Exposure of a pedestrian in a 6G cell-free network at 28 GHz, street by street

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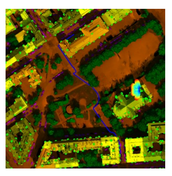
At equal total network power, cell-free exposure varies about 20 dB less along the walk than with a collocated array. Snapshot maxima are below 1% of the local power-density thresholds in both studied cities.

1 Question

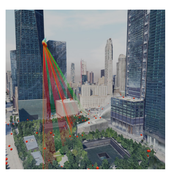
A cell-free network replaces a large antenna array with hundreds of small access points on the facades. Their phases are coordinated so that the waves add in phase at the device. Does this change the exposure of the pedestrian who holds it?

The answer depends on the street, where buildings, trees and cars block and reflect waves of 10.7 mm. The body absorbs the power in the first millimeter of skin. Both the street and the body are part of the model.

2 Method in New York



1 Configuration
Two addresses are the endpoints of the walk. The area has a photogrammetric 3D mesh. A neural network assigns every face to one of six classes, such as building, vegetation or terrain. Each class has a material.



2 Propagation
The large-scale channel parameters are from ray tracing at a coarse set of points along the walk. A stochastic channel model [3] computes the channel at every position, continuous in time.

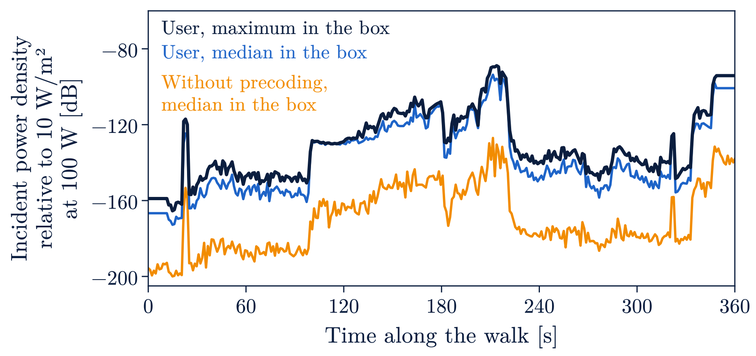


3 Hybridization
The last scatterers of the channel model radiate to the user. Their fields are summed, with the precoding weights, on a Huygens box around the ear.



4 Exposure
The box is the source of a finite-difference time-domain (FDTD) simulation with an anatomical head model at 0.5 mm resolution. The output is the absorbed power density over 4 cm^2 of skin.

3 New York: a walk of six minutes



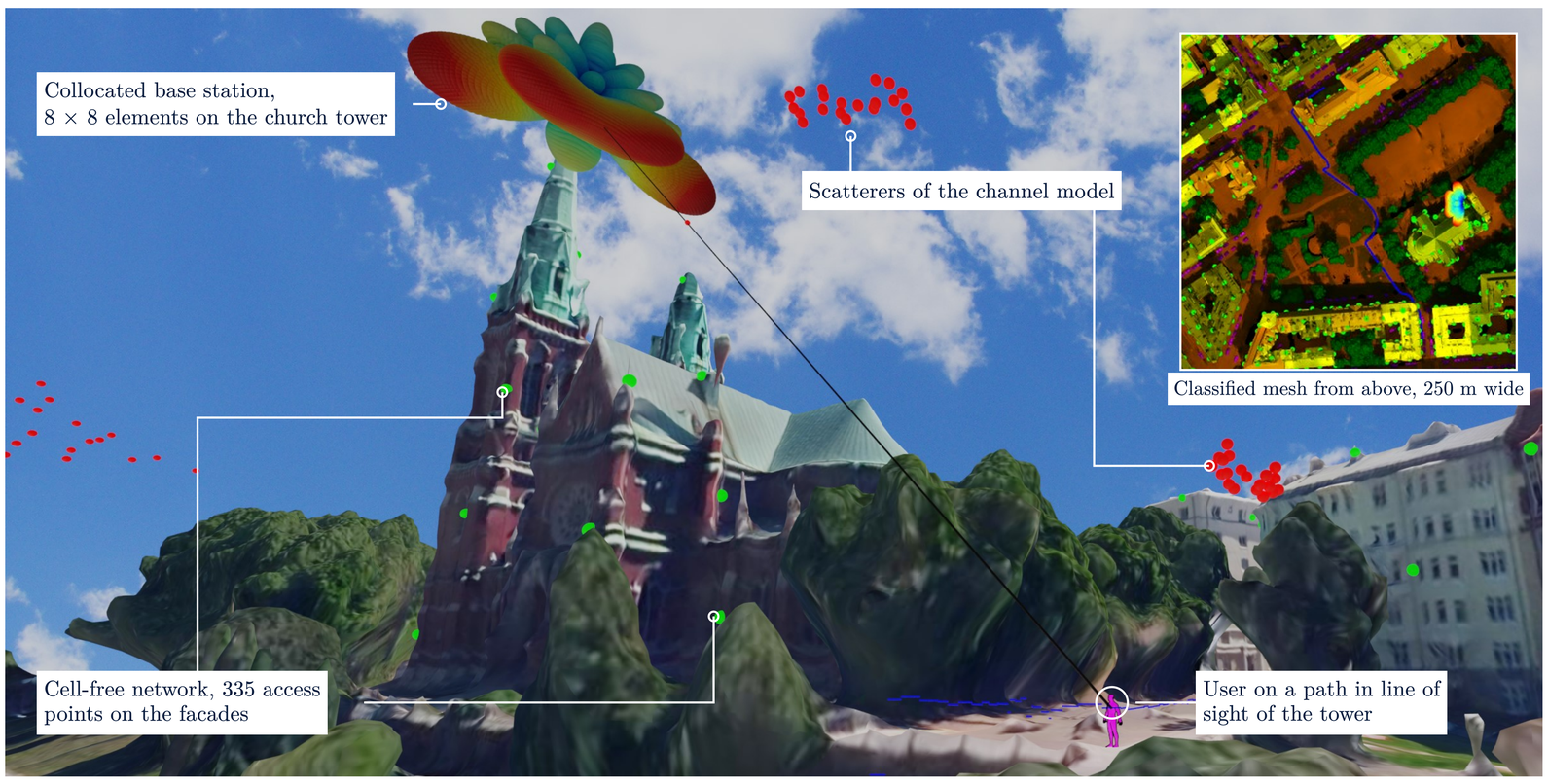
Walk at the World Trade Center, device at the right ear, 100 W total. The normalization of 10 W/m^2 is below the local reference level of 30.5 W/m^2. Box: 5.1 cm × 4.1 cm × 7.1 cm around the ear.

User exposure with precoding is 32 dB higher than with unprecoded transmission. The signal at a pedestrian 5 m away is 10 dB lower. The box maximum is 7 dB above its median.

9905
Helsinki positions, 160 s each on GPU hardware

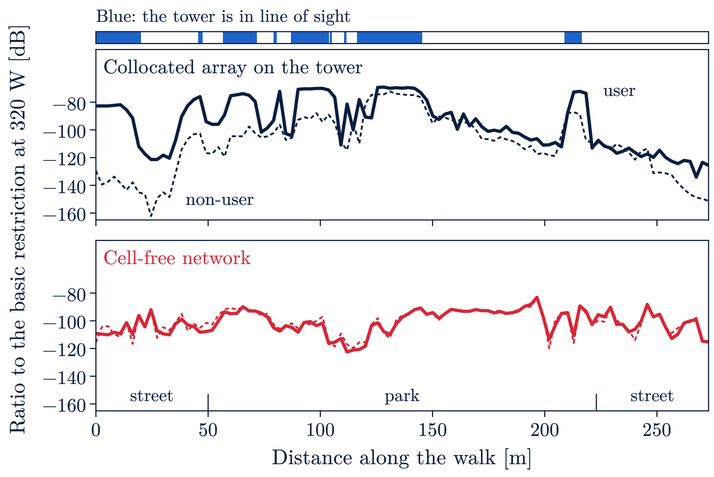
< 1%
snapshot maxima relative to local thresholds, both cities

4 Helsinki: collocated array and cell-free network



St. John's Church as a photogrammetry mesh. The beam of the collocated array (colored pattern) is directed at the user. Green: access points of the cell-free network. Red: scatterers for this position. Inset: the 273 m walk in blue. Here the mesh is used for the channel model's line-of-sight classification. This case has no ray tracing.

5 Exposure along the walk

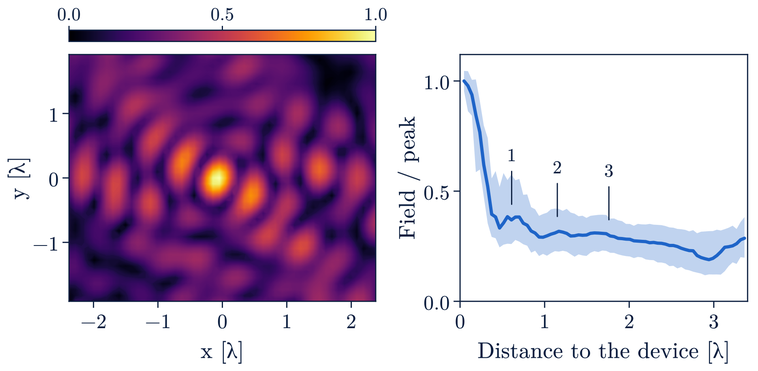


Absorbed power density over 4 cm^2, relative to the limit of 20 W/m^2, for 320 W in total. Solid: user. Dashed: non-user, without precoding.

With the array on the tower, the exposure is high where the tower is in line of sight. The user's exposure is higher than the non-user's, because the beam is directed at the device.

In the cell-free network, an access point is in line of sight most of the time. The user and non-user curves nearly coincide, and exposure varies about 20 dB less along the walk at equal total network power.

6 Hot-spot at the device



Electric field around the device, averaged over 316 positions of the New York walk, relative to the peak. Right: field against distance, with three sidelobes.

At a given instant, the hot-spot can have any shape. Averaged over the walk, the field has a peak at the device, 0.44 λ wide. Far from the device, the field is 25% of the peak, so the time-averaged field at the hot-spot is 12 dB higher.

The quantity averaged under the guidelines [2] is power:

$$S_{\text{field}} = |\langle \mathbf{E} \rangle \times \langle \mathbf{H} \rangle|, \qquad S_{\text{power}} = \langle |\mathbf{E} \times \mathbf{H}| \rangle,$$

with $\langle \cdot \rangle$ the average over time. In S_{power}, fields of opposite sign no longer cancel, and the peak is 0.92 λ wide.

7 Conclusions

- The power absorbed in a pedestrian's skin is calculated from the network's precoding weights in a 3D model of an existing street.
- Exposure is more uniform with a cell-free network than with a collocated array, for users and non-users.
- Each hybrid-method position takes 160 s on GPU hardware. The FDTD cost is proportional to the fourth power of frequency. The closed-form law of Chapter 5 is an alternative to FDTD.

References
[1] R. Wydaeghe *et al.*, "Hybrid ray-tracing-QuaDRiGa/FDTD method for realistic 28 GHz exposure with 6G CF-MaMIMO in 3D outdoor environments," *npj Wireless Technology*, vol. 2, art. 13, 2026, doi: 10.1038/s44459-026-00031-4. [2] ICNIRP, "Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz)," *Health Phys.*, vol. 118, no. 5, 2020. [3] S. Jaeckel *et al.*, "QuaDRiGa: a 3-D multi-cell channel model with time evolution for enabling virtual field trials," *IEEE Trans. Antennas Propag.*, vol. 62, no. 6, 2014.

Acknowledgement
This work was supported by the European Research Council (ERC) through ATTO under Grant 695495, by Methusalem through SHAPE: Next Generation Wireless Networks, and by the Research Foundation Flanders (FWO) through file number K215823N.

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