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Electromagnetic Simulation Software

Design and Assessment of a 5G Base Station using Massive MIMO for Fixed Wireless Access

Tarun Chawla - Technical Manager, Business Development

Greg Skidmore - Director, Propagation Software & Govt. Services

Design and Assessment of a 5G Base Station Antenna for Fixed Wireless Access

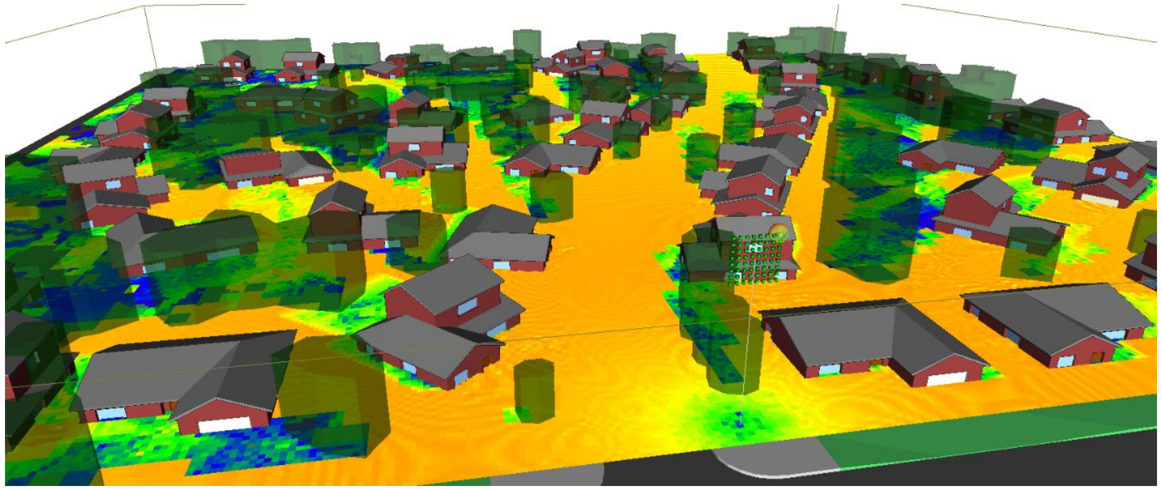
FWA is a key application for early 5G rollouts, with goal of providing “last-mile” broadband connectivity

In this webinar, we will

- Design a mm wave MIMO antenna for 5G FWA
- Evaluate its potential performance in a suburban neighborhood FWA scenario

Overall objective:

- Demonstrate simulation-based methodology for designing complex systems and then assessing their performance in realistic virtual environments



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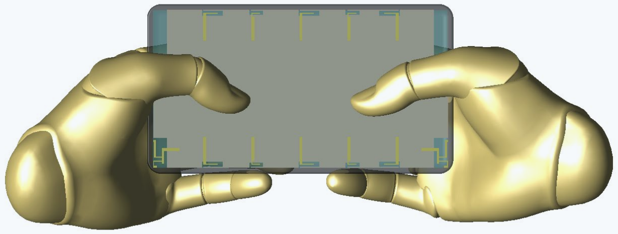
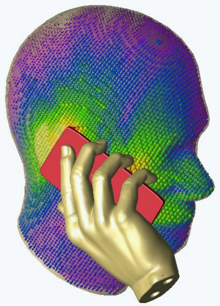
About Remcom

- Founded in 1994
- Located in State College, PA, USA
- 35 employees
- International presence: global distribution network
- Commercial and government sales and contracting
- Create, maintain, and support a number of government propagation tools

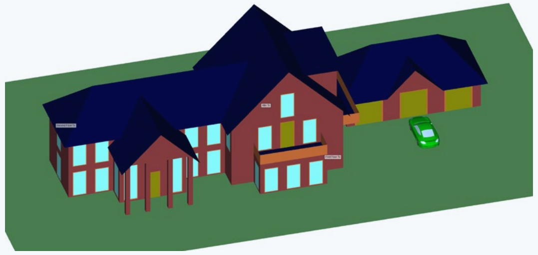
Products Used in Webinar

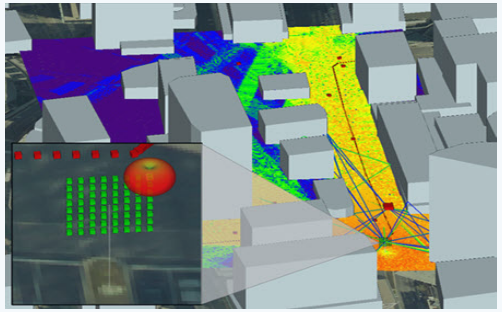
3D Full-Wave Solver: Antennas, EM Scattering, Medical Devices, Biological Effects





mmWave Urban, Indoor, Outdoor and O2I/I2O Channel Modeling and Propagation





2D Planar Massive MIMO Array using XFdtd®

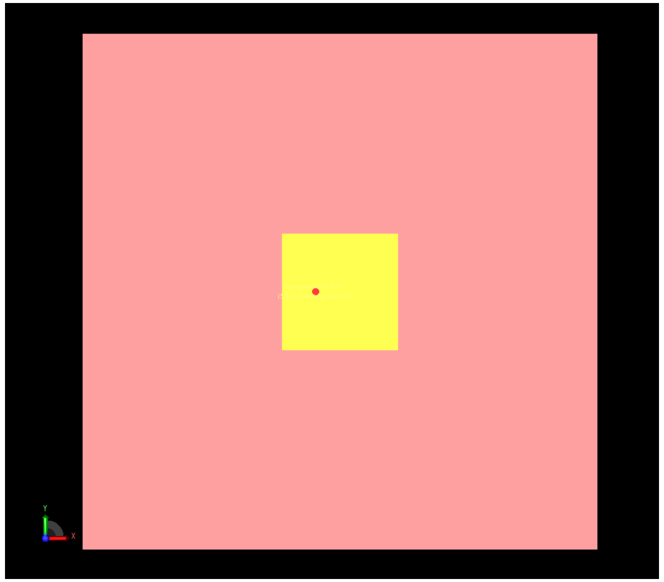
Massive MIMO Simulation

- A planar array of 64 patches is considered as a Massive MIMO base station and is simulated using Remcom's XFdtd® Electromagnetic Simulation Software
- Patch antennas are designed for operation at 28 GHz and are located on top of a substrate
- The phasing at each antenna port is adjusted to create beams that sweep in a single plane
- Having a two dimensional array allows for a narrow beam in two directions
- The combination of the two arrays provides coverage over most of the far-zone sphere

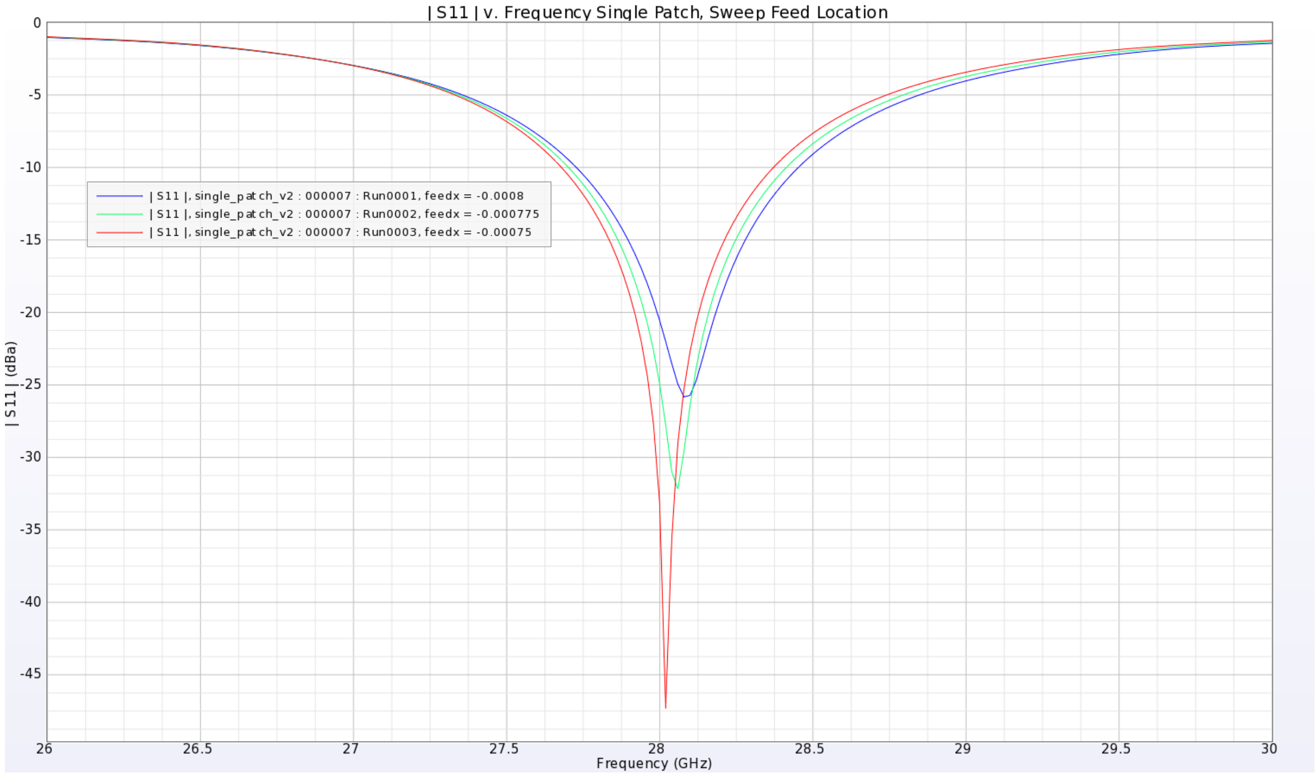
Designing and Tuning the Patch

- Initially a single patch geometry was used to find the best feed location to produce optimal return loss
- Square patches are 3.4x3.4 mm in size on a 0.254 mm thick dielectric (diel constant = 2.2, loss tan = 0.0009)
- A parameter sweep was performed that varied the feed location on the patch
- A location 0.75 mm away from the center point of the patch was found to give best results

Patch Tuning Results



Single Patch Geometry with
Feed Location Indicated



Example Results of S11 for swept feed location

Phasing Calculations

- For a beam steered toward (θ_d, φ_d) phases for element located at (x_n, y_n) are found from
  - $w_n = e^{[-j(2\pi/\lambda)\ \sin(\theta_d)[x_n \cos(\varphi_d) + y_n \sin(\varphi_d)]]}$ [1]
- x_n and y_n locations are in meters and represent the location of the feeds referenced to the lower left (0, 0) feed
- Spacing of feeds is a half wavelength in both x and y directions

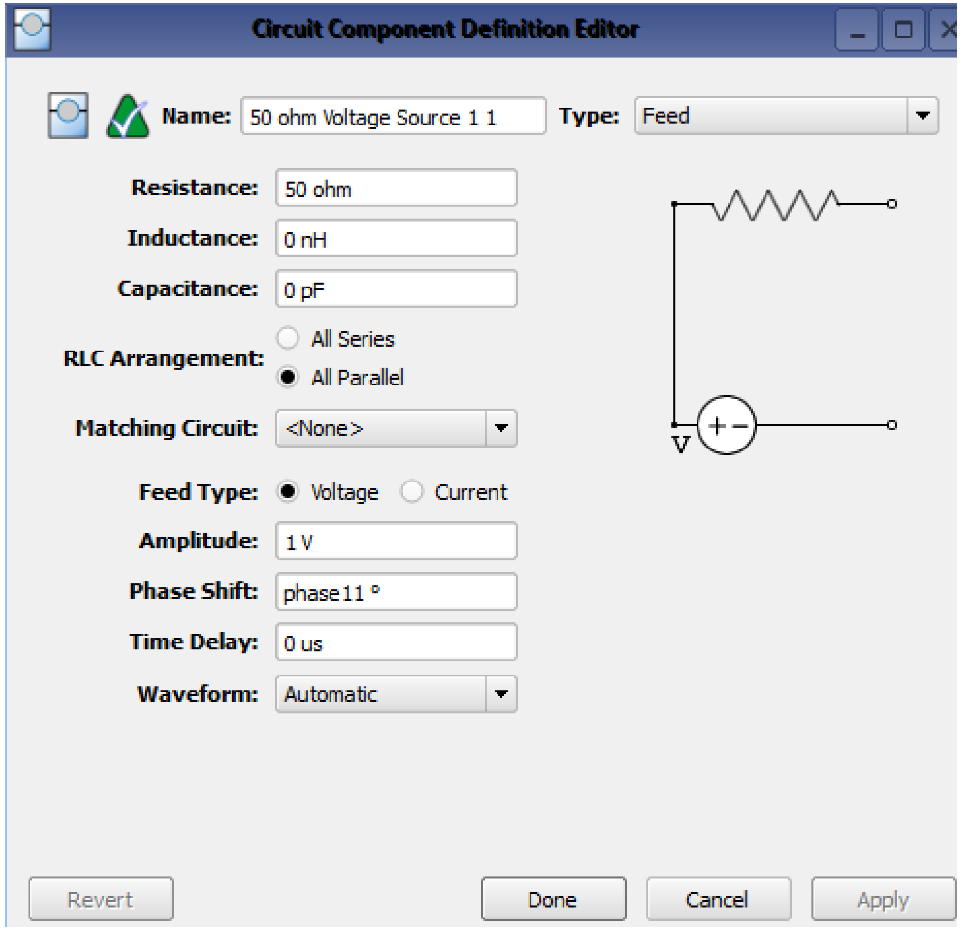
[1]: http://www.antenna-theory.com/arrays/weights/twoDuniform.php

Example Phases for θ_d = 45 deg, φ_d = 60 deg

phase (deg)	xn							
yn	0	1	2	3	4	5	6	7
0	0	-63.6396	-127.279	169.0812	105.4416	41.80195	-21.8377	-85.4773
1	-110.227	-173.867	122.4937	58.85413	-4.78548	-68.4251	-132.065	164.2957
2	139.5459	75.90631	12.2667	-51.3729	-115.013	-178.652	117.7083	54.06865
3	29.31888	-34.3207	-97.9603	-161.6	134.7604	71.12083	7.481223	-56.1584
4	-80.9082	-144.548	151.8126	88.17302	24.53341	-39.1062	-102.746	-166.385
5	168.8648	105.2252	41.58559	-22.054	-85.6936	-149.333	147.0271	83.38754
6	58.63777	-5.00184	-68.6415	-132.281	164.0793	100.4397	36.80011	-26.8395
7	-51.5893	-115.229	-178.868	117.4919	53.85229	-9.78732	-73.4269	-137.067

Phases Assigned to Feeds

- Each patch has a unique feed circuit component with a parameterized phase shift
- The phase shift parameters are computed in a spreadsheet and imported to XFdtd via a script
- Magnitudes are not adjusted in these simulations.



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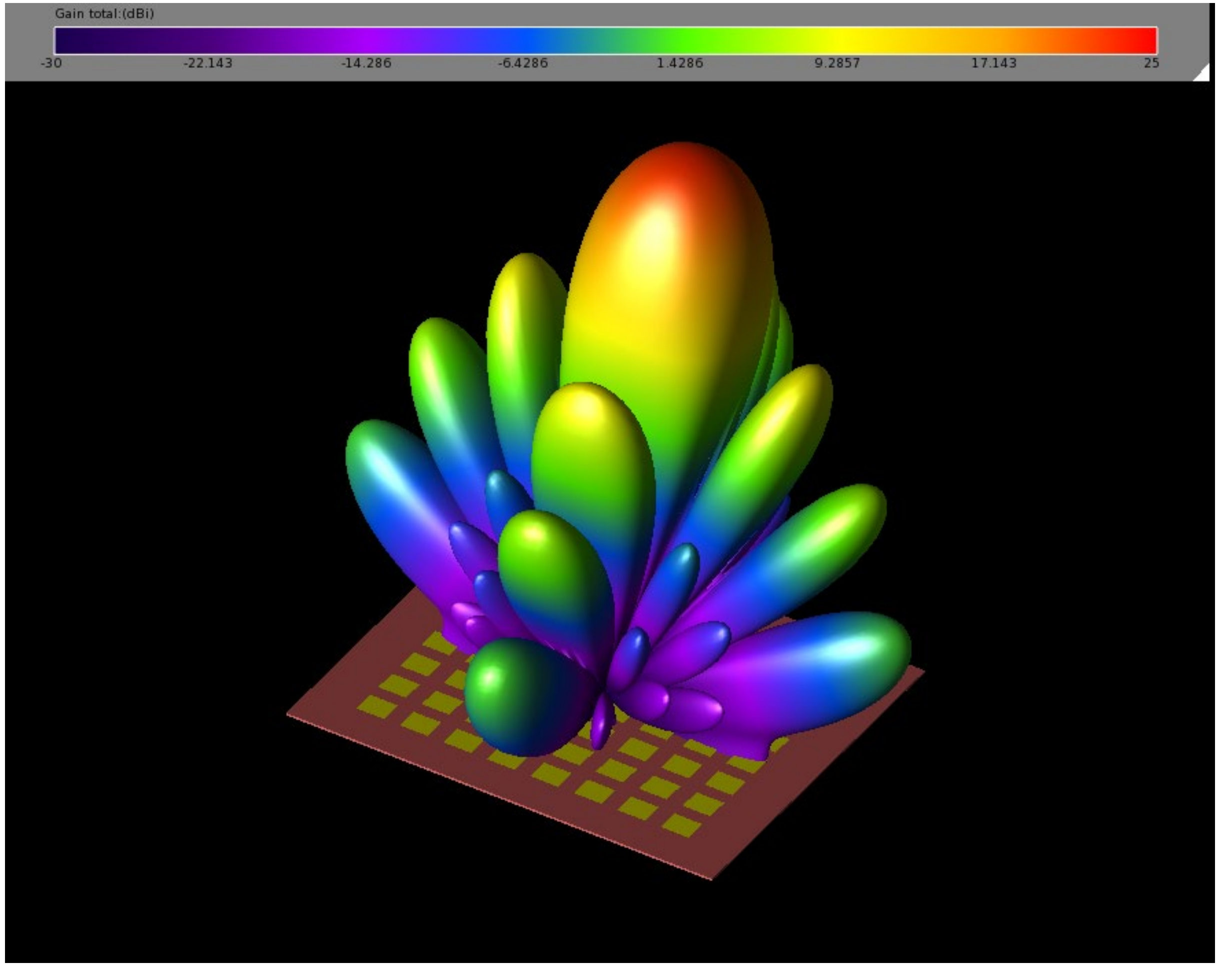
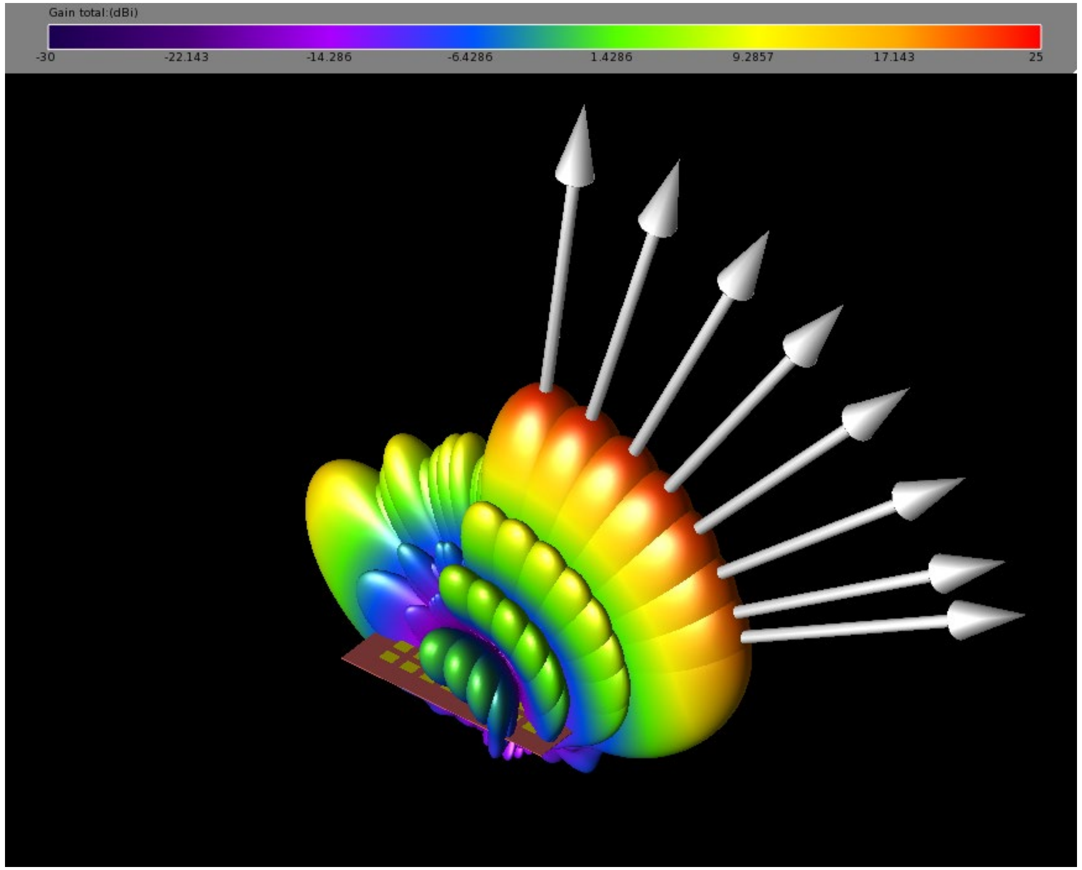
Gain Pattern for Array Directed at (0, 0)

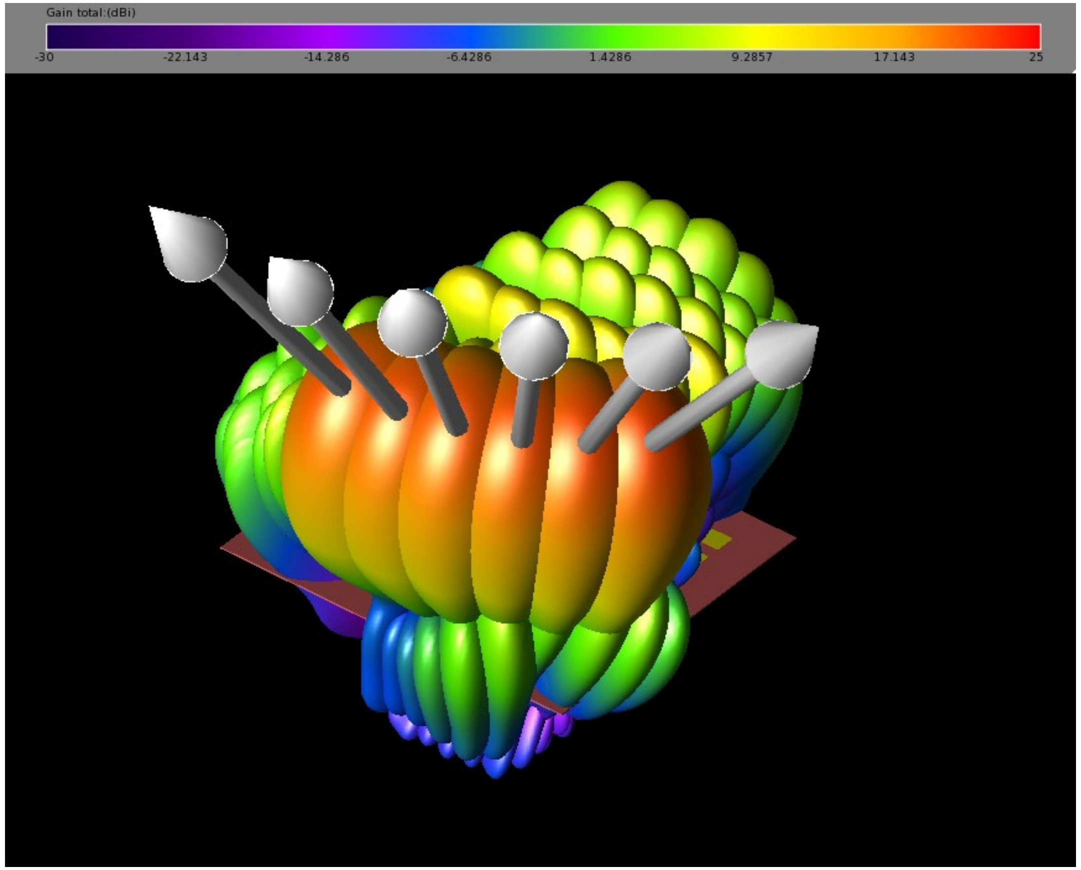
- Peak Gain is 23.2 dBi
- Main Lobe toward (0,0)



Multiple Beams Possible



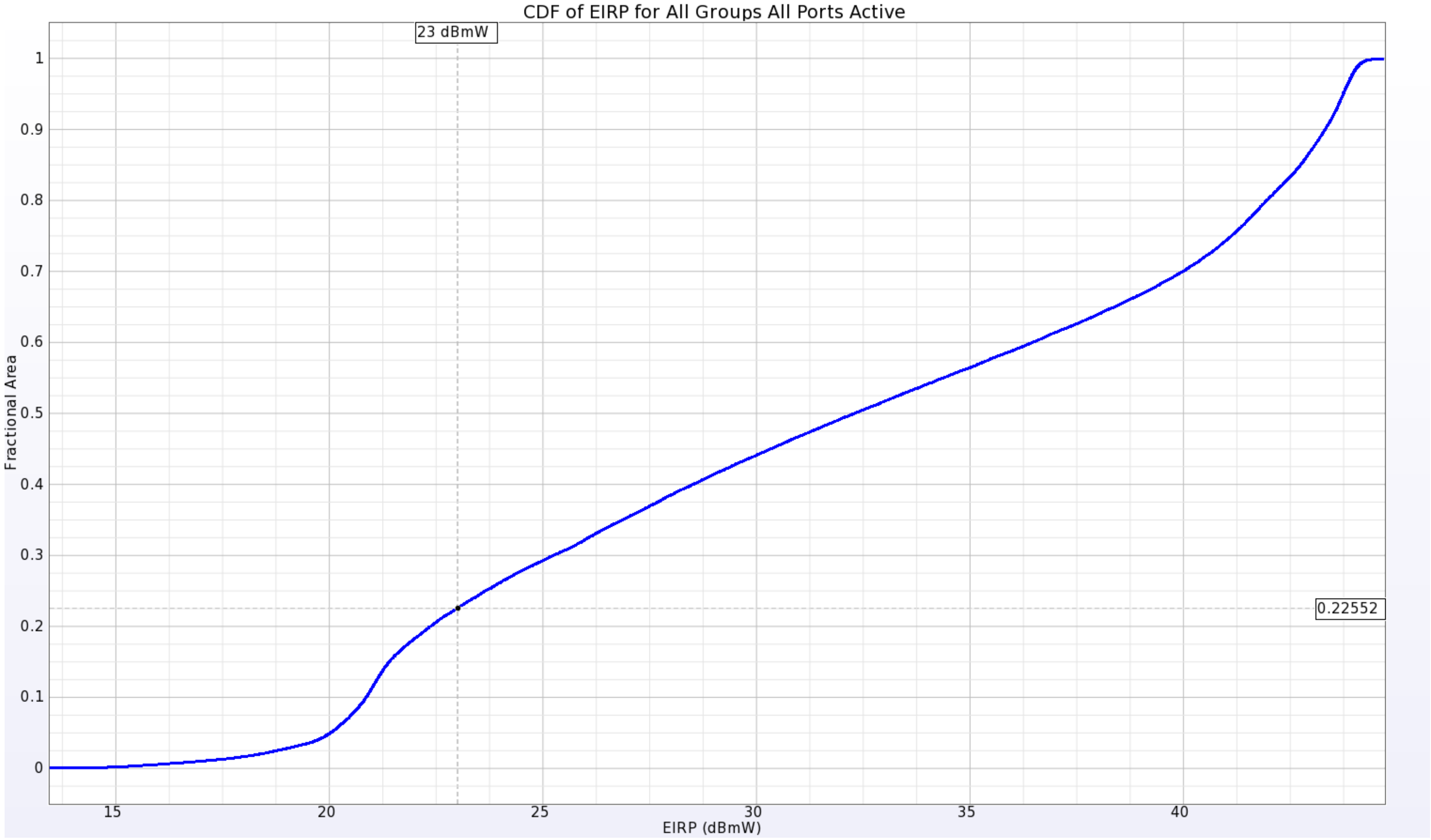
Beams in YZ plane



Beams at Theta=45, vary Phi

CDF of EIRP for 8x8 Array, All Ports Active

- At 23 dBmW input power, about 78% of the sphere has positive gain
- Maximum EIRP possible is 45 dBmW



Analysis of Base Station in Fixed Wireless Access Scenario using Wireless InSite®

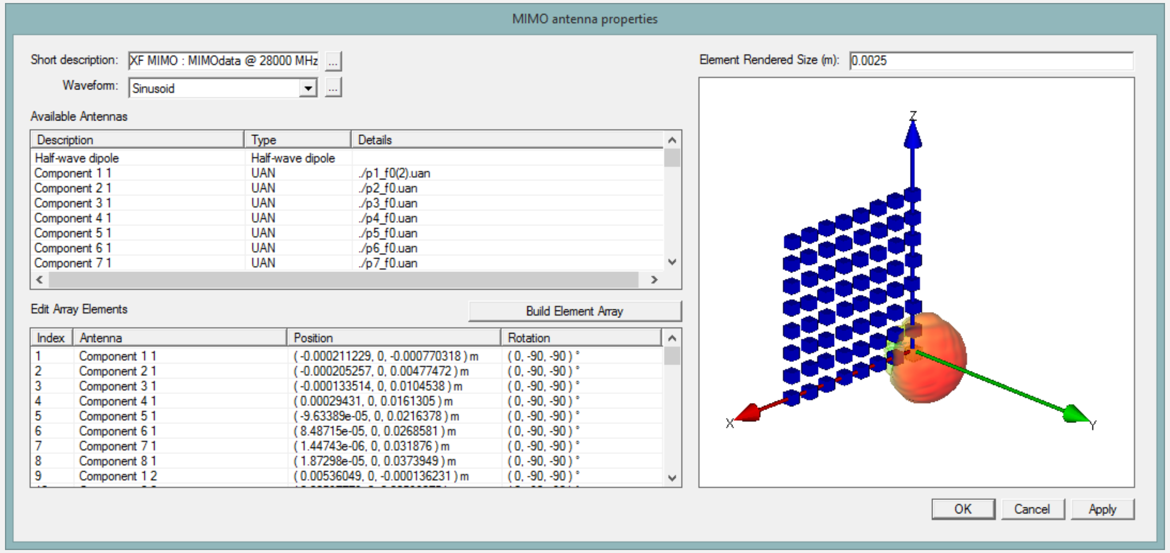
Suburban Fixed Wireless Access Scenario

- 64-Element planar array used as base station for suburban FWA
  - Placed at one end of street, atop utility pole (12m height)
  - Assessed single component carrier, 100 MHz (5G NR), at 28 GHz band

- Consumer premises equipment (CPE's)
  - Placed in multiple alternative configurations at each house
  - Focus of study on single street in front of base station

Massive MIMO Base Station

8x8 Patch Array, after loading into Wireless InSite®



- Imported patch antenna array designed in XFdtd®
  - 8x8 array (64 elements)
  - Vertically polarized
- Power & Frequency
  - Output power: 37 dBm
  - 28 GHz carrier frequency
    - 100 MHz bandwidth (single component carrier)

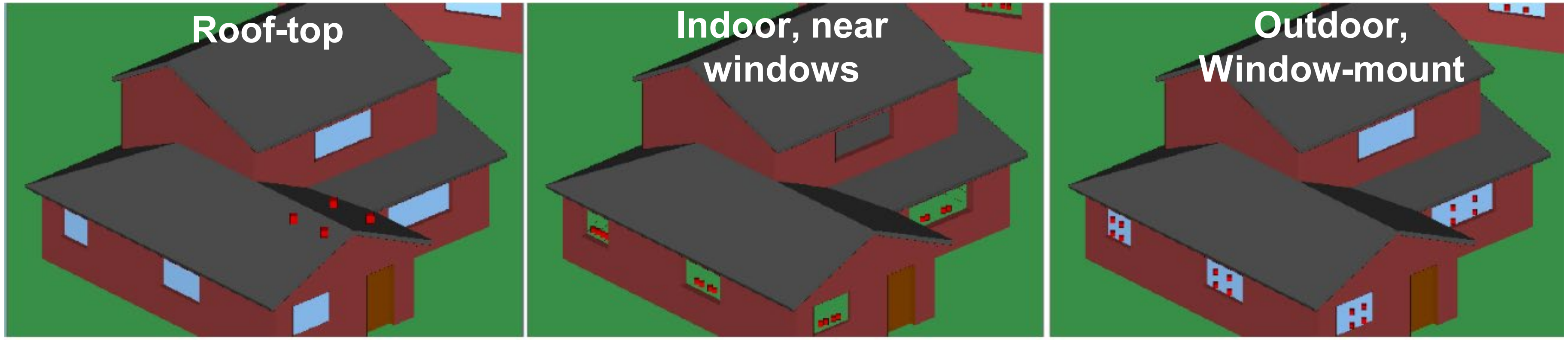
Consumer Premises Equipment

- Three configurations
  - Roof-top (technician installation)
  - Indoor, near window (consumer install.)
  - Outdoor, window mount* (either)

- *3rd option is based on concepts that some vendors have devised to avoid window attenuation

- Antenna patterns
  - Assume arrays with beamsteering
  - 2 cross-pol beams allow 2x2 MIMO
    - For study, defined as two omni antennas ($\pm 45^{o}$ polarization), but with high gain

- Gain:
  - Indoor system: 12dBi (omnidirectional beamsteering)
  - Outdoor systems: 18dBi (directional)



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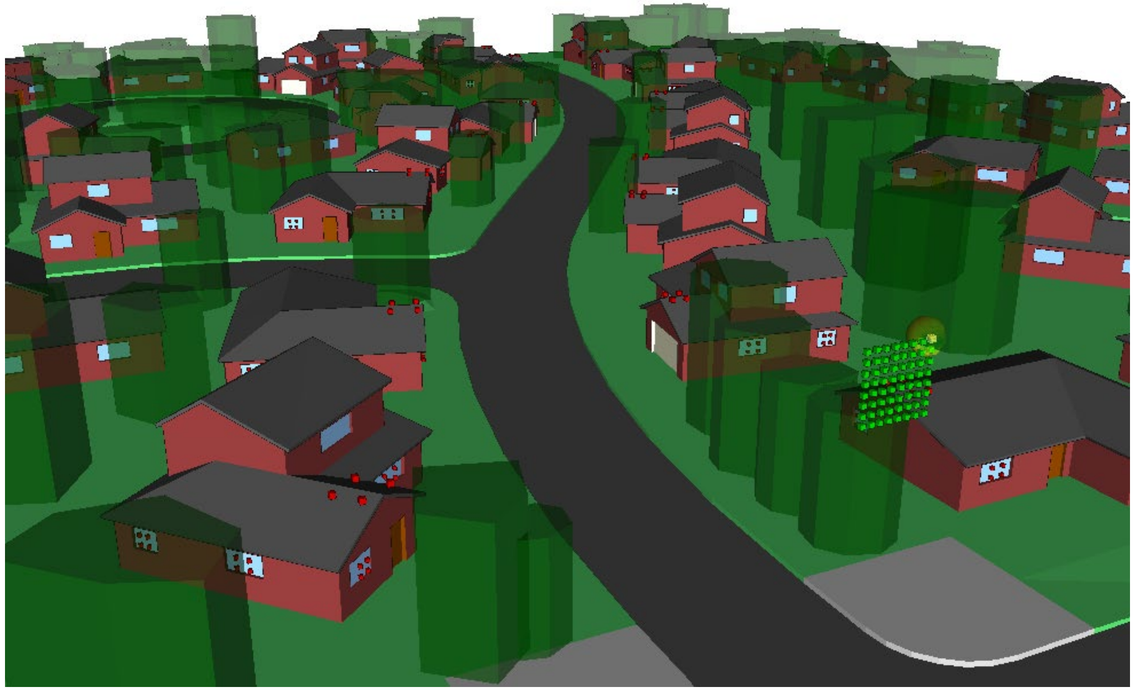
Material Properties

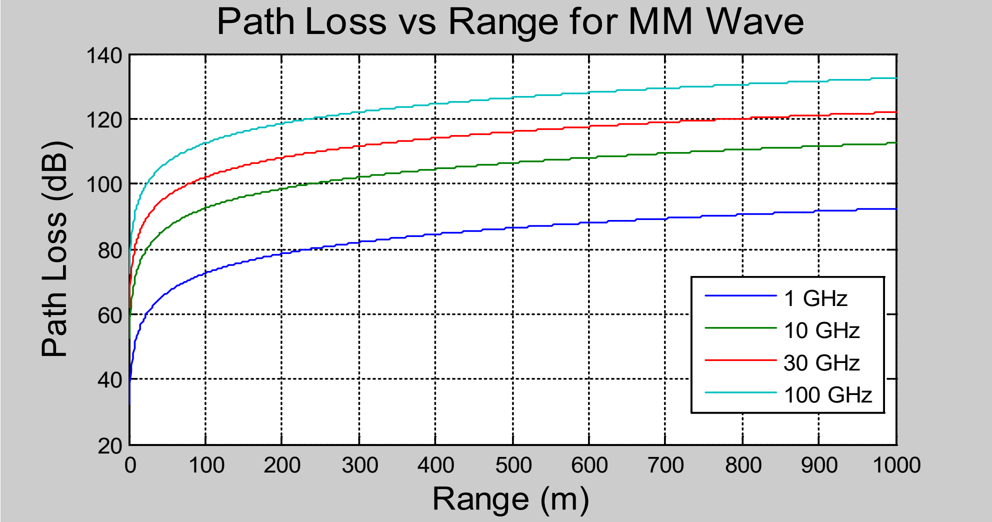
- Material properties assigned to houses & environment based on type
  - Houses
    - Walls: brick, backed by wood studs and sheetrock
    - Windows: 2-pane glass
    - Doors: wood
    - Garage doors: metal
    - Roof: asphalt (shingles)
  - Roads: asphalt
  - Corners: concrete
  - Grass: generic ground with medium level of moisture
  - Foliage: loss based on Weissberger model, described later

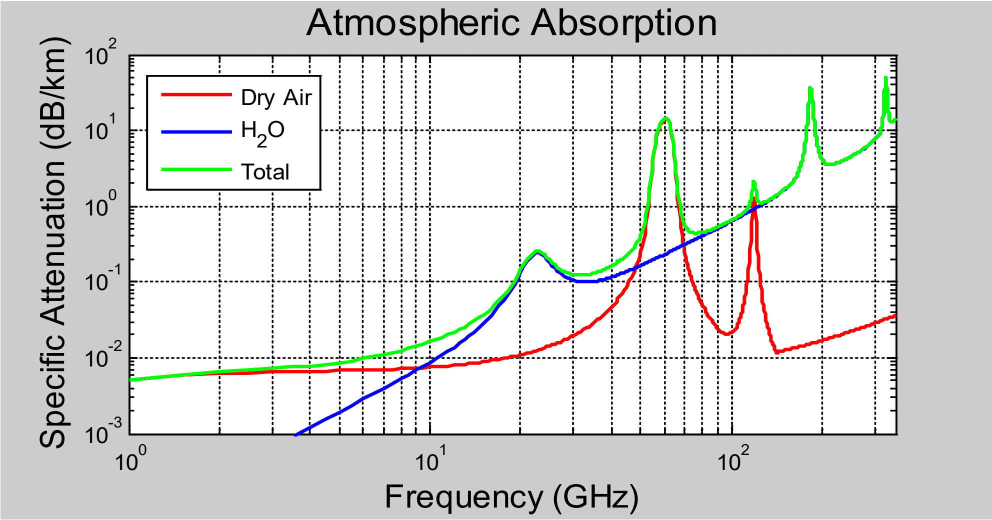


mmWave Challenges: High Path Loss

- Sources of propagation loss
  - Path Loss: at 30 GHz, ~15-30dB greater than bands < 6 GHz
  - Atmospheric absorption: significant at some bands, but only about 0.13dB/km at 28 GHz

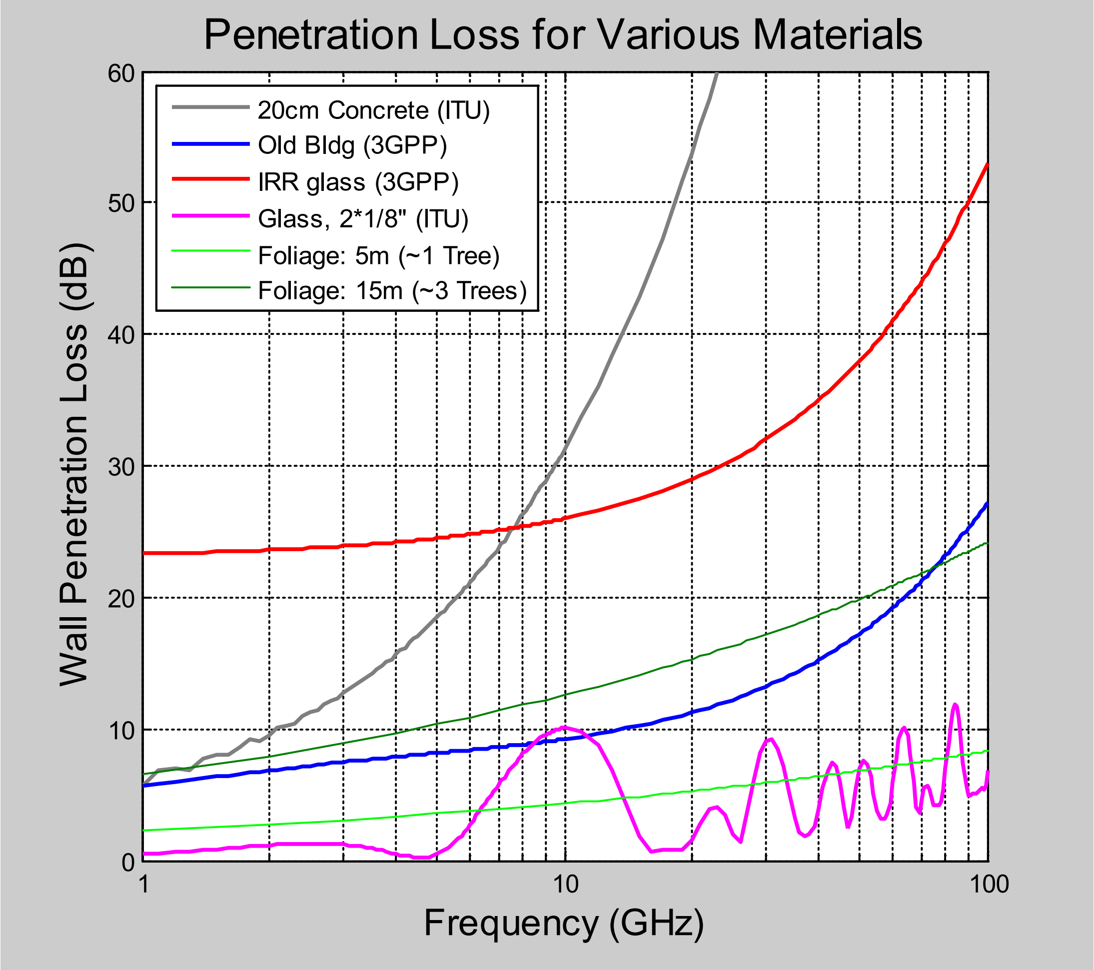
- Wireless Insite's X3D ray model includes these effects in its calculations





mmWave Challenges: High Penetration Loss

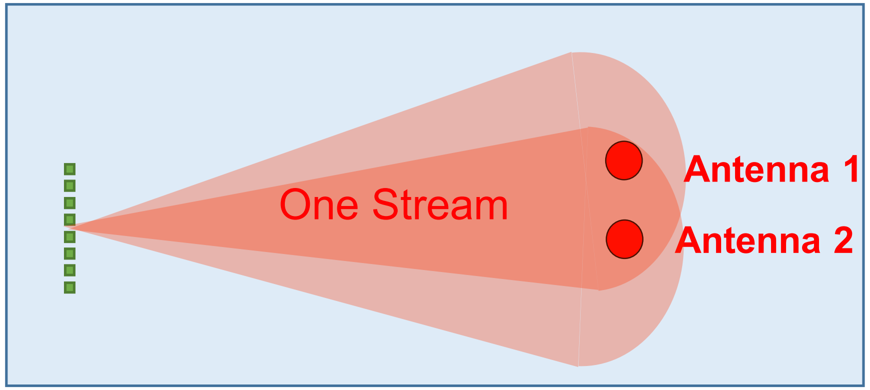
- Penetration loss from structures and trees can be severe at 28 GHz
  - Refs: Weissberger [2], ITU-R p.2040[3], 3GPP TR38.901 [4]
  - Diffractions around corners also drop off rapidly, making primarily LOS
  - Reflections & scattering also vary with frequency
- Wireless InSite ray model captures these effects through its modeling of materials



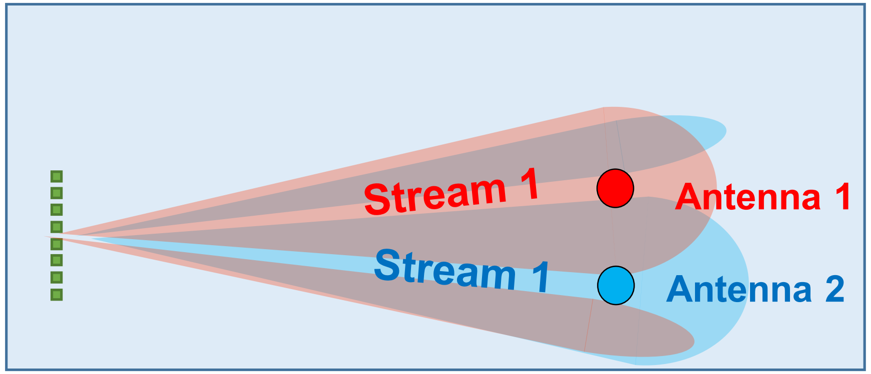
MIMO Beamforming & Spatial Multiplexing

- Evaluated 3 MIMO techniques:
  - Beamforming using precoding tables
    - Chooses best beam to CPE from predefined list
  - Adaptive beamforming with Max. Ratio Transmission (MRT)
    - Creates beam based on channel conditions to maximize gain to CPE
  - Spatial Multiplexing
    - Uses Singular Value Decomposition (SVD) to create isolated data streams to each Rx antenna (spatial multiplexing)

Beamforming to CPE Antennas



Spatial Multiplexing: Multiple Streams



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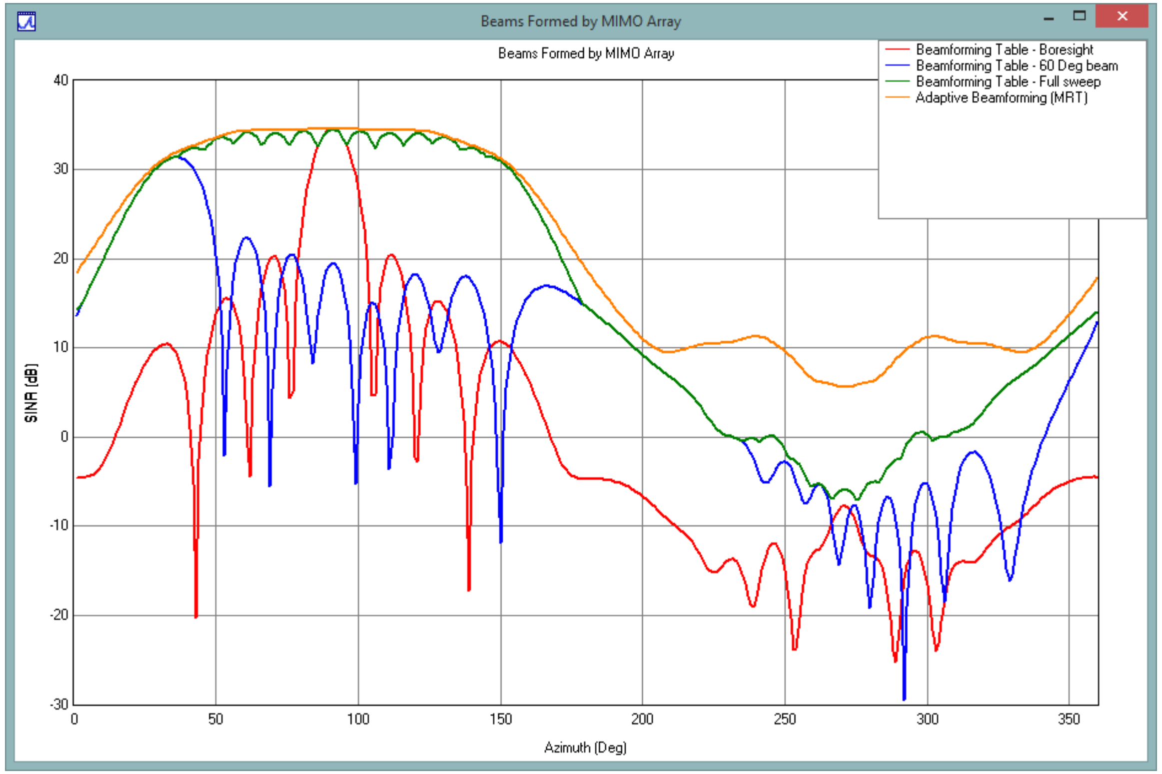
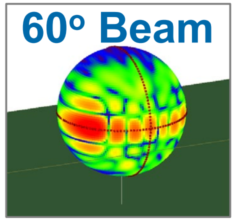
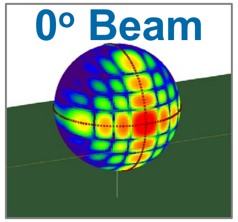
Predefined Beams

- Generated table of beamforming coefficients using two-step process:
  - Used scripts in XF to compute weighting coefficients for each beam during design
  - Converted to precoding tables as inputs to Wireless InSite
- Beam coverage
  - ±60° horizontal, 10° spacing
  - -30° to +10° vertical, 10° spacing
  - 78 total beams (13 wide x 5 high)
- Quick assessment of beams shows they are working
  - Nearly as effective as adaptive beamforming (MRT)

Analysis verifies beamforming using precoding tables



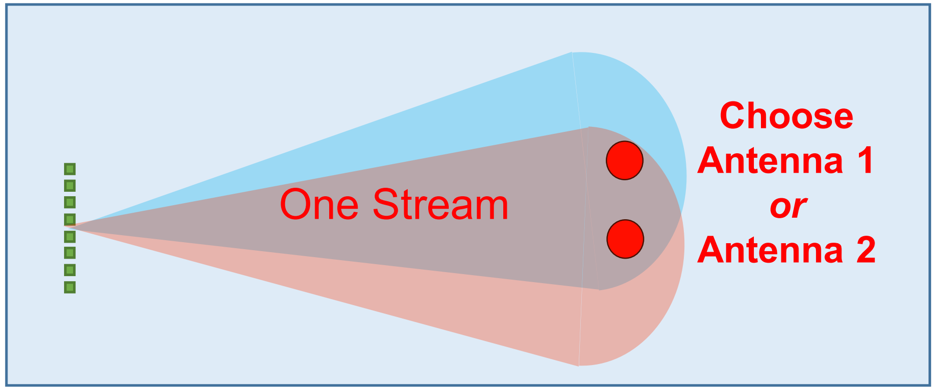




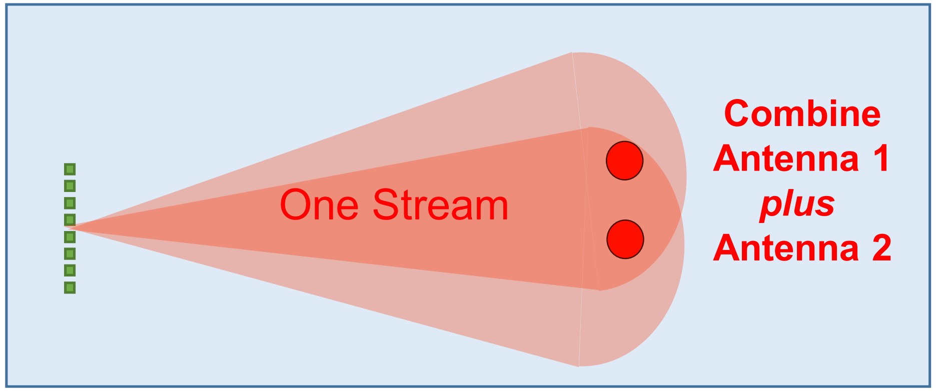
MIMO Receiver Techniques

- CPE was assumed to have sufficient antennas to form two cross-pol beams, modeled as two antennas
- For spatial multiplexing, allowed for 2x2 MIMO
- For beamforming, Wireless InSite supports 3 Rx diversity techniques:
  - Selection Combining (best signal)
  - Equal Gain Combining: combine in phase to increase SNR
  - Max Ratio Combining (MRC): combine, adjusting mag and phase to increase SNR
- For this demo, used MRC

Techniques used with Tx Beamforming:
Selection Combining: Best Signal



MRC or EGC: Combine Signals



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Signal-to-Noise Calculations

- SINR is a key measure for determining throughput of a channel

$$\textbf{SINR} = \frac{\textbf{Signal}}{\textbf{Interference + Noise}}$$

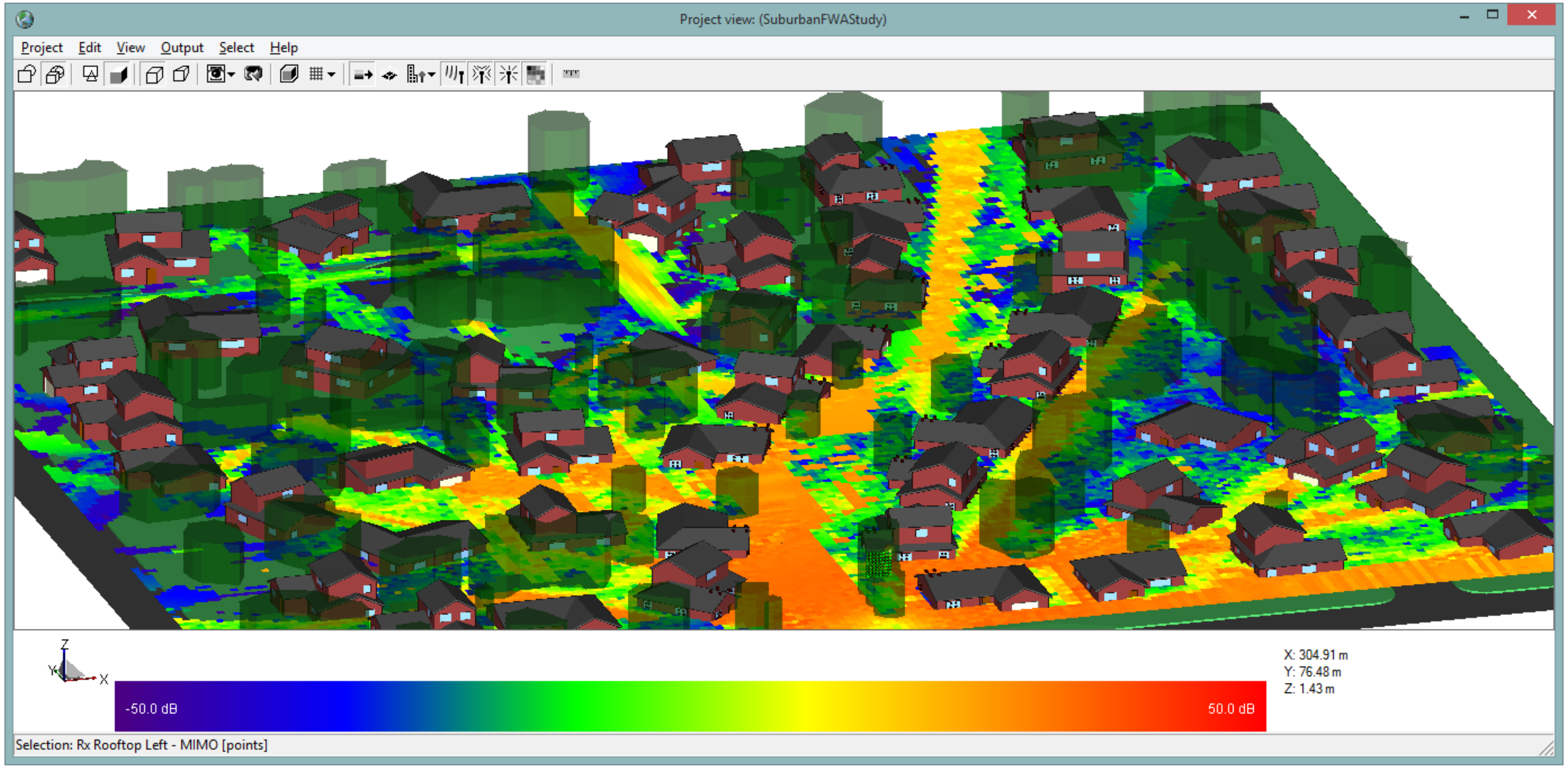
- Sources of noise and interference
  - Ambient RF noise
  - Interference from other base stations
  - Interference from beams to other UEs or streams to other UE antennas

- In this study, we assume minimal interference
  - Base stations will be beamforming to stationary houses with narrow beams
  - Noise: ambient noise from literature: -168dBm/Hz (-88 dBm noise power)
  - Assume receiver noise figure: 5dB

Estimating Peak Downlink throughput for 5G NR

- Wireless InSite allows tables to be constructed that define throughput as a function of SINR
- For this study, created a table of estimated throughput vs. SNR based on data available in the literature for LTE-A Pro
  - Allows rough estimates of throughput (MBps) for 20 MHz bandwidth
  - This was scaled up to 100 MHz bandwidth (approx. 5x higher throughput for the same SNR)
  - Modulation coding schemes extend from QPSK to 256 QAM
- What these throughput estimates represent
  - Peak throughput for downlink transmission for 100 MHz component carrier
  - Carrier aggregation could increase this by the number of carriers
  - Uplink/downlink percentage will decrease by percentage of time used for uplink
- Maximum peak throughput for 100 MHz component carrier is 489 MBps
  - Requires greater than 33dB SNR

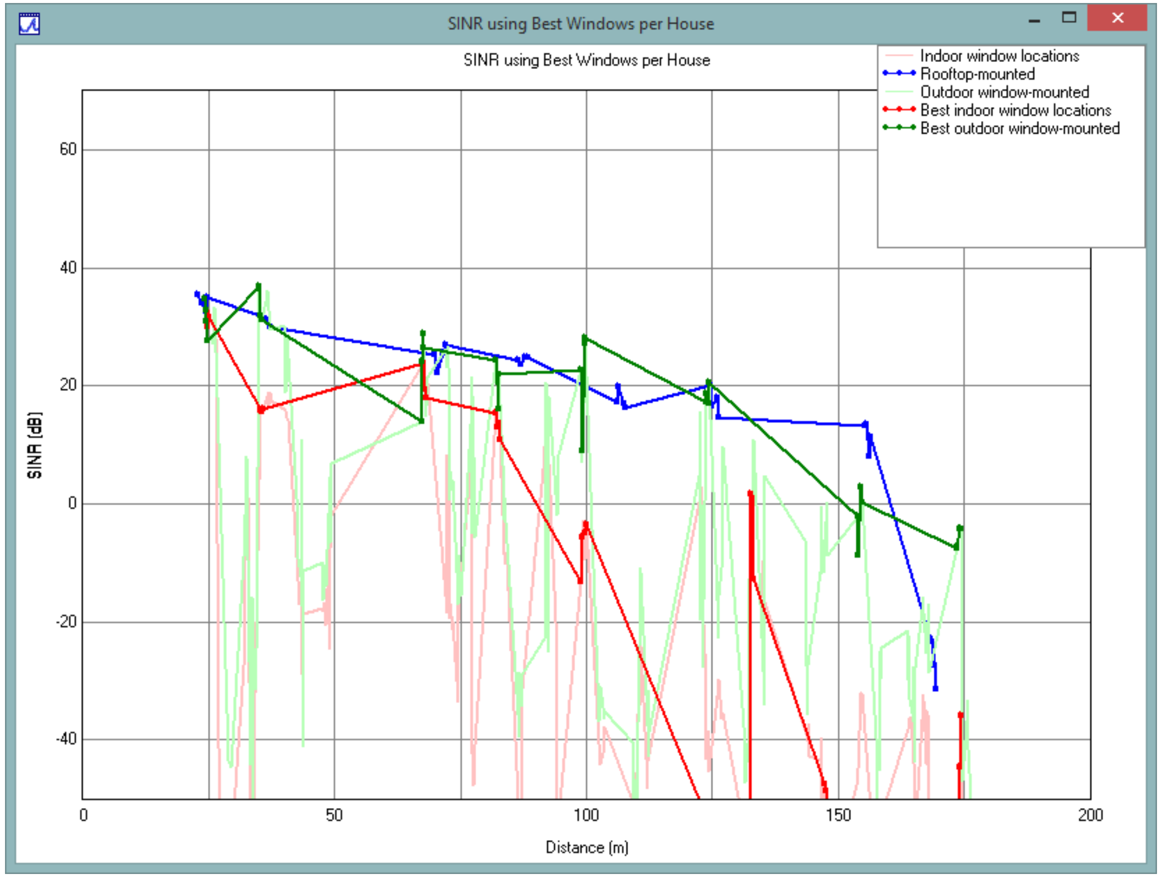
Baseline: Field Map using Dipole Antennas



Field map using dipole antennas include multipath and attenuation by clutter and atmosphere

SINR for best windows of each house

- Plot shows SINR from a dipole transmitter at each window location
  - Faded lines include all windows
  - Identified best (dark red & green)
  - Created smaller receiver set for remainder of analysis
- Clearly significant variability around the windows of home
  - Suggests some amount of testing required to find good reception
  - In most cases, optimal locations were within or near LOS of the base station
- Remainder of this talk will focus on these optimal locations

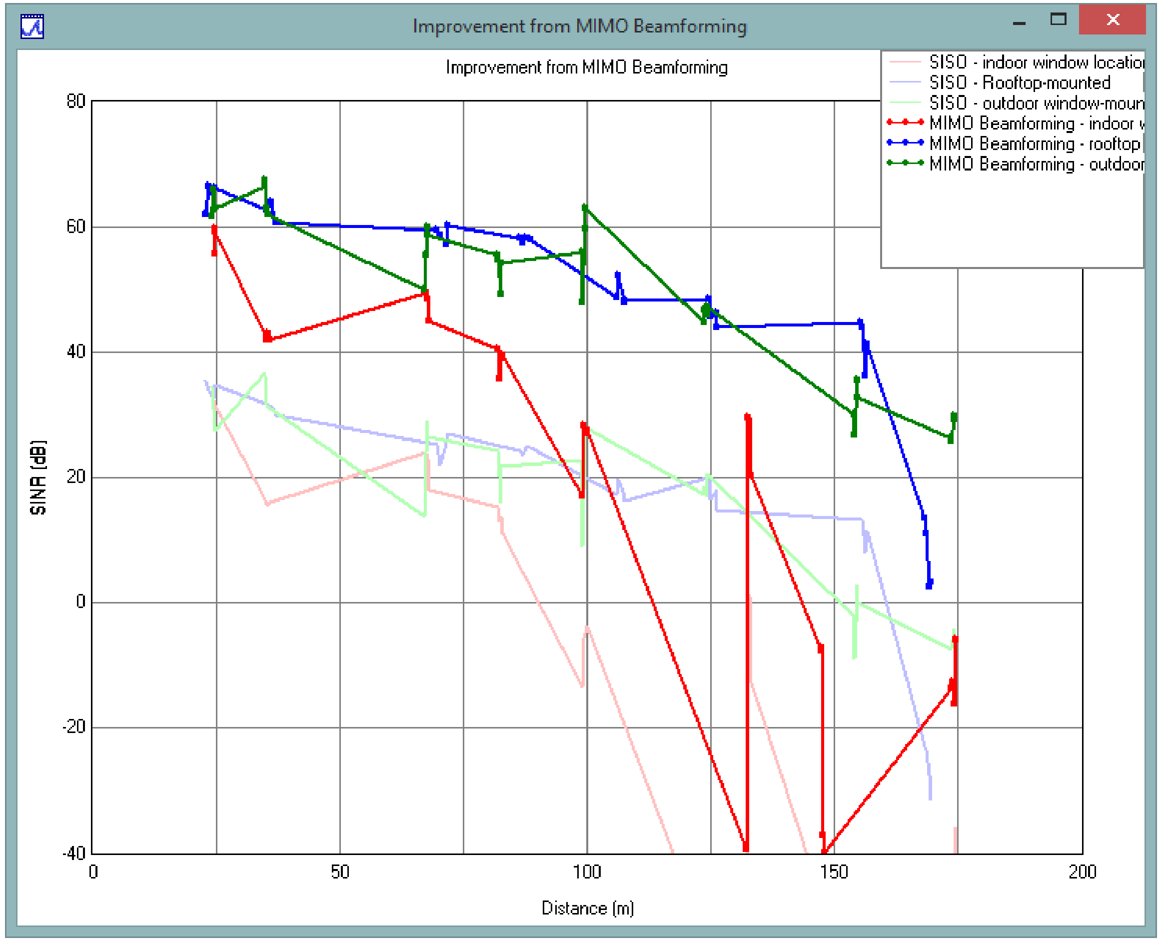


Improvement from MIMO Beamforming

- Used predefined beams from precoding table
- SINR increased by 25-30dB for all three CPE configurations

*Note: adaptive beamforming (MRT) showed very similar results

MIMO Beamforming Provides 25 – 30 dB Improvement



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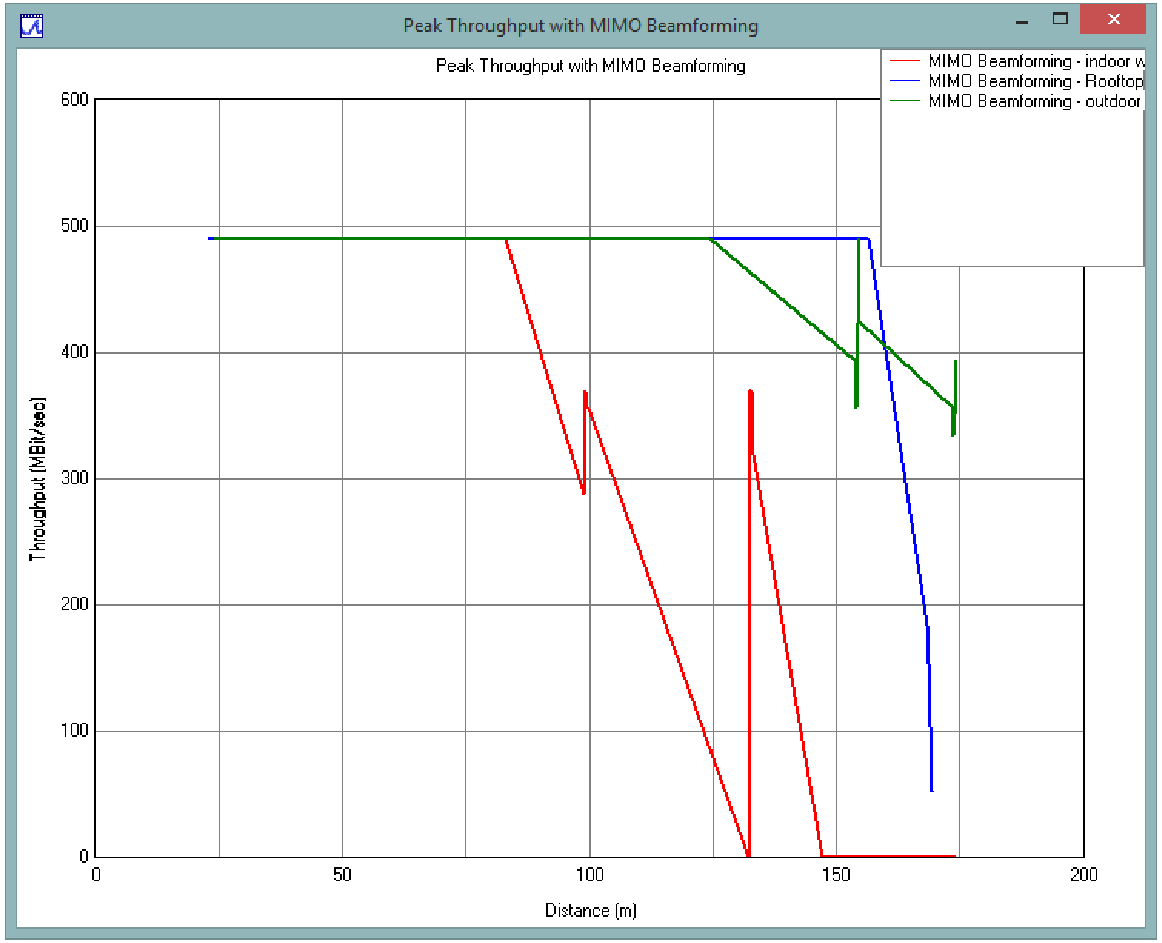
Estimated Peak DL Throughput for 100 MHz band

- Using tables described earlier, estimated peak DL throughput
  - *Note: this is peak during DL transmission (might average 70%DL/30%UL)

- Observations
  - Indoor locations have very short range (~60 meters), and are mostly through windows in LOS
  - Both outdoor configurations do reasonably well to end of street
  - However, either roof-top or an optimal window location are required for a good connection

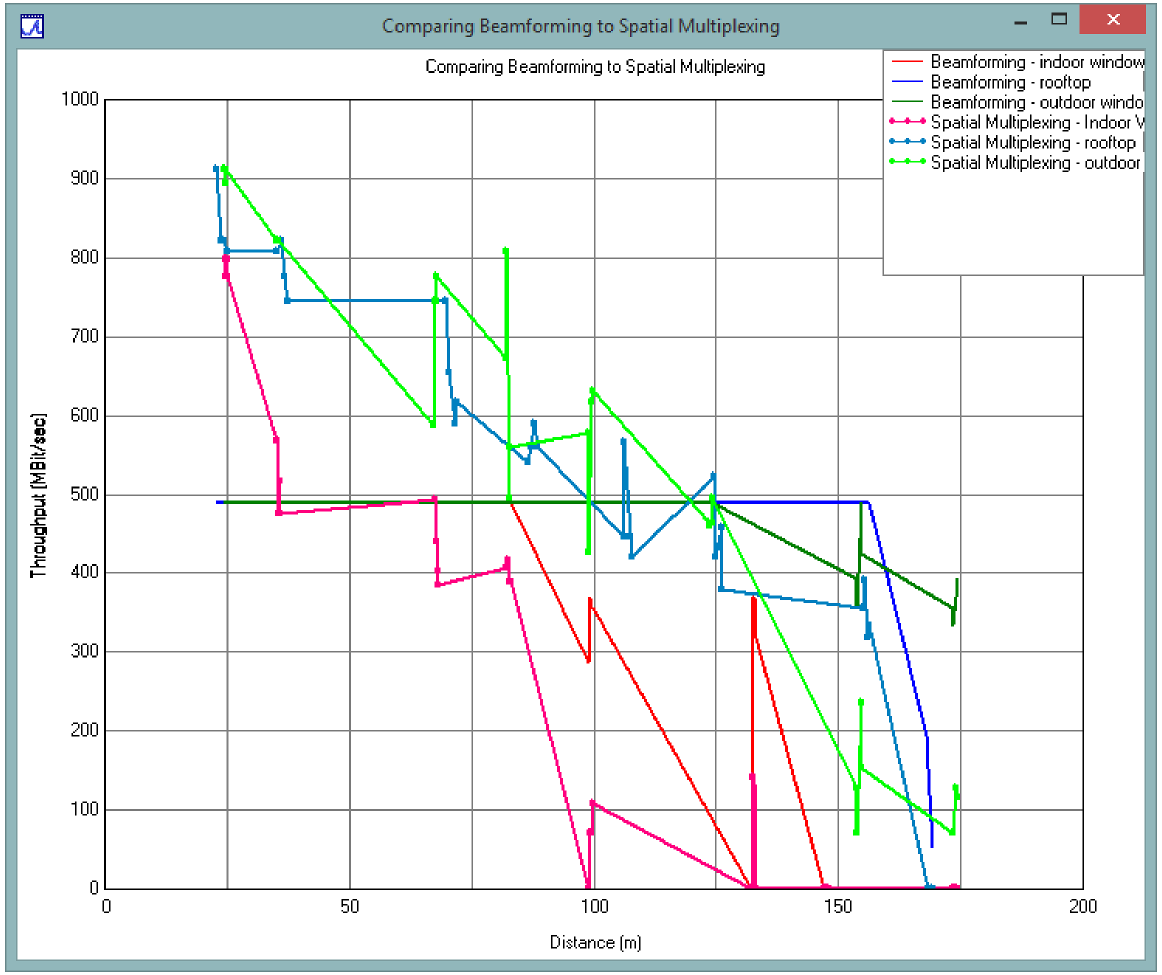
Precoding Table (78 Beams)



MIMO Spatial Multiplexing

- Using SVD, base station and CPE coordinate to create 2 streams (2x2 MIMO)

- Observations
  - Without beamforming, SNR to indoor placements too weak
  - Outdoor locations can see improved throughput at short ranges
  - Beamforming does better at longer ranges, where needed to boost SNR
  - In all cases, either roof-top antenna (technician-installed) or an optimal window required to achieve reasonable connection



Summary

In this presentation, we demonstrated how Remcom's tools can be used to design a MIMO array for 5G and assess its performance in a realistic scenario

This included:

- Design and analysis of the array in XFdtd®
- Evaluation of its performance in a suburban FWA scenario in Wireless InSite®

An actual assessment could include evaluation of multiple designs, additional scenarios, additional bands (e.g., for carrier aggregation), interference from other base stations, and many other types of analysis.

Our goal was to demonstrate a simulation-based methodology that can be used to aid in the process of designing antennas and evaluating their potential performance in realistic 5G deployment scenarios.

Contact

Contact us:

Toll Free: 1-888-773-6266 (US/Canada)

Tel: 1-814-861-1299

Email: sales@remcom.com

www.remcom.com

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