5G Boot Camp

PART FOUR:
Charactering 5G channel

Keysight Technologies

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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*

**Channel**
*Characterizing & Emulating*

**Field Testing and Drive Test**

- Protocol R&D
- RF / RRM DVT
- Functional KPI
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
  SCME CDL, 3D MIMO
  Conducted and OTA
- 5G: 100GHz, 1GHz BW
  3D, Spatial GSCM / CDL.
  Conducted and OTA FR1 and FR2

- PROPSIM team (previously 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
Radio Channel = Propagation path between Tranceivers =>
Antenna beam pattern * Multipath Propagation * Mobility + Interference

PROPAGATION

Total Signal
Path Loss
Shadowing
Fast Fading

INTERFERENCE

Ideal reception

Noise
- Thermal Noise
- Broadband noise from PAs

Real-life reception
Adjacent cells/Users
Modulated waveforms
- Co-channel interference
- Adjacent channel interference

Noise & Interference
Conventional SISO Channel Model

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

\[ h(t) = \sum_{i=1}^{L} \beta_i(t)e^{j\phi_i(t)} \delta[t - \tau_i(t)] \]
Extension to MIMO Channel model

• 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

\[ H_{n,m}(t,\tau) = \sum_{m=1}^{M} \left[ \begin{array}{c} F_{n,m,H}(\phi_{n,m}) \\ F_{n,m,P}(\phi_{n,m}) \end{array} \right] \left[ \begin{array}{cc} a_{n,m,PP} & a_{n,m,PH} \\ a_{n,m,HP} & a_{n,m,HH} \end{array} \right] \left[ \begin{array}{c} F_{n,m,PP}(\phi_{n,m}) \\ F_{n,m,PH}(\phi_{n,m}) \end{array} \right] \\
\times \exp(j2\pi\lambda_{0}^{-1}(\mathbf{r}_{n,m} \cdot \mathbf{r}_{n,1})) \exp(j2\pi\lambda_{0}^{-1}(\mathbf{r}_{n,m} \cdot \mathbf{r}_{n,1})) \times \exp(j2\pi v_{n,m}\tau)\delta(t - \tau_{n,m}) \right] \\
\]
5G 3D Channel Models

3GPP TR 36.873 FOR ELEVATION BEAMFORMING AND FD-MIMO

Channel matrix:

\[ H_{u,s}(t) = \sum_{n=1}^{N} \sum_{m=1}^{M} F^T_{u} (\Omega_{n,m}^{rx}) h_{n,m}(t) F_{s} (\Omega_{n,m}^{tx}) \exp(j2\pi \nu_{n,m}), \]

Antenna field patterns of MS and BS:

\[
F_{s} (\Omega_{n,m}^{tx}) = \begin{bmatrix}
F_{s}^v(\phi_{n,m}^{AoD} , \vartheta_{n,m}^{AoD}) \\
F_{s}^h(\phi_{n,m}^{AoD} , \vartheta_{n,m}^{AoD})
\end{bmatrix},
\]

\[
F_{u} (\Omega_{n,m}^{rx}) = \begin{bmatrix}
F_{u}^v(\phi_{n,m}^{AoA} , \vartheta_{n,m}^{AoA}) \\
F_{u}^h(\phi_{n,m}^{AoA} , \vartheta_{n,m}^{AoA})
\end{bmatrix}
\]

Propagation matrix:

\[
h_{n,m}(t) = \begin{bmatrix}
\exp(j\phi_{v,n,m}^o) \\
\sqrt{(\kappa_{v,n,m}^H)^2} \exp(j\phi_{h,n,m}^o)
\end{bmatrix}
\]

\[
\begin{bmatrix}
\exp(j\phi_{v,n,m}^h) \\
\exp(j\phi_{h,n,m}^h)
\end{bmatrix}
\]

Doppler term:

\[
v_{n,m} = \left[ v \right] \left( \cos(\alpha_v - \phi_{n,m}^{AoA}) \cos \vartheta_{n,m}^{AoA} \cos \gamma_v + \sin \vartheta_{n,m}^{AoA} \sin \gamma_v \right) \frac{1}{\lambda_0},
\]
Geometry based stochastic channel model

**Description of the Method**

- Angular 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)
ME3: Urban Macro cell Outdoor to Indoor (MIMO)
ME4: Urban microcell outdoor-to-indoor (MIMO)
ME5: Urban microcell outdoor (MIMO)

TX Antenna
RX Antenna
METIS 5G Measurement Campaigns mm-Wave

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

- 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?

Click video

Fast fading filtered out on gain curves to have clearer visual

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

Fading Cluster AoD’s are dynamic
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.
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

MODELING 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)
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

<table>
<thead>
<tr>
<th>Cluster #</th>
<th>Normalized delay</th>
<th>Power in dB</th>
<th>AOD in [°]</th>
<th>AOA in [°]</th>
<th>ZOD in [°]</th>
<th>ZOA in [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.000</td>
<td>0</td>
<td>9.3</td>
<td>173.5</td>
<td>106.5</td>
<td>83.5</td>
</tr>
<tr>
<td>2</td>
<td>0.107</td>
<td>-2.9</td>
<td>28.7</td>
<td>-2.9</td>
<td>106.5</td>
<td>83.5</td>
</tr>
<tr>
<td>3</td>
<td>0.215</td>
<td>-4.2</td>
<td>53.3</td>
<td>-1.5</td>
<td>106.5</td>
<td>83.5</td>
</tr>
<tr>
<td>4</td>
<td>0.323</td>
<td>-5.5</td>
<td>87.7</td>
<td>-1.5</td>
<td>106.5</td>
<td>83.5</td>
</tr>
<tr>
<td>5</td>
<td>0.430</td>
<td>-6.8</td>
<td>122.2</td>
<td>-1.5</td>
<td>106.5</td>
<td>83.5</td>
</tr>
<tr>
<td>6</td>
<td>0.537</td>
<td>-8.1</td>
<td>155.5</td>
<td>-1.5</td>
<td>106.5</td>
<td>83.5</td>
</tr>
<tr>
<td>7</td>
<td>0.644</td>
<td>-9.4</td>
<td>188.8</td>
<td>-1.5</td>
<td>106.5</td>
<td>83.5</td>
</tr>
<tr>
<td>8</td>
<td>0.751</td>
<td>-10.7</td>
<td>222.2</td>
<td>-1.5</td>
<td>106.5</td>
<td>83.5</td>
</tr>
</tbody>
</table>

Table 7.7.1-4. CDL-D

<table>
<thead>
<tr>
<th>Cluster #</th>
<th>Cluster PAS</th>
<th>Normalized delay</th>
<th>Power in dB</th>
<th>AOD in [°]</th>
<th>AOA in [°]</th>
<th>ZOD in [°]</th>
<th>ZOA in [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Spread LOS path</td>
<td>0.000</td>
<td>0</td>
<td>9.3</td>
<td>173.5</td>
<td>106.5</td>
<td>83.5</td>
</tr>
<tr>
<td>2</td>
<td>Laplacian</td>
<td>0.107</td>
<td>-2.9</td>
<td>28.7</td>
<td>-2.9</td>
<td>106.5</td>
<td>83.5</td>
</tr>
<tr>
<td>3</td>
<td>Laplacian</td>
<td>0.215</td>
<td>-4.2</td>
<td>53.3</td>
<td>-1.5</td>
<td>106.5</td>
<td>83.5</td>
</tr>
<tr>
<td>4</td>
<td>Laplacian</td>
<td>0.323</td>
<td>-5.5</td>
<td>87.7</td>
<td>-1.5</td>
<td>106.5</td>
<td>83.5</td>
</tr>
<tr>
<td>5</td>
<td>Laplacian</td>
<td>0.430</td>
<td>-6.8</td>
<td>122.2</td>
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<td>83.5</td>
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<tr>
<td>6</td>
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<td>0.537</td>
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<td>106.5</td>
<td>83.5</td>
</tr>
</tbody>
</table>

PROPSIM UI
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.
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

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Standard & Advanced Test Scenarios
Field to Lab Test Scenarios

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$\text{QUALITY OF SERVICE & TIME TO MARKET = SUCCESSFUL BUSINESS.}$
PROPSIM 5G Solutions for Base Station 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
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

*Note: OTA refers to Over-The-Air testing.
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)
- Seamlessly 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

- 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

Meets & Exceeds 5G NR requirements

Software

- 5G FR1 and FR2 3GPP & Advanced test scenarios
- Virtual Drive Testing in lab

5G Boot Camp: 7 Key Measurement Challenges and Case Studies