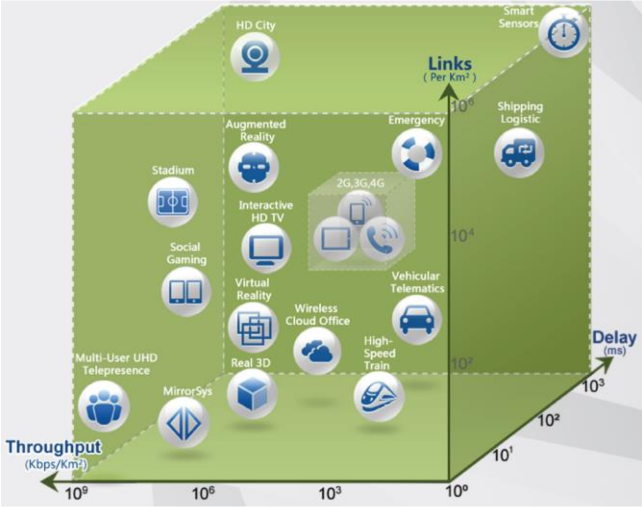
Design
the Difference
with
Digital twin

Altair Technology Conference 2017

5G Antenna Design
&
Network Planning

ATC 2017

Challenges for 5G



Source: Huawei 5G Technology Vision

5G Service and Scenario Requirements

- Massive growth in mobile data demand (1000x capacity)
- Higher data rates per user (10x)
- Massive growth of connected devices (10-100x)
- Lower latency for real-time connections (5x)
- Higher energy efficiency for longer battery life (100x)
- New use cases like connected cars, machine-to-machine (IoT)

Key Solutions

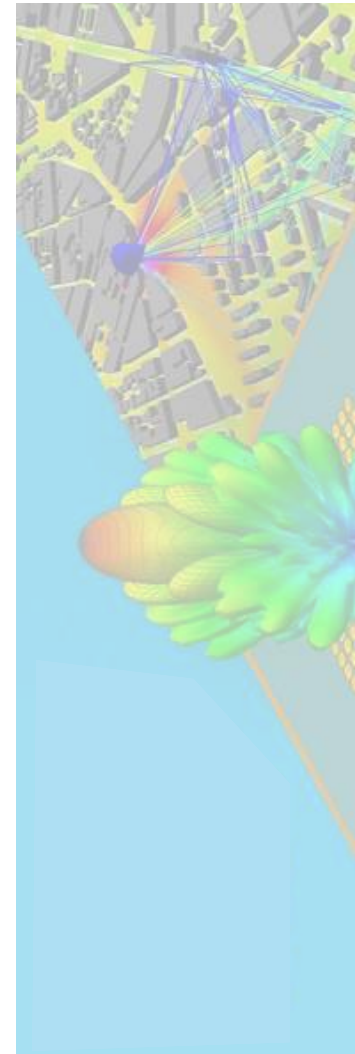
- Increased spectrum with trend to higher frequencies
  - 700 MHz for basic coverage
  - 3.5 GHz for high data rate services & capacity
  - 26/28 GHz for fiber like data rates & capacity hotspots
- Ultra-dense networks
- Massive MIMO antennas for beamforming & spatial multiplexing

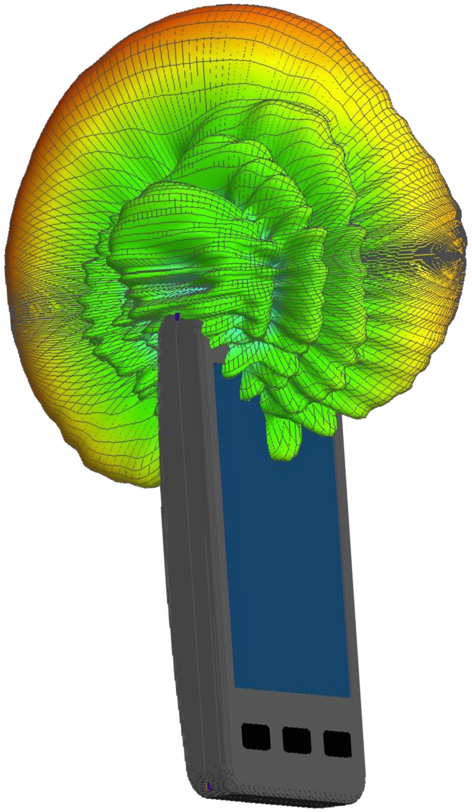
Introduction: Altair's complete solutions for 5G analysis

- **FEKO** for 5G Antenna Design Challenges
  - Case study I: Mobile antenna design at 26 GHz
  - Case study II: Base-station antenna design at 26 GHz

- **WinProp** for 5G Radio Channel & Coverage Analysis
  - Case study I: 5G radio channel statistics for beamforming and channel analysis
  - Case study II: 5G radio planning for different frequency bands and antenna assumptions

- **Conclusions**





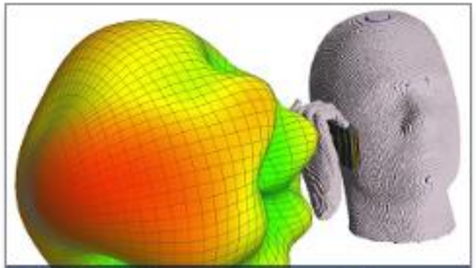
Antenna Design for Mobile Devices

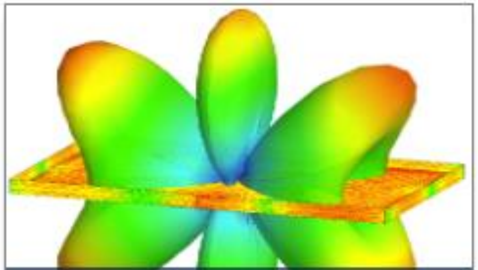
Design Aspects at 5G frequency

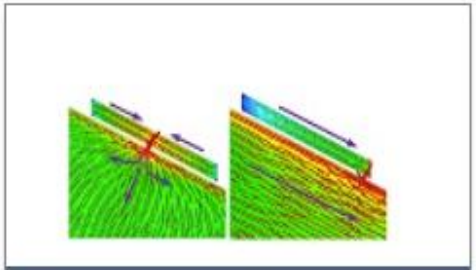
- At 26 GHz:
  - Electrically more antenna real estate available
  - Better matching without matching circuit
  - In-band coupling reduced due to electrical separation
  - Device integration aspects

- Need to achieve high gain requirement
- More sophisticated feeding and control circuits needed
- Good isolation between array elements must be achieved

- Optimization approach based on multi-variable and multi-goal


FEKO Webinar Recording: EM Design in the Electronics Industry

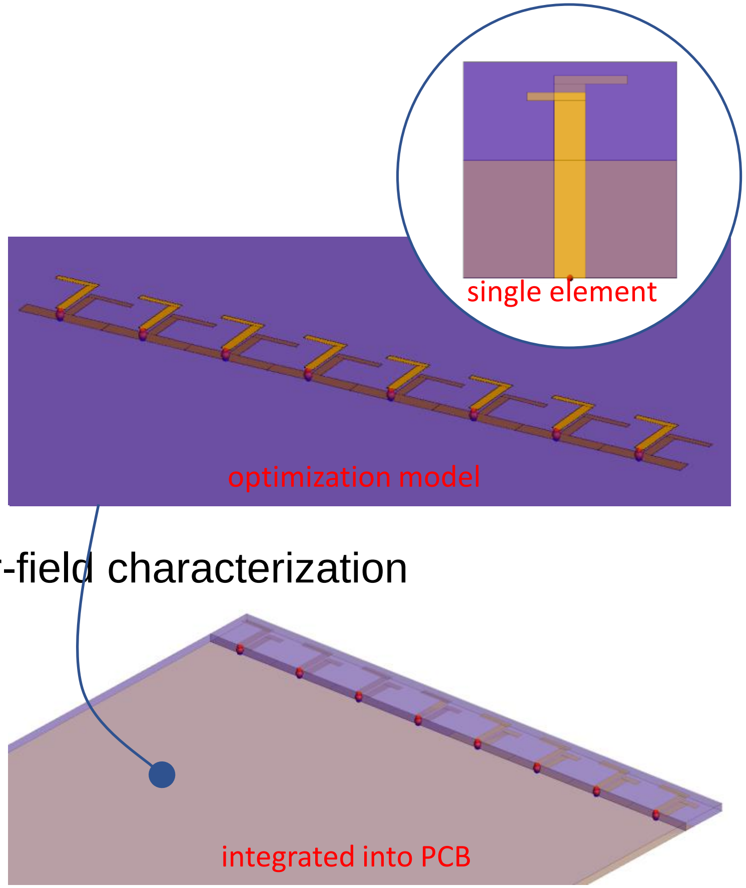

FEKO Webinar Recording : Designing with Characteristic Mode


FEKO Webinar Recording: The CMA Advantage

Array Design

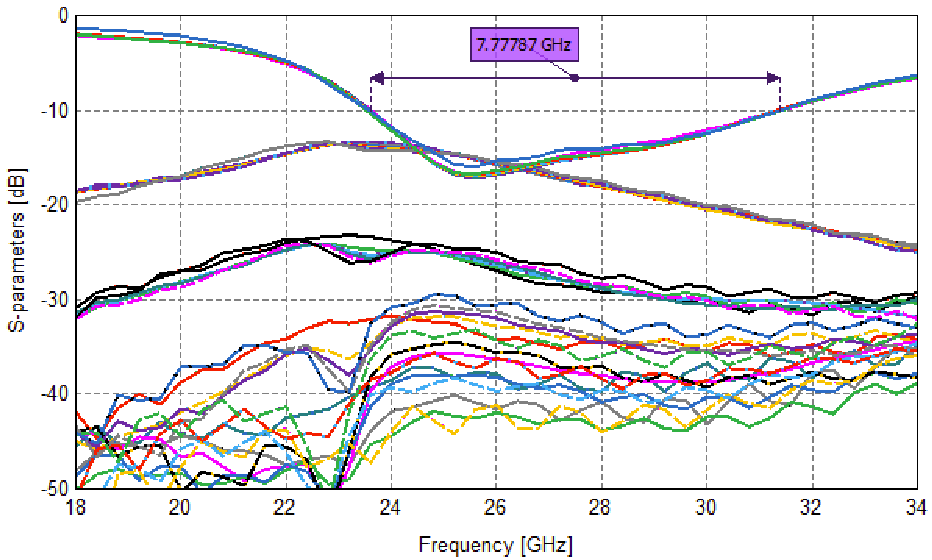
- Design based on [1] re-optimized for 24-28 GHz band
  - WB dipole antenna element in linear 8x array
  - Printed, Rogers RT5880 substrate
  - Optimization with 5x frequency points
  - 8 geometric parameters considered
  - S_{nn} & S_{mn} optimization goals

- Optimized with FEKOs GRSM method
  - Optimized geometry integrated into PCB
  - Simulated with FDTD for full S-parameter and far-field characterization

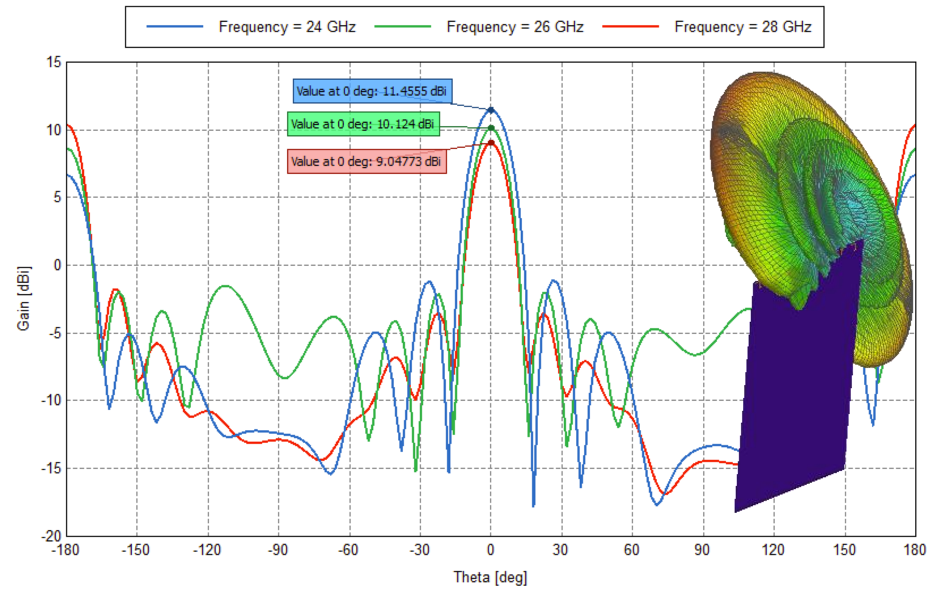


[1] UWB mm-Wave Antenna Array with Quasi Omnidirectional Beams for 5G Handheld Devices - N. Parchin, et. al, ICUWB 2016

Optimized Array Design – S-parameter and Gain

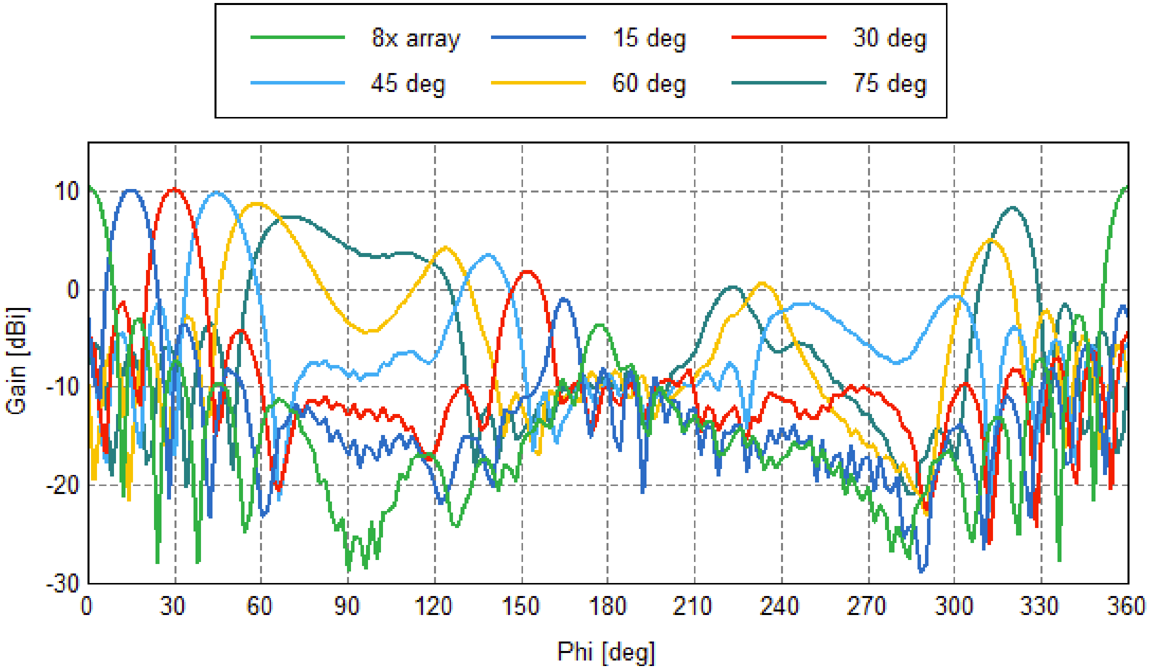


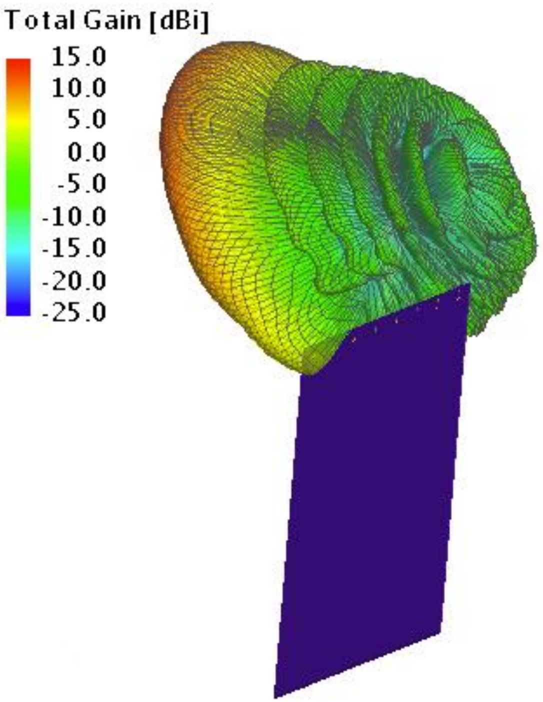
S parameters vs Frequency



Gain vs Frequency

Array Design – Gain & Beam Steering at 26 GHz



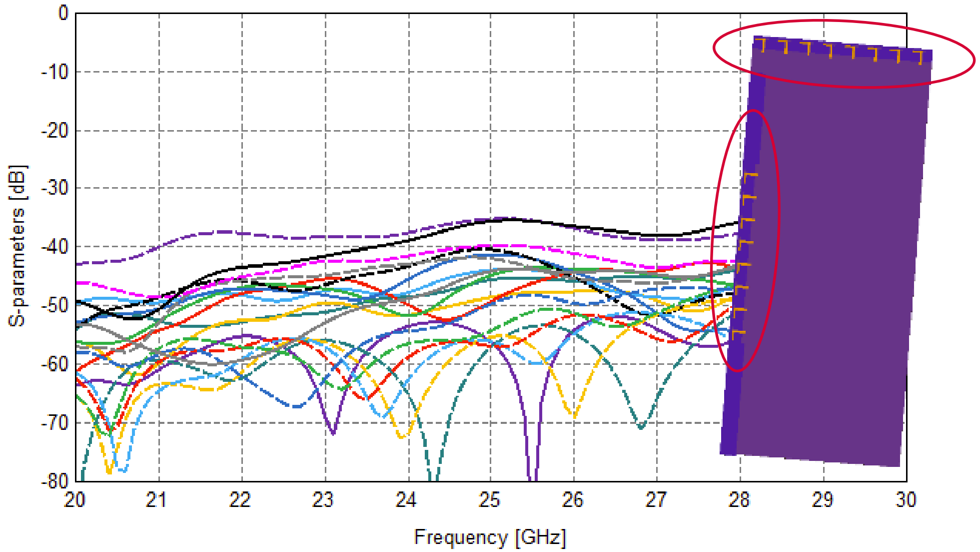


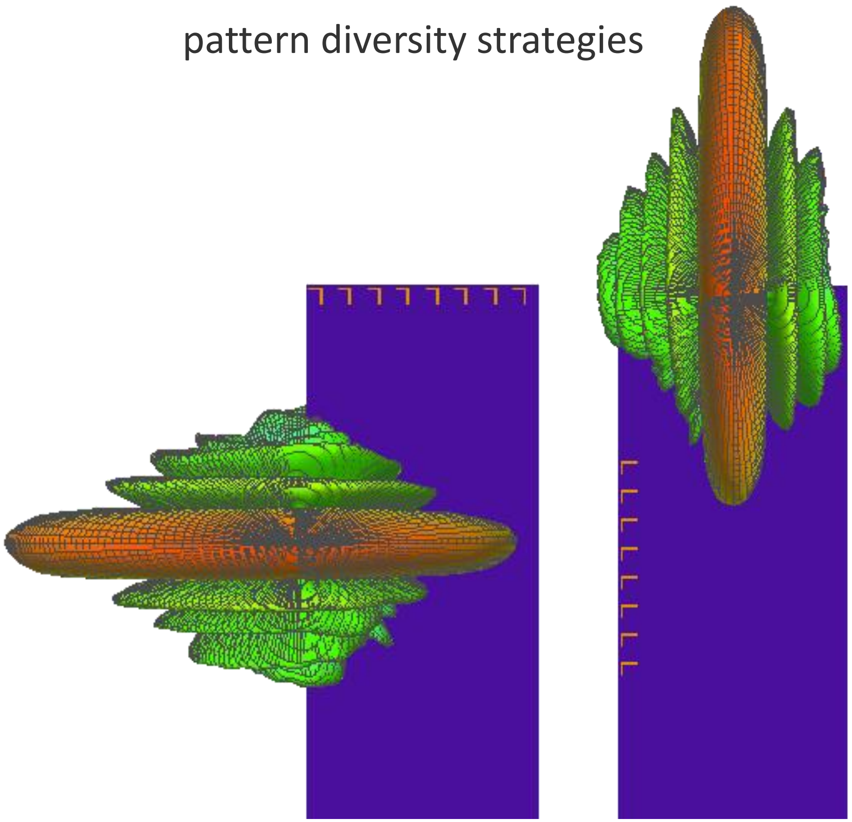
Beam steering for the 8 element array: equal amplitude, constant phase delay

Array Design – Dual MIMO Configuration

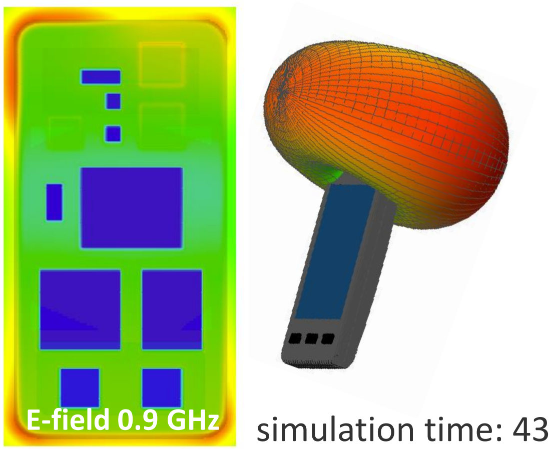
Dual MIMO configuration 2x 8x arrays:
Isolation < -30dB in operational bandwidth

pattern diversity strategies

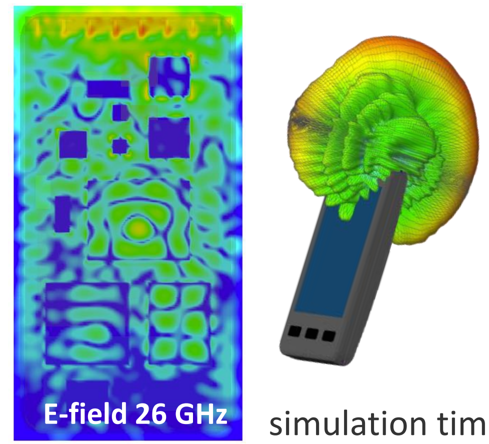




Device: From Antenna Integration to Antenna Placement

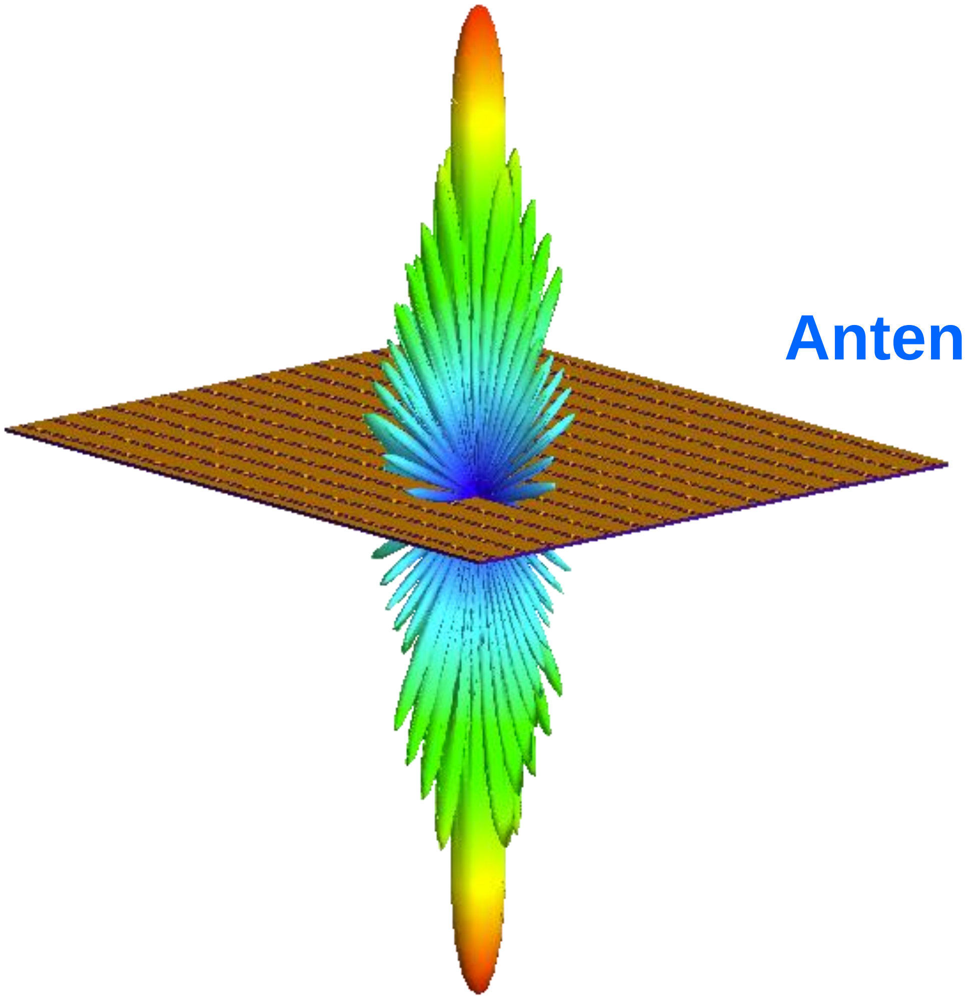


simulation time: 43min



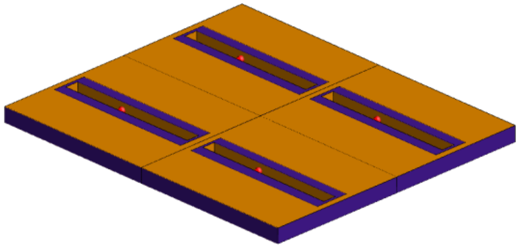
simulation time: 56min

- Previously, extremely detailed CAD geometry was cumbersome
  - Over-discretize the FDTD mesh to resolve geometric detail
- Now default meshing is < 1mm, most detail is inherently captured
  - Despite the electrical size at 26 GHz, the integrated antenna simulation can be run in < 1hr
- PCB: part of antenna at low frequency → large ground plane at 26 GHz



Antenna Design for Base Station

Design Approach



2×2 slot array

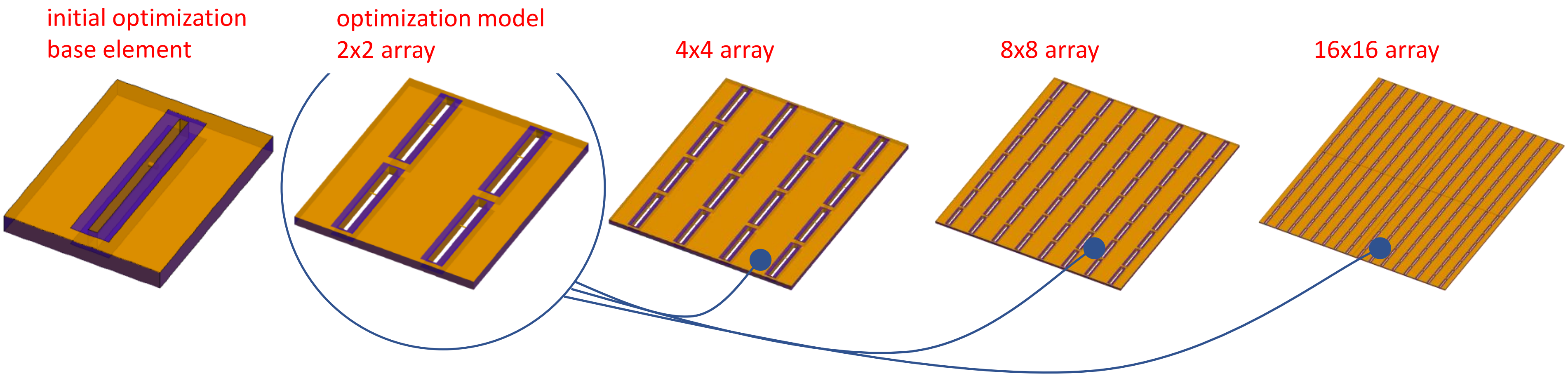
- Optimization of 2x2 planar array using GRSM optimization method
  - Optimization at center frequency
  - 8 geometric parameters considered: Ws, Ls -> Distances between antennas
  - S_{nn} & S_{mn}, gain optimization goals
  - Solved with MoM

- Extend to full array
  - Simulate with FDTD/MLFMM to capture full S-parameters over operational bandwidth, farfield / beam steering /etc.

- **Advantages of this approach:**
  - Optimization of the sub-array with PGF(Planar Green Function) extremely fast
  - MoM (MLFMM) extremely efficient for multiport S-parameter simulation

Array Design

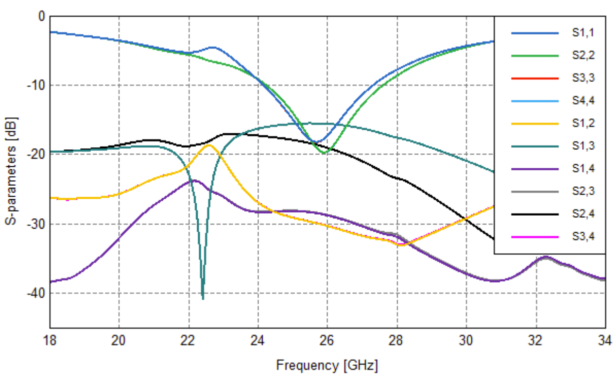
- Design based on [1] (designed to operate in 22 GHz band) – re-optimized for 26 GHz band
  - Loop design, including slot to increase efficiency
  - Printed, low cost, FR4 substrate



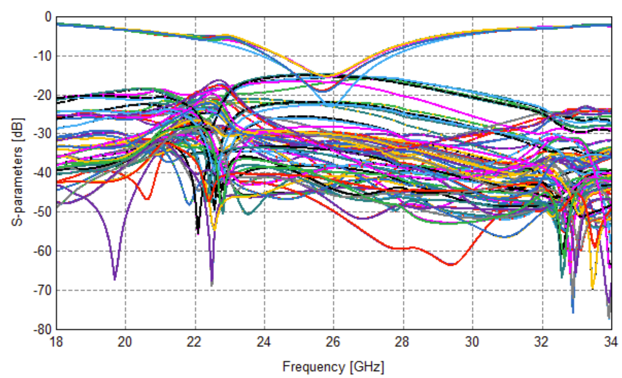
[1] 8×8 Planar Phased Array Antenna with High Efficiency and Insensitivity Properties for 5G Mobile Base Stations - N. Parchin, et. al, EUCAP 2016

Array Design – S-parameter

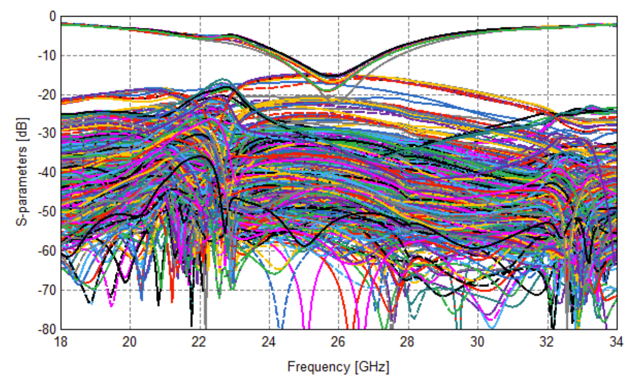
- Optimization strategy holds for all 3 array configurations:
  - Resonance frequency 26 GHz maintained
  - Slight loss of bandwidth for the larger arrays, but still > 2 GHz
  - Worst case coupling of ~ -15 dB maintained



4x4 array



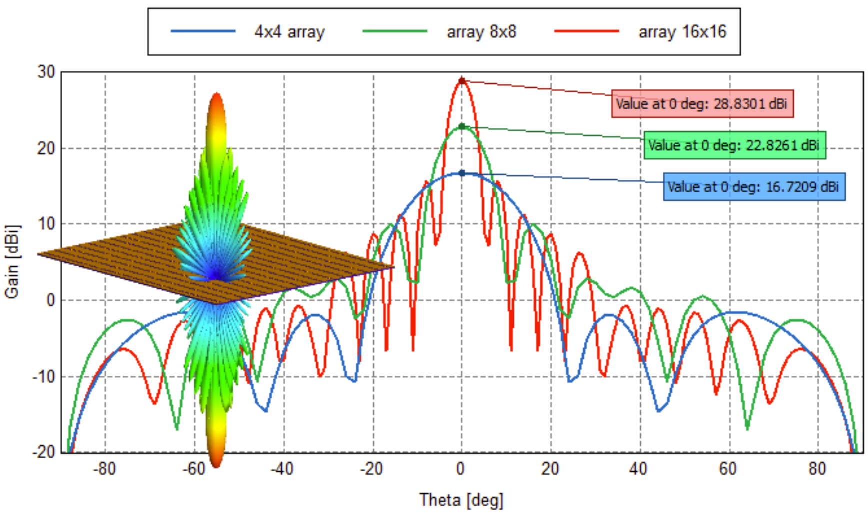
8x8 array



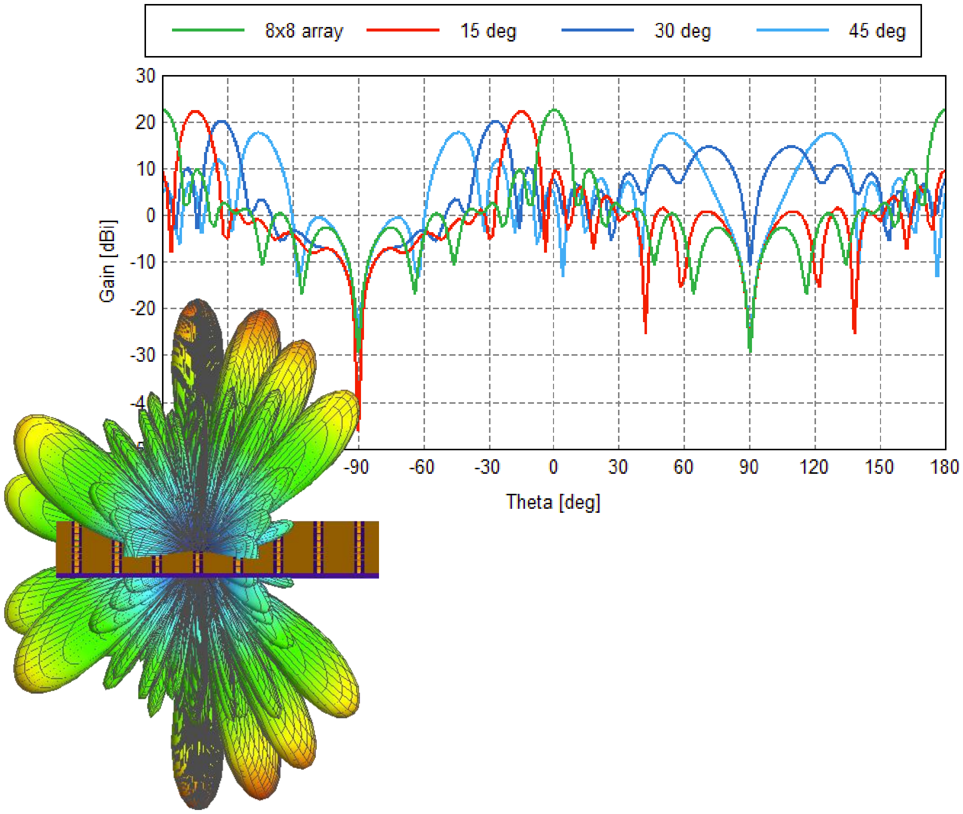
16x16 array

Array Design – Gain & Beam Steering

Gain for 4x4, 8x8, 16x16 array configurations



Beam steering for the 8x8 array

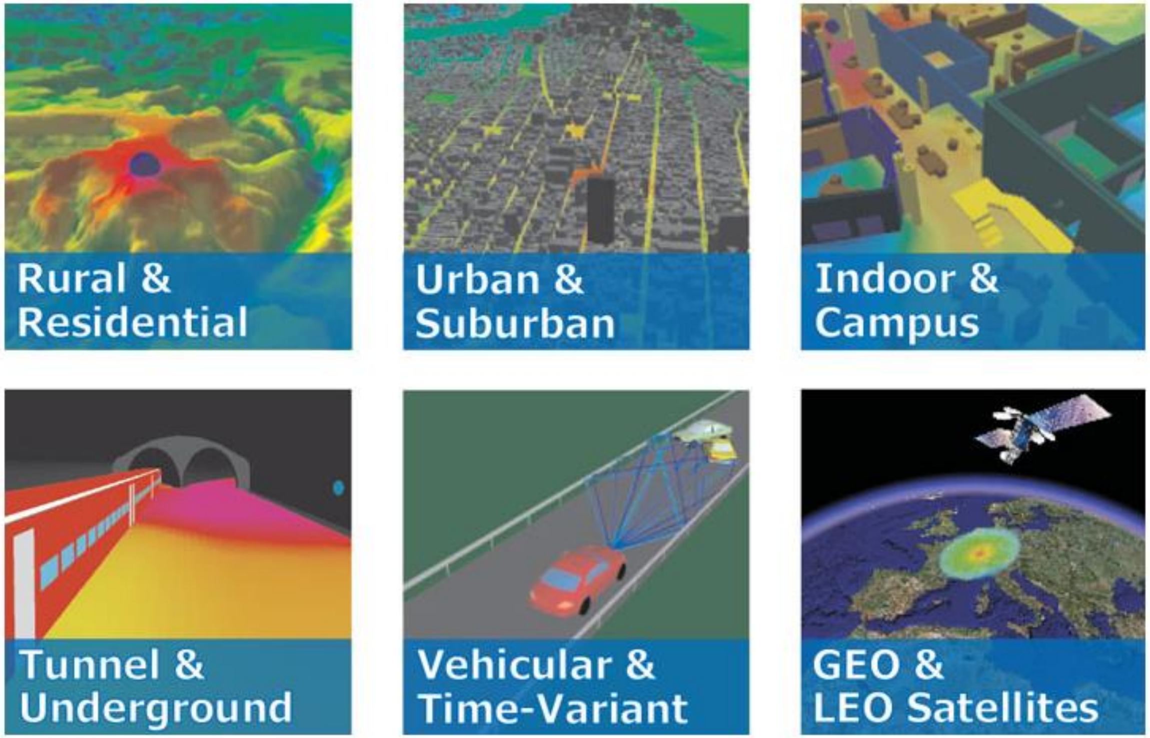


Radio Channel & Coverage Analysis

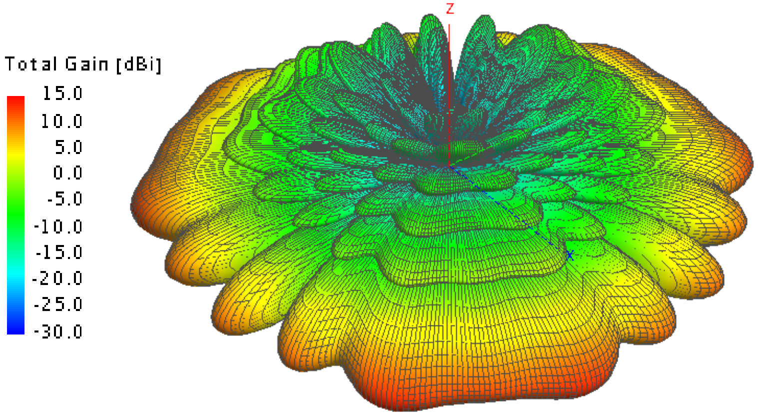
WinProp Software Suite

Radio Planning Tool

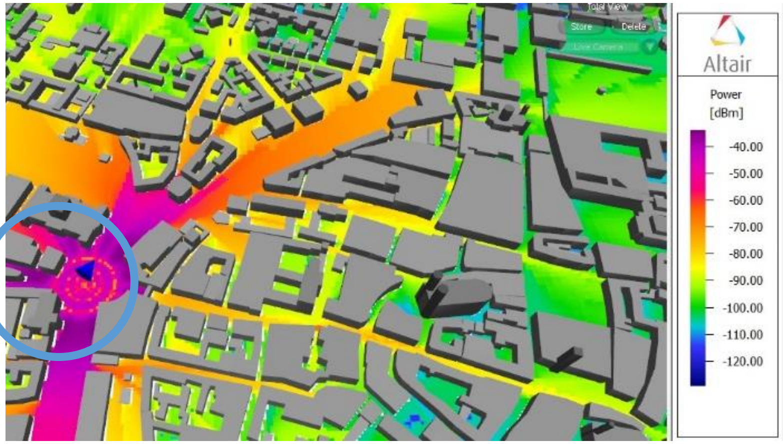
- Wave propagation models for various scenarios
  - Rural/Suburban
  - Urban
  - Indoor/Tunnel
- Radio network planning of various systems
  - Mobile cellular
  - WLAN
  - Broadcasting
  - Mesh/sensor networks
- Applications
  - Radio channel analysis
  - Radio network planning



FEKO ⇔ WinProp Interaction



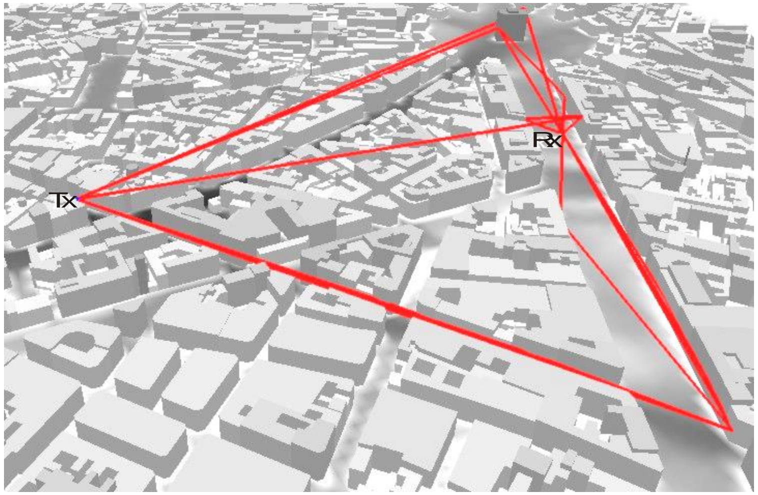
3D pattern for outdoor 3-sector antenna computed in **FEKO**



Urban radio coverage considering this antenna computed in **WinProp**

Wave Propagation Analysis

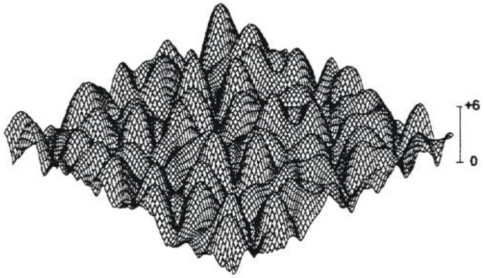
Radio Channel



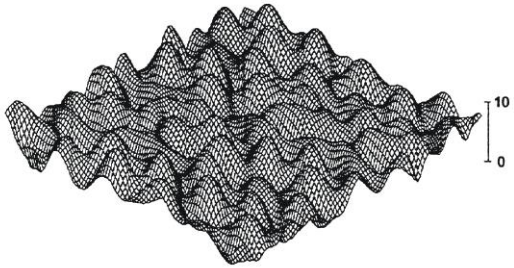
Multipath Propagation

- Multiple propagation paths between Tx and Rx
- Shadowing, reflection, diffraction, scattering
- Different delays and attenuations
- Destructive and constructive interference
- Depending on frequency
- Various bands of interest for 5G: 700 MHz, 3.5 GHz, 26 GHz, …

Superposition of Multiple Paths



No line of sight (Rayleigh fading)



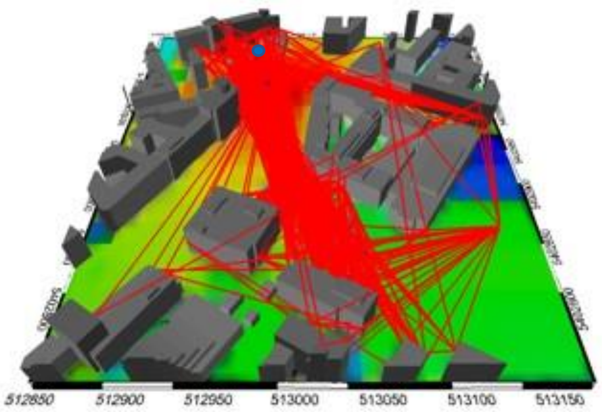
Line of sight (Rice fading)

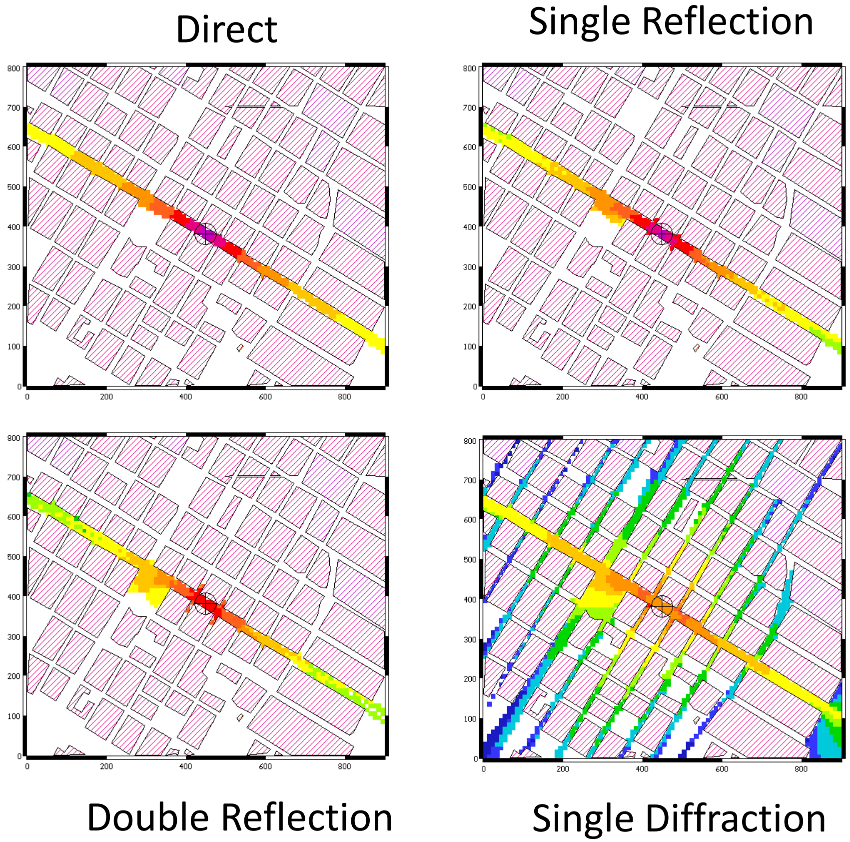
Wave Propagation > 6 GHz

Coverage for Tx Below Rooftop Level (as in 5G)

Multipath situation

- Multiple reflections
- Wave guiding in street canyon
- Few rays over the rooftops (diffraction)





Wave Propagation > 6 GHz

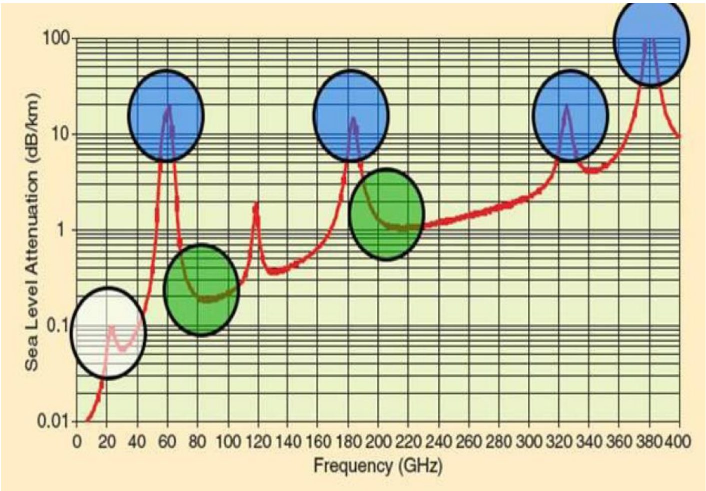
Impact at interactions due to higher frequency

- Transmission
  - Penetration of walls hardly feasible
  - LOS and NLOS regions will dominate (impact of street grid)
- Reflection
  - Specular paths will dominate (besides direct path)
- Diffraction
  - Highly attenuated for higher frequencies as diffraction coefficient ~ 1/sqrt(frequency)
  - Will more and more disappear for frequencies > 26 GHz
- Scattering
  - Roughness becomes large for most surfaces (due to small wavelength) ➔ diffuse scattering
  - 5G transmission will use highly directive antennas on both ends ➔ scattering difficult to be used for reliable connection

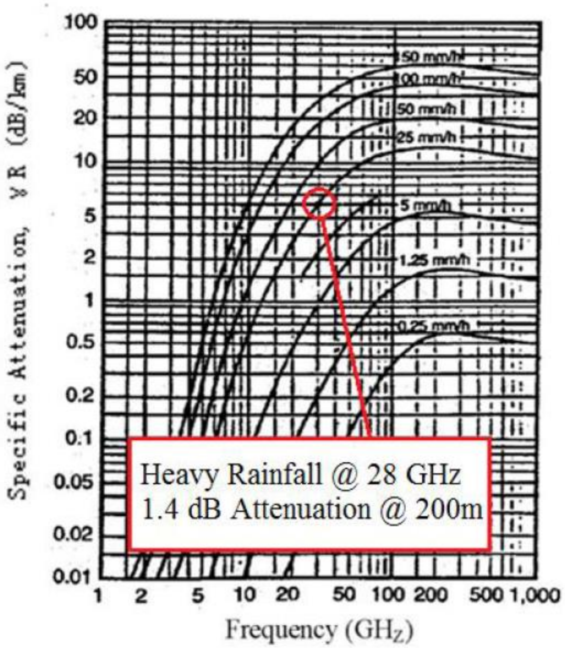
Wave Propagation > 6 GHz

Atmospheric absorption and rain attenuation at mm-wave frequencies

- Additional attenuation tolerable for cell sizes on the order of 200m
  - Atmospheric loss < 0.1 dB/km at 30 GHz, but 20 dB/km at 60 GHz due to oxygen a bsorption
  - Rain attenuation limited for frequency bands around 26 GHz and 28 GHz

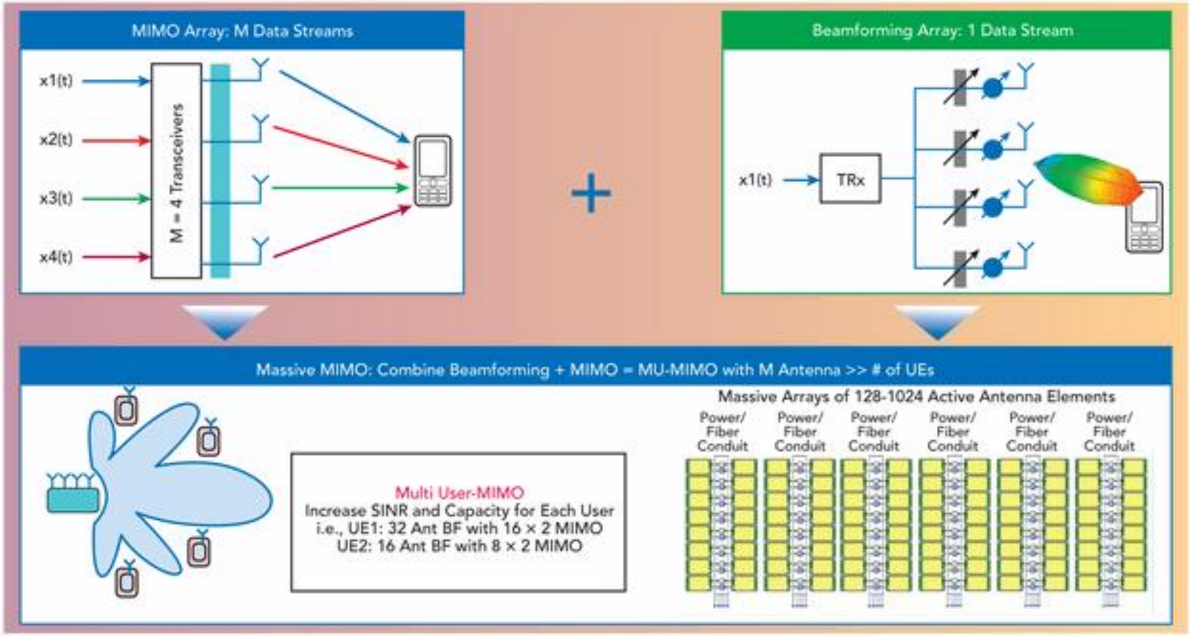


Source: T. S. Rappaport et al.: MM-Wave Mobile Communications



5G Radio Channel

5G Radio Channel

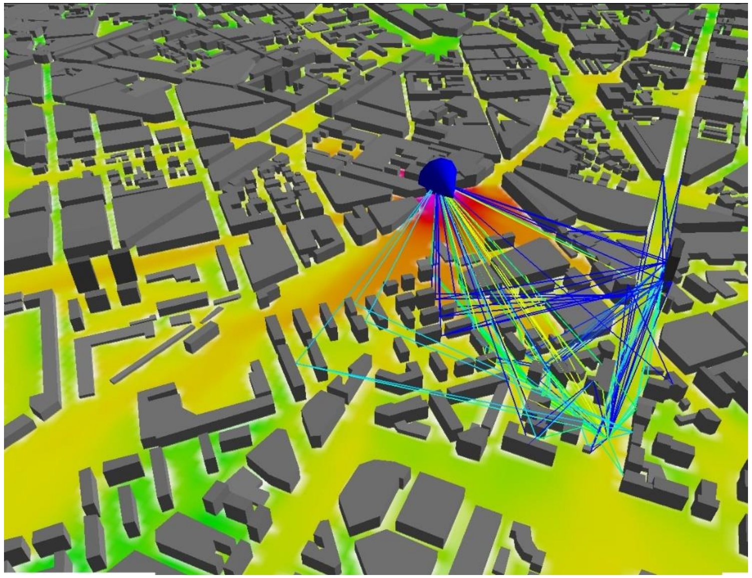


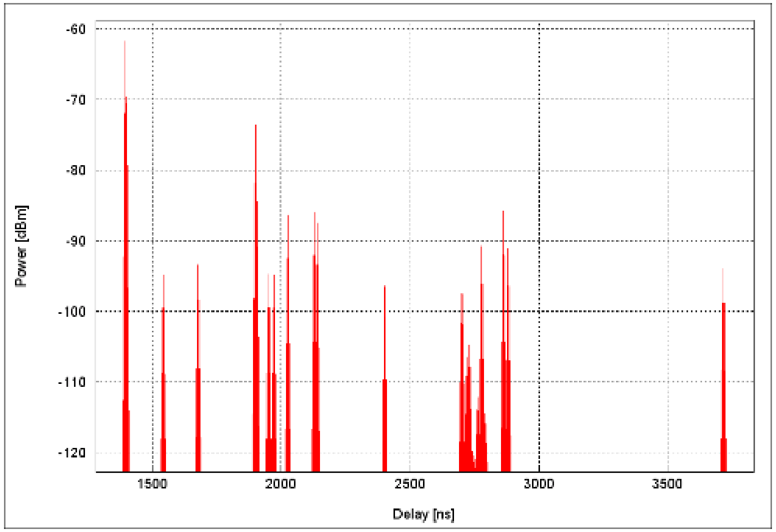
Massive MIMO antenna arrays

- Arrays with 100s of antenna for separating 10s of users in same radio resources (time/frequency) & at mm waves, large arrays are compact
- Combination of
  - ➢ Beamforming, Spatial Multiplexing(MIMO), Relevant channel statistics
  - ➢ Delay spread, Azimuth/elevation angular spread both for BS and MS
  - ➢ Evaluation of cumulative, distribution function (CDF)

WinProp 3D Ray Tracing

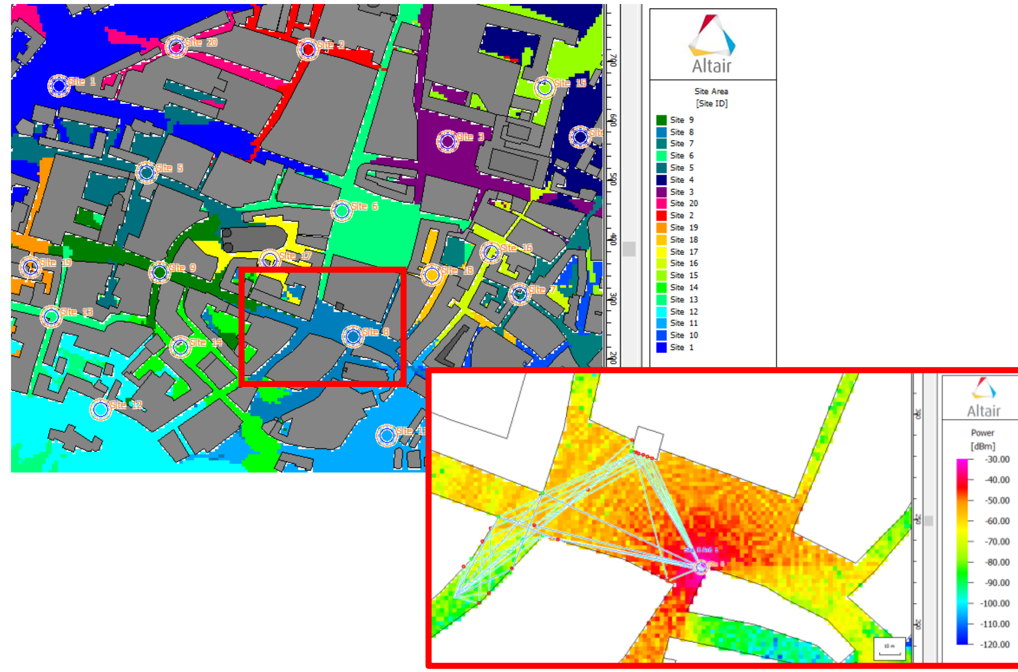
- Ultra-fast due to single preprocessing of scenario
- Ray tracing considers dominant characteristics
    - Reflection (Fresnel coefficients)
    - Diffraction (GTD/UTD)
    - Scattering
    - Shadowing / Wave guiding
    - Penetration into buildings
- Prediction of radio channel in time, frequency and spatial domain
    - Field strength
    - Propagation delays
    - Angles at Tx and Rx

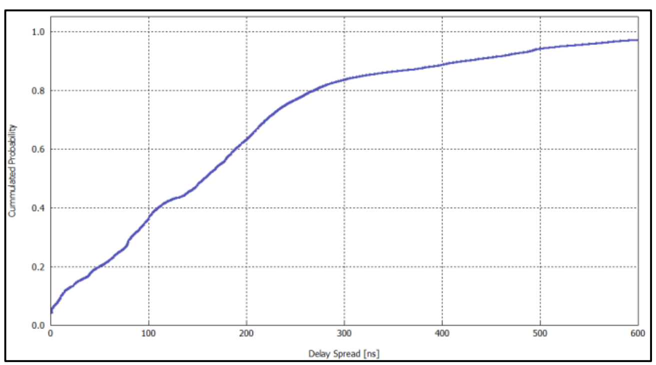




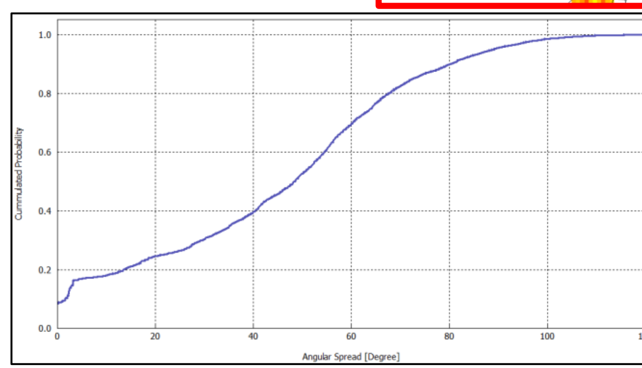
5G Radio Channel: Channel Statistics

- Computed for individual cells
- Consideration of omni BS antenna
- Cell areas given by best server map
- Delay spread at 26 GHz
- Azimuth angular spreads at 26 GHz





Delay spread

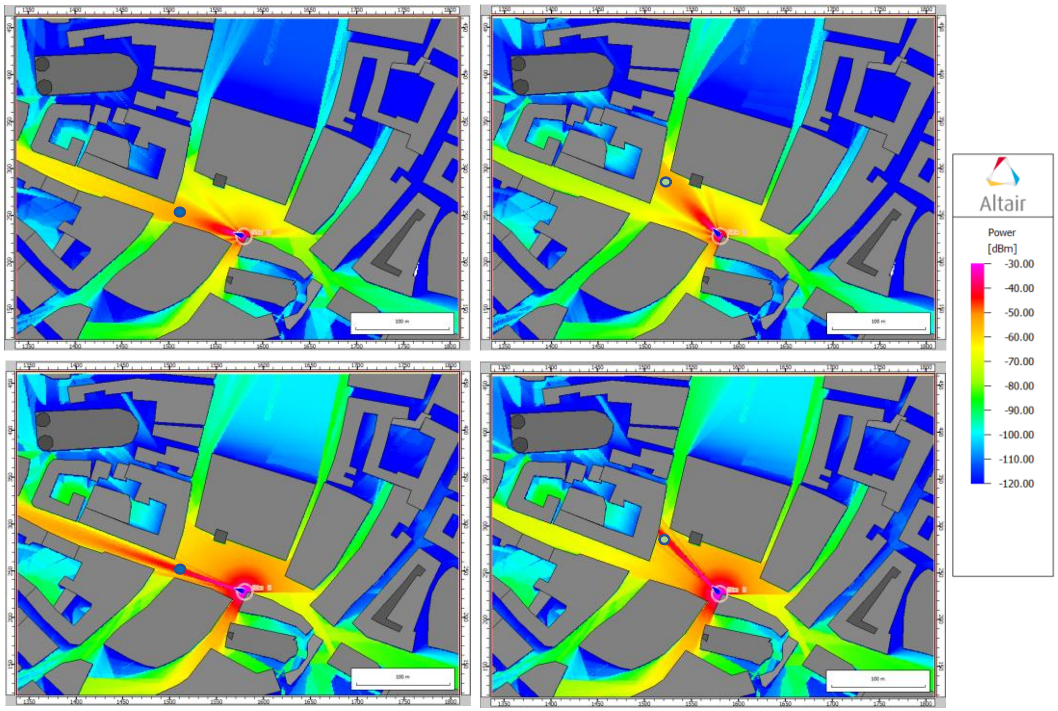


Angular spread

5G Radio Channel: Beamforming

- Massive MIMO arrays
  - transmit different signals to different users simultaneously in same frequency band
  - increase Rx power levels and SNIR for dedicated user
  - reduce interference for others

4x4 array on BS side



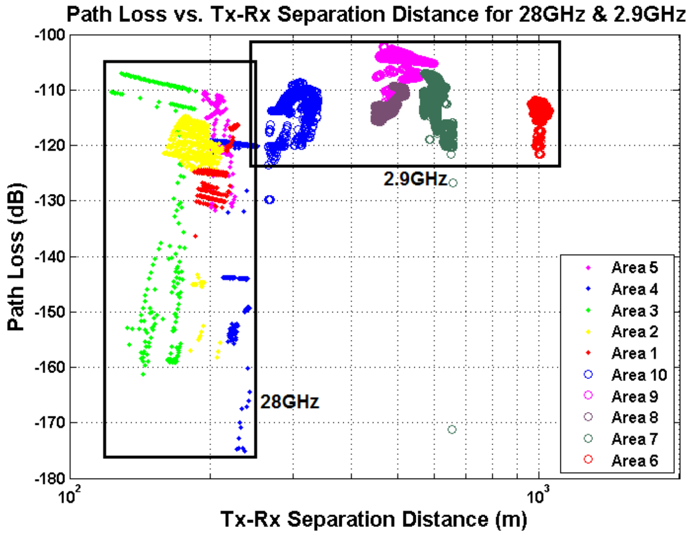
16x16 array on BS side

5G Radio Channel Analysis(1)

- Comparison of simulated path loss at 28 GHz & 2.9 GHz
  - New York city scenario
  - WinProp 3D ray tracing model
  - BS at street intersections
  - Areas marked in black rectangles evaluated in below diagram

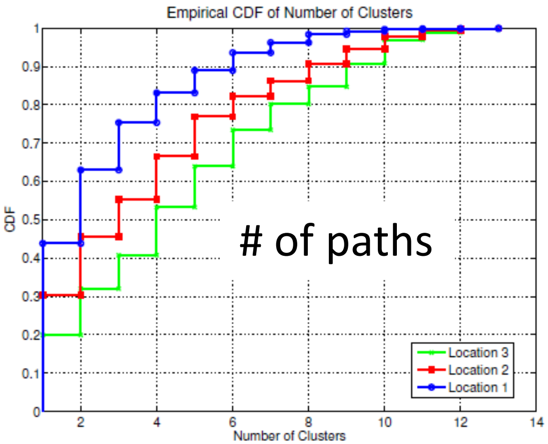
28GHz 2.9GHz

- Path loss over BS ➔ MS distance gives much smaller range for 28 GHz
- Wide range of path loss for same/similar distances at 2.9 GHz

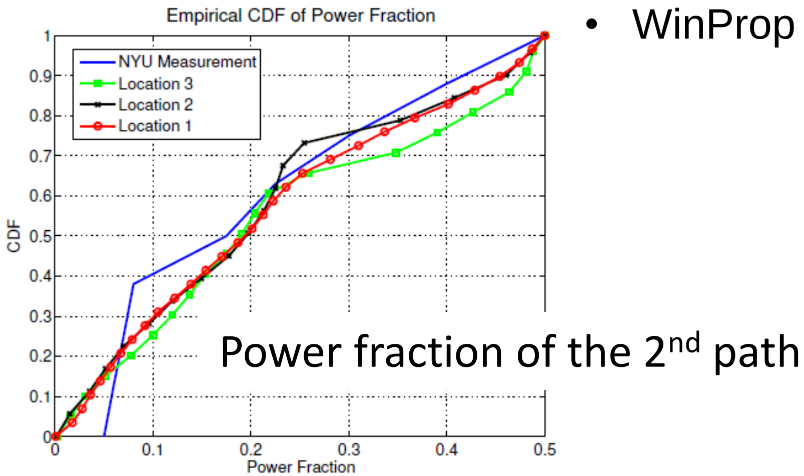


Source: Qualcomm Z. Zhang et al.: Coverage and Channel Characteristics of Millimeter Wave Band Using Ray Tracing, IEEE ICC 2015

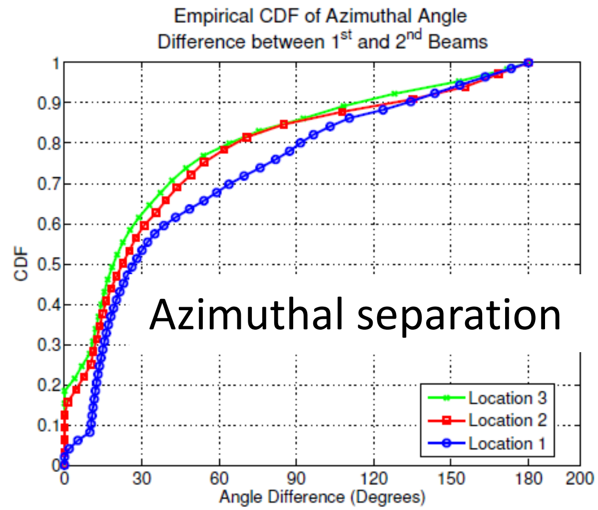
5G Radio Channel Analysis(2)



1. # of paths between BS and MS: on median, there are 2-4 paths.
2. Power fraction of the second strongest path (at least 10° away): on average, 7 dB weaker
3. Azimuthal separation between two strongest paths on average about 20° (see fig. 3)



- WinProp simulation results in agreement to NYU measurements



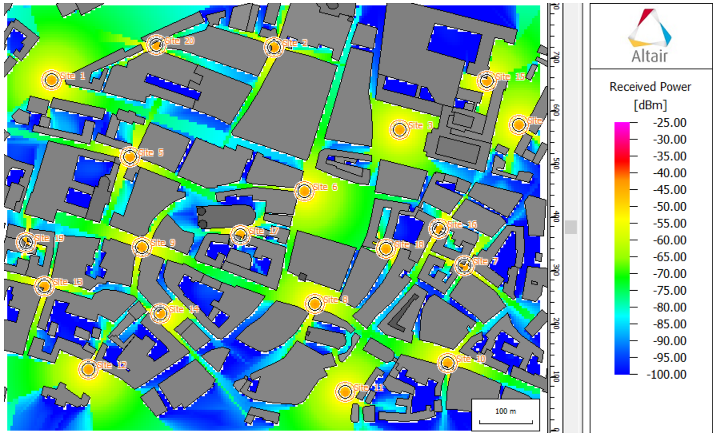
Source: Qualcomm Z. Zhang et al.: Coverage and Channel Characteristics of Millimeter Wave Band Using Ray Tracing, IEEE ICC 2015

5G Radio Network Planning

5G Radio Network Planning: Deployment Scenarios(1)

- Ultra-dense networks for provision of required high data rate volumes
  - More than 1,000 small power base stations in 1km^2 urban area
  - Multi-threading required to predict multiple base stations simultaneously
- Strong signal-to-noise-and-interference-ratio (SNIR) requirements for high data rates
- 3.5 GHz frequency bands for area-wide services and the 26/28 GHz bands for capacity hotspots
- Network planning allows to simulate the coverage before the deployment ➔ 5G deployment strategies

3.5GHz

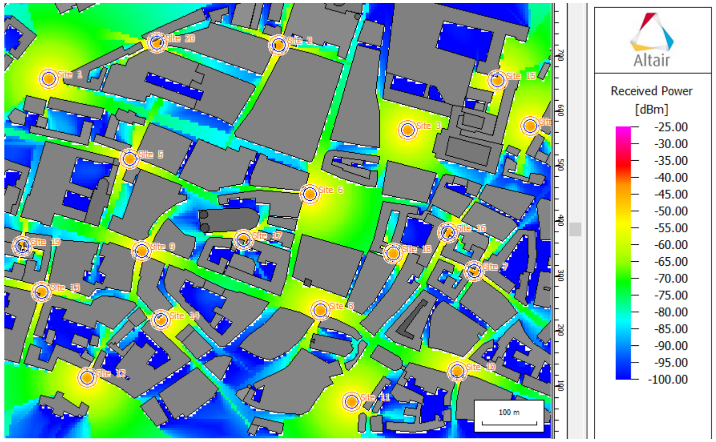


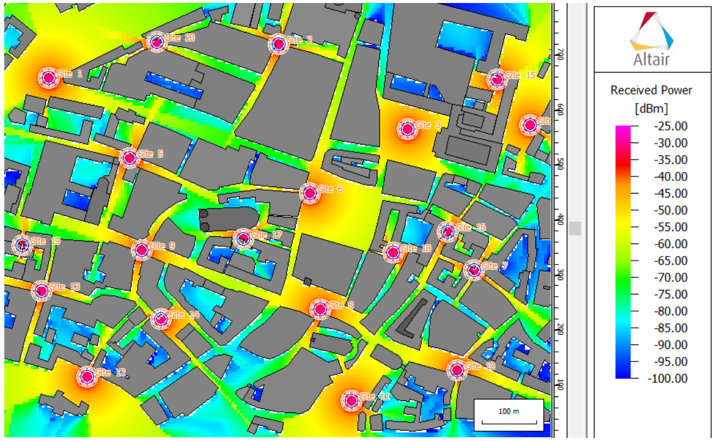
26GHz

5G Radio Network Planning: Deployment Scenarios(2)

- Beamforming on base station side
  - Increase Rx power levels and SNIR for dedicated user
  - Reduce interference for others
  - 4x4 antenna matrix provides antenna gain of 16.7 dBi (considered at BS EIRP)
- Optional beamforming on mobile station side
  - Array of 8 linear antenna elements provides antenna gain of 13.3 dBi
- Consider MS beamforming gain in network planning at 26 GHz (see results on the right)

26GHz without MS beamforming





26GHz with MS beamforming

Conclusions

- **5G** will provide **higher throughputs** and many **new applications**
  - **massive MIMO usage & higher frequency bands** (e.g. 26 and 28 GHz)

- **5G** mobile phone and base station antenna design in **FEKO**
  - FEKO combines **optimization** and **dedicated solvers** for arrays and electrically large structures
  - **Ideal solution** for **5G antenna design**

- **5G** radio channel and radio coverage analysis in **WinProp**
  - For **all types of environments**: urban, dense urban, suburban, rural, industrial, indoor, tunnel, stadium,…
  - Evaluation of **3D spatial channel profiles** and **channel statistics** for massive MIMO
  - WinProp **3D ray tracing model** correctly predicts the mm wave propagation
  - Ultra-dense networks require fast model for the **efficient network planning**