Radio Coverage Planning for Heterogeneous Wireless Networks, Including 5G

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Altair

OUTLINE

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- Altair Solution
- Radio Coverage Planning in Heterogeneous Wireless Networks
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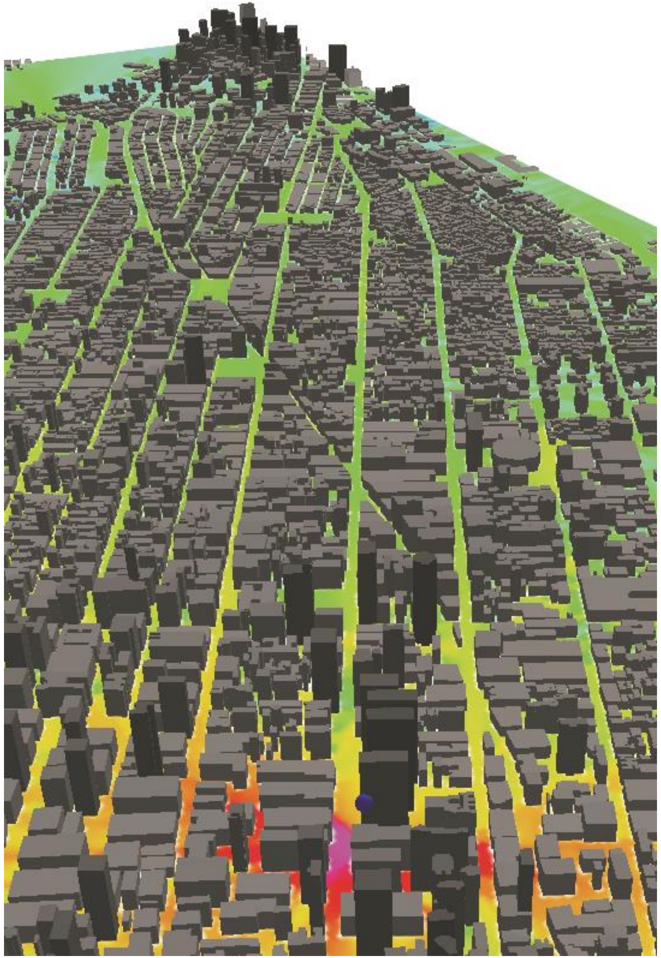
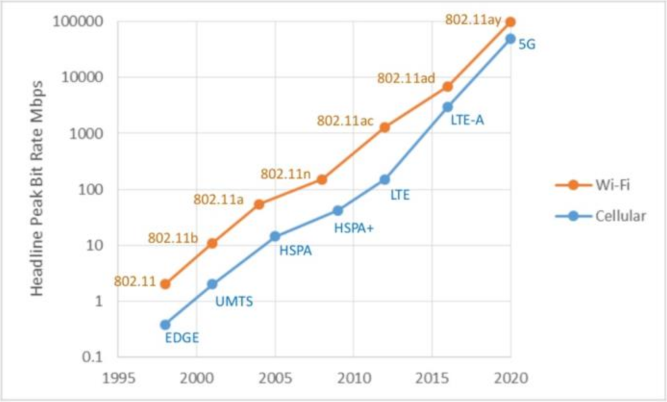
  - 5G network planning
  - Urban cells
  - Indoor multi-floor scenarios
  - HetNet environments
  - Broadcasting scenarios
  - Tunnel / mining scenarios
  - Industrial environments
- Conclusions



MOTIVATION

Evolution in the Wireless Domain

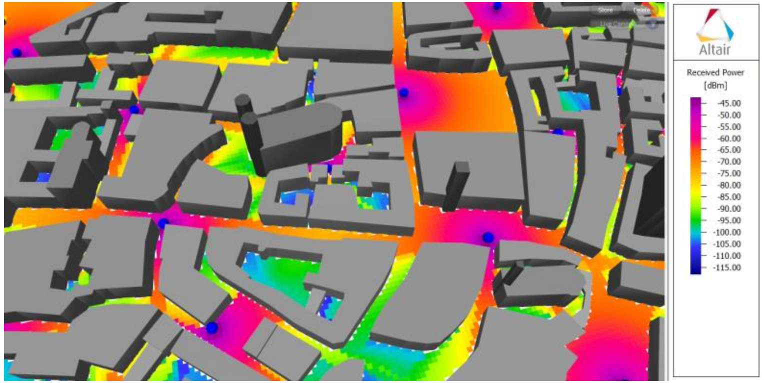
- Cellular – LTE, LTE-A towards 5G
- WiFi – Wireless local area networks 802.11ac, ad, ay
- Trend to higher frequencies / mm waves
  in order to provide the required higher data rates & throughputs
- Massive MIMO antenna installations on both base stations
  and mobiles for beamforming & spatial multiplexing



Source: Plum Consulting

Performance of Wireless Networks

- Depends significantly on radio channel
- Highly accurate wave propagation models required,
  for channel statistics but also for prediction of the radio coverage
- Radio network planning to analyze the performance at different
  frequencies as well as for different deployment strategies
- Various scenarios and environments are of interest
  (e.g. urban, indoor, virtual drive tests)



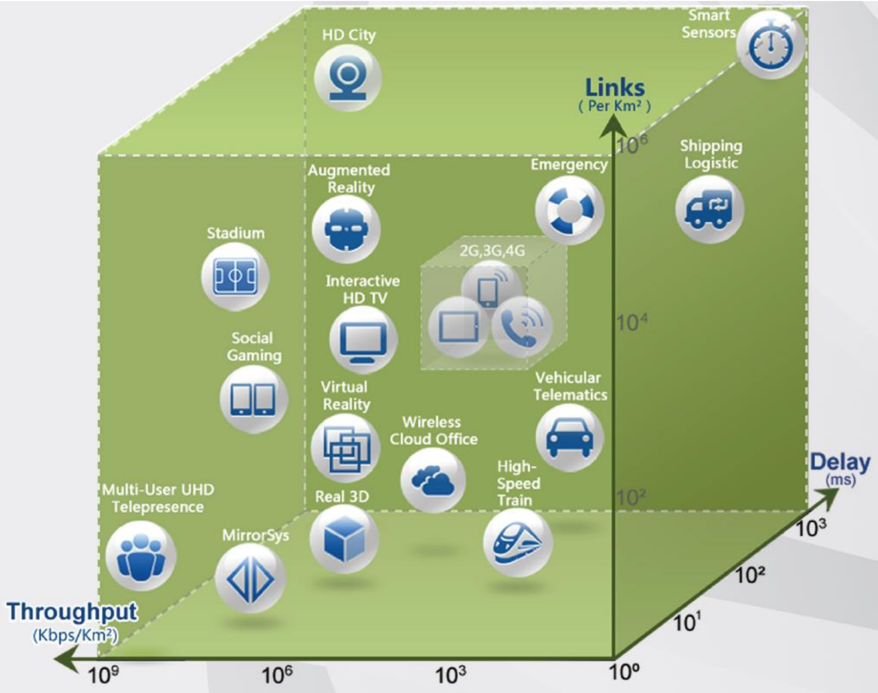
CHALLENGES FOR 5G

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 GHz for fiber like data rates & capacity hotspots
- Ultra-dense networks
- Massive MIMO antennas for beamforming and spatial multiplexing



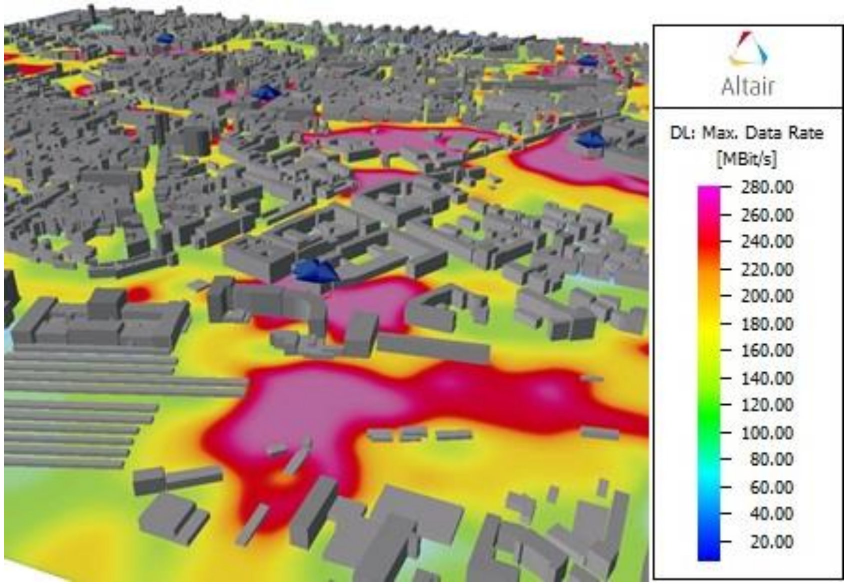
Source: Huawei 5G Technology Vision

ALTAIR SOLUTION

ALTAIR SOLUTION FOR THE WIRELESS NETWORK DESIGN

We talk about all wireless solutions and services in arbitrary scenarios, including:

- Cellular (5G / LTE / UMTS / GSM)
- WiFi (e.g. 802.11n)
- IoT for connecting mesh/sensor networks
- Trunked Radio (e.g. TETRA for public safety), DECT
- Broadcast (analogue/digital)
- Co-Existence of Radio Networks and Electromagnetic Exposure

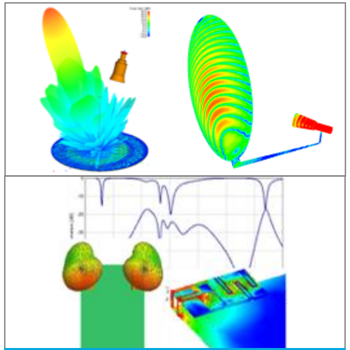


Focusing on simulations related to:

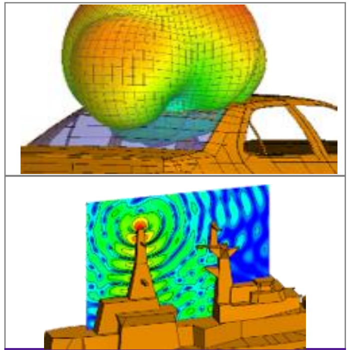
- Design and placement of base station / mobile station antennas using Feko & WinProp
- Radio coverage and radio channel modelling including the environment with WinProp
- Deployment and optimization of radio networks based on radio coverage and capacity

INTRODUCING ALTAIR FEKO

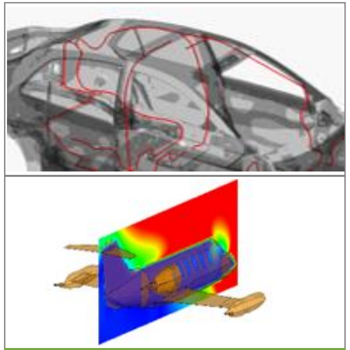
Feko is a global leading comprehensive electromagnetic simulation software based on a suite of accurate and parallelized solvers with true hybridization in an integrated and easy to use interface



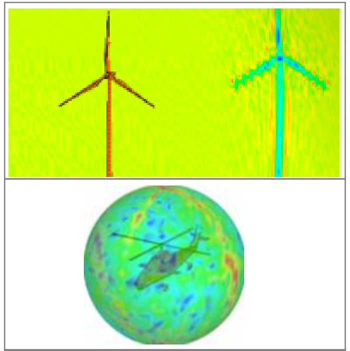
Antenna Design



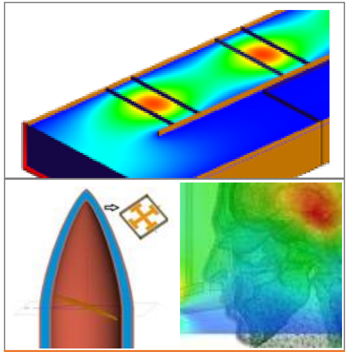
Antenna Placement



Electromagnetic Compatibility (EMC)



Scattering / RCS

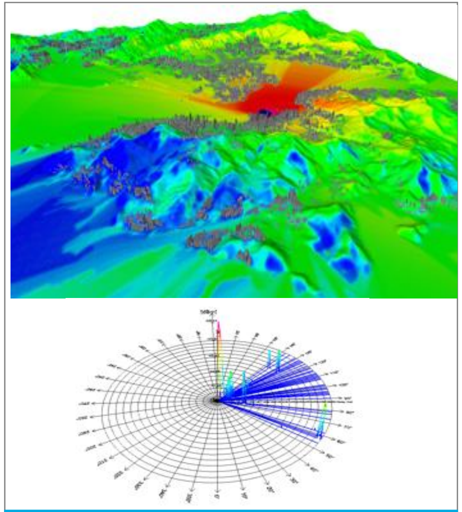


Others (including RF devices, radomes and bio-electromagnetics)

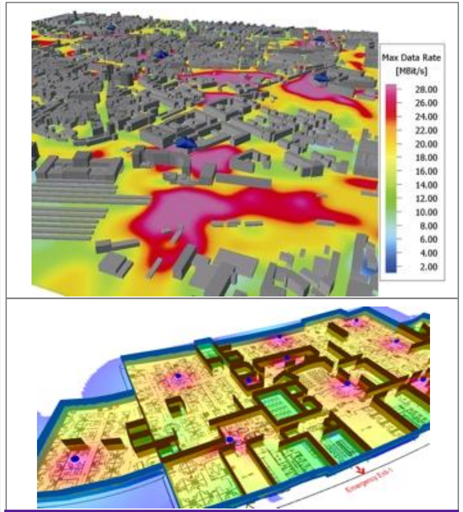
Multiphysics Analysis and Optimization

INTRODUCING ALTAIR WINPROP

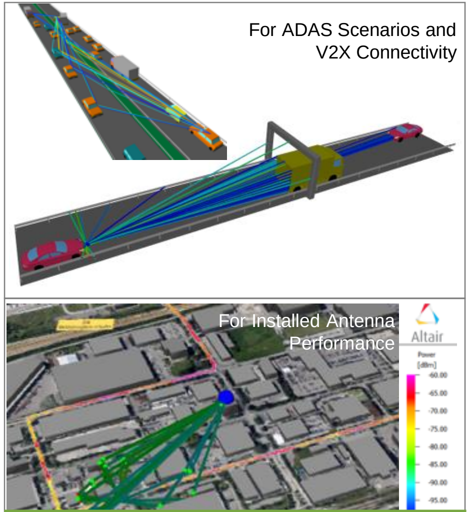
WinProp is a reference software focused on wireless propagation modelling and radio network planning, providing accurate and fast propagation models for a wide range of scenarios and air interfaces



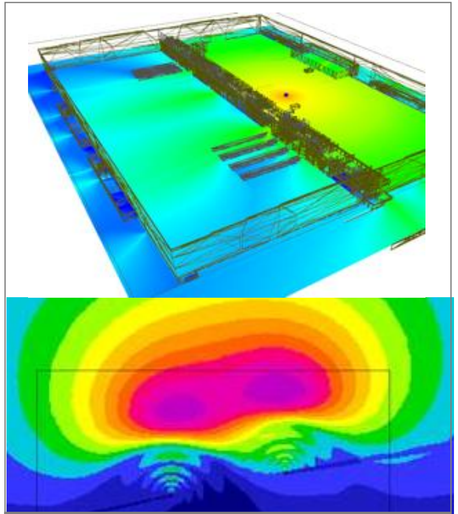
Radio Coverage and Radio Channel Modelling



Deployment and Optimization of Radio Networks

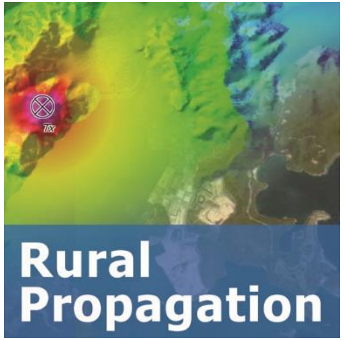


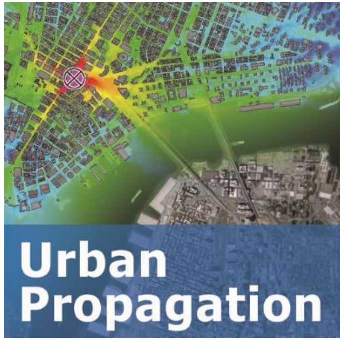
Virtual Drive Tests for ADAS & Antenna Performance Analysis

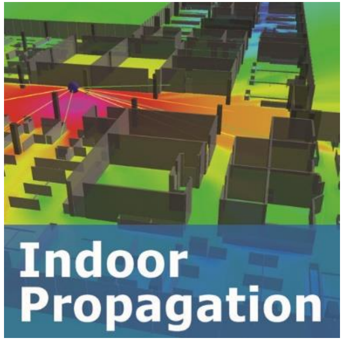


Co-Existence of Radio Networks and Electromagnetic Exposure

INDIVIDUAL PROPAGATION MODELS FOR VARIOUS SCENARIOS





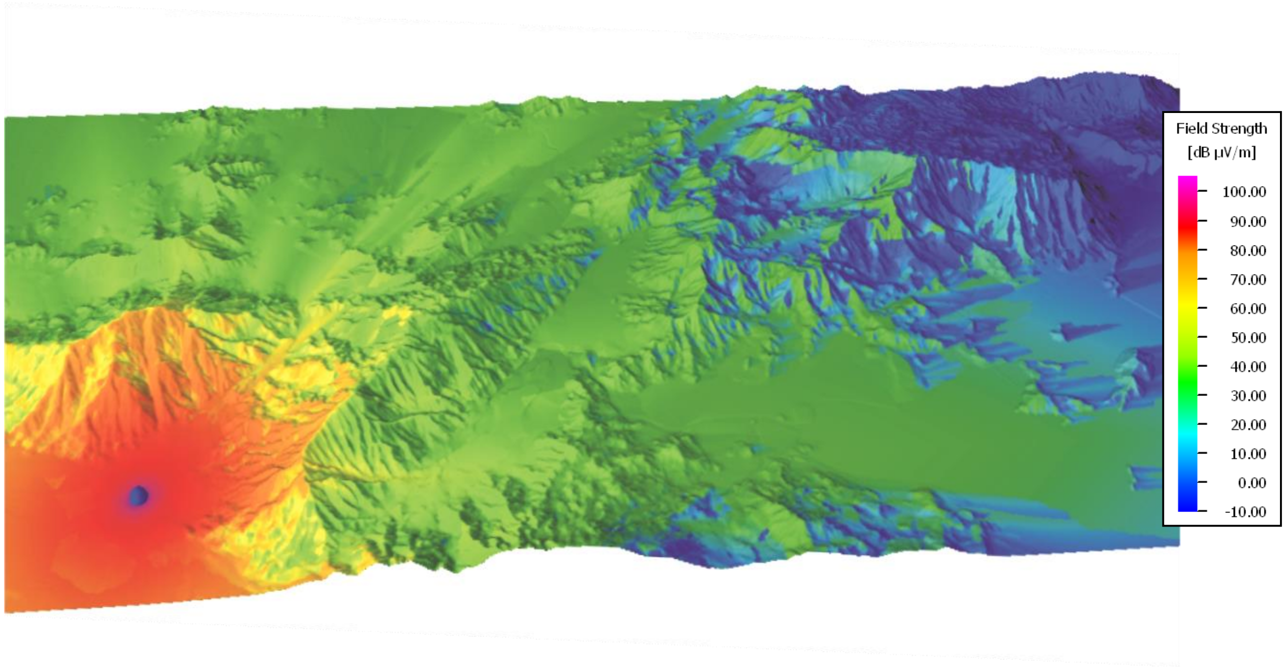


	Rural Propagation	Urban Propagation	Indoor Propagation
Map Data	Topography pixel data	2.5D building vector data	3D vector data
Optional Data	Clutter losses / heights Ground properties	Material properties Topography pixel data Vegetation objects	Material properties Subdivisions, furniture
Propagation Models	Empirical models (Hata, ITU,…) Vertical plane models **Dominant path model** ***3D Standard Ray Tracing (SRT)***	Vertical plane models (WI) **Dominant path model** ***3D Intelligent Ray Tracing (IRT)***	Direct ray models (Multi-Wall) **Dominant path model** ***3D Ray Tracing SRT/IRT***

RURAL SCENARIOS

Topography

- Pixel data with arbitrary resolutions
- Rectangular coordinate system required
- Coordinates either metrical (e.g. UTM) or geodetic
- Various coordinate datums and projections
- Curvature of earth optionally considered for large areas
- Clutter data (land usage) optional

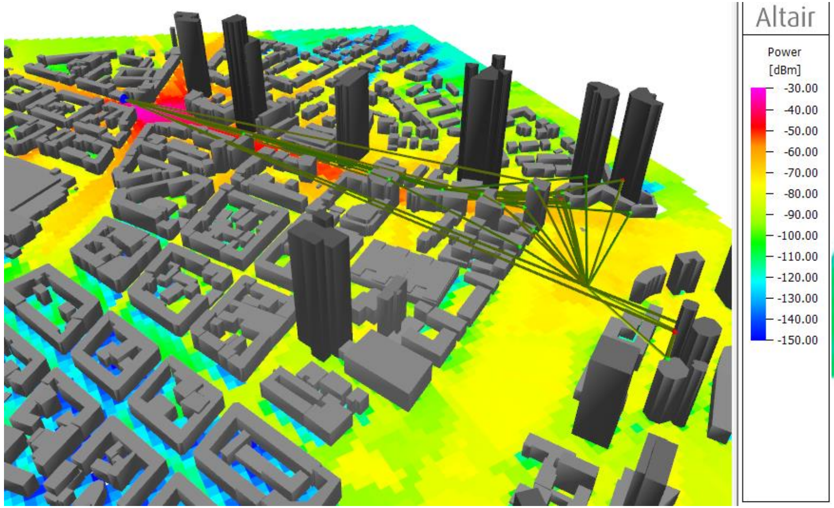


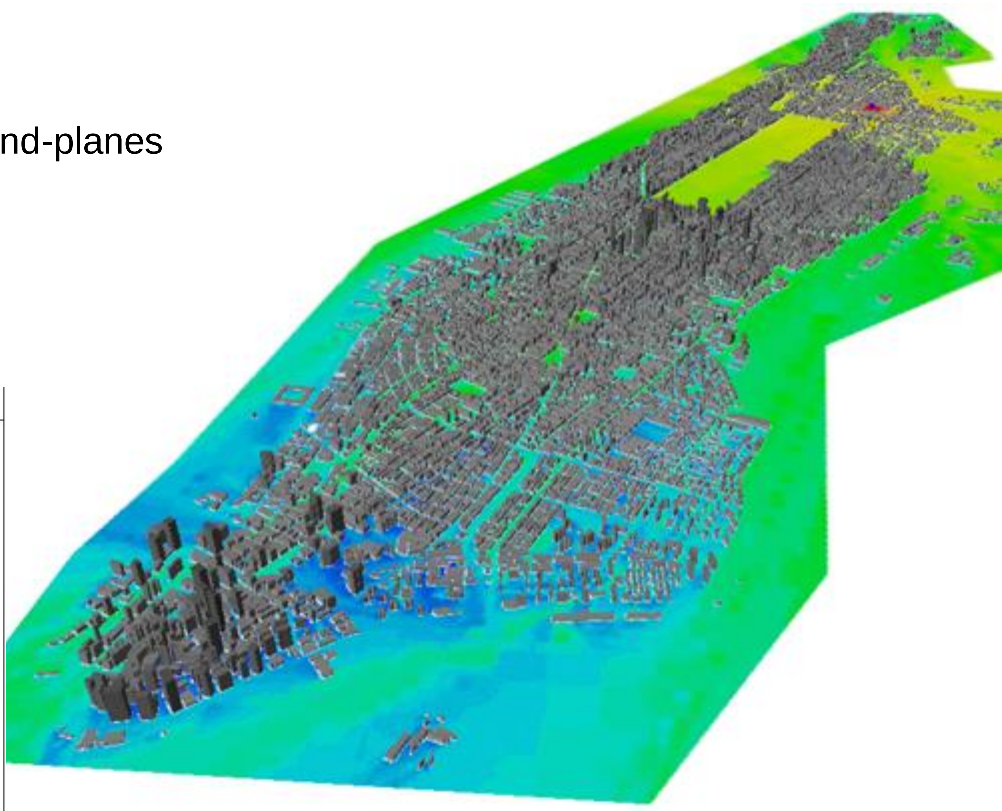
- Class properties: Height, clearance, frequency dependent attenuation, electrical properties of ground

URBAN SCENARIOS

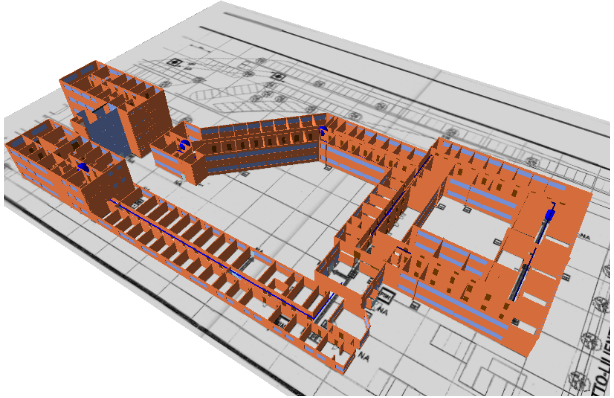
Building Vectors

- Buildings as vertical cylinders with polygonal ground-planes
- Individual material properties of building surfaces
- Vegetation possible in same format
- Topography can be considered optionally





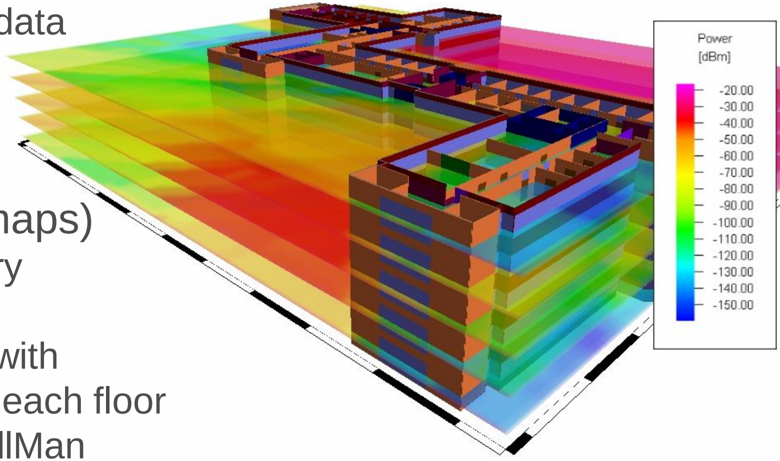
INDOOR SCENARIOS

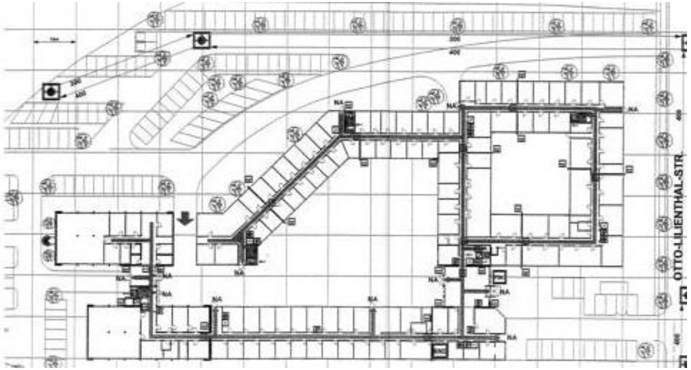


Office building

3D vector databases

- Planar polygons with arbitrary number of corners
- Individual or homogenous material properties
- Subdivisions with different material properties possible
- Definition of floors (multi floor buildings)
- Furniture (or persons) as volumes with additional loss
- Conversion of CAD data





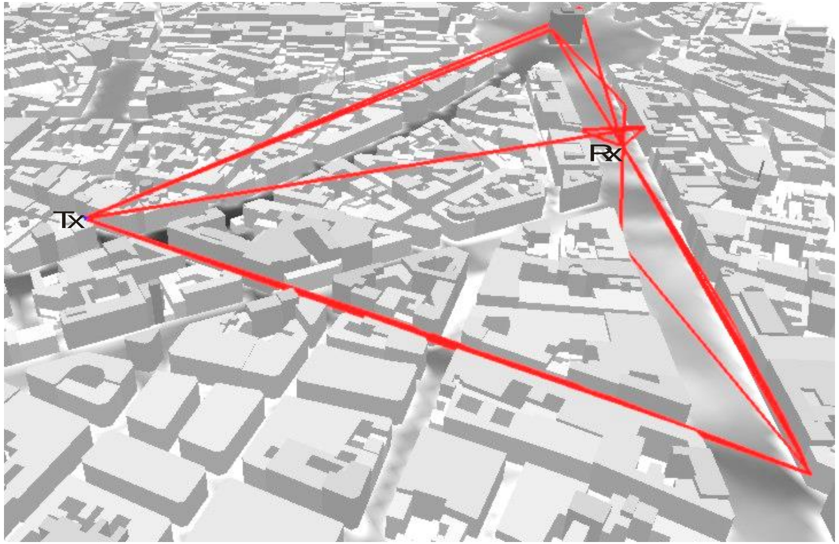
Office building

Pixel databases (bitmaps)

- Bitmaps with arbitrary resolutions
- Multi floor buildings with different bitmaps for each floor
- Import bitmap in WallMan and draw walls manually

5G AIR INTERFACE AND RADIO NETWORK PLANNING

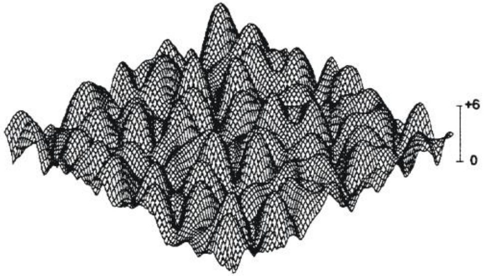
RADIO CHANNEL



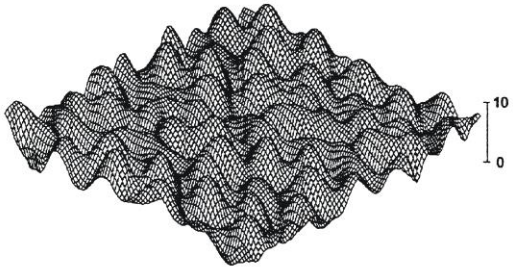
Multipath Propagation

- 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



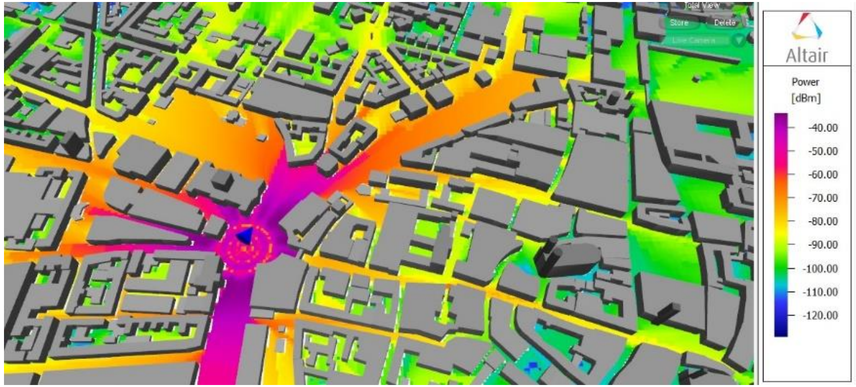
No line of sight (Rayleigh fading)



Line of sight (Rice fading)

WAVE PROPAGATION > 6 GHZ

Impact at interactions due to higher frequency

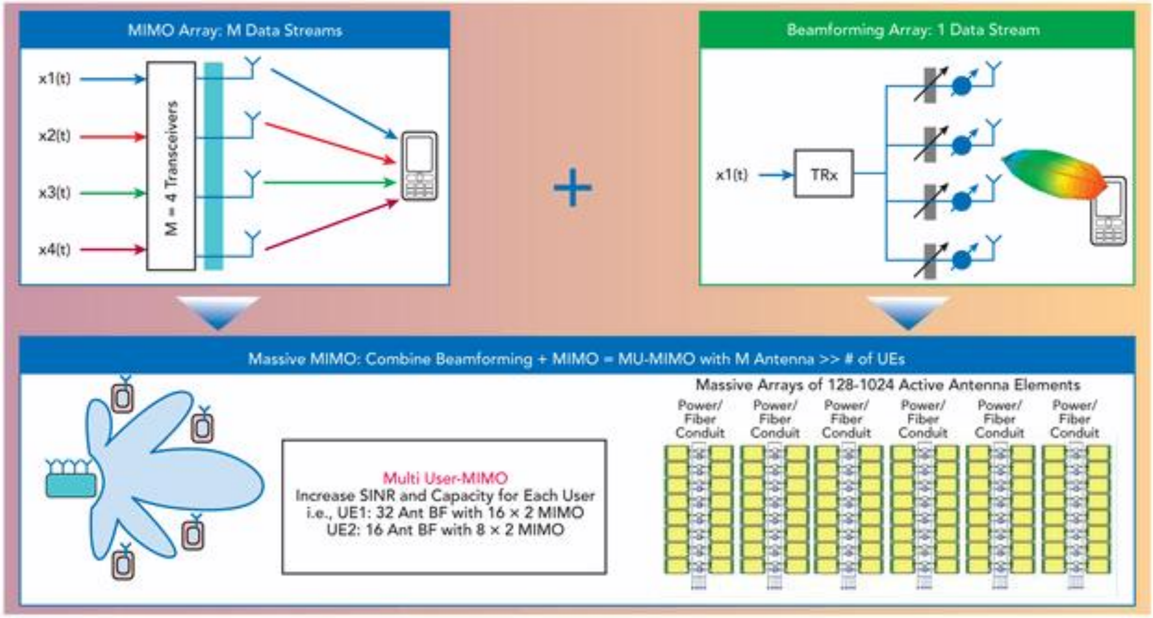


- Transmission
  - Penetration of walls hardly feasible
  - LOS and OLOS regions will dominate (impact of street grid)
- Reflection
  - Specular paths will dominate (besides direct path)
  - For LOS and OLOS regions
- Diffraction
  - Highly attenuated for higher frequencies as diffraction coefficient ~ 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

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
- Relevant channel statistics
  - Delay spread
  - Azimuth angular spread both for BS and MS
  - Elevation angular spread
  - Evaluation of cumulative distribution function (CDF)

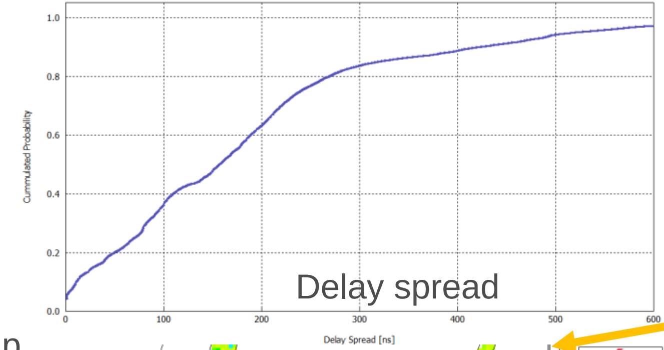


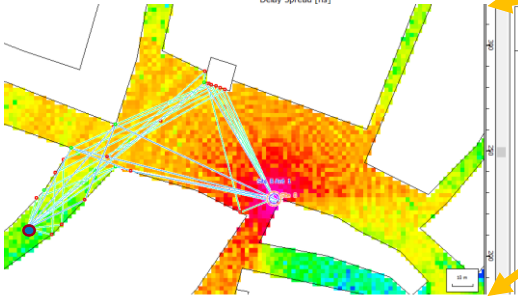
Source: Microwave Journal

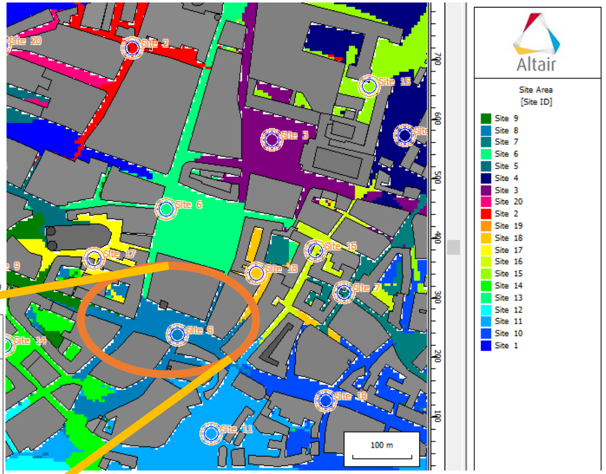
5G RADIO CHANNEL

Channel Statistics

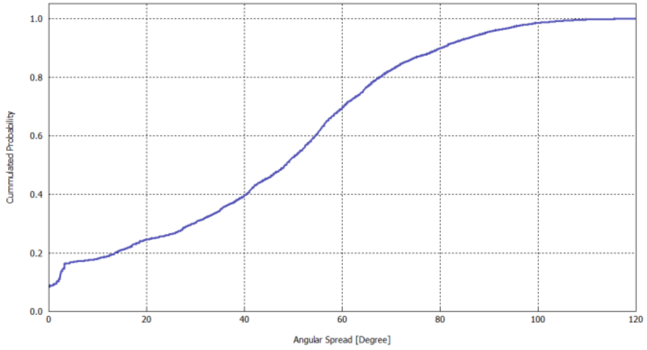
- Computed for individual cells
- Consideration of omni BS antenna
- Cell areas given by best server map
- Delay spread at 26 GHz
- Azimuth angular spreads at 26 GHz



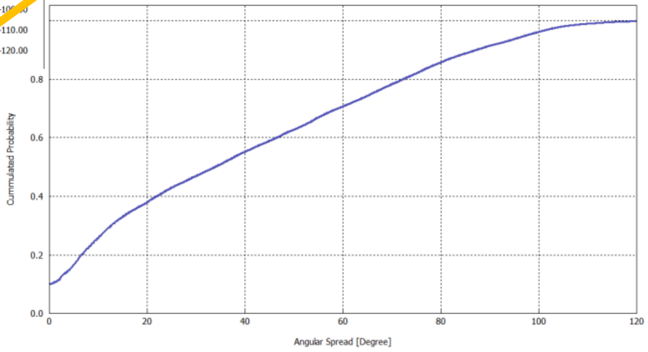




Angular spread BS



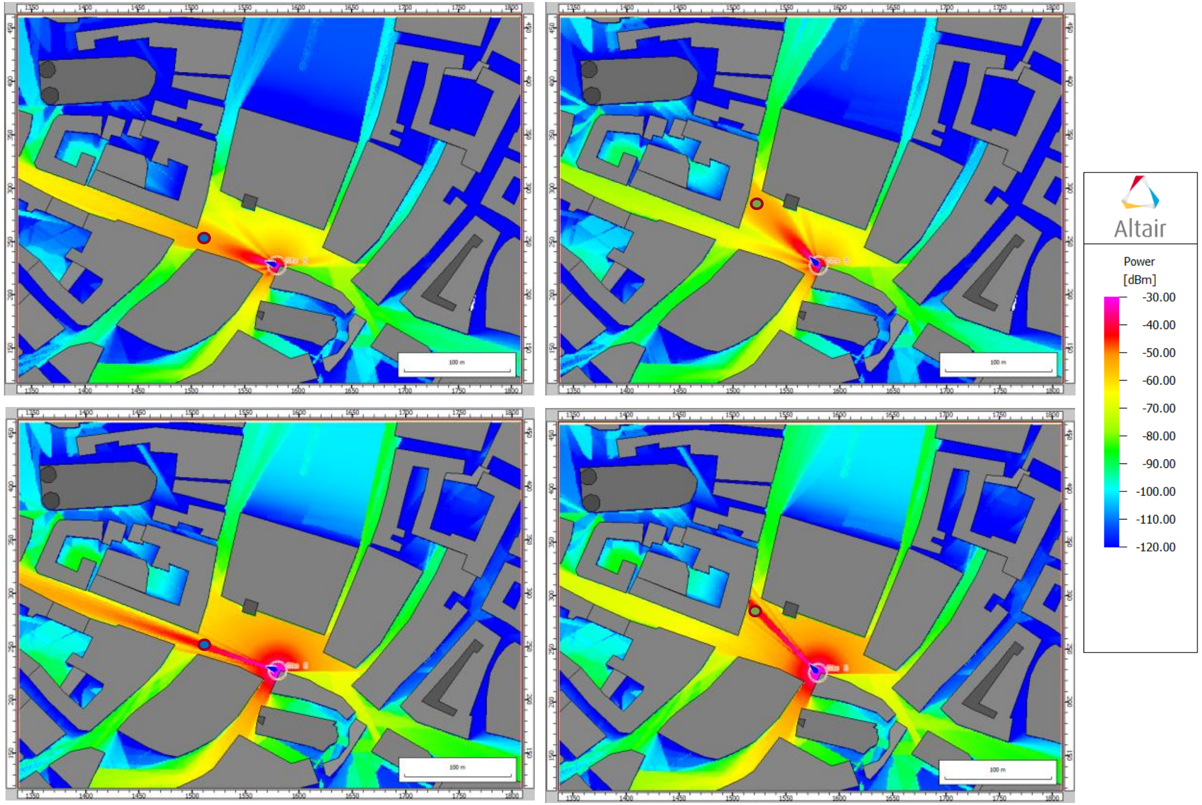
Angular spread MS



5G RADIO CHANNEL

Beamforming

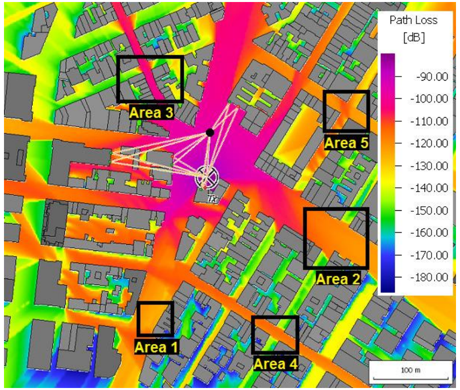
- Massive MIMO antenna arrays used to
  - Transmit different signals to different users simultaneously in same frequency band
  - Increase Rx power levels and SNIR for dedicated user
  - Reduce interference for others
- Example shows separation of two different users
  - 4x4 antenna elements on BS side (upper pictures)
  - 16x16 antenna elements on BS side (lower pictures)



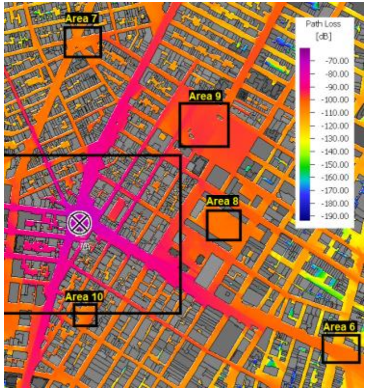
5G RADIO CHANNEL

5G Radio Channel Analysis I

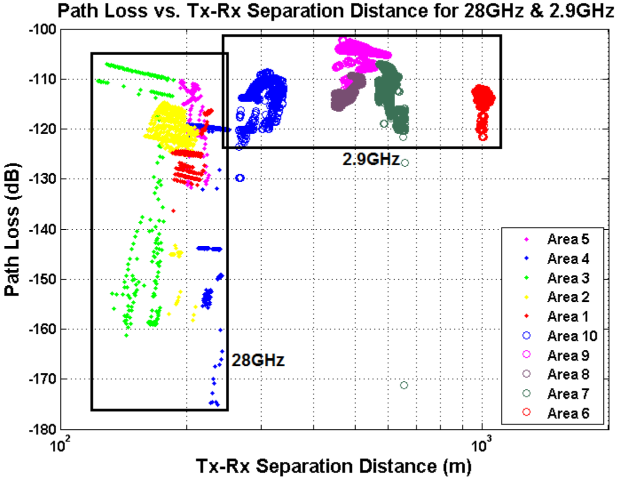
- Comparison of simulated path loss at 28 GHz



and 2.9 GHz

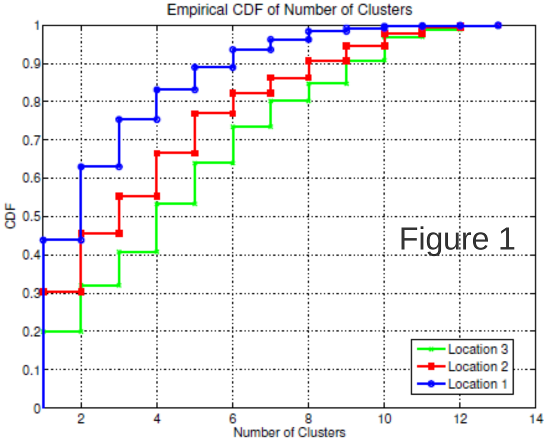


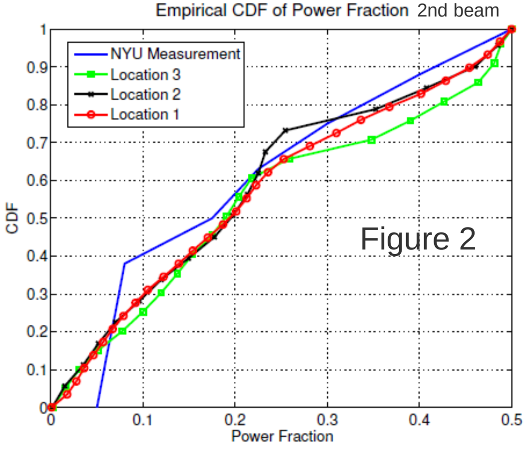
  - New York city scenario
  - WinProp 3D ray tracing model
  - BS at street intersections
  - 3 different BS locations analyzed
  - Areas marked in black rectangles evaluated in below diagram
  - Path loss over BS ➔ MS distance gives much smaller range for 2.9 GHz
  - Wide range of path loss for same/similar distances at 28 GHz
  - Hence simple path loss model not sufficient
    but 3D ray-optical model required
  - Alternative to measurements is the usage of 3D ray tracing engine



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

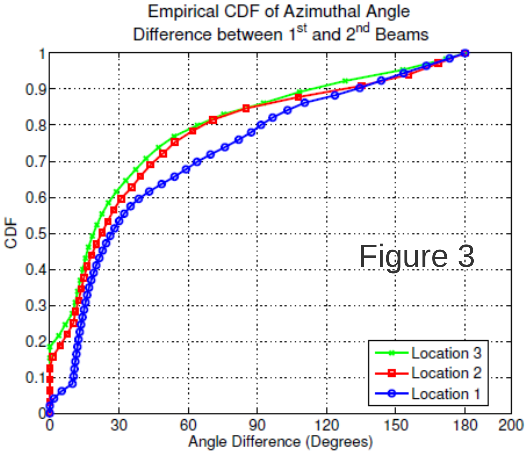
5G RADIO CHANNEL





5G Radio Channel Analysis II

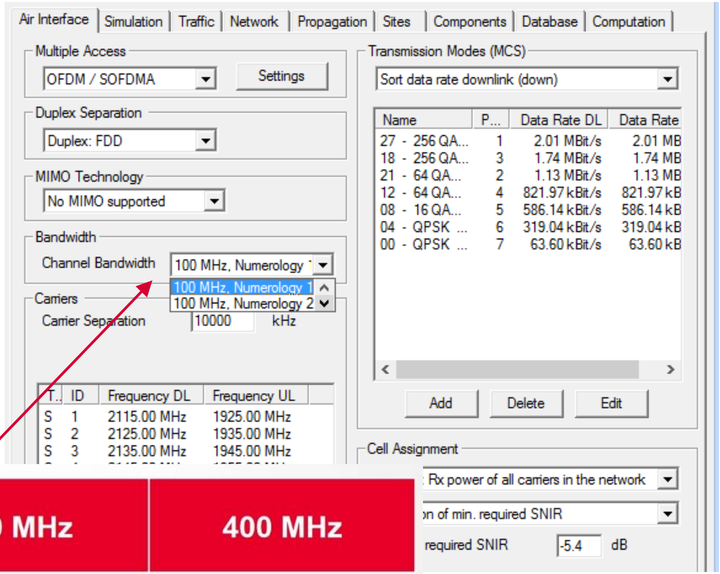
- Beam diversity at 28 GHz
  - New York city scenario
  - WinProp 3D ray tracing model
  - BS at street intersections
  - 3 different BS locations analyzed
  - Statistics on number of paths between BS and MS
    ➔ on median there are 2-4 clusters (see figure 1)
  - If dominant direction is blocked alternative path required
  - Power fraction of the second strongest path
    (at least 10° away) ➔ on average 7 dB weaker (see figure 2)
  - 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 AIR INTERFACE PARAMETERS

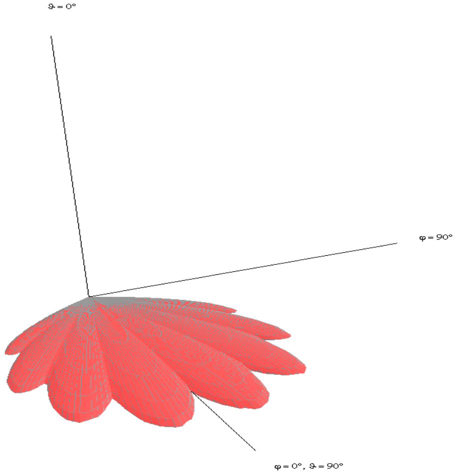
- Channel bandwidth up to 400 MHz
- Variable subcarrier spacing and slot length (numerology μ)
- Number of subcarriers depends on numerology/bandwidth
- Numerology and bandwidth combination selectable in GUI
- Duplex: FDD or TDD
- Evaluation of beam pattern/configuration

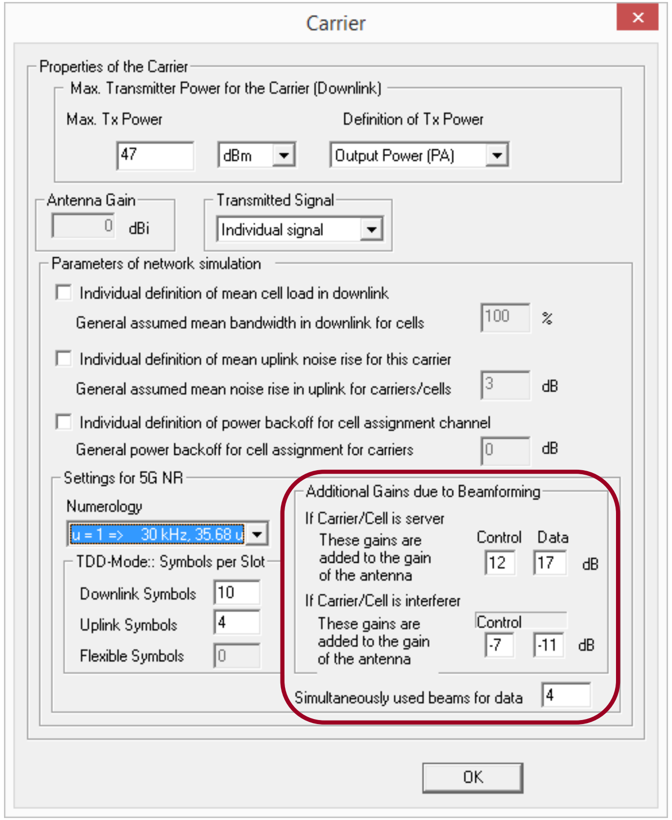


	Subcarrier Spacing / Slot Length	20 MHz	50 MHz	100 MHz	200 MHz	400 MHz
μ=0	**15 kHz** 1 ms	2048 FFT 1320 sc (110 PRBs) 30.72 Msps	4096 FFT 3300 sc (275 PRBs) 61.44 Msps	Not possible > 275 PRBs	Not possible > 275 PRBs	Not possible > 275 PRBs
μ=1	**30 kHz** 500 µs	1024 FFT 660 sc (55 PRBs) 30.72 Msps	2048 FFT 1644 sc (137 PRBs) 61.44 Msps	4096 FFT 3300 sc (275 PRBs) 122.88 Msps	Not possible > 275 PRBs	Not possible > 275 PRBs
μ=2	**60 kHz** 250 µs	512 FFT 324 sc (27 PRBs) 30.72 Msps	1024 FFT 816 sc (68 PRBs) 61.44 Msps	2048 FFT 1644 sc (137 PRBs) 122.88 Msps	4096 FFT 3300 sc (275 PRBs) 245.76 Msps	Not possible > 275 PRBs
μ=3	**120 kHz** 125 µs	Not possible < 20 PRBs	512 FFT 408 sc (34 PRBs) 61.44 Msps	1024 FFT 816 sc (68 PRBs) 122.88 Msps	2048 FFT 1644 sc (137 PRBs) 245.76 Msps	4096 FFT 3300 sc (275 PRBs) 491.52 Msps

5G AIR INTERFACE PARAMETERS, CONTINUED

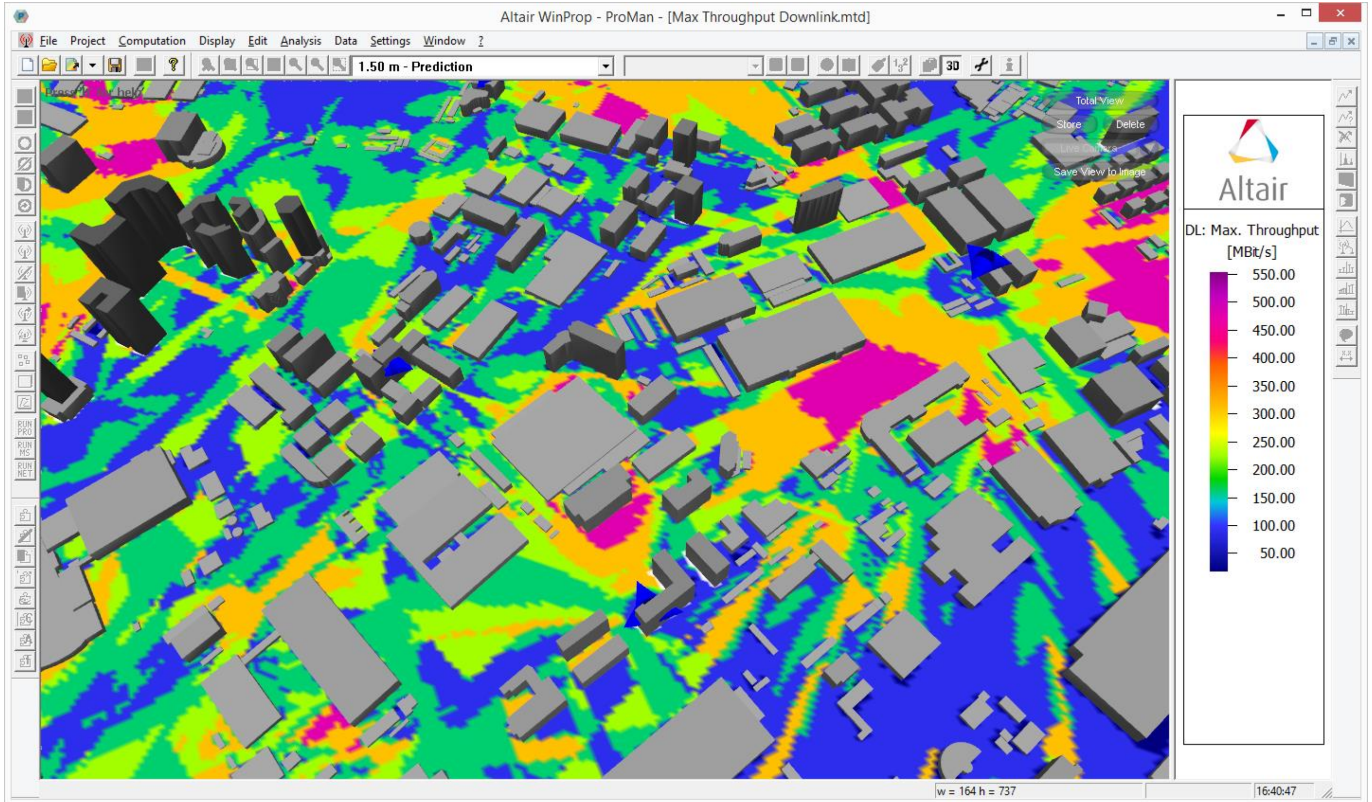
- At the cell / carrier level the beamforming gains and number of used beams can be defined
- Different gains for serving and interfering cells, both for control and data channels
- Alternatively the individual beam patterns or the envelope pattern can be considered
- Example of envelope for 8 beams over 120 deg:

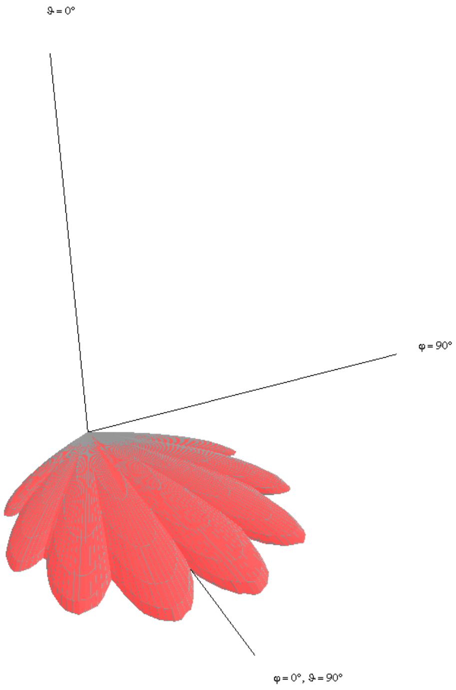




5G RADIO NETWORK PLANNING

DL Throughput for antenna configuration with 8 beams per sector



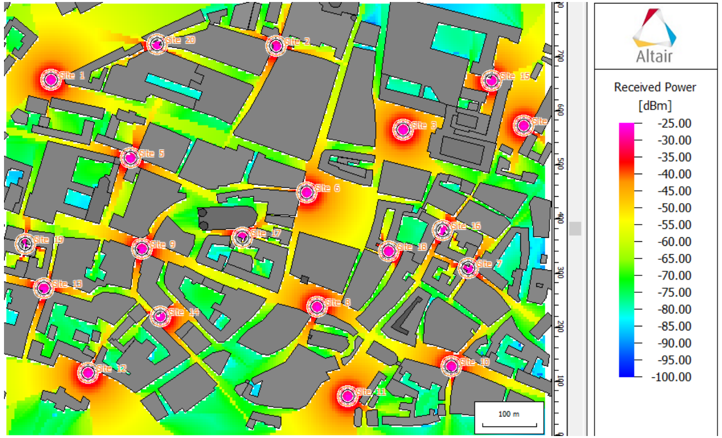


5G RADIO NETWORK PLANNING

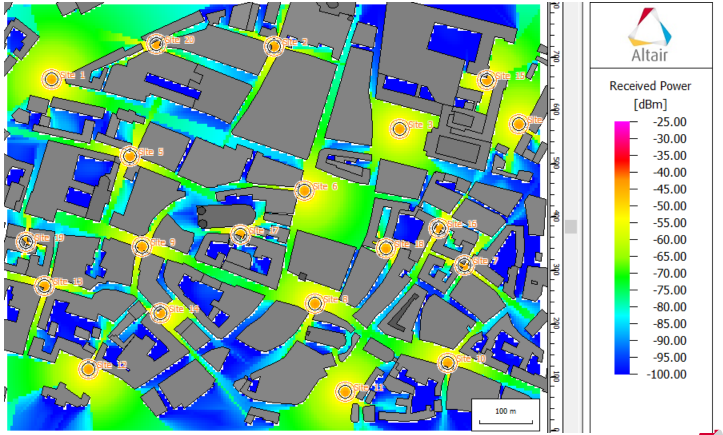
5G Deployment Scenarios

- Ultra-dense networks for provision of required high data rate volumes
- Coverage of radio network limited by signal and interference power
- Strong signal-to-noise-and-interference-ratio (SNIR) requirements for high data rates
- Beamforming on base station side
  - Increase Rx power levels and SNIR for dedicated user
  - Reduce interference for others
- 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

3.5 GHz



26 GHz

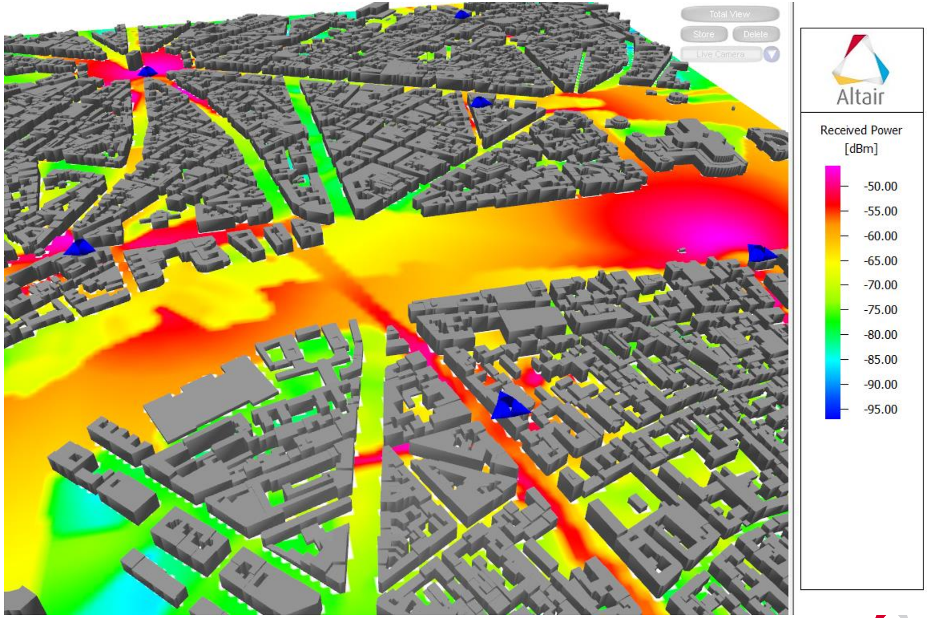


URBAN CELLS

URBAN CELLS

Radio Network Planning in Urban Scenario

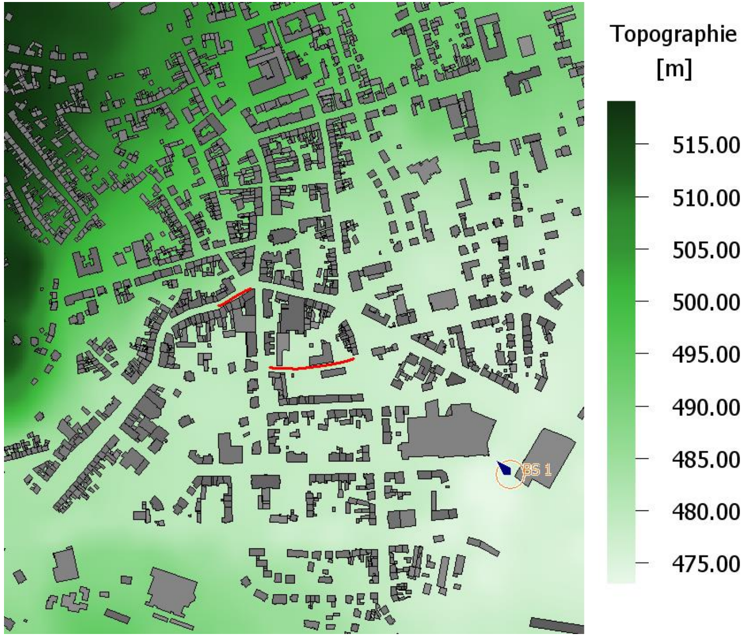
- WinProp **propagation models** combine **high accuracy** with **short computation time** for large urban scenarios
- WinProp **won several benchmarks** and is **used by multiple operators**
- **All air interfaces** of interest (5G, LTE, UMTS, WiFi, …)
- **Wide frequency range** (100 MHz up to 100 GHz)
- For **all types of cells** (macro, micro, small) with transmitting antennas above / below / on rooftop level
- For **optimization** of existing radio networks or evaluate different **deployment strategies**
- For **all types of environments**: rural, suburban, urban, dense urban
- **Indoor coverage** in urban buildings
- WinProp propagation engine can be integrated via **API** into your planning tool

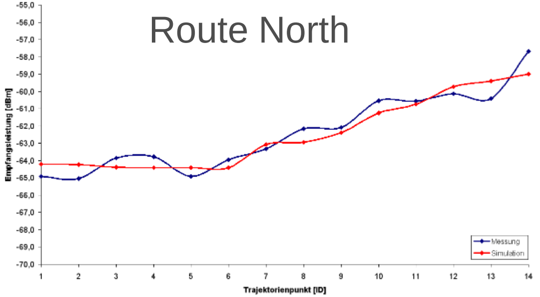


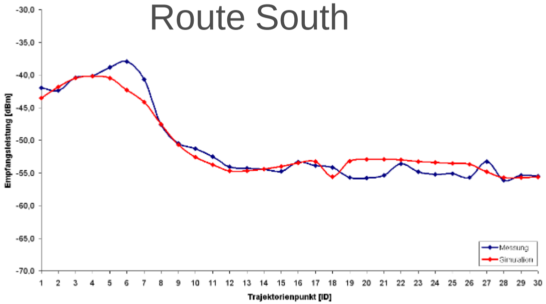
URBAN CELLS

Verification of Model Accuracy in Urban Scenario

- Measurements with high resolution 3D channel sounder in urban macro cell reference scenario
- Tx height: 26.5 m
- Tx frequency: 2.53 GHz
- Tx power: 46 dBm
- Rx height: 1.9 m





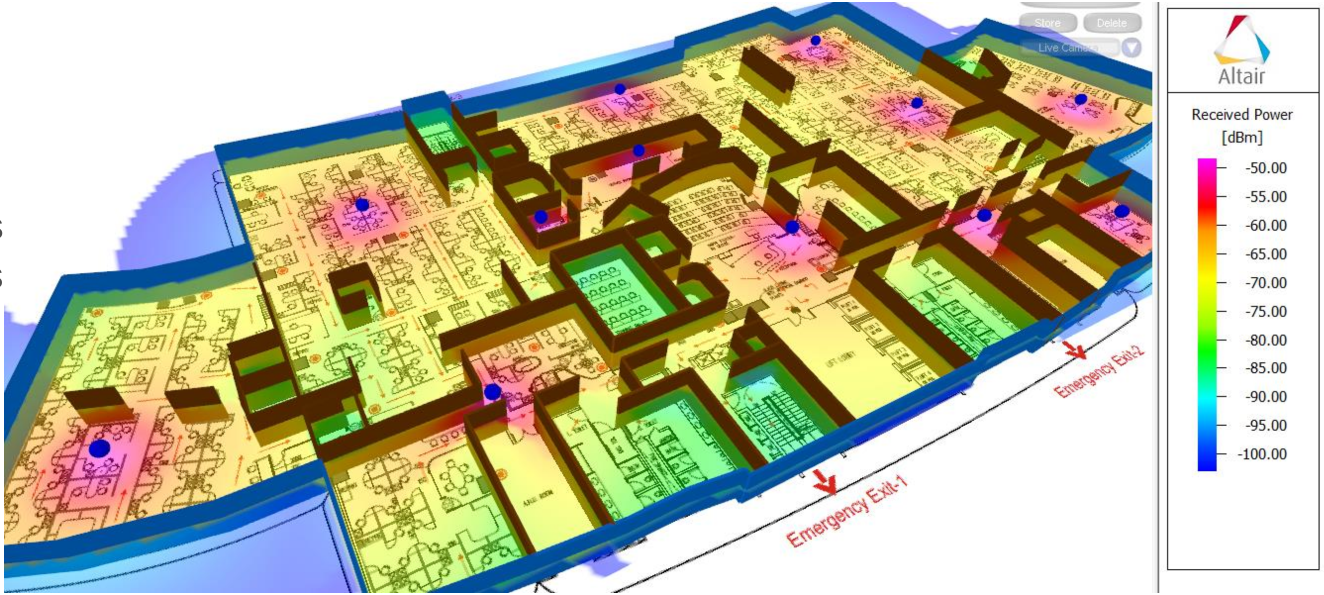


INDOOR MULTI-FLOOR

INDOOR MULTI-FLOOR

Indoor Radio Network Planning

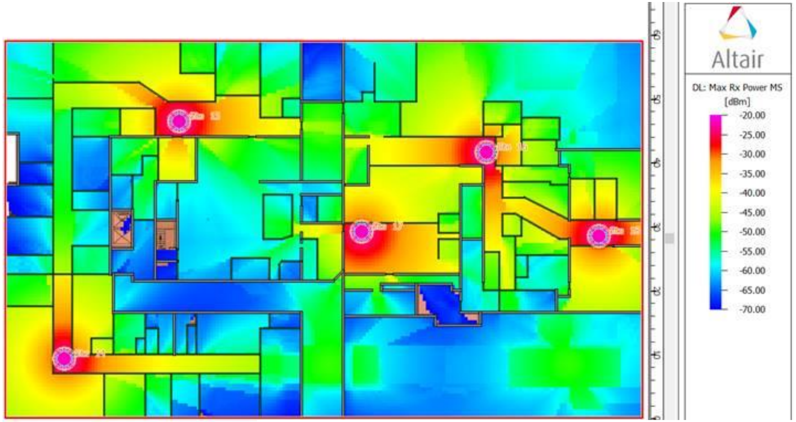
- Processing 3D building vector data with outer and inner walls including subdivisions like doors/windows
- Conversion of CAD data or definition based on imported bitmap
- Material catalogue with typical construction materials and their electrical properties
- Computation of Rx coverage and throughput (data rate)
- For WiFi / DECT planning
- For planning of indoor sites of cellular network

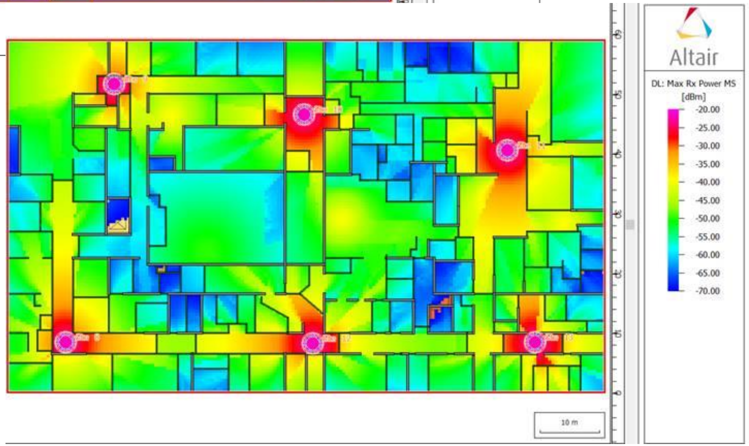


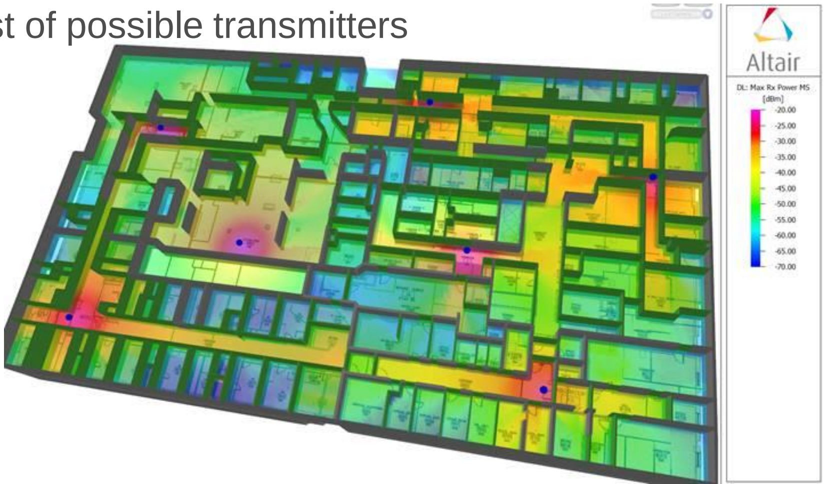
INDOOR MULTI-FLOOR

Planning of Required Access Points per Floor

- Define multi-floor database with different material types in WallMan
- Run radio coverage per transmitter
- Network planning computes the superposed coverage per floor
- OptMan allows to derive required subset out of predefined list of possible transmitters

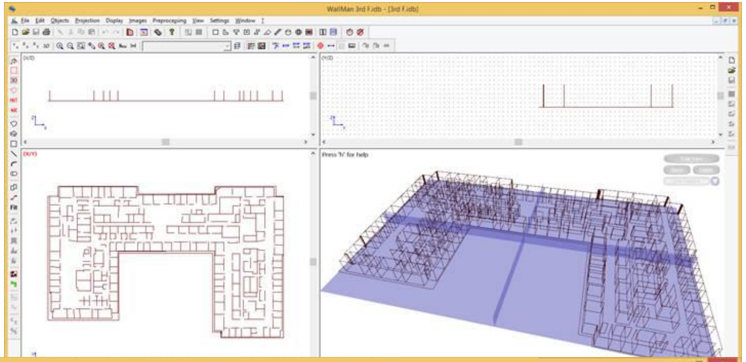






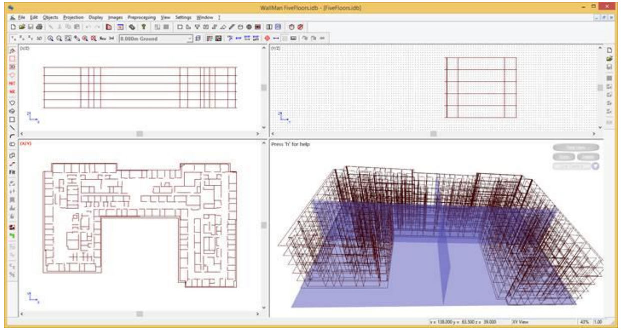
HETEROGENEOUS NETWORKS

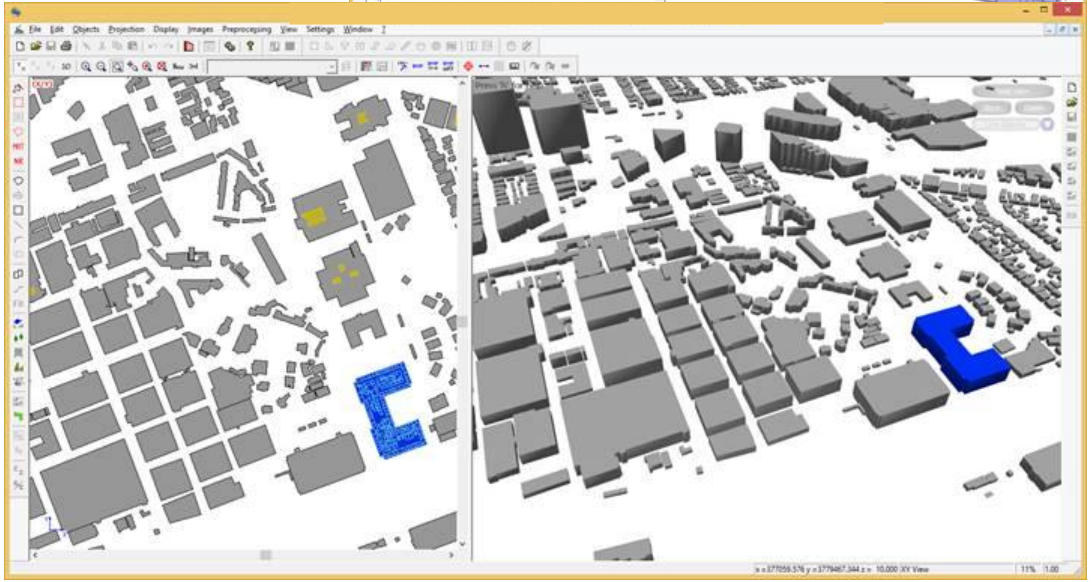
HETEROGENEOUS NETWORKS



Combine urban and indoor building data in WallMan

- Convert urban buildings as polygonal cylinders
- Convert indoor wall data from CAD (dwg/dxf)
- Create multi-floor building and import in urban scenario
- Use cases:
  - Detailed indoor coverage analysis
  - Are indoor repeaters required?
  - Analysis of interference from indoor cells to surrounding cellular network

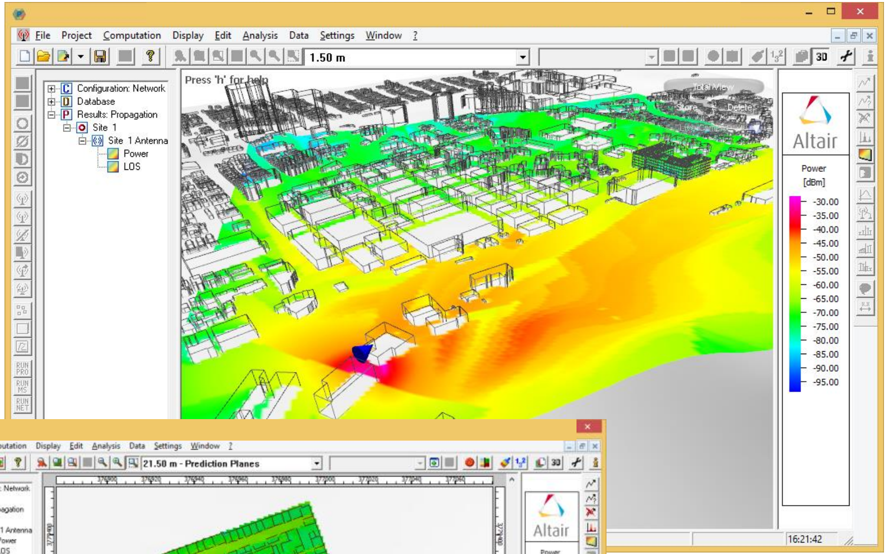


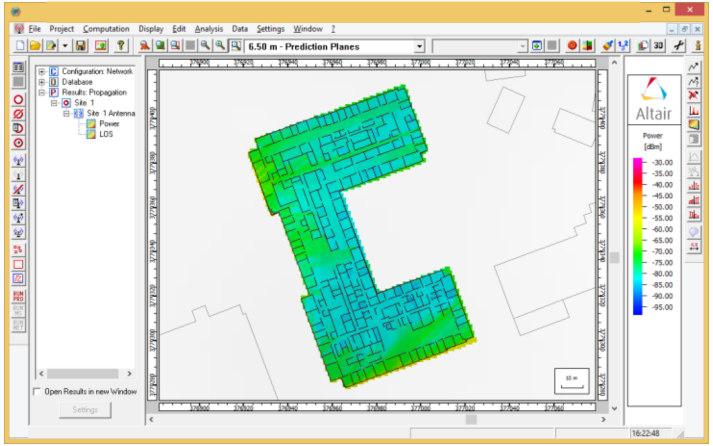


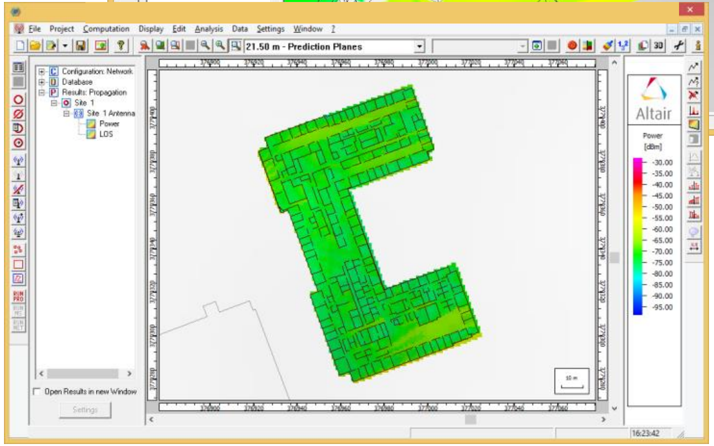
HETEROGENEOUS NETWORKS

Predict outdoor and indoor radio coverage in ProMan

- Deploy transmitter network (outdoor and indoor sites)
- Predict outdoor plus indoor coverage on several floors
- Use cases:
  - Detailed indoor coverage analysis
  - Are indoor repeaters required?
  - Analysis of interference from indoor cells to surrounding cellular network





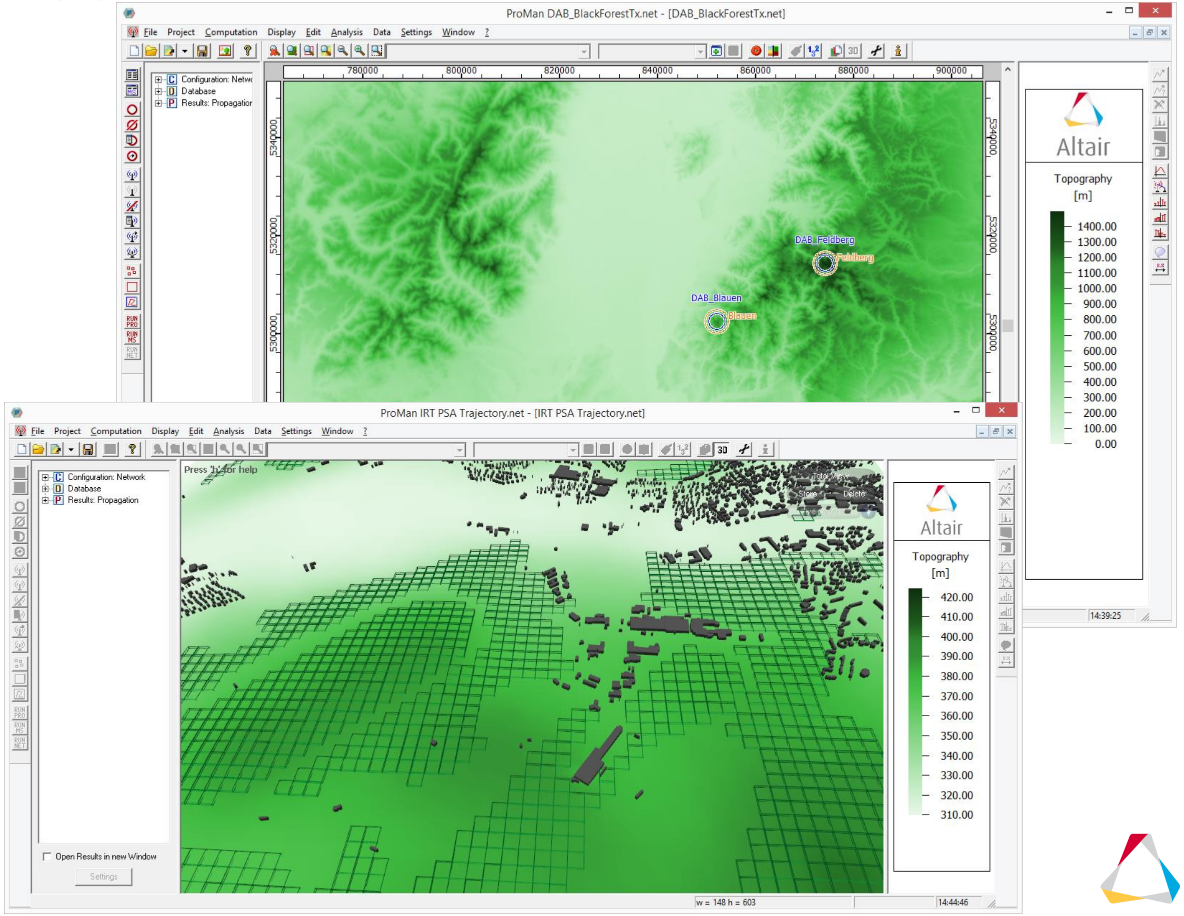


BROADCASTING SCENARIOS

BROADCASTING SCENARIOS

Building and Vegetation Data

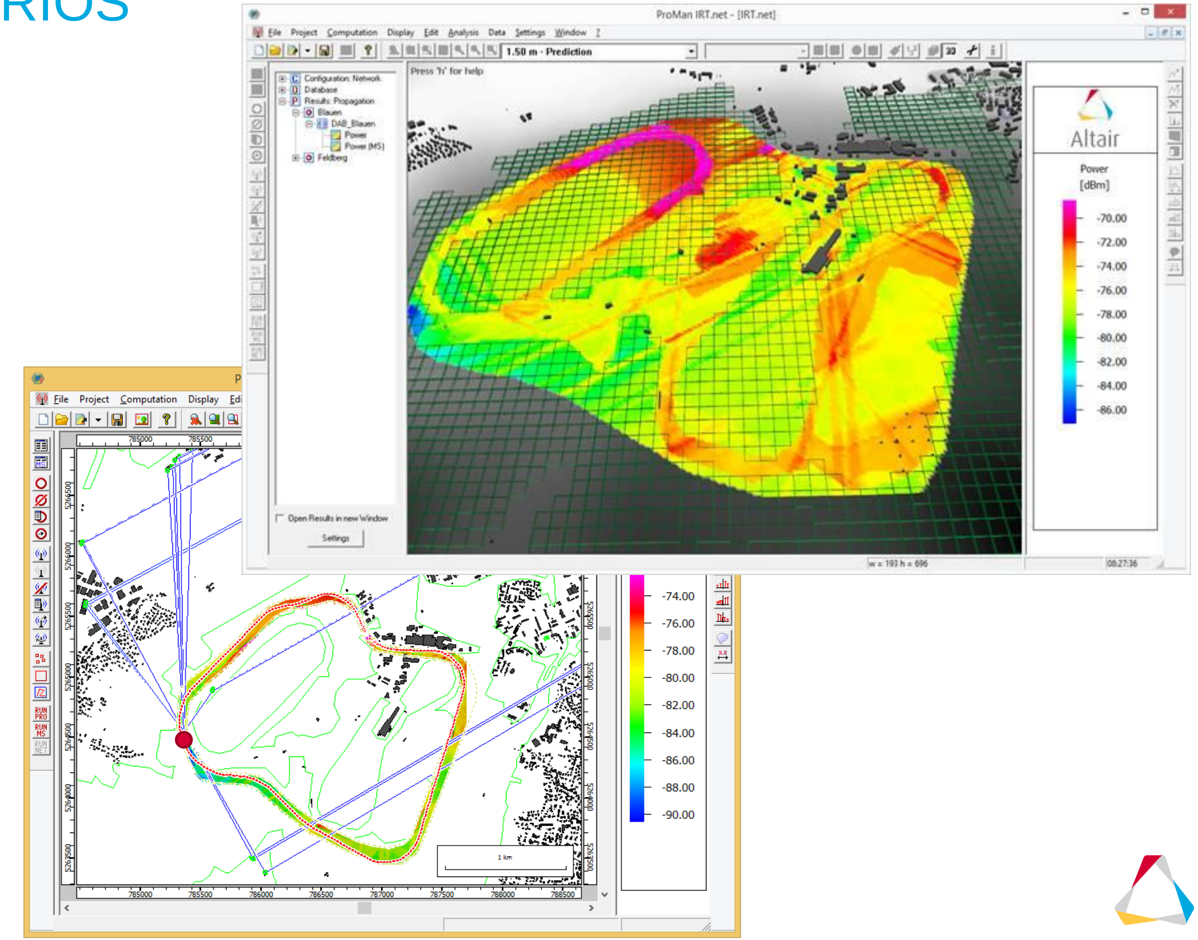
- Converted from open street map
- Buildings as polygonal cylinders
- Vegetation blocks (optionally)
- Superposed to topographical layer
- Definition/import of trajectory



BROADCASTING SCENARIOS

Propagation Study in ProMan

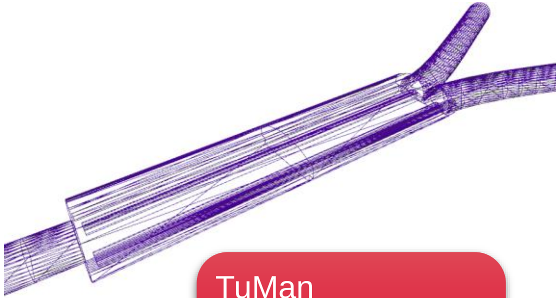
- Definition of DAB transmitters (location / Tx power / frequency)
- Tx antenna pattern and orientation
- Prediction of Rx power levels
- Multipath considered in ray tracing
- Superposition of Rx antenna pattern along trajectory (rotated according to driving direction)
- Example of rays for one Rx point along trajectory

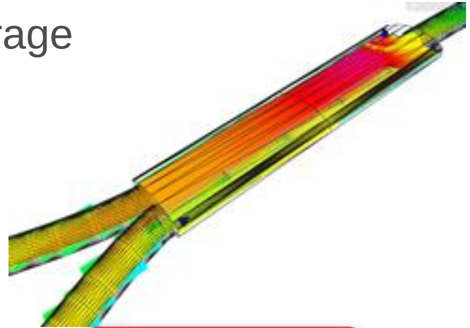


TUNNEL / MINING SCENARIOS

SIMULATION WORKFLOW IN WINPROP

- **TuMan**: Definition of tunnel based on cross sections and curvature of the tunnel
- **WallMan**: Integration of tunnel with additional objects, e.g. train
- **ProMan**: Project set-up & simulation of radio channel and coverage





TuMan

- Definition of tunnel
- Based on cross section
- Based on curvature
- Import of bitmap
- Additional obstacles in cross sections feasible

WallMan

- Import of train model
- Configuration and assignment of materials
- Integration of additional objects like trains or stations with tunnel database

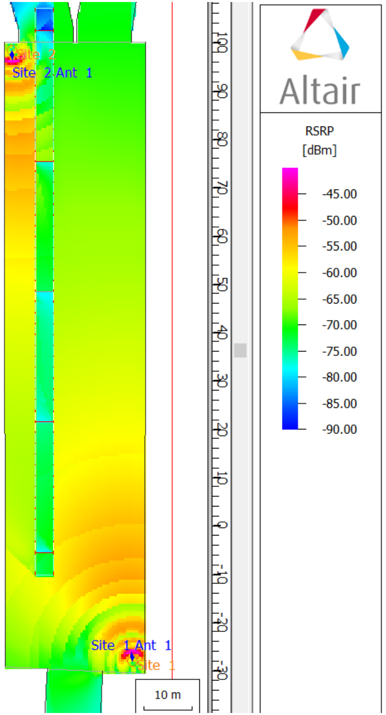
ProMan

- Definition of transmitter network based on air interface
- Assignment of transmitter antenna patterns
- Simulation of radio coverage in tunnel, station and inside train

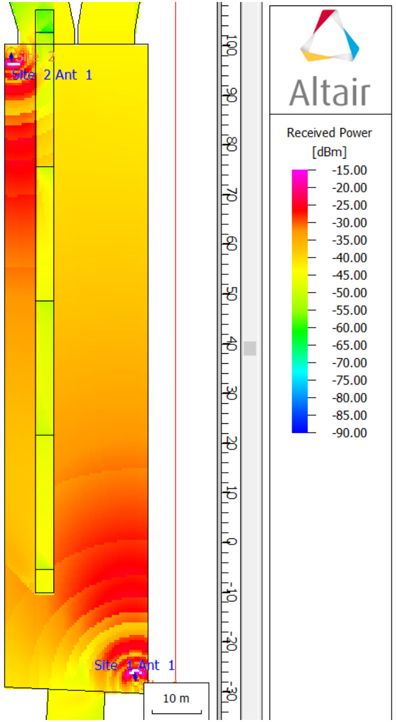
ANALYSIS OF NETWORK PLANNING RESULTS IN STATION

- Radio coverage analysis in station:

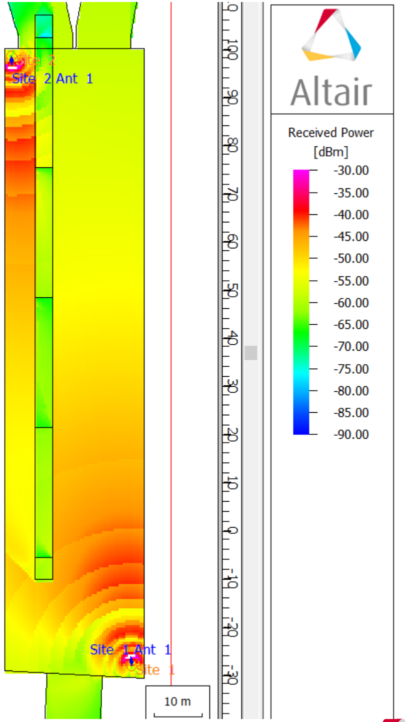
LTE



TETRA



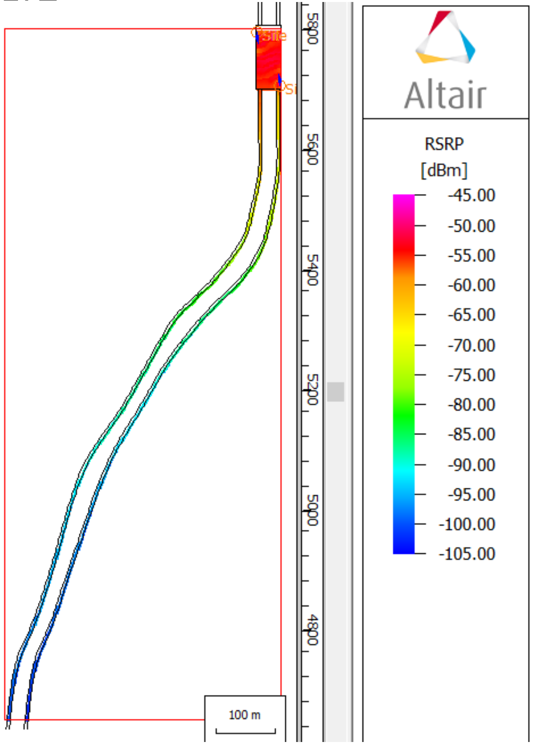
WiFi



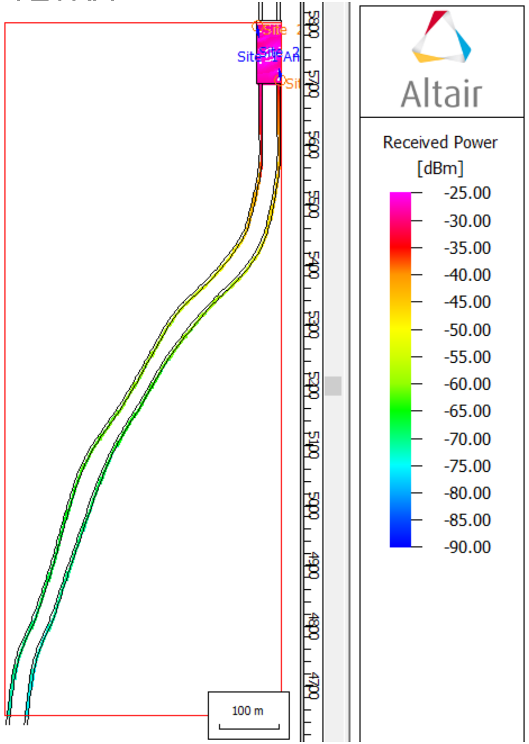
ANALYSIS OF NETWORK PLANNING RESULTS IN TUNNELS

- Radio coverage analysis in tunnels:

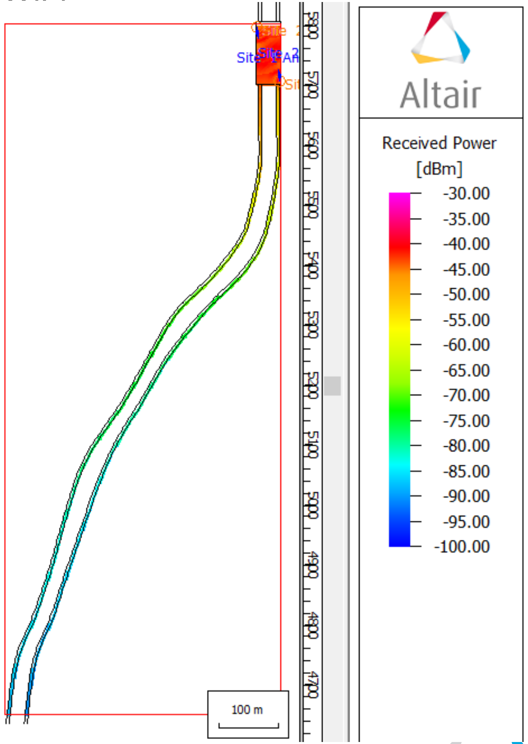
LTE



TETRA



WiFi



TUNNEL & STATION RADIO COVERAGE

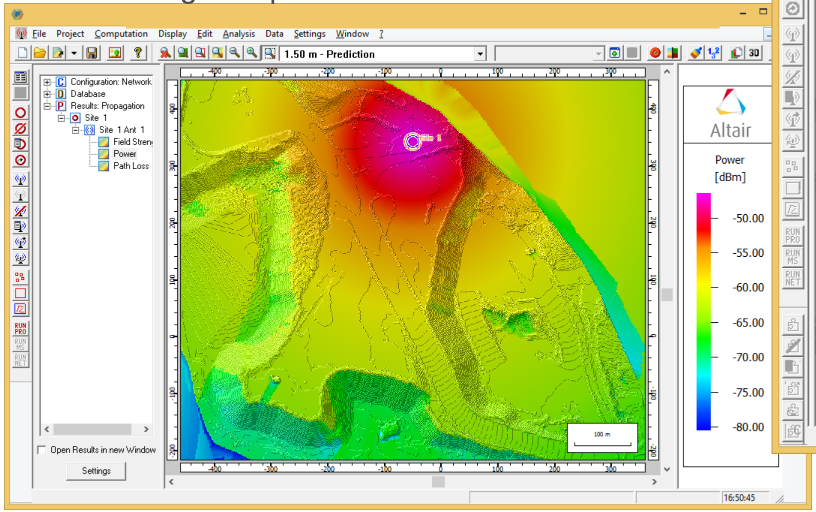
- Comparison of different deployment options using key performance indicators
- Omni and/or directional Tx antennas for stations and tunnels
- Optional usage of leaky feeder cables for tunnels (especially for TETRA in worst case scenario)
- Transmitter deployment and radio planning simulation in ProMan
- Evaluation of simulation results using the statistic features (CDF/PDF) in ProMan for the different air interfaces (LTE, TETRA, WiFi) and scenarios (station and tunnel)

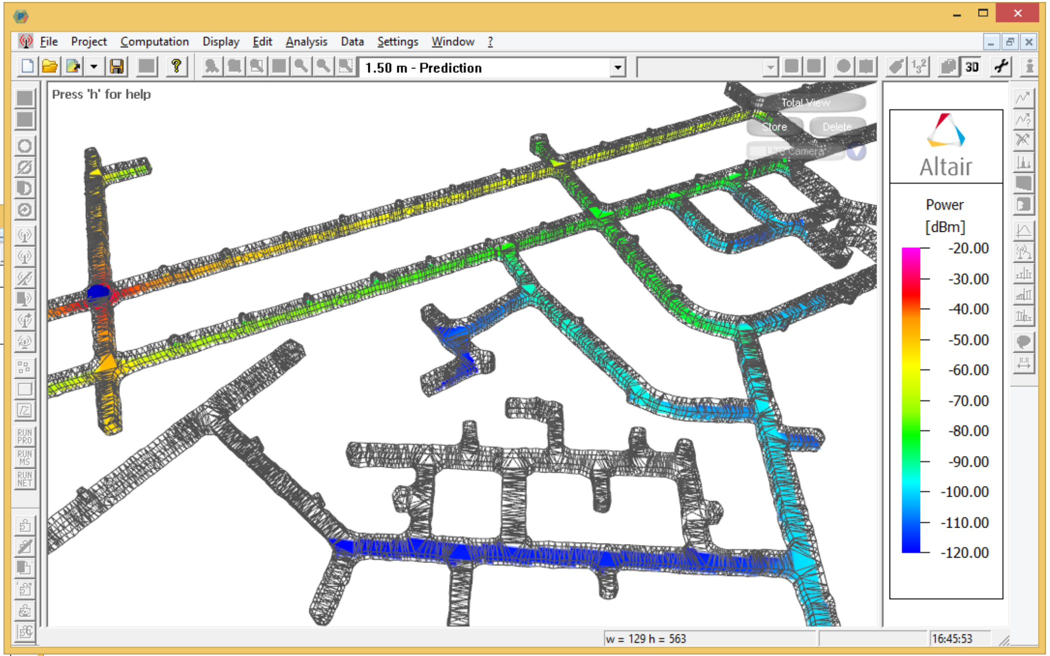
Radio coverage	Station	Tunnel
Wireless cellular service LTE	100% above -95 dBm	80% above -95 dBm
Emergency service TETRA	100% above -95 dBm	98% above -95 dBm
WiFi 802.11ac	99% above -75 dBm	61% above -75 dBm

MINING SCENARIOS

Open / Underground Scenarios

- Convert map data (topography / tunnels / obstacles)
- Usage of dominant path model (DPM)
- Use cases:
  - Radio coverage analysis
  - Planning of repeaters



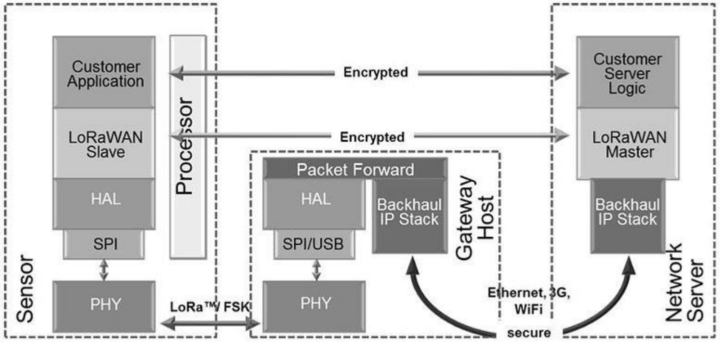


INDUSTRIAL SCENARIOS

RADIO PLANNING FOR IOT

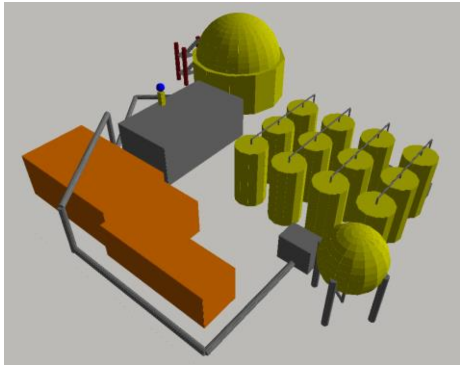
IoT wireless sensor networks based on LoRa / LPWAN

- LoRaWAN is a Low Power Wide Area Network (LPWAN) specification intended for wireless battery operated sensors (LoRa stands for long range)
- LoRaWAN specification allows secure bi-directional communication and provides seamless interoperability among smart things
- LoRaWANs typically laid out in a star-of-stars topology
- Gateways relaying messages between end-devices and a central server
- Gateways are connected to the network server via standard IP connections
- End-devices use single-hop wireless communication to one or many gateways



Source:

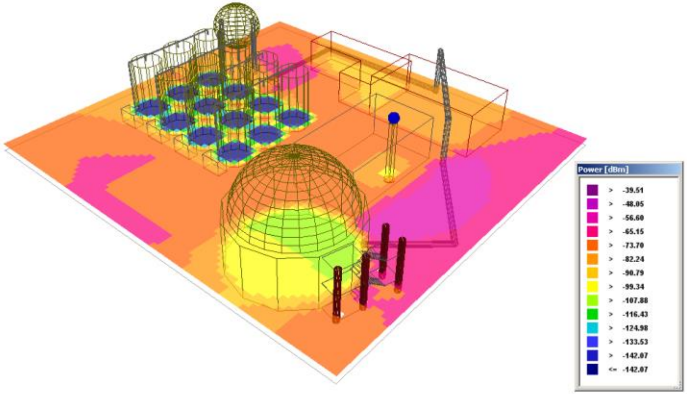
LoRa Alliance™
Wide Area Networks for IoT

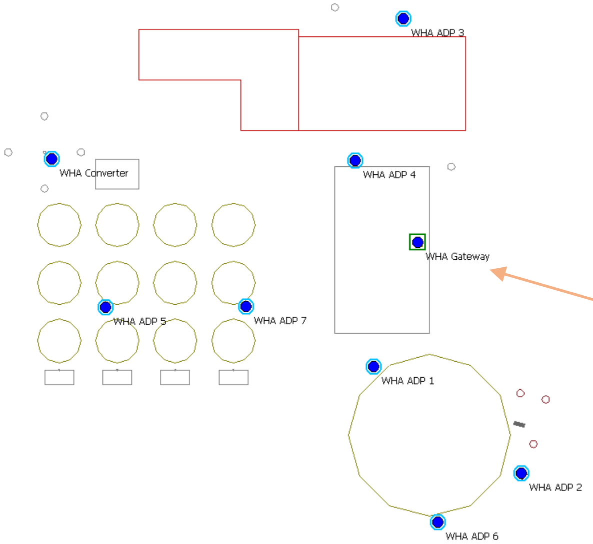


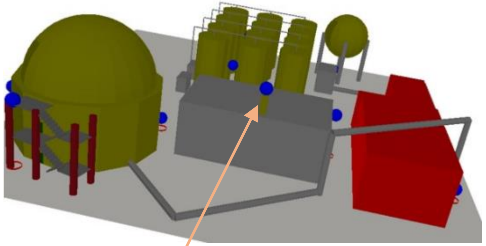
INDUSTRIAL SCENARIOS

Wireless Sensors (IoT): Planning of Sensor Networks

- Monitoring of processes and constructions (assembly lines, industrial automation, environment, …)
- Distribution or placement of sensor nodes
- Path loss computation between nodes depending on scenario (rural / urban / indoor)
- Connectivity analysis
- WirelessHart, ZigBee, LoRa







Gateway

CONCLUSIONS

CONCLUSIONS

Radio Coverage Planning for Heterogeneous Wireless Networks, Including 5G

- Feko & WinProp offer **highly accurate modeling of the antenna and the radio channel**
- For **all types of environments**: rural, suburban, urban, indoor, tunnel, station buildings, airports, stadiums, industrial, mining, factories, production halls, …
- **All air interfaces / radio networks** of interest (incl. 5G, LTE, TETRA, PMR, WiFi, Broadcasting)
- **Wide frequency range** (100 MHz up to 100 GHz)
- **Material catalogue** with properties for typical construction materials
- Evaluate different **deployment strategies**
- **Virtual-drive tests** for the evaluation of the **installed antenna performance** (3D antenna patterns computed in Feko)
- **Substitution of measurement campaigns** by simulations (better reproducibility, reduced effort, lower costs)
- Analyze interference between different radio systems (**co-existence** studies)

WINPROP DEMO

Thank You for Your Attention!

http://www.altairhyperworks.com/winprop