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Electromagnetic Simulation Software

5G Millimeter Wave Frequencies and Mobile Networks White Paper:

MM Wave Coverage, Including Propagation Challenges

IWPC Conference: MM Wave Market Opportunities

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Remcom's Participation in IWPC White Paper on MM Wave Key Features & Challenges

In June 2019, the IWPC released a comprehensive report that identifies the key features, obstacles, and potential solutions for deployment of mmWave for 5G

- Title: "5G Millimeter Wave Frequencies and Mobile Networks -- a Technology Whitepaper on Key Features and Challenges" [1]
- Draws on expertise from 14 participating companies in the wireless industry
- Remcom was fortunate to able to contribute our expertise and tools in propagation modeling and simulation

Remcom's role: performed simulations to predict coverage in a downtown urban scene and analyzed results to determine percentage of area covered

- Compared uplink and downlink coverage and throughput for mmWave versus sub-6 GHz
- Used to inform the discussion on potential requirements for mmWave deployment, such as the increased density of base stations that would likely be needed

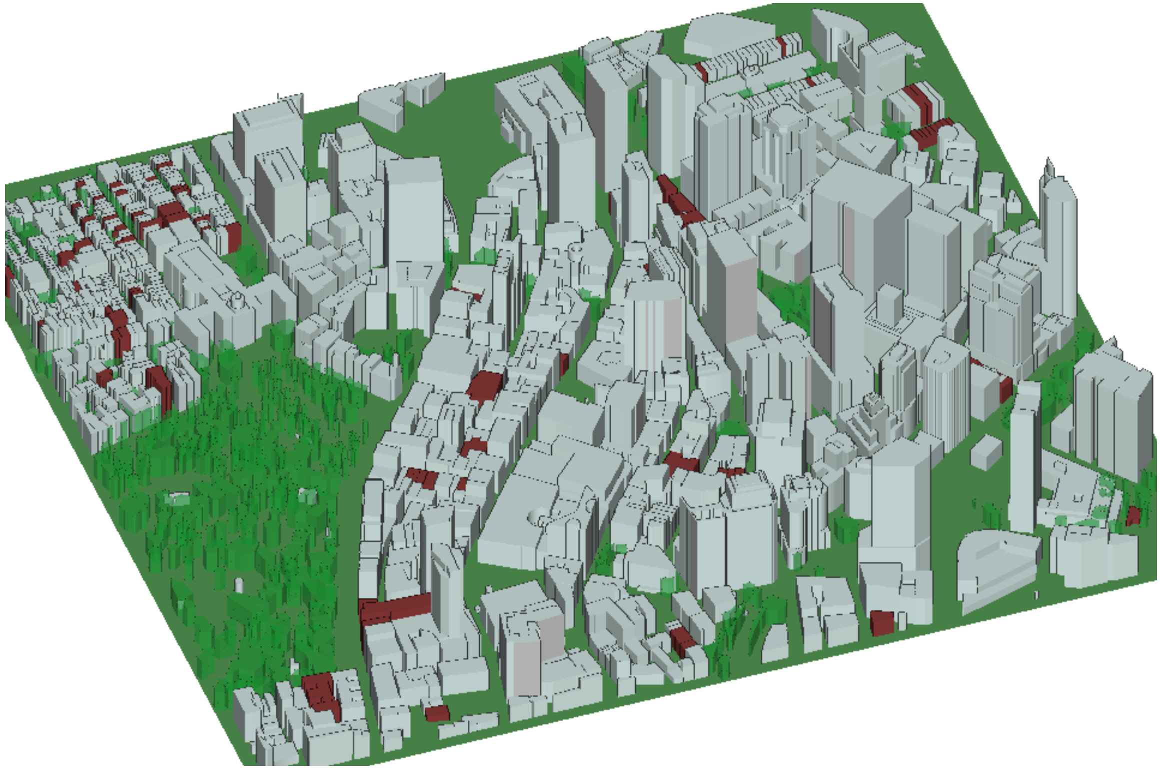
Coverage Scenario for Downtown Urban Scene

Focus of study: eMBB in dense urban scene

- Identified a downtown urban scene with buildings and trees
- Limited to outdoor analysis

Worked with a Tier 1 carrier to obtain base station locations

- Based on sub-6GHz deployment
- 28 GHz gNB's were co-sited at same locations to allow direct comparison of coverage
- ISD: 300 – 500 meters

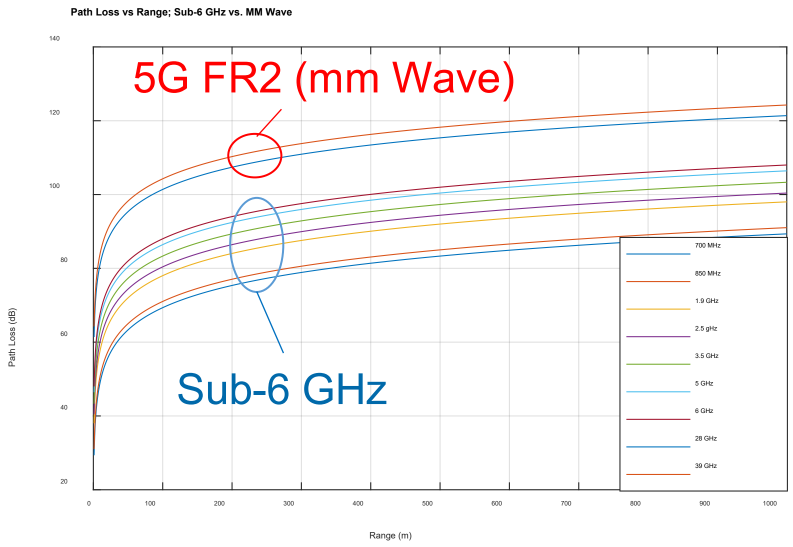


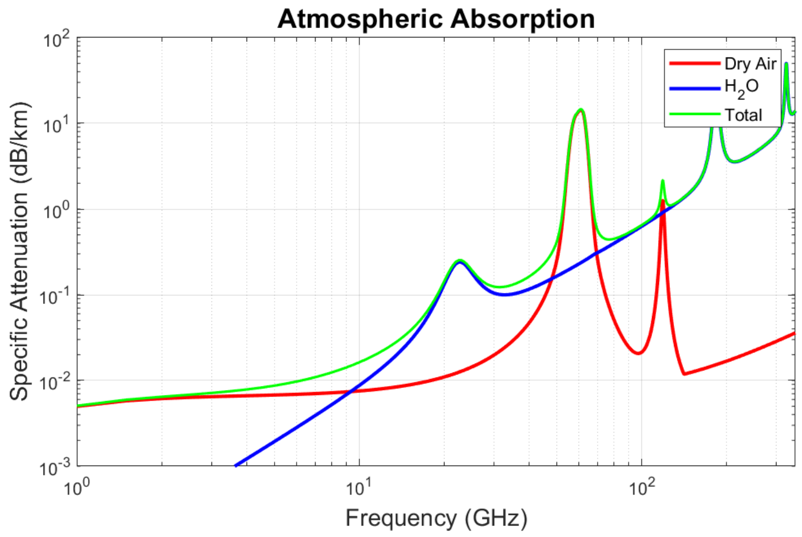
MM Wave Challenges: Propagation Losses

Sources of propagation loss

- **Path Loss:** at 28 GHz, ~15-30dB greater than bands < 6 GHz
- **Atmospheric absorption:** significant at some bands, but only about 0.13dB/km at 28 GHz
- **Rain attenuation:** can be significant, but not bad at few hundred meters

Limits inter-site distances for outdoor applications





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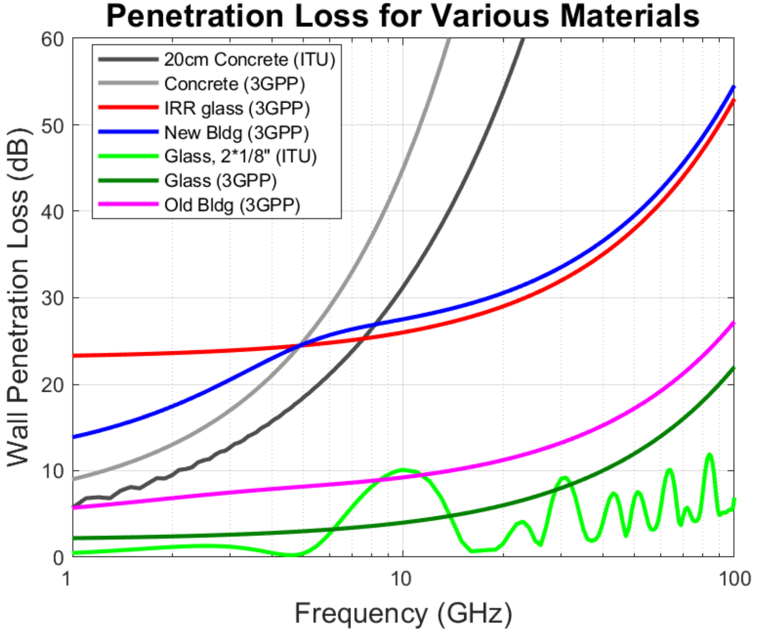
MMWave Challenges: Attenuation from Building Walls

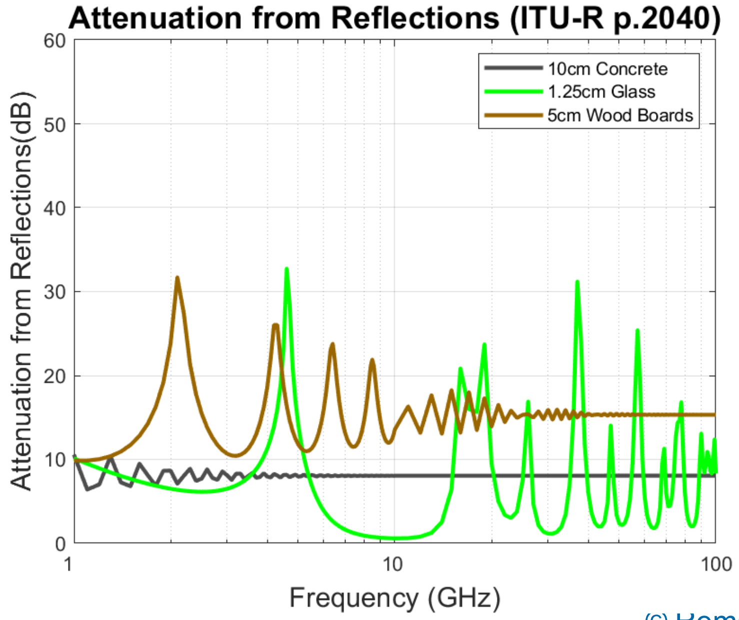
Wall attenuation increases substantially with frequency, making mm Wave better suited to outdoor, near LOS (materials from [2]-[3])

Reflections, however, are similar to sub-6 GHz -- though scattering due to surface roughness (not shown) can impact higher frequencies

Wall Attenuation



Wall Reflection



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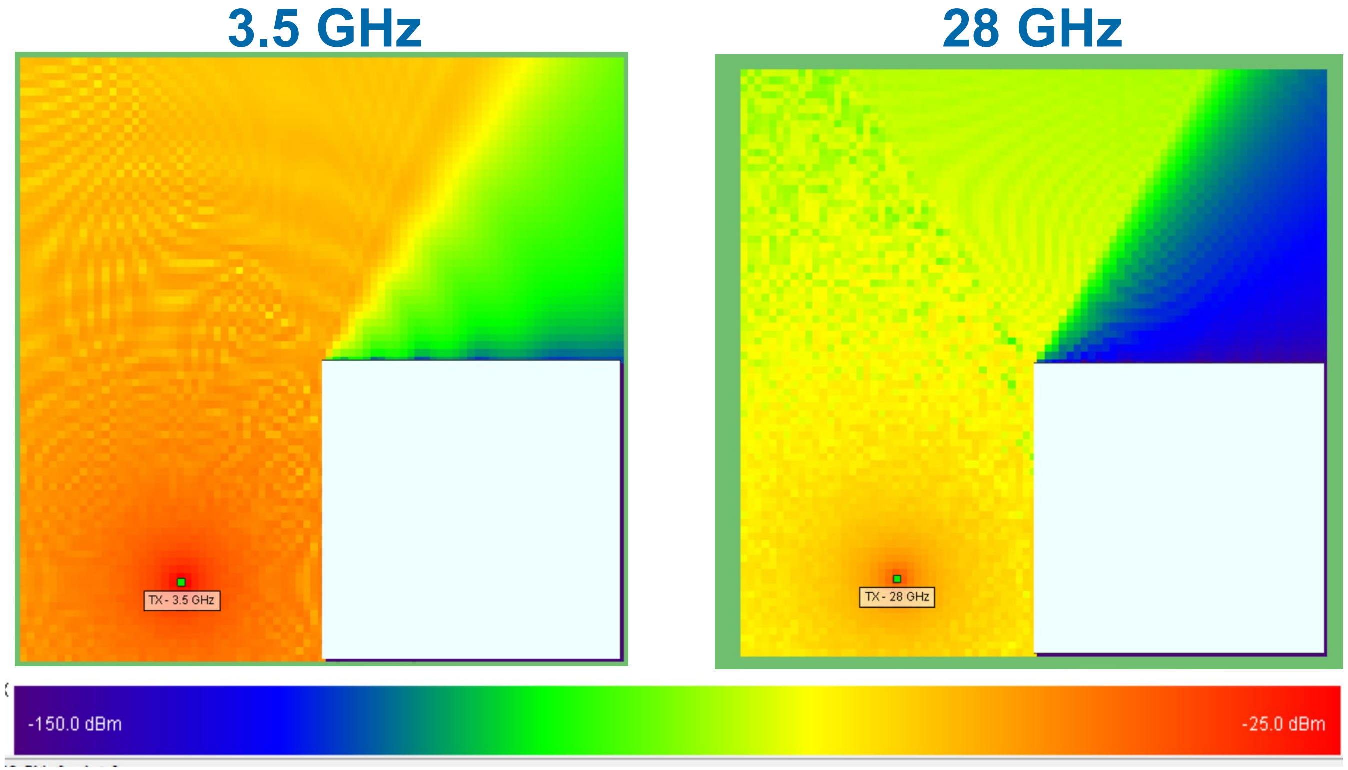
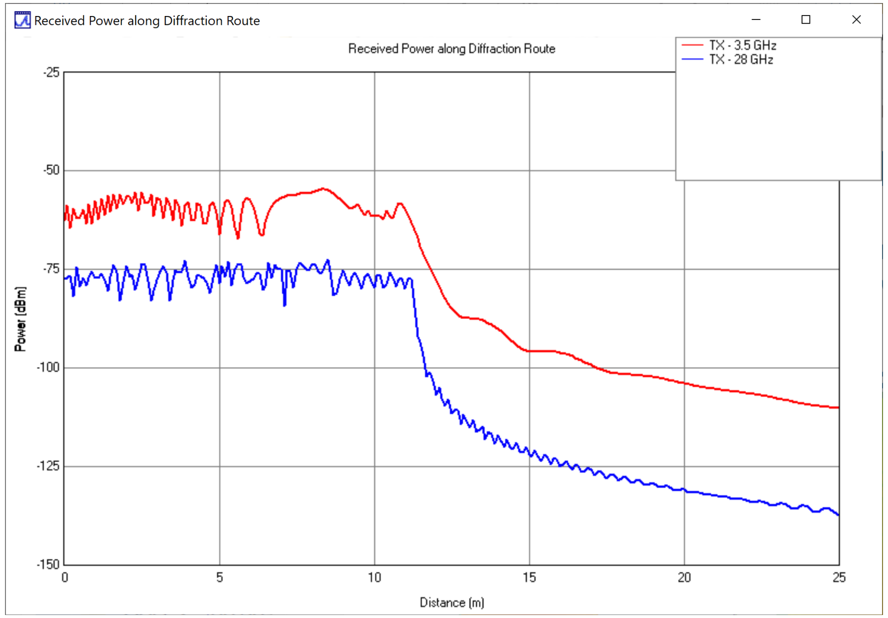
MM Wave Challenges: Diffraction Around Corners

Diffractions around corners drop off more rapidly with frequency

- Wireless InSite example simulation results below show crisper shadow boundary at 28 GHz
- In plot, ~18dB is due to additional path loss; ~9.5dB is due to additional diffraction loss



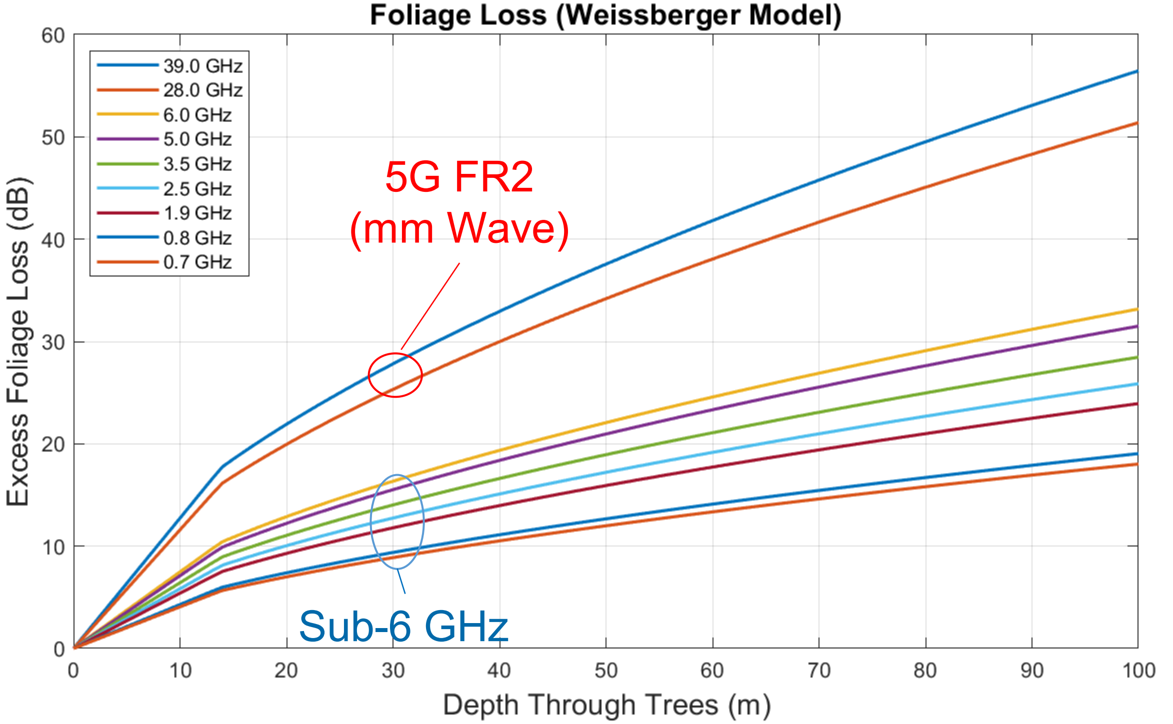


MM Wave Challenges: Foliage Penetration

Penetration loss from trees higher at mm Waves than sub-6 GHz

- (plot uses Weissberger model [4])
- Signals will have harder time penetrating into parks or tree-lined streets

Foliage Attenuation



Wireless InSite

Request a demonstration of Wireless InSite here.

Used Wireless InSite® 3D Ray Model

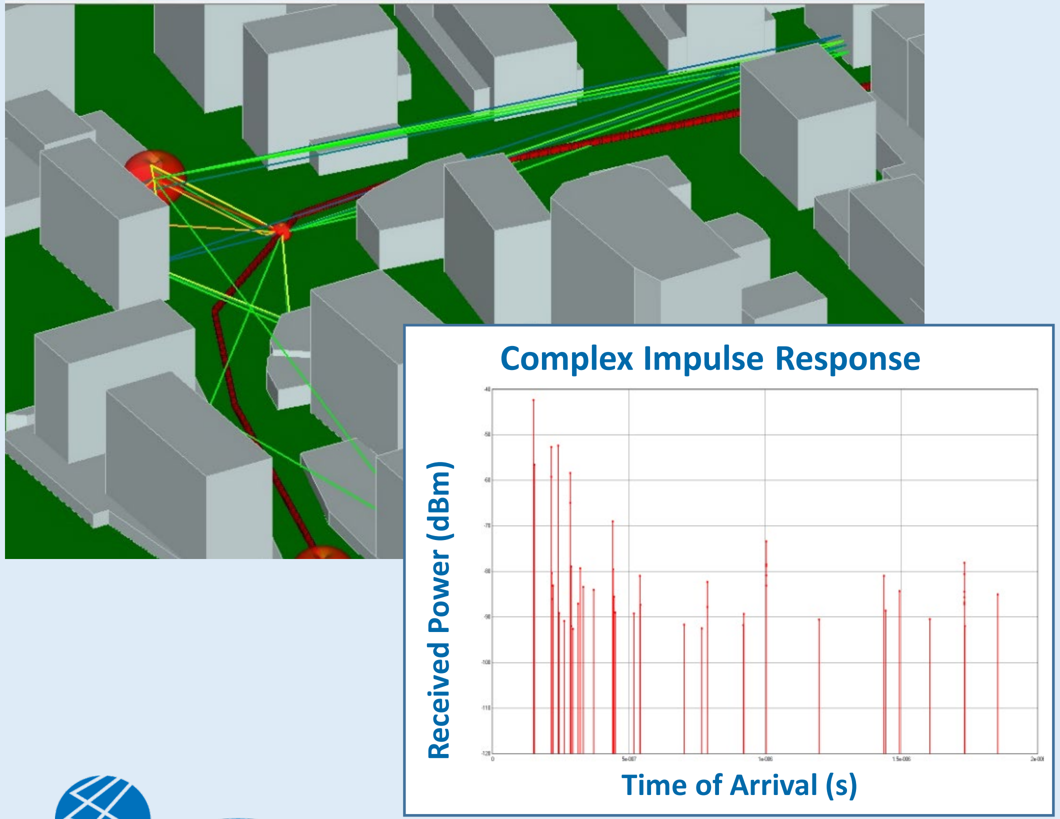
Used Wireless InSite® 3D ray-tracing to capture key propagation effects

- Incorporates effects from previous slides (path loss, atmosphere, foliage, bldgs.)
- Handles complex multipath interactions with buildings
- Simulates massive MIMO antennas
- Provides accurate channel data, with w/full time, angle, phase & polarization

Results were then used to estimate throughput

Post-processing was performed to generate coverage distributions for full scene

Propagation Paths for Channel between 1 Transmit/Receive MIMO Antenna Pair

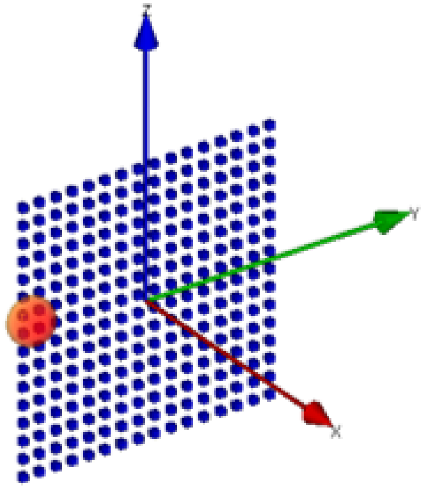


Specifications for gNBs

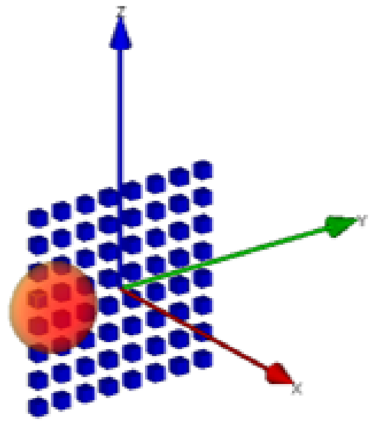
Specification	28 GHz	Mid-Band Sub-6GHz
Array Configuration	16x16, cross-pol (512 elements)	8x8, cross-pol (128 elements)
Polarization	Cross-Pol Beams (±45°)	
Transmit Power (dBm)	43 dBm	
Element Gain (dB)	Approx. 6dB (patch array)	
Peak Array Gain (dB)	30 dBi	24 dBi
Peak EIRP (dBm)	73 dBm (per polarization)	67 dBm (per polarization)
Noise Figure (uplink)	5dB	5dB
SCS	120 kHz	30 kHz
DL/UL Slots	4:1	4:1
System Bandwidth	400 MHz	100 MHz

MIMO Arrays

28 GHz
16x16, xpol



Sub-6 GHz
8x8, xpol



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User Equipment

UEs were placed in a coverage grid, 1.5 m above ground

Two power levels were used:

- Max power (ideal)
- 50th pctl power (conservative)
- Values were chosen for consistency with analyses by other participants in study

Cross-pol beams used to represent multiple antennas

Specification	28 GHz	Mid-Band Sub-6GHz
Array Configuration	2 isotropic xpol beams	2 isotropic cross-pol beams
Polarization	Cross-Pol (±45°)	Cross-Pol (±45°)
EIRP: Max (dBm)	23 dBm	26 dBm
EIRP: 50% (dBm)	11.5 dBm	19.3 dBm
Noise Figure (downlink)	10dB	8dB

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MIMO Beamforming & Interference

Massive MIMO beamforming was used to calculate maximum power to each UE

- Used MRT-MRC (adaptive; maximizes beam)
- Provided ideal maximum SINR for a single stream

Then scaled based on SINR to 2 or 4 layers when appropriate (see next slide on throughput)

Interference

- On the downlink, included interference between base stations
- On the uplink, assumed system is noise-limited (ignored interference from other UEs)

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Throughput Analysis

Bandwidth Assumptions

- TDD, DL:UL = 4:1
- 28 GHz: 400 MHz
- Sub-6 GHz: 100 MHz

MCS, layers determined from SINR

- Table shows limits/band on MCS, layers
- MCS's mapped to SINR based on data in literature
- Conditions were incorporated to allow additional layers

Throughput estimated based on formula from 3GPP TS 38.306 v15.5.0

- Coverage thresholds: 50 Mbps DL, 7 Mbps UL

Upper Limits on MCS and Layers

Freq. Band	DL/ UL	MCS	# Layers	Max Through-put (Mbps)
Sub-6GHz	DL	Up to 256 QAM	Up to 4	1870
	UL	Up to 64 QAM	Up to 2	188
28 GHz	DL	Up to 64 QAM	Up to 2	2586
	UL	Up to 16 QAM	1 layer	237

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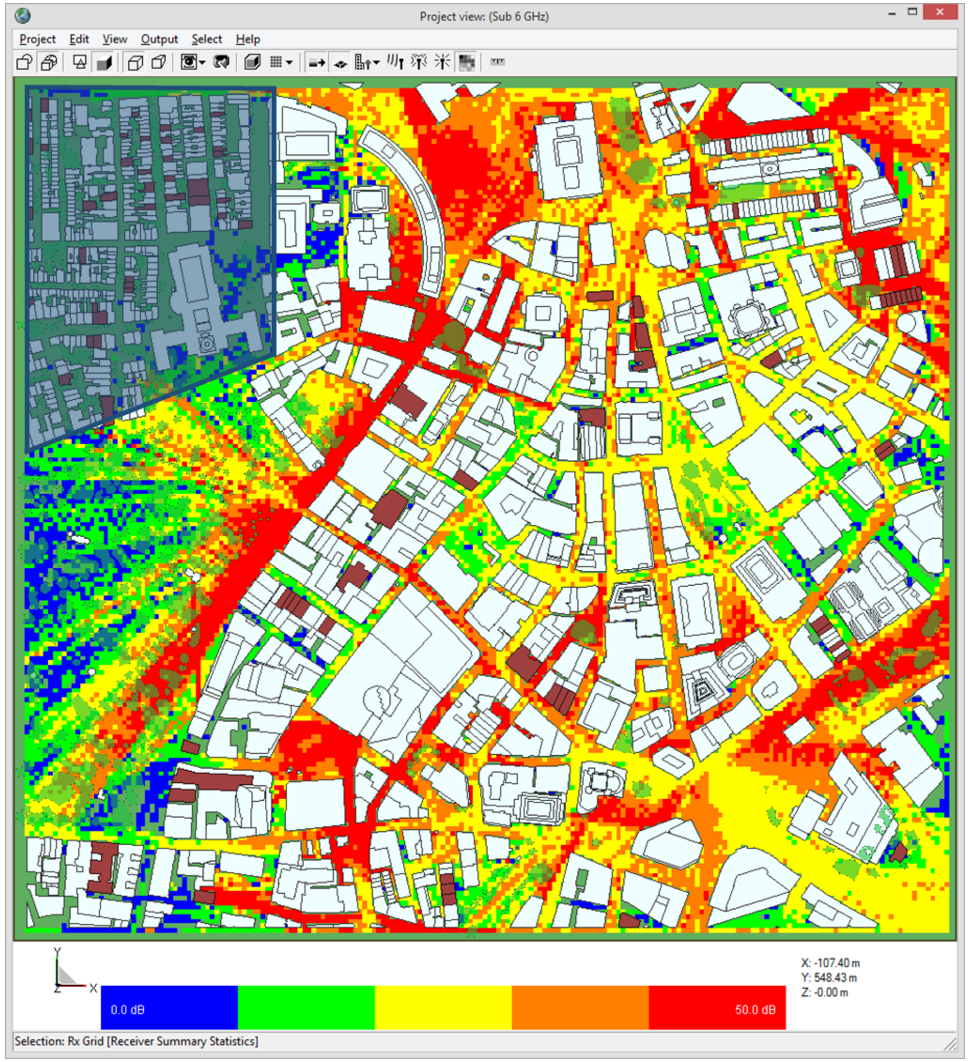
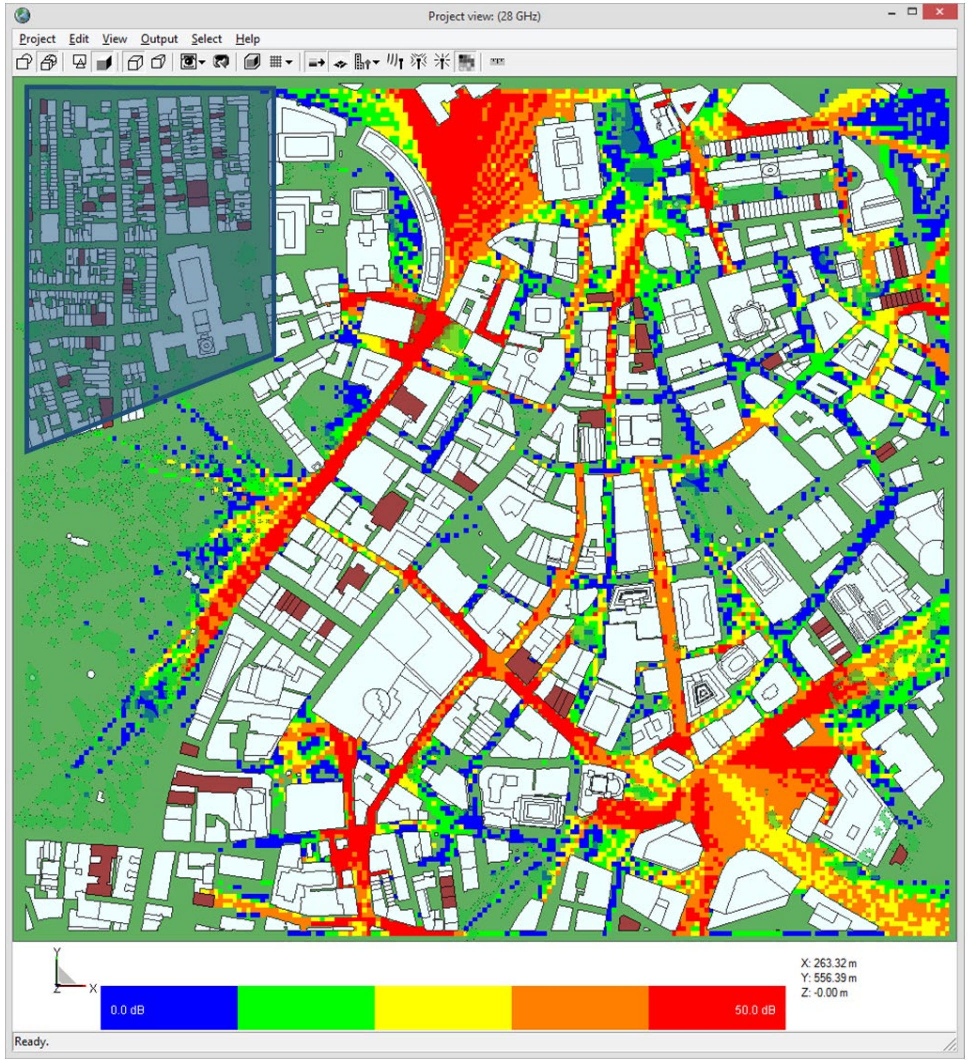
Downlink Coverage Comparison: SINR

Sub-6 GHz



28 GHz



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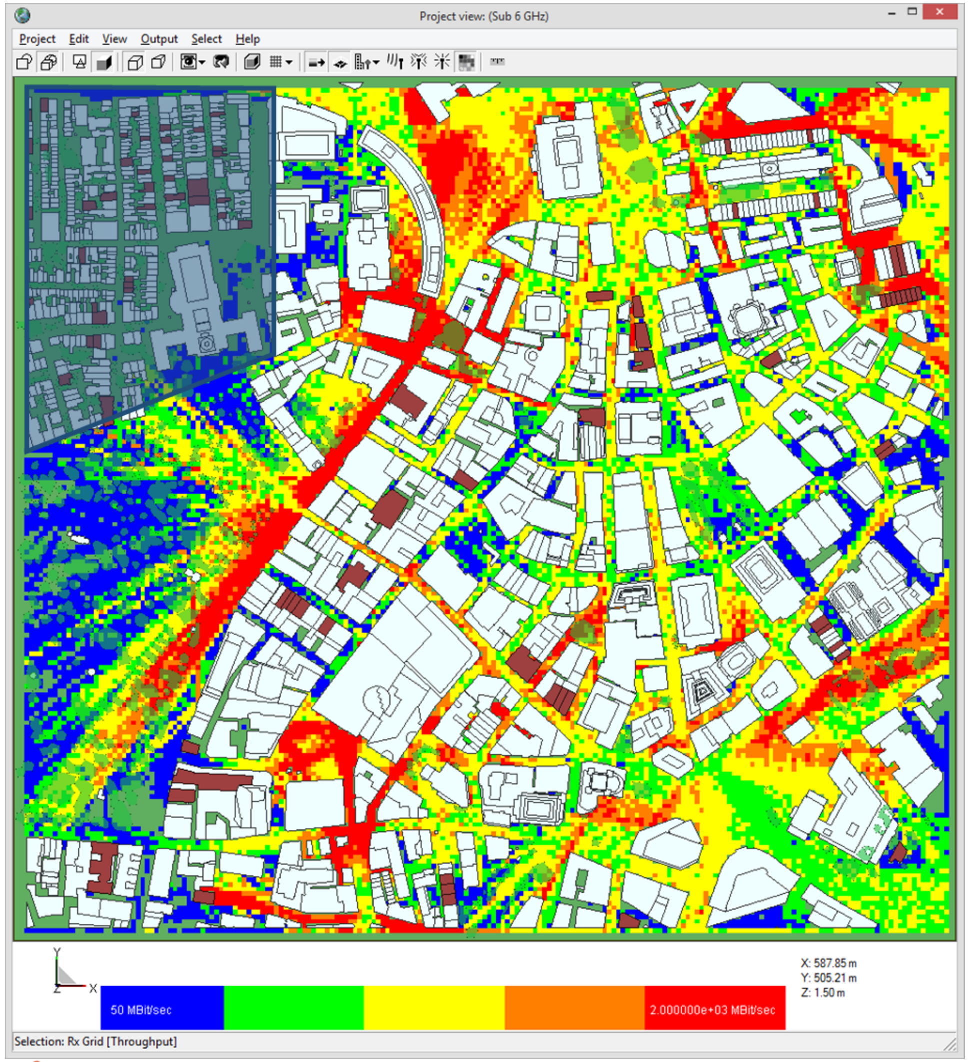
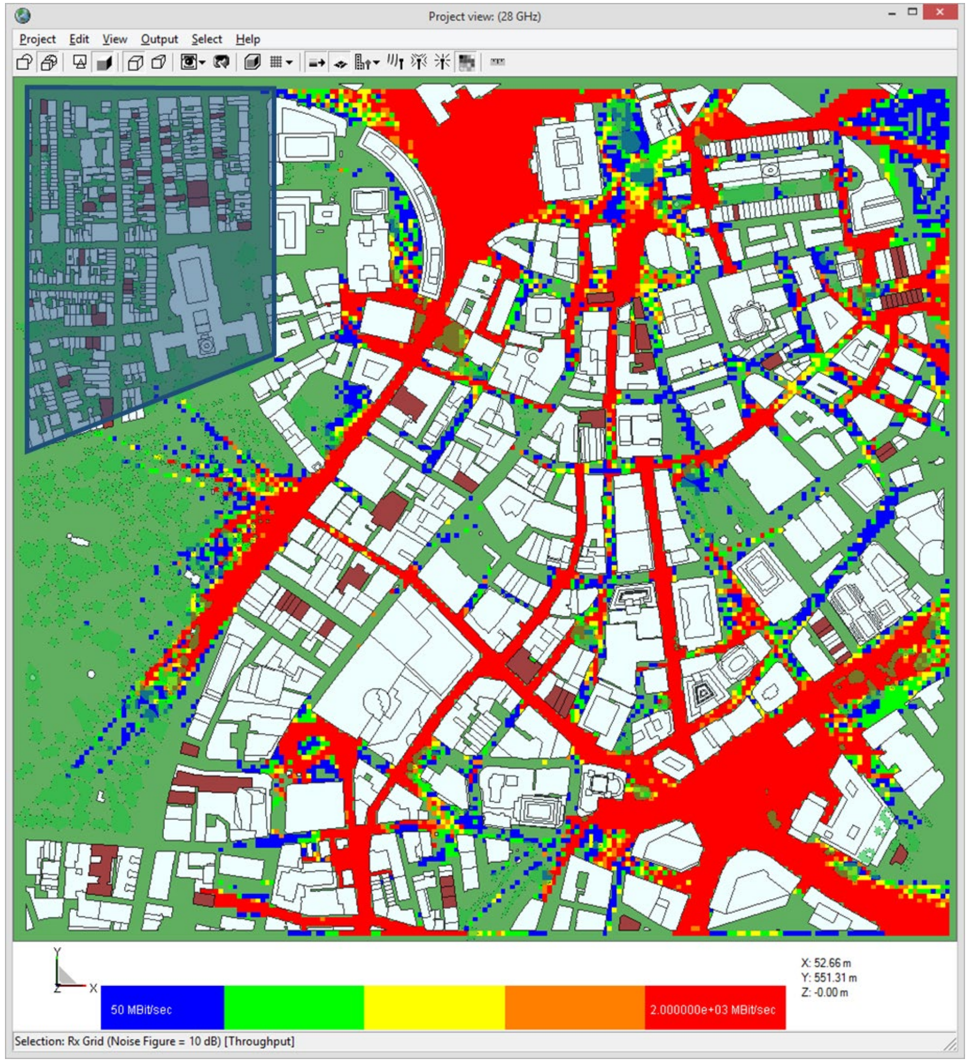
Downlink Coverage Comparison: Throughput

Sub-6 GHz



28 GHz



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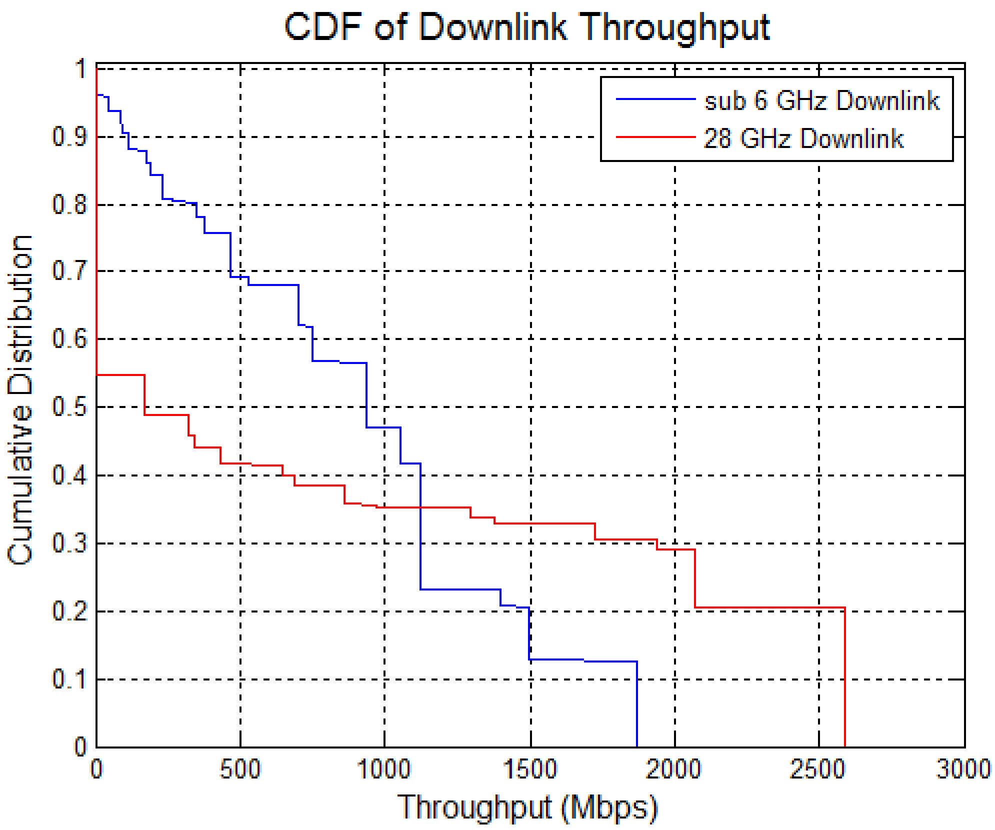
Downlink Coverage Results Summary



% of Area Covered

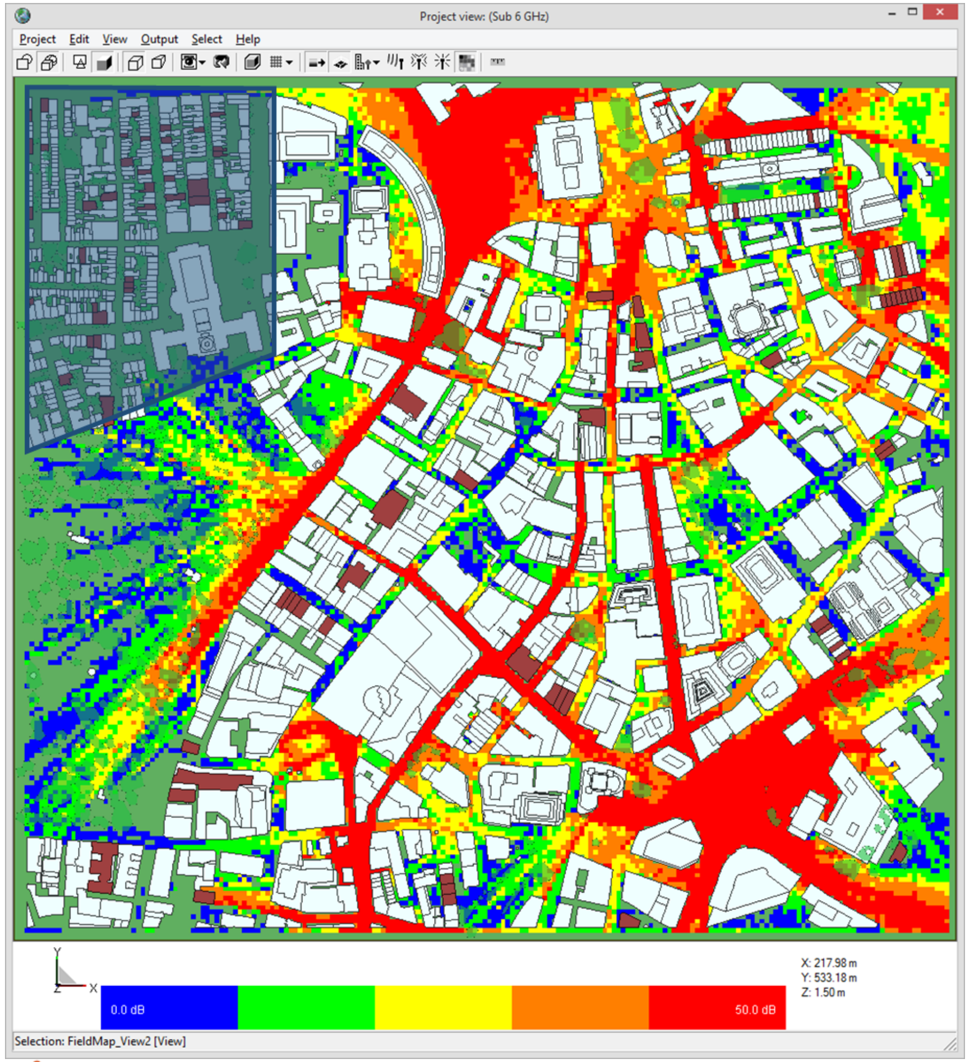
Frequency	% Coverage	
	> 50 Mbps	> 1000 Mbps
Mid-band Sub-6 GHz	93.8%	47.0%
28 GHz	54.7%	35.3%

Downlink Coverage Threshold: 50 Mbps

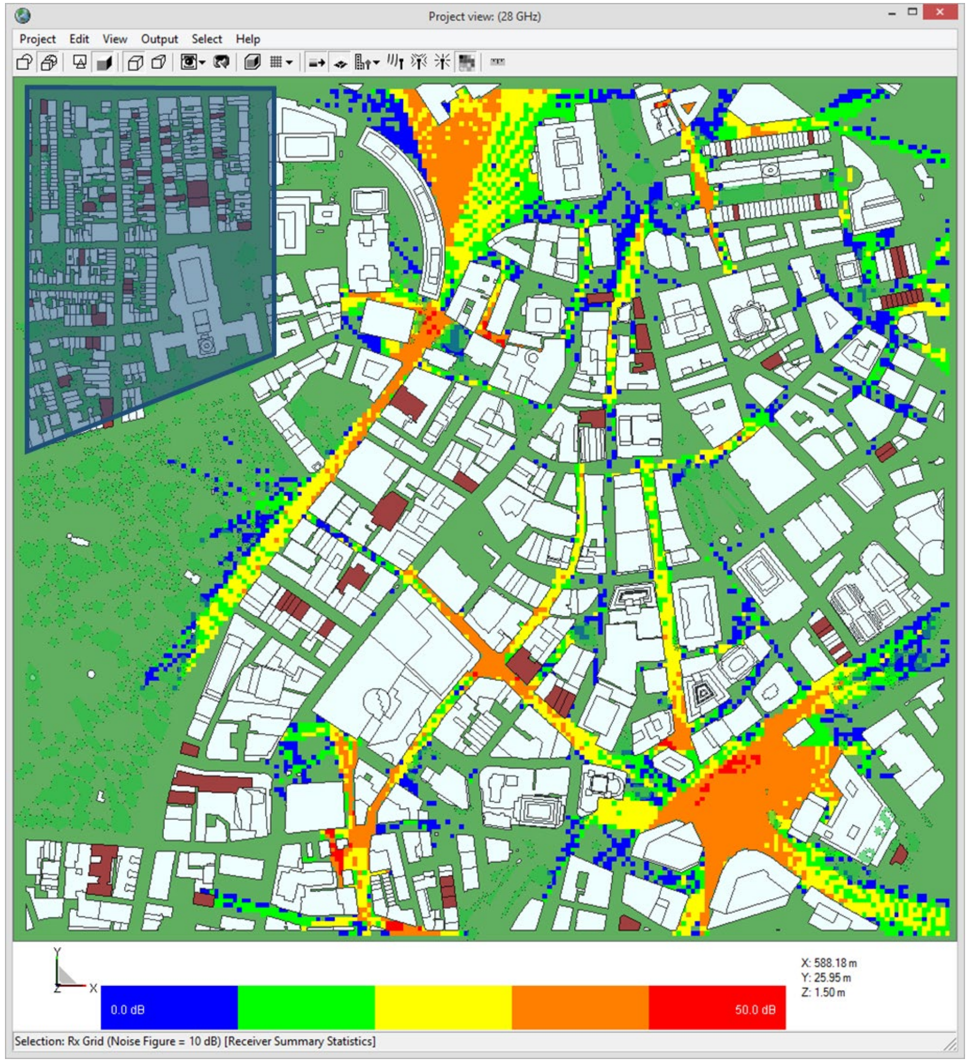
- Sub-6 GHz: ~94% of area
- 28 GHz: ~55% of area

Uplink Coverage: SINR (Peak EIRP)

Sub-6 GHz



28 GHz



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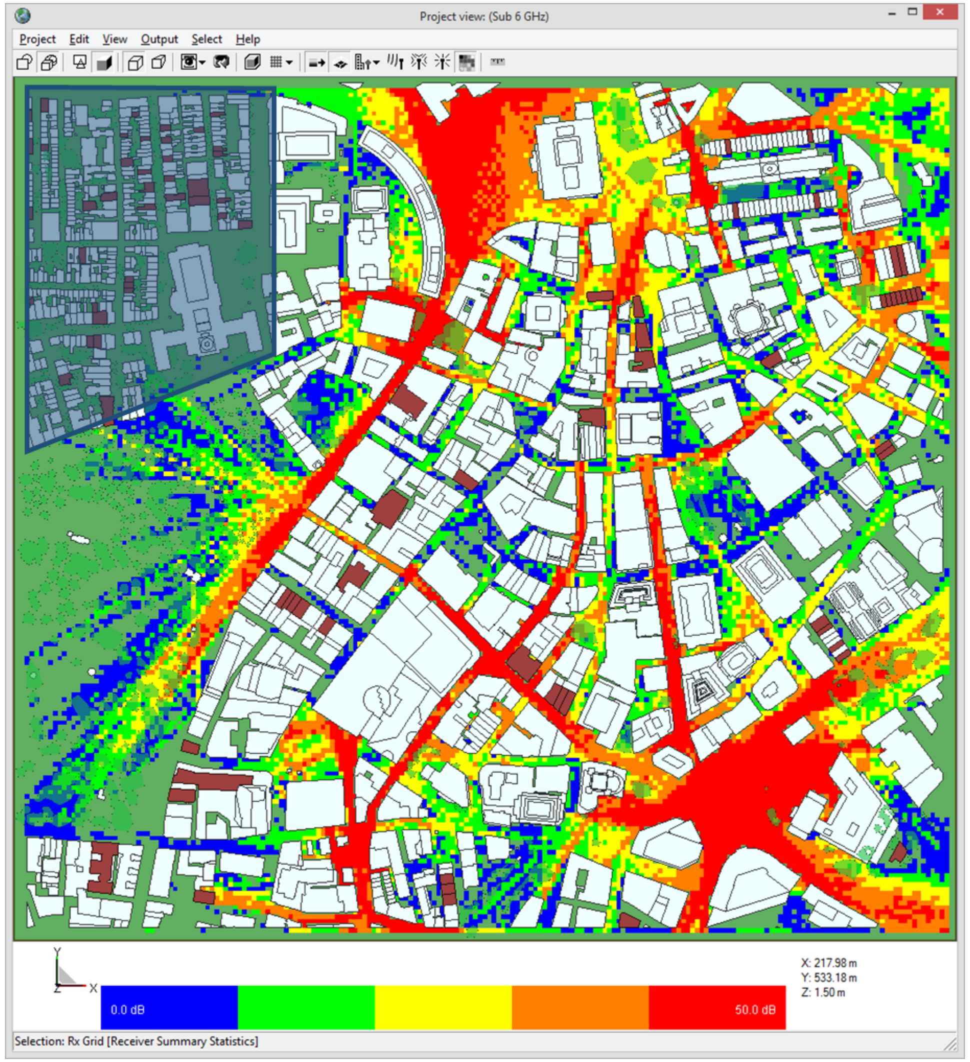
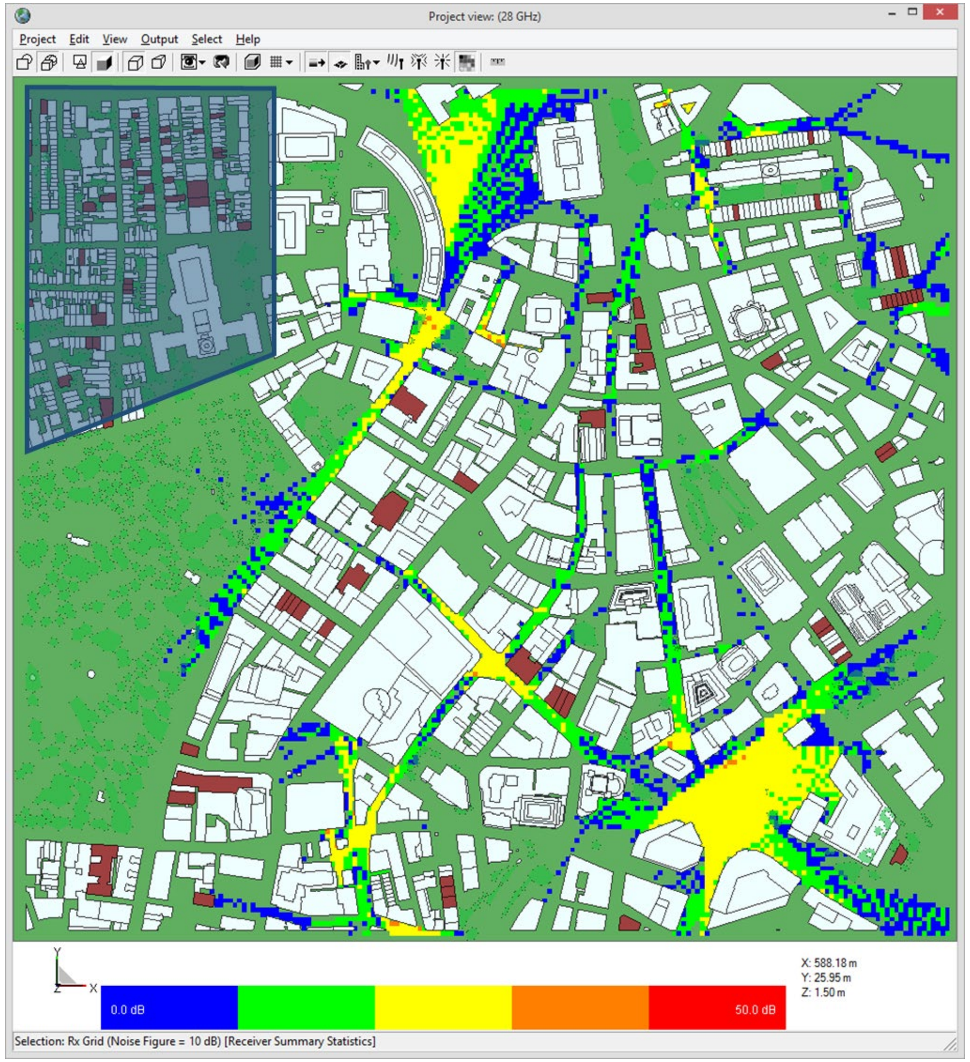
Uplink Coverage: SINR (50th Pctl EIRP)

Sub-6 GHz



28 GHz



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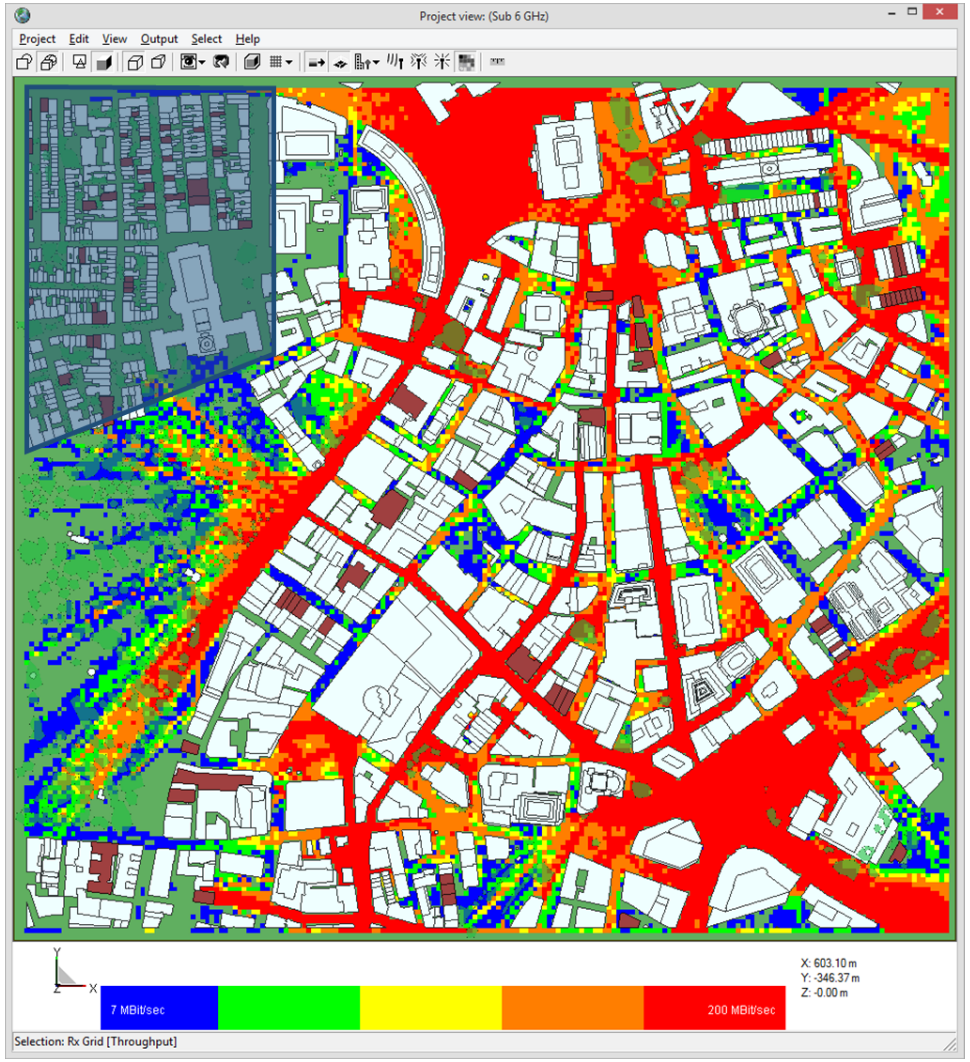
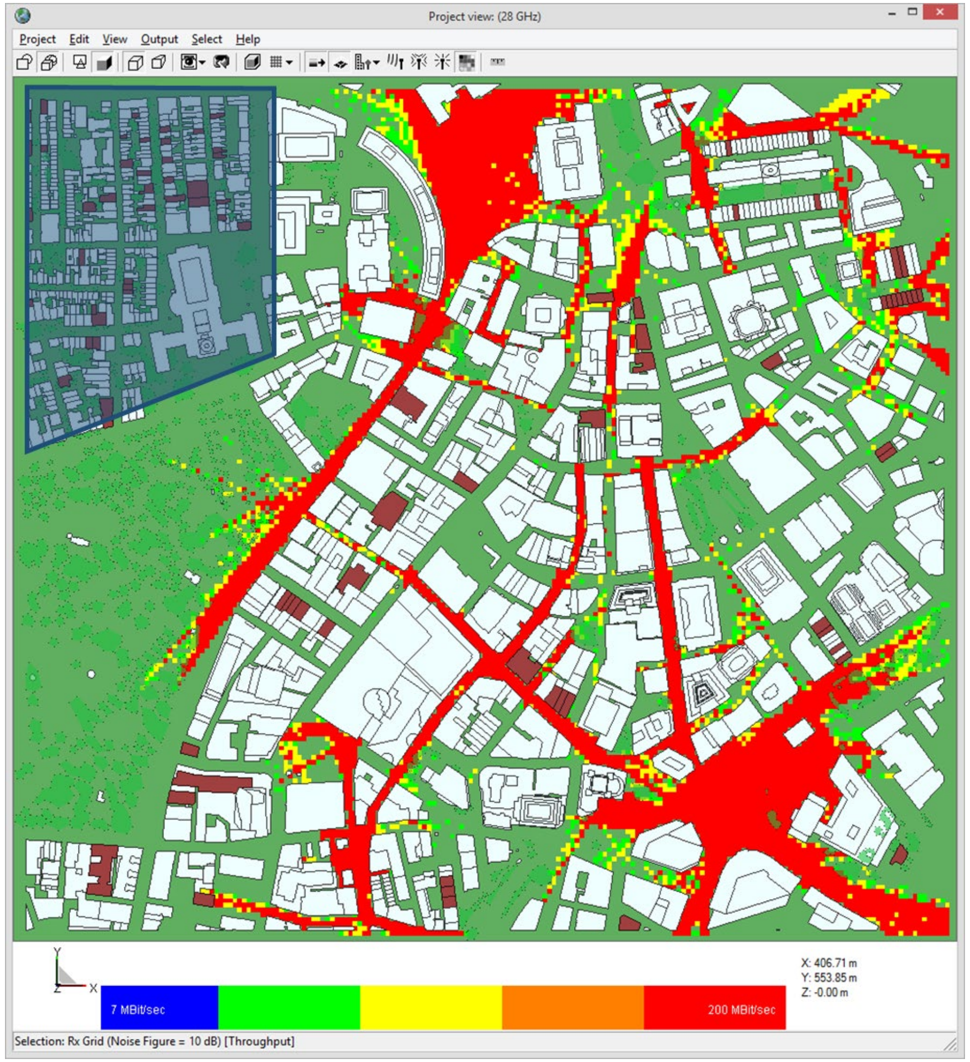
Uplink Coverage: Throughput (Peak EIRP)

Sub-6 GHz



28 GHz



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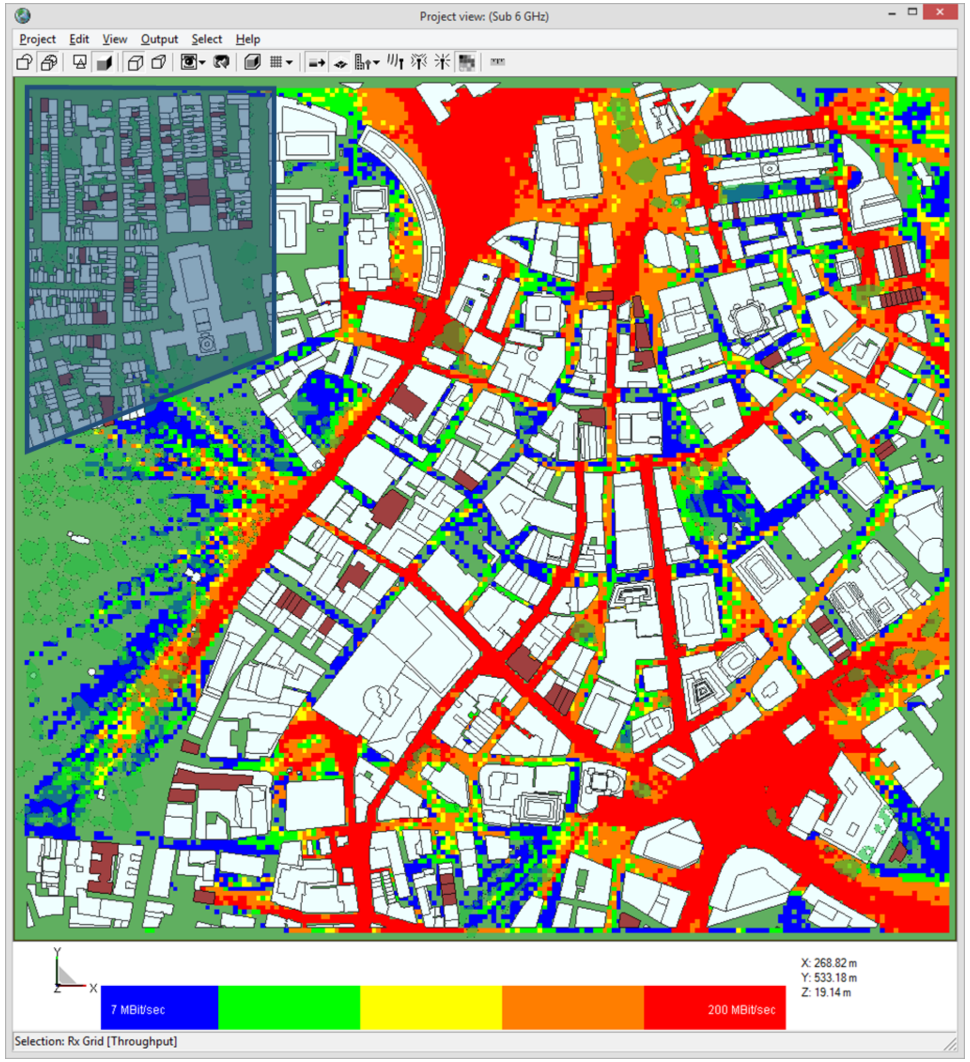
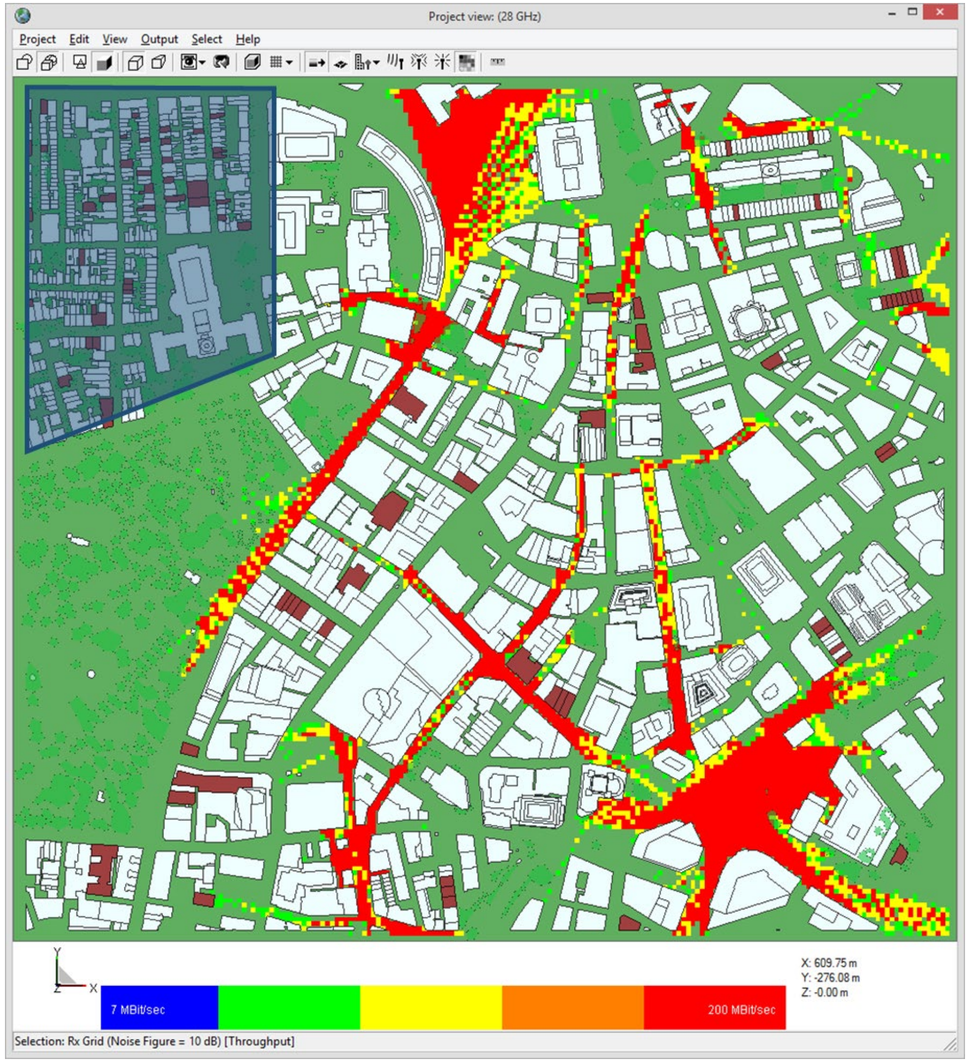
Uplink Coverage: Throughput (50^{th} Pctl EIRP)

Sub-6 GHz



28 GHz



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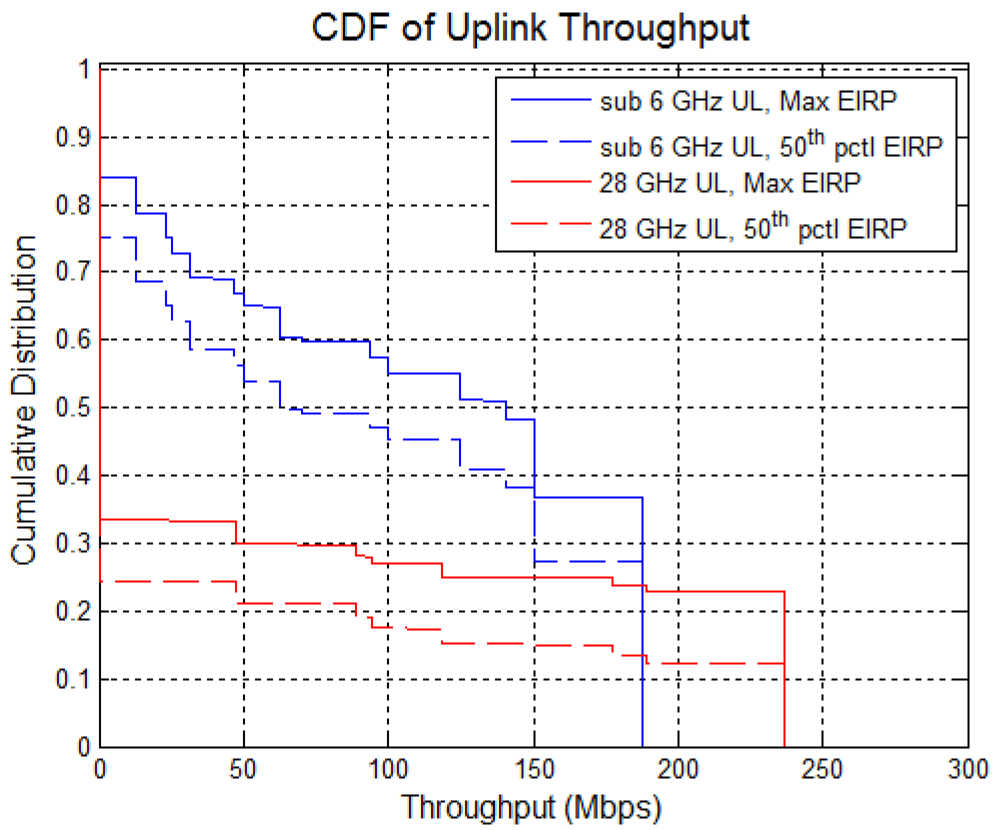
Uplink Coverage Results Summary



% of Area Covered

Frequency	Threshold	% Coverage	
		> 7 Mbps	> 100 Mbps
Mid-band Sub-6 GHz	50th pctl EIRP	75%	47%
	Peak (ideal) EIRP	84%	57%
28 GHz	50th pctl EIRP	24%	17%
	Peak (ideal) EIRP	33%	27%

Uplink coverage threshold: 7 Mbps

- Sub-6 GHz: ~75-84% of area
- 28 GHz: ~24-33% of area

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Conclusions

In this study, Remcom evaluated coverage in dense urban scene for mm Wave gNB's co-sited with Sub-6GHz for direct comparison

Simulations used Wireless InSite® MIMO to predict SINR using beamforming and estimate throughput, and post-processed results to determine percentage of coverage based on specified thresholds (DL>50 Mbps, UL > 7 Mbps)

General findings

- Downlink: Sub-6 GHz covered ~94%, while 28 GHz covered ~55%
- Uplink: Sub-6 GHz covered 75-84%, while 28 GHz covered 24-33%
- Suggests mm Wave requires 2x as many base stations for downlink; 2.5 – 3x for uplink

Results are consistent with results from other participants in coverage analysis, strengthening the value of the outcome from coverage assessments in the IWPC white paper

References

Download the IWPC's full whitepaper here.

[1] "5G Millimeter Wave Frequencies And Mobile Networks - A Technology Whitepaper on Key Features and Challenges," International Wireless Industry Consortium, June 2019, https://www.iwpc.org/WhitePaper.aspx?WhitePaperID=24

[2] ITU-R p.2040-1 "Effects of building materials and structures on radiowave propagation above about 100 MHz," July, 2015.

[3] 3GPP, TR 38.901 (V14.0.0 Release 14), "5G; Study on channel model for frequencies from 0.5 to 100 GHz," European Telecommunications Standards Institute (ETSI) TR 138 901 V14.0.0 (2017-05).

[4] Mark A. Weissberger, "An initial critical summary of models for predicting the attenuation of radio waves by trees," ESD-TR-81-101, IIT Research Institute Final Report, 1982.

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