# 5G Boot Camp

**PART FOUR:**
**Charactering 5G channel**

*Keysight Technologies*

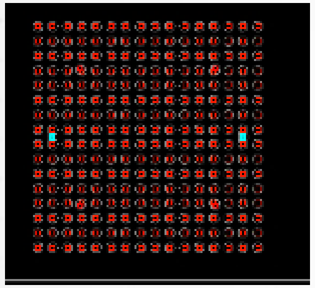
***NOV. 2019***

*Stephen Chiu / GM of ESBI Technologies*

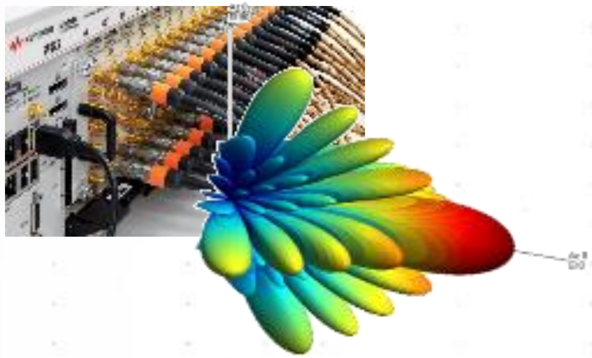
KEYSIGHT TECHNOLOGIES

# 7 Key Measurement Challenges

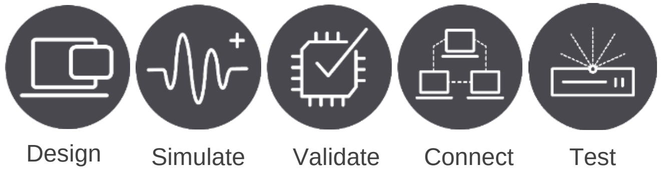
**Signal Quality**
*mmW, Waveform, Fidelity*



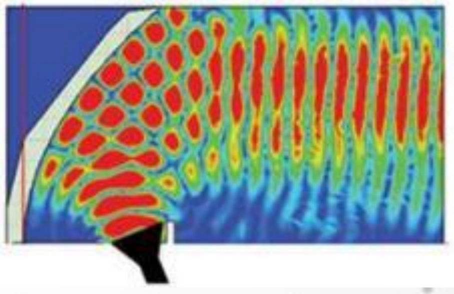
**Lots of Channels**
*MIMO/Beamforming*



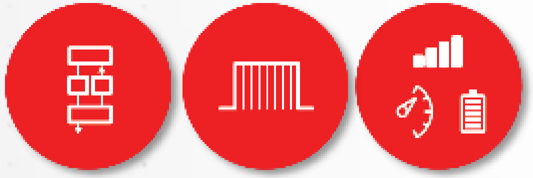
**Connect Design & Test**
*Components, Systems*




**Life Beyond Connectors**
*Over-the-Air*

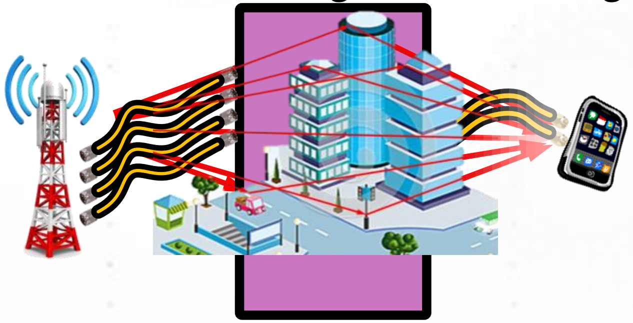


**Performance on the Network**
*Network Emulation*



*Protocol R&D*
*RF / RRM DVT*
*Functional KPI*

**Channel**
*Characterizing & Emulating*



**Field Testing and Drive Test**

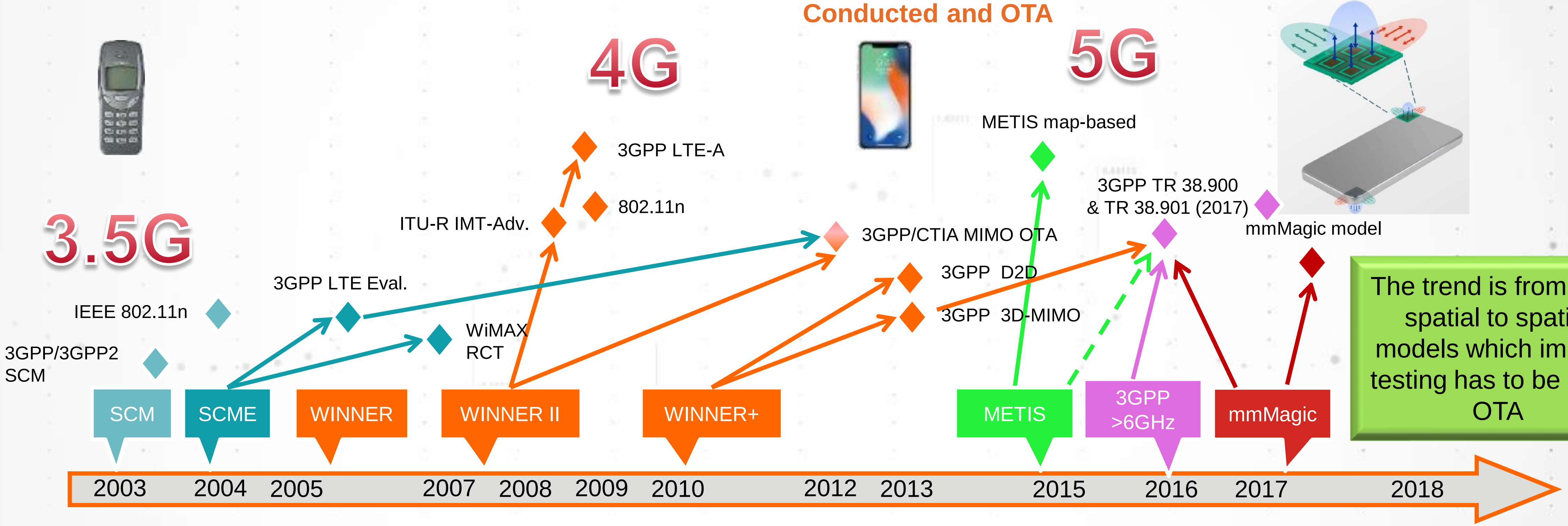
# The evolution of channel models

**2G: 3GHz, 200KHz BW**
**Non-spatial TDL.**
**Conducted**

**3G: 3GHz, 5MHz BW**
**Non-spatial TDL.**
**Conducted**

**4G: 6GHz, 20MHz BW**
**Non-spatial TDL.**
**SCME CDL, 3D MIMO**
**Conducted and OTA**

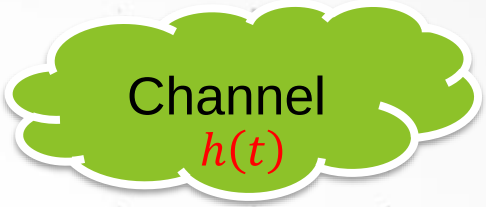
**5G: 100GHz, 1GHz BW**
**3D, Spatial GSCM / CDL.**
**Conducted and OTA FR1 and FR2**

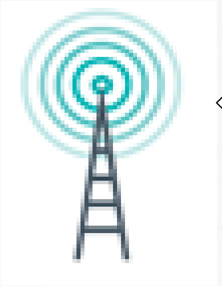



The trend is from non-spatial to spatial models which implies testing has to be done OTA

- PROPSIM team (previosuly Elektrobit) have led the development of the theory & practice of channel modeling.
- Today, we are considered the authority in the area of Spatial Channel Models.
- Anite (now part of Keysight) was appointed to lead the radio channel modelling Task Group within the METIS project.
- TDL - Tapped delay line (time only), CDL – Cluster delay line (time and space), SCME – Spatial channel model extended

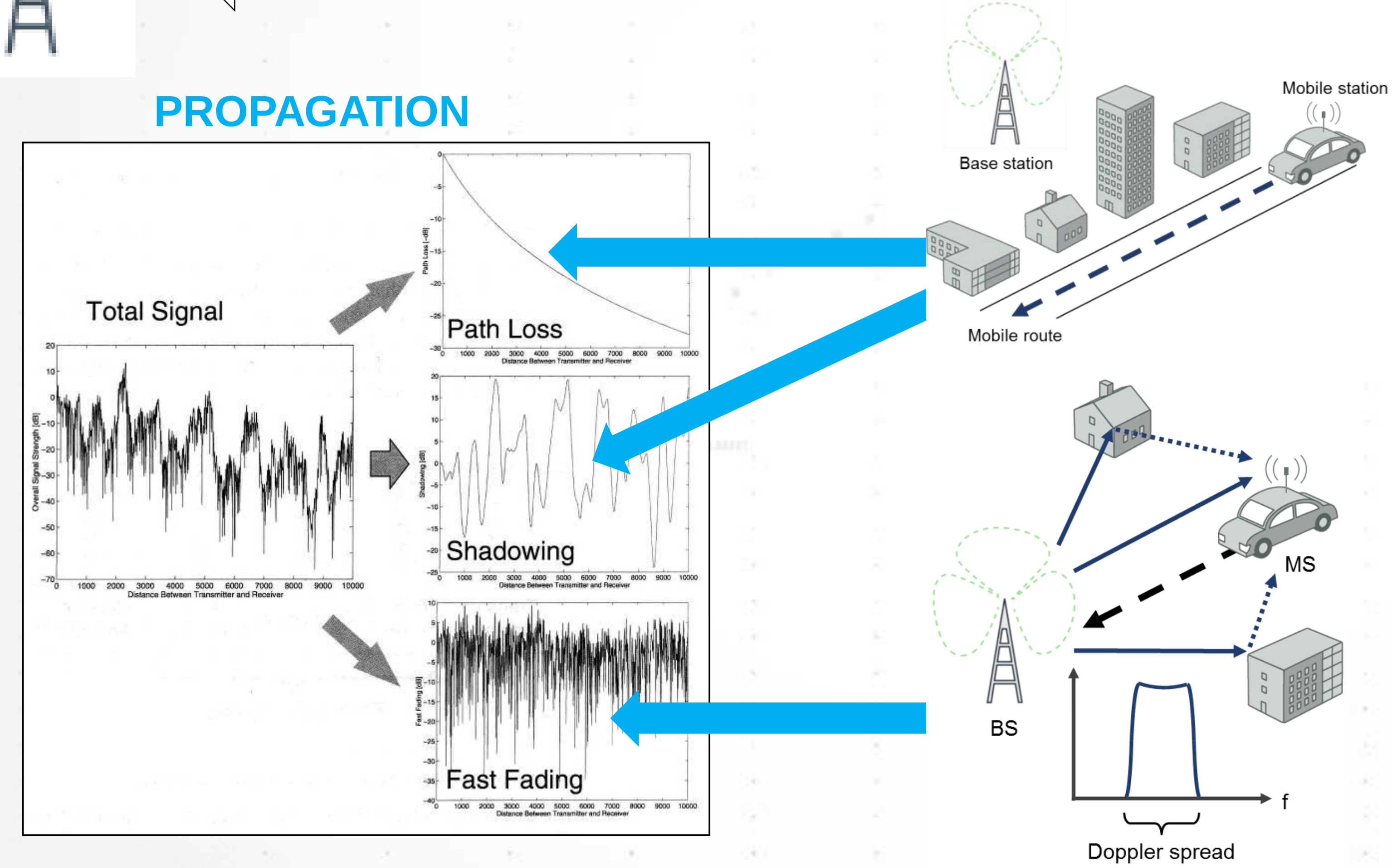
# What is the Radio Channel?



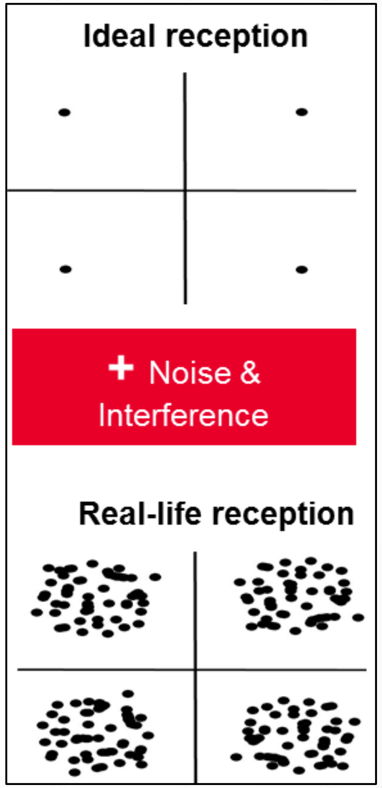



**Radio Channel** = Propagation path between Tranceivers =>
Antenna beam pattern * Multipath Propagation * Mobility + Interference

## PROPAGATION




## INTERFERENCE




**Noise**

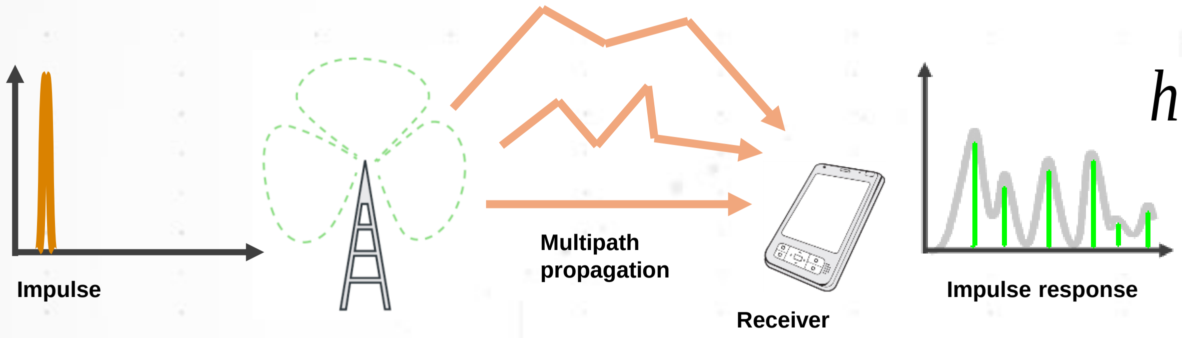
- Thermal Noise
- Broadband noise from PAs

**Adjacent cells/Users Modulated waveforms**

- Co-channel interference
- Adjacent channel interference

# Conventional SISO Channel Model

- Radio channel is characterized in two domains
  - Time & Frequency

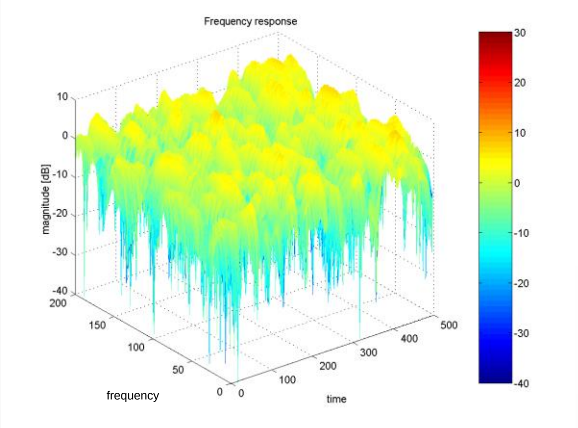



$$h(t) = \sum_{i=1}^{L} \beta_i(t) e^{j\phi_i(t)} \delta[\tau - \tau_i(t)]$$

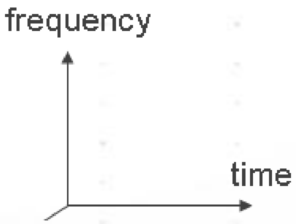
Path attenuation

Path phase

Path delay




delay spread ⇔ frequency selectivity (coherence bandwidth)



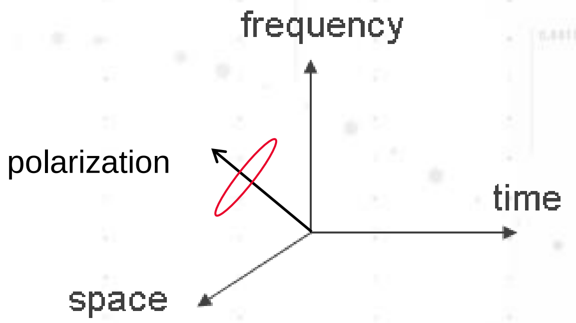

Doppler spread ⇔ time selectivity (coherence time)

# Extension to MIMO Channel model

$$H_{u,s,n}(t;\tau)=\sum_{m=1}^{M}\begin{bmatrix}F_{rx,u,V}(\varphi_{n,m})\\ F_{rx,u,H}(\varphi_{n,m})\end{bmatrix}^{T}\begin{bmatrix}\alpha_{n,m,VV} & \alpha_{n,m,VH}\\ \alpha_{n,m,HV} & \alpha_{n,m,HH}\end{bmatrix}\begin{bmatrix}F_{tx,s,V}(\phi_{n,m})\\ F_{tx,s,H}(\phi_{n,m})\end{bmatrix}$$
$$\times\exp\left(j2\pi\lambda_0^{-1}(\bar{\varphi}_{n,m}\cdot\bar{r}_{rx,u})\right)\exp\left(j2\pi\lambda_0^{-1}(\bar{\phi}_{n,m}\cdot\bar{r}_{tx,s})\right)$$
$$\times\exp\left(j2\pi\upsilon_{n,m}t\right)\delta(\tau-\tau_{n,m})$$

- Radio channel = Tx antenna + propagation + Rx antenna
- Radio channel is characterized in four domains
  - Time
  - Frequency
  - Space
  - Polarization
- Mobile radio channel will cause dispersion and time variability in all dimensions

delay spread ⇔ frequency selectivity (coherence bandwidth)




Doppler spread ⇔ time selectivity (coherence time)

angle spread ⇔ spatial selectivity (coherence distance)

➢ azimuth, elevation

# 5G 3D Channel Models

## 3GPP TR 36.873 FOR ELEVATION BEAMFORMING AND FD-MIMO

### Channel matrix:

$$\mathbf{H}_{u,s}(t) = \sum_{n=1}^{N}\sum_{m=1}^{M} \mathbf{F}_u^T(\Omega_{n,m}^{rx})\,\mathbf{h}_{n,m}(t)\,\mathbf{F}_s(\Omega_{n,m}^{tx})\exp(j2\pi\upsilon_{n,m}t),$$

### Antenna field patterns of MS and BS:

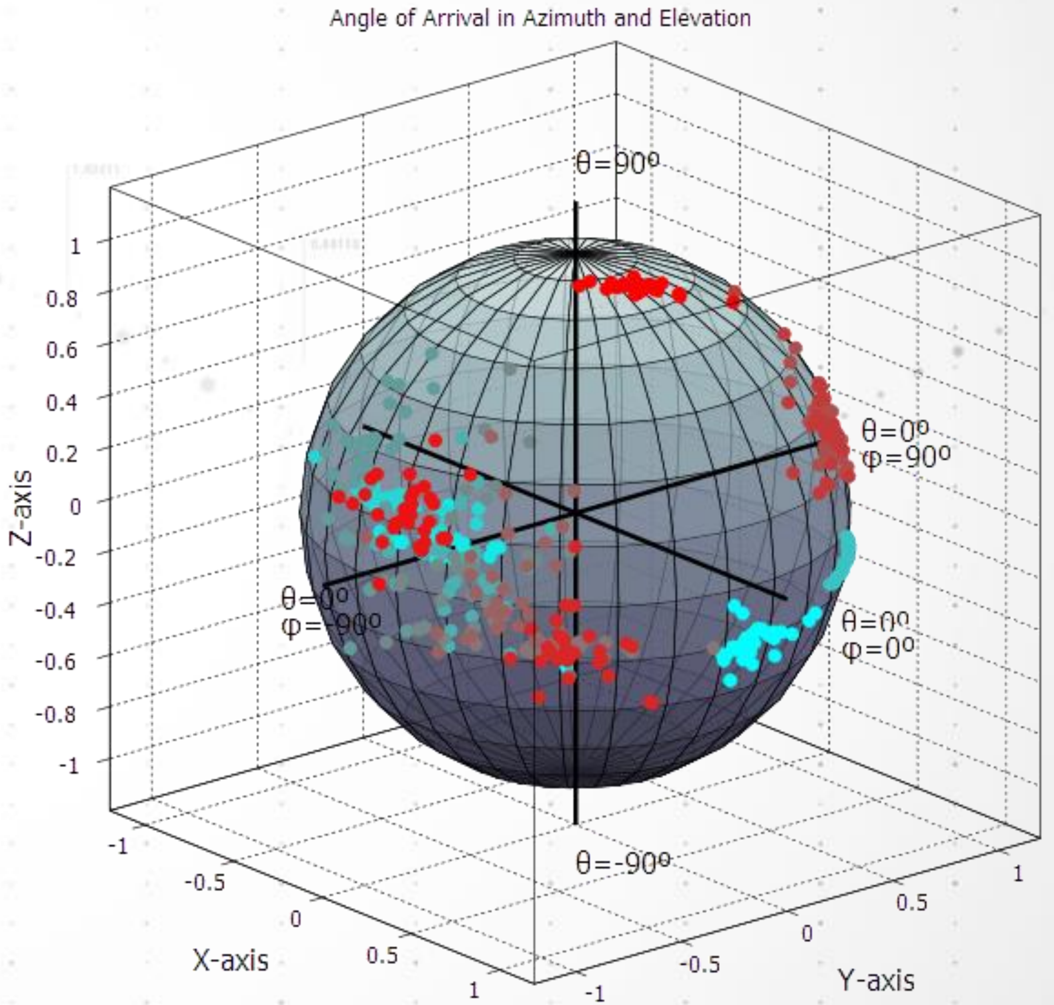
$$\mathbf{F}_s(\Omega_{n,m}^{tx}) = \begin{bmatrix} F_s^v(\varphi_{n,m}^{AoD}, \vartheta_{n,m}^{AoD}) \\ F_s^h(\varphi_{n,m}^{AoD}, \vartheta_{n,m}^{AoD}) \end{bmatrix} \quad \mathbf{F}_u(\Omega_{n,m}^{rx}) = \begin{bmatrix} F_u^v(\varphi_{n,m}^{AoA}, \vartheta_{n,m}^{AoA}) \\ F_u^h(\varphi_{n,m}^{AoA}, \vartheta_{n,m}^{AoA}) \end{bmatrix}$$

### Propagation matrix:

$$\mathbf{h}_{n,m}(t) = \begin{bmatrix} \exp\left(j\Phi_{n,m}^{vv}\right) & \sqrt{\left(\kappa_{n,m}^{V}\right)^{-1}}\exp\left(j\Phi_{n,m}^{vh}\right) \\ \sqrt{\left(\kappa_{n,m}^{H}\right)^{-1}}\exp\left(j\Phi_{n,m}^{hv}\right) & \exp\left(j\Phi_{n,m}^{hh}\right) \end{bmatrix}$$

### Doppler term:

$$\upsilon_{n,m} = \frac{\left|\bar{v}\right|\left(\cos(\alpha_v - \varphi_{n,m}^{AoA})\cos\vartheta_{n,m}^{AoA}\cos\gamma_v + \sin\vartheta_{n,m}^{AoA}\sin\gamma_v\right)}{\lambda_0},$$



# Geometry based stochastic channel model

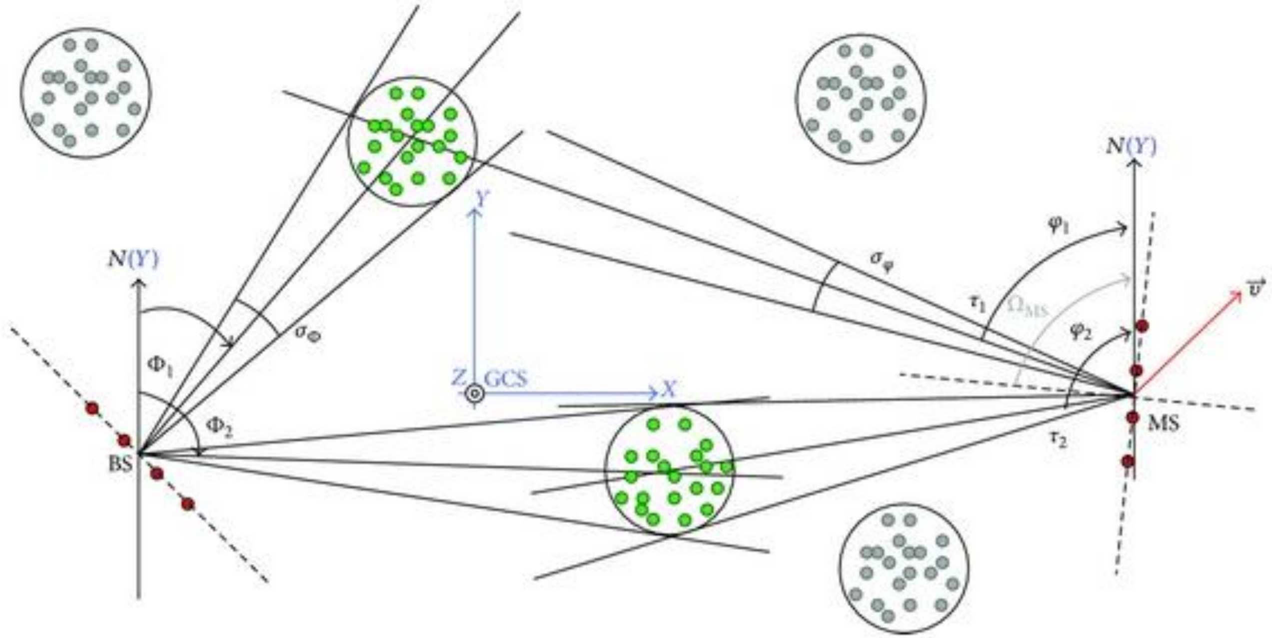
## DESCRIPTION OF THE METHOD

Agular definitions based on a global coordinate system (3D)

Multipaths modeled as clusters with spatial parametrization

Clusters consist of reflectors /rays that create angular spreads

Supports separation of propagation parameters and antennas




System level model defines cluster parameters with distributions

CDL models uses fixed set of table parameters instead of distribution based random values

MS and BS end cluster angles are independent I.e. the model does not solve paths between MS and BS

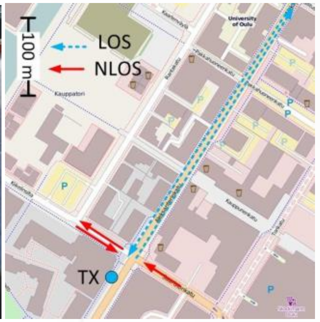
# METIS 5G Measurement Campaigns 2.3 & 5.25GHz

## REFERENCE: METIS CHANNEL MODEL

ME1: Urban Vehicle to Vehicle (SIMO)

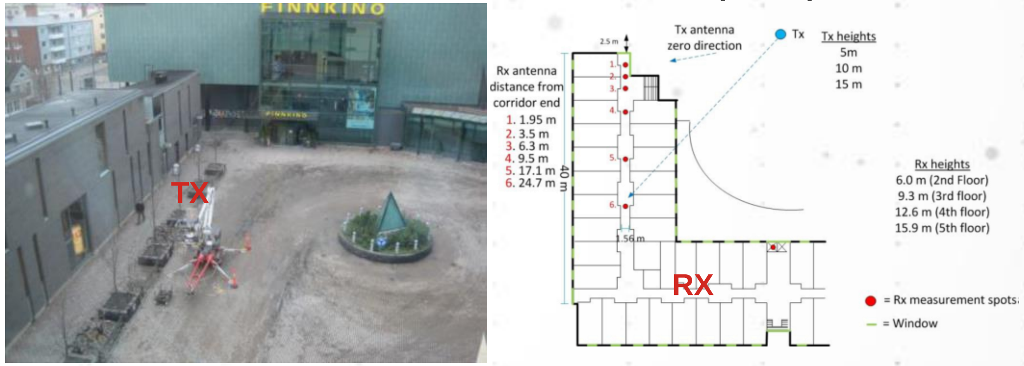

ME2: Urban Macro cell Outdoor (O2O)

ME5: Urban microcell outdoor (MIMO)

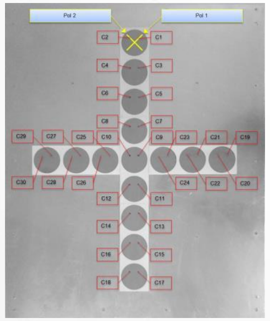



ME3: Urban Macro cell Outdoor to Indoor (MIMO)


ME4: Urban microcell outdoor-to-indoor (MIMO)




TX Antenna




RX Antenna

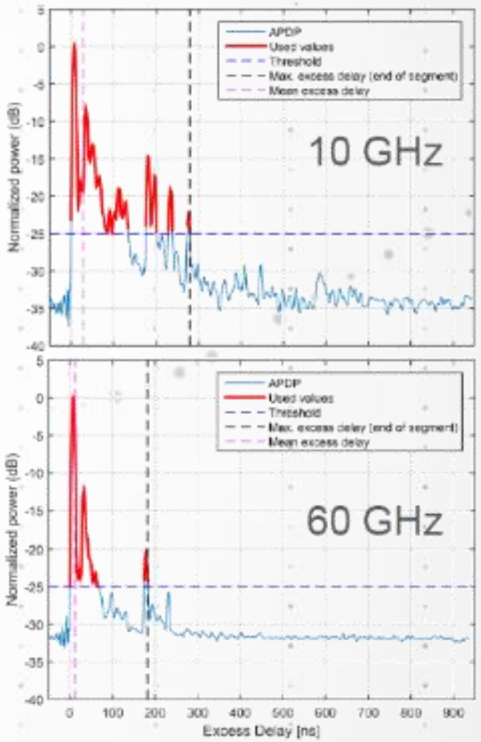

Figure A-35: Measurement equipment: transmitter (left) and receiver (right).

# METIS 5G Measurement Campaigns mm-Wave

## REFERENCE: METIS CHANNEL MODEL

Office, 60 GHz


Path Loss 26 GHz

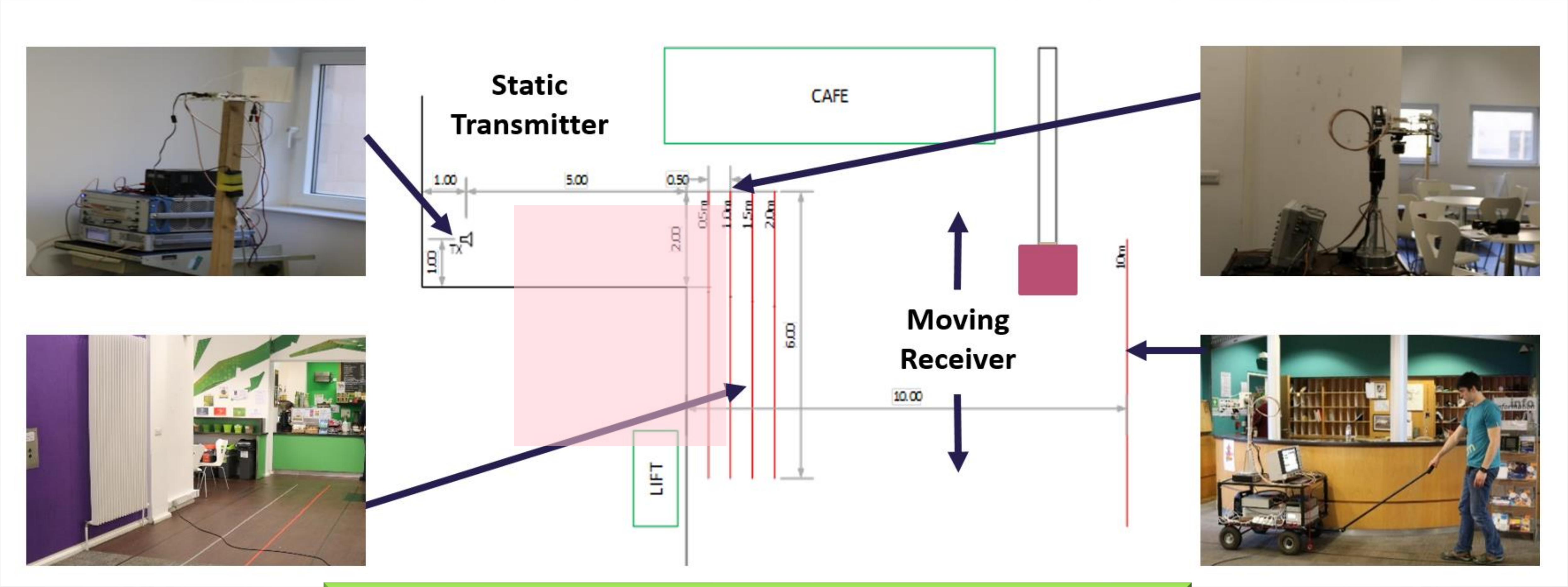




Shopping Mall 60 GHz

# What about the Channel at mmWave?

## CORNER DIFFRACTION STUDY

ftp.3gpp.org/tsg_ran/WG1_RL1/TSGR1_84b/Docs/R1-162872.zip




How well do 60 GHz signals bend round corners?

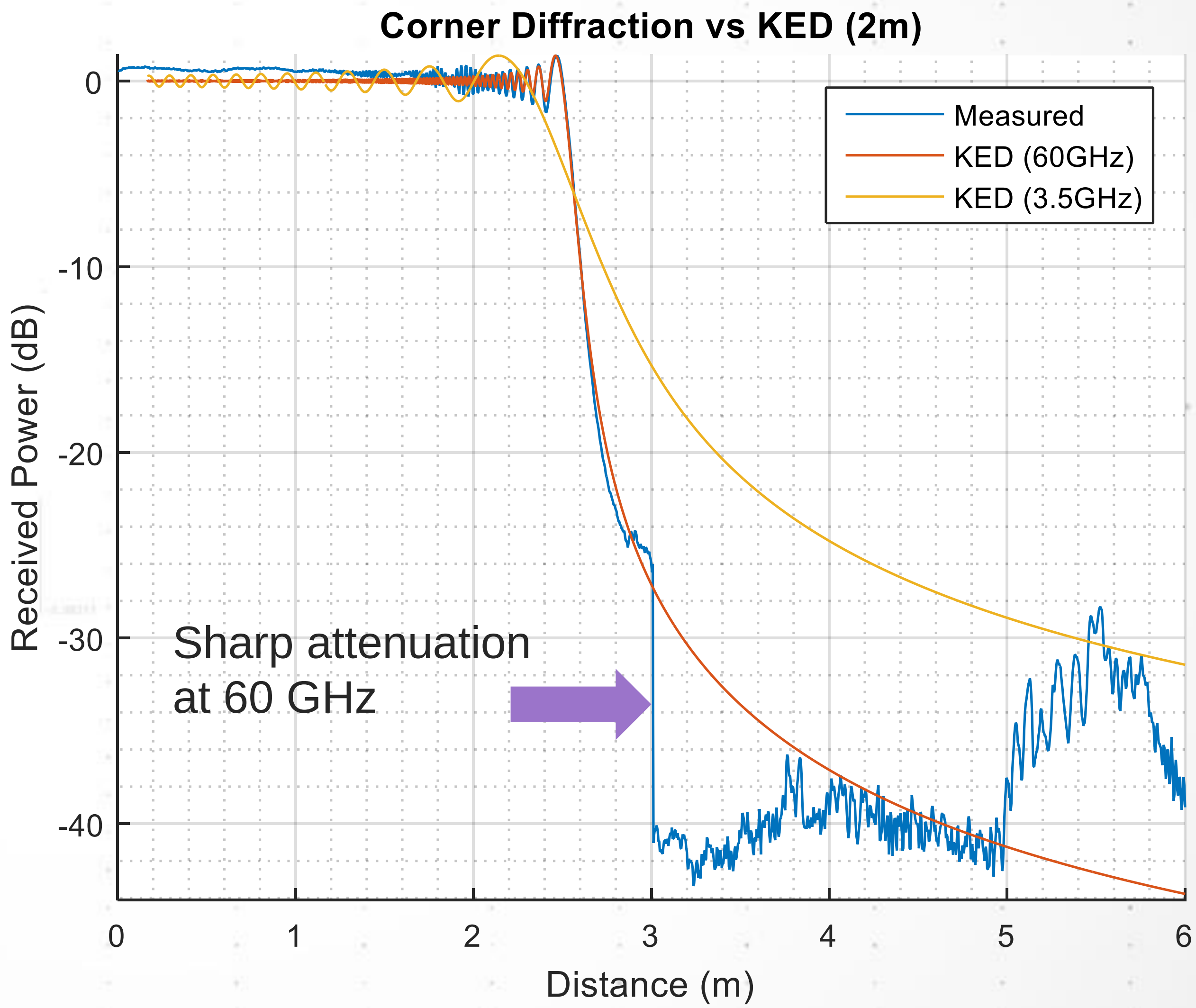
# Simulated vs. measured at 3.5 GHz and 60 GHz

## CORNER DIFFRACTION STUDY

AT 3.5 GHZ THE SHADOW EFFECT IS MUCH LESS PRONOUNCED

EVEN AT 2M DISTANCE WITH 40CM OF TRAVEL:

- 60 GHZ IS AT -25 DB
- 3.5 GHZ IS AT -8 DB




KED: Knife Edge Diffraction

# Simultaneous tests of 10 & 60GHz Outdoor Channels

## REFERENCE: METIS CHANNEL MODEL

- Consistent delays of dominant propagation paths, while less multi-paths were observed at 60 GHz

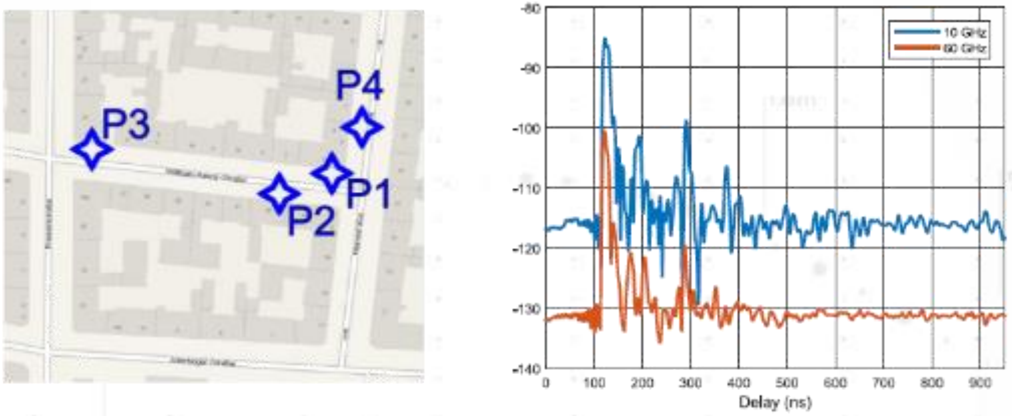



**Figure 5-11: Location map (left), APDP in dBm for LOS measurement from P1 to P2 (right).**

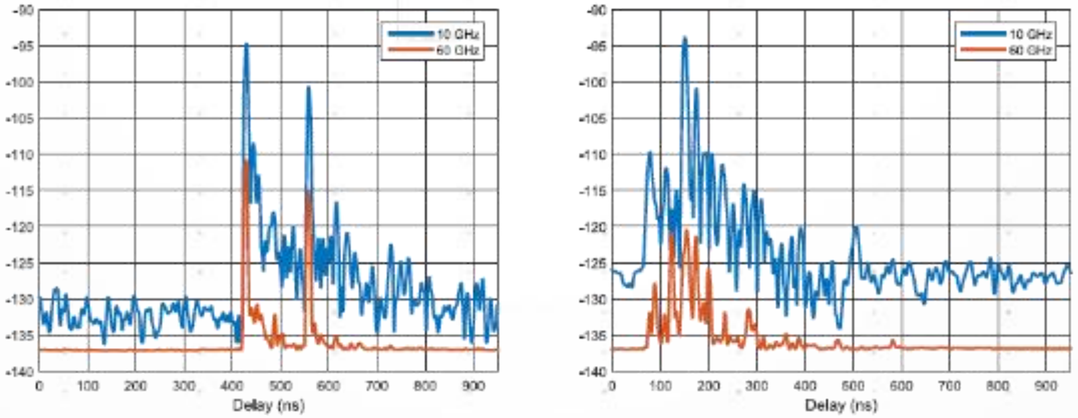
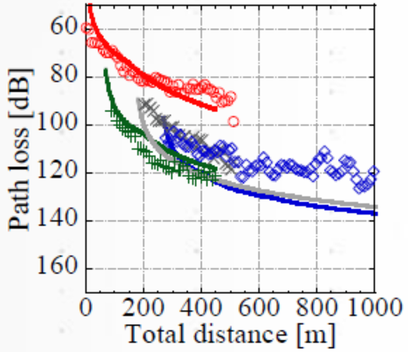



**Figure 5-12: APDPs in dBm for LOS measurement from P3 to P1 (left) and NLOS measurement from P1 to P4 (right).**

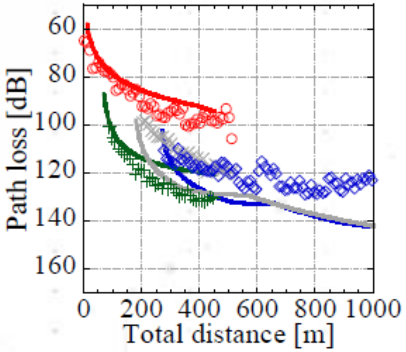
# Comparison of measurement and M.2135 results.

## REFERENCE: METIS CHANNEL MODEL

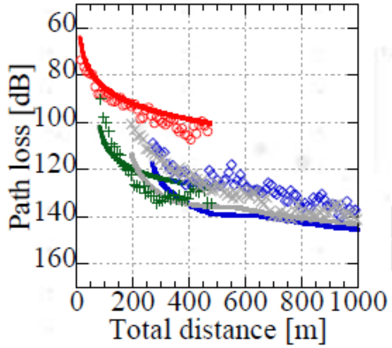
- ITU M.2135 path loss model shows decent matching with measurements in LOS environments even above the designed frequency of 6 GHz



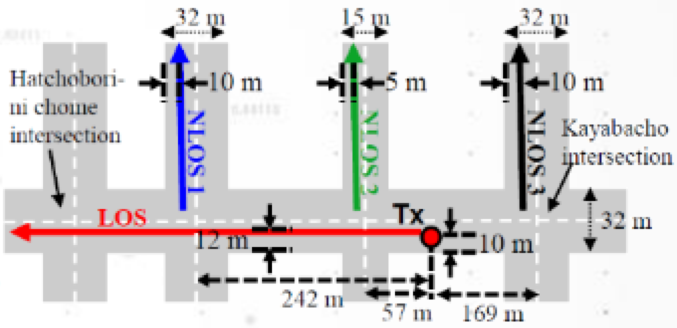

(a) 800 MHz

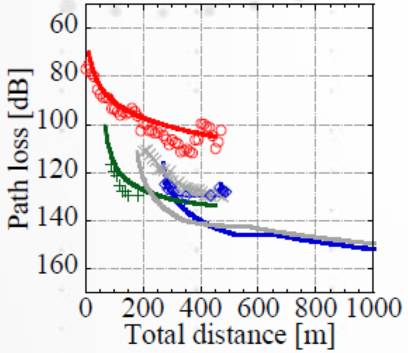



(b) 2.2 GHz

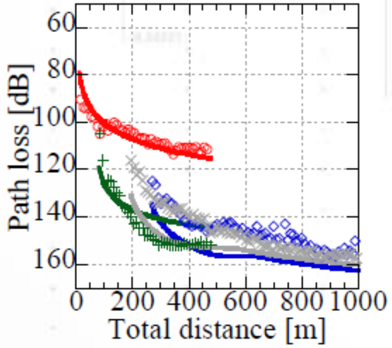



(c) 4.7 GHz

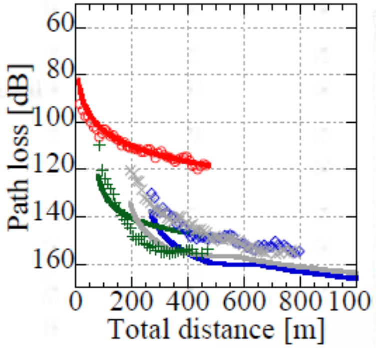



(d) 8.45 GHz




(e) 26 GHz

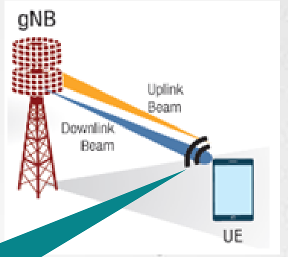



(f) 37 GHz

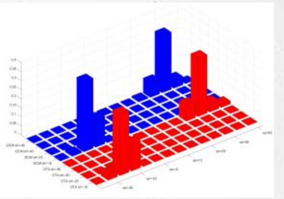
Legend

| | LOS | NLOS1 | NLOS2 | NLOS3 |
|---|---|---|---|---|
| M. 2135 | red-solid | blue-solid | green-solid | gray-solid |
| Measurement | ○ red-circle | ◊ blue-diamond | + green-plus | × gray-cross |

# 5G Challenge: Highly Dynamic Fading Channel in Field – connected state UE mobility

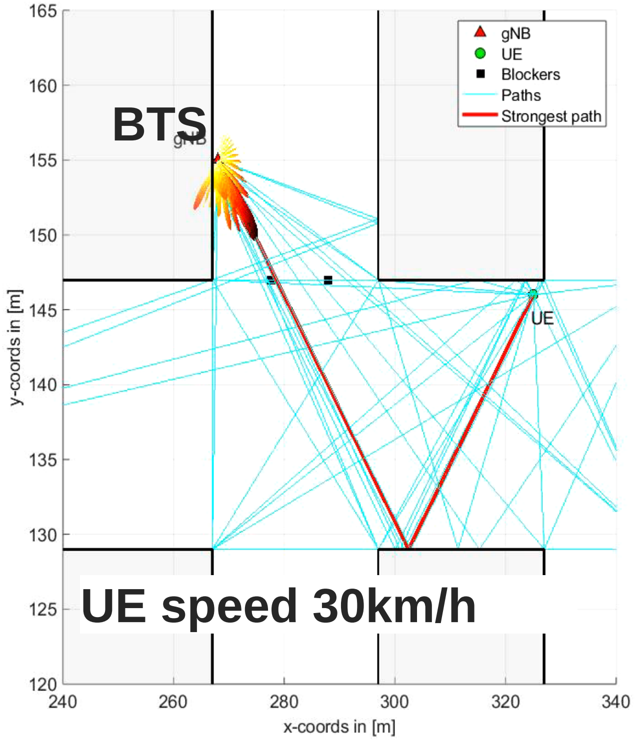


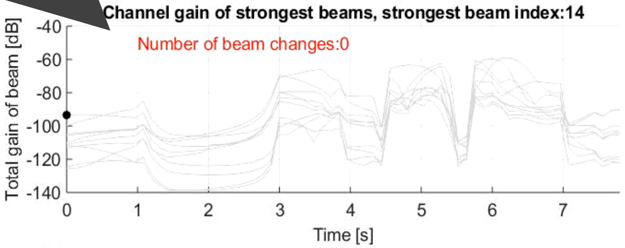

**Where is my next Beam?**
Fast & reliable beam management needed

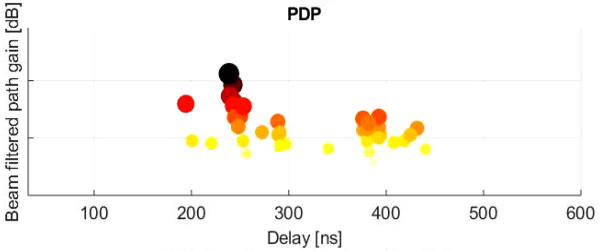


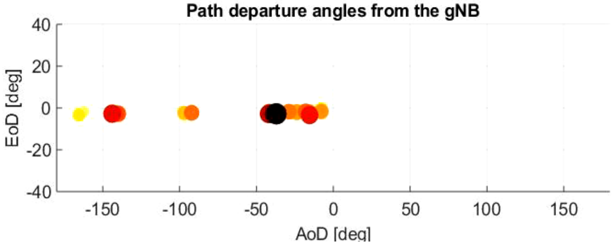
Fast fading filtered out on gain curves to have clearer visual

- BTS and UE(s) need to have seamless interoperability on beam refinement and change, and eventually handover to next cell and/or fallback to LTE
- Highly blocking channel conditions – high probability on link collapse - how to mitigate?




**Fading Cluster AoD's are dynamic**

Click video

# 3GPP TR 38.901 - Stochastic model overview

## CHANNEL MODEL FOR UP TO 100 GHZ

- **Extended from existing sub-6 GHz channel models:** 3D MIMO model (3GPP TR 36.873) or IMT-Advanced (ITU-R M.2135).
- Developed for **performance evaluations of 5G physical layer techniques**
- Designed to cover testing of both **Mobile Equipment and Access Network of 3GPP systems**
- **Supported scenarios are urban microcell street canyon, urban macro cell, indoor office, and rural macro cell**
- Key properties of the models
  - **Frequency range from 0.5 to 100 GHz**
  - **Bandwidth is supported up to 10% of the center frequency but no larger than 2 GHz**
  - **Spatial** consistency is supported
  - System-level, Link-level CDL-models and non-spatial TDL-models

| Channel Model and Scenario | Description | LOS | NLOS |
|---|---|---|---|
| 3GPP 5G 38.901 UMi CDL-A | [11] | - | √ |
| 3GPP 5G 38.901 UMi CDL-B | [11] | - | √ |
| 3GPP 5G 38.901 UMi CDL-C | [11] | - | √ |
| 3GPP 5G 38.901 UMi CDL-D | [11] | √ | - |
| 3GPP 5G 38.901 UMi CDL-E | [11] | √ | - |
| 3GPP 5G 38.901 UMi O2I | [11] | - | √ |
| 3GPP 5G 38.901 UMi O2I CDL-A | [11] | - | √ |
| 3GPP 5G 38.901 UMi O2I CDL-B | [11] | - | √ |
| 3GPP 5G 38.901 UMi O2I CDL-C | [11] | - | √ |
| 3GPP 5G 38.901 UMa | [11] | √ | √ |
| 3GPP 5G 38.901 UMa CDL-A | [11] | - | √ |
| 3GPP 5G 38.901 UMa CDL-B | [11] | - | √ |
| 3GPP 5G 38.901 UMa CDL-C | [11] | - | √ |
| 3GPP 5G 38.901 UMa CDL-D | [11] | √ | - |
| 3GPP 5G 38.901 UMa CDL-E | [11] | √ | - |
| 3GPP 5G 38.901 UMa O2I | [11] | - | √ |
| 3GPP 5G 38.901 UMa O2I CDL-A | [11] | - | √ |
| 3GPP 5G 38.901 UMa O2I CDL-B | [11] | - | √ |
| 3GPP 5G 38.901 UMa O2I CDL-C | [11] | - | √ |
| 3GPP 5G 38.901 RMa | [11] | √ | √ |
| 3GPP 5G 38.901 RMa CDL-A | [11] | - | √ |
| 3GPP 5G 38.901 RMa CDL-B | [11] | - | √ |
| 3GPP 5G 38.901 RMa CDL-C | [11] | - | √ |
| 3GPP 5G 38.901 RMa CDL-D | [11] | √ | - |
| 3GPP 5G 38.901 RMa CDL-E | [11] | √ | - |
| 3GPP 5G 38.901 InO | [11] | √ | √ |
| 3GPP 5G 38.901 InO CDL-A | [11] | - | √ |
| 3GPP 5G 38.901 InO CDL-B | [11] | - | √ |
| 3GPP 5G 38.901 InO CDL-C | [11] | - | √ |
| 3GPP 5G 38.901 InO CDL-D | [11] | √ | - |
| 3GPP 5G 38.901 InO CDL-E | [11] | √ | - |

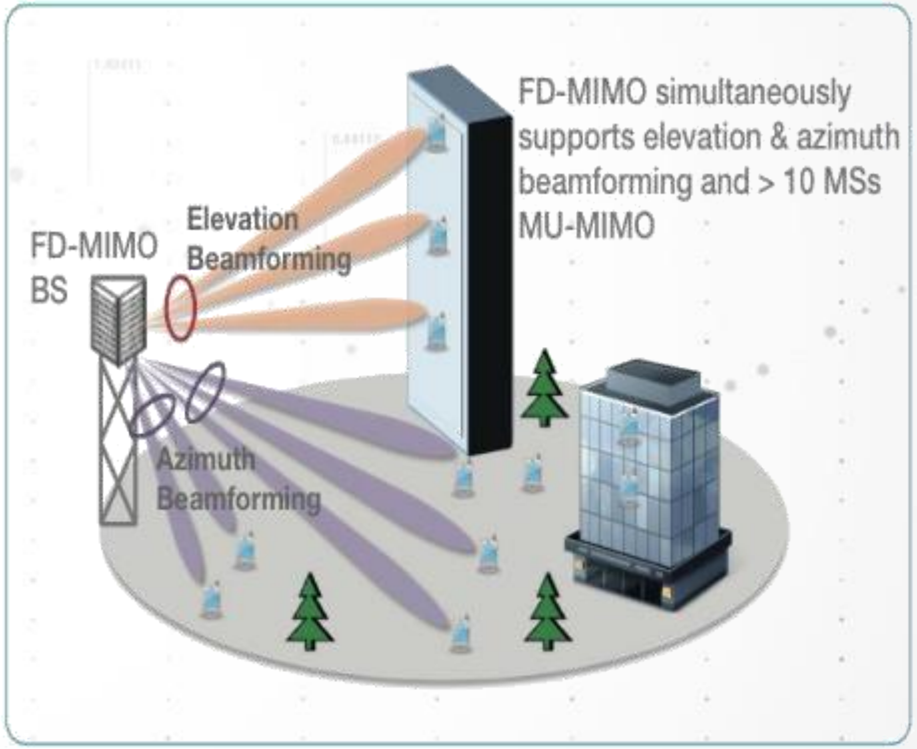
**LOS / NLOS**

# 5G Channel Models

## 3GPP 36.873 AND 38.901

- 3GPP 36.873
  - **3D Spatial** channel model for Elevation Beamforming and **FD-MIMO**. (Full Dimensions)
  - Applicable 2 to 6GHz.

- 3GPP 38.901
  - Aligned with earlier channel models for <6 GHz such as the 3D SCM model (3GPP TR 36.873) or IMT-Advanced (ITU-R M.2135).
  - **3D Spatial Channel model**(s) for frequencies from **0.5GHz up to 100GHz**.



# 3GPP TR 38.901 – 0.5 to 100 GHz

## SCENARIOS OF INTEREST

- **UMi** (Street canyon, open area) with O2O and O2I:3D scenario, where the BSs are mounted below rooftop levels of surrounding buildings.
  - Example: [Tx height:10m, Rx height: 1.5-2.5 m,  ISD: 200m]
- **UMa with O2O and O2I**:3D scenario, where the BSs are mounted above rooftop levels of surrounding buildings.
  - Example: [Tx height:25m, Rx height: 1.5-2.5 m,  ISD: 500m]
- **Indoor**: office environments, and shopping malls, In-H.
  - Example: [Tx height: 2-3m, Rx height: 1.5m, area:  500 square meters]
- **Backhaul**: including outdoor above roof top backhaul in urban area and street canyon scenario where small cell BSs are placed at lamp posts.
- **D2D/V2V**: In open area, street canyon, and indoor scenarios
- Other scenarios such as Stadium (open-roof) and Gym (close-roof).

# 3GPP TR 38.901

## MODELLING OBJECTIVES

- Support frequency range up to **100 GHz**.
  - The critical path of the SI is 6 – 100 GHz
  - Take care of mmW propagation aspects such as blocking and atmosphere attenuation.
- The model should be **consistent in space, time and frequency**.
- Support **large channel bandwidths** (2GHz, or up to 10% of carrier frequency).
- Aim for the channel model to cover a range of coupling loss considering current typical cell sizes, e.g. up to km-range macro cells. (**5G system** using higher frequency bands to **existing deployments**.)
- Accommodate **UT mobility**
  - Mobile speed up to **500 km/h**.
  - Develop a methodology considering that model extensions to **D2D and V2V** may be developed in future SI.
- Support **large antenna arrays** (Massive MIMO)

# Channel models for link-level evaluations

## CLUSTERED DELAY LINE (CDL) MODELS

- TR 38.901 specifies five different CDL channel profiles;
  - CDL-A, CDL-B and CDL-C are constructed for **NLOS**
  - CDL-D and CDL-E are constructed for **LOS**
- The RMS delay spread values of both CDL models are normalized and they can be scaled in delay for a desired RMS delay spread

**Table 7.7.1-2. CDL-B**

| Cluster # | Normalized delay | Power in [dB] | AOD in [°] | AOA in [°] | ZOD in [°] | ZOA in [°] |
|---|---|---|---|---|---|---|
| 1 | 0.0000 | 0 | 9.3 | -173.3 | 105.8 | 78.9 |
| 2 | 0.1072 | -2.2 | 9.3 | -173.3 | 105.8 | 78.9 |
| 3 | 0.2155 | -4 | 9.3 | -173.3 | 105.8 | 78.9 |
| 4 | 0.2095 | -3.2 | -34.1 | 125.5 | 115.3 | 63.3 |
| 5 | 0.2870 | -9.8 | -65.4 | -88 | | |
| 6 | 0.2986 | -1.2 | -11.4 | 155 | | |
| 7 | 0.3752 | -3.4 | -11.4 | 155 | | |
| 8 | 0.5055 | -5.2 | -11.4 | 155 | | |
| 9 | 0.3681 | -7.6 | -67.2 | -89 | | |
| 10 | 0.3697 | -3 | 52.5 | 132 | | |
| 11 | 0.5700 | -8.9 | -72 | -83 | | |
| 12 | 0.5283 | -9 | 74.3 | 95 | | |
| 13 | 1.1021 | -4.8 | -52.2 | 103 | | |
| 14 | 1.2756 | -5.7 | -50.5 | -87 | | |
| 15 | 1.5474 | -7.5 | 61.4 | -92 | | |
| 16 | 1.7842 | -1.9 | 30.6 | -13 | | |
| 17 | 2.0169 | -7.6 | -72.5 | -90 | | |
| 18 | 2.8294 | -12.2 | -90.6 | 58 | | |
| 19 | 3.0219 | -9.8 | -77.6 | -79 | | |
| 20 | 3.6187 | -11.4 | -82.6 | 65 | | |
| 21 | 4.1067 | -14.9 | -103.6 | 52 | | |
| 22 | 4.2790 | -9.2 | 75.6 | 88 | | |
| 23 | 4.7834 | -11.3 | -77.6 | -60 | | |

Per-Cluster Parameters

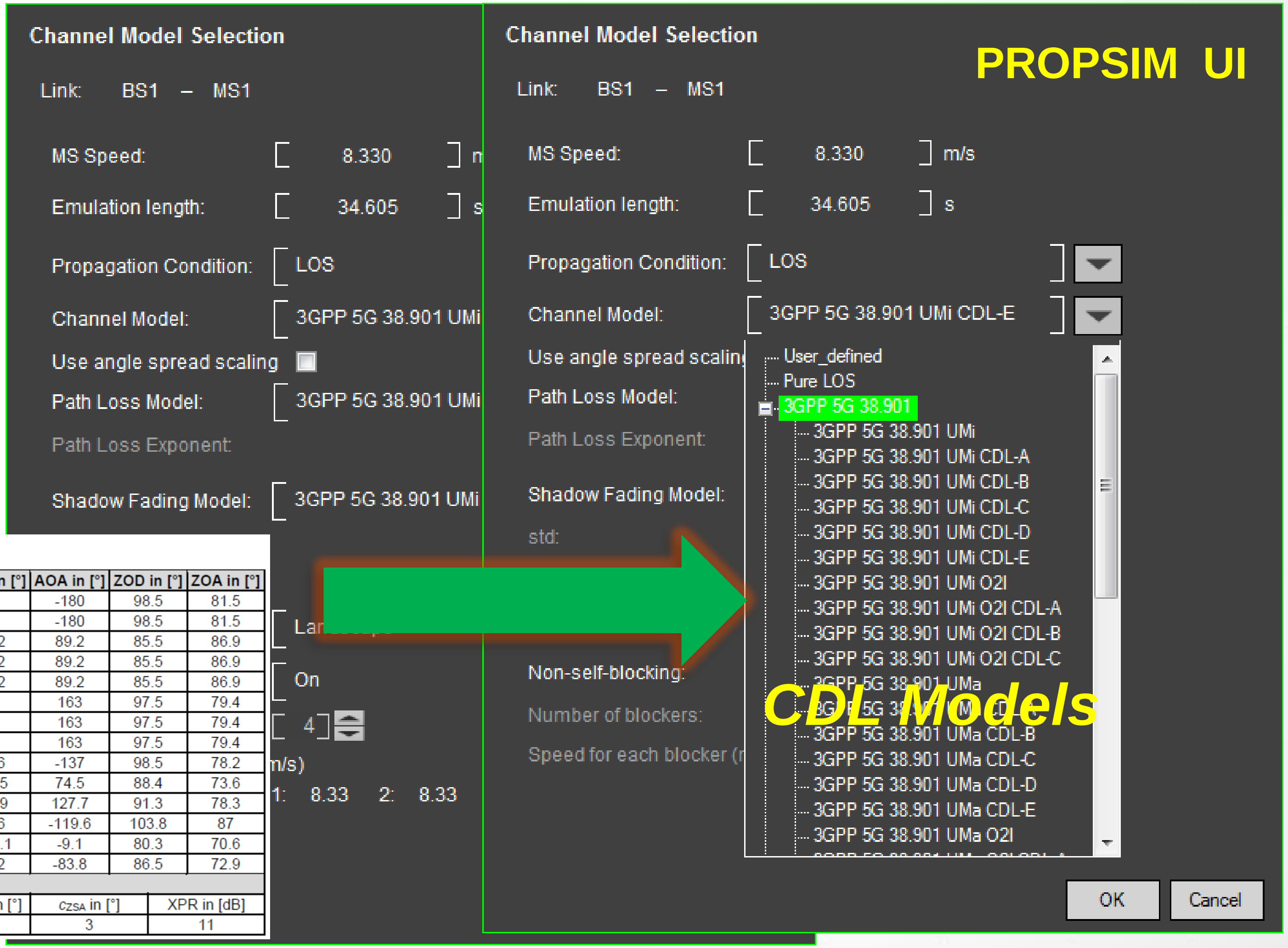
| Parameter | $c_{ASD}$ in [°] | $c_{ASA}$ in [°] | $c_{ZSD}$ in [°] |
|---|---|---|---|
| Value | 10 | 22 | 3 |

**Table 7.7.1-4. CDL-D.**

| Cluster # | Cluster PAS | Normalized Delay | Power in [dB] | AOD in [°] | AOA in [°] | ZOD in [°] | ZOA in [°] |
|---|---|---|---|---|---|---|---|
| 1 | Specular(LOS path) | 0 | -0.2 | 0 | -180 | 98.5 | 81.5 |
| | Laplacian | 0 | -13.5 | 0 | -180 | 98.5 | 81.5 |
| 2 | Laplacian | 0.035 | -18.8 | 89.2 | 89.2 | 85.5 | 86.9 |
| 3 | Laplacian | 0.612 | -21 | 89.2 | 89.2 | 85.5 | 86.9 |
| 4 | Laplacian | 1.363 | -22.8 | 89.2 | 89.2 | 85.5 | 86.9 |
| 5 | Laplacian | 1.405 | -17.9 | 13 | 163 | 97.5 | 79.4 |
| 6 | Laplacian | 1.804 | -20.1 | 13 | 163 | 97.5 | 79.4 |
| 7 | Laplacian | 2.596 | -21.9 | 13 | 163 | 97.5 | 79.4 |
| 8 | Laplacian | 1.775 | -22.9 | 34.6 | -137 | 98.5 | 78.2 |
| 9 | Laplacian | 4.042 | -27.8 | -64.5 | 74.5 | 88.4 | 73.6 |
| 10 | Laplacian | 7.937 | -23.6 | -32.9 | 127.7 | 91.3 | 78.3 |
| 11 | Laplacian | 9.424 | -24.8 | 52.6 | -119.6 | 103.8 | 87 |
| 12 | Laplacian | 9.708 | -30.0 | -132.1 | -9.1 | 80.3 | 70.6 |
| 13 | Laplacian | 12.525 | -27.7 | 77.2 | -83.8 | 86.5 | 72.9 |

Per-Cluster Parameters

| Parameter | $c_{ASD}$ in [°] | $c_{ASA}$ in [°] | $c_{ZSD}$ in [°] | $c_{ZSA}$ in [°] | XPR in [dB] |
|---|---|---|---|---|---|
| Value | 5 | 8 | 3 | 3 | 11 |

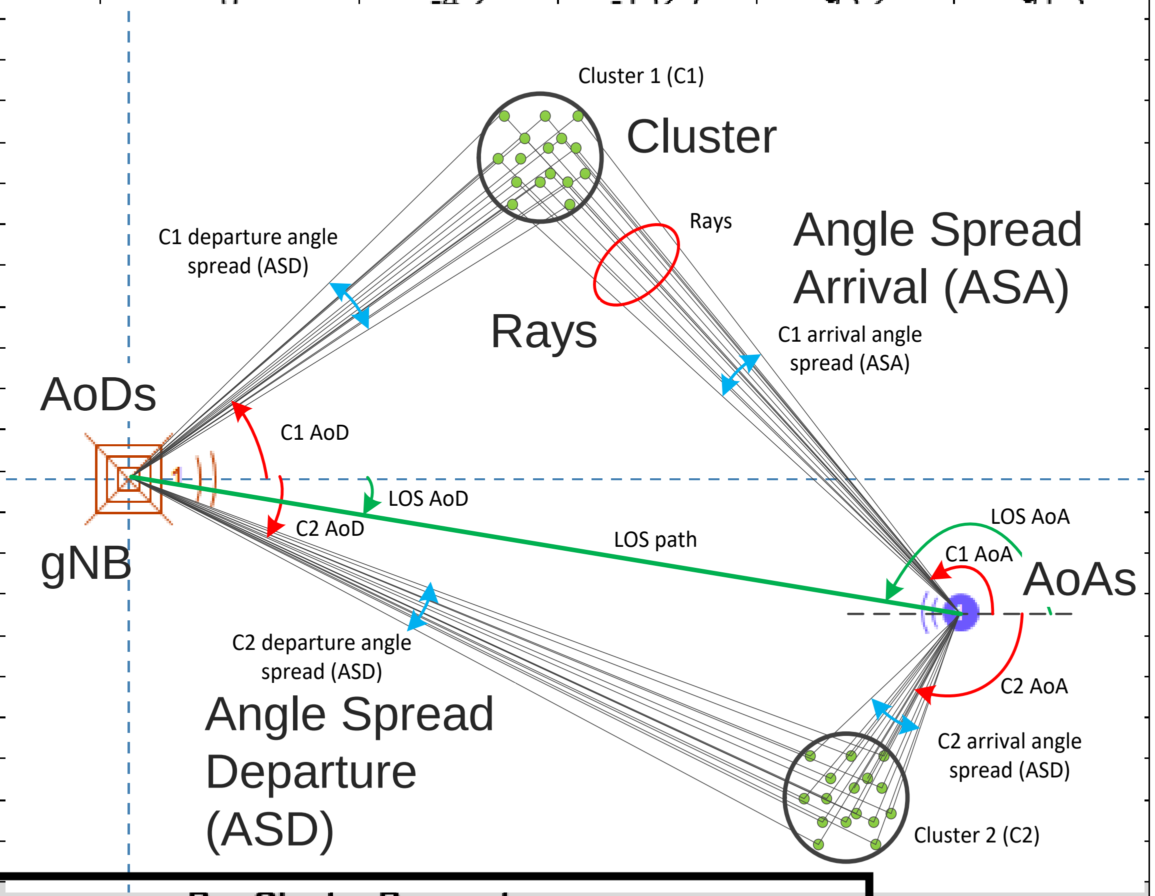


# Channel models for FR2: CDL-A

- Example: TR 38.901 CDL-A
- CDL-A is a non line of sight (NLoS) model
- Each CDL comprises 23 clusters
- Each cluster comprises 20 multipath components (rays) around the cluster perimeter
- Each cluster has an AoD and AoA. These values are used to create the ray AoAs within a spread (ASA or ASD) defined by $C_{ASA}$ and $C_{ASD}$ in the table.
- **Etc -** Full details is in TR 38.901
- Diagram to the right shows the concept of the CDL models but showing only two clusters.

**TR 38.901 Table 7.7.1-1. CDL-A**

| Cluster # | Normalized delay | Power in [dB] | AOD in [°] | AOA in [°] | ZOD in [°] | ZOA in [°] |
|---|---|---|---|---|---|---|
| 1 | 0.0000 | -13.4 | -178.1 | 51.3 | 50.2 | 125.4 |
| 2 | 0.3819 | 0 | -4.2 | -152.7 | 93.2 | 91.3 |
| 3 | 0.4025 | | | | | |
| 4 | 0.5868 | | | | | |
| 5 | 0.4610 | | | | | |
| 6 | 0.5375 | | | | | |
| 7 | 0.6708 | | | | | |
| 8 | 0.5750 | | | | | |
| 9 | 0.7618 | | | | | |
| 10 | 1.5375 | | | | | |
| 11 | 1.8978 | | | | | |
| 12 | 2.2242 | | | | | |
| 13 | 2.1718 | | | | | |
| 14 | 2.4942 | | | | | |
| 15 | 2.5119 | | | | | |
| 16 | 3.0582 | | | | | |
| 17 | 4.0810 | | | | | |
| 18 | 4.4579 | | | | | |
| 19 | 4.5695 | | | | | |
| 20 | 4.7966 | | | | | |
| 21 | 5.0066 | | | | | |
| 22 | 5.3043 | | | | | |
| 23 | 9.6586 | | | | | |



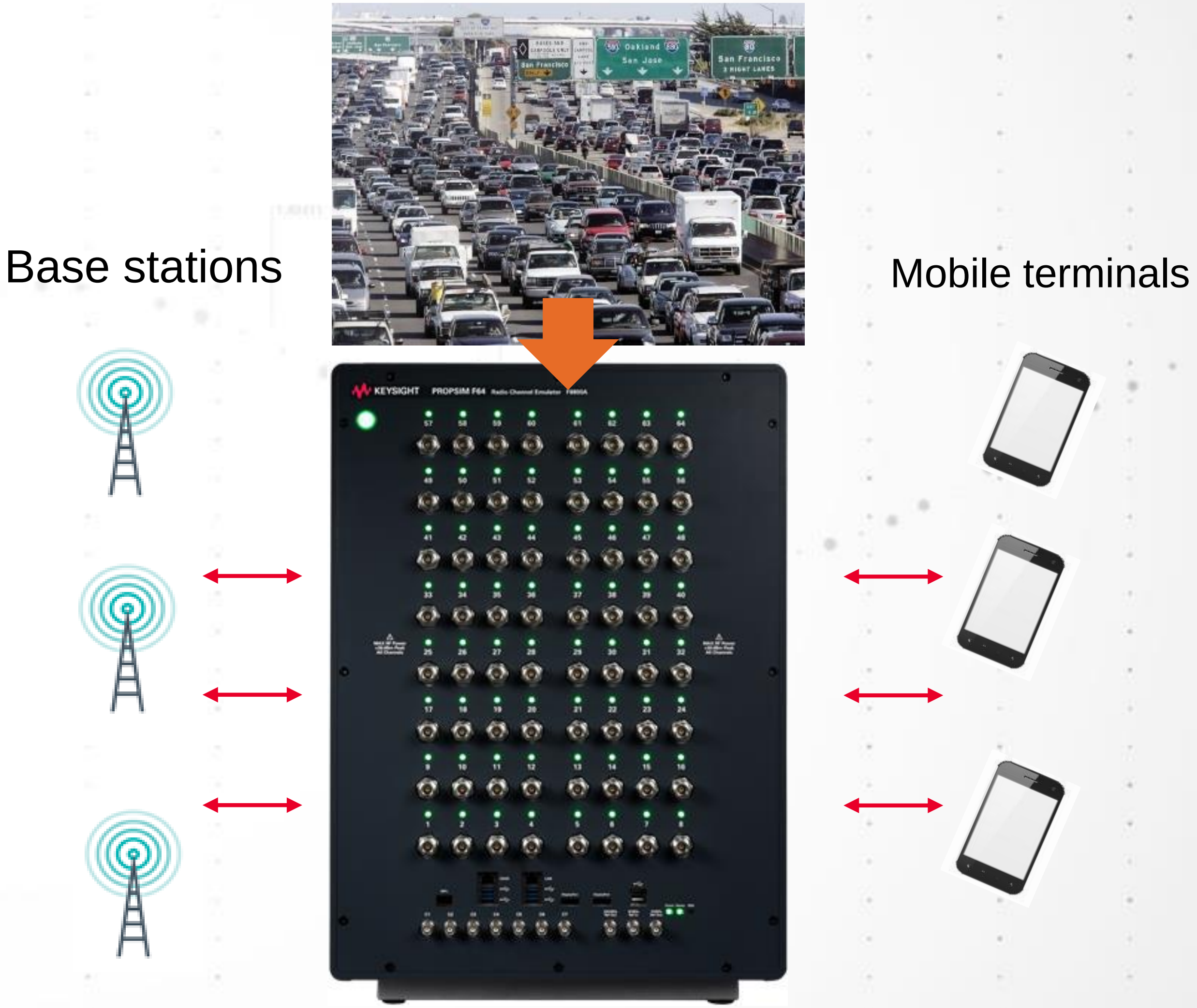

| | Per-Cluster Parameters | | | | |
|---|---|---|---|---|---|
| Parameter | $c_{ASD}$ in [°] | $c_{ASA}$ in [°] | $c_{ZSD}$ in [°] | $c_{ZSA}$ in [°] | XPR in [dB] |
| Value | 5 | 11 | 3 | 3 | 10 |

# What is Standalone RF Channel Emulation?

## ENABLES REAL-WORLD LIKE END-TO-END PERFORMANCE TESTING IN LAB

Real Time Emulation of radio wave propagation and interference to multiple BTS and Mobile simultaneously

- ✓Attenuation
- ✓Shadowing
- ✓Fast fading
- ✓Doppler effect
- ✓Noise and Interference
- ✓Antenna pattern embedding - Adaptive antenna systems
- ✓3D Beamform channels



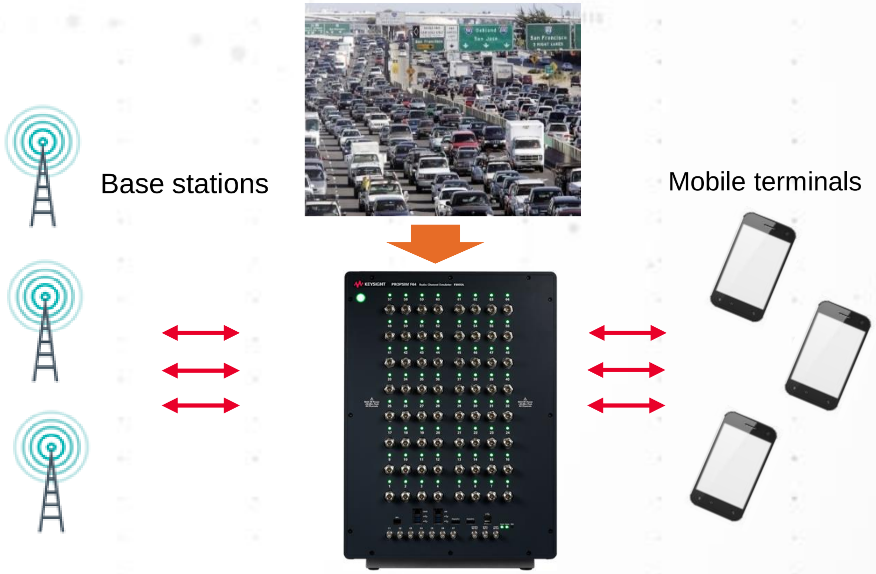
# Why companies invest on Channel Emulation tools?

**QUALITY OF SERVICE & TIME TO MARKET = SUCCESSFUL BUSINESS.**

## Each Mobile/Base Station/Device version (HW/SW) must be tested for

- ✓ Receiver sensitivity and AGC
- ✓ Channel Estimation algorithms
- ✓ Min/max delay-Doppler (velocity scenarios)
- ✓ Diversity/MIMO DSP Algorithms
- ✓ Intersymbol/Intercarrier Interference, SNR mitigation
- ✓ Synchronization
- ✓ Radio Link Control, Radio Resource Management
- ✓ Mobility Management
- ✓ Network Vendor Interoperability, Device Vendor Interoperability

## Radio Channel Emulation enables quick End-to-End full signaling Validation and Interoperability test in Lab




$$$

**Standard & Advanced Test Scenarios**
**Field to Lab Test Scenarios**

# PROPSIM 5G Solutions for <u>Base Station</u> performance & device interoperability testing

## Challenges

**Complex RF conditions at field FR1 and FR2**

**Verification of the 5G NR BS performance**

- Sub-6GHz massive MIMO 16TRX, 32TRX, 64TRX, 128TRX
- MU-MIMO performance optimization up to 4/8/16/32 layers

**mmWave hybrid beamforming with wide signal BWs**

- Beam management testing under various channel conditions
- Wide bandwidths up to 400 MHz per carrier, CA 800/1200 MHz
- Standalone (SA) and Non-Standalone (NSA) operating modes

**Coexistence and mobility tests**

- Scheduling and load management at network level

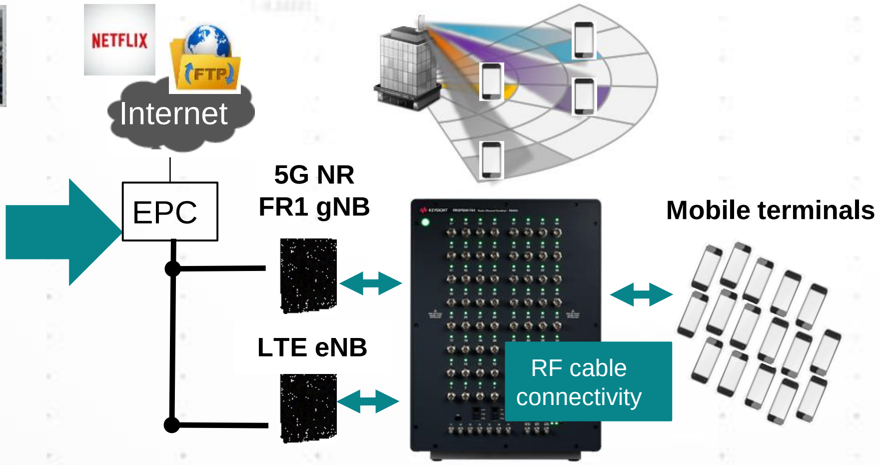
## Solutions

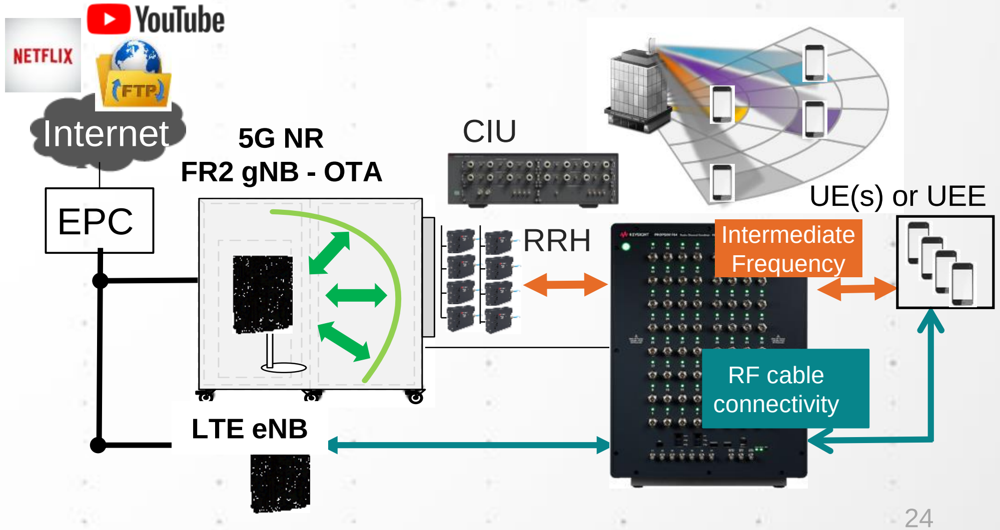
**PROPSIM Geometric Channel Modeling (GCM) 5G Tools**

- ✓ Channel modeling science ready & proven
- ✓ Antenna array modeling incl. patterns and DUT orientations in the scenario

**PROPSIM 5G Channel Emulation solutions**

- ✓ Capacity 16/32/64/128 element massive MIMO solutions sub 6 GHz
- ✓ All 5G NR BWs from 5 MHz up to 400 MHz
- ✓ CA up to 1.2 GHz Contiguous, 16CC non-contiguous
- ✓ Sub 6 GHz and mmWave solutions (CIU + RRH)
- ✓ Complete performance test solutions with UEE's and real UE's
- ✓ RF, IF and OTA*) connectivity methods

# PROPSIM 5G Solutions for Device performance testing


## Challenges

**5G Channel Modeling**

- Complex modeling science

**5G Channel Emulation**

- Realtime channel emulation
- Wide Bandwidths 100/200/400MHz
- CA 8CC/12CC/16CC
- Network Emulator and Real gNB support (NV-IOT)
- mmW OTA solutions
- Sub 6 GHz solutions

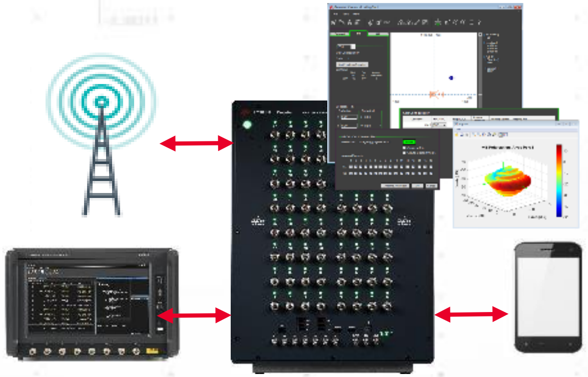
## Solutions

**PROPSIM Geometric Channel Modeling (GCM) 5G Tools**

✓ Channel Modeling Science ready & proven

**PROPSIM 5G Channel Emulation solutions**

✓ Realtime very low insertion delay
✓ BW 100/200/400 MHz up to 1.2 GHz
✓ CA up to 12CC (1.2 GHz)
✓ Seamslessly integrates with ***UXM 5G***, validated with 5G BTS
✓ Complete mmWave OTA solutions using CIU with RRHs
✓ Complete Sub 6 GHz performance test solutions
✓ Device NV-IOT solutions (Network Vendor Interoperability)


# PROPSIM F64 Key Features

- **Single F8800A platform up to 64TRX, 1024 MIMO ch.**
  - HW configurations 8, 16, 24, 32, 40, 48, 56, 64 TRX
  - 64 TRX up to 100 MHz BW (160 MHz WLAN opt.)
  - 32 TRX up to 200 MHz BW
  - 16 TRX up to 400 MHz + 16 TRX up to 100/160 MHz BW
- **Carrier Aggregation TDD & FDD**
  - Non-contiguous CA up to 16CC
  - Contiguous up to 1200 MHz, other 200/400/600/800 MHz
- **RF range up to 450 - 6000 MHz per TRX port**
  - HIGH-IF 6-12 GHz with external HW (CIU)
  - mmW bands 28/39GHz with external HW (RRH)
- **5G Channel Models and test scenarios**
- **PROPSIM GCM 5G channel modeling software**
  - Advanced channel modeling science ready & proven
  - TR38.901 channel models available
- **Integrated calibration, no need for external VNA**

# Platform+Software = PROPSIM Channel Emulation Solution

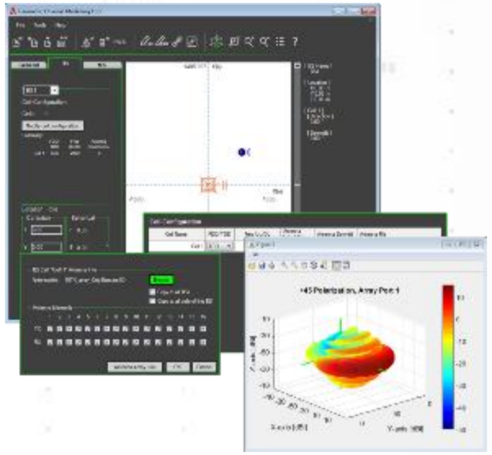
## Hardware Platform


Meets & Exceeds
5G NR requirements

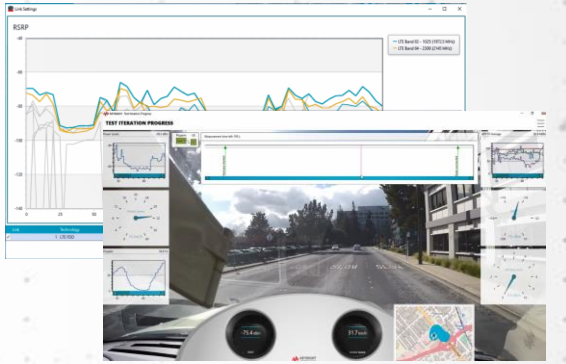
## Software

- Intuitive Graphical user interface to create & run standard and most advanced channel emulation scenarios
- Versatile tools to create and modify user defined test topologies and Test Scenarios
- Comprehensive standard channel model library
- Mobile Network Operator Acceptance test scenarios
- Remote command interface for test automation

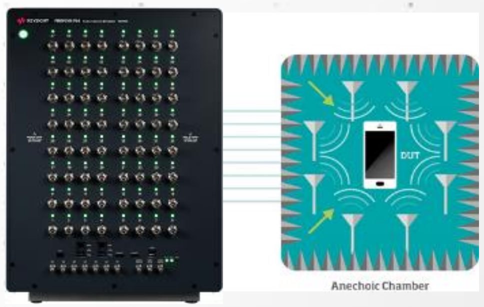
**5G FR1 and FR2 3GPP & Advanced test scenarios**



**Virtual Drive Testing in lab**



**Tier-1 Mobile Network Operator Acceptance test scenarios**




**MIMO OTA**