JONES DAY

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June 6, 2016

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 WT Docket No. 10-112

Dear Ms. Dortch:

On June 2, 2016, representatives of The Boeing Company ("Boeing") met with staff of the Federal Communications Commission ("Commission") to discuss the above-referenced proceeding and, more specifically, Boeing's further technical analysis regarding the strong potential for co-primary spectrum sharing between the proposed Upper Microwave Flexible Use ("UMFU") service and next-generation broadband satellite communications systems in the 37.5-40.0 GHz band. A list of attendees is attached.

The discussion tracked closely with the attached technical presentation, which demonstrates that satellite systems can successfully operate in the 37.5-40.0 GHz band using the higher space-to-earth power flux density limits maintained by the International Telecommunication Union[1] without causing appreciable interference to future UMFU systems. The discussion also referenced a recent *ex parte* filing by Straight Path Communications, Inc. ("Straight Path") in which Straight Path claimed that "[m]any of the phased array receivers" that will be used by future UMFU systems "are more susceptible to interference from satellites than current point-to-point links with fixed narrow beams along the horizon."[2] Straight Path provided no technical showing to support this claim. Boeing indicated that it would review any such technical showing that Straight Path places into the record of this proceeding.

[1] See ITU Radio Regulations, Article 21 (Table 21 4).

[2] *See* Letter from Davidi Jonas, CEO and President, Straight Path Communications, Inc., to Ms. Marlene H. Dortch, Secretary, Federal Communications Commission, at 3 (June 1, 2016).

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

June 2, 2016 Ex Parte Meeting Attendees

Wireless Telecommunications Bureau

- Simon Banyai
- Stephen Buenzow (by phone)
- Brian Regan
- John Schauble
- Chris Helzer
- Paul Powell
- Catherine Schroeder
- Blaise Scinto
- Charles Oliver (by phone)
- Nancy Zaczek

Office of Engineering and Technology

- Michael Ha
- Barbara Pavon (by phone)
- Martin Doczkat

International Bureau

- Jose Albuquerque
- Robert Nelson
- Chip Fleming

Boeing Participants

- Audrey Allison
- Christopher Foster
- Carlos Nalda
- Bruce Olcott
- Robert Vaughan

V-band Satellite and Terrestrial Spectrum Sharing: Statistical Analysis

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Agenda

- **Overview – Statistical Analysis Supports Sharing**
- **Updated Satellite to Mobile Sharing Assessments**
  - Satellite to Mobile Handset
  - Satellite to Base Station
- **Updated Mobile to Satellite Earth Station Receivers Sharing Assessment**
  - Mobile Handset to Satellite Earth Station Receivers
  - Base Station to Satellite Earth Station Receivers
- **Statistical Performance Modeling and Results**
- **Summary of Sharing Analysis**
- **Path Forward for Further Technical Study**

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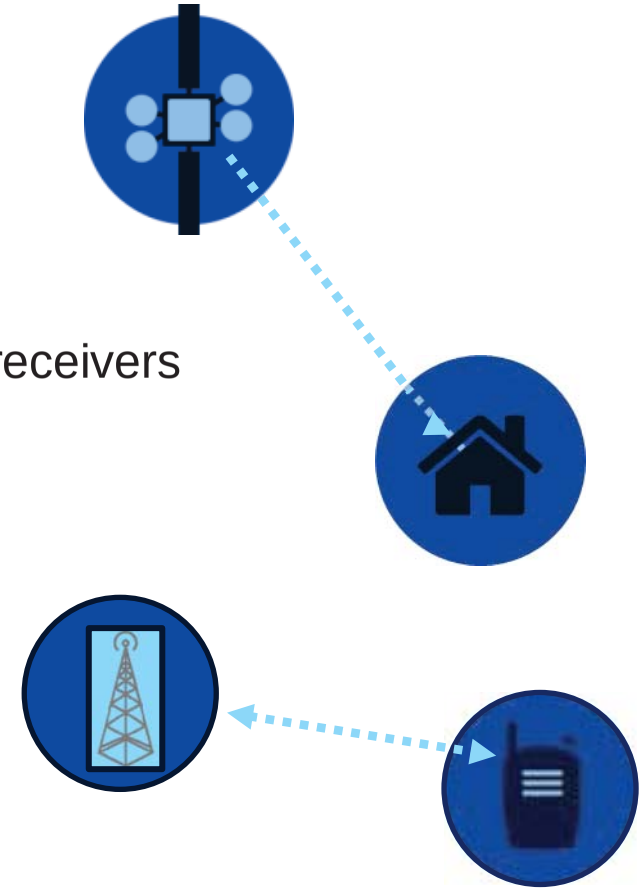
Overview – Spectrum Sharing Can be Achieved

- **37.5 – 40.0 GHz**
  - FSS satellite downlink allocation (gateway only)
  - Proposed use by terrestrial 5G mobile
- **Achieve shared usage between:**
  - 5G base stations and handsets
  - High-capacity satellites and satellite earth station receivers
- **Measures contributing to shared use:**
  - 5G beam forming and power control
  - Highly directional satellite receivers using nulling
    - Results in significant angular separation between 5G transmissions and satellite receiver reception paths
  - Limit on 5G base station power level
  - Satellite transmissions at (or near) ITU pfd levels



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Activities Conducted Since 5 May Meeting

- **Technical interaction with multiple 5G operators and suppliers**
  - Review of sharing and interference analyses
  - Technical discussions of link budget assumptions, 5G system goals, and 5G beamforming approaches
- **Statistical modeling of satellite – 5G interference**
  - Generic 5G system model similar to other analyses
  - Results are consistent with prior analysis
    - Satellite interference into terrestrial system is minimal at ITU PFD levels
    - 5G interference into satellites remains the closest scenario
  - Further work is required
- **Updates included in this analysis package**

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Satellite Operations into Terrestrial 5G Receivers

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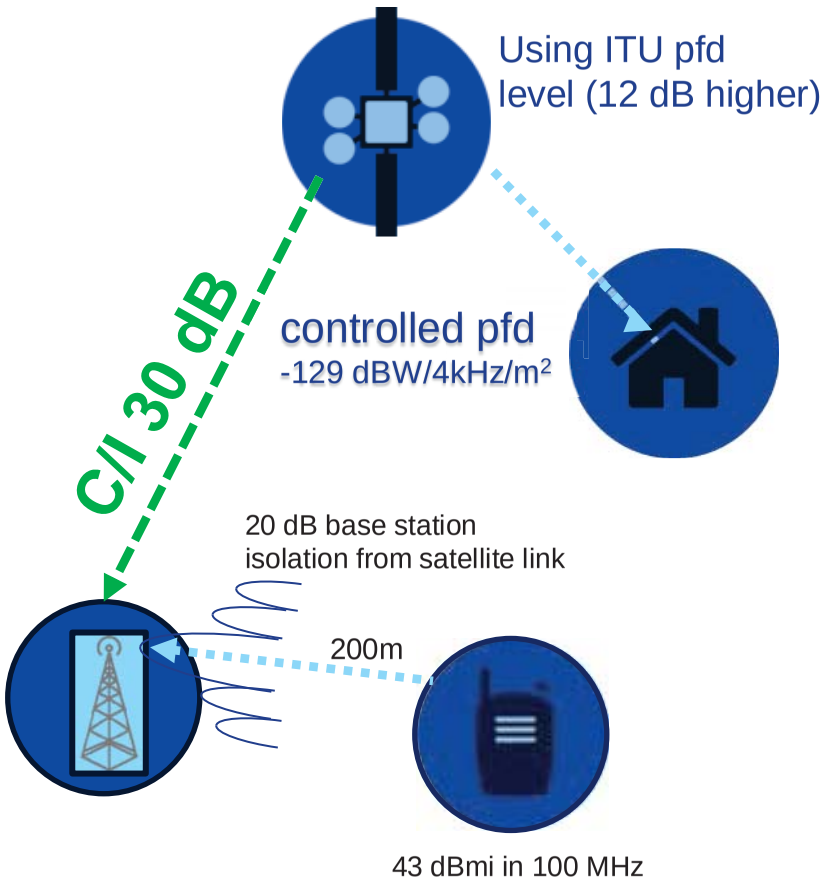
Satellite Operations and 5G Receivers Mobile to Base Station Link (Return)

Boeing Satellite Systems

- **5G performance impacted < 0.2 dB using higher ITU operating limit**

Mobile Handsets to Base Station		
5G Mobile EIRP	43.0	dBm
Mobile to Base Station Distance	200.0	m
Mobile to Base Station Path Loss[1]	141.2	dB
Transmit Bandwidth	100.0	MHz
5G Mobile PFD at Base Station	-118.9	dBW/4kHz/m^2
Satellite PFD at Base Station	-129.0	dBW/4kHz/m^2
5G Base Station Rx Isolation	20.0	dB
C/I due to Satellite Interference	30.1	dB
Rx Gain at 5G Base Station [2]	27.0	dB
5G Received Power at Base Station	-71.2	dBm
Received Noise Power	-87.0	dBm
5G Return Link C/N	15.8	dB
5G Return Link C/(I+N)	15.6	dB
Interference Degradation	0.16	dB
Interference to Noise ratio, I_{SAT}/N_{5G}	-14.3	dB
	3.7	%



[1]Rappaport, Theodore; Ben-Dor, Eshar; Murdock, James N.; Qiao, Yijun, "38 GHz and 60 GHz Angle-dependent Propagation for Cellular & Peer-to-Peer Wireless Communications." IEEE ICC 2012 - Wireless Communications Symposium.
[2]Fox, R.; Kung, A; "Comments of Straight Path Communications, Inc." Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service, RM-11664, January 5, 2015.

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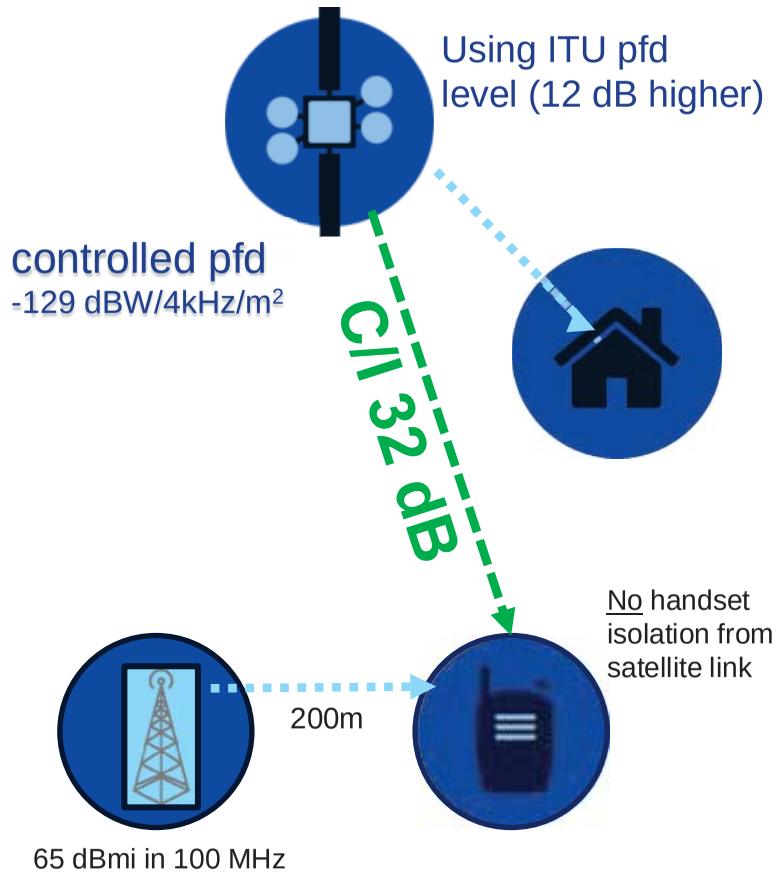
Satellite Operations into 5G Users Base Station to Mobile Link (Forward)

Boeing Satellite Systems

- **5G Performance impacted < 0.6 dB using higher ITU operating limit**

Base Station to Mobile Handsets		
5G Base Station EIRP	65.0	dBm
Mobile to Base Station Distance	200.0	m
Mobile to Base Station Path Loss[1]	141.2	dB
Transmit Bandwidth	100.0	MHz
5G Base Station PFD at Mobile	-96.9	dBW/4kHz/m^2
Satellite PFD at Mobile	-129.0	dBW/4kHz/m^2
5G Mobile Rx Isolation	0.0	dB
C/I due to Satellite Interference	32.1	dB
Rx Gain at 5G Mobile[2]	13.0	dB
5G Received Power at Mobile	-63.2	dBm
Received Noise Power	-87.0	dBm
5G Forward Link C/N	23.8	dB
5G Forward Link C/(I+N)	23.2	dB
Interference Degradation	0.60	dB
Interference to Noise ratio, I_{SAT}/N_{5G}	-8.3	dB
	14.9	%

[1]Rappaport, Theodore; Ben-Dor, Eshar; Murdock, James N.; Qiao, Yijun, "38 GHz and 60 GHz Angle-dependent Propagation for Cellular & Peer-to-Peer Wireless Communications." IEEE ICC 2012 - Wireless Communications Symposium.
[2]Fox, R.; Kung, A; "Comments of Straight Path Communications, Inc." Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service, RM-11664, January 5, 2015.



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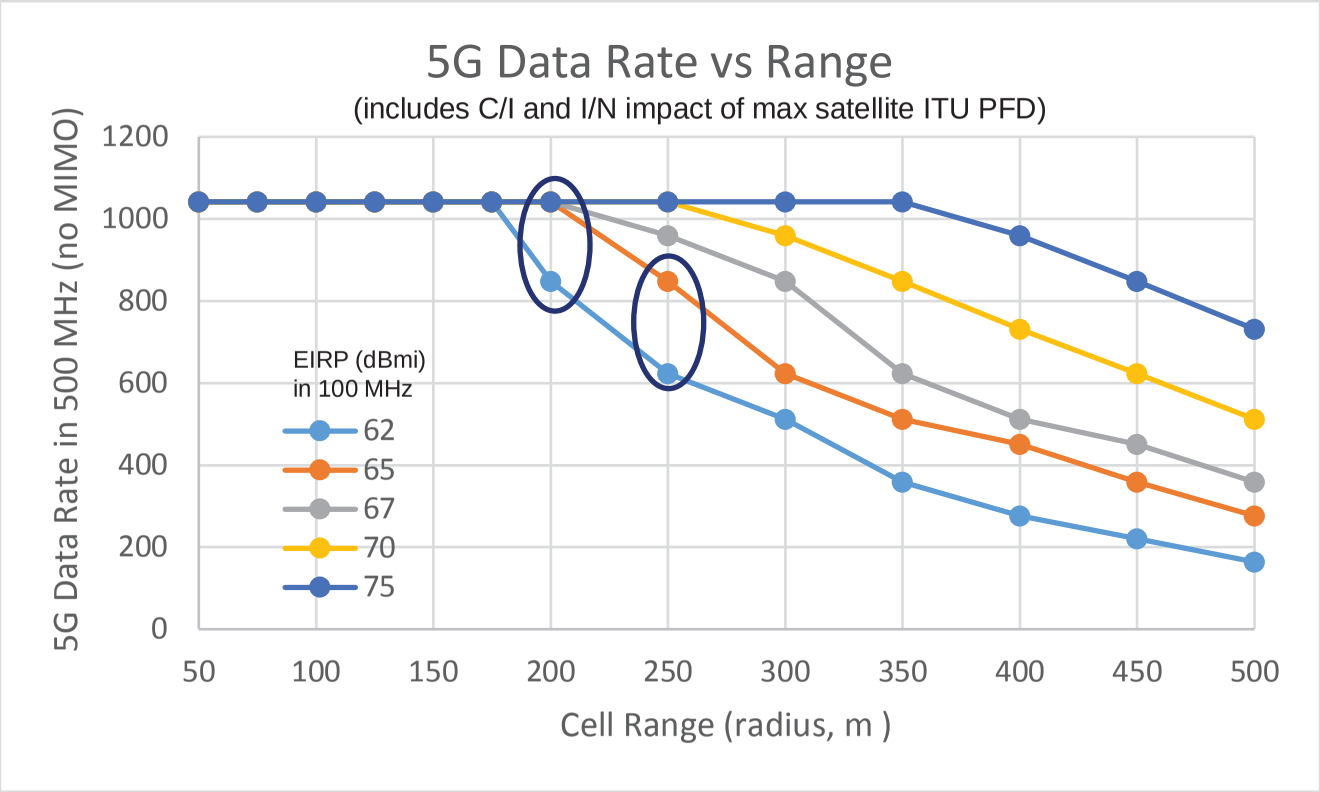
Satellite Interference into 5G Users
5G Link Operating Range and Data Rate

Boeing Satellite Systems



- **0.2 to 0.6 dB impact on links in urban environments (<u>less</u> if link is in LOS free space conditions)**
- **Requires 0.6 dB more link power (EIRP)**
- **65 dBmi in 100 MHz supports 5G data rates 800 Mbps -1 Gbps for 400-500m cells**
- **Can increase 4-8x with improved modulation/ coding and MIMO**

Data Rate calculated using LTE waveform modulations/coding, 500 MHz bandwidth, derated using 62.5% FW duty cycle and 40% system overhead – see **Fox, R.; Kung, A; "Comments of Straight Path Communications, Inc." Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service, RM-11664, January 5, 2015**

Planned 5G systems operating in multiple environments will have minimal impacts from maximum ITU satellite PFD operation

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Terrestrial 5G Operations into Satellite Earth Station Receivers

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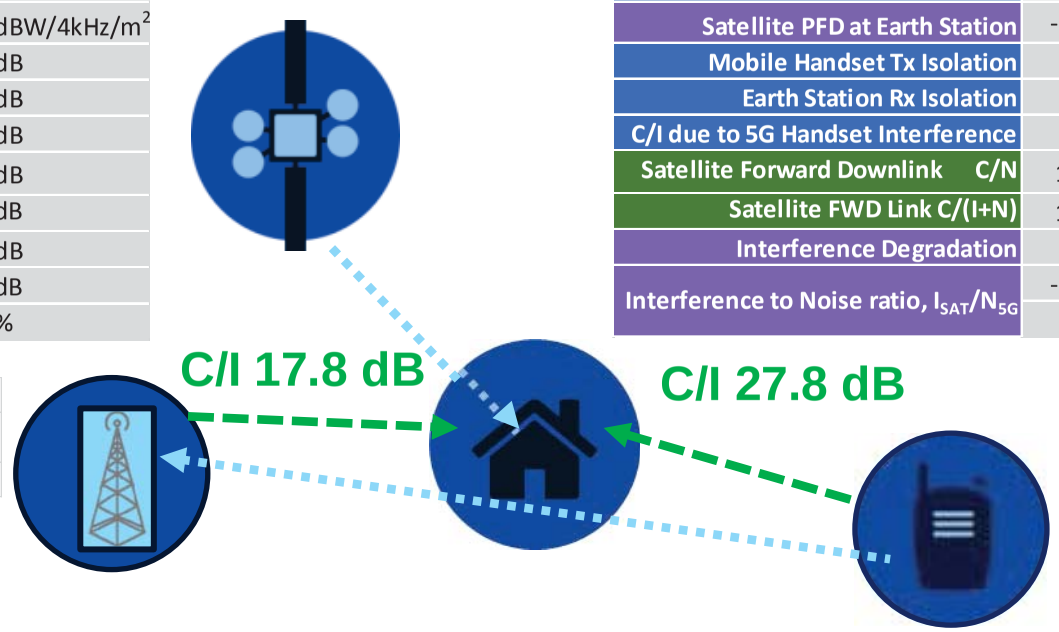
5G User Operations into Satellite Earth Station Receivers

Boeing Satellite Systems

- **Two scenarios considered in statistical link budgets**
  - 5G Mobile Handset into Satellite Receive Earth Station
  - 5G Base Station into Satellite Receive Earth Station

5G BASE STATION INTO RECEIVE EARTH STATION		
5G Mobile Base Station EIRP[1]	65.0	dBm
Handset to Earth Station Distance	100.0	m
Handset to Earth Station Path Loss[2,3]	130.0	dB
Base Station Transmit Bandwidth	100.0	MHz
Base Station PFD at Earth Station	-85.8	dBW/4kHz/m^2
Satellite PFD at Earth Station	-138.0	dBW/4kHz/m^2
Base Station Tx Isolation	20.0	dB
Earth Station Rx Isolation	50.0	dB
/I due to 5G Base Station Interference	17.8	dB
Satellite Forward Downlink C/N	11.20	dB
Satellite FWD Link C/(I+N)	10.33	dB
Interference Degradation	0.87	dB
Interference to Noise ratio, I_{SAT}/N_{5G}	-6.56	dB
	22.1	%

5G MOBILE HANDSET INTO RECEIVE EARTH STATION		
5G Mobile Handset EIRP[1]	43.0	dBm
Handset to Earth Station Distance	100.0	m
Handset to Earth Station Path Loss[2,3]	130.0	dB
Handset Transmit Bandwidth	20.0	MHz
Handset PFD at Earth Station	-100.8	dBW/4kHz/m^2
Satellite PFD at Earth Station	-138.0	dBW/4kHz/m^2
Mobile Handset Tx Isolation	15.0	dB
Earth Station Rx Isolation	50.0	dB
C/I due to 5G Handset Interference	27.8	dB
Satellite Forward Downlink C/N	11.20	dB
Satellite FWD Link C/(I+N)	11.11	dB
Interference Degradation	0.09	dB
Interference to Noise ratio, I_{SAT}/N_{5G}	-16.57	dB
	2.2	%



1	Fox, R.; Kung, A; "Comments of Straight Path Communications, Inc." Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service, RM-11664, January 5, 2015.
2	Akdeniz, M.R.; Yuanpeng Liu; Samimi, M.K.; Shu Sun; Rangan, S.; Rappaport, T.S.; Erkip, E., "Millimeter Wave Channel Modeling and Cellular Capacity Evaluation," Selected Areas in Communications, IEEE Journal on , vol.32, no.6, pp.1164,1179, June 2014
3	Angle-dependent Propagation for Cellular & Peer-to-Peer Wireless Communications." IEEE ICC 2012 - Wireless Communications Symposium.

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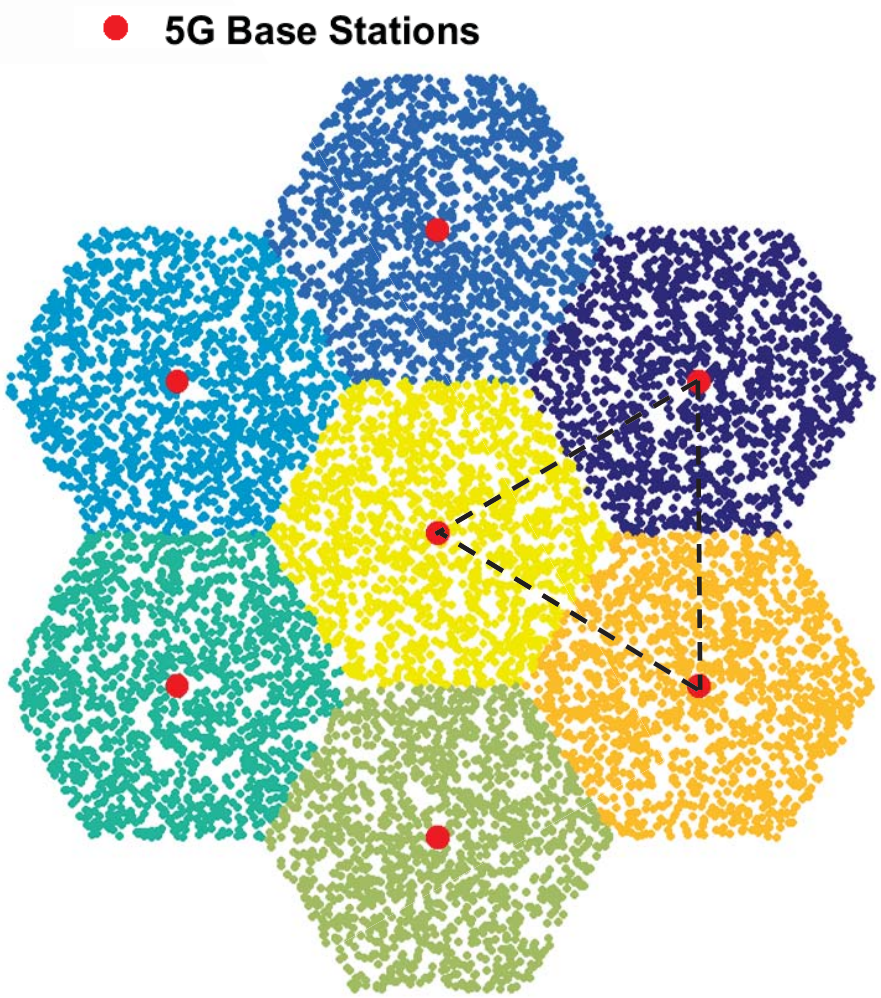
Base Station / Mobile User Geometry

- **100k Monte Carlo independent random draws to specify three locations**
  - 5G Mobile Handsets
  - Receive earth stations
  - Satellite transmitter
- **Each location distributed uniformly**
  - Mobile handsets and satellite receive earth stations are uniformly spread at ground level
  - Satellite position is uniformly distributed over a spherical shell > 45 degrees elevation
- **Exactly one earth station and one co-frequency mobile chosen per draw**
  - Many independent trials generate representative statistics for look angles and distances
  - Statistical link budgets created between 5G users (handsets and base stations) and satellite users



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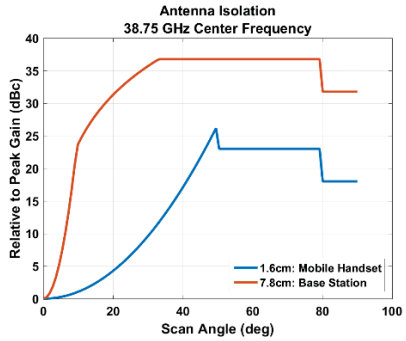
Transmit and Receive Isolation

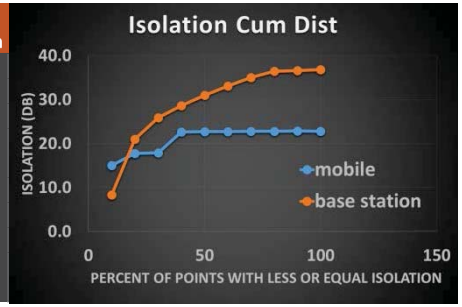
Boeing Satellite Systems

- **5G base station and handset Tx Isolation given by ITU-R S.1428**

Diameter From Peak Gain				
η	50.0	50.0	%	Efficiency
G	13.0	27.0	dBi	Peak Gain
D	1.6	7.8	cm	Antenna
	0.0	7.8E-02	m	Diameter
λ	0.0	7.7E-03	m	Wavelength
f	38.8	38.8	GHz	Center Frequency
$G = 10\log_{10}(\eta(\pi D/\lambda)^2)$				

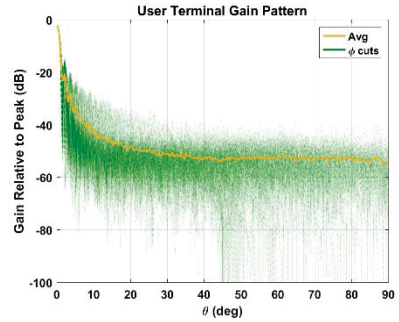


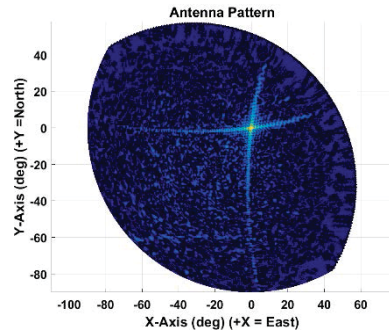
	mobile	base station
10	15.0	8.3
20	17.8	21.0
30	17.9	25.9
40	22.6	28.6
50	22.7	31.0
60	22.7	33.1
70	22.8	35.0
80	22.8	36.4
90	22.8	36.6
100	22.8	36.8

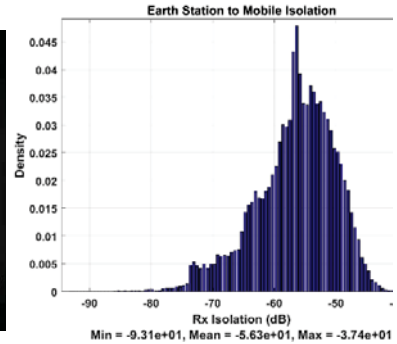


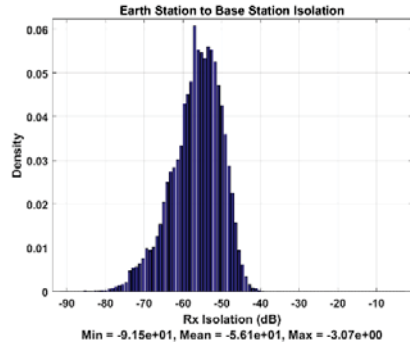
Base Station Tx Isolation: >20dB in 80% of trials
Handset Transmit Isolation >15dB in 90% of trials

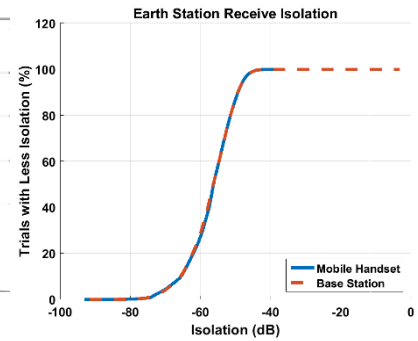
- **Earth station terminal Rx Isolation given by phased array with scan and distortion**











Earth Station Rx: 56dB mean isolation toward 5G users

Beamforming enables sharing by providing isolation

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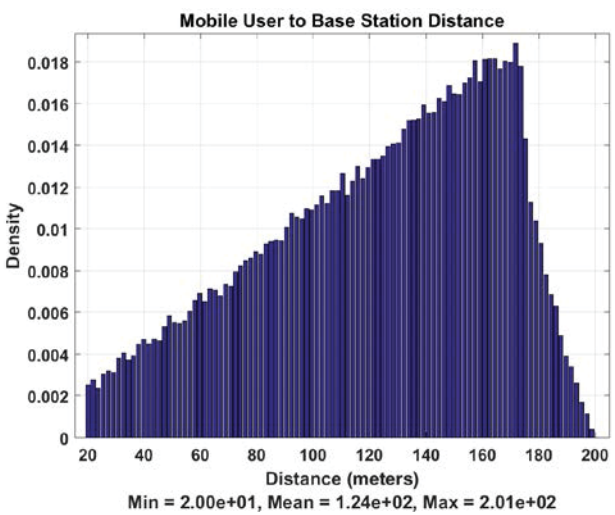
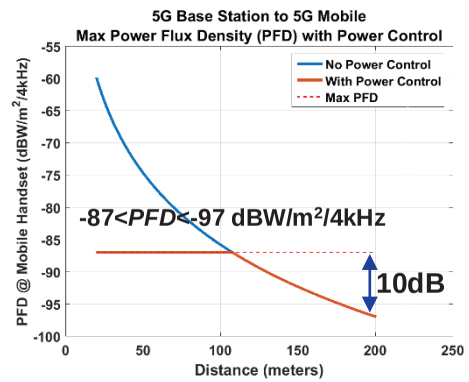
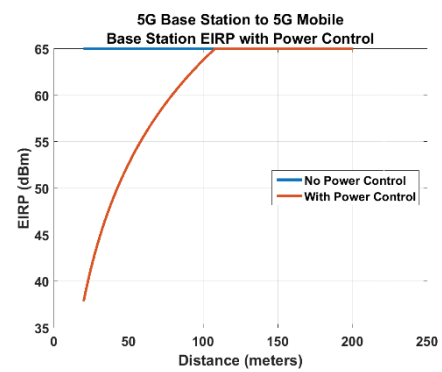
Distance, Path Loss and Power Control

- **Distance between the handset and base station sets 5G path loss**
- **Power Control limits receive PFD on the 5G link to a dynamic range**
  - Minimum PFD computed at max range with non-line of sight losses, max EIRP
  - Maximum PFD is minimum PFD plus dynamic range (e.g.10 dB)

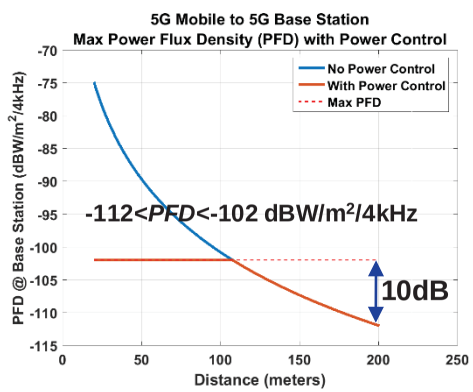


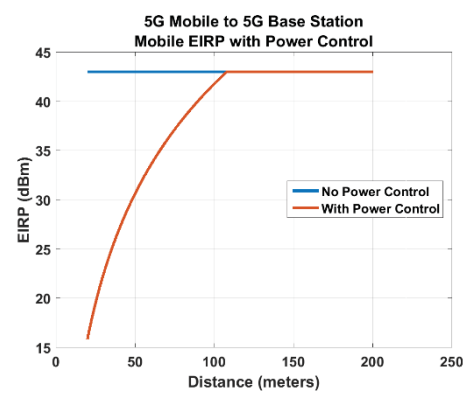
Base Station to Mobile, PFD and EIRP





Mobile to Base Station, PFD and EIRP





Power control limits received interference close to base stations

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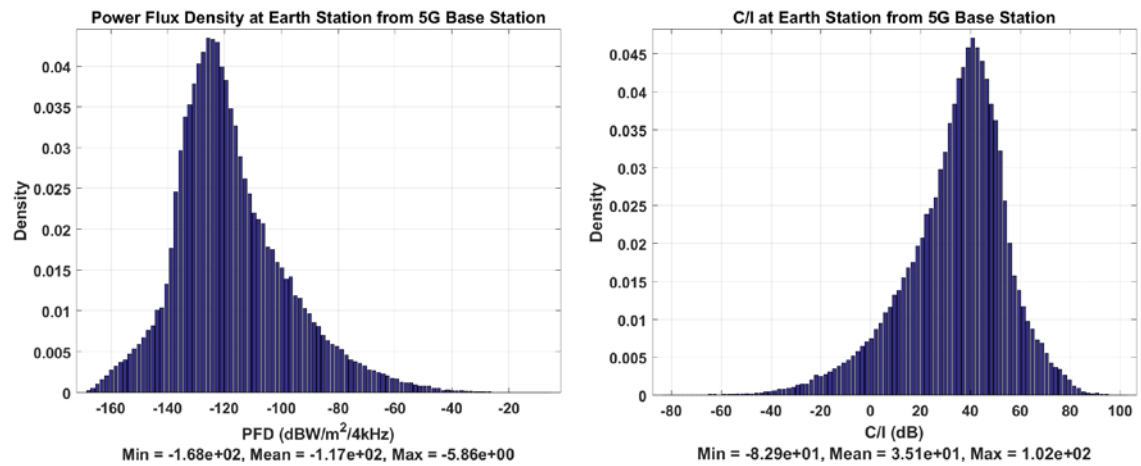
PFD and C/I at Earth Station Receive Terminal

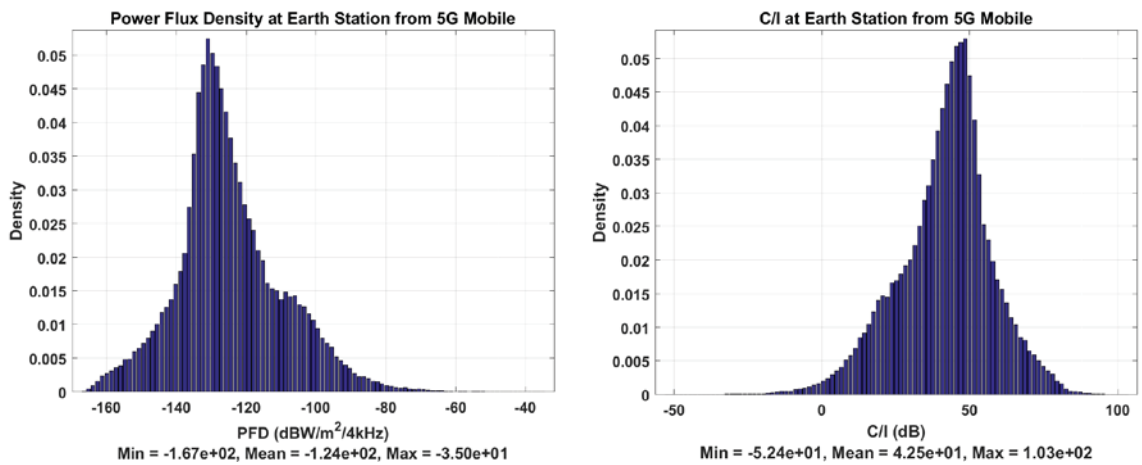
Boeing Satellite Systems

- **PFD from 5G base stations and users at receive earth stations includes:**
  - EIRP with power control
  - Non line-of-sight losses
  - Tx Isolation from angle between intended target and the earth station
- **C/I at receive earth stations includes:**
  - Nominal -138 dBW/m^2/4kHz satellite PFD
  - Rx Isolation toward 5G mobile users and base station from representative antenna pattern

Base Station to Earth Station Receiver PFD and C/I



Mobile to Earth Station Receiver PFD and C/I



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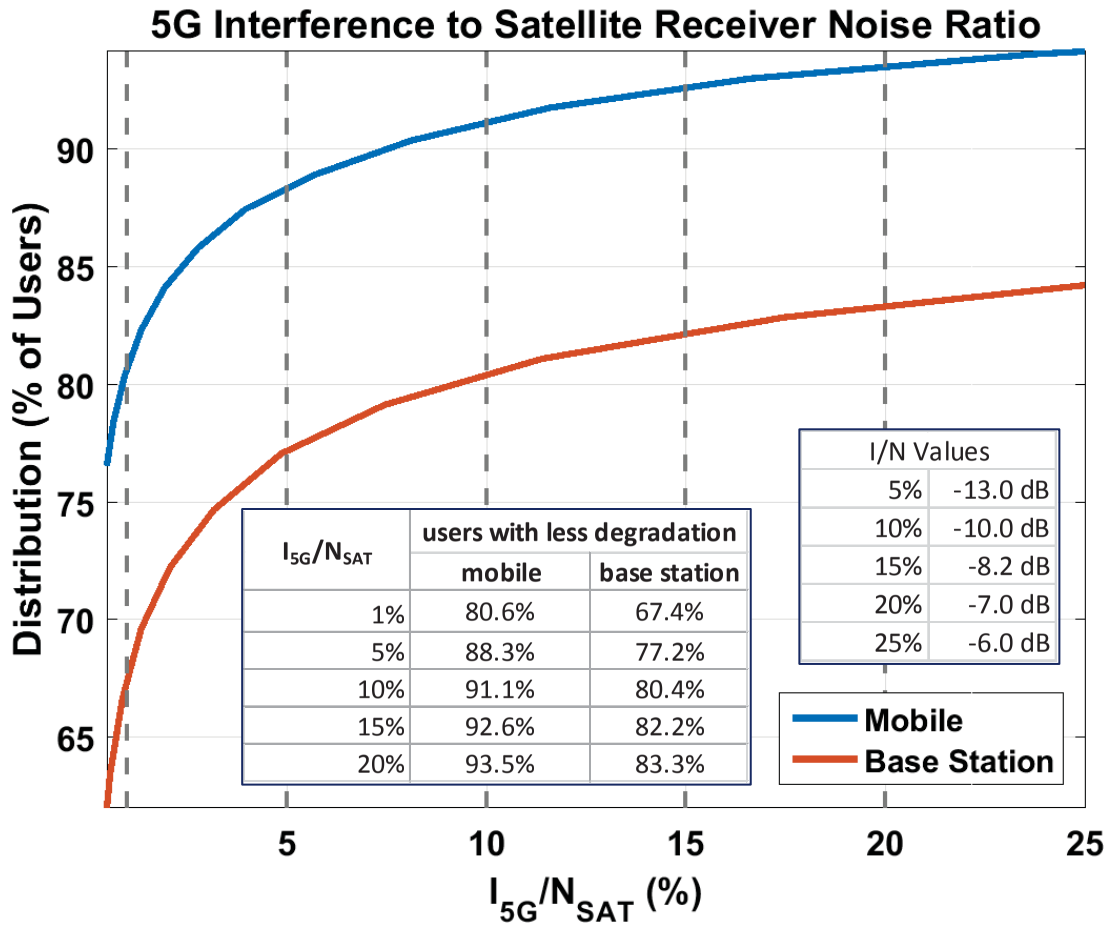
Percent of total link from 5G transmitters at Earth Station Receive Terminal

- **Total link impact is given as the ratio I_{5G} / N_{SAT}**
  - I_{5G} is mobile handset or base station transmitter interference into the satellite receive earth station
  - Using C/I_{5G} from prior page, we can derive the ratio above
- **15% of earth stations receive interference power that is 25% of system noise**
- **Operating earth stations near base stations is difficult, even with proposed power level restrictions**



I_{5G}/N_{SAT}	users with less degradation	
	mobile	base station
1%	80.6%	67.4%
5%	88.3%	77.2%
10%	91.1%	80.4%
15%	92.6%	82.2%
20%	93.5%	83.3%

I/N Values	
5%	-13.0 dB
10%	-10.0 dB
15%	-8.2 dB
20%	-7.0 dB
25%	-6.0 dB

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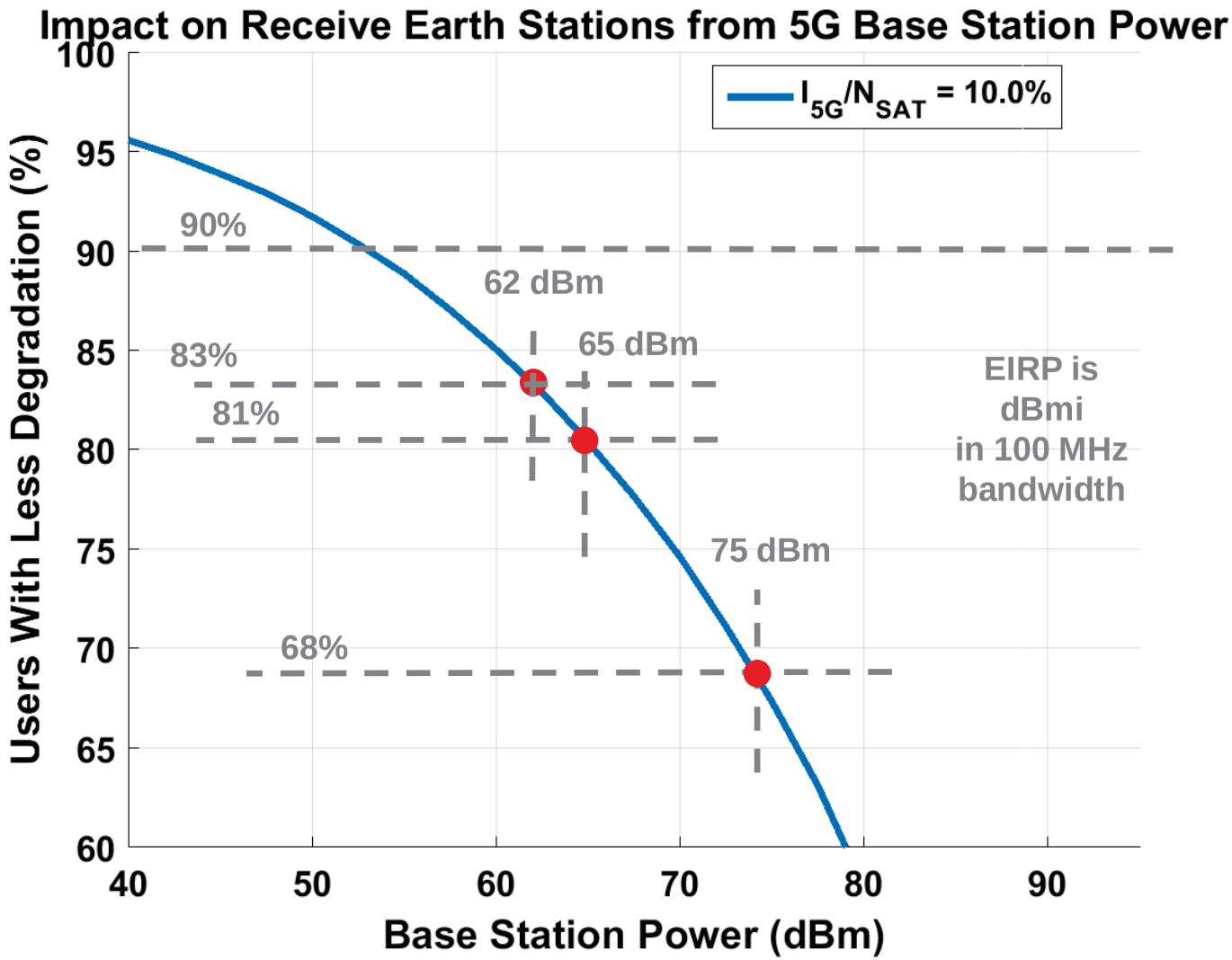
5G Base Station Interference vs. Base Station Power

Boeing Satellite Systems

- **Link impact as a function of base station power**
  - Number of satellite users impacted increases with increasing base station power
  - In addition to 10% system noise increase, satellite system capacity drops ~15% between 62 and 75 dBm per 100 MHz



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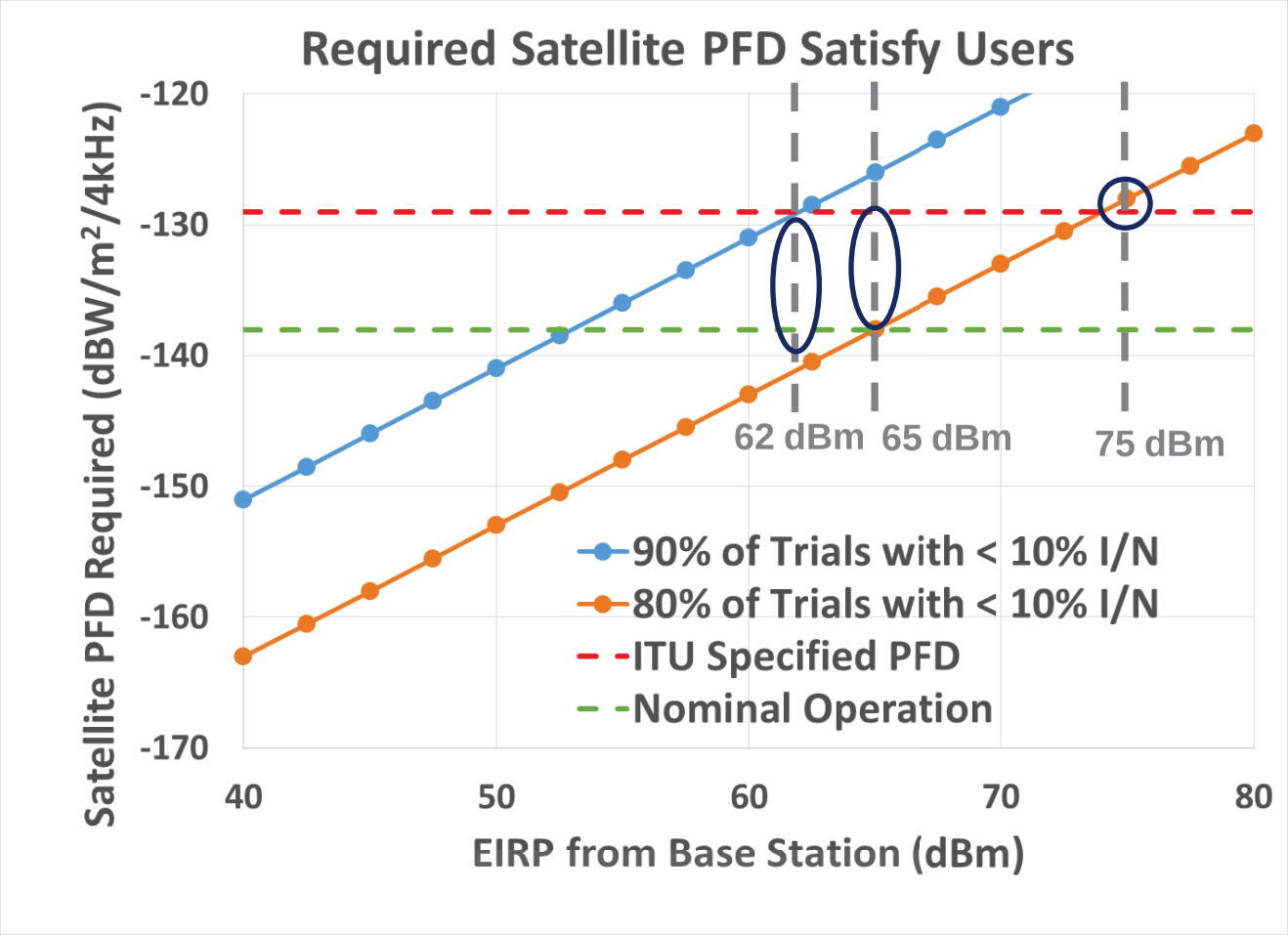
Satellite Capacity and Operating Power will be impacted by higher 5G EIRP operation

Boeing Satellite Systems

- **Higher 5G base station EIRP yields limited increase in 5G service range/data rate**
- **FSS system could raise operating PFD in affected areas due to higher 5G base-station EIRP**
  - Operations up to ITU PFD limit would only impact 5G system by (0.2-0.6 dB)
  - Greater impact to FSS capacity (+9 dB power to overcome 75 dBm interference and retain 80% FSS system operating capacity



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Future Sharing Assessments – Satellites and Terrestrial 5G

- **Continue modeling with further updated assumptions for 5G system design and operations**
  - 5G antenna patterns for more accurate isolation modeling
  - Multiple access schemes and 5G spectral reuse
  - More detailed power control models
- **Utilize simulations to perform additional sensitivity studies**
  - 5G deployment geometry (varying cell radius)
  - Multiple NGSO satellite coverage (select best link)
  - Mixed propagation paths and models
    - LoS vs. NLoS propagation (NLoS boundaries)
    - Other impairments / blockages (e.g. rain, foliage)

Initial sharing assessments enhanced by detailed modeling
Further dialogue and study will improve sharing guidelines

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Summary – 5G and Satellite Spectrum Sharing at 37.5-40.0 GHz

- **FSS satellite usage and terrestrial 5G spectrum sharing is possible in the 37.5-40.0 GHz band**
  - Downlink-only band for FSS satellites
  - Sharing is enabled because of high elevation angles
  - Sharing is also enabled by key beamforming techniques inherent to satellite and 5G system design for high data rates

- **5G systems are protected from satellite downlink using ITU PFD limit, with minimal degradation to 5G operations (0.2-0.6 dB)**
- **Satellite earth station receivers offer high isolation (>50 dB) and may be able to share with 5G mobile and base stations**
  - Statistical simulations support Boeing's initial interference assessments
  - Satellite earth stations will be most impacted by base-station forward links
  - 5G EIRP must be limited near proposed value (62-65 dBm) to facilitate sharing without hindering 5G data rate goals
- **Both systems can achieve the vision of broadband data rates and rapid deployment with appropriate sharing guidelines**

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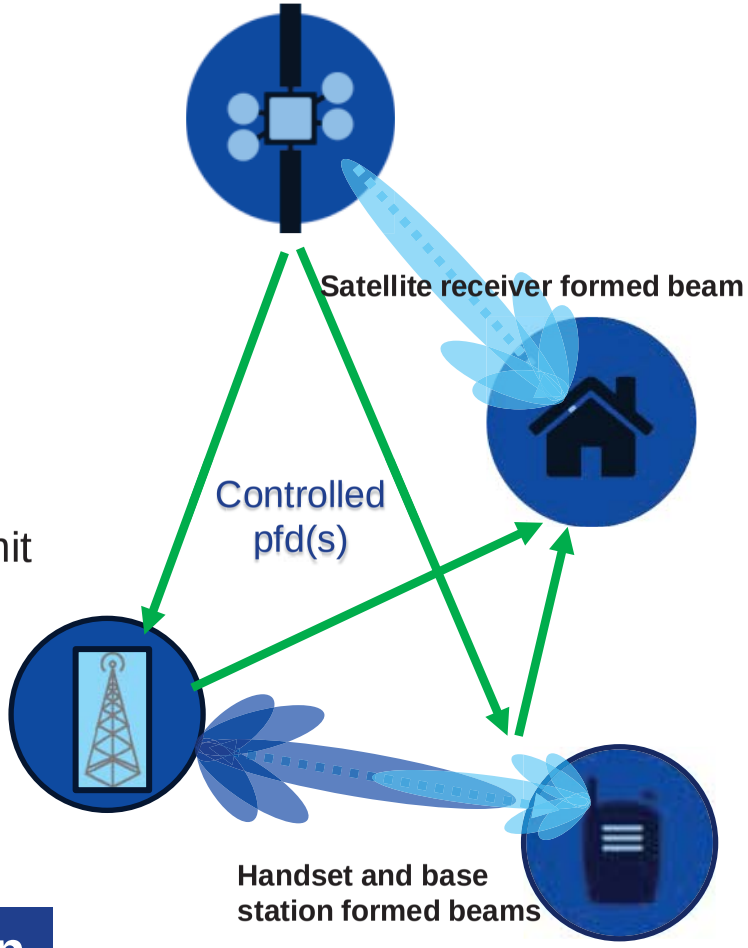
Path forward for 37.5-40.0 GHz - Recommendations

- **Measures to ensure efficient spectrum use:**
  - Remove prohibition on satellite end user receivers
    - Allow unrestricted deployment of satellite receivers
  - Permit satellite downlinks at (or near) ITU PFD levels
  - Require mobile services to use beam forming
    - Facilitate both inter- and intra-service sharing
    - Apply modest off-axis sidelobe isolation requirements consistent with planned 5G system design(s)
  - Require mobile services to use power control
    - Limits interference into LOS satellite user terminals
  - Adopt base station transmitter power / EIRP density limit
    - Reduces aggregate interference into upward facing satellite user terminals
    - Limits near the current FCC proposed value support high data rate 5G service over broad range of cell sizes
  - Require disclosure of base station locations
    - Enables satellite user terminal nulling and LOS selection



Significant further study and consultation with wireless industry required

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