7 Key Measurement Challenges

Signal Quality
mmWave, Waveform, Fidelity

Lots of Channels
MIMO & Beamforming

Channel
Characterizing & Emulating

Life Beyond Connectors
Over-the-Air

Performance on the Network
Network Emulation

Connect Design & Test
Components & Systems

Field & Drive Test

Protocol R&D
RF/RRM DVT
Functional KPI

Design Simulate Validate Connect Test
Suppose You Want to Design and Test a Motorbike

Understanding the channel is critical to success.
What is the Radio Channel?

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

PROPAGATION

INTERFERENCE

Channel $h(t)$

Noise
- Thermal noise
- Broadband noise from PAs

Adjacent cells / users
- Co-channel interference
- Adjacent channel interference
Evolution of Channel Models

- **2G** <3 GHz, 200 kHz BW
  Non-spatial TDL
- **3G** <3 GHz, 5 MHz BW
  Non-spatial TDL
- **4G** < 6 GHz, 20 MHz BW
  Non-spatial TDL – conducted tests
  SCME CDL – MIMO OTA (radiated)
  3D MIMO (for BS elevation beamforming studies)
- **5G** 0.5 – 100 GHz, >1 GHz BW
  Spatial CDL and GSCM

Channel models have been developed over many decades based primarily on channel measurements (sounding)

More recently, *Ray Tracing* of modeled environments has become possible

The trend is from non-spatial to spatial models, which implies testing has to involve Antennas – OTA testing of antenna is embedded into test model

TDL – Tapped delay line (time only)
CDL – Cluster delay line *(time and space)*
GSCM – Geometric spatial channel models *(dynamic cluster parameters)*
5G Challenge: Highly Dynamic Fading Channel in Field – Connected State UE Mobility

• Base stations and UEs 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?

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

Fast fading filtered out on gain curves to have clearer visual

Fading Cluster AoDs are dynamic

Click video
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 2 m of distance with 40 cm of travel:
  • 60 GHz is at -25 dB
  • 3.5 GHz is at -8 dB
Effect of Channel Models at Sub-6 GHz - PAS Results

BTS: 64X & 4 USER MU-MIMO, BS BEAM SCANNING OVER SPHERE

38.901 UMi LoS channel model
- LoS – The base station easily achieves good isolation between the UEs

38.901 UMi NLoS channel model
- NLoS – Angular dispersion of the radio channel makes it more challenging to achieve isolation between the UEs
High cell capacity on 5G rely on the base station’s massive MIMO ability to leverage time variant spatial channel for MU-MIMO.

Sub-6 GHz example of 4 static mobile devices in urban micro NLoS conditions:

Each cluster for each mobile device is "moving" in angular space over time, even though the mobile devices are standing still!
• 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 support up to 10% of the center frequency, but no larger than 2 GHz
  • Spatial consistency support
  • System-level, link-level CDL-models, and non-spatial TDL-models

LOS / NLOS
Use Cases for Massive MIMO Testing

3GPP TR 38.901 CHANNEL MODEL SCENARIOS

Urban microcell (UMi)
UMi street canyon (O2O)
Base stations mounted below rooftops

UMi outdoor to indoor (O2I)

UMa outdoor to indoor (O2I)

UMa street canyon
Base stations mounted above rooftops

Urban macrocell (UMa)
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 for NLoS
  - CDL-D and CDL-E for LoS
- RMS delay-spread values of both CDL models are normalized, and they can be scaled in delay for a desired RMS delay spread
Channel Models for FR2: CDL-A

- Example: TR 38.901 CDL-A
- CDL-A is a 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 only shows two clusters
What Is Standalone RF Channel Emulation?

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

Real-time emulation of radio wave propagation and interference to multiple base stations and mobiles simultaneously

✓ Attenuation
✓ Shadowing
✓ Fast fading
✓ Doppler effect
✓ Noise and interference
✓ Antenna pattern embedding - Adaptive antenna systems
✓ 3D Beamform channels
Brief 3GPP Status on 5G Fading Performance Testing

NO 3GPP TEST PLAN FOR BEAM MANAGEMENT OR E2E PERFORMANCE TESTS

<table>
<thead>
<tr>
<th>Band</th>
<th>Demod</th>
<th>RRM testing UE only</th>
<th>Channel model</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR1</td>
<td>Conducted TDL fading models</td>
<td>Conducted TDL fading models</td>
<td>TDL 12-tap correlation matrix based models. Rayleigh fading + Jakes Doppler</td>
</tr>
<tr>
<td>FR2</td>
<td>OTA TDL cable replacement fading models. 1-AoA single probe</td>
<td>OTA TDL cable replacement fading models. 1-AoA and 2-AoA (TBD)</td>
<td>TDL 12-tap correlation matrix based models - OTA cable replacement models</td>
</tr>
</tbody>
</table>

- Currently, there is no NR work item/study item that has FR2 beam management scope at 3GPP
- For UE, there is a test plan for FR2 RRM tests with 2 AoAs but it does not focus on beam management
- For base station, there is no RRM nor beam management tests in 3GPP

Conformance tests in 3GPP do not test UEs or base stations for mobility beam management at all.
End-to-end fading performance testing with real base stations and UEs is not in 3GPP scope.
Field testing at mmWave is limited as networks are not widely available.

Testing in the lab is typically more efficient due to greater control over variables, and the availability of better tools and equipment.

Issues to be solved:
- Interoperability & performance of daily/weekly releases
- Blockage management of signal at mmWave
- Beam management verification
- Benchmarking of all products

For all daily / weekly / monthly releases
Under various network conditions

City center square
Street canyon
Shopping mall
High-speed train
Metro station...
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, RRM
✓ Mobility management
✓ Network vendor interoperability, device vendor interoperability

Radio channel emulation enables quick and comprehensive end-to-end signaling validation and interoperability test in the lab

Why Companies Invest on Channel Emulation Tools?

QUALITY OF SERVICE & TIME TO MARKET = SUCCESSFUL BUSINESS

Standard & advanced test scenarios
Field-to-lab test scenarios

$$$

Base stations

Mobile terminals

17
Challenges

Complex RF conditions in the field at FR1 and FR2
5G NR base station performance verification
Sub-6 GHz massive MIMO 16, 32, 64, or 128 TRX
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 and real UEs
- RF, IF and OTA connectivity methods
PROPSIM 5G Solutions

DEVICE PERFORMANCE TESTING

Challenges

5G channel modeling
- Complex modeling science

5G channel emulation
- Wide bandwidths 100/200/400MHz
- CA 8CC/12CC/16CC
- Network emulator and real gNB support (NV-IOT)
- mmWave OTA solutions
- Sub-6 GHz solutions

Solutions

PROPSIM Geometric Channel Modeling (GCM) 5G Tools
- Channel modeling science ready & proven

PROPSIM 5G channel emulation solutions
- 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
PROPSIM F64 Key Features

• Single F8800A platform up to 64 TRX, 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)
  • mmWave 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