Using Modeling and Simulation to Assess Challenges and Solutions for 5G Fixed Wireless Access

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Author: Greg Skidmore
Remcom, Inc.

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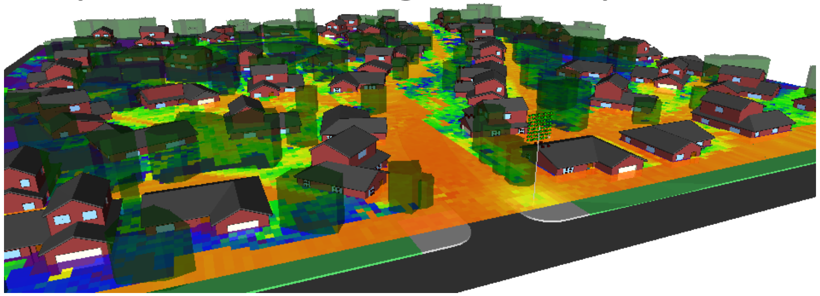
5G Fixed Wireless Access

- Fixed Wireless Access (FWA) is one of the major planned use cases for early rollouts of 5G, with a goal of providing wireless broadband for the last mile to homes and businesses
- The need for high bandwidth is driving many solutions to millimeter wave bands
  - This poses some challenges for deployment
  - Technologies like MIMO beamforming and densification are among the solutions
- Careful design and placement of the base stations and CPE's are a critical part of making FWA work; this study shows some issues that may need to be considered and an approach for using simulations to assess potential solutions

Simulation-Based Assessment of FWA

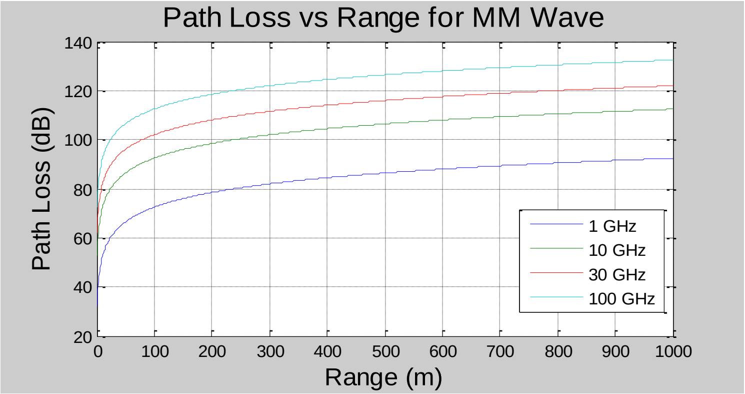
- This talk presents a case study using an innovative modeling and simulation methodology to assess 5G FWA in a suburban neighborhood
  - The approach uses ray-tracing from Wireless InSite® to predict propagation between antennas, augmented with MIMO beamforming and throughput analysis
- This method was used to investigate some of the critical challenges that FWA faces for operation at higher frequencies, such as 28 GHz

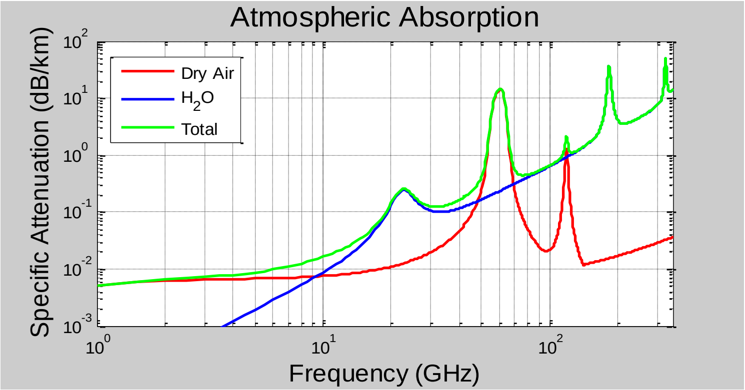


MM Wave Challenges: High Path Loss

- Sources of propagation loss
  - **Path Loss:** ~15-30dB greater at 28 GHz than bands < 6 GHz
  - **Atmospheric absorption:** significant at some bands, but minimal at 28 GHz

- Result: best-suited to shorter ranges





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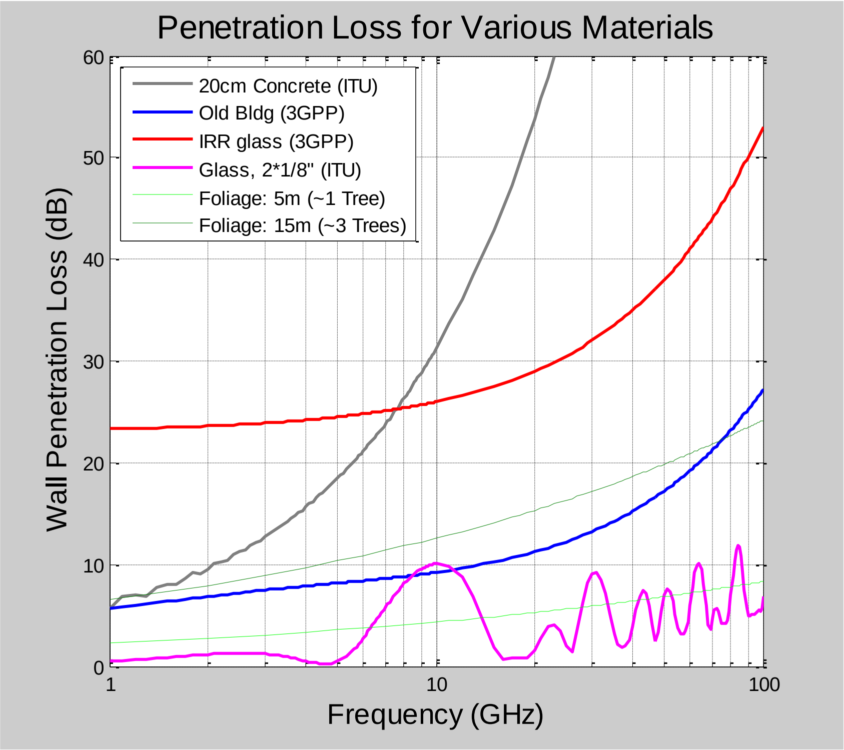
MM Wave Challenges: High Penetration Loss and Weaker Multipath

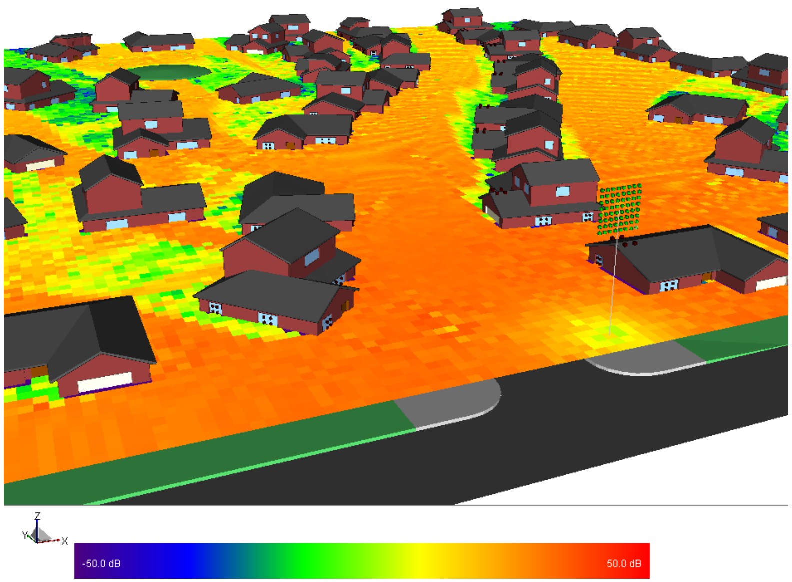
- Penetration loss from structures and trees severe at 28 GHz [1-3]
- Multipath
  - Diffractions around corners also drop off rapidly → primarily LOS
  - Reflections also weaker at higher frequencies due to scattering
- Diffuse scattering in non-specular directions further complicates

- Ray model captures these effects through its modeling of materials

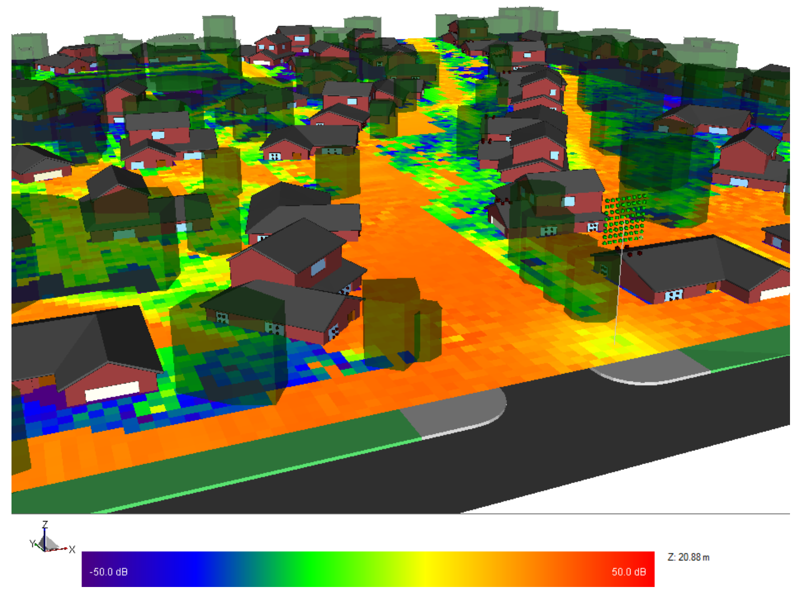


Effect of Trees on Coverage

SINR without Trees



SINR with Trees



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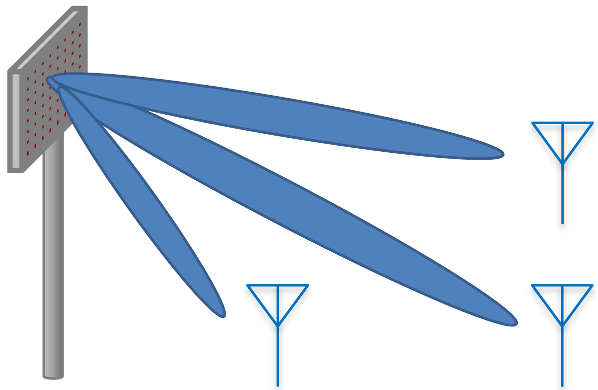
Solutions: Massive MIMO Beamforming

- What is *Massive* MIMO?
  - Tens to hundreds of base station antennas
  - Directs beams to each CPE; high gain increases SINR and throughput
  - Multiple beams within one frequency band increase overall spectral efficiency

- MM Wave enables large arrays
  - Spacing typically ~0.5 wavelength
  - Large array just a few centimeters at 30 GHz +

Massive MIMO Beamforming

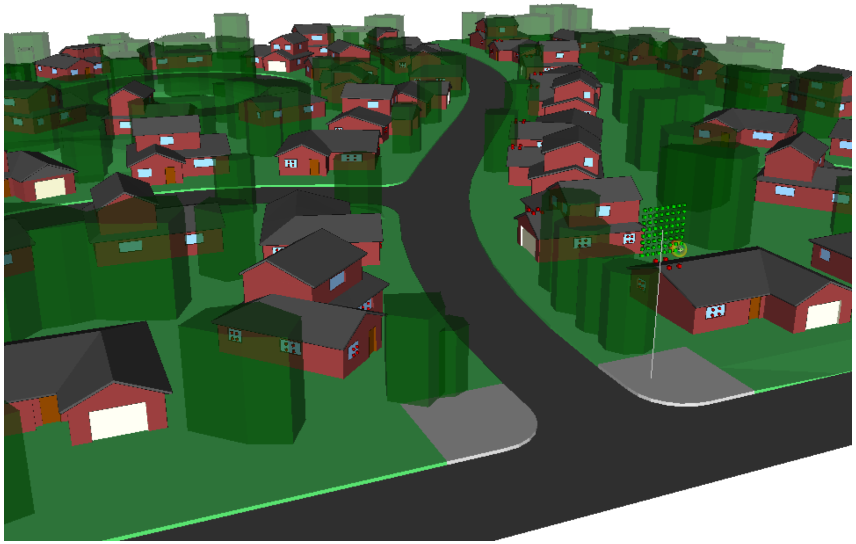


Other Solutions

- Exterior antennas (roof, wall, or window mounted) or indoor close to low-loss windows
  - Customer installation ideal
- Densification to reduce range (e.g., antennas on street lights) – though puts antennas within clutter
- Using taller poles when possible (e.g., utility poles)

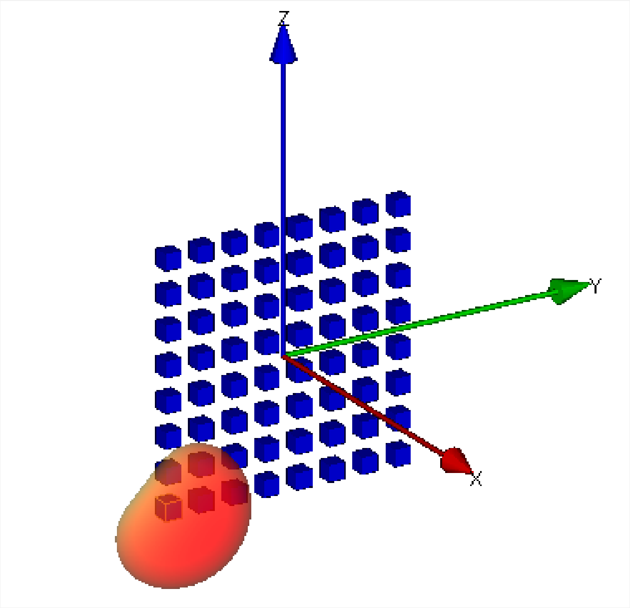
Suburban Fixed Wireless Access Scenario

- Massive MIMO Base Station
  - 128-element array
  - Atop utility pole or street light
  - 5G NR: 100 MHz component carrier @ 28 GHz
- 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 in Wireless InSite®



- MIMO Patch Array
  - 8x8 array, dual polarized
  - (128 total elements)
- Power & Frequency
  - Output power: 37 dBm
  - 28 GHz carrier frequency
    - 100 MHz bandwidth (single component carrier)

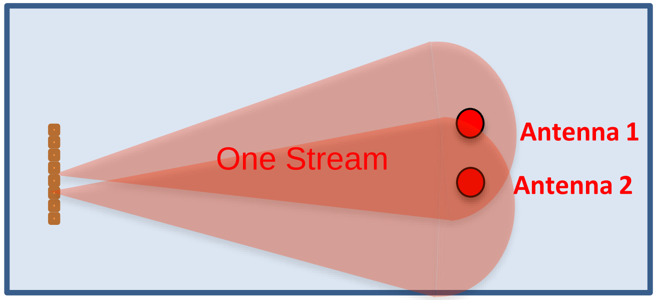
MIMO Beamforming & Spatial Multiplexing

- Evaluated 2 MIMO techniques:

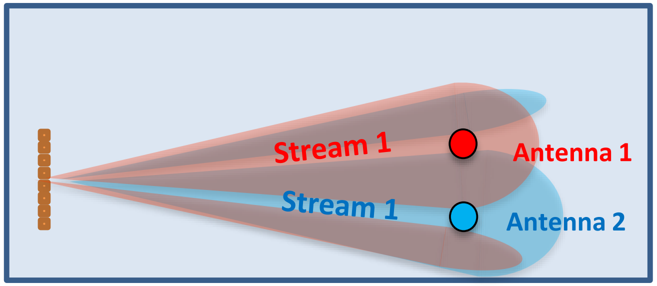
  1. Adaptive beamforming with Max. Ratio Transmission (MRT)
     - Use channel state to maximize gain to each CPE
     - Alternatively, could use a fixed grid of beams

  2. Spatial Multiplexing
     - Singular Value Decomposition (SVD) to create multiple data streams

Beamforming to CPE Antennas



Spatial Multiplexing: Multiple Streams



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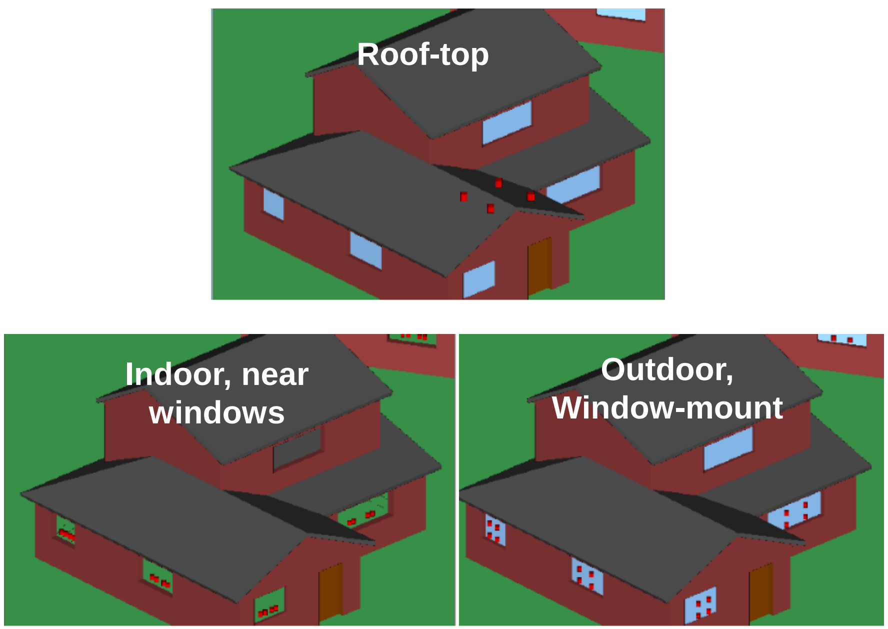
Consumer Premises Equipment



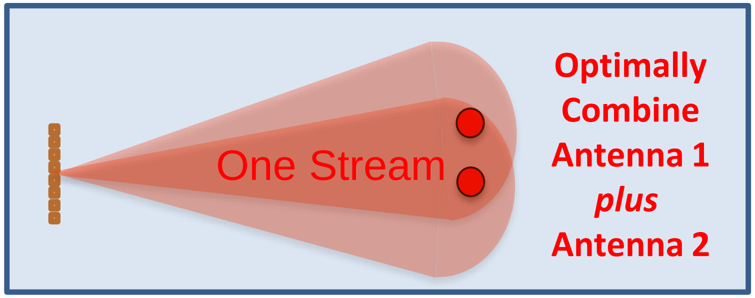
- Three configurations
  - **Roof-top** (technician installation)
  - **Indoor, near window** (consumer install.)
  - **Outdoor, window mount*** (either)

* Vendors have devised concepts to avoid window attenuation

MIMO Receiver Techniques

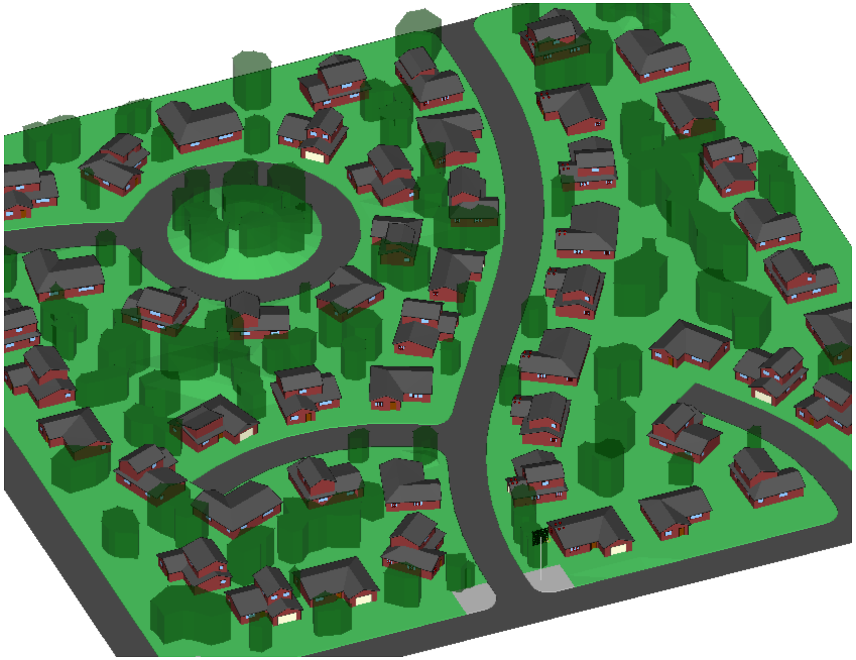
- CPE modeled with two cross-pol beams
  - Gain from beam steering:
    - Indoor: 12dBi (omnidirectional)
    - Outdoor: 18dBi (more directional)
- Supports 2x2 MIMO (spatial multiplexing)
- For Tx beamforming case, maximal ratio combining (MRC) further increases SNR

Maximal Ratio Combining to increase SNR



Material Properties

- Houses
  - Walls: brick, backed by wood studs and sheetrock
  - Windows: 2-pane glass
  - Doors: wood
  - Garage doors: metal
  - Roof: asphalt (shingles)
- Roads: asphalt
- Paved street corners: concrete
- Grass: generic ground with medium level of moisture
- Foliage: used Weissberger model



Signal-to-Noise Calculations

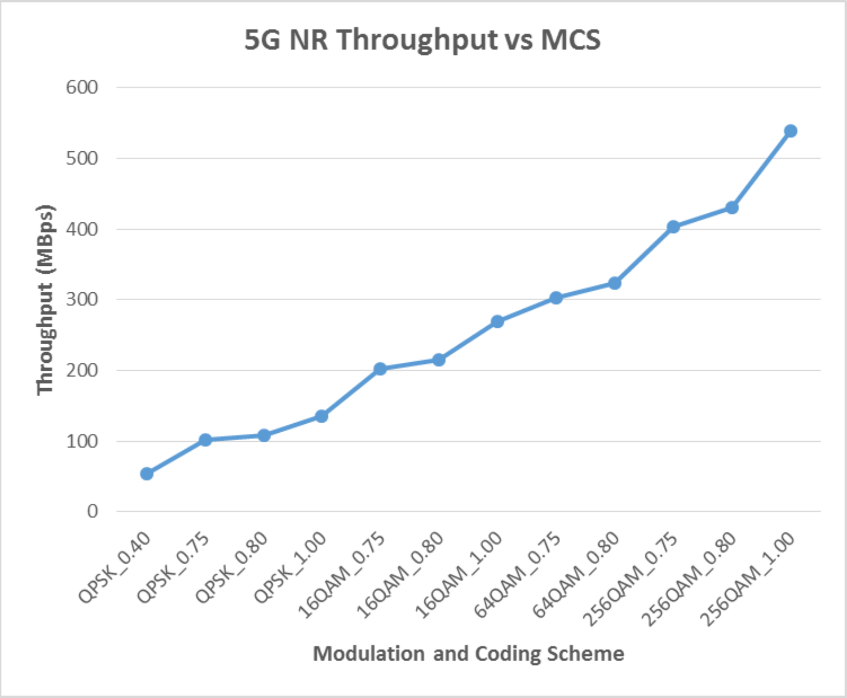
- SINR is a key measure for determining throughput of a channel

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

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

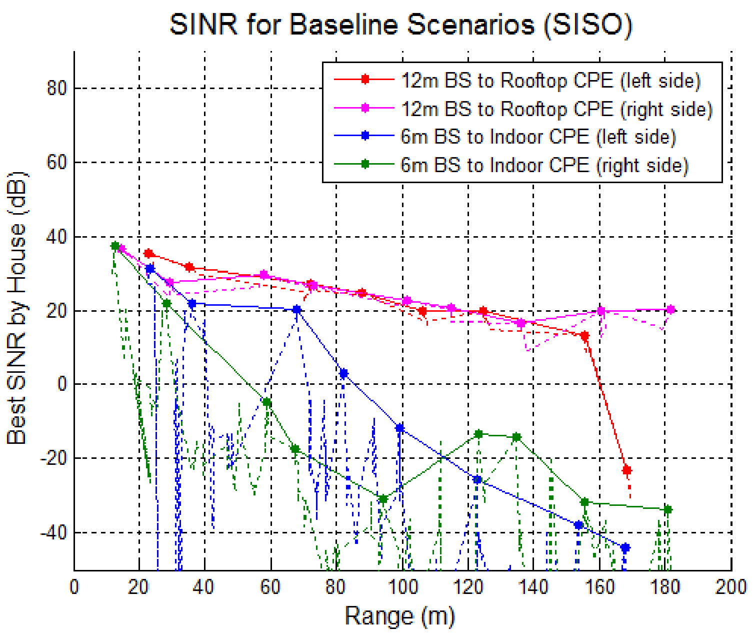
Peak Downlink Throughput for 5G NR

- Estimated Throughput for 100 MHz band based on 3GPP TS [4]
- Modulation & coding schemes extends from QPSK up to 256 QAM
- Values were scaled down to 70% of the above to account for TDD uplink



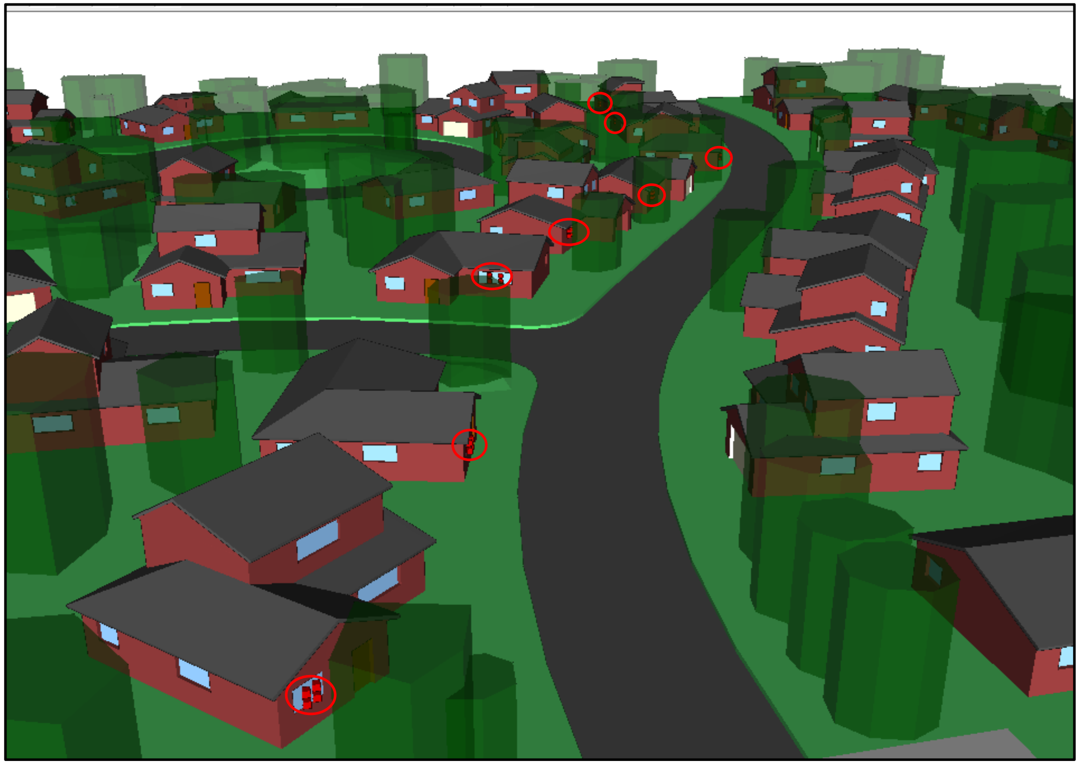
Results for Baseline Case (SISO)

- Baseline case:
  - Single antennas (SISO)
- Two cases:
  - Utility pole to rooftop CPE
  - Streetlight to indoor/window CPE
- Significant variability among windows
  - Identified "best" per house (solid line)



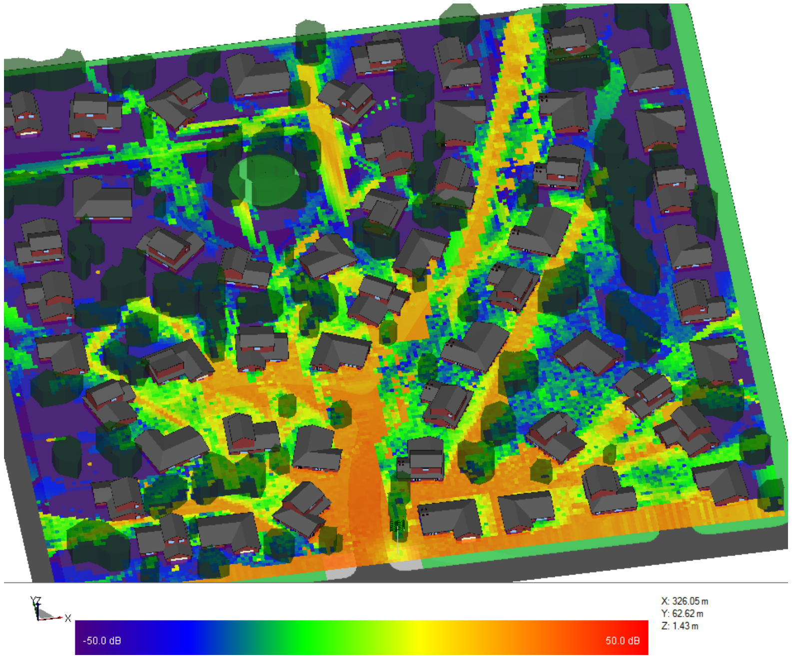
Windows on left side of Street with "Best" Reception

- For window receivers, plotted results for antennas with best reception
- Most are in or near LOS to the base station (some front and some back windows)

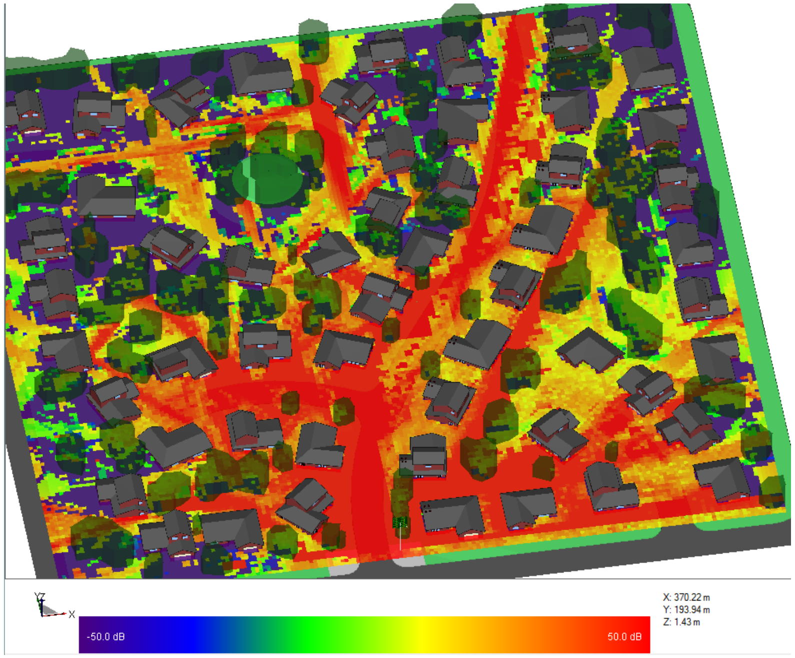


Improvement from Beamforming

SINR for SISO Baseline



SINR w/MIMO Beamforming



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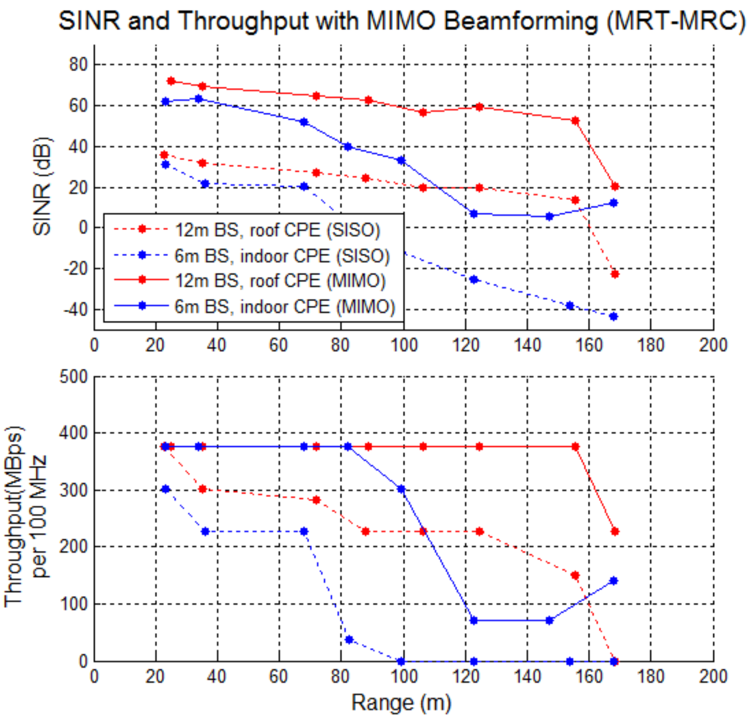
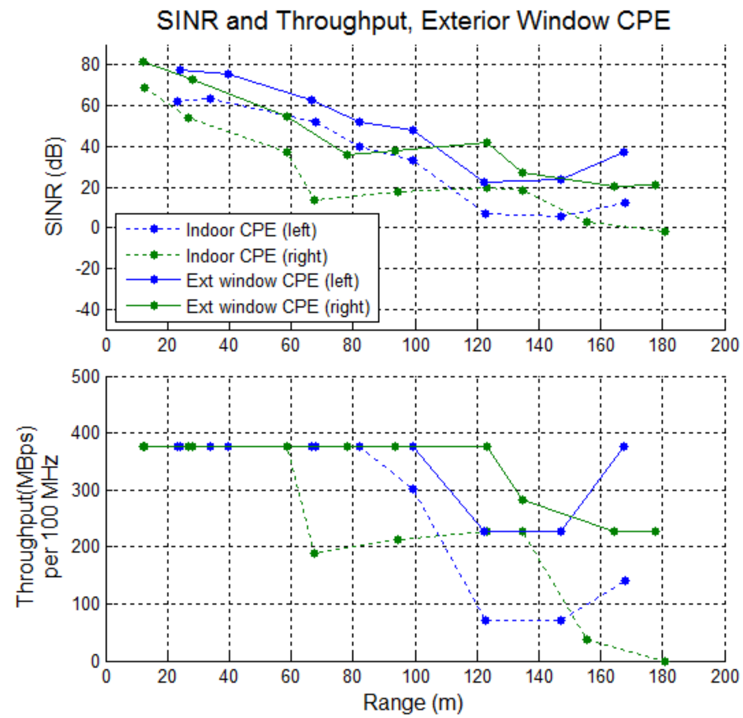
Improvement from Beamforming

- Beamforming + combining achieve 30-40dB higher SNR
- Allows high throughput farther down street
  - Interior system still much shorter range



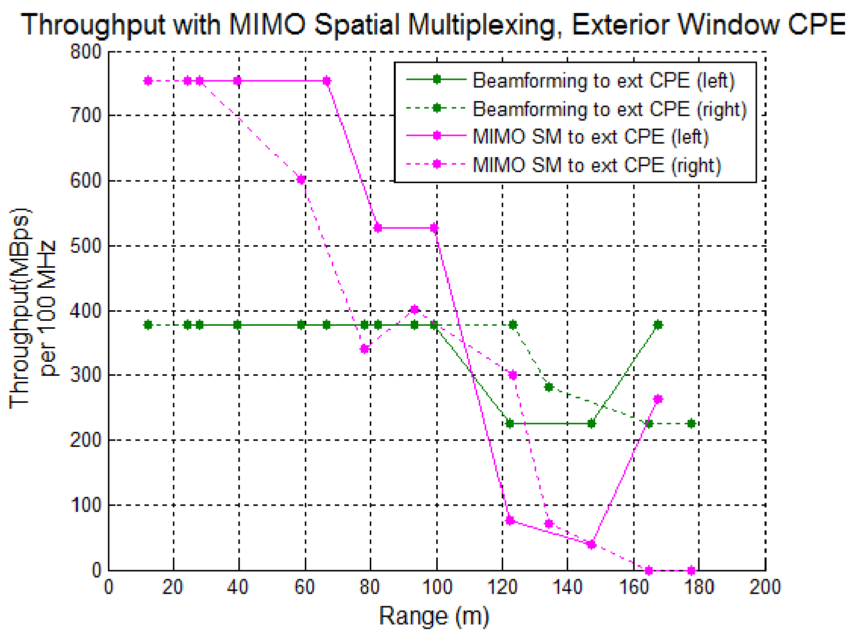
Improvement from Exterior Window

- Exterior mounted systems achieved 10-20dB higher SNR
- Throughput is moderate to high to end of street



Potential Benefit to Throughput from Spatial Multiplexing

- 2x2 MIMO has potential to double throughput with 2 streams
- Successful at short ranges, but does not extend as far



Conclusions

- This talk has presented a simulation-based methodology for assessing wireless systems for 5G
- This was used in a case study to assess MIMO systems for FWA in a simulated suburban neighborhood
  - Results show some of the challenges and range limitations that millimeter wave systems could face for 5G FWA in neighborhoods, as well as tradeoffs and different options for overcoming these challenges
- The study could be expanded to evaluate other deployment scenarios, networks with multiple base stations, or other conditions

Simulation results in this paper were generated using Wireless InSite®, developed by Remcom, Inc.

References

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

[2] *Study on 3D channel model for LTE*, 3GPP, TR 36.873 (V12.2.0), July 2015.

[3] Weissberger, Mark A., *An Initial Critical Summary of Models for Predicting the Attenuation of Radio Waves by Trees*, Final Report, ESD-TR-81-101, EMC Analysis Center, August 1982.

[4] *User Equipment (UE) radio access capabilities (Release 15)*, 3GPP TS 38.306 V15.2.0 (2018-06).