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May 15, 2017

VIA ELECTRONIC FILING

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street S.W.
Washington D.C. 20554

Re: Oral *Ex Parte* Notice
GN Docket No. 14-177, IB Docket Nos. 15-256 and 97-95;
RM-11664 and 11773; and WT Docket No. 10-112

Dear Ms. Dortch:

On May 11, 2017, representatives of The Boeing Company ("Boeing") met with staff of the Federal Communications Commission ("Commission") to discuss the above-referenced proceedings and Boeing's continuing technical studies demonstrating the ability for spectrum sharing between the Upper Microwave Flexible Use Service ("UMFUS") and next-generation broadband satellite communications systems in the 37.5-40.0 GHz band ("39 GHz"). A list of meeting attendees is provided as Attachment 1 to this letter.

During the meeting, Boeing highlighted a substantive change in its position regarding beneficial modifications to the Commission's rules to facilitate spectrum sharing in the 39 GHz band. As in the past, Boeing is requesting that the Commission remove the prohibition on the operation of satellite end user terminals in the 39 GHz band so that such terminals can receive broadband satellite signals on an opportunistic, unprotected basis. Boeing, however, is no longer requesting that the Commission make any changes to the power flux density ("PFD") limits that are included in Section 25.208(r) for satellites in non-geostationary satellite orbit ("NGSO") or in Section 25.208(q) for satellites in geostationary satellite orbit ("GSO"). As the Commission is aware, these rules specify PFD limits that apply in clear sky conditions and less restrictive PFD limits that apply during conditions of rain fade. Boeing no longer believes that any changes to these PFD limits are necessary.

Instead, Boeing is requesting solely that the Commission complete the studies that are identified in the Notes to paragraphs (q) and (r) in order to define the conditions under which individual satellites are permitted to increase their transmit PFD levels toward the Sections 25.208(q)(2) and (r)(2) limits to compensate for rain fade. Boeing is further advocating that the

Commission adopt equivalent power flux density ("EPFD") limits that can be used to restrict the downlink transmissions of GSO and NGSO satellites (both individually and in the aggregate) in order to ensure that the operations of such satellites do not cause harmful interference to UMFUS base stations or end user receivers in the 39 GHz band.

An EPFD approach is appropriate because it can accurately model and regulate the simultaneous transmissions from multiple satellites operating at varying points in the sky toward fixed or mobile UMFUS receivers at any point on the ground. The Commission already employs EPFD limits to regulate the operation of NGSO systems in the Ku-band,[1] and is in the process of adopting the same approach for NGSO systems in the Ka-band.[2] In contrast, the existing single-entry PFD limits are inadequate to reliably model or regulate the aggregate emissions of multiple satellites toward UMFUS receivers in the 39 GHz band.

In advocating for an EPFD approach, Boeing acknowledges that the simultaneous operation of a very large number of NGSO and GSO systems in the same spectrum may require satellite operators to sometimes employ transmit PFD levels that are below the Section 25.208 limits in order to comply with an appropriate EPFD mask. Satellite system operators could alternatively comply with EPFD limits using other measures, such as limiting the number of satellites radiating toward the same point on the ground, or refraining from operating NGSO satellites at lower elevation angles. Regardless of the approach employed by satellite system operators, however, the use of an EPFD approach would ensure that the aggregate emissions from all satellites operating in the 39 GHz band will not exceed the power levels identified by the Commission in Sections 25.208(q) and (r) as necessary to protect UMFUS receivers.

The adoption of EPFD limits for GSO and NGSO satellites will in no way restrict the ability of UMFUS licensees to innovate in the development of UMFUS equipment that can operate in the 39 GHz band. The implementation of EPFD limits will require the identification and use of reference UMFUS receive antenna patterns to define the appropriate EPFD mask. Once defined, however, UMFUS licensees will be free to develop and use other types and configurations of UMFUS receivers without any concern that they will experience harmful interference from satellite transmissions. This is because the adopted EPFD limits will ensure that satellite signals will be received on the ground at power levels that are only a small fraction of the power levels of co-frequency UMFUS systems. Therefore, any newly developed UMFUS receiver that can withstand interference from other UMFUS devices will be able to easily reject or otherwise withstand interference from the relatively faint transmissions of distant co-frequency satellites.

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[1] *See* 47 CFR §§ 25.146, 25.208(g)-(m).

[2] *See* Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters, IB Docket No 16-408, *Notice of Proposed Rulemaking*, FCC 16-170, ¶ 19 (Dec. 15, 2016).

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In demonstrating the exceedingly low levels of interference that would be experienced by UMFUS receivers from satellite downlink transmissions in the 39 GHz band, Boeing conducted all of its studies employing an assumption that UMFUS receivers will point randomly in all directions (including directly toward transmitting satellites), rather than point at the target UMFUS transmitter. In some cases, Boeing also modeled the UMFUS receiver handsets pointing directly at the worst-case source of interference. These somewhat unrealistic, worst case assumptions are addressed in the first part of the attached presentation. When more realistic assumptions are employed (*i.e.*, that UMFUS receivers will operate directionally toward their target transmitters), the aggregate impacts of satellite transmissions into UMFUS receivers becomes negligible.

Boeing also conducted multiple additional studies on the potential impacts of multipath transmissions from satellite signals that may reflect off objects (such as buildings) into UMFUS receivers. Employing accurate models involving nine major cities, Boeing conducted detailed simulation of 22 different multipath scenes including 58 different UMFUS receiver types and locations with more than one million trials at each location to assess the various satellite signal paths at each location, resulting in 448 million simulations, which required the use of 3,400 CPU-days of computing capacity on a supercomputing cluster. The results demonstrate that multipath transmissions only negligibly increase aggregate interference into UMFUS receivers and only in certain conditions. In many conditions (particularly those involving urban settings), the overall interference was reduced because the additional energy that resulted from reflected signals was more than offset by the reduced energy that resulted from the blockage of some satellite transmissions by buildings or other large objects.

Boeing's studies thoroughly demonstrate that broadband satellite systems can operate in the 39 GHz band on an opportunistic basis without causing harmful interference to co-frequency UMFUS systems. The Commission should therefore facilitate the shared use of this spectrum in order to ensure that millimeter wave spectrum is used efficiently and robustly to provide broadband services that are truly accessible to all Americans.

Thank you for your attention to this matter. Please contact the undersigned if you have any questions.

Sincerely,

Bruce A. Olcott
Counsel to The Boeing Company

Attachments

Marlene H. Dortch
May 15, 2017

ATTACHMENT 1
May 11, 2017 Ex Parte Meeting Attendees

Wireless Telecommunications Bureau

- John Schauble
- Joel Taubenblatt
- Blaise Scinto
- Charles Oliver
- Nancy Zaczek (by phone)
- Simon Banyai
- Janet Young
- Steve Buenzow
- Tim Hilfiger

Office of Engineering and Technology

- Michael Ha
- Bahman Badipour
- Barbara Pavon
- Martin Doczkat
- Nicholas Oros

International Bureau

- Jose Albuquerque
- Diane Garfield
- Kal Krautkramer
- Michael Mullinix

Boeing Participants

- Bruce Chesley
- Robert Vaughan
- Matthew Dzugan
- Robert Hawkins
- Audrey Allison
- Bruce Olcott

Marlene H. Dortch
May 15, 2017

ATTACHMENT 2
Meeting Presentation

Spectrum Frontiers FNPRM V-band FSS Downlink Spectrum Sharing Discussion

11 May 2017

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TOPICS

- **FSS Downlink Spectrum Sharing and EPFD approach**
- **Multipath Environment Scenarios Update and Results**
  - UMFUS device pointing scenarios
  - Additional multipath environments modeled
    - Various receiver locations within scenes
    - Other scenes modeled (U.S. cities and suburbs)
  - Results and conclusions
- **Clear Sky and Multiple System Downlink EPFD Modeling**
  - Multiple system modeling approach
  - GSO and multiple NGSO EPFD modeling and results
  - Regulatory structure and path forward for FSS EPFD regulations into UMFUS

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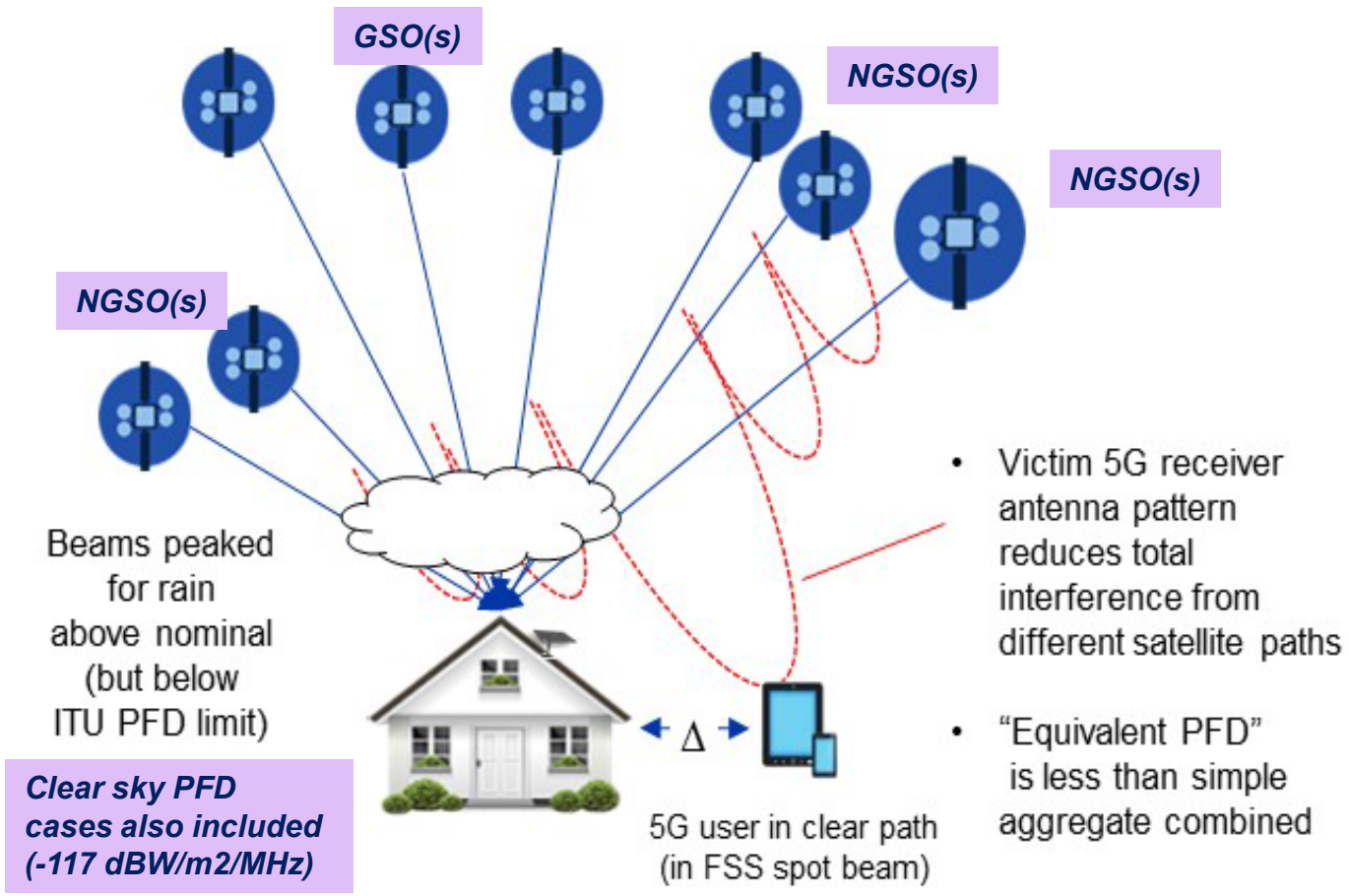
Extended EPFD methodology models full range of FSS sharing with UMFUS



$$ePFD = 10log_{10}\left(\sum_{k=1}^{Nsats} 10^{\frac{(G_r^k(\theta_k,\phi_k)+PFD_k)}{10}}\right) - (G_{r-pk})$$

N_{sats} = Number of total NGSO satellites radiating beams at the particular ground point

PFD_k = incident PFD of the kth NGSO satellite at the ground point in dBW/m2/MHz

$G_r^k(\theta_k, \phi_k)$ = Gain of the 5G victim receiver antenna in the direction toward the kth NGSO satellite, in dBi

G_{r-pk} = Peak gain of the 5G victim receiver (usually G_r (0,0) at boresight), in dBi

$$INR_{dB} = [ePFD + G_{r\text{-}pk} - 10\log_{10}(4\pi/\lambda^2) - k - T_r]$$

$$(I/N)_{deg} = 10\log_{10}(10^{(INR/10)}+1)$$

λ = wavelength in m; $\lambda \sim= (0.3/F_c)$ where F_c is in GHz

G_r = Isotropic gain of the 5G receiver in the direction of the arriving PFD signal, in dBi

K = Boltzmann's constant, -228.6 dB W/K-Hz

T_r = 5G receiver noise temperature in dB/K, calculated as $10\log_{10}(T_b+290*[10^{(NF/10)}-1])$ where T_b= background temperature (usually 290K for terrestrial background and/or rain) and NF = noise figure of the 5G receiver in dB

5G receiver points beams randomly at satellite or LOS at user/base station

- **ePFD methodology correctly models impacts for FSS/UMFUS sharing**
- **Expanded analysis includes multipath, 5G pointing, clear sky PFDs, and multiple GSO+NGSO systems**

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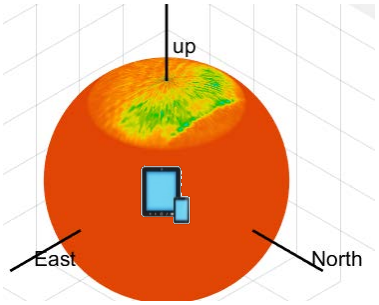
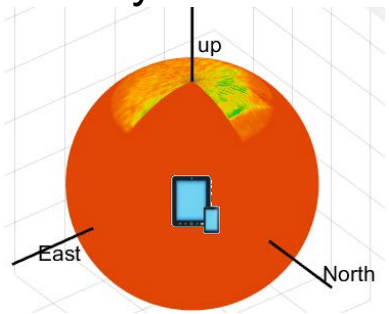
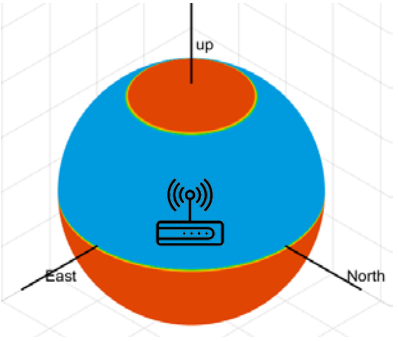
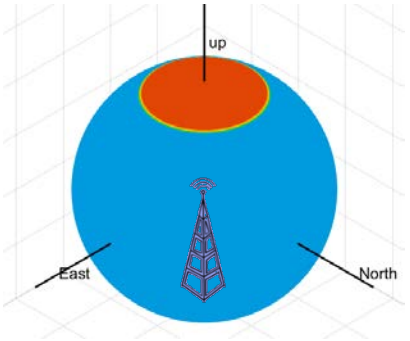
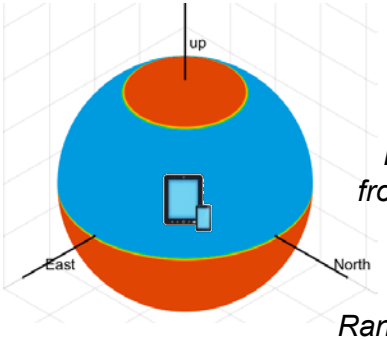
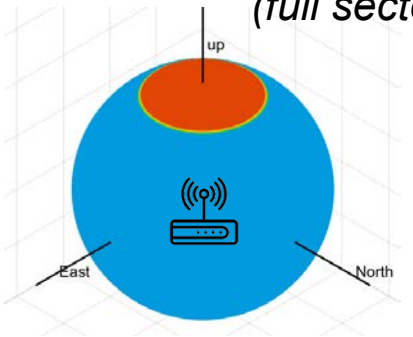
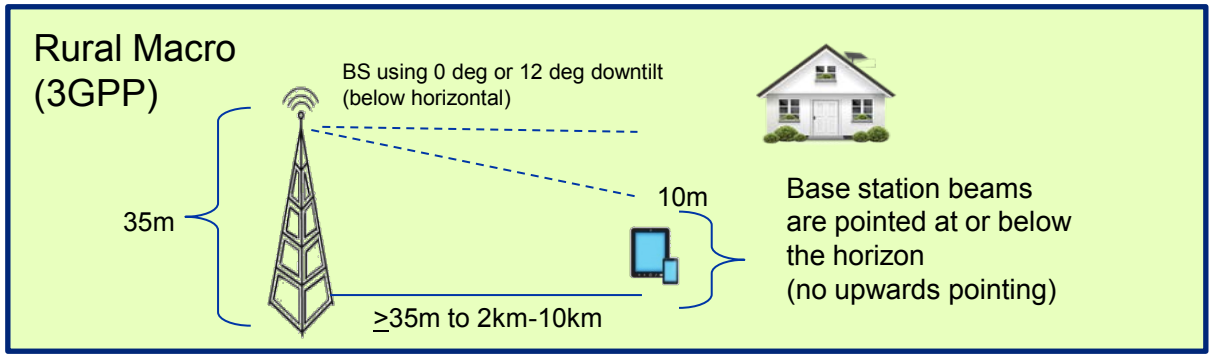
UMFUS Device Pointing – Random Pointing Cases

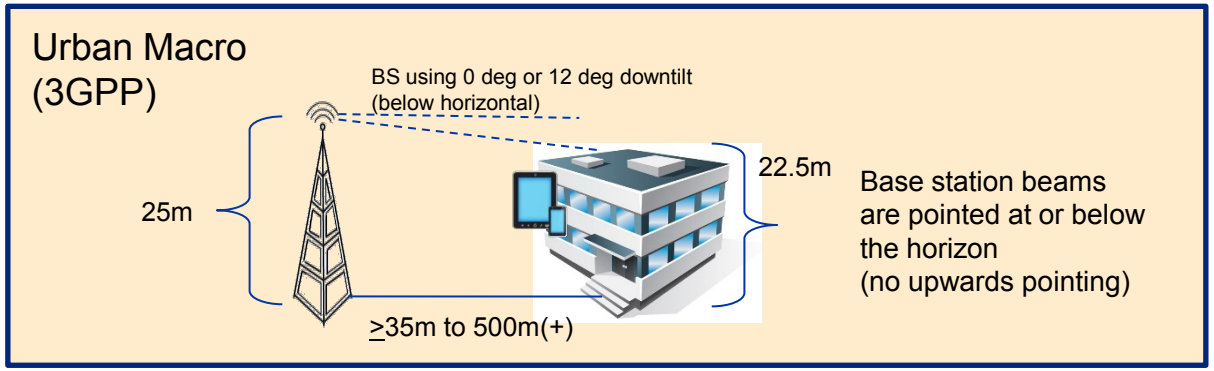
Random Pointing

UE/Handsets	CPE	Base Stations
Handset oriented to Point at worst ray  **Example – Clear Sky**  **Example - Multipath**	Uniform random pointing *(above horizon sector)*  *Elevation limited from horizon to +60°* *Random CPE Azimuth alignment (full 360-deg)*	Uniform random pointing *(full sector)*  *Elevation ranges from -60 to +60°* *Multiple base station sectors with random Azimuth alignment (full 360-deg)*
Uniform random pointing  *Elevation limited from horizon to +60°* *Random UE Azimuth alignment (full 360-deg)*	Uniform random pointing *(full sector)*  *Elevation ranges from -60 to +60°* *Random CPE Azimuth alignment (full 360-deg)*	

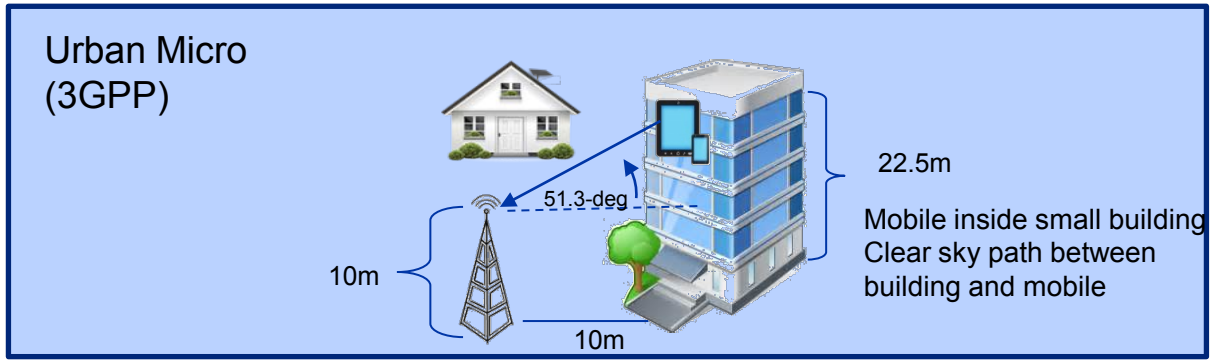
Random pointing scenarios continue to include arbitrary handset orientation and arbitrary azimuth orientations with 3GPP planar array scan ranges (e.g. +/- 60-deg sectors)

UMFUS Device Pointing – "Cellular"



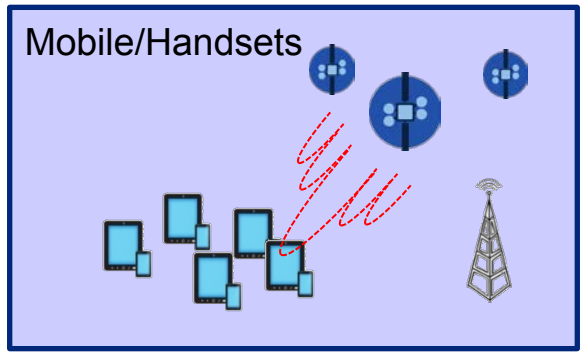


Beams pointed toward users – BS downwards pointing only
Small regions near BS have upwards pointing elevation angles

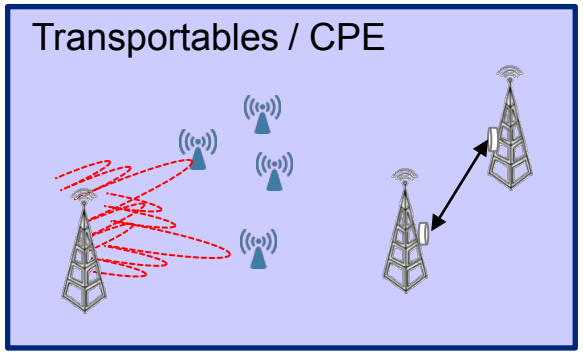


Beams pointed toward users – BS upwards pointing to 51.3-deg

- **3GPP definitions are used for various cell types**
- **Cell is defined using ISD (radius), base station height, and range of potential user heights**
- **Users are randomly distributed on surface of the earth and then uniformly distributed in height**
- **Base station and user beams are electronically steered towards each other**
  - CPE has installation/alignment offset of physical boresight with electronic steering towards BS
  - UE/Handset has similar random physical boresight with electrical steering towards BS



Random physical boresight within (+/-60 deg) of base station electrical steering towards base station



Random physical boresight towards BS within(+/-22.5 deg) electrical steering towards base station

FSS DL interference into UMFUS in Multipath Environment

- UMFUS Device Beam Pointing
- Updates and Additional Scenarios (Scenes)

11 May 2017

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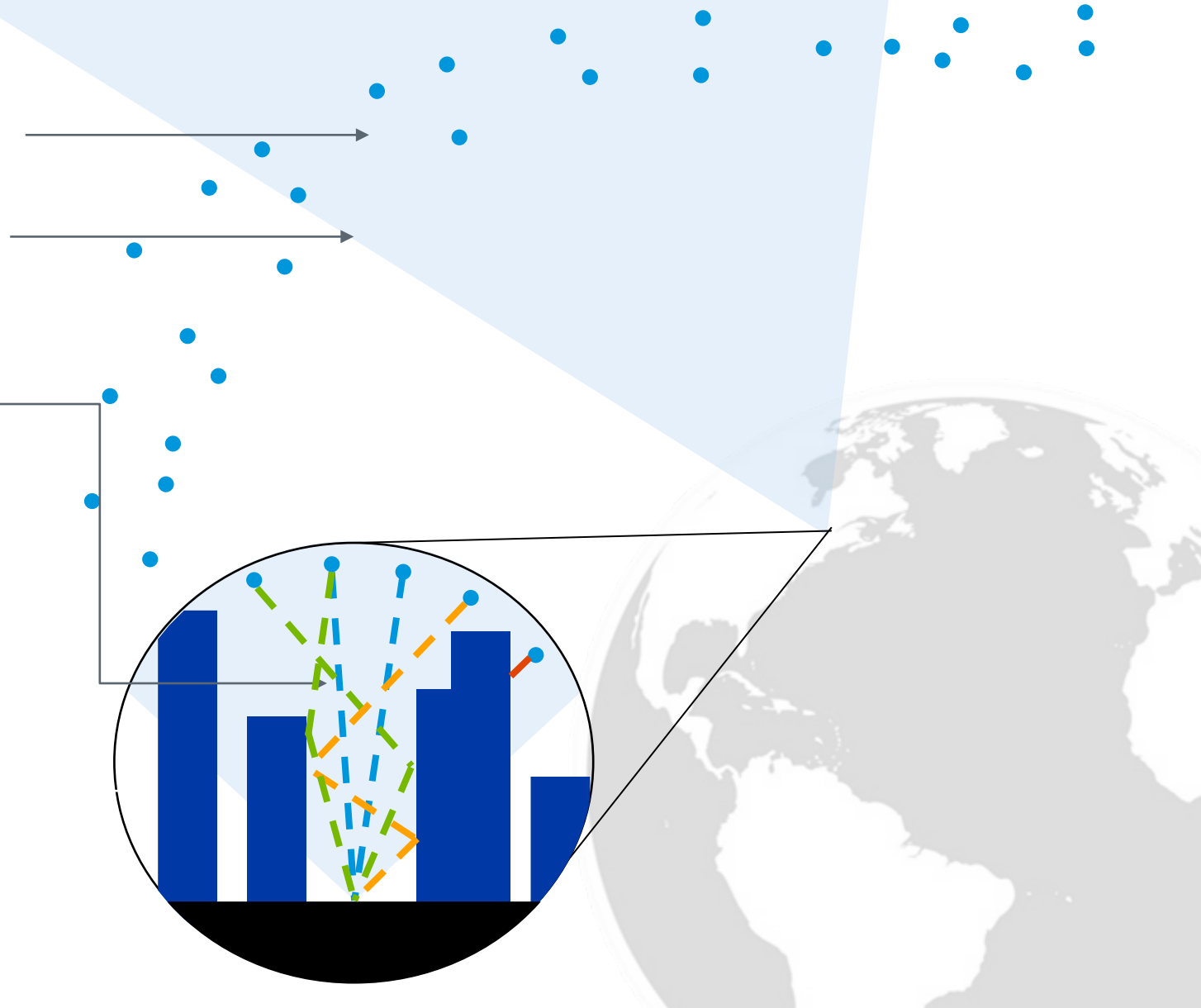
Downlink Interference: Multipath Modeling Approach

- **Assumptions:**
- **Boeing's constellation of 2956 LEO satellites is transmitting at 39 GHz**
- **All satellites at 50° elevation angle or higher are assumed to be radiating down to the site of interest**
- **Signal-Paths to the site-of-interest under consideration are of three main types:**
  - Direct Line of Sight
  - Single Reflection
  - Double Reflection
- **Individual satellite PFD levels are commensurate with in-beam rain-fade conditions**
- **Multipath analysis typically tracks about two to three times as many rays as there are satellites radiating**



Additional Multipath Cases

Boeing has greatly increased the quantity and accuracy of multipath simulation results since our last visit on March 29, 2017.

March

New York
1 Urban Setting
10,000 simulations each

Miami
1 Suburban Setting
10,000 simulations each

Added more monte-carlo simulations for higher fidelity results

New York
1 Urban Setting
1,000,000 simulations each

Miami
1 Suburban Setting
1,000,000 simulations each

Added victim locations within each city to explore effect of exact location

New York
3 Urban Settings
2 Suburban Settings
1,000,000 simulations each

Miami
2 Urban Settings
1 Suburban Setting
1,000,000 simulations each

Added more cities to verify consistency of effects

TODAY

New York
3 Urban Settings
2 Suburban Settings
1,000,000 simulations each

Miami
2 Urban Settings
1 Suburban Setting
1,000,000 simulations each

Atlanta
1 Urban Setting
1 Suburban Setting
1,000,000 simulations each

Chicago
1 Urban Setting
1 Suburban Setting
1,000,000 simulations each

Houston
1 Urban Setting
1 Suburban Setting
1,000,000 simulations each

Los Angeles
1 Urban Setting
1 Suburban Setting
1,000,000 simulations each

San Francisco
1 Urban Setting
1 Suburban Setting
1,000,000 simulations each

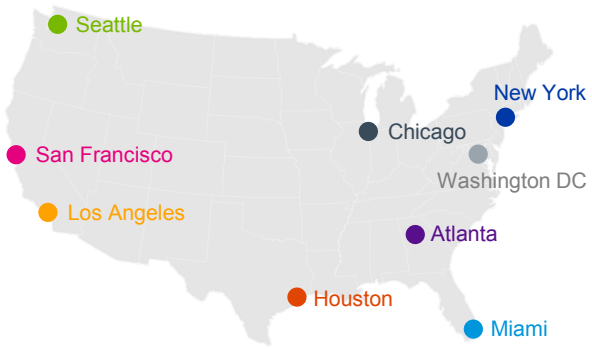
Seattle
1 Urban Setting
1 Suburban Setting
1,000,000 simulations each

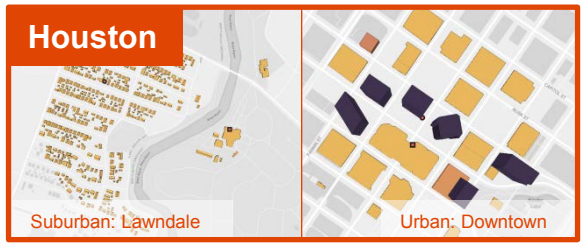
Washington DC
1 Urban Setting
1 Suburban Setting
1,000,000 simulations each

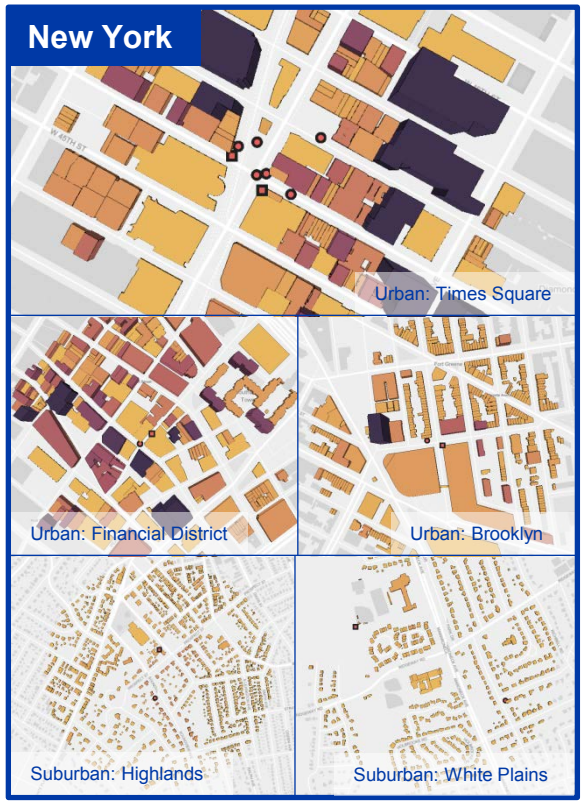
3400 cpu-days' worth of computation performed on a Boeing supercomputer

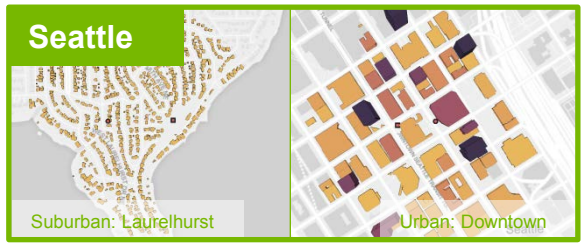
KEY
- User Handset Location
- User CPE Location
- Base Station Location

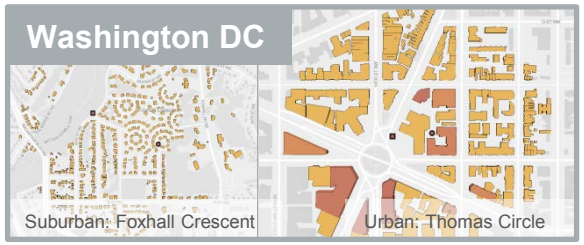
Additional Multipath Environments – Scenes/Locations

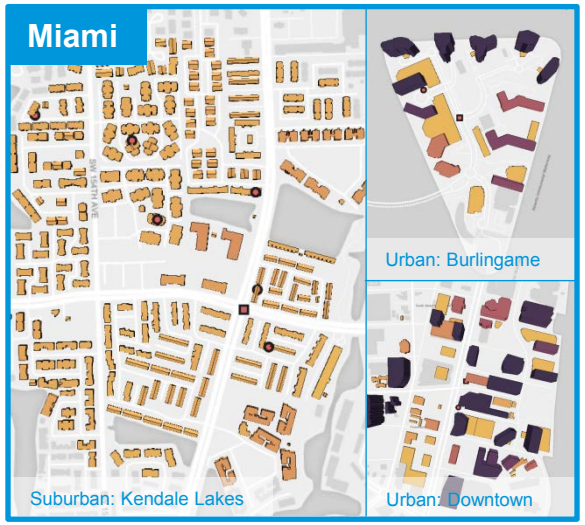


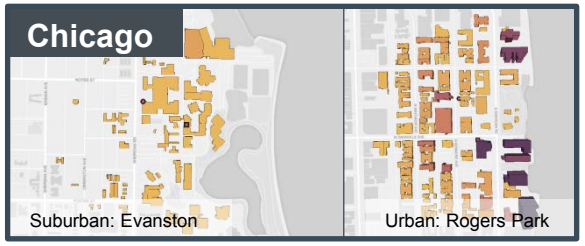




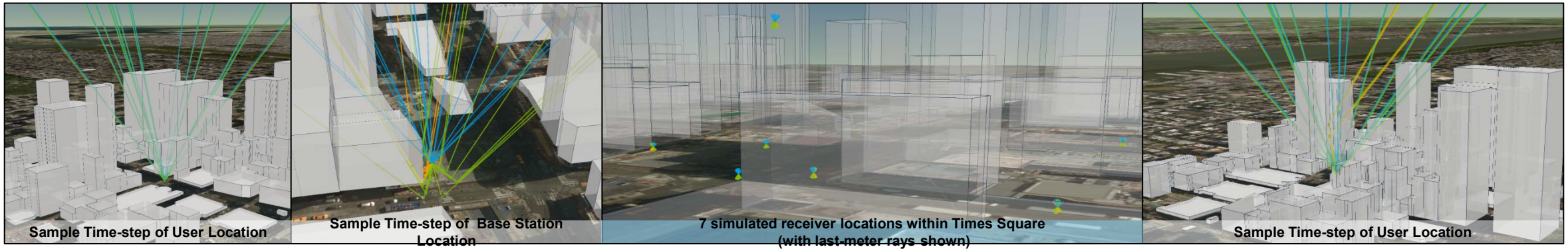




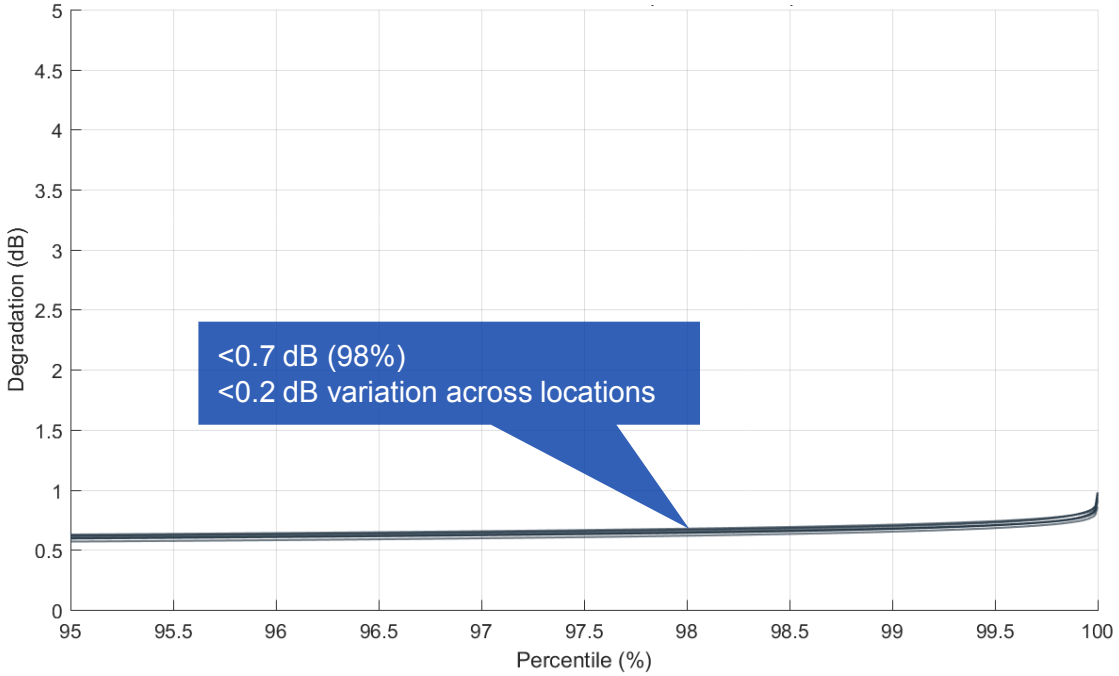




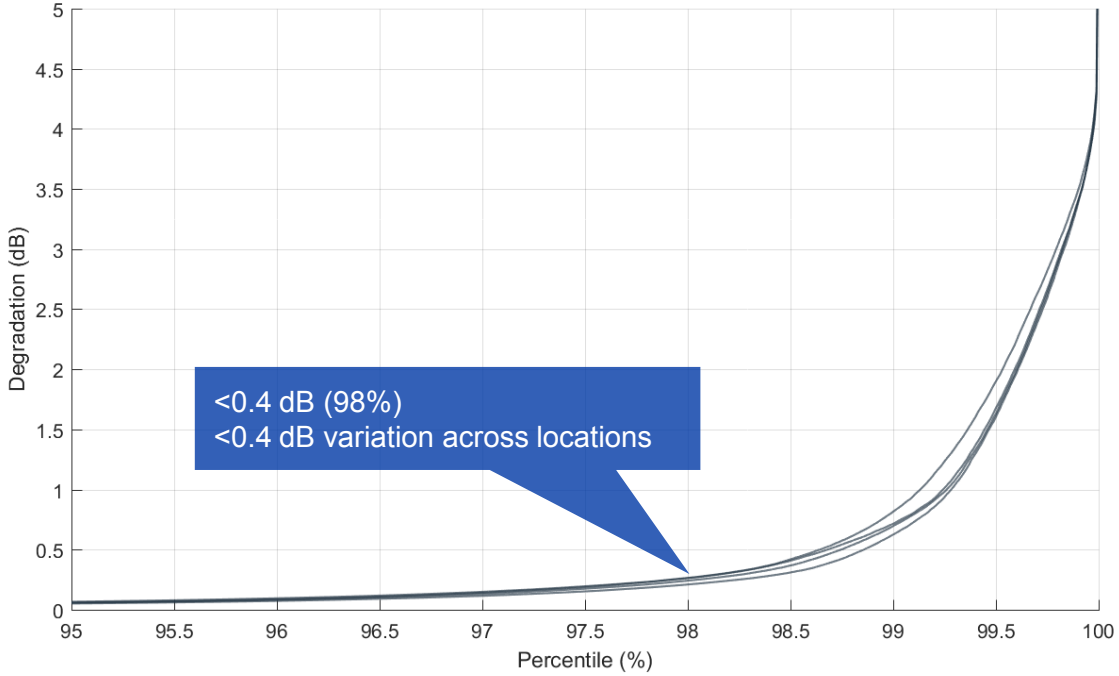
Additional Receiver Locations within Multipath Environments



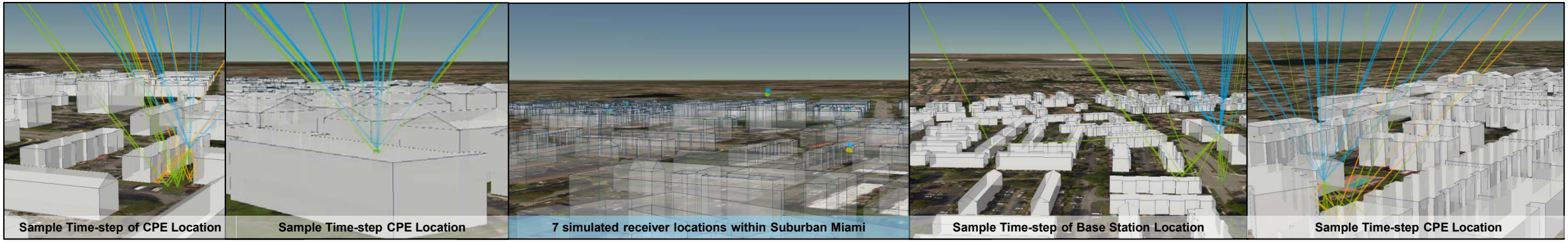
New York Urban **Handsets** (Worst Case Pointing, Rain Event)



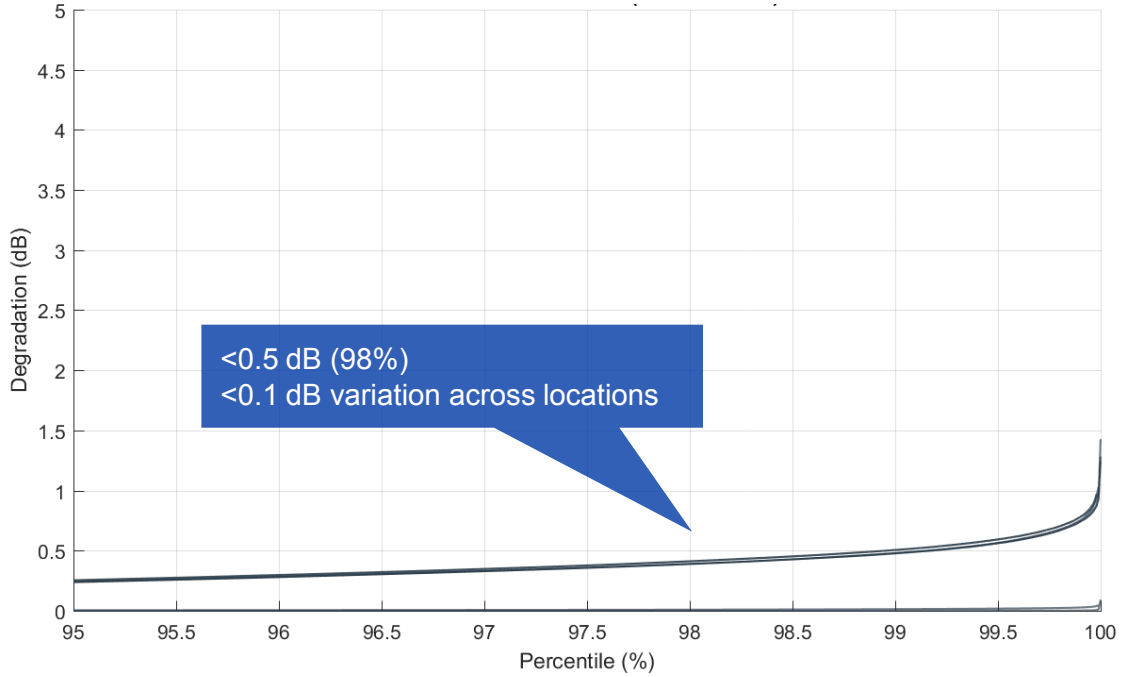
New York Urban **Base Stations** (Random Pointing, Rain Event)



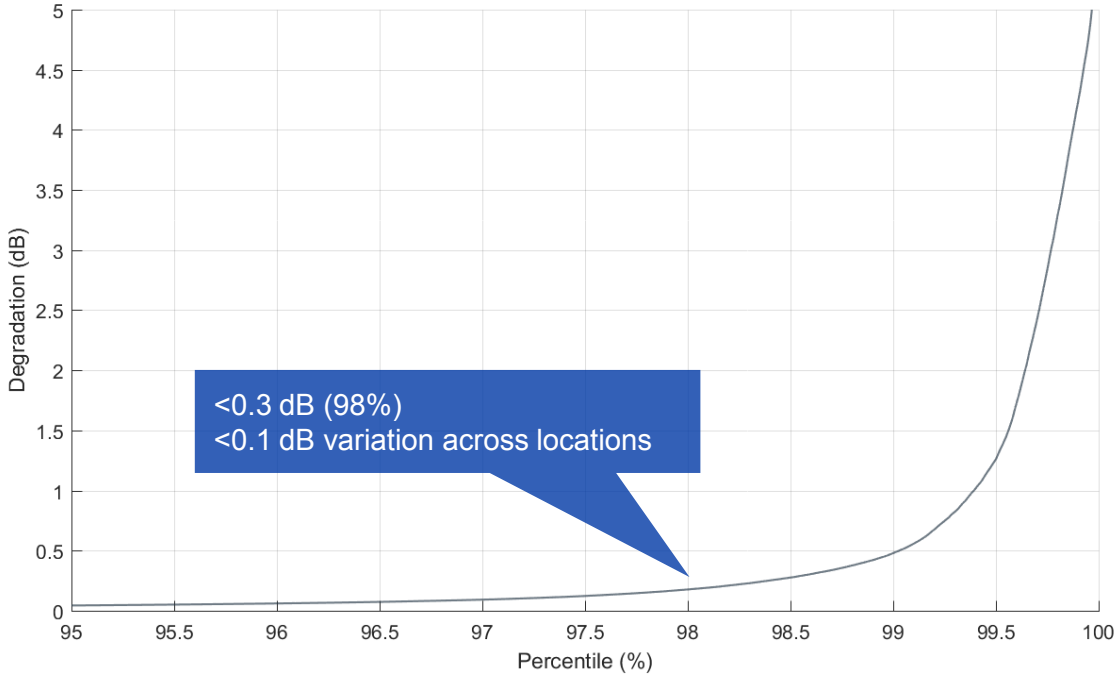
Additional Receiver Locations within Multipath Environments



Miami Suburban **CPEs** (Random Pointing, Rain Event)

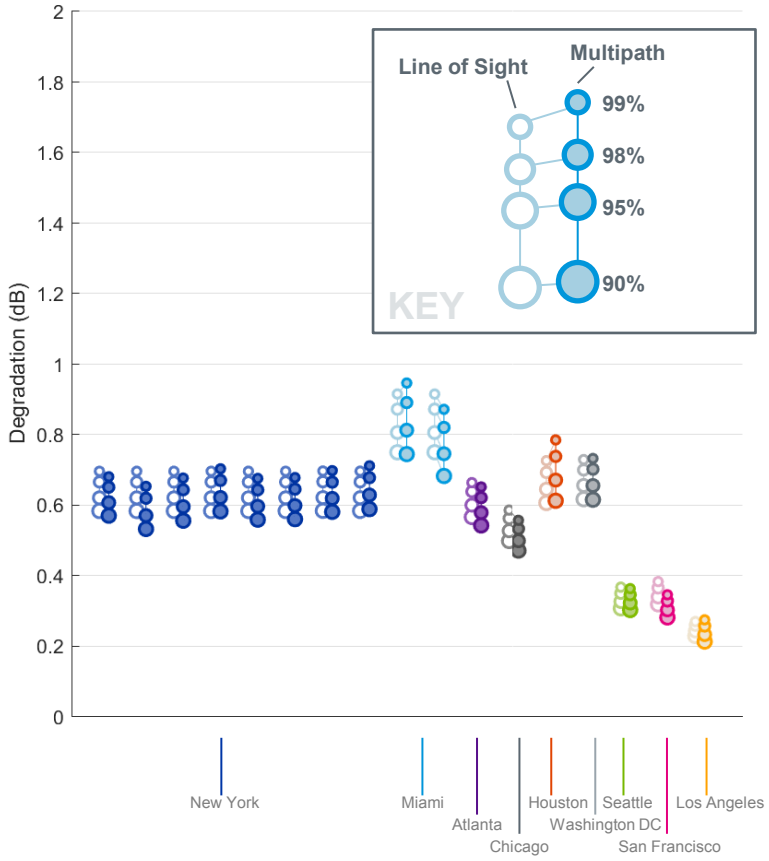


Miami Suburban **Base Stations** (Random Pointing, Rain Event)

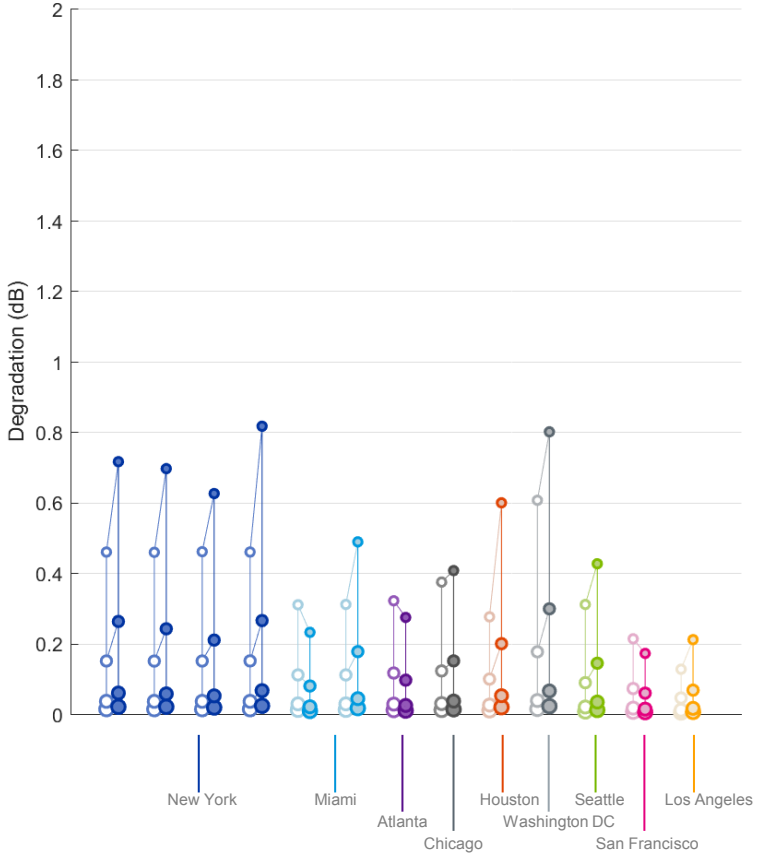


Additional Multipath Environments – Urban Results

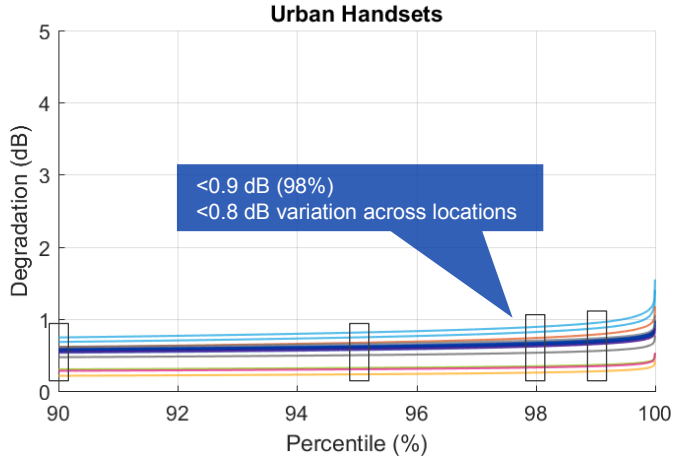
Urban **Handsets** (Worst Case Pointing, Rain Event)

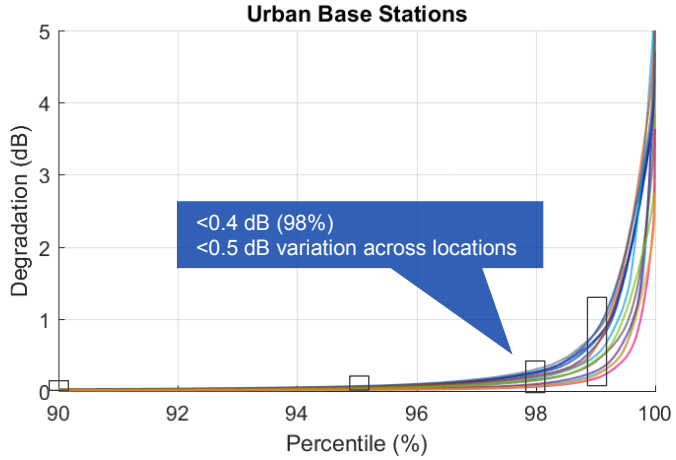


Urban **Base Stations** (Random Pointing, Rain Event)



Multipath CDFs (all metro areas)

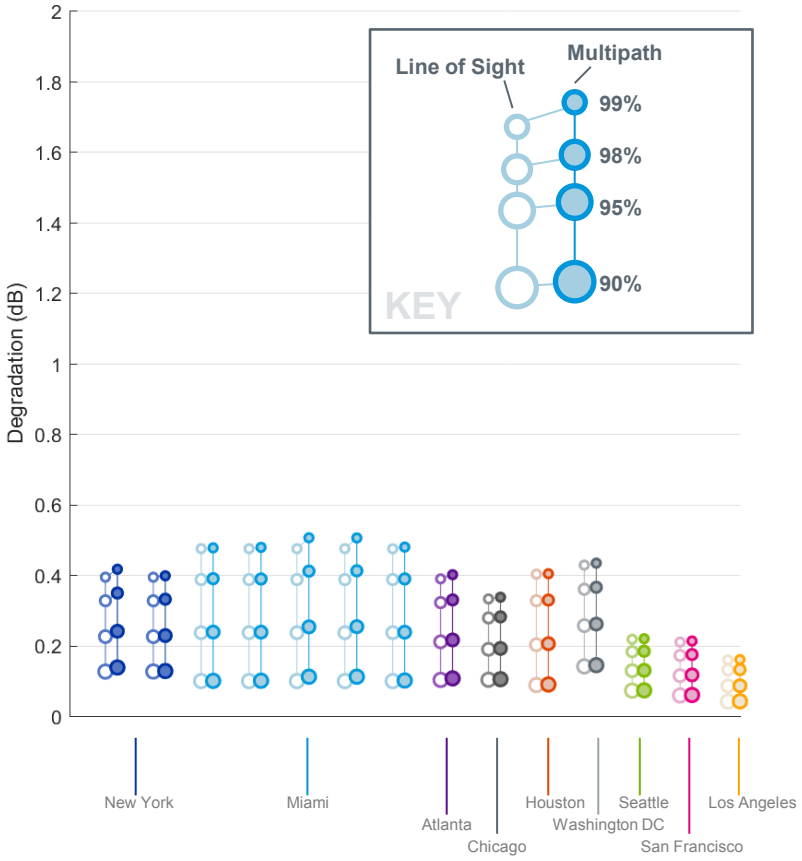




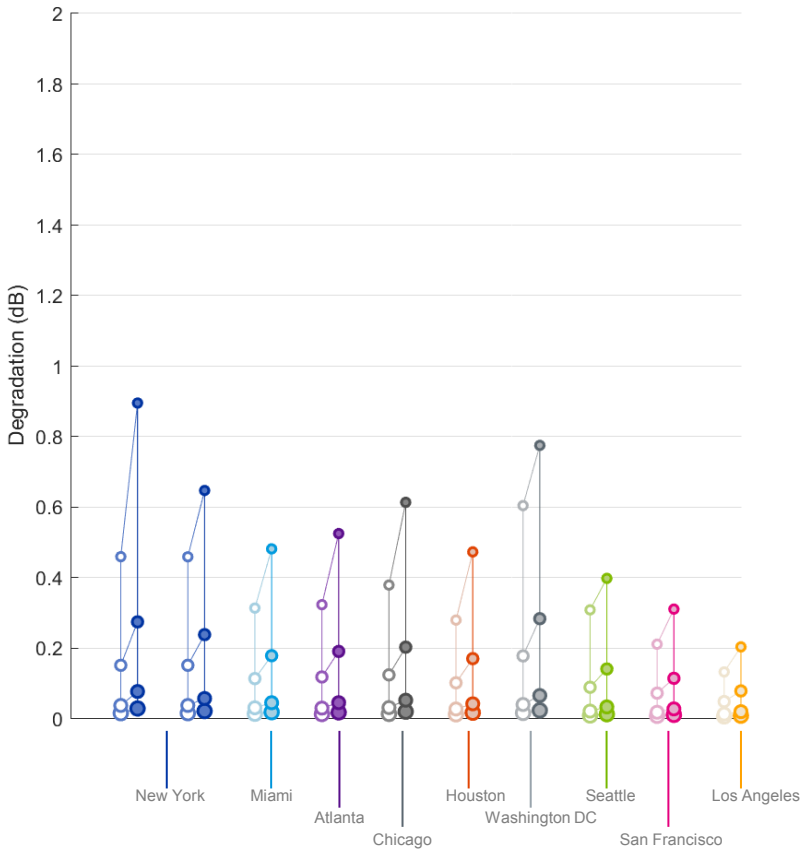
Urban multipath results are consistent across many locations and scenes modeled

Additional Multipath Environments – Suburban Results

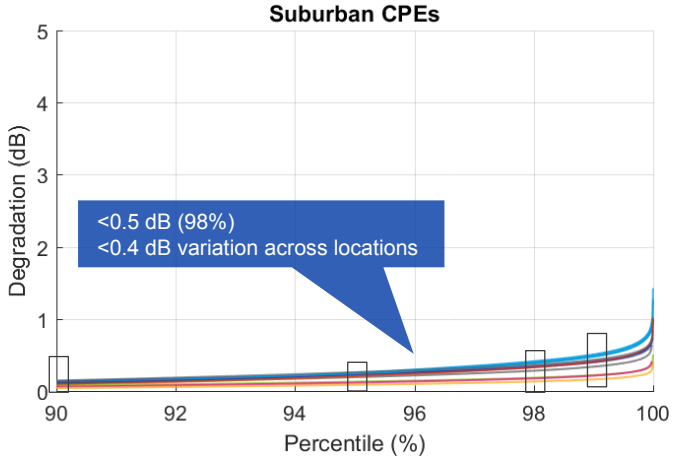
Suburban **CPEs** (Random Pointing, Rain Event)

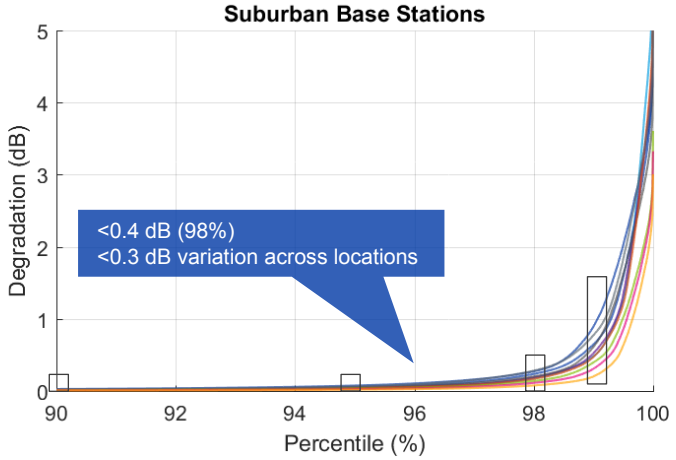


Suburban **Base Stations** (Random Pointing, Rain Event)



Multipath CDFs (all metro areas)

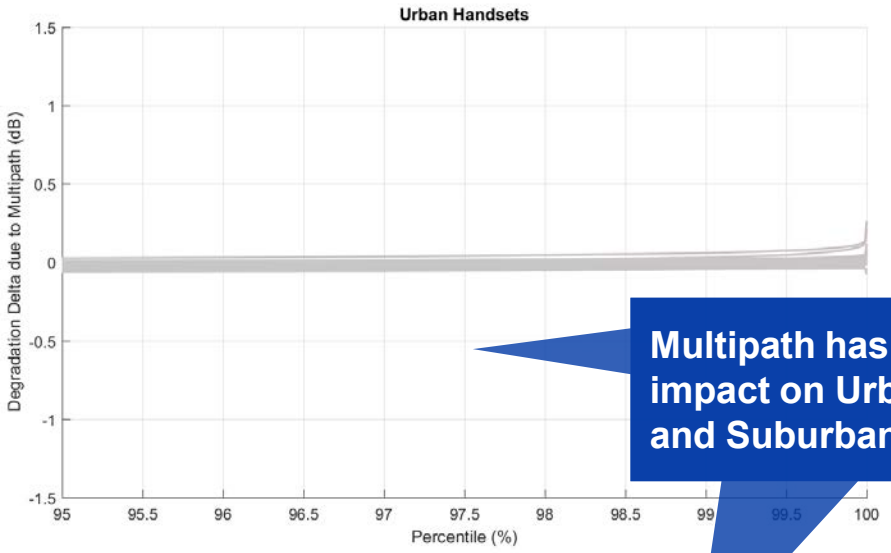


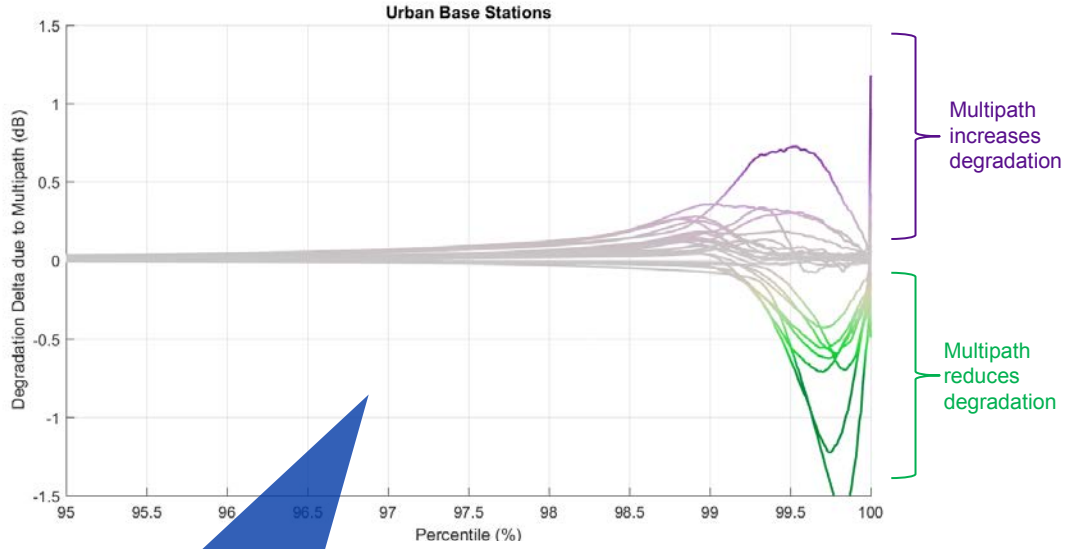


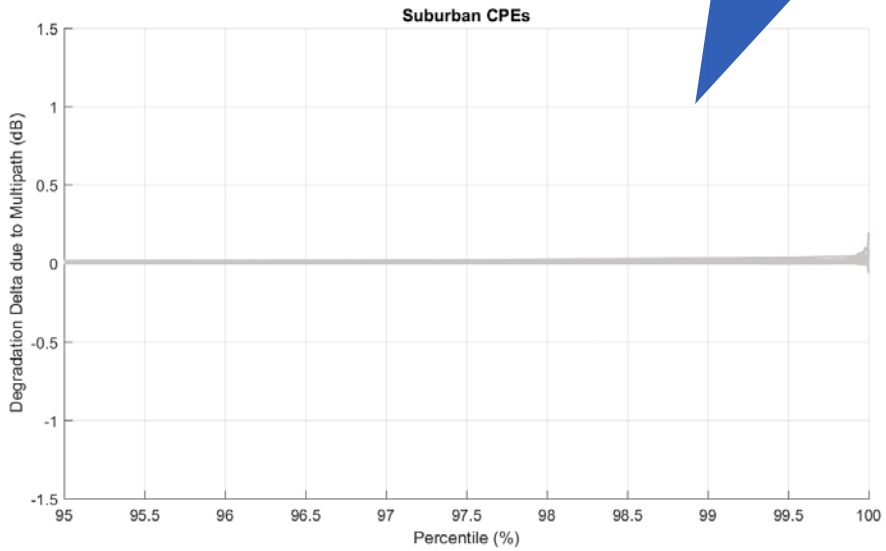
Suburban multipath results are consistent across many locations and scenes modeled

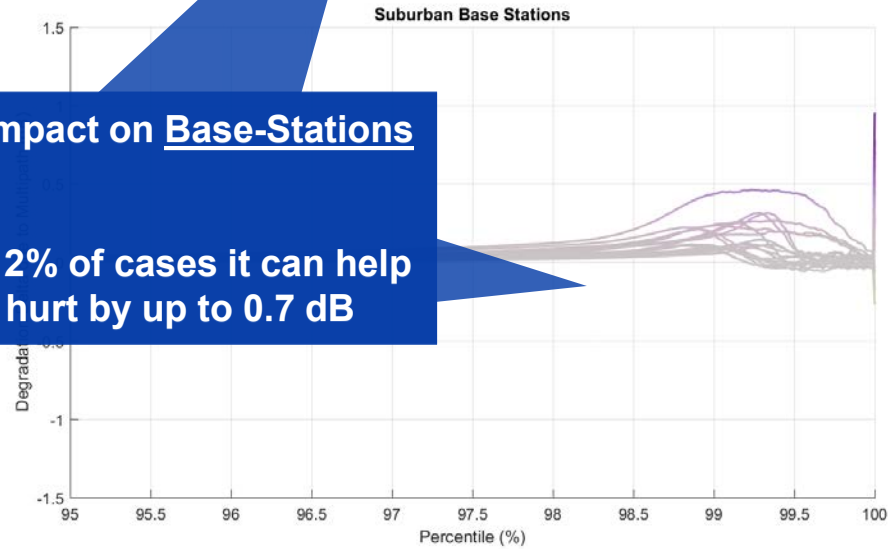
Comparing Multipath to Clear Line-of-Sight

Analysis of the difference between the multipath analysis and the clear LOS analysis









Multipath has little-to-no impact on Urban Handsets and Suburban CPEs

Multipath has little impact on Base-Stations 98% of the time.

In the most extreme 2% of cases it can help by up to 1.5 dB, and hurt by up to 0.7 dB

FSS Downlink Sharing with UMFUS

- Multi-system constellation modeling
- Impacts of system operation and 5G pointing
- Current regulations and EPFD framework for UMFUS

11 May 2017

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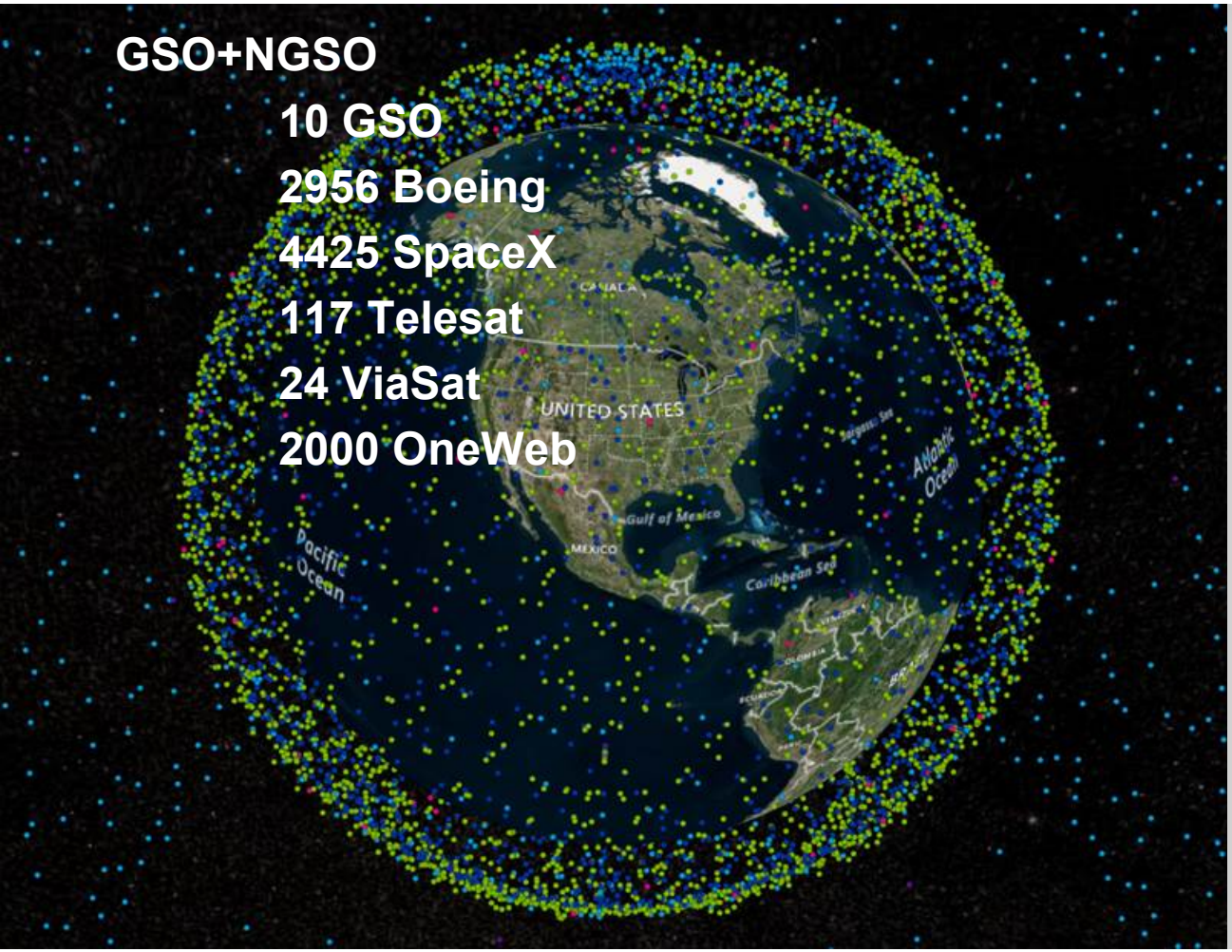
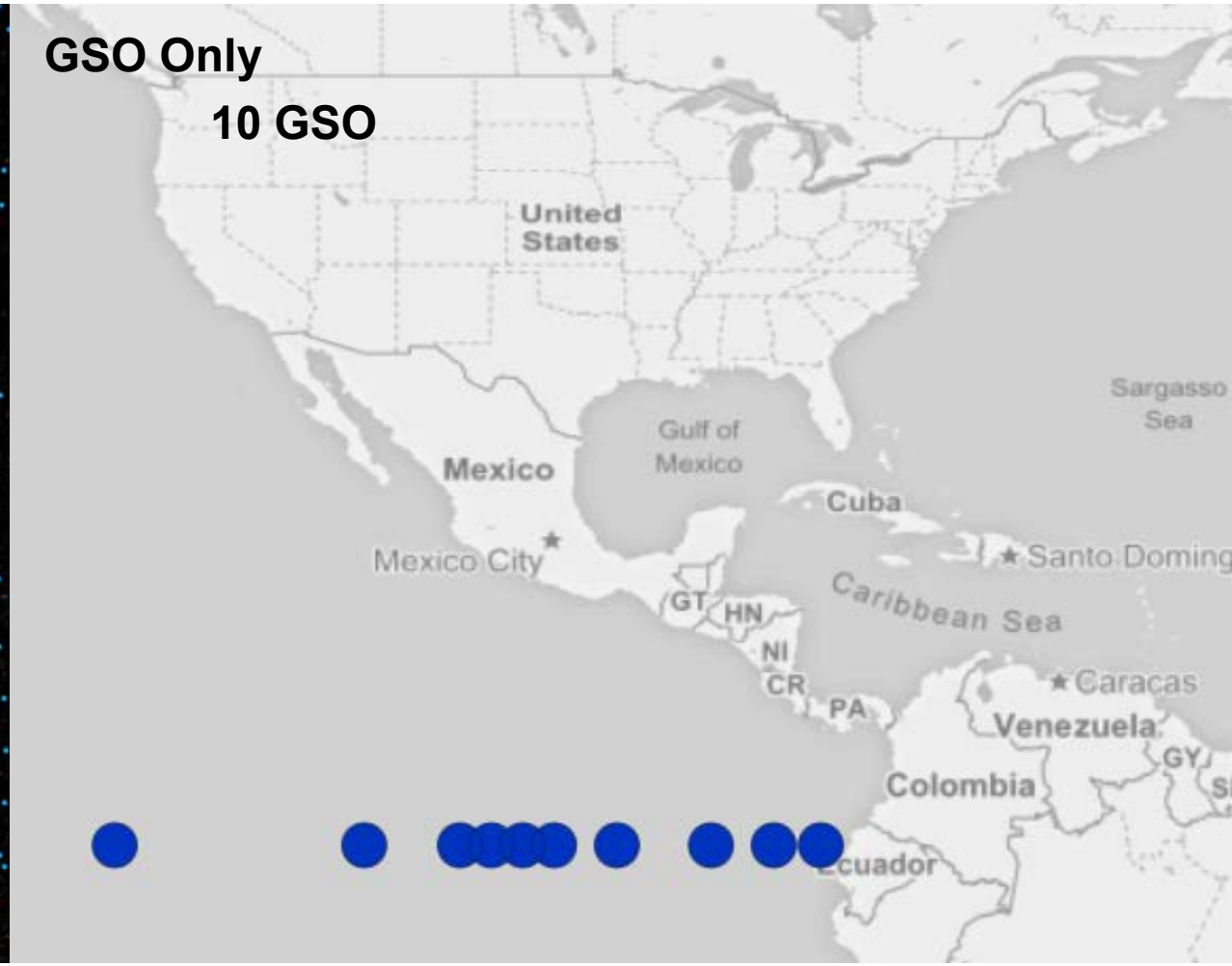
Constellation Modeling





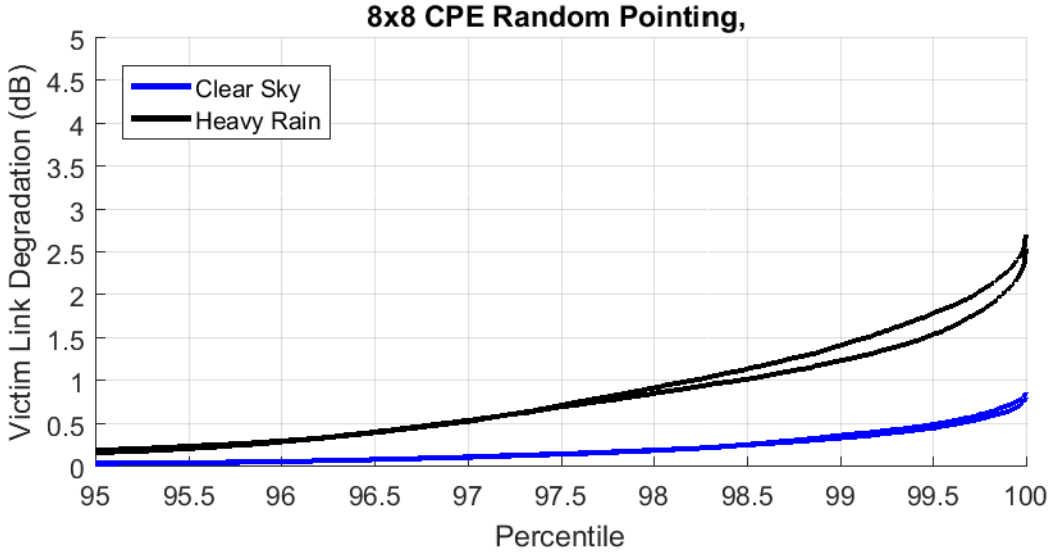
All constellations have a 4° self-exclusion angle for in-line events

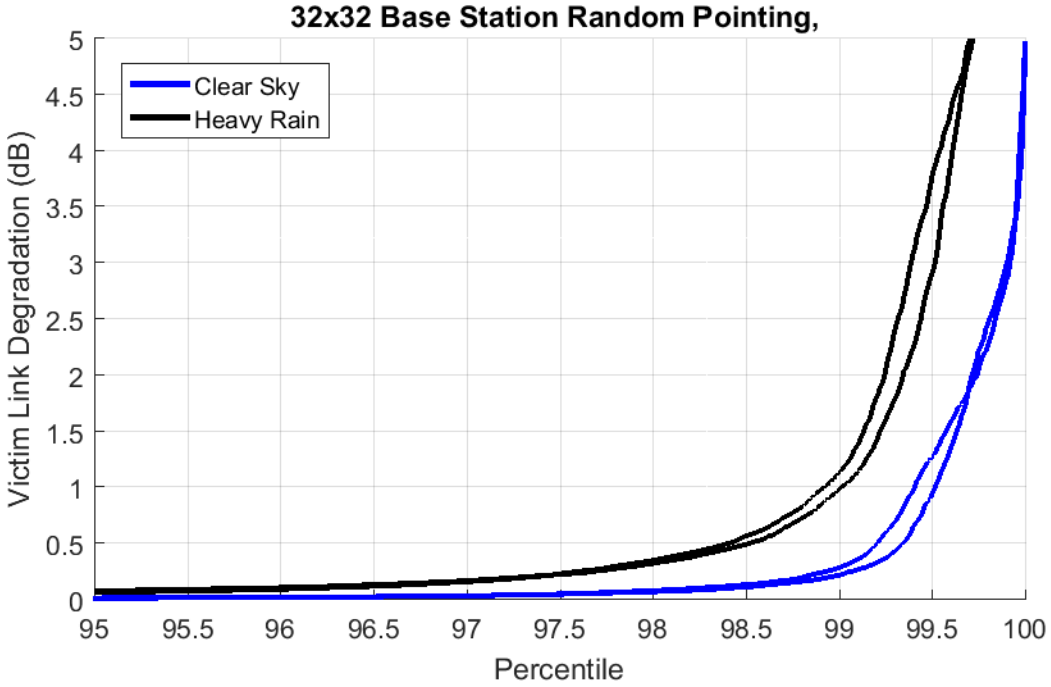
GSO-NGSO have a 10° exclusion angle for in-line events

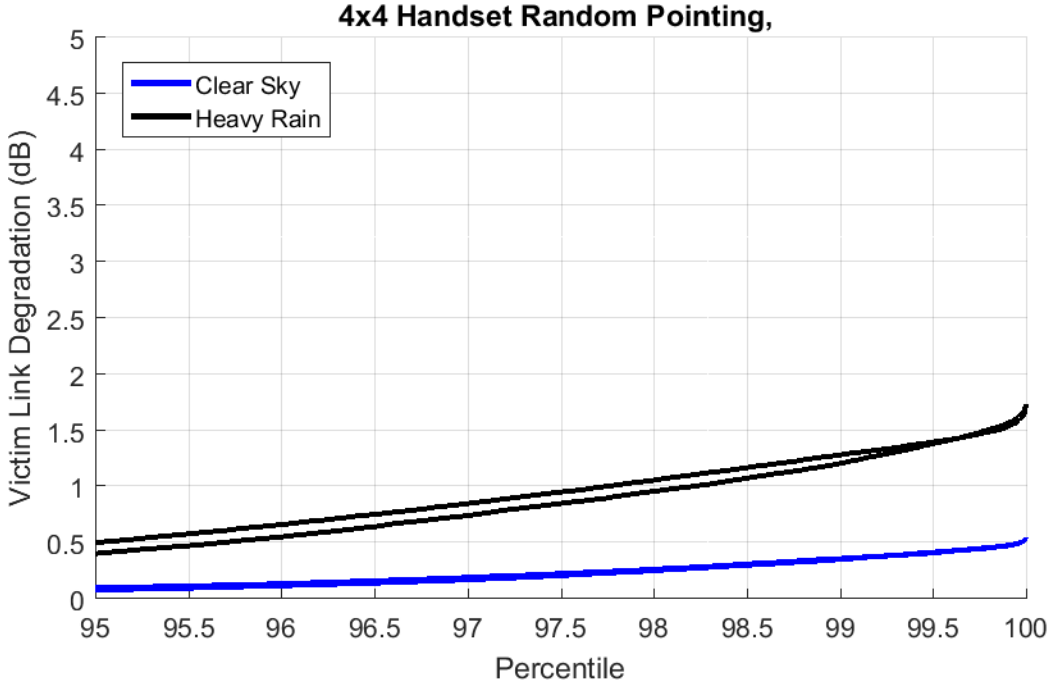
NGSO-NGSO have a 10° exclusion angle for in-line events

GSO Aggregate EPFD into UMFUS

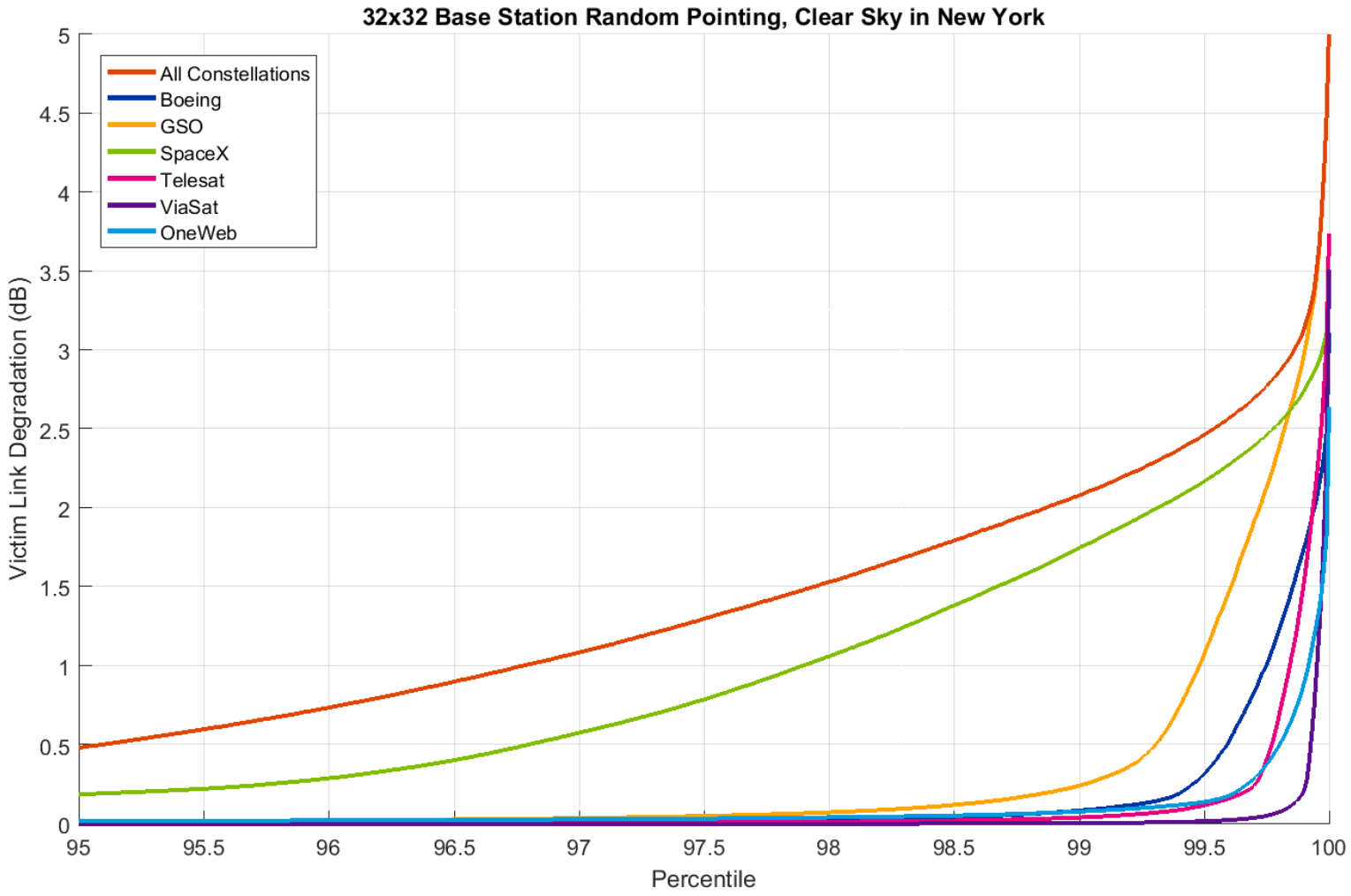
EPFD from GSO orbit locations is minimal and limited by 5G beamforming and antenna rejection







Combined GSO & NGSO Systems EPFD into UMFUS

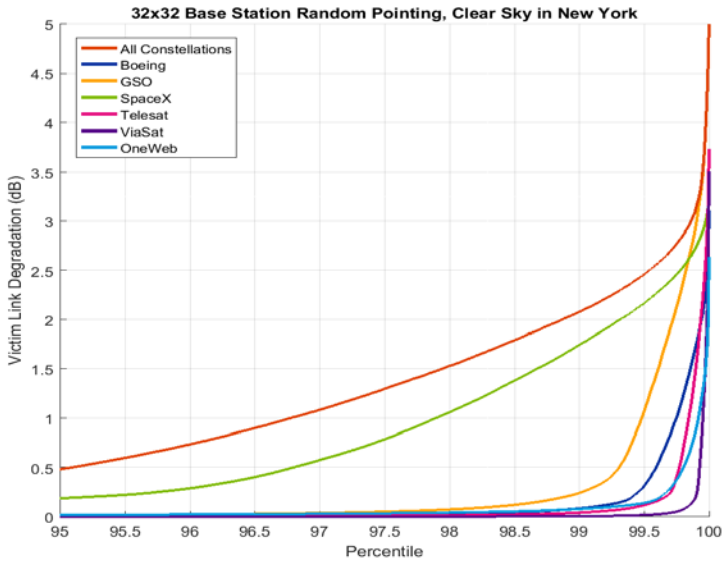


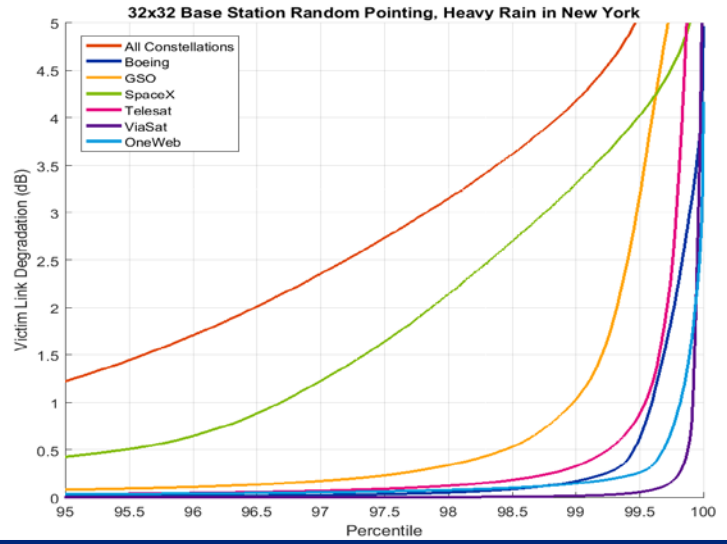
Constellation	Modeled Minimum Elevation Angle
Boeing	45°
SpaceX	35°
Telesat	10°
ViaSat	25°
OneWeb	60°

- Combined systems interference can be significantly higher depending on system operation (elevation angle) and 5G pointing assumptions
- Impacts can be constrained by EPFD regulations

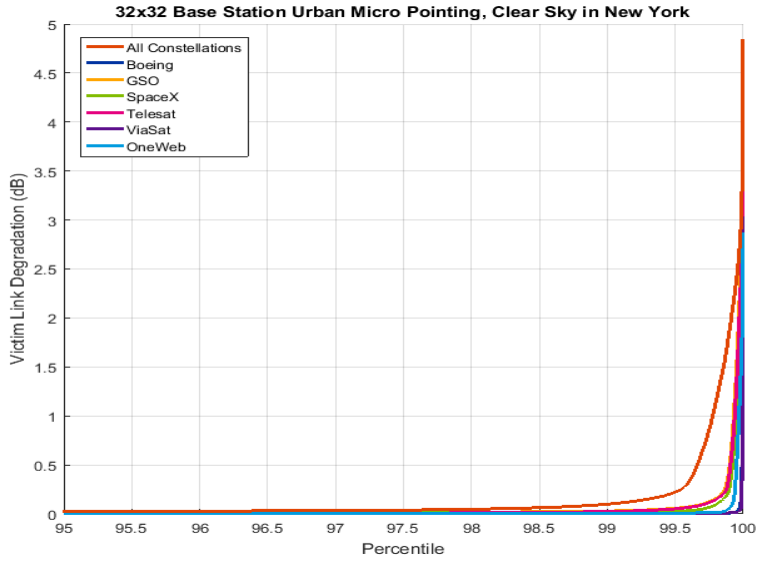
5G Receiver Pointing Assumption Also Drives Results

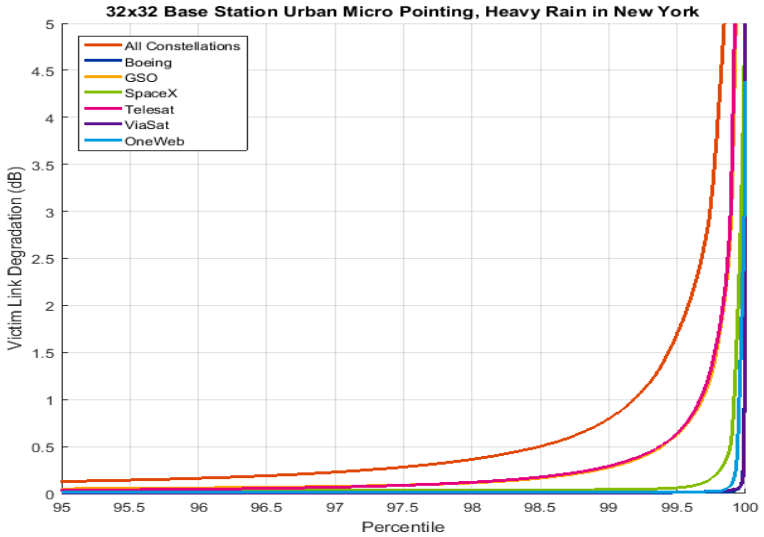
Random Pointing





Cellular Pointing (Urban Micro)





More realistic “cellular” pointing approach significantly reduces potential interference into UMFUS

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FCC V-band Satellite Downlink PFD Regulations and Possible Framework for FSS UMFUS EPFD Regulations

BOEING

• **25.208(q)(1) – GSO PFD in Clear Sky** (-117 dBW/m2/MHz)	• **No Change**
• **25.208(q)(2) – GSO PFD during rain-fade** (-105 dBW/m2/MHz)	• **No Change**
+ **NOTE to PARAGRAPH (q) – Conditions for PFD in heavy rain** →	• **Add 25.208(q)(3) – GSO clear sky and rain fade EPFD masks**
• **25.208(r)(1) – NGSO PFD in Clear Sky** (-117 dBW/m2/MHz)	• **No Change**
• **25.208(r)(2) – NGSO PFD during rain-fade** (-105 dBW/m2/MHz)	• **No Change**
+ **NOTE to PARAGRAPH (r) – Conditions for PFD in heavy rain** →	• **Add 25.208(r)(3) – NGSO+GSO clear sky and rain fade EPFD masks**

- ***Regulatory structure in 25.208 contains GSO and NGSO single satellite PFD levels***
- ***Adding EPFD regulations for combined GSOs and combined GSOs+NGSOs in clear sky and in rain fade can resolve the Note(s) and protect UMFUS***

Summary - V-band Downlink Spectrum Sharing

- **EPFD approach correctly models FSS-UMFUS interference**
- **Multipath impacts to FSS-UMFUS interference modeling are minor and consistent across locations and scenes modeled**
- **EPFD analyses have been extended to include clear sky and heavy rain cases, GSOs and NGSOs and multiple system modeling**
  - GSO system contributions are small contributors
  - 5G receive “random” pointing cases may be too conservative vs actual “cellular” pointing
  - Multiple NGSO systems contributions are manageable even assuming worst case conditions
  - An appropriate EPFD framework including clear sky, rain fade, GSO and NGSO+GSO cases can fully describe UMFUS interference