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Electromagnetic Simulation Software

Wireless InSite® Simulation of MIMO Antennas for 5G Telecommunications

Overview

- To keep up with rising demand and new technologies, the wireless industry is researching a wide array of solutions for **5G**, the next generation of wireless networking

- Technologies based on **Multiple Input, Multiple Output** (MIMO), including Massive MIMO, are among key concepts

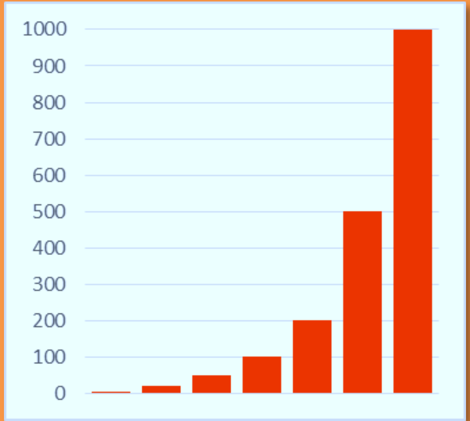
- As a leading provider of wireless simulation tools, Remcom is developing an innovative and efficient MIMO simulation capability

- In this talk, we give an overview of 5G and MIMO concepts, and a preview of our upcoming Wireless InSite MIMO simulation capability

5G OBJECTIVES AND CHALLENGES

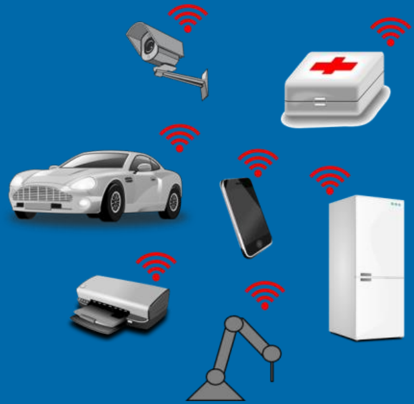
Challenges For 5G

Massive Growth In Mobile Data Demand



1000x Increase

Massive Growth of Connected Devices



5 Billion (2010) → 50 Billion+ (2020)

Increasingly Diverse Use Cases and Requirements

- Traditional
  - Cell Phones
  - Tablets
  - Laptops
- Emerging Technologies
  - Connected Cars
  - Machine-to-Machine
  - Internet of Things

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Challenges and Objectives of 5G

Challenges

- Massive Growth in Mobile Data Demand
- Massive Growth in Connected Devices
- Increasingly Diverse Use Cases and Requirements

Objectives

- 1000x Capacity
- 10-100x Devices (50-500B)
- 10-100x Data Rates (~10 Gbps)
- 5x Lower Latency
- 100x Energy Efficiency
- 10x Longer Battery Life for low-power devices

Challenges and Scenarios for 5G[1]

Challenges		Scenarios
Very High Data Rate	→	Amazingly Fast
Very Dense Crowds of Users	→	Great Service in a Crowd
Very Low Latency	→	Real-Time, Reliable Connections
Mobility	→	Best Experience Follows You
Many Devices w/Low Energy Cost	→	Ubiquitous Things Communicating

[1] METIS: Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society

Some of the Key Solutions

- Some of the key solutions
  - Increased spectrum, much of it at higher frequencies (e.g., mm waves)
  - Massive MIMO
  - Ultra-Dense Networks
  - Moving Networks
  - Machine-to-machine/Device-to-device Communications
- Focus of this talk is on MIMO, including Massive MIMO, with some reference to its use with millimeter waves

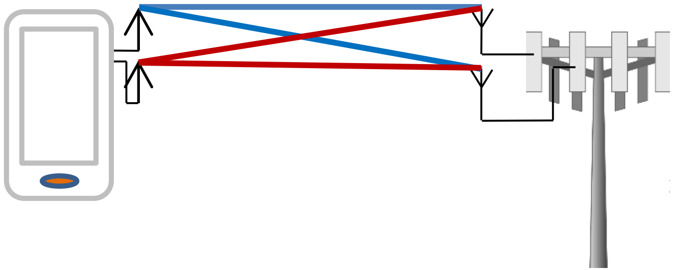
How MIMO Helps to Address 5G Challenges

MIMO AND 5G

MIMO

- Multiple Input, Multiple Output
- Use techniques such as spatial multiplexing and precoding
  - Create multiple streams to increase data rate
  - May use beamforming to increase SNR
  - Techniques require varying levels of channel state info (CSI)

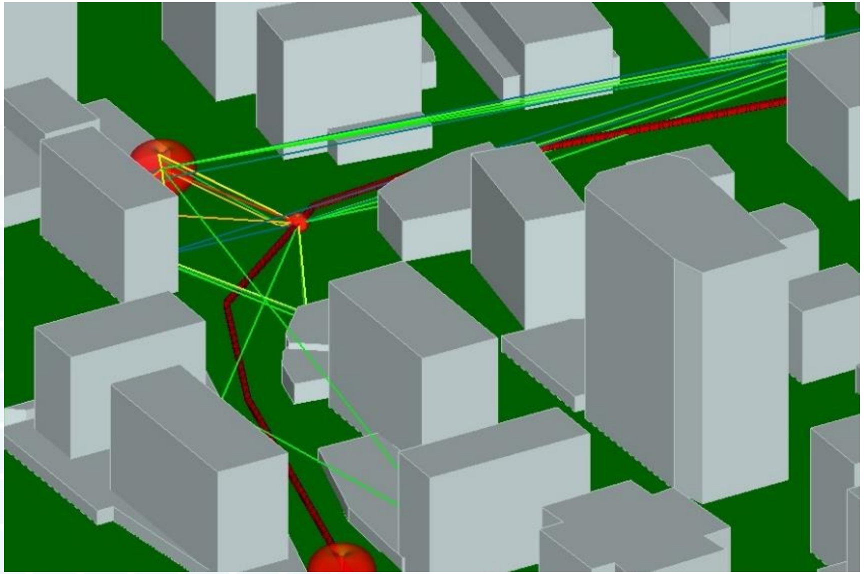
MIMO Multi-Streaming Concept



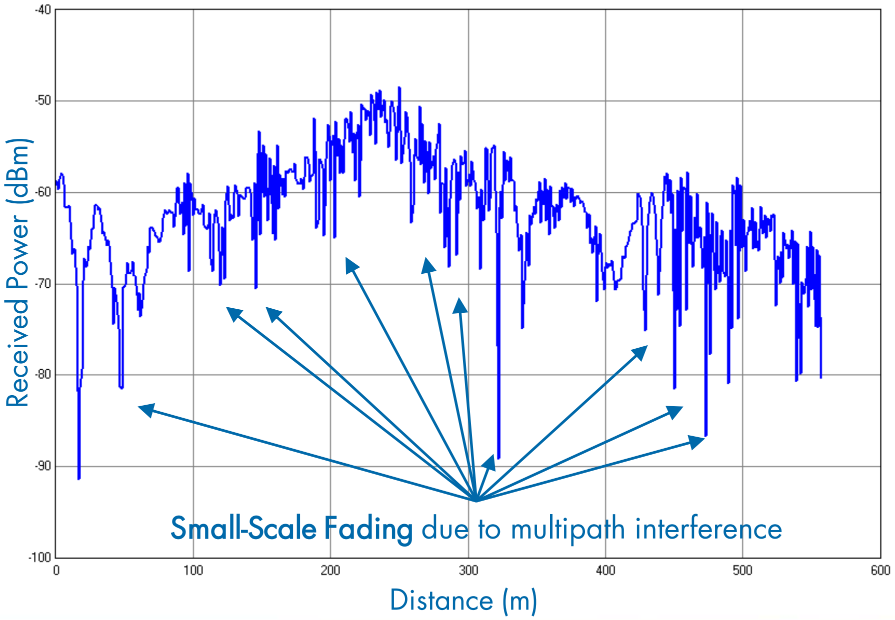
MIMO Techniques	Requires CSI?	Description of Technique
Precoding	Both ends	Split signal into multiple streams and use coding for beamforming
Spatial Multiplexing	At transmitter	▪ Split signal; transmit different streams from each antenna ▪ Works if channel characteristics (spatial signature) uncorrelated ▪ Can be combined with precoding if have channel state info (CSI)
Diversity Coding	Not required	Takes advantage of variation in fading for each antenna pair to provide diversity; can use if no channel state information

Multipath and Fading

Wireless InSite example showing multipath between base station and user equipment



Small-scale fading from multipath causes rapid fluctuations along route



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Multi-User MIMO (MU-MIMO)

- MIMO transmission to multiple terminals at same time

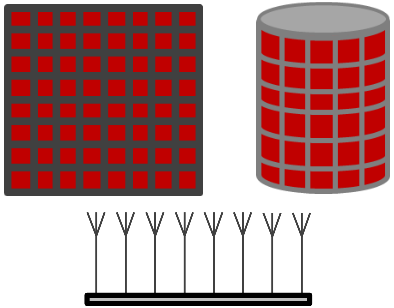
Key Advantages [2]:	
Increased Data Rate	More independent, simultaneous data streams
Improved Reliability	More antennas means more distinct propagation paths
More Energy Efficient	Can focus energy toward terminals
Reduced Interference	Can avoid directions where interference harmful

- Exists in 4G LTE and LTE-A, but with small # antennas
  - LTE-Advanced allows for up to just 8 antennas, and most systems have far fewer

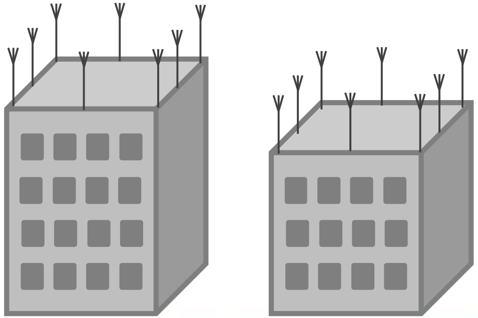
Massive MIMO

- Scales up current state-of-the-art by orders of magnitude
  - Arrays with 100s of antennas serving 10s of users in same time-frequency
  - Enabler for future broadband, connecting people and things with network infrastructure
  - If used with mm wave, large arrays could be very compact
- MIMO antenna layouts
  - Linear, rectangular, or cylindrical arrays
  - Distributed antennas
- Core method: spatial multiplexing
  - Relies on knowledge of propagation channel on uplink and downlink

MIMO Array Concepts



Distributed Antennas



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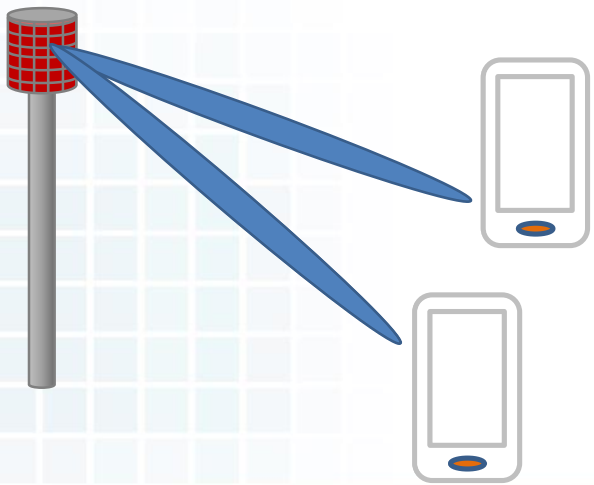
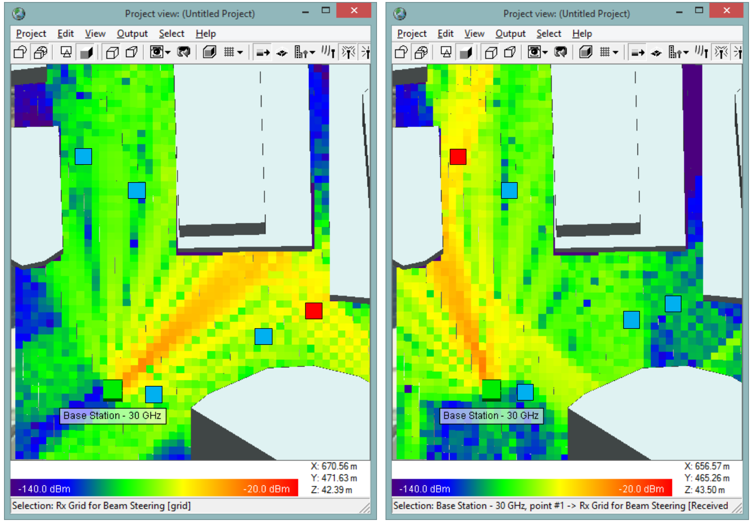
Beamforming Using Spatial Multiplexing

- Massive MIMO uses beamforming to send multiple data streams
  - Offers way to share frequency in close proximity, increasing capacity / data rate
  - Uses pilot signals to characterize channel

Typical Conceptualized



Each case demonstrates idea of optimizing for one user (■) while minimizing interference to others (■)



Wireless InSite showing how multipath could influence beamforming to > one device

Potential Benefits of Massive MIMO[2,3]

- Increase Capacity 10x+
  - Aggressive spatial multiplexing with large numbers of antennas
- Improve radiated energy-efficiency 100x
  - With large arrays, energy can also be focused with extreme sharpness
  - Reduces both power consumption and potential interference
- Can use inexpensive, low-power components
  - Conventional 50 Watt amplifiers replaced by hundreds of low-cost, milliWatt amplifiers
- Significantly reduces latency (eliminates impact of fading)
- Increases robustness to interference and jamming
  - With large arrays, algorithms can reduce these effects

Key Challenges for Massive MIMO[2,3]

- Reciprocity and uplink/downlink calibration
  - Pilot signals used to get channel state information; larger arrays means much more channel data for mobile devices to process and send
  - Solution is generally to use pilots received at base station and assume reciprocity
    - Propagation follows reciprocity, but hardware differences must be calibrated
- Pilot "contamination"
  - Pilot signals typically used to characterize channel between MIMO elements
  - With massive MIMO, easy to use up all available pilot sequences
  - May get duplicate pilot sequences, contaminating processing for beam-forming
- Need for "favorable" propagation
  - Channel responses from base station to terminals must be sufficiently different
  - Evidence in research seems to suggest that conditions typically are valid for favorable propagation, so not likely to be a significant issue

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Use of Simulations in MIMO R&D

- MIMO R&D: simulations can support active research areas
  - Better channel characterization for R&D
    - Good channel state information (CSI) is key to success of method; deterministic simulations can provide more realistic prediction of multipath channels than statistical methods
  - Predict potential for pilot contamination for typical scenarios
  - Examples: study impact of antenna alignments, polarization, correlation between channels – evaluate algorithms using predicted channel characteristics
- Virtual prototyping
  - Industry and researchers are prototyping solutions and testing concepts
  - While testbeds now exist with 32 or 64 element arrays [4, 5], some value to being able to test in any arbitrary environment with any antenna array technology using simulation
  - Virtual testbeds could evaluate alternatives before even reaching prototype stages

MIMO in Wireless Insite with a demonstration

WIRELESS INSITE'S MIMO CAPABILITY

Overview of Wireless InSite MIMO Capability

- New capability will target these key shortfalls in tools used in industry:
  - Most channel models in industry are statistical and cannot predict potential correlation between channels
    - Research suggests that correlation coefficient between channels is much larger than would be expected using independent, identically distributed random variables [3] – typical assumption used in many channel models
  - With Massive MIMO, computational complexity for a deterministic ray-tracing model will rise by orders of magnitude
    - One base station becomes hundreds of transmitting elements!
  - Details of antenna pattern, polarization, and phase will be critical to properly modeling effects
    - Most models simply don't have this level of detail

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Key Benefits of Wireless InSite MIMO Capability

Key Benefits of Wireless InSite MIMO

1. Positions and moves MIMO Arrays

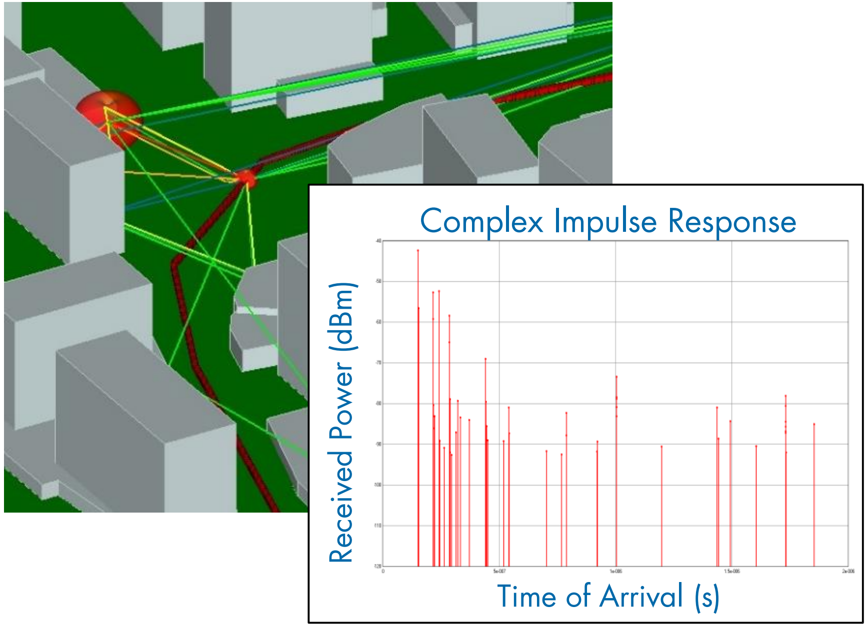
2. Predicts channel characteristics between each MIMO element
   - Magnitude, phase, time of arrival per path within channel
   - Includes antenna and polarization effects
   - Heterogeneous arrays (independent patterns and rotations)

3. Rapid frequency sweeps
   - Gather information across one or more bands

4. Optimizes to minimize increase in Run-time from significant increase in antennas

5. Preliminary Tests: 4x4 MIMO: just 1.3x increase
   64x4 MIMO: just 4x increase

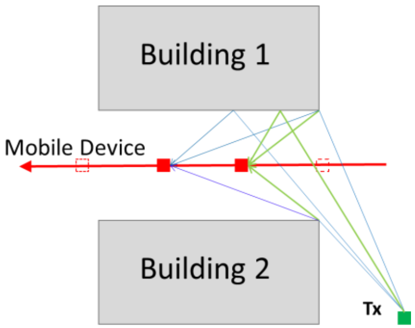
Propagation paths for channel between one pair of elements from Tx/Rx MIMO arrays



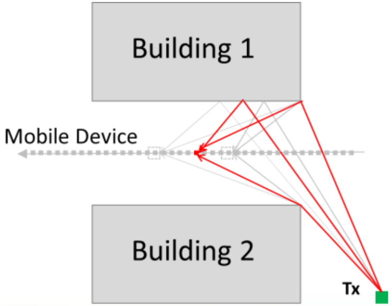
APG Optimizes for Mobile Devices

- Adjacent Path Generation (APG) further reduces Run-time and memory footprint for mobile devices
  - Limits full ray-tracing to coarse spacing along route of travel
  - Uses Remcom proprietary techniques to find exact paths to each mobile location
  - Then finds exact paths to each MIMO array element on each end of link (uplink/downlink)
- Run-time reduction may be order of magnitude or more, depending on the spacing of points along route

High-fidelity ray-tracing to coarse set



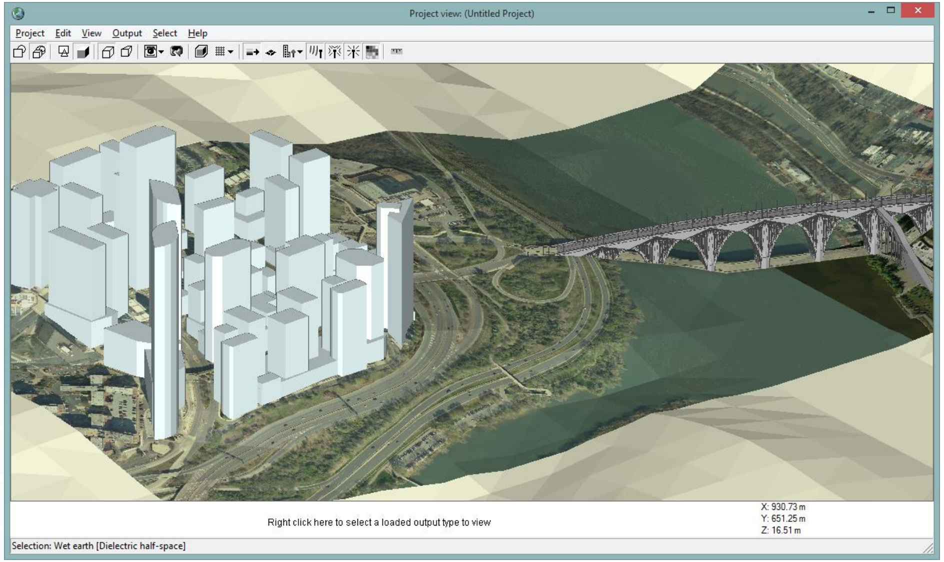
APG rapidly generates paths to precise points



Value of Wireless InSite Capability

- Provides efficient simulation of MIMO antennas with ability to model details of antennas and channel characteristics
  - Ability to deterministically predict variation of paths across MIMO array elements overcomes significant shortfall in statistical models commonly used today
  - Efficient calculation of paths for large arrays overcomes shortfall of current brute-force ray models
- Used to perform virtual assessment of systems, scenarios, and performance in complex environments
- Offers tool for R&D, virtual testing and evaluation of concepts, enabling 5G research of potential MIMO solutions

Wireless InSite Demonstration



MIMO for Small Cell in Rosslyn, VA

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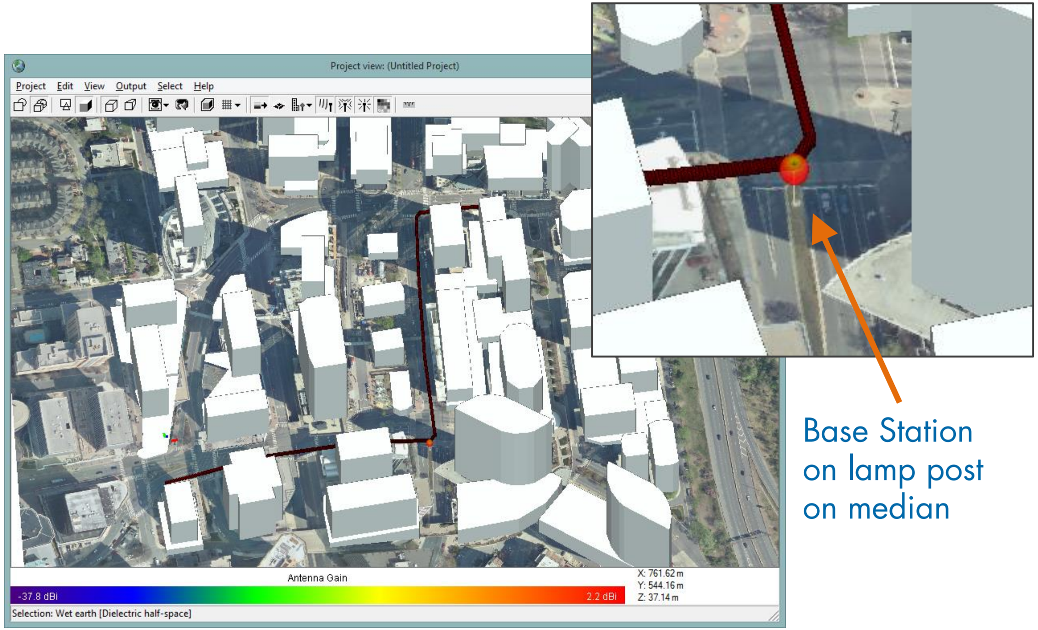
Small Cell Scenario

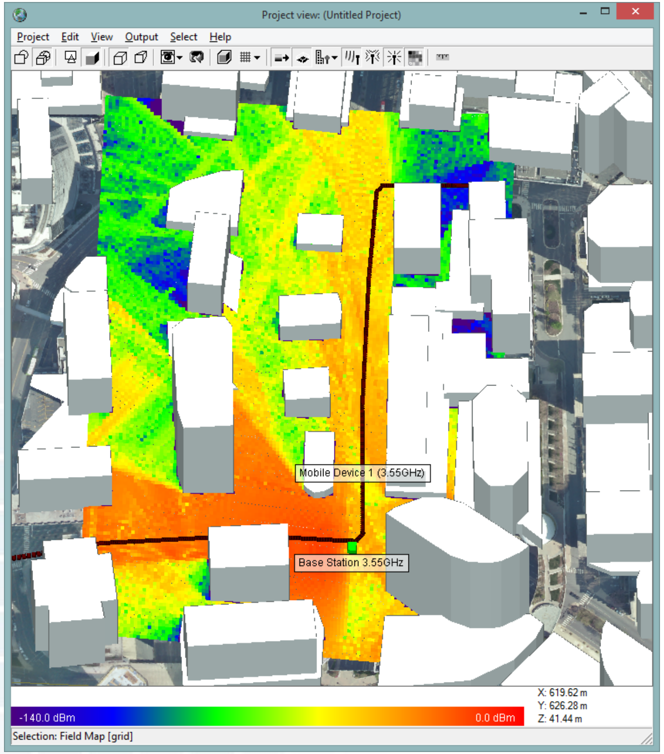
- Small cell base station
  - At intersection of Wilson and Lynn
  - Mounted on lamp post in median on Lynn Street
- Predict signal received by mobile device (red route)
  - Travels along Wilson, turns onto Lynn, then turns onto side street
  - Moving at ~10m/s (22 mph)
- Start with single antennas
  - Use dipoles, 3.55 GHz

Placement of Route and Base Station in Rosslyn



Base Station on lamp post on median

Baseline SISO Scenario



- 1 Dipole at Base Station and Handset
- Field Map shows significant urban multipath in area
  - Much of route within LOS
  - Still may have spatial diversity due to multipath
  - End of route is beyond LOS and has significant shadowing

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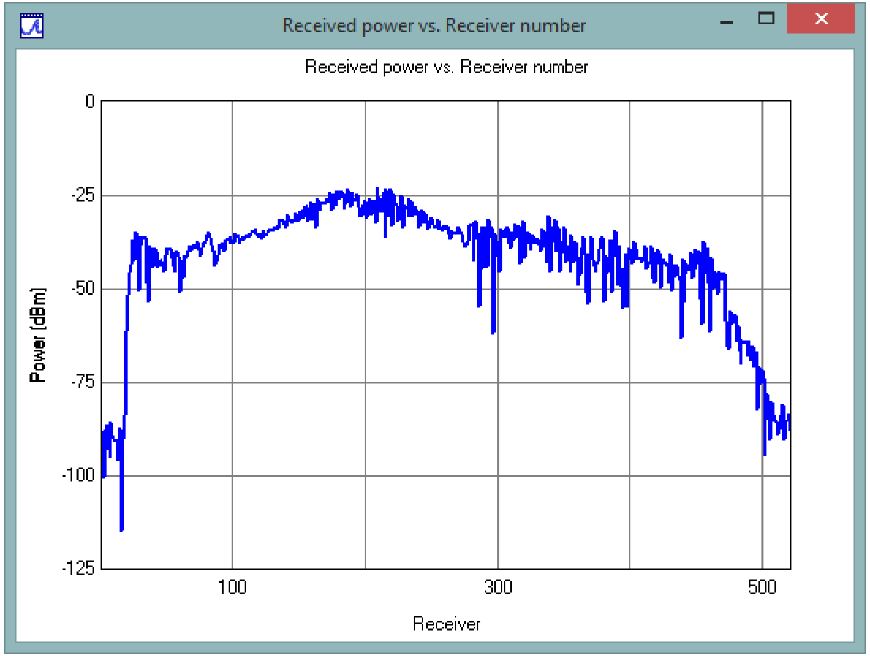
Baseline SISO Scenario

- Plot showing received power along route
- Wireless InSite results show:
  - Shadowing at beginning of route (hill and structures)
  - Shadowing at end (turns corner)
  - Small-scale fading along route due to multipath



(Note: 10 points/second)

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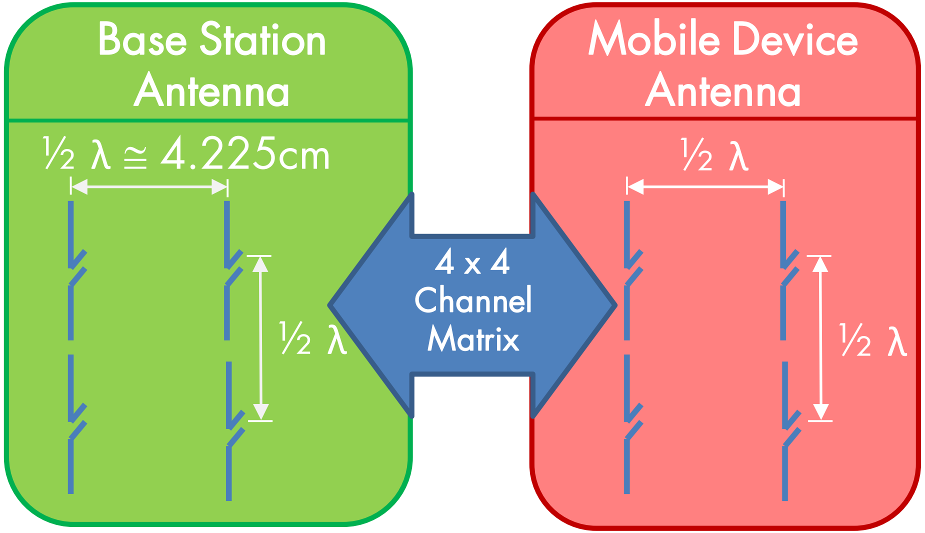
4x4 MIMO Scenario

- Define 4-element MIMO antenna
  - 4-element arrays (2x2)
  - Frequency: 3.55 GHz
  - ½ λ Spacing (4.225 cm)
- Assign to both base station and mobile device
- Channel matrix: 4 x 4 (16 total pairs)

4-Element MIMO Antennas
(2x2 Dipole Arrays)



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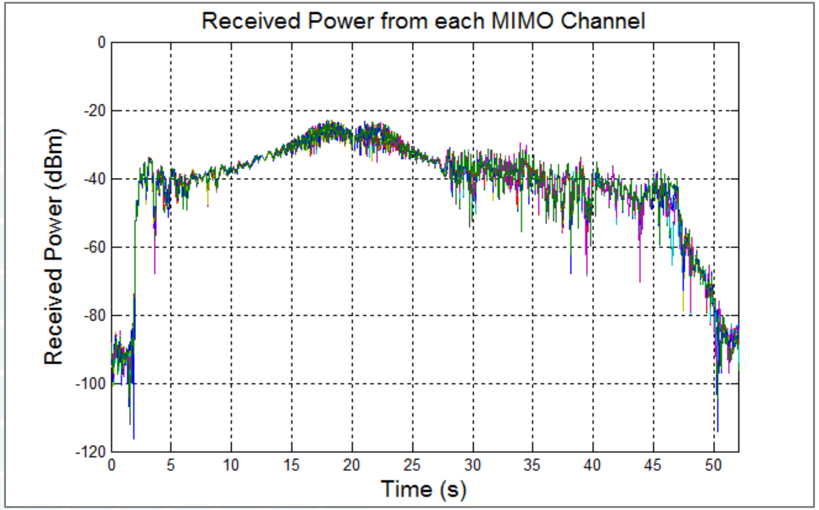
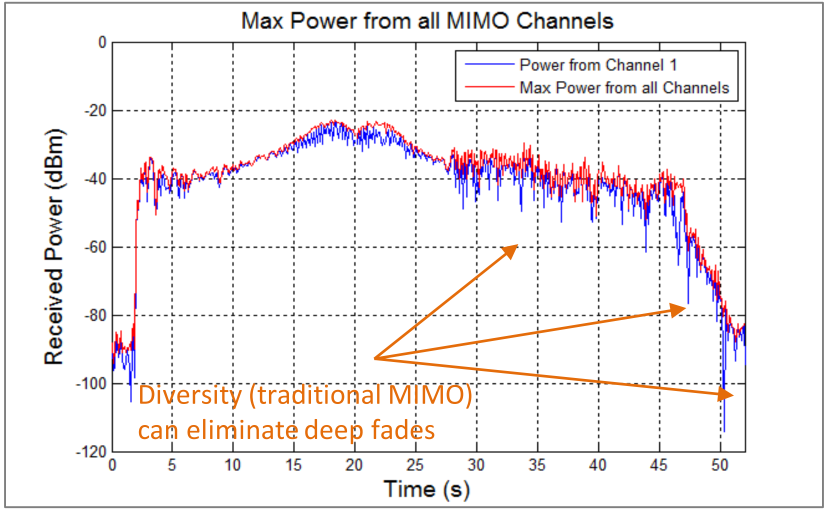
4x4 Channel Matrix Output

- Large-scale fading consistent across channels, but deep fades from multipath vary significantly
  - Simple diversity techniques (e.g., using max received power) can eliminate deep fades
  - MIMO techniques can use this to transmit multiple streams over same frequency with "orthogonal" coding





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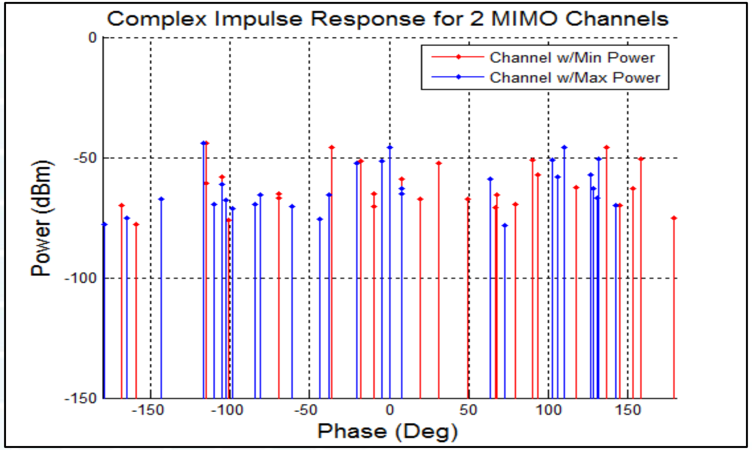
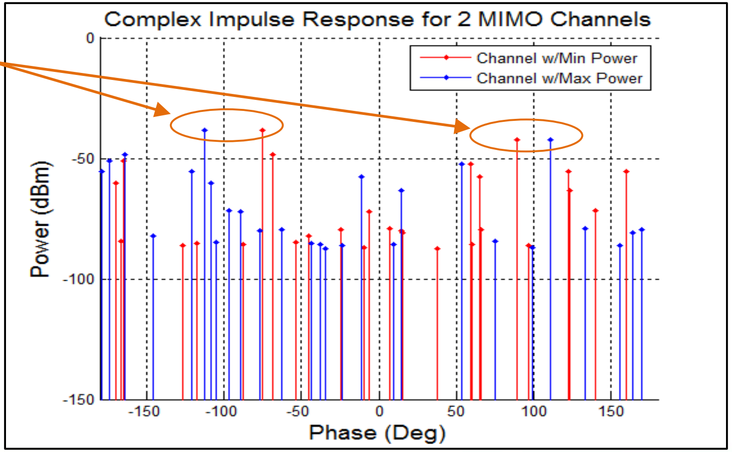
Channel Impulse Responses

- Wireless InSite multipath results can be used to generate MIMO channel impulse responses for each element of channel matrix
  - Could apply various MIMO techniques to evaluate how best to maximize capacity, data rate, etc. for small cell
  - Deterministic simulation results can be used to predict correlation between channels (key requirement for MIMO spatial multiplexing gain)

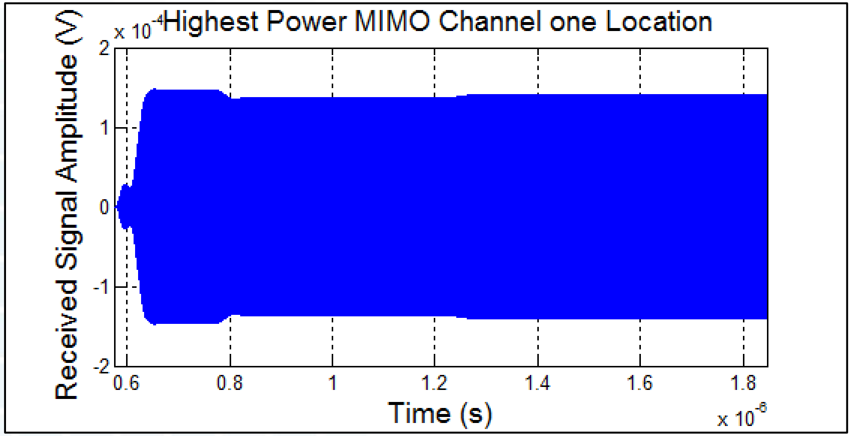


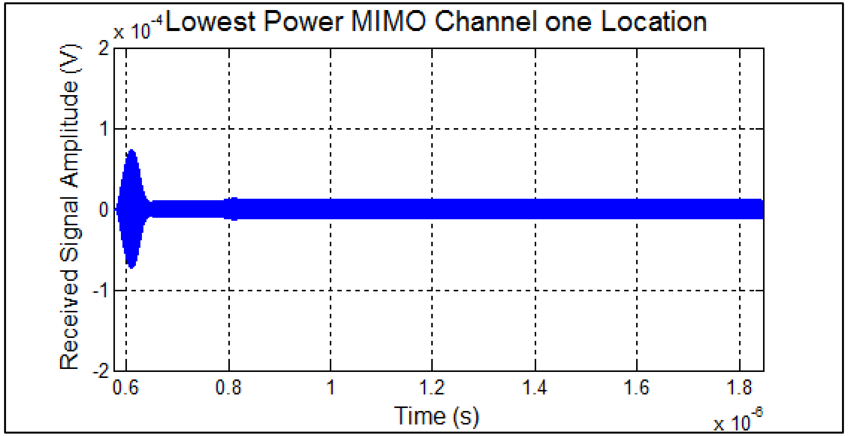
Some key differences in impulse response



Sample Signal Traces

- Signal Traces for two MIMO channels (same mobile device location)
- Shows just how much signal impacted by multipath with changes in position of just a few cm on each end





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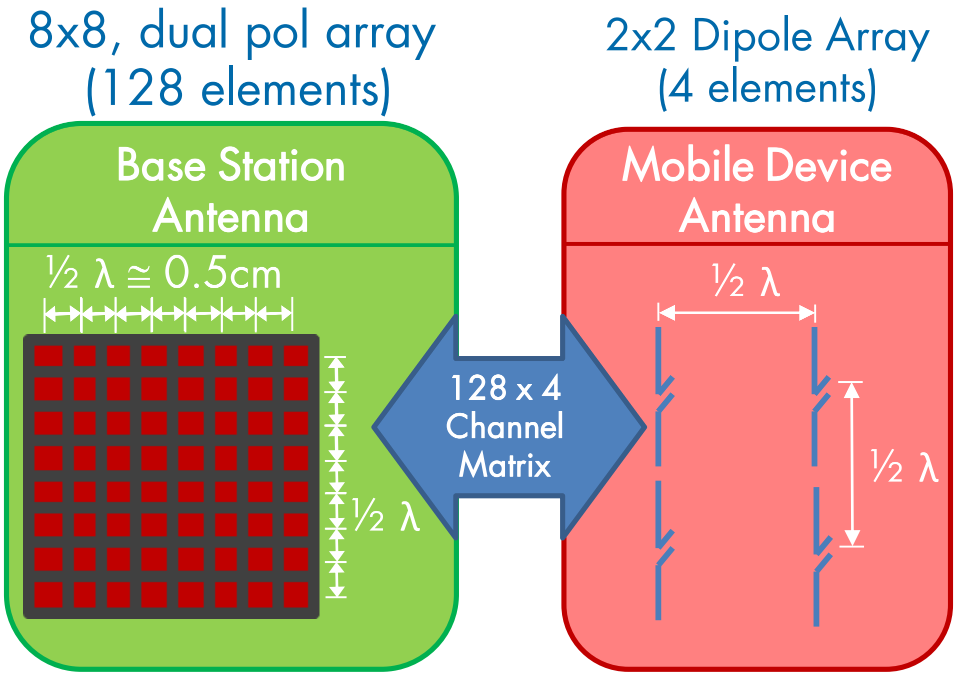
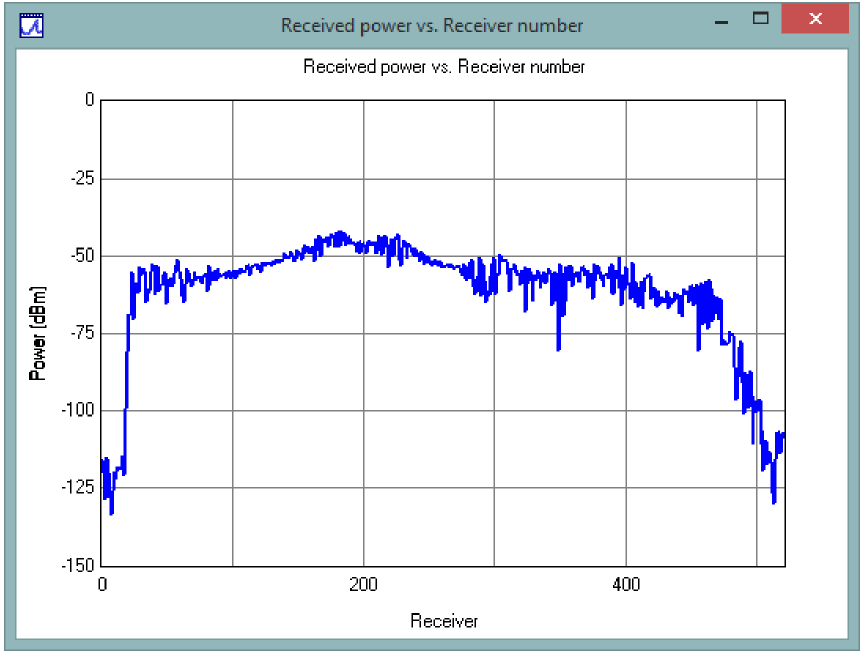
30 GHz Massive MIMO Scenario

- Define 128-element Massive MIMO Base Station antenna
  - 64-element array (8x8)
  - Dual Polarization (2x elements)
  - Frequency: 30 GHz
  - ½ λ Spacing (0.5 cm)
- Mobile devices still uses 4-element array
- Channel matrix: 128 x 4 (512 total pairs)



Baseline SISO Scenario

- SISO scenario simulated at 30 GHz
- Results similar to 3.55 GHz
  - Similar shadowing and fading
- Received power is about 20dB lower
  - Caused by higher path loss at mm Wave frequencies



(Note: 10 points/second)

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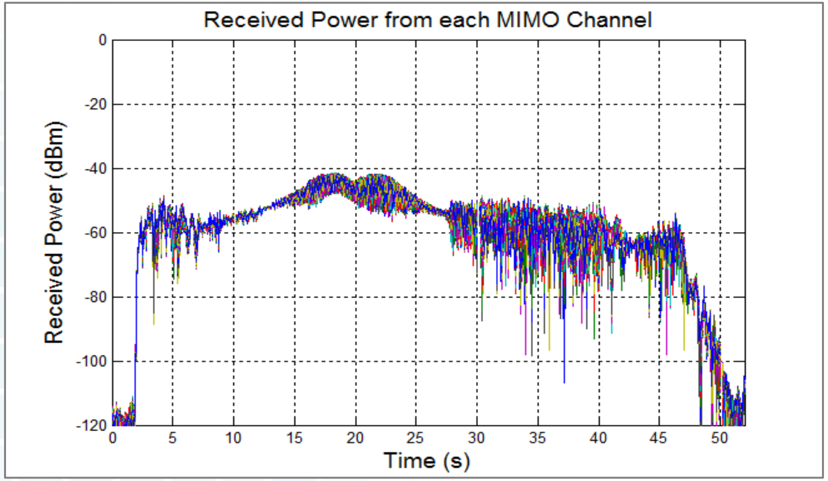
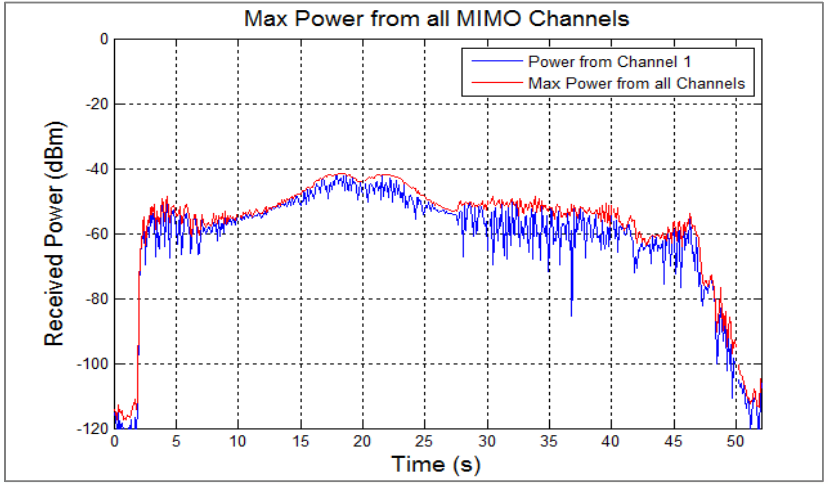
128x4 Channel Matrix Output

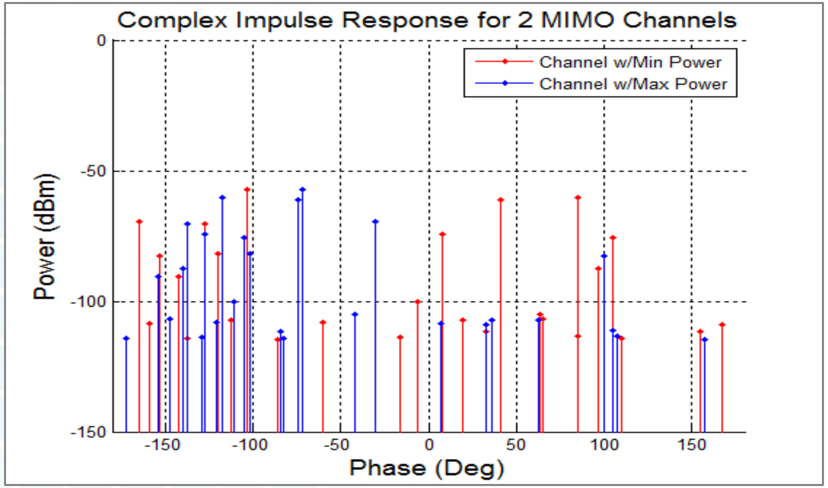
- Wireless InSite results are similar to 4x4 case, but even more variation between channels and even deeper fading
  - Simple diversity technique (e.g., max power) does even better at eliminating small-scale fading
  - Likely much more spatial diversity allowing for multiple streams and beamforming

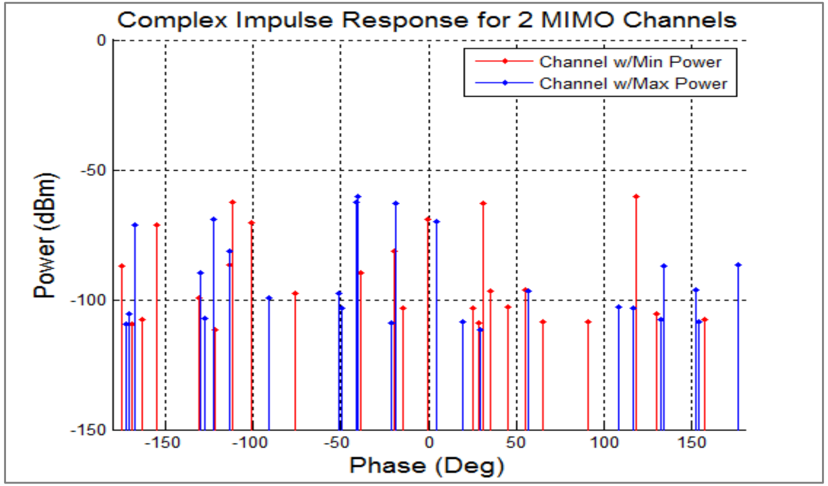




Massive MIMO Scenario

- Plots show complex impulse response for 2 sample areas where fading was significant
  - At superficial level, appears to be even more variation for this case





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3. L. Lu, G. Ye Li, A. Swindlehurst, A. Ashikhmin, R. Zhange, "An Overview of Massive MIMO: Benefits and Challenges," *IEEE Journal of Selected Topics in Signal Processing*, Vol 8, Mo. 5, October 2014, pp. 742-758.

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Wireless InSite's MIMO Capability

SUMMARY

MIMO in Wireless InSite

- MIMO and Massive MIMO are key concepts for 5G
- Remcom's Wireless InSite MIMO capability provides an efficient method to predict channel characteristics for large-array MIMO antennas in complex multipath environments
- Key benefits to the wireless industry
  - Provides capability to perform R&D and assessment of MIMO solutions and algorithms
  - Enables virtual testing of prototypes and design concepts in simulated environment that captures complex aspects of realistic deployment scenarios
- Status of Development
  - Beta versions of computational engine are in development and testing, and the graphical interface and planned outputs are still being finalized

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