KEYSIGHT

Actions for 6G Radio Channel Characterization

one6G Open Lecture 5 – Channel Modeling
23rd March 2023
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- Keysight Technologies Finland
  - Senior specialist
- University of Oulu, Finland
  - Docent (adjunct prof.)
- Research interests
  - Radio channel characterization: measurements, estimation, modelling, emulation
  - Over-the-air test systems, antenna measurements, fading emulation

Pekka Kyösti

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  - What is radio channel characterization?
  - Why is it done?
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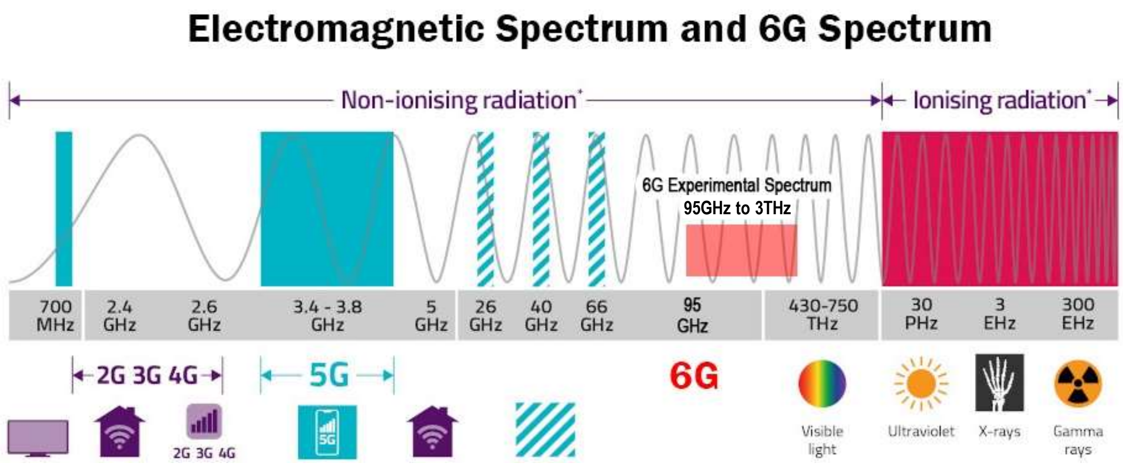
- Summary



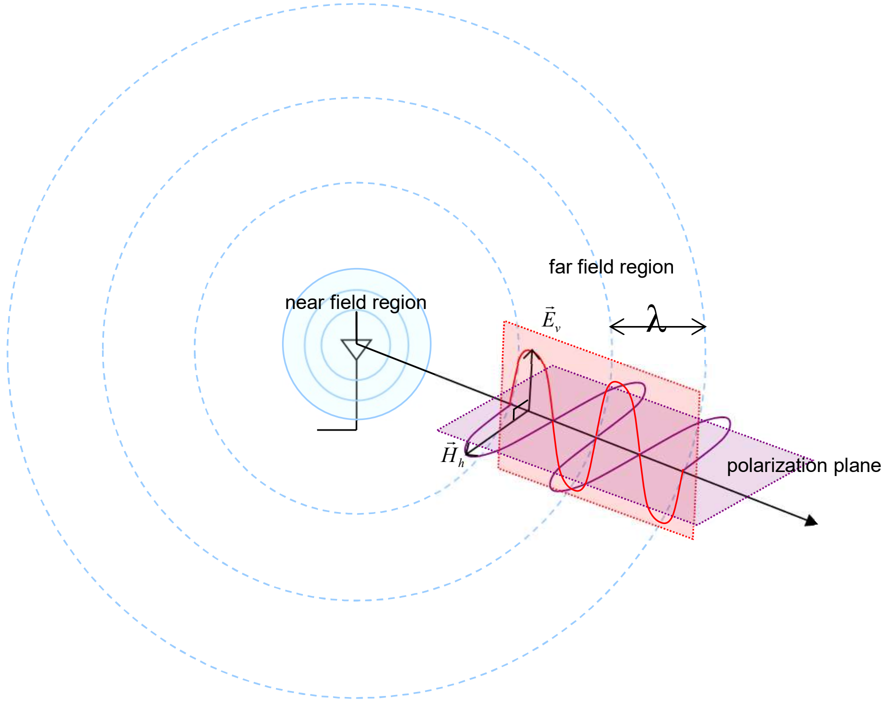
Sub-THz = 100–300 GHz

Introduction

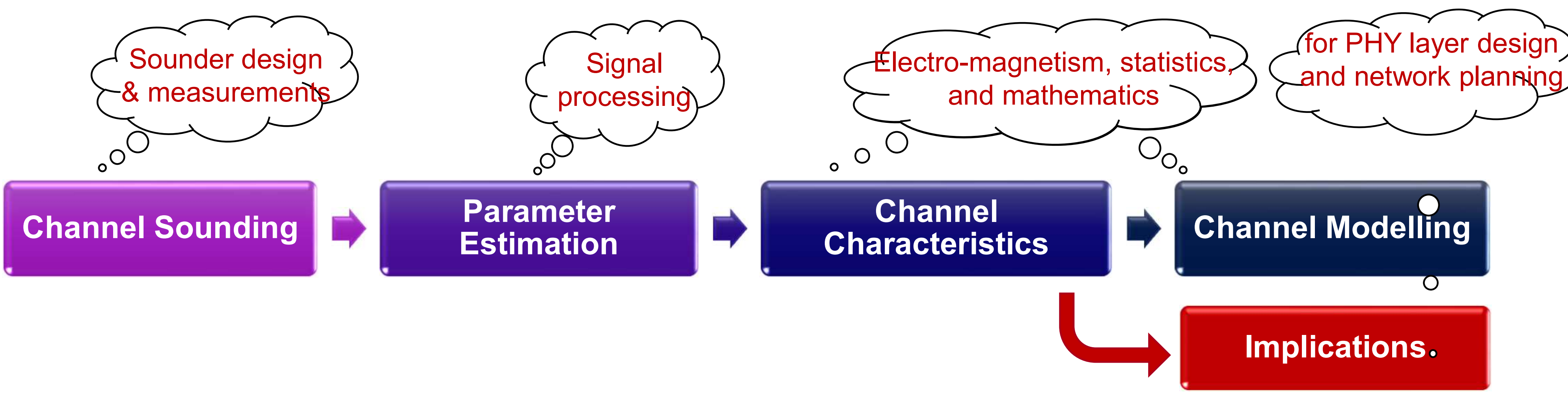
What is radio channel characterization?

"Radio channel characterization is a combination of physics, mathematics, and engineering.

- Physics, because the modelled phenomenon, propagation of electromagnetic radiation, is a part of physical reality and follows the laws of physics (Maxwell's equations).
- Mathematics, because as in any modelling, the model is a mathematical structure, aiming at the highest possible descriptiveness with the lowest complexity.
- Engineering, because the models are applied in the field of telecommunications and the requirements are set by the field of usage. Moreover, channel measurement require good engineering practices."



What is radio channel characterization?



- For understanding and simulating the channel in which the system will operate
- New channel measurements and models are needed for:

✓ New frequency bands

✓ New environments

✓ New deployment methods (transmission scheme)

Example questions to address (= Implications)

At sub-THz radio frequencies: 100-300 GHz

- Which link distances are feasible?
  - How high antenna gains are needed?
  - How high mobility can be supported?
- Do we have any theoretical or physical reasons to think that channels above 100 GHz will be significantly different from those below 100 GHz?
- How to define “typical” above-100 GHz channels based on use cases and deployment scenario/applications?
- What is the spatial coherence of channels, which is relevant to improvement of beam-training via the location information?
- What is the scattering behavior of a plane wave incident on a rough surface? Do we know characteristics smoothly over wide range of frequencies up to 300 GHz?
- How many multi-paths are present in sub-THz propagation channels?
  - How many useful beams one can allocate?
  - What is the channel delay spread when beamforming is performed?
  - Can lower frequency beam directions be useful for sub-THz beamforming? ...

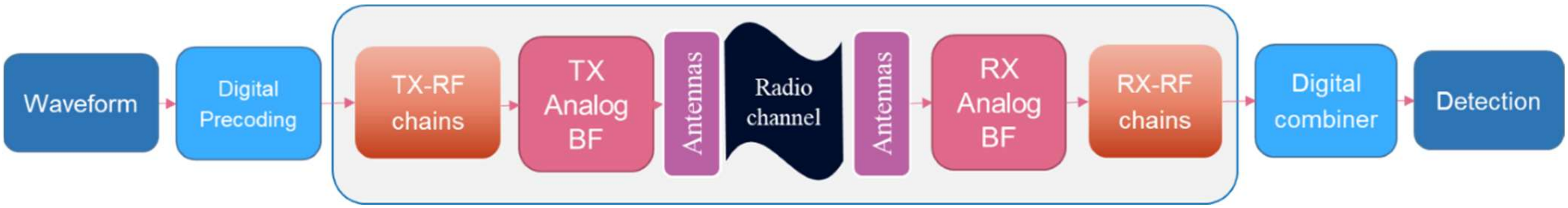
What are the requirements for 6G channel models

- Pretty much same as for 5G
- Models still need to be based on empirical evidence → measurements
- Now in 6G interest towards ”new” frequencies above 100 GHz
- More importance on radar / localization / sensing
- More importance on RF non-idealities
- RIS must be included

METIS:

1. Wide range of propagation scenarios
2. High frequencies and large bandwidth
3. Very large antenna arrays
4. Spatial consistency and mobility
5. Specular scattering
6. Dual mobility
7. Flexible trade-off between accuracy and complexity

Propagation + antenna + RF modelling (system model)



$$\mathbf{y}(t) = \mathbf{D}_{\mathrm{rx}}(t,f)\, F_{\mathrm{rx}}\left(\mathbf{B}_{\mathrm{rx}}(t,f) \sum_{l=1}^{L} \left(\mathbf{G}_{\mathrm{rx}}(f, \Omega_l^{\mathrm{rx}})\, \mathbf{h}_l(t) e^{-j2\pi f \tau_l}\, \mathbf{G}_{\mathrm{tx}}(f, \Omega_l^{\mathrm{tx}})^T \right) \mathbf{B}_{\mathrm{tx}}(t,f)^T\, F_{\mathrm{tx}}\big(\mathbf{D}_{\mathrm{tx}}(t,f)^T \mathbf{x}(t)\big) \right)$$

Finger Blockage

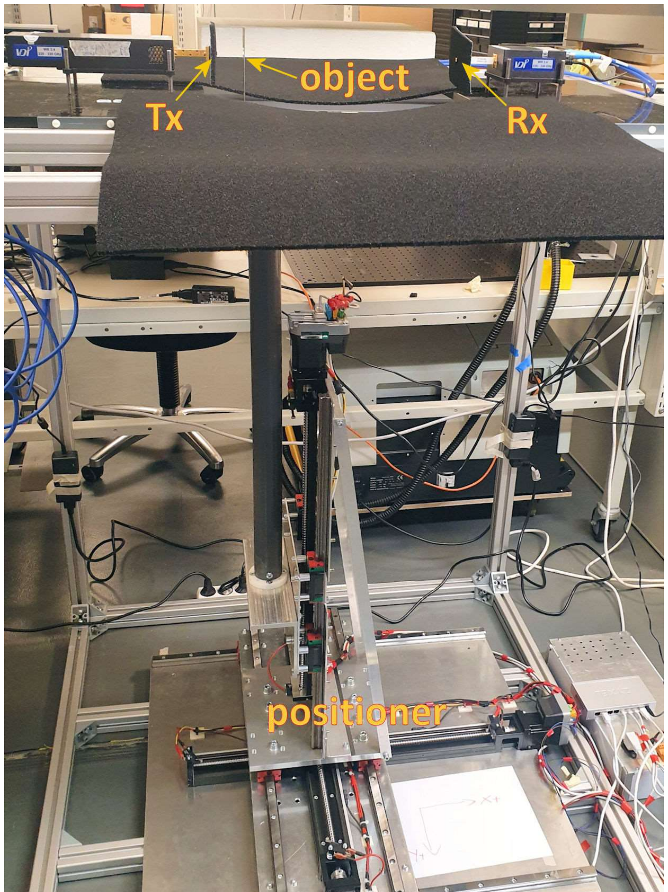
~300 GHz

What does a finger make to radio signal?

- 1.5 cm wide finger at 300 GHz is 15 λ
- At 700 MHz 15 λ corresponds to size of a large van

Frequency	700 MHz	1.0 GHz	2.0 GH<	3.5 GHz	[illegible]	[illegible]	300 GHz
wavelength (cm)	42.9	30.0	15.0	8.6	[illegible]	[illegible]	0.1
15 wavelenghts	6.4 m	4.5 m	2.3 m	1.3 m	10.8 cm	10.4 cm	1.5 cm
example object	large van	mid-size car	small city car	human body	head	hand palm	finger

Blockage Effect of a Finger at 300 GHz



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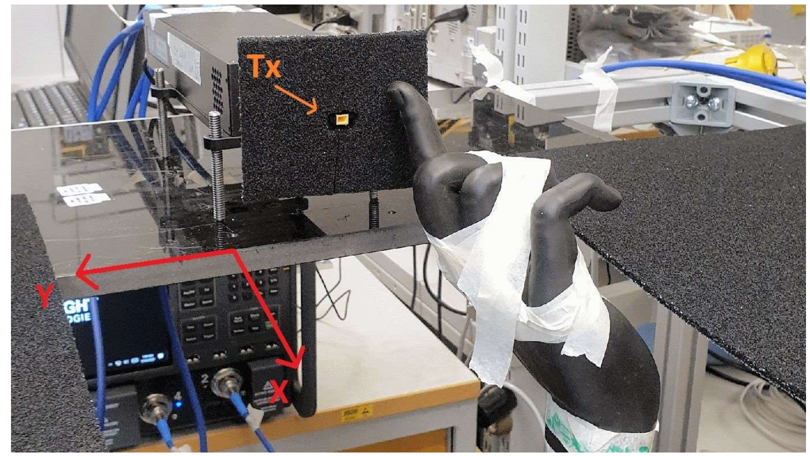
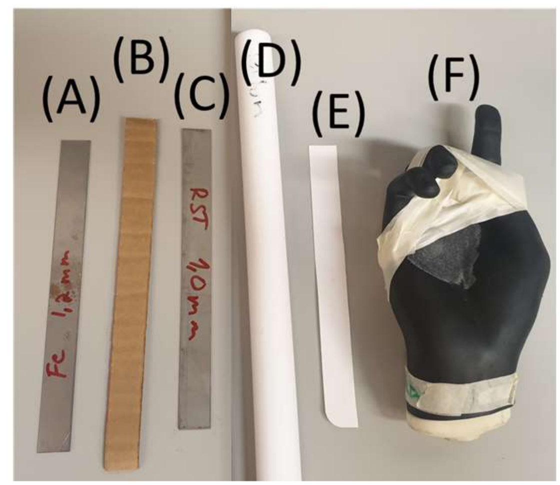
Measurement frequency:
220 – 330 GHz

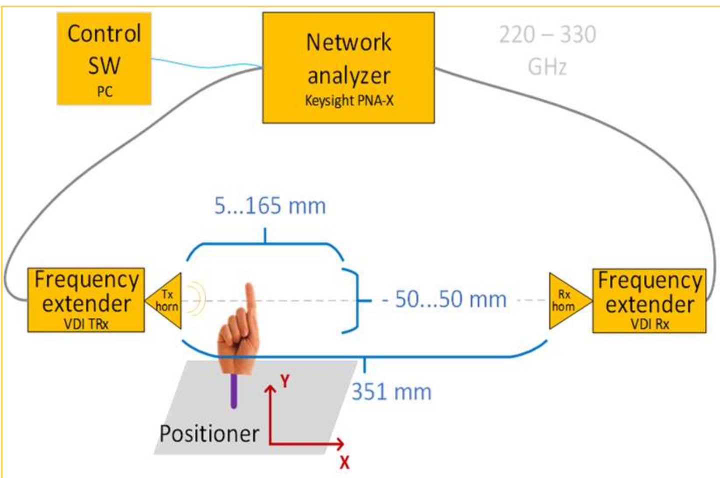


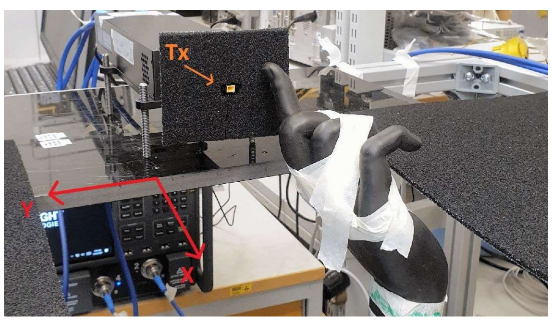
A. Iron strip
B. Corrugated cardboard strip
C. Stainless steel strip
D. Nylon rod
E. Cardboard strip
F. Phantom finger



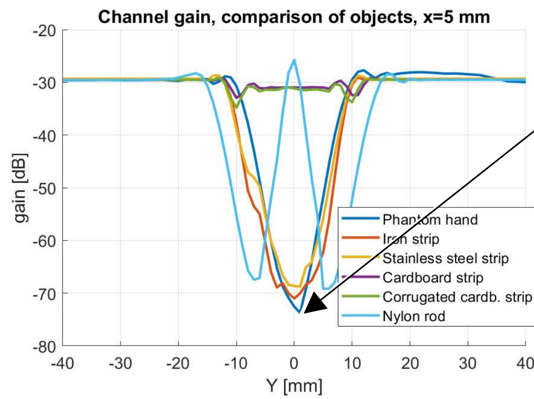
Blockage Effect of a Finger at 300 GHz

Measurement system

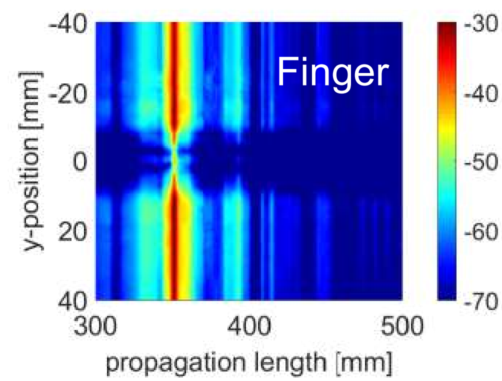


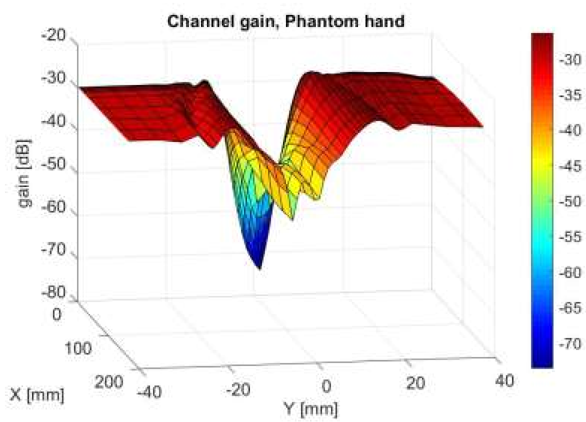


Some results



Up to 44.2 dB attenuation if obstacle is 5 mm from antennas





Attenuation vs. x/y locations

P. Kyösti, N. Tervo, M. Berg, M. E. Leinonen, K. Nevala and A. Pärssinen, “Measured Blockage Effect of a Finger and Similar Small Objects at 300 GHz,” ***EuCAP 2021***.

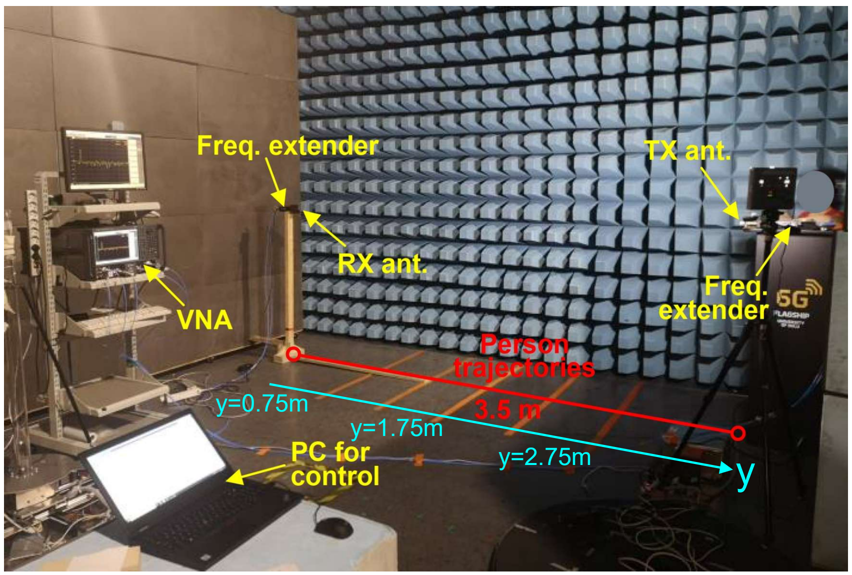
Human Blockage

~140 GHz

D-Band Human Body Shadowing (1/2)

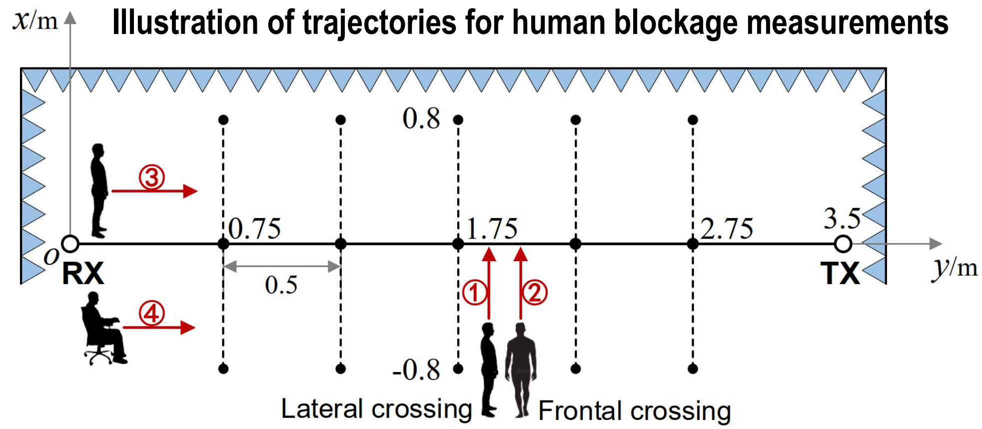
Measurement system

- ✓ 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



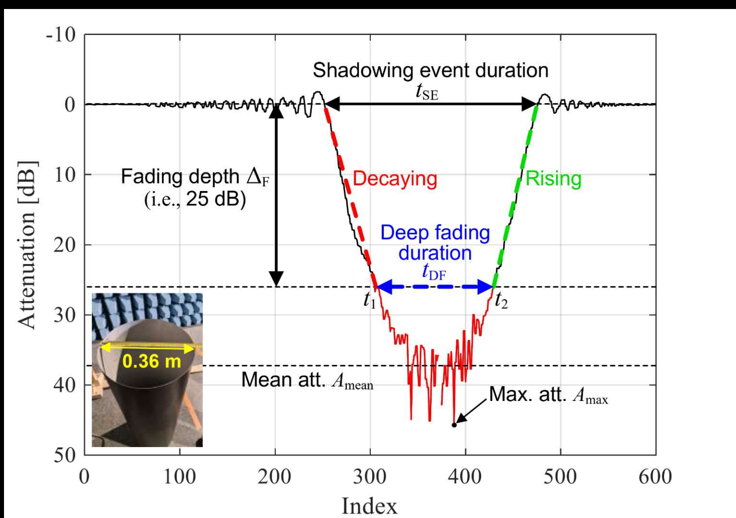
Measurement setup

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

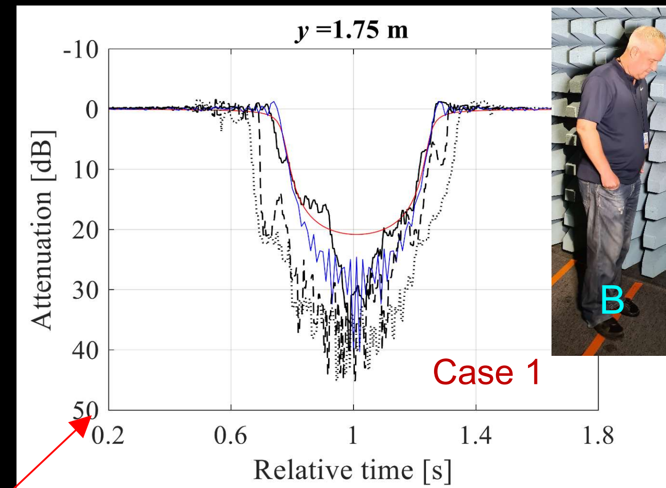
D-Band Human Body Shadowing (2/2)

Initial Results of Single Person Human Blockage Effect

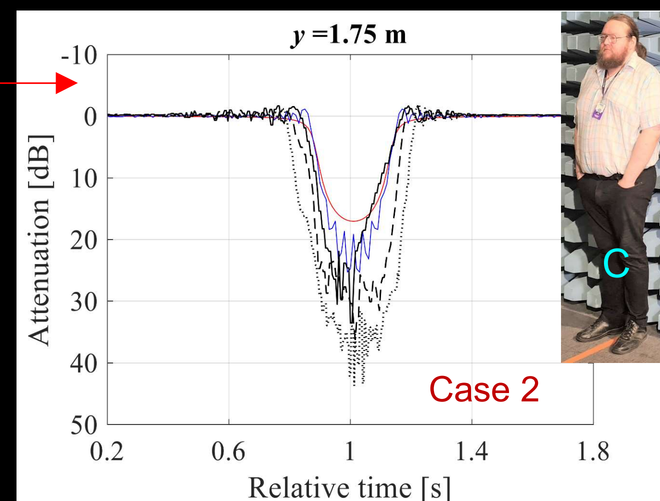
- ✓ Reference measurement results using standard cylinder
- ✓ Characterization of human body shadowing with volunteer A/B/C



Reference measurement with metallic cylinder



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



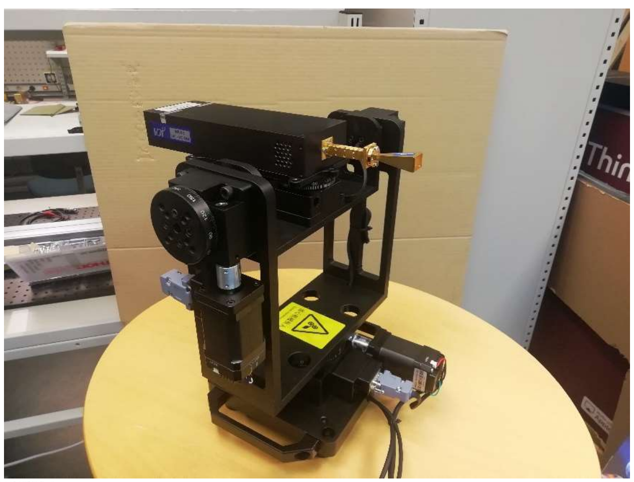
P. Zhang, P. Kyösti, M. Bengtson, V. Hovinen, K. Nevala, J. Kokkoniemi, and A. Pärssinen, "Experimental Characterization of D-Band Human Body Shadowing," accepted to **EuCAP 2023.**

Double Directional Indoor Propagation

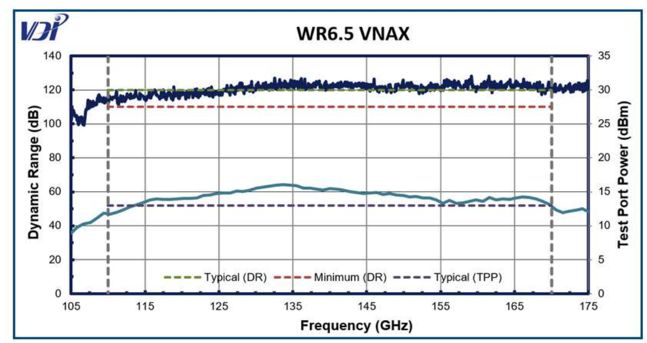
D-band (~140 GHz)

Channel sounder

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



Measurement setup

- The environment is a T-shaped office corridor
- Both LOS and NLOS positions
- Some limitations on the scanned angular ranges
  - set by the measurement time and RF cables

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°

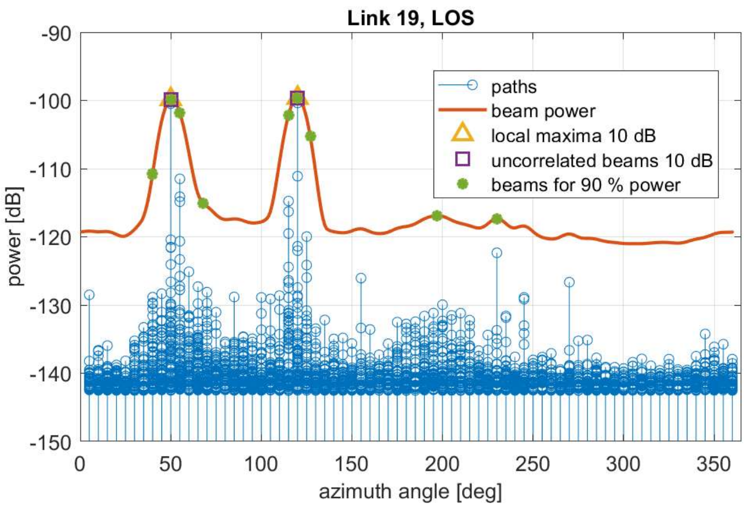
Number of Beams

~140 GHz

How Many Beams Does Sub-THz Channel Support?

- Is line of sight (LOS) the only path that has enough gain to conduct communication or positioning signals?
- Are there spare beam directions available if the LOS path is temporally blocked?
- Do antenna arrays and related phase control circuits need capability to control multiple simultaneous beams or is only one sufficient?
- Is spatial multiplexing a viable option at sub-THz?
- Can one rely with a positioning system to have only LOS path is present?

- These questions affect research and design of antennas, RF circuits, algorithms, and systems

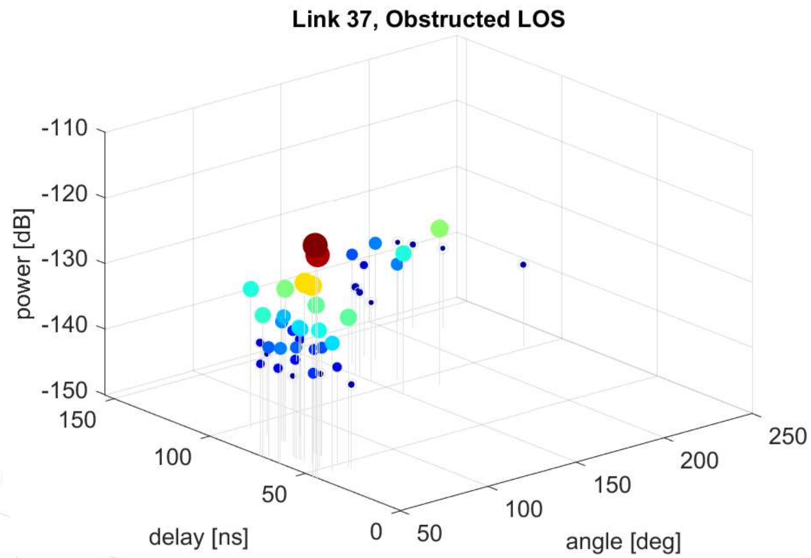


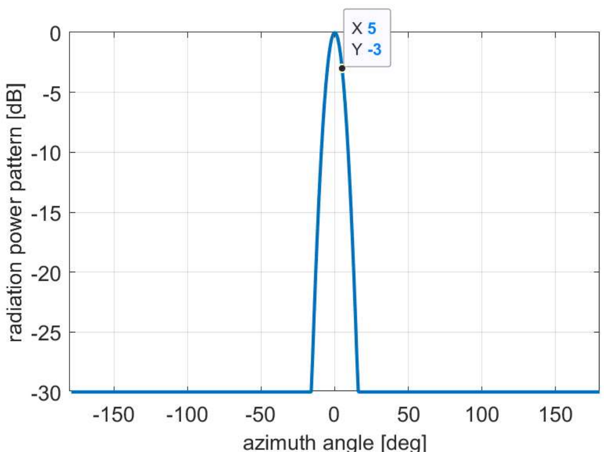
How to count beam numbers?

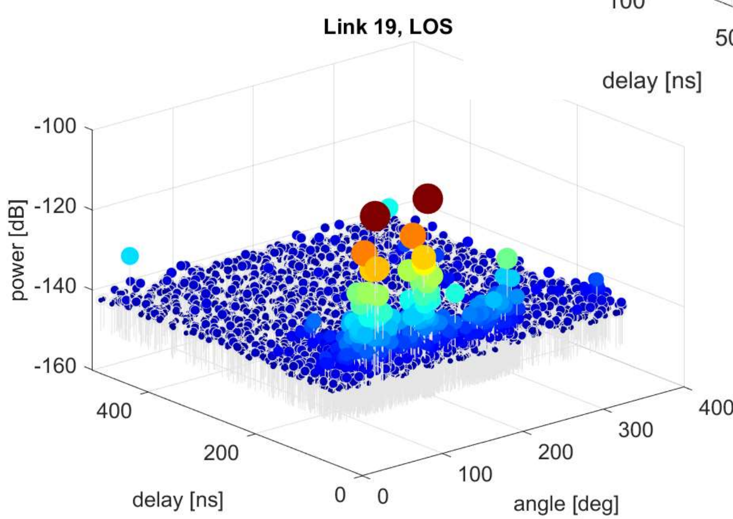
- Data = measured Power Angular Delay Profile (PADP)

$$P_q(\Omega, \tau) = \Sigma_{l=1}^{L_q} P_{l,q}\, \delta\left(\Omega - \Omega_{l,q}\right)\, \delta\left(\tau - \tau_{l,q}\right)$$

- Choose beam shape, here synthetic 3GPP antenna gain pattern (here 10° HPBW)
- Apply methods M1-3



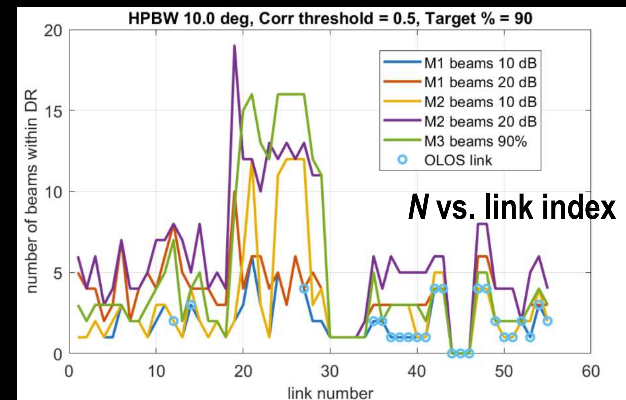


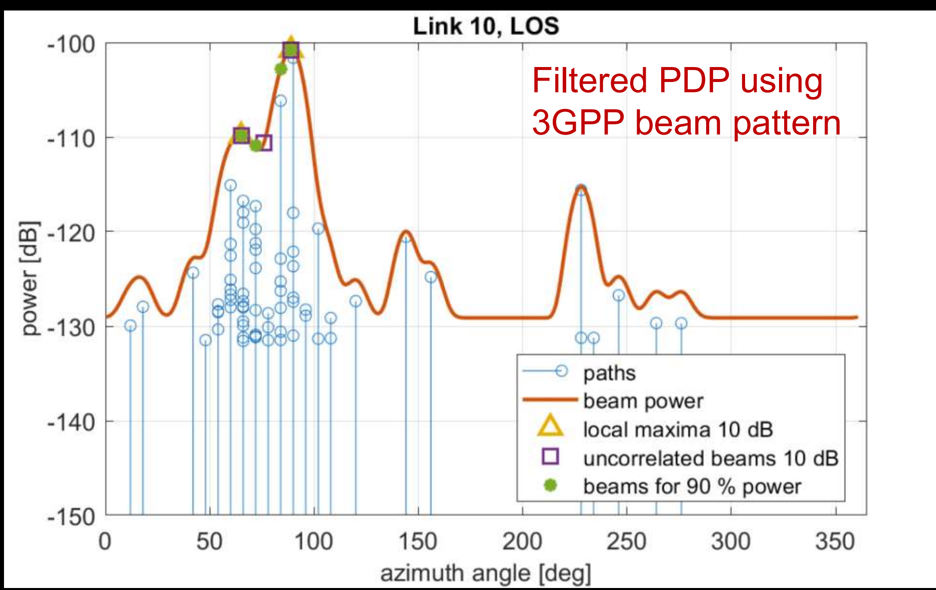


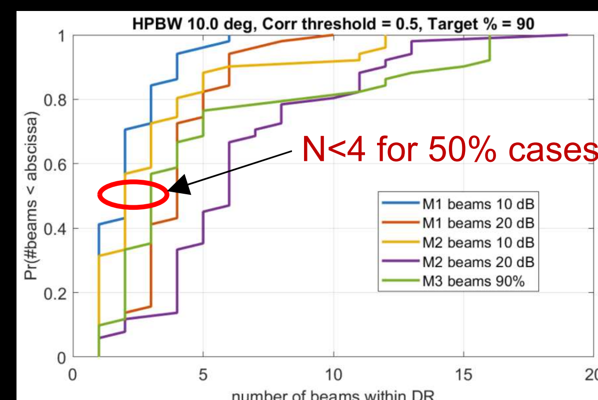
How Many Beams Does Sub-THz Channel Support?

Three Methods to Evaluate the Number of Beams

- ✓ Using ray-tracing assisted measurement data from Aalto Univ.
- ✓ Method 1: Number of local maxima
- ✓ Method 2: Number of uncorrelated beams
- ✓ Method 3: Minimum number of beams for X% power







P. Kyösti, M. F. De Guzman, K. Haneda, N. Tervo and A. Pärssinen, "How Many Beams Does Sub-THz Channel Support?" ***IEEE Antennas Wireless Propag. Lett.***, vol. 21, no. 1, pp. 74-78, Jan. 2022

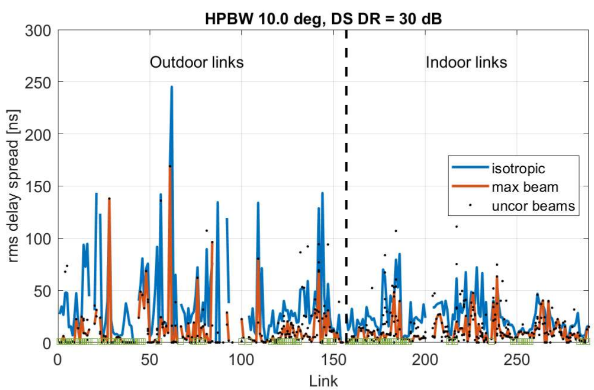
Aalto University

Beamforming Impact on Delay Spread

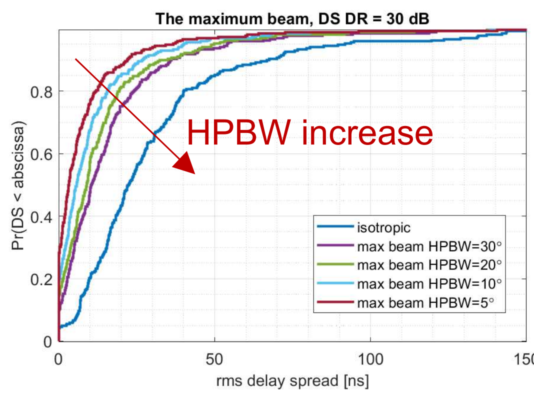
~140 GHz

Beamforming Impact on Delay Spread

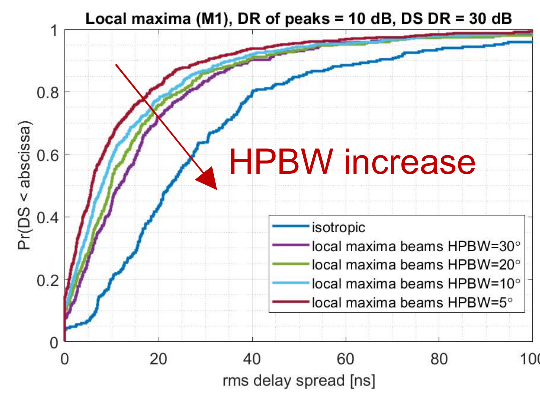
- ✓ Time dispersion of the radio channel has impact on waveform design, e.g., the cyclic prefix (CP) length
- ✓ RMS delay spread for ***omni-directional channel***, ***max. beam directional channel***, and ***uncorrelated beam channel***
- ✓ Measured D-band channel data from Aalto Univ. in multiple indoor and outdoor environments



DS vs. link index



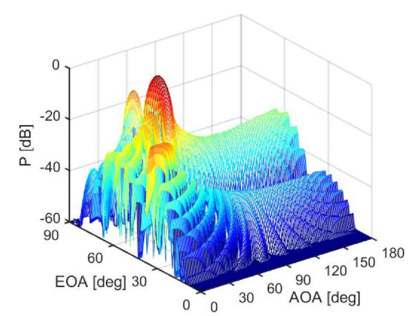
CDF of DS for max. beam directional channel



CDF of DS for local max. beam channel

- ✓ Double-directional data from Aalto Univ. is available
- ✓ New metric is needed to measure the degree of time dispersion, as well as its impact on system design

P. Kyösti, P. Zhang, M. F. de Guzman, K. Haneda, N. Tervo, A. Pärssinen, “Beamforming Impact on Delay Spread in Measured D-Band Radio Channels,” in **2nd** ***INTERACT COST Meeting***.



Beam pattern of a UPA

Aalto University

Stored Channel Model

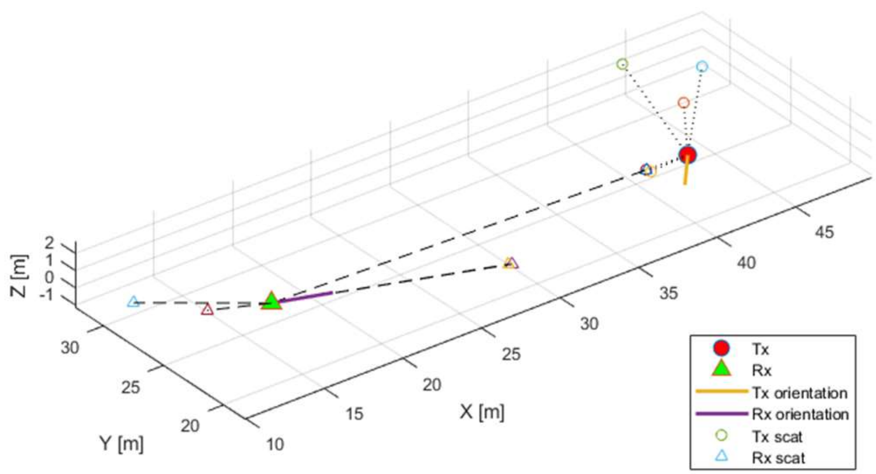
~140 GHz

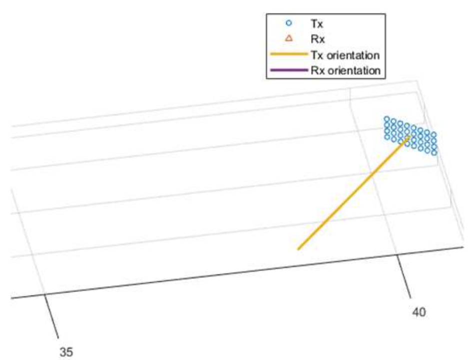
Stored Channel Model

- The collection of propagation paths from measurements at 140 GHz
- The stored channel model will contain discrete impulse responses h of a form

$$h(\boldsymbol{p}_{\mathrm{Tx}}, \boldsymbol{p}_{\mathrm{Rx}}) = \sum_{l=0}^{L} |\alpha_l| \delta(\boldsymbol{\Omega} - \boldsymbol{\Omega}_l^{\mathrm{Tx}}) \delta(\boldsymbol{\Omega} - \boldsymbol{\Omega}_l^{\mathrm{Rx}}) \delta(\tau - \tau_l),$$

- where $\boldsymbol{p}_{\mathrm{Tx}}$ and $\boldsymbol{p}_{\mathrm{Rx}}$ denote Rx and Tx locations, $\boldsymbol{\Omega}_l^{\mathrm{Tx}}$ and $\boldsymbol{\Omega}_l^{\mathrm{Rx}}$ angles of arrival and departure, τ_l is a propagation delay, and α_l is a complex amplitude of l-th propagation path



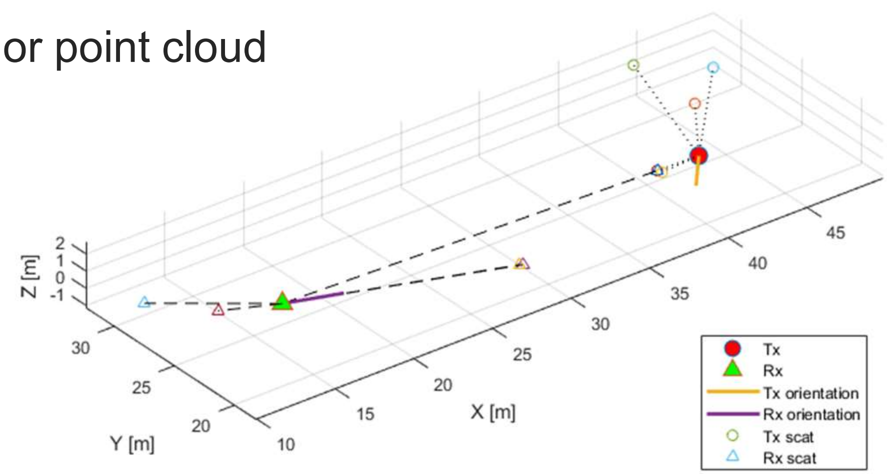


Data and a Matlab implementation will available from Hexa-X project. Deliverable D2.3

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.

Stored Channel Model

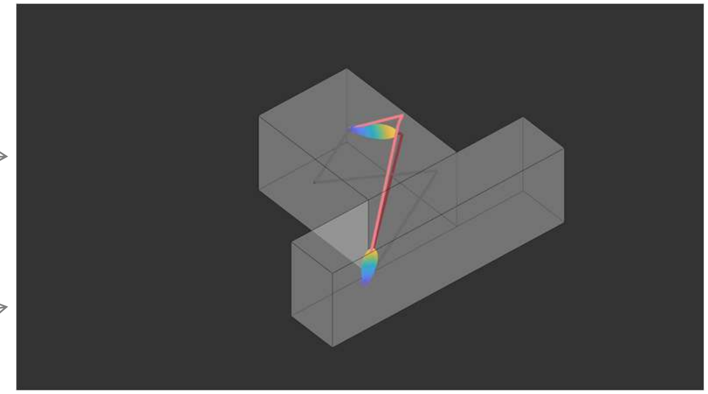
- Coordinates and types of interaction points are available in the ray-tracing assisted measurement data, as well as channel coefficients for each multipath/interaction
  → Propagation delays and angles of arrival/departure
    → Array antenna elements can be specified in the same coordinate system
    → (radiative) near-field effects and spherical waves can be modelled
    → Frequency variation on array geometry across the considered BW can included
- Measured environments are characterized by a layout or point cloud
  → Support for localization and sensing investigations

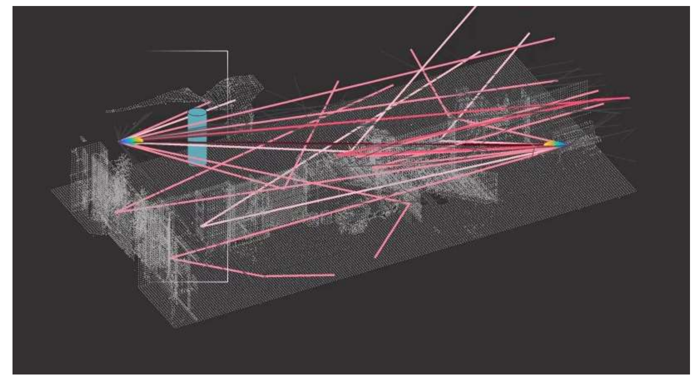


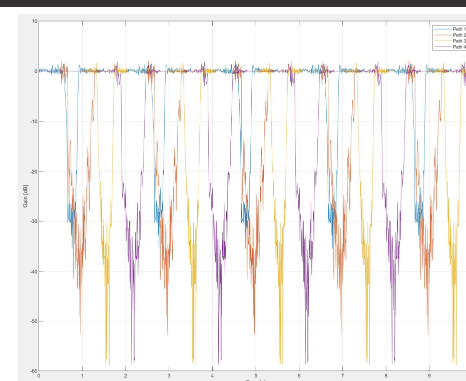
Channel modelling work

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
    → 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
- The first emulation of such time variant D-band channel model







Summary

Summary

- New channel measurements and models are needed for 6G though requirements for 6G channel models are not dramatically new
- Measurements are laborious
- Many implications can be made even from limited measurement data
- More data must be collected to perform extensive statistical analysis of propagation
- Ray tracing can be used to complement measurements and to extend models
- The very first channel emulation of a D-band channel model at Keysight

Recent publication

1. K. Rikkinen, P. Kyösti, M. E. Leinonen, M. Berg and A. Pärssinen, "THz Radio Communication: Link Budget Analysis toward 6G," in *IEEE Commun. Mag.*, vol. 58, no. 11, pp. 22-27, November 2020.
2. P. Kyösti, N. Tervo, M. Berg, M. E. Leinonen, K. Nevala and A. Pärssinen, “Measured Blockage Effect of a Finger and Similar Small Objects at 300 GHz,” in *EuCAP 2021.*
3. 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*.
4. Y. Lyu, P. Kyösti and W. Fan, "Sub-THz VNA-based Channel Sounder Structure and Channel Measurements at 100 and 300 GHz," in *PIMRC*, 2021.
5. Y. Lyu, A. W. Mbugua, K. Olesen, P. Kyösti and W. Fan, "Design and Validation of the Phase-Compensated Long-Range Sub-THz VNA-Based Channel Sounder," in *IEEE Antennas and Wireless Propag. Lett.*, vol. 20, no. 12, pp. 2461-2465, Dec. 2021.
6. P. Kyösti, M. F. De Guzman, K. Haneda, N. Tervo and A. Pärssinen, “How Many Beams Does Sub-THz Channel Support?” in *IEEE Antennas Wireless Propag. Lett.*, vol. 21, no. 1, pp. 74-78, Jan. 2022.
7. J. Kokkoniemi, V. Hovinen, K. Nevala and M. Juntti, "Initial Results on D Band Channel Measurements in LOS and NLOS Office Corridor Environment," *in EuCAP* 2022.
8. Y. Lyu, A. W. Mbugua, K. Olesen, P. Kyösti and W. Fan, "On the Phase-Compensated Long-Range VNA-based Channel Sounder for sub-6 GHz, mmWave and sub-THz frequency bands," in *EuCAP*, 2022.
9. P. Kyösti, P. Zhang, M. F. De Guzman, K. Haneda, N. Tervo, A. Pärssinen , “Beamforming Impact on Delay Spread in Measured D-Band Radio Channels,” in *COST INTERACT* Meeting, Lyon, June 2022.
10. P. Zhang, P. Kyösti, K. Haneda, P. Koivumäki, Y. Lyu, and W. Fan, “Out-of-Band Information Aided mmWave/THz Beam Search: A Spatial Channel Similarity Perspective,” in *IEEE Commun. Mag.*, Dec 2022.
11. P. Kyösti, P. Zhang, A. Pärssinen, K. Haneda, P. Koivumäki, and W. Fan, “On the Feasibility of Out-of-Band Spatial Channel Information for Millimeter-Wave Beam Search,” accepted to *IEEE Trans. Antenna Propag,* Feb 2023.
12. P. Zhang, P. Kyösti, M. Bengtson, V. Hovinen, K. Nevala, J. Kokkoniemi, and A. Pärssinen, “Measurement-Based Characterization of D-Band Human Body Shadowing,” accepted to *EuCAP 2023*.

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Thank you