KEYSIGHT

Modelling and emulation of D-band radio channel

RF Sampo seminar
Oulu, 16.3.2023
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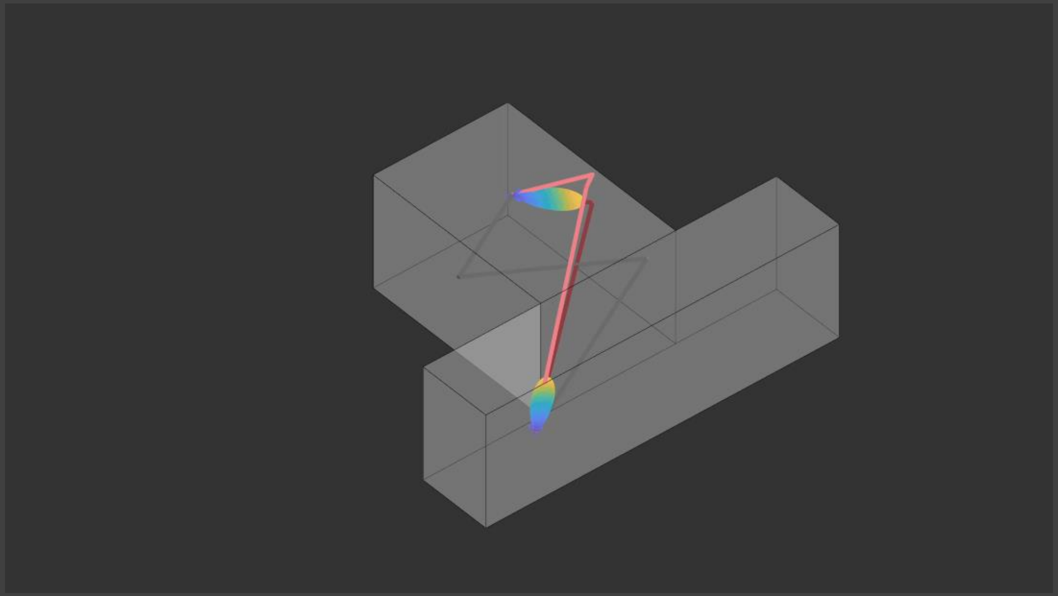
Outline

- Introduction
  - Motivation
- Model ingredients
  - Propagation data
  - New channel measurement
- Channel modelling
- Emulation
  - Validation by lab measurements
- Summary



Introduction

Introduction

- Sub-THz (100-300 GHz) frequency band may provide tens of GHz bandwidths
  - Interest in 6G research though commercial applications are far in future
- Channel characterization is ongoing in many research projects
- Channel emulation will be needed at some point of time

→A modelling and emulation trial for specific indoor scenarios:

- Use case: A virtual reality user (indoor)
  - f_c=140 GHz, BW > 1 GHz, link distance <20 m moderate or no mobility

Propsim

Radio Channel Reconstructed

Why we do channel modelling and emulation?

- Radio channel is a fundamental part of any wireless system
- The channel itself cannot be engineered
- System design must be able to utilize channel characteristics
- Channel models describe the radio propagation channel
- Testing against channel models reveals real-life performance

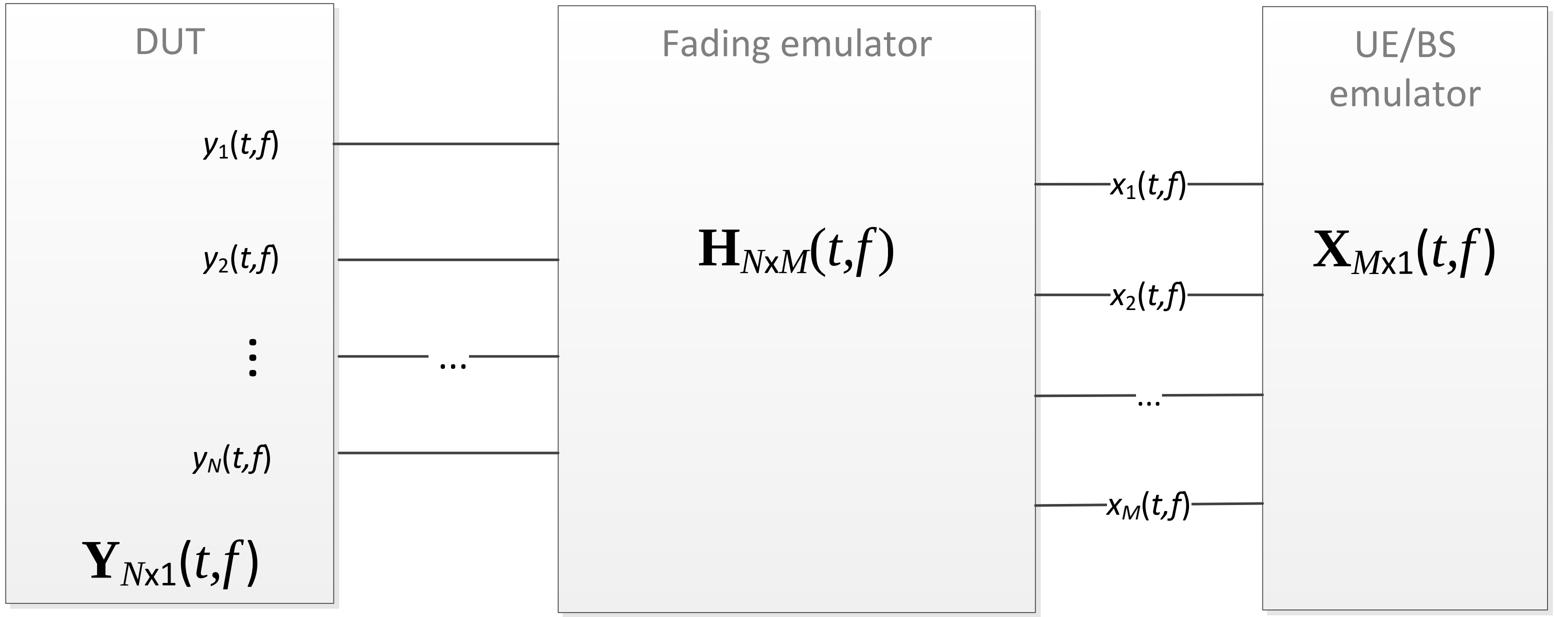
➢ The PROPSIM Channel Emulation Solution recreates radio channel conditions defined by channel models

What is fading emulation?

Conducted MIMO fading channel emulation

$$\mathbf{Y}(t,f) = \mathbf{H}(t,f)\mathbf{X}(t,f) + \mathbf{N}$$

$$\mathbf{H}(t,f) = \iint \mathbf{G}_{rx}(\Omega_2,t,f)\mathbf{h}(\Omega_1,\Omega_2,t,f)\mathbf{G}_{tx}^{T}(\Omega_1,t,f)\, d\Omega_1 d\Omega_2$$



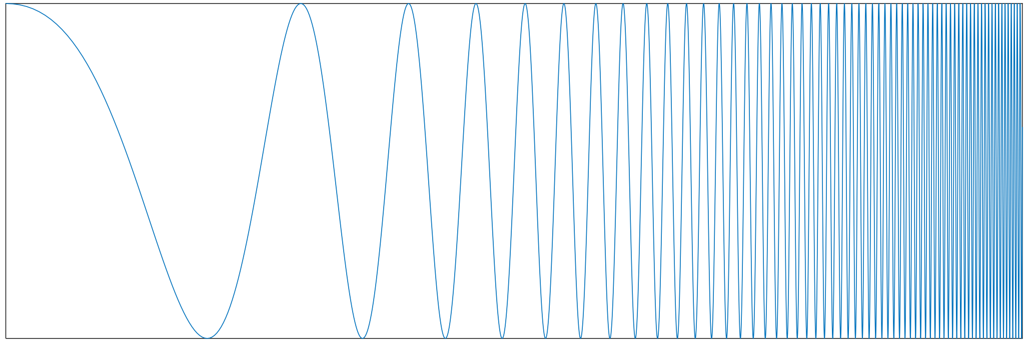
What is this talk about?

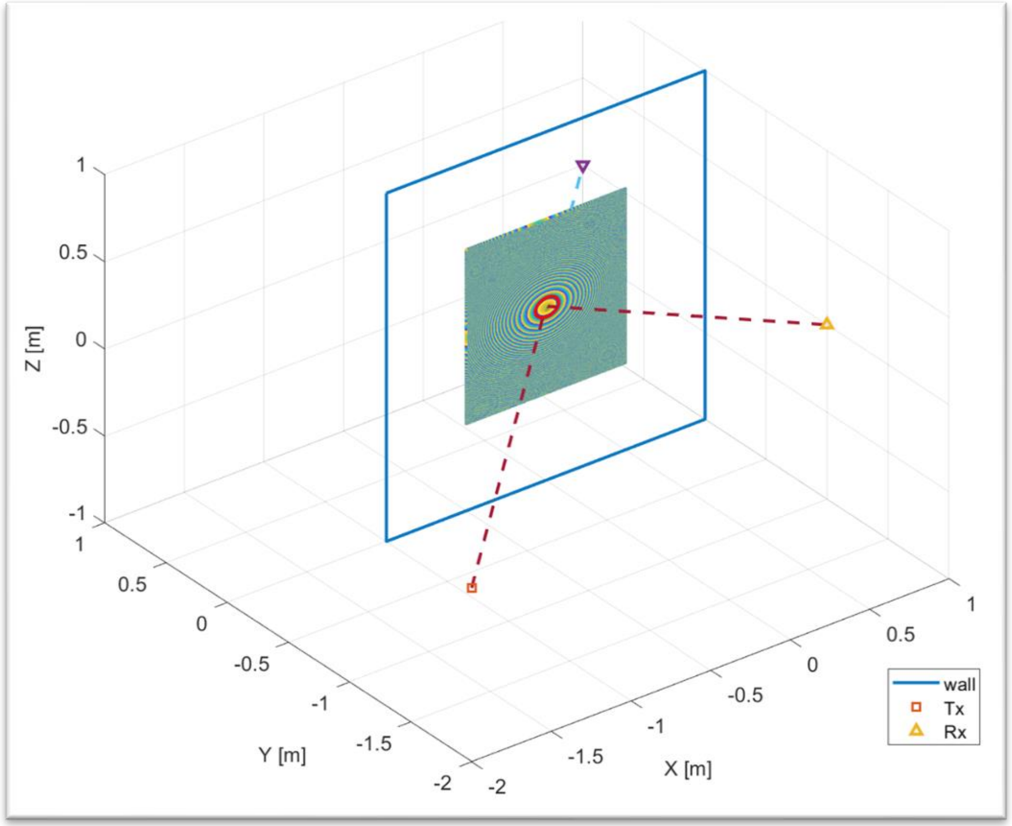
- Make the first in the world radio channel emulation of a 6G channel model using Propsim fading emulator.
- The channel model is based on D-band (140 GHz) propagation measurements conducted by the University of Oulu, Aalto University, and Keysight.
- Channel models are implemented in Propsim and emulated in laboratory. The emulated channel is measured from Prosim input/output and compared to the original channel model.
- Key elements:
  - 6G sub-THz propagation + measurement, 6G channel model, wideband 6G channel emulation, comparison of the model and the emulated channel

Sub-THz radio channel

New frequency area

- Sub-THz radio frequencies: 100–300 GHz
  - Molecular absorption at specific frequencies
  - High transmission loss (no penetration)
  - High diffraction loss (weak diffraction)
  - Strong shadowing by obstacles (e.g. human body)
  - Dominant paths are LoS and reflections
- Signal bandwidths of several GHz
  - Well available, support for very high data rates
- High path loss $\rightarrow$ need for high gain antennas
  - Beam alignement





Model Ingredients

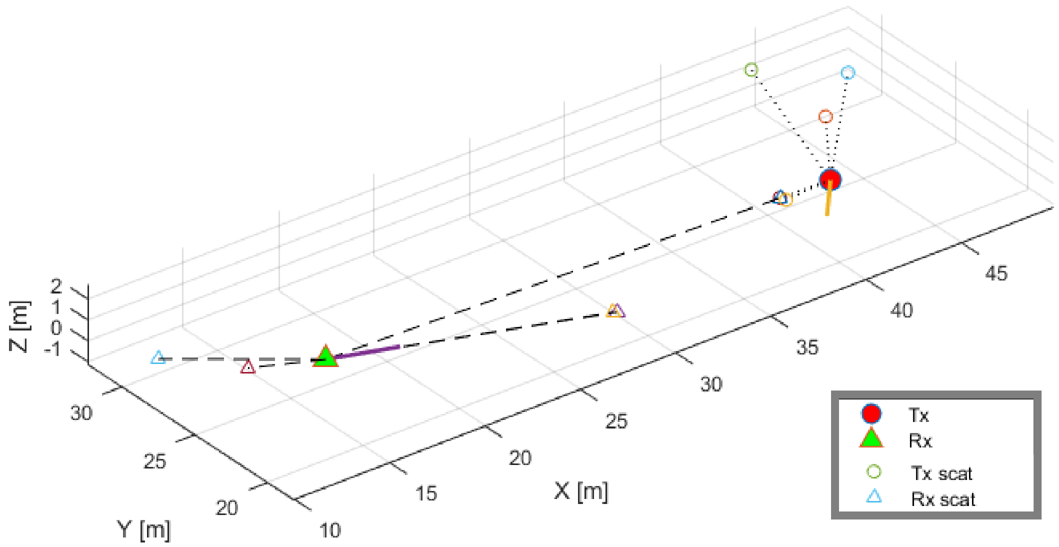
Propagation data from Aalto & UOulu

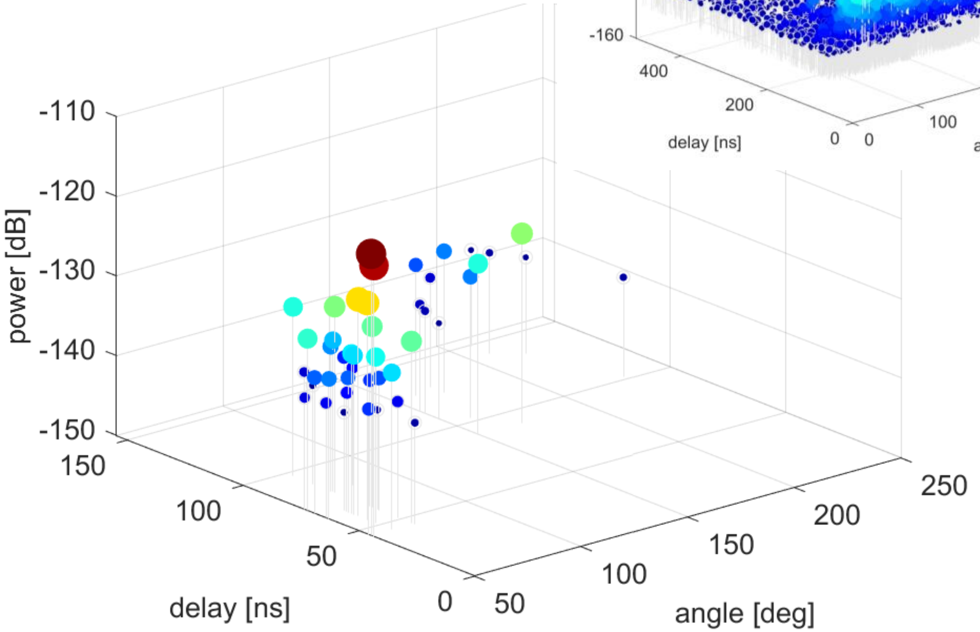
Multipath propagation data

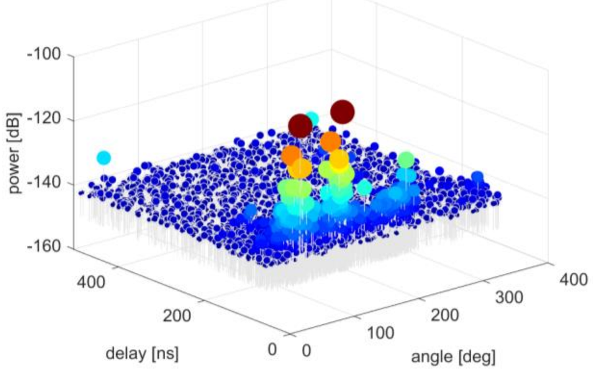
P. Kyösti, K. Haneda, J-M Conrat, A. Pärssinen, "Above-100 GHz wave propagation studies in the European project Hexa-X for 6G channel modelling," in *EuCNC* 2021.

Aalto University

- The collection of propagation paths from measurements at 140 GHz
- Coordinates and types of interaction points are available in the ray-tracing assisted measurement data, as well as channel coefficients for each multipath/interaction
  → Propagation delays and angles of arrival/departure
- Measured environments are characterized by a layout or point cloud
  → Support for localization and sensing investigations

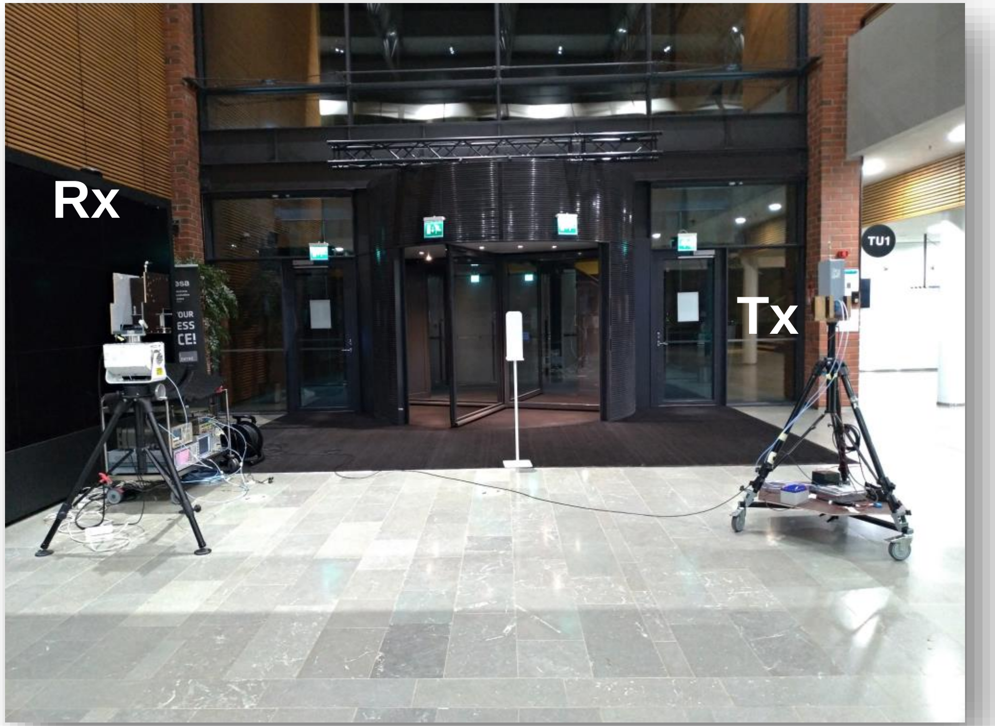


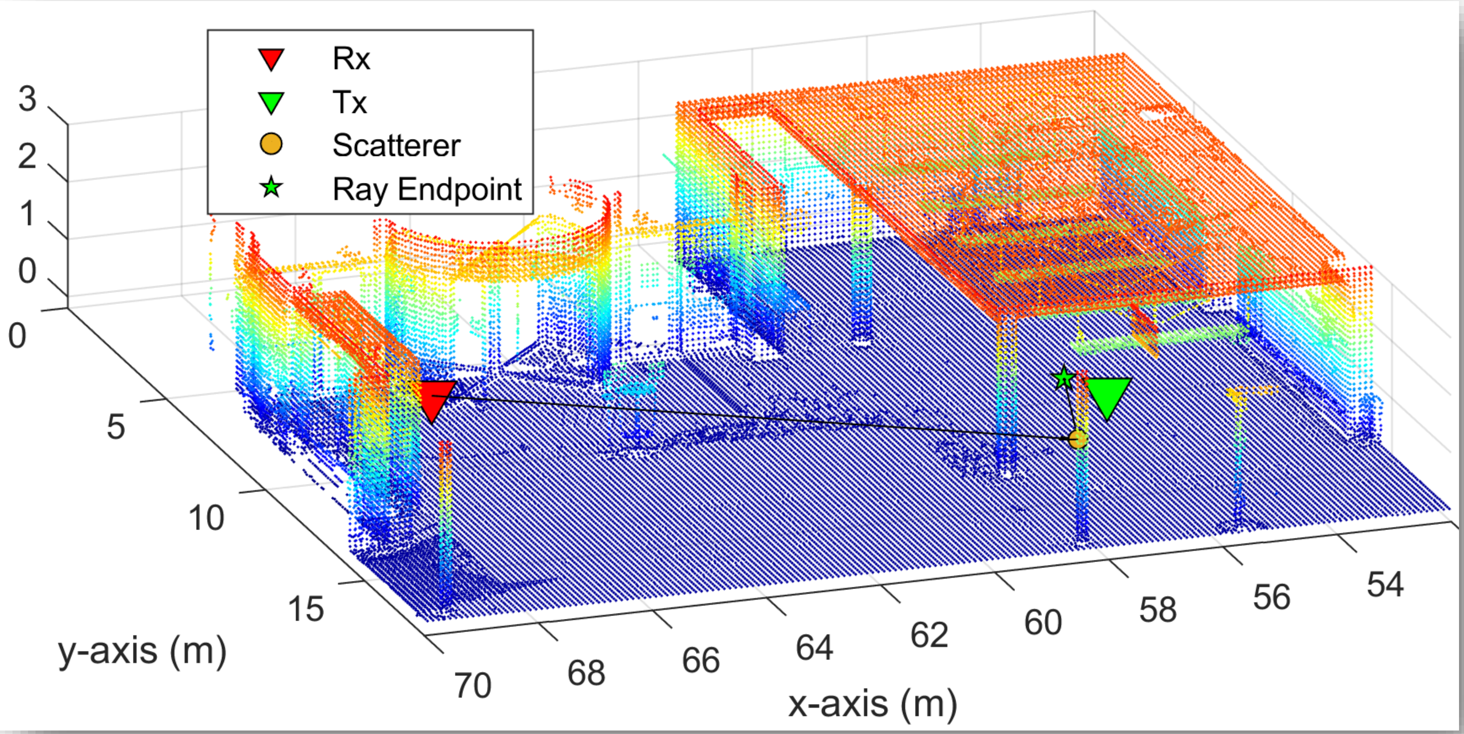




Aalto Entrance hall measurements

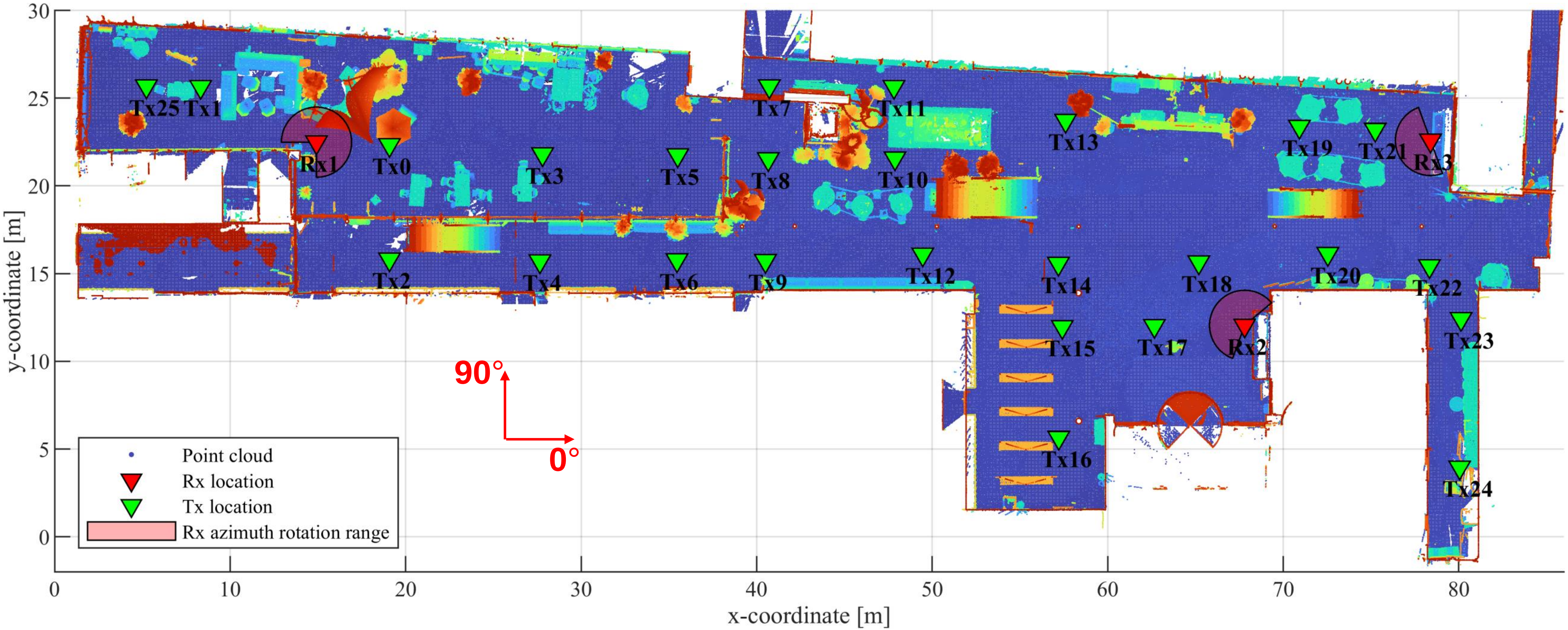
140 GHz





M. F. De Guzman, P. Koivumäki and K. Haneda, “Double-directional Multipath Data at 140 GHz Derived from Measurement-based Ray-tracer,” in VTC2022-Spring, Helsinki, Finland, June 2022.

Aalto Entrance hall measurement



Each Tx location is measured with up to three Rx locations

Tx and Rx antennas are at 1.85 m height

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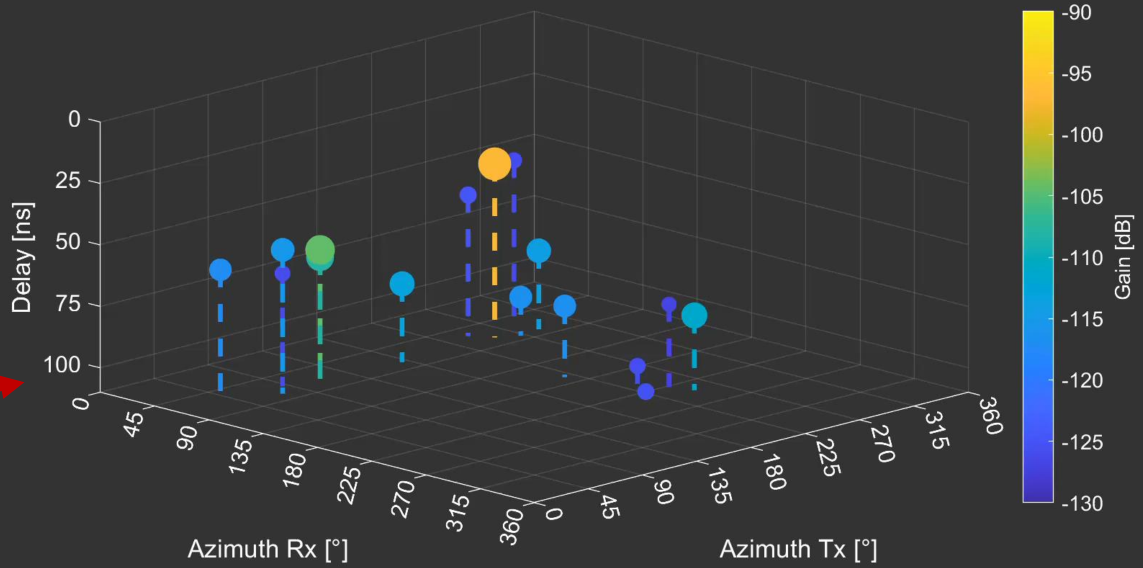
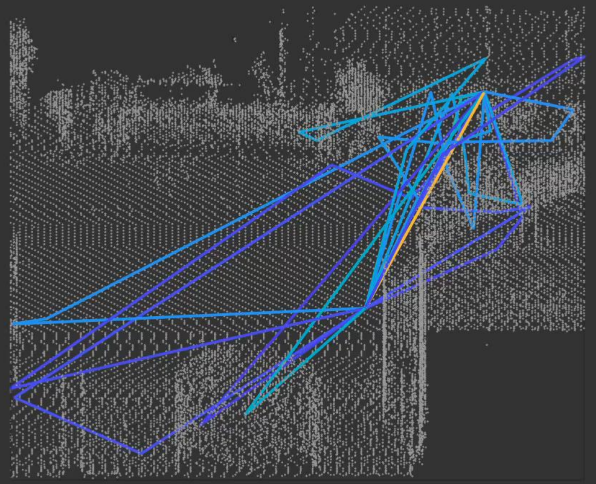
Example propagation channel

From Aalto's measurement

Time invariant double-directional power-angular-delay profile (PADP)

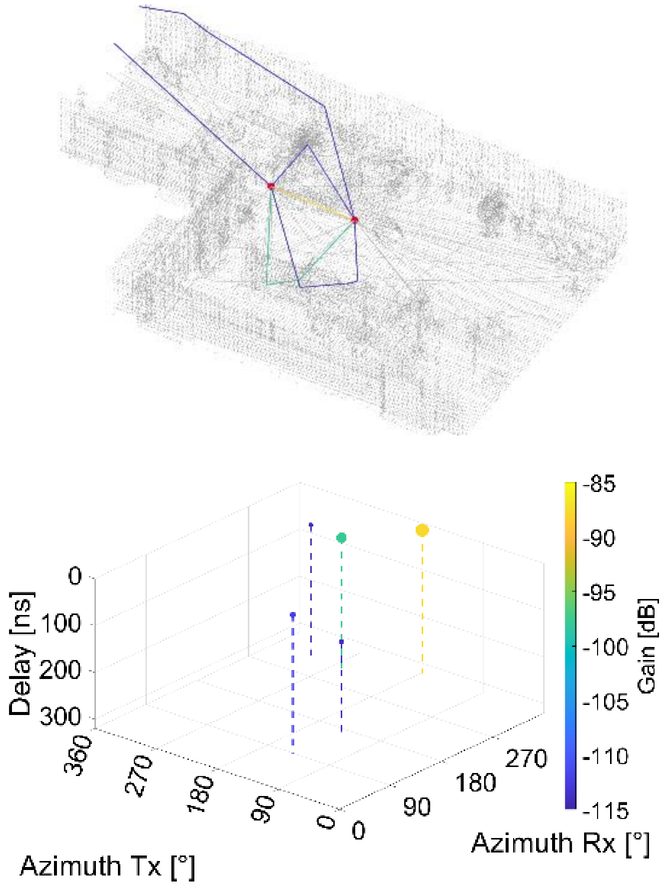


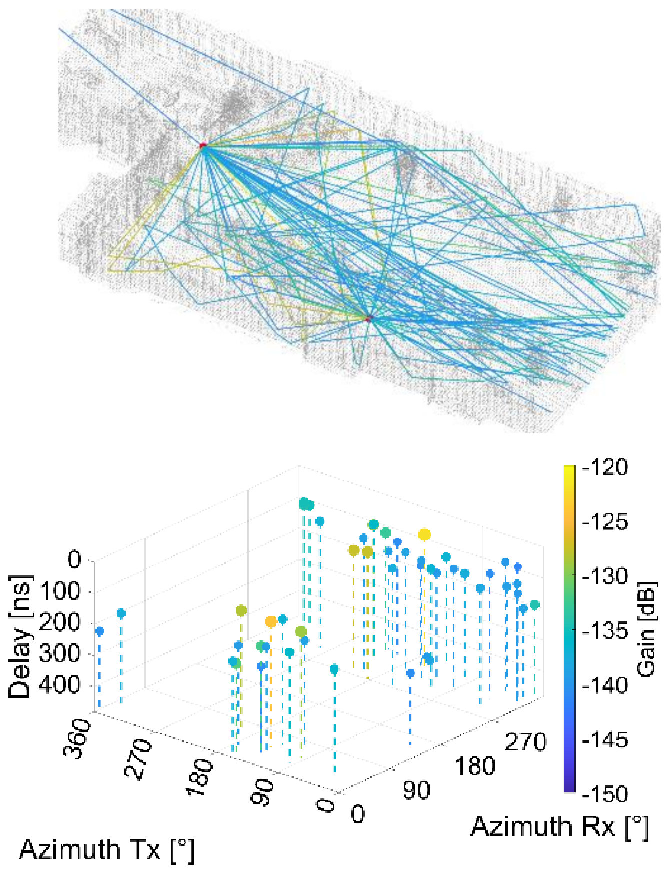
Point cloud of the environment from laser scanning
Tx, Rx, and multipath

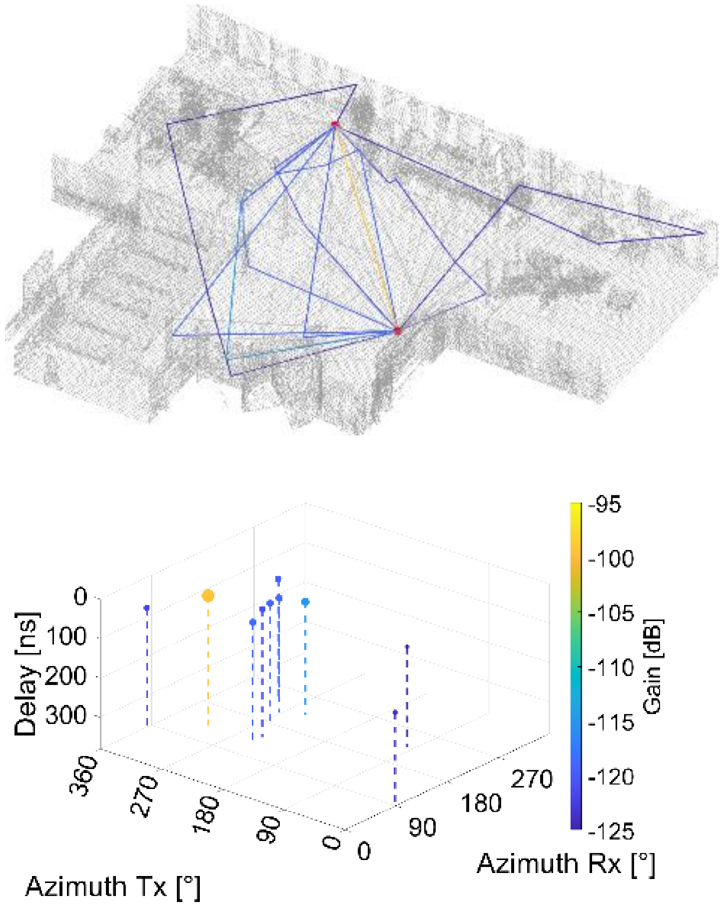


Multipath parameters

Aalto data



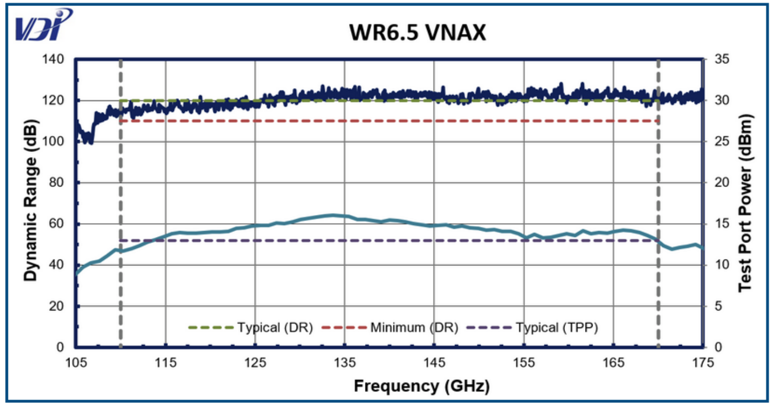




UOulu corridor measurement - Channel sounder

- Core of the measurement setup is Keysight PNA-X network analyzer
- VDI vector network analyzer extension module (VNAX) WR6.5 is used in the D-band
- Pasternack 10/9 degree (Az/El) 25 dBi horn antennas are used at both ends
- Custom azimuth/elevation rotation stages at both ends for angular scanning
- Custom control software

WR6.5 VNAX Specifications	
Standard Frequency Coverage (GHz)	110-170
Dynamic Range (BW = 10Hz, dB, typical)	120
Dynamic Range (BW = 10Hz, dB, minimum)	110
Magnitude Stability (±dB)	0.25
Phase Stability (±degrees)	4
Test Port Power (dBm typ. power)	13
Directivity (dB)	30



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UOulu corridor measurement setup

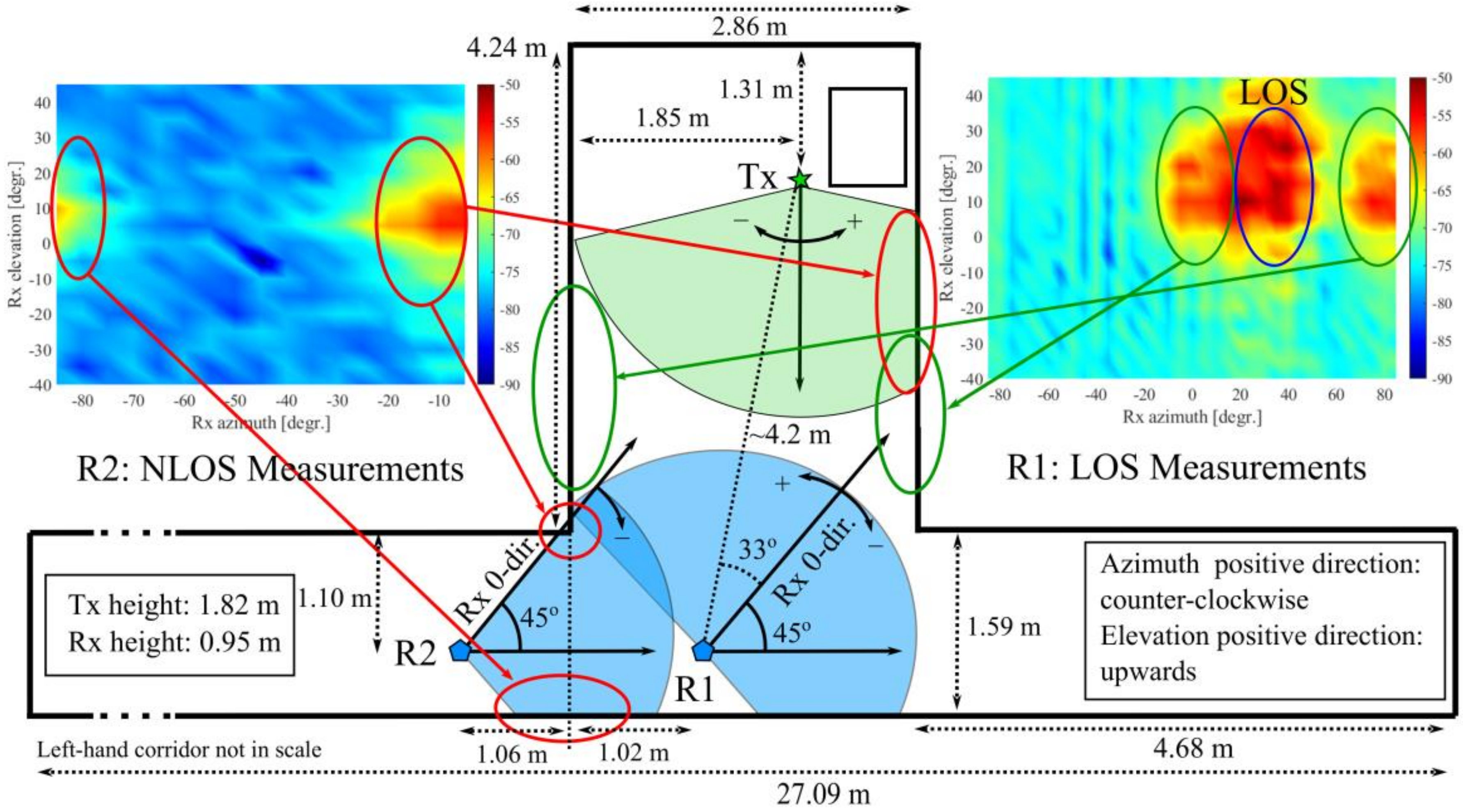
- The environment is a T-shaped office corridor
- Both LoS and NLoS positions
- Bi-directional propagation at 140 GHz
  - Path gains, delays, AoA, AoD, EoA, EoD

Parameter	Value
Frequency	110–170 GHz
Total bandwidth	60 GHz
Sub-band bandwidth	15 MHz
Impulse response length	66.7 ns
Impulse response resolution	16.7 ps / 5 mm
Maximum distance	20 meters
Antenna gain (Tx/Rx)	25 dBi
Antenna 3-dB beamwidth	10° / 9° (Az/El)
Tx scan range at R1	-80° – 80° (Az), -40.5° – 40.5° (El)
Tx scan range at R2	-80° – 60° (Az), -40.5° – 13.5° (El)
Rx scan range at R1	-90° – 90° (Az), -40° – 45° (El)
Rx scan range at R2	-90° – 0° (Az), -40° – 45° (El)
Tx angle resolution	10° / 9° (Az/El)
Rx El angle resolution	5°

Source: J. Kokkoniemi, V. Hovinen, K. Nevala and M. Juntti, "Initial Results on D- Band Channel Measurements in LoS and NLoS Office Corridor Environment," 16th European Conference on Antennas and Propagation, 2022.

Data Analysis

Very sparse channel in general and the energy is mostly coming from the large surfaces!



Model Ingredients

Blockage measurement: Keysight + UOulu

Channel sounder

- Core of the measurement setup is Keysight PNA-X network analyzer
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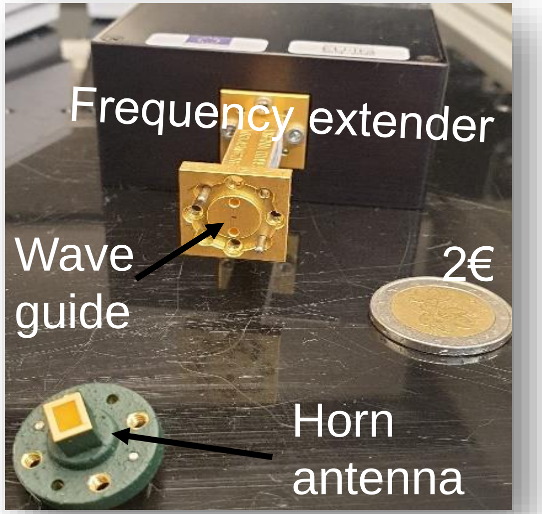

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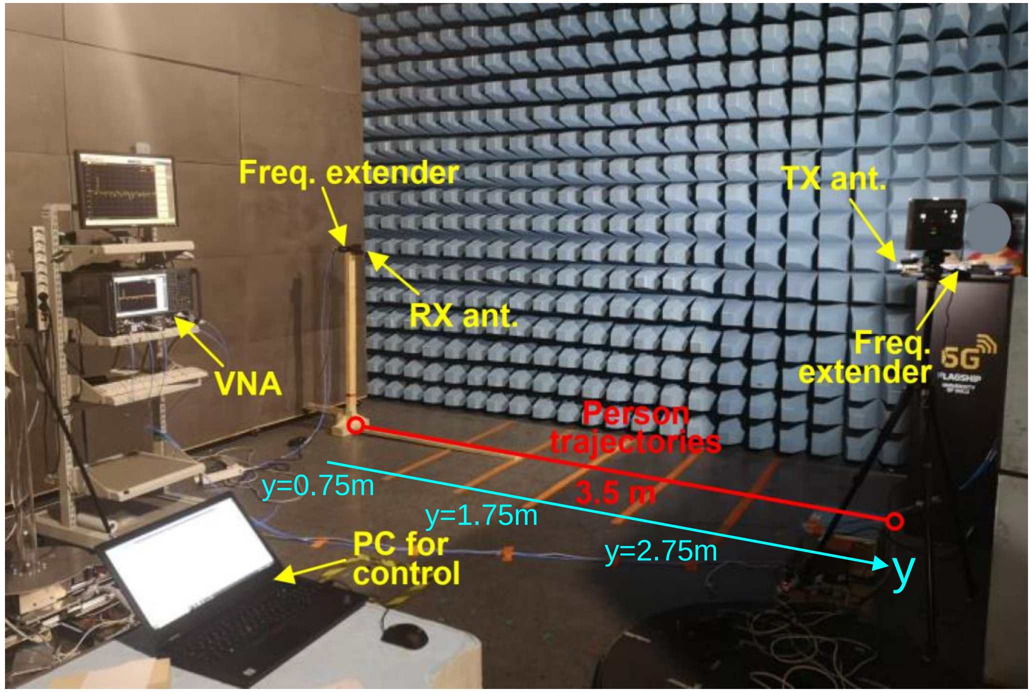
D-Band Human Body Shadowing (1/3)

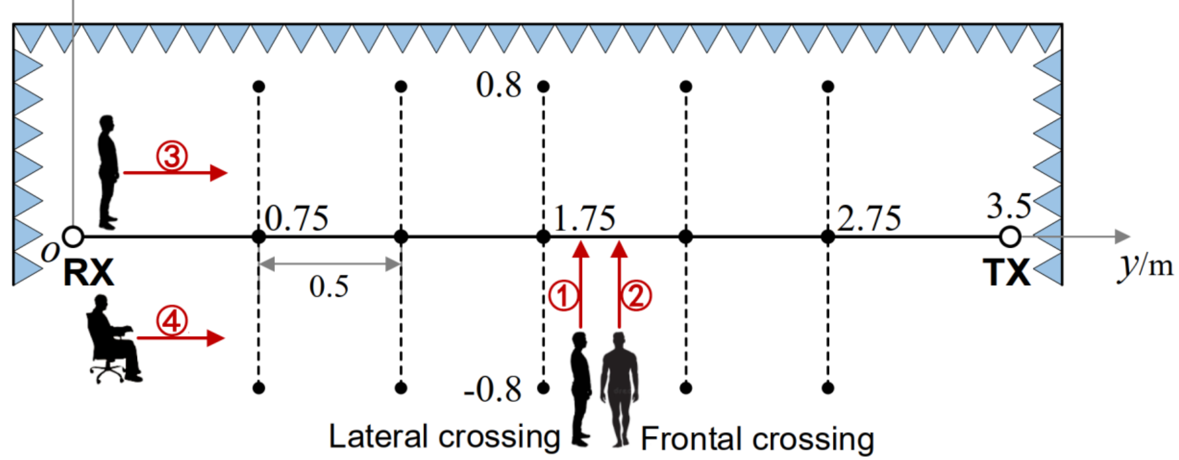
Measurement system

- ✓ VNA-based continuous-time measurements in anechoic chamber
- ✓ Different user cases (single human blocker)



Measurement system and scenario

Illustration of trajectories for human blockage measurements



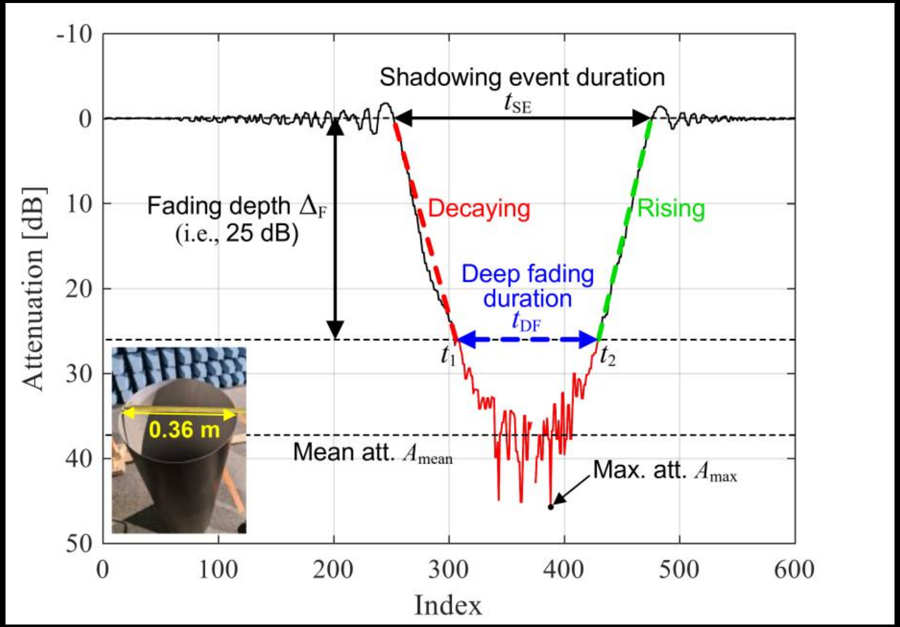
Measurement setup

Parameter	Unit	Value
Freq. range	GHz	139–141
Bandwidth	GHz	2
Freq. point	/	201
Delay resolution	ns	0.5
Max. excess delay	ns	100
IF bandwidth	kHz	100
TX/RX ant. gain	dBi	25
TX/RX HPBW	deg	10

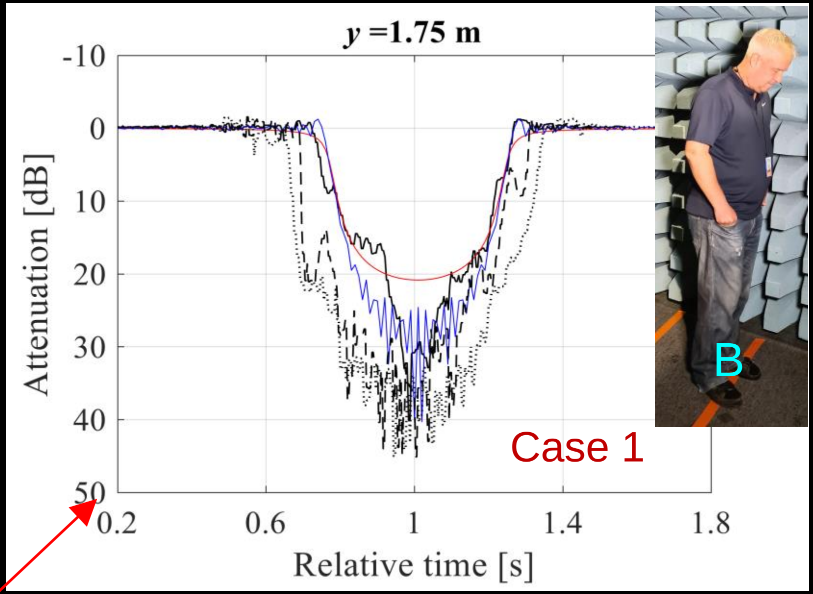
D-Band Human Body Shadowing (2/3)

Initial Results of Single Person Human Blockage Effect

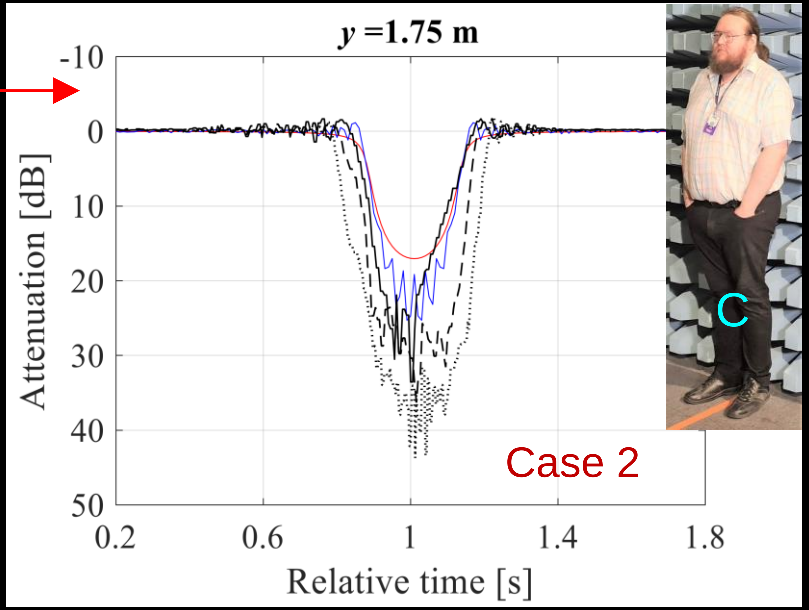
- ✓ Reference measurement results using standard cylinder
- ✓ Characterization of human body shadowing with volunteer A/B/C



Reference measurement with metallic cylinder



Comparison of D-band human blockage attenuation from measurement and theoretical models



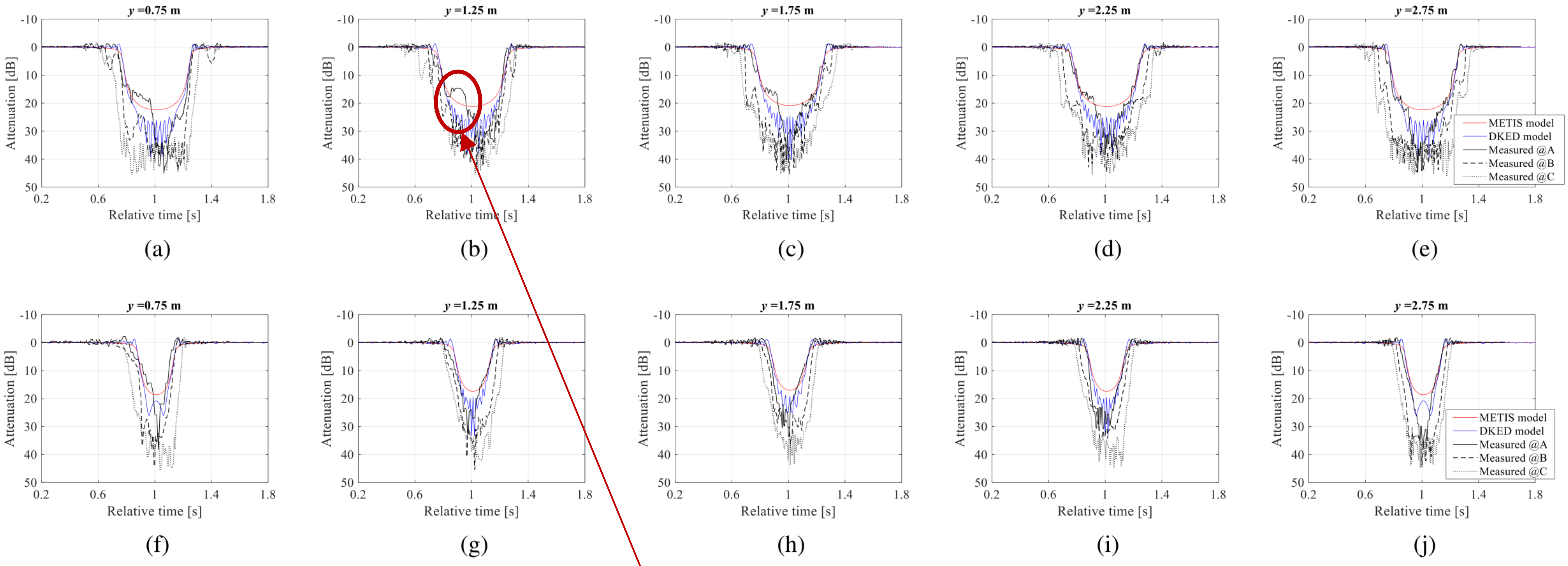
P. Zhang, P. Kyösti, M. Bengtson, V. Hovinen, K. Nevala, J. Kokkoniemi, and A. Pärssinen, "Experimental Characterization of D-Band Human Body Shadowing," accepted to **EuCAP 2023.**

Attenuation by Human Blockage (3/3)

Additional attenuation caused by human blockage @different volunteers, y-axis locations

Case 1

Case 2



The natural swinging motion of the body parts (e.g., hands, torso, and head) will cause significant fluctuation at higher frequency

Channel Modelling

Extensions to measured propagation data

1. Inclusion of human blocking events
2. Inclusion of small Doppler shifts for multipath
3. Inclusion of continuous transition scenario by interpolating measured LOS & NLOS paths using ray tracing
4. Inclusion of adaptive beam steering by Tx and Rx arrays

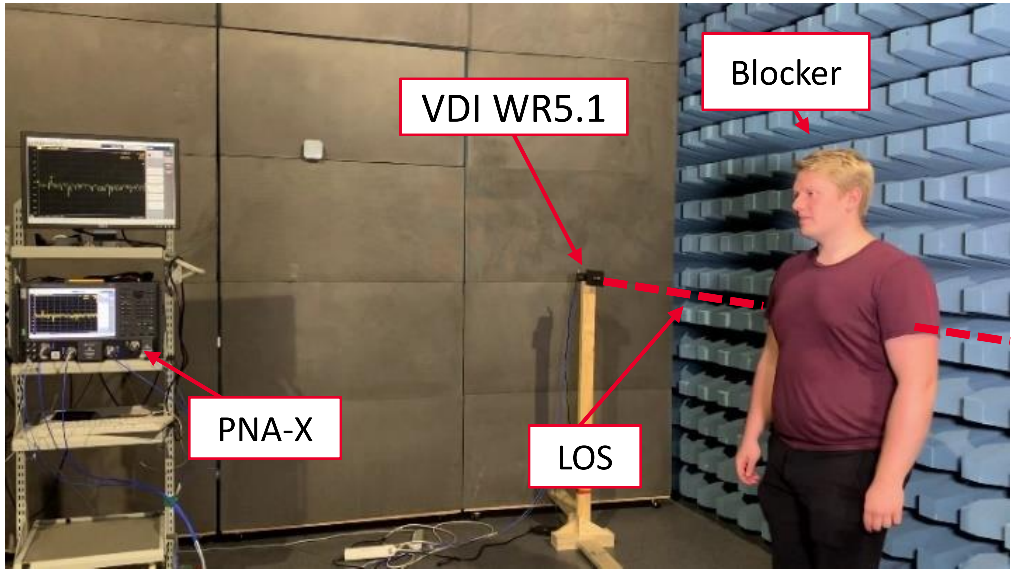
Channel modelling

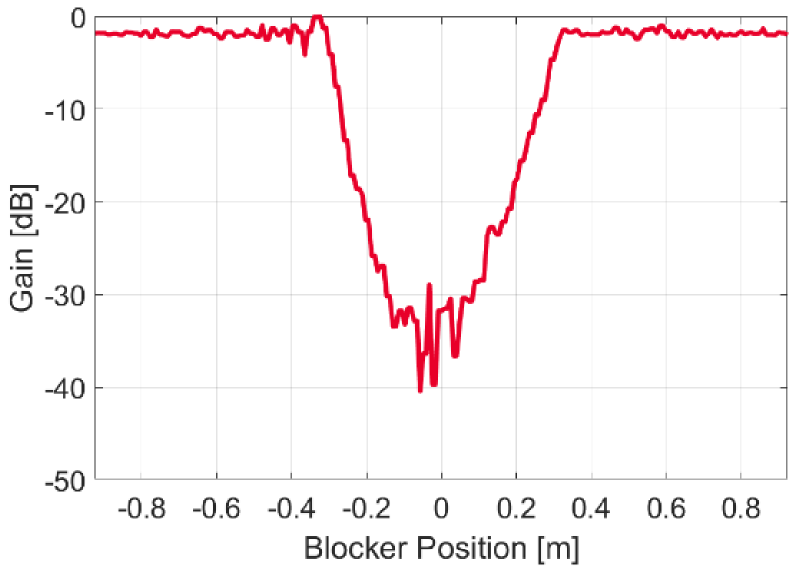
Inclusion of human blockage

Human blockage

Introducing dynamics

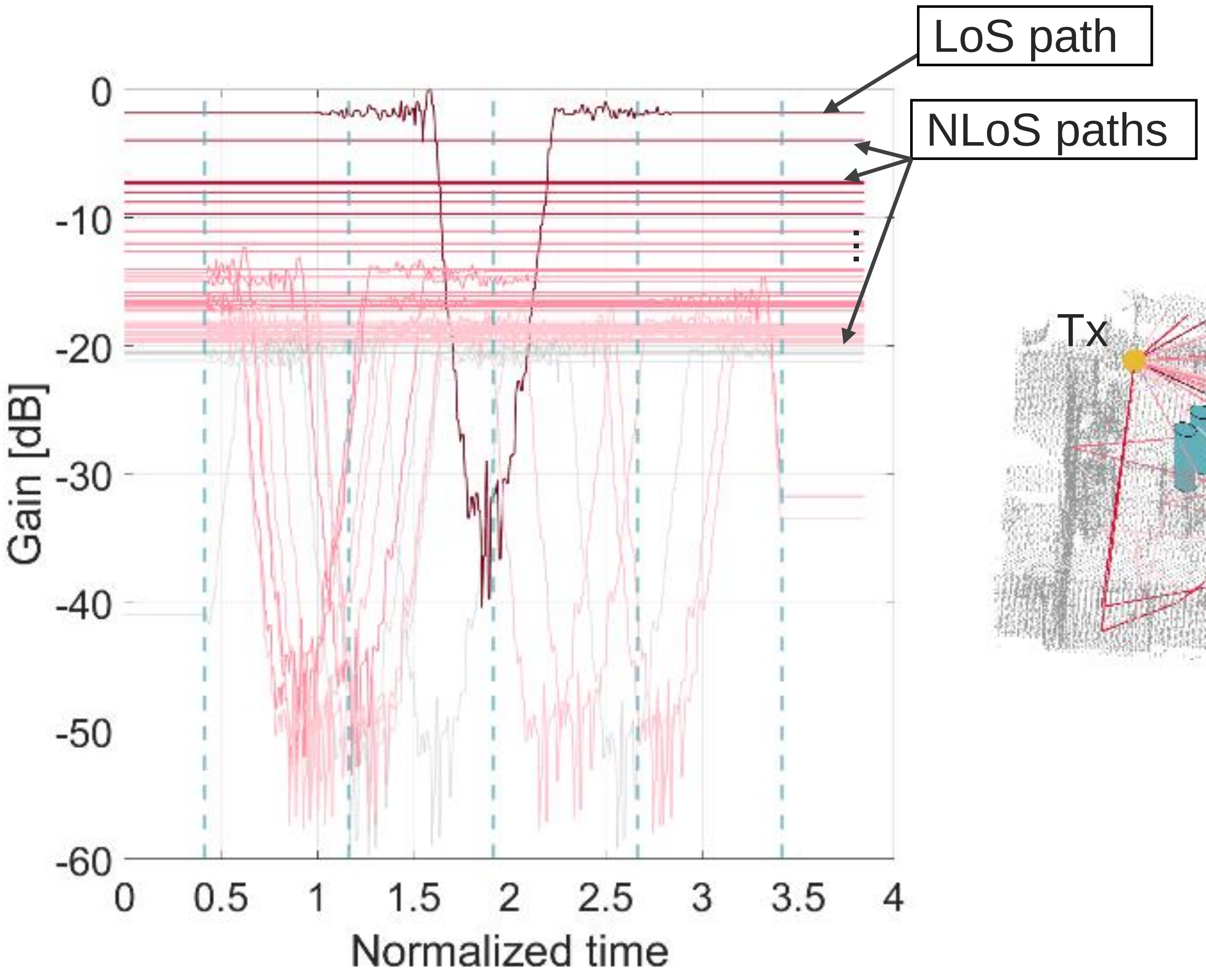
- Human blockage at 140 GHz
- Measurements performed with UOULU

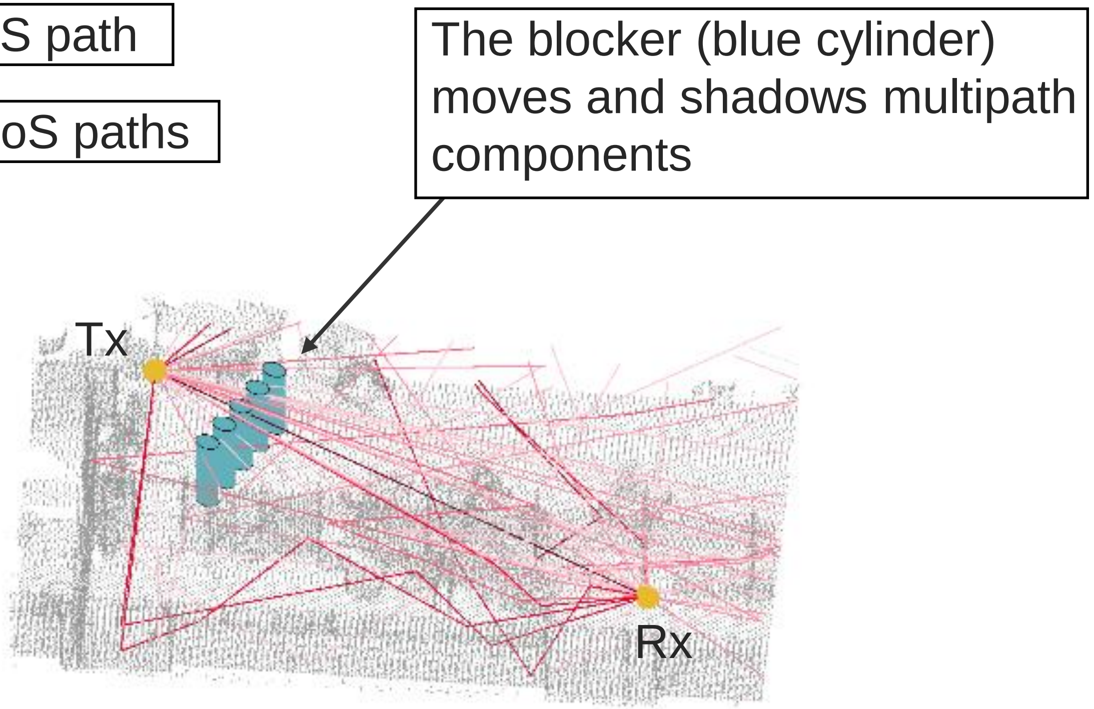




P. Zhang, P. Kyösti, M. Bengtson, V. Hovinen, K. Nevala, J. Kokkoniemi and A. Pärssinen, Experimental Characterization of D-Band HumanBody Shadowing, Oulu: EuCAP, 2022.

Blockage scenario





Blockage scenario

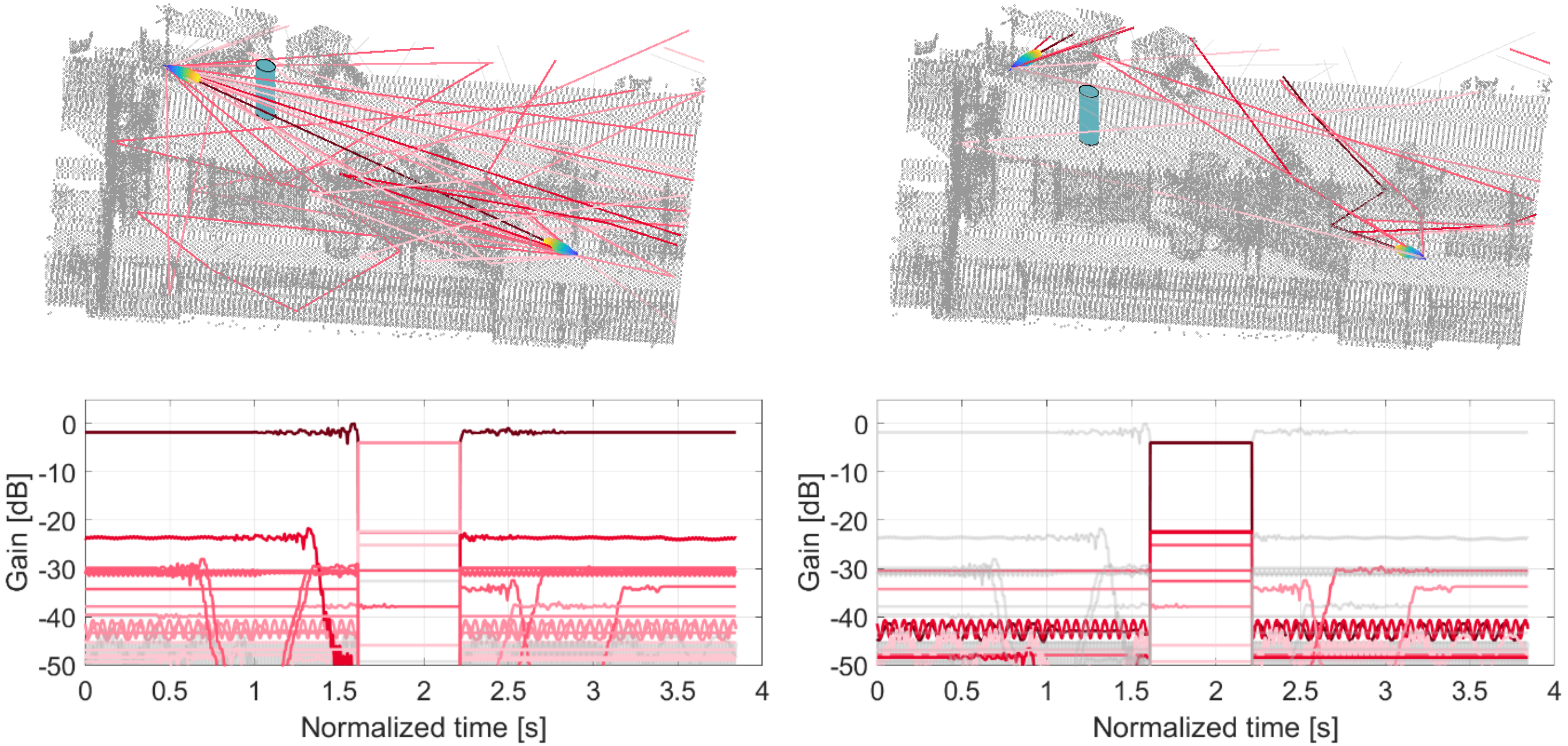
Model overview

$$H(t,\tau) = \sum_{n=1}^{N} \delta(\tau - \tau_n) \sqrt{\frac{P_n(t)}{N}} F_{rx}(t, \Omega_n^{Rx}) \exp(j\Phi_{\mathrm{n}}) F_{tx}(t, \Omega_n^{Tx}) \exp\left(j2\pi\, f_{d,n}\, t\right)$$

- $P_n(t)$ - Time variant power for each path including the blockage impact
- $F_{rx}(t, \Omega_n^{Rx}), F_{tx}(t, \Omega_n^{Tx})$ - Antenna pattern
- Φ_{n} - Initial random phase for each path
- $f_{d,n}$ - Optional Doppler spectrum following SUI-spectrum

Blockage scenario

Moving blocker – beam switch

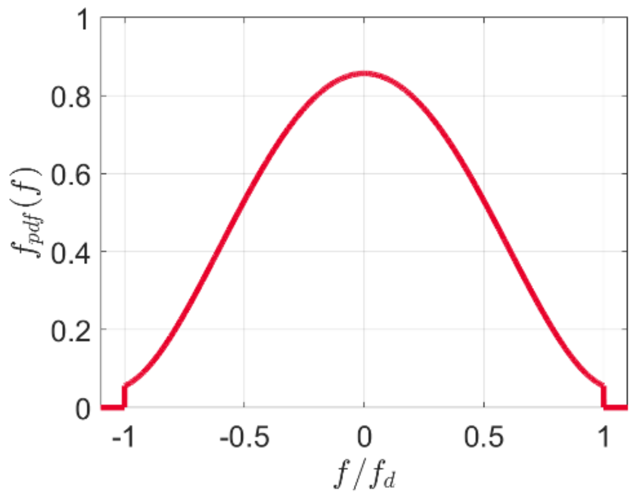


Channel modelling

Inclusion of Doppler shifts

Adding small Doppler components

SUI spectrum



- To mimic a small motion of the environment
- SUI-model – for small environmental Doppler
- Based on a static link (i.e. no moving terminals)
- $f_{max} = 8\ Hz$ selected

- Doppler shifts for multipath are drawn randomly from the SUI distibution:

$$f_d(f) = \begin{cases} \frac{1}{1.1673 f_{max}} - \frac{1.72 f}{1.1673 f_{max}^3} + \frac{0.785 f^4}{1.1673 f_{max}^5} & -f_{max} \le f \le f_{max} \\ 0 & \text{else where} \end{cases}$$

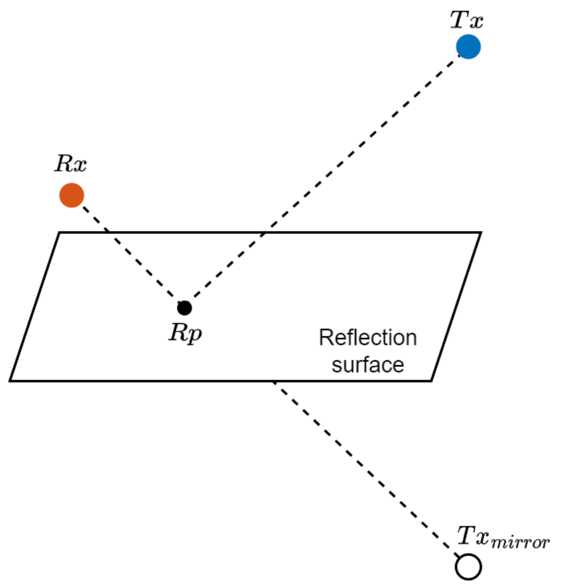
Channel modelling

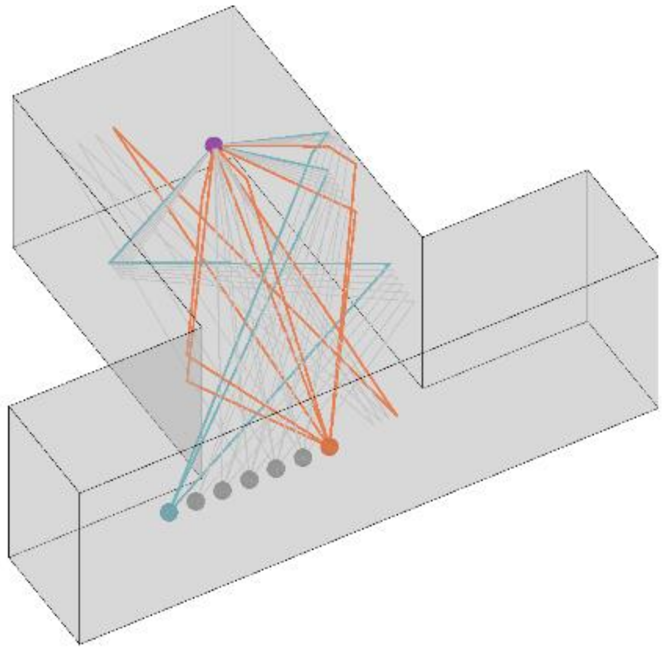
Inclusion of transition

Transition scenario

Interpolating measurement data

- Simple environment – image method used for ray tracing
- Comparison of spatial information of rays with channel sounding data
- Determination of gain at LoS and NLoS for each identified path



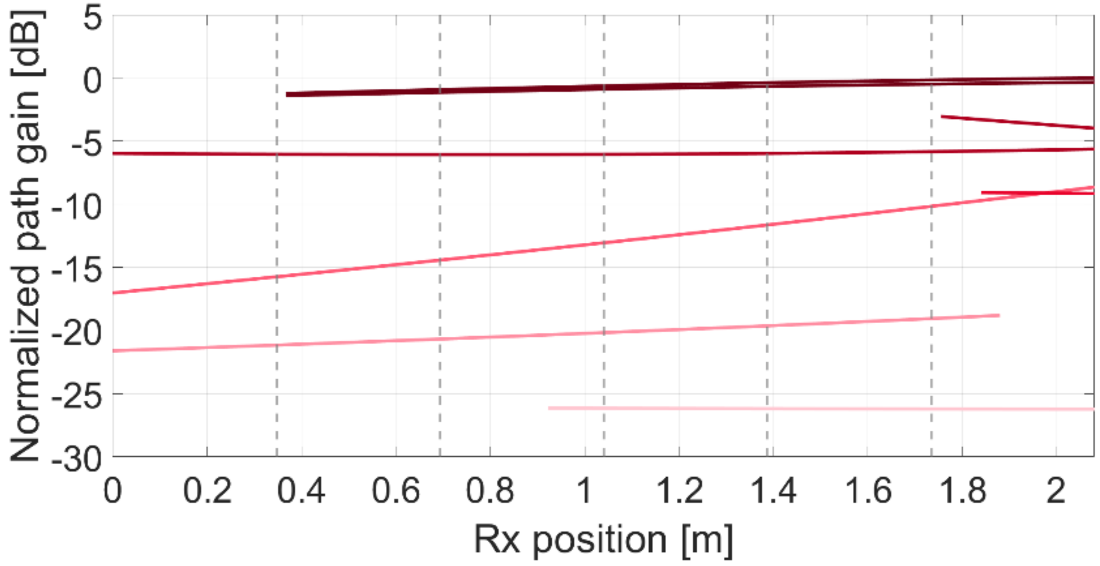


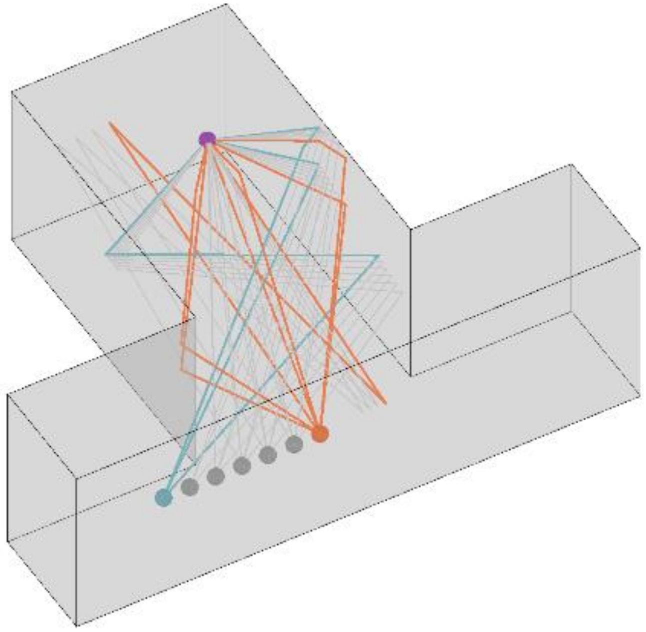
Transition scenario

Transition

- The transition at position x is calculated as

$$P_n(x) = P_{FSPL}\big(l_n(x)\big) + P_{ant} + P_{RL}\big(\theta(x)\big)\ [dB]$$





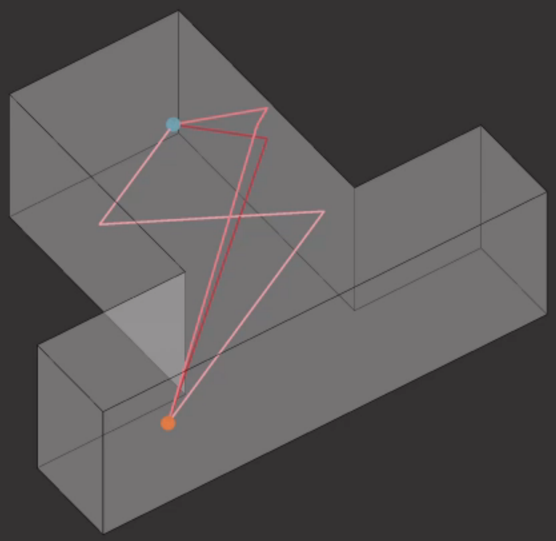
Transition scenario

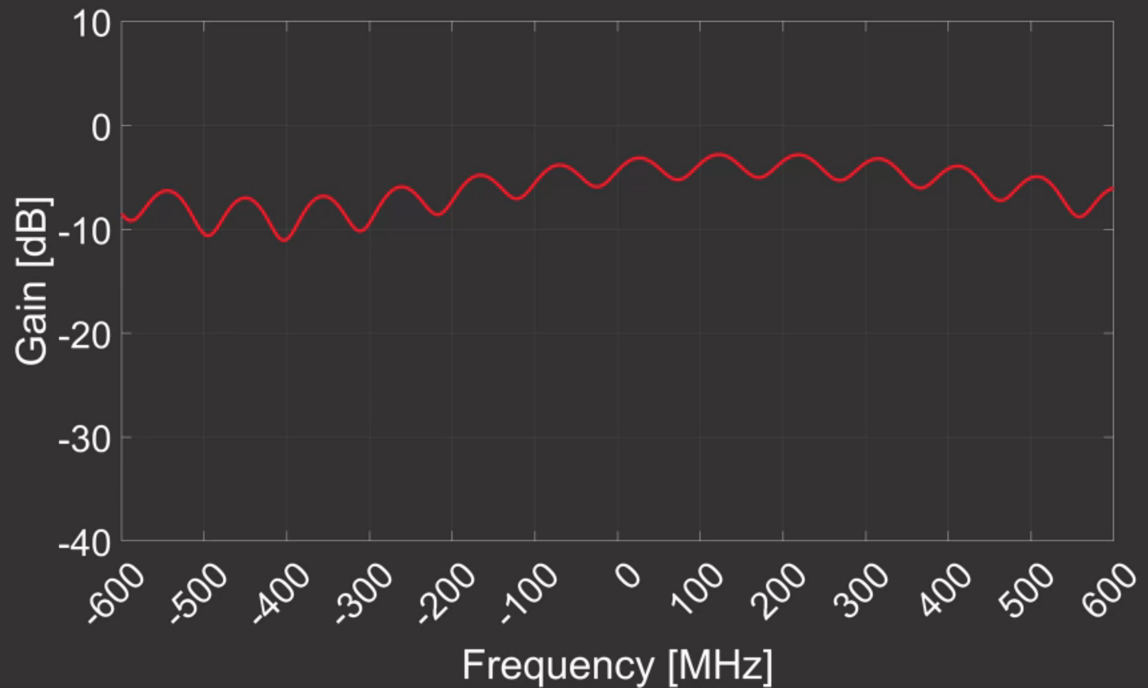
Model

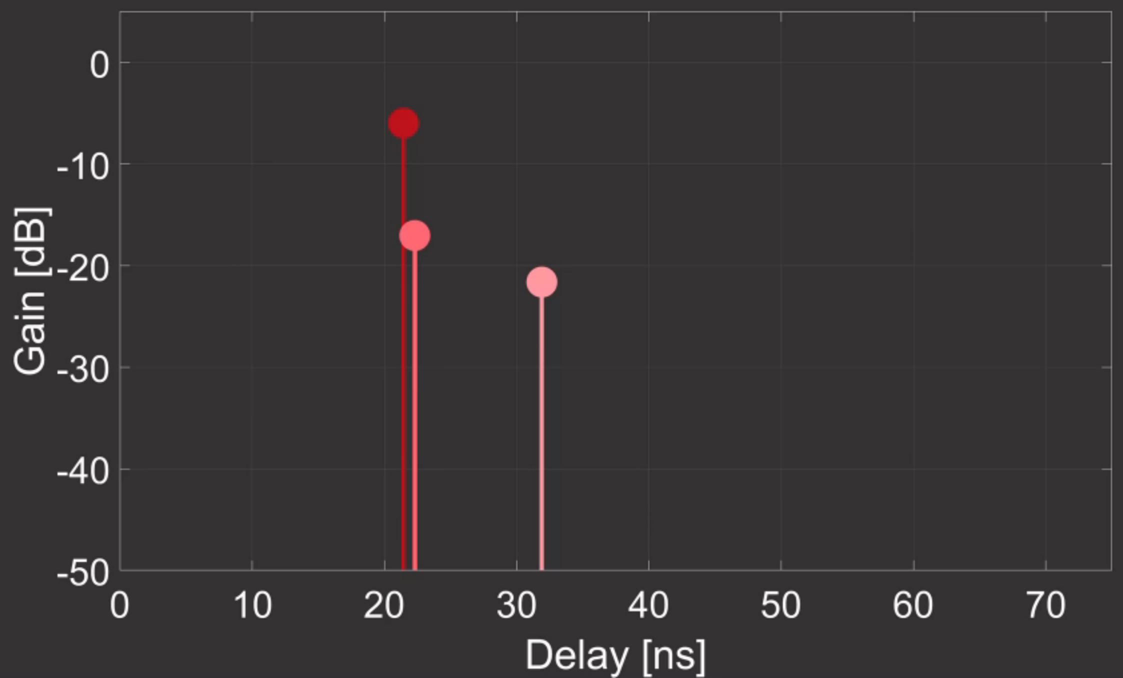
$$H(x,\tau) = \sum_{n=1}^{N} \delta(\tau - \tau_n(x)) \sqrt{\frac{P_n(x)}{N}} F_{rx}(x, \Omega_n^{Rx}) \exp(j\Phi_\text{n}) F_{tx}(x, \Omega_n^{Tx}) \exp\left(j2\pi \frac{l_n(x)}{\lambda}\right)$$

- $\tau_n(x) = \frac{l_n(x)}{c}$ – Delay of path based on the path length $l_n(x)$ and speed of light c
- $P_n(x)$ - Power of the path n
- $\exp\left(j2\pi \frac{l_n(x)}{\lambda}\right)$ - Phase term calculated based on the path length and the wavelength $\lambda = 2.14\, mm$ at $140\, GHz$
- x - The position of the moving terminal

D-band directional measurement extended with ray tracing to NLOS→LOS transition







Channel modelling

Inclusion of antenna beams

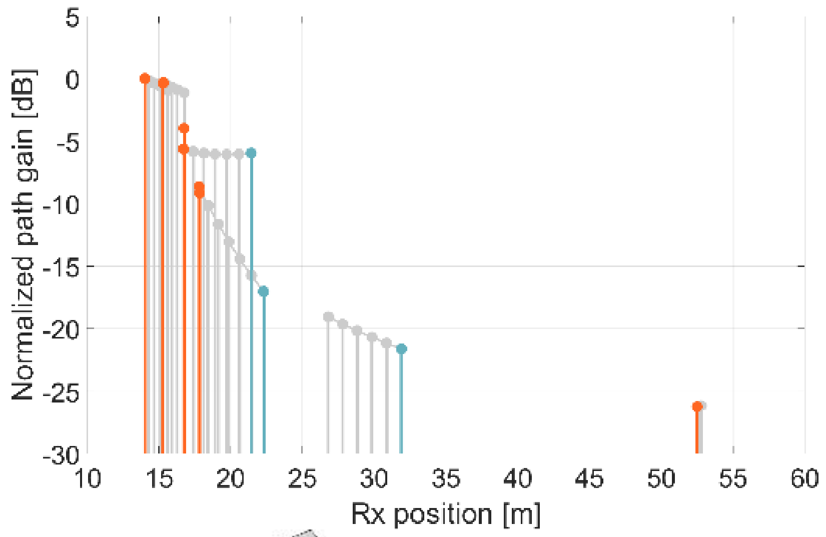
Transition scenario

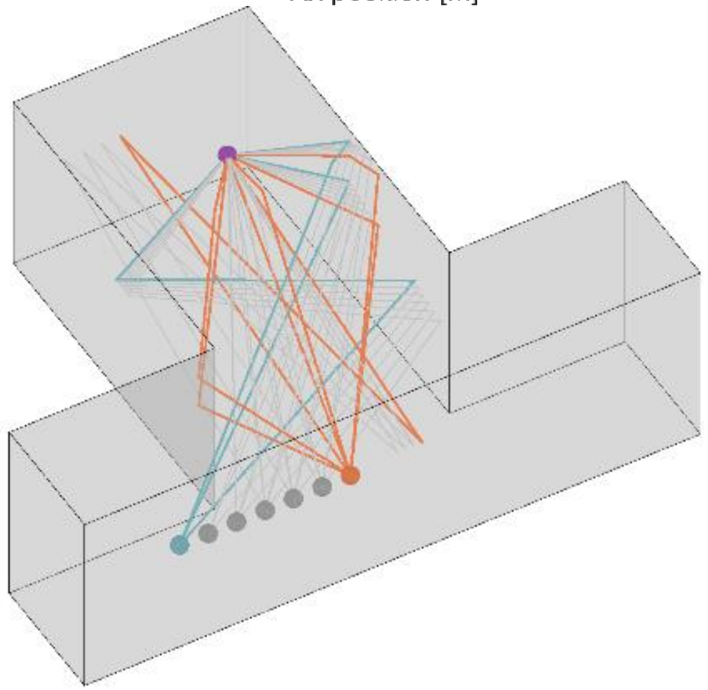
With isotropic pattern

- Baseline data is about the propagation channel

→ antenna effect removed

→ corresponds to use of isotropic antennas at both link ends

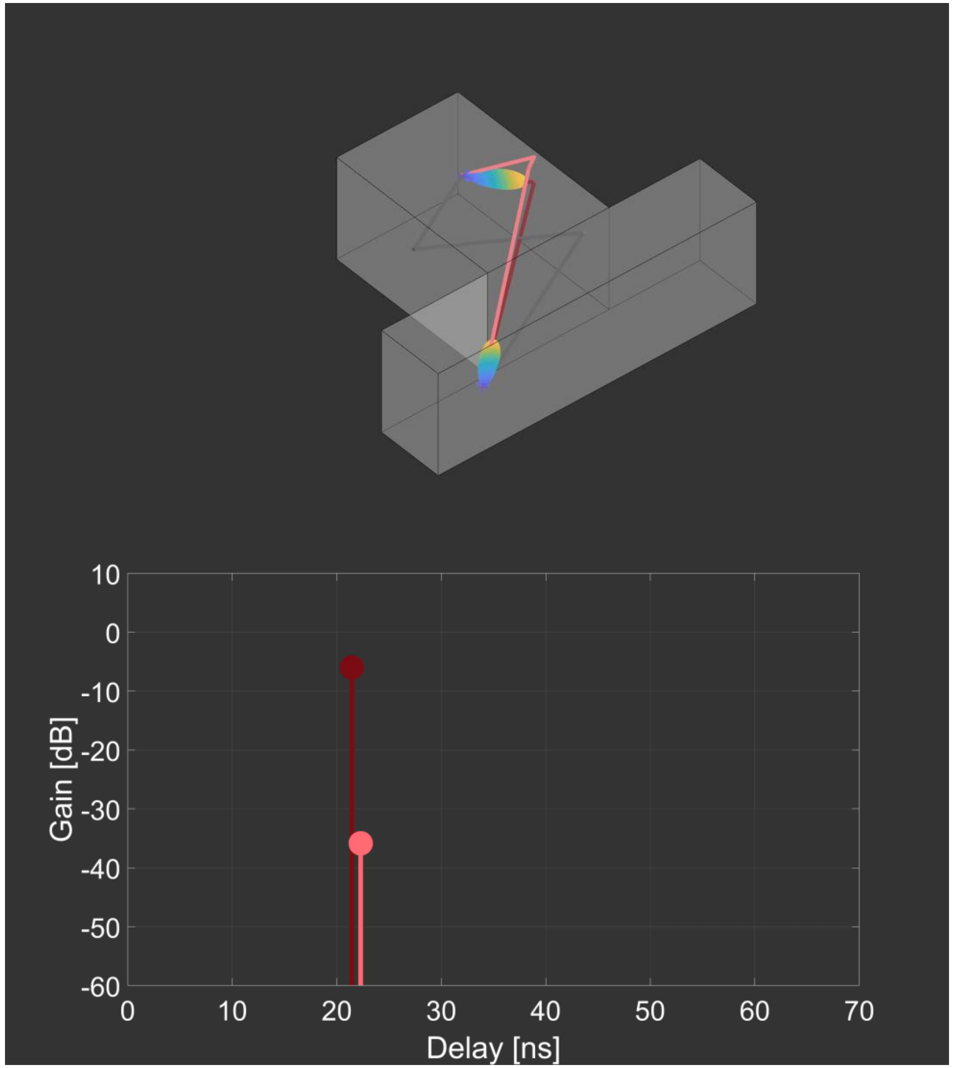




Transition scenario

With directive antenna pattern

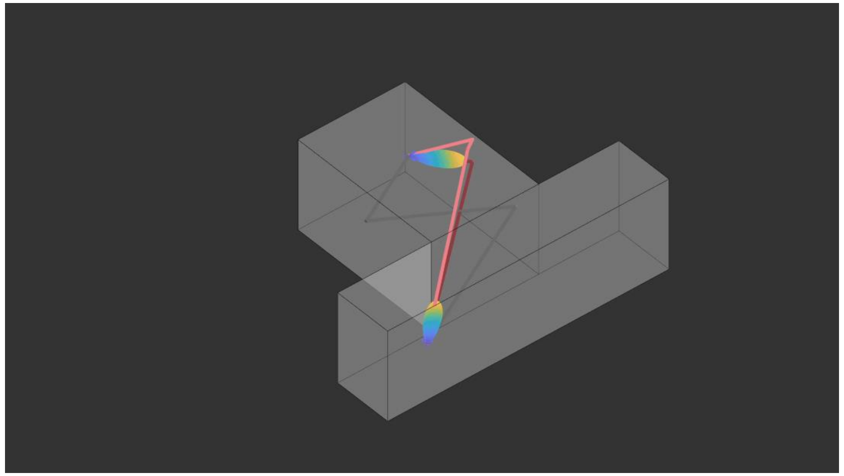
- Antenna beams are steered at each time instant to the direction providing the highest gain
- Practically only one high gain tap remains (in this scenario)
- Switch from a reflected path to the LOS path when Rx becomes visible to Tx

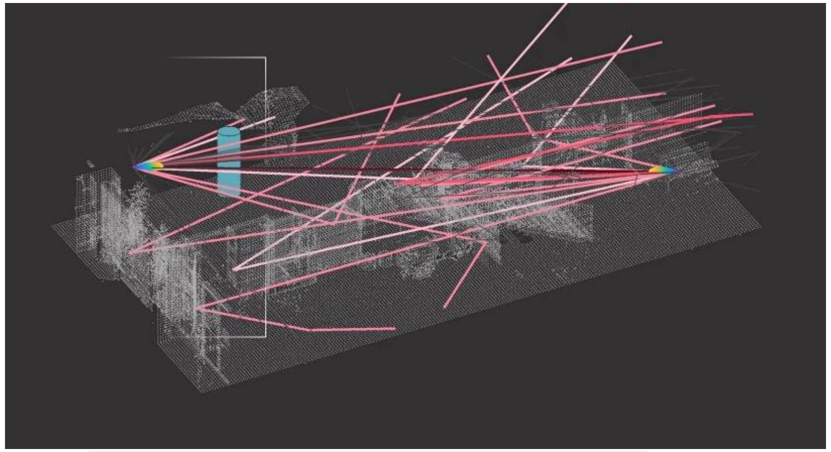


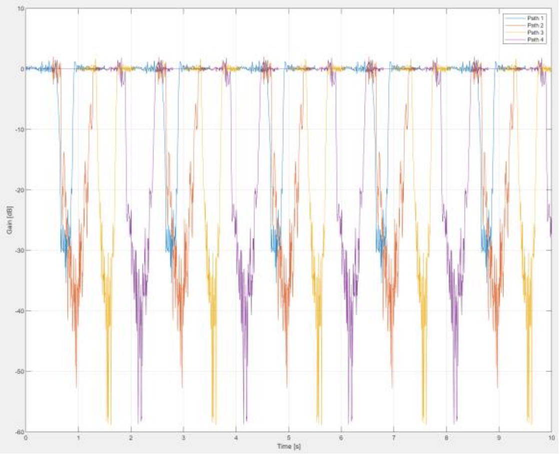
Channel modelling work

Recent KEYSIGHT TECHNOLOGIES efforts

- Research projects collect measurement data and develop channel modeling concepts
- Keysight has extended the stored channel model and implemented PoC demo using measurement data from University of Oulu and Aalto University
  - Embedding of time variant antenna beams
  - Interpolation of multipath between Tx/Rx locations using ray tracing
    $\rightarrow$ Enables trajectories of Tx/Rx (for communication and sensing)
  - Introduction of small artificial Doppler shifts for multipath
  - Addition of time variant attenuation by measured human blockage pattern
    - E.g. by defining blocker trajectories or drawing blockage events randomly







Emulation

Validation by lab measurements

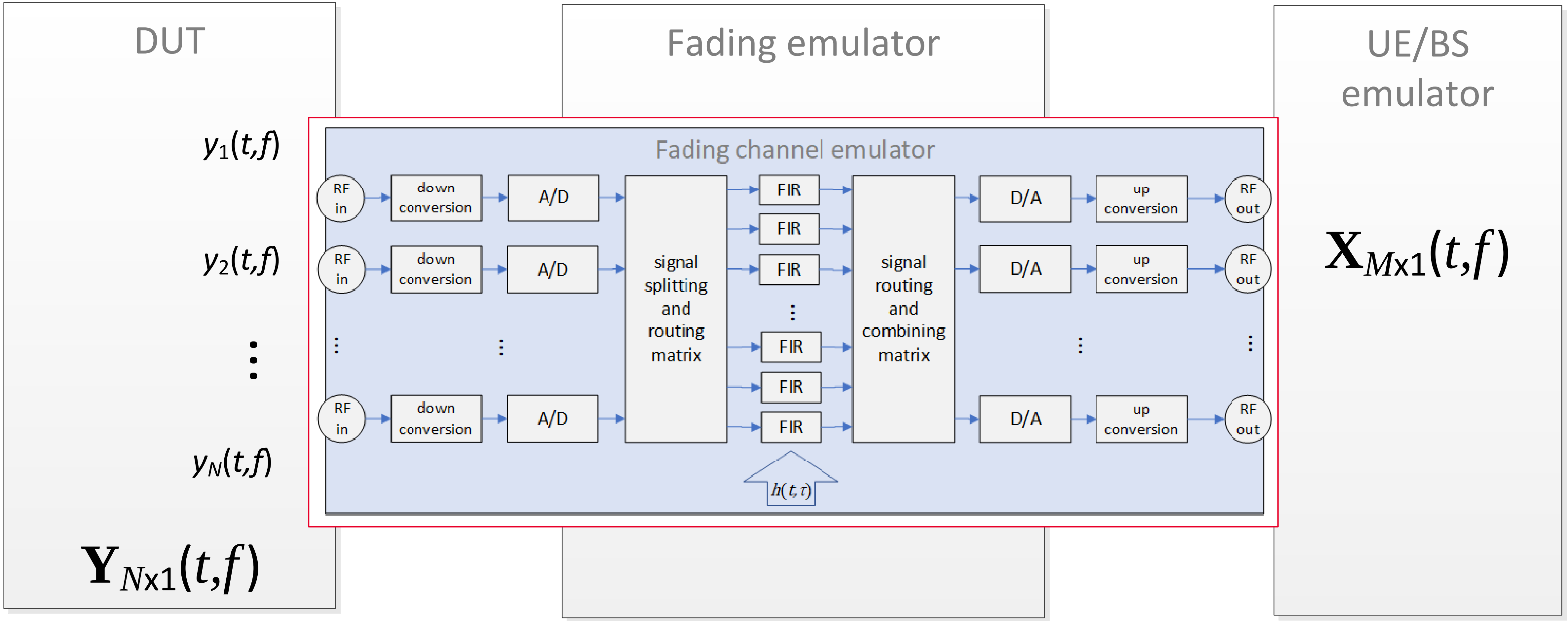
Emulation in the lab

- Channel models were implemented in Keysight Channel Studio GCM (SW)
- Emulation files for Keysight Propsim were generated
- Models were emulated at 2.0 GHz centre frequency and BW = 1.2 GHz
- Emulator's performance was measured in two different setups:

1. Network analyser + Propsim
   - for evaluating channel frequency and impulse responses, and power delay profiles (PDP)
2. Signal generator + Propsim + Signal analyser
   - for the Doppler Power Spectrum

Emulation

In the lab

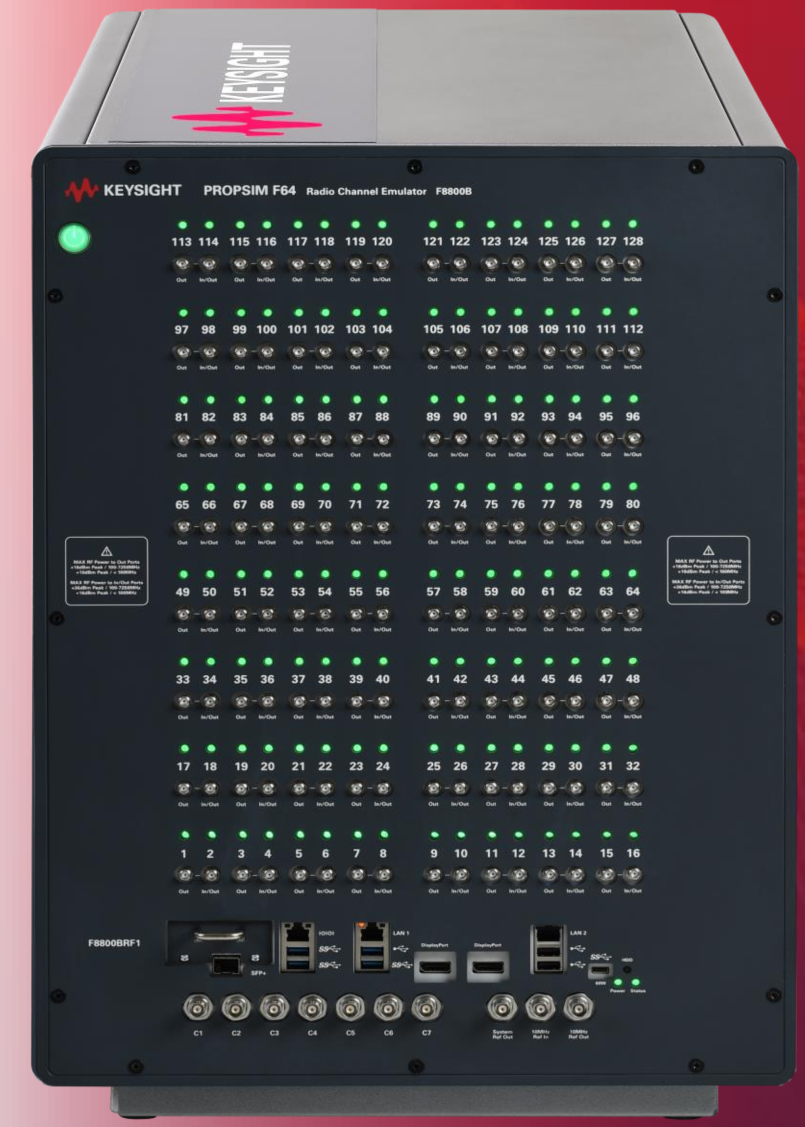


PROPSIM F64

- Supports fading capacity needs that extend beyond the use cases and configurations of PROPSIM FS16
- End-to-end realistic and repeatable real-world performance testing of 5G multi-mode devices and base stations in the laboratory
- The optimal solution for Massive MIMO testing
- Full Antenna Array Sampling
- From 8 to 64 bidirectional TRX ports or unidirectional TX and RX ports
- Embedded VSA/VSG wireless signal analyzer

View F8800A Data Sheet

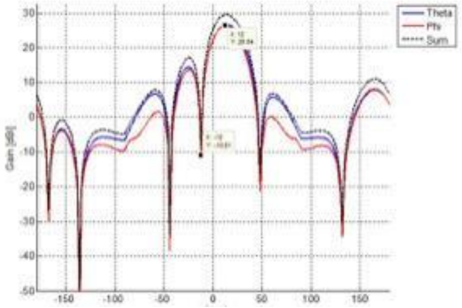
View F8800B Data Sheet

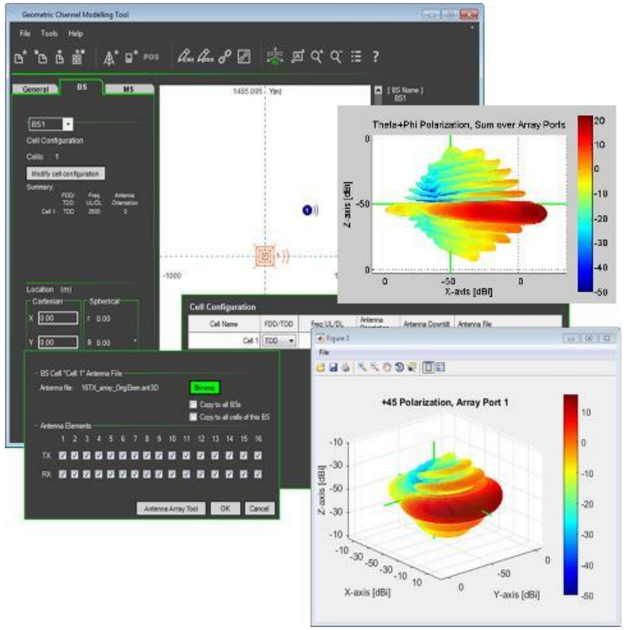


Keysight Channel Studio (SW)

- ✓ User-defined 3D spatial scenarios and dynamic modeling of movement
- ✓ Arbitrary and complex test scenarios including
  - Multi-frequency and multi-RAT HetNet test scenarios
  - Device-to-Device (D2D) supporting IoT and V2X scenarios
  - Complex field to lab scenarios such as High-Speed Train test scenarios.
- ✓ Antenna model embedding
  - Including antenna library and Antenna Array Tool for modeling arrays and beams
- ✓ Available standard channel models
  - 3GPP TR38.901, TR36.873 and SCME
  - IMT-Advanced
  - Winner
  - TGn/ac/ax

- ✓ LTE 3D / Massive MIMO
  - Static and dynamic 3D beamforming and MU-MIMO test cases
  - 3GPP TR 36.873 3D MIMO channel models
  - CMCC eNB CP5/CP6 acceptance test plans
- ✓ 5G mmW test cases
  - 3GPP TR38.901 Channel models
  - Supports mmW model frequencies including 28/39GHz at OTA/IF domain
- ✓ V2V, V2X, D2D scenarios
  - Drop the cars on the map
  - Select antennas, multiple per car supported
  - Choose the environment



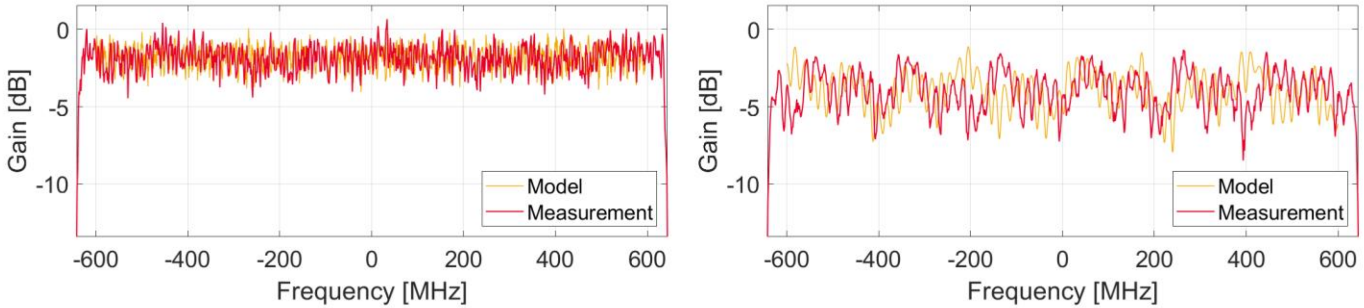


Validation

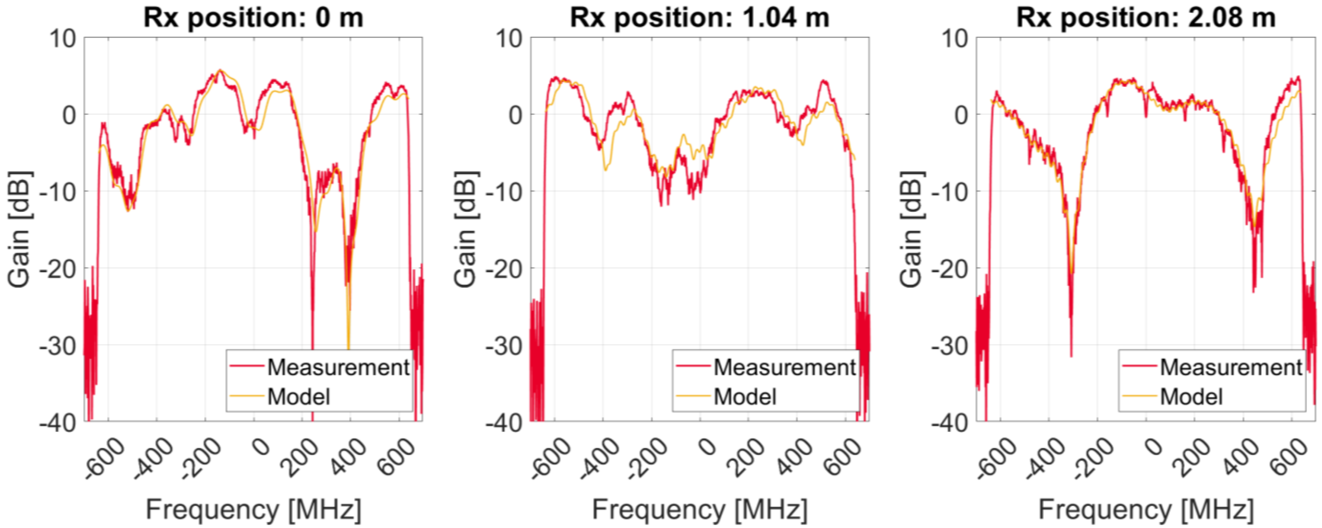
Channel Frequency Response (CFR)

- Instantaneous CFRs at various time instants
- Measured by Keysight PNA-X
- Good match between the model and the emulation

Blockage model

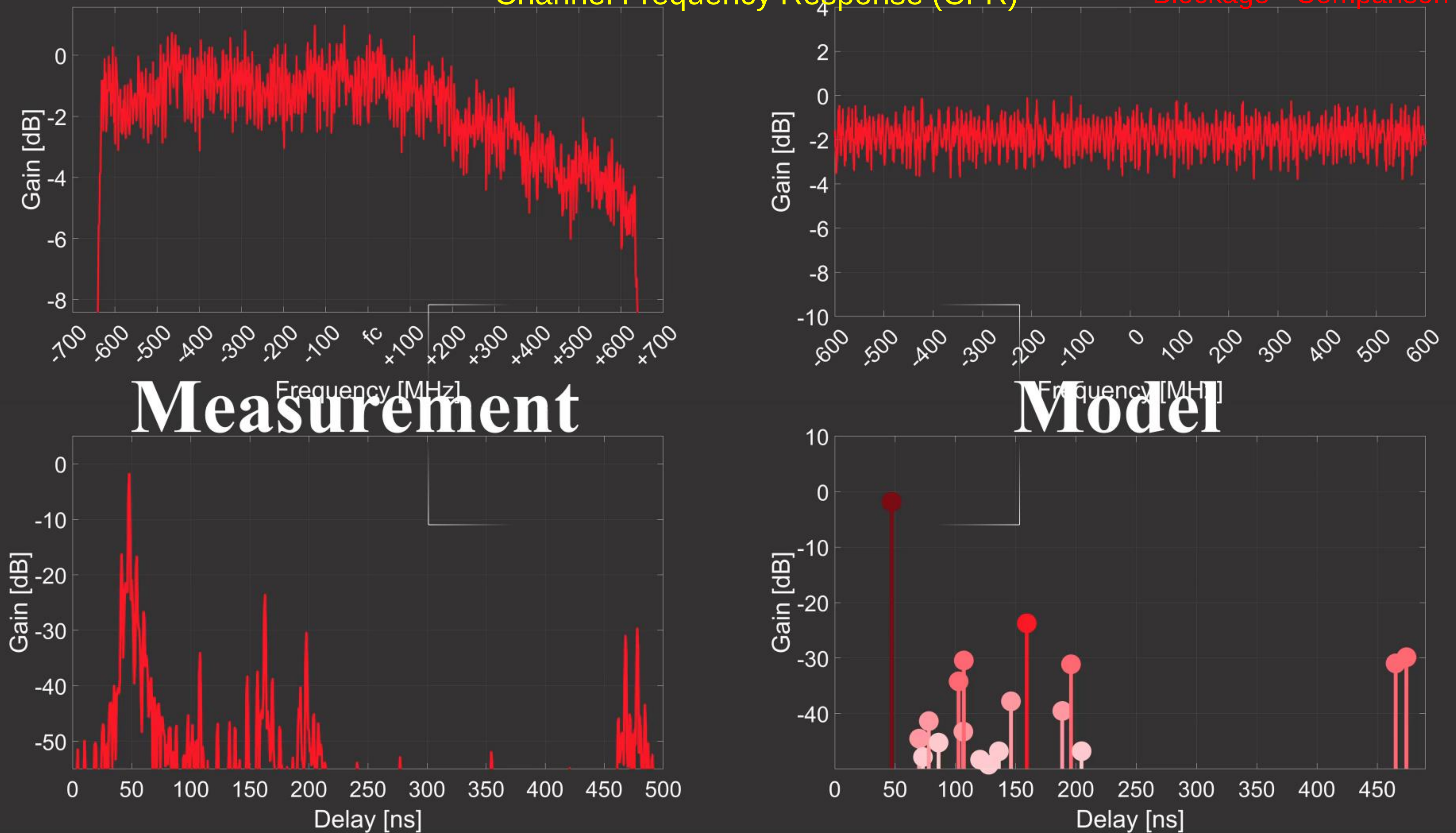


Transition model



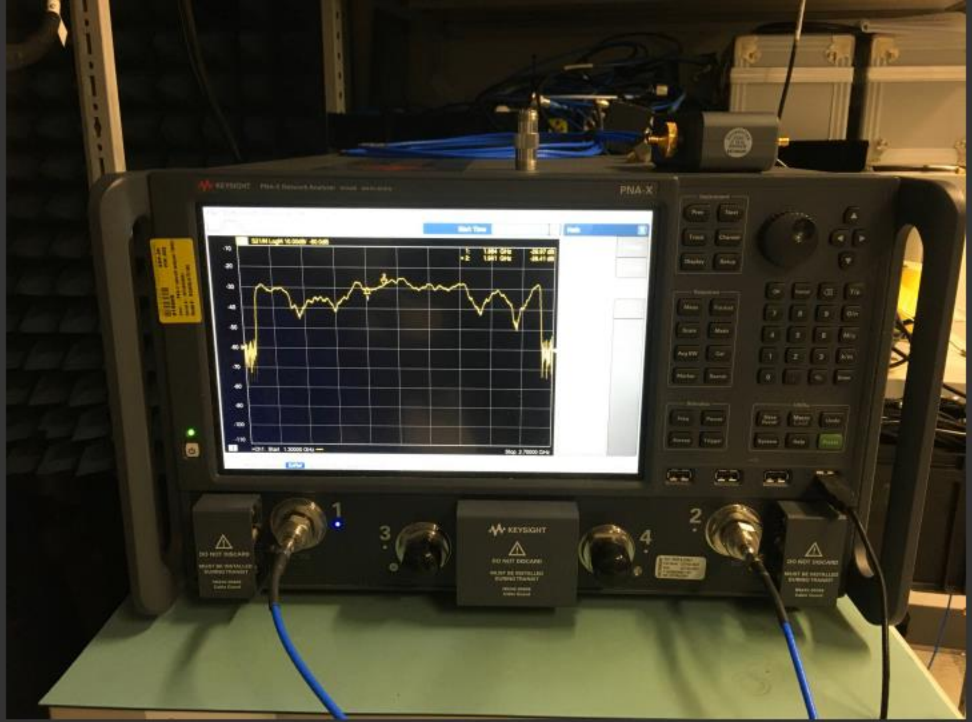
Channel Frequency Response (CFR)

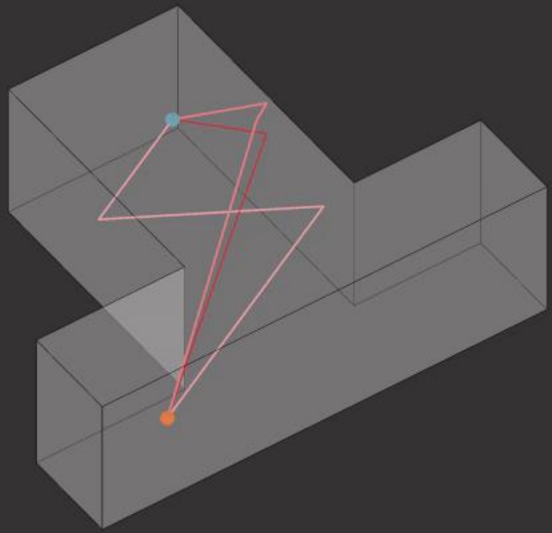
Blockage - Comparison

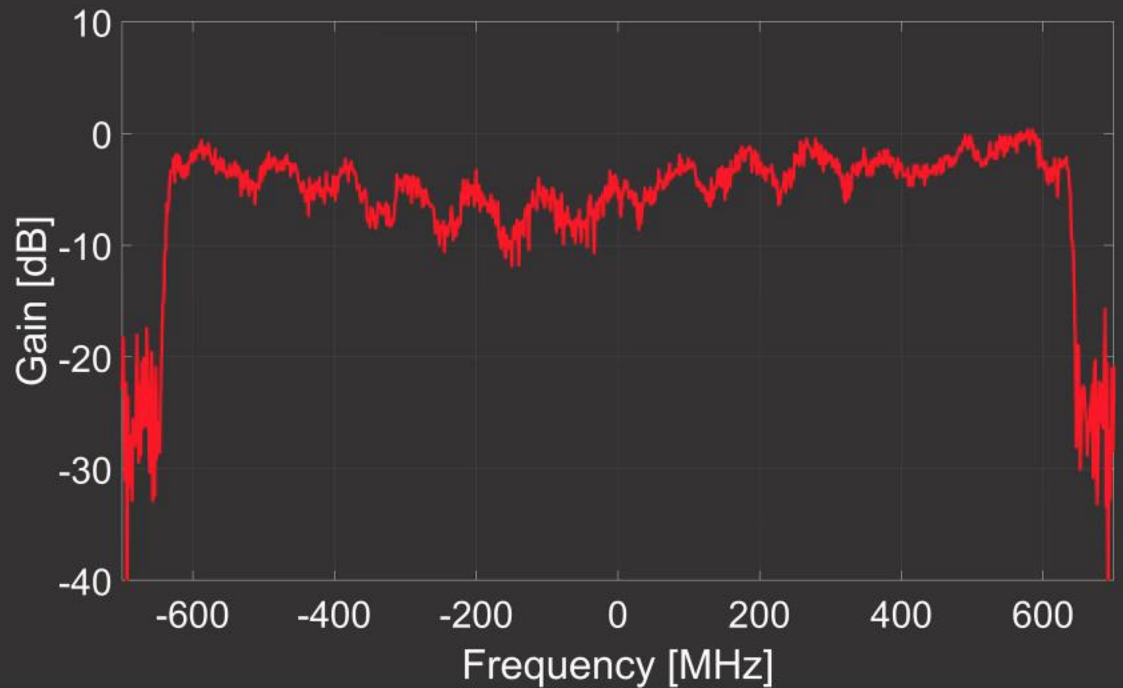


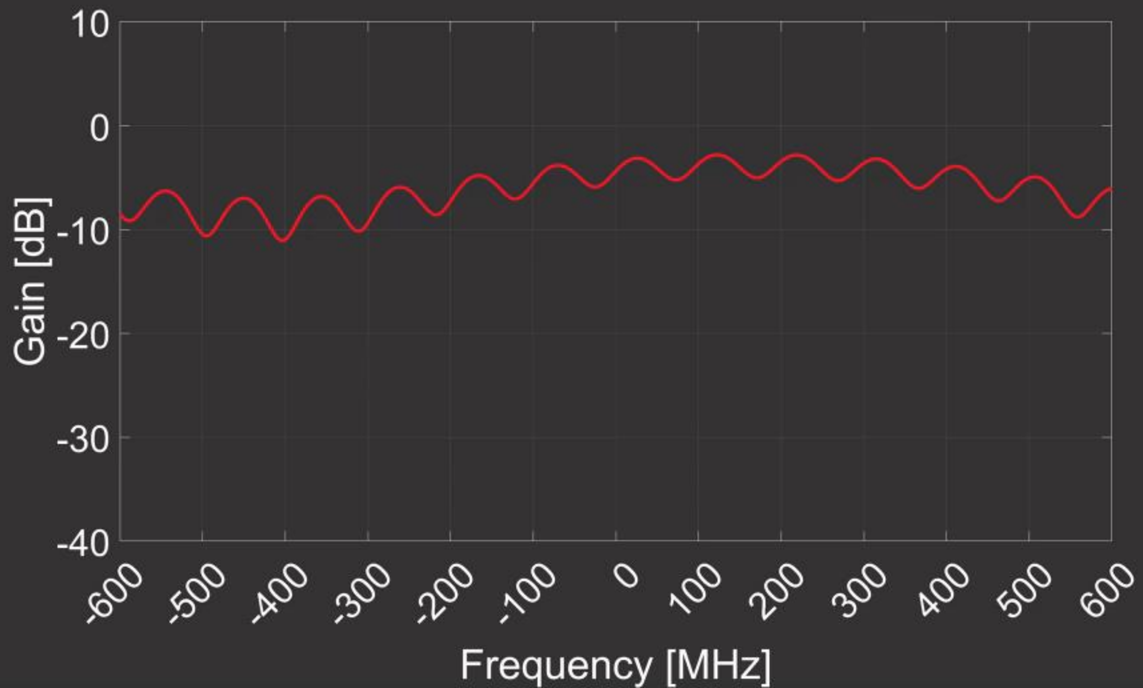
Channel Frequency Response (CFR)

Transition - measurement







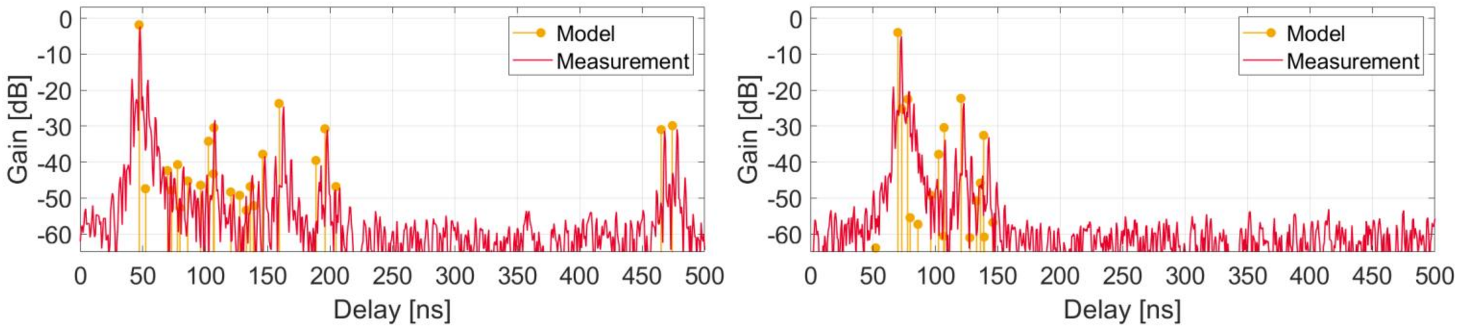


Validation

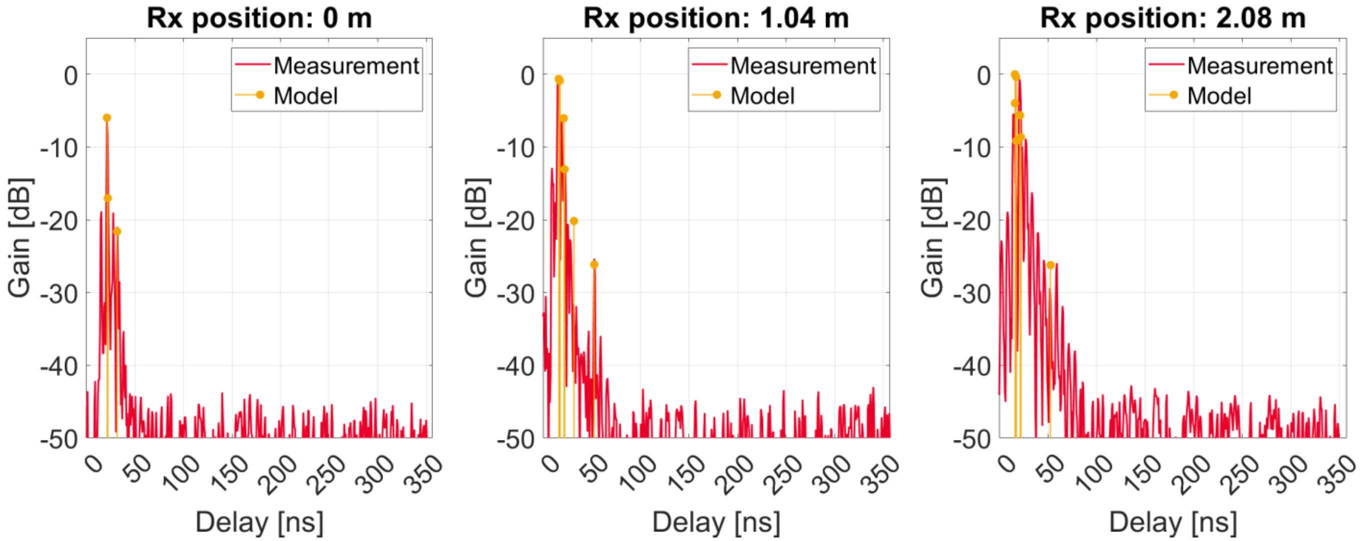
Channel Impulse Response (CIR)

- Instantaneous CiRs at various time instants
- Measured by Keysight PNA-X
- Good match between the model and the emulation

Blockage model

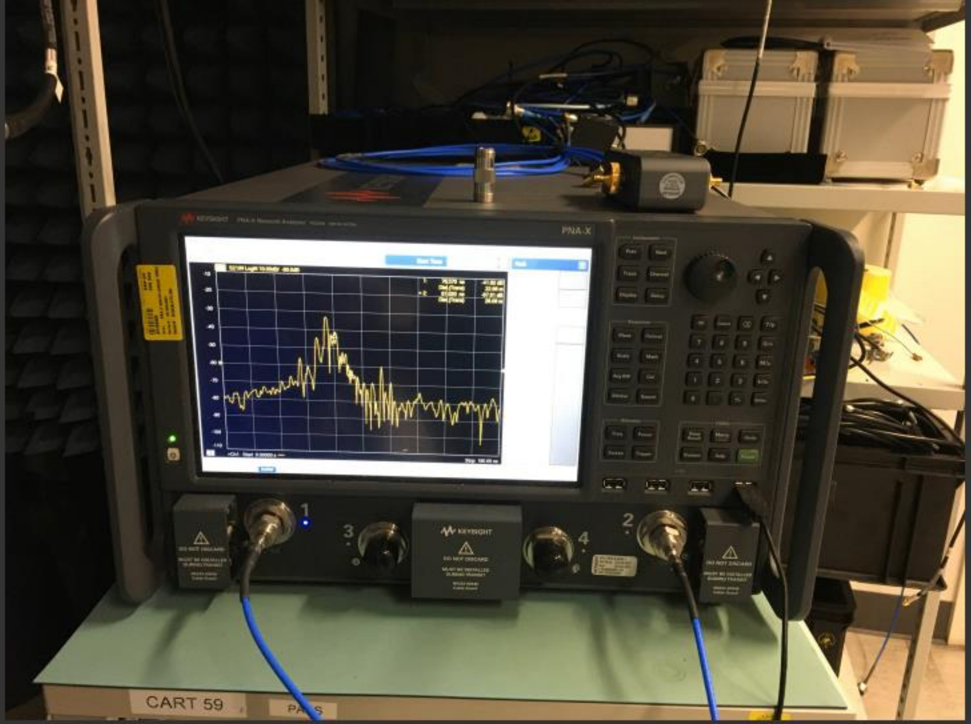


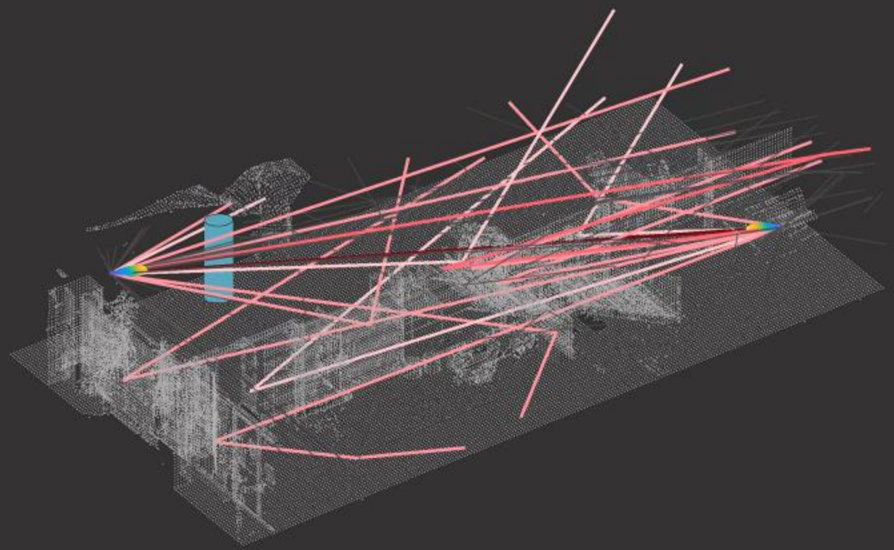
Transition model

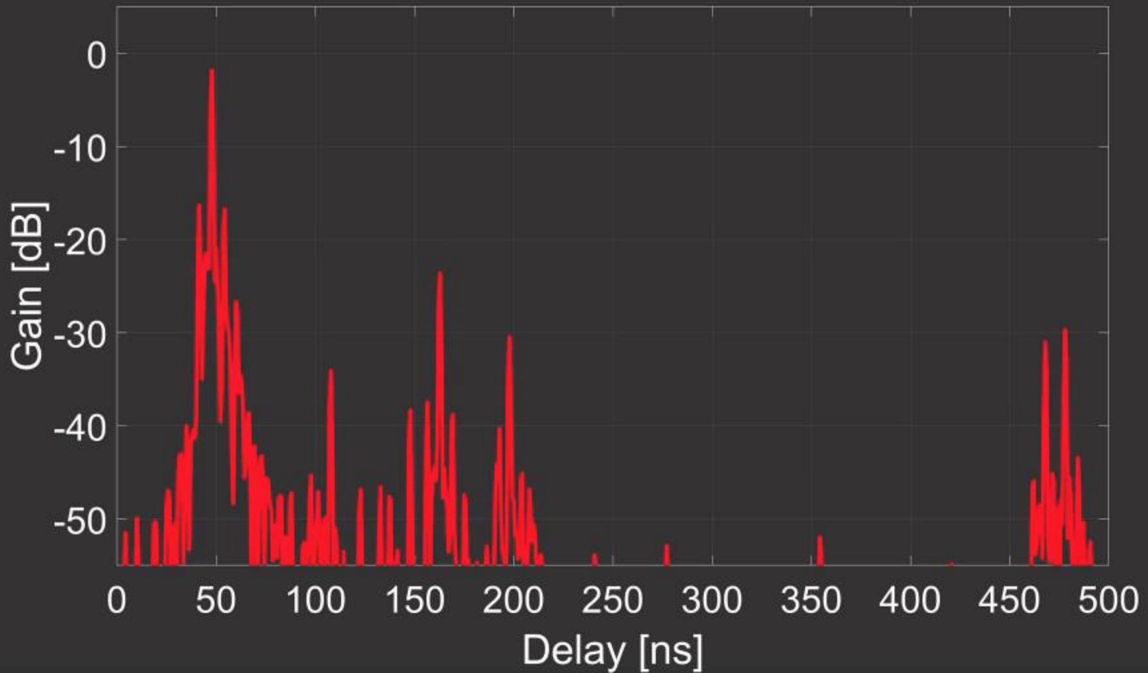


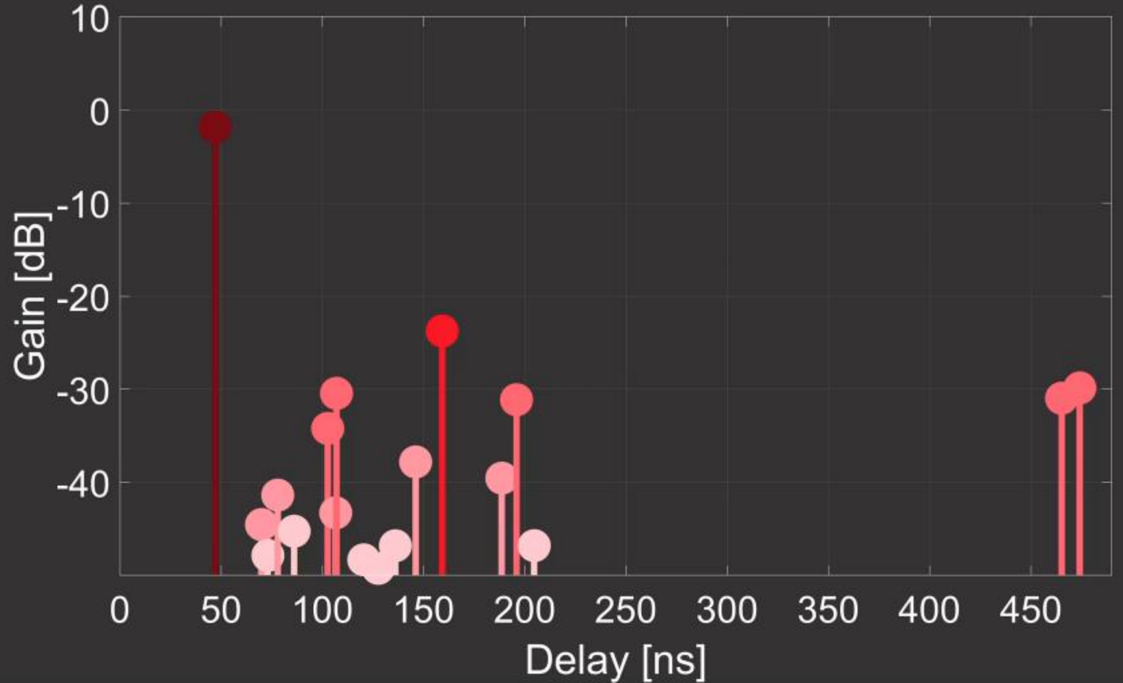
Channel Impulse Response (CIR)

Blockage - Measurement



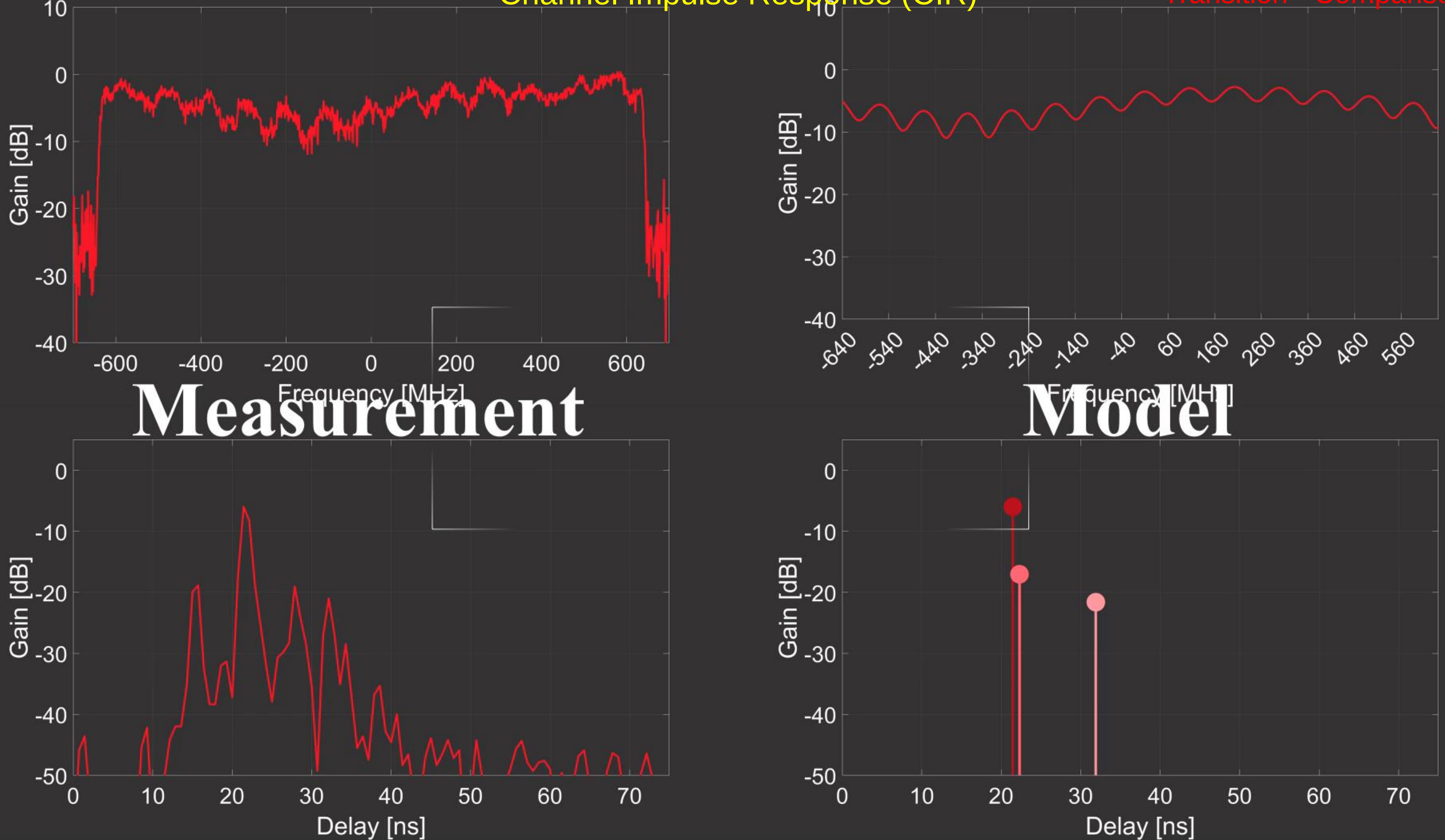






Channel Impulse Response (CIR)

Transition - Comparison



Summary

Summary

- Specified measurement-based dynamic channel models at sub-THz (140 GHz)
- Emulated models with Keysight Propsim™ at an IF
- Validated the emulations by lab measurements and comparison to the models

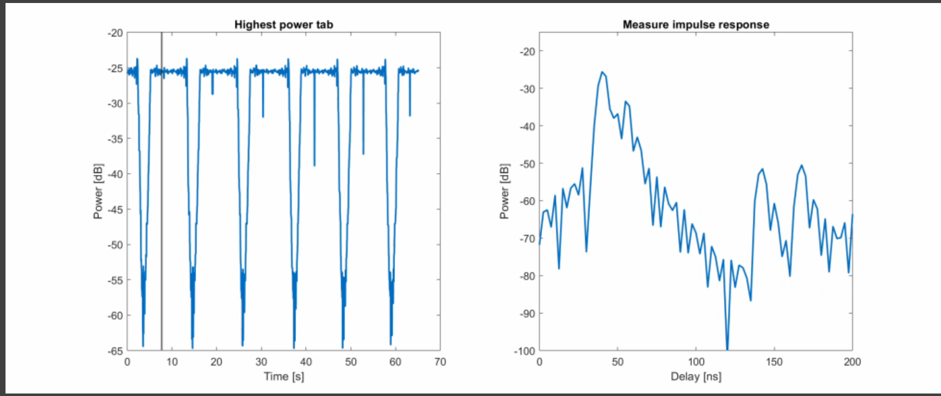
➢Good match in: Power delay profiles, Wide band frequency responses, Time-variant shadowing by human blockage

→The world's first HW emulation of a 6G channel model

- Thanks for the good co-operation to
  - Oulu University: P. Zhang, V. Hovinen, K. Nevala, J. Kokkoniemi, A. Pärssinen
  - Aalto University: F. De Guzman, P. Koivumäki, K. Haneda

KEYSIGHT

Emulation & Lab Measurement



KEYSIGHT

Thank you