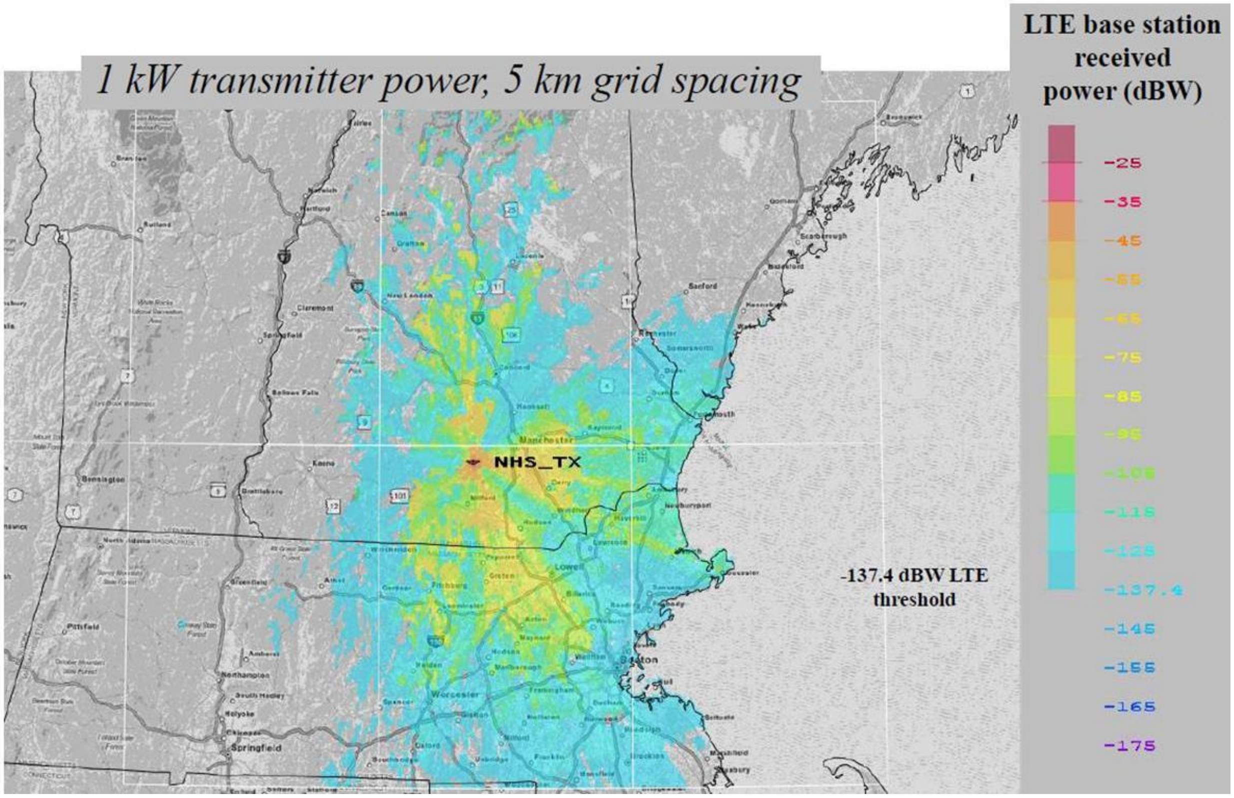


Figure 4.2.4-5 NHS Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

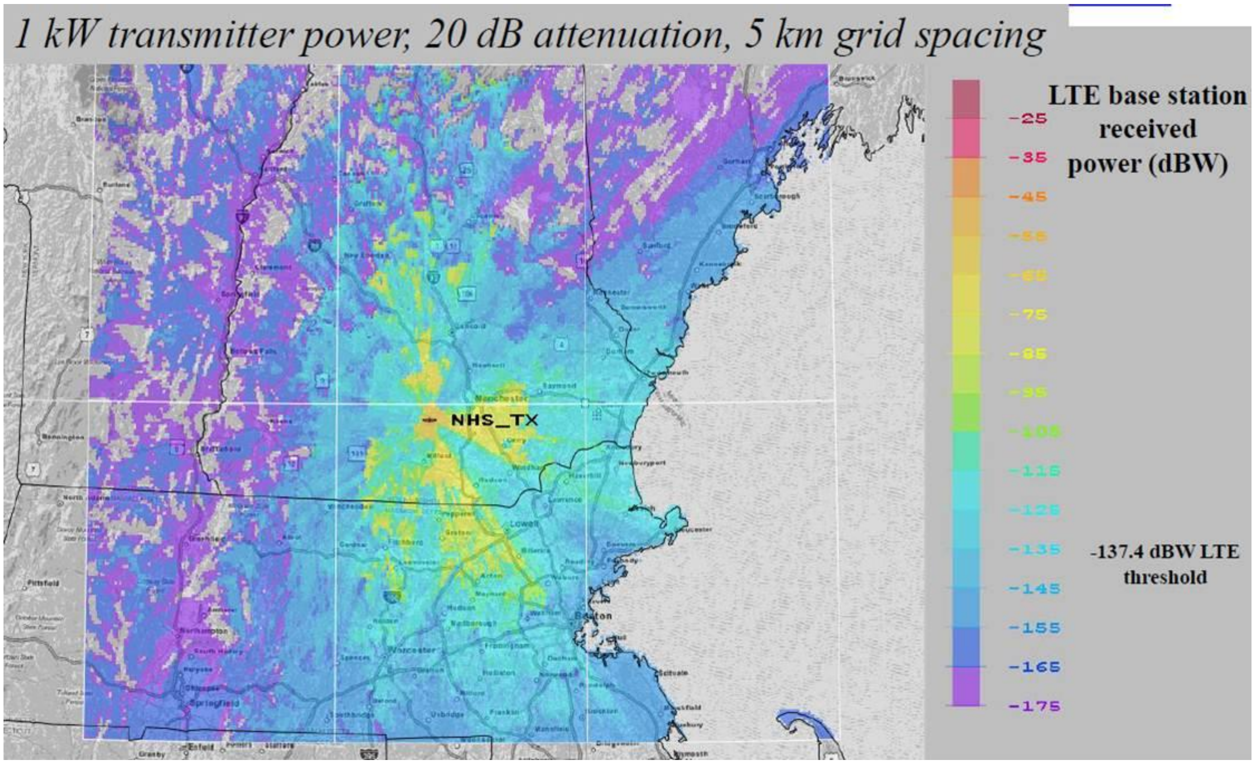


Figure 4.2.4-6 NHS Power Contours

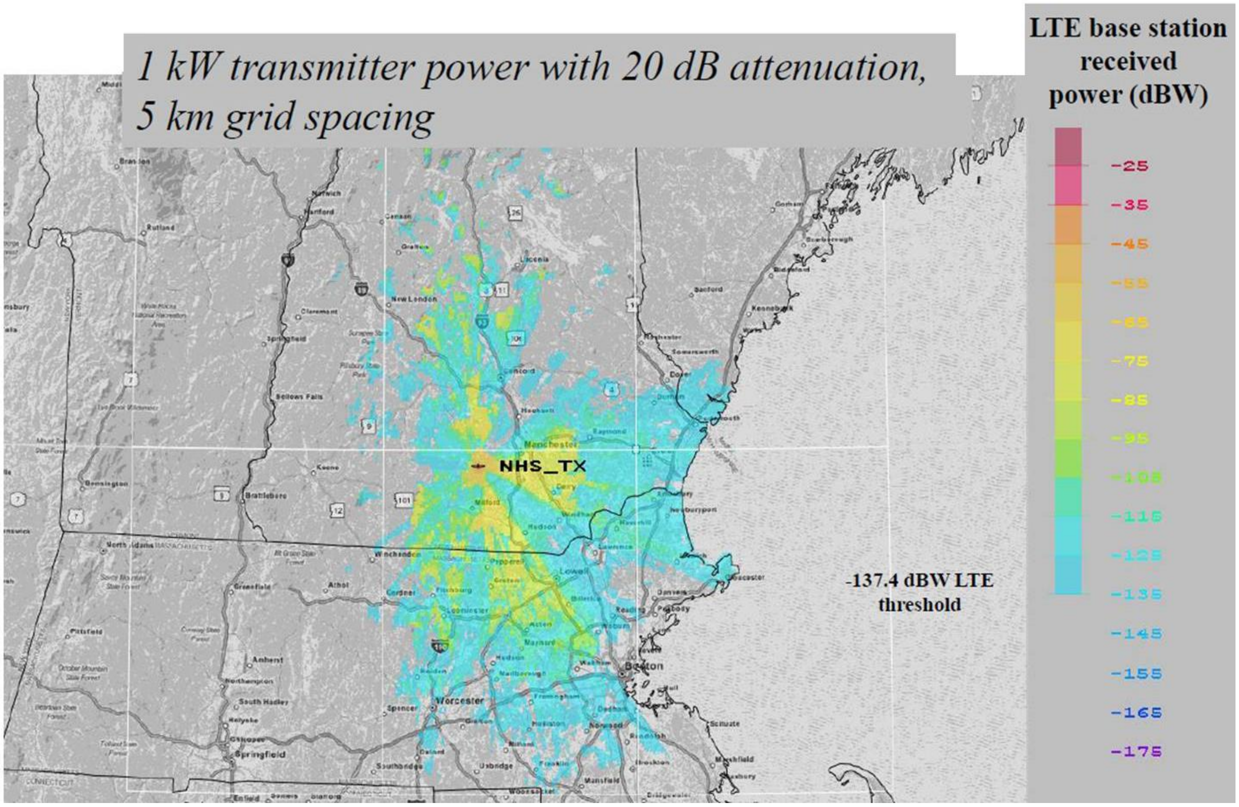


Figure 4.2.4-7 NHS Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

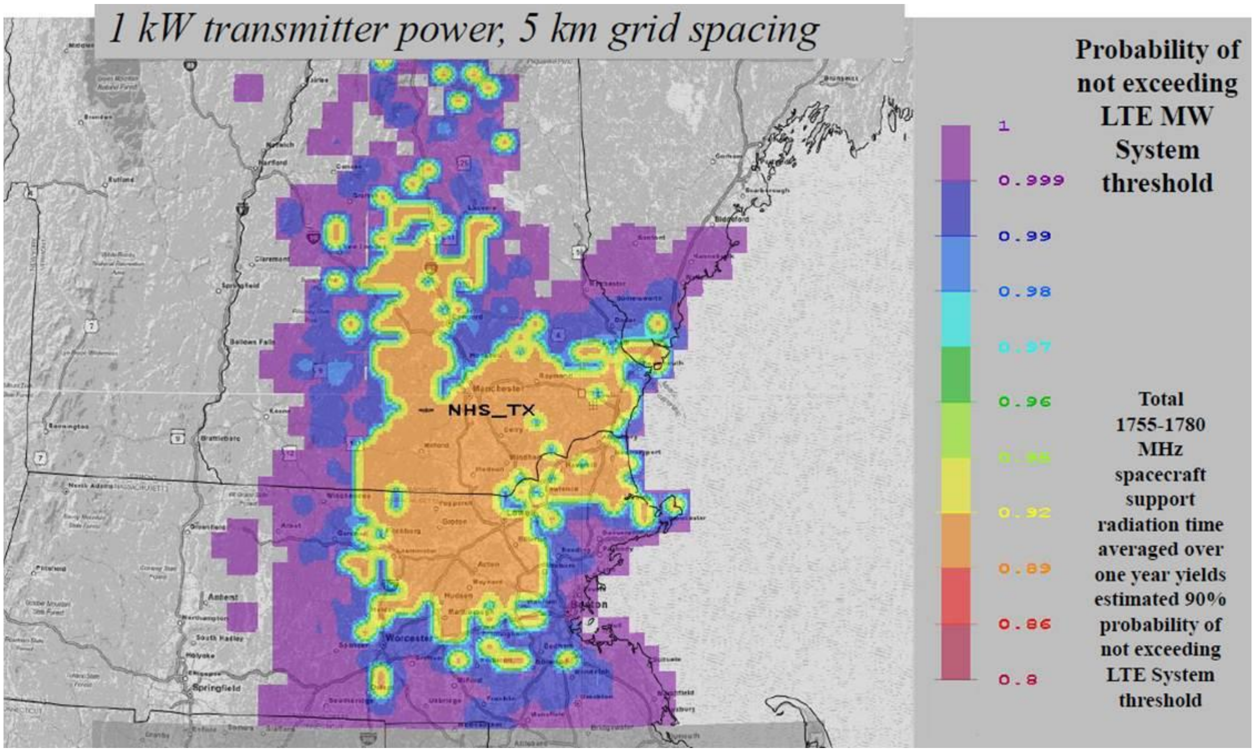


Figure 4.2.4-8 NHS LTE System Threshold Exceedance, 1755-1780 MHz

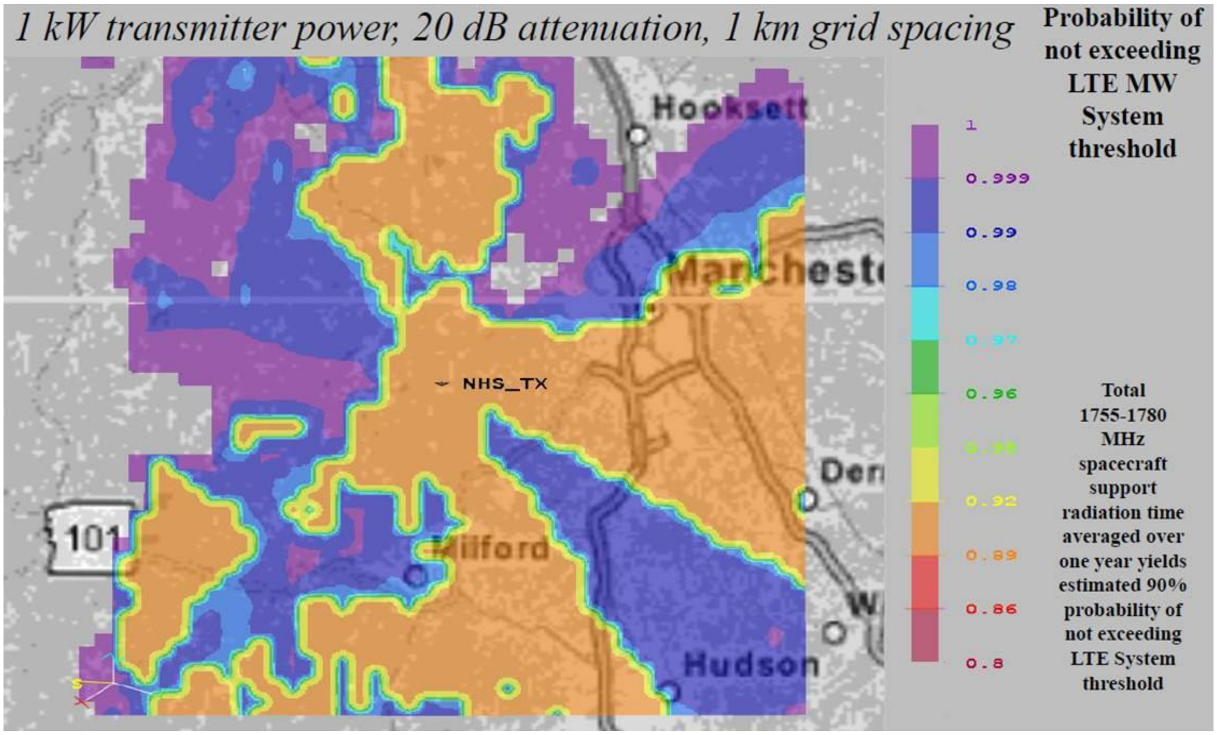


Figure 4.2.4-9 NHS LTE System Threshold Exceedance, 1755-1780 MHz (Plots of this type are magnified by a factor of five compared with the previous plots)

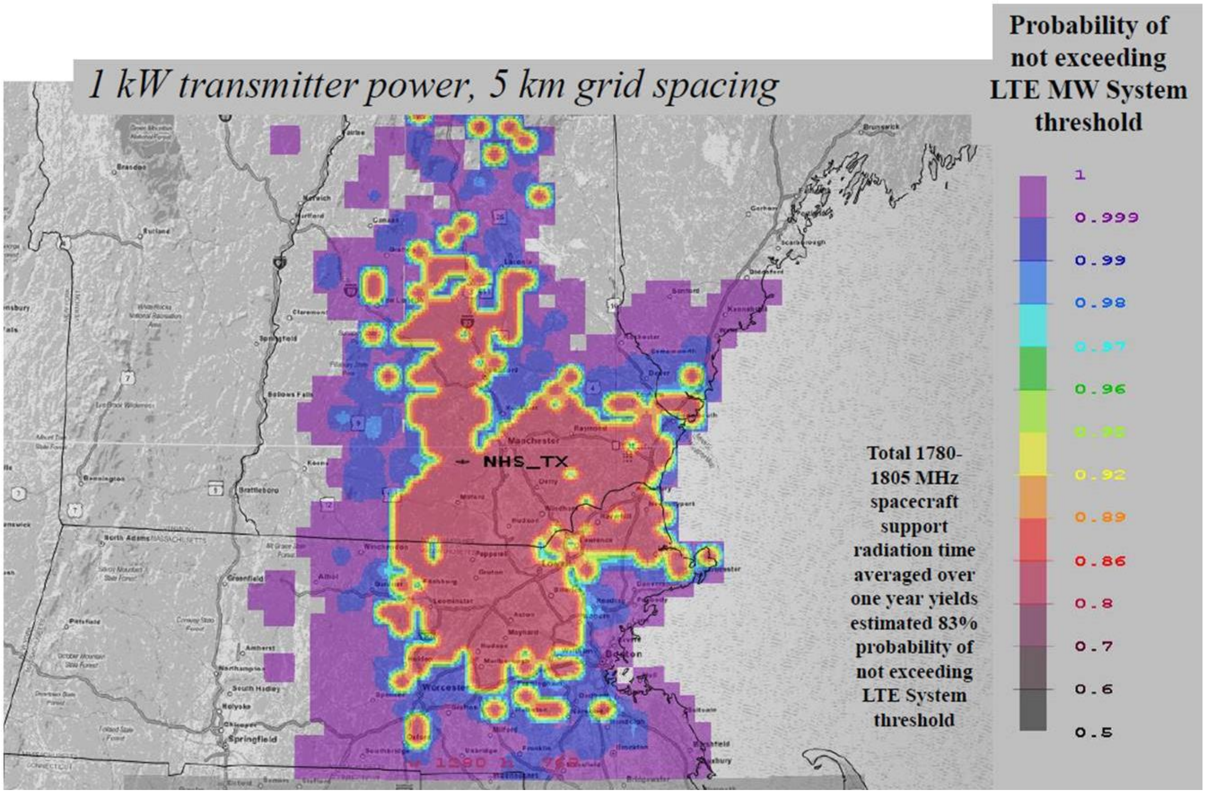


Figure 4.2.4-10 NHS LTE System Threshold Exceedance, 1780-1805 MHz

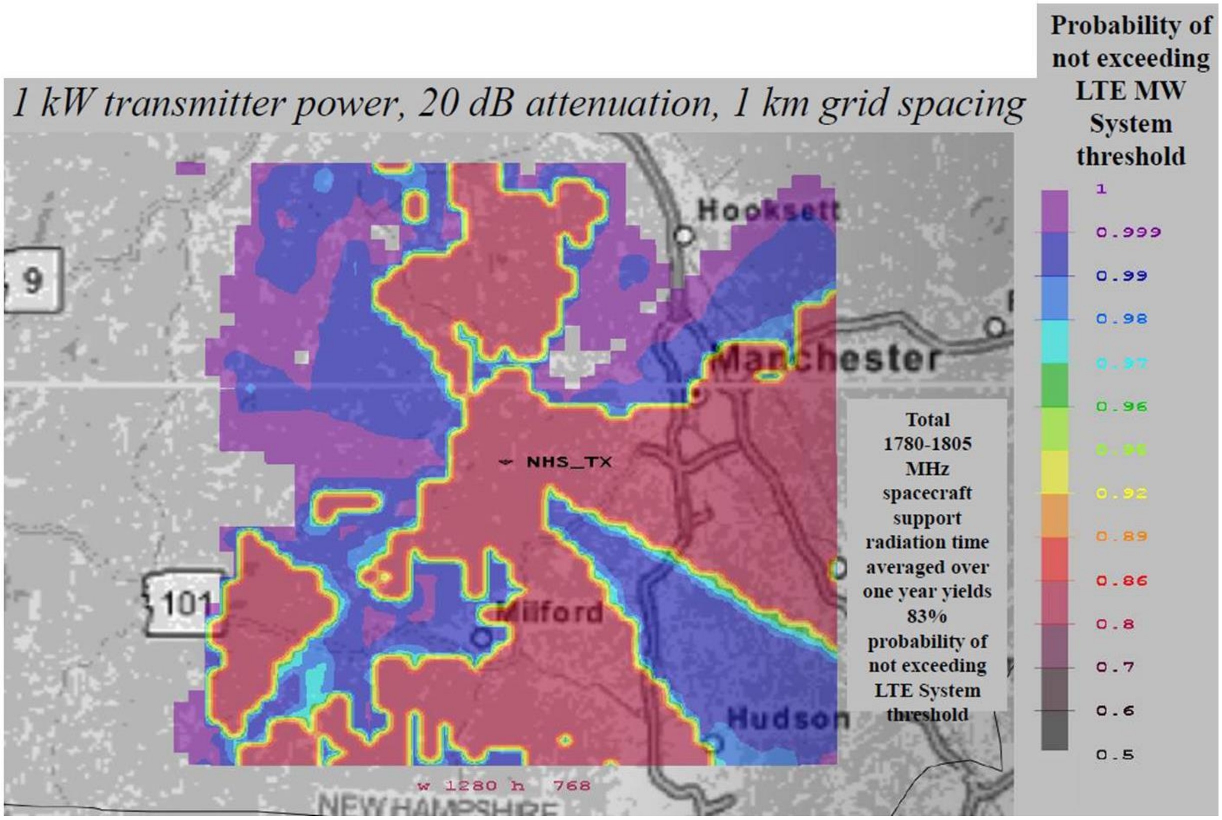
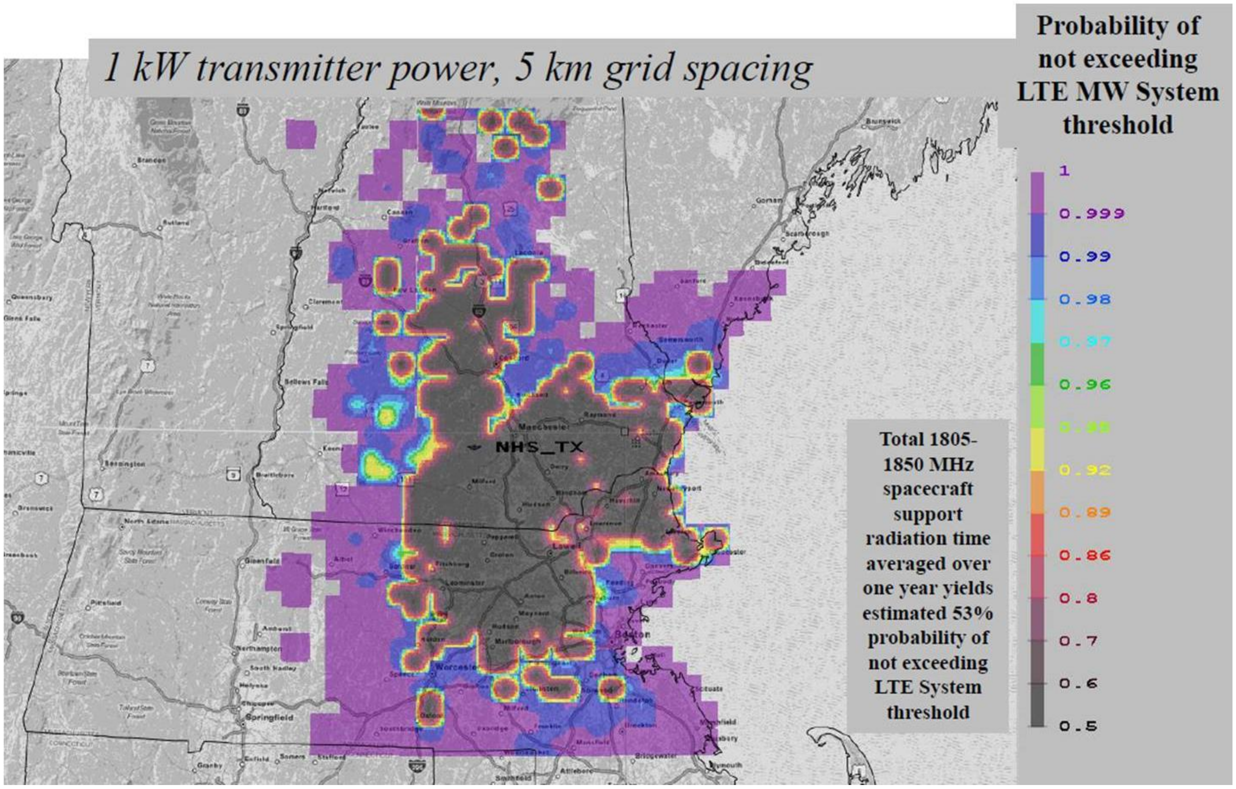


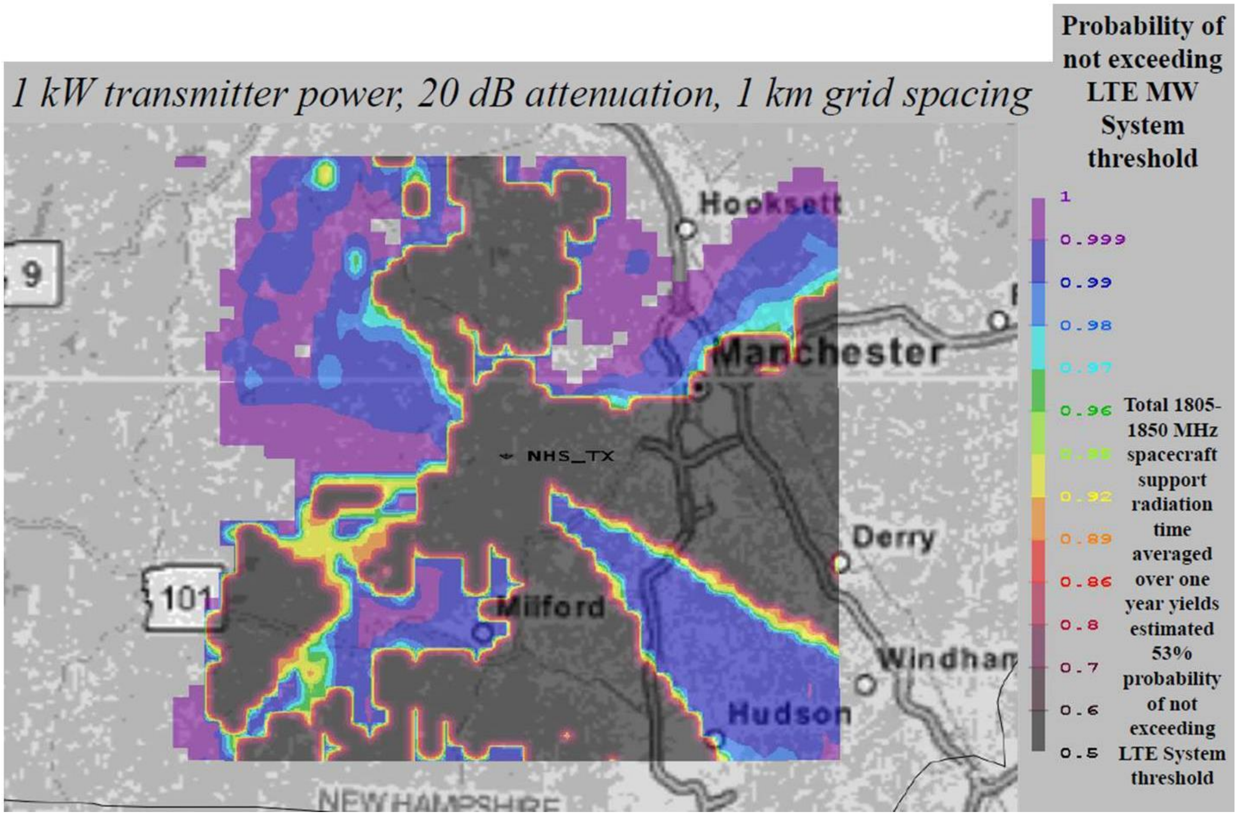
Figure 4.2.4-11 NHS LTE System Threshold Exceedance, 1780-1805 MHz


1 kW transmitter power, 5 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1805-1850 MHz spacecraft support radiation time averaged over one year yields estimated 53% probability of not exceeding LTE System threshold

Figure 4.2.4-12 NHS LTE System Threshold Exceedance, 1805-1850 MHz


1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1805-1850 MHz spacecraft support radiation time averaged over one year yields estimated 53% probability of not exceeding LTE System threshold

Figure 4.2.4-13 NHS LTE System Threshold Exceedance, 1805-1850 MHz

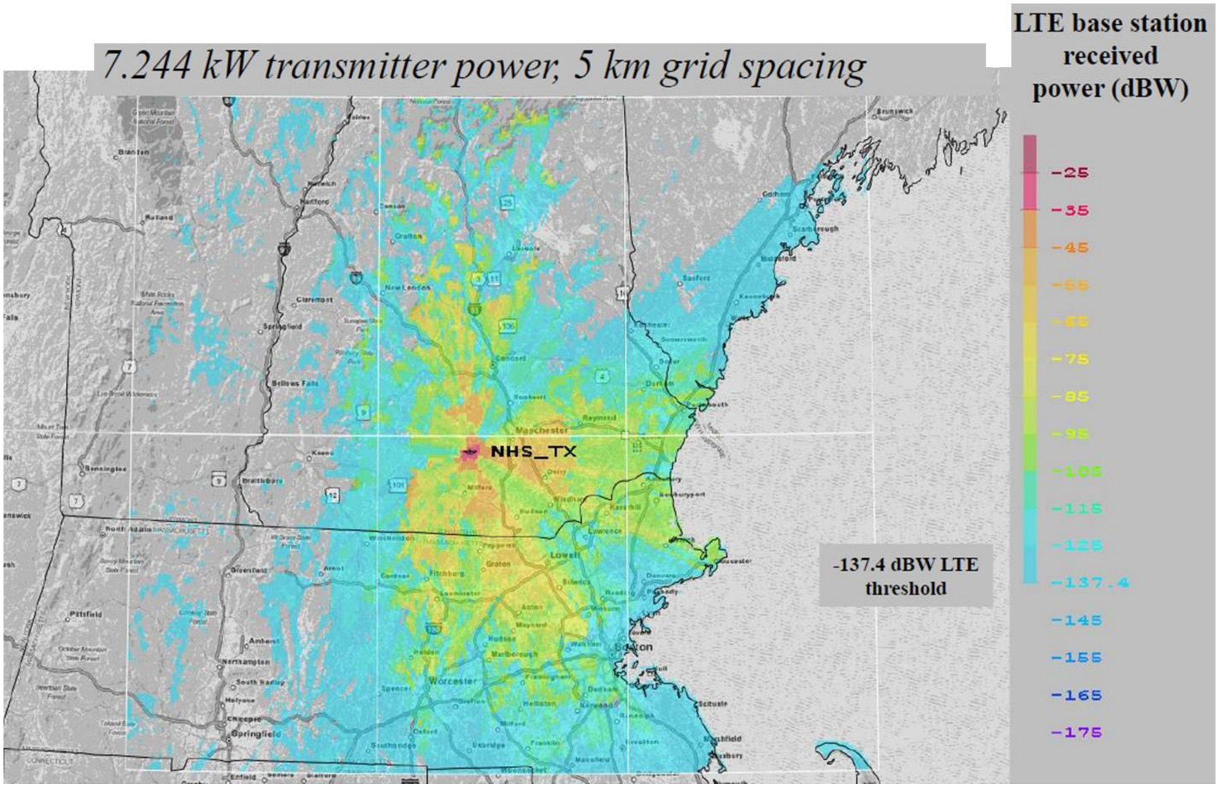


Figure 4.2.4-14 NHS Radiated Power (38.6 dBW, max power example)

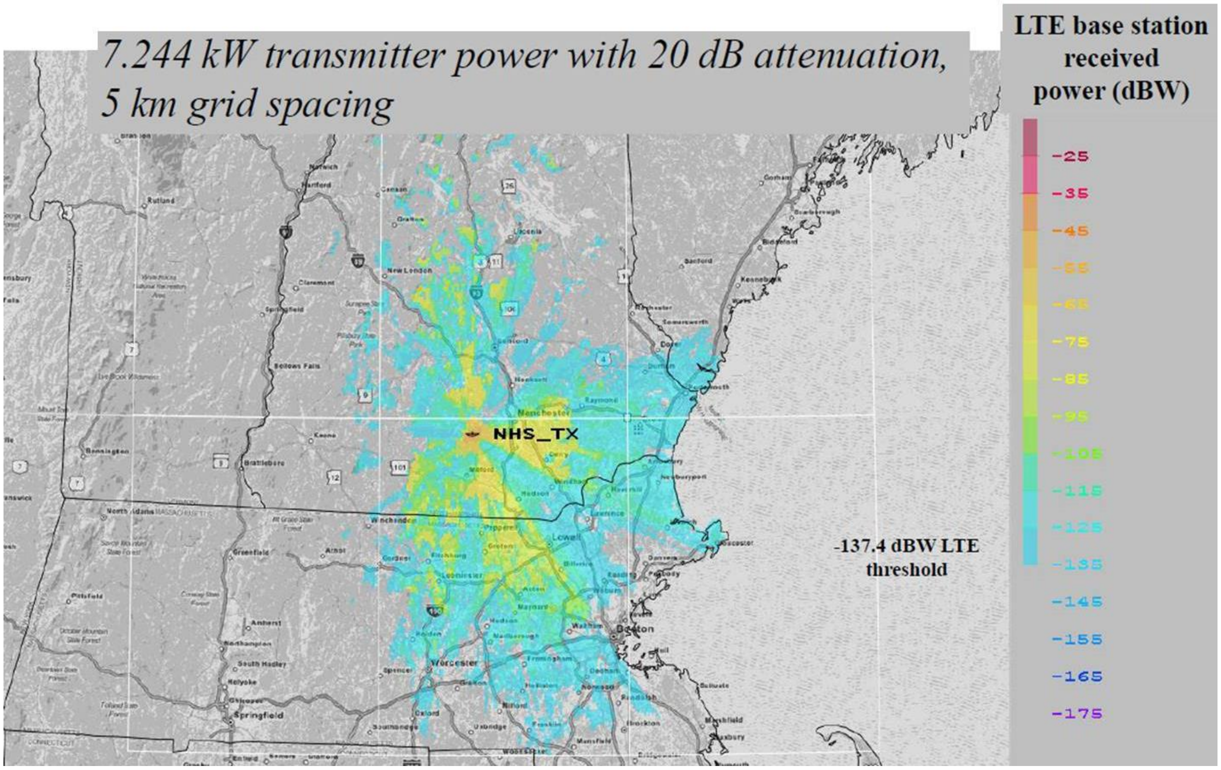


Figure 4.2.4-15 NHS Radiated Power (18.6 dBW, max power example with attenuation)

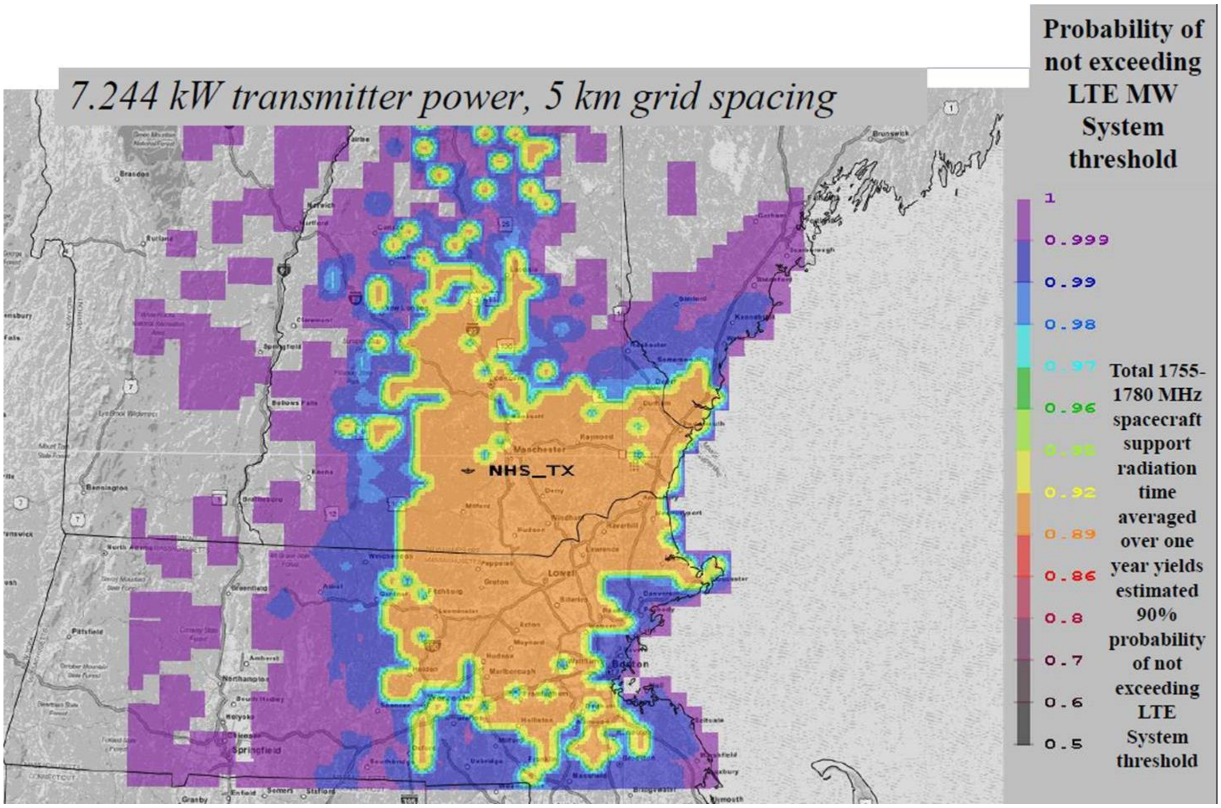


Figure 4.2.4-16 NHS LTE System Threshold Exceedance, 1755-1780 MHz (38.6 dBW, max power example)

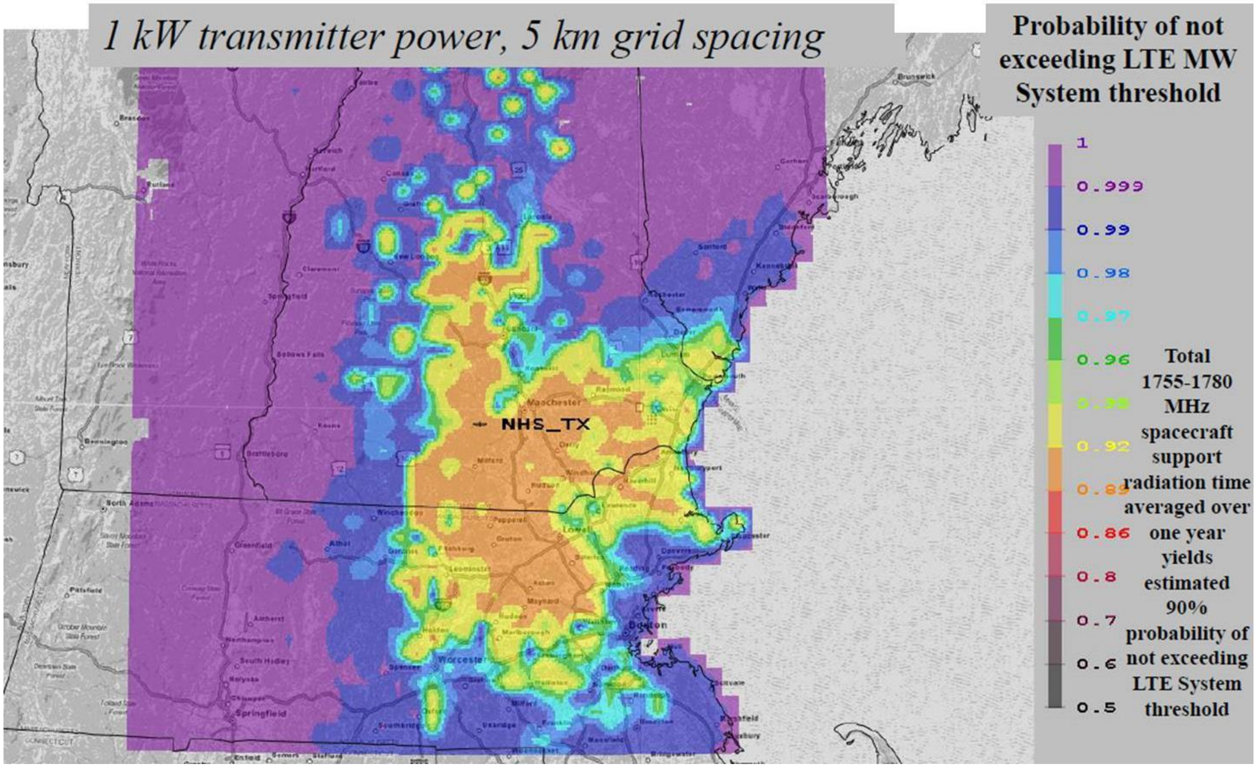


Figure 4.2.4-17 NHS LTE System Threshold Exceedance, 1755-1780 MHz (Gaussian distribution applied with 10 dB standard deviation to receive power levels)

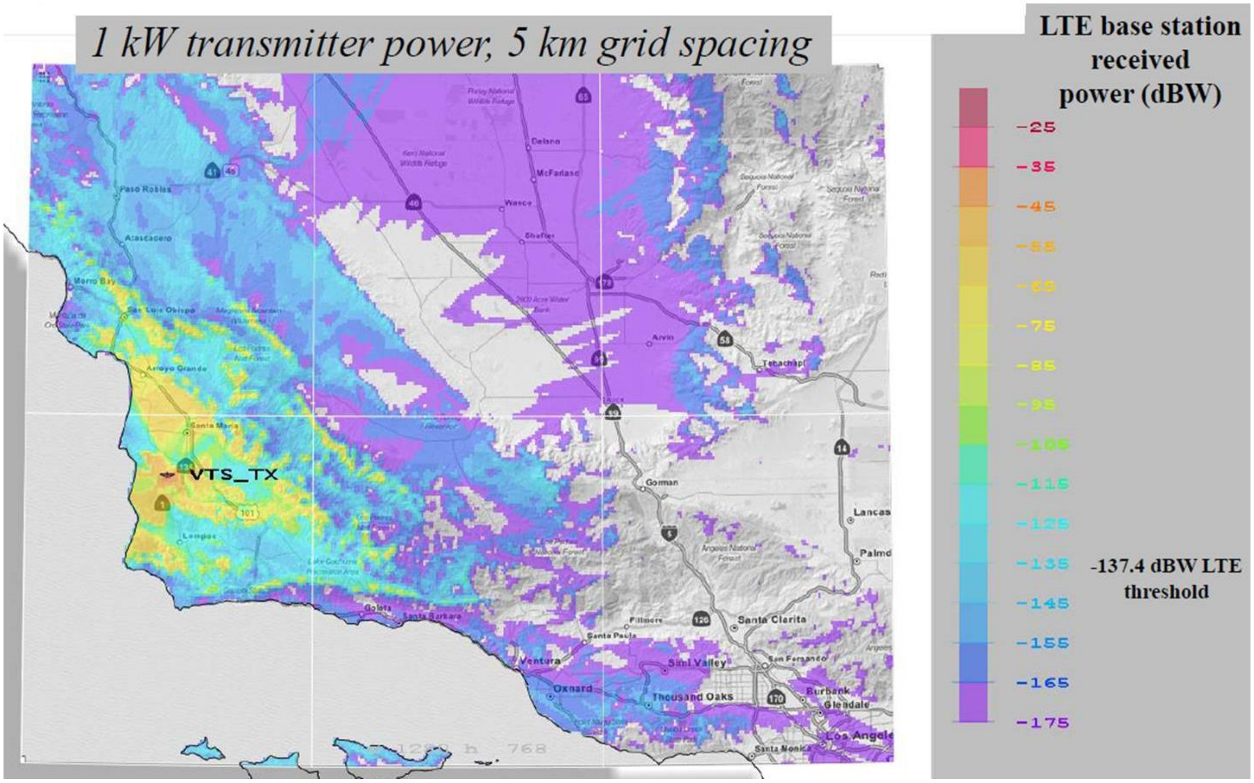


Figure 4.2.4-18 VTS Power Contours

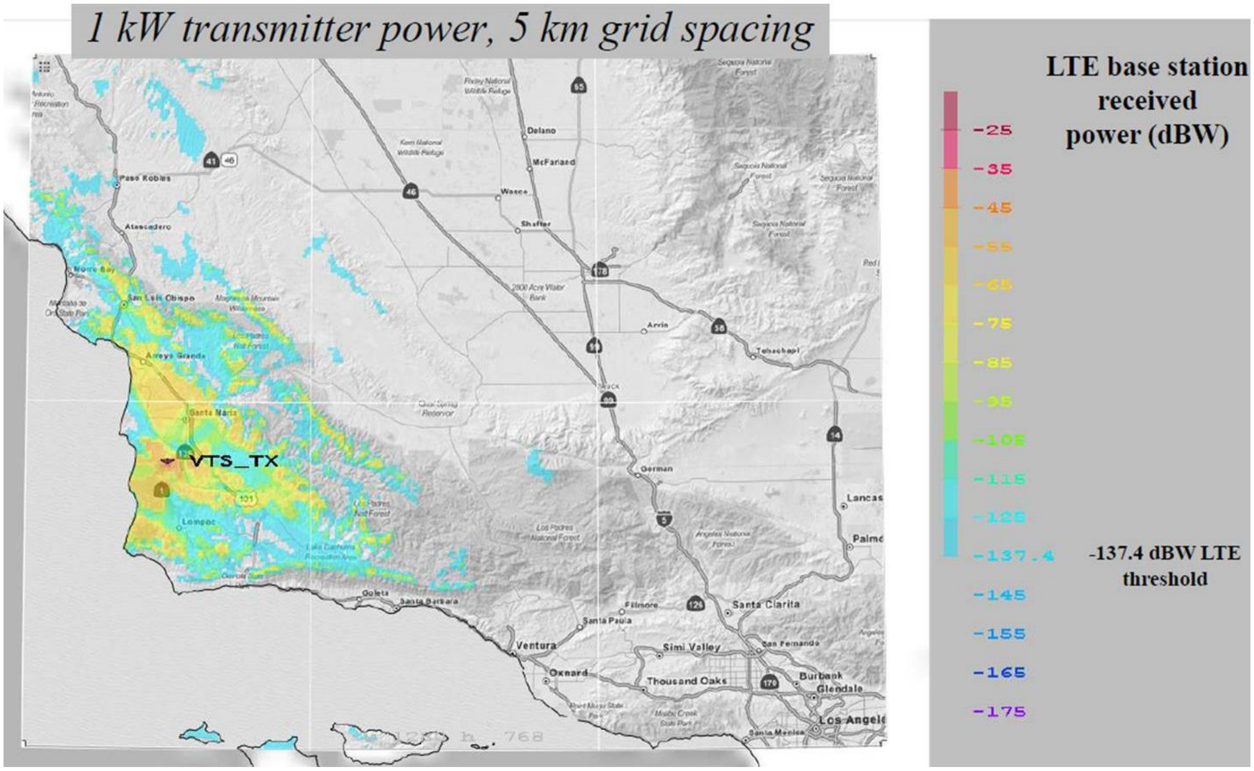


Figure 4.2.4-19 VTS Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

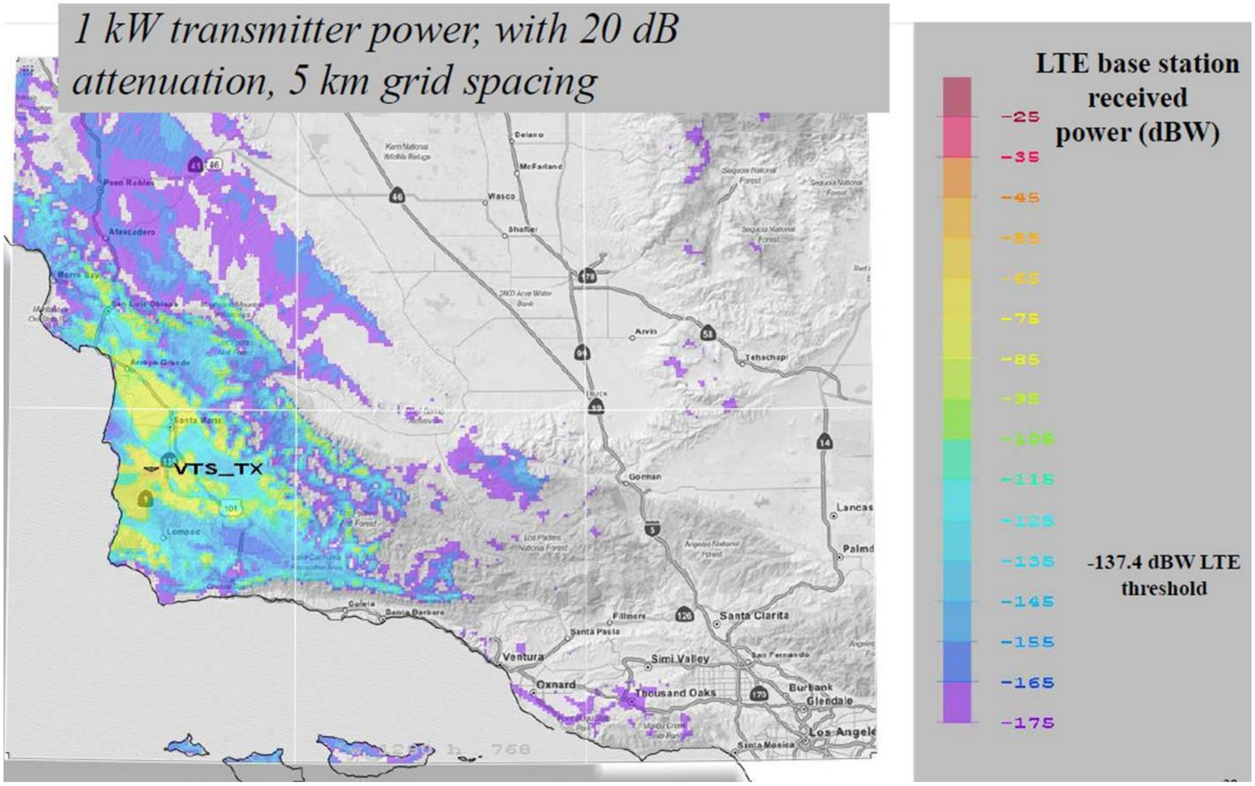


Figure 4.2.4-20 VTS Power Contours

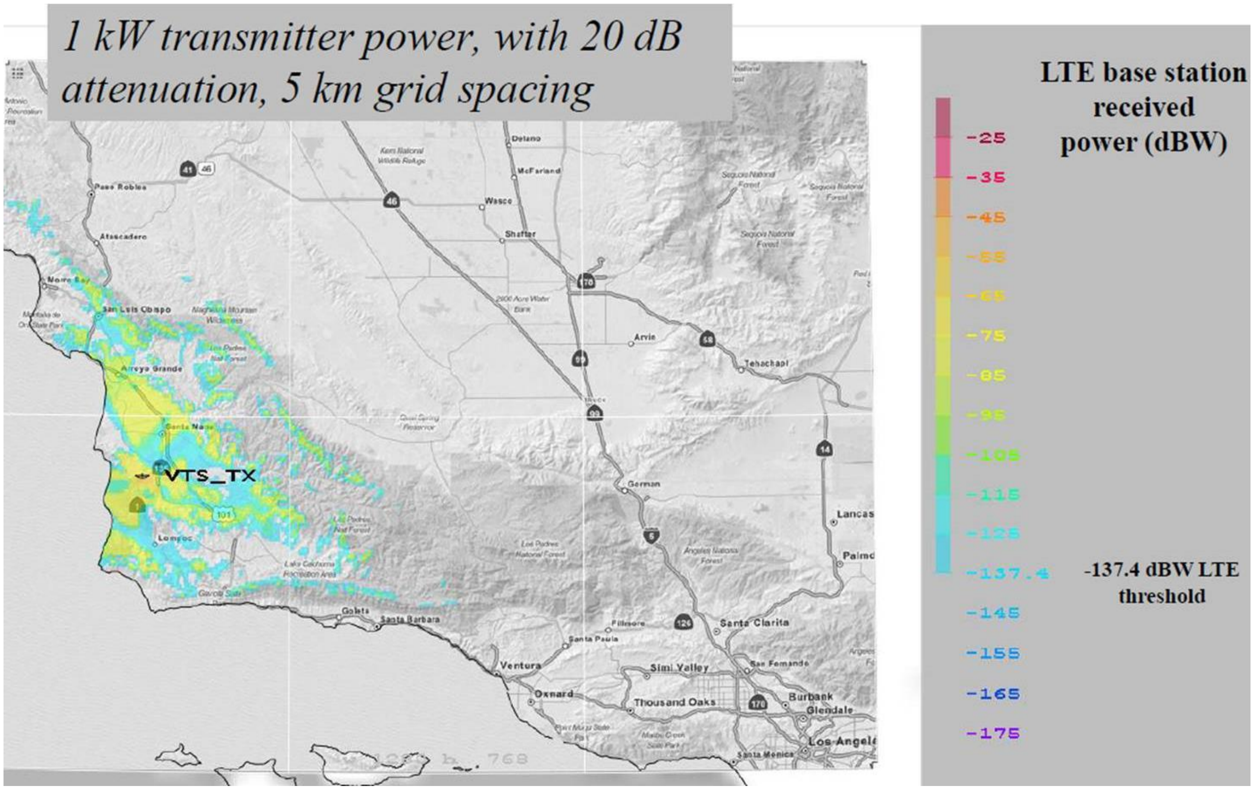


Figure 4.2.4-21 VTS Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

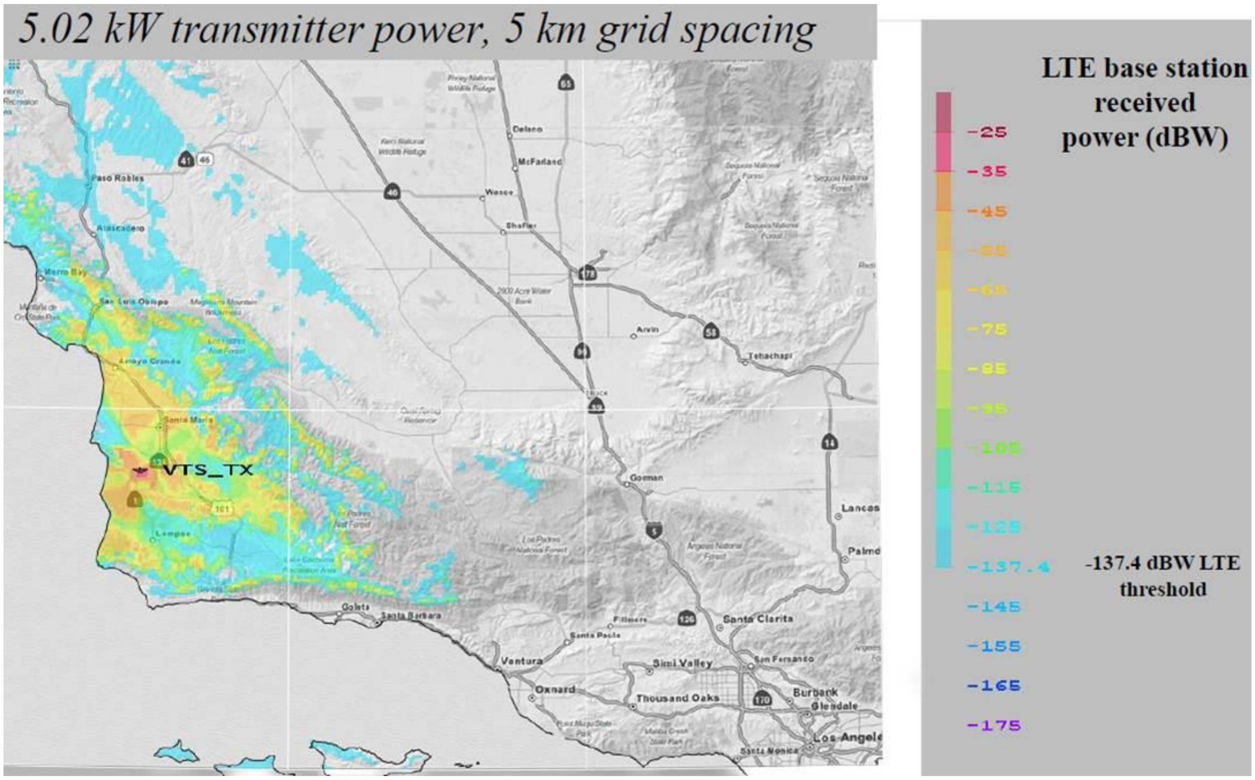


Figure 4.2.4-22 VTS Radiated Power (37.05 dBW, max power example)

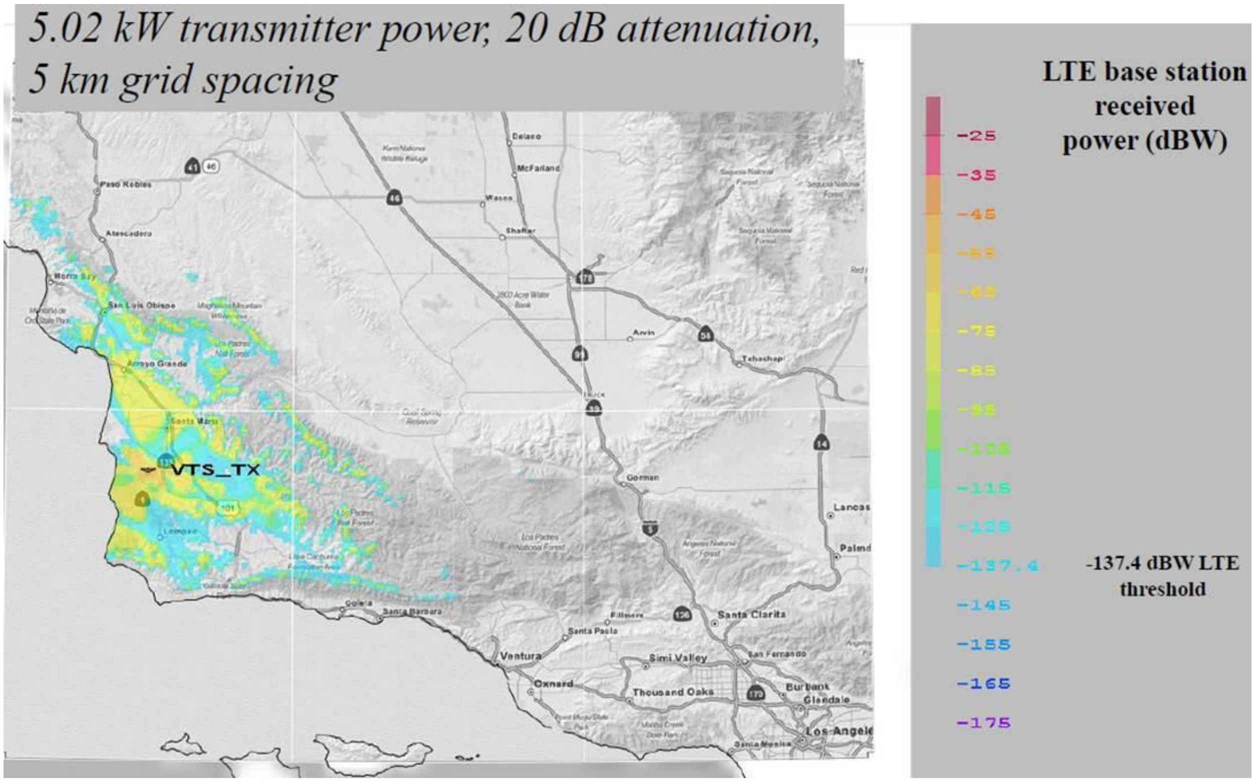


Figure 4.2.4-23 VTS Radiated Power (17.05 dBW, max power with attenuation)

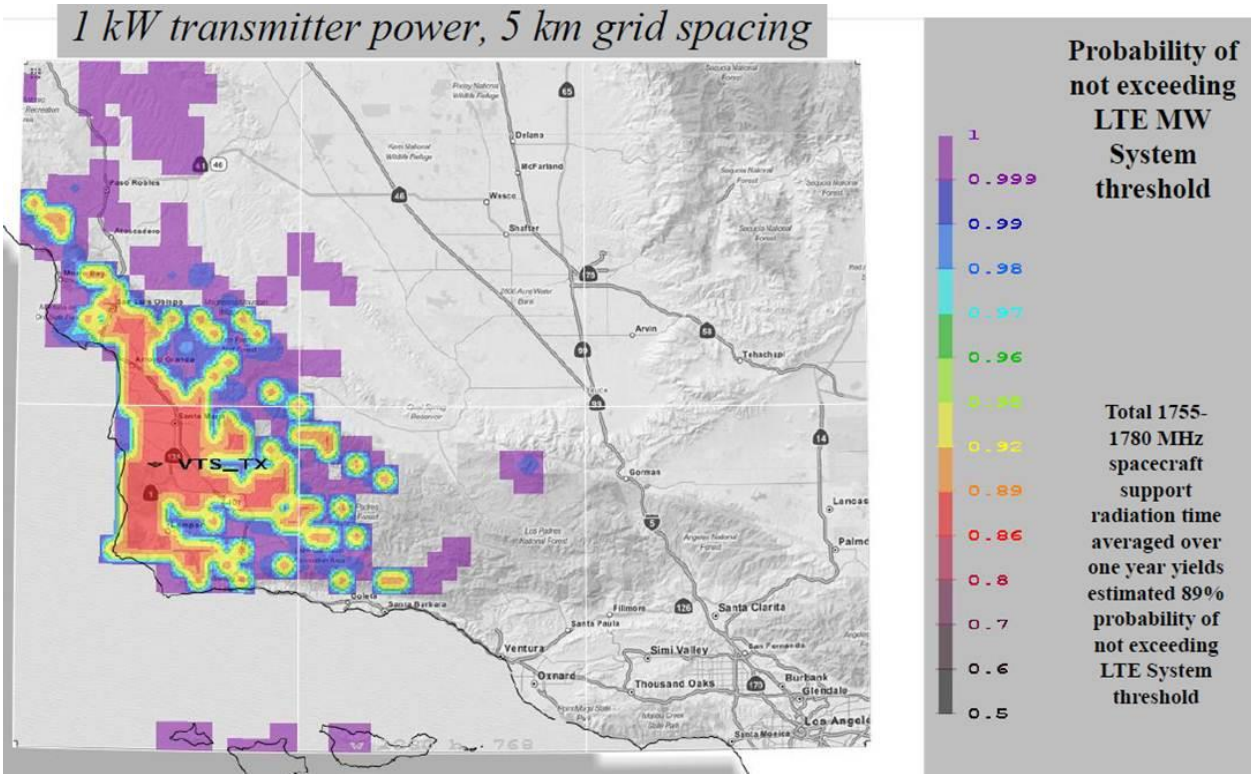


Figure 4.2.4-24 VTS LTE System Threshold Exceedance, 1755-1780 MHz

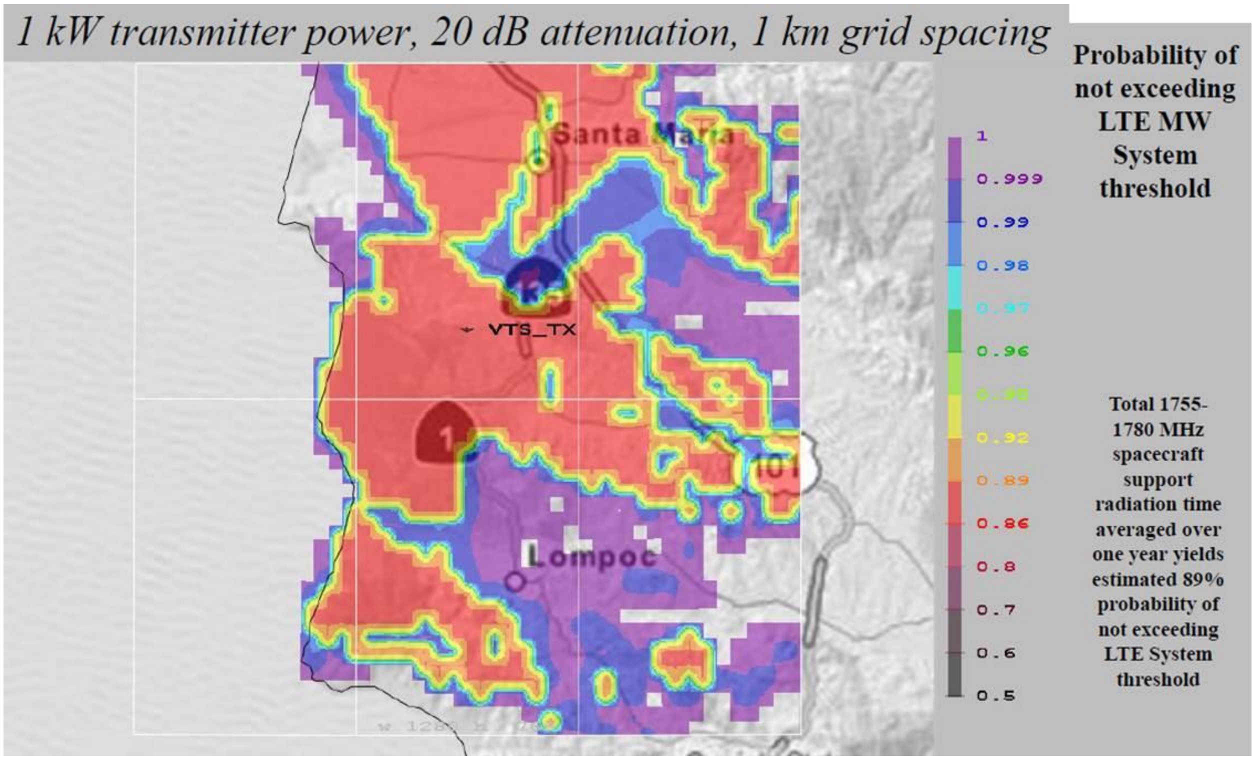


Figure 4.2.4-25 VTS LTE System Threshold Exceedance, 1755-1780 MHz

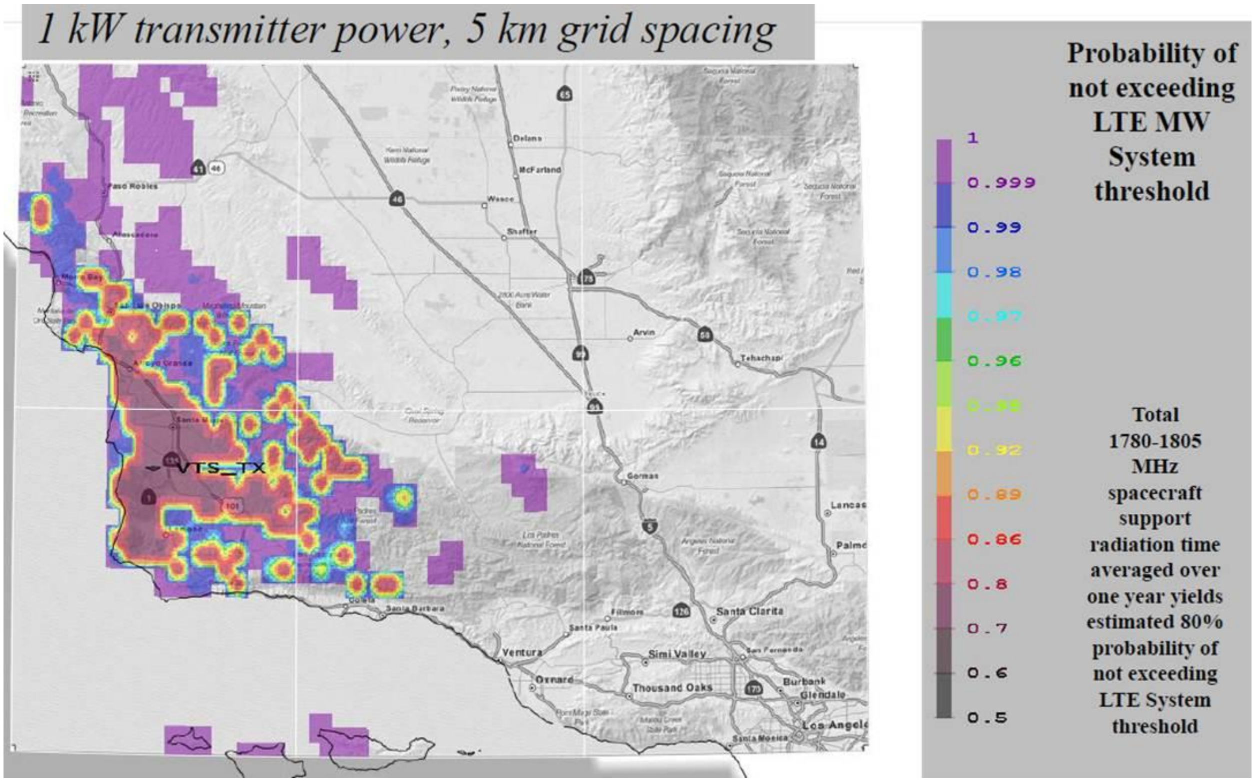


Figure 4.2.4-26 VTS LTE System Threshold Exceedance, 1780-1805 MHz

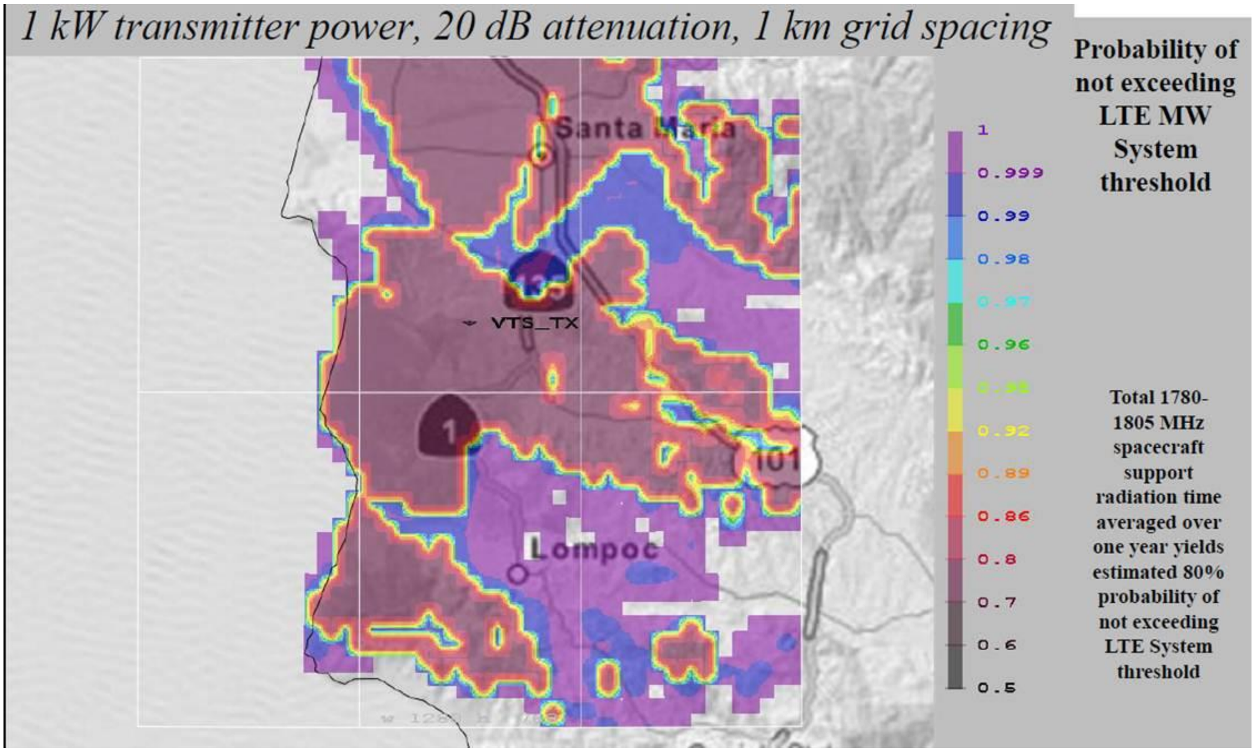


Figure 4.2.4-27 VTS LTE System Threshold Exceedance, 1780-1805 MHz

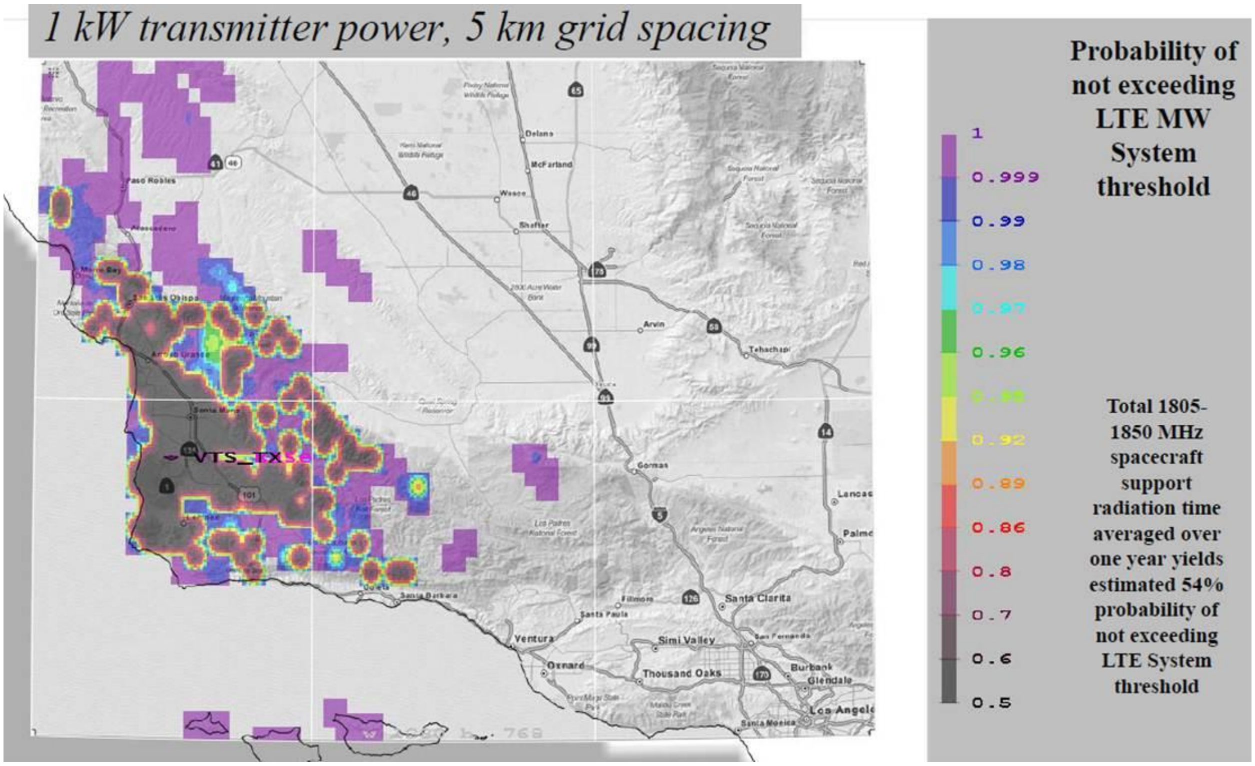


Figure 4.2.4-28 VTS LTE System Threshold Exceedance, 1805-1850 MHz

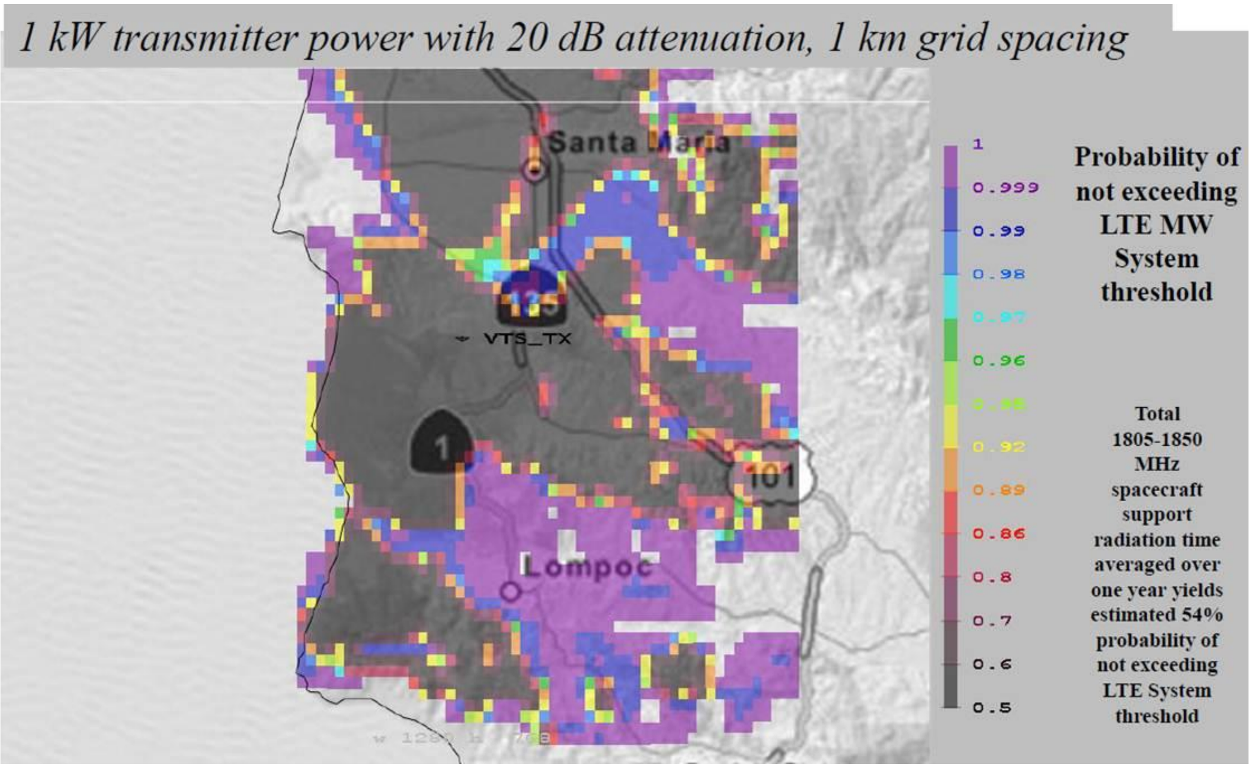


Figure 4.2.4-29 VTS LTE System Threshold Exceedance, 1805-1850 MHz

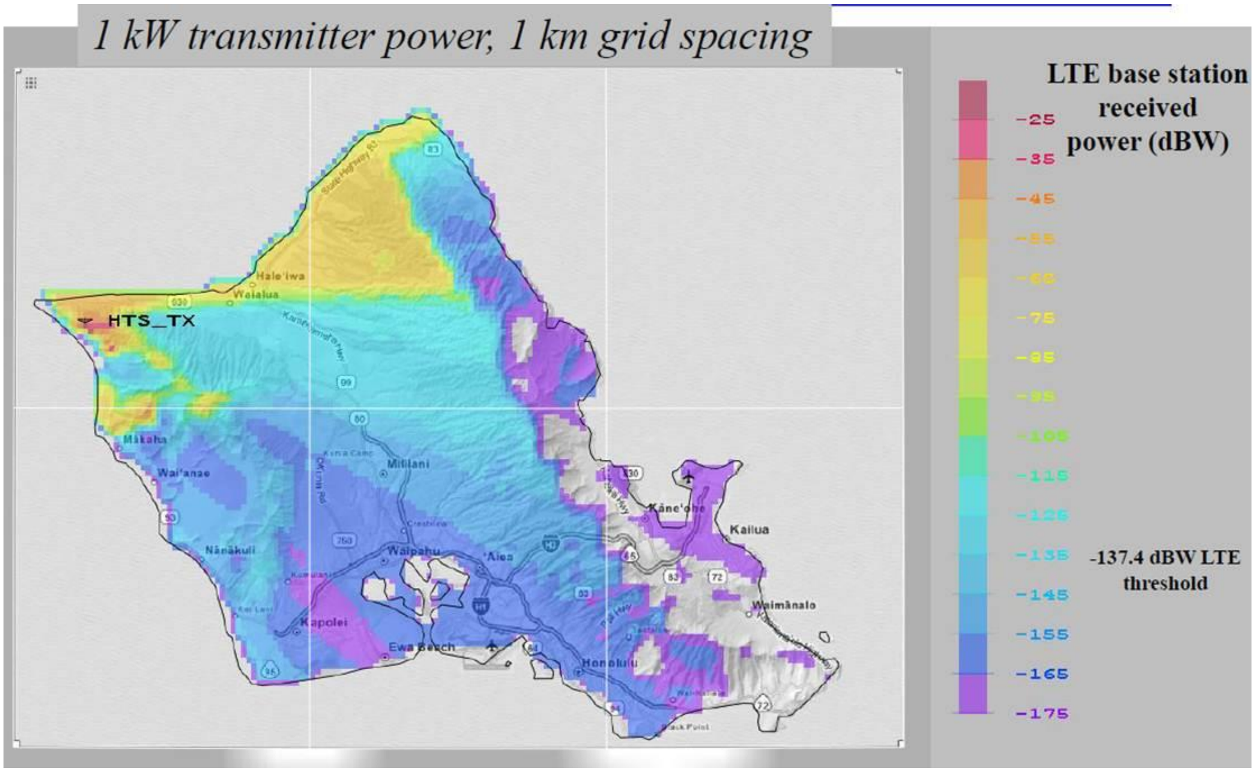


Figure 4.2.4-30 HTS Power Contours

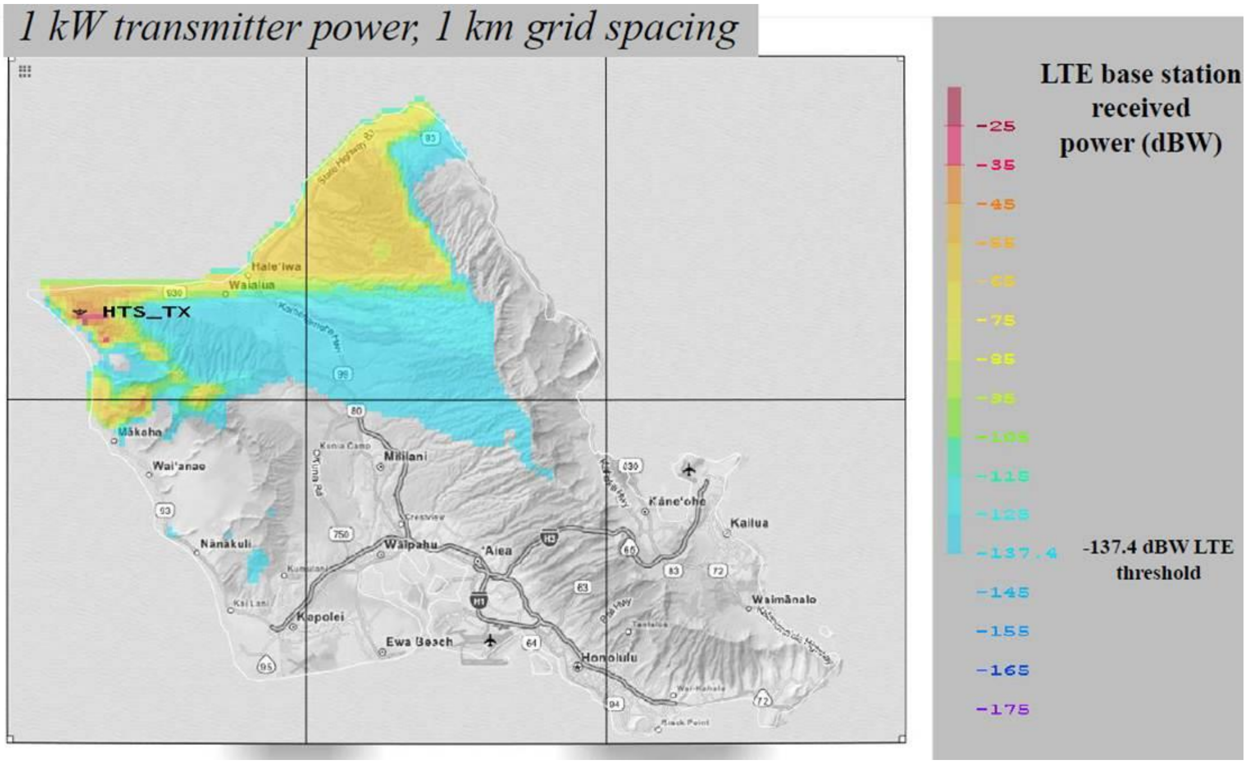


Figure 4.2.4-31 HTS Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

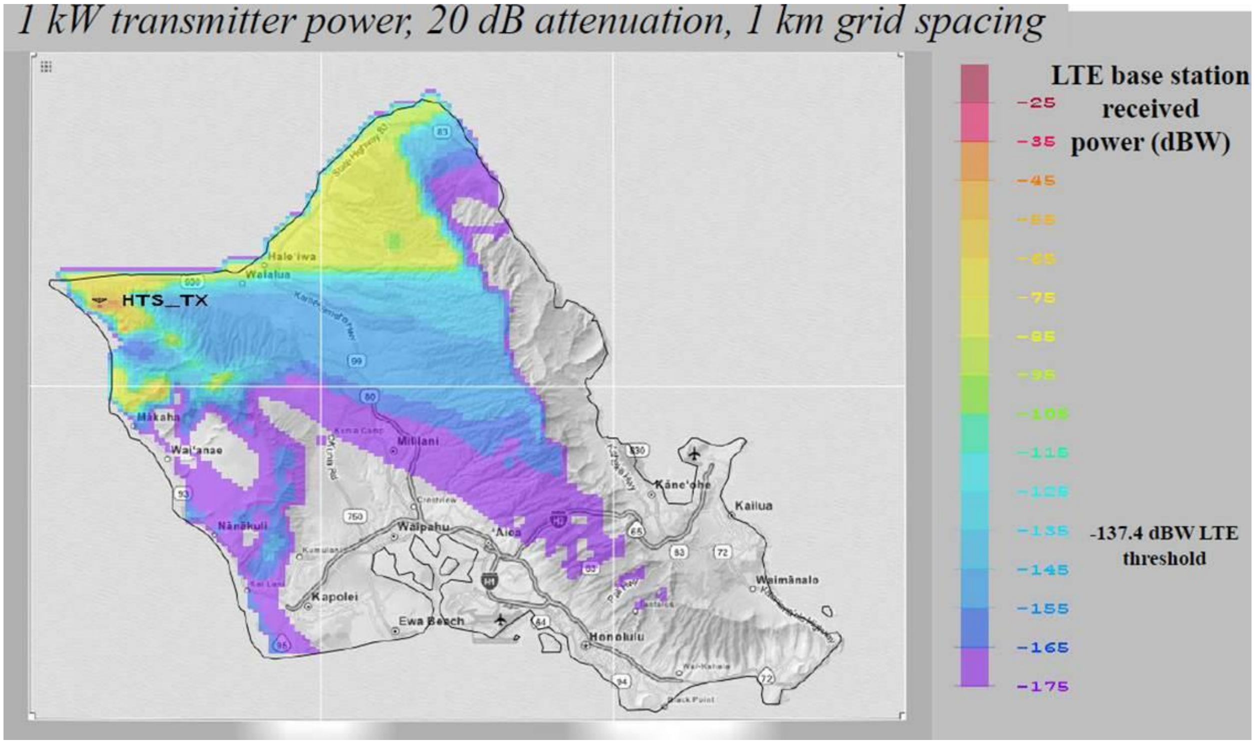


Figure 4.2.4-32 HTS Power Contours

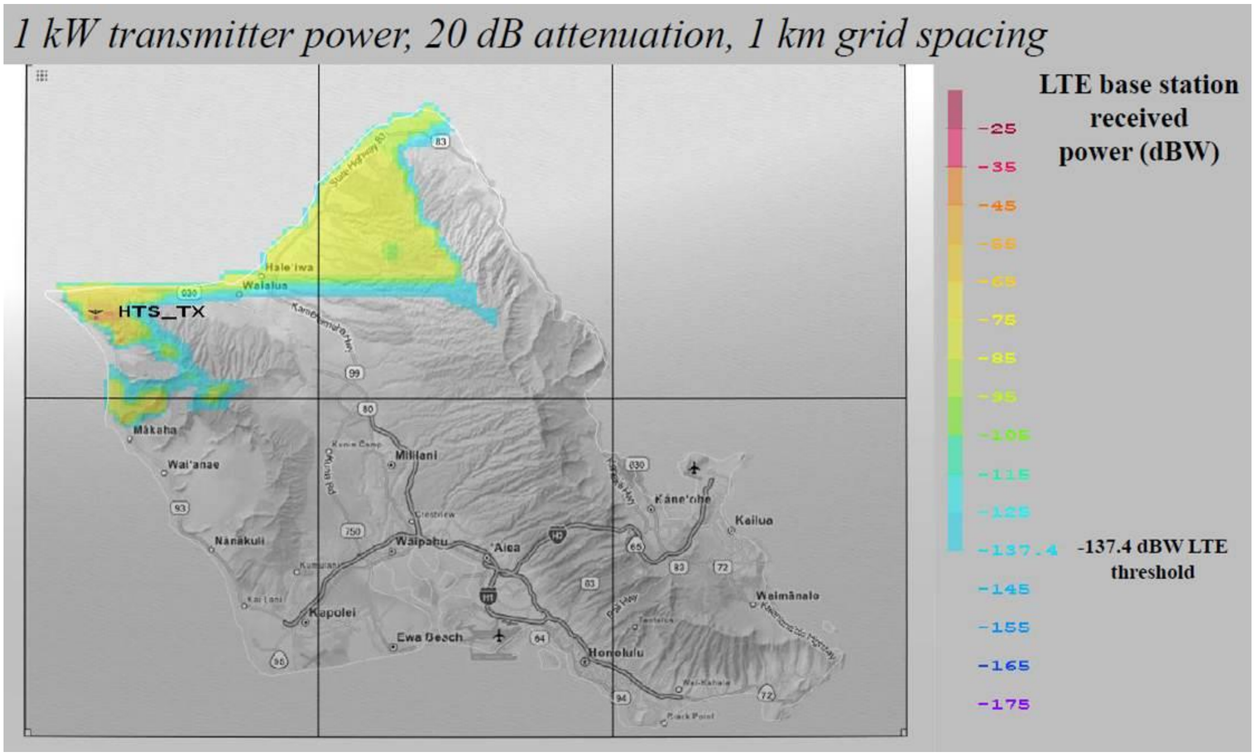


Figure 4.2.4-33 HTS Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

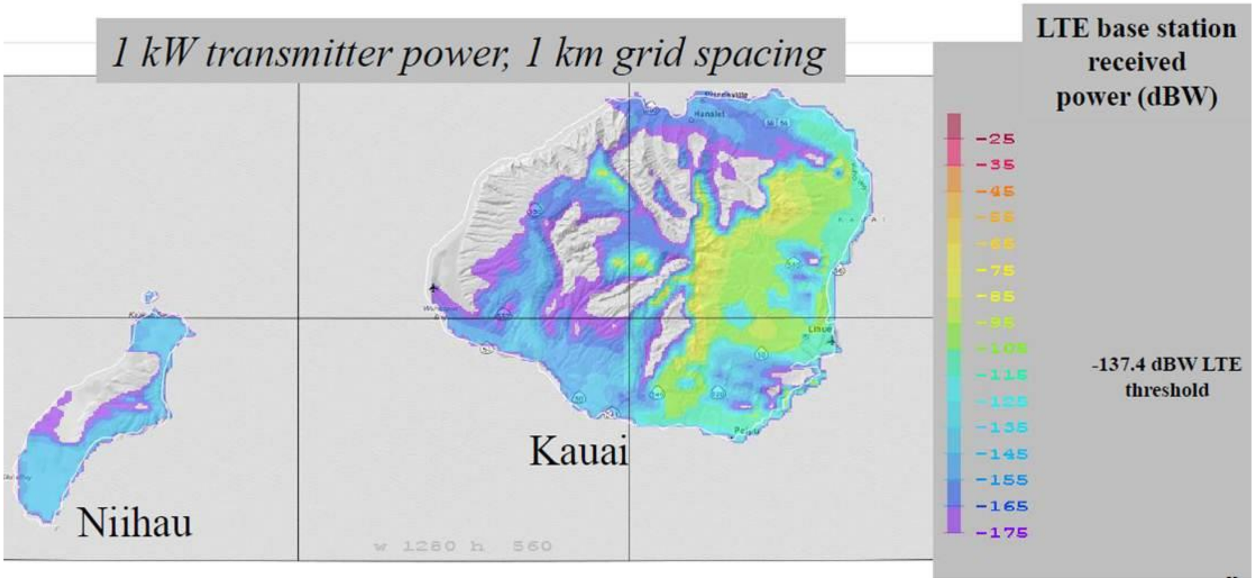


Figure 4.2.4-34 HTS Power Contours

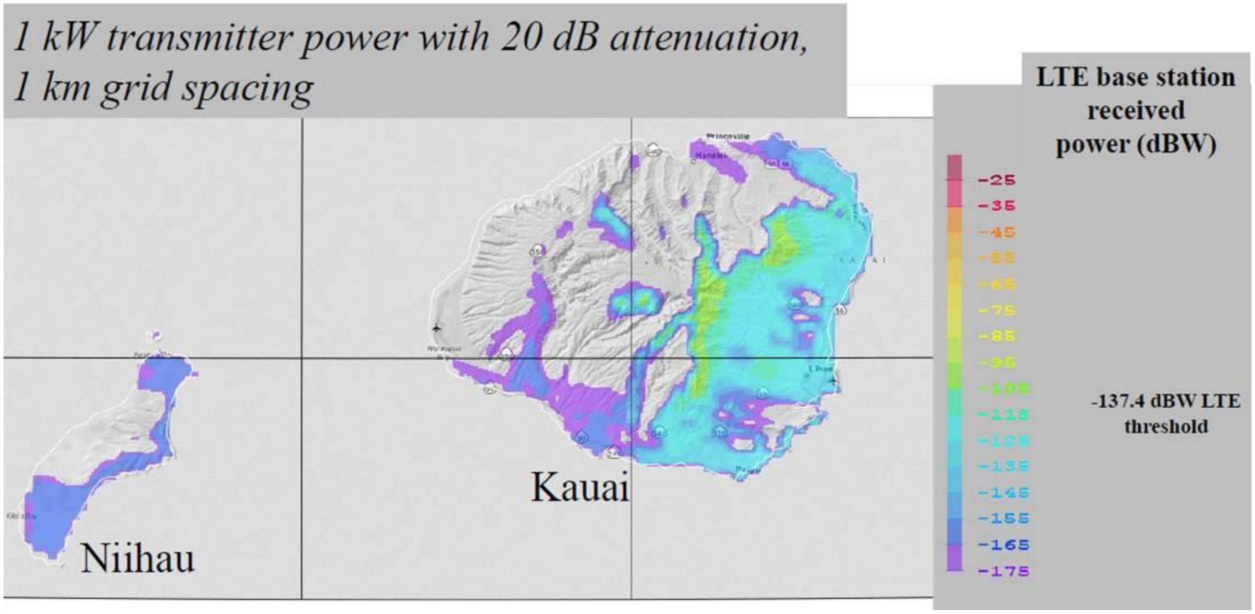


Figure 4.2.4-35 HTS Power Contours

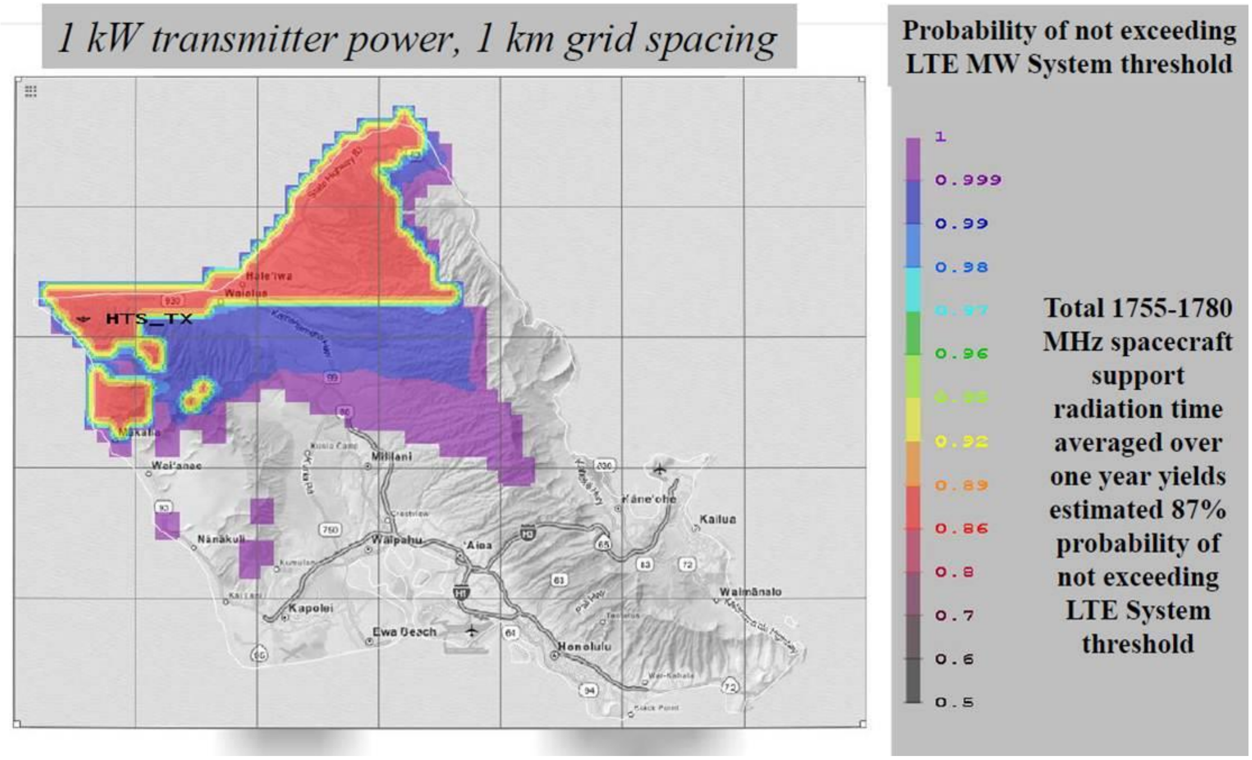


Figure 4.2.4-36 HTS LTE System Threshold Exceedance, 1755-1780 MHz

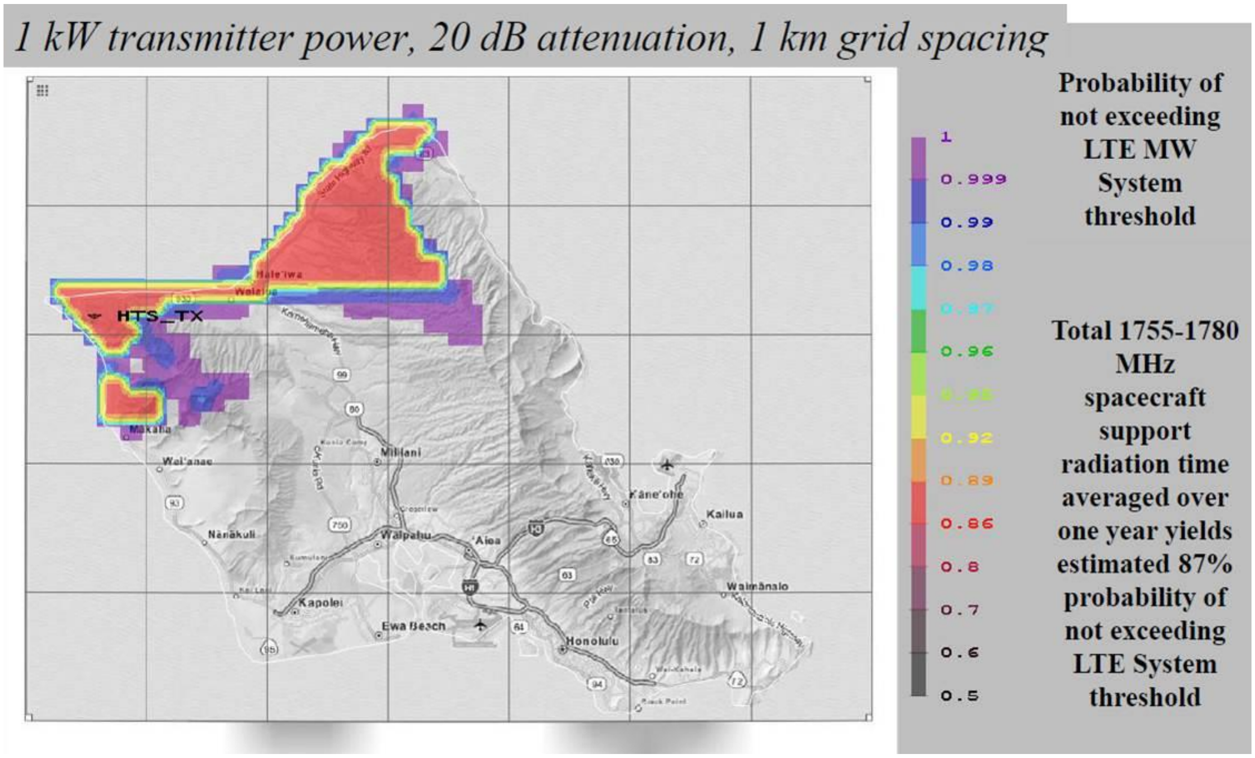


Figure 4.2.4-37 HTS LTE System Threshold Exceedance, 1755-1780 MHz

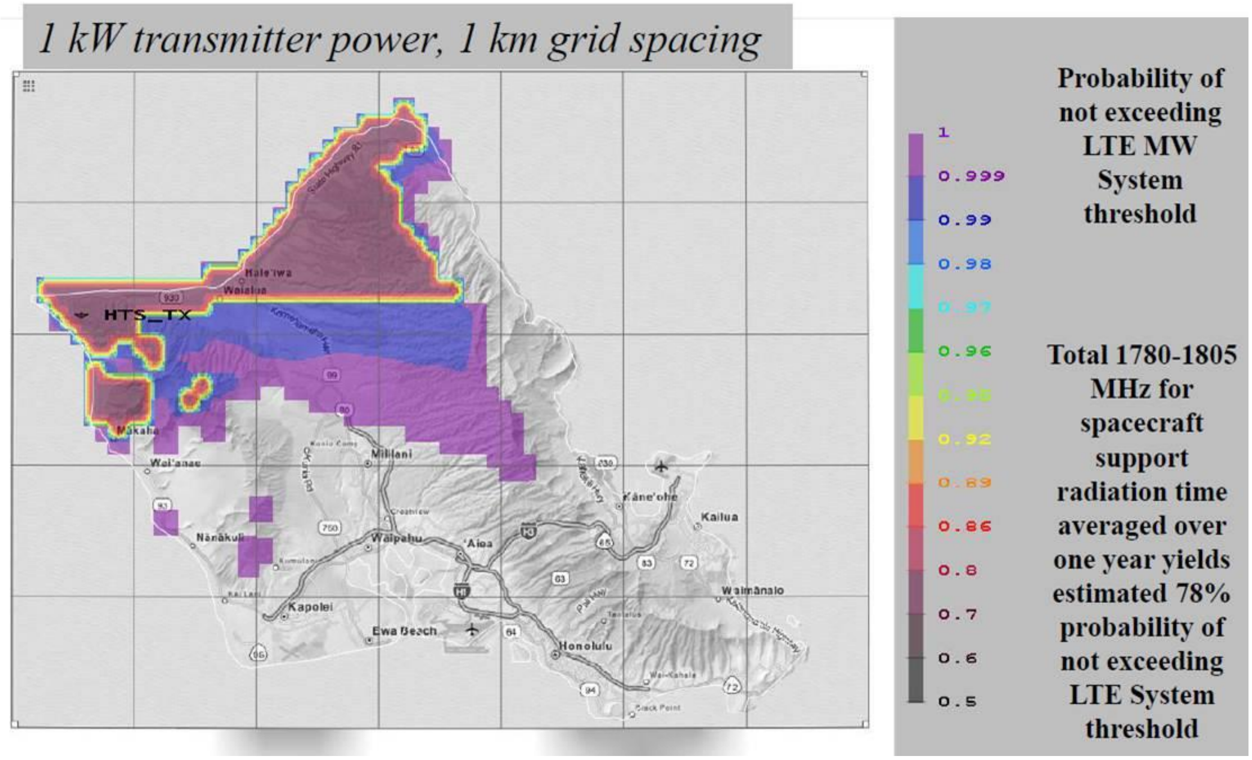


Figure 4.2.4-38 HTS LTE System Threshold Exceedance, 1780-1805 MHz

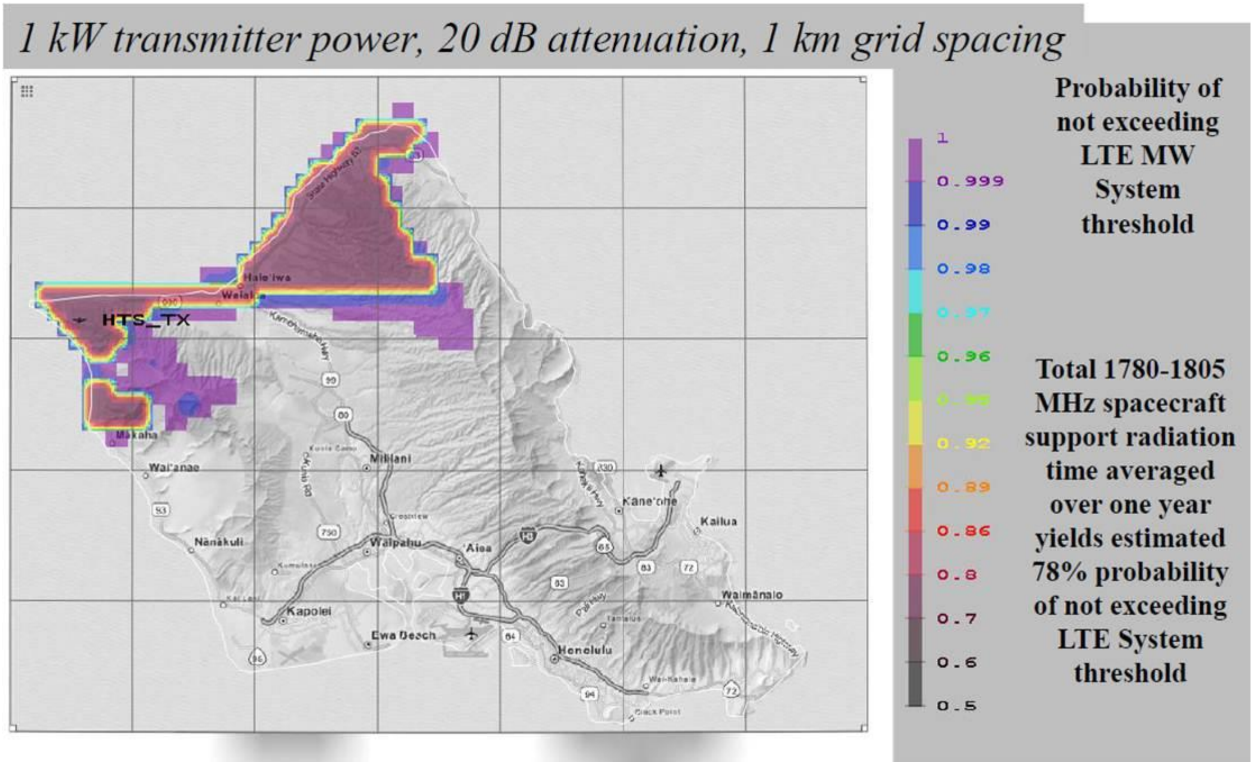


Figure 4.2.4-39 HTS LTE System Threshold Exceedance, 1780-1805 MHz

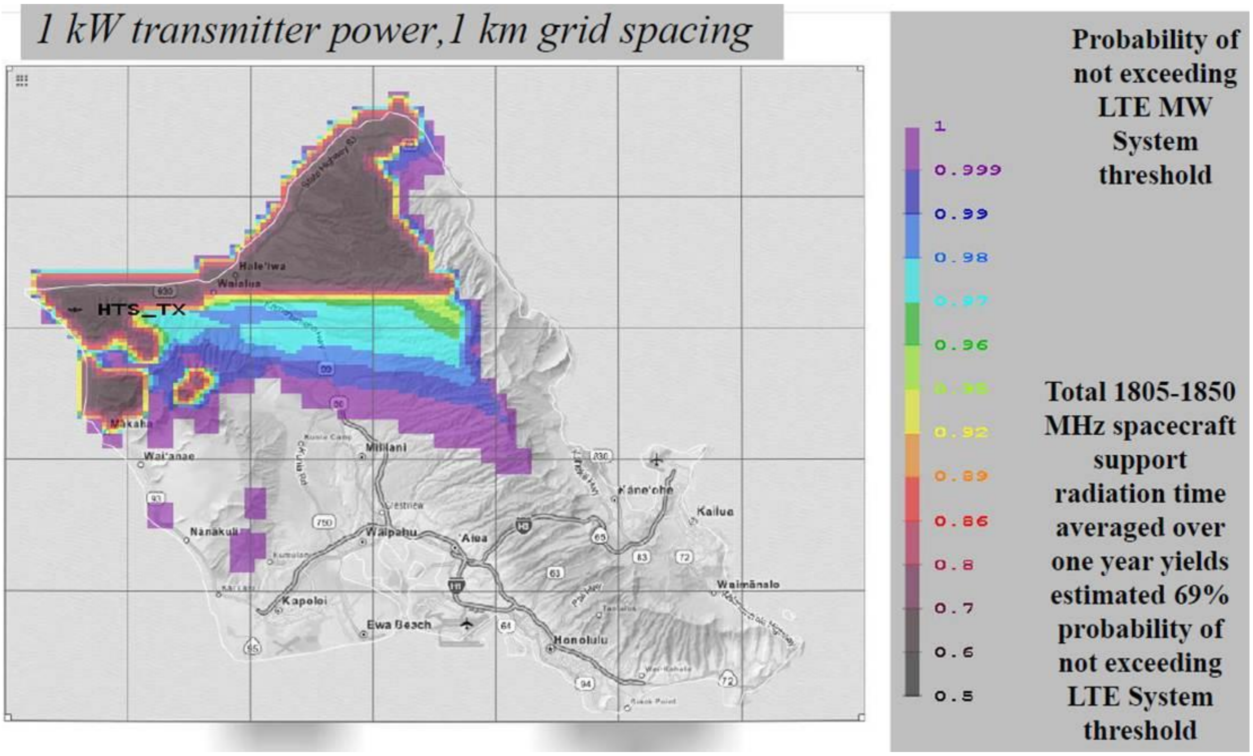


Figure 4.2.4-40 HTS LTE System Threshold Exceedance, 1805-1850 MHz

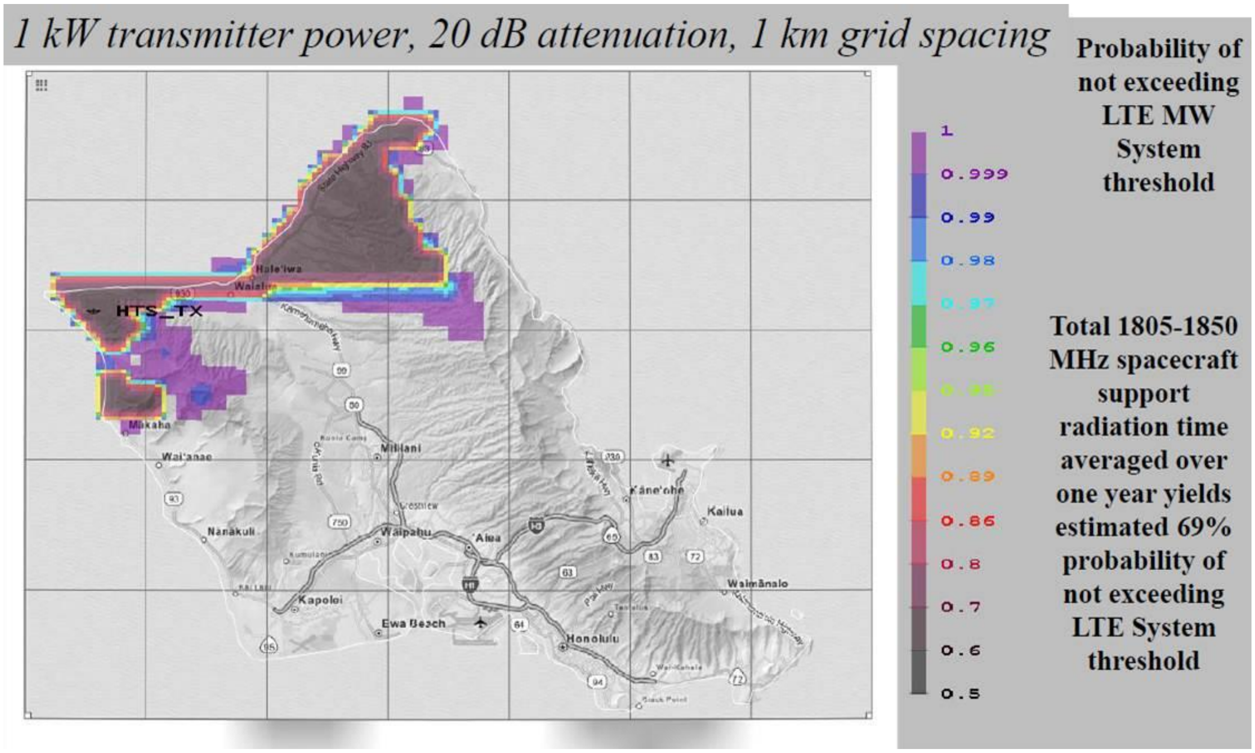


Figure 4.2.4-41 HTS LTE System Threshold Exceedance, 1805-1850 MHz

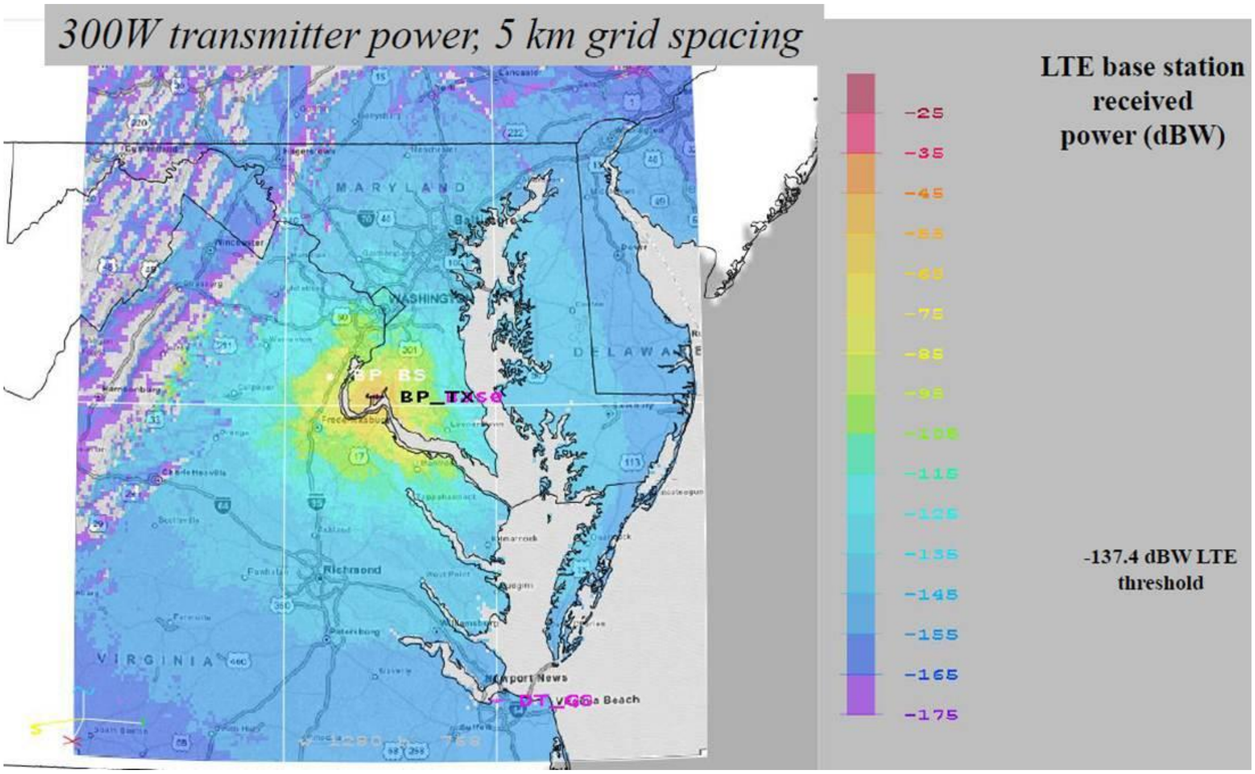


Figure 4.2.4-42 BP, MD Power Contours

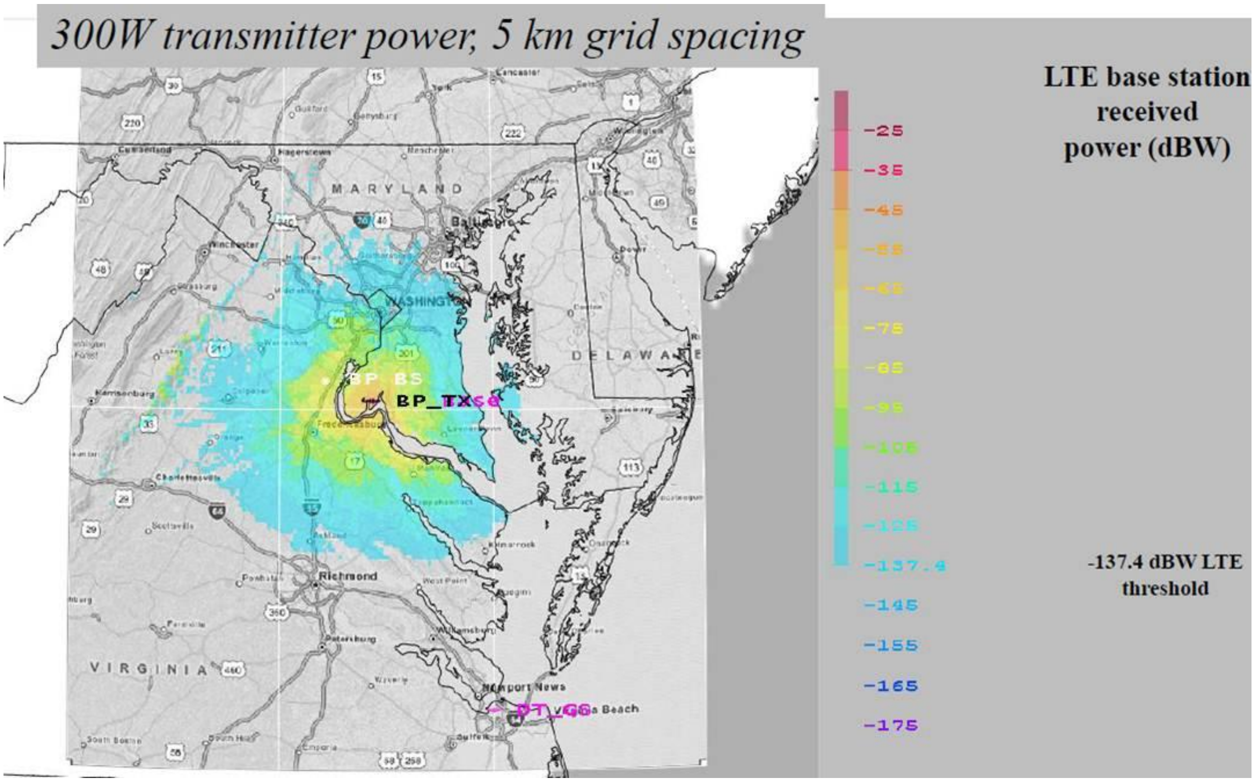


Figure 4.2.4-43 BP, MD Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

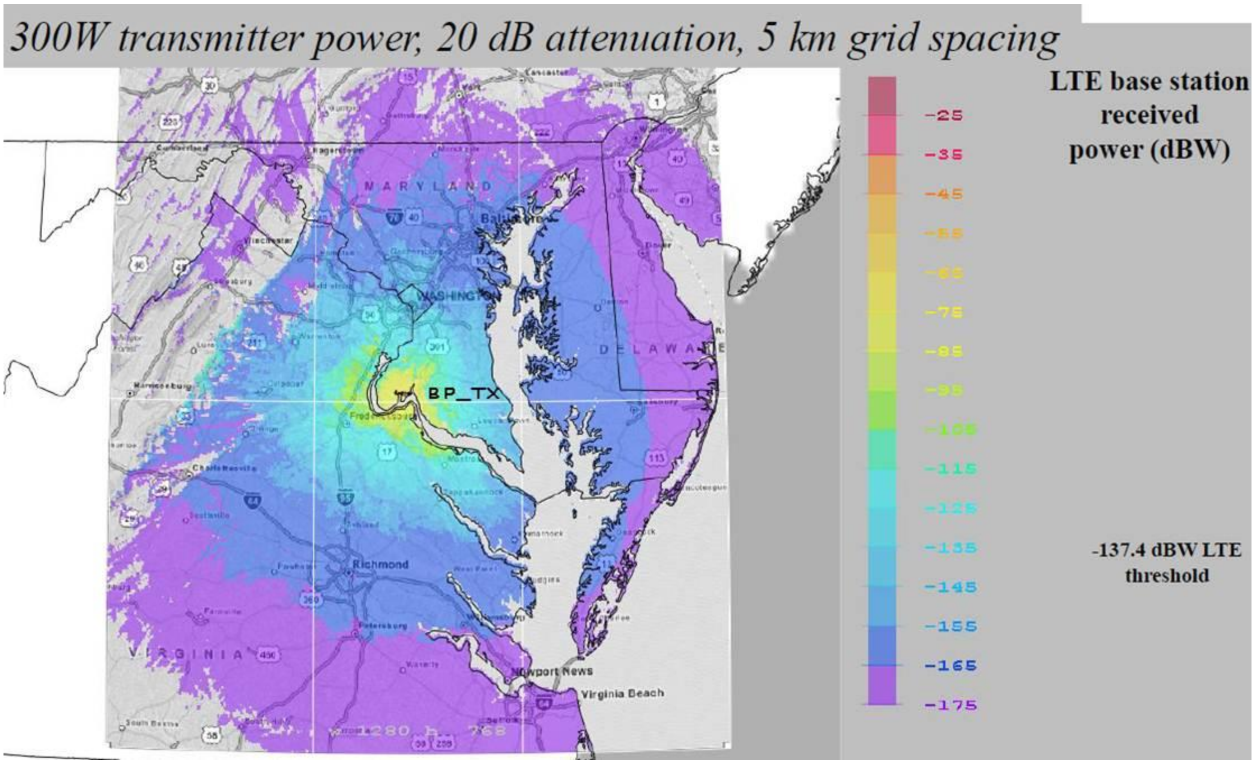


Figure 4.2.4-44 BP, MD Power Contours

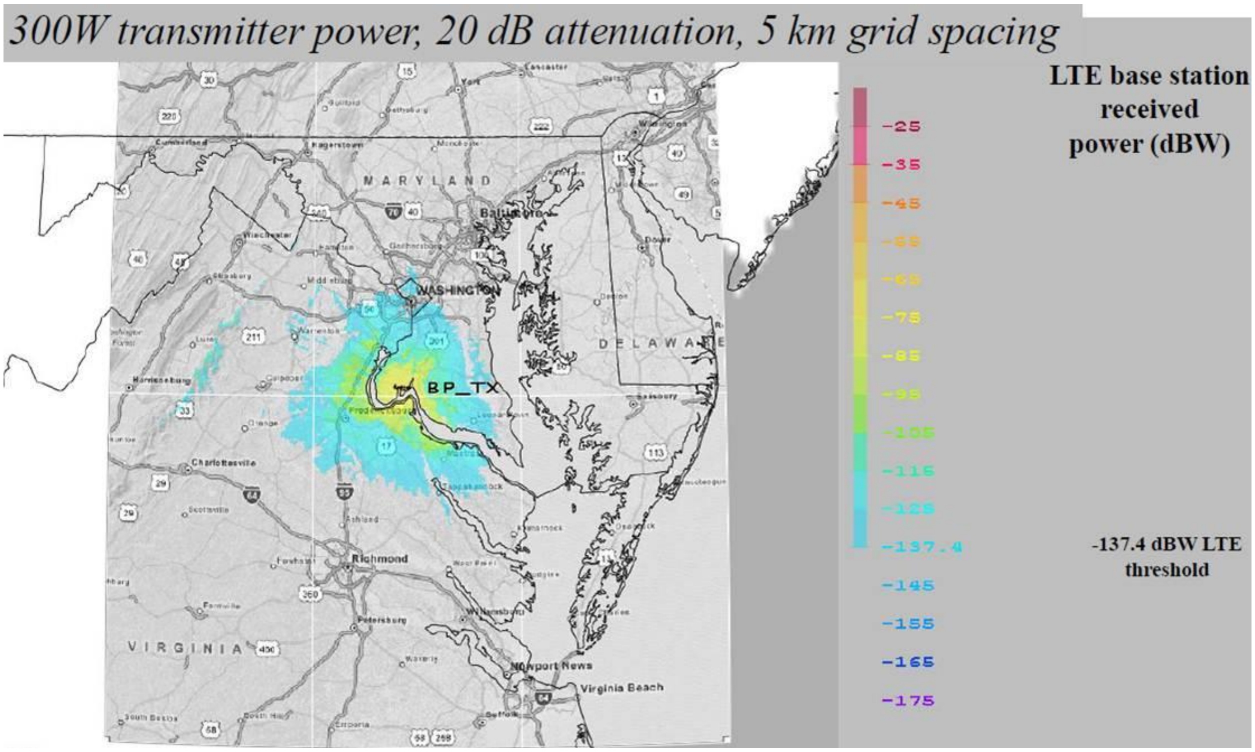


Figure 4.2.4-45 BP, MD Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

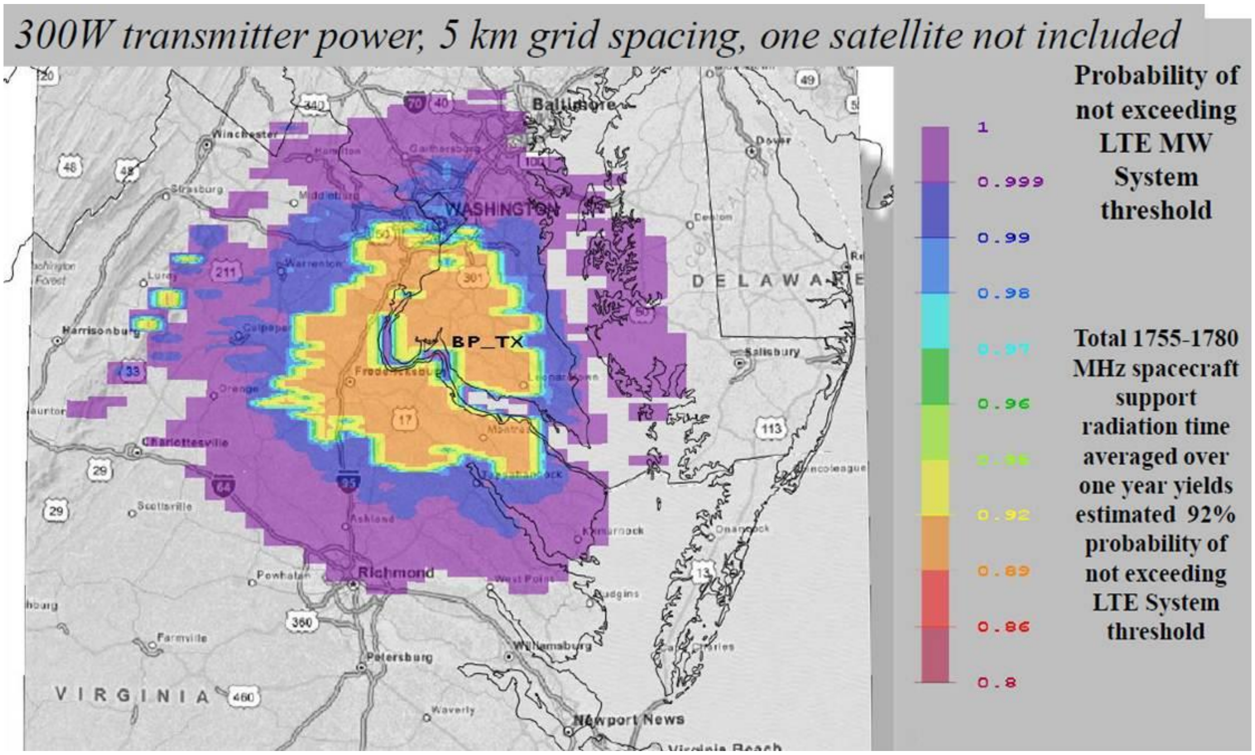


Figure 4.2.4-46 BP, MD LTE System Threshold Exceedance, 1755-1780 MHz

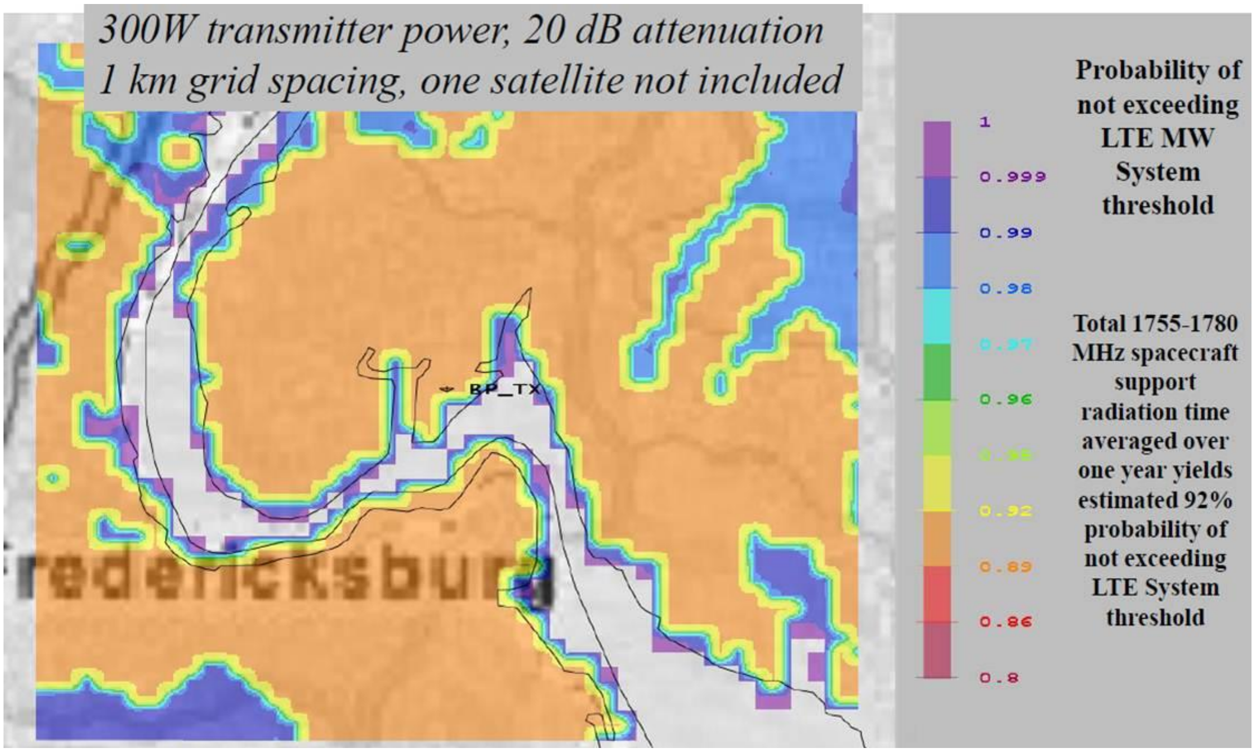


Figure 4.2.4-47 BP, MD LTE System Threshold Exceedance, 1755-1780 MHz

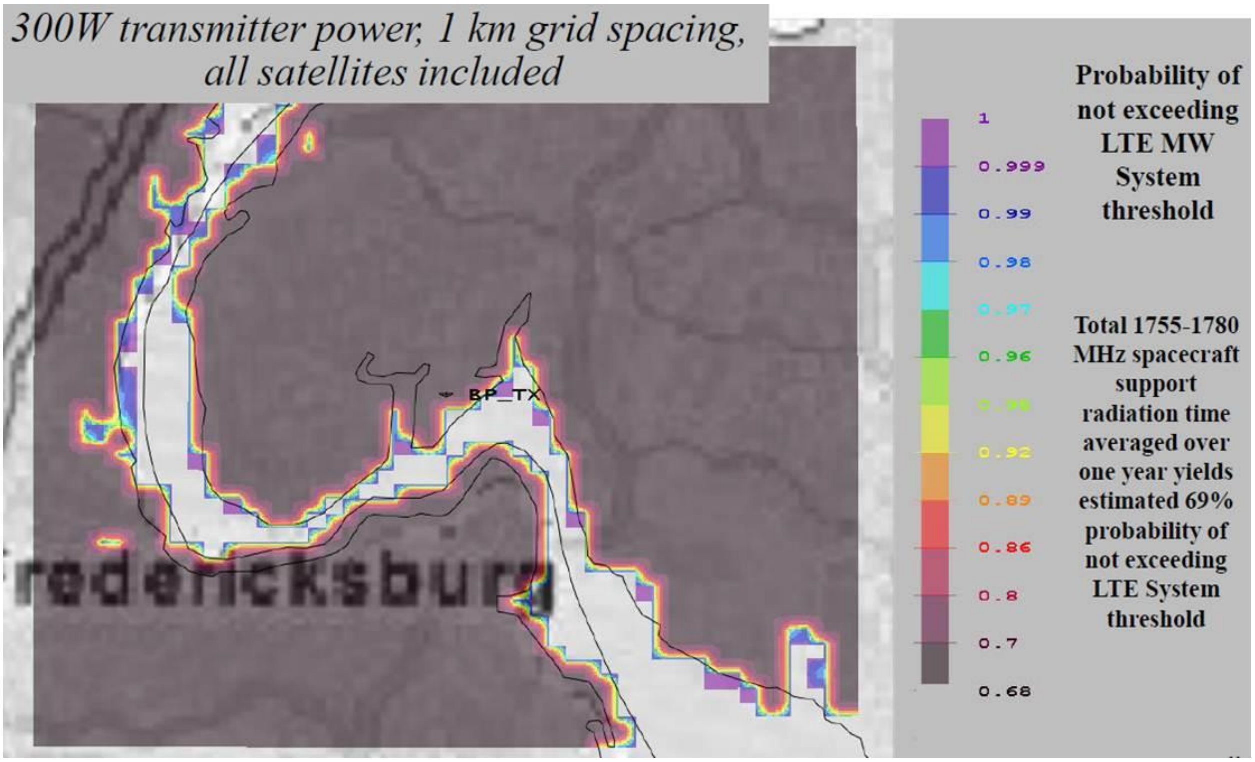


Figure 4.2.4-48 BP, MD LTE System Threshold Exceedance, 1755-1780 MHz

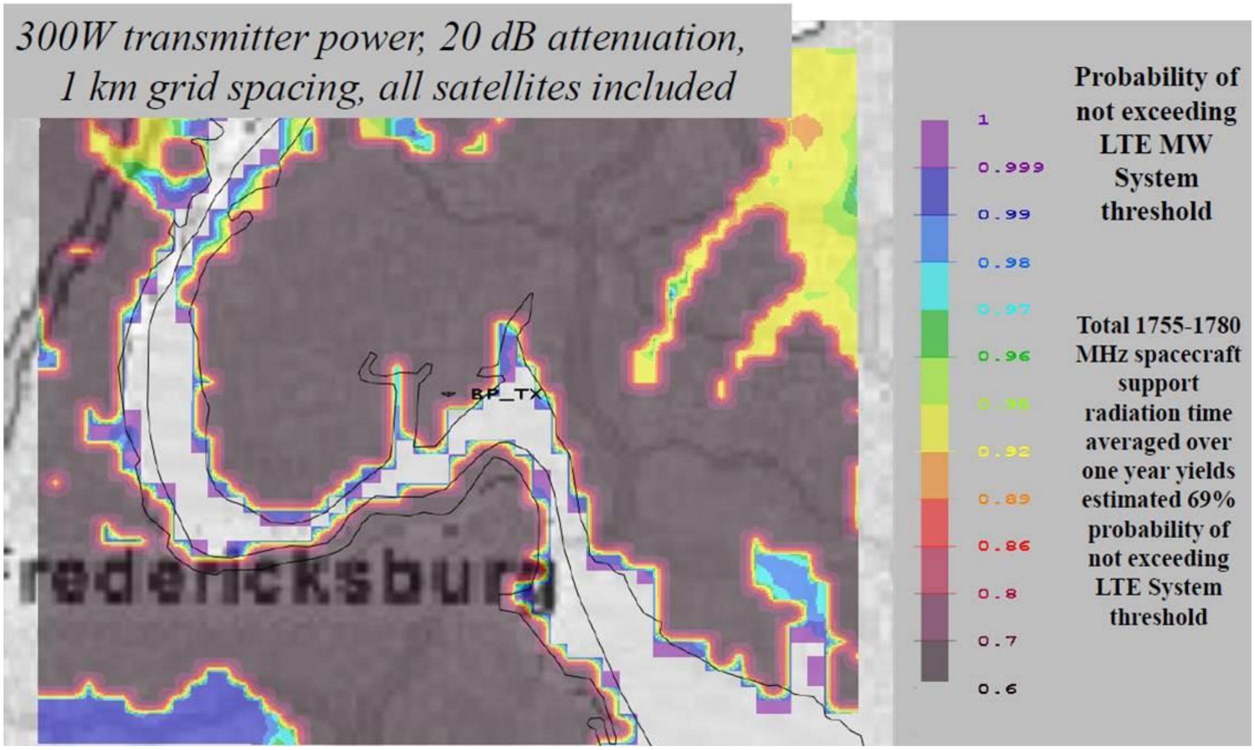


Figure 4.2.4-49 BP, MD LTE System Threshold Exceedance, 1755-1780 MHz

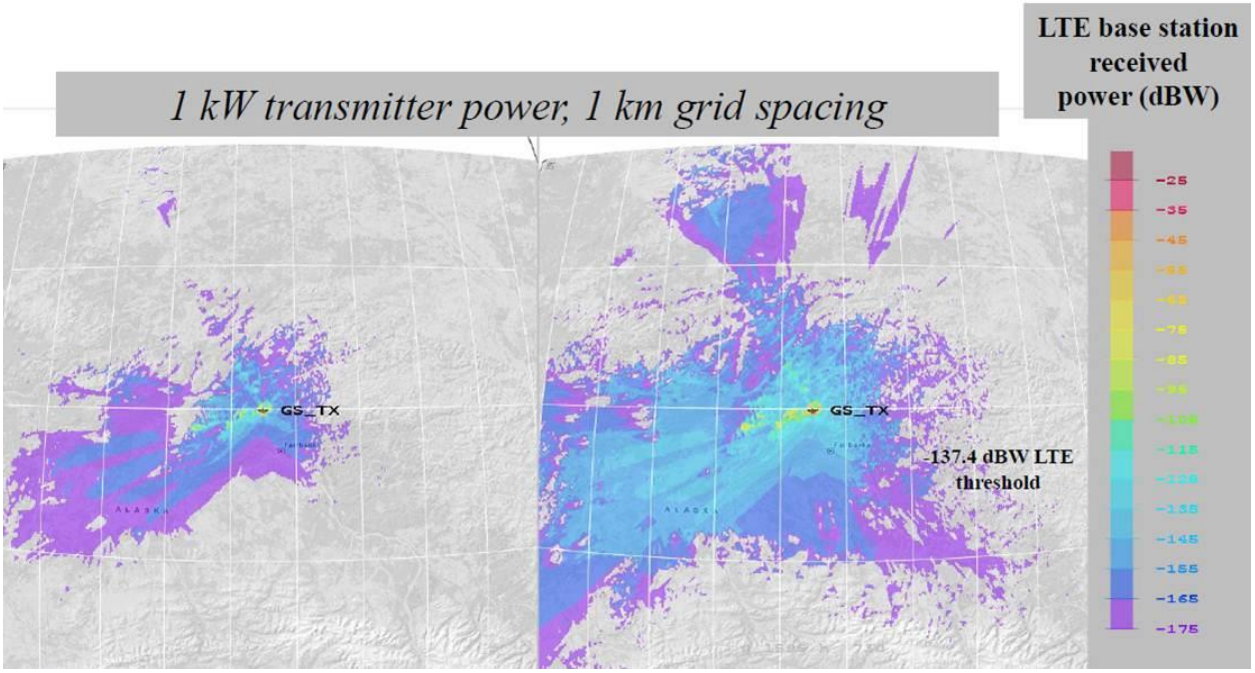


Figure 4.2.4-50 FB, AK Power Contours

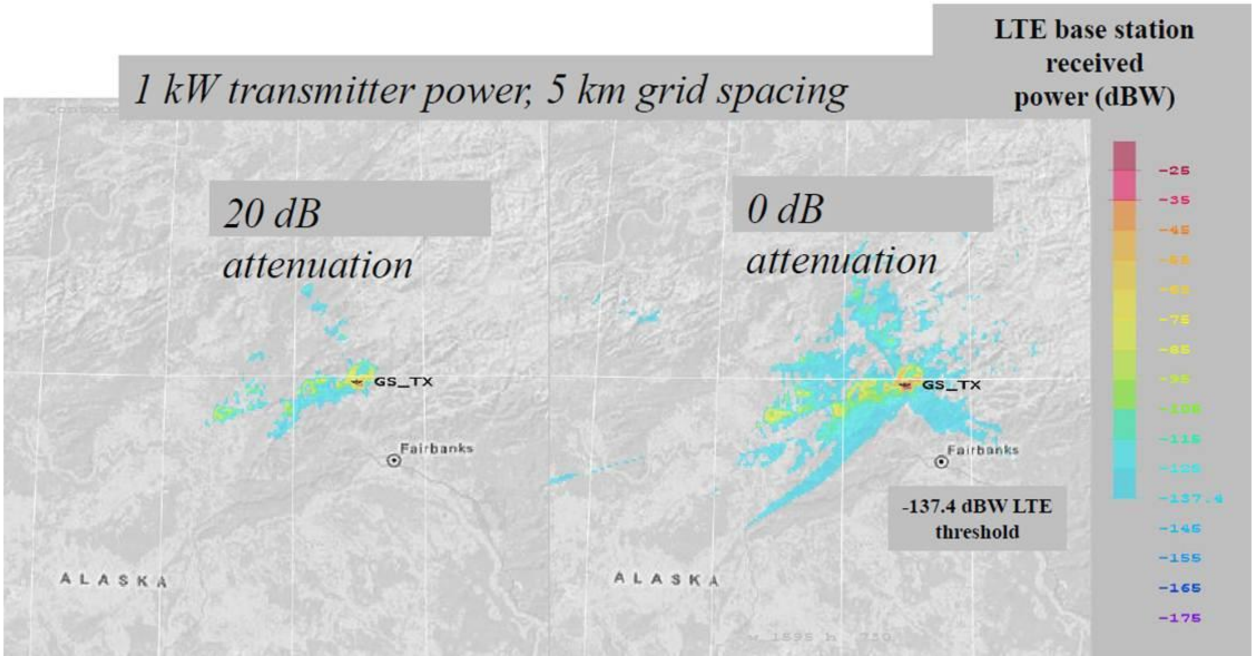


Figure 4.2.4-51 FB, AK Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

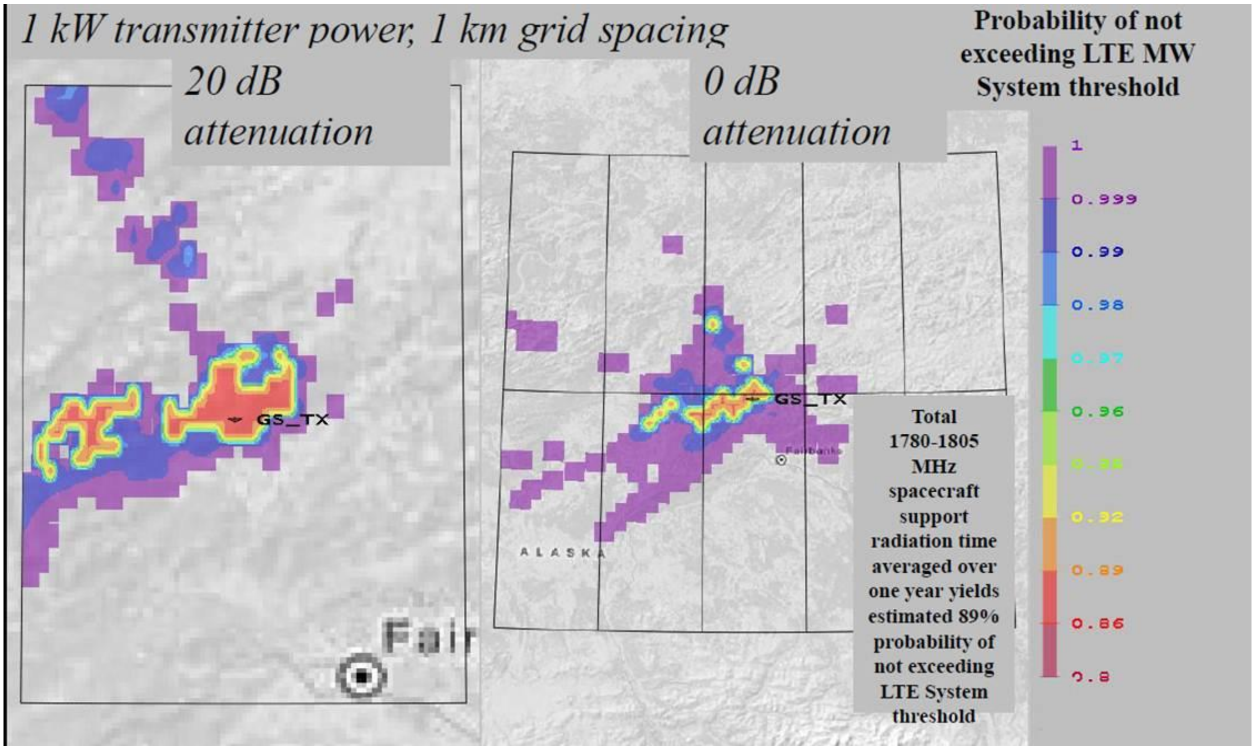


Figure 4.2.4-52 FB, AK LTE System Threshold Exceedance, 1780-1805 MHz

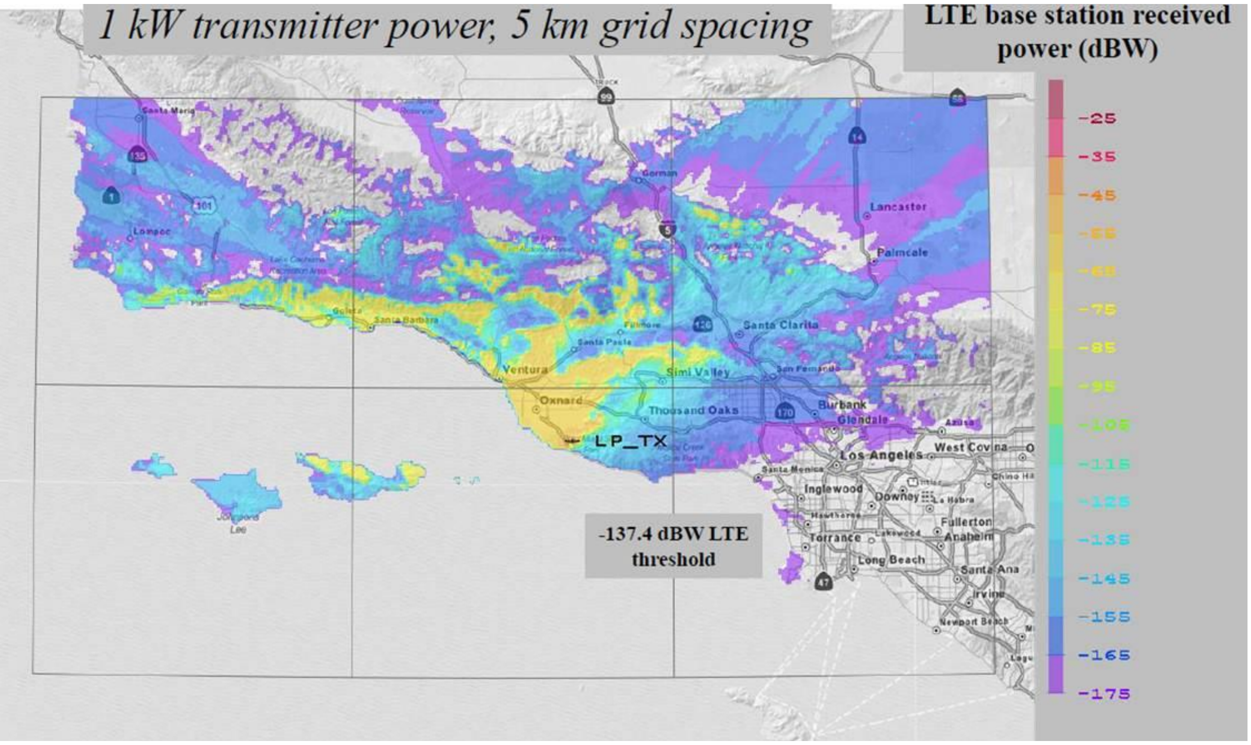


Figure 4.2.4-53 LP, CA Power Contours

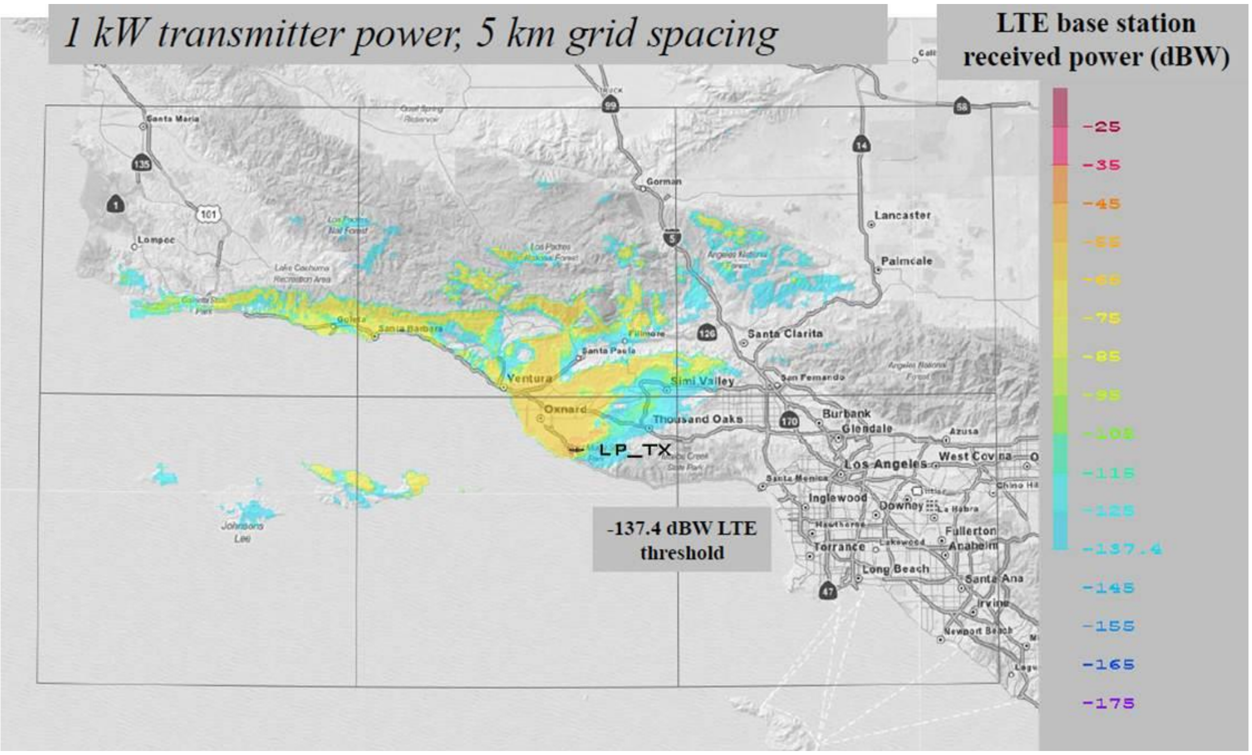


Figure 4.2.4-54 LP, CA Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

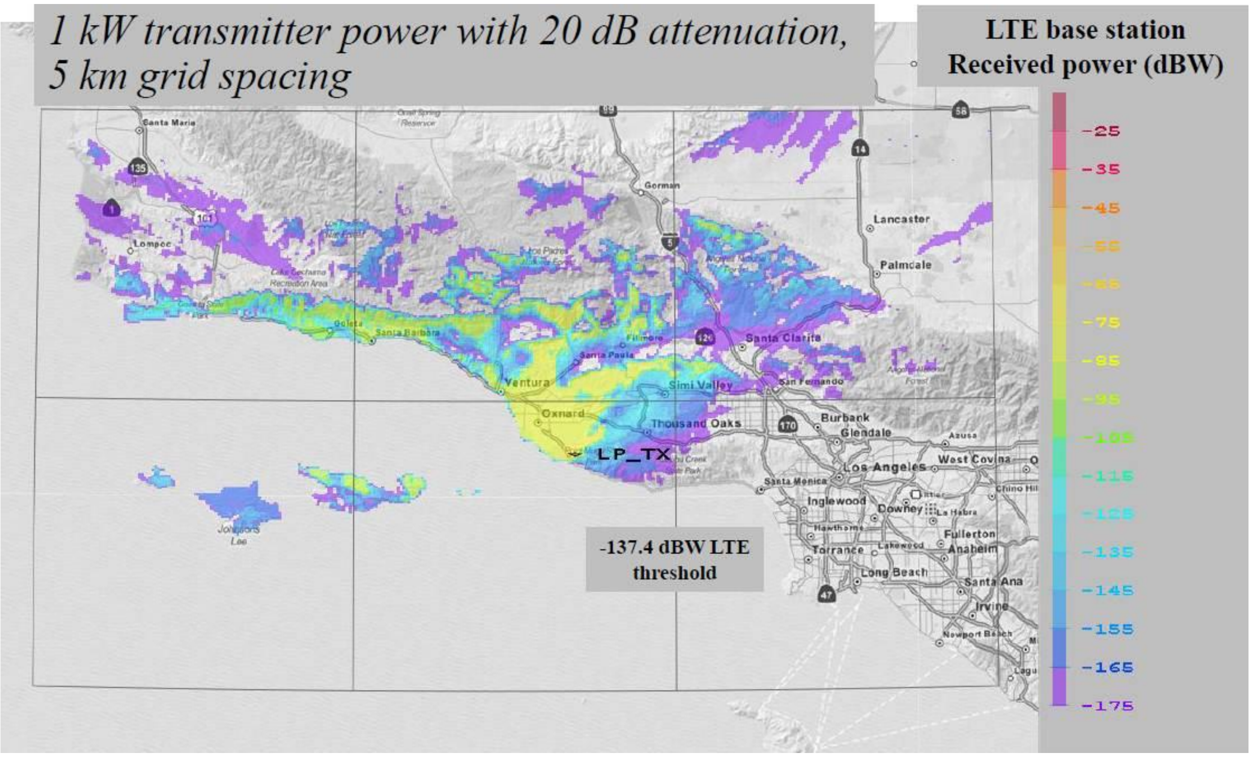
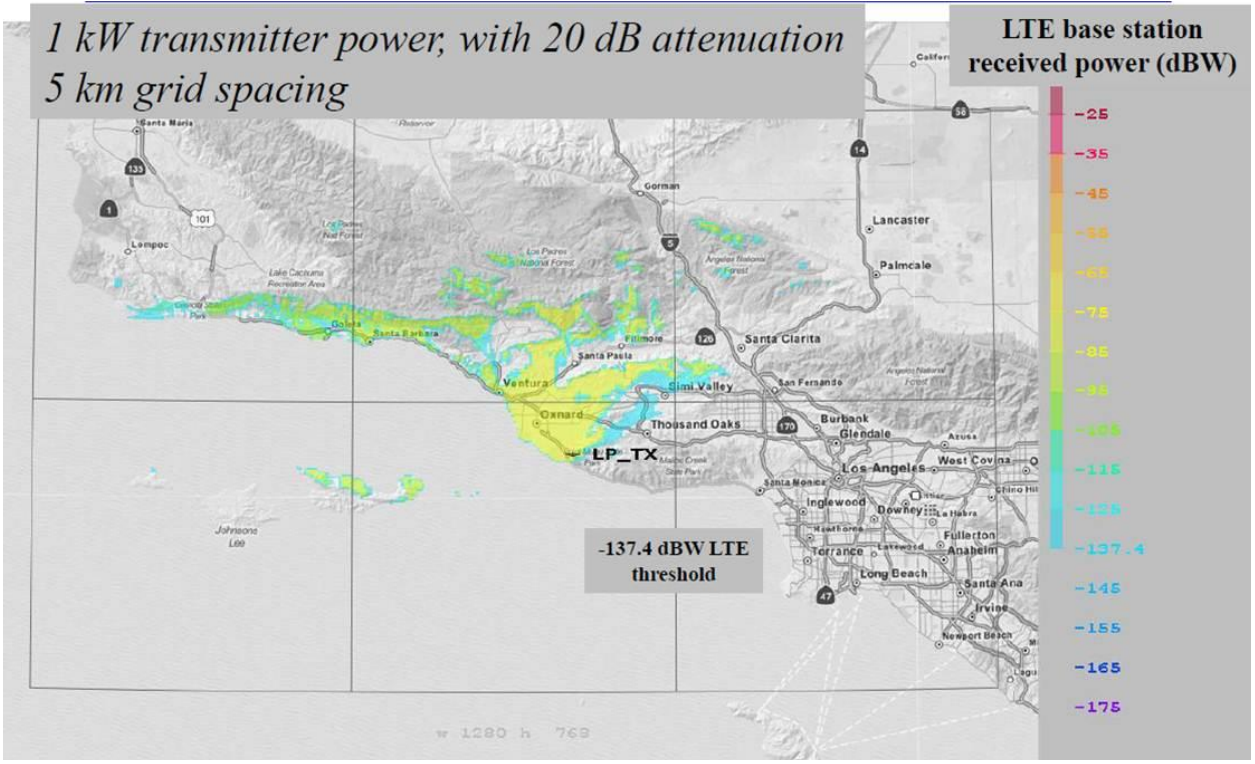


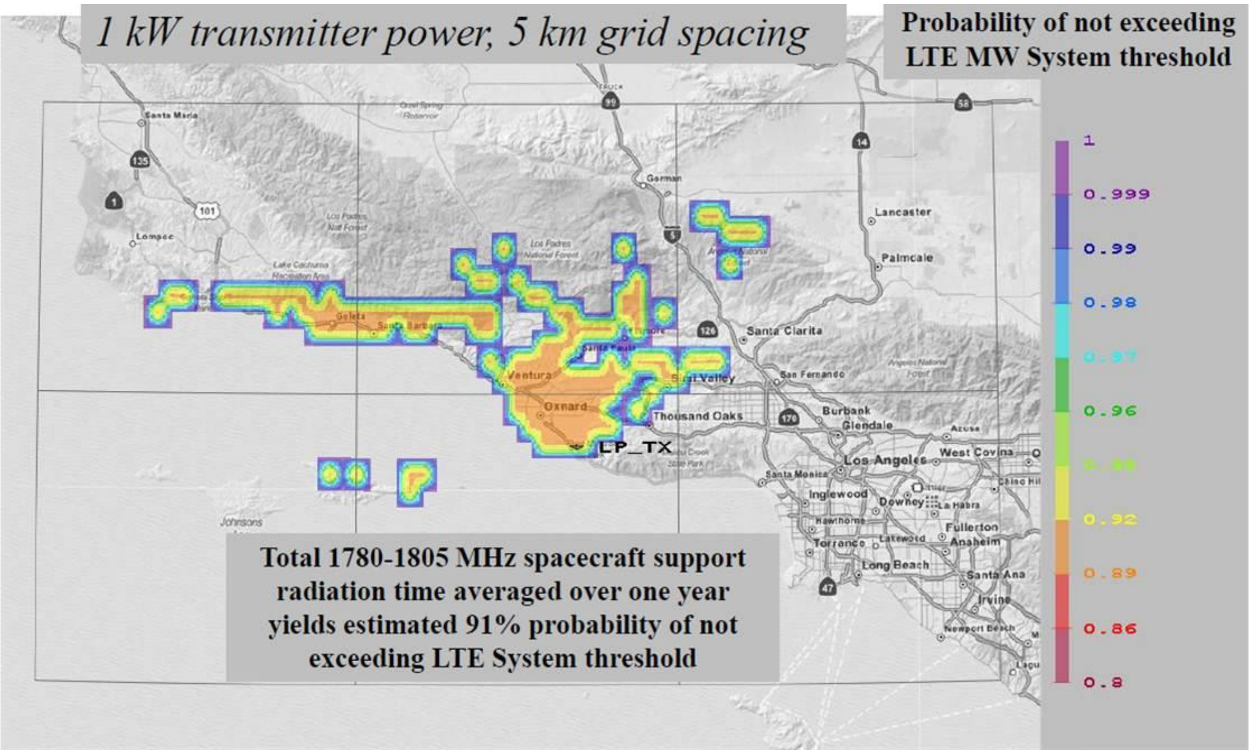
Figure 4.2.4-55 LP, CA Power Contours


1 kW transmitter power, with 20 dB attenuation
5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

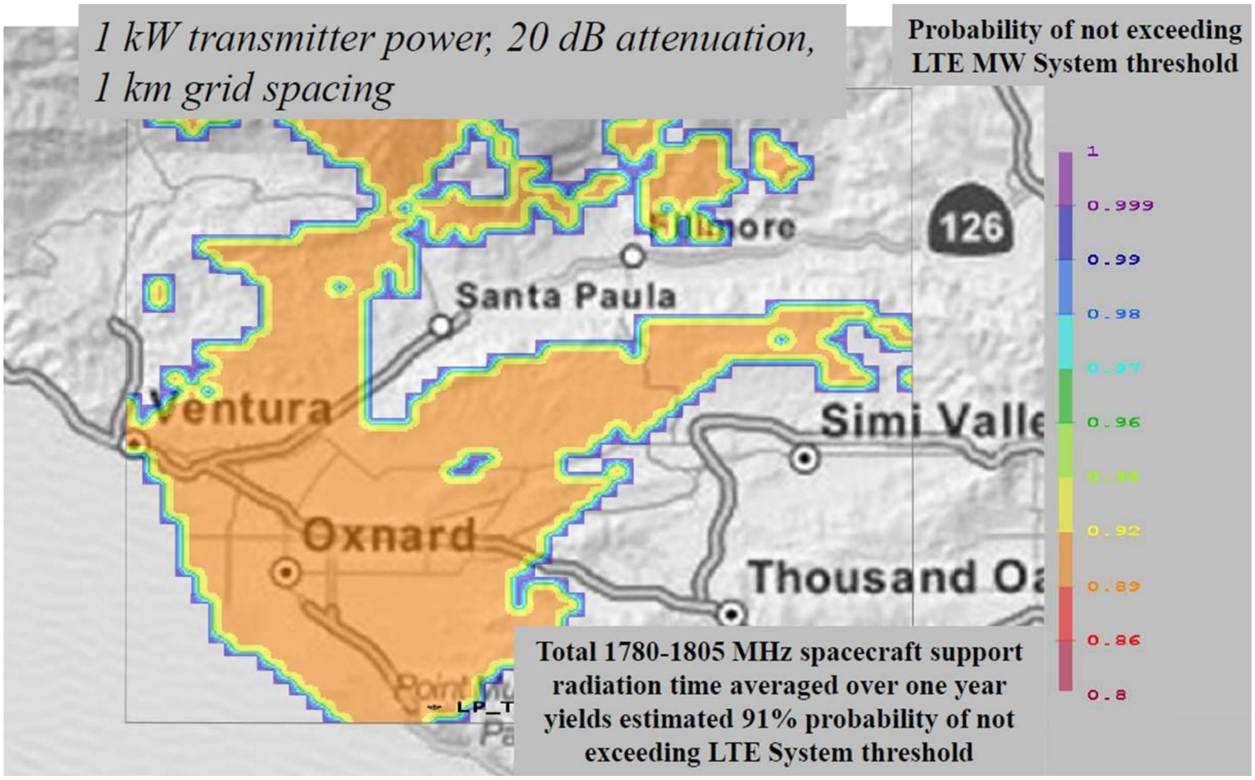
Figure 4.2.4-56 LP, CA Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold


1 kW transmitter power, 5 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1780-1805 MHz spacecraft support radiation time averaged over one year yields estimated 91% probability of not exceeding LTE System threshold

Figure 4.2.4-57 LP, CA LTE System Threshold Exceedance, 1780-1805 MHz


1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1780-1805 MHz spacecraft support radiation time averaged over one year yields estimated 91% probability of not exceeding LTE System threshold

Figure 4.2.4-58 LP, CA LTE System Threshold Exceedance, 1780-1805 MHz

4.2.4.4 Technical Rationale

The following topics are elaborated in this Appendix to Section 4.2.4.2:

- ITM Parameters
- Transmitter and Receiver Parameter Choices
- RFI Overlap for Two Antennas Operating at a Site
- Mathematical definition of Threshold Non-Exceedance Calculation

4.2.4.4.1 Irregular Terrain Model (ITM) - Input Parameter Value Choices

Table 4.2.4-1: ITM Parameters.

Parameter	Selected	Options
Polarization	Vertical	Vertical Horizontal
Radio climate	Contental subtropical	Equatorial Contental subtropical Maritime tropical Desert Contental Temperate Maritime temperate, over land Maritime temperate, over sea
Dielectric constant of ground	15 – Average Ground	4- Poor ground 15 - Average ground 25 - Good ground 81 - Fresh/sea water
Conductivity of ground	0.005 - Average ground	0.001 - Poor ground 0.005 - Average ground 0.02 - Good ground 0.01 - Fresh water 5.00 - Sea water
Reliability statistic values	50%	Greater than zero, less than 100%
Confidence statistic values	50%	Greater than zero, less than 100%
Surface Refractivity	301 - Contental Temperate (Use for Avg. Atmospheric Conditions)	280 - Desert (Sahara) 301 - Contental Temperate (Use for Avg. Atmospheric Conditions) 320 - Continental Subtropical (Sudan) / Maritime Temperate, Over Land (UK and Contenital West Coast) 350 - Maritime Temperate, Over Sea 360 - Equatorial (Congo) 370 - Maritime Subtropical (West Coast of Africa)

4.2.4.4.2 Transmitter and Receiver Parameter Choices

Table 4.2.4-2: Transmitter and Receiver Parameter Choices.

Parameter	Selected
Transmitter Frequency (MHz)	1762
Transmitter Power (dBm)	60
Peak Antenna Gain (dBi)	Site Dependent
Antenna Gain at Horizon[32] (dBi)	16
EIRP @ Horizon	Site Dependent
Transmitter Antenna Height (m)	30
Receiver Antenna Height (m)	30
Receiver Antenna Down tilt (deg)	3
Receiver 3dB Beamwidth (el) (deg)	10
Receiver 3dB Beamwidth (az) (deg)	70
Receiver Antenna Gain at Horizon (dBi)	18
Receiver Ref Sensitivity (dBm)	-101.5
Receiver Interference @ 1 dB desense (dBm)	-107.37
Receiver Interference @ 3 dB desense (dBm)	-101.5
Receiver Sensitivity (1 dB desense, dBW)	-207.94
Receiver Sensitivity (3 dB desense, dBW)	-202.07

Note that the analysis assumes the LTE antenna is pointing at the SATOPS antenna, in azimuth.

4.2.4.4.3 Modeling of RFI Overlap for 2 Antennas

Radiation time for each antenna pointing angle was delivered as a sum of the time radiated in that direction by antenna A and the time radiated in that direction by antenna B. This causes some radiation time and thus some threshold exceedance time to be double-counted.

The overlapping threshold exceedance time can be described as:

$$PRFI\ Overlap=Pant\ A\ onANDant\ A\ exceeding\ thresholdANDant\ B\ onANDant\ B\ exceeding\ threshold$$

This double-counted time was calculated and removed from the threshold exceedance times.

4.2.4.4.4 RFI Overlap for 2 Antennas Calculation

Assuming independence between antenna A and antenna B,

$$\begin{aligned} P(RFI\ Overlap) &= P(ant\ A\ on) * P(ant\ A\ exceeds\ threshold \mid ant\ A\ on) * P(ant\ B\ on) \\ &\quad * P(ant\ B\ exceeds\ threshold \mid ant\ B\ on) \end{aligned}$$

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[32] "Antenna Models for Electromagnetic Compatibility Analyses," NTIATM-13-489, National Telecommunication and Information Administration Technical Memorandum, October 2012.

Assuming the same radiation time for and received power distribution from the 2 antennas,

$$P(ant\ A\ on) = P(ant\ B\ on)$$

$$P(ant\ A\ exceeds\ threshold \mid ant\ A\ on) = P(ant\ B\ exceeds\ threshold \mid ant\ B\ on)$$

then

$$\begin{aligned} P(RFI\ Overlap) &= 2 * P(ant\ A\ on) * 2 * P(ant\ A\ exceeds\ threshold \mid ant\ A\ on) \\ &= 2 * [(Radiate\ \%/2) * P(ant\ A\ exceeds\ threshold \mid ant\ A\ on)] \\ &= 2 * (Threshold\ Exceedance\ \%/2) \end{aligned}$$

$2 * (Threshold\ Exceedance\ \%/2)$ is the correction factor that was used to remove double-counted threshold exceedance times from our calculations

Non-Exceedance Calculation:

- Non-Exceedance Calculation is

$$P(NE) = \sum_{i=1}^{n}\sum_{j=1}^{m} P\left(NE \left| \left[Az_i \bigcap El_j\right]\right.\right) P\left(Az_i \bigcap El_j\right) + \left[1 - \sum_{i=1}^{n}\sum_{j=1}^{m} P\left(Az_i \bigcap El_j\right)\right]$$

  where $P(NE)$= Probability of Non-Exceedance

  (Equation excludes correction factor discussed earlier)

- Without Variance:

  $P\left(NE \middle| \left[Az_i \cap El_j\right]\right)$ is strictly 1 or 0 based on the following condition

$$P\left(NE \left| \left[Az_i \bigcap El_j\right]\right.\right) = \begin{cases} 1\ if\ MeanRxPwr < Threshold \\ 0\ if\ MeanRxPwr\ \geq Threshold \end{cases}$$

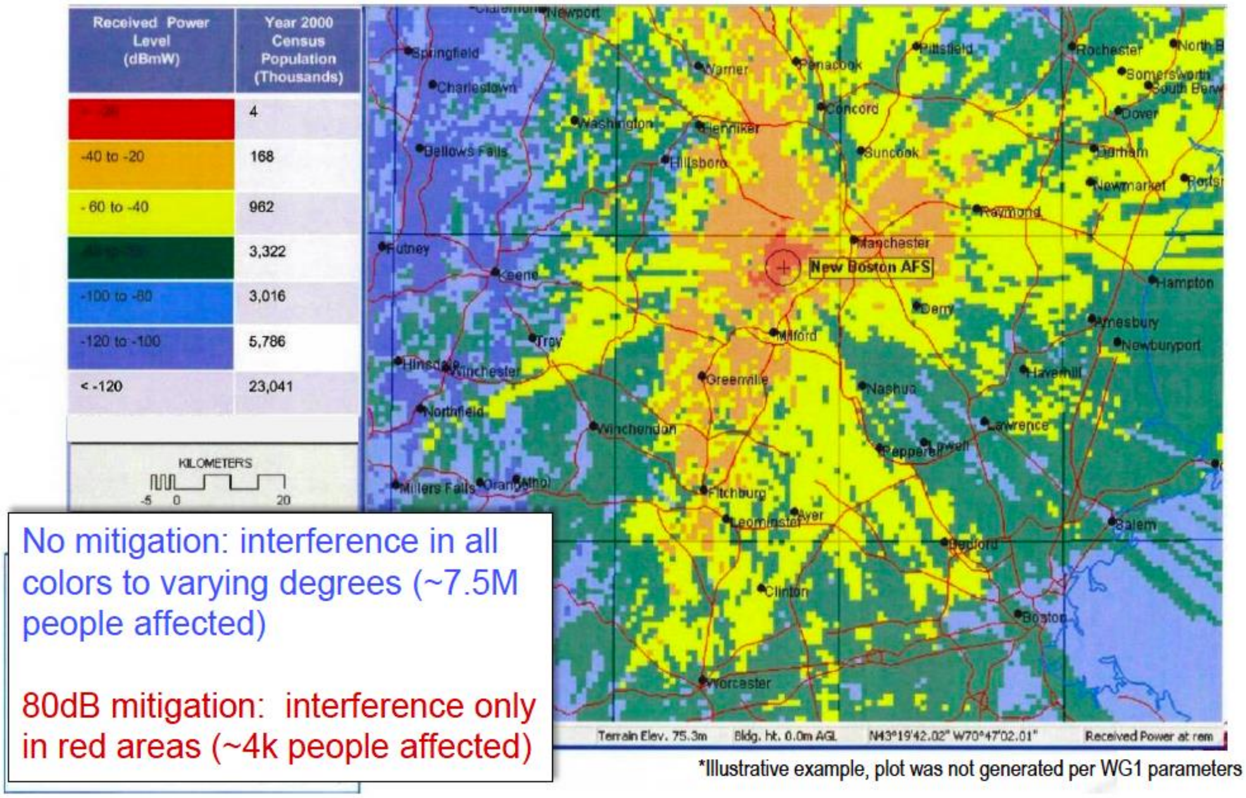
- With Variance:

  $P\left(NE \middle| \left[Az_i \cap El_j\right]\right)$ is based on the Q-function because received power for a given Az/El pointing direction is log normal and follows the condition

$$P\left(NE \left| \left[Az_i \bigcap El_j\right]\right.\right) = 1 - Q\left(\frac{Threshold - MeanRxPwr}{\sigma}\right)$$

4.2.5 Mitigation Concepts into LTE Base Station Receivers

Mitigation techniques are very important to facilitate the operation of mobile broadband systems close to SATOPS ground stations. The following illustrative example shows the possible benefit of mitigation in general.



No mitigation: interference in all colors to varying degrees (~7.5M people affected)

80dB mitigation: interference only in red areas (~4k people affected)

*Illustrative example, plot was not generated per WG1 parameters

Figure 4.2.5-1. Possible Benefit of Mitigation.

There are numerous mitigation techniques that appear to offer the opportunity for SATOPS ground stations to coexist with LTE systems under certain conditions. These include options listed in Table 4.2.5-1. The mitigation techniques are listed in alphabetical order. Effectiveness and feasibility may vary case-by-case. Each mitigation technique is discussed in detail in the remainder of this section.

While all the mitigation schemes offered in Table 4.2.5-1 under the heading “Concept” are theoretically plausible, it should be noted that the cost of technical research, prototyping, proof of concept testing, standardization, and development of the commercial products for implementing any of these techniques may not be trivial, even if such techniques prove to be practical and applicable to the case of LTE operation near the SATOPS ground stations.

The RF shielding around the SATOPS ground station seems to offer a very good solution and possibly the most attractive in terms of its cost-effectiveness, applicability and practicality of the technique that is involved, however the construction lag could limit the use of the shared spectrum for a considerable period of time.

Since the implementation of time sharing, which is the exchange of operational schedules between the commercial operator and the SATOPS operator, greatly depend on the predictability of the SATOPS ground station transmission times. This information is classified and for security concerns cannot be made available to the LTE operators, the time sharing technique cannot be considered as a practical mitigation scheme at the present time.

It is also technically possible for the LTE base stations to avoid using the shared spectrum in the “interference zones” and thereby mitigate the interference from the SATOPS ground stations. However, this method (i.e. the Frequency Selective Scheduling (FSS) that detects and avoids the interference after channel sounding) is not part of the standards and its realization depends on the vendor-specific product. As FSS is not generally available to LTE operators at this time, its implementation again would impose the above-mentioned cost and time constraints.

When FSS is not available, the entire shared spectrum must then be avoided so as not to compromise the offered mobile data rates during the SATOPS transmission times. Since the mobile data traffic demand in the “interference zones” around the existing SATOPS ground stations is not expected to be as high as the demand in the more densely populated urban areas, relying on the other bands available to an operator and not using the shared spectrum would certainly be a viable alternative, but this would be tantamount to the mobile operator forfeiting one-sidedly its right to use of the shared spectrum.

It would be therefore appropriate to consider these factors, as well as the cost of research, development, realization, and implementation of any these methods, including the required time intervals, in the valuation of the shared spectrum in the forthcoming auctions. These mitigation options will change with time and may be possible in the future.

Table 4.2.5-1: Discussed mitigation concepts to enhance co-existence between SATOPS uplink transmit operations and LTE base station receivers

Concept	Implementation
AFSCN digital waveform upgrade	SATOPS
Base station accepts more interference	BS
Cell Tower Antenna Configuration	BS
Digital Ranging Cancellation	BS
Dual Band	SATOPS
Front End Signal Cancellation	BS
Limit use of SATOPS	SATOPS
Multiple In/Multiple Out (MIMO)	BS
Offloading/ Scheduling	SATOPS
Operational Pointing Restrictions	SATOPS
Reduce Antenna Sidelobes	SATOPS
SATOPS site relocation	SATOPS
Selection of SATOPS channels	SATOPS
Selective Receiver RF Filtering	BS
Self Optimizing networks (SON)	BS
Spectrum Efficient Waveform	SATOPS
Spectrum Landscaping/ Shielding	BS or SATOPS
Time / Frequency Sharing[33]	BS
Uplink Power Control	SATOPS

4.2.5.1 AFSCN Digital Waveforms

The AFSCN upgrade to digital equipment is currently underway but may take substantial number of years. This upgrade will reduce emission bandwidths for SATOPS uplinks from AFSCN sites. For example, a commonly used uplink emission will be reduced from 900 kHz to a 225 kHz bandwidth within -20 dB from peak power. The upgraded signal structure for this example is shown in Figure 4.2.1-3. Such an upgrade could be applied to additional AF, Navy and other sites as well if funds are allocated to the Government for complete system wide implementation. The equipment needed for this smaller bandwidth, when implemented, will reduce out-of-band energy and the amount of bandwidth impacted at the cellular base station. Implementation at sites other than the AFSCN would take at least 5 years from start of implementation, given appropriate funding.

4.2.5.2 Cell Tower Antenna Configurations

By planning the deployment of cell towers surrounding a SATOPS site, Government/industry co-existence can be enhanced by orienting the sectors so that the main beam of the cellular antenna is never pointed in the direction of a SATOPS terminal. Another method is the use of antenna down tilt on the cellular base stations. These mitigation techniques were evaluated in the analysis of section 4.2.1 and can provide anywhere from 11.4 to 30.4 dB based on the data in

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[33] Time/Frequency sharing is also referred to as Dynamic Spectrum Access (DSA)

section 4.2.1.2.3. The concept is shown in the below figures. The application of these techniques will be limited by a tradeoff with reduction in effective base station coverage area.

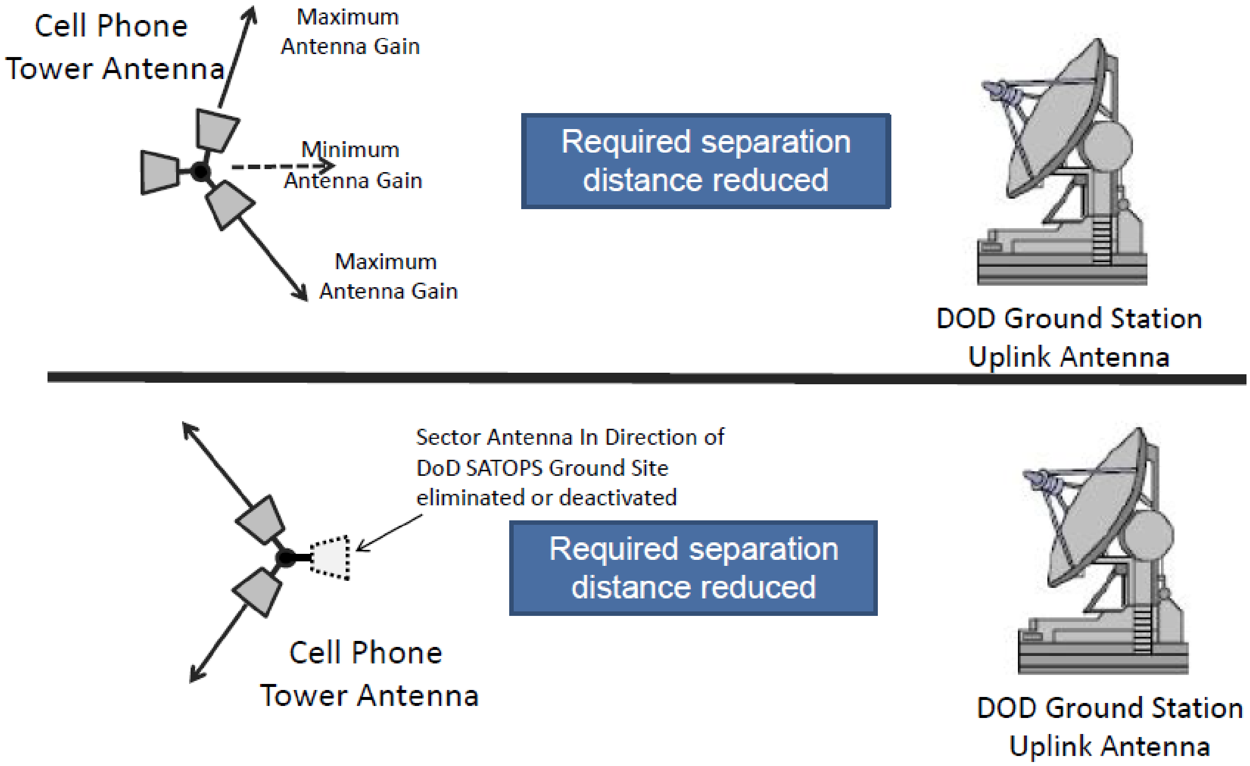

Figure 4.2.5-2.Cell tower antenna sector configuration to enhance co-existence.

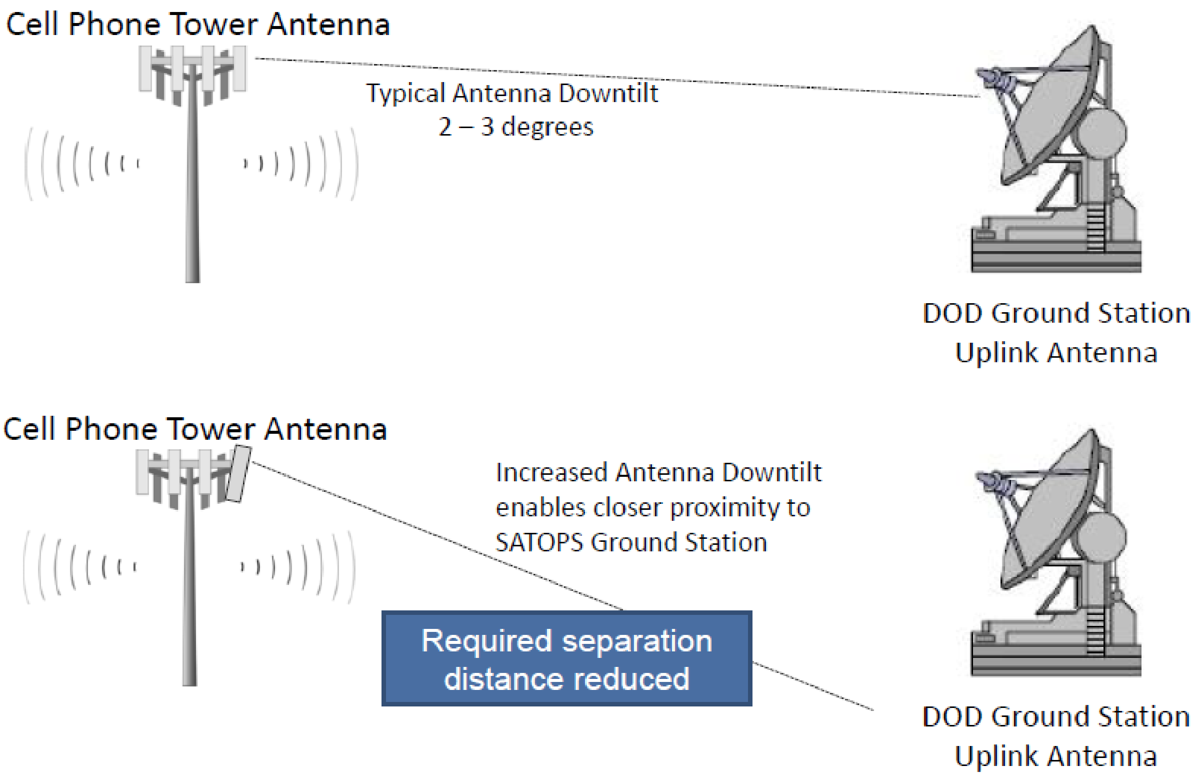

Figure 4.2.5-3.Cell tower antenna down tilt to enhance co-existence.

4.2.5.3 SATOPS Signal Cancellation

Interference cancellation techniques have been studied extensively for their application to mobile wireless system[34], are expected to be included in future releases of LTE, and have been demonstrated to improve the performance of LTE. Application of these and other similar techniques could be effective for mitigating interference from SATOPS signals, especially because such techniques perform best when there is significant difference between the power levels of desired and interfering signals. Although cancellation techniques are anticipated for future releases of LTE, near-term implementations are also possible. A cancellation black box could be designed to operate in between the base station antenna and receiver input that would be capable of detecting the presence of a SATOPS signal and performing the cancellation. While exact performance would be situation dependent and also subject to cost, high performance improvement (approximately up to 30 dB reduction in effective interference power) may be achievable. Cost factors would include the design of the cancellation box and the cost to procure and install it on each base station. This may be cost prohibitive to apply to all base stations in the vicinity of SATOPS sites, but may be effective for specific base stations in particularly desirable market areas. The cancellation box would require its own RF front end, which would add to the cost, but could also allow for additional dynamic range and help to avoid receiver saturation

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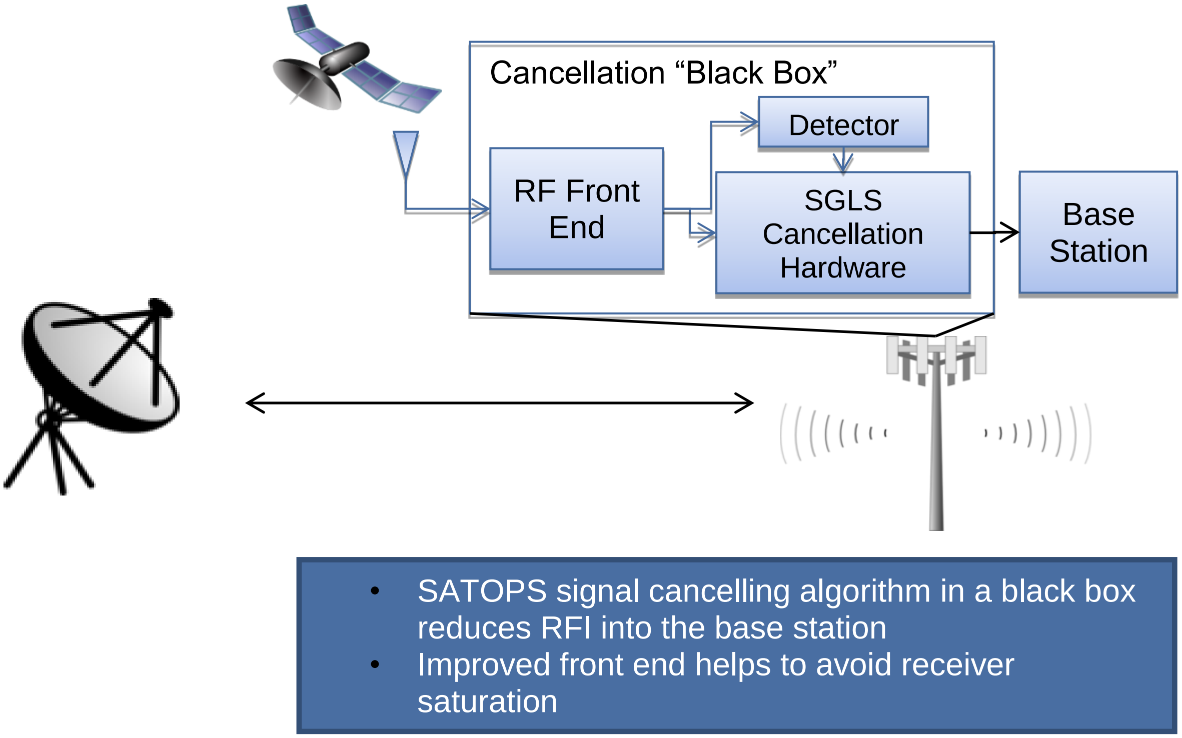
[34] Andrews, Jeffrey "Interference Cancellation for Cellular Systems; a Contemporary Overview" IEEE Wireless communications, April 2005

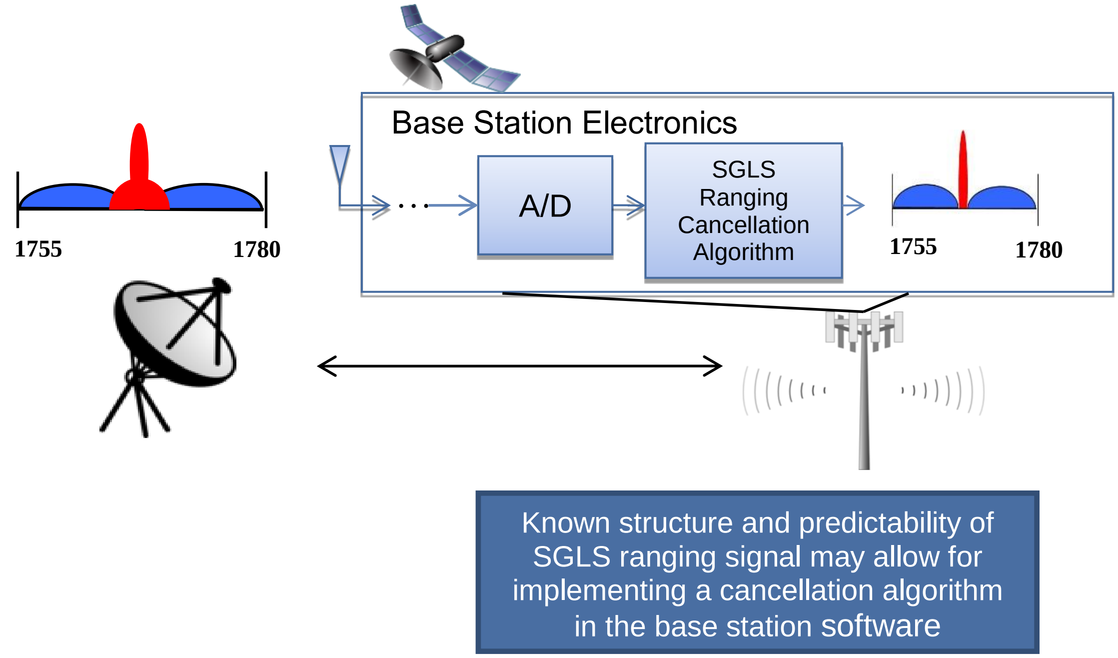
caused by the high power SATOPS signal. Figure 4.2.5-4 illustrates the cancellation box approach.

It is also possible that some level of interference cancellation could be implemented through software within the digital signal processors of the base station. This may be achievable with limited processing power given the known structure of the SATOPS signal. The portion of the SATOPS signal used for ranging may be particularly suitable for software cancellation given that it is a pseudorandom high rate signal. Cancellation of the ranging signal would not eliminate interference from the entire SATOPS signal, but could reduce the bandwidth impacted by the interference e.g., from 2 MHz to 200 kHz. This could be effective in combination with other mitigation techniques targeted at mitigating narrow band interference, such as time/frequency sharing (which is discussed in section 4.2.5.15). Given that the commanding portion of the signal has the majority of the signal energy this may be the dominant interfering component which could even cause receiver saturation, thus the effectiveness of cancelling the ranging signal only may be limited. Figure 4.2.5-5 illustrates the software implementation of interference cancellation.



- SATOPS signal cancelling algorithm in a black box reduces RFI into the base station
- Improved front end helps to avoid receiver saturation

Figure 4.2.5-4. SGLS cancellation hardware to minimize RFI and avoid receiver saturation.



Known structure and predictability of SGLS ranging signal may allow for implementing a cancellation algorithm in the base station software

Figure 4.2.5-5. SGLS Ranging cancellation algorithm to reduce the bandwidth of RFI.

4.2.5.4 Operational Pointing Direction of SATOPS antenna

Due to normal operation of a SATOPS terminal there may exist a mission limit on the minimum elevation/azimuth angles the SATOPS antenna may use (particularly for geosynchronous orbit (GSO) spacecraft) and this would enhance the potential for sharing. Such mitigation is only feasible under the limitation that SATOPS operations are not being impeded. SATOPS at many sites do need full half hemisphere coverage based upon mission requirements. Operational factors that may apply for any given site will be based on the missions supported by the particular antennas at that site.

As an example consider the station located at Cape Canaveral Air Force Base (CCAFB)[35], due the proximity to the Cape Canaveral Launch facility the main mission of this antenna is likely to support launch operations. To analyze such an operational scenario it is assumed that the pointing direction is limited such that the azimuth is between 0 degrees (Due North) and 180 degrees (Due South) with easterly pointing azimuth directions allowed. Such type of operation may be representative of the operational characteristics during launch and early operation of a satellite system. The results are based on using the systems listed above for channel 1 with the satellite uplink station transmitting at maximum power at all times. Taking advantage of operational SATOPS pointing requirements should be considered on a site-by-site basis as part of coordination between the local licensee and the SATOPS site operator.

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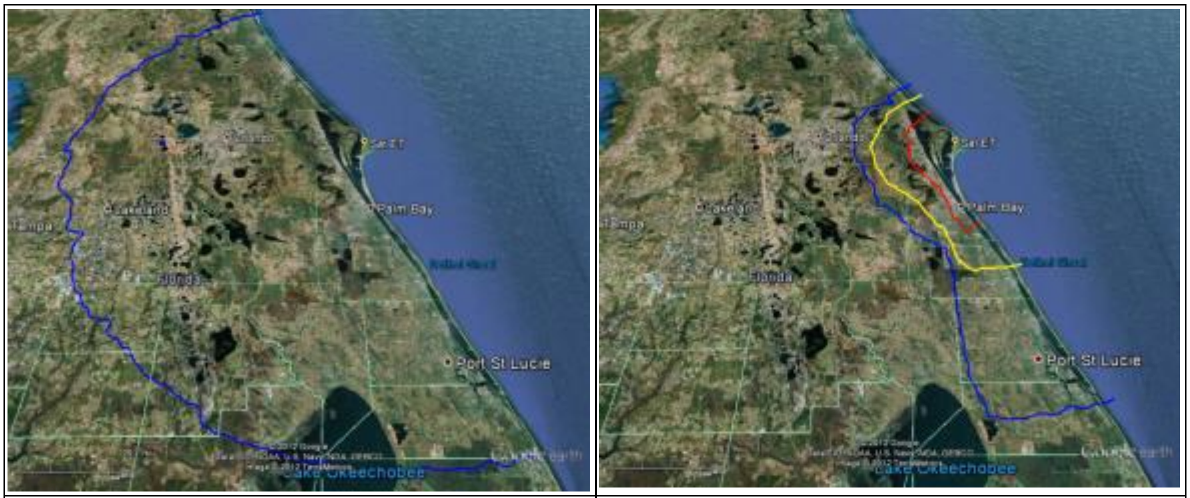
[35] It should be noted the operations at CCAFB may not be extensive and these results are not easily transferred to other sites.



Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking). No Power Control.

Interference at or below 1 dB desense for 100% of the time. Yellow line is Opt 1 and red is Opt 2 base station mitigation using the BS receive antenna.

Figure 4.2.5-6. 1 dB Desense for EVCF, baseline scenario showing impact of limiting SATOPS pointing direction, All Channel 1 Satellites.

4.2.5.5 Limit Ranging operation of SATOPS channels

DoD instruction[36] provides guidance that ranging operations should occur at the payload frequencies. To the extent possible, operations are continuing to shift this service to payload frequencies. This could continue to reduce the amount of time that SATOPS channels are used and will increase the ability to share between BS and SATOPS operations. This mitigation technique is only applicable to satellite systems which have payload spectrum use outside the SGLS bands.

DoD indicates that ranging at payload bands is already maximally used during nominal operations. The main use of SATOPS in the 1755-1850 MHz band is for TT&C during launch, early orbit activities and anomaly resolution (LEO&A). LEO&A also includes support of low data rate research spacecraft, training, testing, support of spacecraft during the initial activation phase, and control of LEO spacecraft during their disposal reentry. It should be clearly noted that L-band is used on a regular basis for primary TT&C for certain legacy space programs, such as GPS. Also, this band is used for low data rate applications for research type spacecraft and for disposal operations associated with low earth orbit spacecraft. LEO&A SATOPS requires low frequency (L-band) support due to the requirement to support randomly oriented spacecraft through all weather conditions.

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[36] DoD Instruction 3100.12, September 14, 2000, *www.dtic.mil/whs/directives/corres/pdf/310012p.pdf* (last visited November 5, 2010).

4.2.5.6 Dual Band

This is an effort the DoD is undertaking to have spacecraft be configured to be able to uplink in 1755-1850 MHz and 2025-2110 MHz. This capability is already implemented on a few space systems and some ground equipment, but total implementation is very uncertain and problematic as to when, if ever, it will be completed. If and when this is accomplished, future growth and LTE sharing can be more easily accommodated by flexible DoD operational use of either band. Currently, none of the Government spacecraft to date can change their frequencies on orbit, although such equipment could be installed in the future. Therefore all of the current spacecraft that do not have this capability will need to continue to be supported in 1755-1850 MHz for up to 30 or more years depending on the specific spacecraft.

4.2.5.7 Offloading / Scheduling

Although, theoretically SATOPS interference to LTE could be reduced by optimally scheduling spacecraft supports across SATOPS sites, opportunities in this regard are very limited because both government and LTE systems have requirements to operate in an unscheduled manner 24/7. Due to the heavy loading of SATOPS sites, particularly AFSCN and specific needs of the various space systems, only very minimal offloading of scheduled contacts could be shifted between sites.

4.2.5.8 Multiple Input Multiple Output (MIMO)

MIMO antenna technology is included in the current release of LTE, and future releases will improve on the MIMO features implemented. This technology can improve the rate of the system via spatial multiplexing, increasing the quality of service for UEs, potentially even in the presence of interference from SATOPS. MIMO can also provide antenna diversity. This antenna diversity can improve robustness to interference on par with the product of the number of antennas employed by both the base station and the UE. For example, a base station with two antenna elements receiving from a UE that also has two antenna elements could improve tolerance to interference by approximately a factor of four. Note that the same antennas in a MIMO system cannot be used to provide both spatial multiplexing and antenna diversity at the same time. Implementations of MIMO with more antenna elements could allow for increased interference tolerance in combination with improvements in rate via spatial multiplexing. Optimal use of MIMO accounting for SATOPS interference would require additional implementation effort beyond what is currently included in the LTE standard.

Multi-User MIMO (MU-MIMO) is a variant of MIMO planned for future releases of LTE that would allow spatial multiplexing of multiple UEs by a single base station, and may eventually even allow for spatial multiplexing across multiple base stations. More advanced deployments of MU-MIMO could possibly account for an interfering SATOPS transmitter in the context of spatial multiplexing. Implementation would be significantly more complex and require further study, but could theoretically provide greater performance improvements than diversity approaches alone.

4.2.5.9 Reduced SATOPS Antenna Side lobes

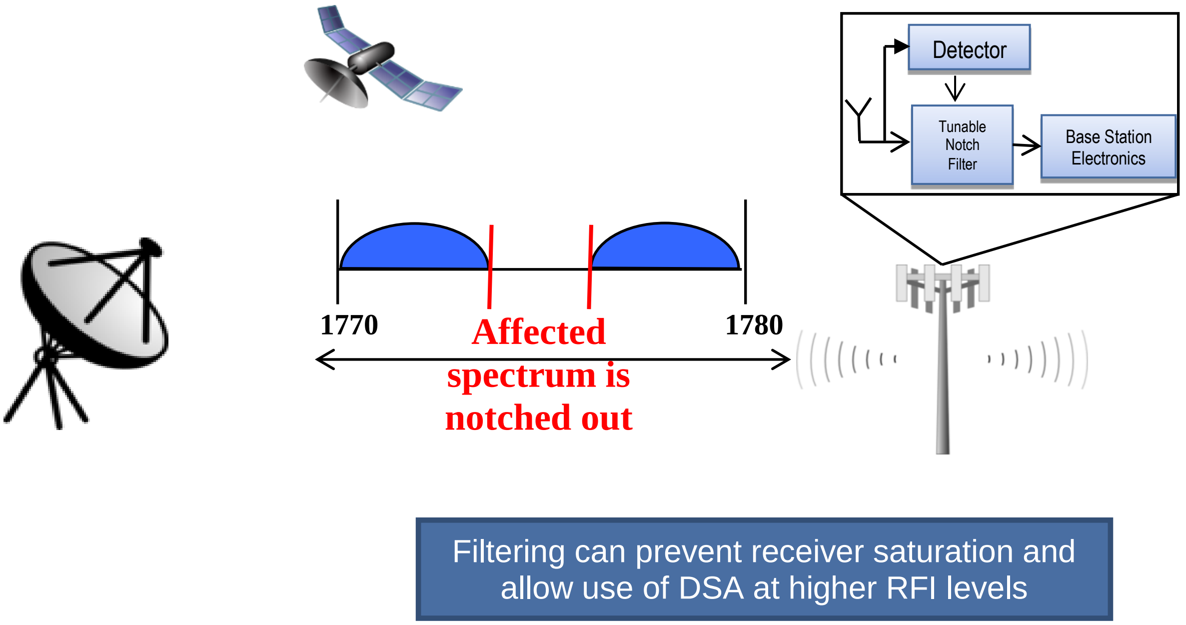
Reducing the antenna side lobe levels of SATOPS terminals can directly reduce the interference level a LTE base station may receive by perhaps 10-30 dB, depending on the sophistication of the techniques employed. In most cases, this would be a major effort that probably would require replacement of the SATOPS antenna systems.

4.2.5.10 Selection of SATOPS Transmission Channels

Some DoD satellites have the capability to operate only on a single frequency and a few satellites have the capability of supporting two frequencies. For the satellites that have the capability to operate on multiple channels, some operations could be shifted to channels that do not impact commercial operations and could result in a reduction in the amount of time a base station receiver may receive interference. Since most SATOPS ground station must be capable of communicating with most satellite, this mitigation technique has only limited applicability to specific satellite systems which have the support for multiple SGLS channels. Even for these systems, each supported frequency may still interfere with LTE operations, requiring more complicated pre-planning for optimal SATOPS channel selection. As stated earlier, this technique has very limited utility since both Government and LTE operations are not known accurately ahead of time in many cases.

4.2.5.11 Selective Receiver RF Filtering

Front end selective filtering is a concept where the LTE base station will implement a tunable notch filter to significantly reduce the signal level from the SATOPS uplink station (by approximately tens of dB). This is a proven technique that can help to avoid receiver saturation and enhance the performance of time/frequency sharing techniques.



Filtering can prevent receiver saturation and allow use of DSA at higher RFI levels

Figure 4.2.5-7. Front end selective filtering to avoid receive saturation.

4.2.5.12 Self Optimizing Networks

Cellular systems are in the process of using self organizing and self optimizing network tools that optimize LTE architectures in an adaptive manner. Further evaluation should consider how these techniques can be used to manage and improve operation in a dynamic fashion around the SATOPS sites.

4.2.5.13 Spectrum Efficient Waveforms

Classical communications theory indicates that AFSCN SATOPS emission bandwidth can be reduced by up to a factor of 8 and required power reduced as much as 18 dB with the use of new modulation (such as QPSK, 8PSK, 16-ary or higher order) and coding formats (such as Low Density Parity Check codes). These techniques would require new spacecraft and ground equipment. This would require up to 30 or more years to fully implement on all spacecraft. Note for comparison, that the implementation of new digital waveforms (see section 4.2.5.1) on the ground uses the existing modulation and coding, and can be done without modification of spacecraft equipment.

4.2.5.14 Spectrum Landscaping / Shielding

Shielding of antennas could significantly attenuate (10-50 dB or more depending on complexity) interfering signals arriving at a base station receiver and would enhance the opportunity for SATOPS sharing with LTE systems. Shielding can include natural features e.g., trees, bushes, hills as well as man-made structures. Shielding can be installed at the SATOPS site or at the base station site to provide the additional attenuation. In addition, placement of individual base stations can be selected to take advantage of natural shielding in the surrounding area, such as trees or buildings in the direction of the SATOPS site. It should be clearly noted that this may be a very attractive technique because the locations of the SATOPS and base station sites are fixed and known and thus shielding techniques could be tailored to the particular desired architecture. The amount of attenuation that can be obtained can be quite considerable and is been the subject of various studies[37]. Also, in many circumstances, the cost and other limiting factors could be quite low. Installation of shielding could potentially impact Government and/or LTE operations by obstructing desirable coverage areas. This tradeoff must clearly be considered in engineering the specific shielding solutions. Figure 4.2.5-10 illustrates one example showing the tradeoff between achieved attenuation of an interfering signal (arriving at 0 degrees) vs. attenuation of desired signals in a broader coverage area (+/- 50 degrees) due to the placement of a 10 foot square attenuating screen .

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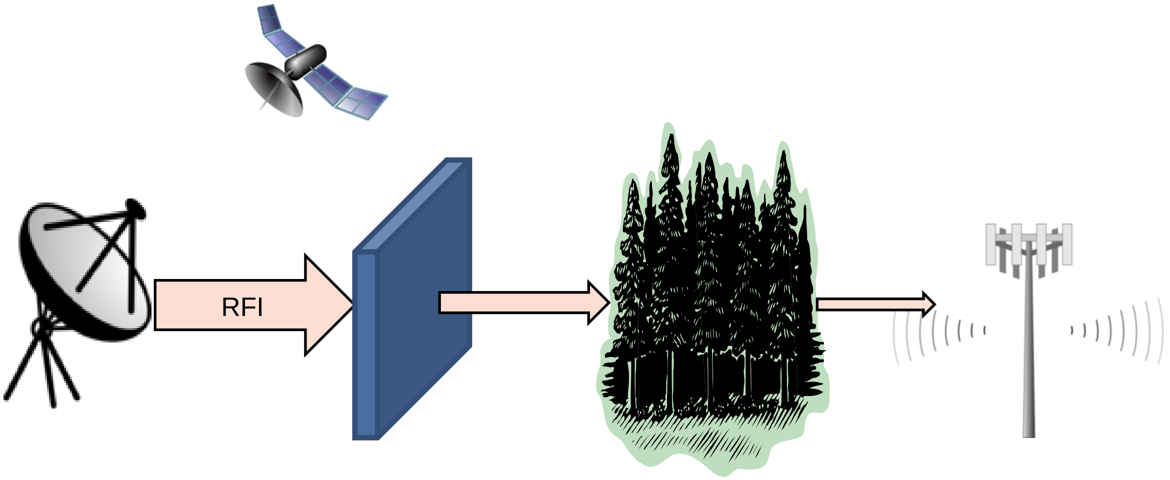
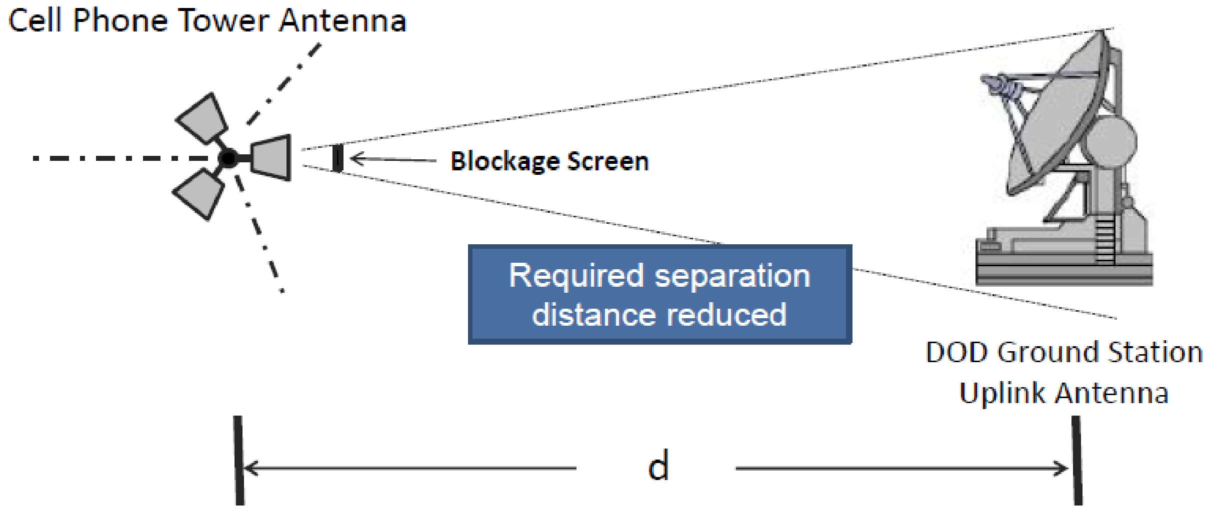
[37] Goldhirsh, Julius, Wolfhard J Vogel “Handbook of Propagation Effects for Vehicular and Mobile Satellite Systems” rev 3 Jan 2001



- RF Shielding near satellite uplink sites and/or LTE base stations can greatly reduce side lobe RFI
- Shielding can include natural features e.g., trees, as well as man-made structures

Figure 4.2.5-8. Shielding of interference from man-made and natural structures.



Required separation distance reduced

As “d” increases, blockage screen can be reduced in size

Figure 4.2.5-9. Representation of screen at the base station blocking reception of DOD Ground link operations.

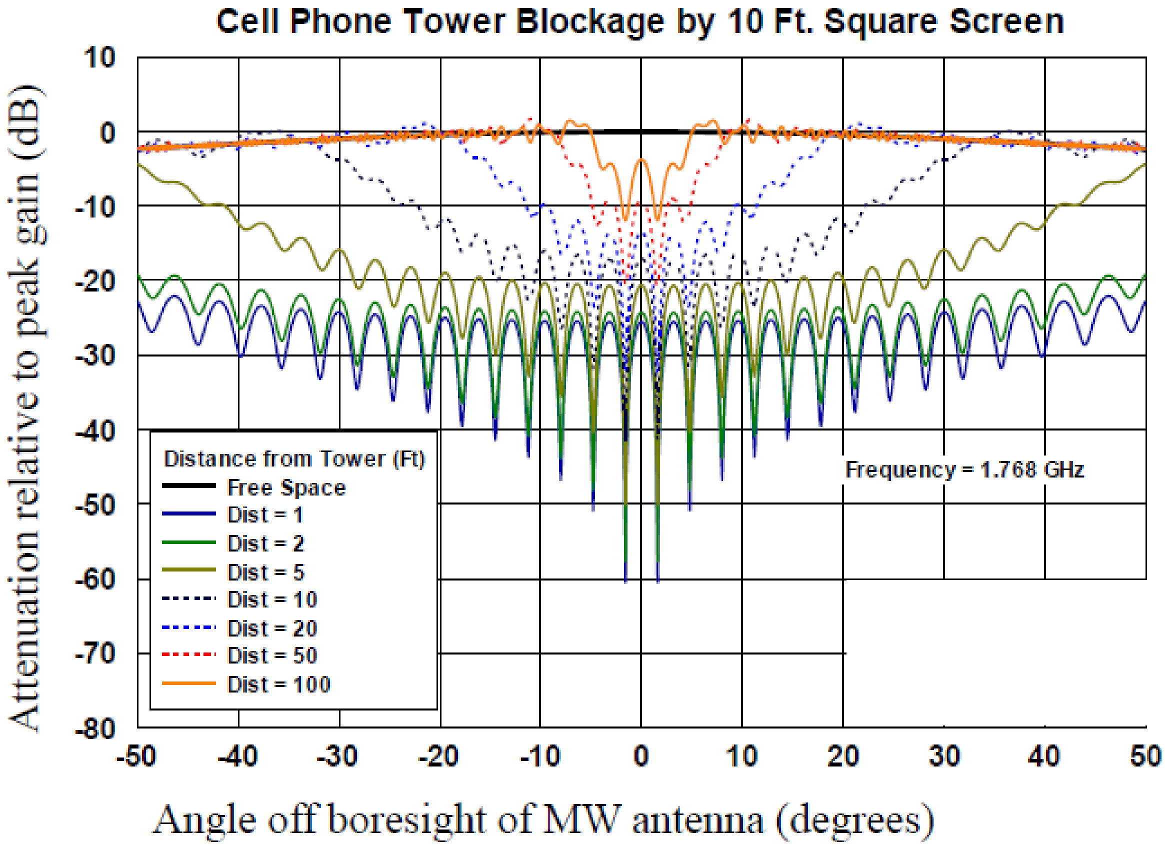


Figure 4.2.5-10. Estimate of attenuation by a 10 ft square screen.

4.2.5.15 Time/Frequency Sharing

Since SATOPS ground stations use a small number of channels in the 1755-1850 MHz band at any one time, time/frequency sharing may be possible. At any given moment, about 95% of the spectrum in the 1755-1850 MHz band will be free from SATOPS signal power, thus LTE base stations could theoretically schedule operations to minimize the impact of SATOPS interference. Current LTE equipment may not have the ability to schedule around SATOPS interference, but because LTE base stations currently schedule operations in time and frequency on the order of tens of milliseconds, future LTE equipment could support such a capability. This mitigation is only effective if the base station front end is not saturated by the interfering SATOPS signal, and thus may not be useful in locations very close to the SATOPS site, but may significantly improve performance in other regions. Cost factors include development of software for LTE scheduling in the presence of SATOPS interference as well as implementation of a means to detect the SATOPS interference.

The sensitive nature of SATOPS operations limits the practicality of providing advance notice of the SATOPS schedule to LTE operators, but the SATOPS signal detection by the LTE base station in real-time is expected to be feasible given the high power and known signal structure of the SATOPS emissions. Implementation may be assisted by cooperative testing with SATOPS sites. One implementation option would be the placement of LTE receivers tuned to listen for operations of SATOPS transmitters. If the locations receive a signal level above a certain threshold, the base station and/or system operator would be notified that SATOPS operations are occurring and would execute options to mitigate interference (e.g., shift users to other bands or other means).

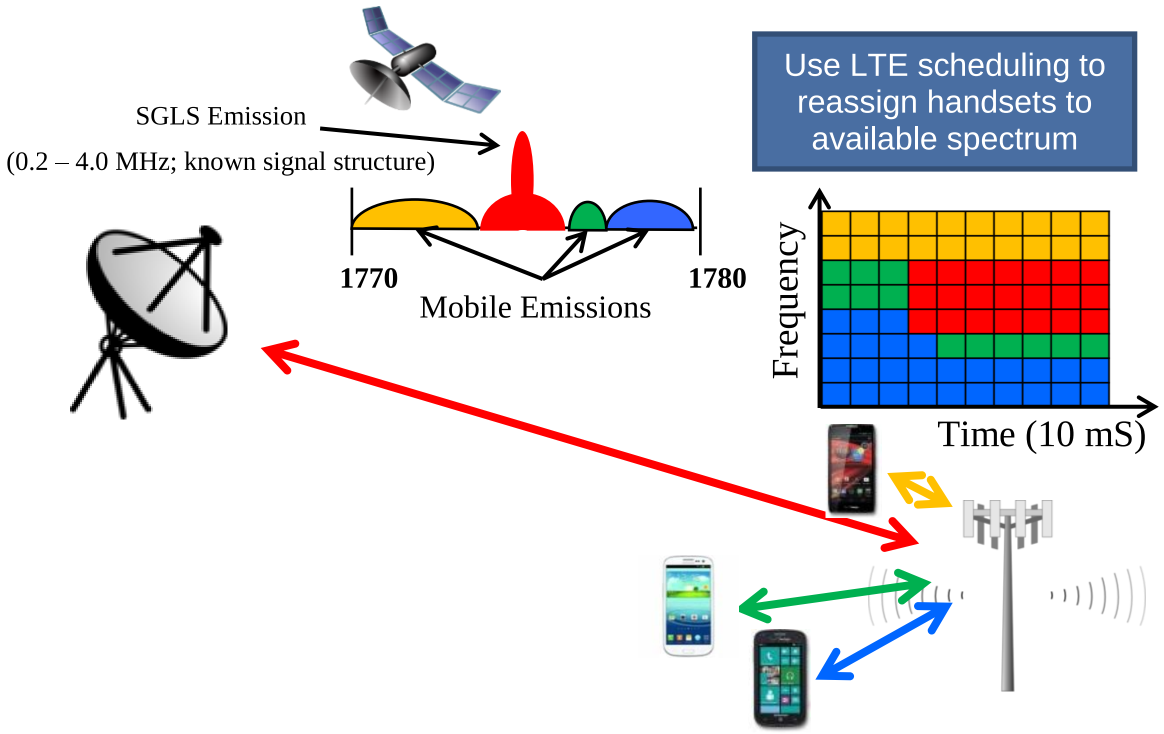


Figure 4.2.5-11. LTE Scheduling of spectrum resources to avoid use of channel in use by SATOPS station.

4.2.5.16 Uplink Power Control

Use of power control on SATOPS ground stations may allow for some improvement in sharing with LTE systems. This technique will not apply to situations where the communications with a satellite is at risk or under anomaly conditions. Under such operations the SATOPS uplink station will operate at maximum power to ensure communications. Anomaly operation is not the normal condition and occurs approximately <1% of the time. It is not possible to predict when such anomaly conditions will occur and the duration of such conditions. Also, typically, Government mission requirements are set to provide assured access. This is fundamental to military operations because critical national security needs can change very quickly. Therefore such uplink power control could cause an unacceptable risk to satellite health and safety, if the power is too low to ensure communication with the satellite. Reduced SATOPS uplink power increases the risk of not being able to contact and command the satellite successfully. This could potentially cause damage to the satellite or result in loss of the satellite. The Government must take much more care in the avoidance of mission degradation because, in many cases, that would be a safety-of-life issue.

Shown below in Table 4.2.5-2 is a bounding link budget for the USKW satellite communicating with NHS showing the range of power from the maximum feasible at the NHS site to the minimum to close the link with a small margin. As indicated, the link has over 46 dB of margin relative when the satellite is at minimum elevation. Note that the USKW example shown is not typical of SATOPS operational cases in practice, but is shown for illustrative purposes. Under anomaly operations the satellite receive gain may be 16 dB lower due to the possibility of a tumbling satellite. Also shown in the table is a link budget for a GSO satellite, USGAE-10. As indicated communications with this satellite will not have as much link margin and is illustrative that the ability of this technique to reduce interference to the LTE base station has limitations. As seen it is highly dependent upon the mission and current state of the spacecraft that is being commanded by the SATOPS terminal. Note also that reduction in uplink power may increase the susceptibility of SATOPS space-borne receivers to aggregate interference from LTE operations (see section 4.2.6).

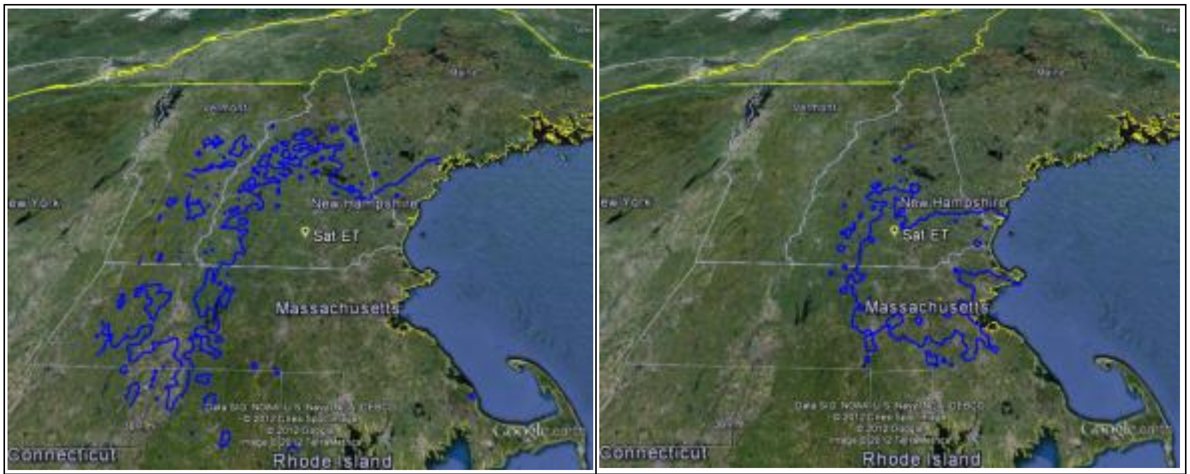
Table 4.2.5-2: Link budget for USKW and USGAE-10 satellite showing impact of power control.

SATOPS Parameters	**USKW**		**USGAE-10**	
	Max Power	Min Power	Max Power	Min Power
Tx Frequency (MHz)	1762	1762	1812	1812
Tx Power (dBm)	68.6	23.66	68.6	65.03
Peak Antenna Gain (dBi)	45	45	45	45
Peak EIRP (dBm)	113.6	68.66	113.60	110.03
Satellite Altitude (km)	630	630	35768	35768
Minimum Elevation (deg)	3	3	-	-
Distance from SGLS station to Satellite at minimum elevation (km)	2589.3	2589.3	41702.79	41702.79
Free Space Loss (dB)	165.64	165.64	190.02	190.02
Satellite Rx Gain (dBi)	6	6	-4	-4
Noise Bandwidth (MHz)	4.004	4.004	2.9	2.9
Noise Temperature (K)	288	288	630	630
Required C/N (dB)	15	15	20	20
C/N (dB)	61.95	17.00	25.57	22.00
Margin (dB)	46.95	2.00	5.57	2.00

Shown in Figure 4.2.5-12 to Figure 4.2.5-15 are the comparison of operations for channel 1 with maximum power at minimum elevation angle with the SATOPS terminal tracking the satellite with the lowest elevation angle and using power control. The satellite characteristics are those found in Table 4.2.3-16. These figures were computed for a grid of base stations with 5 km spacing and distributed with-in 150 km of the SATOPS uplink terminal. The computation assumed that the transmit power is set such that the C/N at the satellite has 2 dB of margin above the minimum C/N required for communication. For the satellite systems listed to operate in channel 1, the 2 dB margin level will result in a power reduction of 28-43 dB.

Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking). No Power Control.	Interference at or below 1 dB desense for 100% of the time. Power Control to C/N of 17 dB.

Figure 4.2.5-12. 1 dB Desense for HTS, baseline scenario showing no power control and power control to 17 dB C/N, all Channel 1 Satellites are considered.

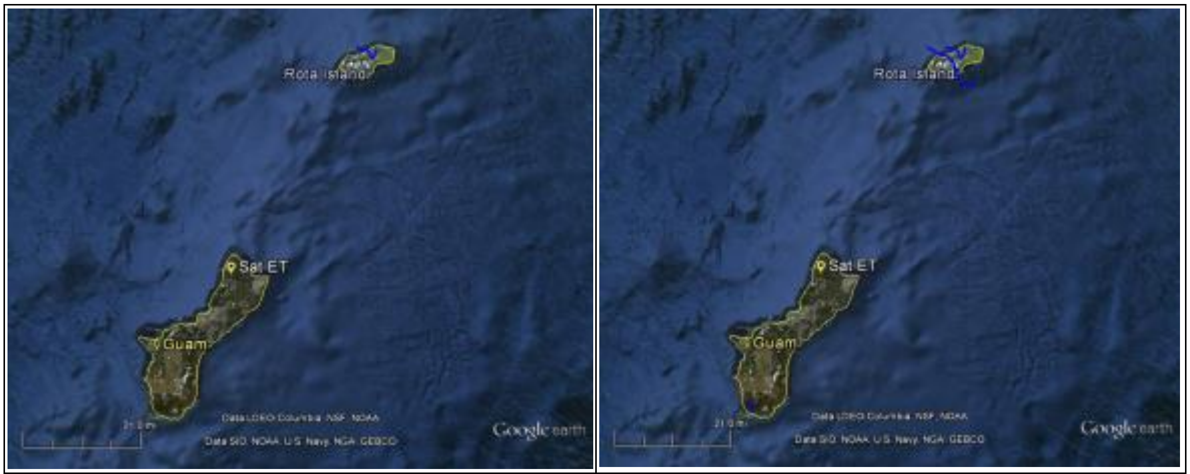


Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking). No Power Control.	Interference at or below 1 dB desense for 100% of the time. Power Control to C/N of 17 dB.

Figure 4.2.5-13. 1 dB Desense for NHS, baseline scenario showing no power control and power control to 17 dB C/N, all Channel 1 Satellites are considered.

Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking). No Power Control.	Interference at or below 1 dB desense for 100% of the time. Power Control to C/N of 17 dB.

Figure 4.2.5-14. 1 dB Desense for VTS, baseline scenario showing no power control and power control to 17 dB C/N, all Channel 1 Satellites are considered.



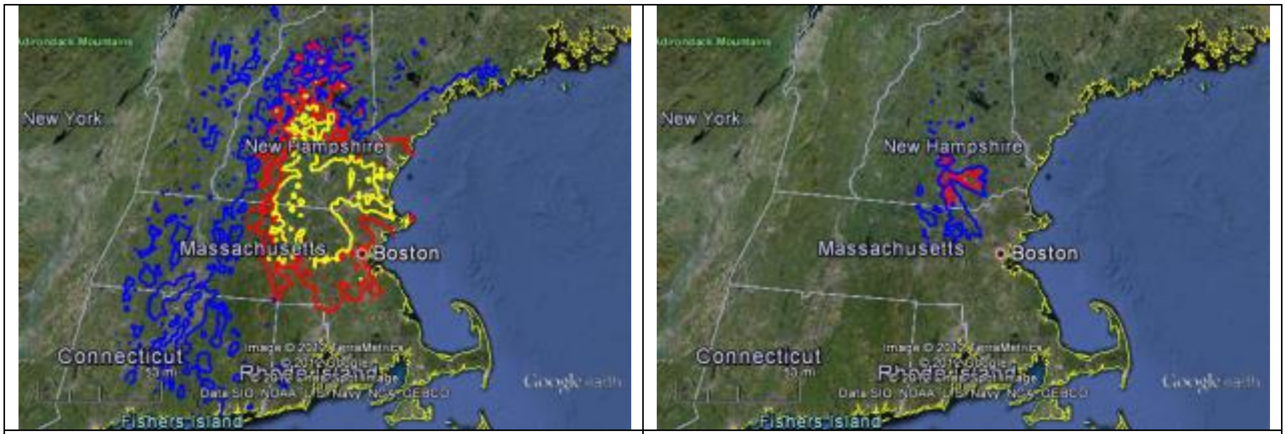
Interference of 1 dB desense assuming SATOPS terminal is pointing at 3 degrees elevation (no satellite tracking). No Power Control.	Interference at or below 1 dB desense for 100% of the time. Power Control to C/N of 17 dB.

Figure 4.2.5-15. 1 dB Desense for GTS, baseline scenario showing no power control and power control to 17 dB C/N, all Channel 1 Satellites are considered.

4.2.5.17 Summary

A survey of available techniques, analysis, and simulation results indicate that interference can be significantly reduced by the application of various mitigation methods. While techniques do vary in their effectiveness, no particular techniques are recommended or discouraged. All techniques should continue to be evaluated and considered for use in the context of ongoing improvement of sharing between SATOPS and LTE operations.

Figure 4.2.5-16 illustrates the impact of mitigation on the reduction of the size of the zone for a 1 dB desense. The 0 dB mitigation is based on the zone expected when the satellite uplink terminal is operating at its maximum power and pointed at 3 degrees elevation in all directions around the earth terminal location. The figure on the right shows the effect of the dimensions of zone due to 40-60 dB mitigation. This clearly demonstrates the possible increase in area available for effective LTE operations.



Amount of Mitigation: Blue = 0 dB, Red = 20 dB, Yellow = 40 dB	Amount of Mitigation: Blue = 60 dB, Red = 80 dB

Figure 4.2.5-16. Reduction in desense zone around NHS site based on amount of mitigation implemented, 0 dB is full power operations at minimum elevation angle for uplink site.

4.2.6 Analysis of LTE Interference to Space-Borne Satellites

4.2.6.1 Introduction

A key aspect of assessing the feasibility between LTE and Federal SATOPS systems in the 1761-1842 MHz band is the question of whether the aggregate interference resulting from all LTE operations will cause harmful interference to SATOPS receivers on Federal spacecraft. Figure 4.2.6-1 illustrates this problem. This section presents analysis and results for predicting aggregate RFI to SATOPS receivers that would result from commercial LTE network operations in the 1755-1850 MHz band, in this case the aggregate emission from all transmitting mobile devices is computed. Low risk of harmful interference from aggregate LTE to SATOPS is predicted based on current assumptions, however, establishment of regulations to ensure continued protection of satellite receivers is recommended

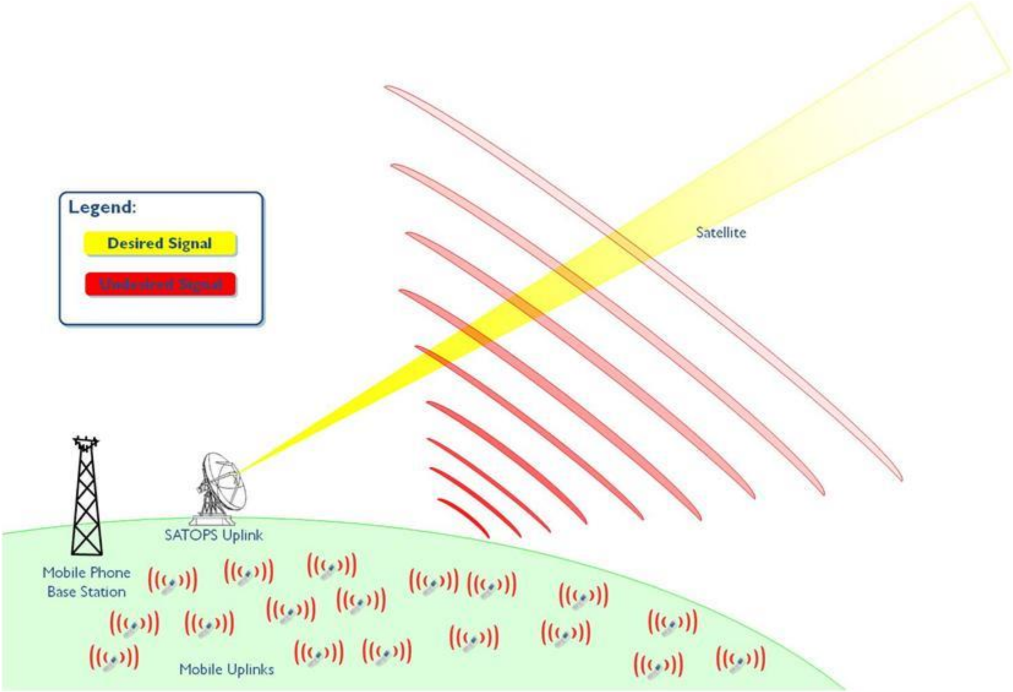


Figure 4.2.6-1. Aggregate LTE Interference to SATOPS Receivers

4.2.6.2 LTE Aggregate Interference Model

To evaluate aggregate LTE interference to Federal SATOPS receivers in 1761-1842 MHz, DoD created a model to represent UEs distributed across the U.S. and compute the resulting total interference power at DoD spacecraft. Only UE transmitters were examined in this analysis based on the assumption that 1755-1850 MHz would be used for LTE uplinks, and that base station transmissions would be accomplished at another frequency. The same model can be used to examine interference due to base station transmissions if expectations for LTE change in the future.

The model is run for each DoD program and accounts for the parameters of that program, as well as parameters that describe the LTE network. LTE parameter inputs to the model are based on the CSMAC WG1 Final Report[38]. Key inputs to the model include:

- Spacecraft sensitivity - the threshold interference power density incident at the spacecraft antenna that would be considered harmful. This sensitivity is computed for each program based on link requirements contained in relevant interface documentation. The threshold represents the amount of additive thermal noise power that would result in failure to meet the link closure requirement.

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[38] "Commerce Spectrum Management Advisory Committee Final Report Working Group 1 – 1695-1710 MHz Meteorological-Satellite" January 22, 2013

- Spacecraft position – the location of the Federal satellite in space. This input is handled parametrically. Only spacecraft altitude is entered into the model. Interference power is then computed for all possible locations of the spacecraft at that altitude and the highest interference value is identified.
- LTE antenna gain - the nominal gain of all LTE transmitters towards the spacecraft. UEs are assumed to have an omni-directional antenna pattern.
- UEs/Base Station – the number of UEs that are transmitting in the area served by a single base station. The value provided by CSMAC WG 1 of 18 UEs/Base Station is understood to represent the number of simultaneously transmitting UEs per base station in a 10 MHz bandwidth network. (See Section 4.2.1)
- LTE channel bandwidth - the assumed channel bandwidth of the LTE network. For the purposes of this analysis, a 10 MHz LTE network is assumed to completely overlap the bandwidth of the Federal SATOPS receiver in the 1755-1850 MHz band. (See Section 4.2.1)
- Rural/Urban cell radius - the coverage area of each individual base station. This value is used to determine how many base stations (and thus how many UEs) are operating in a given land area. Note that cell radii take on one of two values depending on whether the base station is in an area considered to be urban or rural. The radius values used in the model are half the inter-site distances identified in the CSMAC WG 1 report. (See Section 4.2.1.2)
- Rural/Urban UE power - the mean transmitter power of UEs, depending on whether the UE is in a rural or suburban area. Values used in the model are based on power distribution statistics for the UE provided in the CSMAC WG 1 report. (See Section 4.2.1.2)
- Rural/Urban UE variance - a statistical metric for the variation of UE transmitter power due to power control of the UE. Both the mean and variance terms are derived from UE transmit power distributions provided by CSMAC WG 1. (See Section 4.2.1.2)

The modeling method for the distribution of LTE systems across the U.S. was recommended by CSMAC WG 1. It identifies a list of the top 100 cities in the U.S. in terms of most desired LTE market areas. A map of these market areas is shown in Figure 4.2.6-2. LTE systems operating with suburban parameters (defined by CSMAC WG 1) are placed in a circular land area with 30 km radius at each of these cities. In addition, LTE systems operating with rural parameters are placed in a ring of land area with 30 km inner radius and 100 km outer radius around the suburban circle. No LTE systems are assumed to operate outside of these 100 cities. With this approach and the input parameters described above, the resulting 10 MHz LTE network consists of approximately 170,000 base stations and 3 million simultaneously transmitting UEs across the US[39]. Note that only a fraction of these UEs would effectively impact any given SATOPS receiver since the SATOPS bandwidth is only a fraction of the 10 MHz LTE network bandwidth, and out-of-band interference effects were not considered in this analysis.

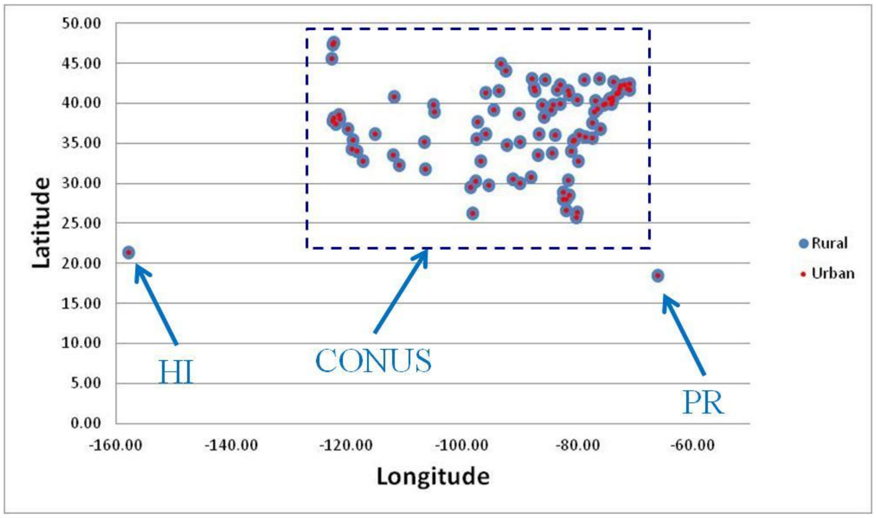

Figure 4.2.6-2. Modeled LTE Market Areas

With the LTE network distribution modeled across the U.S., interference is calculated for each market area that has a positive elevation angle to the victim satellite location using typical link analysis. Total market area transmit power is assumed to be the sum of all transmitter powers in the market area. The resulting market area transmit power is assumed to have a flat/constant power spectral density across the 10 MHz bandwidth. The propagation path is assumed to be from the center of the urban area circle to the satellite location. Free space path loss is assumed and the SATOPS receiver is assumed to have a constant antenna gain towards all interference sources. Atmospheric loss is included but amounts to less than a tenth of a dB at this frequency range. Total interference at the spacecraft is determined by summing power contributions from each market area. The uncorrelated nature and large number of individual transmitters makes

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[39] Note the number of base stations and simultaneously transmitting UEs originally presented in the federal submittal in section 4.4.3 are not consistent with the values presented here due to a typographical error in section 4.4.3. Also note that the correct number of UEs was used in the analysis and is accurately reflected in the result both here and in section 4.4.3.

power summing appropriate. It is assumed that total resulting interference power can be well approximated as a flat increase in thermal noise across the band. In this way, the estimated aggregate interference power density can be compared directly against a SATOPS interference power density threshold without having to explicitly account for individual SATOPS mission bandwidths.

The standard deviation of the aggregate interference is also computed based on the variance of the power distribution for individual UEs. This allows for an evaluation of whether the aggregate interference should be expected to fluctuate significantly over time due to UE power control. The computation is straightforward using the basic property that the variance of a sum of random variables multiplied by some constants is equivalent to the sum of the square of the constants multiplied by the variance of the individual random variables. Thus the variance of the aggregate interference, which is the sum of all the UE transmit powers multiplied by appropriate link parameters, is equivalent to the sum of the square of the link parameters multiplied by the individual UE transmitter variance.

4.2.6.3 LTE Aggregate Interference Analysis Results

Modeling was conducted for most relevant major Air Force, Navy, and NOAA SATOPS space programs. An interference power density threshold at the satellite receiver was computed for each program based on relevant requirements and interface documentation. Interference thresholds for all programs were then used to determine a single threshold that would protect all programs from harmful interference. An interference level of -205 dBW/Hz into a SATOPS receiver, assuming a 0 dBi antenna and no other losses, (equivalent to a power flux density of -179 dBW/Hz/m^2) was determined to be a safe interference level at geostationary orbit for most programs. Note that while this threshold is referenced to a geostationary orbit, it effectively protects programs in non-geostationary orbit as well. This can be conceptually explained recognizing that the differences in distance between the SATOPS site and the interference sources to the spacecraft are approximately equal regardless of the spacecraft's altitude. This means a carrier to interference plus noise ratio, which is a useful metric for evaluating the severity of interference, is insensitive to the orbit of the spacecraft. Also note that while the threshold is presented her on a per Hz basis, this can be readily translated to other reference bandwidths with the assumption that aggregate LTE emissions will have an approximately constant power spectral density across their band of operations. For example, the -205 dBW/Hz threshold can also be stated as a -175 dBW/kHz or -145 dBW/MHz threshold.

The model was used to calculate the interference power density present at the geostationary orbit due to the LTE network for the worst-case point in the spacecraft's orbit and using the LTE parameter and deployment assumptions described above. The resulting estimated interference power density is -212.6 dBW/Hz. Comparing this to the aforementioned -205 dBW/Hz threshold, there is 7.6 dB of positive margin. Figure 4.2.6-3 plots the interference power density estimated for all longitudes in the geostationary orbit.

The -205 dBW/Hz threshold is not sufficient to protect a few experimental programs which have much more conservative requirements than most programs. It is not conclusive that these programs will or won't receive harmful interference from the planned LTE network. Additional consideration for these programs, and possible future programs that may have similar requirements, may be required during the development of transition plans. Transition planning is expected to follow after the CSMAC WGs complete their recommendations.

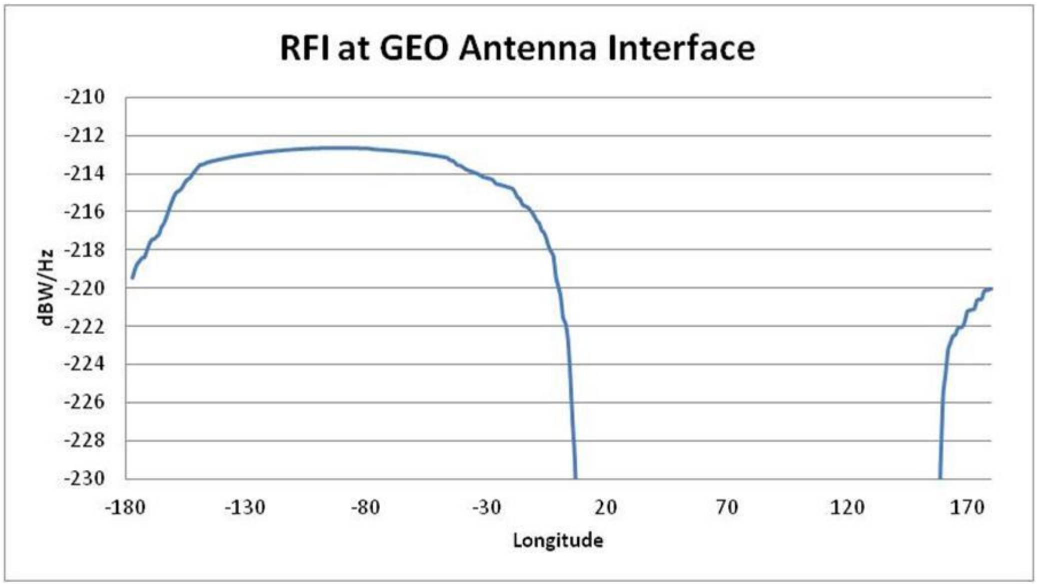


Figure 4.2.6-3. Estimated interference power density at geostationary orbit

The analysis and modeling use some assumptions which are expected to over-estimate the level of interference. One of the most significant of those is that the modeling assumes all UEs have direct line of site to the satellite. In practice, UEs are used in buildings, in cars, near trees etc. Transmitting through a window or a wall from inside a building adds significant attenuation. Other assumptions that may over-estimate interference include representation of the network during peak demand with a very large deployment of approximately 170,000 base stations. Due to these assumptions, practical interference from LTE deployment in the U.S. is expected to be significantly less than that predicted by the model. Furthermore, we recognize that the program requirements used to identify the interference threshold are often based on the most stressing cases anticipated for the spacecraft, indicating that spacecraft may be more tolerant of interference during nominal operations.

Consideration of emissions from U.S. systems is anticipated to under-estimate aggregate interference to SATOPS receivers, since other countries may deploy networks in the band and will be visible to U.S. satellites, use and will continue to be use the band for fixed and mobile services internationally. The field-of-view of a SATOPS receiver in geostationary orbit covers almost an entire hemisphere as shown in Figure 4.2.6-4. Thus mobile wireless deployments in Central America, South America, Western Europe, and East Asia could also contribute to aggregate interference levels depending on the specific satellite locations. While systems outside of the U.S. were considered to be beyond the scope of the WG 3 effort, the effects of such systems should be considered in on-going SATOPS-LTE band sharing processes.

Figure 4.2.6-4. Field of View of a Geostationary Satellite at 102 Degrees West Longitude.

Modeling and analysis is based on LTE parameters from CSMAC WG 1 and SATOPS receiver parameters from a large representative set of national security space programs. The analysis results and modeling are highly dependent on the parameters assumed for the LTE systems. The CSMAC WG 1 parameters are assumed to represent the commercial industry's best approximation of how LTE systems would operate in this band. However, commercial LTE technology changes rapidly relative to the long life cycles of national security spacecraft. Possible changes to LTE parameters due to evolving technology could conceivably result in eventual harmful interference to SATOPS systems. For this reason, a regulatory mechanism to prevent such an outcome is recommended. Specifically, NTIA and FCC should develop a process to estimate the projected interference resulting from licensees. If it is estimated that aggregate interference from LTE will exceed the -205 dBW/Hz threshold, the FCC and the licensees will modify operations, deployment plans, and/or regulations as needed to ensure that LTE deployments do not cause harmful interference to Federal spacecraft. The threshold and projection process should be included in national regulations, transition plans, and in the language of the auction winner's license to ensure enforceability.

4.2.6.4 Aggregate Interference Analysis Summary and Conclusions

Analysis under current assumptions indicates that aggregate LTE interference to SATOPS spacecraft receivers will not be harmful. A basic methodology for estimating the interference, drawing heavily from CSMAC WG 1 description of LTE parameters, was described. With this methodology, an interference power density of -212.6 dBW/Hz at geostationary orbit was predicted and compared to an interference threshold for SATOPS of -205 dBW/Hz, resulting in an approximately 7.6 dB positive margin. However, recognizing that mobile technologies evolve rapidly relative to long SATOPS lifecycles, a regulatory mechanism is needed to project estimated interference levels. Specifically, FCC should include in their rulemaking a process for a technical showing of compatibility between mobile licensees and SATOPS uplinks. Specifically, it should be shown that aggregate interference levels from licensees are not projected to exceed a threshold of -205 dBW/Hz interference power density into a reference antenna of 0 dBi (equivalent to -178.5 dBW/Hz/m^2 power flux density at 1800 MHz), measured at geostationary orbit. This technical showing should be provided no later than 2 years after the issuance of initial licenses and should provide a projection based on deployment 5 years into the future. The showing should also be updated periodically, where an appropriate period should be determined by FCC that captures significant changes in deployment strategies and technology without excessive analytical burden. Note that the technical information provided by individual licensees is anticipated to be proprietary and thus the overall determination of compatibility, accounting for all licensee inputs, will need to be determined by the FCC. If aggregate interference is ever projected or otherwise found to exceed the threshold, FCC and the mobile licensees will modify operations and deployment plans appropriately to protect SATOPS receivers from harmful interference.

Recommendation 4.2.6-1: CSMAC recommends that the FCC propose in their rulemaking a requirement on licensees which overlap any of the 1761-1842 MHz band that specifies a technical showing of compatibility with satellite uplinks.

- The aggregate for all licensees on the same frequency is a compliance level, in terms of power flux density at the geostationary orbit (GSO), not to exceed -179 dBW/Hz/m^2 .
- The initial showing shall be provided no later than 2 years after the issuance of the license and must contain technical data supporting the current deployment and an projected estimate of the deployment for 5 years in the future.
- The showing shall be updated on a periodic basis to be determined by the FCC.
- Due to the nature of such a showing, all data shall be proprietary between the licensee, FCC and NTIA (including government earth station operators).

Recommendation 4.2.6-2: CSMAC recommends the FCC consider in its rulemaking methods to ensure that the following conditions be met to ensure the aggregate commercial wireless mobile broadband emissions will not exceed the acceptable threshold power level, including:

- Method to aggregate the individual showings into a single value expected at the GSO arc from all licensees.
- The actions to be taken by the FCC to reduce the projected aggregate emissions if it is projected to exceed the threshold.
- The actions to be taken by the FCC to eliminate harmful interference if it does occur, to include potential cessation of operations by the commercial licensee(s) on the affected frequency until interference is resolved.

Recommendation 4.2.6-3: CSMAC recommends the NTIA investigate measures that can be implemented in its NTIA manual to enhance future spectrum sharing with mobile broadband networks. One approach could be to specify power radiated at the horizon from new SATOPS terminals similar to that found in the NTIA manual at Section 8.2.35.

4.3 EW Technical Appendices

Table 4.3-1: DoD EW Test and Training Ranges, 1755-1850 MHz Operations

DoD Electronic Warfare Testing Sites
Yuma Proving Ground (YPG), Yuma, AZ
Electronic Proving Ground (EPG), Ft. Huachuca, AZ
White Sands Missile Range (WSMR), NM
Dugway Proving Grounds, Utah Test and Training Range (UTTR), UT
Aberdeen Proving Ground, MD
Glendora Lake Hydro-Acoustic Test Facility, IN (GSM Site)
NSWC Crane, IN Realistic Ground Antenna (RGA) Range on NSWC Crane, IN proper (GSM Site)
NAS Patuxent River, MD
DoD Electronic Warfare Multi-Use (Testing/Training/LFE) Sites
Joint Readiness Training Center (JRTC), Ft. Polk, LA
National Training Center Irwin (NTC), Ft. Irwin, CA
Mid Atlantic EW Range (MAEWR), MCAS Cherry Point, NC
MCAS Yuma, AZ
NAWS China Lake, CA
Fallon Range Training Complex (FRTC), NAS Fallon, NV
Nevada Test and Training Range (NTTR), NV
NAS Whidbey Island, WA
Pine Castle EW Range, FL
DoD Electronic Warfare Training Sites
Ft. Hood, TX
Ft. Lewis, WA
Joint Base McGuire-Dix-Lakehurst Dix, NJ
Ft. Bliss, TX
Ft. Gordon, GA
Camp Atterberry Joint Maneuver Training Center (CAJMTC), IN (GSM Site)
Ft. Meade, MD
Ft. Bragg, NC
Camp Bullis Military Training Reservation, TX
Muscatatuck Urban Training Center, IN (GSM Site)
MAGTF Training Center 29 Palms, CA

This table is representative of the major DoD Test and Training Ranges where EW RDT&E, training and LFE operations are conducted in the 1755-1850 MHz band. The table is not all-inclusive and is subject to change

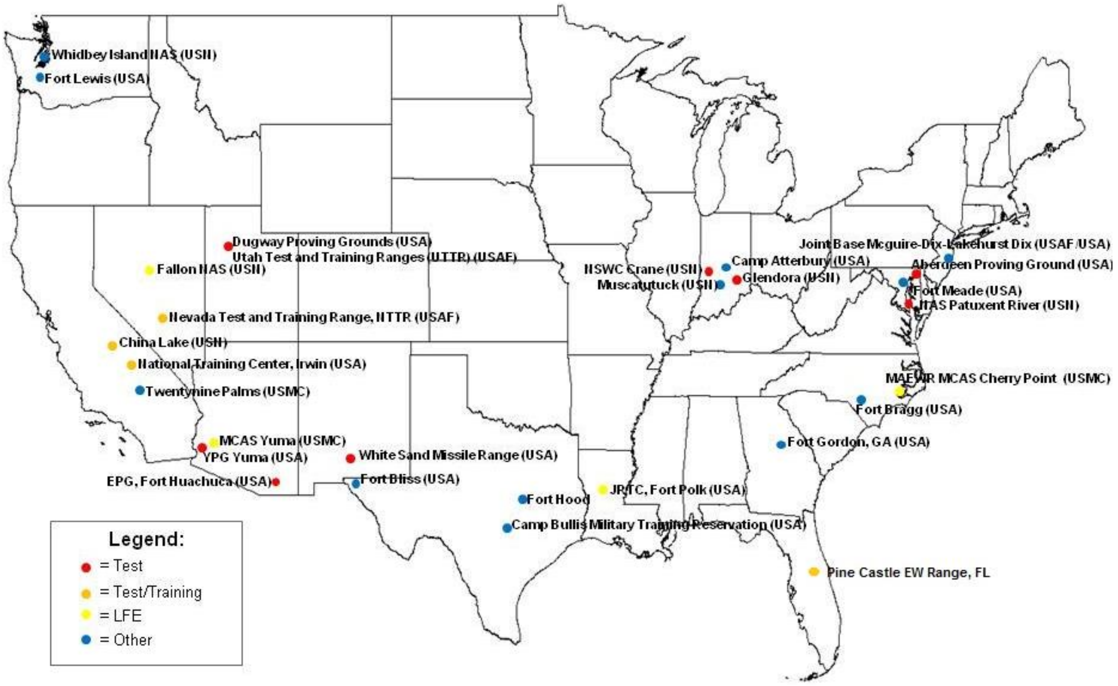


Figure 4.3-1. DoD EW Test and Training Ranges, 1755-1850 MHz Operations.

This map is representative of the major DoD Test and Training Ranges where EW RDT&E, training and LFE operations are conducted in the 1755-1850 MHz band. The map is not all-inclusive and is subject to change

4.4 Government Cleared Submissions to CSMAC WG 3

This section contains all of the information that was cleared through the government review process for use and discussion within the CSMAC WG 3 process. These inputs may contain views from those involved in the development and approval of inputs from the government and does not capture any input or review from the CSMAC working group 3.

4.4.1 Government Satellite Control – First Submittal – October 2012

DEPARTMENT OF DEFENSE

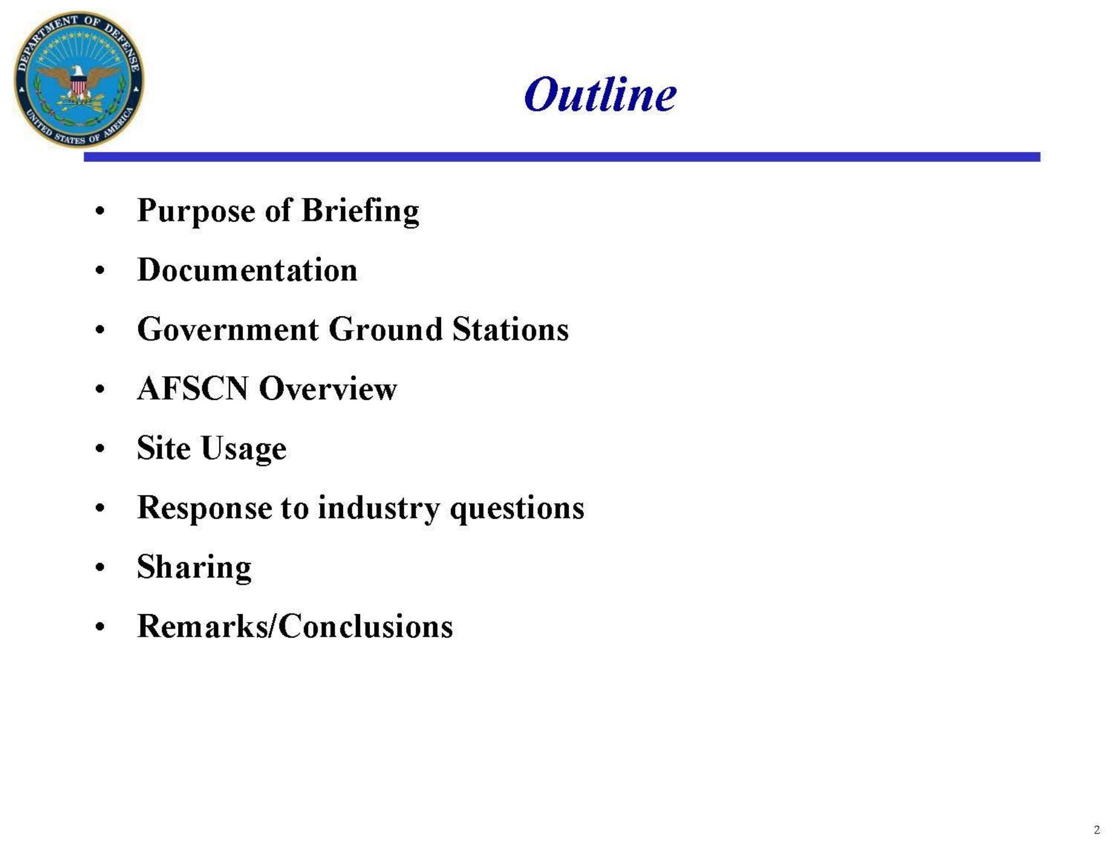
UNITED STATES OF AMERICA

Government Satellite Control Overview

Col Harold Martin

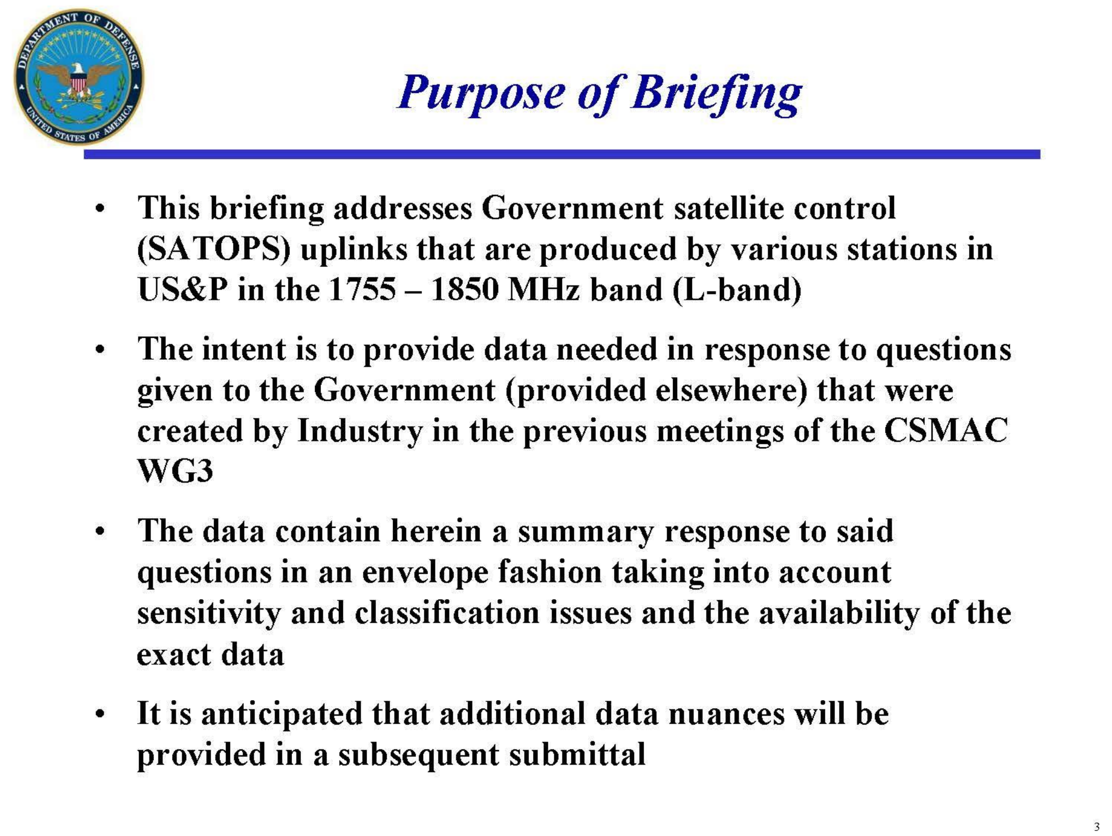
Dr. Albert Merrill

2 October 2012



Outline

- Purpose of Briefing
- Documentation
- Government Ground Stations
- AFSCN Overview
- Site Usage
- Response to industry questions
- Sharing
- Remarks/Conclusions



Purpose of Briefing

- This briefing addresses Government satellite control (SATOPS) uplinks that are produced by various stations in US&P in the 1755 – 1850 MHz band (L-band)
- The intent is to provide data needed in response to questions given to the Government (provided elsewhere) that were created by Industry in the previous meetings of the CSMAC WG3
- The data contain herein a summary response to said questions in an envelope fashion taking into account sensitivity and classification issues and the availability of the exact data
- It is anticipated that additional data nuances will be provided in a subsequent submittal

Documentation

- **NTIA: "An Assessment of the Viability of Accommodating Wireless Broadband in the 1755 - 1850 MHz Band, Mar 12"**
  - See Pages 30-32, B-23-B-28, D-22
- **NTIA: "The Potential For Accommodating Third Generation Mobile Systems In The 1710 - 1850 MHz Band, Mar 2001"**
- **SGLS specifications: ICD-000502B, 6 Feb 12**
- **For Official Use Only DoD internal data bases are used to create this briefing**
- **The material in this presentation is available for public release**
- **Address further documentation requests to Col Martin**

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Basic Concept

- **This data is a reasonably accurate engineering summary response to industry questions**
- **The intent is to satisfy basic industry needs without violating Government sensitivity/classification requirements**
- **This is only a snapshot of the present and near future SATOPS L-band use**
- **This data will change in the future**
- **Any conclusions, sharing arrangements, or license agreements, etc. must be left to future additional data surveys and senior policy determinations**

This only defines the general scope

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Government Tracking Stations

(from NTIA report)

AFSCN

- Vandenberg Tracking Station, Vandenberg AFB, California (VTS)
- New Hampshire Tracking Station, New Boston AFS, New Hampshire (NHS)
- Thule Tracking Station, Thule Air Base, Greenland (TTS)
- Guam Tracking Station, Andersen AFB, Guam (GTS)
- Hawaii Tracking Station, Kaena Point, Oahu, Hawaii (HTS)
- Colorado Tracking Station, Schriever AFB, Colorado (CTS)
- Oakhanger Telemetry and Command Station, Borden, Hampshire, England (TCS)
- Diego Garcia Tracking Station, British Indian Ocean Territory, Diego Garcia (DGS)
- Eastern Vehicle Checkout Facility, Cape Canaveral AFS, Florida (EVCF) (Launch support only)

Navy Facilities

- Prospect Harbor, Maine (Navy) (PH, ME)
- Laguna Peak, California (Navy) (LP, CA)
- Blossom Point, Maryland (BP, MD)
- Quantico, Virginia (QN, VA)

Other Facilities

- Laurel, Maryland (L, MD)
- Buckley AFB, Colorado (BAFB)
- Fairbanks (NOAA), Alaska (FB, AK)
- Joint Base San Antonio, Texas (SA, TX)
- Kirtland AFB, New Mexico (KAFB)
- Fort Belvoir, Virginia (FB, VA)
- Camp Parks, California (CP, CA)

Government SATOPS

Air Force Satellite Control Network
and the Navy Satellite Control Network

24/7 Global Access to Satellites

Support 100% of NSS Launches
Provide Support to Other Launches (e.g., NASA, NOAA, Commercial)

Launch and Early Orbit, Payload and Bus Mgmt, Payload Data, Emergency/Anomaly Recovery & Disposal Ops

SATOPS Users

AFSCN and NAVSOC supports both DoD and non-DoD National Security Satellites, NASA, NOAA, R&D

Examples: GPS (military/civilian utilization), communications, weather and other missions providing essential space support for military operations <u>and essential civilian use</u>

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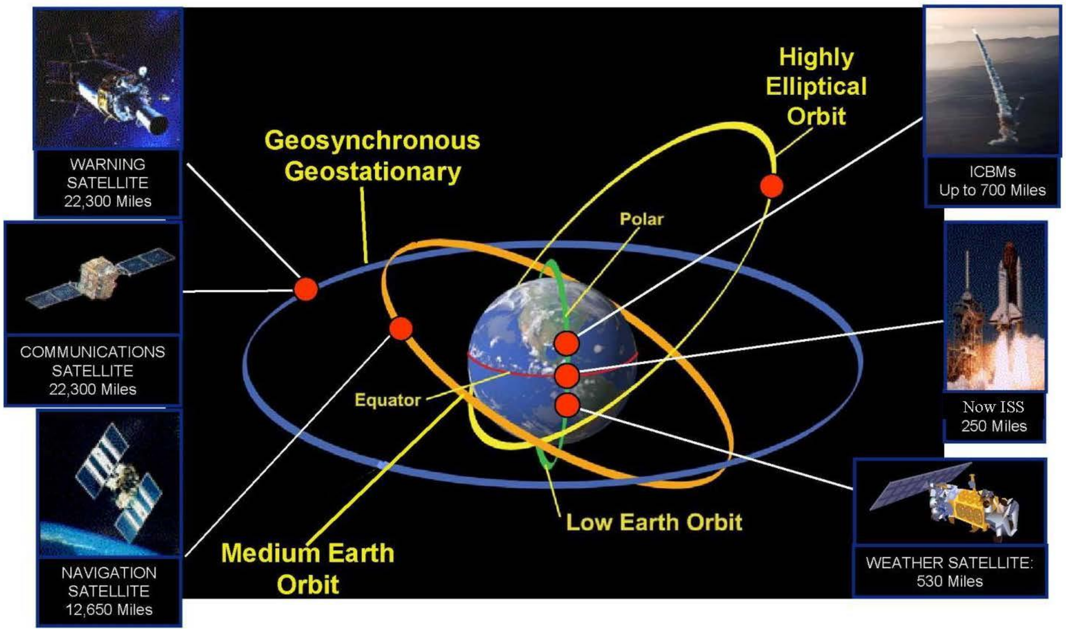
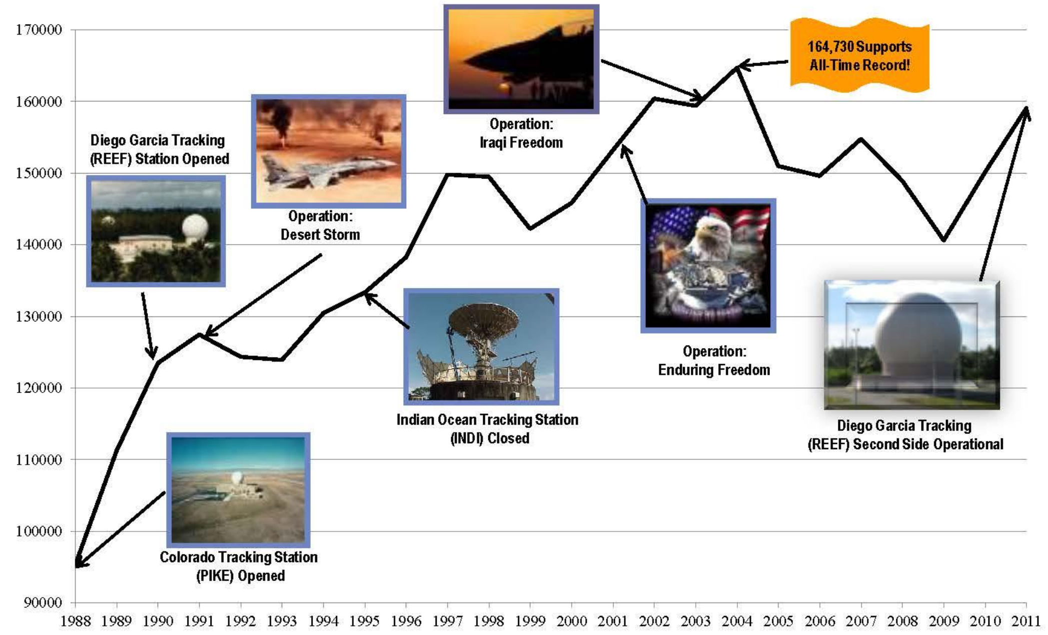
AFSCN Supported Orbits



2112

AFSCN Support Count



164,730 Supports All-Time Record!

Diego Garcia Tracking (REEF) Station Opened

Operation: Desert Storm

Operation: Iraqi Freedom

Operation: Enduring Freedom

Indian Ocean Tracking Station (INDI) Closed

Diego Garcia Tracking (REEF) Second Side Operational

Colorado Tracking Station (PIKE) Opened

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AFSCN Ops

- **Satellite Command and Control Operations for World Wide Assured Access**
  - Launch Support / Payload Deployment
  - Early Orbit Checkout/Calibration
  - Emergency Rescue/Anomaly Resolution
  - Position Mgmt, Fuel Management
  - Satellite Health, Maintenance & Configuration
  - Mission data reception, relay and dissemination for multiple users
  - High-power commanding for anomalous satellites and vehicle emergencies
  - Active tracking for precise orbit determination
- **Resource Scheduling & Control**
  - Deconfliction & Resource Allocation
  - Day-to-day operations with constant satellite support per day
- **Orbital Analysis**
  - Radio Frequency Interference Analysis
  - Assistance in Collision Avoidance

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New Boston Air Force Station, NH

2115

Prospect Harbor, ME

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Typical Daily AFSCN Scheduling Sequence

- **Based on inputs from satellite users, 22 SOPS publishes the daily schedule of AFSCN satellite contacts**
  - Covers 24 hr period, operations are continuous unless there is maintenance
  - Has an average of approximately 25 contacts per antenna in each 24 hr period
  - Schedule specifies for every satellite contact:
    - Site
    - Satellite #
    - Start/stop time
    - Equipment configuration incl. power level and transmit frequencies
- **Operations at RTSs**
  - Each satellite contact includes setup time, satellite contact time for sending commands, doing ranging, and receiving telemetry
  - Satellite contact times can be a few as 15 minutes or as long as several hours, depending on the orbit and mission requirements

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General DoD Site Information

- **Antenna patterns follow classical parabolic characteristics and are provided separately**
- **All sites adhere to NTIA Manual 5.6.2 that limits all SATOPS radiation to 3 degrees or higher**
- **All sites transmit over a 360 degrees azimuth as needed**
- **All sites listed only are used for uplink radiation in L-band**
- **For sites with multiple antennas, the percentage of radiation from at least one antenna as averaged over a year is presented in a later chart**
- **For sites with multiple antennas, only maximum gain and power are presented**
- **Question was asked regarding the Oakhanger, UK AFSCN RTS exclusion zones and the Government accepts the OFCOM information supplied by Industry in a previous meeting and views this matter closed**

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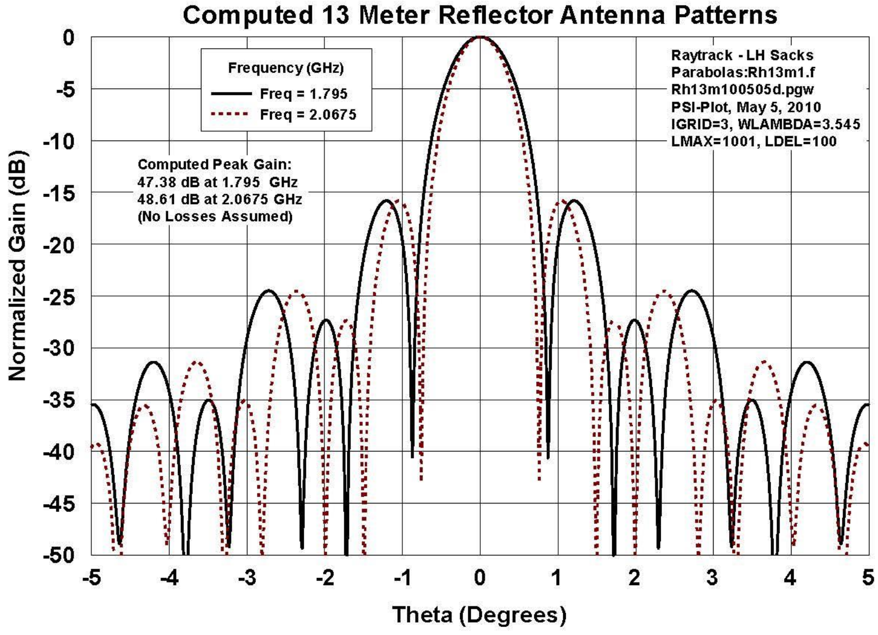
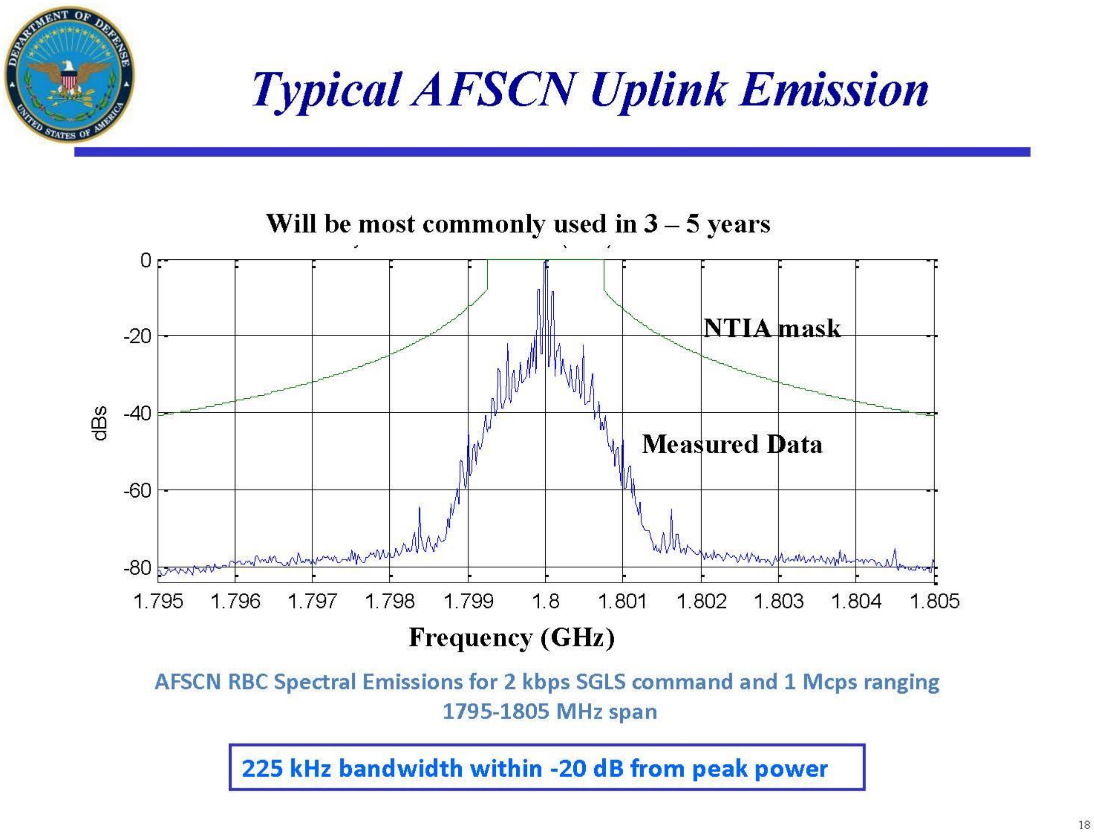
General Operational Information

- **90% of all SATOPS L-band radiation in US&P is done by four major AFSCN sites**
  - NHS, VTS, HTS, GTS
  - Only one spacecraft supported for each antenna for any given time (typically 2 antennas/site)
  - All AFSCN sites support all channels and have same basic configurations
- **AFSCN supports more than 150 spacecraft**
  - LEOs, MEOs, and GEOs are supported as required with no preset order
  - ~40% of all spacecraft are GEOs
  - ~17% of the total spacecraft are in 1755 – 1780 MHz band
  - About 45% of all spacecrafts have multiple frequencies in L-band
  - About 40% have additional bands which are not suitable for SATOPS assured access
  - Approximately 3% are configured for 2025 – 2110 MHz operations
- **AFSCN traditionally has used 20 channels with 4 MHz width**
  - Now uses 440 channels with 160 kHz separation
  - Several modulation formats are used (1 kilosymbol commands plus ranging is most common)
  - Spacecrafts have been assigned frequencies with this new width for the last 5 years
  - Power varies from 500 W (4%), 1000 W (95%), 2250 W (1%), 7244 W (0.1%)
  - High power used only for anomalies
- **Anomalies (~ 1%) require maximum SATOPS support using similar RTS actions**

Typical AFSCN Antenna Pattern

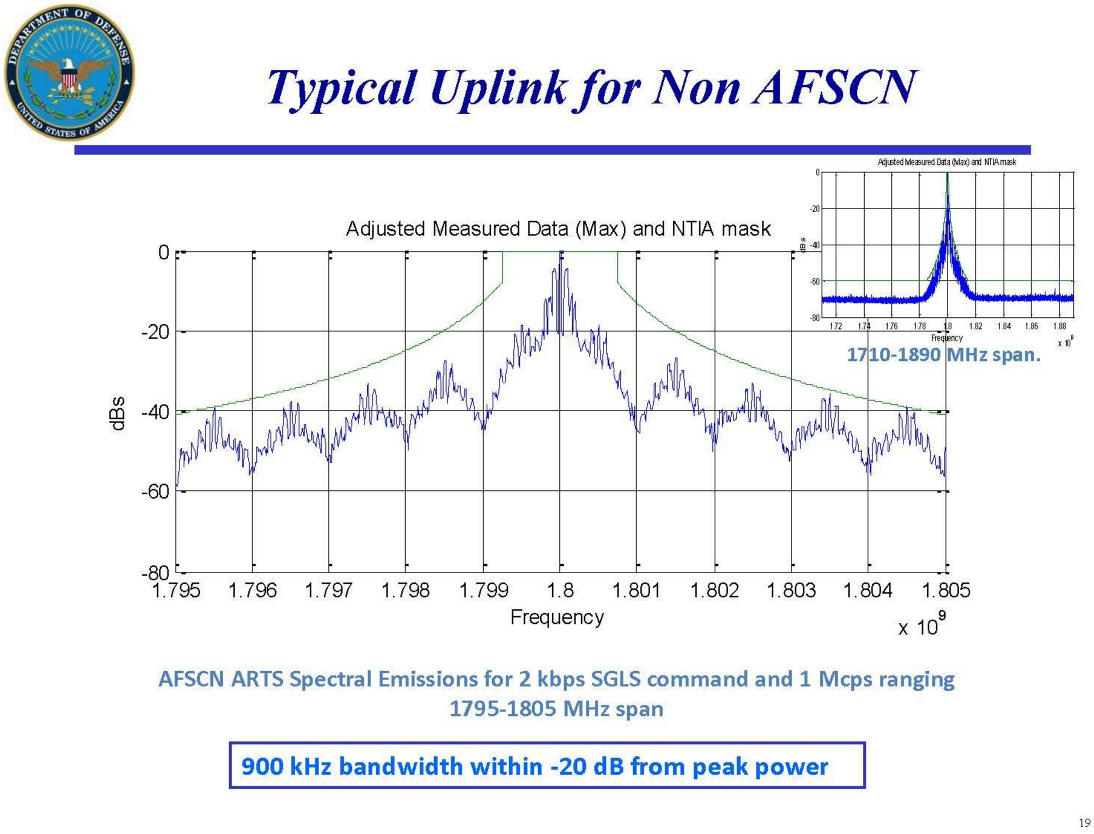




Typical AFSCN Uplink Emission

AFSCN RBC Spectral Emissions for 2 kbps SGLS command and 1 Mcps ranging
1795-1805 MHz span

225 kHz bandwidth within -20 dB from peak power

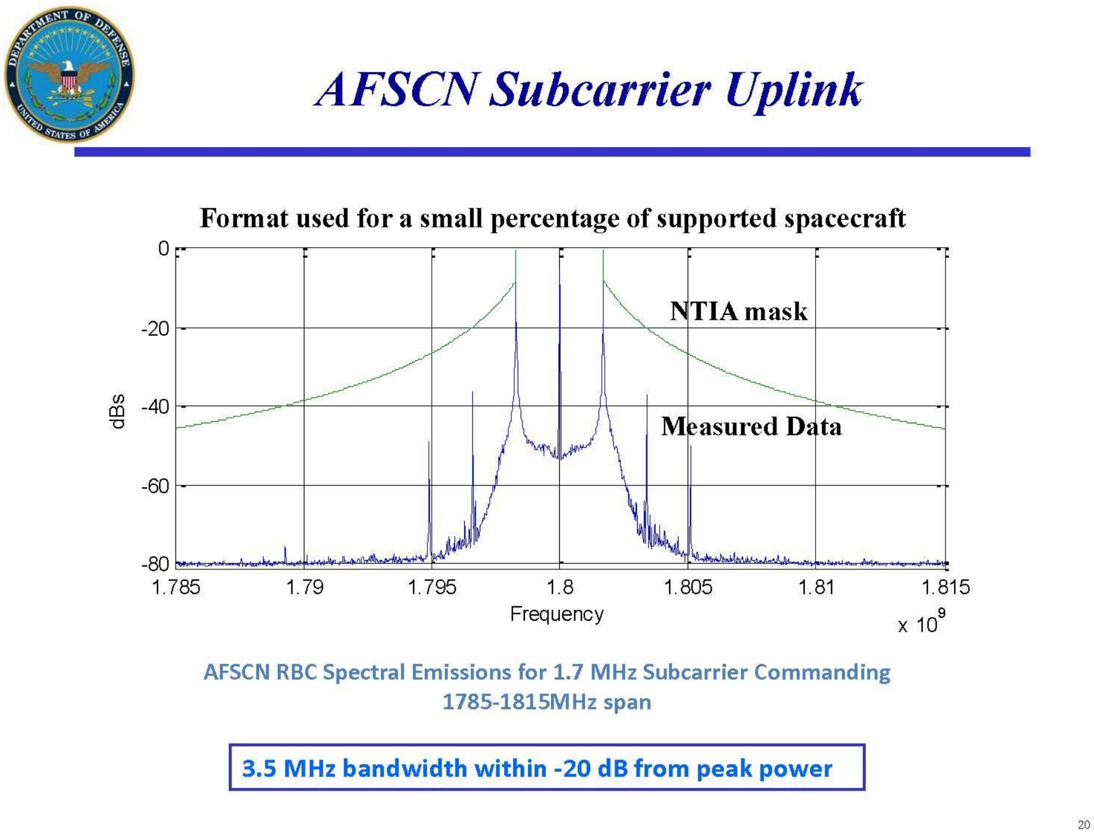


Typical Uplink for Non AFSCN

1710-1890 MHz span.

AFSCN ARTS Spectral Emissions for 2 kbps SGLS command and 1 Mcps ranging
1795-1805 MHz span

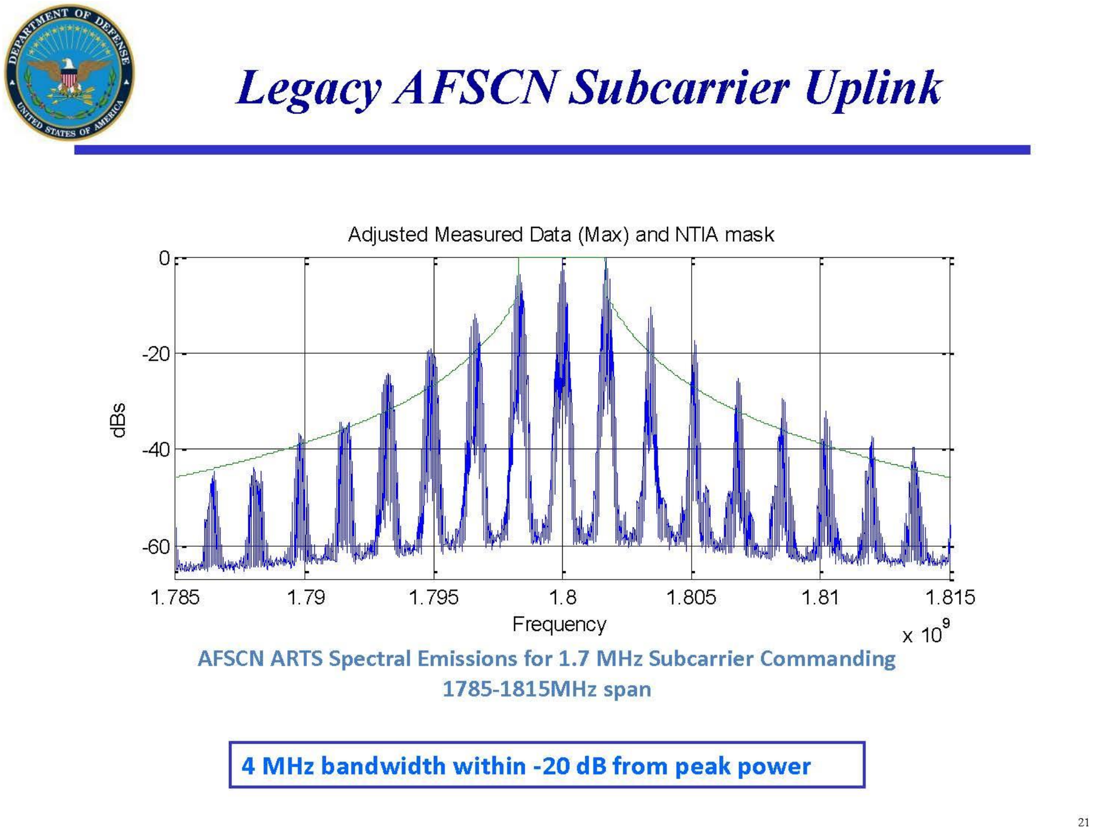
900 kHz bandwidth within -20 dB from peak power



AFSCN Subcarrier Uplink

AFSCN RBC Spectral Emissions for 1.7 MHz Subcarrier Commanding
1785-1815MHz span

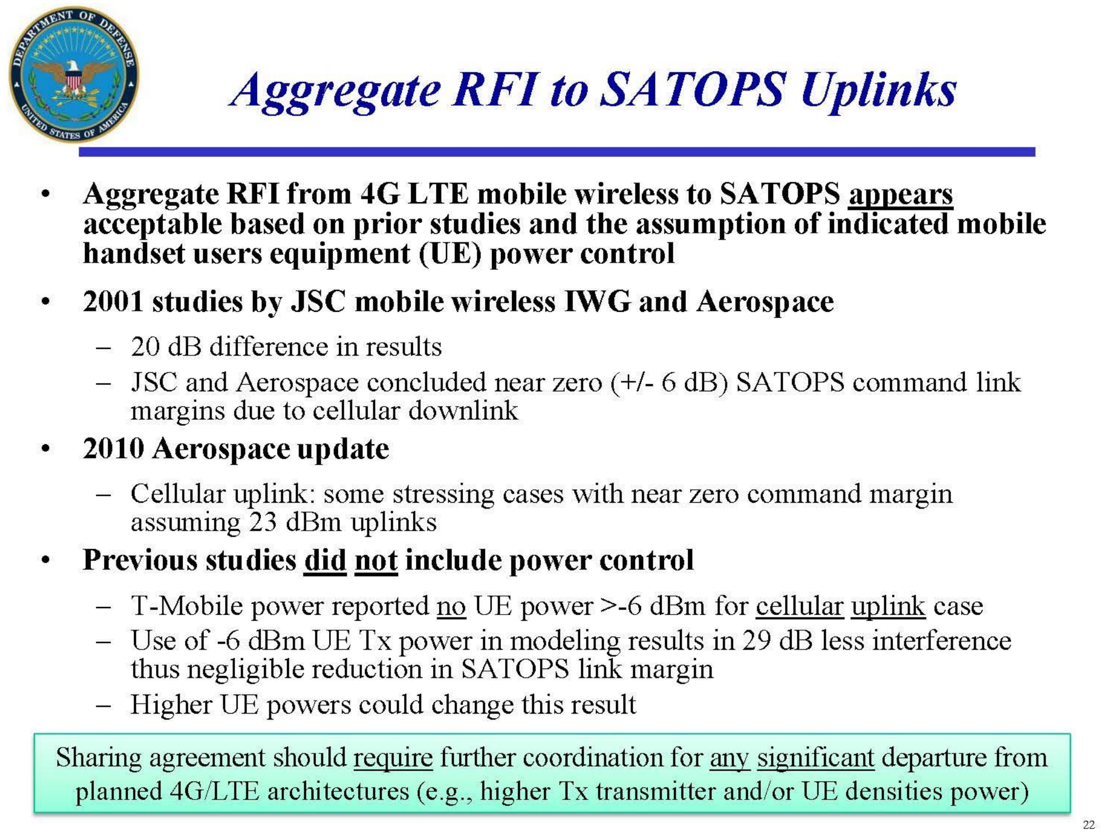
3.5 MHz bandwidth within -20 dB from peak power



Legacy AFSCN Subcarrier Uplink

AFSCN ARTS Spectral Emissions for 1.7 MHz Subcarrier Commanding
1785-1815MHz span

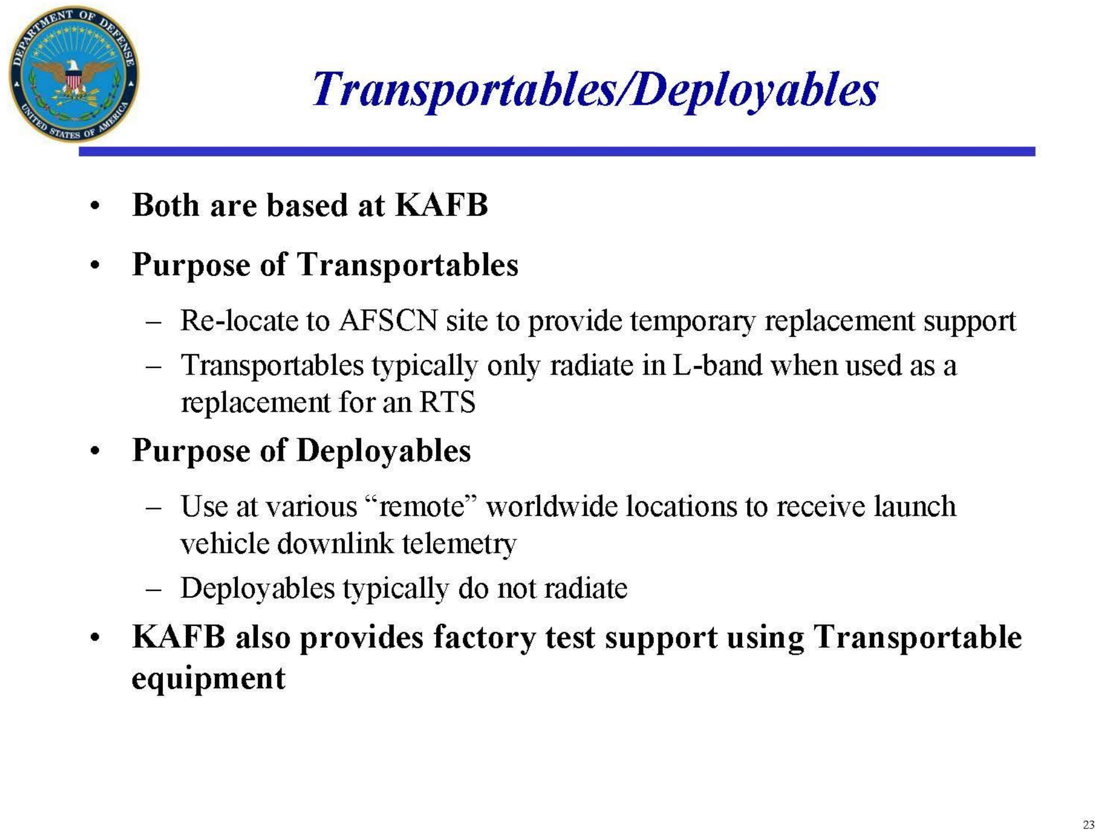
4 MHz bandwidth within -20 dB from peak power



Aggregate RFI to SATOPS Uplinks

- **Aggregate RFI from 4G LTE mobile wireless to SATOPS appears acceptable based on prior studies and the assumption of indicated mobile handset users equipment (UE) power control**
- **2001 studies by JSC mobile wireless IWG and Aerospace**
  - 20 dB difference in results
  - JSC and Aerospace concluded near zero (+/- 6 dB) SATOPS command link margins due to cellular downlink
- **2010 Aerospace update**
  - Cellular uplink: some stressing cases with near zero command margin assuming 23 dBm uplinks
- **Previous studies did not include power control**
  - T-Mobile power reported no UE power >-6 dBm for cellular uplink case
  - Use of -6 dBm UE Tx power in modeling results in 29 dB less interference thus negligible reduction in SATOPS link margin
  - Higher UE powers could change this result

Sharing agreement should require further coordination for any significant departure from planned 4G/LTE architectures (e.g., higher Tx transmitter and/or UE densities power)



Transportables/Deployables

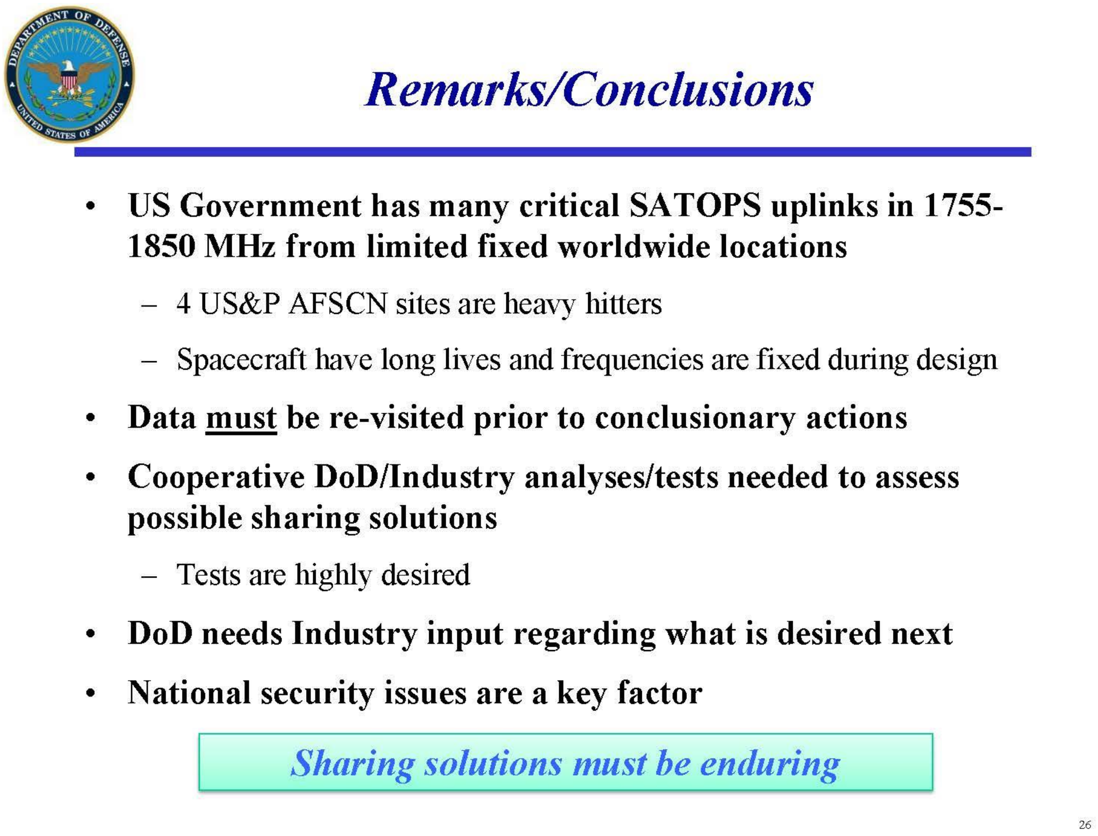
- **Both are based at KAFB**
- **Purpose of Transportables**
  - Re-locate to AFSCN site to provide temporary replacement support
  - Transportables typically only radiate in L-band when used as a replacement for an RTS
- **Purpose of Deployables**
  - Use at various “remote” worldwide locations to receive launch vehicle downlink telemetry
  - Deployables typically do not radiate
- **KAFB also provides factory test support using Transportable equipment**

US&P Site List

Government Sites	Latitude	Longitude	Elevation above MSL (m)	Max Radiated Power (dBW)	Max Antenna Gain (dB)	Auth Spectrum Use (MHz)
VTS	34-49-22.8N	120-30-7.2W	269	37.1	45	81
NHS	42-56-45.6N	71-37-44.4W	200	38.6	45	81
GTS	13-36-54N	144-51-21.6E	218	37.1	45.1	81
HTS	21-33-43.2N	158-14-31.2W	430	32.1	45.4	81
CTS	38-48-21.6N	104-31-40.8W	1910	31.2	45	81
EVCF	28-29-09N	080-34-33W	-15	23	28	81
BP, MD	38-25-53.5N	77-05-06.4W	19	25	46	81
L, MD	Not Applicable					
BAFB	39-42-55N	104-46-29W	1688	32	43	81
FB, AK	64-48-14N	14-75-23.4W	415.7	20	43	81
SA, TX						
KAFB	34-59-46N	106-30-28W	1631	28	38.4	81
FB, VA						
QN, VA						
CP, CA	37-43-51N	121-52-50W		30	42	81
PH, ME	44-24-16N	068-00-46W	9.1	31	38	81
LP, CA	34-06-31N	119-03-53W	460.2	31	43	81

Sharing

- **DoD has studied this issue**
- **T-Mobile spectrum survey/compatibility test**
- **SATOPS uplink impact to mobile wireless**
- **Mobile wireless impact to SATOPS uplinks**
- **Possible mitigation techniques**
- **Possible cooperative tests**



Remarks/Conclusions

- **US Government has many critical SATOPS uplinks in 1755-1850 MHz from limited fixed worldwide locations**
  - 4 US&P AFSCN sites are heavy hitters
  - Spacecraft have long lives and frequencies are fixed during design
- **Data <u>must</u> be re-visited prior to conclusionary actions**
- **Cooperative DoD/Industry analyses/tests needed to assess possible sharing solutions**
  - Tests are highly desired
- **DoD needs Industry input regarding what is desired next**
- **National security issues are a key factor**

Sharing solutions must be enduring

4.4.2 Sharing and Interference Mitigation – February 2013

Sharing and Interference Mitigation Techniques

Col Harold Martin
Mr. Matthew Clark
Dr. Albert Merrill

6 Feb 2013

Purpose

Discuss key techniques that may be applicable to mitigate interference between satellite earth station transmissions and mobile wireless (MW) LTE base station receivers

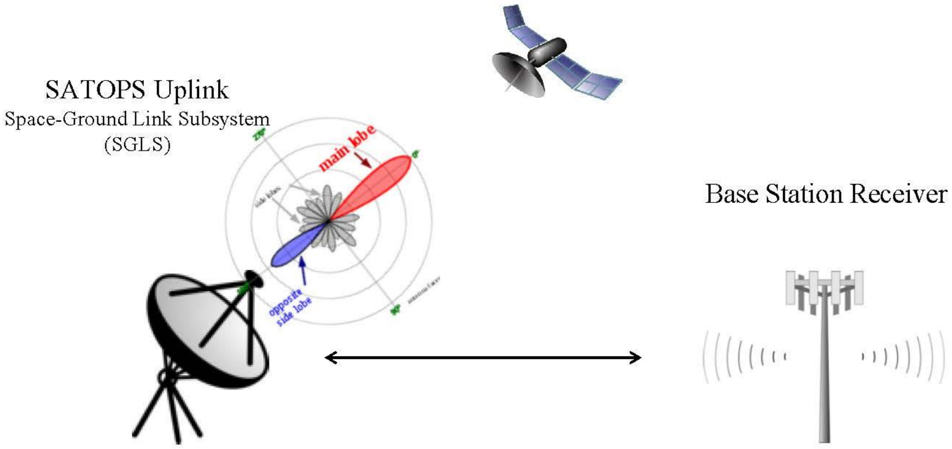
Agenda

- **SATOPS-MW Sharing Basics**
- **Benefit of Mitigations**
- **Mitigation Techniques**
  - Shielding
  - Cell Tower Antenna Configuration
  - Dynamic Spectrum Access (DSA) Time/Frequency Sharing
  - Filtering
  - Signal Cancellation
  - Other Techniques (per CSMAC WG3 doc 38)
  - Possible Future Techniques
- **Summary of Mitigations**
- **Conclusions**

SATOPS-MW 1755-1850 MHz Sharing Basics

SATOPS Uplink
Space-Ground Link Subsystem
(SGLS)

Base Station Receiver



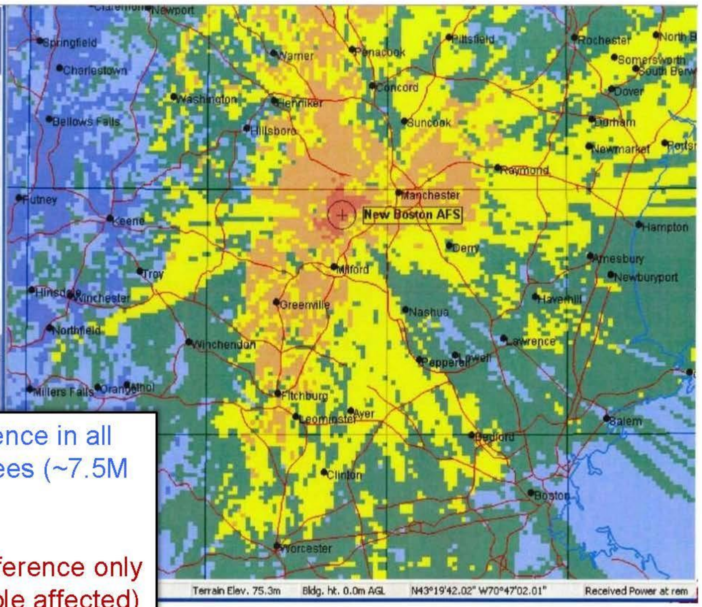
EIRP: ~ +104 dBm

Interference threshold:
~ -107 dBm

Required separation distance is proportional to the interference power received at the Base Station

Possible Benefit of Mitigation

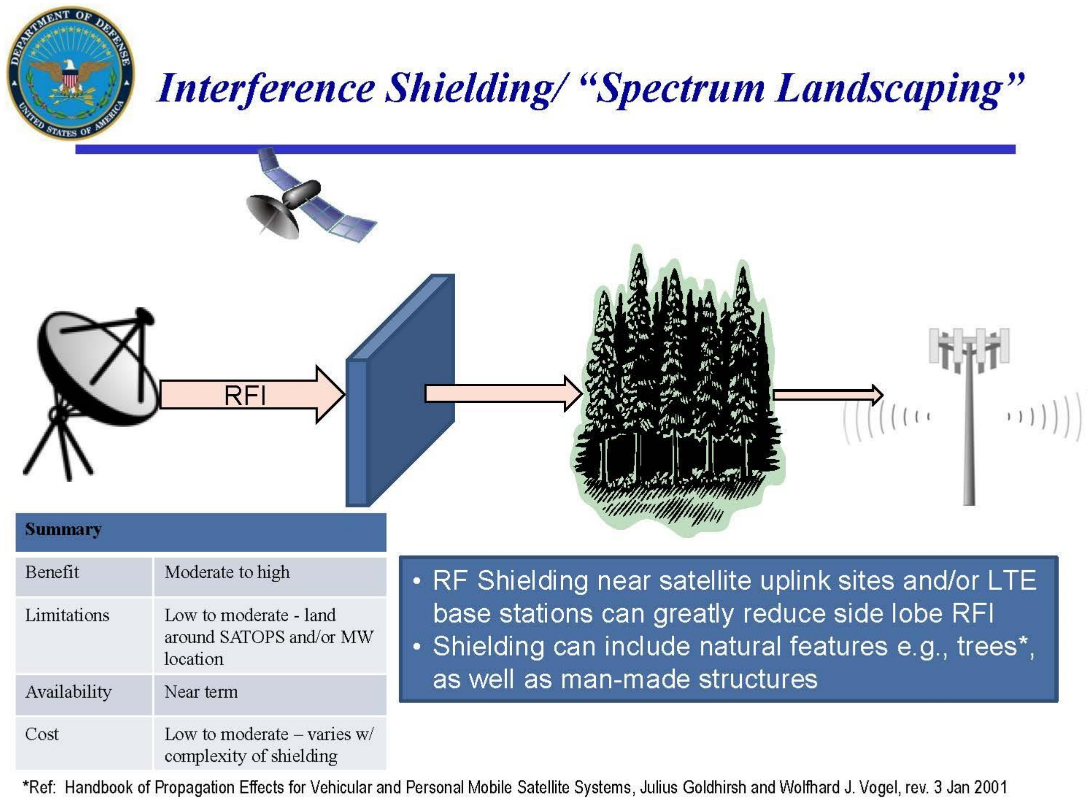
Received Power Level (dBmW)	Year 2000 Census Population (Thousands)
> -20	4
-40 to -20	168
- 60 to -40	962
-80 to -60	3,322
-100 to -80	3,016
-120 to -100	5,786
< -120	23,041



No mitigation: interference in all colors to varying degrees (~7.5M people affected)

80dB mitigation: interference only in red areas (~4k people affected)

*Illustrative example, plot was not generated per WG1 parameters



Interference Shielding/ "Spectrum Landscaping"

Summary	
Benefit	Moderate to high
Limitations	Low to moderate - land around SATOPS and/or MW location
Availability	Near term
Cost	Low to moderate – varies w/ complexity of shielding

- RF Shielding near satellite uplink sites and/or LTE base stations can greatly reduce side lobe RFI
- Shielding can include natural features e.g., trees*, as well as man-made structures

*Ref: Handbook of Propagation Effects for Vehicular and Personal Mobile Satellite Systems, Julius Goldhirsh and Wolfhard J. Vogel, rev. 3 Jan 2001

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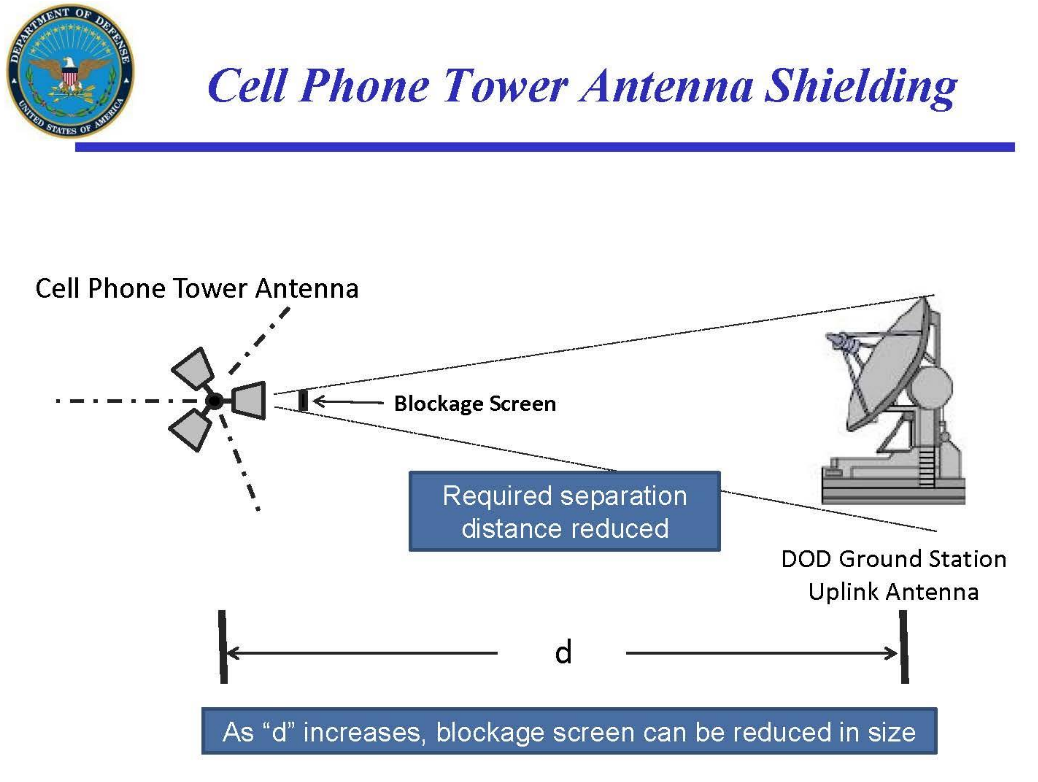
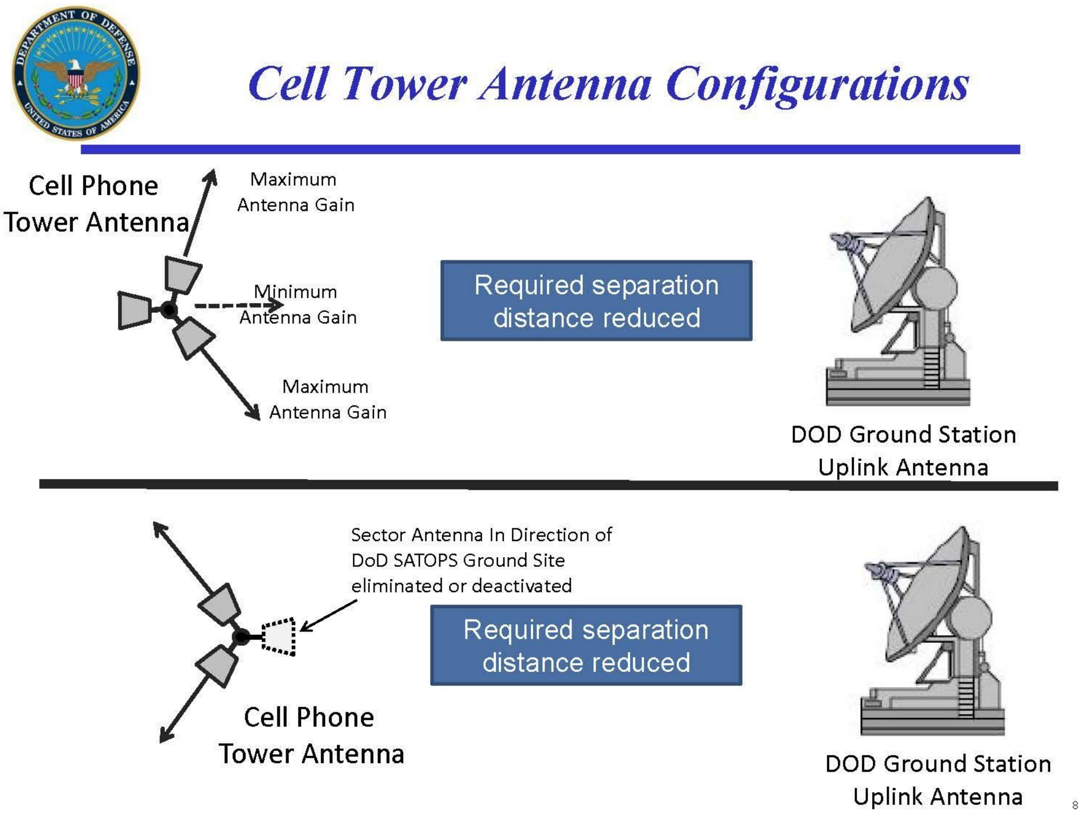


Cell Phone Tower Antenna Shielding

Required separation distance reduced

As "d" increases, blockage screen can be reduced in size

2139



Cell Tower Antenna Configurations

Cell Phone Tower Antenna

Maximum Antenna Gain

Minimum Antenna Gain

Maximum Antenna Gain

Required separation distance reduced

DOD Ground Station Uplink Antenna

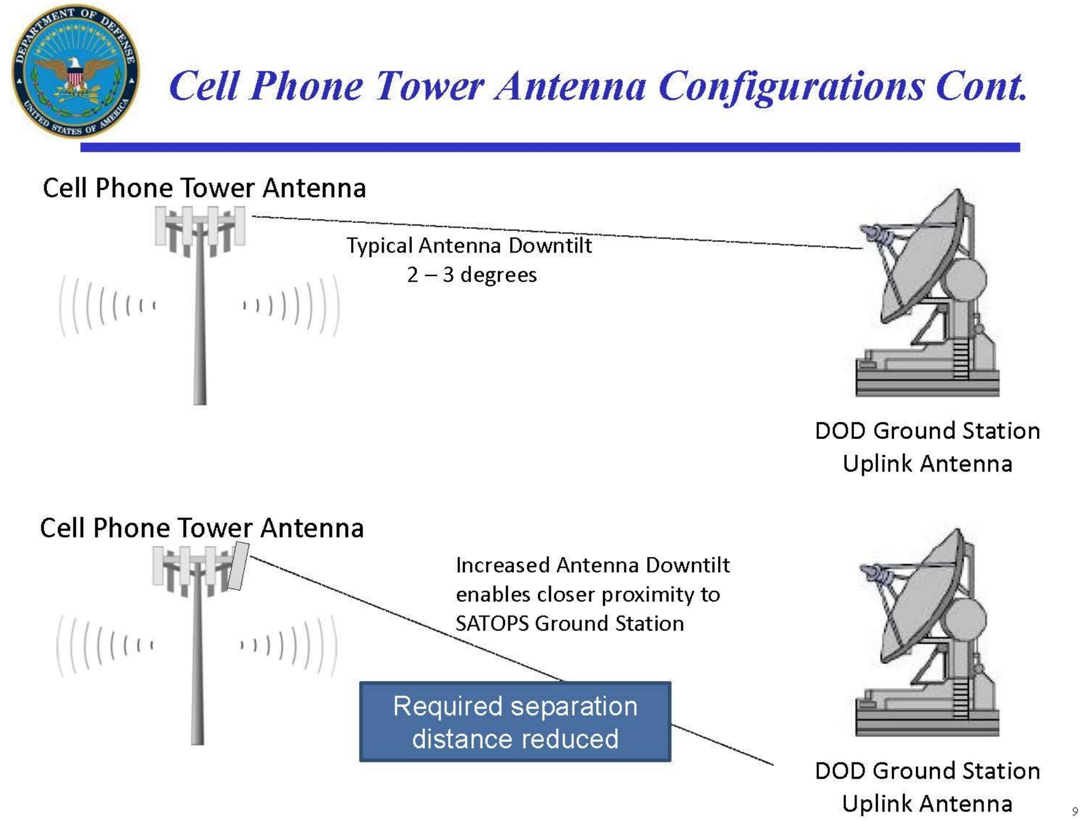
Sector Antenna In Direction of DoD SATOPS Ground Site eliminated or deactivated

Required separation distance reduced

Cell Phone Tower Antenna

DOD Ground Station Uplink Antenna

2140



Cell Phone Tower Antenna Configurations Cont.

Cell Phone Tower Antenna

Typical Antenna Downtilt 2 – 3 degrees

DOD Ground Station Uplink Antenna

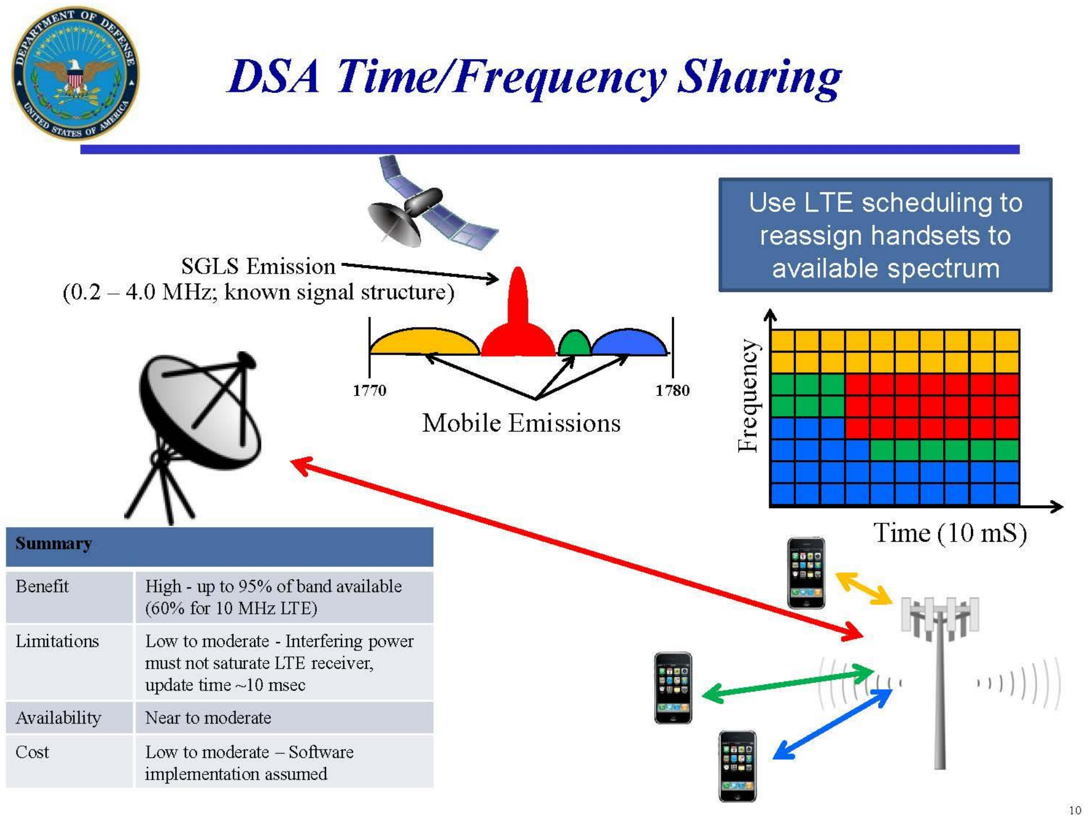
Cell Phone Tower Antenna

Increased Antenna Downtilt enables closer proximity to SATOPS Ground Station

Required separation distance reduced

DOD Ground Station Uplink Antenna

2141

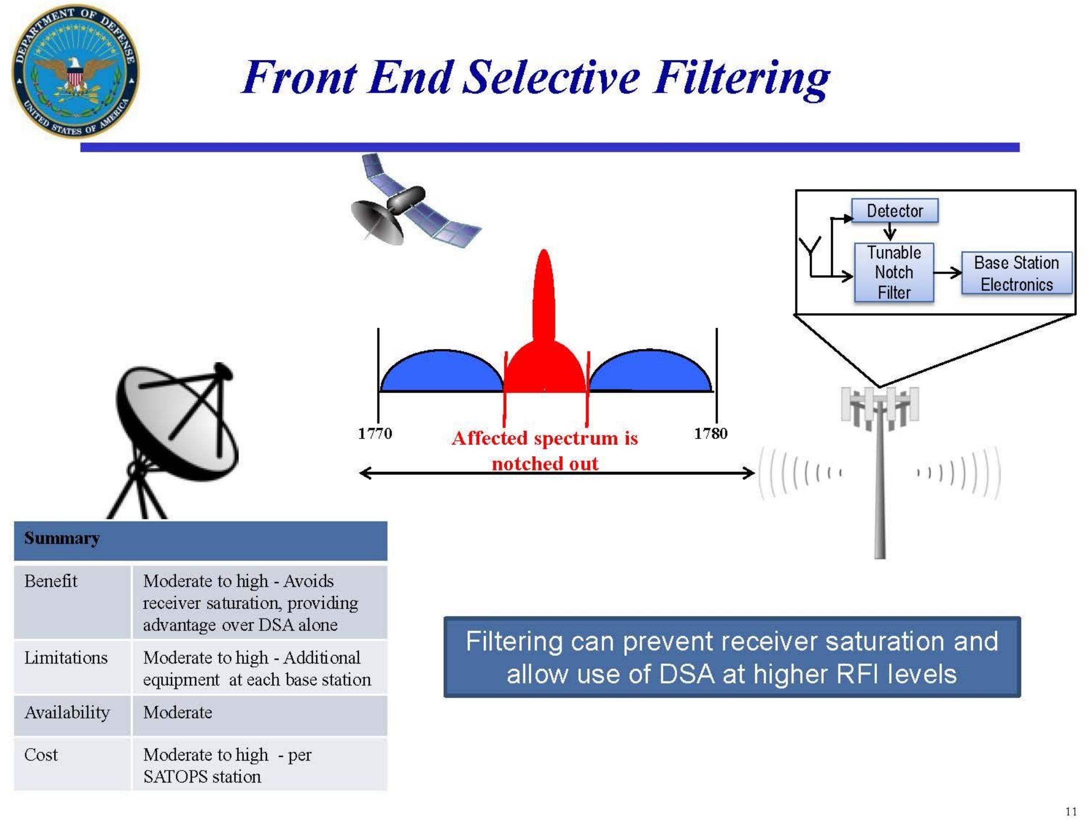


DSA Time/Frequency Sharing

Use LTE scheduling to reassign handsets to available spectrum

SGLS Emission
(0.2 – 4.0 MHz; known signal structure)

Summary	
Benefit	High - up to 95% of band available (60% for 10 MHz LTE)
Limitations	Low to moderate - Interfering power must not saturate LTE receiver, update time ~10 msec
Availability	Near to moderate
Cost	Low to moderate – Software implementation assumed

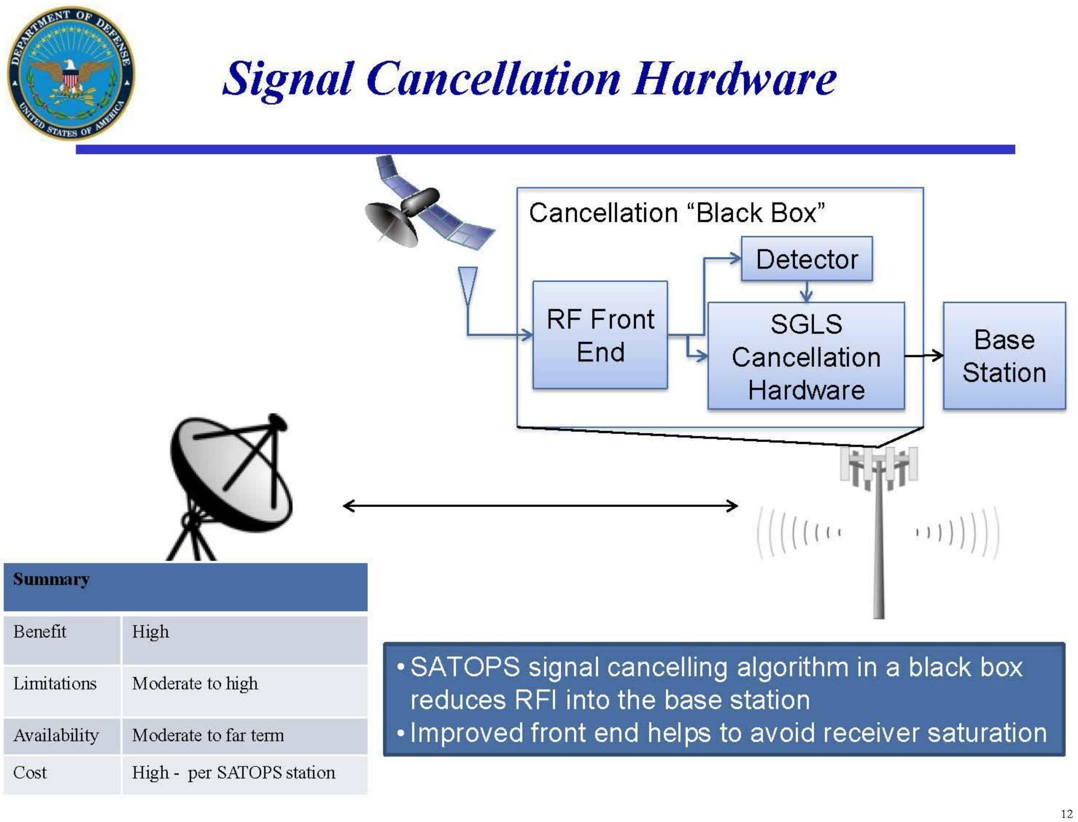


Front End Selective Filtering

Affected spectrum is notched out

Summary	
Benefit	Moderate to high - Avoids receiver saturation, providing advantage over DSA alone
Limitations	Moderate to high - Additional equipment at each base station
Availability	Moderate
Cost	Moderate to high - per SATOPS station

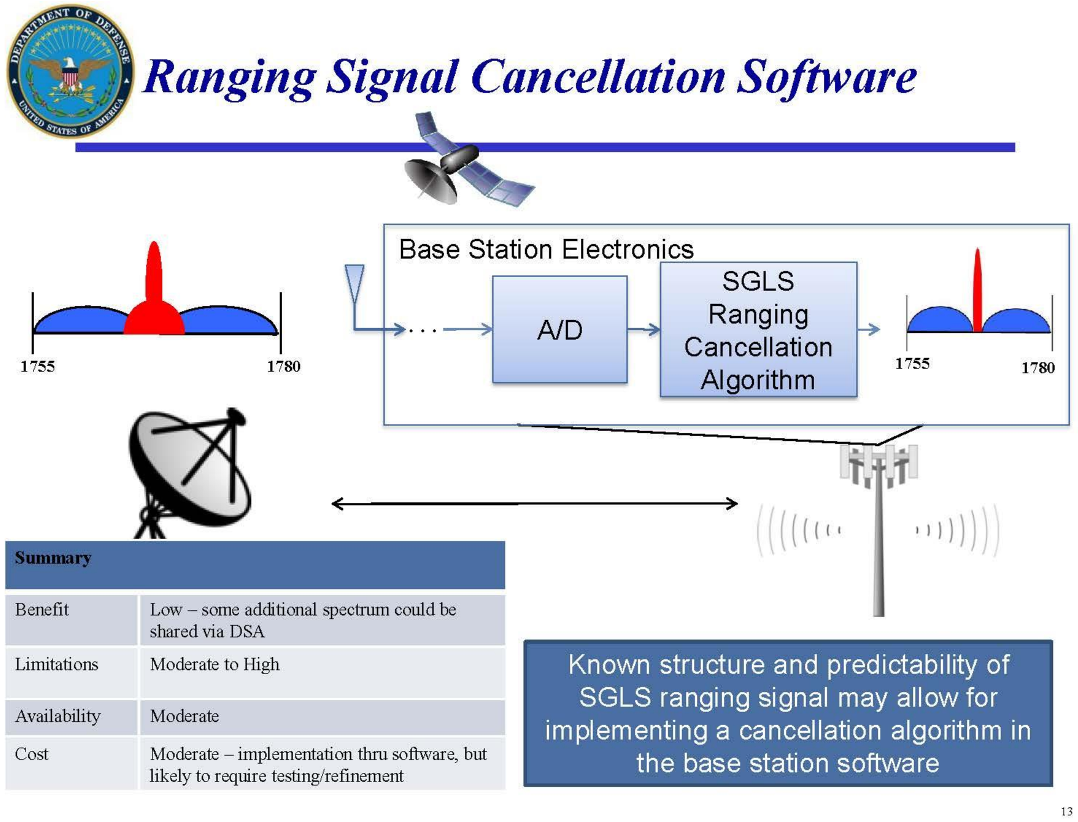
Filtering can prevent receiver saturation and allow use of DSA at higher RFI levels



Signal Cancellation Hardware

Summary	
Benefit	High
Limitations	Moderate to high
Availability	Moderate to far term
Cost	High - per SATOPS station

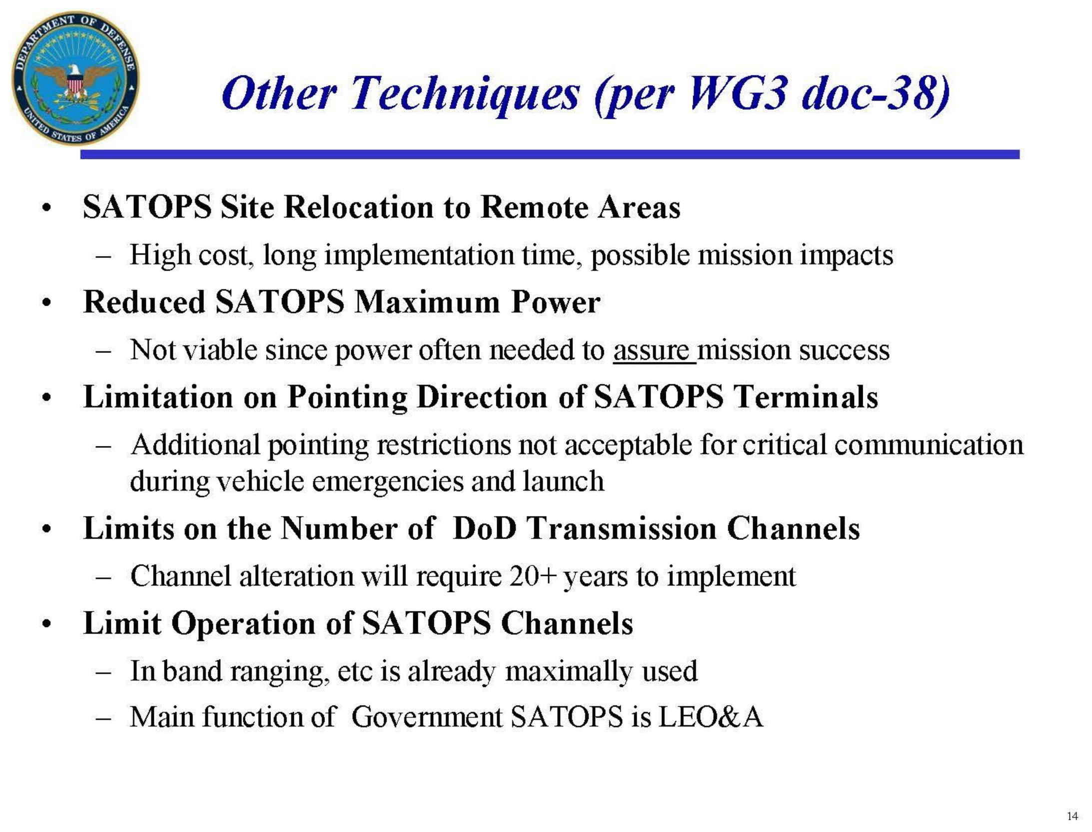
- SATOPS signal cancelling algorithm in a black box reduces RFI into the base station
- Improved front end helps to avoid receiver saturation



Ranging Signal Cancellation Software

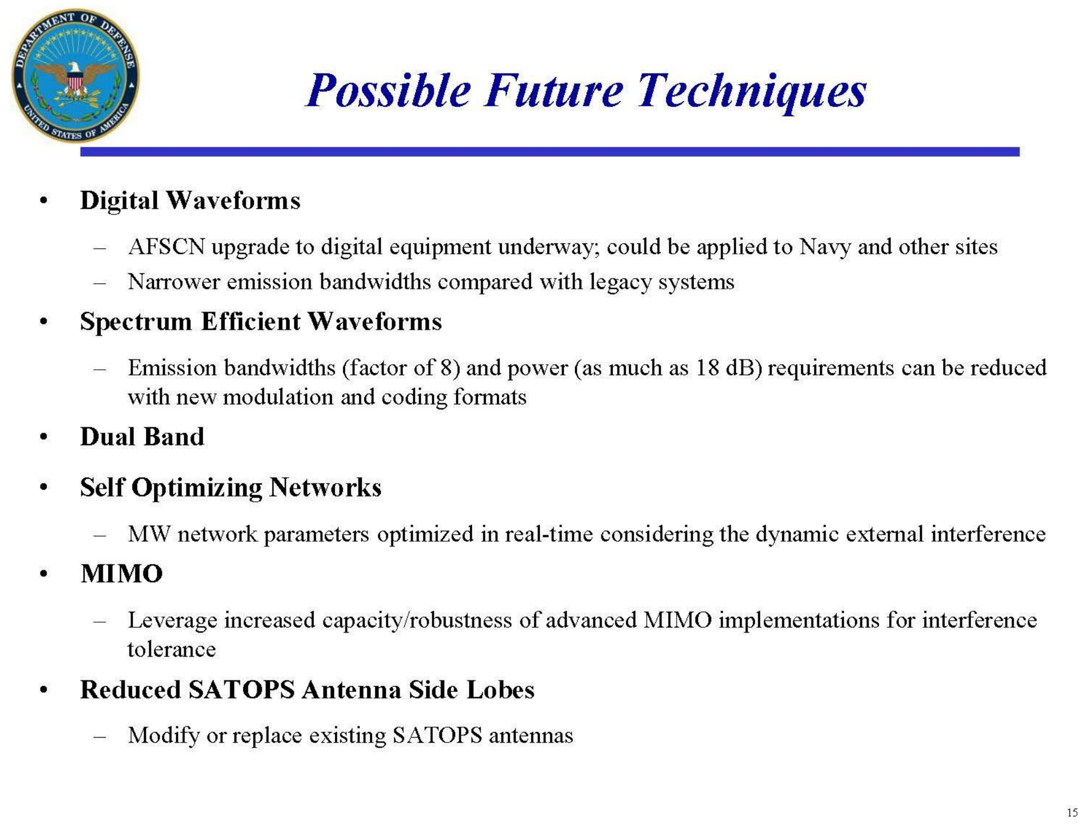
Summary	
Benefit	Low – some additional spectrum could be shared via DSA
Limitations	Moderate to High
Availability	Moderate
Cost	Moderate – implementation thru software, but likely to require testing/refinement

Known structure and predictability of SGLS ranging signal may allow for implementing a cancellation algorithm in the base station software



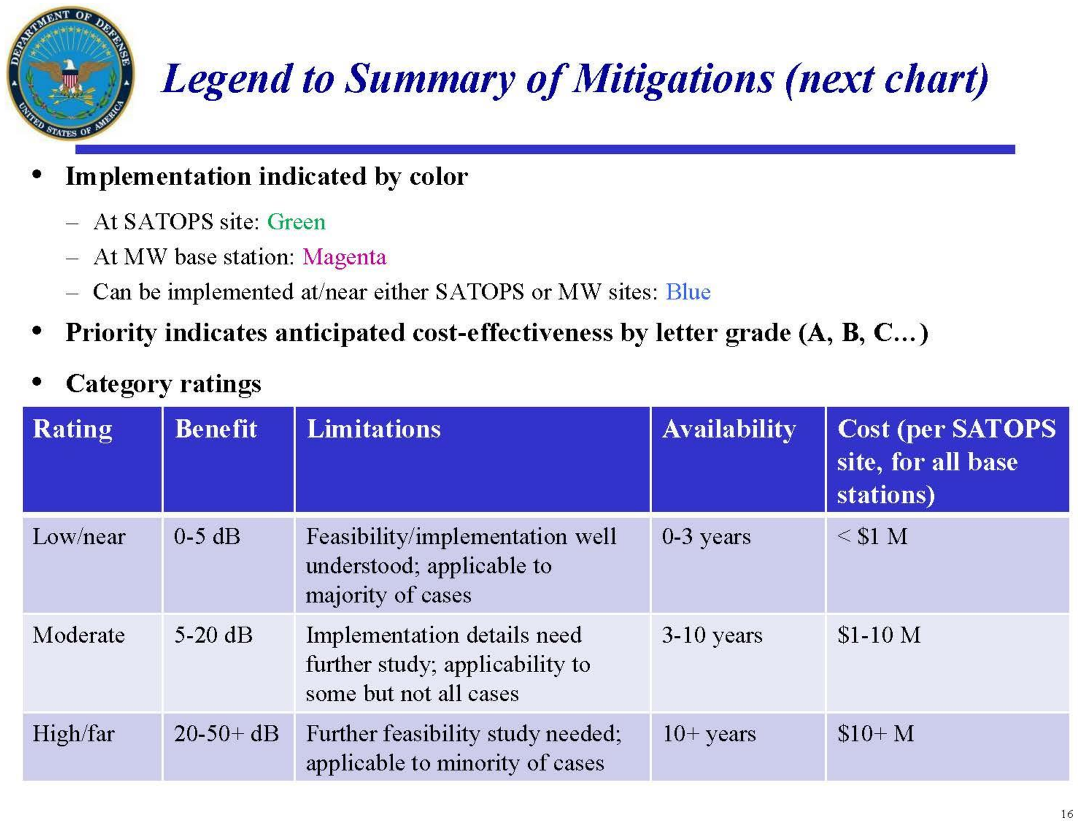
Other Techniques (per WG3 doc-38)

- **SATOPS Site Relocation to Remote Areas**
  - High cost, long implementation time, possible mission impacts
- **Reduced SATOPS Maximum Power**
  - Not viable since power often needed to assure mission success
- **Limitation on Pointing Direction of SATOPS Terminals**
  - Additional pointing restrictions not acceptable for critical communication during vehicle emergencies and launch
- **Limits on the Number of DoD Transmission Channels**
  - Channel alteration will require 20+ years to implement
- **Limit Operation of SATOPS Channels**
  - In band ranging, etc is already maximally used
  - Main function of Government SATOPS is LEO&A



Possible Future Techniques

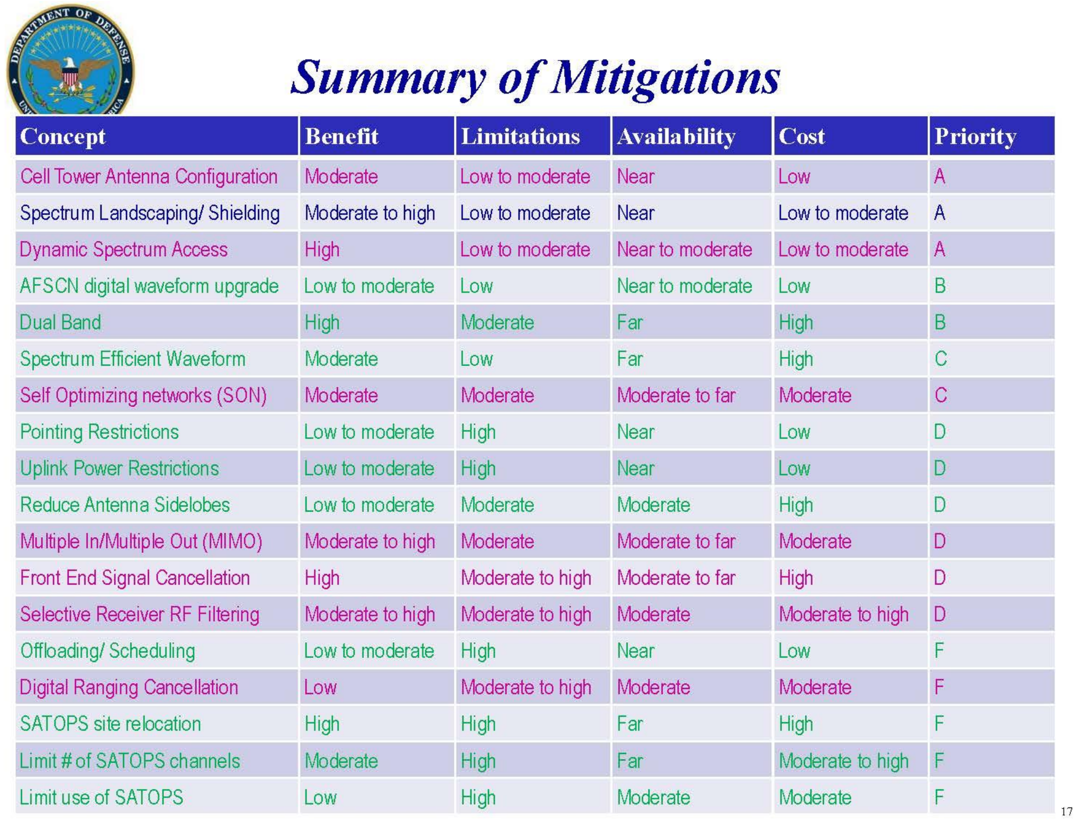
- **Digital Waveforms**
  - AFSCN upgrade to digital equipment underway; could be applied to Navy and other sites
  - Narrower emission bandwidths compared with legacy systems
- **Spectrum Efficient Waveforms**
  - Emission bandwidths (factor of 8) and power (as much as 18 dB) requirements can be reduced with new modulation and coding formats
- **Dual Band**
- **Self Optimizing Networks**
  - MW network parameters optimized in real-time considering the dynamic external interference
- **MIMO**
  - Leverage increased capacity/robustness of advanced MIMO implementations for interference tolerance
- **Reduced SATOPS Antenna Side Lobes**
  - Modify or replace existing SATOPS antennas



Legend to Summary of Mitigations (next chart)

- **Implementation indicated by color**
  - At SATOPS site: Green
  - At MW base station: Magenta
  - Can be implemented at/near either SATOPS or MW sites: Blue
- **Priority indicates anticipated cost-effectiveness by letter grade (A, B, C…)**
- **Category ratings**

Rating	Benefit	Limitations	Availability	Cost (per SATOPS site, for all base stations)
Low/near	0-5 dB	Feasibility/implementation well understood; applicable to majority of cases	0-3 years	< $1 M
Moderate	5-20 dB	Implementation details need further study; applicability to some but not all cases	3-10 years	$1-10 M
High/far	20-50+ dB	Further feasibility study needed; applicable to minority of cases	10+ years	$10+ M



Summary of Mitigations

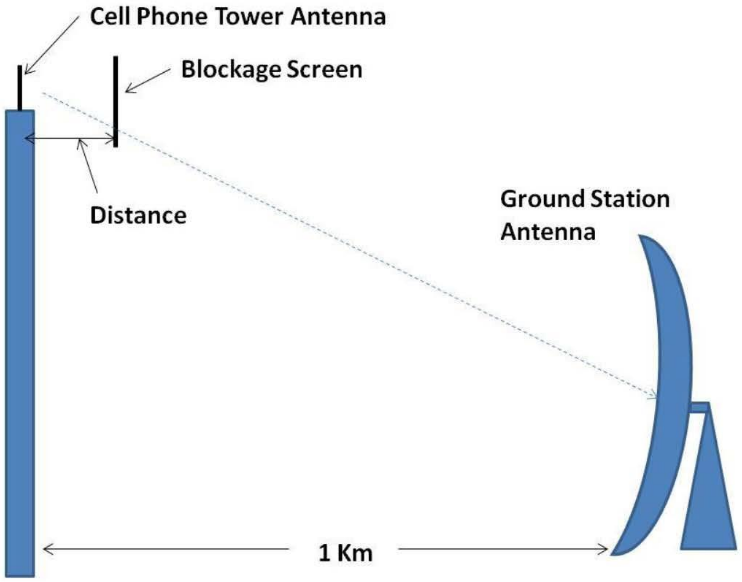
Concept	Benefit	Limitations	Availability	Cost	Priority
Cell Tower Antenna Configuration	Moderate	Low to moderate	Near	Low	A
Spectrum Landscaping/ Shielding	Moderate to high	Low to moderate	Near	Low to moderate	A
Dynamic Spectrum Access	High	Low to moderate	Near to moderate	Low to moderate	A
AFSCN digital waveform upgrade	Low to moderate	Low	Near to moderate	Low	B
Dual Band	High	Moderate	Far	High	B
Spectrum Efficient Waveform	Moderate	Low	Far	High	C
Self Optimizing networks (SON)	Moderate	Moderate	Moderate to far	Moderate	C
Pointing Restrictions	Low to moderate	High	Near	Low	D
Uplink Power Restrictions	Low to moderate	High	Near	Low	D
Reduce Antenna Sidelobes	Low to moderate	Moderate	Moderate	High	D
Multiple In/Multiple Out (MIMO)	Moderate to high	Moderate	Moderate to far	Moderate	D
Front End Signal Cancellation	High	Moderate to high	Moderate to far	High	D
Selective Receiver RF Filtering	Moderate to high	Moderate to high	Moderate	Moderate to high	D
Offloading/ Scheduling	Low to moderate	High	Near	Low	F
Digital Ranging Cancellation	Low	Moderate to high	Moderate	Moderate	F
SATOPS site relocation	High	High	Far	High	F
Limit # of SATOPS channels	Moderate	High	Far	Moderate to high	F
Limit use of SATOPS	Low	High	Moderate	Moderate	F

Conclusions

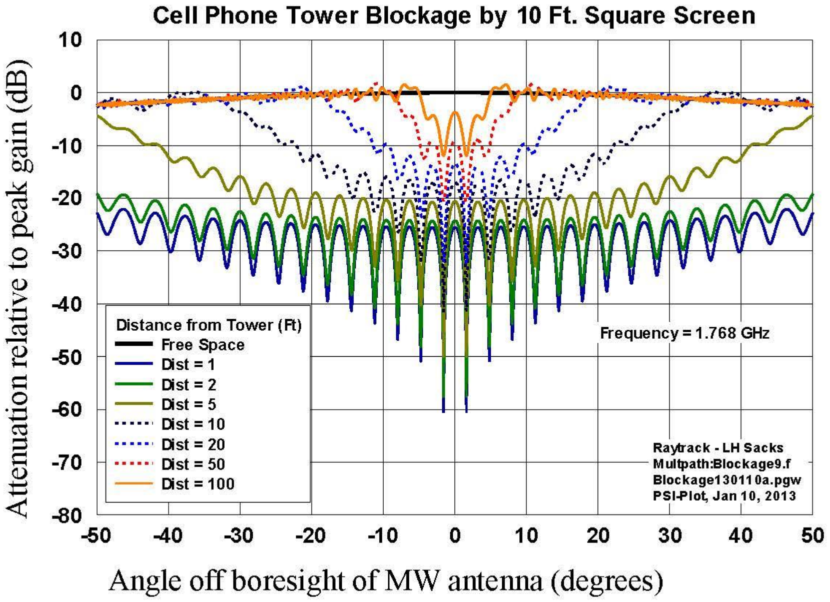
- **Shielding (at SATOPS and/or MW site) offers low cost reduction of RFI**
- **DSA allows high percentage of MW spectrum use in RFI impacted areas**
- **Other options slowly phased in can greatly improve our ability to share long-term**
- **Cost effective maximally resilient MW networks will provide more effective shared use of the spectrum for both SATOPS and MW**
- **Needed technology is well in hand**
- **Cost and implementation time are primary factors**
  - Mitigations must be appropriately included in transition plans and processes to allow for Federal reimbursement funding

Backups

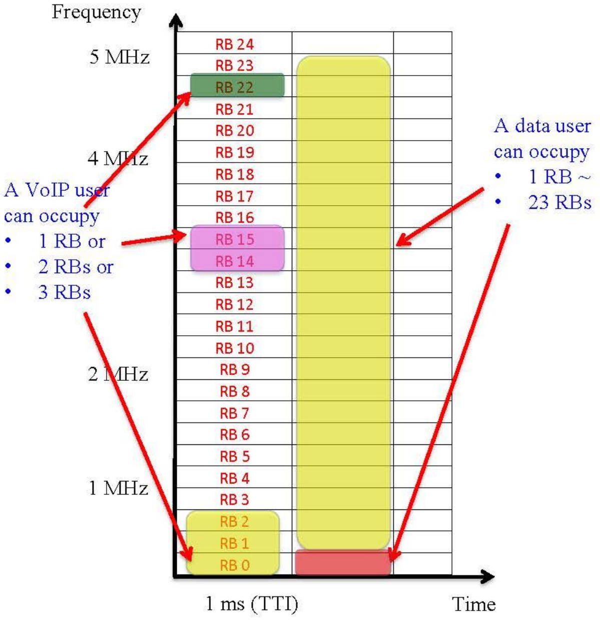
Cell Phone Tower Antenna Shielding



Shielding Near Base Station



LTE – Configurable and Dynamic



A VoIP user can occupy
- 1 RB or
- 2 RBs or
- 3 RBs

A data user can occupy
- 1 RB ~
- 23 RBs

- **LTE networks are configurable**
- **Every handset under control by the base station**
- **Subscribers scheduled with high resolution**
  - 1 mS, 180 kHz
- **Schedule can be updated quickly**
  - ~10 mS

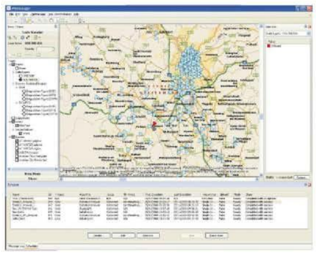
Possible to leverage flexibility of LTE for sharing

2154

Network Management/Optimization

- **Possible to schedule around interfering frequencies using Self Optimizing Network Tools**
- **Several companies offer Self Optimizing Network Solutions now**
  - Nokia Siemens
  - Eden Rock Communications
  - Optimi
- **Real time network configuration optimization**

www.edenrockcomm.com



xNetManager

www.optimi.com

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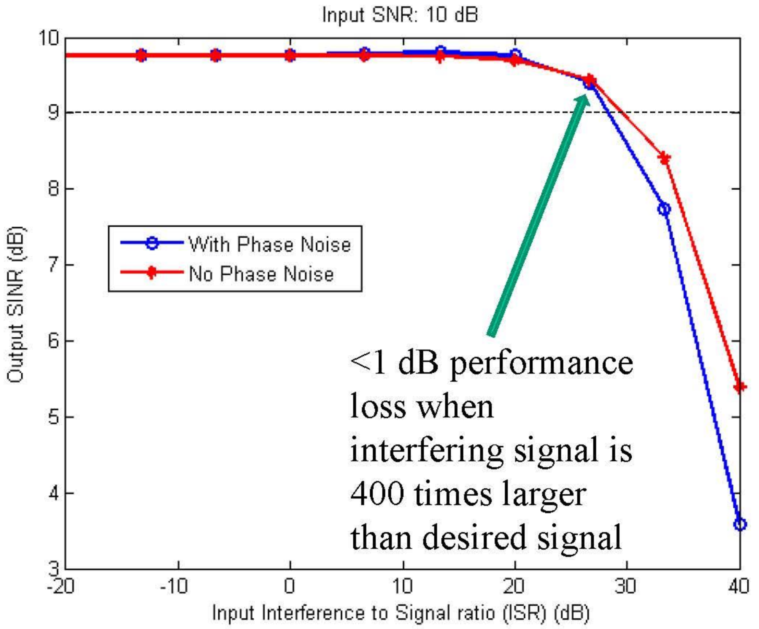
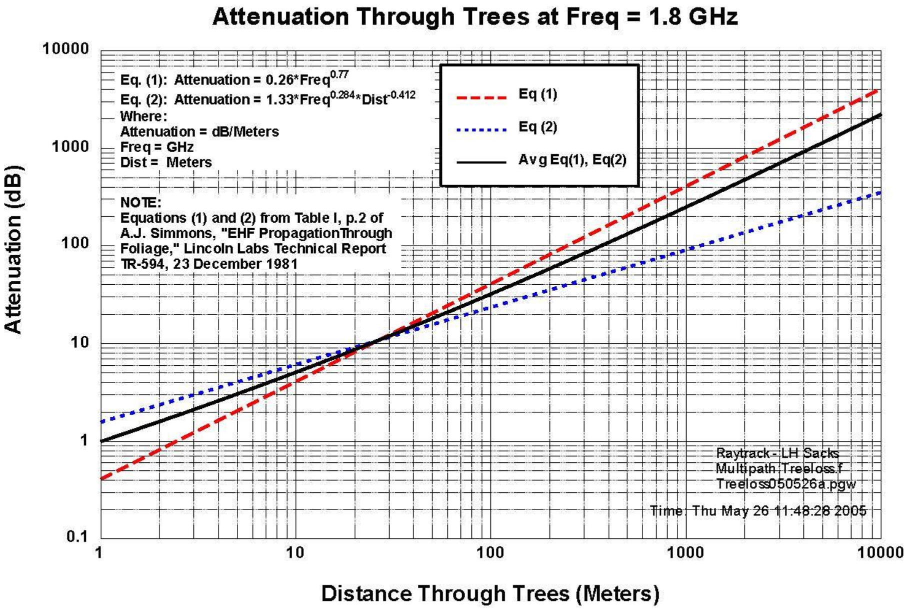
SGLS Ranging Cancellation Performance



<1 dB performance loss when interfering signal is 400 times larger than desired signal

2156

Attenuation Through Trees


Attenuation Through Trees at Freq = 1.8 GHz

Eq. (1): Attenuation = $0.26*Freq^{0.77}$
Eq. (2): Attenuation = $1.33*Freq^{0.284}*Dist^{-0.412}$
Where:
Attenuation = dB/Meters
Freq = GHz
Dist = Meters

NOTE:
Equations (1) and (2) from Table I, p.2 of A.J. Simmons, "EHF PropagationThrough Foliage," Lincoln Labs Technical Report TR-594, 23 December 1981

Raytrack - LH Sacks
Multipath.Treeloss.f
Treeloss050526a.pgw
Time: Thu May 26 11:48:28 2005

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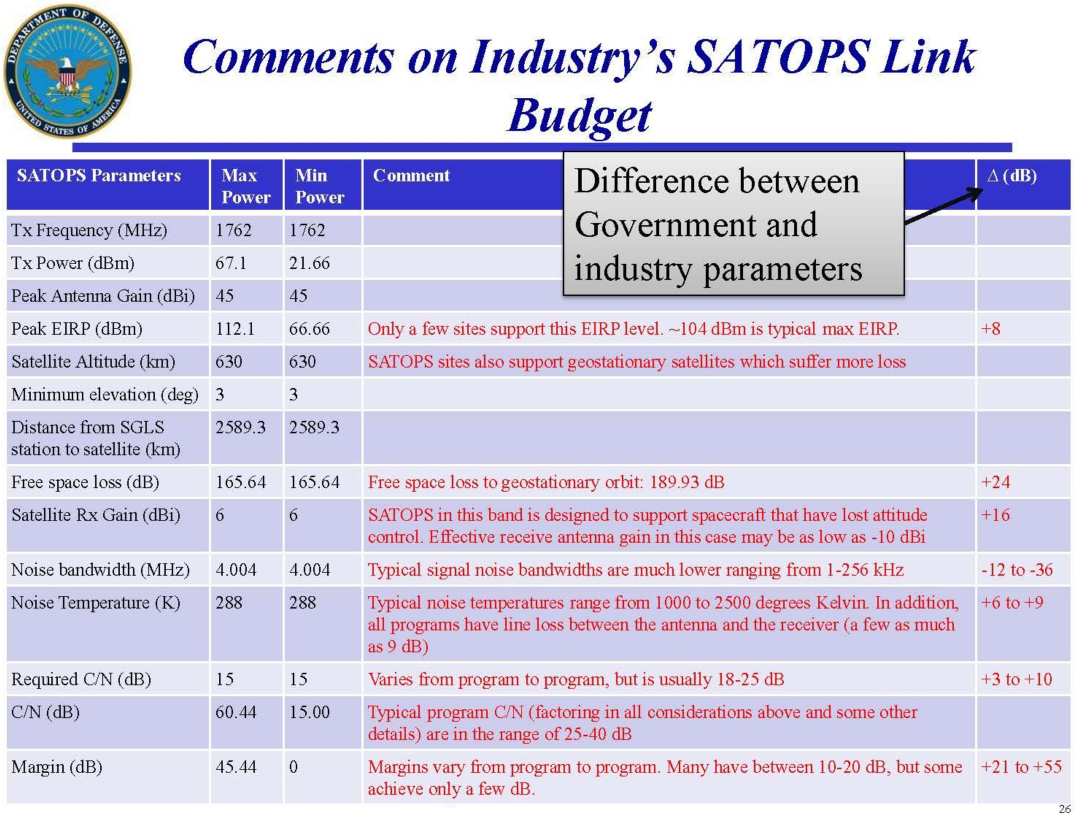


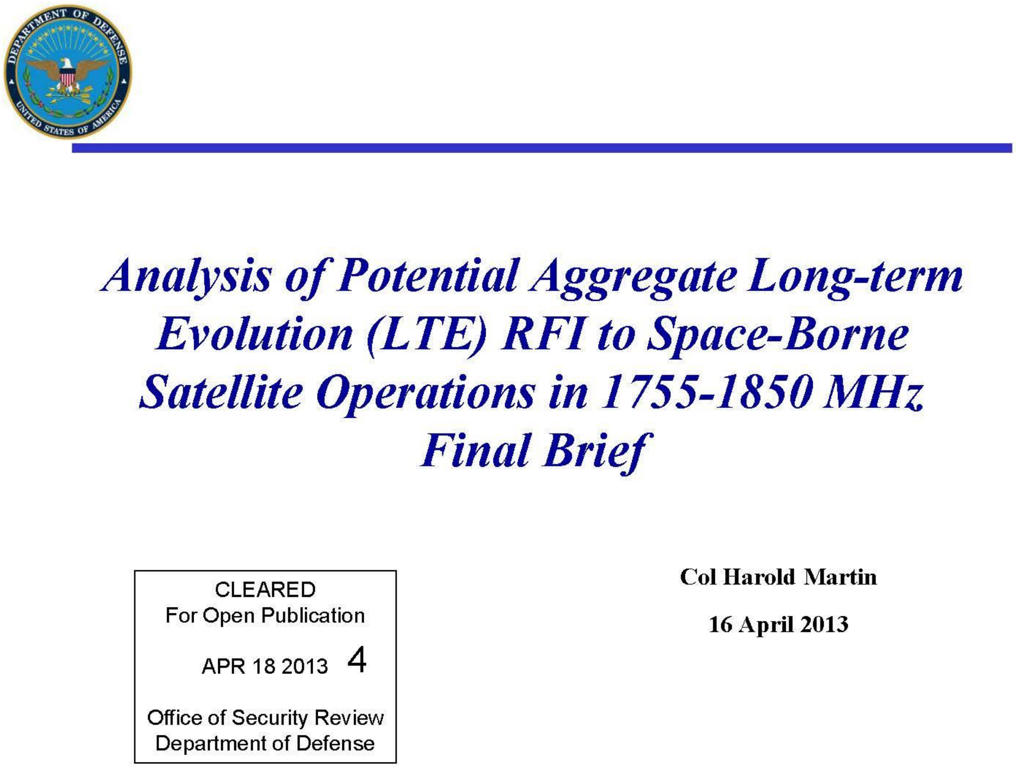
Comments on Industry's SATOPS Link Budget

SATOPS Parameters	Max Power	Min Power	Comment	Δ (dB)
Tx Frequency (MHz)	1762	1762		
Tx Power (dBm)	67.1	21.66		
Peak Antenna Gain (dBi)	45	45		
Peak EIRP (dBm)	112.1	66.66	Only a few sites support this EIRP level. ~104 dBm is typical max EIRP.	+8
Satellite Altitude (km)	630	630	SATOPS sites also support geostationary satellites which suffer more loss	
Minimum elevation (deg)	3	3		
Distance from SGLS station to satellite (km)	2589.3	2589.3		
Free space loss (dB)	165.64	165.64	Free space loss to geostationary orbit: 189.93 dB	+24
Satellite Rx Gain (dBi)	6	6	SATOPS in this band is designed to support spacecraft that have lost attitude control. Effective receive antenna gain in this case may be as low as -10 dBi	+16
Noise bandwidth (MHz)	4.004	4.004	Typical signal noise bandwidths are much lower ranging from 1-256 kHz	-12 to -36
Noise Temperature (K)	288	288	Typical noise temperatures range from 1000 to 2500 degrees Kelvin. In addition, all programs have line loss between the antenna and the receiver (a few as much as 9 dB)	+6 to +9
Required C/N (dB)	15	15	Varies from program to program, but is usually 18-25 dB	+3 to +10
C/N (dB)	60.44	15.00	Typical program C/N (factoring in all considerations above and some other details) are in the range of 25-40 dB	
Margin (dB)	45.44	0	Margins vary from program to program. Many have between 10-20 dB, but some achieve only a few dB.	+21 to +55

Difference between Government and industry parameters

26

4.4.3 Aggregate LTE to SATOPS – April 2013



Analysis of Potential Aggregate Long-term Evolution (LTE) RFI to Space-Borne Satellite Operations in 1755-1850 MHz Final Brief

CLEARED
For Open Publication
APR 18 2013 4
Office of Security Review
Department of Defense

Col Harold Martin

16 April 2013

Agenda

- Purpose
- Executive summary
- Interference model
- Analysis results
- Summary and Observations

2163

Purpose

- To present analysis and results for predicting aggregate radio frequency interference (RFI) to national security space-borne receivers that would result from commercial LTE network operations in the 1755-1850MHz band
- National Security Space stakeholders concur with analysis methodology, results and conclusions.

2164

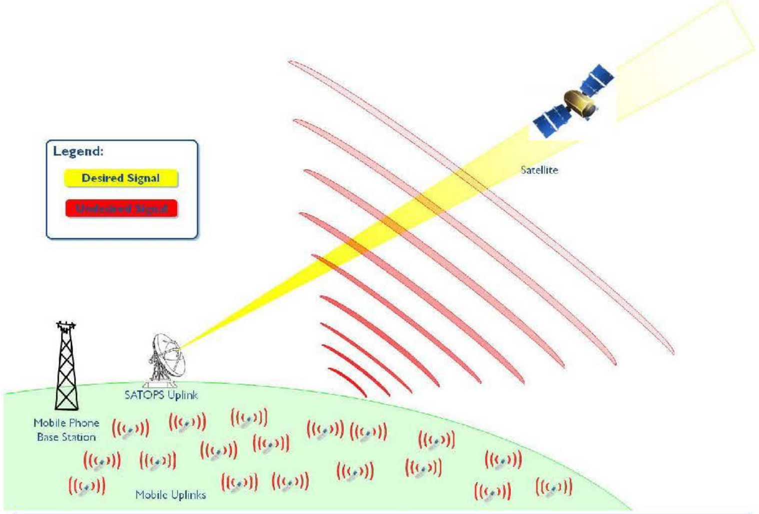
Executive Summary

- **Examined aggregate Long-Term Evolution LTE interference to satellite operations (SATOPS) receivers in the 1755-1850 MHz band**
  - Analysis is based on CSMAC Working Group 1 (WG1) assumptions about LTE parameters (November 2012 revision)
- **Conclude that there is low risk of interference from aggregate LTE to SATOPS based on current assumptions**
- **Recommend establishment of rules/regulations capturing a threshold of -205 dBW/Hz for aggregate LTE emissions to ensure continued protection of satellite receivers**

Model predicts minimal impact to national security spacecraft from LTE

2165

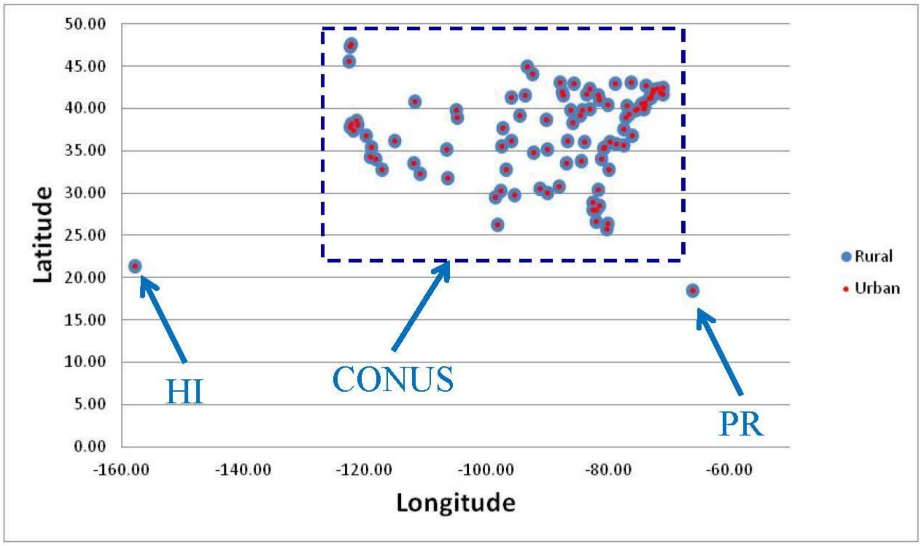
Purpose of Model



This analysis examines interference from LTE handset transmissions only

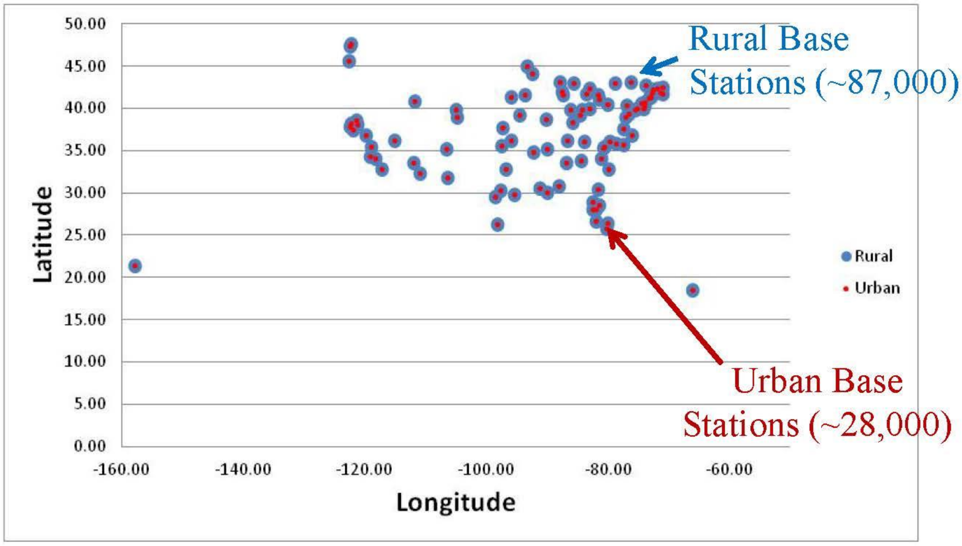
2166

CSMAC WG1 “Grid Model” Method

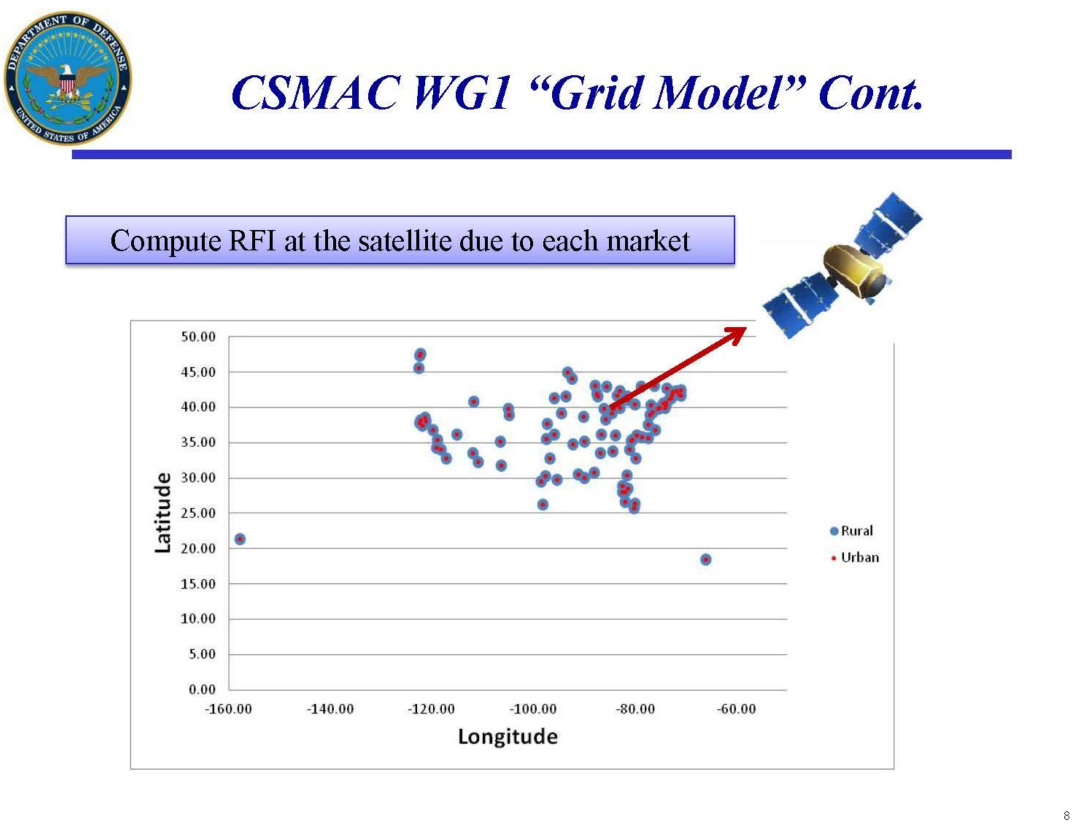


LTE network modeled as urban and rural base stations in top 100 cellular U.S. market areas

CSMAC WG1 “Grid Model” Method

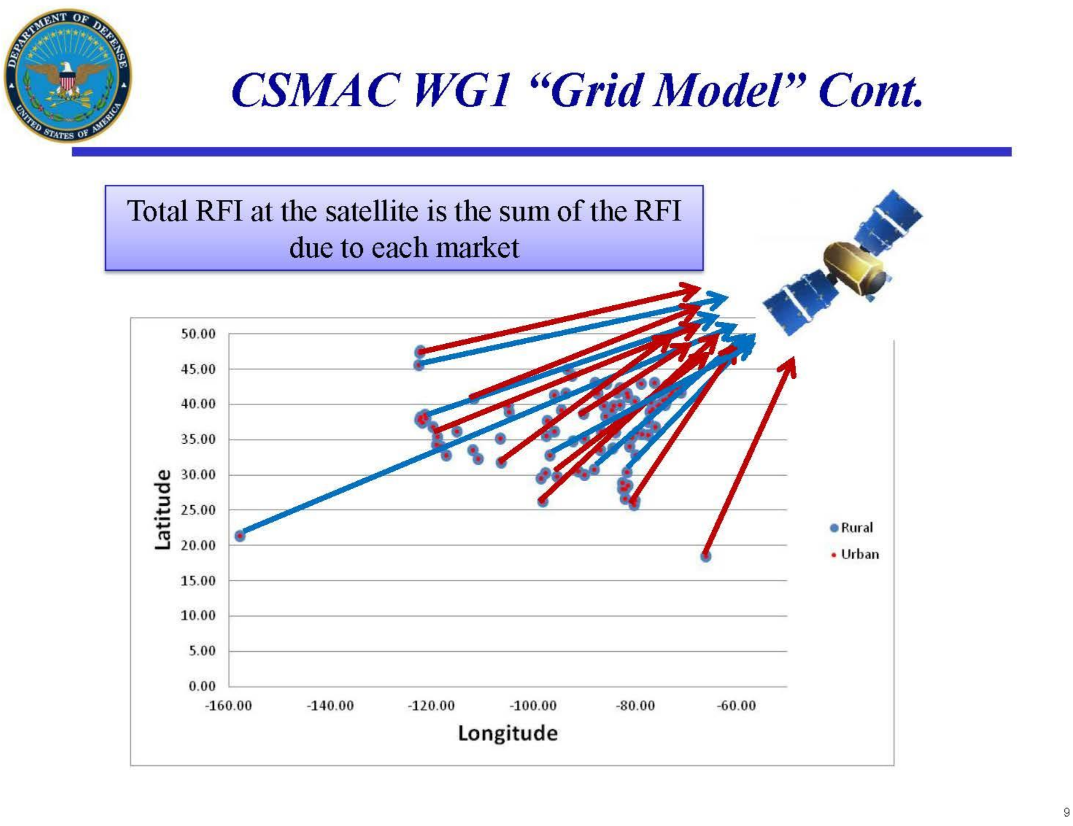


LTE network modeled as urban and rural base stations in top 100 cellular U.S. market areas



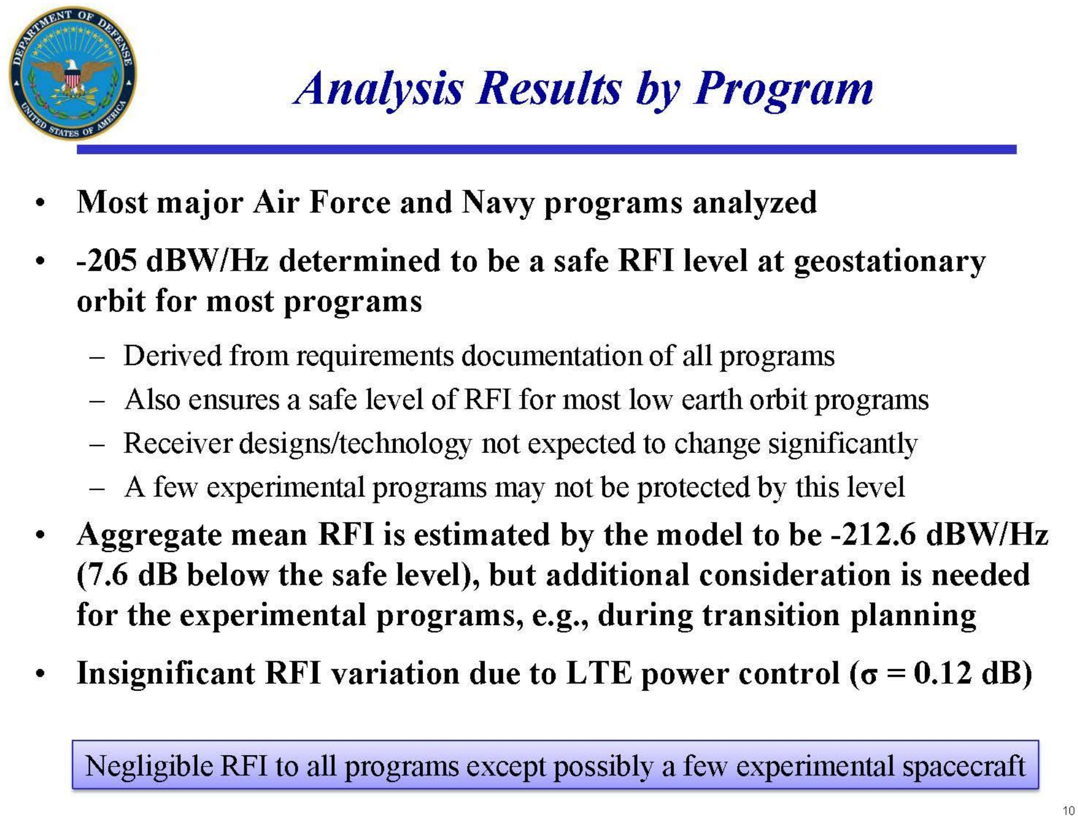
CSMAC WG1 "Grid Model" Cont.

Compute RFI at the satellite due to each market



CSMAC WG1 "Grid Model" Cont.

Total RFI at the satellite is the sum of the RFI due to each market

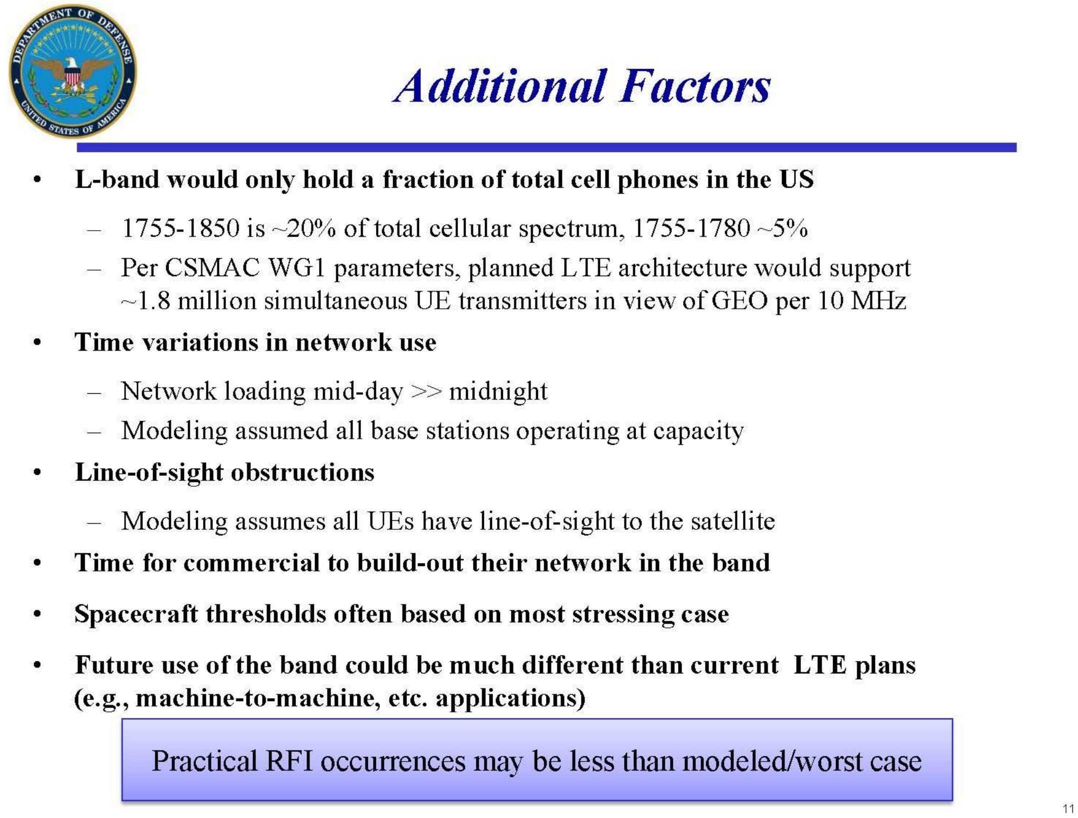


Analysis Results by Program

- **Most major Air Force and Navy programs analyzed**
- **-205 dBW/Hz determined to be a safe RFI level at geostationary orbit for most programs**
  - Derived from requirements documentation of all programs
  - Also ensures a safe level of RFI for most low earth orbit programs
  - Receiver designs/technology not expected to change significantly
  - A few experimental programs may not be protected by this level
- **Aggregate mean RFI is estimated by the model to be -212.6 dBW/Hz (7.6 dB below the safe level), but additional consideration is needed for the experimental programs, e.g., during transition planning**
- **Insignificant RFI variation due to LTE power control (σ = 0.12 dB)**

Negligible RFI to all programs except possibly a few experimental spacecraft

2171



Additional Factors

- **L-band would only hold a fraction of total cell phones in the US**
  - 1755-1850 is ~20% of total cellular spectrum, 1755-1780 ~5%
  - Per CSMAC WG1 parameters, planned LTE architecture would support ~1.8 million simultaneous UE transmitters in view of GEO per 10 MHz
- **Time variations in network use**
  - Network loading mid-day >> midnight
  - Modeling assumed all base stations operating at capacity
- **Line-of-sight obstructions**
  - Modeling assumes all UEs have line-of-sight to the satellite
- **Time for commercial to build-out their network in the band**
- **Spacecraft thresholds often based on most stressing case**
- **Future use of the band could be much different than current LTE plans (e.g., machine-to-machine, etc. applications)**

Practical RFI occurrences may be less than modeled/worst case

2172

Summary and Observations

- There is low risk of interference from aggregate LTE to SATOPS based on current assumptions
- Establishment of rules/regulations defining a threshold of -205 dBW/Hz for aggregate LTE emissions would ensure continued protection of satellite receivers

2173

References

- CSMAC Working Group #1 "Baseline LTE Uplink Characteristics" 12 November 2012 – Rev.2
- Yeh, J. P., "IMT-2000 study" Aerospace Report No. TOR-2002(8584)-1, 15 December 2001

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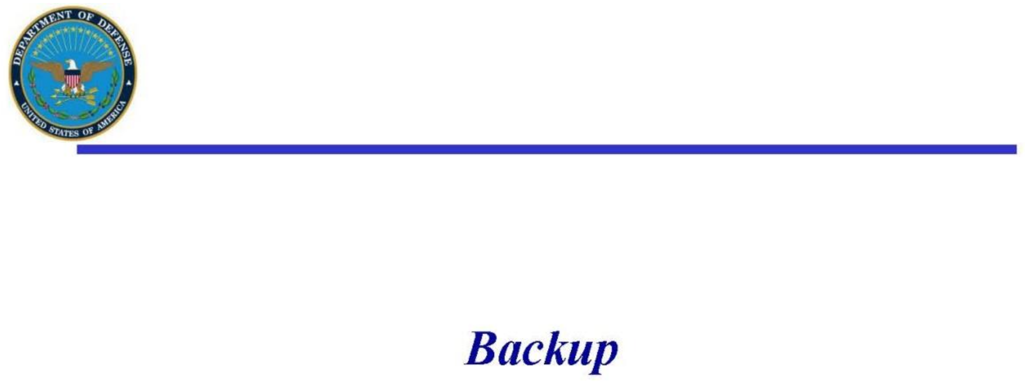
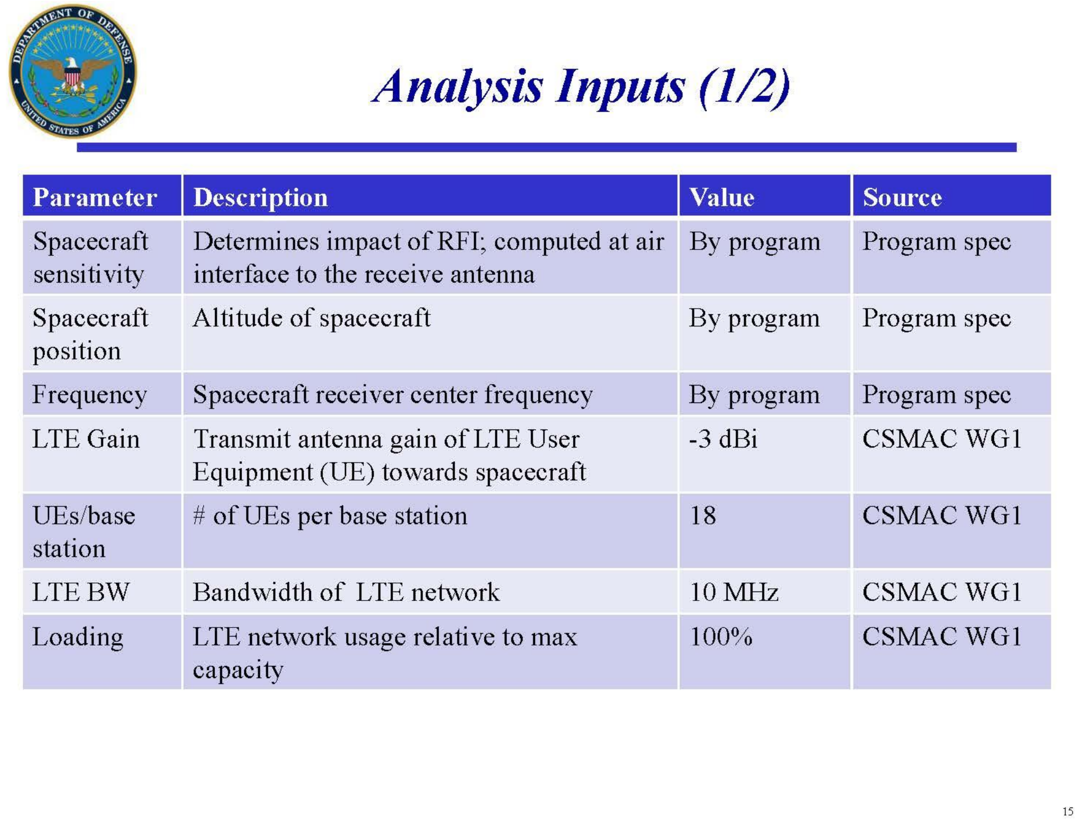


Backup



Analysis Inputs (1/2)

Parameter	Description	Value	Source
Spacecraft sensitivity	Determines impact of RFI; computed at air interface to the receive antenna	By program	Program spec
Spacecraft position	Altitude of spacecraft	By program	Program spec
Frequency	Spacecraft receiver center frequency	By program	Program spec
LTE Gain	Transmit antenna gain of LTE User Equipment (UE) towards spacecraft	-3 dBi	CSMAC WG1
UEs/base station	# of UEs per base station	18	CSMAC WG1
LTE BW	Bandwidth of LTE network	10 MHz	CSMAC WG1
Loading	LTE network usage relative to max capacity	100%	CSMAC WG1

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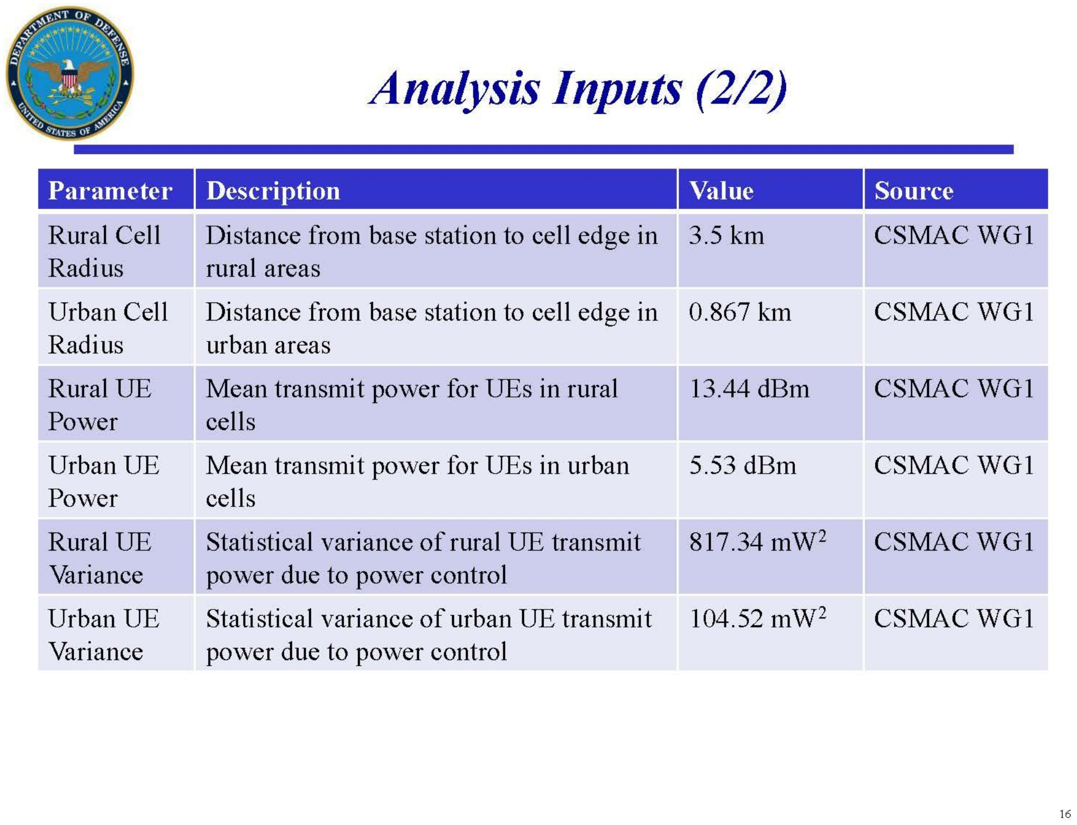
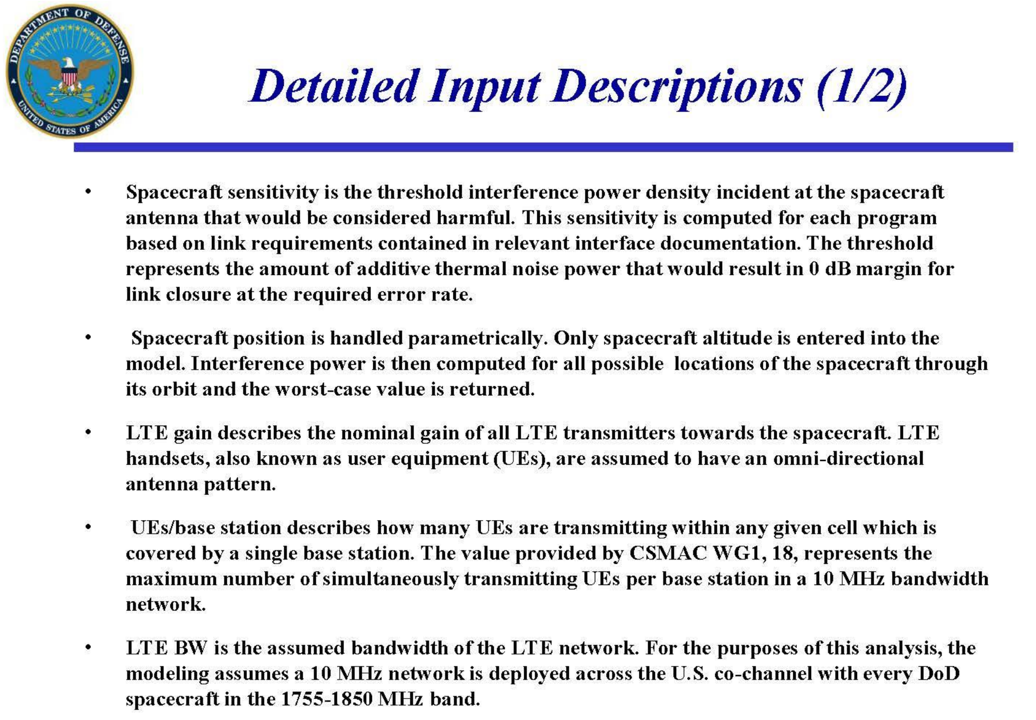


Analysis Inputs (2/2)

Parameter	Description	Value	Source
Rural Cell Radius	Distance from base station to cell edge in rural areas	3.5 km	CSMAC WG1
Urban Cell Radius	Distance from base station to cell edge in urban areas	0.867 km	CSMAC WG1
Rural UE Power	Mean transmit power for UEs in rural cells	13.44 dBm	CSMAC WG1
Urban UE Power	Mean transmit power for UEs in urban cells	5.53 dBm	CSMAC WG1
Rural UE Variance	Statistical variance of rural UE transmit power due to power control	817.34 mW^2	CSMAC WG1
Urban UE Variance	Statistical variance of urban UE transmit power due to power control	104.52 mW^2	CSMAC WG1



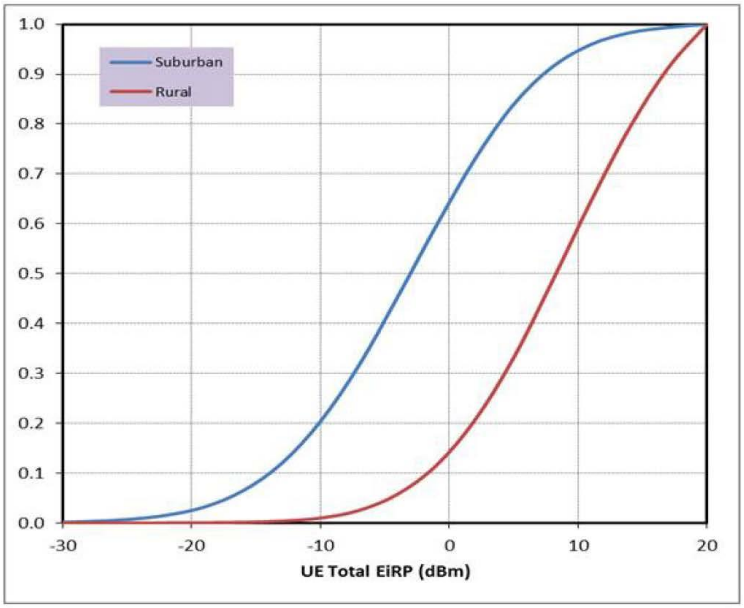
Detailed Input Descriptions (1/2)

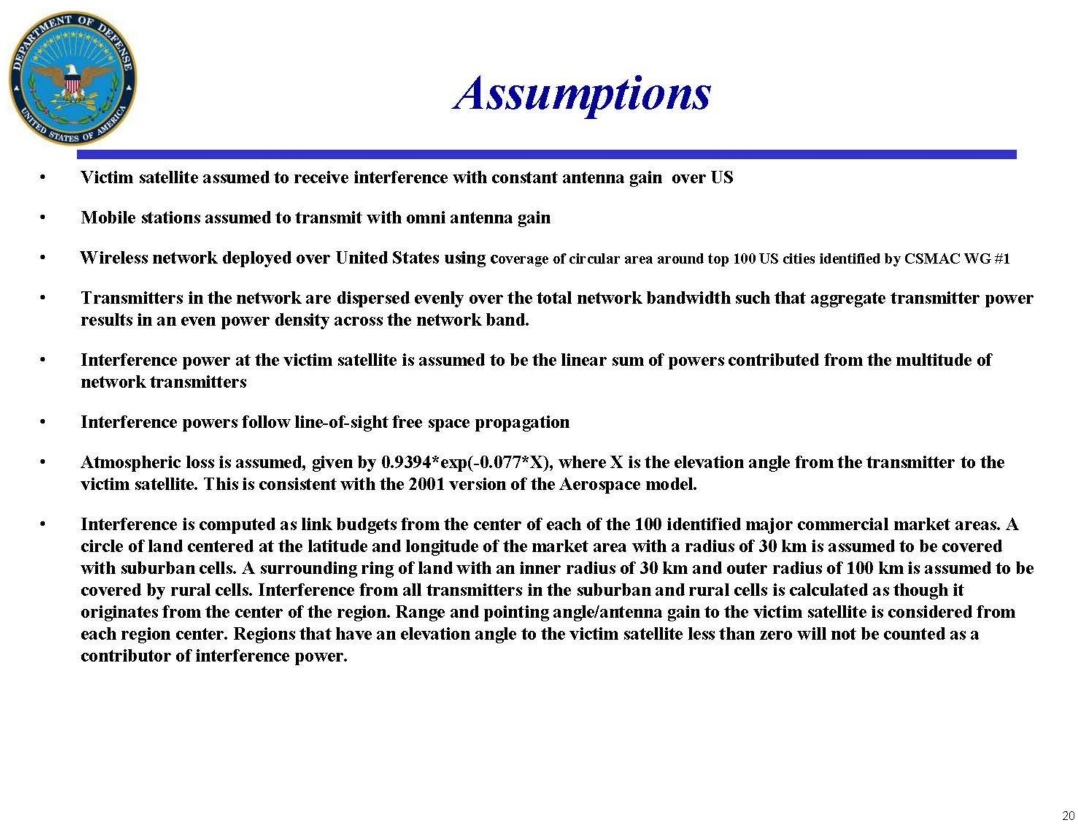
- **Spacecraft sensitivity is the threshold interference power density incident at the spacecraft antenna that would be considered harmful. This sensitivity is computed for each program based on link requirements contained in relevant interface documentation. The threshold represents the amount of additive thermal noise power that would result in 0 dB margin for link closure at the required error rate.**
- **Spacecraft position is handled parametrically. Only spacecraft altitude is entered into the model. Interference power is then computed for all possible locations of the spacecraft through its orbit and the worst-case value is returned.**
- **LTE gain describes the nominal gain of all LTE transmitters towards the spacecraft. LTE handsets, also known as user equipment (UEs), are assumed to have an omni-directional antenna pattern.**
- **UEs/base station describes how many UEs are transmitting within any given cell which is covered by a single base station. The value provided by CSMAC WG1, 18, represents the maximum number of simultaneously transmitting UEs per base station in a 10 MHz bandwidth network.**
- **LTE BW is the assumed bandwidth of the LTE network. For the purposes of this analysis, the modeling assumes a 10 MHz network is deployed across the U.S. co-channel with every DoD spacecraft in the 1755-1850 MHz band.**

Detailed Input Descriptions (1/2)

- **Loading represents the usage of the network relative to capacity. A value of 100% means the network is operating at capacity and could not support one additional subscriber anywhere in the U.S. In reality, LTE networks are never operating at 100% capacity, and even individual cells in high traffic areas only operate near capacity on occasion.**
- **Rural/Urban cell radius describes the coverage area of each individual base station. This value is used to determine how many base stations (and thus how many UEs) are operating in a given land area. Note that cell radii take on one of two values depending on whether the cell is in an area considered to be urban or rural.**
- **Rural/Urban UE power provides the mean/average transmitter power of LTE handsets, depending on whether the handset is in a rural or urban area. Rural cells generally cover larger areas, so UEs operate on average with higher power to cover larger distances.**
- **Rural/Urban UE variance provides a statistical metric for the variation of LTE handset transmitter power due to power control of the handsets. Both the mean and variance terms are derived from UE transmit power distributions provided by CSMAC WG1. UEs operate over a wide range of power levels (from -30 dBm to +20 dBm), thus the values for variance are large relative to the mean.**

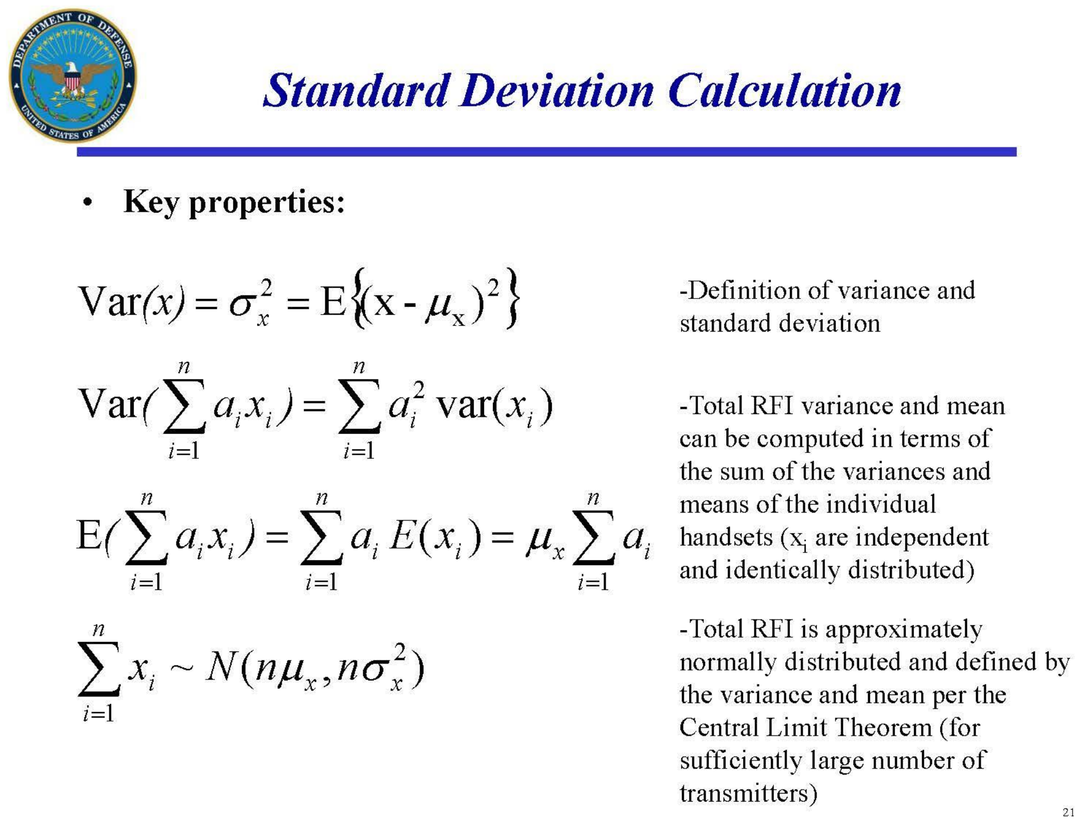
UE Power Control Distribution





Assumptions

- Victim satellite assumed to receive interference with constant antenna gain over US
- Mobile stations assumed to transmit with omni antenna gain
- Wireless network deployed over United States using coverage of circular area around top 100 US cities identified by CSMAC WG #1
- Transmitters in the network are dispersed evenly over the total network bandwidth such that aggregate transmitter power results in an even power density across the network band.
- Interference power at the victim satellite is assumed to be the linear sum of powers contributed from the multitude of network transmitters
- Interference powers follow line-of-sight free space propagation
- Atmospheric loss is assumed, given by 0.9394*exp(-0.077*X), where X is the elevation angle from the transmitter to the victim satellite. This is consistent with the 2001 version of the Aerospace model.
- Interference is computed as link budgets from the center of each of the 100 identified major commercial market areas. A circle of land centered at the latitude and longitude of the market area with a radius of 30 km is assumed to be covered with suburban cells. A surrounding ring of land with an inner radius of 30 km and outer radius of 100 km is assumed to be covered by rural cells. Interference from all transmitters in the suburban and rural cells is calculated as though it originates from the center of the region. Range and pointing angle/antenna gain to the victim satellite is considered from each region center. Regions that have an elevation angle to the victim satellite less than zero will not be counted as a contributor of interference power.



Standard Deviation Calculation

- **Key properties:**

$$\mathrm{Var}(x) = \sigma_x^2 = \mathrm{E}\left\{(\mathrm{x} - \mu_{\mathrm{x}})^2\right\}$$

-Definition of variance and standard deviation

$$\mathrm{Var}\left(\sum_{i=1}^{n} a_i x_i\right) = \sum_{i=1}^{n} a_i^2 \,\mathrm{var}(x_i)$$

$$\mathrm{E}\left(\sum_{i=1}^{n} a_i x_i\right) = \sum_{i=1}^{n} a_i\, E(x_i) = \mu_x \sum_{i=1}^{n} a_i$$

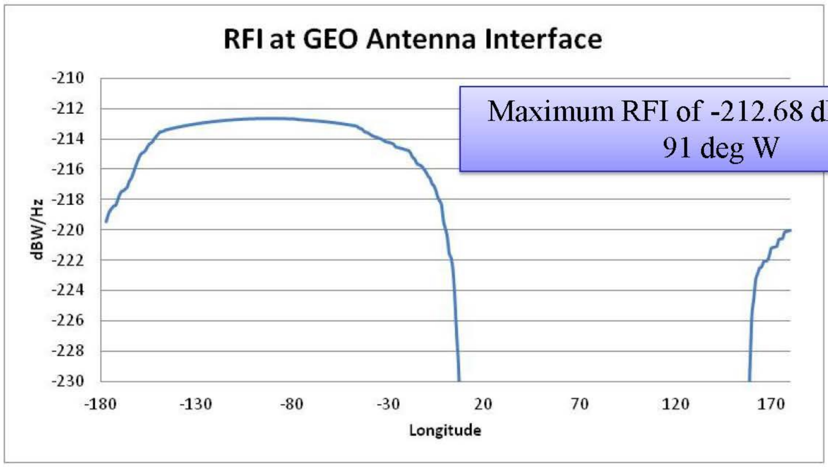
-Total RFI variance and mean can be computed in terms of the sum of the variances and means of the individual handsets (x_i are independent and identically distributed)

$$\sum_{i=1}^{n} x_i \sim N(n\mu_x, n\sigma_x^2)$$

-Total RFI is approximately normally distributed and defined by the variance and mean per the Central Limit Theorem (for sufficiently large number of transmitters)

RFI at GEO

- **RFI vs. geostationary longitude at 1800 MHz frequency**
- **Cellular distribution per CSMAC WG1 “grid model”**



Maximum RFI of -212.68 dBW/Hz @ 91 deg W

4.4.4 Government Satellite Control – Second Submittal – May 2013

CSMAC WG3 Government Satellite Control – Second Submittal

May 2013

Col Harold Martin

CLEARED
For Open Publication
MAY 29 2013 4
Office of Security Review
Department of Defense
13-S-2166

Outline

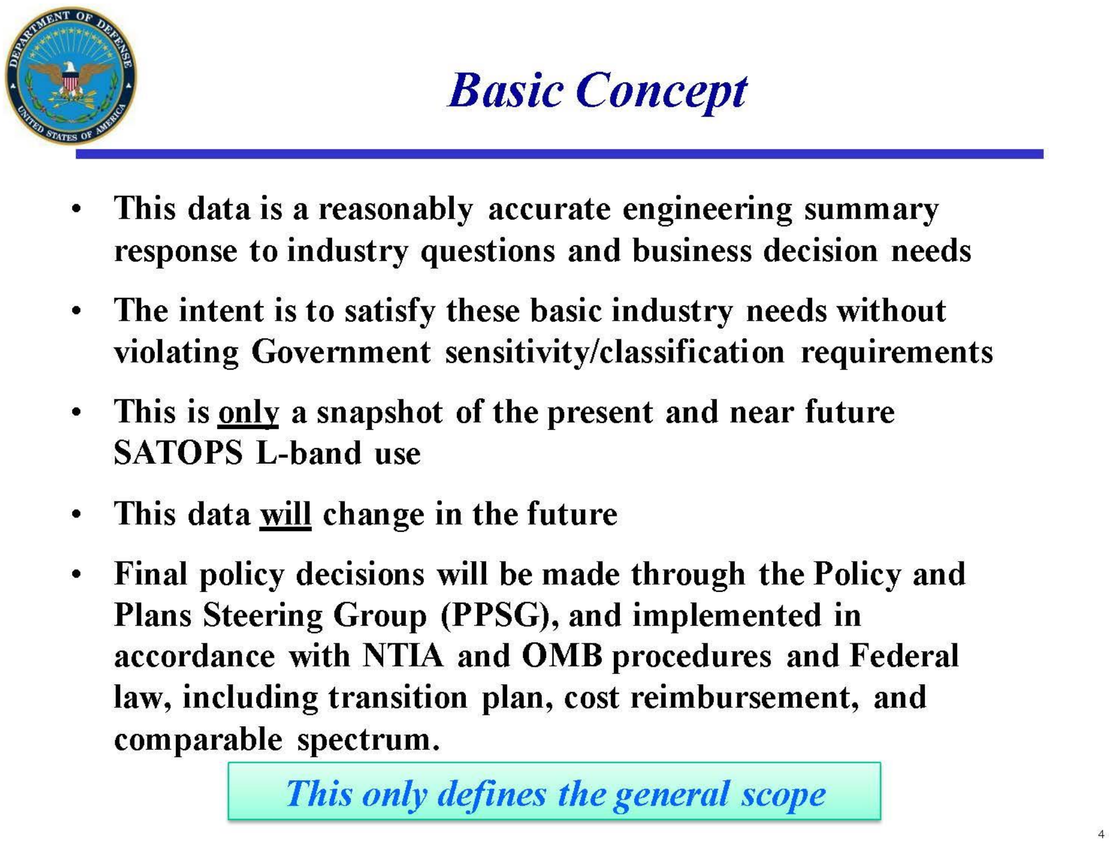
- Purpose of Submittal
- Government Ground Stations
- Additional AFSCN Information
- Site Usage
- Aggregate Mobile Wireless RFI to Government Uplinks
- Sharing
- Remarks

2188

Purpose of Briefing

- This briefing is a second submittal of information regarding Government satellite control (SATOPS) uplinks that are produced by various stations in US&P in the 1755 – 1850 MHz band (L-band)
- The primary content of this second submittal is the additional listing of some government ground stations uplinking in L-band. This submittal also addresses a few minor industry questions and corrects a few items that were incorrect in the first submittal.
- Some items are repeated from the first submittal for clarity only

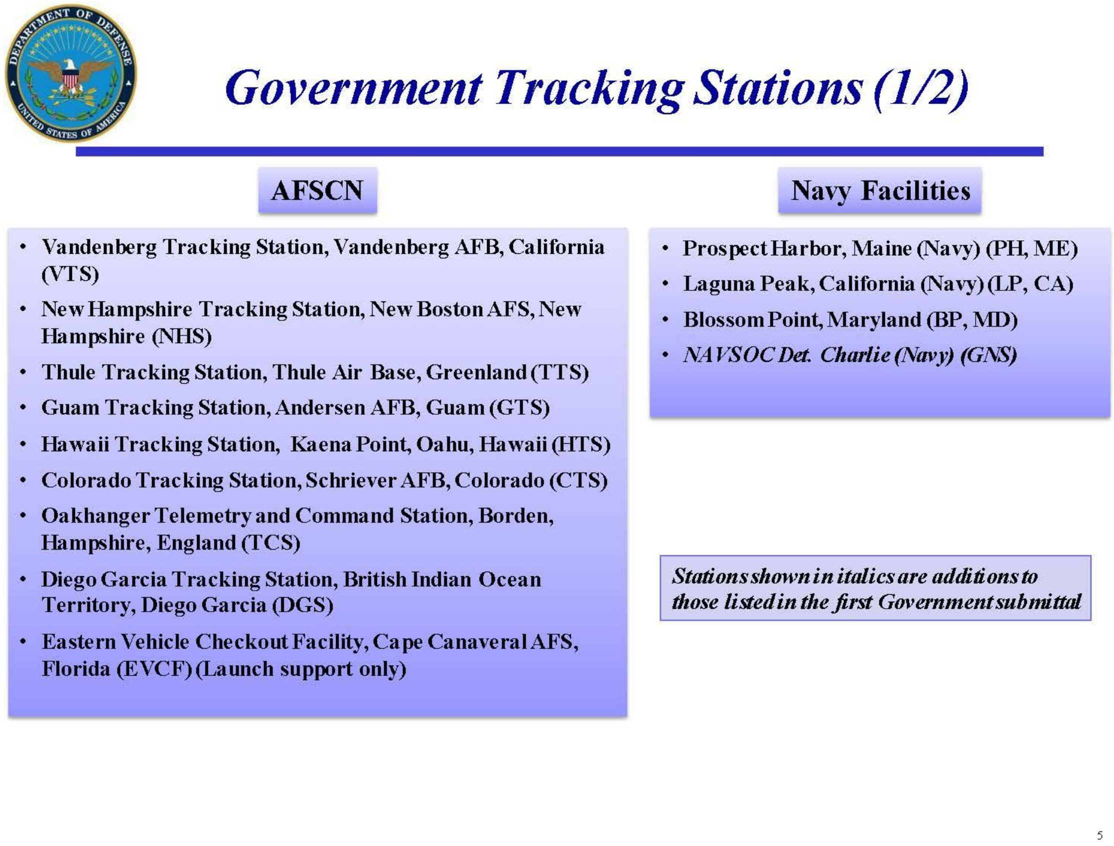
2189



Basic Concept

- This data is a reasonably accurate engineering summary response to industry questions and business decision needs
- The intent is to satisfy these basic industry needs without violating Government sensitivity/classification requirements
- This is only a snapshot of the present and near future SATOPS L-band use
- This data will change in the future
- Final policy decisions will be made through the Policy and Plans Steering Group (PPSG), and implemented in accordance with NTIA and OMB procedures and Federal law, including transition plan, cost reimbursement, and comparable spectrum.

This only defines the general scope



Government Tracking Stations (1/2)

AFSCN

- Vandenberg Tracking Station, Vandenberg AFB, California (VTS)
- New Hampshire Tracking Station, New Boston AFS, New Hampshire (NHS)
- Thule Tracking Station, Thule Air Base, Greenland (TTS)
- Guam Tracking Station, Andersen AFB, Guam (GTS)
- Hawaii Tracking Station, Kaena Point, Oahu, Hawaii (HTS)
- Colorado Tracking Station, Schriever AFB, Colorado (CTS)
- Oakhanger Telemetry and Command Station, Borden, Hampshire, England (TCS)
- Diego Garcia Tracking Station, British Indian Ocean Territory, Diego Garcia (DGS)
- Eastern Vehicle Checkout Facility, Cape Canaveral AFS, Florida (EVCF) (Launch support only)

Navy Facilities

- Prospect Harbor, Maine (Navy) (PH, ME)
- Laguna Peak, California (Navy) (LP, CA)
- Blossom Point, Maryland (BP, MD)
- *NAVSOC Det. Charlie (Navy) (GNS)*

Stations shown in italics are additions to those listed in the first Government submittal

Government Tracking Stations (2/2)

Other Facilities

- Buckley AFB, Colorado (BAFB)
- Fairbanks (NOAA), Alaska (FB, AK)
- Kirtland AFB, New Mexico (KAFB)
- Fort Belvoir, Virginia (FB, VA)
- Camp Parks, California (CP, CA)
- *Annapolis, Maryland (AN, MD)*
- *Monterey, California (MO, CA)*
- *Cape GA, CCAFB, Florida (CAPEG)*
- *Huntington Beach, CA (HB, CA)*
- *Joint Base Lewis-McChord, WA (JB, WA)*
- *Ft Hood, TX (FH, TX)*
- *Ft Bragg, NC (FB, NC)*
- *JIATF-S, Key West, FL (KW, FL)*
- *Patuxent River NAS, MD (PR, MD)*
- *Sacramento, CA (SAC, CA)*

Stations shown in italics are additions to those listed in the first Government submittal

General DoD Site Information

- **Antenna patterns follow classical parabolic characteristics**
- **All sites adhere to NTIA Manual 5.6.2 that limits all SATOPS radiation to 3 degrees elevation or higher**
- **All sites transmit over a 360 degrees azimuth as needed**
- **All sites listed only are used for uplink radiation in L-band**
- **For sites with multiple antennas, the percentage of radiation from at least one antenna as averaged over a year is presented in a later chart**
- **For sites with multiple antennas, only the maximum gain and power of the largest antenna is given**
- **The smallest to maximum mission bandwidths are given. Actual bandwidth used is dependent upon precise mission operations. Of course zero radiation and bandwidth occurs some of the time.**
- **Percentage of GEO spacecraft support and percentage of supports in the 1755 – 1780 MHz band are provided for each site**

General Operational Information

- **Approximately 90% of all SATOPS L-band radiation in US&P is done by four major AFSCN sites**
  - NHS, VTS, HTS, GTS
  - Only one spacecraft supported for each antenna for any given time (typically 2 antennas/site)
  - All AFSCN sites support all channels and have same basic configurations
- **AFSCN supports more than 150 spacecraft**
  - LEOs, MEOs, and GEOs are supported as required with no preset order
  - ~40% of all spacecraft are GEOs
  - ~17% of the total spacecraft are in 1755 – 1780 MHz band
  - About 45% of all spacecrafts have multiple frequencies in L-band
  - About 40% have additional bands which are not suitable for SATOPS assured access
  - Approximately 3% are configured for 2025 – 2110 MHz operations
- **AFSCN traditionally has used 20 channels with 4 MHz width – vast majority of spacecrafts on-orbit are in this configuration**
  - Now uses 440 channels with 160 kHz separation – current practice is to have new spacecrafts transponder assignments conformed to this convention. Remote tracking stations are also being updated.
  - Several modulation formats are used (1 kilosymbol commands plus ranging is most common)
  - Spacecrafts have been assigned frequencies with this new bandwidth for the last 5 years
  - Power varies from 500 W (4%), 1000 W (95%), 2250 W (1%), 7244 W (0.1%)
  - High power used only for anomalies
- **Anomalies (~ 1%) require maximum SATOPS support using similar RTS actions**

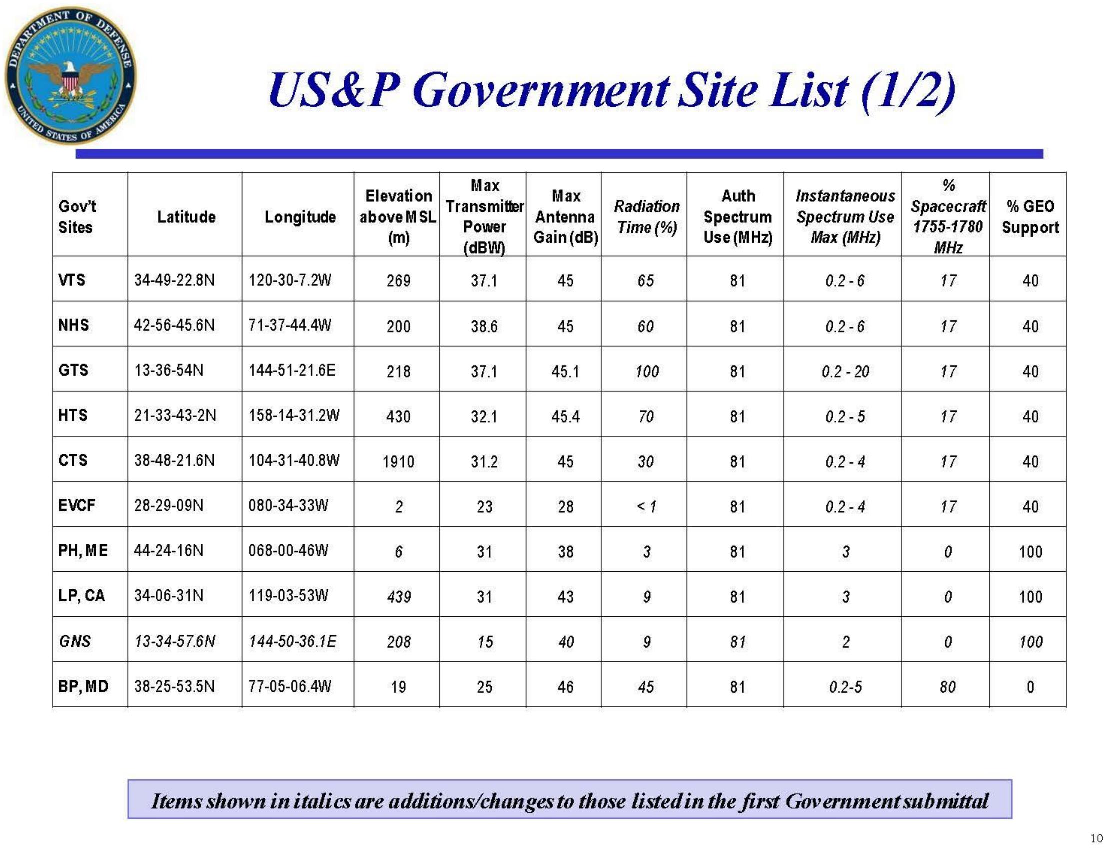
Chart unchanged – provided for informational purposes only

Aggregate RFI to SATOPS Uplinks

- **Aggregate RFI from 4G LTE mobile wireless to SATOPS <u>appears</u> acceptable based on prior studies and the assumption of indicated mobile handset users equipment (UE) power control**
- **2001 studies by JSC mobile wireless IWG and Aerospace**
  - 20 dB difference in results
  - JSC and Aerospace concluded near zero (+/- 6 dB) SATOPS command link margins due to cellular downlink
- **2010 analysis update**
  - Cellular uplink: some stressing cases with near zero command margin assuming 23 dBm uplinks
- **Previous studies <u>did</u> <u>not</u> include power control**
  - WG1 reported ~5 dBm average power for LTE <u>cellular</u> <u>uplink</u> case
  - Use of ~5 dBm UE Tx power in modeling results in ~20 dB less interference thus negligible reduction in SATOPS link margin
  - Higher UE powers could change this result

This subject is under further Government wide review

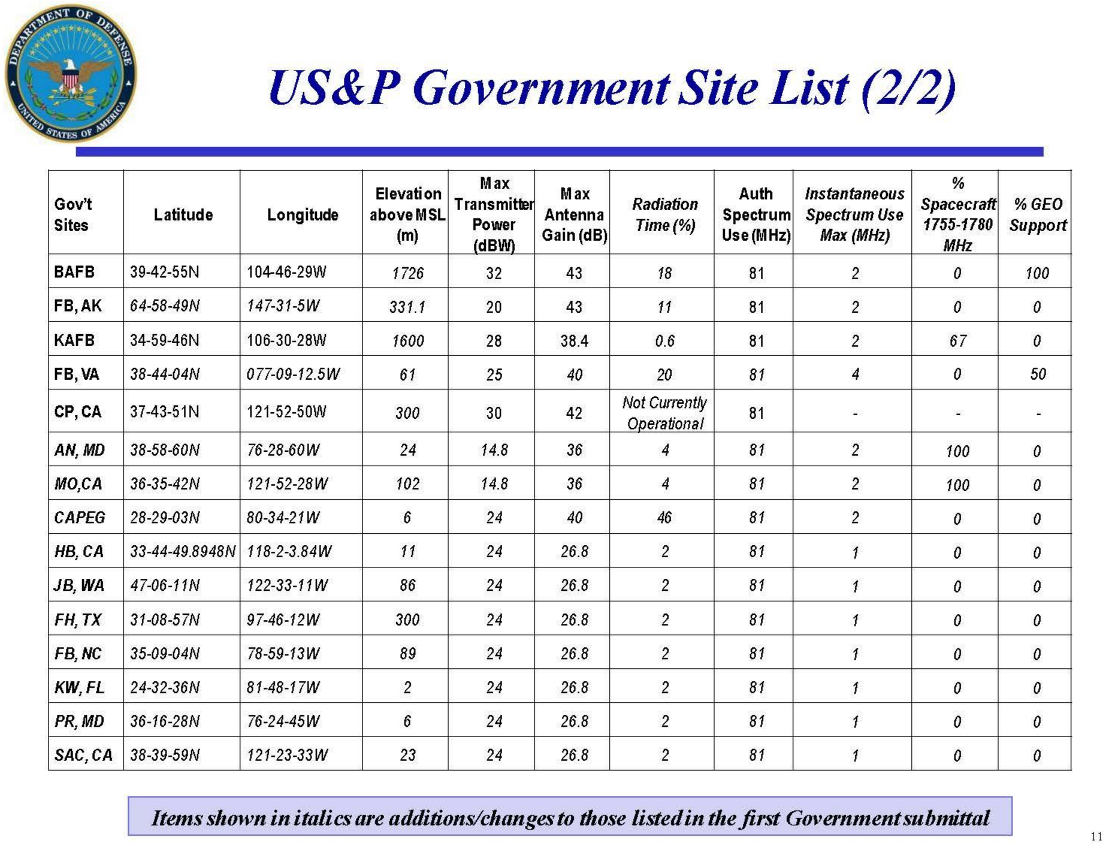
Sharing agreement should <u>require</u> further coordination for <u>any</u> <u>significant</u> departure from planned 4G/LTE architectures (e.g., higher Tx transmitter and/or UE densities power)



US&P Government Site List (1/2)

Gov't Sites	Latitude	Longitude	Elevation above MSL (m)	Max Transmitter Power (dBW)	Max Antenna Gain (dB)	*Radiation Time (%)*	Auth Spectrum Use (MHz)	*Instantaneous Spectrum Use Max (MHz)*	*% Spacecraft 1755-1780 MHz*	% GEO Support
VTS	34-49-22.8N	120-30-7.2W	269	37.1	45	*65*	81	*0.2 - 6*	*17*	40
NHS	42-56-45.6N	71-37-44.4W	200	38.6	45	*60*	81	*0.2 - 6*	*17*	40
GTS	13-36-54N	144-51-21.6E	218	37.1	45.1	*100*	81	*0.2 - 20*	*17*	40
HTS	21-33-43-2N	158-14-31.2W	430	32.1	45.4	*70*	81	*0.2 - 5*	*17*	40
CTS	38-48-21.6N	104-31-40.8W	1910	31.2	45	*30*	81	*0.2 - 4*	*17*	40
EVCF	28-29-09N	080-34-33W	*2*	23	28	*< 1*	81	*0.2 - 4*	*17*	40
PH, ME	44-24-16N	068-00-46W	*6*	31	38	*3*	81	*3*	*0*	100
LP, CA	34-06-31N	119-03-53W	*439*	31	43	*9*	81	*3*	*0*	100
GNS	*13-34-57.6N*	*144-50-36.1E*	*208*	*15*	*40*	*9*	*81*	*2*	*0*	*100*
BP, MD	38-25-53.5N	77-05-06.4W	19	25	46	*45*	81	*0.2-5*	*80*	0

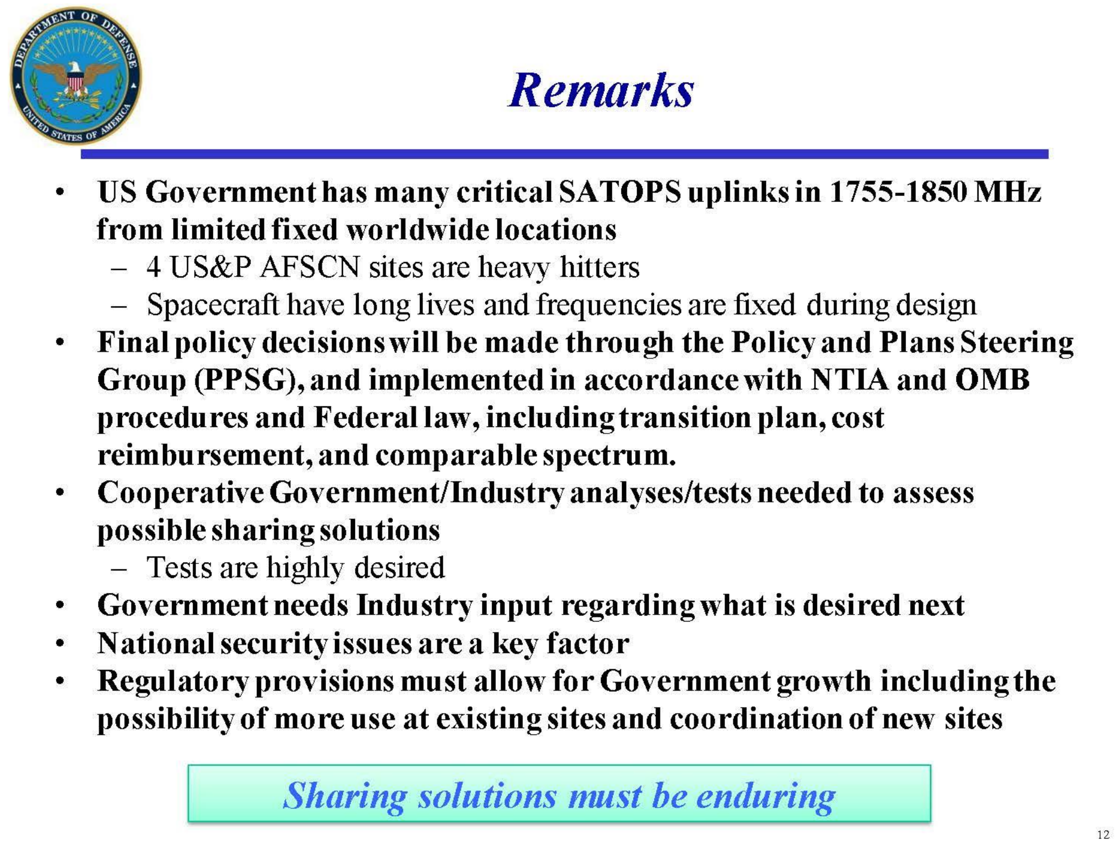
Items shown in italics are additions/changes to those listed in the first Government submittal



US&P Government Site List (2/2)

Gov't Sites	Latitude	Longitude	Elevation above MSL (m)	Max Transmitter Power (dBW)	Max Antenna Gain (dB)	*Radiation Time (%)*	Auth Spectrum Use (MHz)	*Instantaneous Spectrum Use Max (MHz)*	*% Spacecraft 1755-1780 MHz*	*% GEO Support*
BAFB	39-42-55N	104-46-29W	*1726*	32	43	*18*	81	*2*	*0*	*100*
FB, AK	*64-58-49N*	*147-31-5W*	*331.1*	20	43	*11*	81	*2*	*0*	*0*
KAFB	34-59-46N	106-30-28W	*1600*	28	38.4	*0.6*	81	*2*	*67*	*0*
FB, VA	*38-44-04N*	*077-09-12.5W*	*61*	25	*40*	*20*	*81*	*4*	*0*	*50*
CP, CA	37-43-51N	121-52-50W	*300*	30	42	*Not Currently Operational*	81	*-*	*-*	*-*
AN, MD	*38-58-60N*	*76-28-60W*	*24*	*14.8*	*36*	*4*	*81*	*2*	*100*	*0*
MO,CA	*36-35-42N*	*121-52-28W*	*102*	*14.8*	*36*	*4*	*81*	*2*	*100*	*0*
CAPEG	*28-29-03N*	*80-34-21W*	*6*	*24*	*40*	*46*	*81*	*2*	*0*	*0*
HB, CA	*33-44-49.8948N*	*118-2-3.84W*	*11*	*24*	*26.8*	*2*	*81*	*1*	*0*	*0*
JB, WA	*47-06-11N*	*122-33-11W*	*86*	*24*	*26.8*	*2*	*81*	*1*	*0*	*0*
FH, TX	*31-08-57N*	*97-46-12W*	*300*	*24*	*26.8*	*2*	*81*	*1*	*0*	*0*
FB, NC	*35-09-04N*	*78-59-13W*	*89*	*24*	*26.8*	*2*	*81*	*1*	*0*	*0*
KW, FL	*24-32-36N*	*81-48-17W*	*2*	*24*	*26.8*	*2*	*81*	*1*	*0*	*0*
PR, MD	*36-16-28N*	*76-24-45W*	*6*	*24*	*26.8*	*2*	*81*	*1*	*0*	*0*
SAC, CA	*38-39-59N*	*121-23-33W*	*23*	*24*	*26.8*	*2*	*81*	*1*	*0*	*0*

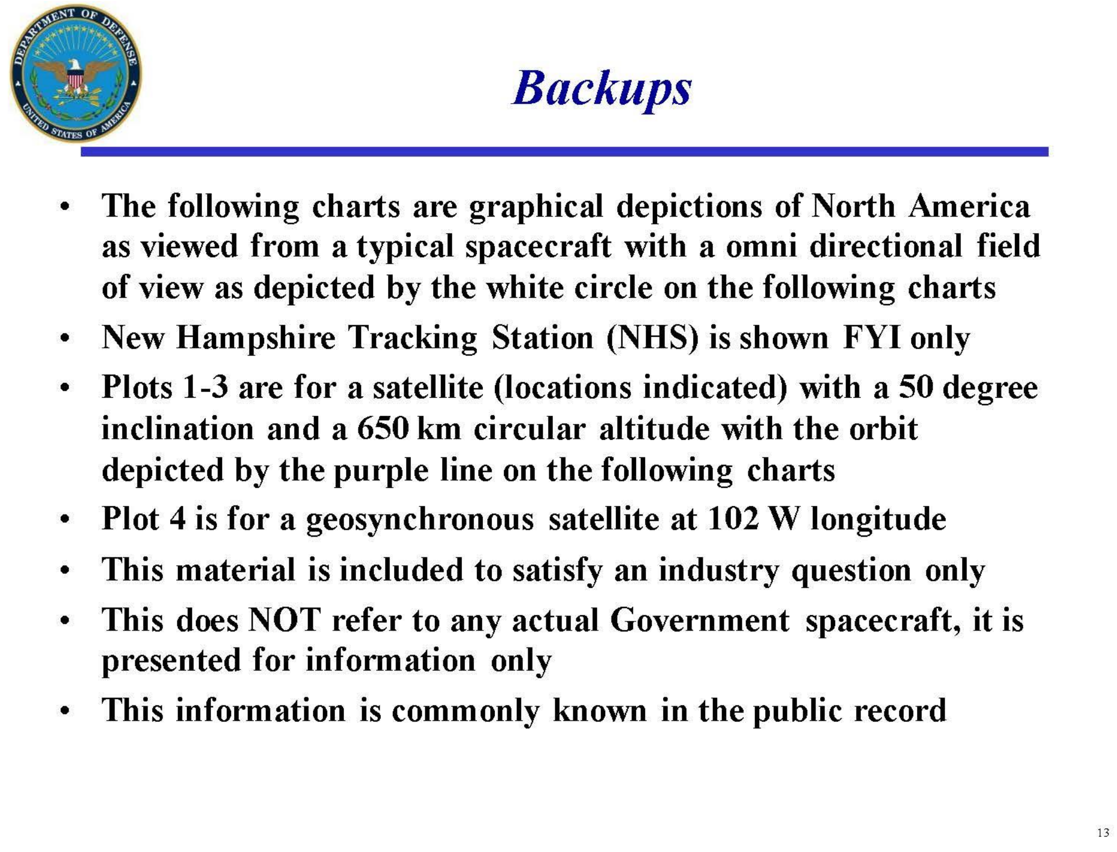
Items shown in italics are additions/changes to those listed in the first Government submittal



Remarks

- **US Government has many critical SATOPS uplinks in 1755-1850 MHz from limited fixed worldwide locations**
  - 4 US&P AFSCN sites are heavy hitters
  - Spacecraft have long lives and frequencies are fixed during design
- **Final policy decisions will be made through the Policy and Plans Steering Group (PPSG), and implemented in accordance with NTIA and OMB procedures and Federal law, including transition plan, cost reimbursement, and comparable spectrum.**
- **Cooperative Government/Industry analyses/tests needed to assess possible sharing solutions**
  - Tests are highly desired
- **Government needs Industry input regarding what is desired next**
- **National security issues are a key factor**
- **Regulatory provisions must allow for Government growth including the possibility of more use at existing sites and coordination of new sites**

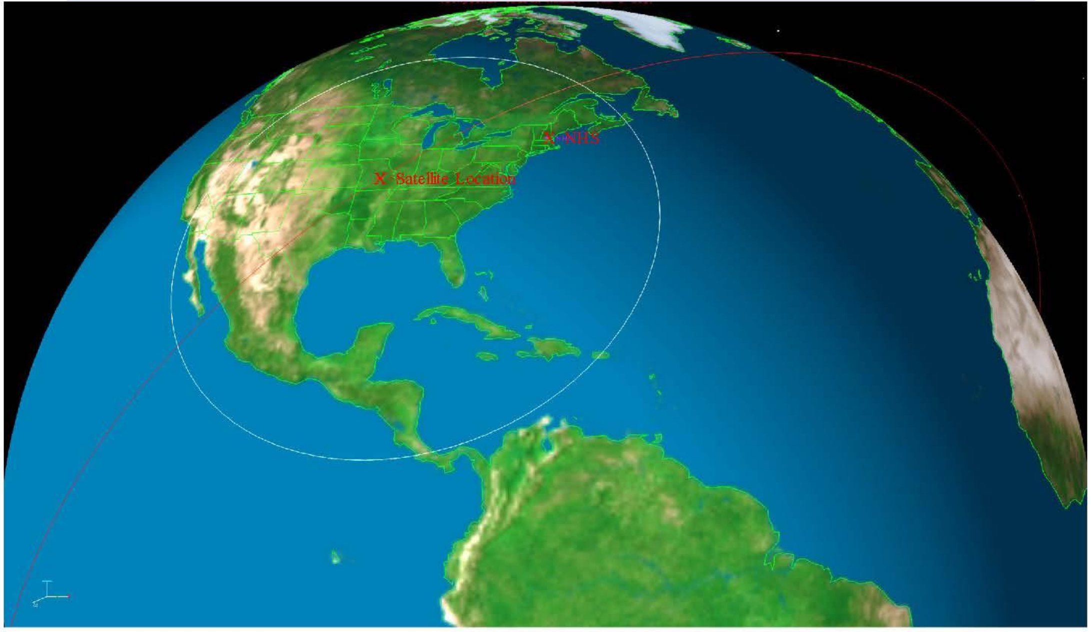
Sharing solutions must be enduring



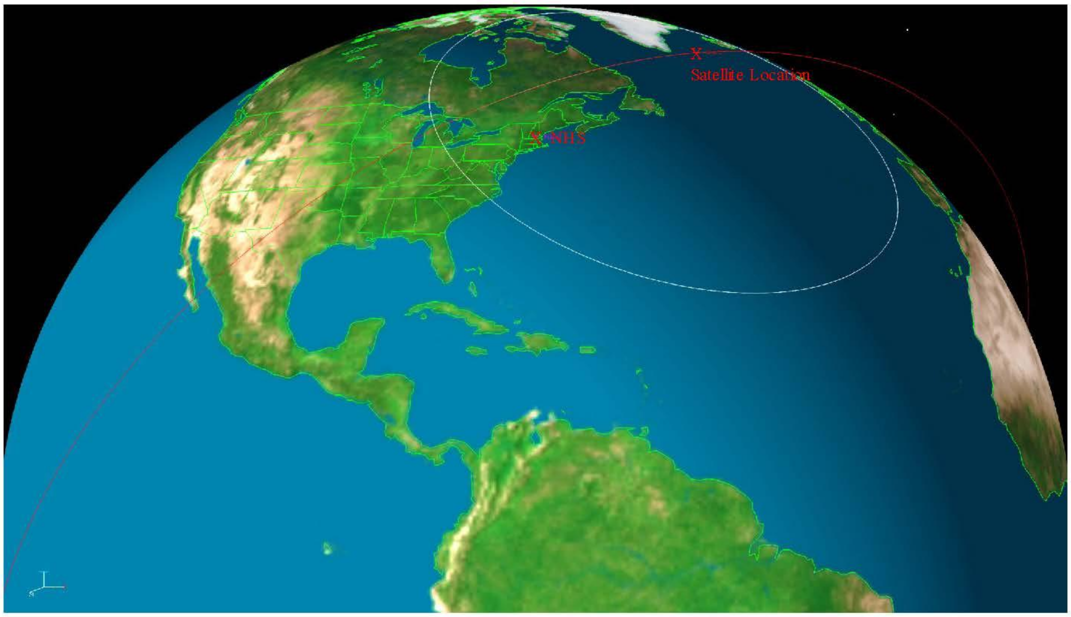
Backups

- **The following charts are graphical depictions of North America as viewed from a typical spacecraft with a omni directional field of view as depicted by the white circle on the following charts**
- **New Hampshire Tracking Station (NHS) is shown FYI only**
- **Plots 1-3 are for a satellite (locations indicated) with a 50 degree inclination and a 650 km circular altitude with the orbit depicted by the purple line on the following charts**
- **Plot 4 is for a geosynchronous satellite at 102 W longitude**
- **This material is included to satisfy an industry question only**
- **This does NOT refer to any actual Government spacecraft, it is presented for information only**
- **This information is commonly known in the public record**

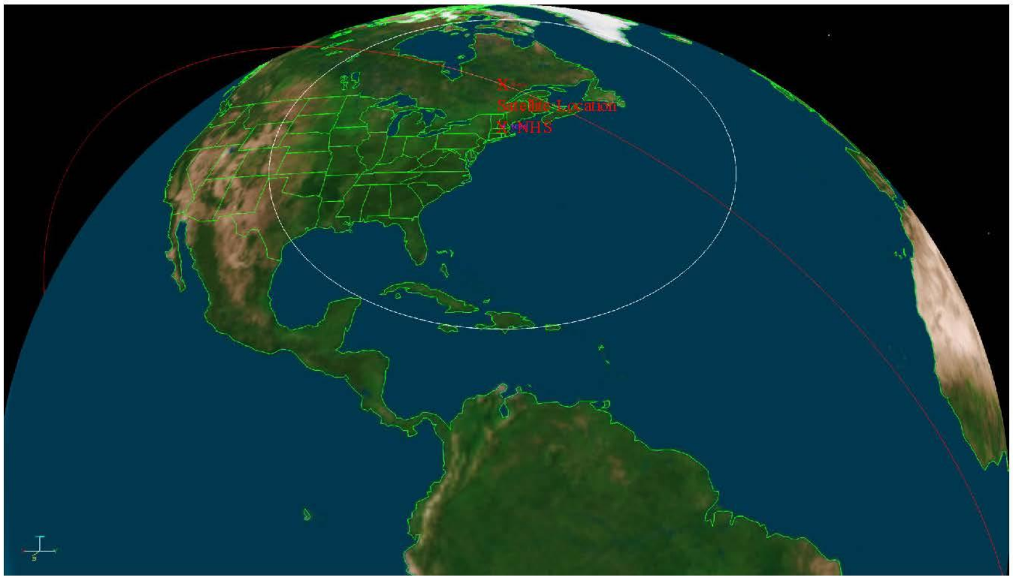
Plot 1 Satellite over mid US



Plot 2 Satellite over North Atlantic



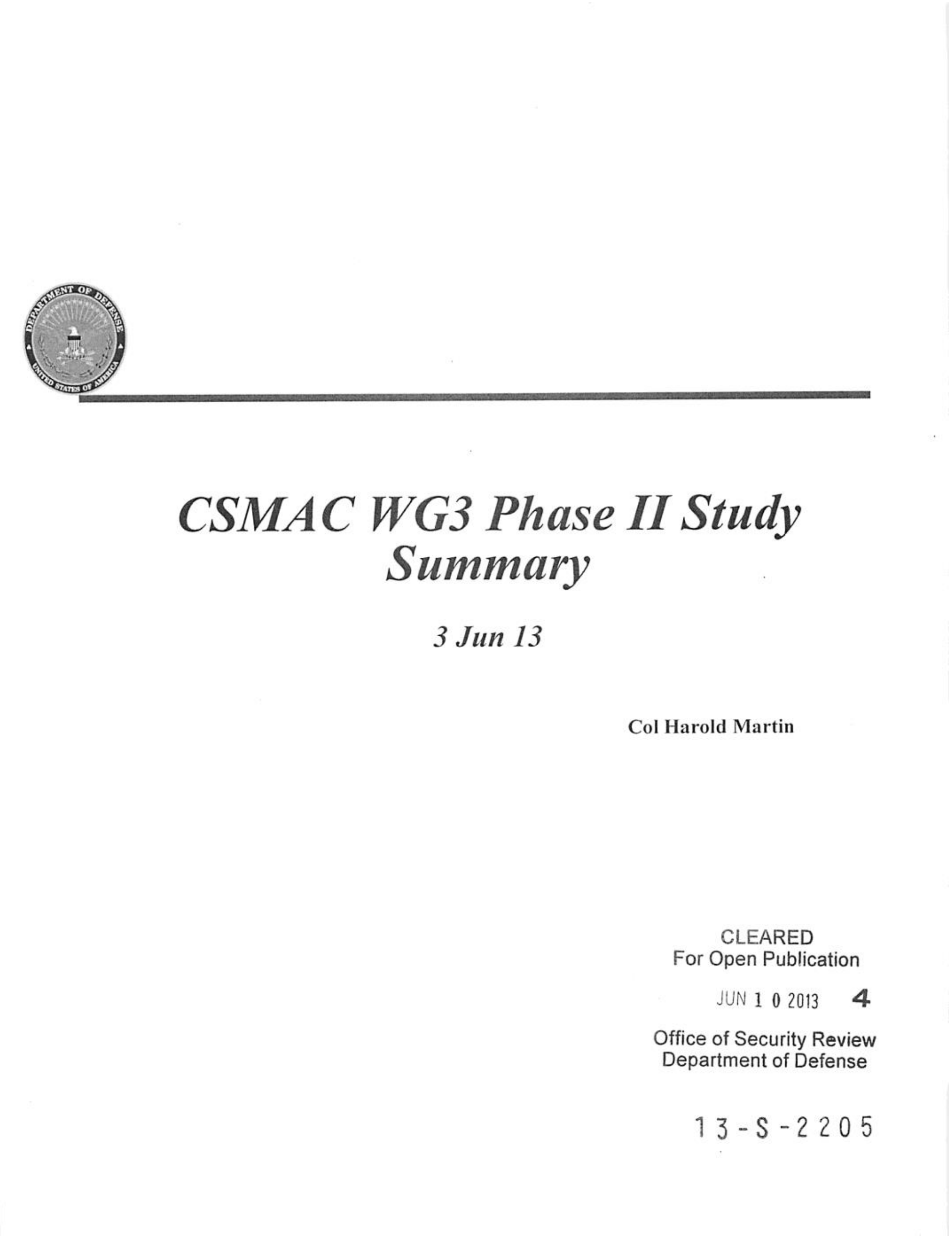
Plot 3 Satellite over Canada



Plot 4 GEO Satellite at 102 W Longitude

4.4.5 Phase 2 Study Summary – June 2013

“Commerce Spectrum Management Advisory Committee (CSMAC) Working Group (WG) 3 Phase II Study Summary”, June 3, 2013. The charts in this section were reprinted with permission of the Aerospace Corporation.



CSMAC WG3 Phase II Study Summary

3 Jun 13

Col Harold Martin

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Office of Security Review
Department of Defense

13-S-2205

Technical Report

Forward

The concepts and analysis provided in this report are intended for Government and Commerce Spectrum Management Advisory Committee (CSMAC) discussion purposes only

The information is provided for use in developing estimates only and is not intended to be representative of actual ground site operating parameters in the future

Government operational information for the 1755-1850 MHz band studied in this report has been summarized and enveloped to avoid presenting individual program or ground site information

Outline

- Executive Overview
- Purpose
- Methodology
- Results
- Summary
- References
- Appendix
  - *A. Study Results*
  - *B. Technical Rationale*

Executive Overview

The Department of Commerce National Telecommunications and Information Administration (NTIA) identified the Commerce Spectrum Management Advisory Committee (CSMAC), as the primary forum to facilitate technical discussions between industry and federal agencies regarding repurposing spectrum for commercial use. CSMAC Working Group 3 is focused on sharing of the 1755-1850 MHz band between federal satellite operations (SATOPS) , DoD electronic warfare and commercial mobile wireless (MW) broadband. CSMAC Working Group 3 and the DoD Chief Information Officer (DoD/CIO) requested a characterization of Government satellite operations at specific ground stations that could potentially impact commercial MW broadband operations in the future.

Government uplink emissions were analyzed from three Air Force Satellite Control Network sites (New Hampshire Station, Vandenberg Tracking Station, Hawaii Tracking Station), two Navy sites (Blossom Point and Laguna Peak Tracking Station) and the NOAA Fairbanks Alaska site. The analyses made use of NTIA's Irregular Terrain Model (ITM) associated with the NOAA/NGDC GLOBE terrain database for propagation prediction in conjunction with historical SATOPS information. The results are presented on maps in the vicinity of the selected SATOPS locations to display, as a function of distance and azimuth from the SATOPS sites, contours of two parameters: 1) the predicted peak received power levels (for median value of path loss), and 2) the probability over time that the received power does not exceed the selected MW interference threshold.

The results of modeling transmitted radiation as a function of distance from each site, with various attenuation scenarios are presented. Potential exceedence of the standard LTE threshold is also presented for each case. In addition, estimates of site usage based on satellite contact parameters are provided. The presentation format for the simulation outputs was specified by CSMAC Working Group 3. Uncertainties associated with each of the models used (mission astrodynamics, power, path loss, terrain, and probabilities) are described, including propagation variabilities and approximations of the terrain data. The models have inherent limitations such as lack of vegetation information, so the data should not be construed to be actual power levels of the AFSCN or other sites.

In summary, this report provides estimates of the areas potentially impacted by Government radio emissions from selected ground facilities. The information is provided for estimating purposes only and is not intended to be representative of actual ground site operating parameters in the future.

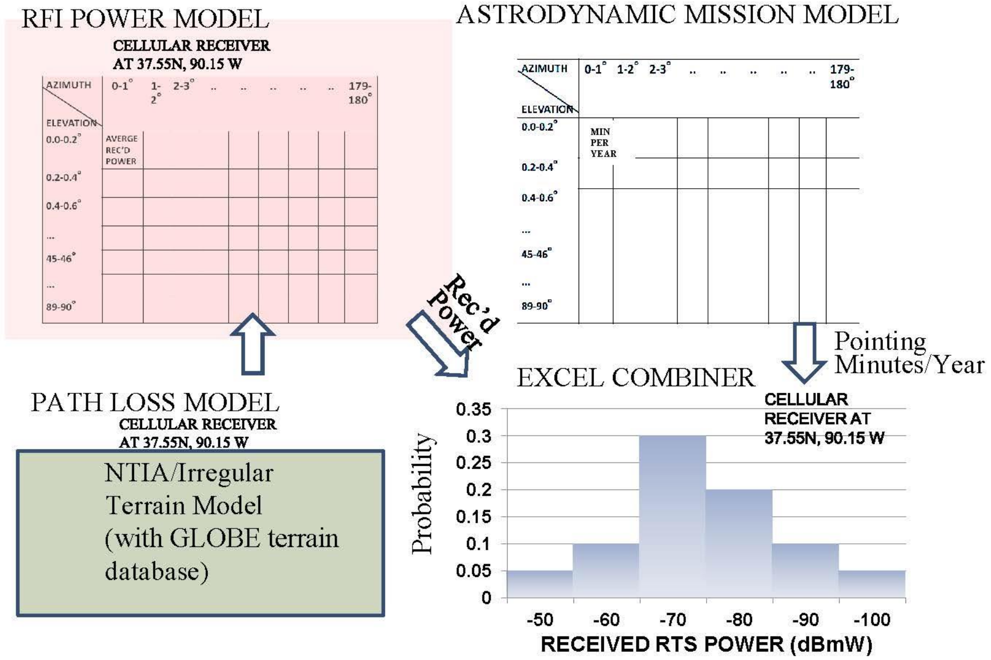
Purpose

- **The purpose of this study is to provide a characterization of Air Force, Navy and NOAA uplink Satellite Operations (SATOPS) in the band 1755-1850 MHz and to estimate areas in the vicinity of Government ground sites that are potentially subject to interference**
- **The intended use of this study is for transmittal to the CSMAC WG3**
- **Info should be used for determining the next steps of evaluation and not for final decisions regarding spectrum sharing within bands**

Methodology

- **Computer Tools Used in Study**
  - *The Power Model is a specialized scenario using the Aerospace SOAP Model (Ref. 1) that computes Radio Frequency Interference (RFI) power received by a cellular base station (receiver) when a SATOPS antenna is pointed in each Azimuth/Elevation (Az/El) cell*
  - *The Path Loss Model computes RFI reduction at a cellular base station (receiver) as input to the Power Model. This computation uses the NTIA Irregular Terrain Model (Ref. 2) with the GLOBE Terrain Data Base (Ref.3).*
  - *The Aerospace Astrodynamics Mission Model computes, for each SATOPS site, the transmit minutes per year (average) in each Az/El cell*
  - *The EXCEL Combiner Model computes, for a cellular base station (receiver), a RFI power histogram and the "probability" of RFI power not exceeding the receiver threshold of harmful interference*
- **The accompanying chart shows the four major computer tools used in this study, and the data flows between them**

Methodology - Calculating Base Station Received Interference (resulting from given Government SATOPS antenna)



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Methodology - Propagation Models

- **No single propagation model is best suited for all purposes**
  - *Some models are conservative regarding predicting interference (i.e., lead to predicting more interference than would really occur)*
  - *Other models are conservative towards identifying low signal levels (i.e., lead to predicting lower received power than would really occur)*
- **Models also have varying degrees of accuracy**
- **While there are varying degrees of uncertainty associated with any model, these types of models are typically applied in spectrum management studies**

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Methodology - Theoretical Bases and Assumptions (1/3)

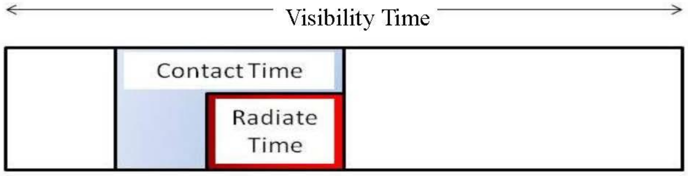
- **Path Loss**
  - *Each path loss is the median value loss computed by the Irregular Terrain Model (the NTIA path loss model adopted by CSMAC) using the "Globe Database" of terrain elevation maps*
- **Pointing Minutes**
  - *Output of Aerospace Astrodynamic "Mission Model" orbital simulation for each SATOPS site*
  - *The minutes of radiate time is the sum of the contributions of all satellites in the "Mission Model" in the spectral band of interest that operate in the band of interest, distributed over all Az/El cells above minimum allowable elevation angle*
  - *Radiate time amounts to a fraction of the total contact time*
  - *Contact start and end times are derived from recorded experience*
  - *Radiate start time is randomly distributed uniformly over contact time*

Methodology - Theoretical Bases and Assumptions (2/3)

- **Received power histogram for antenna sites**
  - *For single antenna sites, at each power level, the "probability" is defined as the sum of the "Mission Model" Az/El cell values (which are the annual transmit minutes for each Az/El) divided by yearly minutes for all the same Az/El cells corresponding to the received power level*
  - *For sites with 2 or more antennas, "probability" is defined as percent time (all site antennas) below threshold RFI level, less percent time of overlap (i.e. simultaneous radiation)*
- **Threshold Exceedance Contours**
  - *The probability that the RFI doesn't exceed threshold power level, assuming that the path loss is, in fact, the median value given by the ITM model (see Model Limitations)*
  - *Is the complement of the sum of probabilities for received power levels exceeding the threshold level*
  - *The "LTE Threshold" is assumed to be -137.37 dBW or (-107.37 dBm) using CSMAC WG-1 documented values (Ref. 4)*

Methodology – Theoretical Bases and Assumptions (3/3)

- **Contact Time**
  - *Based on statistical records averaged for one year for the AFSCN sites and estimated for non-AFSCN sites*
  - *Actual radiation time is less than visibility time as depicted in the figure below*



  - *Note that publicly available ITU registration data may be used to estimate visibility time, but does not indicate actual radiation time*
  - *There is sometimes flexibility in contact time scheduling; many times there is not flexibility*

Methodology – Model Uncertainties

- **Major factors constraining utility of analysis results and conclusions**
  - *Uncertainty of applicability of ITM model to urban propagation*
  - *Uncertainty inherent in use of ITM model without ground truth*
  - *Unknown impact of input variables on ITM model outputs*
- **Minor factors**
  - *Underestimation of SATOPS Radio Frequency Interference (RFI) due to distribution of radiate time*
  - *Underestimation of SATOPS RFI due to not accounting for elevation angle to first path obstruction*
- **Unknown factors**
  - *Possibly inadequate terrain data resolution*
  - *Possible electromagnetic environment factors to which ITM is not sensitive*
  - *Uncertainty in the effect of receiver site constraints*
  - *Changes in the terrain*

Methodology – Impacts of Model Uncertainties

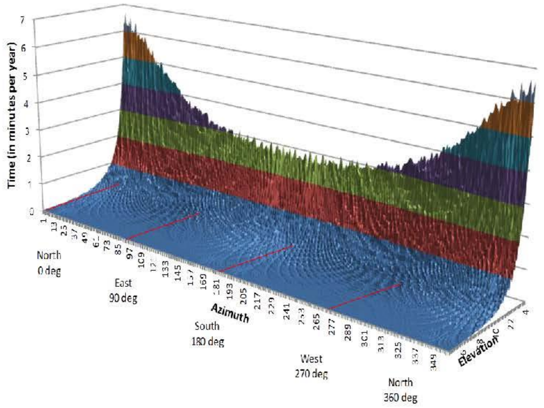
- **Effects of propagation loss uncertainties upon Power and Threshold Exceedance Plots**
  - *Due to change in propagation path electrical parameters (soil conductivity and dielectric constant and surface refraction)*
  - *Due to regional characteristics (climate types and terrain types)*
  - *Due to variations in time (diurnal and seasonal)*
  - *Due to MW station receiver siting (constrained to achieve exposure to handsets while minimizing exposure to interference)*
  - *Due to limited terrain database resolution*
- **Effects of SATOPS modeling enhancements upon power and Threshold Exceedance Plots**
  - *Due to antenna pattern approximation (due to use of envelope mask)*
  - *Due to variation in radiate start/stop times*
  - *Due to use of elevation angle to first obstacle*

2222

Methodology

Visibility Time as a Function of Ground Antenna Pointing Angles

- **The figure represents an example visibility for a single non-geostationary satellite with one frequency uplink accumulated over one year in 1°x 1° Az/El cells**
- **Calculations include the number of minutes per year that a given antenna points in a given azimuth and elevation in supporting one single non-geostationary satellite**
- **Illustrative of the type of data that is combined for multiple satellites in arriving at a composite profile for the earth station's radiation over the year**
- **Note the antenna only points in any given direction a small percentage of the time**



2223

Methodology - Power Contour Plots

- **Power radiated from each of the Government sites along with other computational details are presented in Appendix B**
- **These calculations use 1 kW transmitter power for AFSCN sites for the analysis**
  - *The AFSCN power actually varies from 500 W to ~ 7kW, within the US*
  - *A few maximum power cases are included for comparison*
- **The contours are calculated using the NTIA Irregular Terrain Model (ITM) with the GLOBE Terrain Data Base for propagation loss and are accurate to 1 and 5 km grid spacing as labeled**
  - *1 or 5 km grid spacing, as limited by the GLOBE data base, adds considerable uncertainty because natural terrain features can be greatly varied over these distances*
- **This model does not take into account vegetation or artificial structures so a 20 dB attenuation factor on the radiated signal was also added to some of the analyses cases**

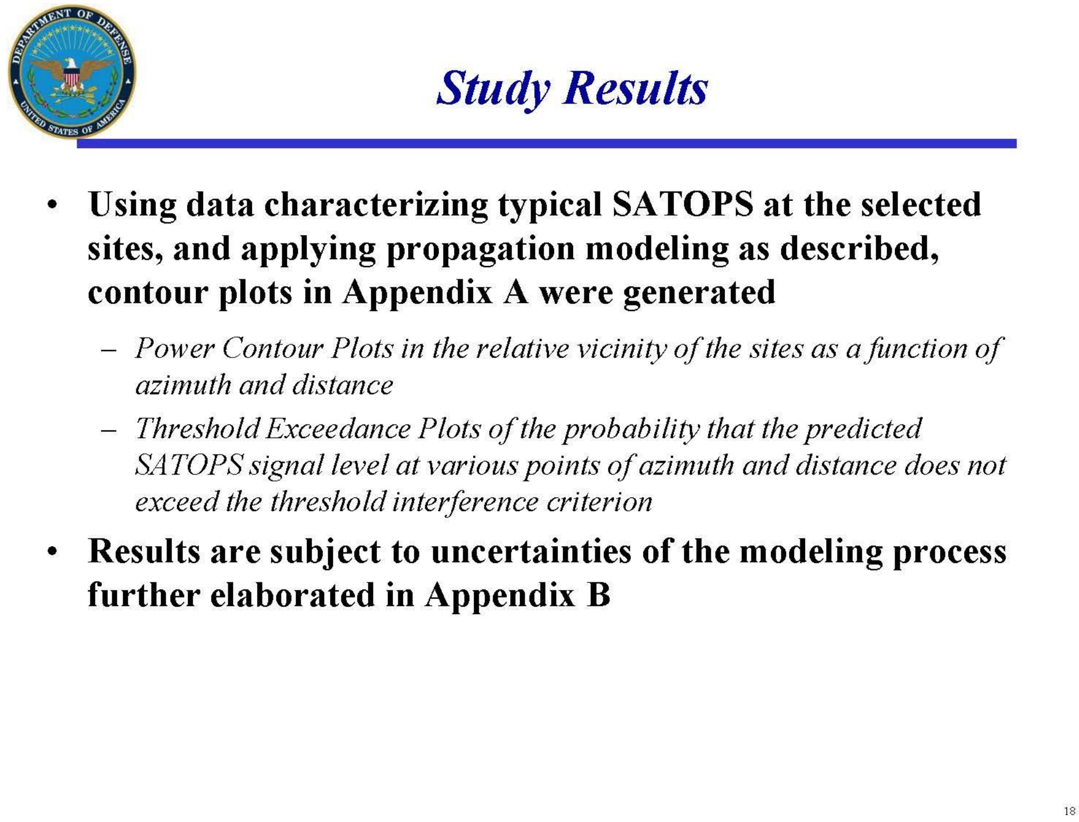
2224

Methodology

Mobile Wireless Long Term Evolution (LTE) System Threshold Exceedance

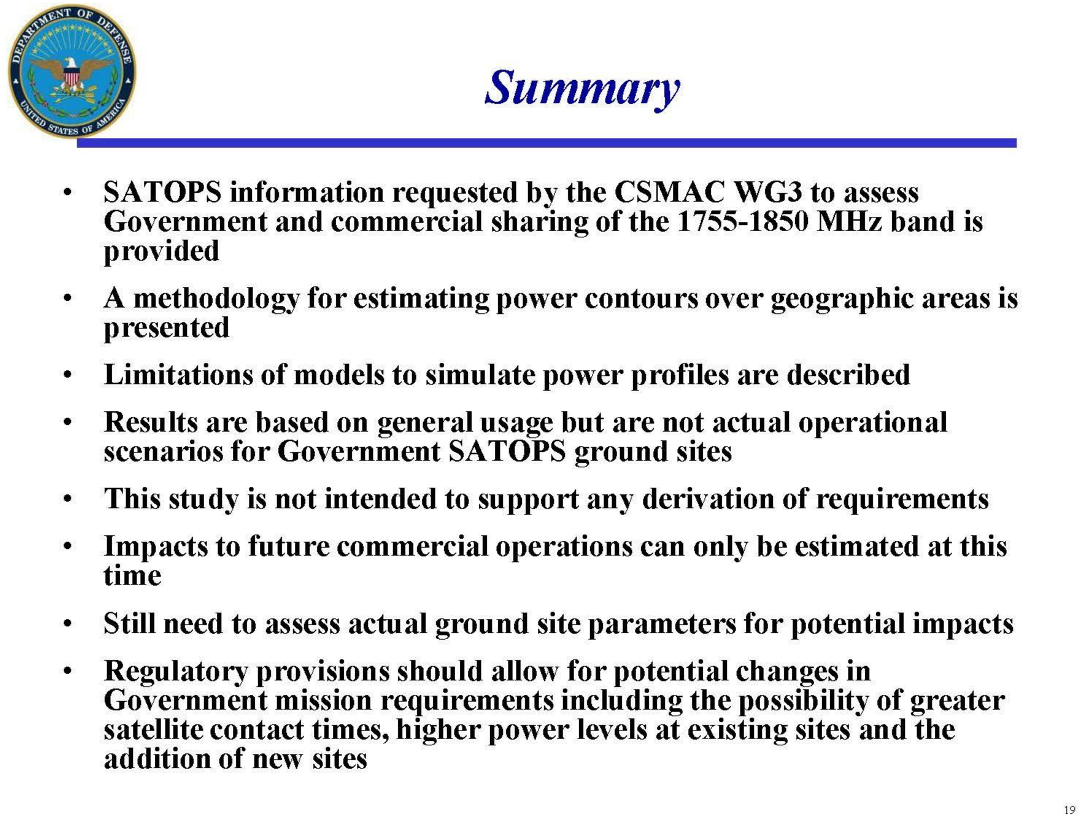
- **The received power level was calculated and compared to the LTE threshold of -137.4 dBW (1dB desense level) for each potential LTE base station site and at each antenna pointing angle**
  - *The percentage non-exceedance time is that which the MW base stations can operate without RFI given the stated LTE threshold*
  - *1 dB desense level is used as the interference criterion for the LTE receiver; it is the level at which the apparent receiver noise floor is increased by 1 dB, thereby reducing the effective sensitivity by 1 dB*
- **The center color of the plot(s) (i.e. nearest to the ground station) represents the minimum value of threshold non-exceedance which is the complement of the site radiation percentage time**
- **This study uses aggregated statistics of radiation to spacecraft over a given band for the past year**

2225



Study Results

- **Using data characterizing typical SATOPS at the selected sites, and applying propagation modeling as described, contour plots in Appendix A were generated**
  - *Power Contour Plots in the relative vicinity of the sites as a function of azimuth and distance*
  - *Threshold Exceedance Plots of the probability that the predicted SATOPS signal level at various points of azimuth and distance does not exceed the threshold interference criterion*
- **Results are subject to uncertainties of the modeling process further elaborated in Appendix B**



Summary

- **SATOPS information requested by the CSMAC WG3 to assess Government and commercial sharing of the 1755-1850 MHz band is provided**
- **A methodology for estimating power contours over geographic areas is presented**
- **Limitations of models to simulate power profiles are described**
- **Results are based on general usage but are not actual operational scenarios for Government SATOPS ground sites**
- **This study is not intended to support any derivation of requirements**
- **Impacts to future commercial operations can only be estimated at this time**
- **Still need to assess actual ground site parameters for potential impacts**
- **Regulatory provisions should allow for potential changes in Government mission requirements including the possibility of greater satellite contact times, higher power levels at existing sites and the addition of new sites**

Study Reference

1. **Satellite Orbit Analysis Program (SOAP), The Aerospace Corporation, OTR-2013 0314155423, 2013**
2. **"Integrated Terrain Model" by NTIA/ITS, see: http://www.its.bldrdoc.gov/resources/radio-propagation-software/itm/itm.aspx**
3. **The Global Land One-km Base Elevation Project (GLOBE) Elevation Database, National Geophysical Data Center, NOAA; available online at: http://www.ngdc.noaa.gov/mgg/topo/globe.html**
4. **Commerce Spectrum Management Advisory Committee, Final Report, Working Group 1-1695-1710 MHz Meteorological-Satellite, dated 1/22/2013, downloaded from: http://www.ntia.doc.gov/other-publication/2013/csmac-wg-1-final-report-v2**
5. **"Antenna Models for Electromagnetic Compatibility Analyses," NTIATM-13-489, National Telecommunication and Information Administration Technical Memorandum, October 2012**
6. **"Government Satellite Control Overview", 2 Oct 12 [Government submittal 1 to CSMAC WG3]**
7. **NTIA Manual of Regulation and Procedures for Federal Radio Frequency Management, May 2012**
8. **"Commerce Spectrum Management Advisory Committee (CSMAC) Working Group (WG) 3 Phase II Study Summary" Aerospace Report No. TOR-2013 00257, May 29, 2013**

Charts 2 through 83 were reprinted with permission of the Aerospace Corporation

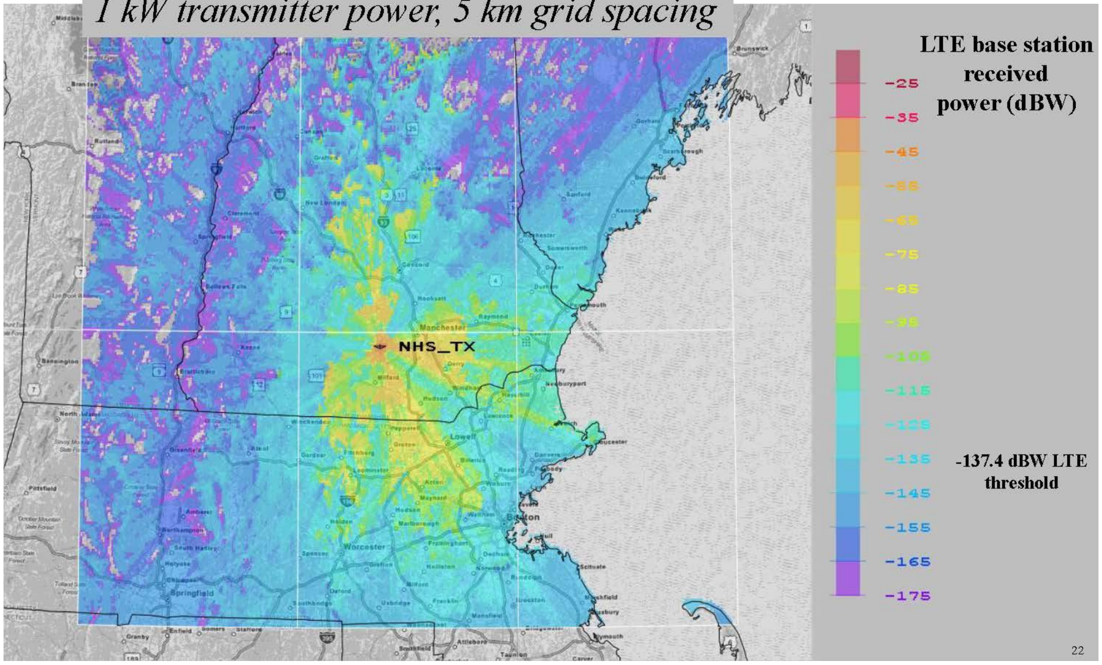
Appendix A: Study Results

Type of Plot	Grid (km)	Site					
		NHS	VTS	HTS	BPTF	FB/AK	LP/CA
Power Contour	5	22-23	36-37	48-49, 51	59-60	67-68	70-71
Power Contour with 20 dB attenuation	5	24-25	38-39	50, 52	61-62	67-68	72-73
LTE Threshold Exceedance 1755-1780 MHz	5	26	42	53	63		
LTE Threshold Exceedance 1755-1780 MHz	1				65	69	
LTE Threshold Exceedance 1755-1780 MHz, with 20 dB attenuation	1	27	43	54	64,66	69	
LTE Threshold Exceedance 1780-1805 MHz	5	28	44	55			74
LTE Threshold Exceedance 1780-1805 MHz	1						75
LTE Threshold Exceedance 1780-1805 MHz, with 20 dB attenuation	1	29	45	56			
LTE Threshold Exceedance 1805-1850 MHz	5	30	46	57			
LTE Threshold Exceedance 1805-1850 MHz, with 20 dB attenuation	1	31	47	58			
Power Contour (radiating at 5.02 kW)	5		40				
Power Contour (radiating at 5.02 kW) with 20 dB attenuation	5		41				
Power Contour (radiating at 7.244 kW)	5	32					
Power Contour (radiating at 7.244 kW) with 20 dB attenuation	5	33					
LTE Threshold Exceedance 1755-1780 MHz (radiating at 7.244 kW)	5	34					
LTE Threshold Exceedance 1755-1780 MHz (with 10 dB standard deviation applied to propagation loss)	5	35					

*Unless otherwise stated in the Table, charts reflect transmit power of 1 kW except BP, MD power of 300 W

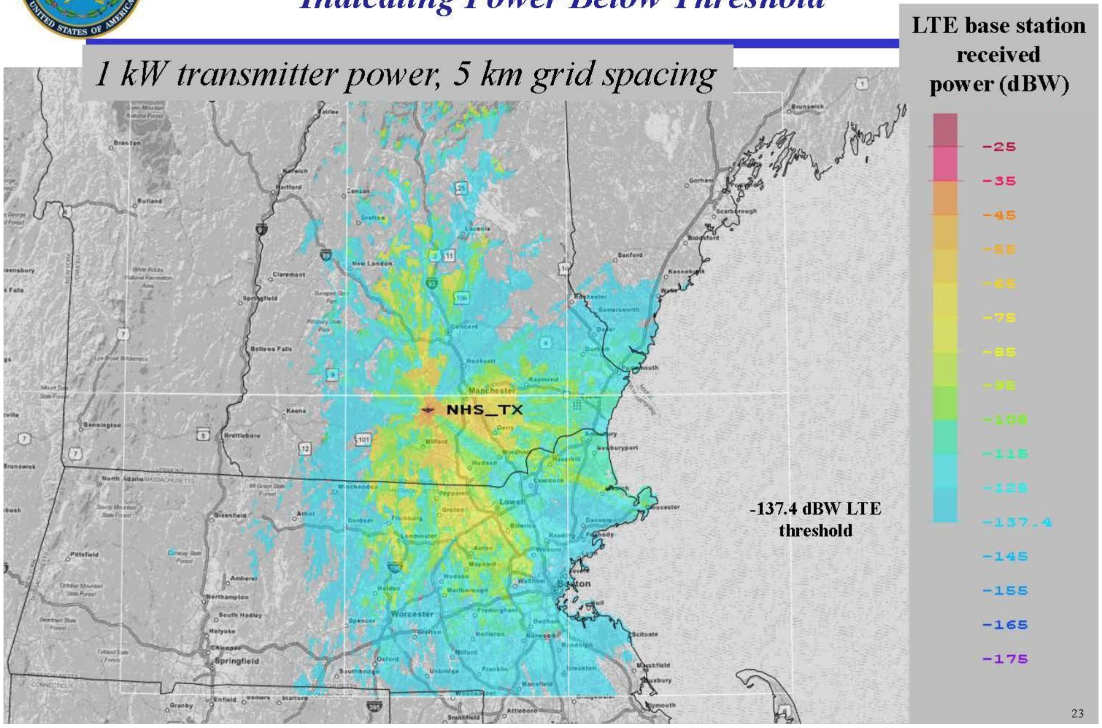
NHS Power Contours

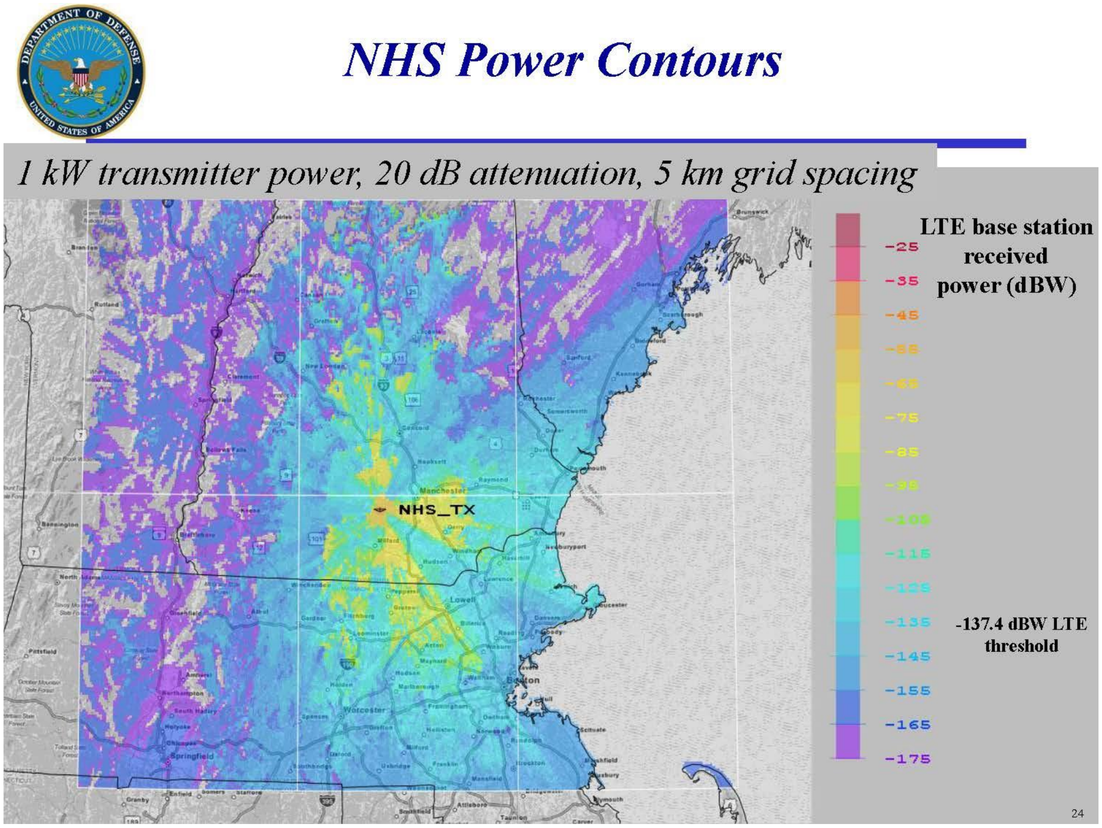
1 kW transmitter power, 5 km grid spacing



NHS Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

1 kW transmitter power, 5 km grid spacing





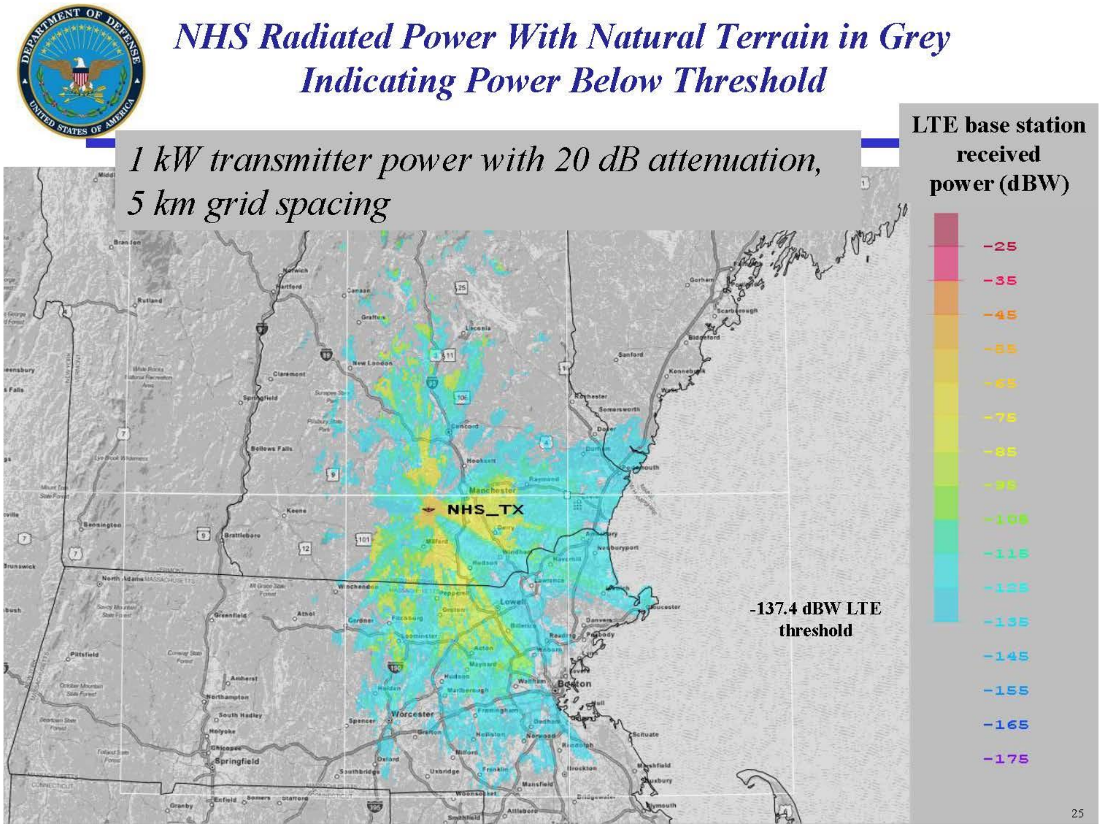
NHS Power Contours

1 kW transmitter power, 20 dB attenuation, 5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

2232



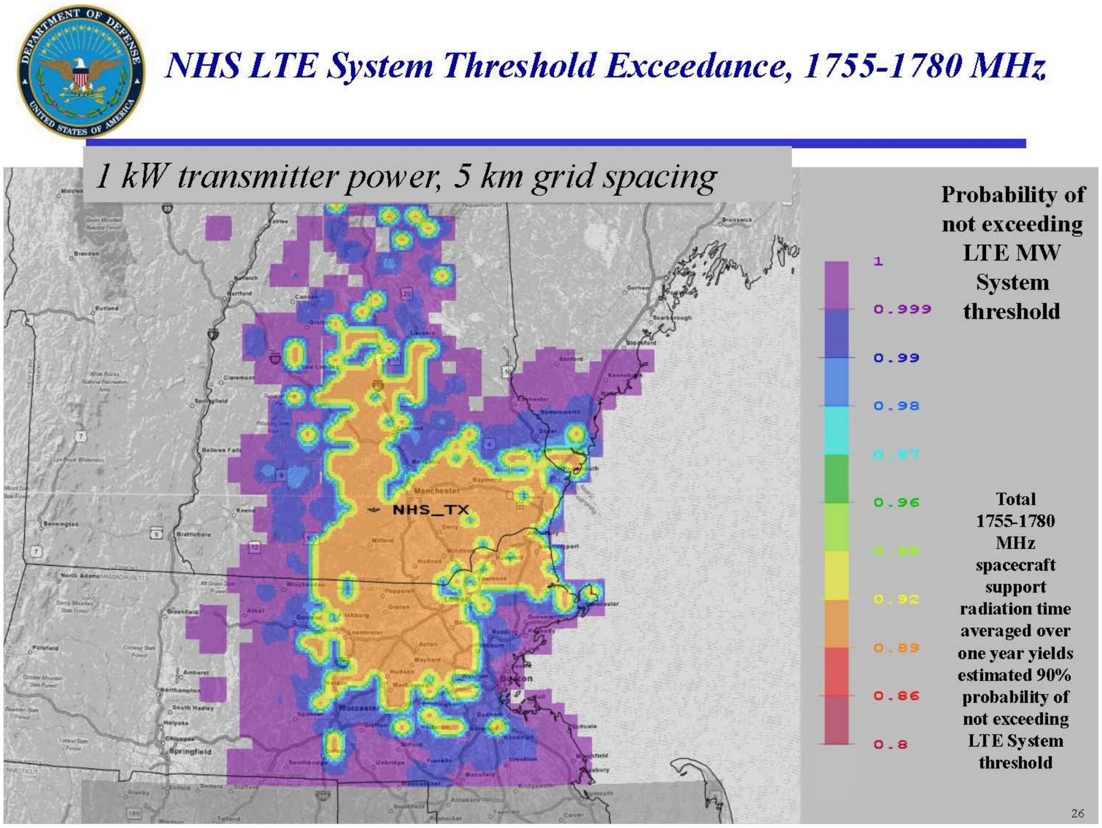
NHS Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

1 kW transmitter power with 20 dB attenuation, 5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

2233

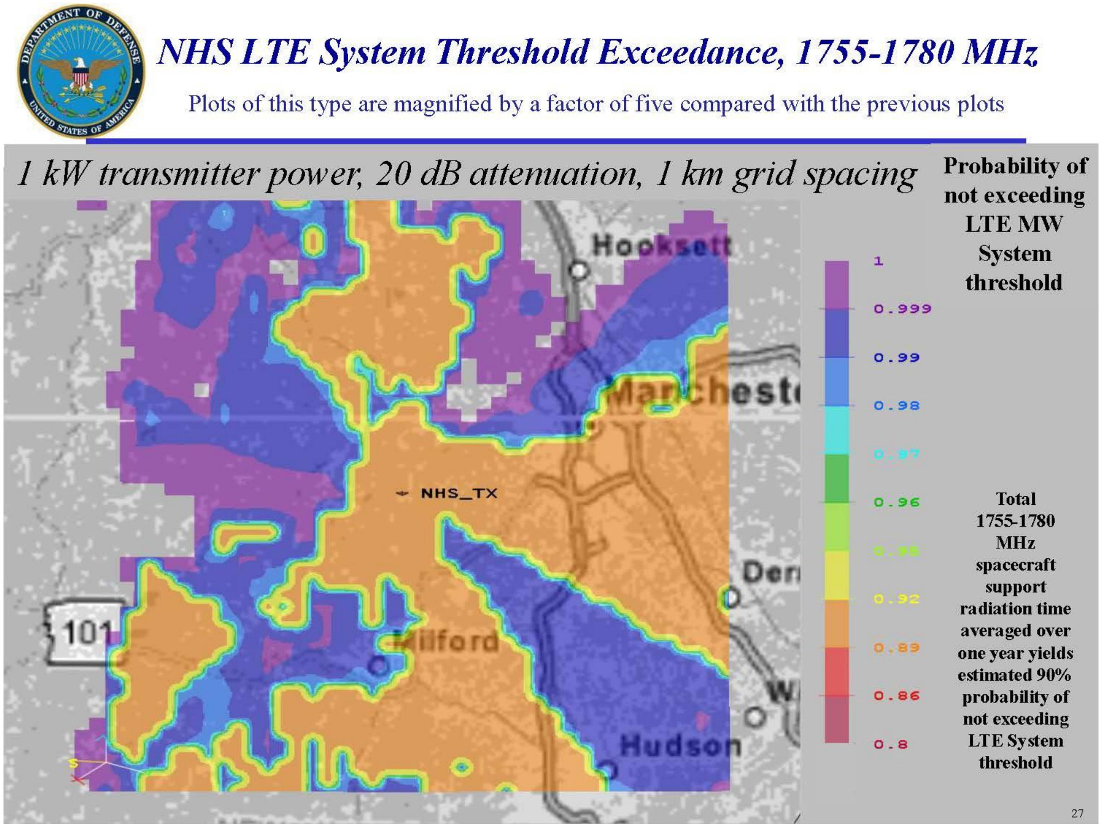


NHS LTE System Threshold Exceedance, 1755-1780 MHz

1 kW transmitter power, 5 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1755-1780 MHz spacecraft support radiation time averaged over one year yields estimated 90% probability of not exceeding LTE System threshold



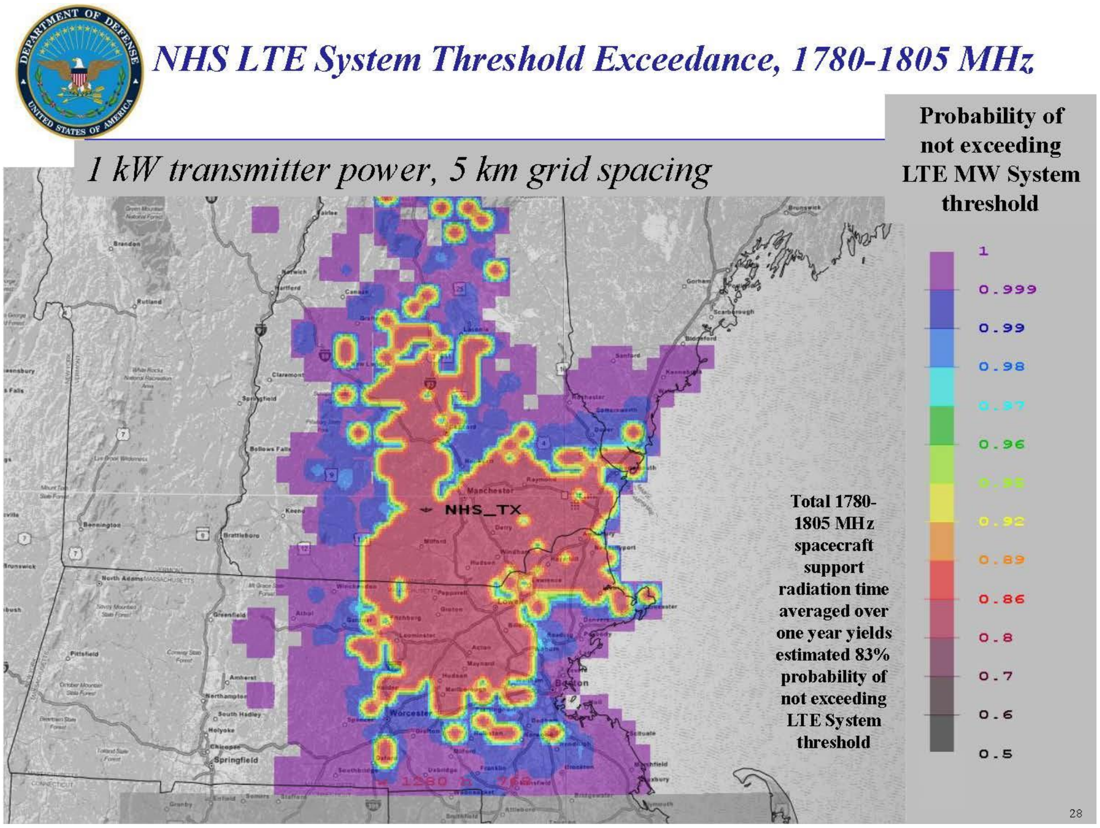
NHS LTE System Threshold Exceedance, 1755-1780 MHz

Plots of this type are magnified by a factor of five compared with the previous plots

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1755-1780 MHz spacecraft support radiation time averaged over one year yields estimated 90% probability of not exceeding LTE System threshold



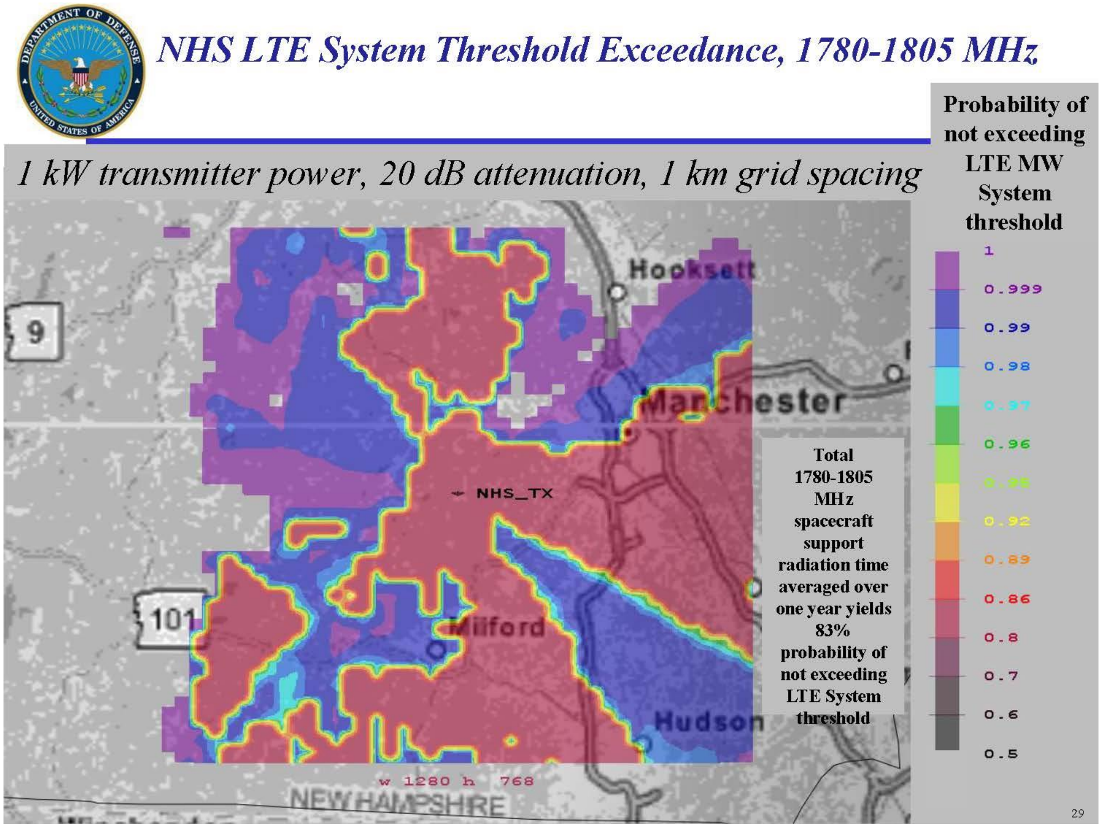
NHS LTE System Threshold Exceedance, 1780-1805 MHz

1 kW transmitter power, 5 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1780-1805 MHz spacecraft support radiation time averaged over one year yields estimated 83% probability of not exceeding LTE System threshold

28 2236



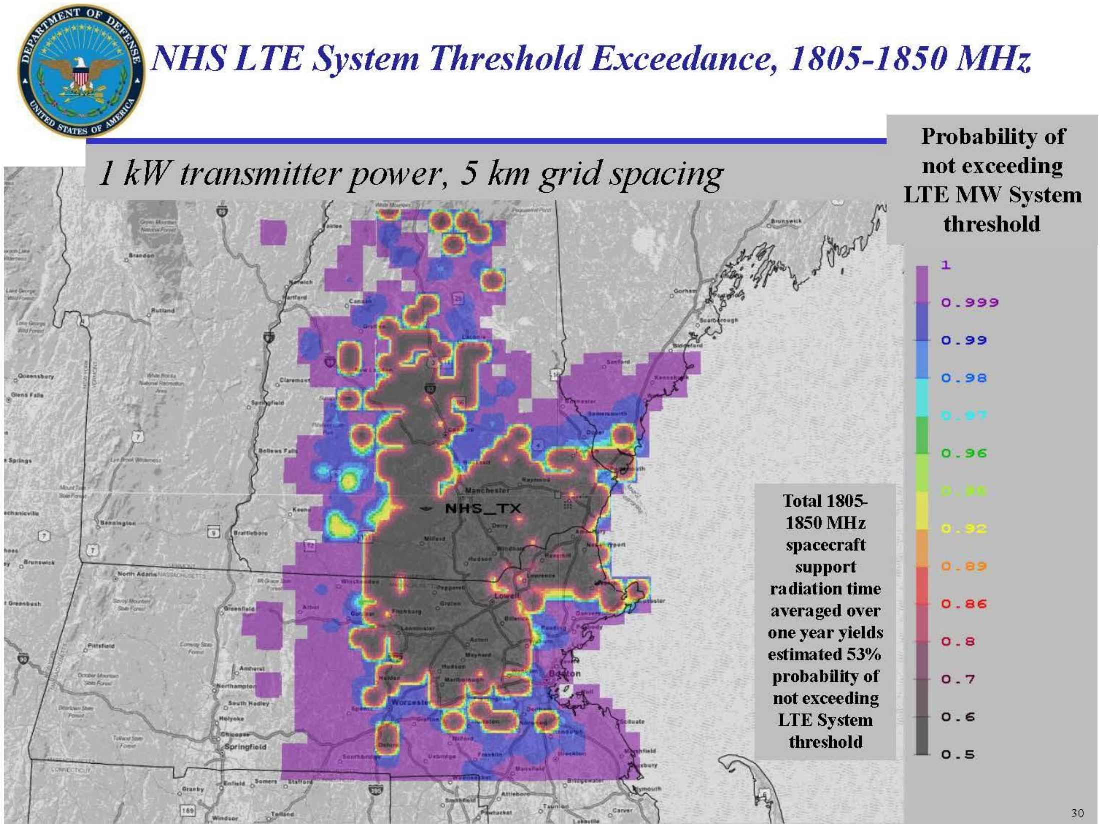
NHS LTE System Threshold Exceedance, 1780-1805 MHz

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1780-1805 MHz spacecraft support radiation time averaged over one year yields 83% probability of not exceeding LTE System threshold

29 2237



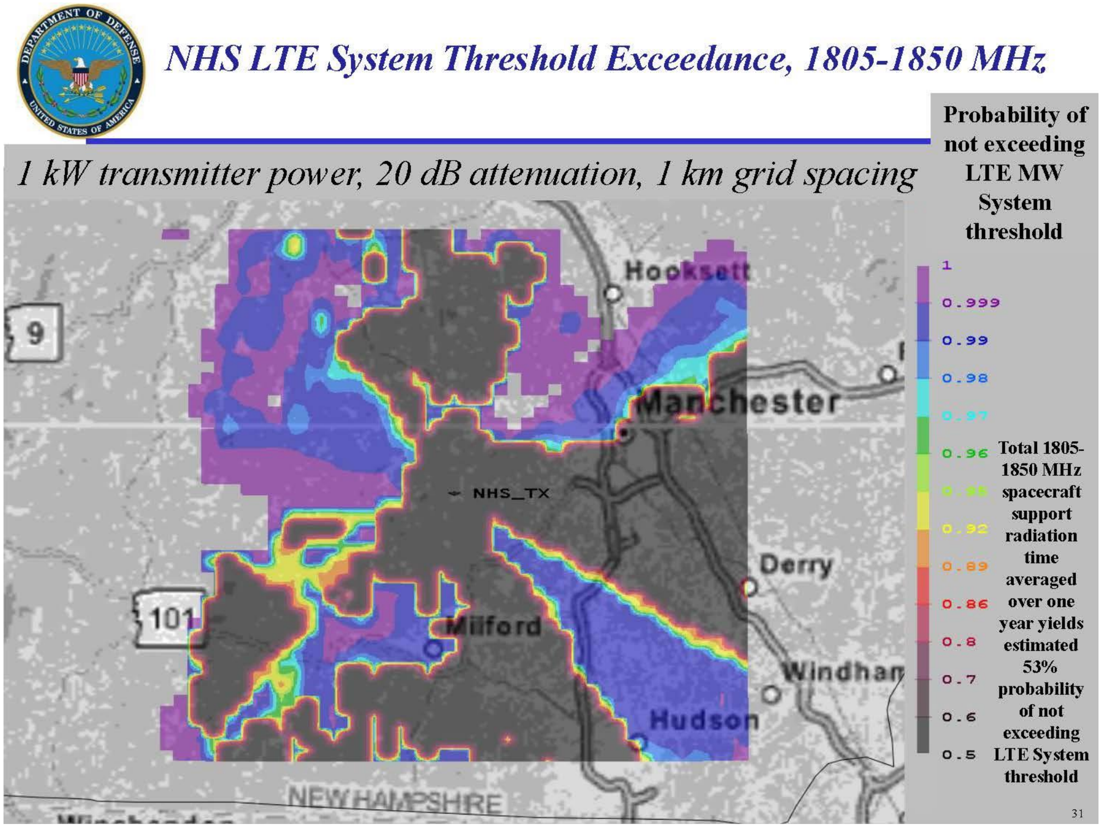
NHS LTE System Threshold Exceedance, 1805-1850 MHz

1 kW transmitter power, 5 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1805-1850 MHz spacecraft support radiation time averaged over one year yields estimated 53% probability of not exceeding LTE System threshold

2238



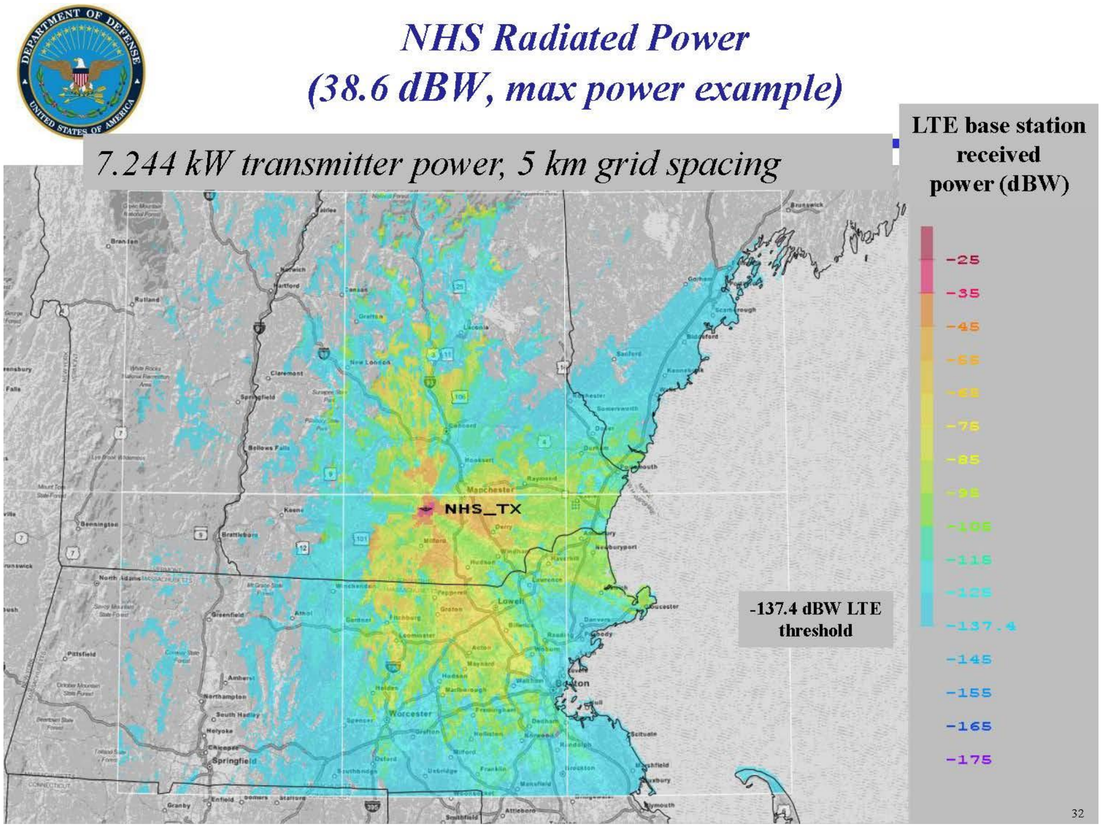
NHS LTE System Threshold Exceedance, 1805-1850 MHz

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1805-1850 MHz spacecraft support radiation time averaged over one year yields estimated 53% probability of not exceeding LTE System threshold

2239

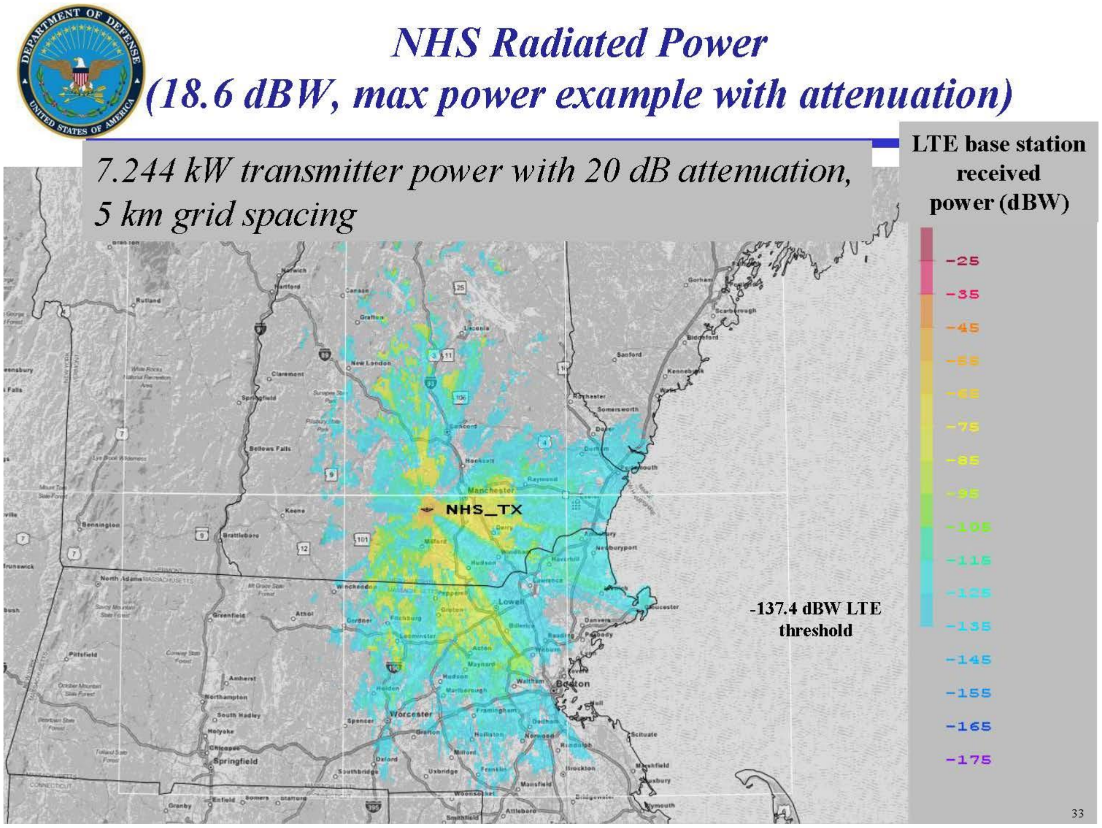


NHS Radiated Power
(38.6 dBW, max power example)

7.244 kW transmitter power, 5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

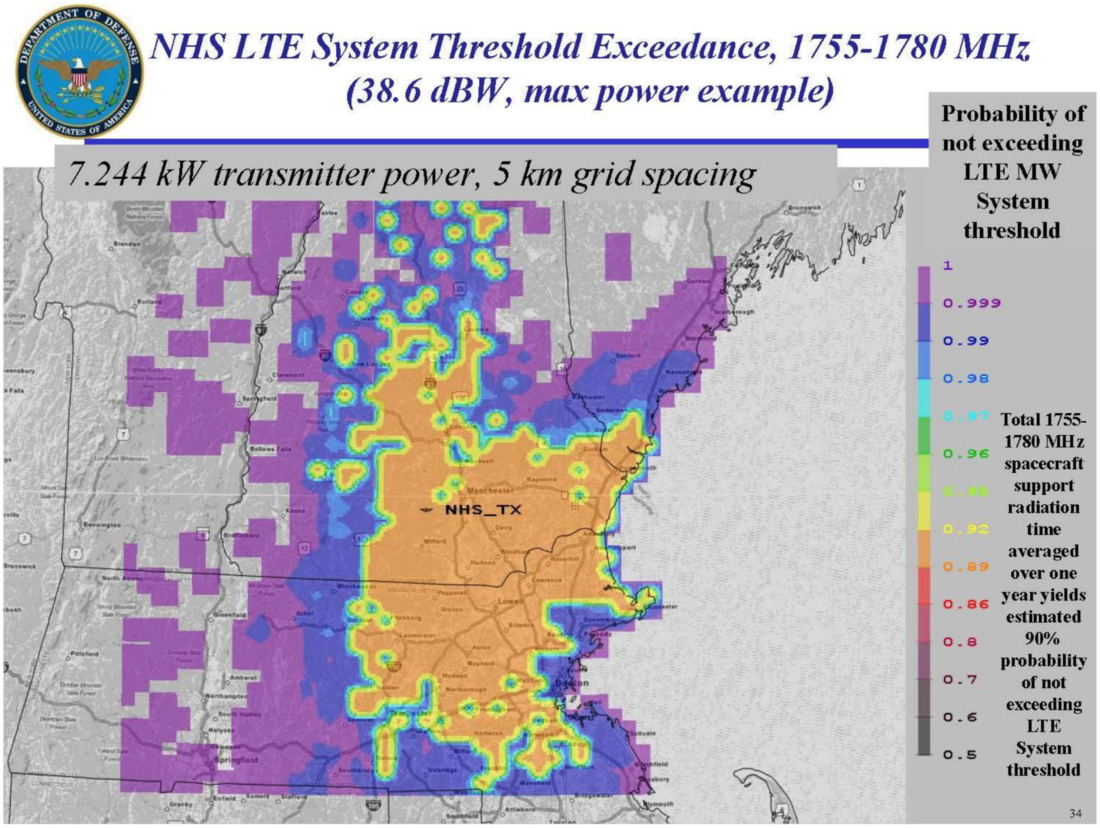


NHS Radiated Power
(18.6 dBW, max power example with attenuation)

7.244 kW transmitter power with 20 dB attenuation, 5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold



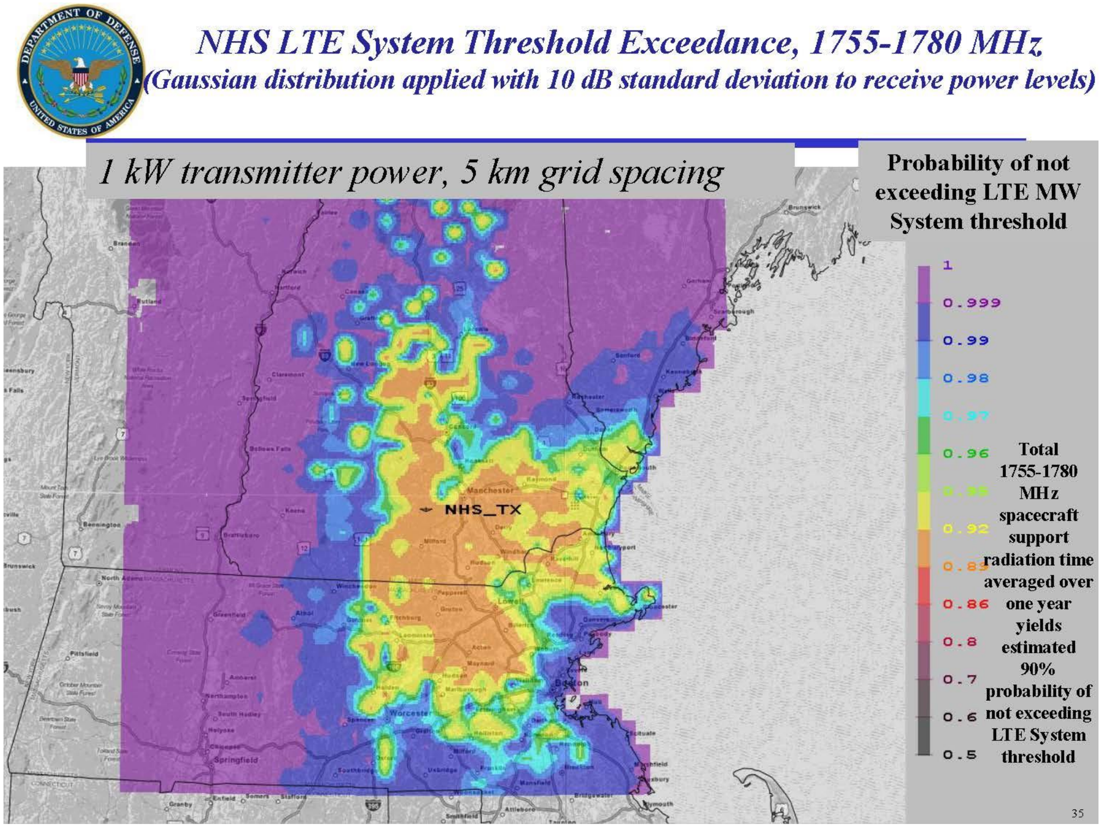
NHS LTE System Threshold Exceedance, 1755-1780 MHz
(38.6 dBW, max power example)

7.244 kW transmitter power, 5 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1755-1780 MHz spacecraft support radiation time averaged over one year yields estimated 90% probability of not exceeding LTE System threshold

2242



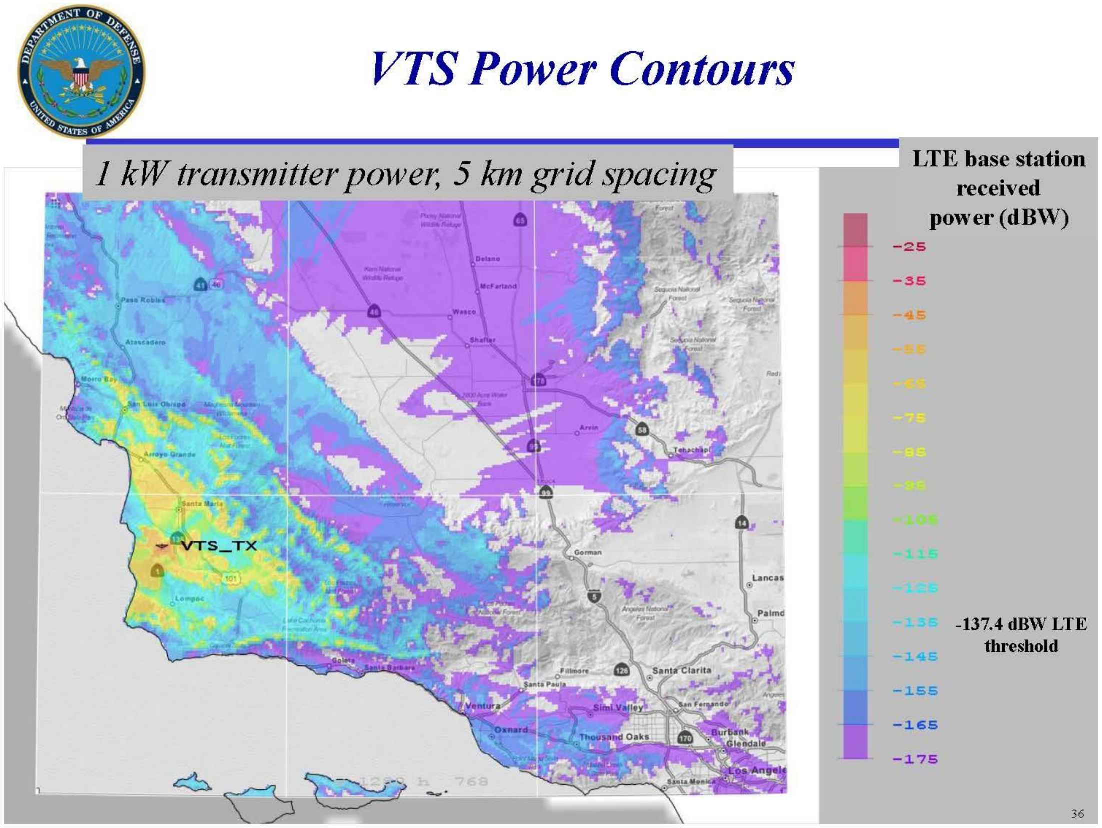
NHS LTE System Threshold Exceedance, 1755-1780 MHz
(Gaussian distribution applied with 10 dB standard deviation to receive power levels)

1 kW transmitter power, 5 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1755-1780 MHz spacecraft support radiation time averaged over one year yields estimated 90% probability of not exceeding LTE System threshold

2243

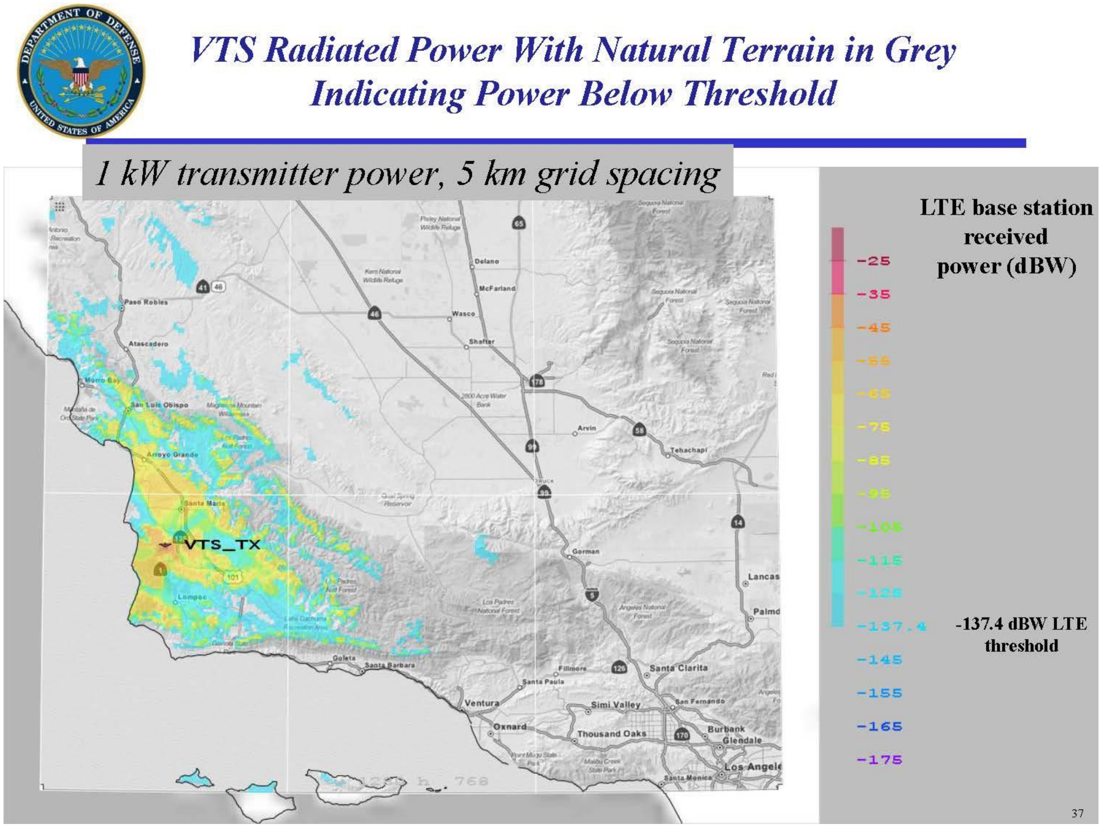


VTS Power Contours

1 kW transmitter power, 5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

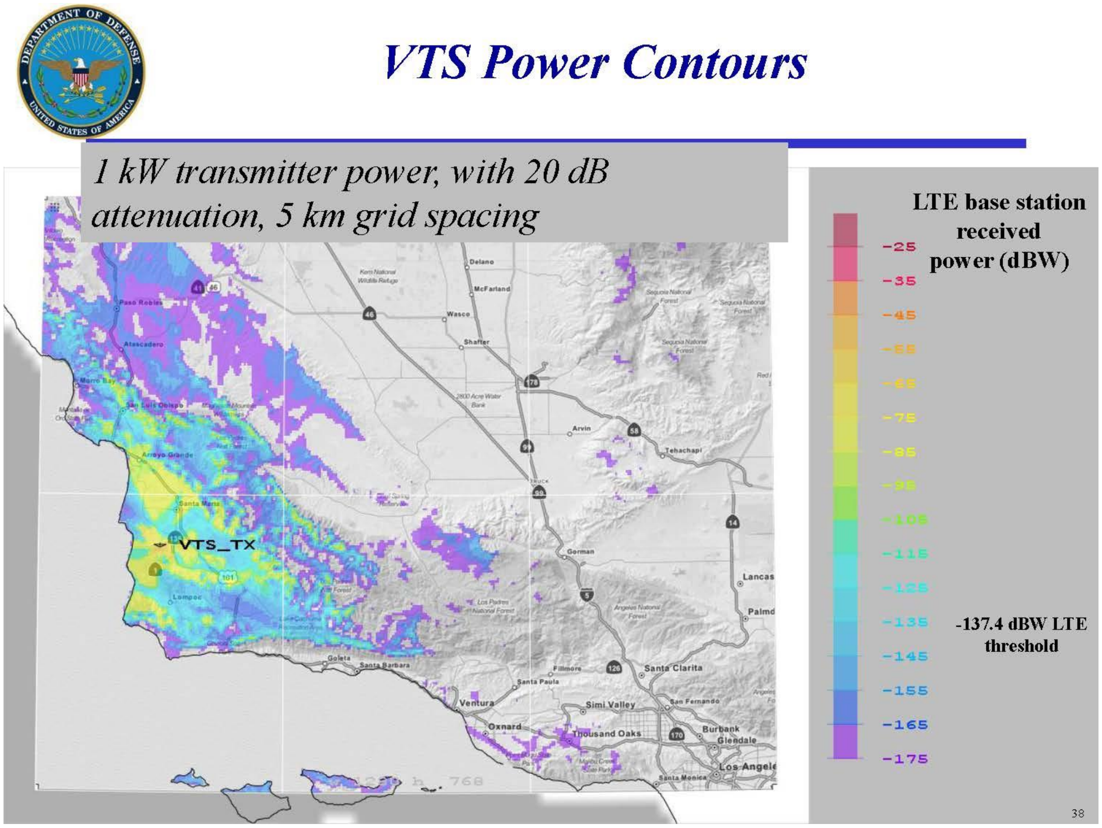


VTS Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

1 kW transmitter power, 5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold



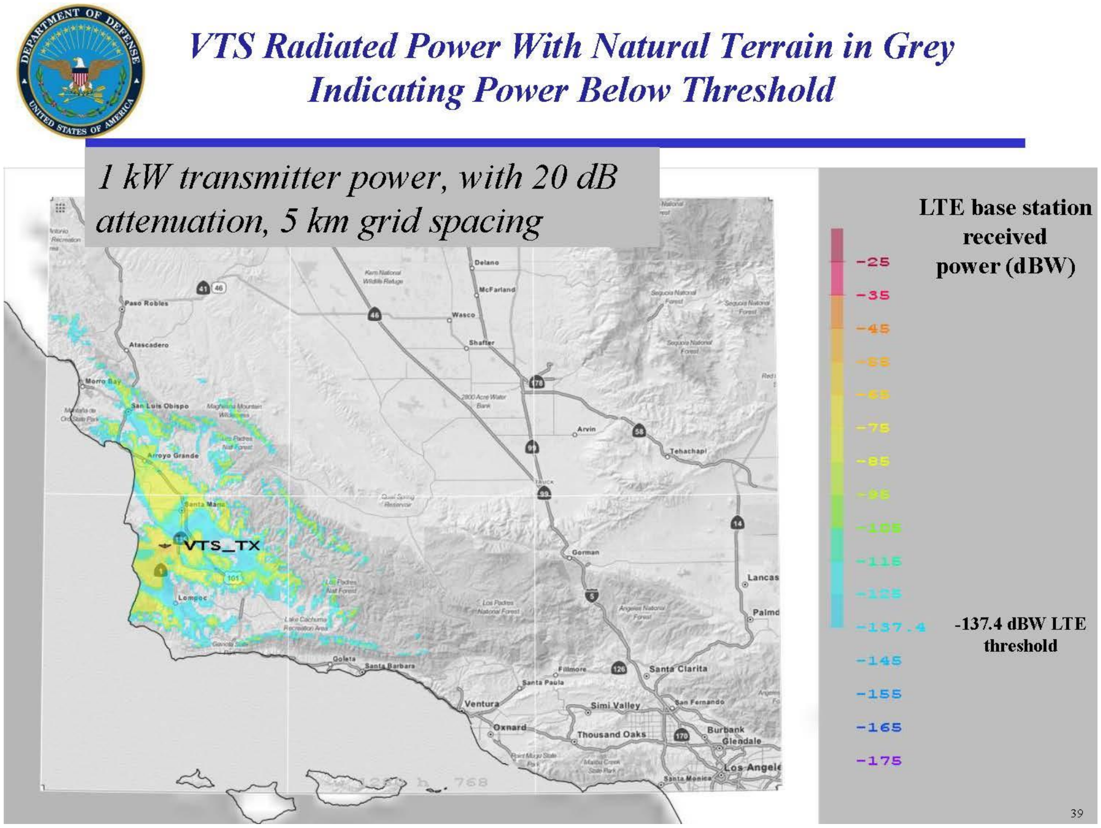
VTS Power Contours

1 kW transmitter power, with 20 dB attenuation, 5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

2246



VTS Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

1 kW transmitter power, with 20 dB attenuation, 5 km grid spacing

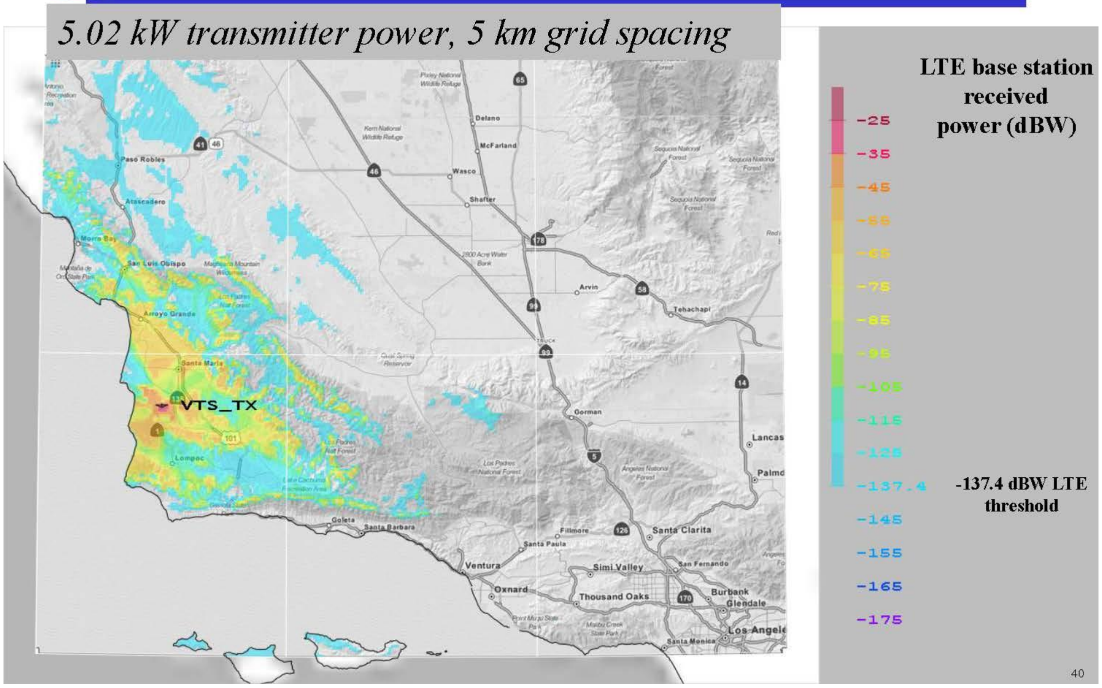
LTE base station received power (dBW)

-137.4 dBW LTE threshold

2247

VTS Radiated Power
(37.05 dBW, max power example)

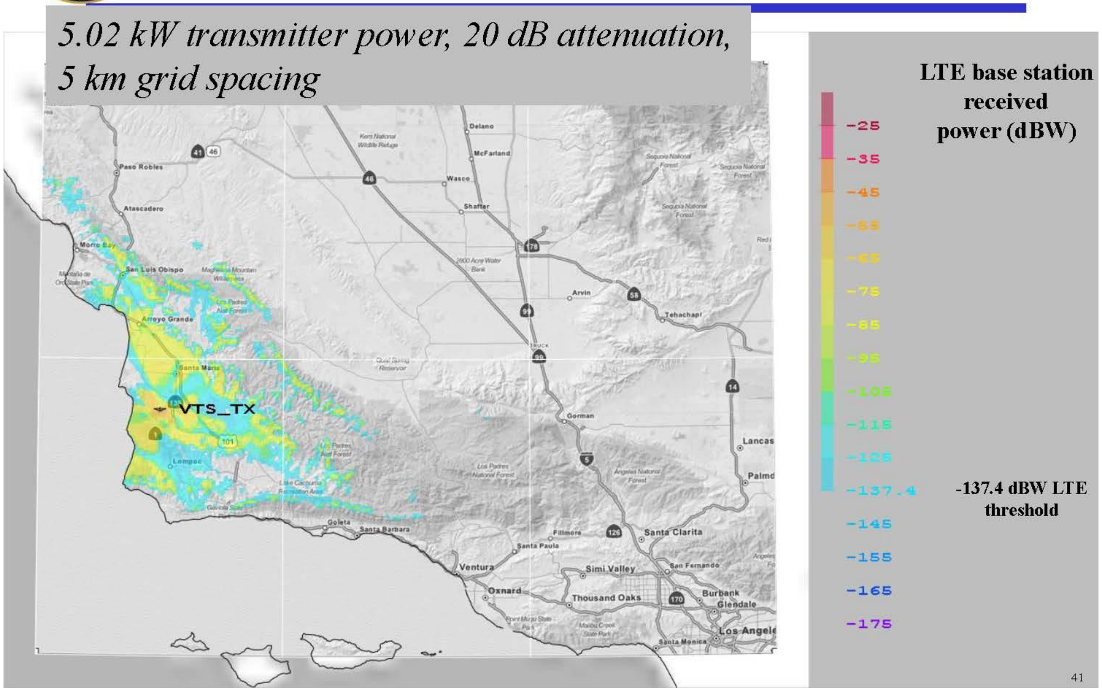
5.02 kW transmitter power, 5 km grid spacing



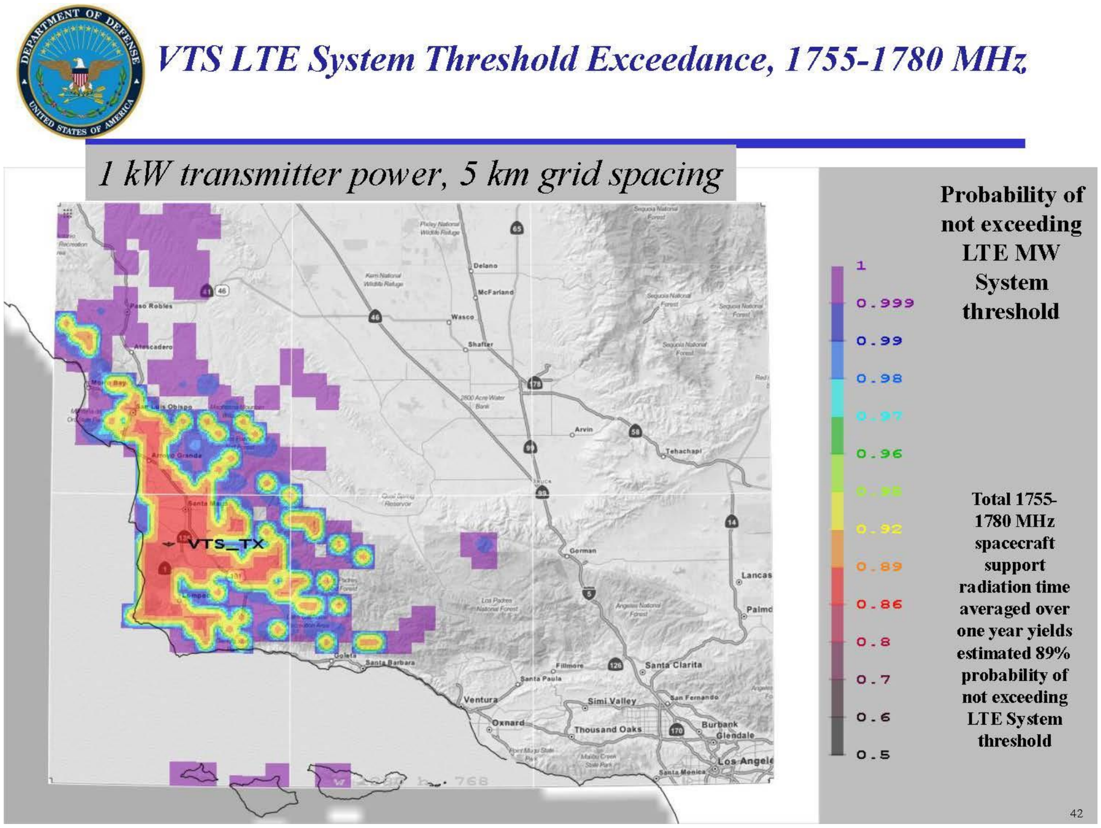
2248

VTS Radiated Power
(17.05 dBW, max power with attenuation)

5.02 kW transmitter power, 20 dB attenuation, 5 km grid spacing



2249



VTS LTE System Threshold Exceedance, 1755-1780 MHz

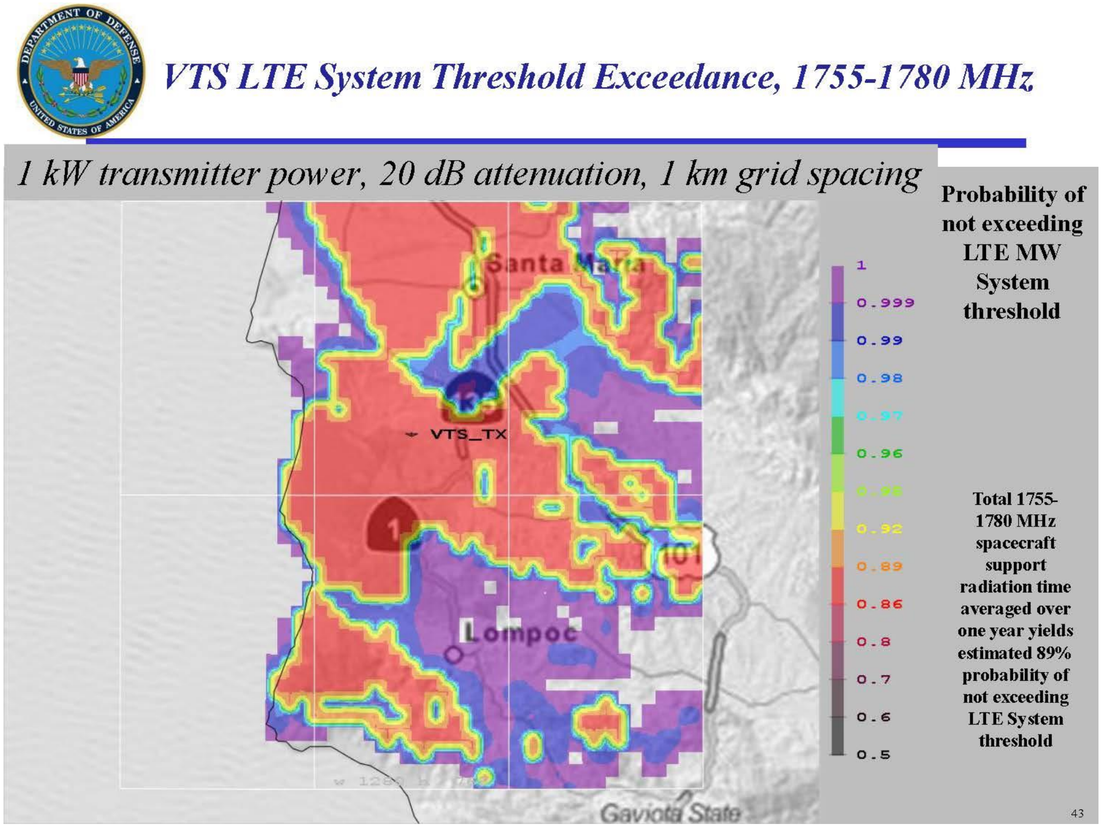
1 kW transmitter power, 5 km grid spacing

1
0.999
0.99
0.98
0.97
0.96
0.95
0.92
0.89
0.86
0.8
0.7
0.6
0.5

Probability of not exceeding LTE MW System threshold

Total 1755-1780 MHz spacecraft support radiation time averaged over one year yields estimated 89% probability of not exceeding LTE System threshold

42



VTS LTE System Threshold Exceedance, 1755-1780 MHz

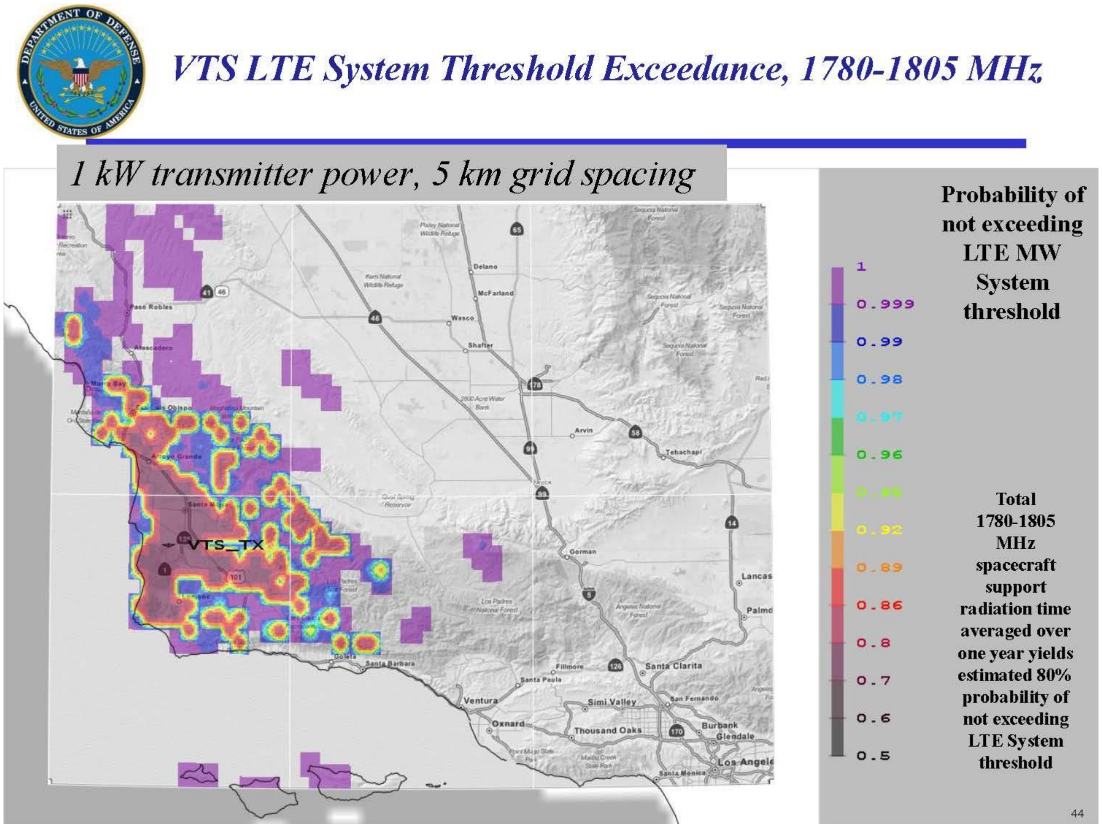
1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

1
0.999
0.99
0.98
0.97
0.96
0.95
0.92
0.89
0.86
0.8
0.7
0.6
0.5

Probability of not exceeding LTE MW System threshold

Total 1755-1780 MHz spacecraft support radiation time averaged over one year yields estimated 89% probability of not exceeding LTE System threshold

43



VTS LTE System Threshold Exceedance, 1780-1805 MHz

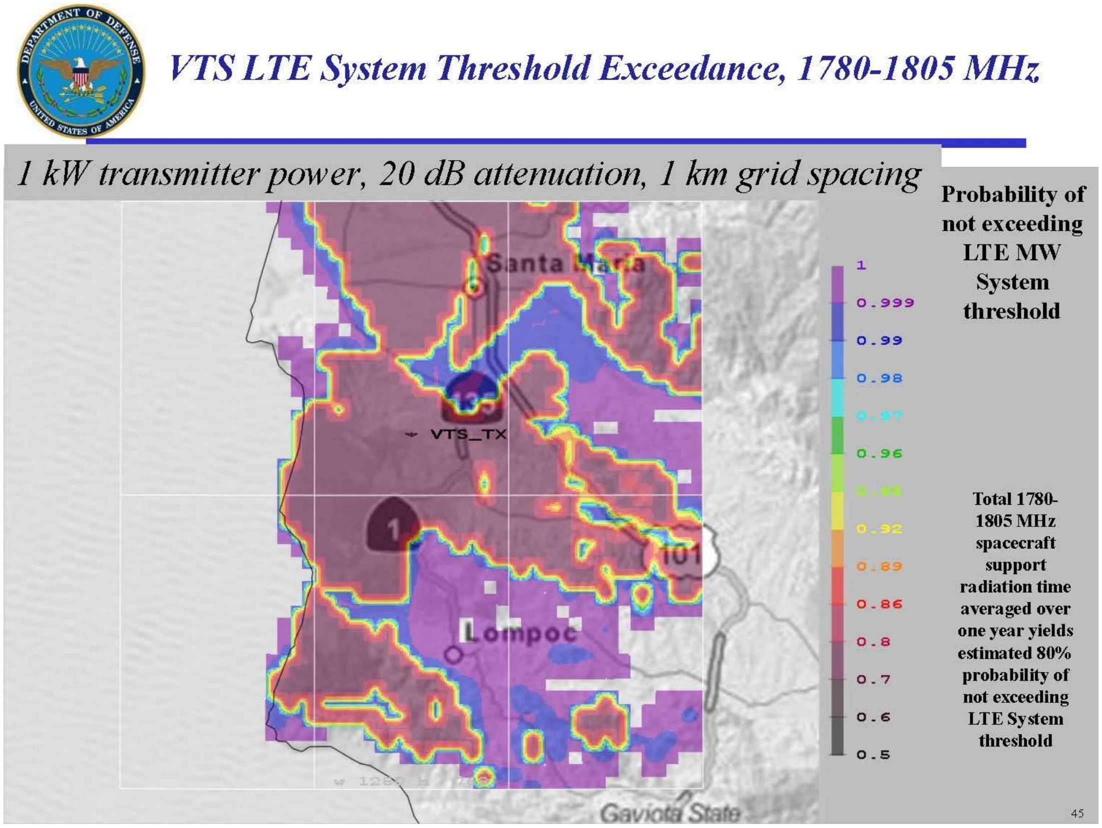
1 kW transmitter power, 5 km grid spacing

Probability of not exceeding LTE MW System threshold

- 1
- 0.999
- 0.99
- 0.98
- 0.97
- 0.96
- 0.95
- 0.92
- 0.89
- 0.86
- 0.8
- 0.7
- 0.6
- 0.5

Total 1780-1805 MHz spacecraft support radiation time averaged over one year yields estimated 80% probability of not exceeding LTE System threshold

2252



VTS LTE System Threshold Exceedance, 1780-1805 MHz

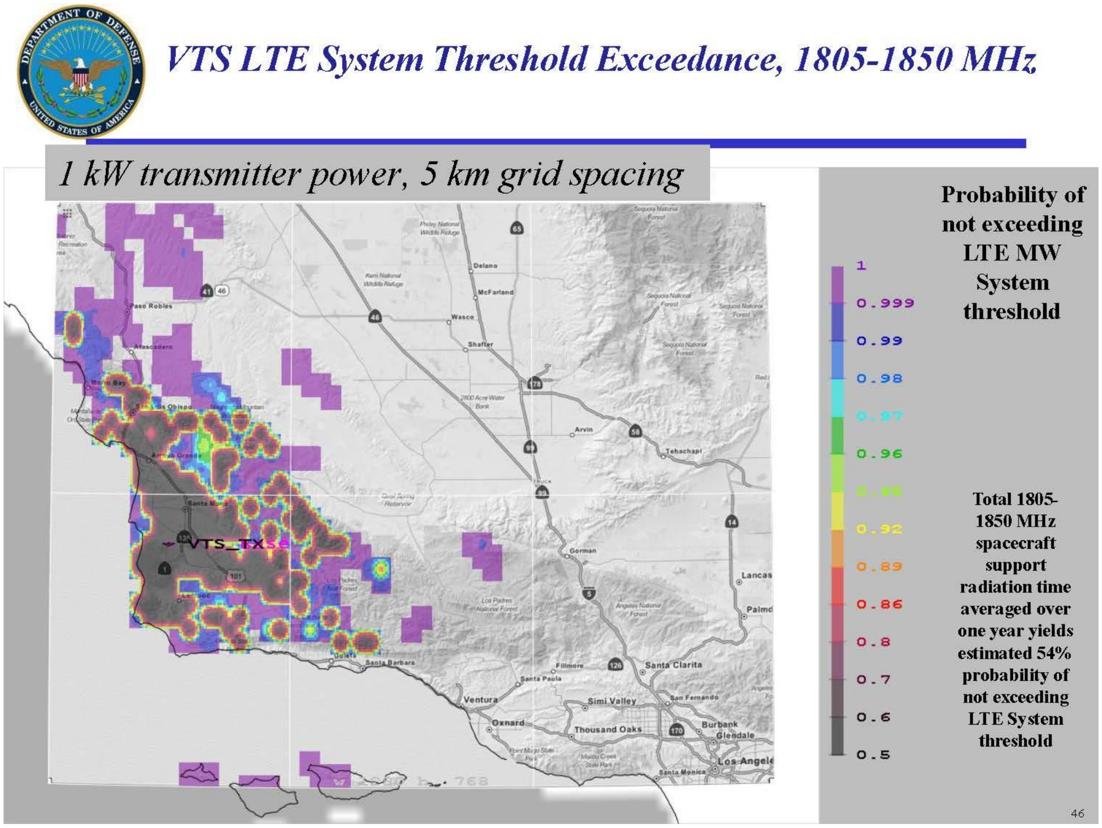
1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

Probability of not exceeding LTE MW System threshold

- 1
- 0.999
- 0.99
- 0.98
- 0.97
- 0.96
- 0.95
- 0.92
- 0.89
- 0.86
- 0.8
- 0.7
- 0.6
- 0.5

Total 1780-1805 MHz spacecraft support radiation time averaged over one year yields estimated 80% probability of not exceeding LTE System threshold

2253



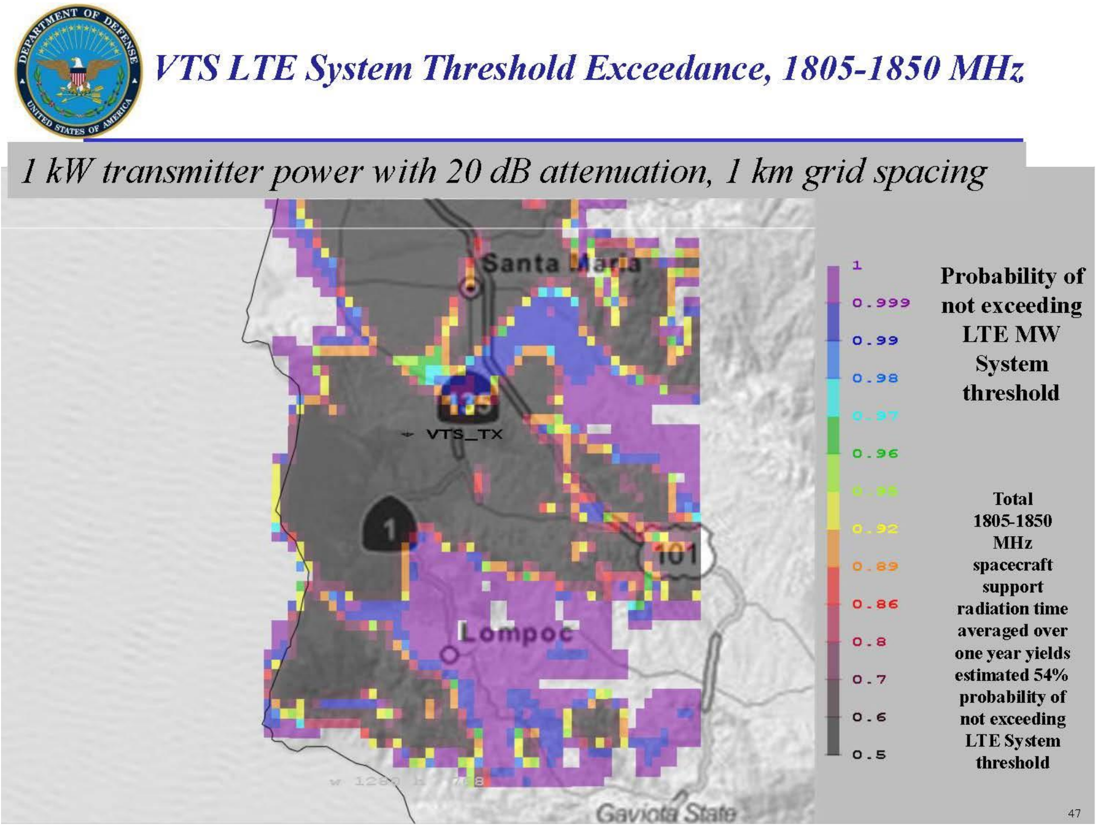
VTS LTE System Threshold Exceedance, 1805-1850 MHz

1 kW transmitter power, 5 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1805-1850 MHz spacecraft support radiation time averaged over one year yields estimated 54% probability of not exceeding LTE System threshold

46



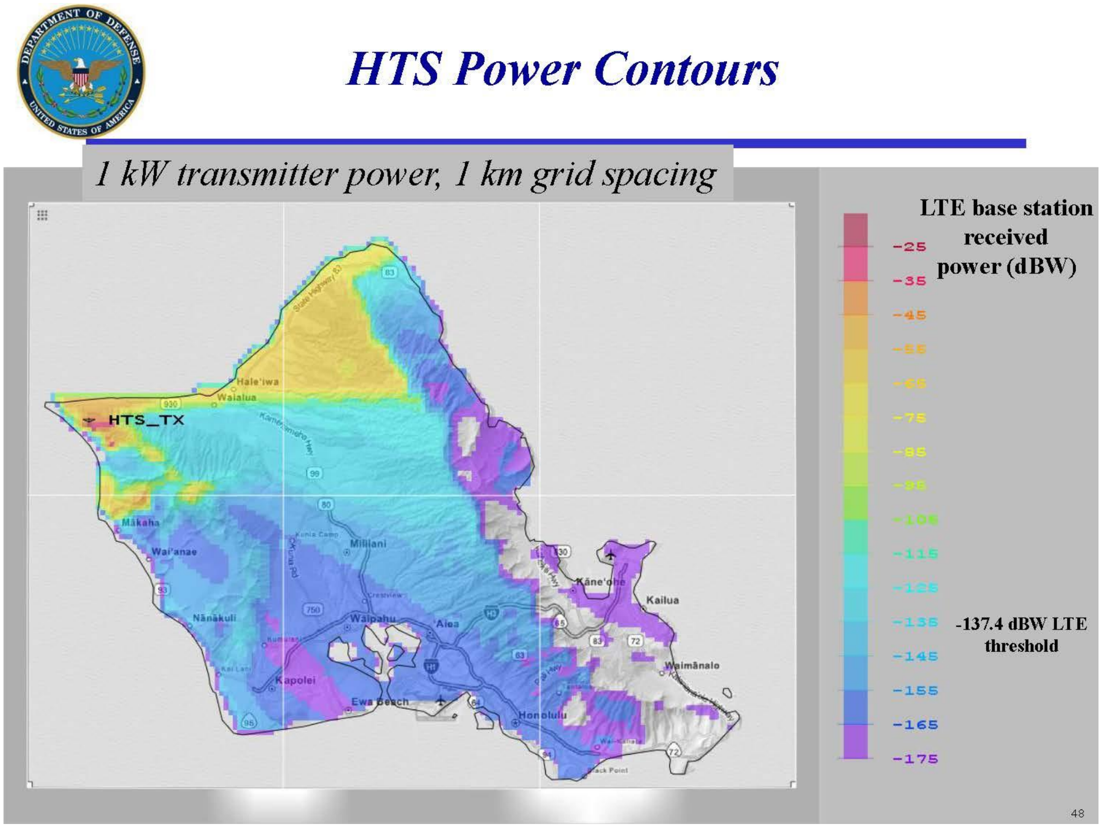
VTS LTE System Threshold Exceedance, 1805-1850 MHz

1 kW transmitter power with 20 dB attenuation, 1 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1805-1850 MHz spacecraft support radiation time averaged over one year yields estimated 54% probability of not exceeding LTE System threshold

47



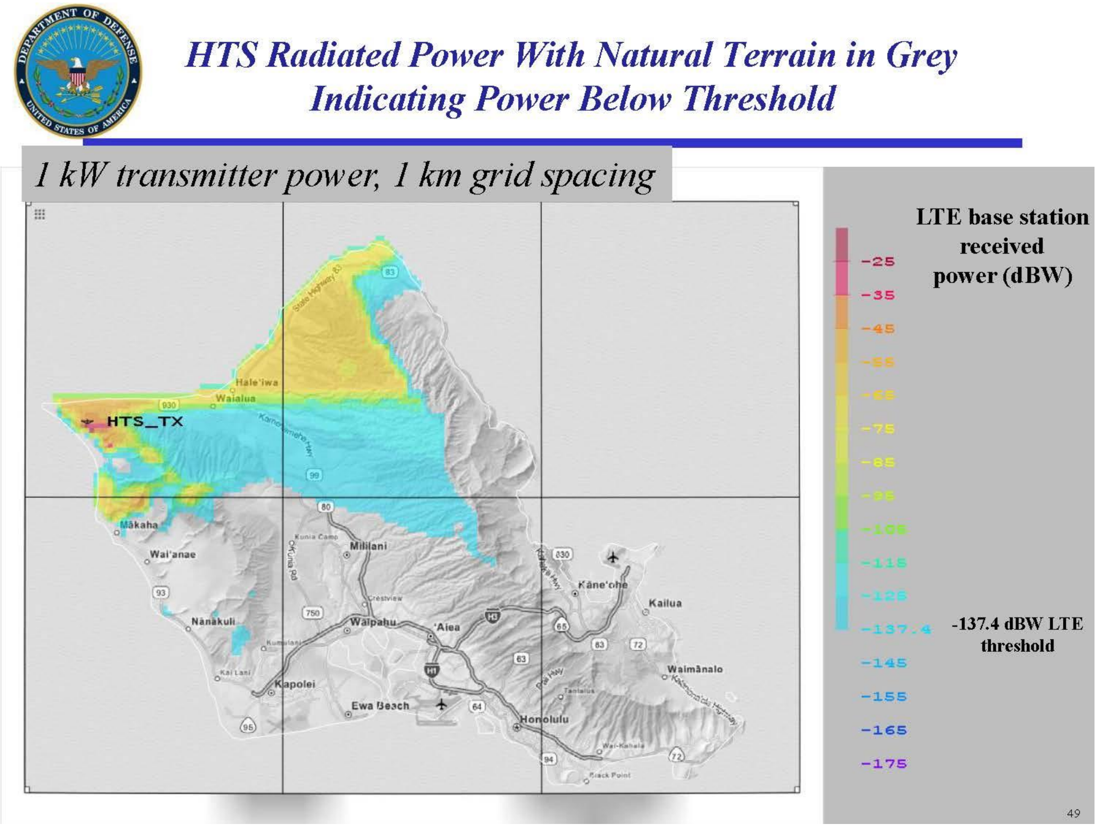
HTS Power Contours

1 kW transmitter power, 1 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

2256



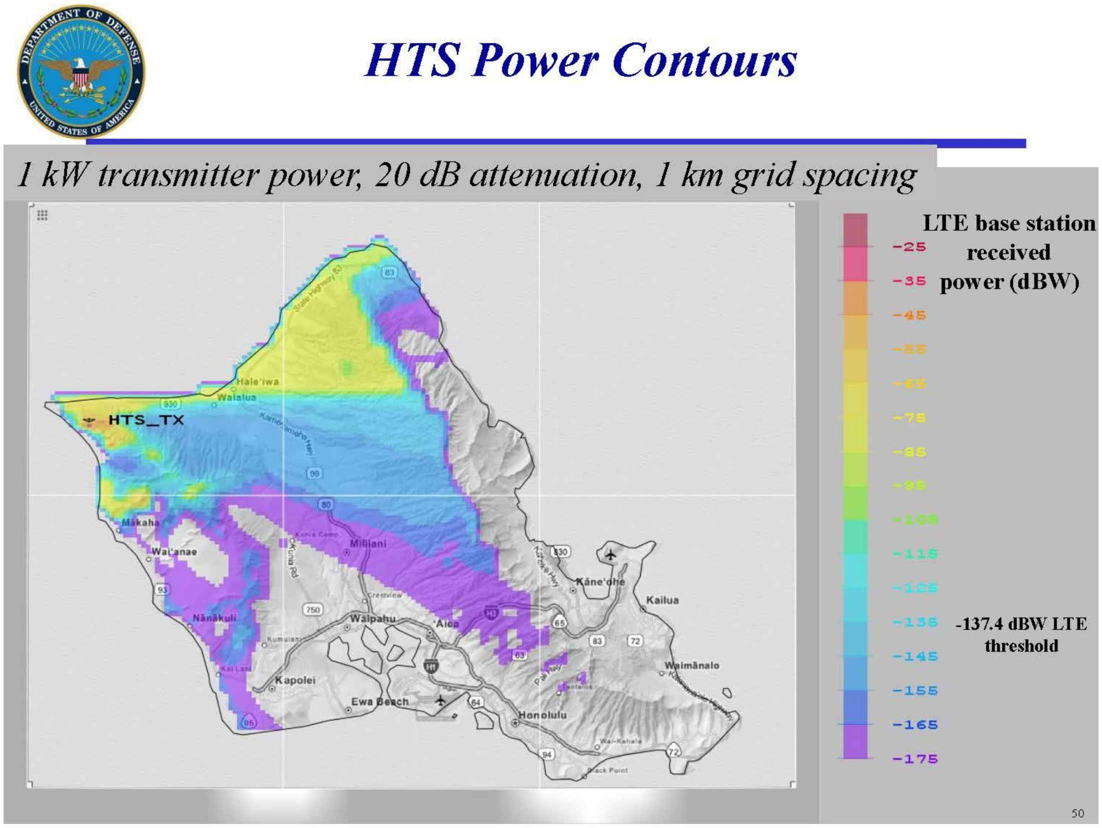
HTS Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

1 kW transmitter power, 1 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

2257

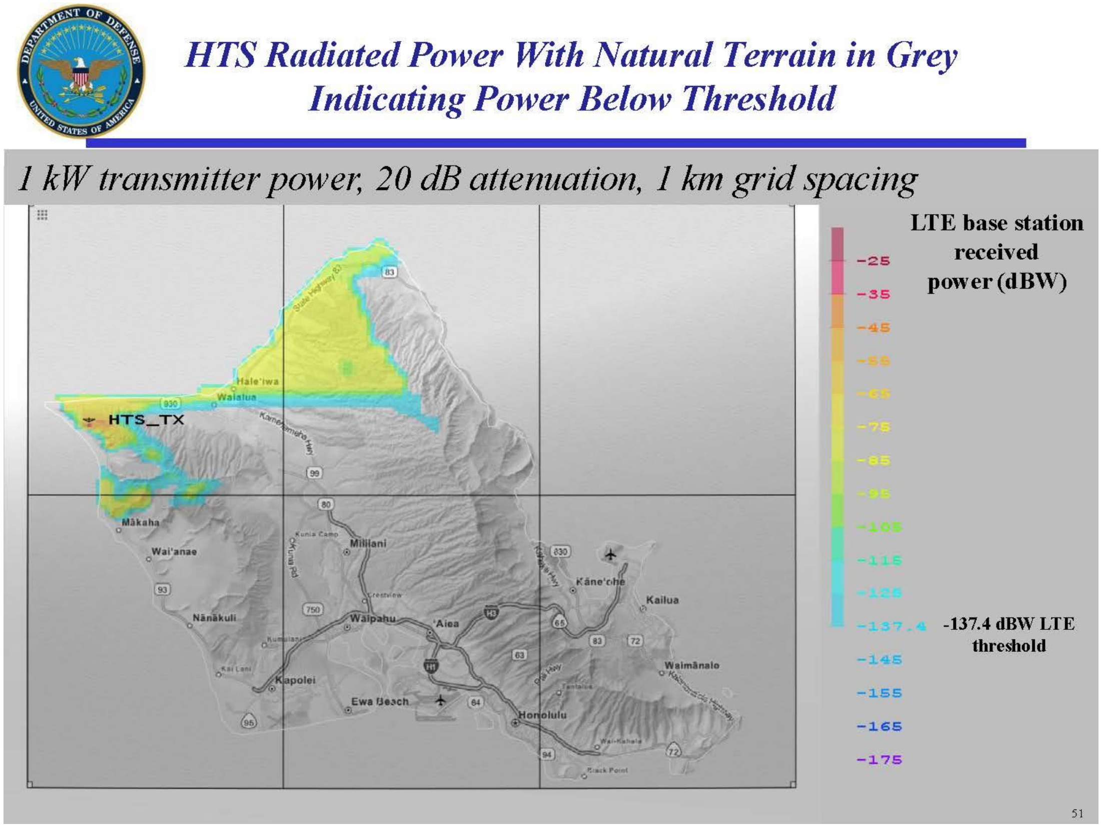


HTS Power Contours

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

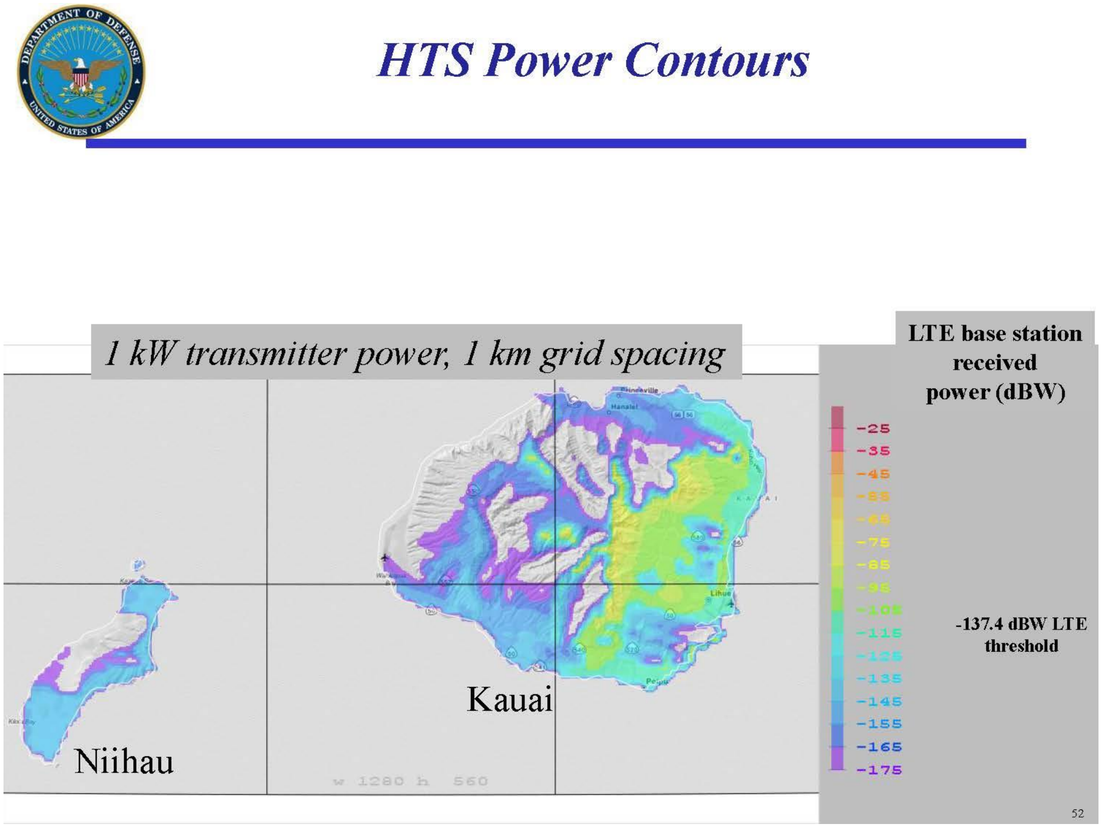


HTS Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold



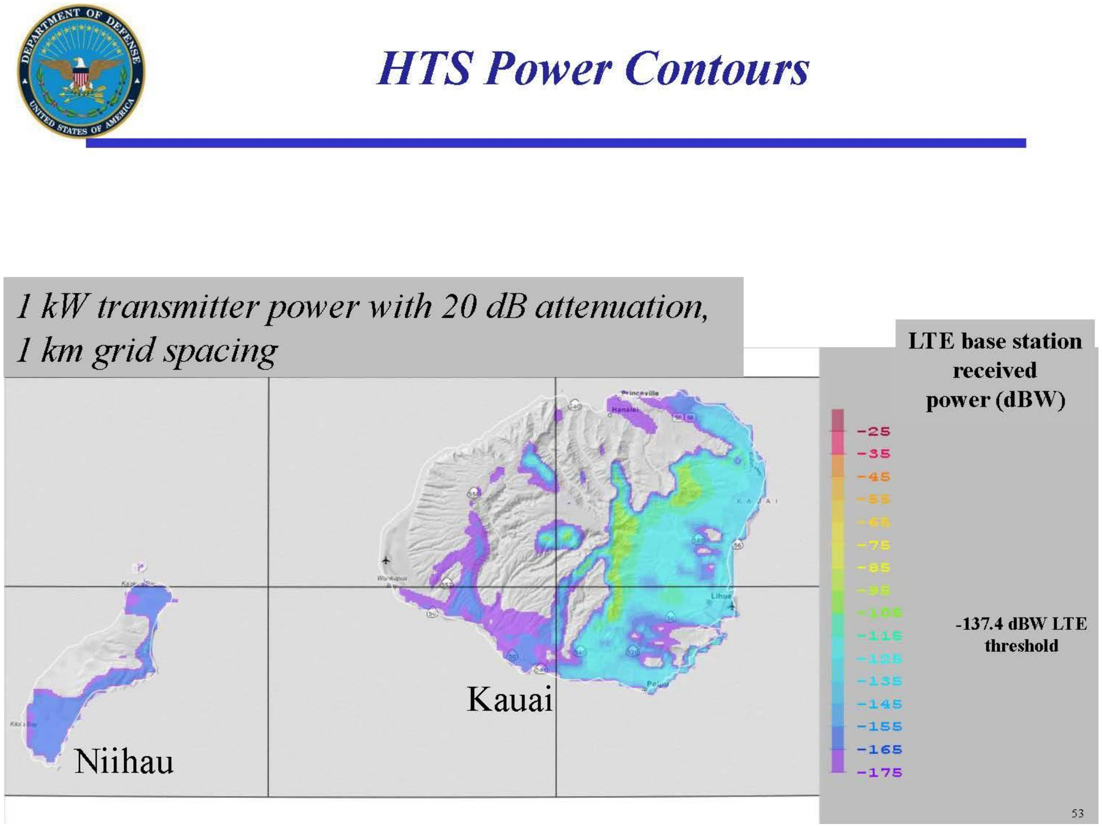
HTS Power Contours

1 kW transmitter power, 1 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

2260



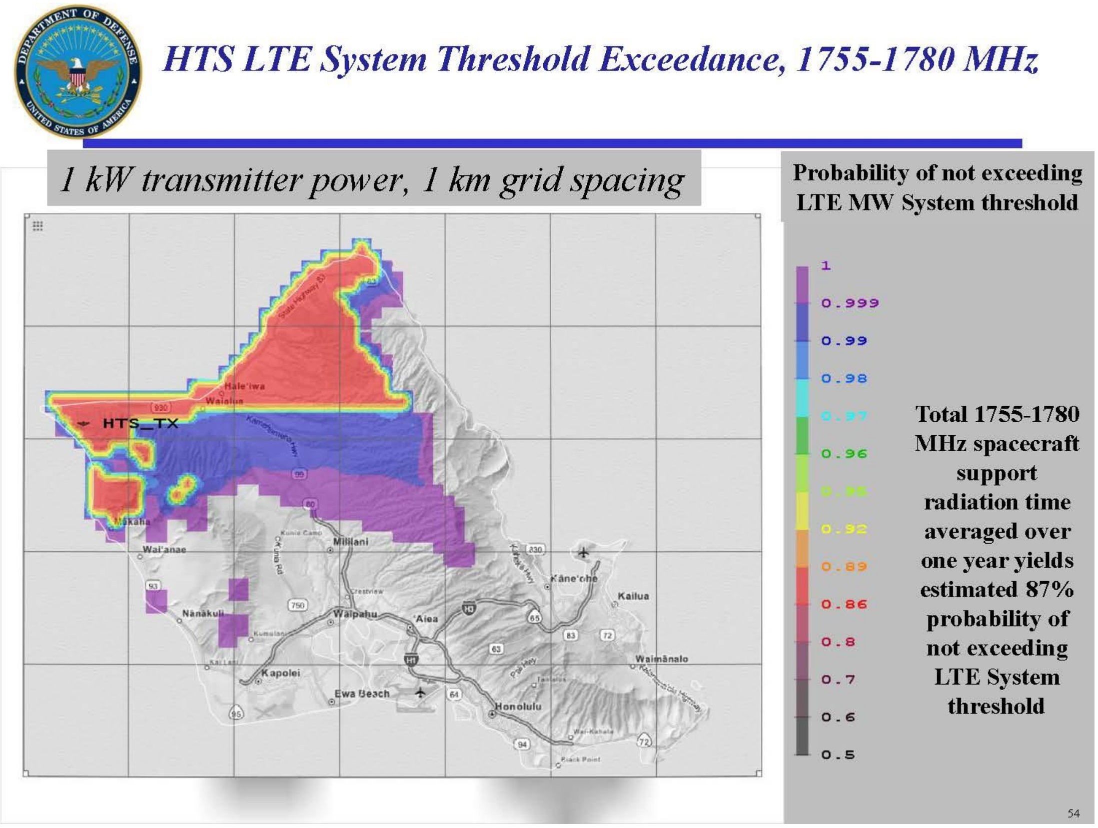
HTS Power Contours

1 kW transmitter power with 20 dB attenuation, 1 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

2261

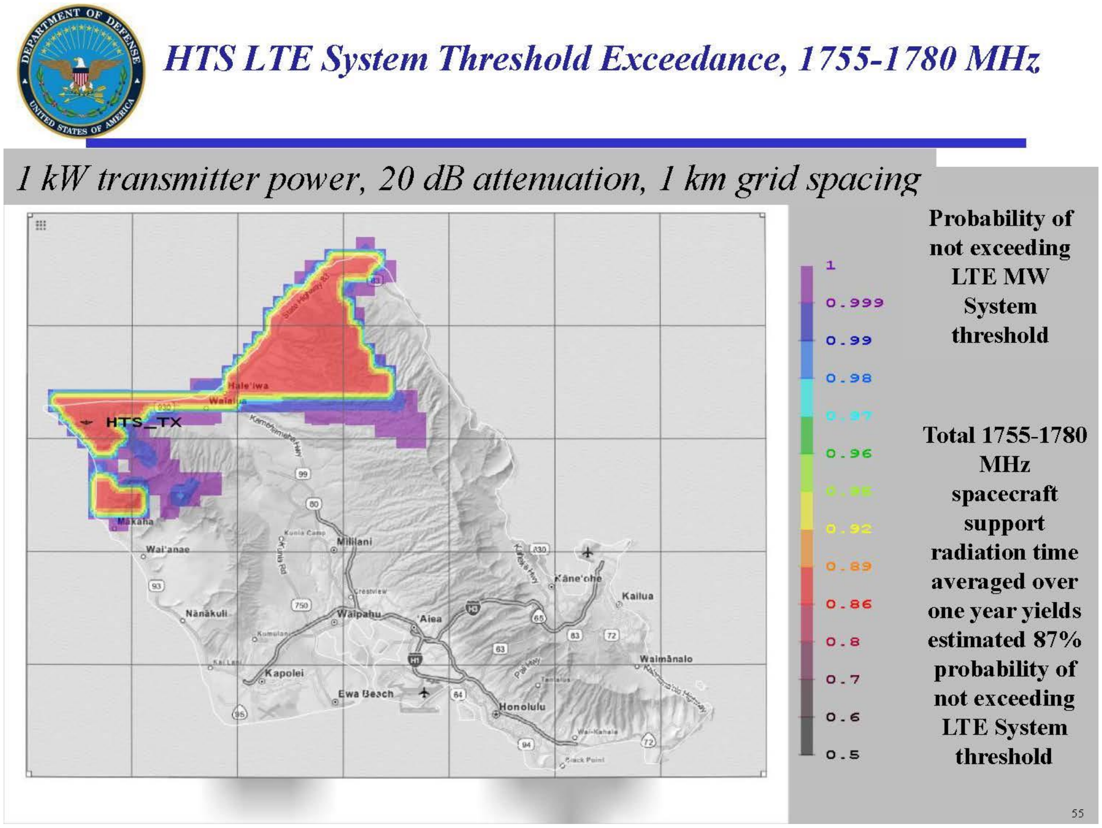


HTS LTE System Threshold Exceedance, 1755-1780 MHz

1 kW transmitter power, 1 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1755-1780 MHz spacecraft support radiation time averaged over one year yields estimated 87% probability of not exceeding LTE System threshold

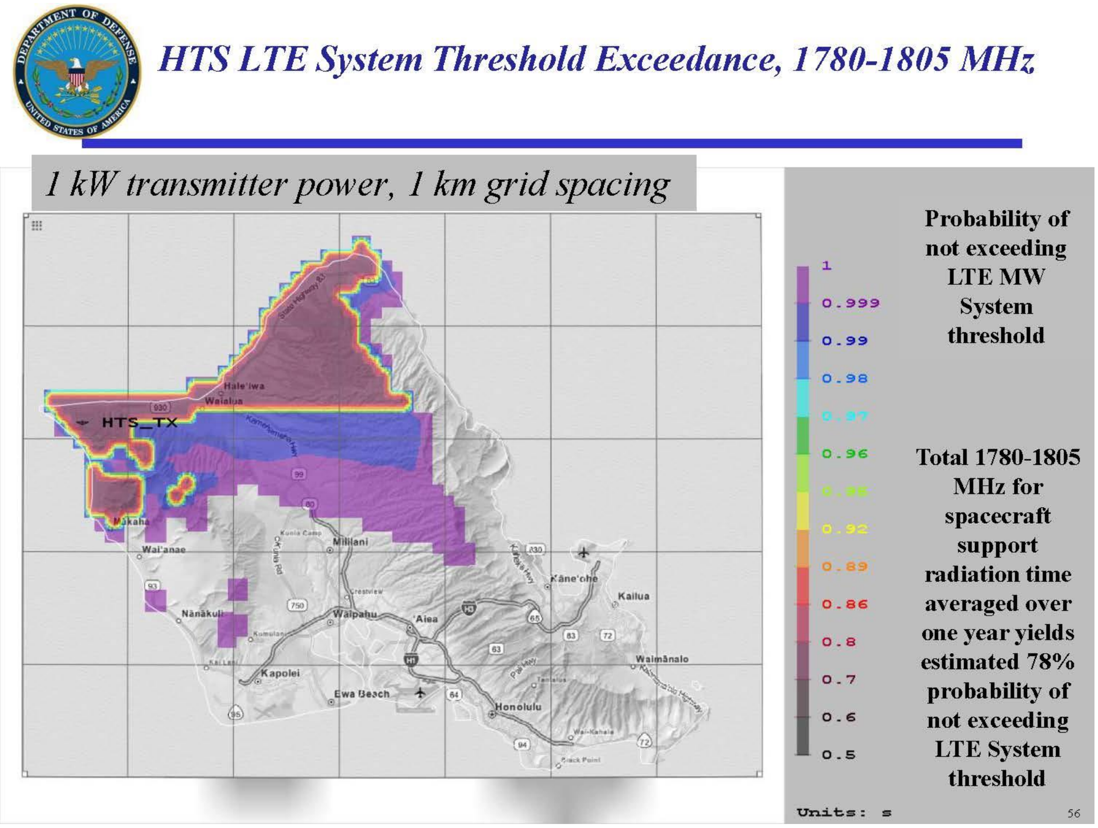


HTS LTE System Threshold Exceedance, 1755-1780 MHz

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1755-1780 MHz spacecraft support radiation time averaged over one year yields estimated 87% probability of not exceeding LTE System threshold

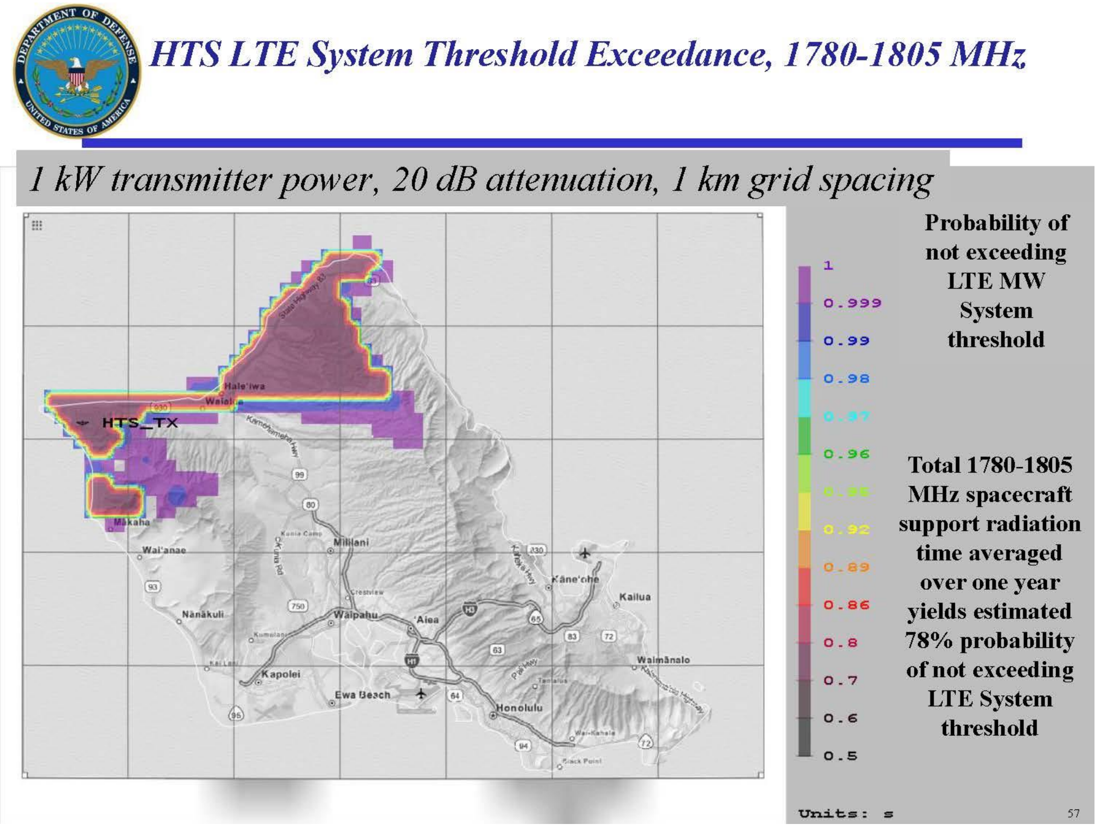


HTS LTE System Threshold Exceedance, 1780-1805 MHz

1 kW transmitter power, 1 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1780-1805 MHz for spacecraft support radiation time averaged over one year yields estimated 78% probability of not exceeding LTE System threshold

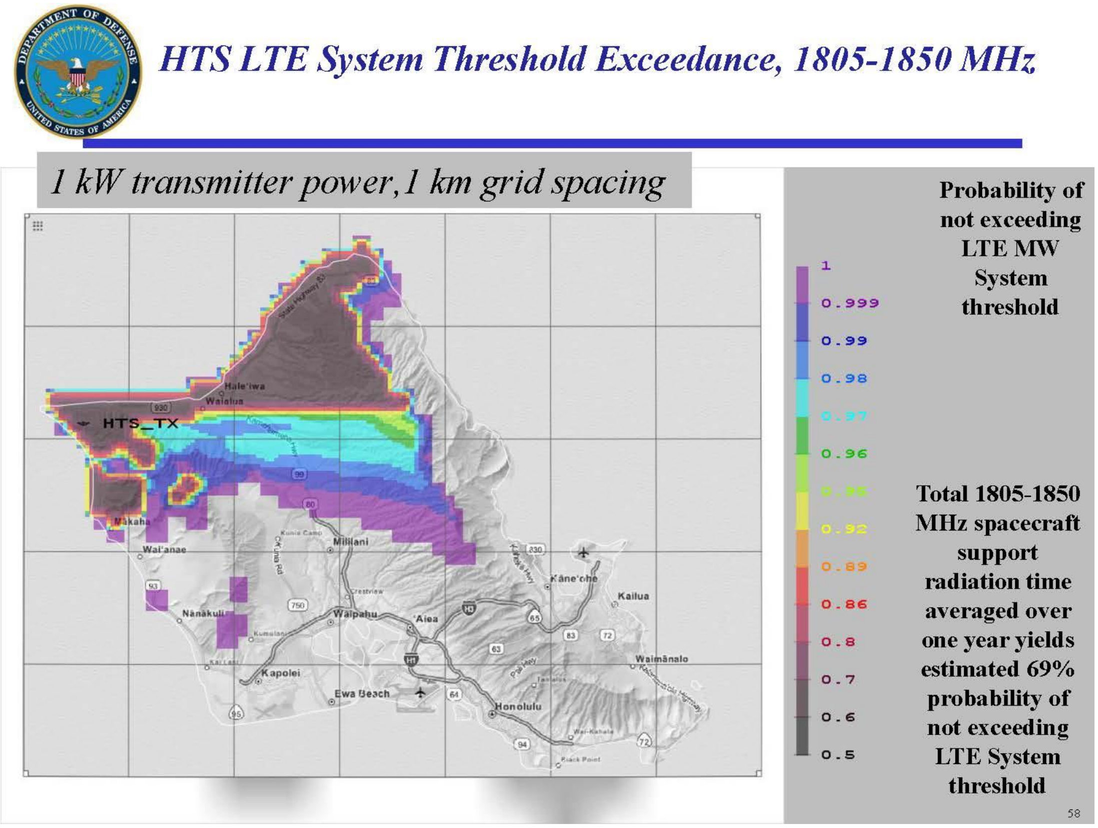


HTS LTE System Threshold Exceedance, 1780-1805 MHz

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1780-1805 MHz spacecraft support radiation time averaged over one year yields estimated 78% probability of not exceeding LTE System threshold



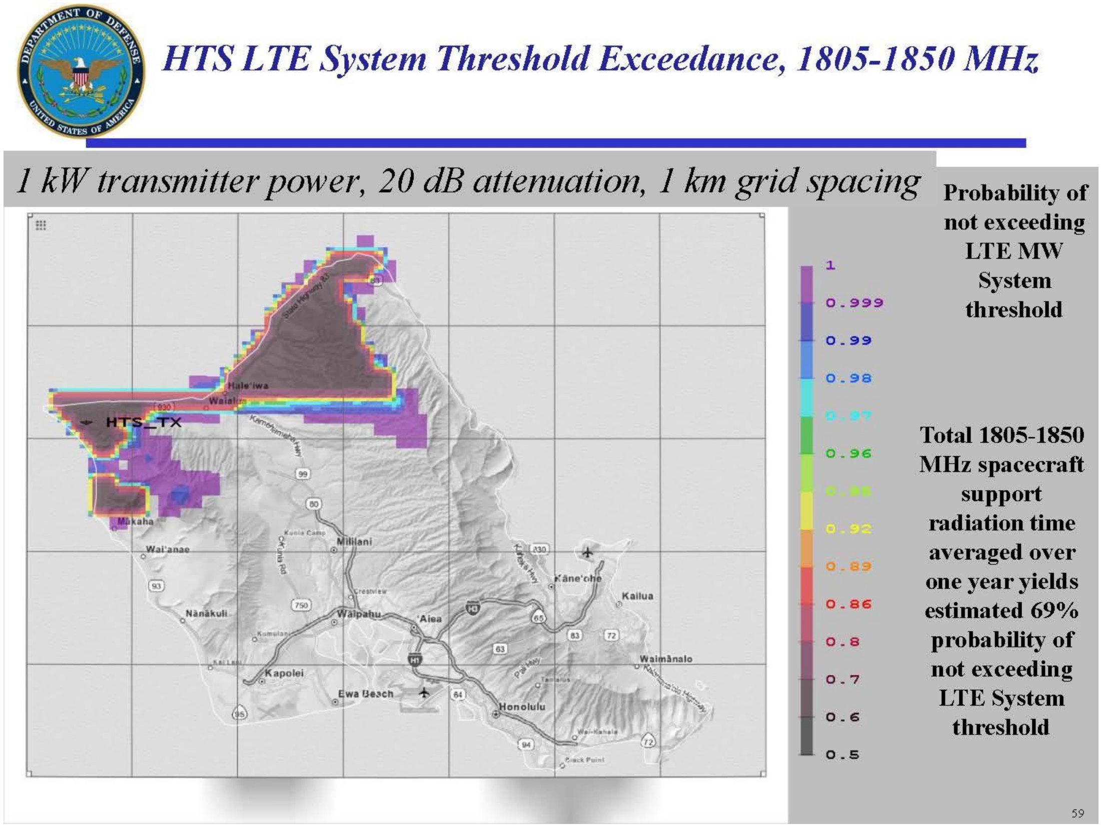
HTS LTE System Threshold Exceedance, 1805-1850 MHz

1 kW transmitter power,1 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1805-1850 MHz spacecraft support radiation time averaged over one year yields estimated 69% probability of not exceeding LTE System threshold

58



HTS LTE System Threshold Exceedance, 1805-1850 MHz

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

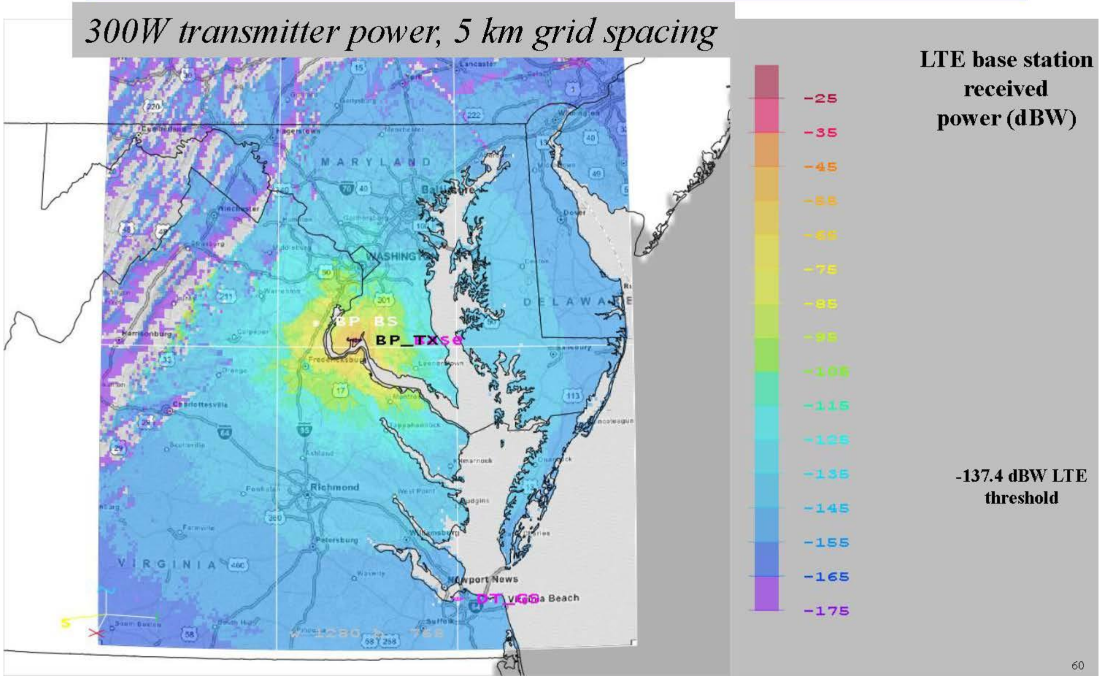
Probability of not exceeding LTE MW System threshold

Total 1805-1850 MHz spacecraft support radiation time averaged over one year yields estimated 69% probability of not exceeding LTE System threshold

59

BP, MD Power Contours

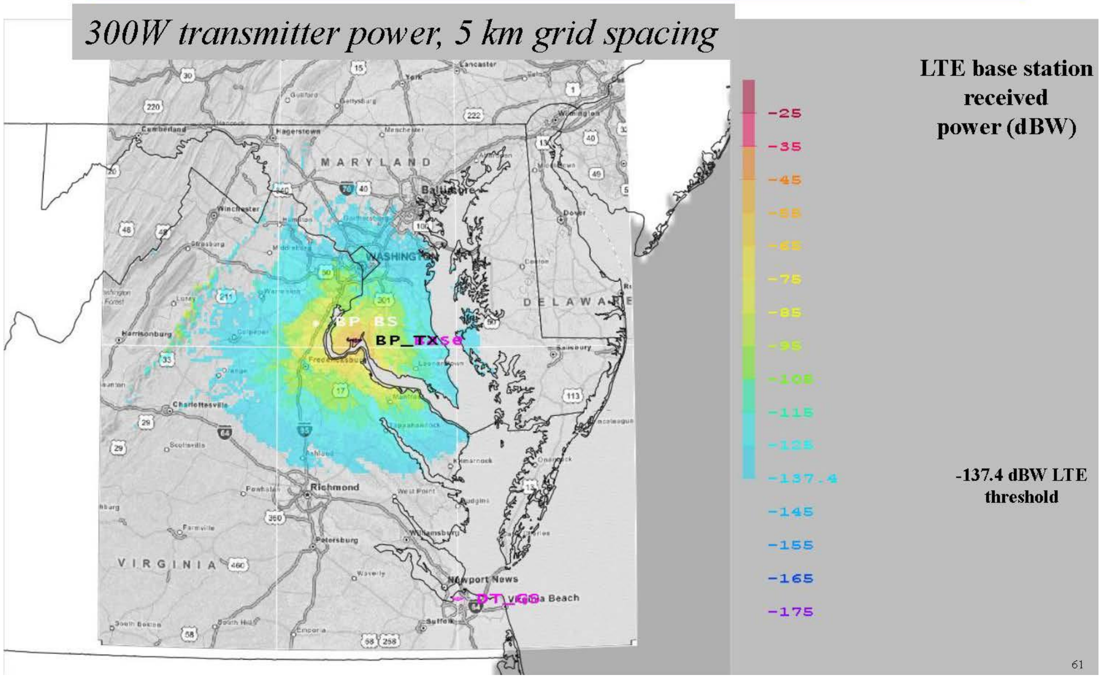
300W transmitter power, 5 km grid spacing



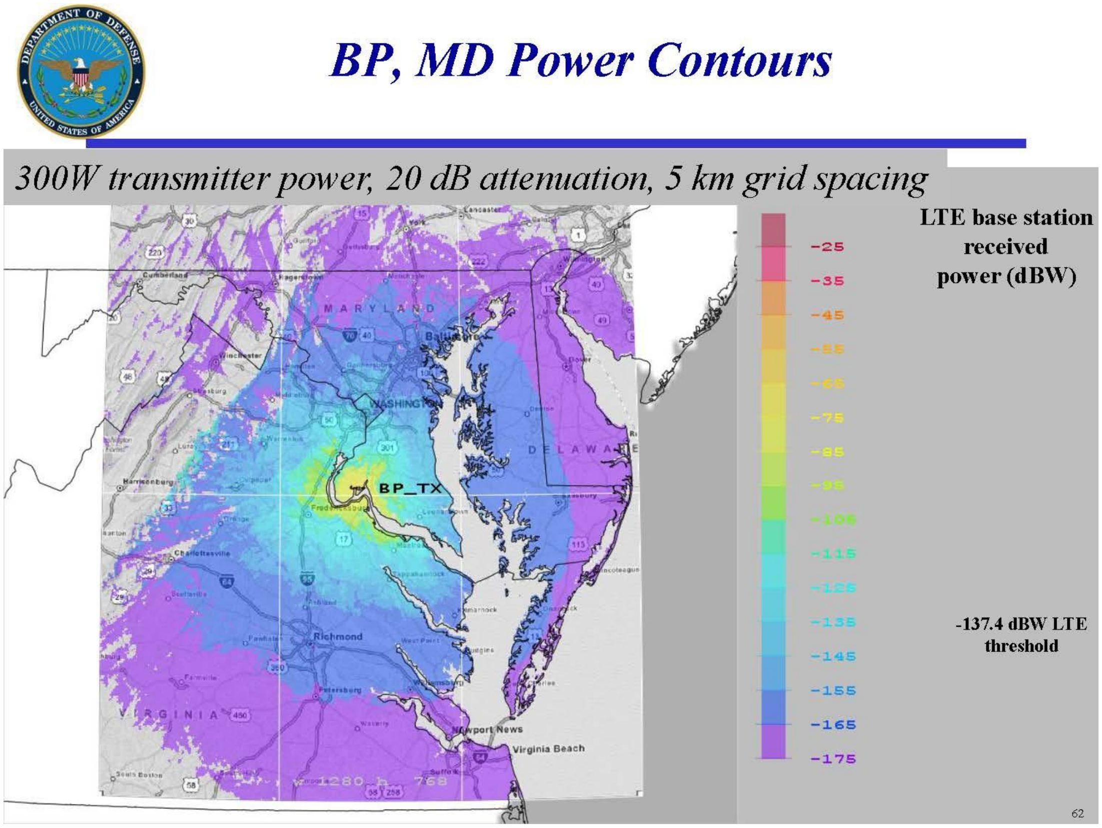
2268

BP, MD Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

300W transmitter power, 5 km grid spacing



2269



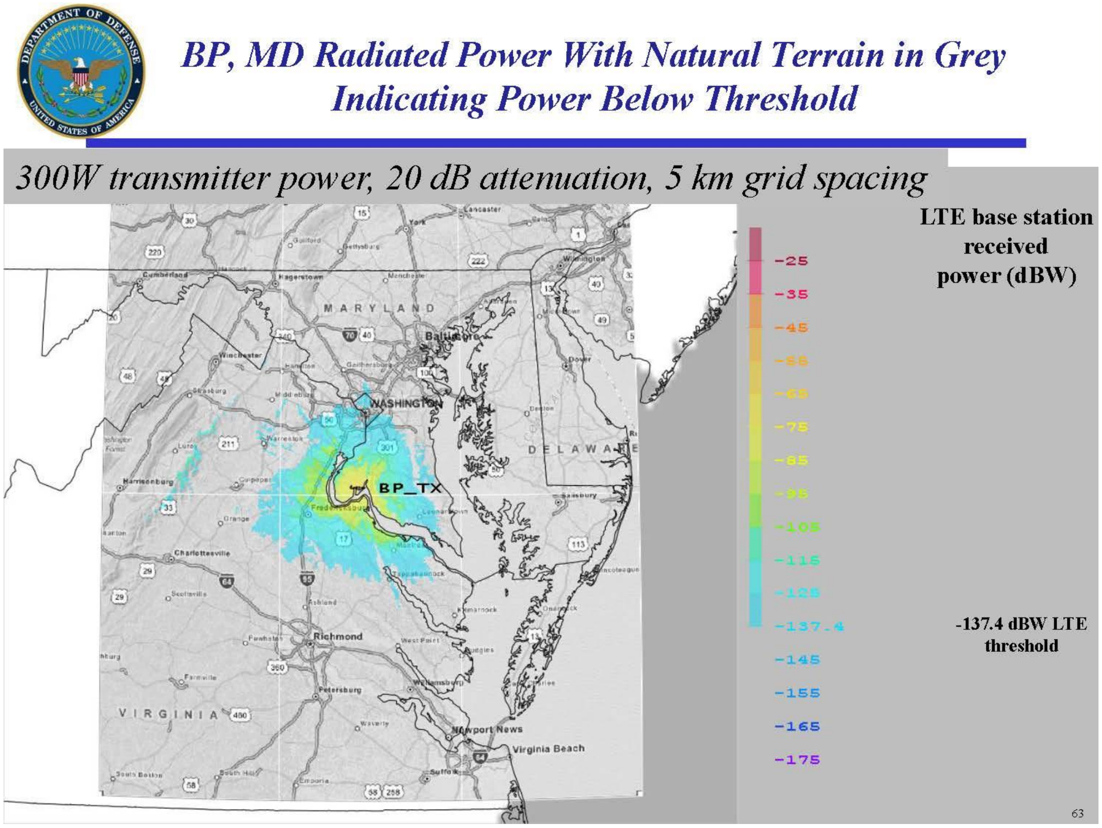
BP, MD Power Contours

300W transmitter power, 20 dB attenuation, 5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

2270



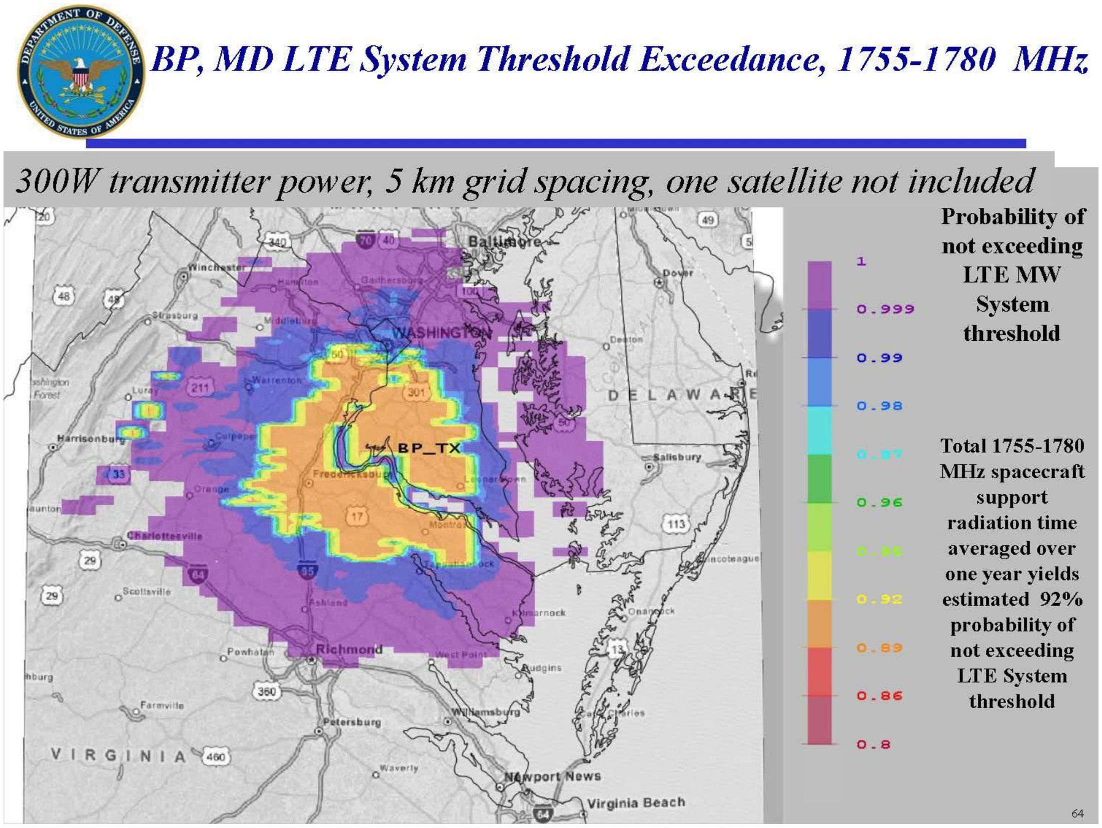
BP, MD Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

300W transmitter power, 20 dB attenuation, 5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

2271



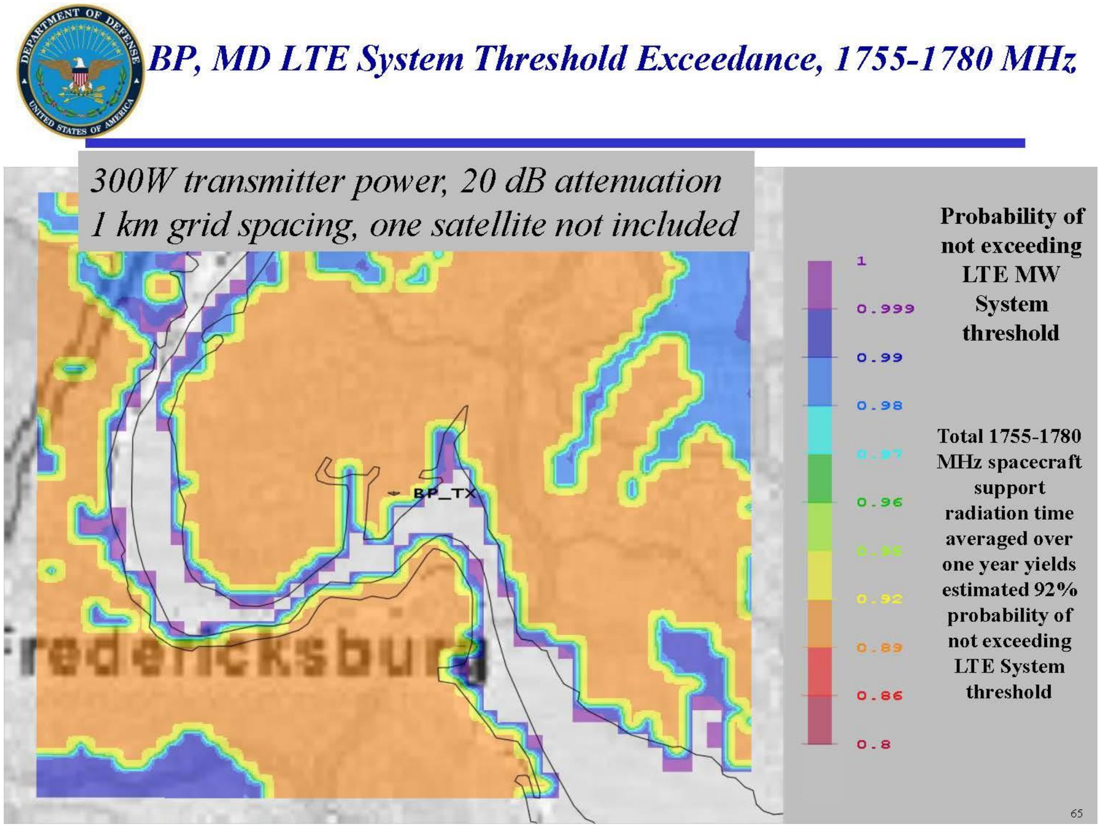
BP, MD LTE System Threshold Exceedance, 1755-1780 MHz

300W transmitter power, 5 km grid spacing, one satellite not included

Probability of not exceeding LTE MW System threshold

Total 1755-1780 MHz spacecraft support radiation time averaged over one year yields estimated 92% probability of not exceeding LTE System threshold

2272



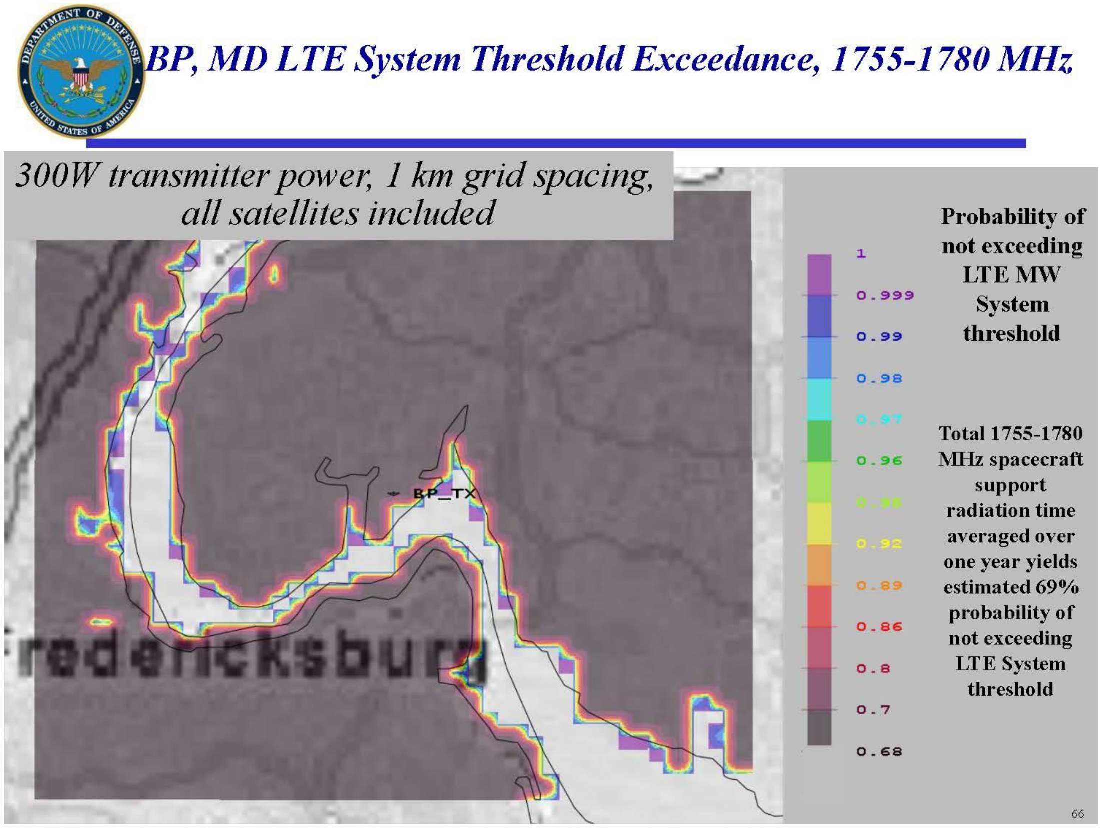
BP, MD LTE System Threshold Exceedance, 1755-1780 MHz

300W transmitter power, 20 dB attenuation
1 km grid spacing, one satellite not included

Probability of not exceeding LTE MW System threshold

Total 1755-1780 MHz spacecraft support radiation time averaged over one year yields estimated 92% probability of not exceeding LTE System threshold

2273

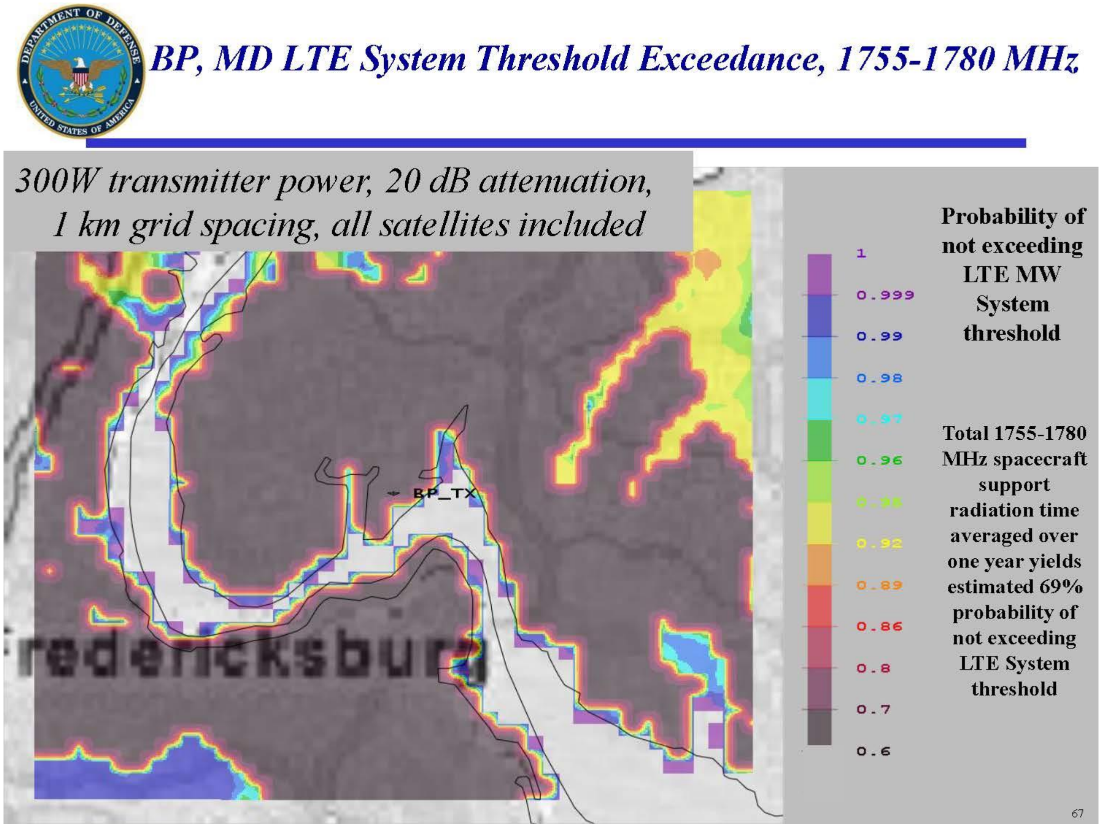


BP, MD LTE System Threshold Exceedance, 1755-1780 MHz

300W transmitter power, 1 km grid spacing, all satellites included

Probability of not exceeding LTE MW System threshold

Total 1755-1780 MHz spacecraft support radiation time averaged over one year yields estimated 69% probability of not exceeding LTE System threshold



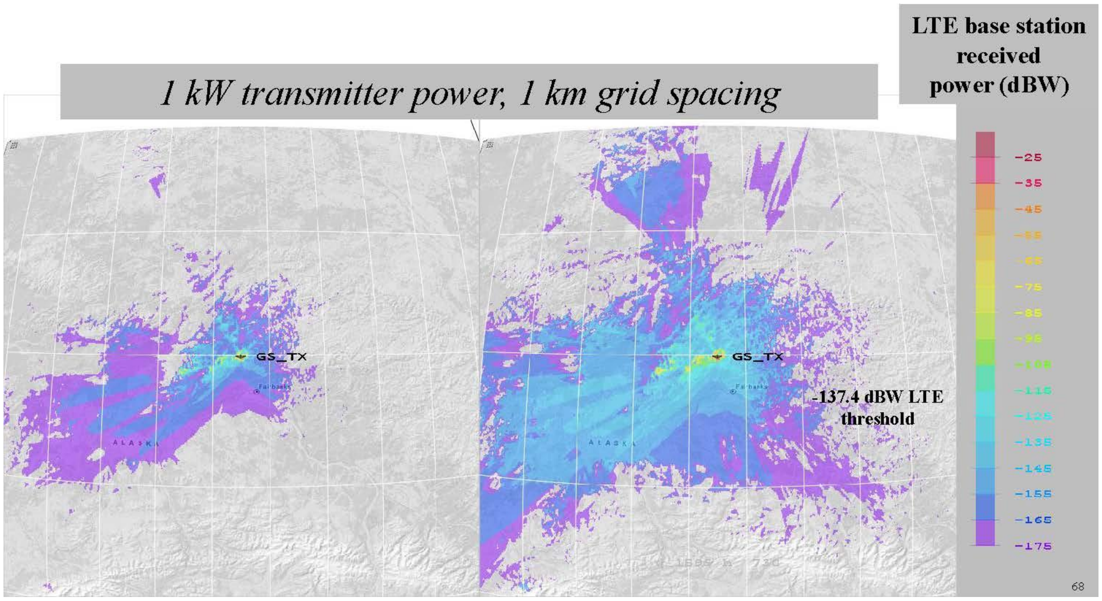
BP, MD LTE System Threshold Exceedance, 1755-1780 MHz

300W transmitter power, 20 dB attenuation, 1 km grid spacing, all satellites included

Probability of not exceeding LTE MW System threshold

Total 1755-1780 MHz spacecraft support radiation time averaged over one year yields estimated 69% probability of not exceeding LTE System threshold

FB, AK Power Contours



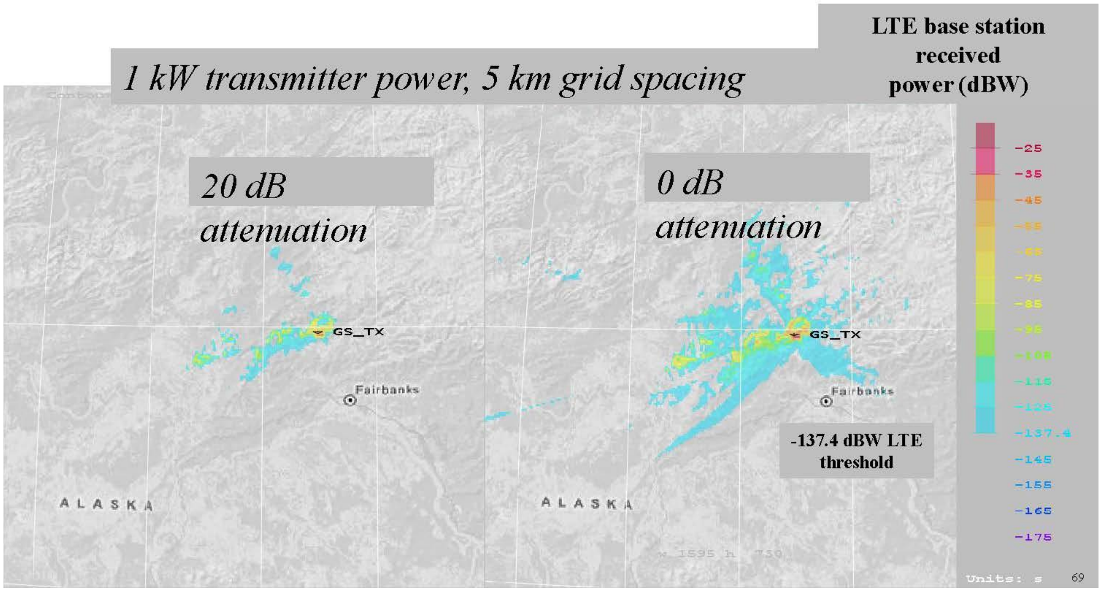
1 kW transmitter power, 1 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

2276

FB, AK Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold



1 kW transmitter power, 5 km grid spacing

LTE base station received power (dBW)

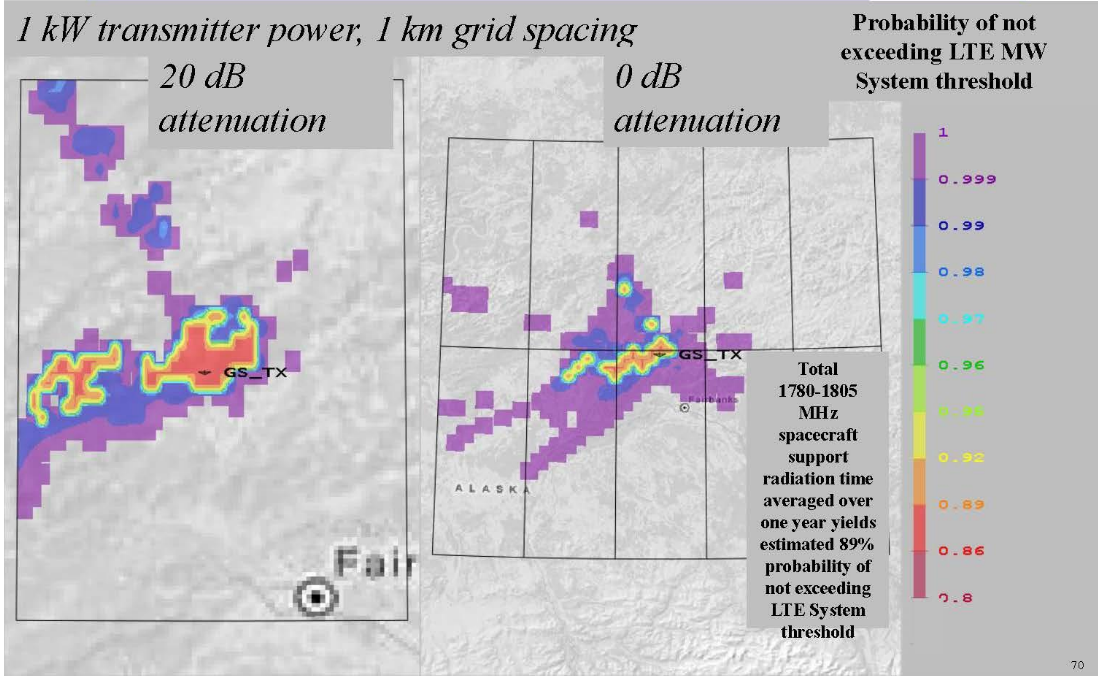
20 dB attenuation

0 dB attenuation

-137.4 dBW LTE threshold

2277

FB, AK LTE System Threshold Exceedance, 1780-1805 MHz



1 kW transmitter power, 1 km grid spacing

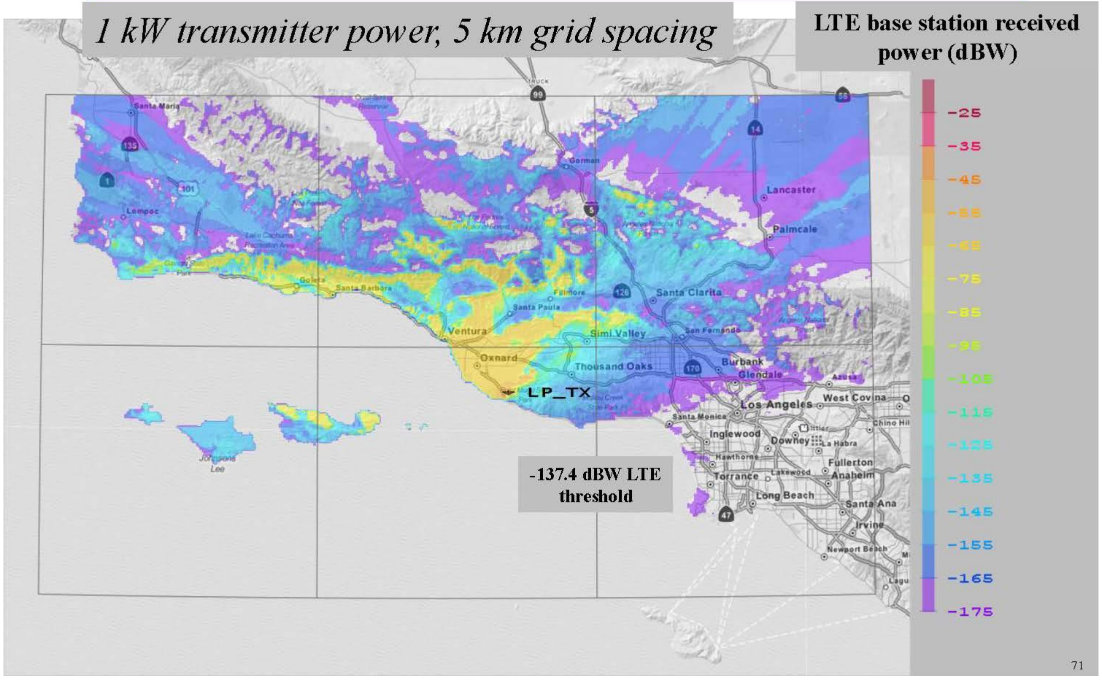
20 dB attenuation

0 dB attenuation

Probability of not exceeding LTE MW System threshold

Total 1780-1805 MHz spacecraft support radiation time averaged over one year yields estimated 89% probability of not exceeding LTE System threshold

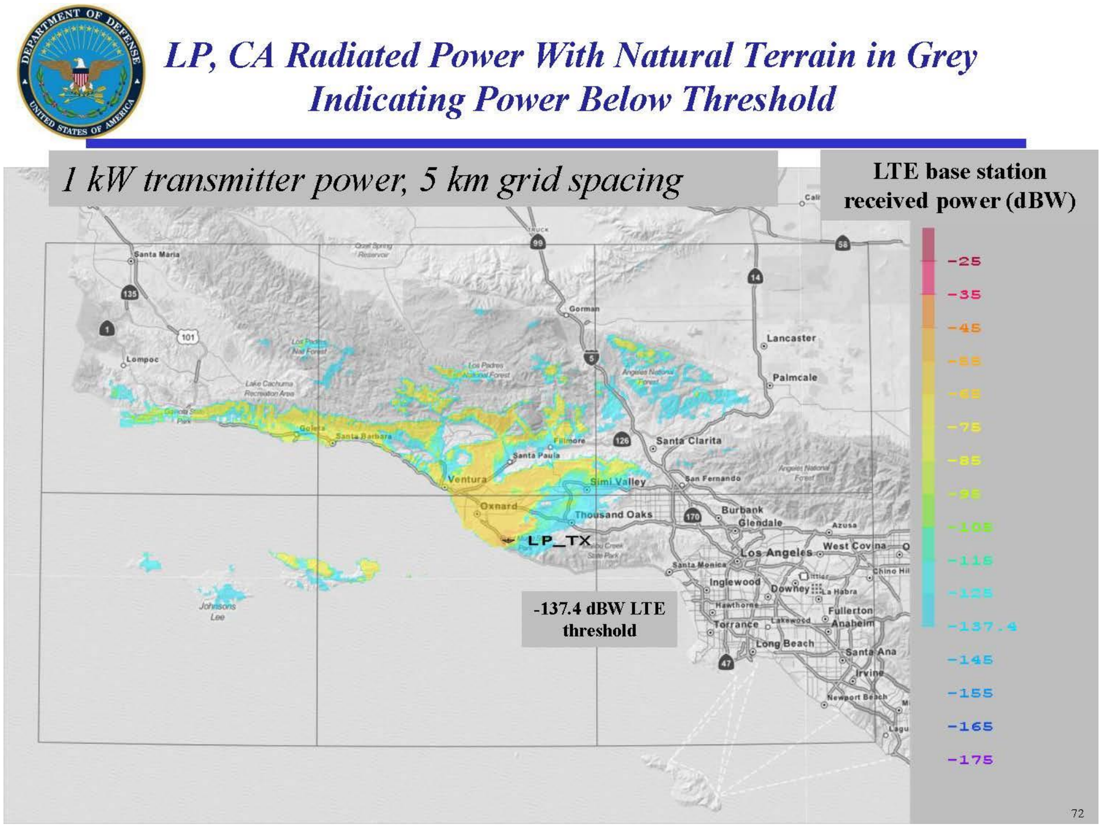
LP, CA Power Contours



1 kW transmitter power, 5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold



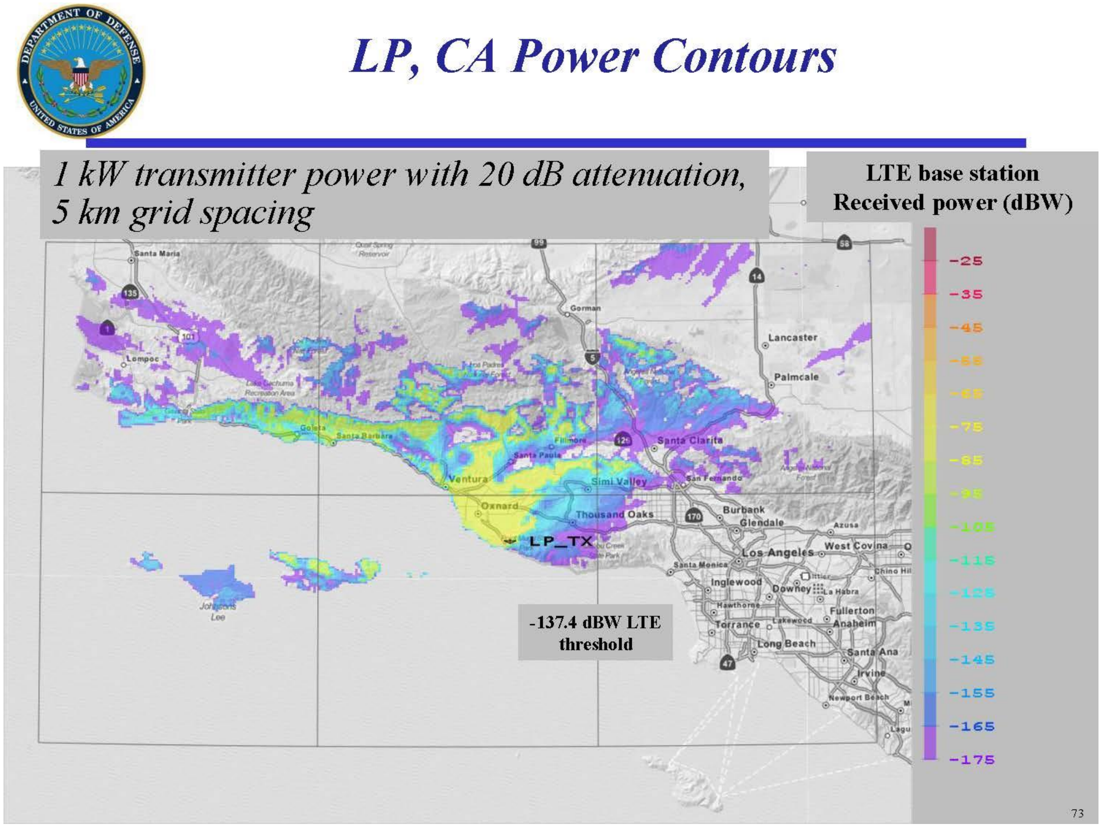
LP, CA Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

1 kW transmitter power, 5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

2280



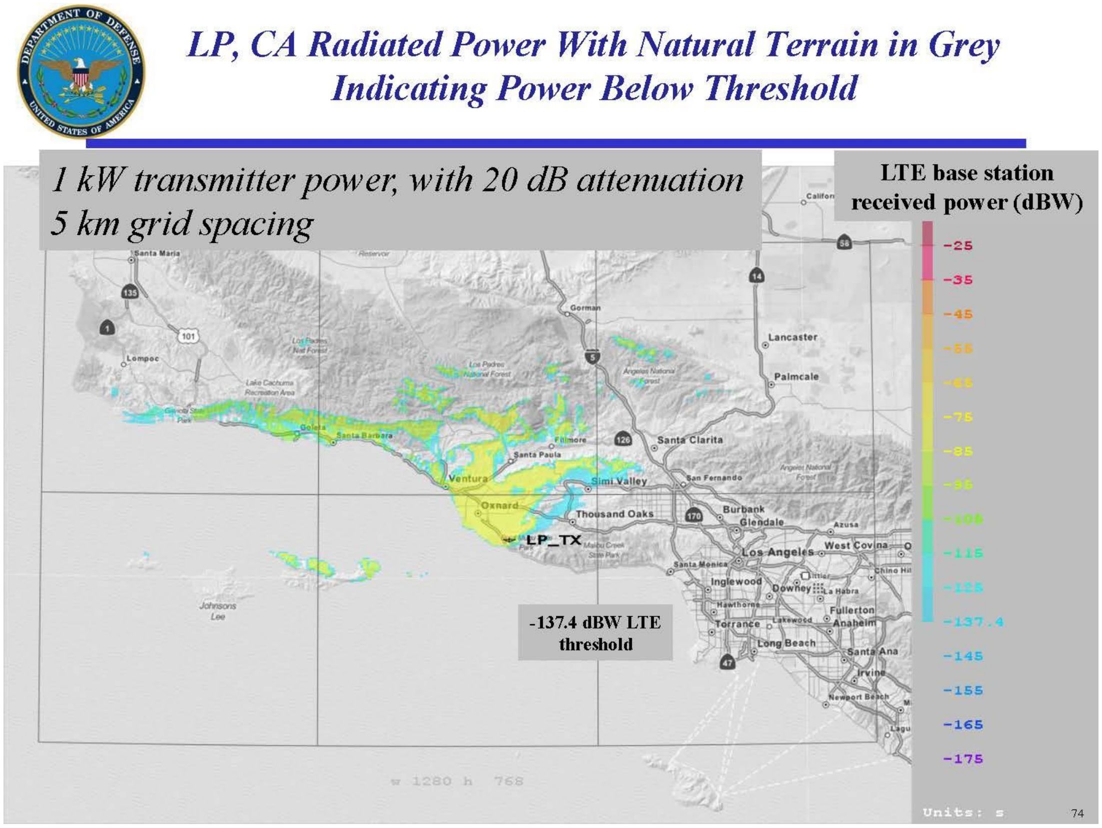
LP, CA Power Contours

1 kW transmitter power with 20 dB attenuation, 5 km grid spacing

LTE base station Received power (dBW)

-137.4 dBW LTE threshold

2281



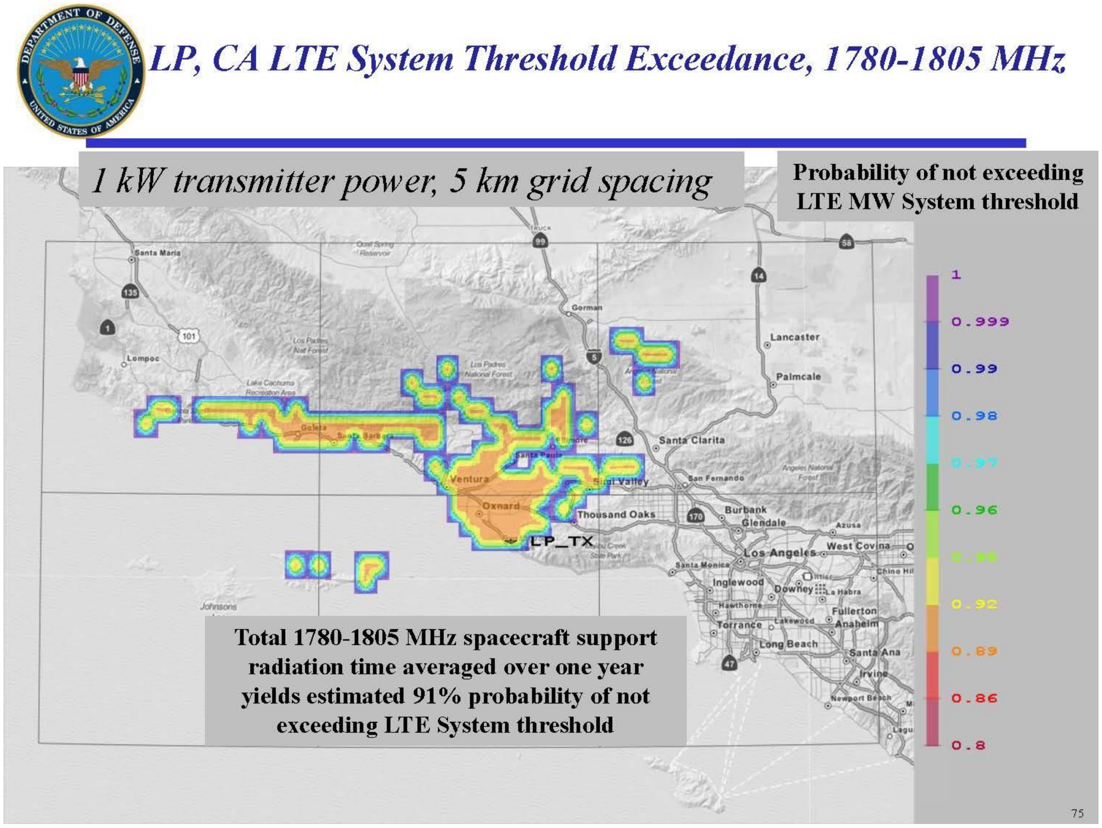
LP, CA Radiated Power With Natural Terrain in Grey Indicating Power Below Threshold

1 kW transmitter power, with 20 dB attenuation
5 km grid spacing

LTE base station received power (dBW)

-137.4 dBW LTE threshold

2282



LP, CA LTE System Threshold Exceedance, 1780-1805 MHz

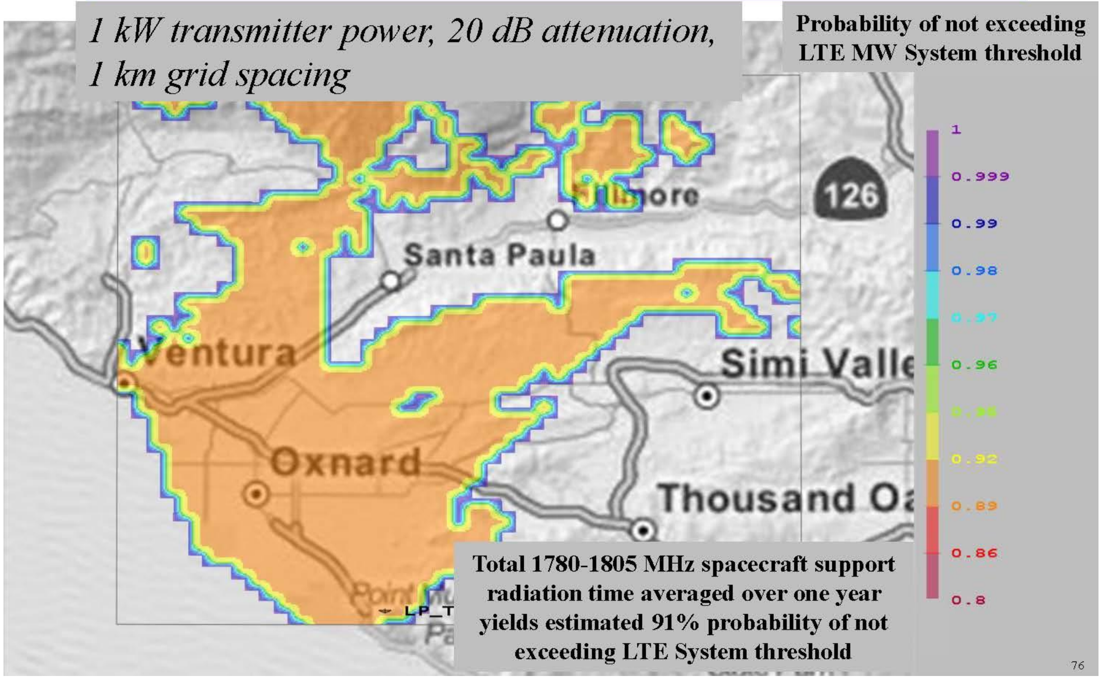
1 kW transmitter power, 5 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1780-1805 MHz spacecraft support radiation time averaged over one year yields estimated 91% probability of not exceeding LTE System threshold

2283

LP, CA LTE System Threshold Exceedance, 1780-1805 MHz



1 kW transmitter power, 20 dB attenuation,
1 km grid spacing

Probability of not exceeding LTE MW System threshold

Total 1780-1805 MHz spacecraft support radiation time averaged over one year yields estimated 91% probability of not exceeding LTE System threshold

Appendix B – Technical Rationale

- **The following topics are elaborated in this Appendix**
  - *ITM Parameters*
  - *Transmitter and Receiver Parameter Choices*
  - *RFI Overlap for Two Antennas Operating at a Site*
  - *Mathematical definition of Threshold Non-Exceedance Calculation*

Irregular Terrain Model (ITM) - Input Parameter Value Choices

- **Electrical Parameters**

1 - Polarization
1-vertical
0-horiziontal
15 - Dielectric constant of ground
4-poor ground
15-average ground
25-good ground
81-fresh/sea water
0.005 - Conductivity of ground
0.001-poor ground
0.005-average ground
0.02-good ground
0.01-fresh water
5.00-sea water

- **Regional and Temporal Parameters**

50 - # of Reliability/Time statistic
50 - # of Confidence/Location statistic
2 - Radio climate
1-Equatorial
2-Contental subtropical
3-Maritime tropical
4-Desert
5-Contental Temperate
6-Maritime temperate, over land
7-Maritime temperate, over sea
301 - Surface Refractivity
280 - Desert (Sahara)
301 - Continental Temperate
320 - Continental Subtropical (Sudan)
350 - Maritime Temperate, Over Sea
360 - Equatorial (Congo)

Transmitter and Receiver Parameter Choices

Transmitter Frequency (MHz)	**1762**
Transmitter Power (dBm)	**60**
Peak Antenna Gain (dBi)	*
Antenna Gain @ Horizon (dBi) (3 deg elev)**	**16**
EIRP @ Horizion (dBm)	*
Transmitter Antenna Height (m)	**30**
Receiver Antenna Height (m)	**30**
Receiver Antenna Down tilt (deg)	**3**
Receiver 3dB Beamwidth (el) (deg)	**10**

Receiver 3dB Beamwidth (az) (deg)	**70**
Receiver Antenna Gain at Horizon (dBi)	**18.0**
Receiver Ref Sensitivity (dBm)	**-101.50**
Receiver Interference @ 1 dB desense (dBm)	**-107.37**
Receiver Interference @ 3 dB desense (dBm)	**-101.50**
Receiver Sensitivity (1 dB desense, dBW)	**-207.94**
Receiver Sensitivity (3 dB desense, dBW)	**-202.07**

*Site Dependent
**Reference NTIA TM 13-489 Section 6.3.1.3 f (Ref 5)

RFI Overlap for 2 Antennas

- **Radiation time for each antenna pointing angle was delivered as a sum of the time radiated in that direction by antenna A and the time radiated in that direction by antenna B**
  - *This causes some radiation time and thus some threshold exceedance time to be double-counted*
- **The overlapping threshold exceedance time can be described as:**

$$\mathit{P(RFI\ Overlap)} = \mathit{P(ant\ A\ on\ AND\ ant\ A\ exceeding\ threshold\ AND}\\ \mathit{ant\ B\ on\ AND\ ant\ B\ exceeding\ threshold)}$$

- **This double-counted time was calculated (as shown on the next slide) and removed from the threshold exceedance times**

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RFI Overlap for 2 Antennas Calculation

- **Assuming independence between antenna A and antenna B,**

$$\text{P(RFI Overlap)} = \text{P(ant A on)*P(ant A exceeds threshold} \mid \text{ant A on)*}\\ \text{P(ant B on)*P(ant B exceeds threshold} \mid \text{ant B on)}$$

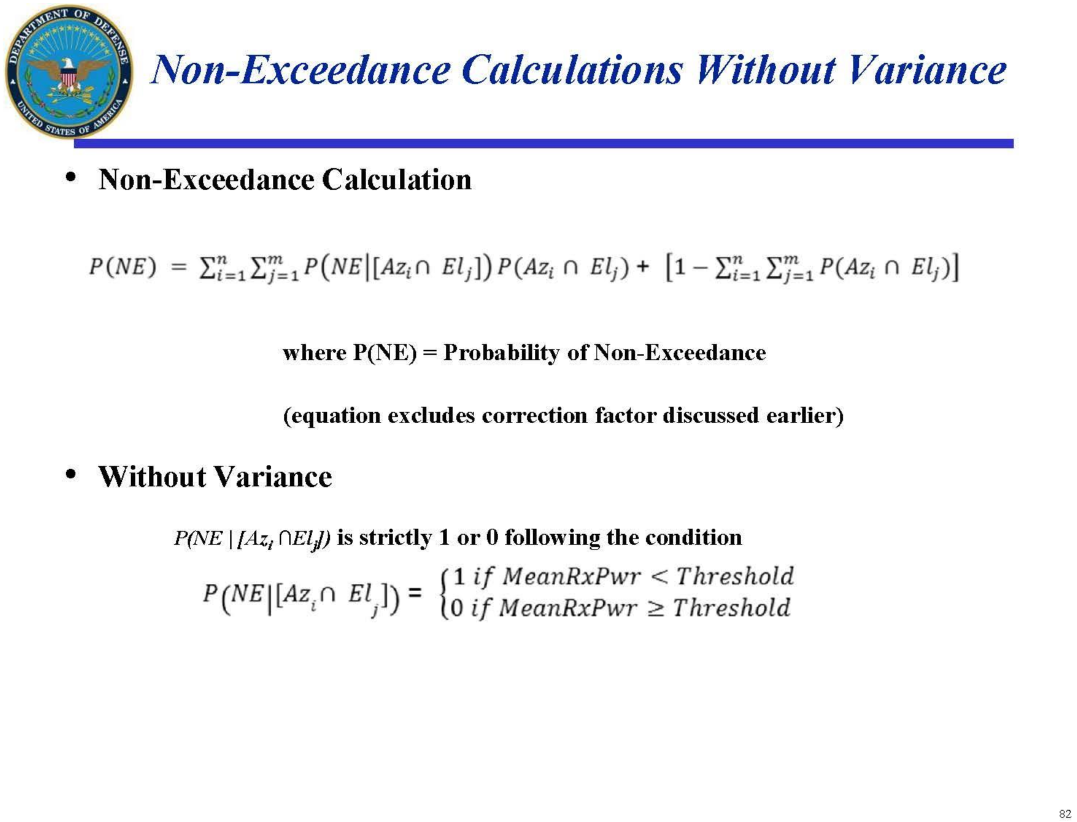
- **Assuming the same radiation time for and received power distribution from the 2 antennas,**

P(ant A on) = P(ant B on) **and**

$\text{P(ant A exceeds threshold} \mid \text{ant A On)} = \text{P(ant B exceeds threshold} \mid \text{ant B On)}$

- $\mathit{P(RFI\ Overlap)} = \mathit{P(ant\ A\ on)}^2 * \mathit{P(ant\ A\ exceeds\ threshold} \mid \mathit{ant\ A\ On)}^2$
  $= [\mathit{(Radiate\ \%\ /\ 2)} * \mathit{P(ant\ A\ exceeds\ threshold} \mid \mathit{ant\ A\ On)}]^2$
  $= \mathit{(Threshold\ Exceedance\ \%\ /\ 2)}^2$
- ***(Threshold Exceedance % / 2)***^{2} **is the correction factor that was used to remove double-counted threshold exceedance times from our calculations**

2289



Non-Exceedance Calculations Without Variance

- **Non-Exceedance Calculation**

$$P(NE) = \sum_{i=1}^{n}\sum_{j=1}^{m} P\left(NE\middle|[Az_i \cap El_j]\right)P(Az_i \cap El_j) + \left[1 - \sum_{i=1}^{n}\sum_{j=1}^{m} P(Az_i \cap El_j)\right]$$

where P(NE) = Probability of Non-Exceedance

(equation excludes correction factor discussed earlier)

- **Without Variance**

$P(NE \mid [Az_i \cap El_j])$ is strictly 1 or 0 following the condition

$$P\left(NE\middle|[Az_i \cap El_j]\right) = \begin{cases} 1 \text{ } if \text{ } MeanRxPwr < Threshold \\ 0 \text{ } if \text{ } MeanRxPwr \geq Threshold \end{cases}$$

5 Full Participant Lists for WG 3

Colin	Alberts	Freedom Technologies
David	Alianti	Alion Science
John	Anton	Scitor supporting SAF/SP
Beau	Backus	Aerospace Corporation
Maj Jennifer	Beisel	
Derr	Bergenthal	Ratheon
Johnnie	Best	Navy
Dan	Bishop	
Vic	Blanco	PEO Space Systems
Michael	Brown	
Mark	Brushwood	AFSMO
Mike	Chartier	Intel
Matthew	Clark	Areospace Corp
Dick	Cote	Air Force/A3SO
Michael	Cotton	NITA
Brooks	Cressman	ITT Excelis
Mike	David	Overlook supporting 3AF/5P
Edward	Davison	NTIA
Arthur	Deleon	US Marine Corp
Richard	Desalvo	Army
Christine	Di Lapi	ITT Excelis
Tom	Dombrowsky	CSMAC Member Participant
Ed	Drocella	NITA
John	Duffy	Aerospace
Larry	Feast	DOD/DISA

Jason	Fortenberry	Army
Mel	Frerking	AT&T
George	Frescholtz	Air Force
Paul	Frew	RIM
Peter	Georgiou	FCC
Alexander	Gerdenitsch	Motorola Mobility
Mike	Goddard	invited guest from UK
Mary	Greczyn	
Jason	Green	Alion Science
Kathrine	Green	ITT Excelis
Rob	Haines	NTIA
Steven	Hobbs	AF/A5RS
Scott	Hoshar	Navy
Mark	Johnson	Navy
Col. Brian	Jordan	DOD CIO
John	Kennedy	FCC
Gitangli	Khushlani	
Tom	Kidd	Navy
Robert	Kindelberger	Navy
Scott	Kotler	NTIA
Robert	Kubik	Samsung
David	Manzi	Raytheon
Jeff	Marks	Alcatel-Lucent
Col Harold	Martin	Air Force
Albert	Mauzy	Navy
Ian	McClymonds	Alion Science
Lynn	McGrath	OSD DOD-CIO
Albert "Buzz"	Merrill	Aerospace
Fred	Moorefield	Air Force
Rich	Mosley	AT&T
James	Norton	General Dynamics
Janice	Obuchowski	CSMAC Member Participant
Glenn	Okui	Navy
James	O'Neill	Navy
Troy	Orwan	DOD CIO
Mark	Paolicelli	USMC
Gary	Patrick	NITA
Michael	Perz	Air Force
Clifton	Phillips	Navy
Carl	Povelites	AT&T
Kimberly	Purdon	USAF AFSMO
John	Quinlan	Whitehouse OMB
John	Radpour	AT&T
Rick	Reaser	CSMAC Member Liaison
Donald	Reese	Air Force
Raymond	Reyes	Army
Charles	Rush	CSMAC Member Liaison
Brian	Scarpelli	TIA
Steven	Schwartz	Army G-2
Wayne	Shaw	Association of Old Crows
Trent	Skidmore	National Coordination Office
Odell "Alden"	Smith	DISA/DSO
Jim	Snider	iSolon.org

Steven	Sparks	YPG
John	Suhy	HQDA Army EW
Thomas	Sullivan	ASRC/ARTS supporting NASA
Carol	Swan	Air Force
Neeti	Tandon	AT&T
Stuart	Timerman	DOD CIO
Gregory	Torba	Air Force
Howard	Watson	
Chris	Wieczorek	T-Mobile
Stephen	Wilkus	Alcatel-Lucent
Lori	Winn	DOD Joint Staff
Maurice	Winn	Alion Science
Susan	Woida	AF/A3SO
Lily	Zeleke	DOD CIO

2292 6 Abbreviations Used in This Report

3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
ACIR	Adjacent Channel Interference Ratio
ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
AFC	Area Frequency Coordinator
AFSCN	Air Force Satellite Control Network
AN, MD	Annapolis, Maryland
AWS	Advanced Wireless Services
BAFB	Buckley Air Force Base
BER	Bit Error Rate
BP, MD	Blossom Point Field Site, Maryland
BS	Base Station
BW	Bandwidth
C/N	Carrier to Noise Ratio
C2	Command and Control
CAPEG	Cape GA, CCAFB, Florida
CDF	Cumulative Distribution Function
CONUS	Continental United States
CP, CA	Camp Parks Communications Annex, Pleasanton, CA
CSEA	Commercial Spectrum Enhancement Act
CSMAC	Commerce Spectrum Management Advisory Committee
CTS	Colorado Tracking Station, Schriever AFB, Colorado
d	Mobile Station Antenna effective height. (m) Link distance. (km)
dB	Decibel
dBi	Decibel Isotropic
dBm	Power ratio in decibels reference to one milliwatt
dBW	Power ratio in decibels reference to one watt
DCI	Downlink Control Information
DE	Directed Energy
DGS	Diego Garcia Tracking Station, British Indian Ocean Territory, Diego Garcia
DL	Downlink, for mobile devices this is link from the base station to the mobile device, for satellite communications this is the satellite to earth station link
DoD	Department of Defense
EA	Electronic Attack
EIRP	Equivalent Isotropic Radiated Power
EM	Electromagnetic Energy

EMS	Electromagnetic Spectrum
eNodeB /eNB	Evolved Node B, also referred to as base station
E-UTRA	Evolved Universal Terrestrial Radio Access
EVCF	Eastern Vehicle Checkout Facility, Cape Canaveral AFS, Florida (Launch support only)
EW	Electronic Warfare
f	Frequency of Transmission (MHz)
FAA	Federal Aviation Administration
FACSFAC	Fleet Area Coordination and Surveillance Facility
FB, AK	Fairbanks (NOAA), Alaska
FB, NC	Ft. Bragg, NC
FB, VA	Fort Belvoir, Virginia
FCC	Federal Communications Commission
FDD	Frequency Duplex Division
FDR	Frequency dependent rejection (dB)
FER	Frame Erasure Ratio
FH, TX	Ft. Hood, TX
FSS	Frequency Selective Scheduling
GHz	Gigahertz
GNS	Guam Tracking Station, Andersen AFB, Guam
G_R	Antenna gain of the BS receiver in the direction of the SATOPS uplink station (dBi)
GSO	Geostationary Satellite Orbit
GTS	Guam Tracking Station, Andersen AFB, Guam
H_B	Base Station Antenna effective height. (m)
HB, CA	Huntington Beach , CA
Hi	Hawaii
H_m	Mobile station Antenna height correction factor as described in the Hata Model for Urban Areas
HTS	Hawaii Tracking Station, Kaena Point, Oahu, Hawaii
Hz	Hertz
I	Received interference power at the output of the BS receiver antenna (dBm)
I_{AGG}	Aggregate interference to the BS system receiver from the SATOPS transmitters (dBm)
I_j	Interference power level at the input of the base station receiver from the j^{th} SATOP transmitter (Watts)
IRAC	Interdepartment Radio Advisory Committee
ISD	Inter Sector Distance, distance between two base station sites
ISR	Intelligence, Reconnaissance and Surveillance
ITU	International Telecommunications Union
JB, WA	Joint Base Lewis-McChord, WA
KAFB	Kirtland AFB, New Mexico
kHz	Kilohertz
KW, FL	JIATF-S, Key West, FL
L	Median path loss. (dB)
LFE	Large Force Employment Exercises
LIMFAC	Limiting Factors
L_L	Building and non-specific terrain losses (dB)
L_P	Propagation loss between BS and SATOPS uplink station (dB)
LP, CA	Laguna Peak, California (Navy)
L_R	BS insertion loss (dB)
LTE	Long Term Evolution
m	meter
MHz	Megahertz
MILDEPS	Military Department
MO, CA	Monterey, California

MOU	Memorandum of Understanding
MSL	Mean Sea Level
N	Number of SATOPS transmitters Noise Power
NASA	National Aeronautics and Space Administration
NDA	Non-Disclosure Agreement
NGSO	Non-Geostationary Satellite Orbit
NHS	New Hampshire Tracking Station, New Boston AFS, New Hampshire
NIB	Non-Interference Basis
NORAD	North American Aerospace Defense Command
NTIA	National Telecommunications and Information Administration
OOB	Out-of-band
P	Transmit power
PDCCH	Physical Downlink Control Channel
PDF	Probability Distribution Function
PH, ME	Prospect Harbor, Maine (Navy)
PNT	Position, Navigation and Timing
PR	Puerto Rico
PR, MD	Patuxent River NAS, MD
PRB	Physical Resource Block
$P_{REFSENS}$	Power at reference sensitivity
QN, VA	Quantico, Virginia
RCC-FMG	Range Commander Council Frequency Management Group
RCIED	Radio Controlled Improvised Explosive Device
RDT&E	Research, Development, Test and Evaluation
RF	Radio Frequency
RFI	Radio Frequency Interference
RLC	Radio Link Control
Rx	Receive
SA, TX	San Antonio Texas
SAC, CA	Sacramento, CA
SATOPS	Satellite Operations
SDS	Spectrum Dependent System(s)
SEM	Spectral Emission Mask
SF	Scale factor
SGLS	Space Ground Link Subsystem
SGP	Series of Satellite Orbital models (SGP, SGP4, SDP4, SGP8 and SDP8)
SME	Subject Matter Experts
SMO	Spectrum Management Office(s)
SNS	Space Network System
SRF	Spectrum Relocation Fund
TCS	Oakhanger Telemetry and Command Station, Borden, Hampshire, England
TT&C	Telemetry Tracking and Command
TTP	Tactics, Techniques and Procedures
TTS	Thule Tracking Station, Thule Air Base, Greenland
Tx	Transmit
U.S.	United States
UE	User Equipment
UL	Uplink, for mobile devices this is link from the mobile device to the base station, for satellite communications this is the earth station to satellite link
UL-MIMO	Uplink Multiple Input Multiple Output
UMTS	Universal Mobile Telecommunications System
US&P	United States and Possessions
VTS	Vandenberg Tracking Station, Vandenberg AFB, California
WG 1	CSMAC Working Group 1
WG 3	CSMAC Working Group 3

x	Frequency in MHz
Δf_{OOB}	Offset frequency for out-of-band emissions