# What will it take for wireless communications to conquer the sky?

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*The views expressed are solely the author's*

# Acknowledgments

Recent collaborators

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# UAVs as end-devices

Two types of traffic

- UAV-generated payload
- BVLoS UAV command & control

The dream

- Seamlessly reuse existing (or soon-to-be-deployed) infrastructure

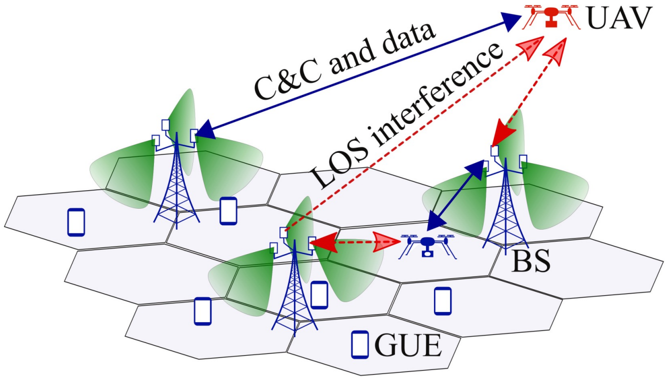
The reality

- Must *prepare the ground* to accommodate aerial end-devices

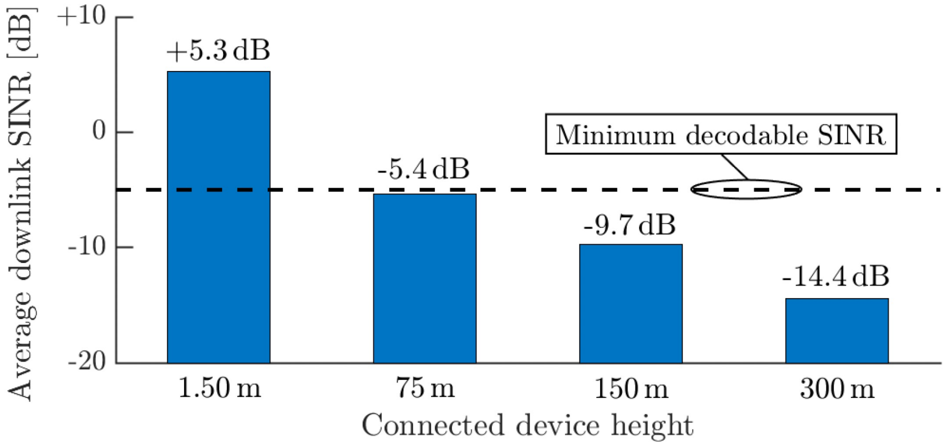
Urban air mobility — air taxis, airport shuttles, first-aid eVTOL:
pilot onboard → remote pilot → autonomous

# Air-to-ground interference

- UAVs experience LoS propagation with several ground BSs
  - Downlink: BS-to-UAV interference
  - Uplink: UAV-to-GUE interference

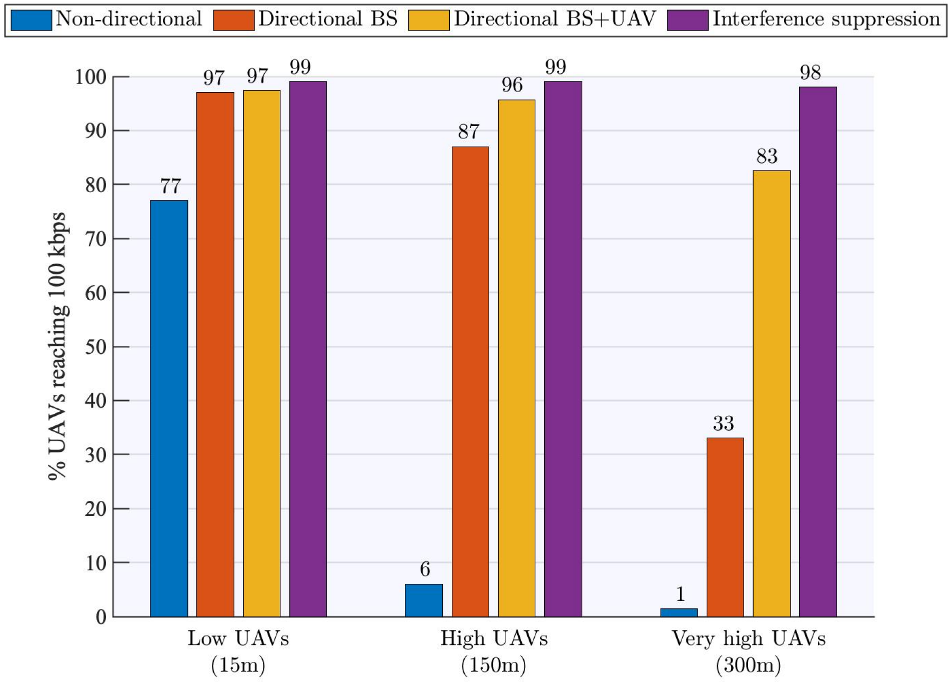



SINR degradation for a connected device as it flies higher



# Air-to-ground interference mitigation

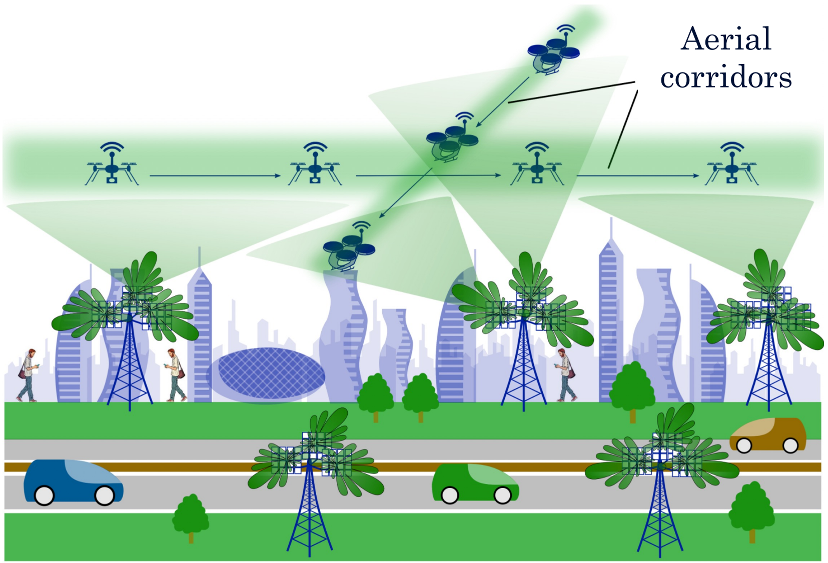
- Comparing four scenarios:
  - (4G): Single user, non-directional
  - (5G): 8x8 mMIMO, directional BS
  - (5G): 8x8 + 2x2, directional BS+UAV
  - (B5G): Inter-cell interference suppression




- Conclusion:
  - Difficult (costly) to provide *ubiquitous* and reliable aerial connectivity

# Connectivity on aerial corridors

- Sky-wide connectivity
  → Connectivity on *aerial corridors*
  - UAVs unlikely to fly unrestricted
  - Predetermined routes to be regulated
  - Safety-driven, network-agnostic




UAVs following predetermined routes, where
ultra-reliable connectivity must be guaranteed

# Network optimization for aerial corridors

# Network optimization for aerial corridors

Design cellular networks to serve:

- Legacy ground users
- UAVs on predefined corridors

Parameters to optimize:

Antenna tilts, transmit power,
SSB codebook, cell association, …

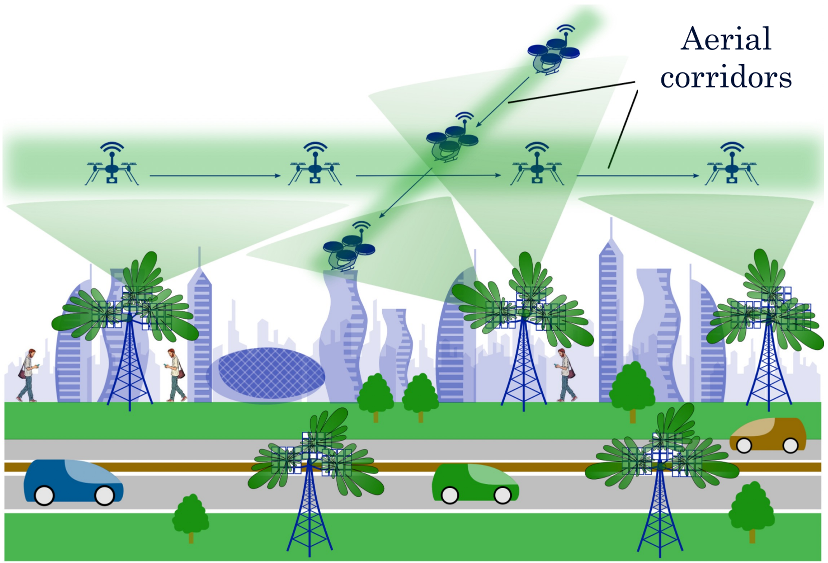
Performance metrics:

RSS, SINR, capacity/volume, …

Not trivial! Candidate tools:

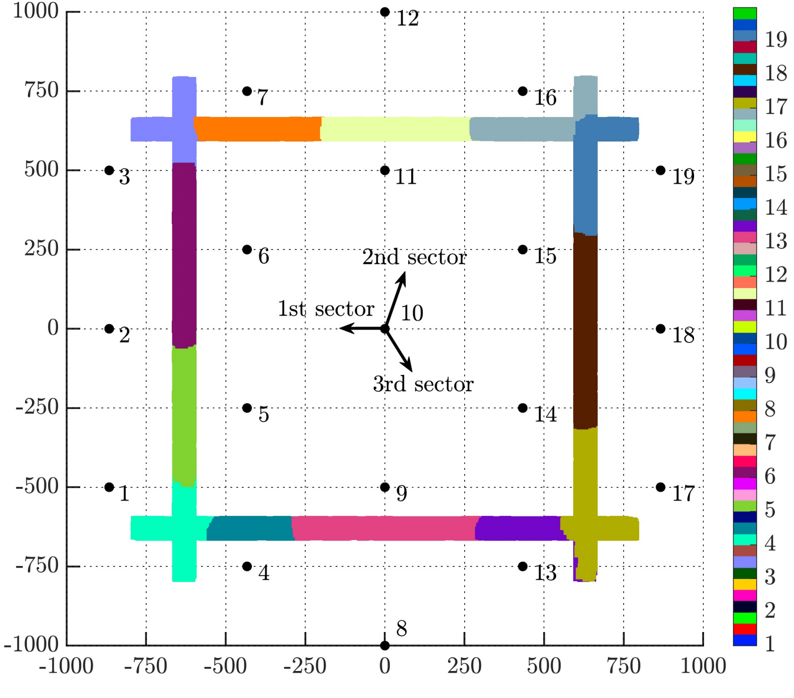
- Quantization theory
- Bayesian optimization

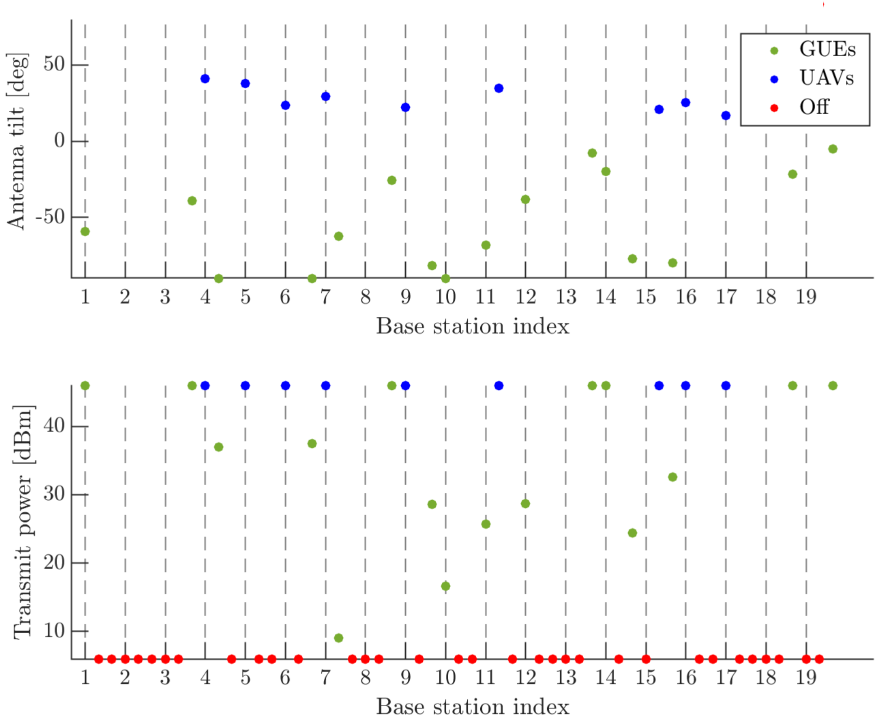
Connectivity for ground users and aerial corridors



# Network optimization for aerial corridors

Example: Bayesian optimization of tilts and power for SINR at GUEs and UAVs

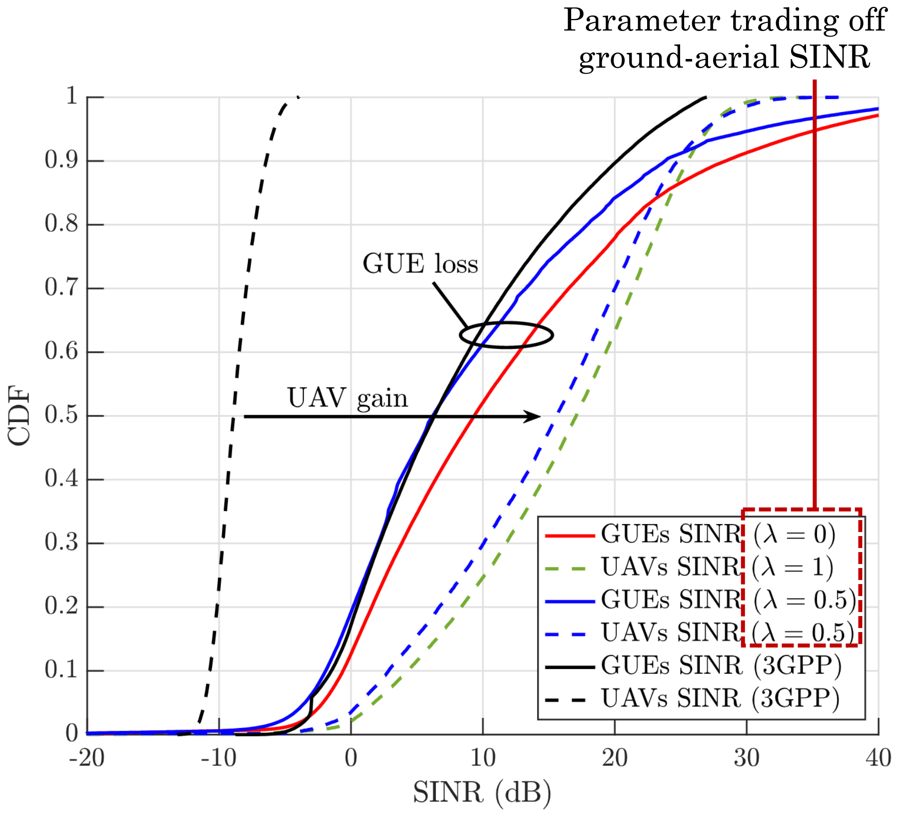


# Network optimization for aerial corridors

Reach a satisfactory trade-off by:

- Boosting the SINR for UAVs compared to the baseline
- Nearly preserving the SINR at ground users compared to all-downtilt, max-power baseline



# Network optimization for aerial corridors

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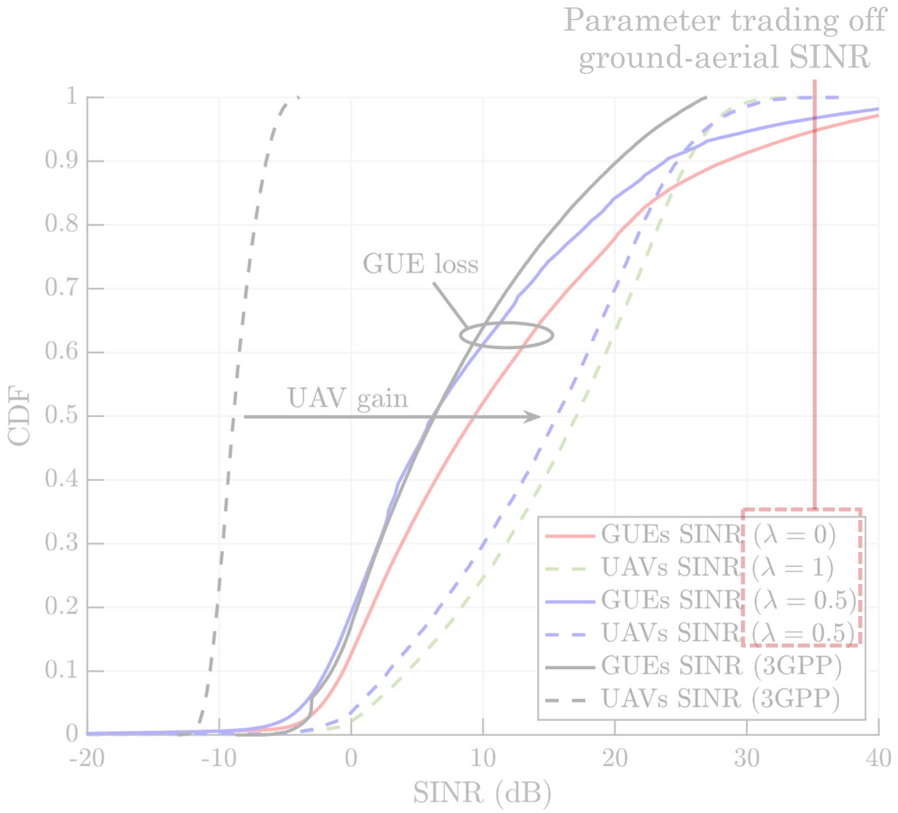
<u>Limitation:</u> model-based approach, 3GPP channel model used (statistical)

<u>Way forward:</u> data-driven design, scenario-specific propagation models



# Data-driven air-to-ground channel modeling

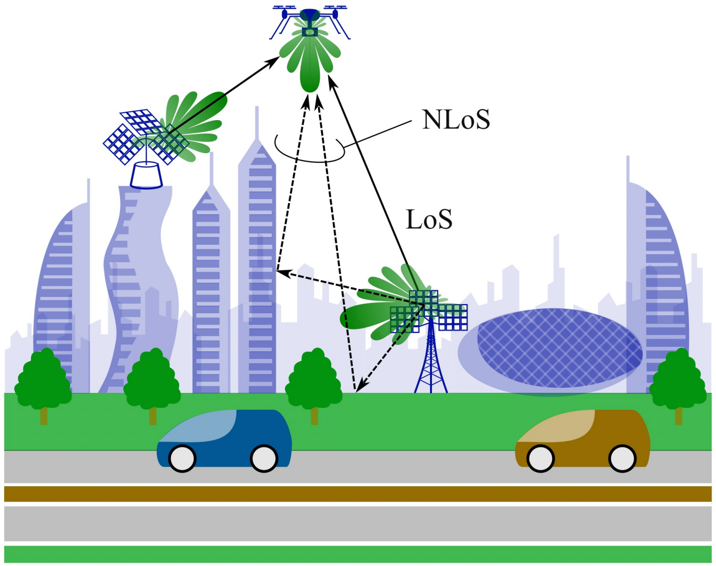
# Data-driven channel modeling

<u>Available channel models:</u>

- 3GPP statistical models
  — Not scenario-specific
- Ray tracing
  — Need blueprint of environment
  — Computationally expensive

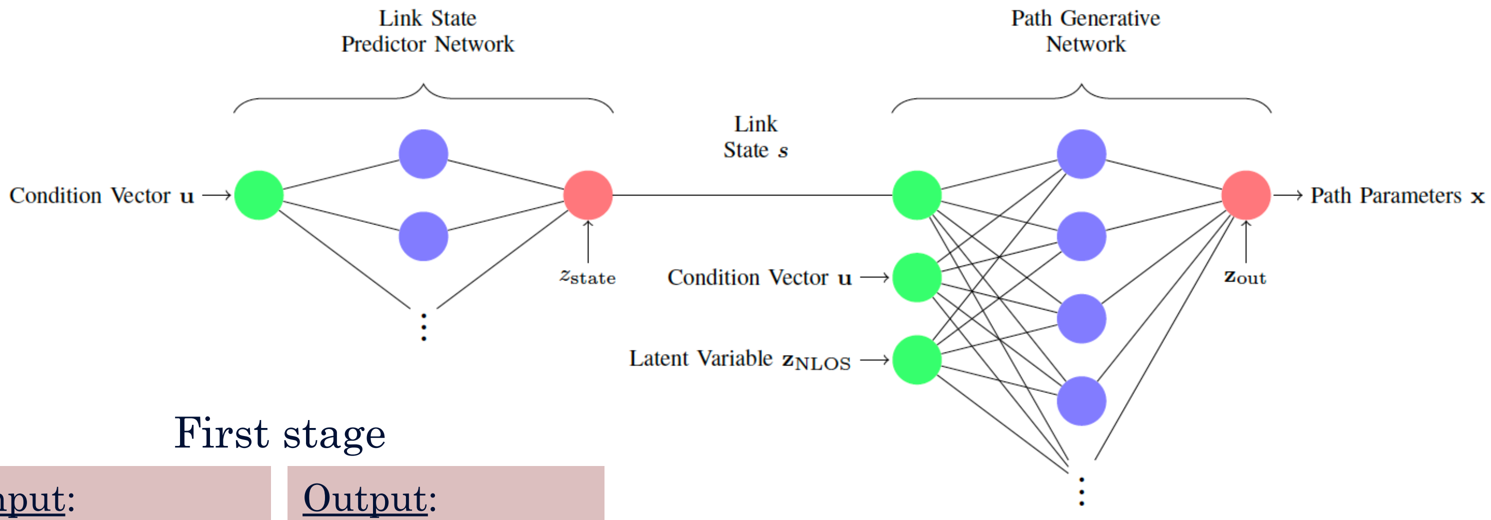
<u>Proposed approach:</u>

- Generative model, producing:
  pathloss, delay, angles for each path
- Training:
  scenario-specific dataset from ray tracing




Scenario-specific air-to-ground model needed

# Data-driven channel modeling




## First stage

<u>Input</u>:
$\mathbf{u} = (\mathbf{d}, c)$
$\mathbf{d}$ is the distance
$c$ is the cell type

<u>Output</u>:
$s$ link state
(LoS vs NLoS)

## Second stage

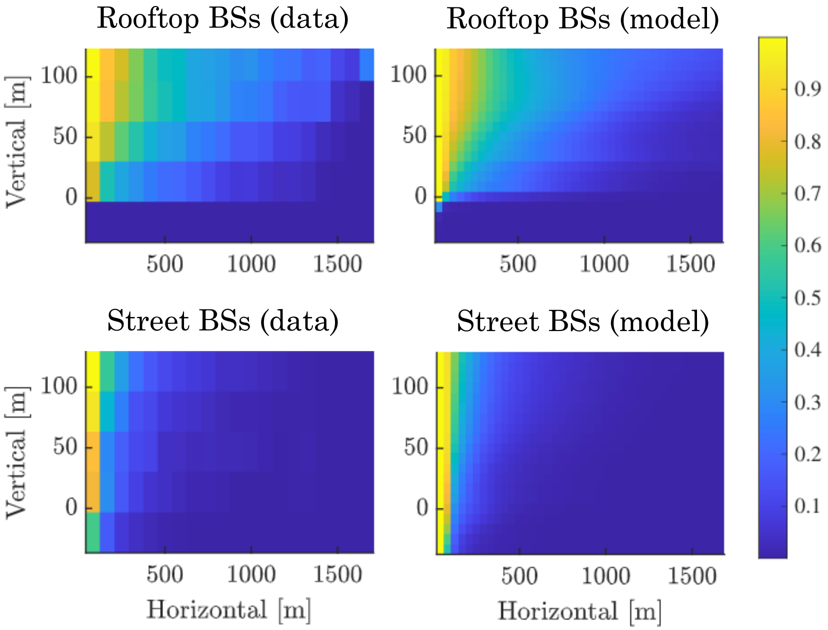
<u>Input</u>:
$\mathbf{u} = (\mathbf{d}, c)$
$s$ link state

<u>Output</u>:
$\mathbf{x}$, containing for each path:
path loss, delay, AoD, AoA, ZoD, ZoA

# Data-driven channel modeling

## Model matches empirical distribution

- LoS probability:
  - Higher UAVs → higher LoS probability
  - Rooftop BSs → LoS for farther UAVs
- Path angular distribution (not shown):
  - Angular spread decreases w/ distance
  - More spread at BS side than at UAV
- …

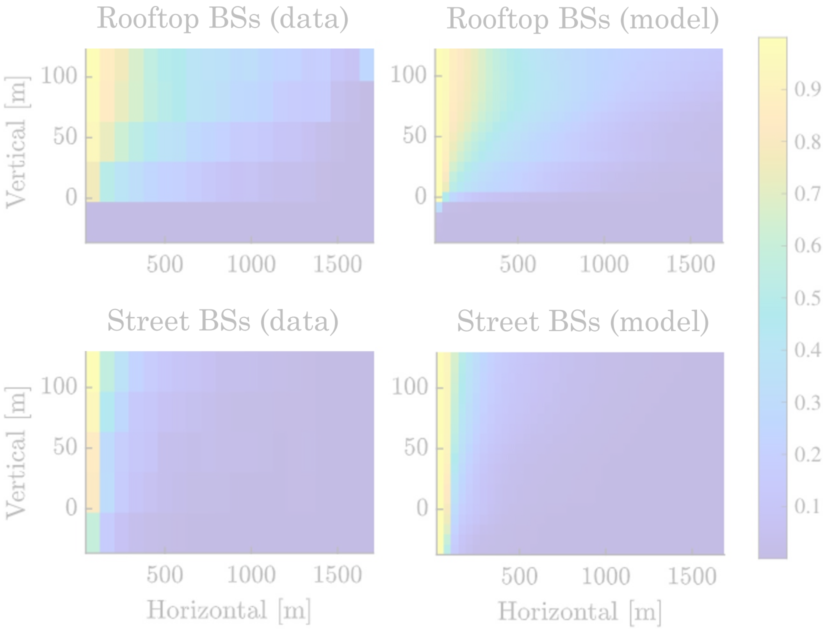



LoS probability for the city of London

# Data-driven channel modeling

<u>Limitation:</u> not spatially consistent (distance-based, not location-based)

<u>Way forward:</u> lightweight digital twin of the propagation environment




LoS probability for the city of London

# Recap and way forward

*What will it take for wireless communications to conquer the sky?*

– New tools to optimize deployments for aerial corridors
  → From model-based to data-driven

– Digital twinning of the propagation environment
  → Lightweight and spatially consistent

– Opportunistic traffic steering across TN-NTN
  → 3D mobility management, trajectory awareness


– G. Geraci, et al., "Integrating terrestrial and non-terrestrial networks: 3D opportunities and challenges," *IEEE Communications Magazine*, 2023.

– G. Geraci, et al., "What will the future of UAV cellular communications be? A flight from 5G to 6G," *IEEE Communications Surveys & Tutorials*, 2022.