Exposure of a user in a factory hall with massive MIMO at 3.5 and 28 GHz

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At equal radiated power, user exposure is two to three times lower with a distributed antenna array than with a collocated array. In this comparison at 320 W, the 95th percentile of exposure is at most 4% of the ICNIRP limits.

1 Question

A massive multiple-input multiple-output (MIMO) base station uses many antenna elements to focus its power on the user. The focus is a hot-spot at the device, and its shape and strength depend on the walls and machines of the hall.

A full-wave simulation of the hall is not possible. At 28 GHz the wavelength is 10.7 mm and the hall is 50 m across. A simulation of the head alone does not contain the hall. Therefore, we use a hybrid method. We ask how the layout of the array changes the exposure.

Exposure quantity	Evaluated	Limit [2]
Incident power density	in free space	10 W/m^2
Peak SAR in 10 g	in the head, 3.5 GHz	2 W/kg
Absorbed power density	on 4 cm^2 of skin, 28 GHz	20 W/m^2

The first quantity has a reference level and the others have basic restrictions. SAR: specific absorption rate.

We report every quantity γ as a percentage of its limit, for a radiated power of 320 W:

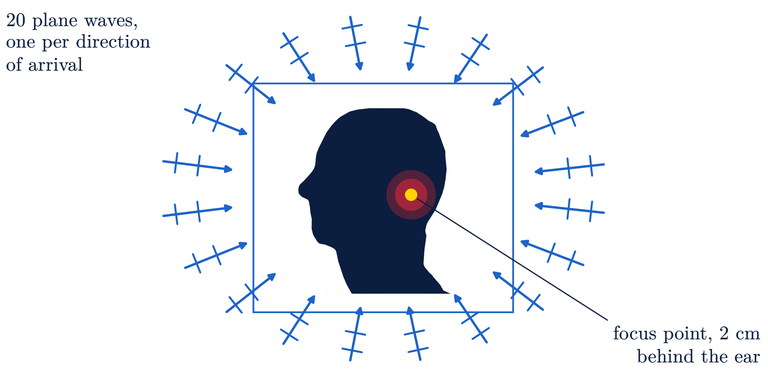
$$\eta = \frac{\gamma}{\gamma_{\text{limit}}}, \qquad \alpha = \frac{\eta_{\text{b}}}{\eta_{\text{r}}},$$

with η_{r} for the reference quantity and η_{b} for the basic quantity. If α is below 1, the head quantities are below the basic restriction when the field is at the reference level.

2 Hybrid method

1. Ray tracing hall, array, user rays per element → **2. FDTD** one plane wave per direction → **3. Combination** weighted sum of the head fields

Ray tracing computes the paths of the waves from every antenna element through the hall, with up to six reflections and two diffractions. At the user, we group the rays into 20 directions.



Head simulation. The finite-difference time-domain (FDTD) method solves Maxwell's equations in the anatomical head model MIDA [3]. Blue frame: simulated volume, with 1.5 million cells of 1.75 mm at 3.5 GHz and 22 million cells of 0.72 mm at 28 GHz. A simulation per direction is enough for all arrays and channels.

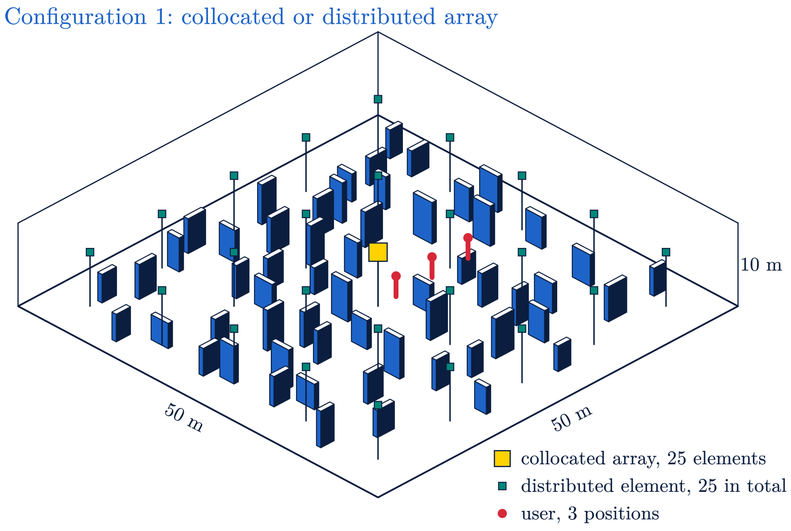
The base station sets the phases of its M elements so that their waves add in phase at the user's device. With the channel h_m of element m, the weights and the total field are

$$w_m = \frac{h_m^*}{\|\mathbf{h}\|}, \qquad \mathbf{E}_{\text{tot}}(\mathbf{r}) = \sum_{i=1}^{20} a_i \, \hat{\mathbf{E}}_i(\mathbf{r}),$$

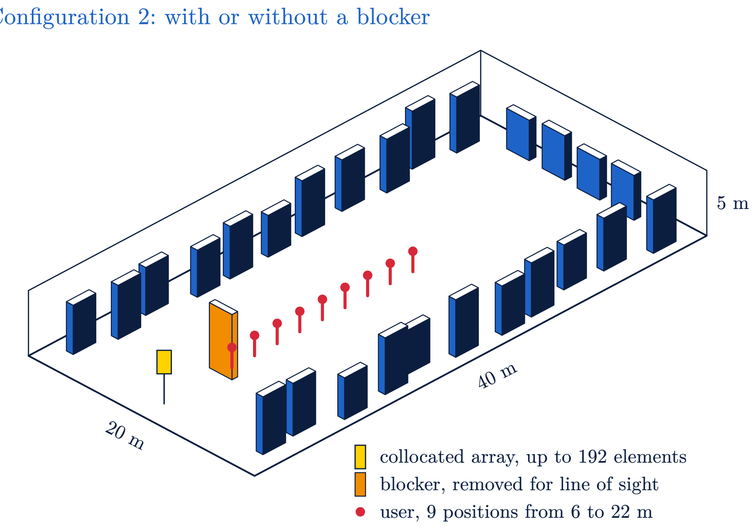
with $\hat{\mathbf{E}}_i$ the field in the head for a unit plane wave from direction i, and a_i the complex amplitude of the weighted rays from that direction.

3 Factory halls

Configuration 1: collocated or distributed array

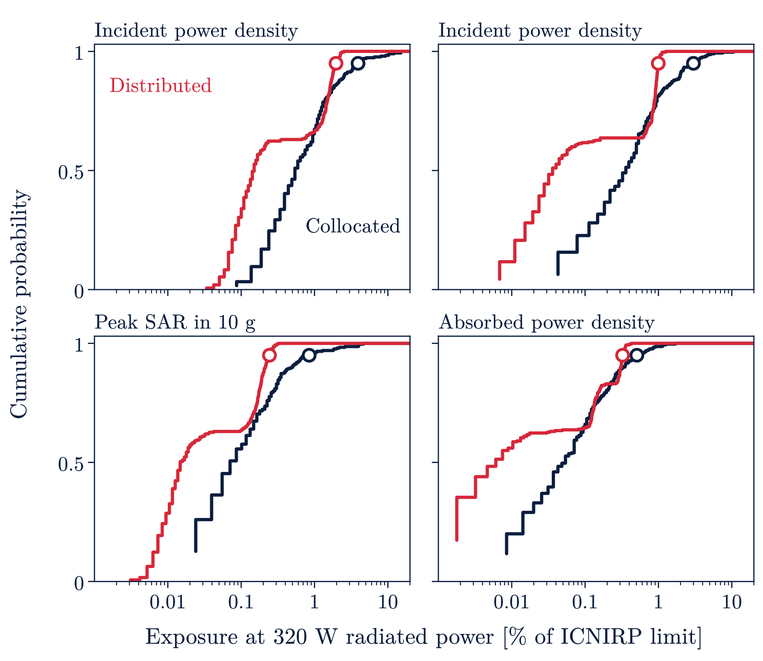


Configuration 2: with or without a blocker



Concrete halls with metal objects placed at random for every channel realization. Left: 100 realizations with three users. Right: five realizations with nine users.

4 Collocated or distributed



Distribution of the exposure over all users and channel realizations in configuration 1. Circles: 95th percentile. Top: reference quantity in free space. Bottom: basic quantity in the head.

Exposure is two to three times lower with the distributed array. The two groups may be due to machinery. With surrounding machines, the nearest elements contribute most. Otherwise, distant elements contribute too.

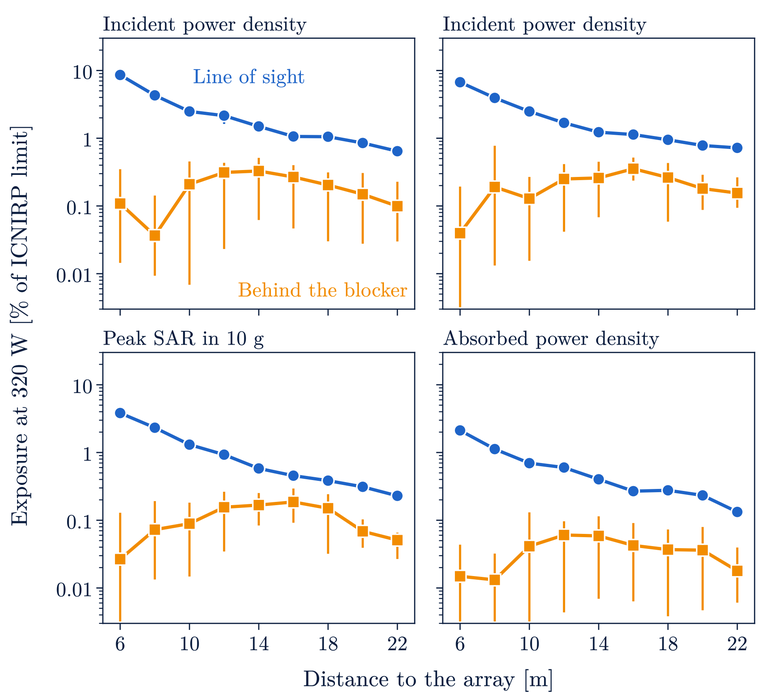
The head quantities are 5 to 10 dB further below their limits than the incident power density. Thus, $\alpha < 1$ in these simulations.

Most groups are absent after device-power normalization. The main cause is propagation, except possibly near-skin APD hot-spots with the distributed array at 28 GHz.

4% of the reference level, 95th percentile at 320 W

0.85% of the basic restrictions, 95th percentile at 320 W

5 Line of sight or blocked



Exposure against distance in configuration 2. Markers: mean. Bars: range over five realizations.

In line of sight, the exposure decreases with distance as a power law. Behind the blocker it is about 100 times lower close to the array and 2 to 10 times lower from 12 m on. The blocker is 5 m from the array.

6 Conclusions

- The hybrid calculation uses ray tracing for a 50 m hall and FDTD for the head at 28 GHz.
- Exposure is two to three times lower with a distributed array at equal radiated power.
- With the incident field at the reference level, the head quantities are 5 to 10 dB below their limits.
- Close to the array, a blocker lowers exposure by up to about 100 times.
- Chapter 4 applies the method outdoors, in a city street.

References

[1] R. Wydaeghe *et al.*, "Realistic human exposure at 3.5 GHz and 28 GHz for distributed and collocated MaMIMO in indoor environments using hybrid ray-tracing and FDTD," *IEEE Access*, vol. 10, pp. 130996–131004, 2022, doi: 10.1109/ACCESS.2022.3227107. [2] ICNIRP, "Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz)," *Health Phys.*, vol. 118, no. 5, 2020. [3] M. I. Iacono *et al.*, "MIDA: a multimodal imaging-based detailed anatomical model of the human head and neck," *PLoS ONE*, vol. 10, no. 4, 2015.

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