MTR200687

MITRE TECHNICAL REPORT

Analysis on the Impact of SATOPS Transmissions on LTE Aggregate Interference

Sponsor: Defense Information Systems Agency Defense Spectrum Organization
Dept. No.: N242
Contract No.: W56KGU-18-D-0004
Project No.: 0720K06X

Bedford, MA

Darcy Swain-Walsh
Jeff Correia
Dr Venki Ramaswamy
Cameron Patterson
Evan Ding
Jerediah Fevold
Ashton Knight
Evan Briggs
Shawn Lefebre

July 2020

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
07/01/2021

2. REPORT TYPE
Technical Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Analysis on the Impact of SATOPS Transmissions on LTE Aggregate Interference

5a. CONTRACT NUMBER
W56KGU-18-D-0004

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Swain-Walsh, Darcy; Correia, Jeff; Ramaswamy, Venti; Patterson, Cameron; Ding, Evan; Fevold, Jerediah; Knight, Ashton; Briggs, Evan; Lefebre, Shawn;

5d. PROJECT NUMBER
0720K06X

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The MITRE Corporation
202 Burlington Road
Bedford, MA 01720

8. PERFORMING ORGANIZATION REPORT NUMBER
PRS-20-3098; MTR200687

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Defense Information Systems Agency
Defense Spectrum Organization

10. SPONSOR/MONITOR'S ACRONYM(S)
DISA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The MITRE Corporation investigated whether current modeling techniques were adequate to support the analysis necessary for evaluation of coordination requests where federal operations include both Department of Defense (DoD) satellite operations (SATOPS) and other terrestrial operations. MITRE's analysis concludes that while much of the predicted disruption occurs over the geographic footprint of the SATOPS emissions, the changes in aggregate interference, when calculated with and without SATOPS interference present, do not warrant a change in the way aggregate interference is modeled for SATOPS coordination zones within the AITs.

15. SUBJECT TERMS
Wireless Communications; Satellite Communications aggregate interference; wireless services; spectrum sharing; cellular signaling; SATOPS; satellite operations

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
				57	Susan Carpenito **19b. TELEPHONE NUMBER** *(Include area code)* 781-271-7646

Abstract

The Defense Spectrum Organization (DSO) within the Defense Information Systems Agency (DISA) executes the Spectrum Sharing Test and Demonstration (SST&D) program as part of the DISA Advanced Wireless Services 3 (AWS-3) transition plan. DSO is responsible for making recommendations regarding the modeling of the aggregate interference caused by Long Term Evolution (LTE) cellular signaling for possible incorporation into various aggregate interference tools (AITs). The Military Services use these AITs to approve or deny the placement of commercially deployed LTE sectors by mobile network operators (MNOs) before federal incumbent assets vacate the band in identified coordination zones (i.e., areas where interference from the LTE uplink could degrade federal operations).

The MITRE Corporation investigated whether current modeling techniques were adequate to support the analysis necessary for evaluation of coordination requests where federal operations include both Department of Defense (DoD) satellite operations (SATOPS) and other terrestrial operations. DoD SATOPS uplinks operate at relatively high power and can transmit at low elevation angles that are in-band to AWS-3 cellular signaling. This can potentially have an impact on the overall volume of LTE traffic due to retransmissions, user equipment output power via closed-loop power control mechanisms, and the shape of the power spectrum of LTE emitter due to standard interference avoidance scheduling schemes. MITRE's analysis concludes that while much of the predicted disruption occurs over the geographic footprint of the SATOPS emissions, the changes in aggregate interference, when calculated with and without SATOPS interference present, do not warrant a change in the way aggregate interference is modeled for SATOPS coordination zones within the AITs.

This page intentionally left blank.

Executive Summary

The Defense Information Systems Agency (DISA) Defense Spectrum Organization (DSO) executes the Spectrum Sharing Test and Demonstration (SST&D) program as part of its Advanced Wireless Services (AWS-3) transition plan. One of DSO's responsibilities in this area is to make recommendations regarding the modeling of the aggregate interference caused by Long Term Evolution (LTE) cellular signaling for possible incorporation into various aggregate interference tools (AITs). The Military Services use these AITs to approve or deny the placement of LTE sectors by Mobile Network Operators (MNO) in coordination zones (i.e., areas where interference from the LTE uplink could degrade Department of Defense [DoD] operations) prior to DoD transitioning systems out of the band.

MITRE investigated whether current modeling techniques are adequate to support the analysis necessary for evaluation of coordination requests (CRs) where DoD operations include both satellite operations (SATOPS) and other terrestrial operations. DoD SATOPS uplinks operate at high power and can transmit at low elevation angles in-band to cellular signaling. This can potentially increase the volume of LTE traffic, influence closed-loop power control, and reshape the power spectrum of LTE interference with DoD SATOPS.

To perform this analysis, MITRE collaborated with the Aerospace Corporation to define a scenario with a low elevation angle and high transmit power incident on an LTE deployment. Denver, CO, was chosen as a representative region for the scenario as it contains both SATOPS and other DoD operations against which CRs are evaluated. MITRE and Aerospace used real CRs submitted by an MNO to obtain parameterization for the interference evaluation. Specifics of these CRs are not included in this report due to non-disclosure restrictions.

To consider worst-case conditions, the location for aggregate interference computation was chosen as 15,000 feet above the sector most impacted by SATOPS uplink interference. The SATOPS interference bandwidth was set at 1MHz and the interference was modeled as additive white Gaussian noise. Several vignettes indicated that other modulation types did not alter results.

Current AITs utilize a probabilistic cumulative distribution function (CDF) for the transmit power of LTE user equipment (UE) as a source of randomization while performing an aggregate interference assessment. The Commerce Spectrum Management Advisory Committee (CSMAC) working group 3 defined curves for urban and rural morphologies in 2012[1]. While each Service implements its AITs uniquely, the overarching concept for how interference is computed is the same. Aggregate interference is computed from the individual contributions made by each piece of LTE UE at a DoD asset location after application of link budget-oriented factors such as platform-specific antenna gain, front-end frequency selectivity and clutter losses between the UE and DoD asset. DSO applies its aggregate interference equation as it was developed in the CSAMC working group 1[2] to perform this calculation.

To analyze the impact of SATOPS interference on an LTE sector, MITRE applied its Multi-UE LTE Emulator (MULE) to predict both modified CDF UE transmit power in the presence of interference as well as the modified power spectrum of the LTE uplink emissions. MULE utilizes a commercial-grade Band 66 (AWS-3) downlink radio head (evolved Node B, or eNB)

---

[1] https://www.ntia.doc.gov/files/ntia/Working_Group_3_Final.pdf

[2] https://www.ntia.doc.gov/files/ntia/publications/wg_1_report.pdf

and 24 commercial off-the-shelf handsets that can be independently placed in the sector between the UE and eNB using Third Generation Partnership Project (3GPP) channel models. For realism, UEs and the eNB scheduler in the MULE environment behave similarly to field-deployed equipment under equivalent loading and interference conditions.

Using the MULE, MITRE parametrically created modified transmit power CDFs for the responses (UE emissions) as a function of the control factors (interference power, interference frequency, and sector loading). Aggregate interference was calculated under scenarios of the latter two control factors by using CDFs corresponding to the power from the SATOPS uplink at the LTE sector antenna in the geographic scenario.

MITRE's simulation of the Denver low-elevation angle geostationary orbit scenario did not predict a significant increase in aggregate interference at the airborne DoD receiver. Based on this result, MITRE does not recommend any changes to the current AITs used to account for interference with DoD SATOPS.

Acknowledgments

The authors wish to acknowledge the Defense Information Systems Agency (DISA) Defense Spectrum Organization (DSO), The Aerospace Corporation, Peraton Inc., Foundry, The Virginia Tech Applied Research Corporation (VT-ARC) and RKF Engineering Solutions, for their contributions and feedback to this study, and most of all to the AWS-3 coordination effort overall, of which this study is just one piece.

Many thanks as well to Nathan Johnson, Surajit Dey and Nevan Shattuck for their contributions to the development of the MULE at MITRE.

This page intentionally left blank.

Table of Contents

List of Figures

List of Tables

This page intentionally left blank.

1 Introduction

The Defense Spectrum Organization (DSO) within the Defense Information Systems Agency leads the Spectrum Sharing Test and Demonstration (SST&D) program as part of the DISA Advanced Wireless Services 3 (AWS-3) transition plan. DSO makes recommendations regarding the modeling of the aggregate interference caused by Long Term Evolution (LTE) cellular signaling for possible incorporation into various aggregate interference tools (AITs). The Military Services use these AITs to approve or deny the placement of commercially deployed LTE sectors by mobile network operators (MNOs) during the early entry phase in federally identified coordination zones (i.e., areas where interference from the LTE uplink could degrade federal operations).

The MITRE Corporation investigated whether current modeling techniques were adequate to address the analysis necessary for evaluation of coordination requests (CRs) where federal operations include both Department of Defense (DoD) satellite operations (SATOPS) and other terrestrial operations. This question arose because DoD SATOPS uplinks operate at relatively high power and can transmit at low elevation angles that are in-band to cellular signaling. This can potentially have an impact on the overall volume of LTE traffic due to retransmissions, user equipment (UE) output power via closed-loop power control mechanisms, and the shape of the power spectrum of LTE interference with DoD SATOPS due to standard interference avoidance scheduling schemes. This report describes the approach MITRE used to conduct the analysis, and the findings and conclusions. The remainder of this section presents the background of the study.

1.1 Spectrum for Commercial Wireless and LTE

As the performance standards and use cases for mobile wireless networks have steadily increased, additional access to radio frequency (RF) spectrum is vital for MNOs to meet demand. Since its release in 2008, the LTE standard has leveraged efficient spectrum use through Orthogonal Frequency-Division Multiplexing (OFDM) and Multiple Input Multiple Output (MIMO), and allowed cellular communications to take maximum advantage of available spectrum through increased spectrum flexibility in bandwidths from 1MHz to 20MHz, as well as carrier aggregation and license-assisted access. Since access to more bandwidth can so readily improve network performance, MNOs have incentives to increase their presence in the spectrum as quickly as possible.

1.2 FCC AWS-3 Auction of Spectrum

In 2014, the Federal Communications Commission (FCC) commenced the AWS-3 auction[3], making the 1695–1710 MHz, 1755–1780 MHz, and 2155–2180 MHz bands available for flexible wireless use, including mobile broadband networks. The bids totaled $41,329,673,325 among 31 bidders.[4] This auction represented the culmination of a multi-year effort to expand commercial wireless spectrum and facilitate spectrum sharing with federal incumbents in the band. While most federal assets were required to vacate the auctioned bands after a set deadline after the auction, some were granted access to the band in perpetuity, and the MNOs must operate in the

---

[3] https://www.fcc.gov/auction/97

[4] https://www.ntia.doc.gov/category/aws-3-transition

presence of those federal assets. In these scenarios, the federal incumbents in the bands and MNOs must have a clear understanding of how their networks would be affected by each other's emitters so they can assess the risk of operating near this equipment. In addition, there are conditional agreements to allow MNOs "early entry" into the bands before the auction deadline, requiring further coordination with the MNOs and federal incumbents who will be required to vacate.

1.3 Regulatory Basis

Current coordination procedures for commercial entry into the AWS-3 band are described in the Federal Communications Commission and National Telecommunications and Information Administration (NTIA) Public Notice DA-14-1023.[5] Included in these procedures are descriptions of three categories of incumbents in the band with which the MNOs must coordinate before entry:

1. Meteorological satellite (MetSat) stations (space-to-earth communication) permitted to operate in the AWS-3 band in perpetuity within defined coordination zones
2. Federal United States and Possessions (US&P) assets scheduled to vacate the AWS-3 band
3. Federal non-US&P assets permitted to operate in the AWS-3 band in perpetuity within defined coordination zones

Details about these categories can be found in the NTIA 2014 Public Notice. The third category is the focus on this paper.

According to the US Table of Allocations as specified in the NTIA manual, the US 91 footnote codifies continuing SATOPS operations. The following is an excerpt:

In the sub-band 1761-1780 MHz, Federal earth stations in the space operation service (Earth-to-space) may transmit at the following 25 sites and non-Federal base stations must accept harmful interference caused by the operation of these earth stations:

Table 1-1. Earth Station State and Site Names

State	Site Name
AK	Fairbanks
CA	Camp Parks
CA	Huntington Beach
CA	Laguna Peak
CA	Monterey
CA	Sacramento
CA	Vandenberg AFB

[5] https://docs.fcc.gov/public/attachments/DA-14-1023A1.pdf

CO	Buckley
CO	Schriever AFB
FL	Cape Canaveral AFS
FL	Cape GA, CCAFB
FL	JIATF-S Key West
HI	Kaena Point, Oahu
MD	Annapolis
MD	Blossom Point
MD	Patuxent River NAS
ME	Prospect Harbor
NC	Ft Bragg
NH	New Boston AFS
NM	Kirtland AFB
TX	Ft Hood
VA	Fort Belvoir
WA	Joint Base Lewis-McChord
GU	Andersen AFB
GU	NAVSOC Det. Charlie

NOTE: Use at Cape Canaveral AFS is restricted to launch support only. If required, successfully coordinated with all affected AWS licensees, and authorized by NTIA, reasonable modifications of these grandfathered Federal systems beyond their current authorizations or the addition of new earth station locations may be permitted. The details of the coordination must be filed with NTIA and FCC.

MNOs have an opportunity for early entry into the AWS-3 band if they and federal incumbents come to a coordination agreement. Both federal and commercial parties have incentives to reach such an agreement, as this could allow MNOs to make use of the spectrum earlier. Alternatively, if it is determined that the deployment of AWS-3 networks would have minimal impact on federal assets, new agreements could be drafted to allow some federal assets to remain in the band.

1.4 SATOPS Coordination

Scenarios investigated in this study and described in this report concern federal earth stations located at 25 sites that will continue operations in the space operation service (earth-to-space) in the 1761–1780 MHz band. These SATOPS earth stations require additional analyses because, as indicated in 1.3 above, Federal regulations state that AWS-3 deployments must accept interference from these earth stations indefinitely. Interference from an AWS-3 deployment could induce degraded network behavior that deviates from the predictions used in other coordination agreements, particularly the early entry agreements mentioned in the preceding subsection. If the interference from an AWS-3 deployment under an early entry coordination agreement were to increase in the presence of a SATOPS uplink transmitting in the area, this could pose a risk to other the federal assets. It is therefore necessary that a model is developed to quantify the change in aggregate interference from LTE deployments in the AWS-3 band in the presence of a SATOPS interferer.

1.5 Overview and Study Question

In order to develop a convincing model of AWS-3 aggregate interference, it is necessary to determine if the possibility of a SATOPS transmission causing changes to network behavior would require adjustment to the model. The first step in making this determination would be to answer the question: *In the worst case, can the aggregate interference increase in the presence of a SATOPS interferer?* If the answer is no, then there is no need to incorporate this early entry scenario into the model. If it is yes, then further investigation will be necessary. MITRE has developed a differential analysis method to quantify the degree to which the aggregate interference would change in the presence of a SATOPS interferer against a baseline without an interferer. This analysis does not intend to predict the magnitude of the aggregate interference in the presence of a SATOPS interferer, but instead intends to isolate the variables that other AITs use in their interference modeling equations that would be sensitive to external interference and determine the degree to which they change the aggregate interference prediction.

Section 2 presents the equation that the Military Services use to calculate aggregate interference and identifies the specific components of that equation addressed in this study.

2 Aggregate Interference Equation

In order to approve or deny new LTE sector deployments, the Military Services make use of AITs to predict the aggregate interference radiated by these sectors. There is general agreement that the factors that influence the aggregate interference of an LTE sector at an arbitrary victim receiver are well parameterized by the following link budget simplification, referred to as the "Aggregate Interference Equation":

$$I_k = NL(P_{Tx}) + EIRP(P_{Tx}) - L_{Cl}(P_{Tx}) - L_p(P_{Tx}, P_{Rx}) - FDR(\Delta f) + G_r(\theta, \varphi) - L_{pol} - L_s$$

This equation describes the components that contribute to aggregate interference at a victim receiver, and a version was first proposed in the Commerce Spectrum Management Advisory Committee (CSMAC) working group 1 report.[6] Table 2-1 defines each component of the equation.

Table 2-1. Aggregate Interference Equation Parameters

I_K	= predicted interfering signal level in the DoD receiver from a single modeled UE, dBm
$NL(P_{Tx})$	= Network loading factor, dB
$EIRP(P_{Tx})$	= modeled UE transmitter effective isotropic radiated power, dBm
$L_{Cl}(P_{Tx})$	= clutter loss between a modeled UE and a DoD receiver, dB
$L_p(P_{Tx}, P_{Rx})$	= interference path propagation loss between a modeled UE and DoD receiver, dB
$FDR(\Delta f)$	= Frequency dependent rejection, dB
$G_r(\theta, \phi)$	= DoD receiver antenna gain in the direction of the interferer transmitter, dBi
L_{pol}	= DoD receiver antenna polarization mismatch loss, dB
L_s	= DoD incumbent receiver system loss, dB

Only the first four factors covered in this equation were of concern in this study, namely, network loading (NL) effective isotropic radiated power (EIRP), clutter loss (L_{Cl}), and path loss (L_p). Furthermore, only the first two terms, NL and EIRP, should be impacted by the presence of a SATOPS interferer. The remaining two factors, L_{Cl} and L_p, would determine the extent to which the aggregate interference at the DoD receiver in an impacted sector would change, and both depend on the geographic location of the receiver relative to the LTE sector.

[6] https://www.ntia.doc.gov/files/ntia/publications/wg_1_report.pdf

3 Approach

This section describes the approach MITRE used to conduct this study.

3.1 Overview of Approach

MITRE leveraged its Multi-UE LTE Emulator (MULE) to predict both modified CDF UE transmit power in the presence of SATOPS interference and the modified power spectrum of the LTE uplink emissions. These runs were compared against a baseline run under normal interference conditions to approximate a delta in the UE reported transmit power across these two scenarios.

While modeling methods vary in implementation, they all apply the aggregate interference equation described in section 2. In this study, MITRE isolated the factors that would be affected by a SATOPS transmission and assessed the extent to which the aggregate interference distribution would change in response to this transmission. This delta should be applicable to any model using the aggregate interference equation.

3.1.1 Differential Analysis of a Baseline Against SATOPS Scenario

MITRE determined that differential analysis represented the most practical approach to evaluating aggregate interference effects. The experiments described in this report compared a baseline scenario, in which an LTE network is unaffected by SATOPS interference, against a scenario with a SATOPS transmitter radiating interference energy injected into the network over cables (see Figure 3-1). The interference was 1MHz bandwidth AWGN centered at three different regions: 1715MHz, 1716.71 MHz, 1718.42 MHz (referred to as Regions 1, 2 and 3, respectively). Sector laydown, SATOPS transmission power and bearing, and DoD receiver location remained the same in all comparisons. The analysis covered primarily:

1. The change in the aggregate interference CDF (in dBm)
2. The change in the Physical Resource Block (PRB) power distribution (in Watts).

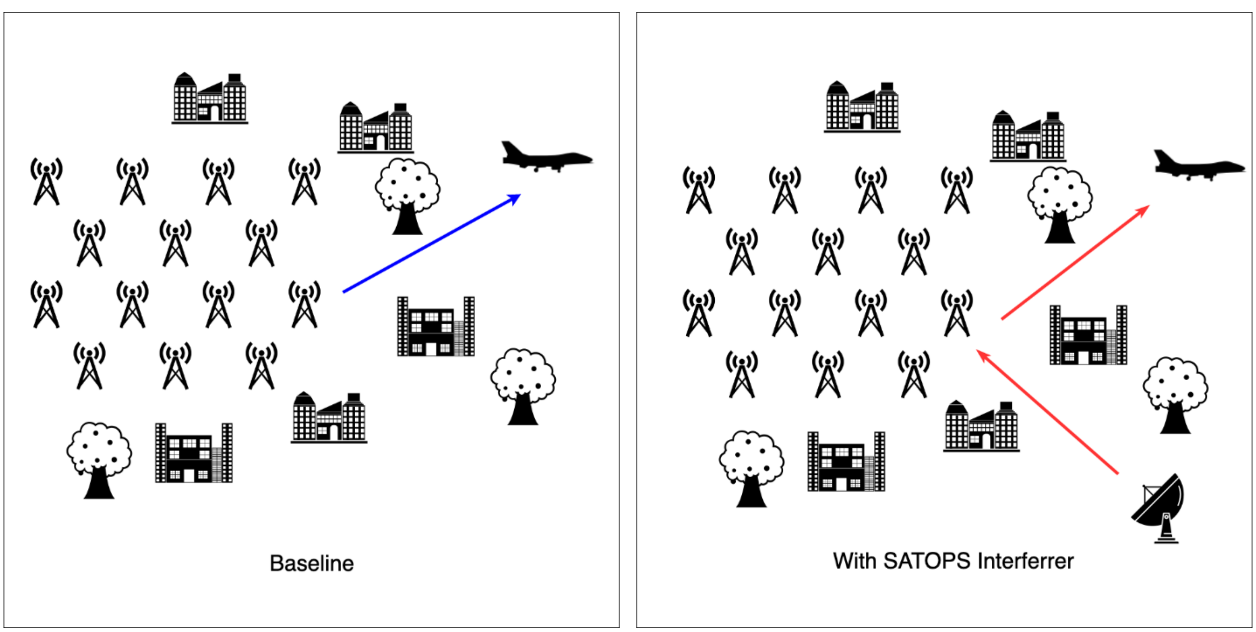


Figure 3-1. Baseline vs. SATOPS Scenario

Figure 3-2 and Figure 3-3 show examples of the resulting products. In Figure 3-2, each curve is a CDF of aggregate interference from LTE uplink transmissions for all sectors in the simulation, propagated to the victim receiver. In this example, the simulation run with a SATOPS transmission targeting a satellite in a geostationary orbit (GSO) in interference Region 3 produced less aggregate interference than the baseline scenario by about 2dB at the 50th percentile point. In Figure 3-3, the power at each PRB is plotted in Watts, as measured at the victim receiver. The baseline is shown in blue, and overlaps the SATOPS interferer scenario in red. The interferer was in Region 1, and the graph clearly shows that this had an effect on the PRB energy in this region.

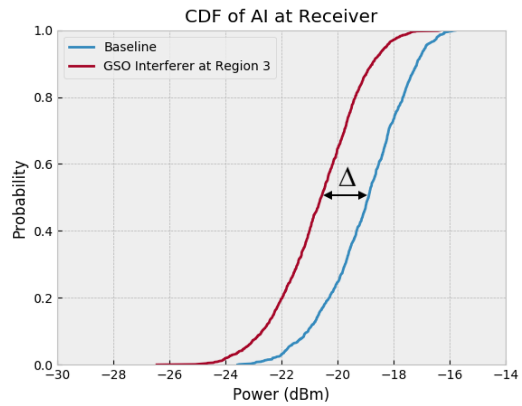


Figure 3-2. Example Comparison of CDFs

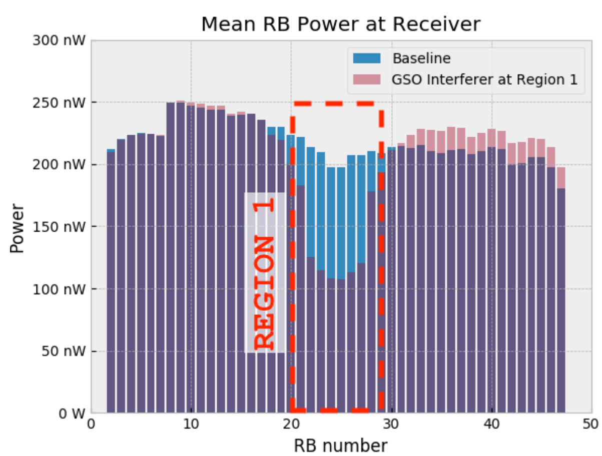


Figure 3-3. Example Comparison of PRB Distributions

3.1.2 Sector-Based Analysis

This study implemented a sector-based analysis by calculating the individual interference contributions originating from each sector in the simulated scenario and summing the contributions to arrive at an aggregate distribution. MITRE collaborated with the Aerospace Corporation to define the scenario, which used Denver, CO as a representative region, as described in Section 3.2. Use of a realistic scenario was important to ensure that the extent of a

SATOPS transmitter impact is based on a plausible radiation footprint. Aerospace performed analysis to predict the interference incident on each of the LTE sectors in the Denver scenario, and MULE used this data to emulate the response of the sectors to this energy, specifically the change in the NL and EIRP variables in the aggregate interference equation. The Aerospace analysis provided the receiver interference power at every sector in the simulation, given a real SATOPS uplink transmission scenario.

The analysis consisted of three parts:

1. Aerospace prediction of SATOPS interference (in dBm) on cell sectors in the Denver area
2. MULE emulation of these SATOPS-impacted LTE sectors
3. Differential Monte Carlo simulation to predict aggregate interference at a hypothetical receiver.

A system-level overview of the simulation process is shown in Figure 3-4. Sections 3.2 to 3.4 present an in-depth description of the scenario and the analysis processes used.

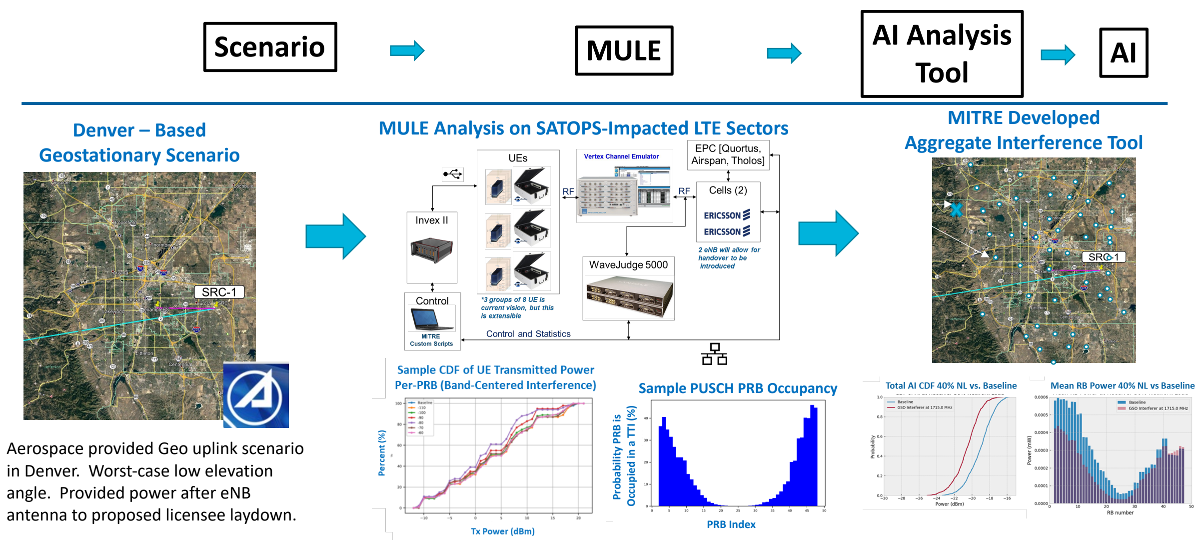


Figure 3-4. Overall Simulation Structure

3.1.3 Monte Carlo Calculation

This study used a stochastic Monte Carlo simulation (see Figure 3-5) to arrive at an estimate for a final aggregate interference distribution. Because the underlying factors behind UE-radiated EIRP are not deterministic, a stochastic simulation was more practical and informative than a deterministic approach. The aggregate distribution was calculated as the sum of all individual sector EIRP distributions as they are received at the victim receiver. Producing one sample for the aggregate distribution required MITRE to draw one sample from each sector, subtract the path loss between the sector tower base and the victim receiver, and then sum all of these samples. MITRE repeated this summation until enough samples were drawn to derive a distribution for the aggregate. While usually 10,000 samples are enough to define a good distribution, this number is arbitrary, and is ultimately the choice of the implementer. In this simulation, as few as 1,000 aggregate samples could produce a satisfactory final distribution, as each sample is already a weighted sum of thousands of similarly distributed random variables.

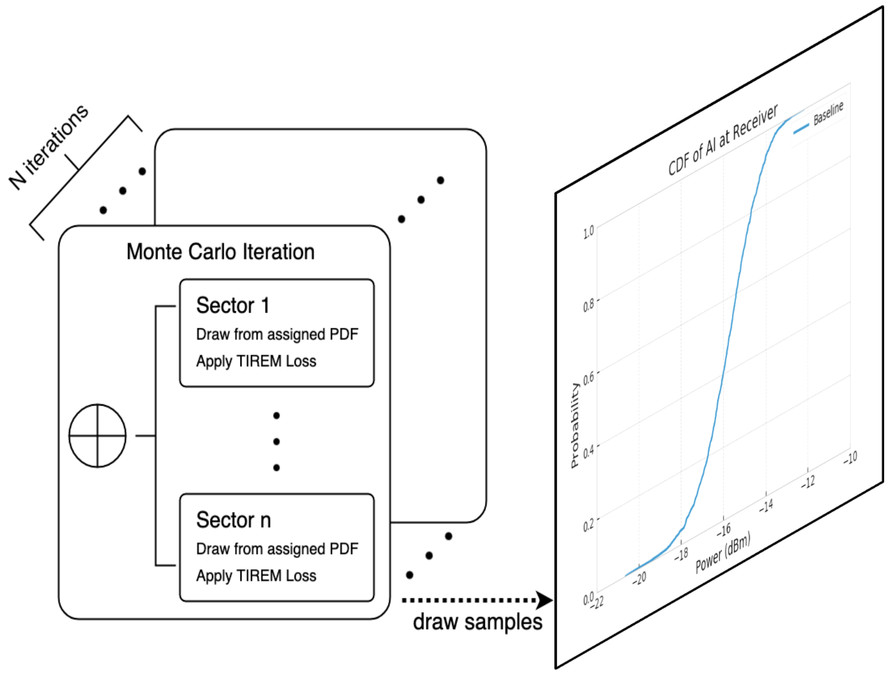


Figure 3-5. Monte Carlo Simulation

3.1.4 MULE Testbed

MITRE used MULE to model Physical Uplink Shared Channel (PUSCH) transmission, specifically emulating an LTE sector and defining a distribution of PUSCH power by taking samples of the reported transmit power from the UE chipset logs. MULE is a testbed consisting of UEs connected through an attenuator board to an RF network capable of connecting to two evolved Node Bs (eNBs) and was designed to emulate the behavior of many real UEs in an LTE Band 66 network. MULE utilizes a commercial-grade Band 66 (AWS-3) downlink radio head (evolved Node B, or eNB) and 24 commercial off-the-shelf handsets that can be independently placed in the sector between the UE and eNB using Third Generation Partnership Project (3GPP) channel models. For realism, UEs and the eNB scheduler in the MULE environment behave similarly to field-deployed equipment under equivalent loading and interference conditions. Each UE in the system reports individual transmit power, which MULE uses to analyze the effects of various configurations and data flow profiles. The outputs of the system come from the simultaneous uplink and downlink waveform recordings, protocol recordings, and protocol and chipset recordings made by the chipset diagnostics software. MULE's protocol analyzer records Downlink Control Information Format 0 (DCI0) messages from the Physical Downlink Control Channel (PDCCH). DCI0 specifies the uplink allocation in terms of starting PRB, number of PRBs, and the modulation and coding scheme (MCS). The overall system architecture of MULE is shown in Figure 3-6.

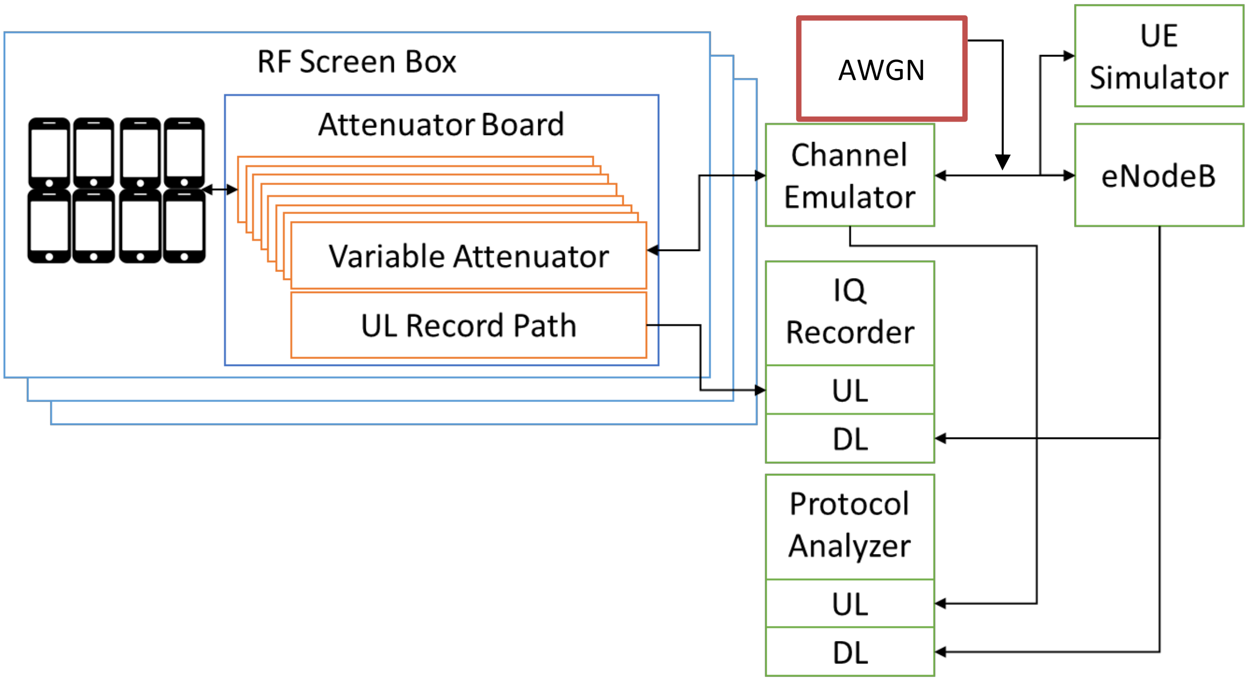


Figure 3-6. MULE Architecture

By varying the UE transmission size and frequency, the RF attenuation, and channel conditions, MULE can approximate a variety of scenarios. The ability to capture UE information via vector signal analyzer (VSA) waveform captures, chipset logs, and RF protocol decoding produces very detailed insight into the behavior of the UEs in the given conditions and can be used to develop a model for the PUSCH transmissions by observing the uplink transmission power directly. This study used configurations where the UE EIRP distribution matched the urban or rural EIRP distributions as presented in the CSMAC working group 3 report[7] as a baseline, and additive white Gaussian noise (AWGN) of varying strengths and spectrum locations was piped into the uplink channel to emulate a SATOPS transmission.

3.2 Denver-based Geostationary Scenario

MITRE and Aerospace chose Denver, CO, as a representative region for the scenario, as it contains both SATOPS and other DoD operations against which CRs are evaluated. MITRE and Aerospace used CRs for a particular major MNO for the interference evaluation; these CRs are not included in this report due to non-disclosure restrictions.

Using deployment plans provided by AWS-3 licensees for base stations in coordination zones around US91 SATOPS sites, Aerospace used its Early Entry Portal Analysis Capability (EEPAC) to estimate worst-case interference from SATOPS sites at each base station. A worst-case impact was created using transmit scenarios with low elevation angles to maximize the footprint of the beam on the LTE deployment.

Aerospace calculated the interference incident on each cell tower in the Denver deployment using antenna patterns, heights and bearings from both the SATOPS earth station and of the eNBs in the Denver deployment, along with a rough terrain model. Aerospace calculated the

[7] https://www.ntia.doc.gov/files/ntia/Working_Group_3_Final.pdf

interference for a variety of transmit scenarios, which would change the azimuth and elevation angles of the SATOPS parabolic dish antenna relative to the LTE deployment, but all other factors would remain the same. The output of this analysis for each scenario was a received interference power from the SATOPS transmitter in dBm for each cell sector in the deployment at the eNB antenna port. That is, this interference power accounts for the gain pattern and bearing of the eNB receive antenna. Specific details on the parameters used for the Aerospace analysis are provided in Appendix A.

Figure 3-7 and Figure 3-8 illustrate the scenario selected for the simulation. The location of the GSO satellite in the sky is shown in cyan in under the label "GSO_10degEl" in Figure 3-7. In addition, the figure shows the location and path of the non-geostationary (NGSO) satellite that Aerospace also simulated. The cyan beam in Figure 3-8 shows the bearing of the SATOPS beam pointing at a GSO satellite low on the horizon (the beam originates from the uplink site on the right and points left over Denver). Aerospace and MITRE selected the GSO as opposed to the NGSO scenario because the beam covers a significant number of busy sectors in Denver, because of the high transmit power required to reach the GSO satellite, and because the low elevation angle would be constantly sustained as the GSO satellite is at a fixed position relative to the ground.

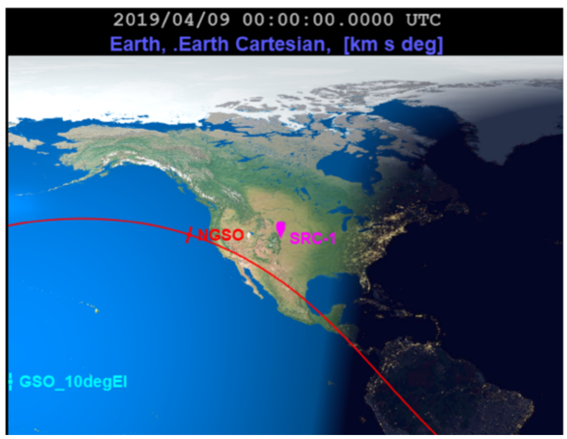


Figure 3-7. Aerospace NGSO and GSO Locations

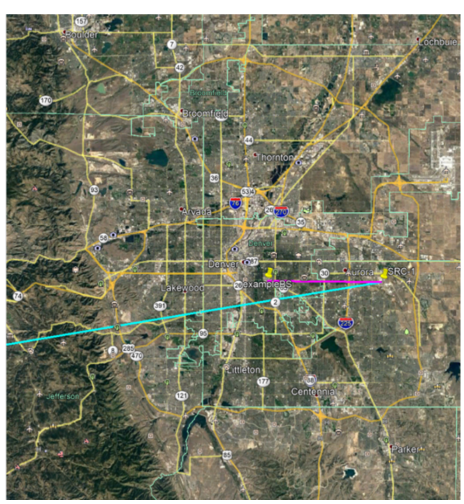


Figure 3-8. Aerospace Model Tx Antenna Bearing

To consider worst-case conditions, the location of the modeled receiver in the aggregate interference computation was chosen as 15,000 feet above the sector most impacted by SATOPS uplink interference. Because the most impacted sectors will also contribute the most to aggregate interference, a receiver at this location will display the largest change in aggregate interference if the UEs in these sectors change the amount of power they emit.

3.3 LTE Sector Modeling

Current AITs utilize the CSMAC 2012 EIRP curve and emission morphologies. MITRE used MULE to demonstrate that the sector emission CDF is closely related to the Reference Signal Received Power (RSRP) distribution of transmitting UEs in the cell sector. MITRE chose to control the transmit power in MULE by selecting an RSRP distribution using a power control equation that reproduced the CSMAC EIRP distribution in both urban and rural morphologies.

3.3.1 UE Laydown

MULE created the EIRP distributions used in simulation by emulating UE laydown distribution. RSRP values were determined by calculating the path loss between the UE and the base station. In selecting an attenuation that would result in the desired RSRP at the UE, MULE placed the UE in a virtual “location” relative to the base station with a path loss equal to the selected attenuation. The process of matching an EIRP distribution (such as the CSMAC CDF) in essence created a path loss distribution among the UEs under test that was similar to the scenario from which the EIRP curve was derived. Thus, in matching the urban and rural CSMAC CDFs in MULE, MITRE recreated UE RSRP distributions characteristic of the laydown and channel conditions of the urban and rural morphologies using the same assumptions as CSMAC. These distributions were the foundation of the Monte Carlo simulation used in the study, and the cell sector responses to a SATOPS interferer were evaluated from a baseline setup that matched the CSMAC assumptions.

The study considered two transmission types: PUSCH and Physical Random-Access Channel (PRACH). MITRE used the MULE testbed to predict PUSCH transmit power and predicted PRACH transmit power via analysis using the methods described in section 3.3.3.

3.3.2 PUSCH Transmission Modeling

The UE emission curves were created directly from MULE output. For every combination of interferer strength and frequency, MULE produced a set of UE grants and transmit powers. Instead of creating a profile for a device in the emulated sector, a distribution was created for the total radiated power for all devices per transmission time interval (TTI), or 1ms. From this large collection of total radiated power per TTI, a continuous probability density function (PDF) was fit using a Gaussian kernel density estimate (KDE). This facilitated more efficient storage and resampling of the distributions, as well as smoothing. Figure 3-9 shows an example of a KDE fit overlaid on a histogram of TTI total EIRP.

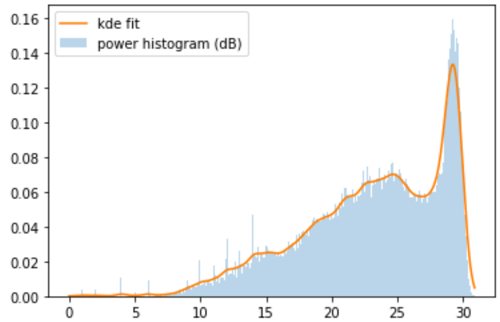


Figure 3-9. Example KDE Fit to Power Histogram

In order to model the sector-wide emissions as a random variable in the Monte Carlo simulation, the continuous PDF was resampled at each sector to approximate the total power in the PUSCH of that sector.

3.3.3 PRACH Transmission Modeling

If the SATOPS interferer is strong enough, it may disconnect a significant number of UEs in a sector. Upon being disconnected, these UEs will begin PRACH transmissions of increasing power as they search for the nearest cell tower. The PRACH power will ramp up the longer the UE is disconnected, and as these transmissions are not scheduled this could increase the number of UEs transmitting in one TTI. MITRE calculated the PRACH power for a UE transmitting as follows:

```
preamble_received_target_power = -104
                                  + delta_preamble
                                  + (preamble_transmission_counter - 1)* power_ramping_step

path_loss = reference_symbol_tx_power - RSRP

p_prach = min(preamble_received_target_power + path_loss, 23)
```

To determine the contribution of PRACH transmissions in a sector to that sector's overall aggregate interference, MITRE assumed that every UE in the cell attempting PRACH would draw power as calculated with this method. The number of UEs attempting PRACH depends on the amount of interference energy in the cell, as well as on the RSRP distributions, which are assigned according to Table 3-1. This study modeled transmission on a per-UE basis (as opposed to applying a resource grid model) because these transmissions are not scheduled by the base station.

Table 3-1. PRACH Model RSRP Probability Distribution

RSRP (dBm)	Probability
–140	0.06
–132	0.67
–128	0.06

–122	0.08
–116	0.06
–110	0.04
–104	0.03

3.3.4 Assignment of UE Emission Curve from Aerospace Calculations

In order to draw EIRP samples from the sectors under test during the simulation, MITRE matched the sectors to their corresponding MULE runs for the given scenario. Every sector sample from the baseline MULE run, without any interferer, is shown as a blue dashed curve in Figure 3-10. To simulate the SATOPS scenario, Aerospace calculated the harm caused to a receiver by the SATOPS uplink for every sector in the simulation. To ensure the result represented a worst-case scenario, MITRE assigned the distributions by rounding up to the nearest interference power that was emulated by the MULE run. For example, if the interference power were swept in increments of 5dBm in a MULE test, a sector that receives –103dBm of power from the SATOPS uplink would draw from a distribution collected under an interference power of –100dBm instead of –105dBm. Figure 3-10 illustrates the distribution assignment process. The assigned baseline EIRP CDF for each sector is shown as a blue dashed line, and the assigned "with interference" curve is shown as a solid colored line.

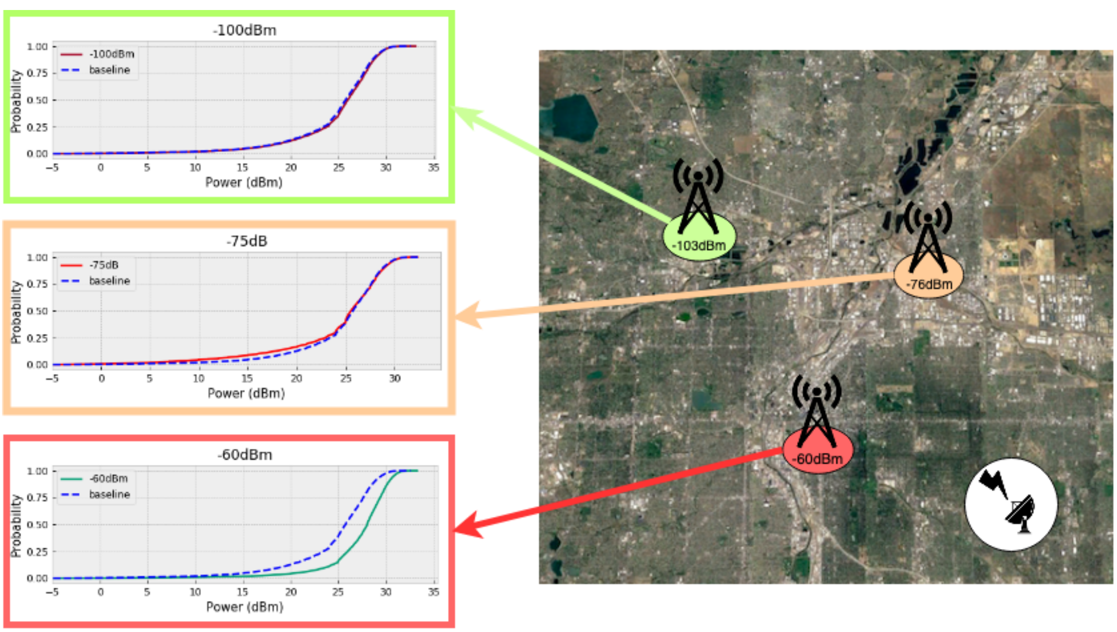


Figure 3-10. Illustration of Power Distribution Assignment from SATOPS Power

3.4 Propagation Modeling

3.4.1 Assumptions on UE Location

In the aggregate interference calculation, all UE transmissions are propagated from the tower base of the sector to which they are attached. This decision is appropriate because, first, the receiver is at a considerable distance from the UE (typically at 15,000 feet elevation and multiple miles away over the ground). Second, the simulation does not calculate power based on attached UEs, but rather samples a distribution of total EIRP of all devices per sector; thus, it is not necessary to model individual UEs to calculate the transmit power. Last, the position of UEs is not affected by the SATOPS transmission, so even if small variations in UE location would affect the aggregate, they would have no effect on the differential between the SATOPS scenario and the baseline, and thus were not a concern in this study.

3.4.2 Path Loss Calculation

MITRE calculated the path loss between the transmitter and receiver using real digital terrain elevation data (DTED) acquired from the United States Geological Survey (USGS) and the Terrain Integrated Rough Earth Model (TIREM) path loss model. For every tower, 1000 elevation samples were taken from the USGS 1 arc-second elevation collection between the transmitter and receiver. In Figure 3-11, a path is traced between the transmitter and receiver on an elevation raster image created from the USGS data using a geospatial information system (GIS) tool. In Figure 3-12, the elevation of the same path is plotted as height above mean sea level (MSL) as a function of Great Circle distance from the transmitter. This data is provided to the TIREM function along with information on the transmitter (height, frequency, antenna polarization), the receiver (height), atmospheric constants (surface refractivity, humidity), and ground constants (relative permittivity, conductivity) (Source: TIREM Handbook). The receiver height depends on the elevation of the DoD asset in the modeled scenario. All other values used in this study, along with their sources, are provided in Table 3-2. Because the study's primary concern was the change in the total energy arriving at the receiver location, and not the specific response of a receiver antenna with a particular pattern and orientation, this simulation used an omnidirectional receiver with a gain of 0dB in all directions.

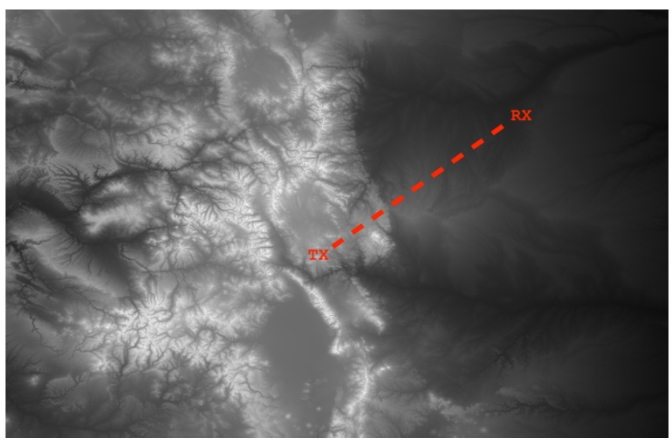


Figure 3-11. Example Path on USGS DTED Data

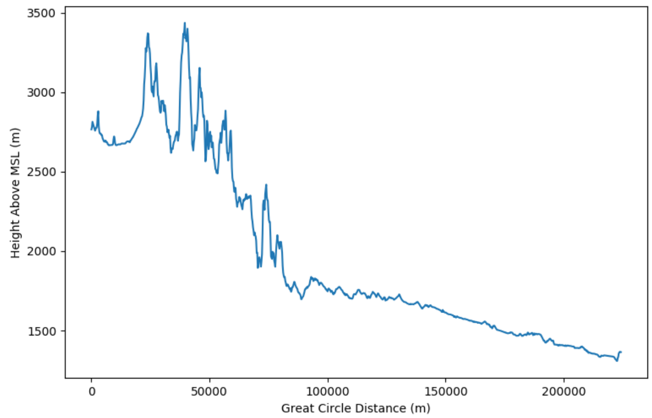


Figure 3-12. Height above MSL vs. Great Circle Distance

Table 3-2. Simulation Constants Used with TIREM

Parameter	**Value (unit)**	**Source**
Relative Permittivity	15	ITS
Conductivity	0.005 (S/m)	ITS
Refractivity	301 (N-units)	ITS
Humidity	5.1 (g/m^3)	NOAA (Co. Springs avg.)
Polarization	Vertical	Terra-Wave Spec
Frequency	1760 (MHz)	FCC AWS-3 Auction

4 MULE Functions and Outputs

4.1 MULE Configuration

4.1.1 RSRP

To establish a baseline consistent with previous AIT modeling conventions, MITRE configured the MULE attenuator board such that the RSRP distribution of the connected UEs produced an EIRP distribution that matched the 2012 CSMAC study used in other tools. The CSMAC report includes EIRP distributions for both urban and rural morphologies, and MITRE conducted MULE baseline runs to match both.

4.1.2 Channel Modeling

MITRE used two channel configurations in the MULE runs for this study:

1. Static channel (direct conduction, no dynamic channel emulation)
2. 3GPP EVA 70Hz (UEs connect to eNB through a channel emulator).

4.1.3 Network Throughput

The UEs attached to the eNB transmitted on the uplink (UL) channel using ping scripts with a fixed packet size and fixed delay between packets. The delay was changed between runs to set the throughput for the run, targeting a certain network load. The LTE resource utilization is not a parameter that can be directly set because the required PRB to reach a certain throughput depends on the MCS for the UE and potentially additional padding depending on the packet size.

4.2 MULE Output

MULE run recorded extensive logs of UE activity in the form of DCI0 protocol decode logs and logs directly from the UE chipset. MULE generated a PDF report automatically from this data so that the details of every run could be analyzed in detail.

4.2.1 MULE Report

For each run, the report included the cell parameters (p0 and alpha), RSRP and channel model for each UE, histograms for MCS, total PRBs and active UEs per subframe, PRB occupancy distribution, time series charts for RSRP, active PRBs and throughput, and CDFs of total transmit (Tx) power and per-PRB Tx power. For a MULE study with over 100 tests such as this experiment, this report could be over 1000 pages long.

4.2.2 Example Output

This section shows examples of the output charts for one MULE test. A typical run consisted of up to 100 test configurations depending on the scenario, with each run having its own set of charts included in the report. The test configuration in this example used a static channel model and no external interference.

Figure 4-1 is an example of a time-series RSRP plot for each individual UE throughout one test. Each UE is identified by its color in the legend under the graph. In this case, the RSRPs were assigned to each UE such that they produced regular samples of the CSMAC Tx power CDF.

The RSRP values remain constant throughout the test because no stochastic channel model is used, so the loss between the UE and the eNB remains constant through the whole test.

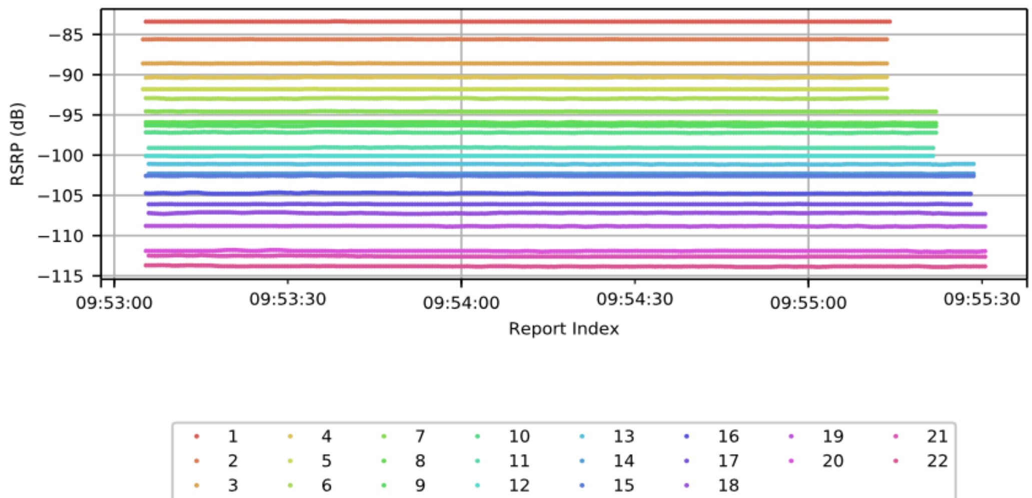


Figure 4-1. Reported RSRP per UE Rolling Average

Figure 4-2 is a histogram of the MCS of each transmission broken down per UE. The UEs can be identified by color using the legend at the bottom of the graph. The UE numbering remained consistent across all the plots in the test; in other words, UE 1 is the same device in all plots broken down by device number in the test.

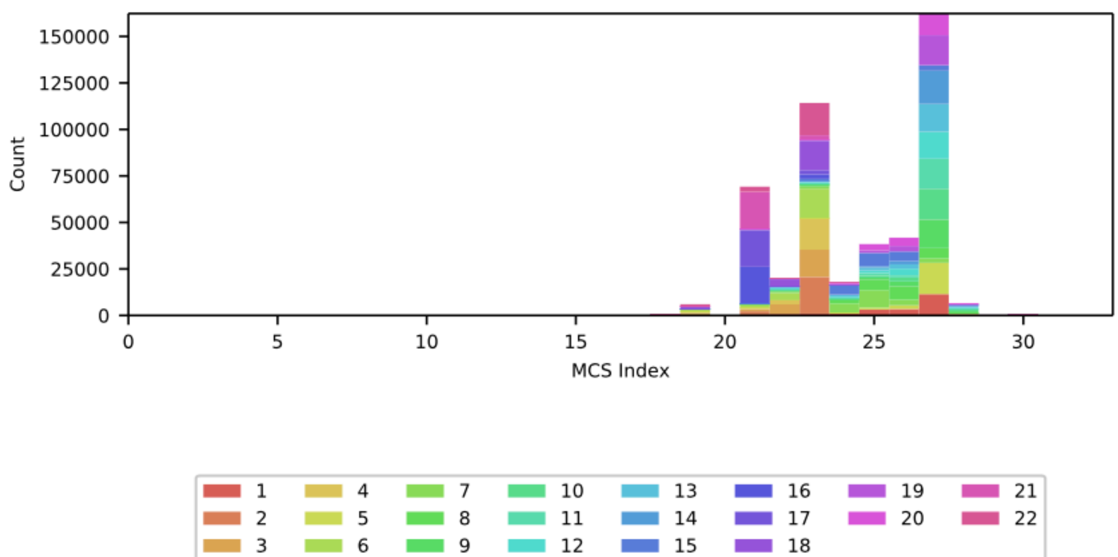


Figure 4-2. MCS Histogram per UE

Figure 4-3 is a histogram of the total allocated PRBs per subframe throughout the test. This count spanned all allocations for all devices in each subframe. This is an important metric for quantifying the network load in a test, which is often calculated as PRB occupancy, or the percentage of PRBs allocated out of the total possible.

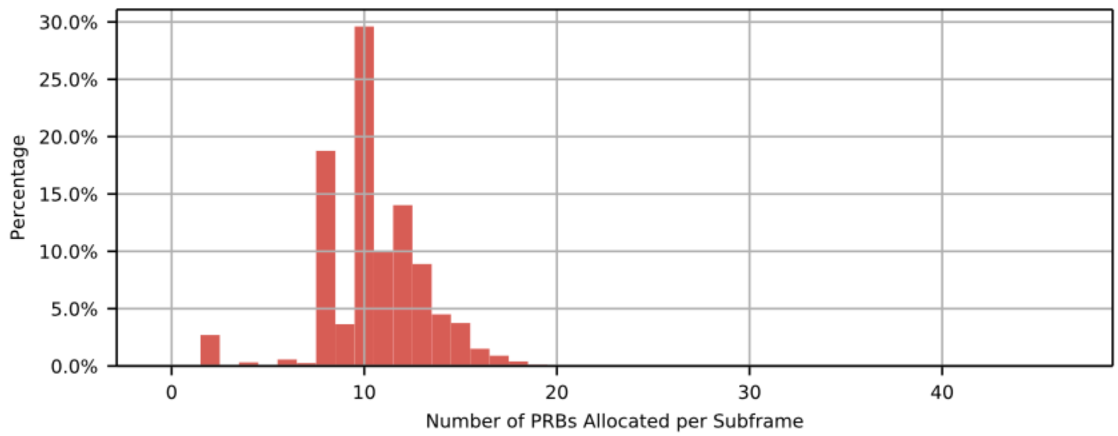


Figure 4-3. Total PRBs per Subframe Histogram

Figure 4-4 is a histogram of the active UEs per subframe. This is a count of the total number of UEs assigned grants during each subframe of the test, without taking into account the number of PRBs in each grant.

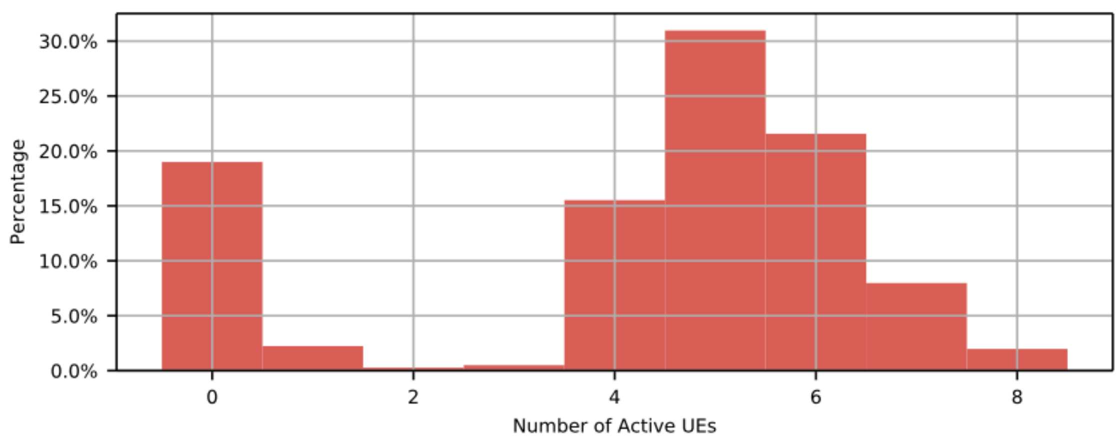


Figure 4-4. Active UEs per Subframe Histogram

Figure 4-5 is a time-series plot of the average number of PRBs allocated per subframe using a 1s rolling average. Because there are often subframes with zero allocations, this plot gives a much better picture of the load on the network throughout the test.

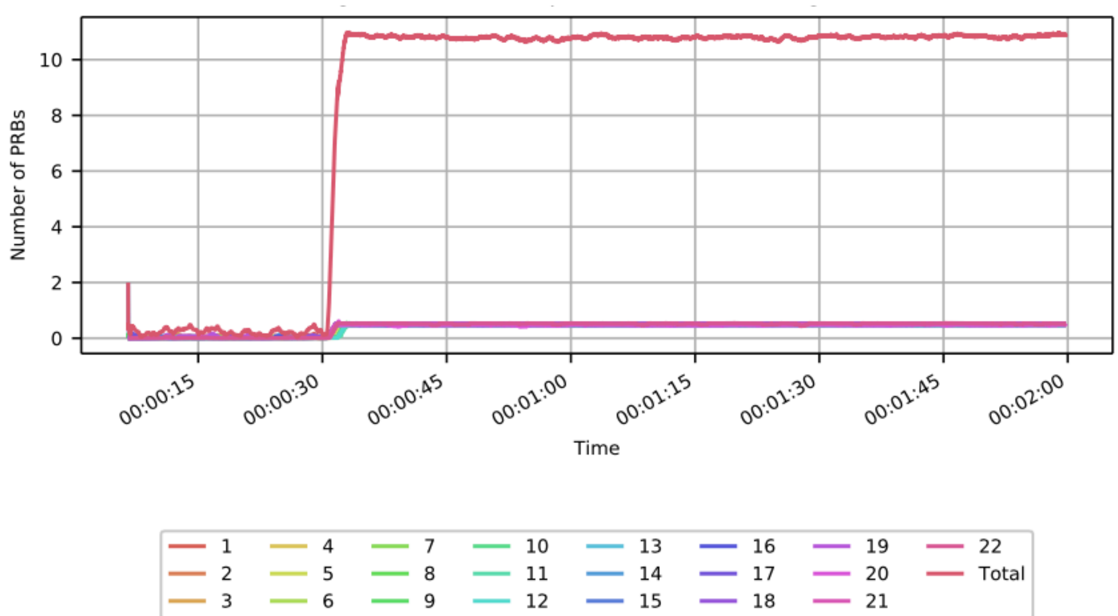


Figure 4-5. Average Number of PRBs per Subframe 1s Rolling Window

Figure 4-6 shows a histogram of the percentage probability of each UL channel PRB being allocated during the test. This metric gives important insight into the scheduler that the eNB used, as well as the power spectrum of the total interference radiated from the sector being emulated.

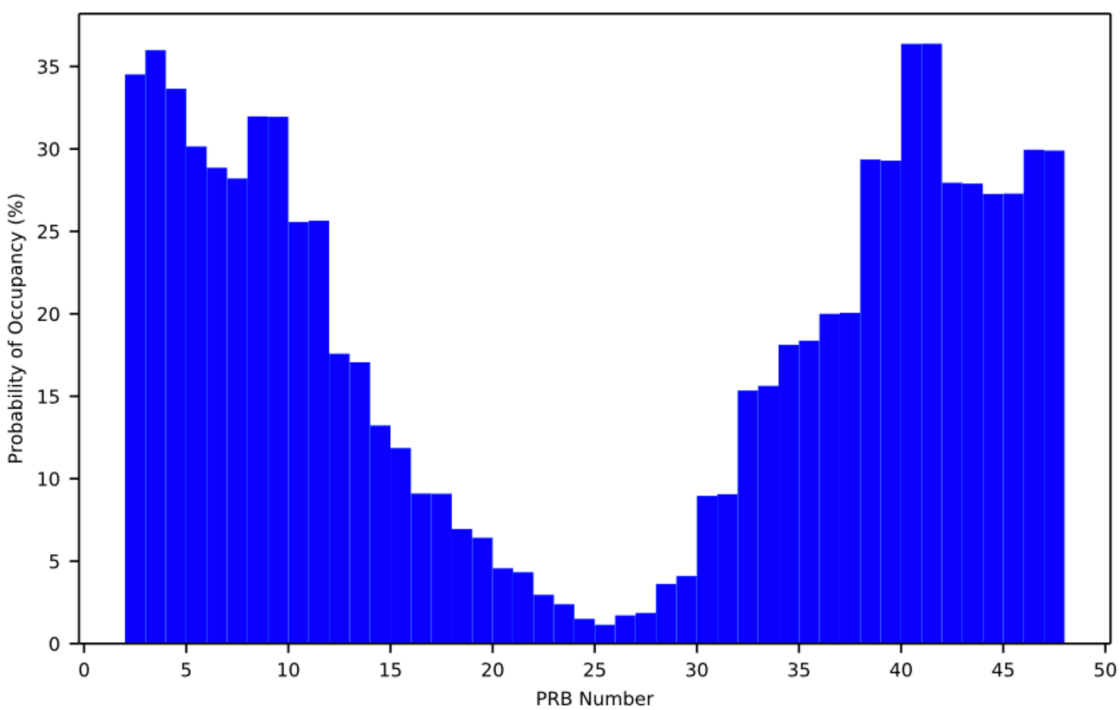


Figure 4-6. UL Grant PRB Occupancy Probability

Figure 4-7 shows CDFs of the reported Tx power per PRB for each individual UE, as well as the typical curve for all grants in the test. Breaking the Tx power down by PRB allowed MITRE to assess the Tx power during the test due to channel conditions independently from the influence of grant size and frequency.

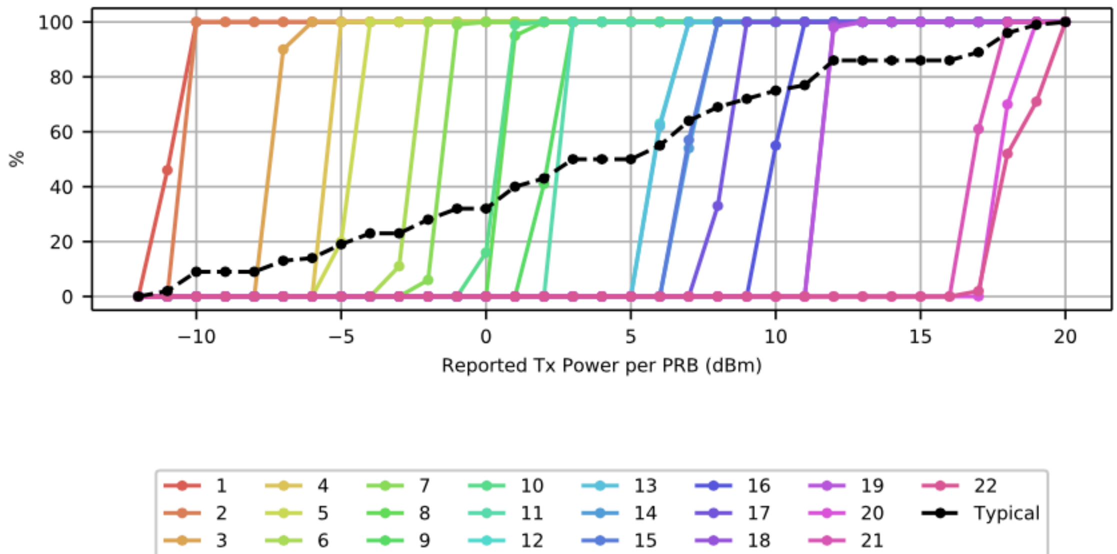


Figure 4-7. PUSCH Reported Tx Power per PRB CDF

Figure 4-8 also depicts per-UE CDFs of reported Tx power; however, these are reported for the entire grant, not by PRB. The typical curve, then, is the CDF of total Tx power across all devices in the sector per subframe. This CDF is the distribution that is sampled to generate the aggregate interference contributions of each sector in the simulation.

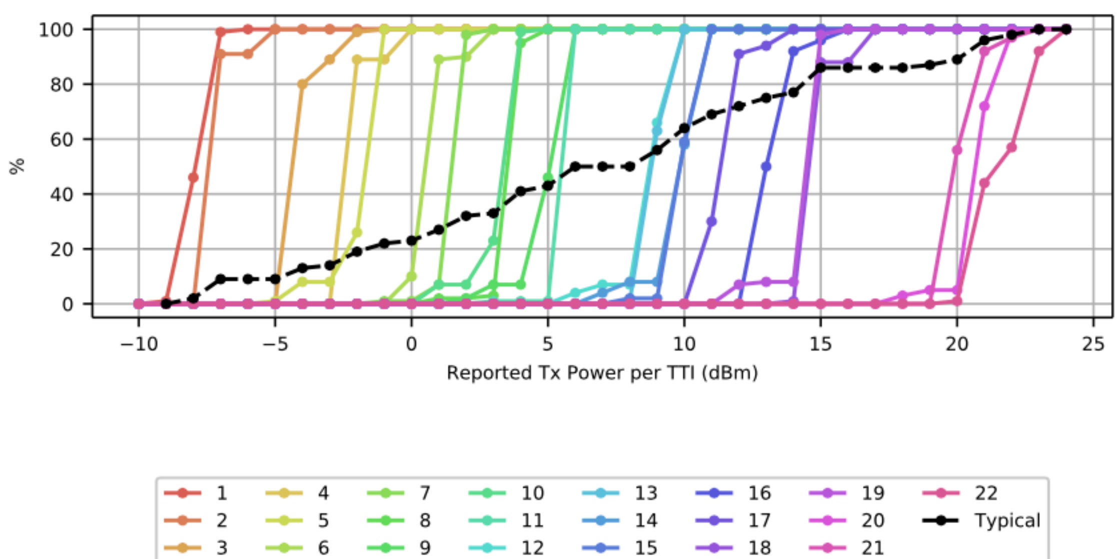


Figure 4-8. PUSCH Tx Power CDF

5 Aggregate Interference Results

This section describes the aggregate interference MITRE calculated using MULE.

5.1 Explanation of Results

The products of each MULE run were a pair of CDFs comparing the baseline scenario to the experiment scenario, as well as two PRB power distributions plotting the mean power of each PRB at the victim receiver in both scenarios. In each scenario, the MULE testbed simulated three levels of network activity. The targets for this "network load" were percentages of PRB occupancy (e.g., a 50% network load would have an average of 25 out of 50 PRBs occupied during the run). However, MULE uses ping to simulate uplink traffic, and can only control the ping size and the delay between pings. This does not always produce the same network load because grant size also depends on the MCS and the transmissions contain some padding and other overhead. MITRE also used two different models for the uplink channel, a static channel, where the UEs were connected directly to the eNB through an attenuator board, and a emulated channel, where the UEs are connected through a channel emulator. The model used by the channel emulated was the 3GPP Extended Vehicular A (EVA) with 70Hz of doppler shift. The MULE scripting targeted certain loads, but the resulting loads typically were different, and the real loads were reported in the results. Table 5-1 shows what targeted offered loads produced the real loads in each run.

Table 5-1. Offered Load Compared to Actual Observed Load

Offered Load	NL for Static Channel	NL for 3GPP EVA – 70 Hz
15%	25%	45%
30%	40%	55%
50%	50%	75%

The interference injected into the uplink path was 1MHz bandwidth AWGN, In addition, each run tested the response of the system to interference injected at three difference center frequencies, referred to as regions 1, 2, 3 three, which are defined in Table 5-2.

Table 5-2. Interference Frequencies Used

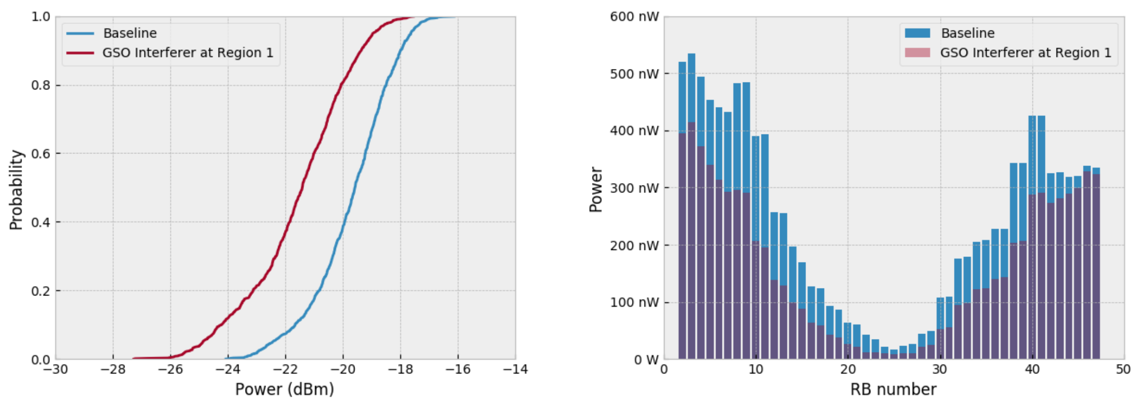
Region Number	Interference Center Frequency
1	1715.0 MHz
2	1716.71 MHz
3	1718.42 MHz

5.2 Static Channel Model

The first trial ran tests replicating a CSMAC-like RSRP distribution with the UEs connected to the base station through a "static channel," or, more simply put, directly connected to the eNB and thus bypassing the channel emulator entirely.

5.2.1 Results

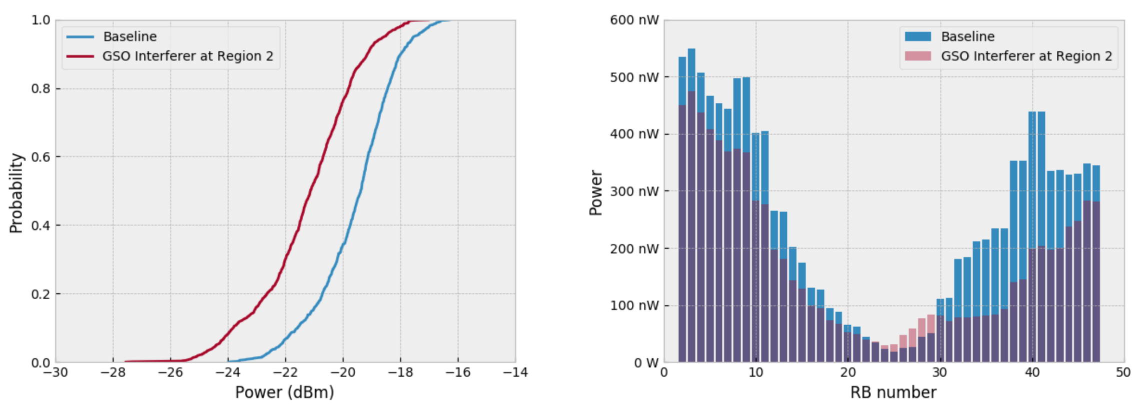
Figure 5-1 through Figure 5-9 present the results for each configuration within this trial. On the left of each figure is a pair of CDFs, the blue representing the aggregate interference from the baseline run and the red representing the run with the SATOPS interferer. On the right is a histogram of the average power per PRB with the same color scheme. Note that these are stacked histograms, and where the bars overlap, they appear purple.



a. Aggregate Interference CDF

b. Average Power By Resource Block

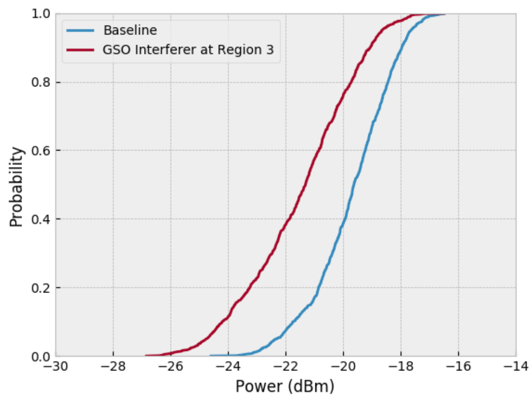
Figure 5-1. Aggregate Interference at DoD Asset 25% Measured Network Loading Static Channel Region 1



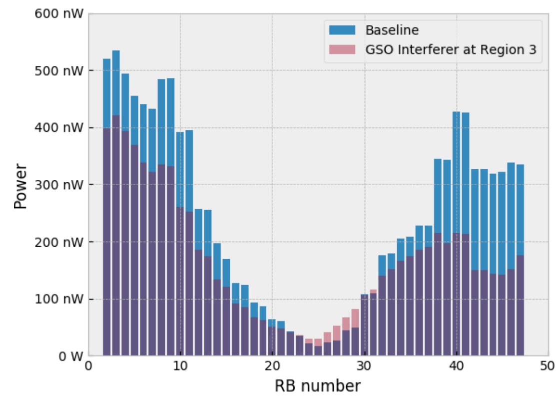
a. Aggregate Interference CDF

b. Average Power By Resource Block

Figure 5-2. Aggregate Interference at DoD Asset 25% Measured Network Loading Static Channel Region 2

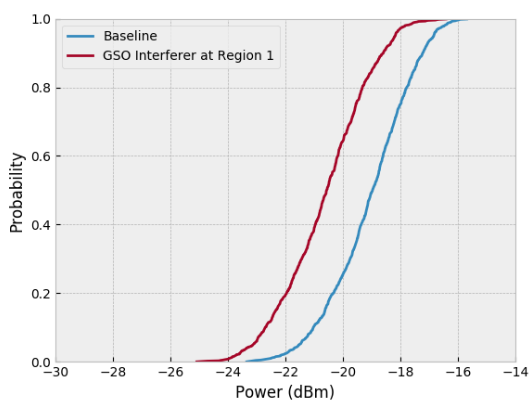


a. Aggregate Interference CDF

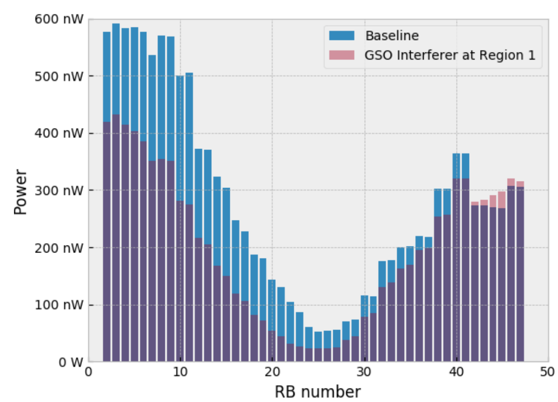


b. Average Power By Resource Block

Figure 5-3. Aggregate Interference at DoD Asset 25% Measured Network Loading Static Channel Region 3

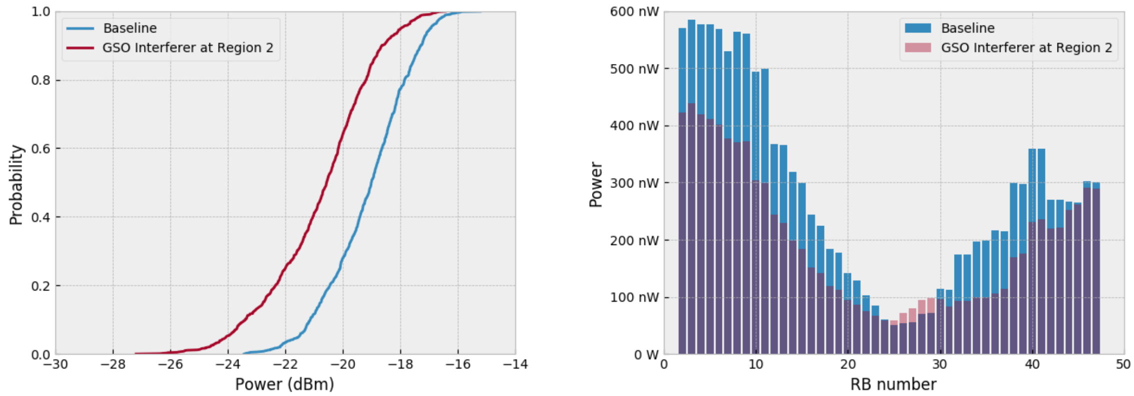


a. Aggregate Interference CDF



b. Average Power By Resource Block

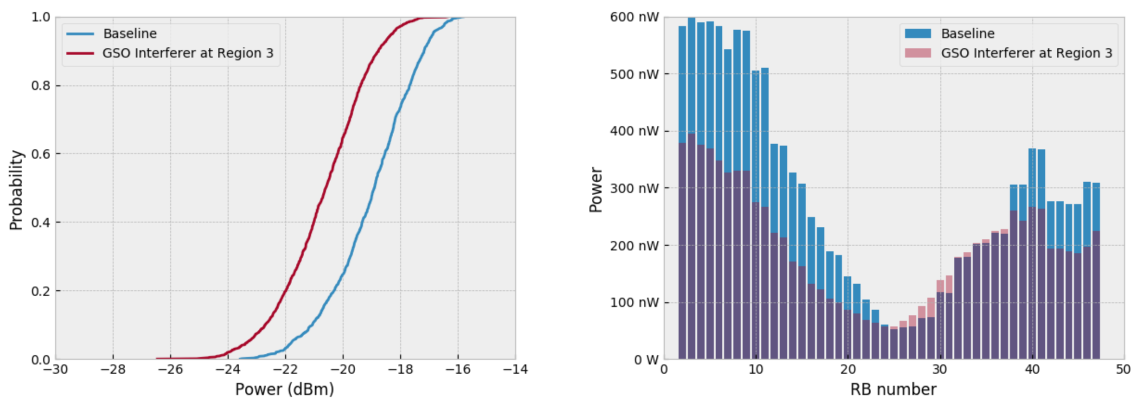
Figure 5-4. Aggregate Interference at DoD Asset 40% Measured Network Loading Static Channel Region 1



a. Aggregate Interference CDF

b. Average Power By Resource Block

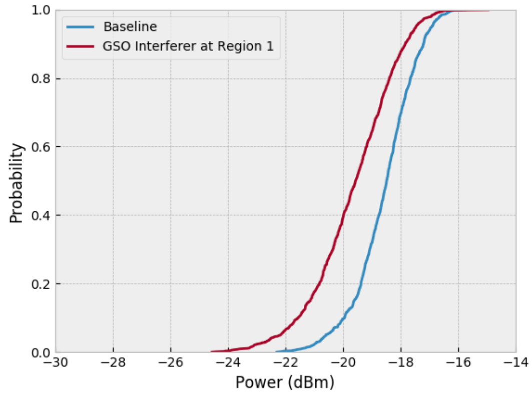
Figure 5-5. Aggregate Interference at DoD Asset 40% Measured Network Loading Static Channel Region 2

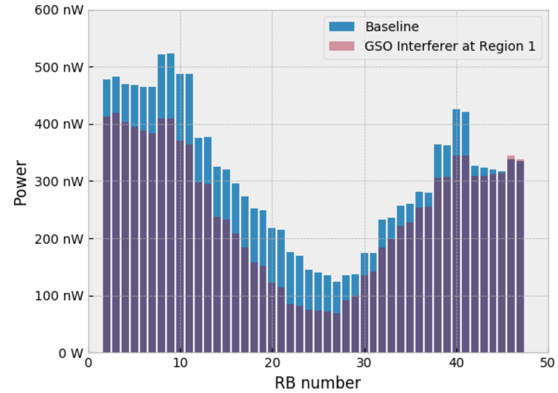


a. Aggregate Interference CDF

b. Average Power By Resource Block

Figure 5-6. Aggregate Interference at DoD Asset 40% Measured Network Loading Static Channel Region 3

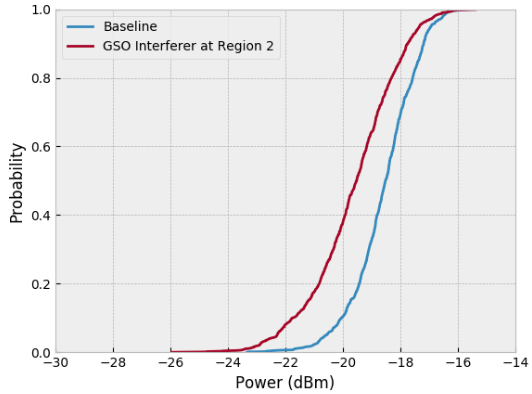


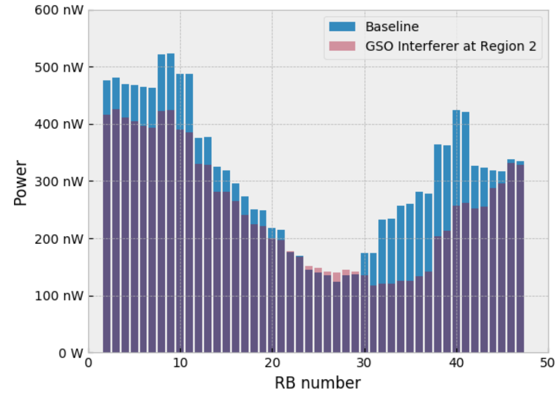


a. Aggregate Interference CDF

b. Average Power By Resource Block

Figure 5-7. Aggregate Interference at DoD Asset 50% Measured Network Loading Static Channel Region 1

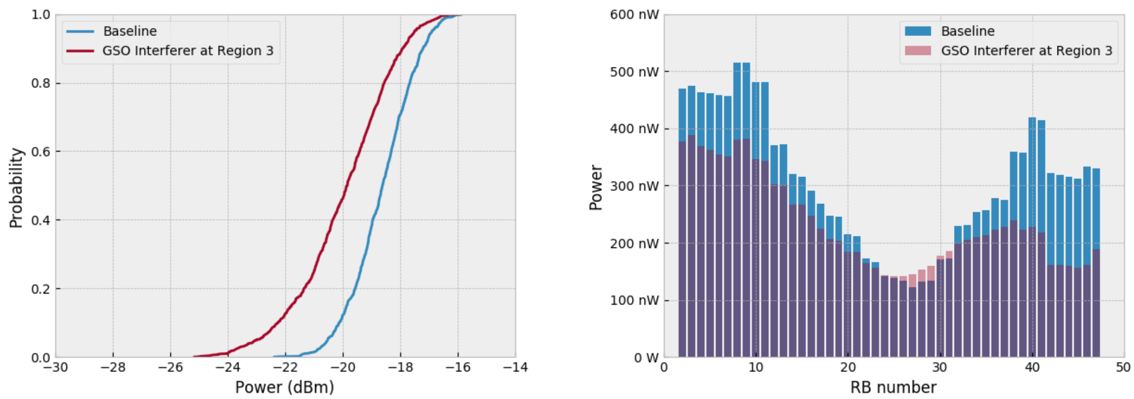




a. Aggregate Interference CDF

b. Average Power By Resource Block

Figure 5-8. Aggregate Interference at DoD Asset 50% Measured Network Loading Static Channel Region 2



a. Aggregate Interference CDF

b. Average Power By Resource Block

Figure 5-9. Aggregate Interference at DoD Asset 50% Measured Network Loading Static Channel Region 3

5.2.2 Discussion

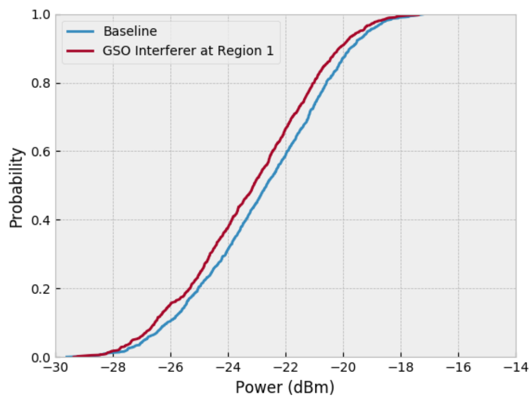
When the channel model was not used, the presence of an interferer in the MULE testbed clearly reduced the aggregate interference in all network loads and interferer regions. The 50th percentile point of the aggregate curve with the SATOPS interferer was at least 1dB lower than the baseline curve in every scenario, the closest pair of curves being the 50% network load in interference Region 2 shown in Figure 5-8. In the higher network load scenarios, the effects of the interference region can be seen quite clearly. In Figure 5-7 through Figure 5-9, the interference region moves from the center of the band to the right edge, and the per-PRB power decreases both inside and outside the interference region as the scheduler avoids the area of the spectrum containing the interferer.

5.3 3GPP EVA – 70Hz Channel – Urban

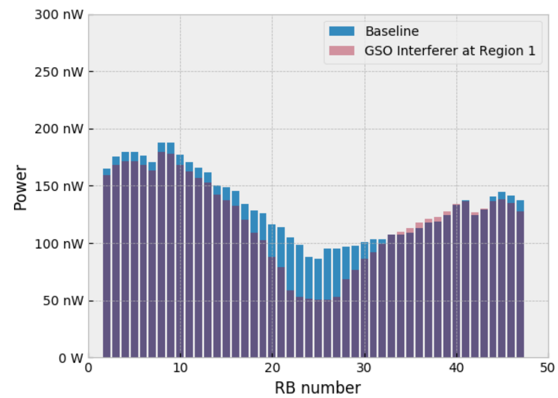
The subsections and figures below present the results for the second trial. The UEs in this trial were connected to the base station through a channel emulator that used the 3GPP EVA model. In addition, the attenuator board was configured such that the UEs measured RSRP values similar to an urban RSRP distribution.

5.3.1 Results

The results for each configuration within this trial are presented in Figure 5-10 through Figure 5-18. The figures follow the same format as those in section 5.2.

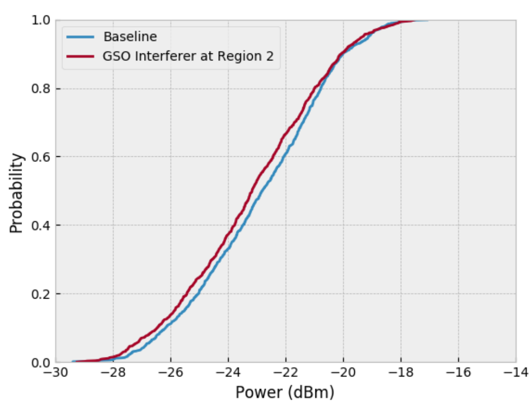


a. Aggregate Interference CDF

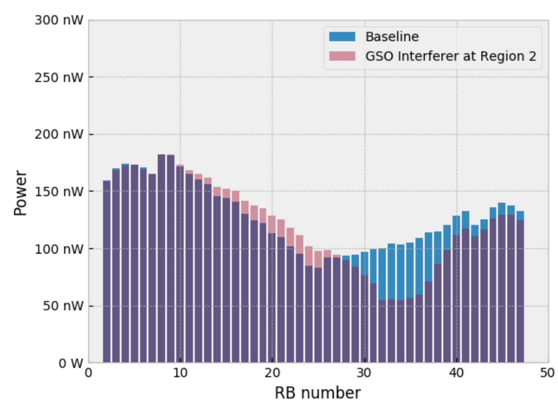


b. Average Power By Resource Block

Figure 5-10. Aggregate Interference at DoD Asset 45% Measured Network Loading 3GPP EVA 70Hz Urban Region 1

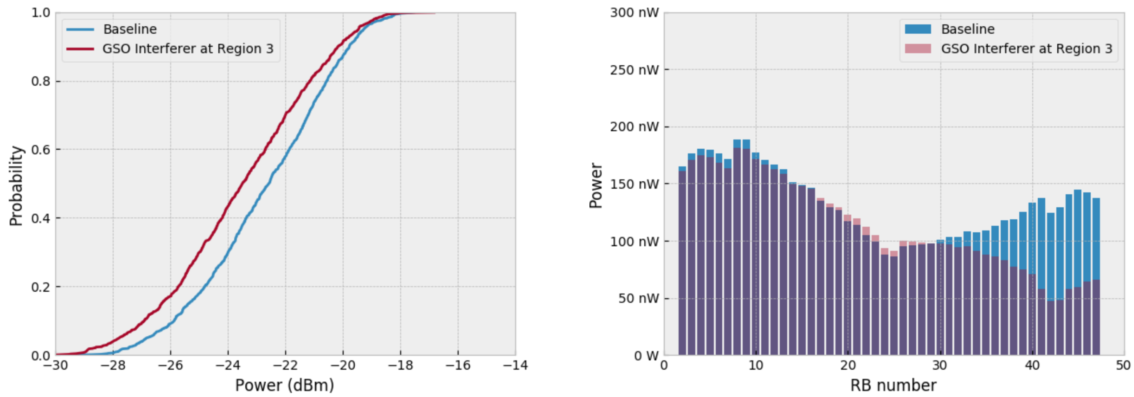


a. Aggregate Interference CDF



b. Average Power By Resource Block

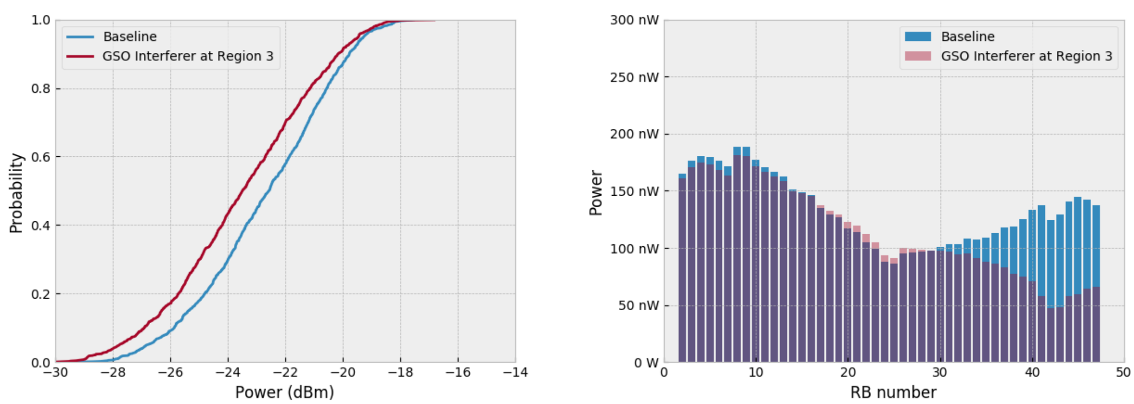
Figure 5-11. Aggregate Interference at DoD Asset 45% Measured Network Loading 3GPP EVA 70Hz Urban Region 2



a. Aggregate Interference CDF

b. Average Power By Resource Block

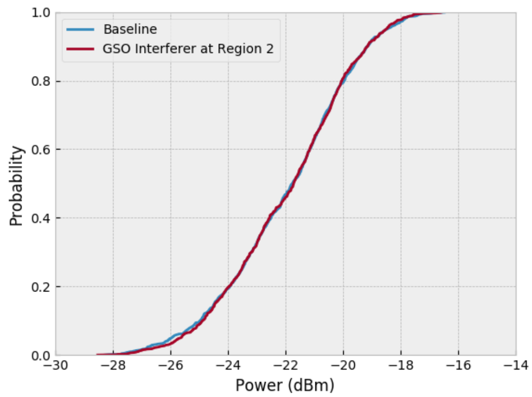
Figure 5-12. Aggregate Interference at DoD Asset 45% Measured Network Loading 3GPP EVA 70Hz Urban Region 3



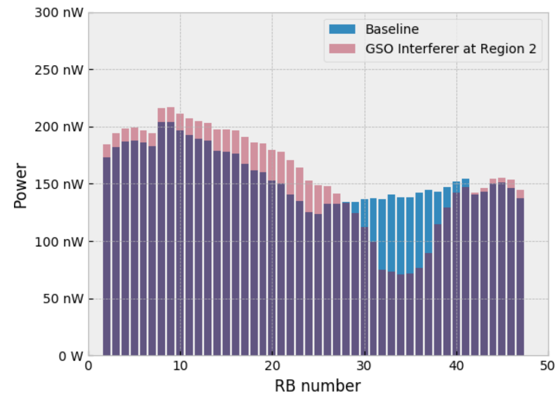
a. Aggregate Interference CDF

b. Average Power By Resource Block

Figure 5-13. Aggregate Interference at DoD Asset 55% Measured Network Loading 3GPP EVA 70Hz Urban Region 1

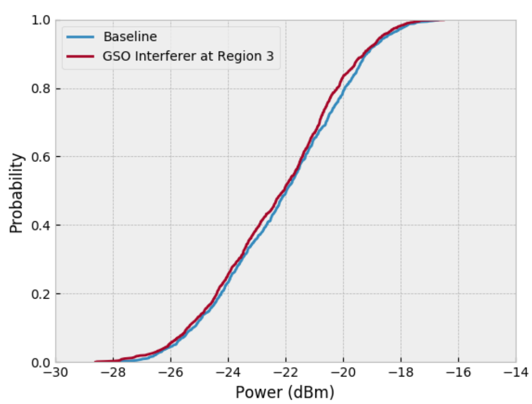


a. Aggregate Interference CDF

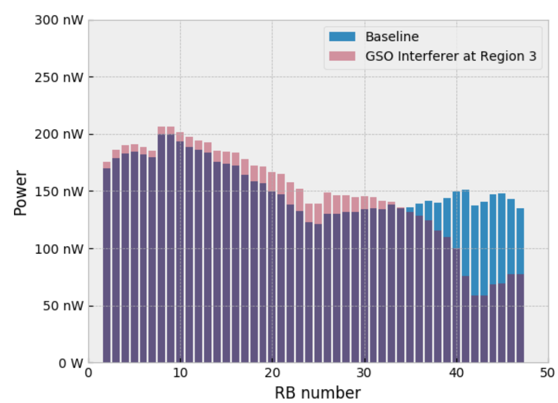


b. Average Power By Resource Block

Figure 5-14. Aggregate Interference at DoD Asset 55% Measured Network Loading 3GPP EVA 70Hz Urban Region 2

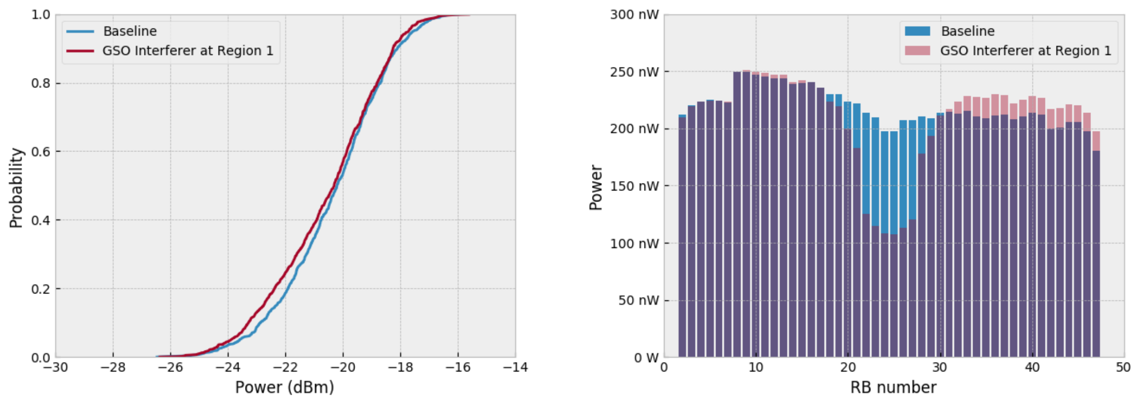


a. Aggregate Interference CDF



b. Average Power By Resource Block

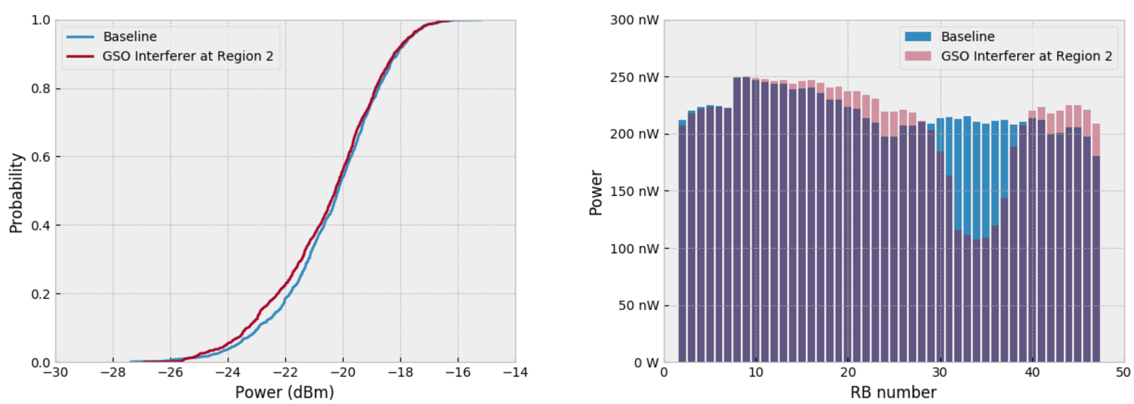
Figure 5-15. Aggregate Interference at DoD Asset 55% Measured Network Loading 3GPP EVA 70Hz Urban Region 3



a. Aggregate Interference CDF

b. Average Power By Resource Block

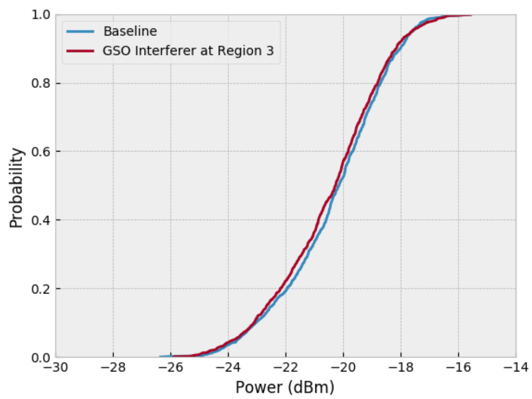
Figure 5-16. Aggregate Interference at DoD Asset 75% Measured Network Loading 3GPP EVA 70Hz Urban Region 1



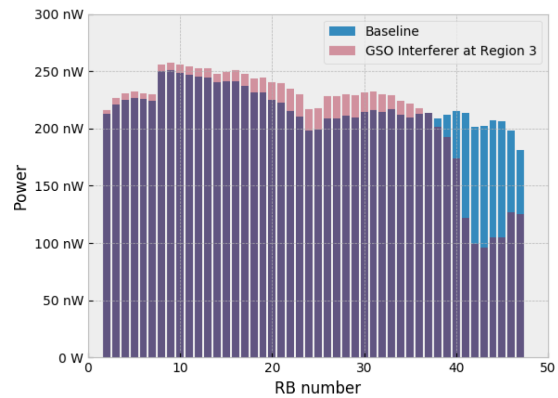
a. Aggregate Interference CDF

b. Average Power By Resource Block

Figure 5-17. Aggregate Interference at DoD Asset 75% Measured Network Loading 3GPP EVA 70Hz Urban Region 2



a. Aggregate Interference CDF



b. Average Power By Resource Block

Figure 5-18. Aggregate Interference at DoD Asset 75% Measured Network Loading 3GPP EVA 70Hz Urban Region 3

5.3.2 Discussion

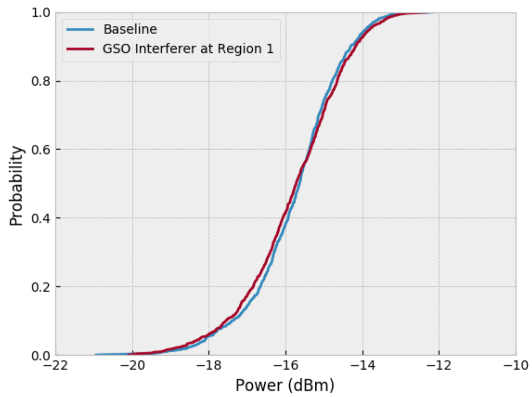
As stated above, in this second trial the path between the UE and the base station included a channel emulator that applied a vehicular channel model with 70Hz of Doppler shift. This emulated channel reduced the scheduler's preference for the edges of the band, thereby increasing the effect of the interferer on PRB allocations. Figure 5-16 through Figure 5-18 show particularly good examples of the interferer driving PRB allocations down within the region of interference, and the scheduler increasing allocations outside the interference region to compensate. In the MULE runs using an urban RSRP distribution, the aggregate interference curves approached each other, but the SATOPS scenario never predicted more aggregate power than the baseline scenario; however, the difference was less than that produced from MULE runs without a channel model.

5.4 3GPP EVA – 70Hz Channel – Rural

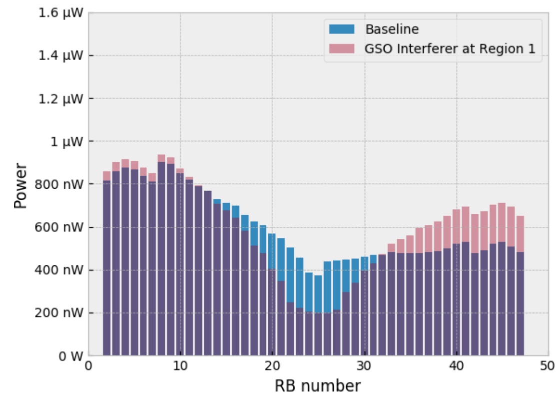
The subsections and figures below present the results for the second trial. The UEs in this trial were connected to the base station through a channel emulator that used the 3GPP EVA model with 70Hz of Doppler shift. In addition, the attenuator board was configured such that the UEs measured RSRP values similar to a rural RSRP distribution.

5.4.1 Results

The results for each configuration within this trial are presented in Figure 5-19 through Figure 5-29. The figures follow the same format as in those in sections 5.2 and 5.3.

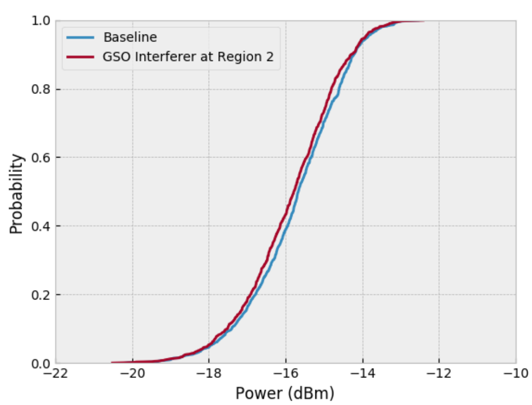


a. Aggregate Interference CDF

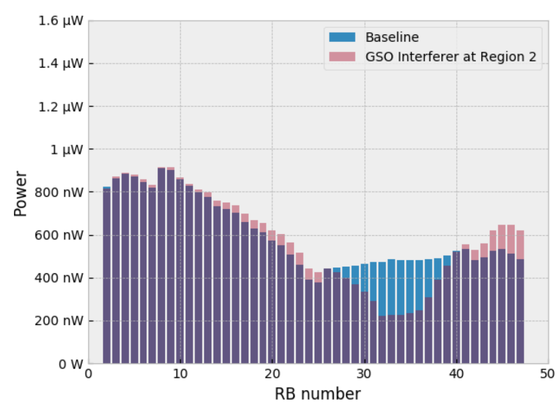


b. Average Power By Resource Block

Figure 5-19. Aggregate Interference at DoD Asset 45% Measured Network Loading 3GPP EVA 70Hz Rural Region 1

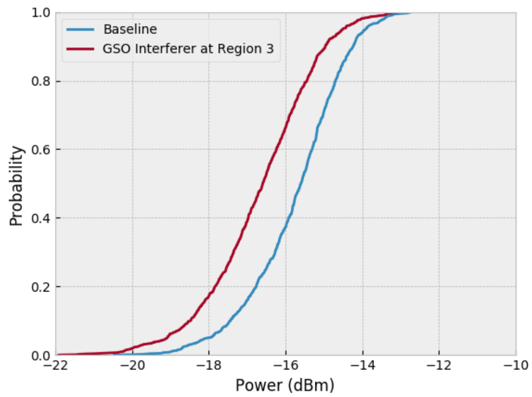


a. Aggregate Interference CDF

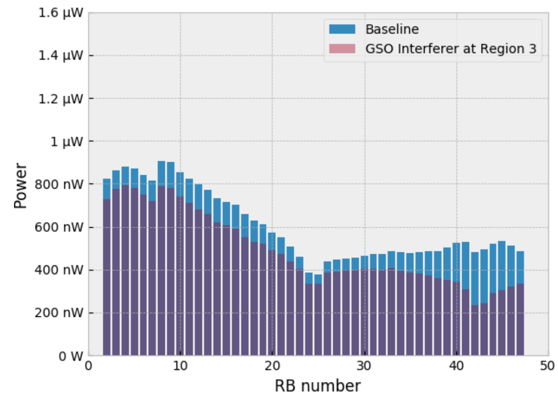


b. Average Power By Resource Block

Figure 5-20. Aggregate Interference at DoD Asset 45% Measured Network Loading 3GPP EVA 70Hz Rural Region 2

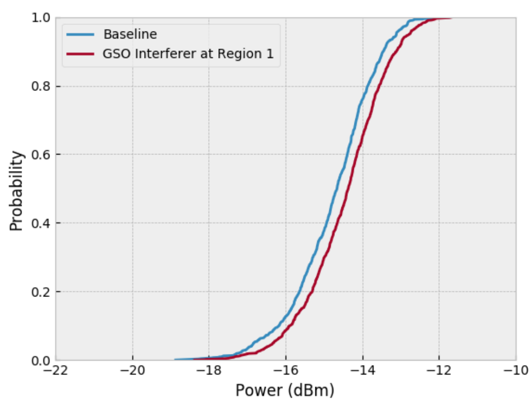


a. Aggregate Interference CDF

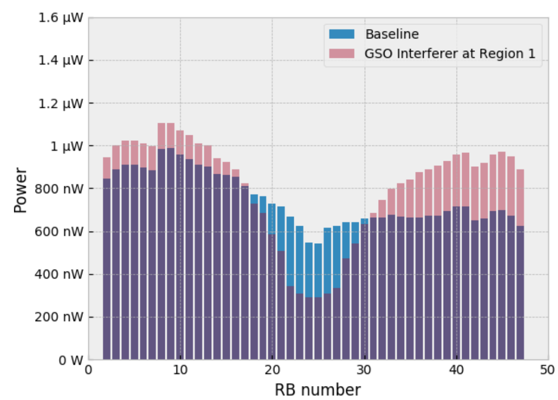


b. Average Power By Resource Block

Figure 5-21. Aggregate Interference at DoD Asset 45% Measured Network Loading 3GPP EVA 70Hz Rural Region 3

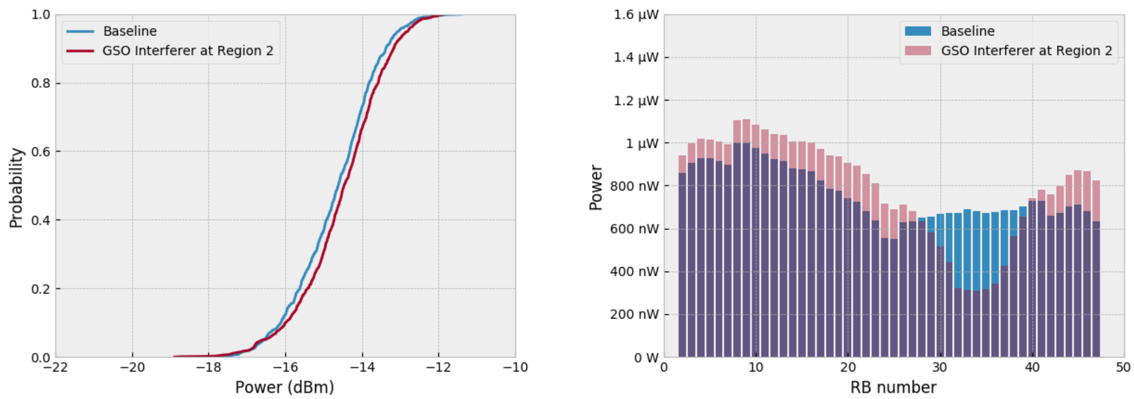


a. Aggregate Interference CDF



b. Average Power By Resource Block

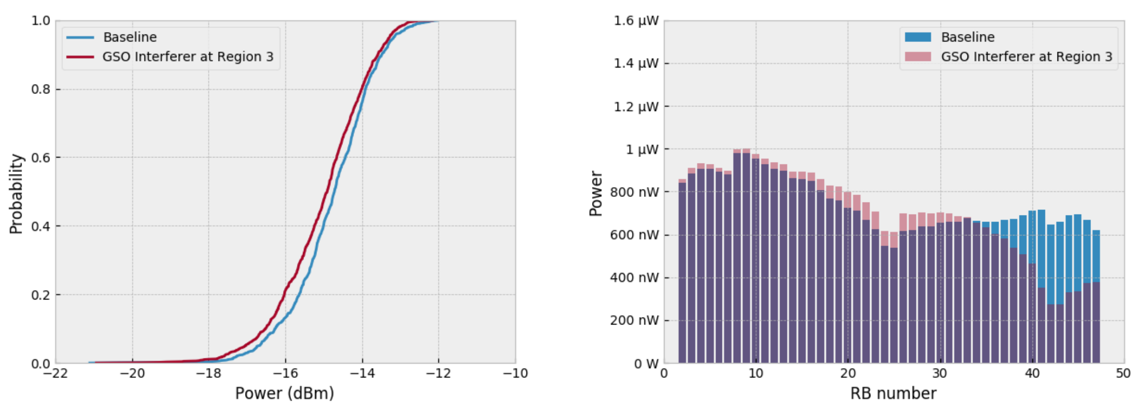
Figure 5-22. Aggregate Interference at DoD Asset 55% Measured Network Loading 3GPP EVA 70Hz Rural Region 1



a. Aggregate Interference CDF

b. Average Power By Resource Block

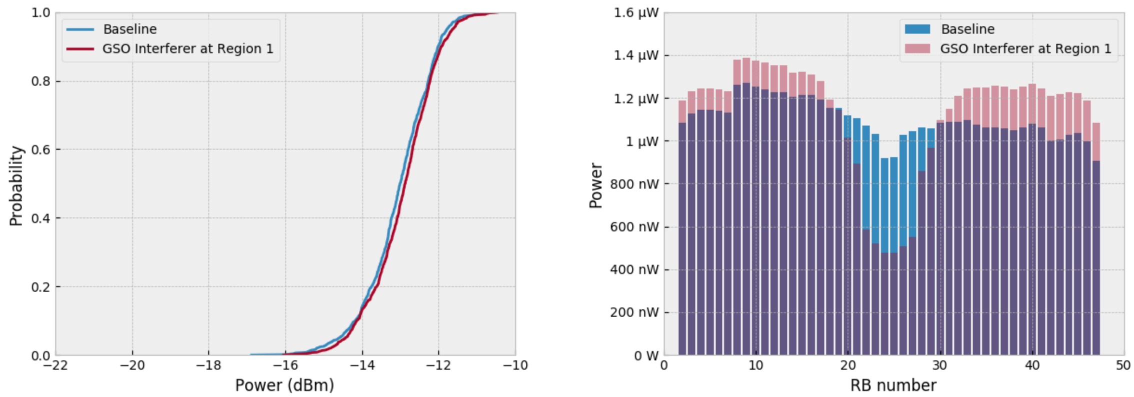
Figure 5-23. Aggregate Interference at DoD Asset 55% Measured Network Loading 3GPP EVA 70Hz Rural Region 2



a. Aggregate Interference CDF

b. Average Power By Resource Block

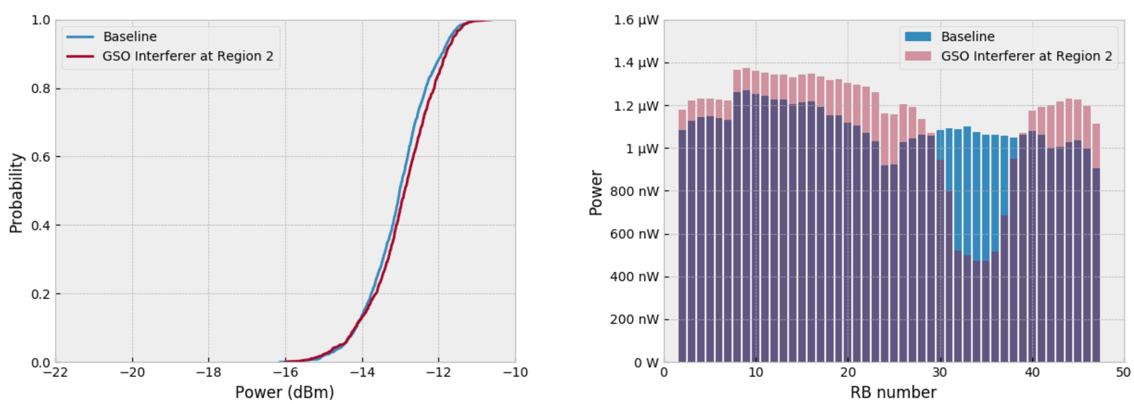
Figure 5-24. Aggregate Interference at DoD Asset 55% Measured Network Loading 3GPP EVA 70Hz Rural Region 3



a. Aggregate Interference CDF

b. Average Power By Resource Block

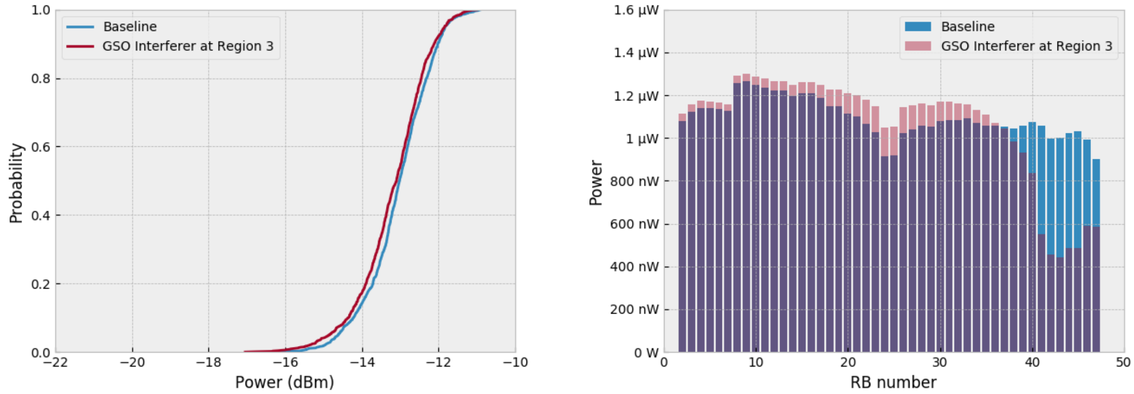
Figure 5-25. Aggregate Interference at DoD Asset 75% Measured Network Loading 3GPP EVA 70Hz Rural Region 1



a. Aggregate Interference CDF

b. Average Power By Resource Block

Figure 5-26. Aggregate Interference at DoD Asset 75% Measured Network Loading 3GPP EVA 70Hz Rural Region 2



a. Aggregate Interference CDF

b. Average Power By Resource Block

Figure 5-27. Aggregate Interference at DoD Asset 75% Measured Network Loading 3GPP EVA 70Hz Rural Region 3

5.4.2 Discussion

Like the second trial, this set used a 3GPP EVA 70Hz channel model; however, the RSRPs were selected to match the CSMAC rural EIRP distribution, so they were increased from the previous trial. The combination of the scheduler being forced to allocate PRBs in the interference region and the higher transmit powers resulted in the first instance in which the SATOPS aggregate interference distribution moved to the right of the baseline. Despite this, even at the largest increase (depicted in Figure 5-26), the 50^{th} percentile of the SATOPS aggregate interference curve is less than 0.5 dB higher than the baseline.

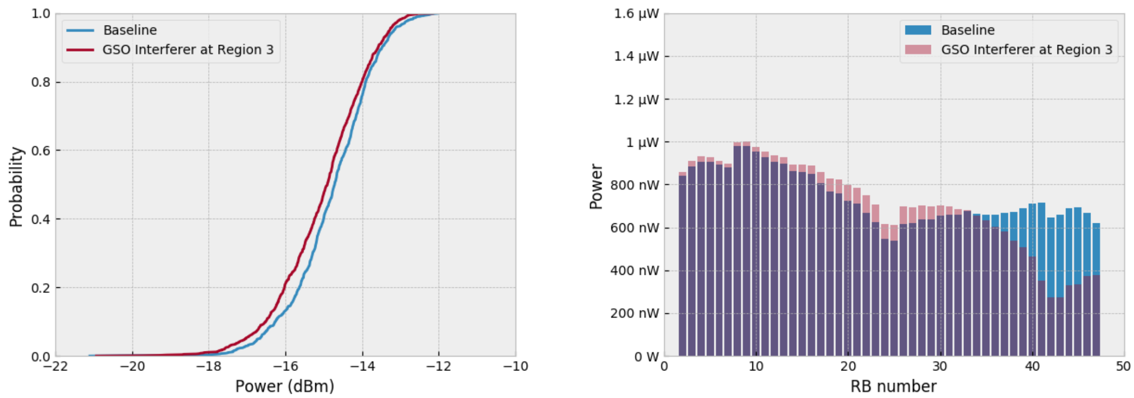
5.5 PRACH Transmissions

5.5.1 PRACH Contribution to Aggregate Interference

To approximate the impact of PRACH transmissions when UE is disconnected from the network, MITRE repeated the same modeling practices described in the previous sections, except all sectors that received greater than –60dB of SATOPS interference instead sampled the total sector radiated power according to the process described in section 3.3.3, assuming 32 UEs transmitting with an equal chance of being assigned to subframes 0–9, and PRBs 20–30 being used for PRACH.

5.5.2 PRB Distribution Changes

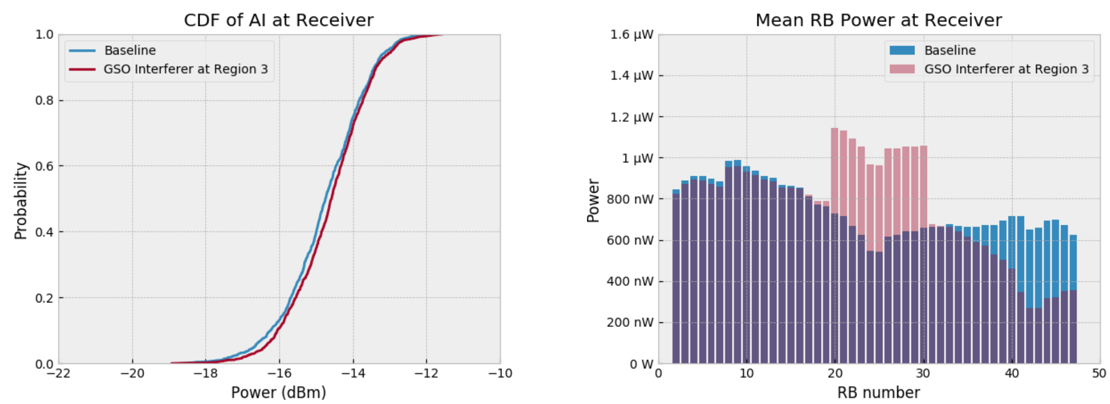
Figure 5-28 and Figure 5-29 depict the results of two MULE runs, both with a Rural RSRP distribution and 3GPP EVA 70Hz channel model. In the first run, the PRACH transmission model was not used, in the second, the sectors receiving over –60dB of interference used the PRACH model instead of the MULE-generated model.



a. Aggregate Interference CDF

b. Average Power By Resource Block

Figure 5-28. Aggregate Interference at DoD Asset 55% Measured NL 70Hz Rural Region 3 without PRACH



a. Aggregate Interference CDF

b. Average Power By Resource Block

Figure 5-29. Aggregate Interference at DoD Asset 55% Measured NL 70Hz Rural Region 3 with PRACH

5.5.3 Discussion

While this model predicted an increase in the aggregate interference, the curve did not move significantly in this trial. The spectral density increased moderately inside the random-access channel (RACH) region, and slightly decreased outside that region, as compared to the trial without the PRACH transmissions. If spectral density in the RACH region is of particular concern this may have to be considered further; however, this behavior is transient and likely over-predicts the frequency of PRACH transmission.

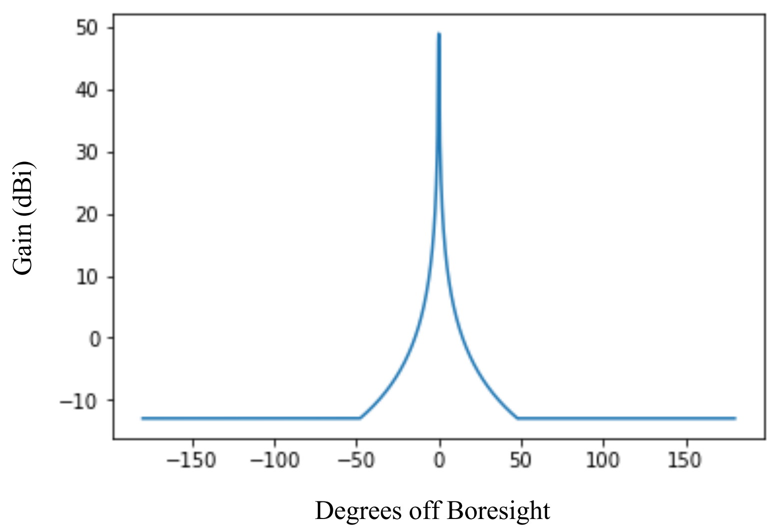
6 Summary and Conclusions

MITRE conducted this study to determine if any additional action would be required to account for SATOPS UL interference incident on LTE deployments in current aggregate interference modeling. If analysis had indicated that LTE aggregate interference could increase in the presence of a SATOPS interferer, this would warrant an adjust in modeling, as this increase could cause harm to a DoD receiver if proper precautions are not taken. However, MITRE's analysis of a worst-case SATOPS scenario showed no significant increase in aggregate interference over a baseline scenario without the interferer. In fact, most scenarios predicted a decrease in aggregate interference, as the interferer would limit the number of opportunities for UEs to transmit due to poor channel conditions. While the UEs had to increase transmit power to overcome the noise, the analysis indicated that the decrease in UEs scheduled per subframe outweighed this in the aggregate radiated power. These findings lead MITRE to the conclusion that no action is necessary to adjust current modeling practices to account for interference from the SATOPS uplink on the LTE network.

Appendix A Aerospace Analysis Parameters

SATOPS Earth Station Assumptions:

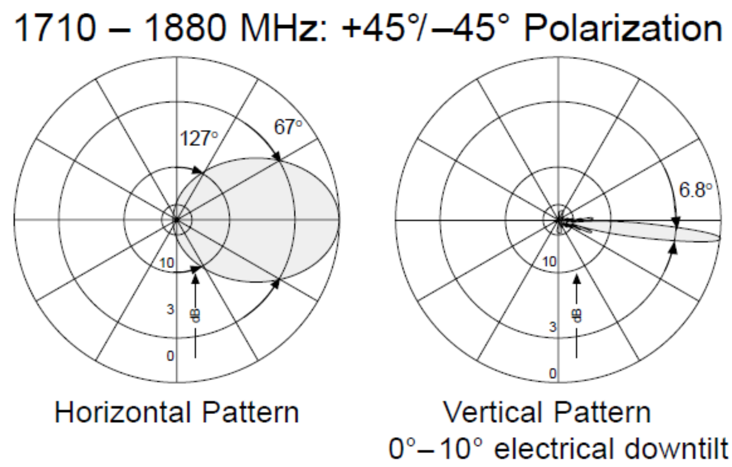
- Peak high-power amplifier output power: 64 dBmi
- Tx Circuit Loss: 2 dB
- Peak Gain 49 dBi
- Antenna feed height: 19.81m per EEPAC
- Path loss:
  - *ITU-R P.452 version 15*
  - *p=50%*
  - *DTED L2 terrain data, 1000 points along path*



SATOPS Ground Station Parabolic Dish Gain Pattern

eNB Receiver Assumptions:

- Peak Gain: 18 dBi; Pattern per ITU-R F.1336-5
- Rx Circuit Loss: 2 dB
- Antenna feed height: various (per provided deployment plan)



eNB Antenna Gain Pattern

Source: This information was shared by The Aerospace Corporation in a presentation to the SSTD LTE Working Group in October, 2019

Appendix B MULE Report Summary

MULE produces an automated report for each run it completes. The report includes all the charts contained in section 4 (MULE Functions and Outputs), as well as tabular summaries of the eNB and UE configurations. The automated report for this test in over 1,000 pages, so it is not included in this report. Please contact the authors to request a copy of this report if desired.

Appendix C Abbreviations and Acronyms

3GPP	3rd Generation Partnership Project
AIT	Aggregate Interference Tool
AWGN	Additive White Gaussian Noise
AWS-3	Advanced Wireless Services 3
CDF	Cumulative Density Function
CR	Coordination Request
CSMAC	Commerce Spectrum Management Advisory Committee
dB	Decibel
DCI0	Downlink Control Indicator Format 0
DoD	Department of Defense

DSO	Defense Spectrum Organization
EEPAC	Early Entry Portal Analysis Capability
EIRP	Effective Isotropic Radiated Power
EVA	Extended Vehicular A
eNB	Evolved Node B
GIS	Geospatial Information System
GSO	Geostationary Orbit
Hz	Hertz
KDE	Kernel Density Estimate
LTE	Long Term Evolution
MCS	Modulation and Coding Scheme
MNO	Mobile Network Operator
MetSat	Meteorological Satellite
MHz	Megahertz
MIMO	Multiple Input Multiple Output
MULE	Multi UE LTE Emulator
NGSO	Non-Geostationary Orbit
NL	Network Loading
NTIA	National Telecommunications and Information Administration
OFDM	Orthogonal Frequency Division Multiplexing
PDCCH	Physical Downlink Control Channel
PDF	Probability Density Function
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PUSCH	Physical Uplink Shared Channel
RF	Radio Frequency
RSRP	Reference Symbol Receive Power
SATOPS	Satellite Operations
TIREM	Terrain Integrated Rough Earth Model
TTI	Transmission Time Interval
Tx	Transmit
UE	User Equipment

UL	Uplink
USGS	United States Geological Survey
USP	United States and Possessions