IMMW Ray-Tracing Propagation in a Large Factory

Date: 2025-05-08

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Abstract

- **In this contribution we investigate the propagation of integrated millimeter devices for both 5.2 and 60 GHz in a large indoor factory scenario using ray-tracing simulations**
  - The impact of different ray-tracing components have been analyzed as well as the propagation differences across both bands
- **Further we compare the propagation using isotropic antennas with a directive antenna array**
- **Results seem to indicate that IMMW as a technology is suitable for these use cases provided there is compensation for the propagation loss in millimeter bands using e.g., larger antenna arrays**

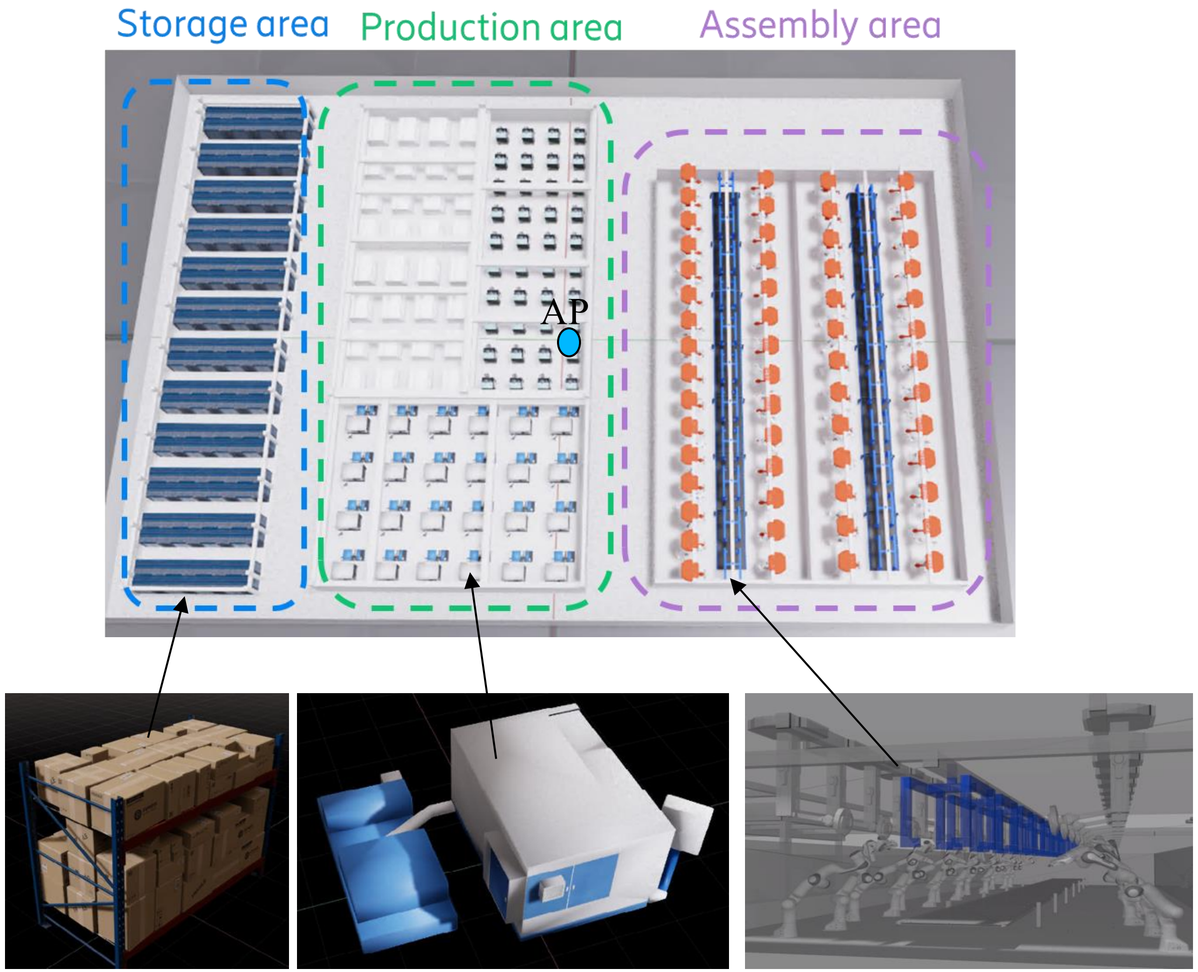
Background

- **Propagation in millimeter bands are known to be challenging and may be a bottleneck for many use cases and applications**
- **In [1] ray-tracing propagation in smaller scenarios such as rooms/houses were investigated**
- **The 11bq PAR [2] states,**
  - ” Use of WLANs based on IEEE 802.11 technology continues to grow and diversify over many market segments including residential, enterprise, **industrial** ”
- **Thus, in this presentation we investigate millimeter wave propagation in a larger factory scenario using ray-tracing**

Scenario Description – Factory Model

The factory layout is inspired from real factories and implemented in [3] with domain randomization. The factory is 80x120x6m, with 3 areas:

- storage area (~18%) contains several groups of racks (shelves) with 3m high.
- production area (~40%) has groups of machines with various sizes.
- assembly area (~42%) has 2 conveyor belts and robot arms.



Deployment:

- Users: around 7000 locations, most of which are 1.5m from ground.
- AP: One at the center of the factory, and 4.8m high

Scenario Description – Ray tracing

Max paths per link: 100 (keeping the 100 strongest paths per link)

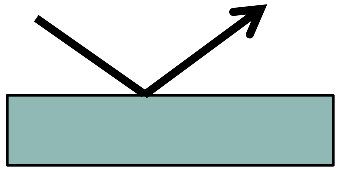
Max path lengths: 600m

Max total order: 4 (limits the number of interactions a path can experience)

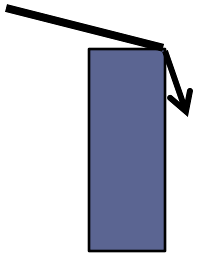
Max specular reflection order: 4

Max diffuse scattering order: 0 or 1

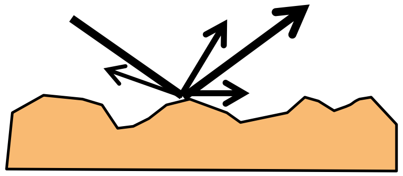
Max diffraction order: 0/1/2



Reflection



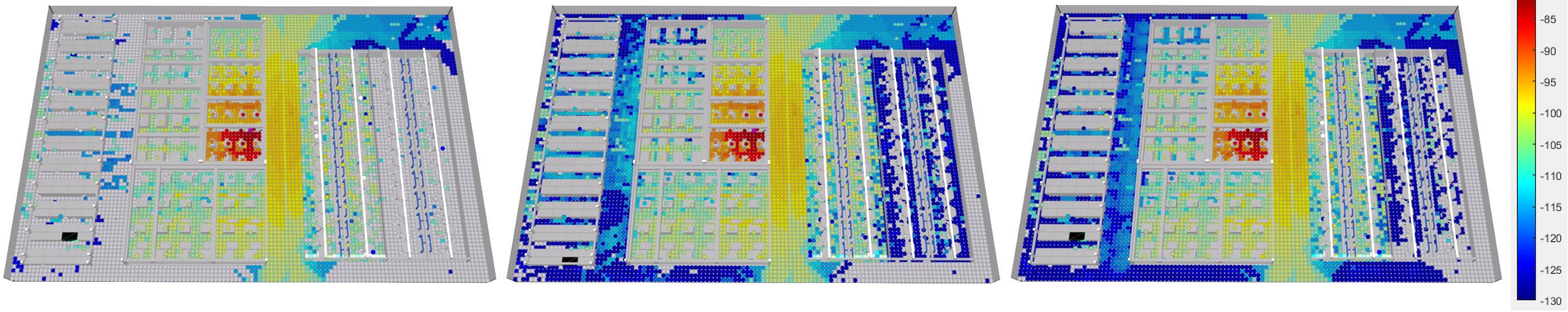
Diffraction



Scattering

Comparison of Ray-Tracing Components

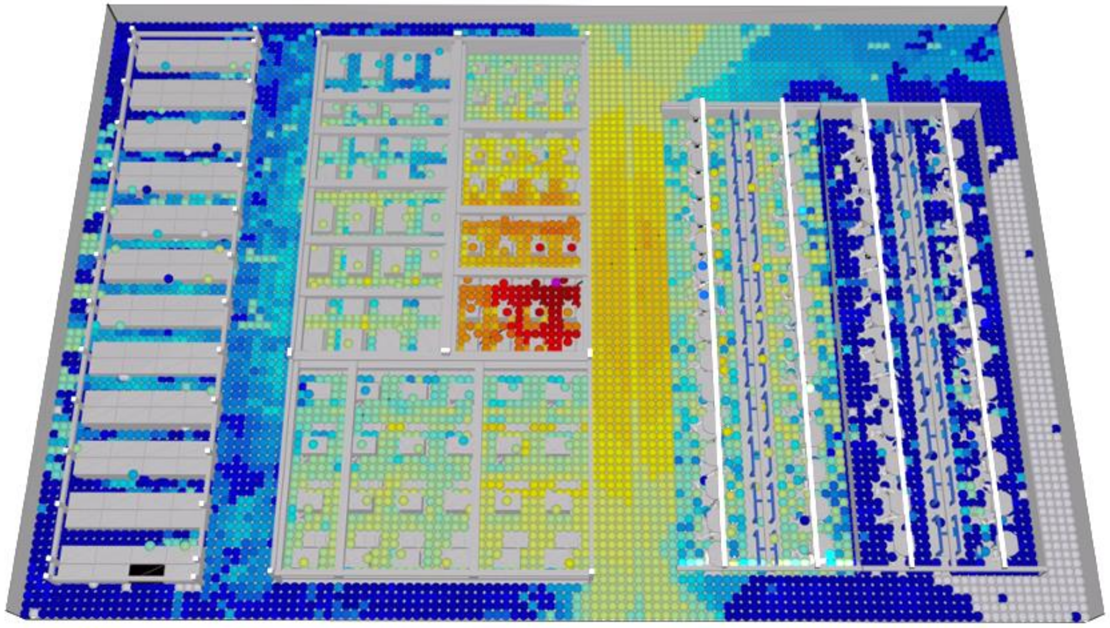
4 specular | **4 specular, 1 diffraction (max 4 orders)** | **4 specular, 1 diffusion (max 4 orders)**



Specular reflections constitute the majority of the received energy, whilst diffraction and diffuse scattering add energy on the lower end.

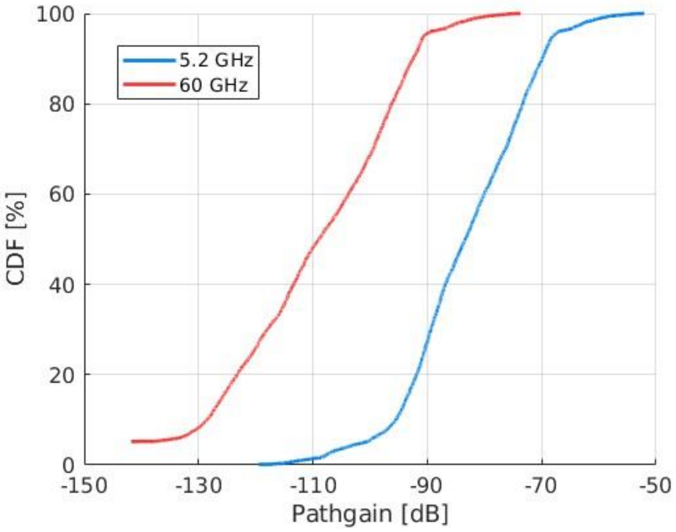
5.2/60 GHz Comparison

60 GHz

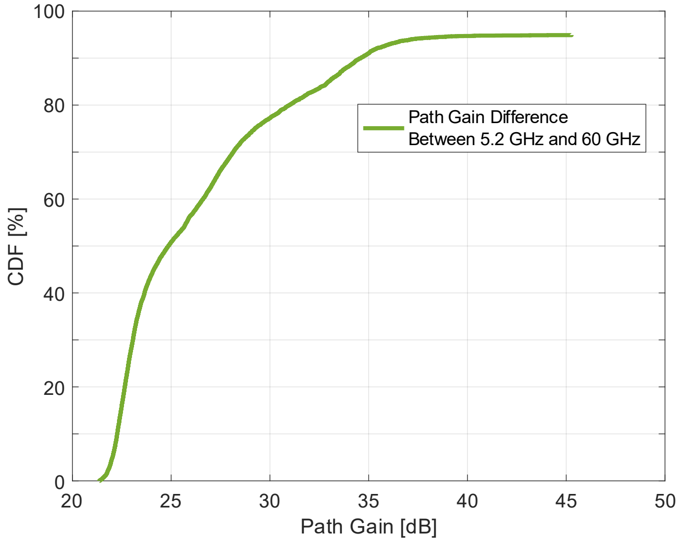


5.2 GHz

Further Comparison



- **Propagation distribution from one AP in 5.2 and 60 GHz is fairly similar in a large factory environment**
  - Slightly steeper slope at 60 GHz
- **Roughly 5% of users in ”good” coverage positions in both 5.2 & 60 GHz**
  - ~20 APs to cover the whole factory
- **Comparing the propagation difference between 5.2 and 60 GHz at each location**
  - 22-35 dB difference up to 90 %-tile
  - Theoretical free-space path loss difference = ~21 dB

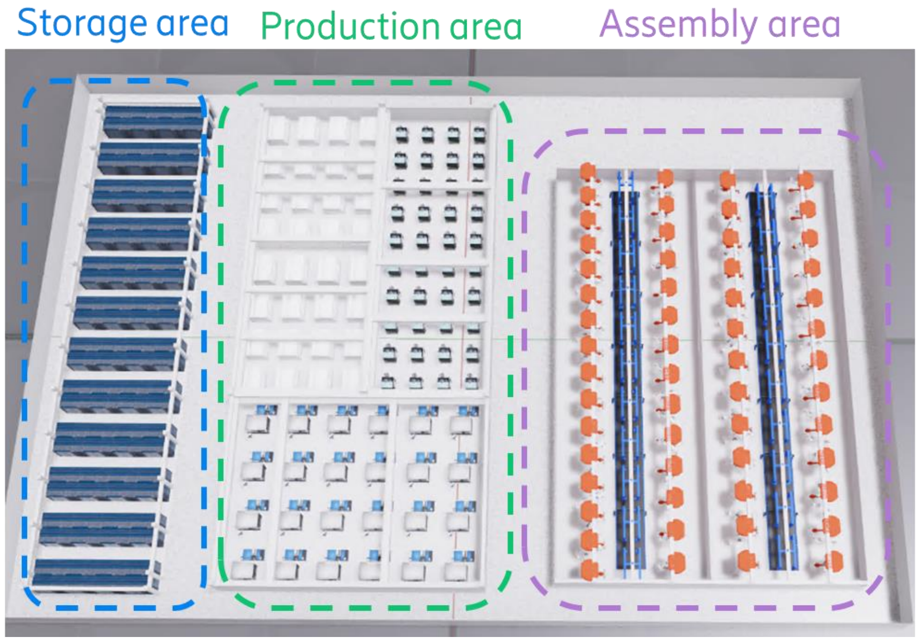


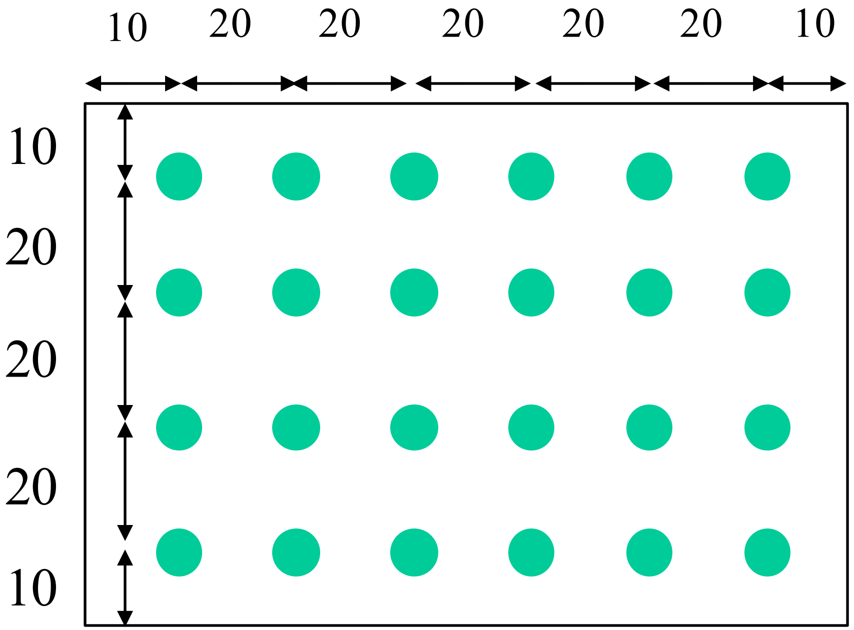
Propagation Results in a Network with Multiple APs

AP: 24 APs in the factory, with 20m inter AP distance. 4.8m high

STA: connects to the AP with the best receiving signal power

Ray tracing parameters: max 4 total order, 4 specular reflection, 2 diffraction, 1 diffuse





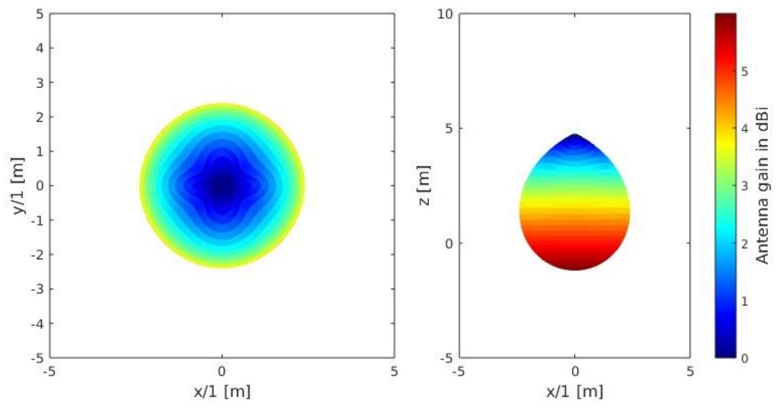
Antenna Models

All isotropic case

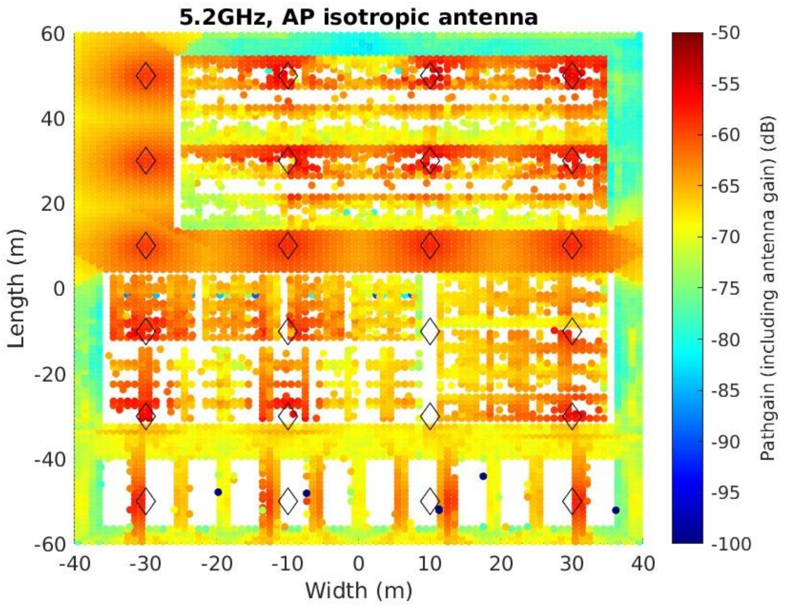
Gain	AP	STA
5.2 GHz	0	-3
60 GHz	9	6

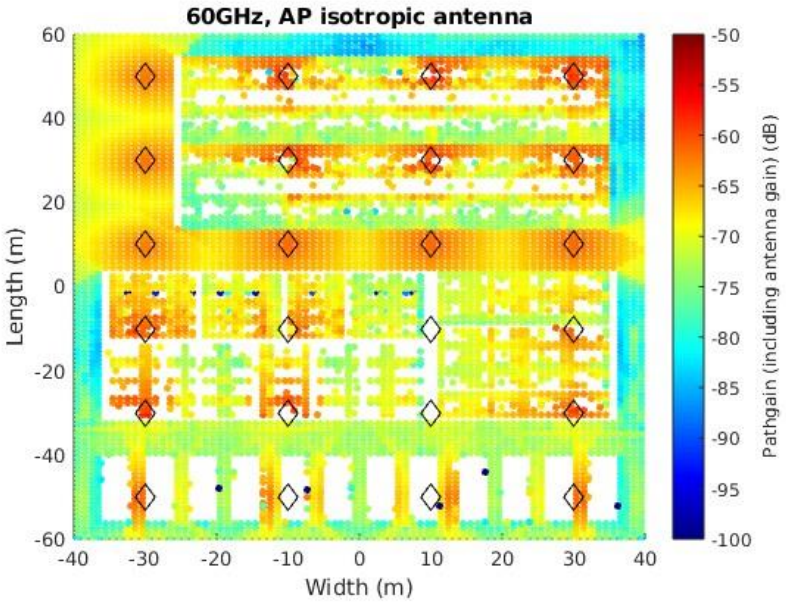
Directional for 60 GHz AP case

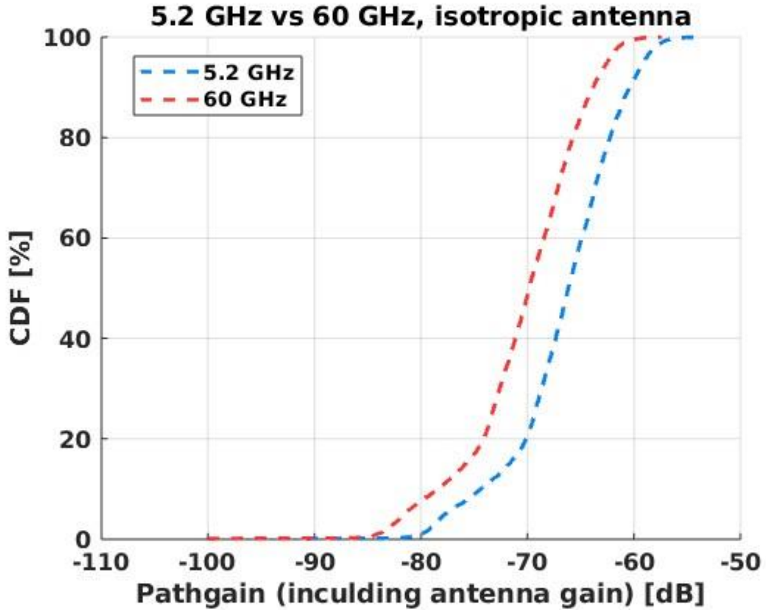
- **Same as in isotropic case but,**
- **AP [4]**
  - M x N = 1 x 1, Mg x Ng = 4 x 4, Dual polarized antenna pairs
  - Half-power beamwidth = 90 degrees
  - SLAv = 25 dB
  - Am = 25 dB
  - GE max = 5 dB



Propagation Results 5.2 GHz vs 60 GHz

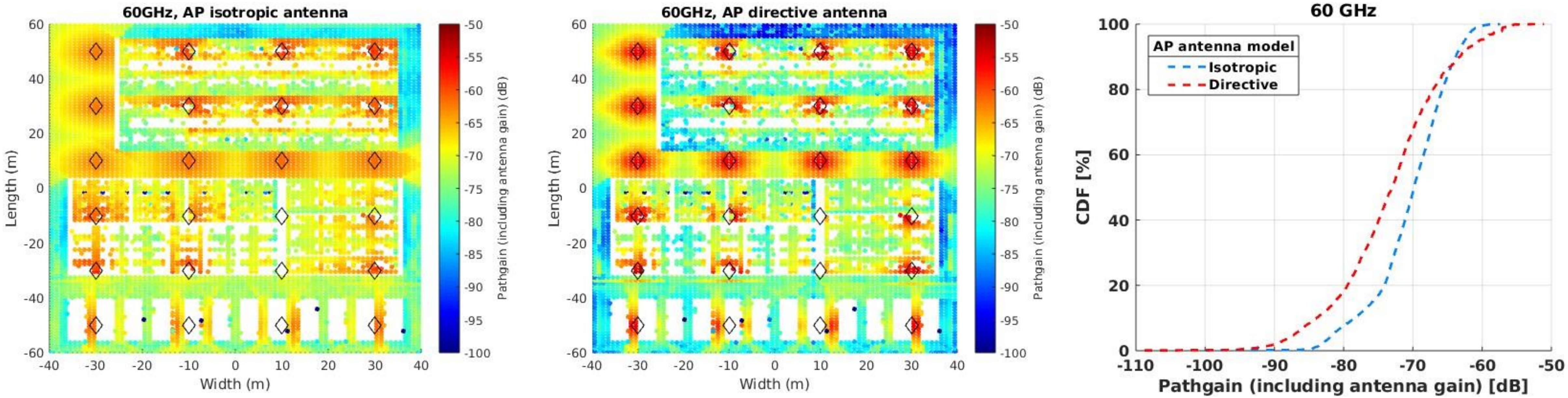






- Assume sufficient spectrum such that no co-channel interference is experienced in a planned deployment
- With a dense AP deployment, the APs in 60 GHz with total 18dBi antenna gains (9 from AP + 9 from STA) still provides weaker path gain as compared to the APs in 5.2 GHz
- However coverage is good, 18 dBm Tx power gives 0 dB SNR at -91 dB path gain for a 1280 MHz channel in 60 GHz (assuming -83 dBm thermal noise and 10 dB noise figure)

Antenna Directivity, 60GHz



- **With the directive antenna model, an AP gives stronger signal towards user directly below, but weaker signal to users on the sides.**
- **~10% of the total users get better path gain, whilst remaining 90% degrade.**
  - Assuming 0 dB SNR at -91 dB path gain means some few users are operating below this point with the directive antenna

Conclusions

- **IMMW seems well suited for industrial scenarios with large (mostly) open rooms**
  - Even with a simple uniform deployment, good coverage can be achieved throughout the factory
- **Theory says ~21 dB difference in free space propagation between 5.2 and 60 GHz, here we see 22-35 dB difference for 90% of locations**
  - Propagation difference between 5.2 and 60 GHz can largely be compensated for by bigger antenna arrays
- **Having good beam steerability seems more important than high directional gain in these scenarios**

References

[1] https://mentor.ieee.org/802.11/dcn/25/11-25-0366-00-00bq-simulation-of-indoor-millimeter-wave-signal-received-power-using-an-omnidirectional-antenna-pattern.pptx

[2] https://development.standards.ieee.org/myproject-web/app#viewpar/15951/11824

[3] Haodong Zhao, MSc Thesis, ‘3D Modeling of Factory Scenarios for 5G Evaluations’, 2023

[4] ITU-R M.2412-0