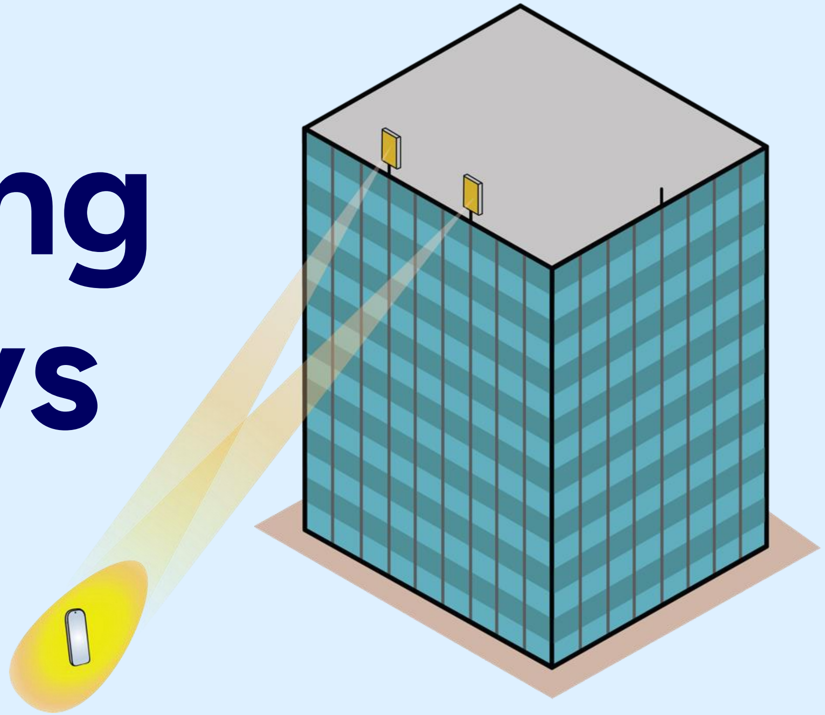
Achieving Beamfocusing with Distributed Arrays



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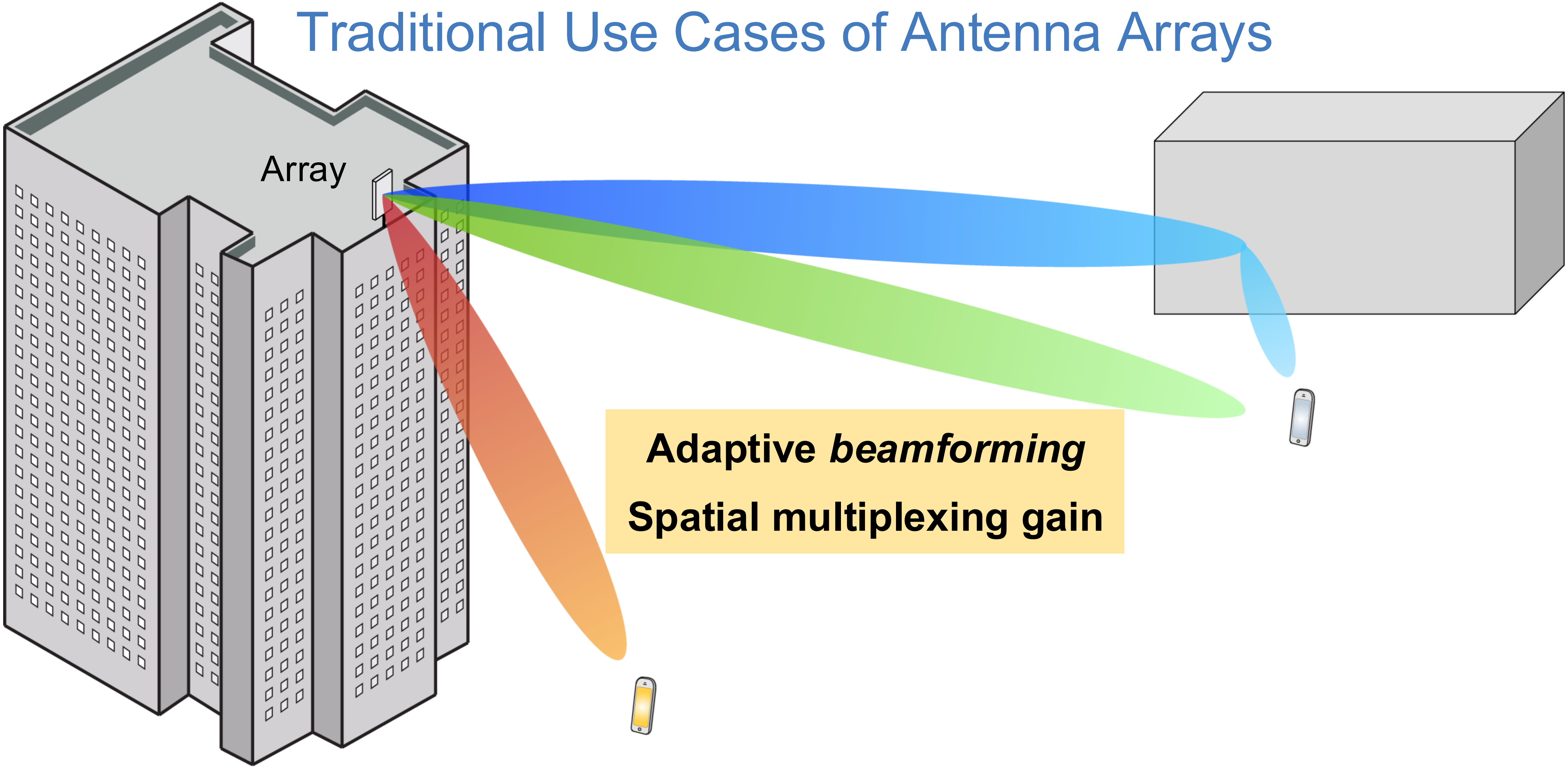
Joint work with: Alva Kosasih, Özlem Tuğfe Demir, et al.

Traditional Use Cases of Antenna Arrays



Adaptive *beamforming*

Spatial multiplexing gain

MIMO = Multiple input, multiple output

Evolution of Antenna Arrays

Massive MIMO

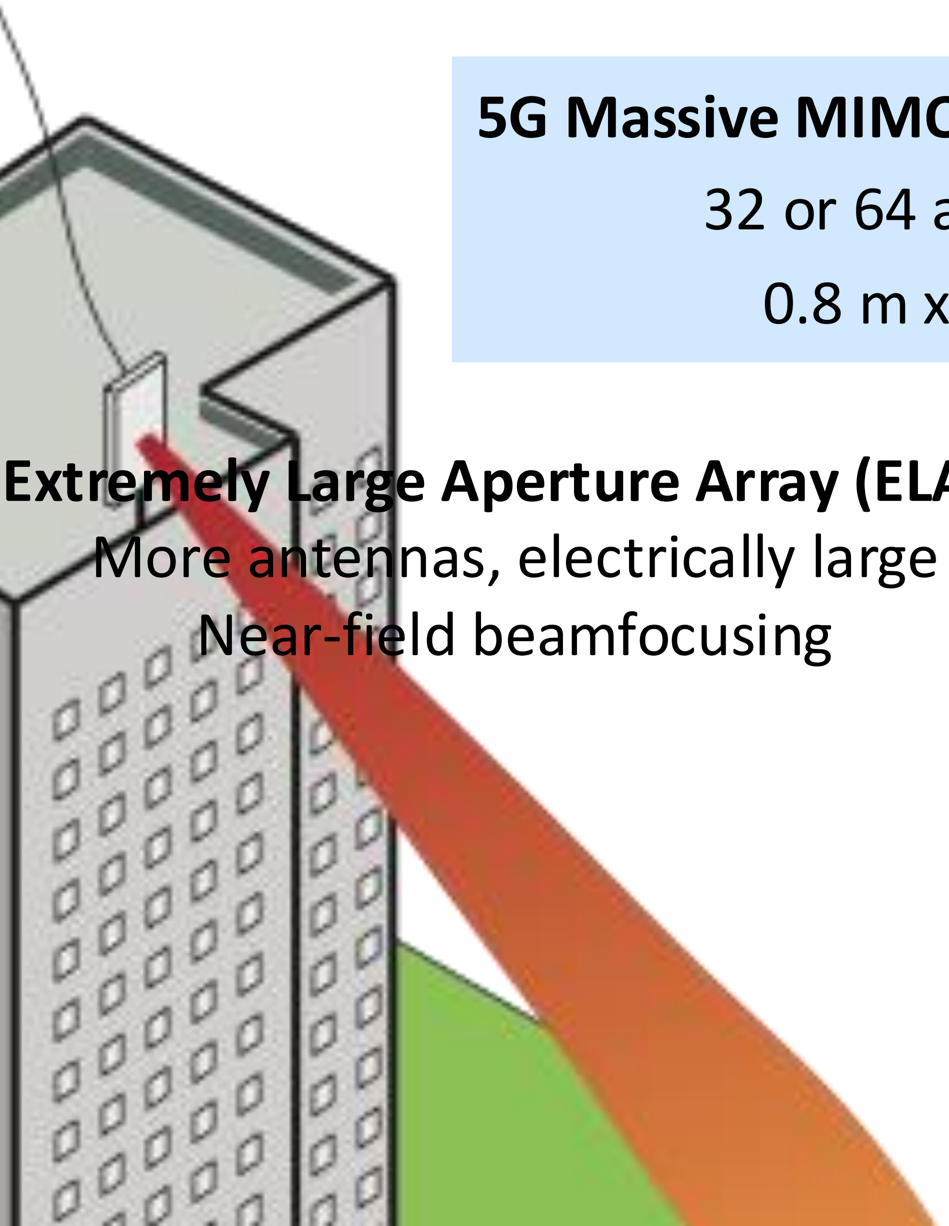
Many antennas, bı

Far-field beamfo

5G Massive MIMO in 3.5 GHz band

32 or 64 antennas

0.8 m x 0.5 m



Extremely Large Aperture Array (ELAA)

More antennas, electrically large

Near-field beamfocusing

Is this practically possible?

Basics of Beamforming and Beamfocusing

Beamwidth (BW) is $\mathrm{BW}_{3\mathrm{dB}} \approx 0.886 \cdot \frac{\lambda}{D}$

Regardless of the distance!

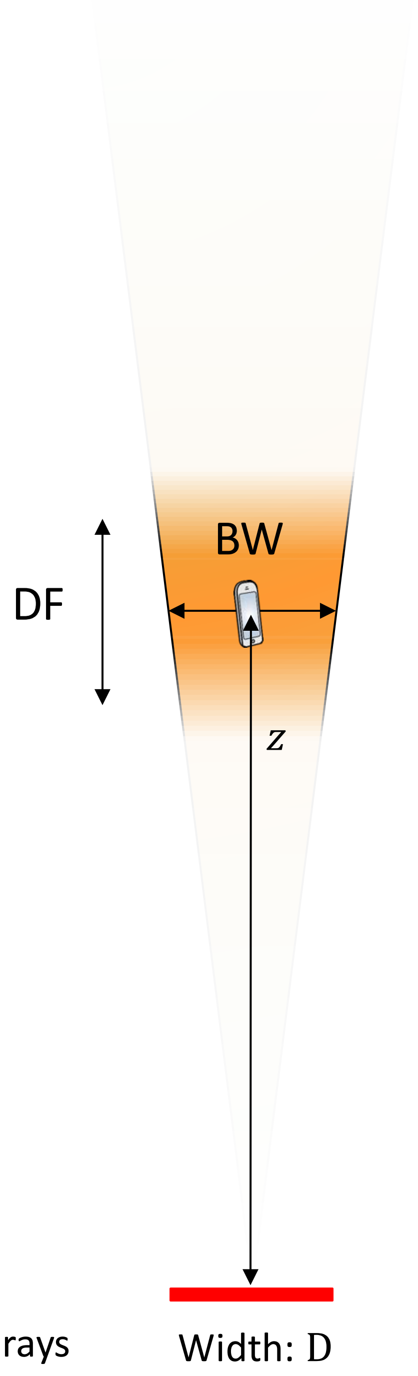
Fraunhofer distance: $d_F = 2 \cdot \frac{D^2}{\lambda}$

Does it determine when the depth is limited?

No! Depth-of-focus (DF) for focusing at distance z is

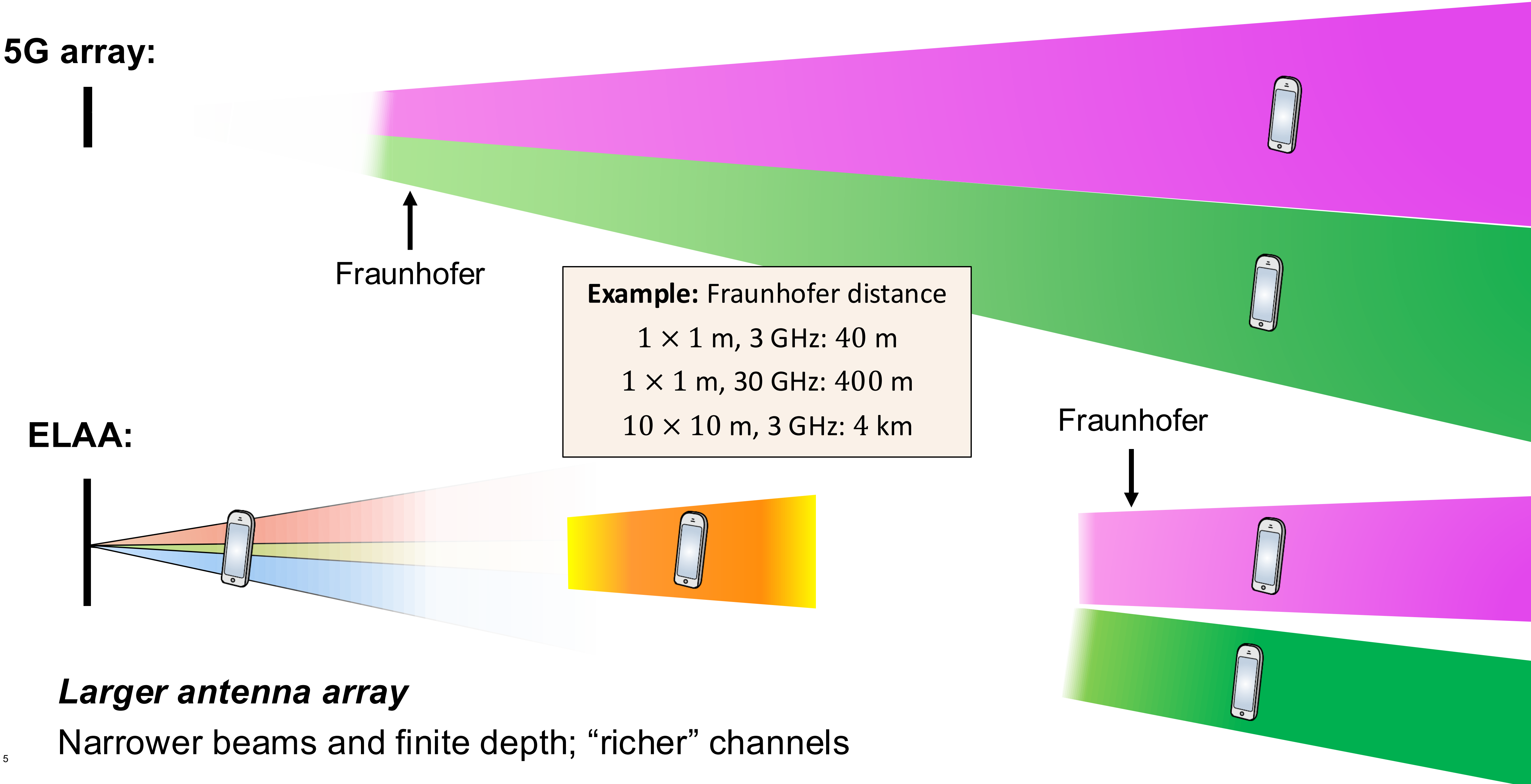
$$d \in \left[\frac{d_F z}{d_F + 10z}, \frac{d_F z}{d_F - 10z}\right]$$

Finite-depth beamfocusing closer than $d_F/10$



Reference: E. Björnson, Ö. T. Demir, L. Sanguinetti, "A Primer on Near-Field Beamforming for Arrays and Reconfigurable Intelligent Surfaces," Asilomar SSC 2021.

The vision: **Spatial Multiplexing** in Both **Angle** and **Depth**

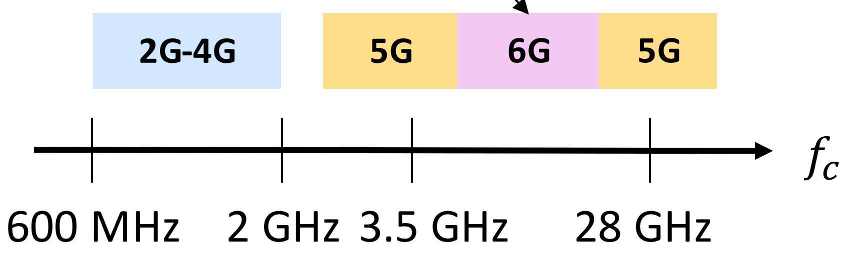


Larger antenna array

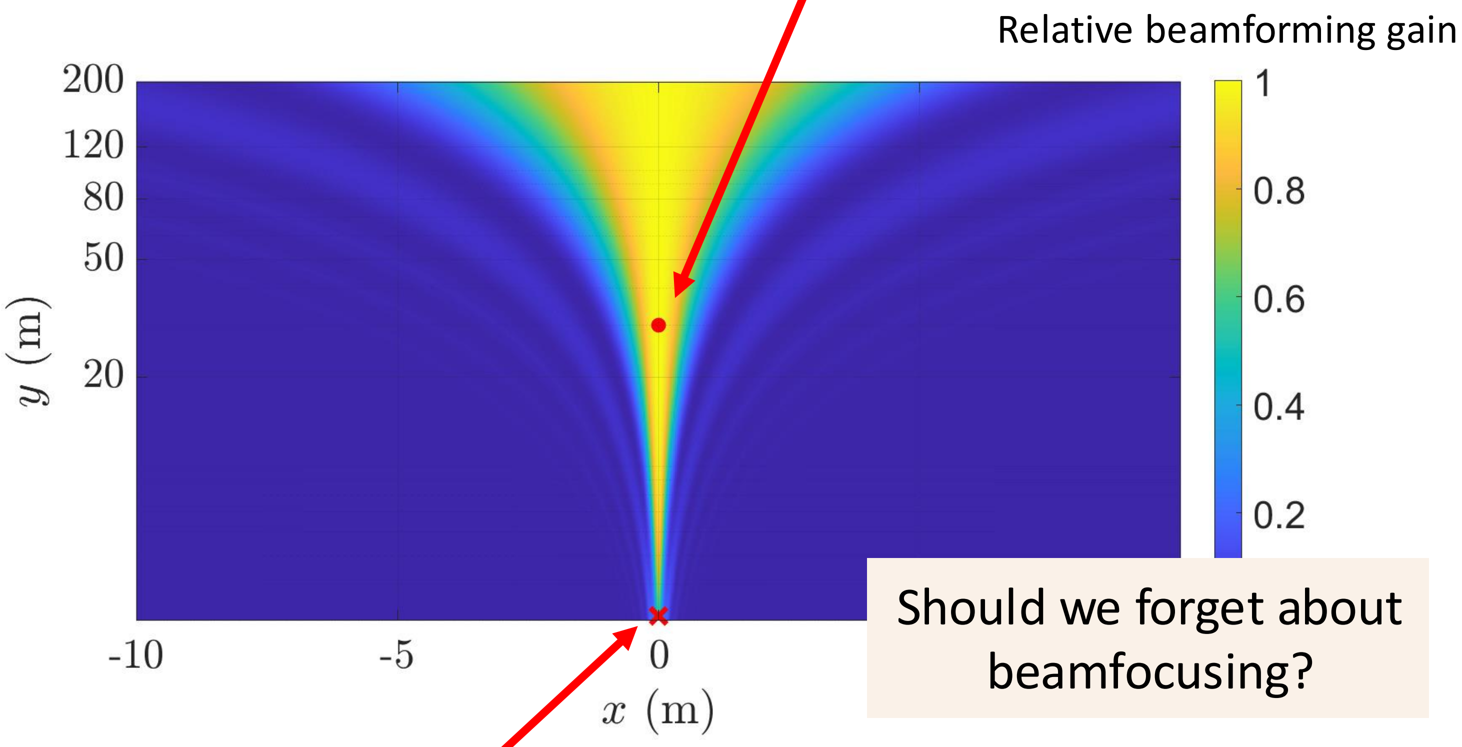
Narrower beams and finite depth; “richer” channels

Can We Do Beamfocusing in 6G?

Frequency range 3 (FR3)
- 7.1-8.4 GHz
- 14.8-15.35 GHz



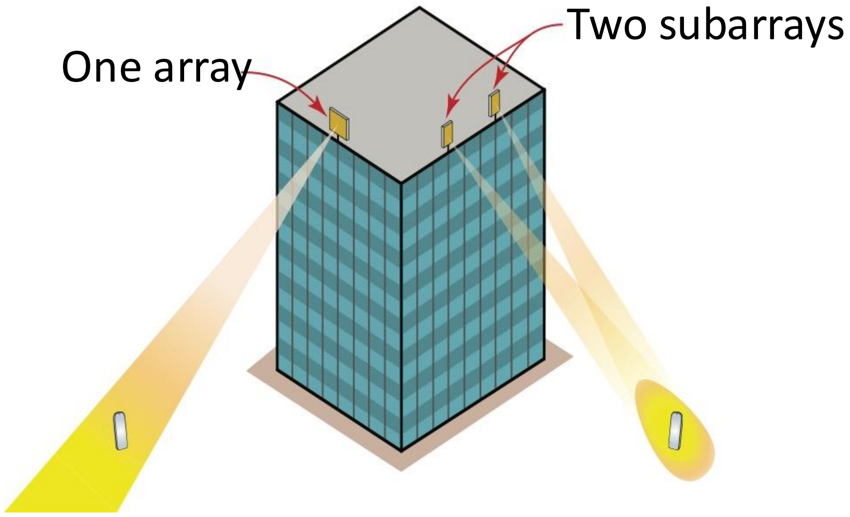
Receiver at 30 m



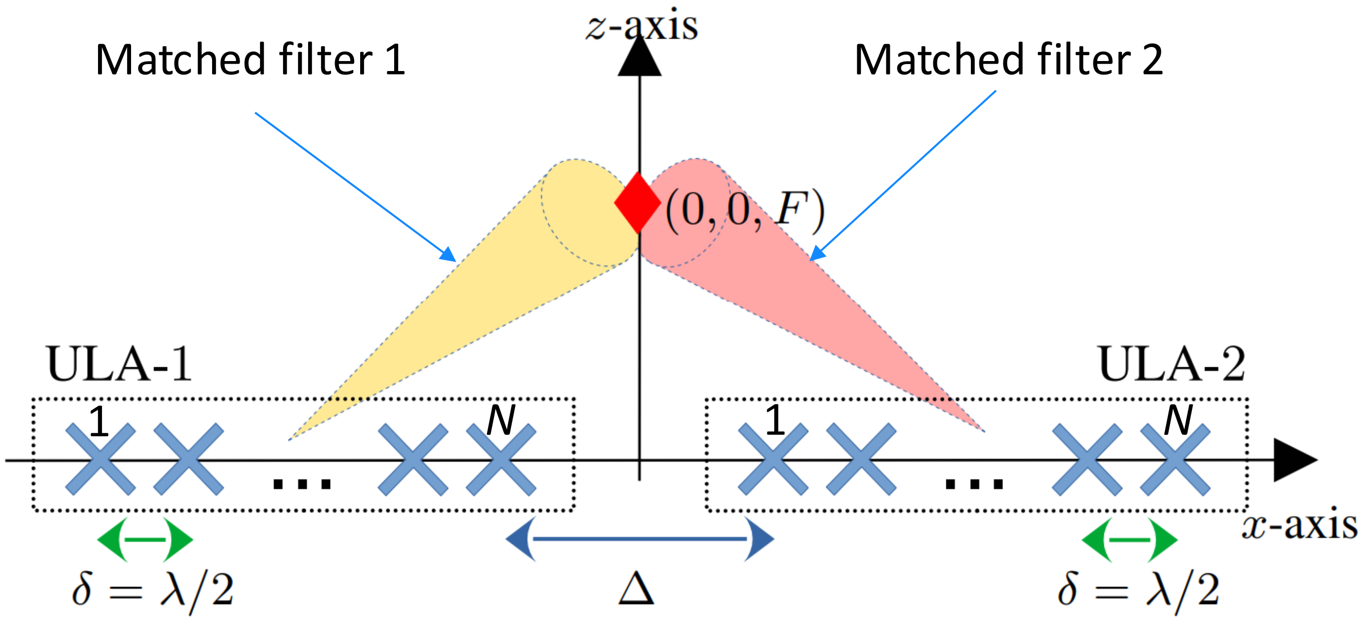
Should we forget about beamfocusing?

What fits into this box?
Uniform linear array (ULA)
48 antennas (0.5 m at 15 GHz)
Fraunhofer distance: 23 m

A Possible Workaround



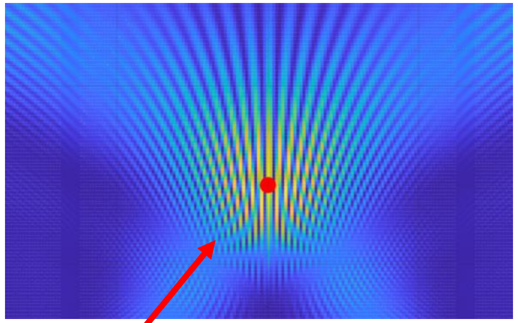
Resembles stereoscopic vision

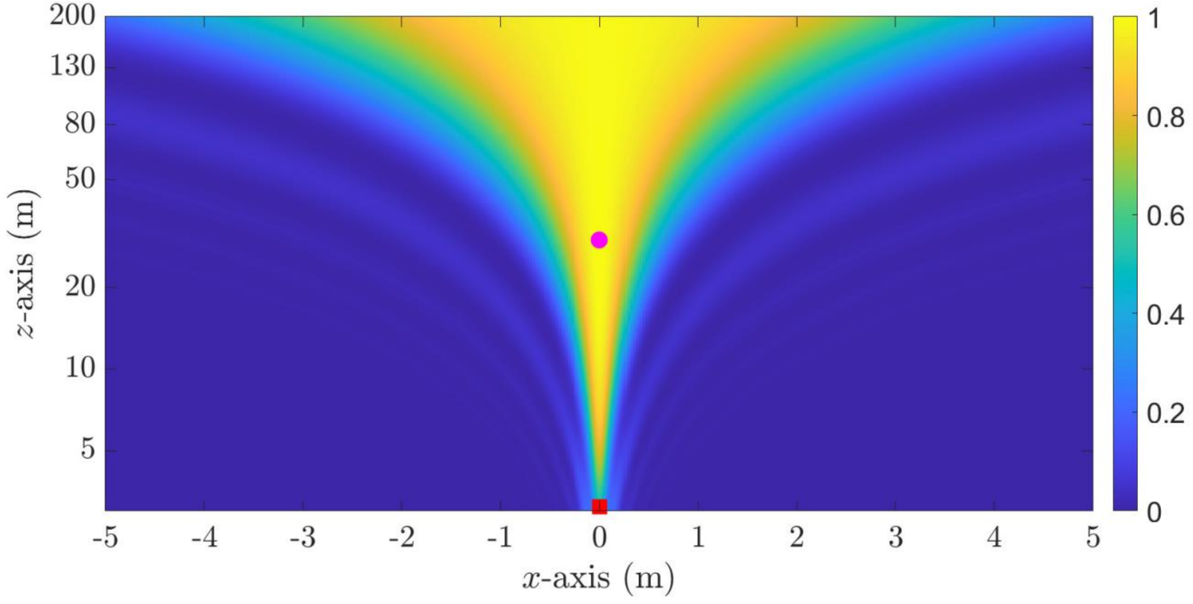


What happens to the beampattern?
Does it resemble having one large array?

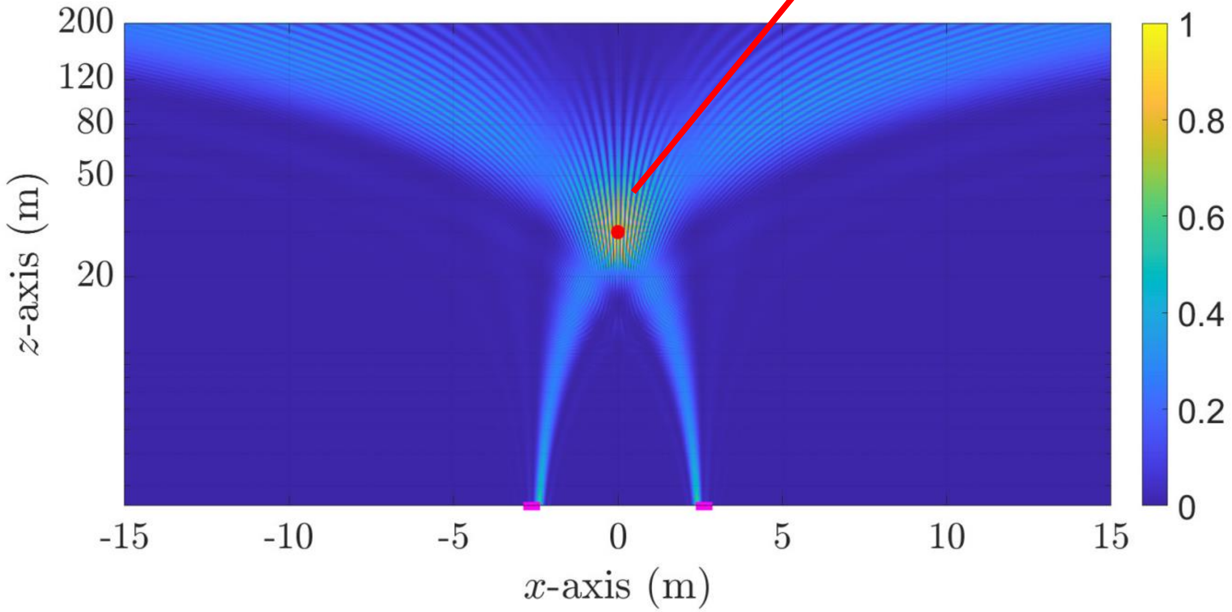
Beampattern Comparison

Novel phenomenon:
Horizontal ripples





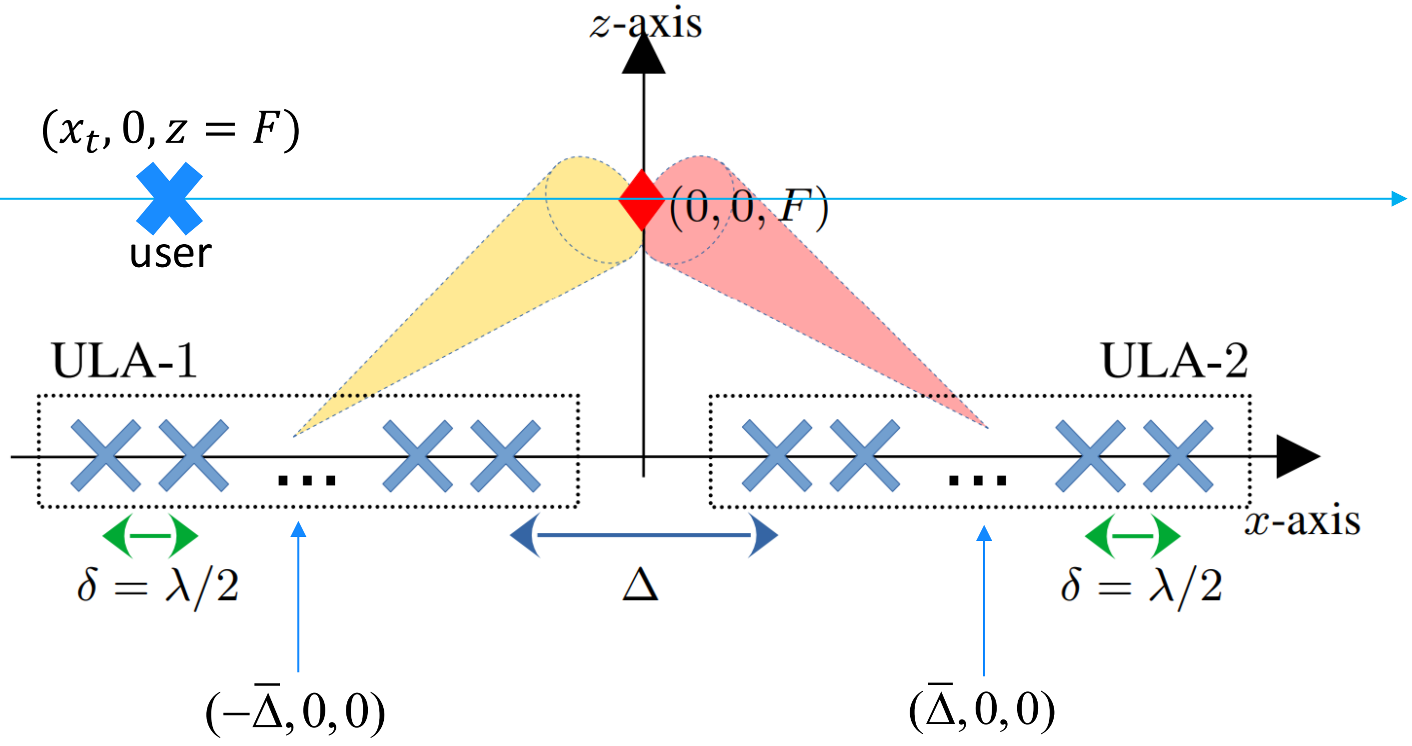
(a) A single ULA.



(b) Two ULAs separated by 5 m apart.

Reference: E. Björnson, F. Kara, N. Kolomvakis, A. Kosasih, P. Ramezani, M. B. Salman, “Enabling 6G Performance in the Upper Mid-Band by Transitioning From Massive to Gigantic MIMO,” arXiv:2407.05630.

Mathematical Characterization



Normalized beamforming gain (from 0 to 1)

$$= \left|\mathrm{sinc}\left(\frac{Nx_t}{2z}\right)\cos\left(\frac{2\pi\bar{\Delta}x_t}{\lambda z}\right)\right|^2 \leq \mathrm{sinc}^2\left(\frac{Nx_t}{2z}\right)$$

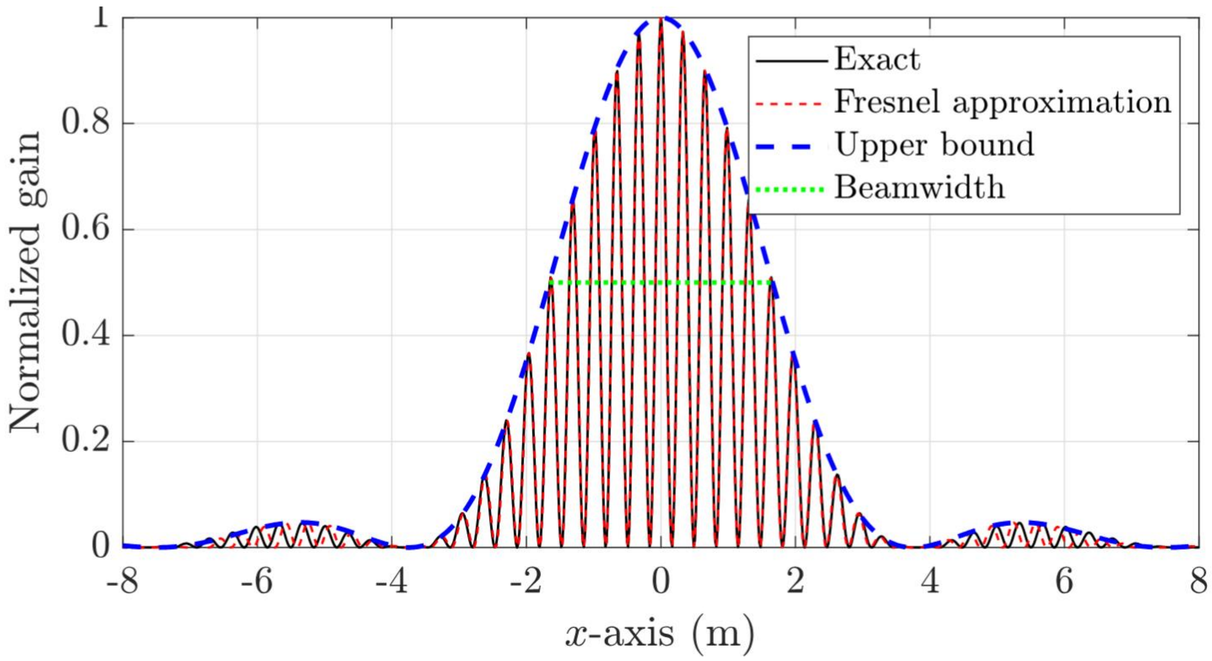
Ripple factor

Envelope

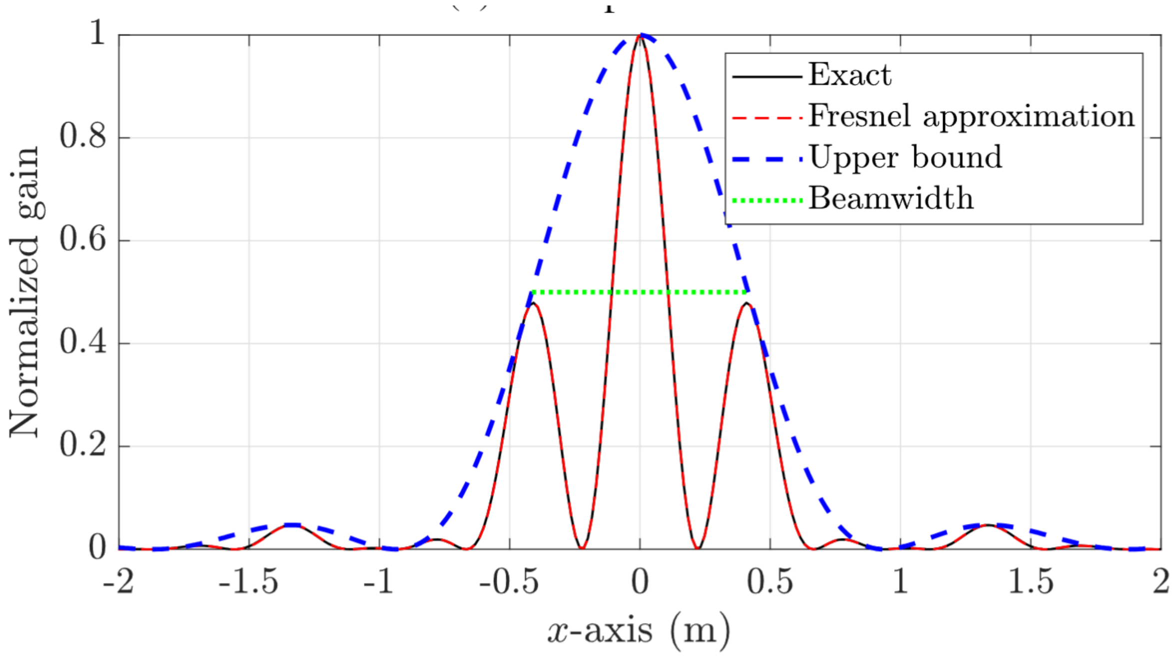
Depends on the number of antennas in each ULA *N*, not the spacing between the ULAs

Reference: A. Kosasih, Ö. T. Demir, E. Björnson, "Achieving Beamfocusing via Two Separated Uniform Linear Arrays," Asilomar SSC 2024.

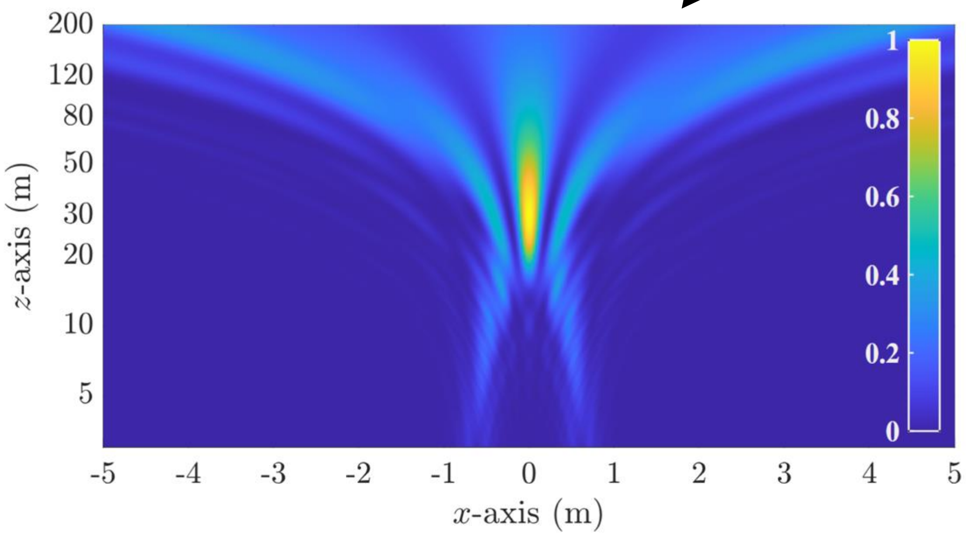
Numerical Example



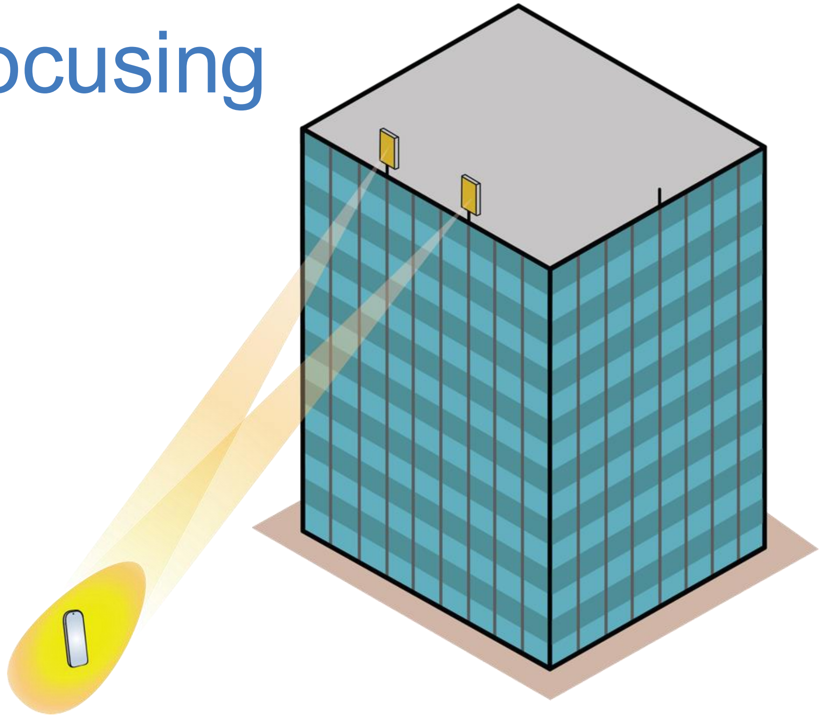
Spacing between arrays: 2 m



Spacing between arrays: 0.72 m



Conclusions: Distributed Arrays Give Beamfocusing



- **Distance domain**
  - The total aperture length matters
  - We achieve the beamfocusing we are looking for!
- **Beamwidth**
  - Fast ripples due to constructive/destructive interference
  - Envelope determined by size of individual arrays

References:

E. Björnson, Ö. T. Demir, L. Sanguinetti, "A Primer on Near-Field Beamforming for Arrays and Reconfigurable Intelligent Surfaces," Asilomar SSC 2021.

E. Björnson, F. Kara, N. Kolomvakis, A. Kosasih, P. Ramezani, M. B. Salman, "Enabling 6G Performance in the Upper Mid-Band by Transitioning From Massive to Gigantic MIMO," arXiv:2407.05630.

A. Kosasih, Ö. T. Demir, E. Björnson, "Achieving Beamfocusing via Two Separated Uniform Linear Arrays," Asilomar SSC 2024.

If you want to know more…

Near-Field Beamfocusing, Localization, and Channel Estimation with Modular Linear Arrays

Alva Kosasih, Özlem Tuğfe Demir, and Emil Björnson, *Fellow, IEEE*

***Abstract*—This paper investigates how near-field beamfocusing can be achieved using a modular linear array (MLA), composed of multiple widely spaced uniform linear arrays (ULAs). The MLA architecture extends the aperture length of a standard ULA without adding additional antennas, thereby enabling near-field beamfocusing without increasing processing complexity. Unlike conventional far-field beamforming, near-field beamfocusing enables simultaneous data transmission to multiple users at different distances in the same angular interval, offering significant multiplexing gains. We present a detailed mathematical analysis of the beamwidth and beamdepth achievable with the MLA and show that by appropriately selecting the number of antennas in each constituent ULA, ideal near-field beamfocusing can be realized. In addition, we propose a computationally efficient localization method that fuses estimates from each ULA, enabling efficient parametric channel estimation. Simulation results confirm the accuracy of the analytical expressions and that MLAs achieve near-field beamfocusing with a limited number of antennas, making them a promising solution for next-generation wireless systems.**

***Index Terms*—Beamfocusing, beamwidth, beamdepth, channel estimation, modular linear array, localization, near field.**

A. Related Works

Three regions classically define the electromagnetic radiation patterns of an antenna array with respect to the propagation distance: the reactive near field, radiative near field, and far field [8]. We focus on the radiative near field, where amplitude variations across the antennas in the array are negligible, and only phase variations are considered. For simplicity, we refer to the radiative near field as the *near field*. Unlike conventional far-field beamforming, which focuses signals on a far-away point, near-field beamforming acts like a lens, concentrating signals on a specific location, known as finite-depth beamforming/beamfocusing. This is accomplished using a matched filter (MF) based on the channel coefficient of each antenna in the array.

Near-field beamfocusing makes spatial multiplexing more practically useful, particularly in line-of-sight and sparse multipath environments. The reason is that the array can separate multiple users simultaneously by distinguishing them in the angular and distance domains, instead of only the angular

https://arxiv.org/pdf/2505.07991