Near-field Communication and Localization in the Upper Mid-Band Spectrum

Presenter: Parisa Ramezani

parram@kth.se

Table of Contents

Upper Mid-Band Spectrum

Upper mid-band is emerging as a promising frequency range for early 6G deployments as it offers a balance between

- Wide bandwidths found in mmWave frequencies
- Favorable propagation conditions of lower mid-band frequencies.

In WRC-2023, ITU identified three candidate bands for 6G:

- 4.4 – 4.8 GHz
- 7.1 – 8.4 GHz
- 14.8 – 15.35 GHz

FR3

Radiative Near-Field Region

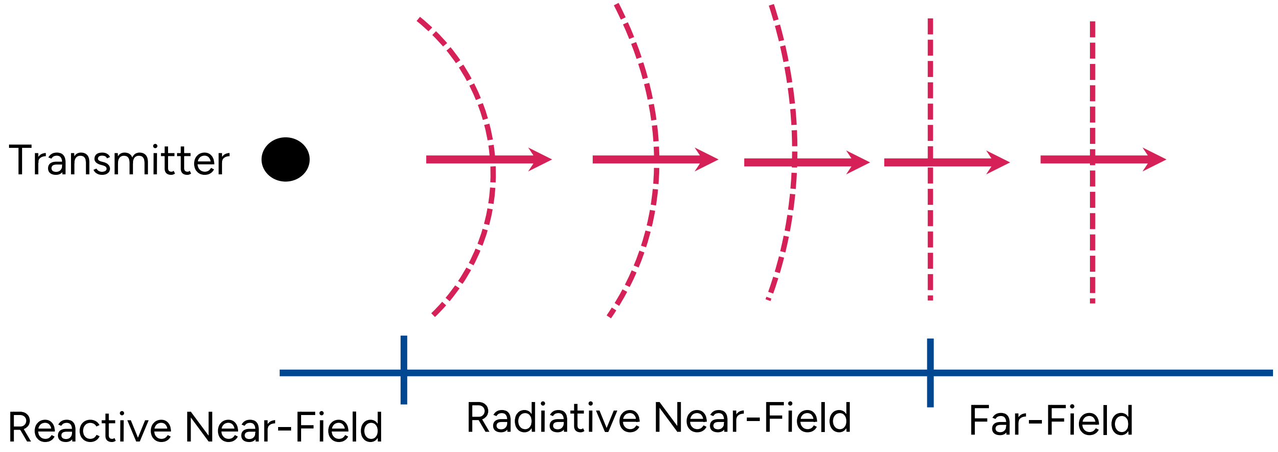
The electromagnetic radiation field emitted by antenna arrays can be divided into two regions: the far-field region and the radiative near-field region.

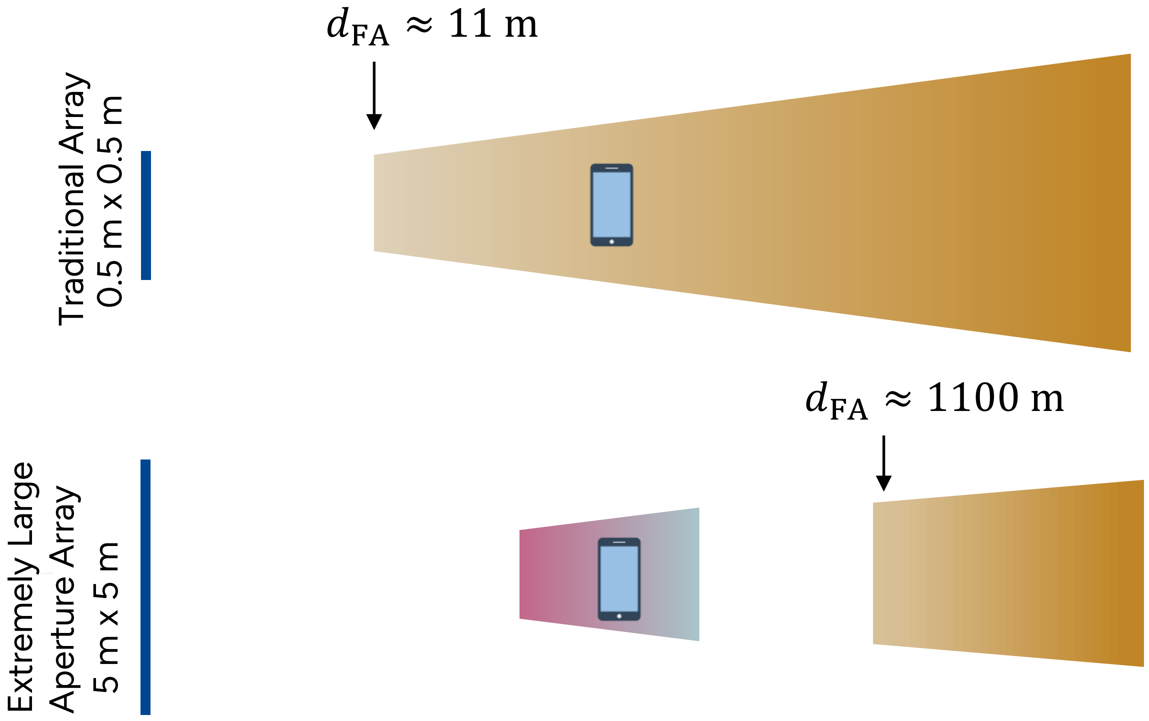
The boundary between these regions is traditionally defined by the phase error-based Fraunhofer distance

$$d_{\mathrm{FA}} = \frac{2D^2}{\lambda}$$

D → Array Aperture

λ → Signal Wavelen



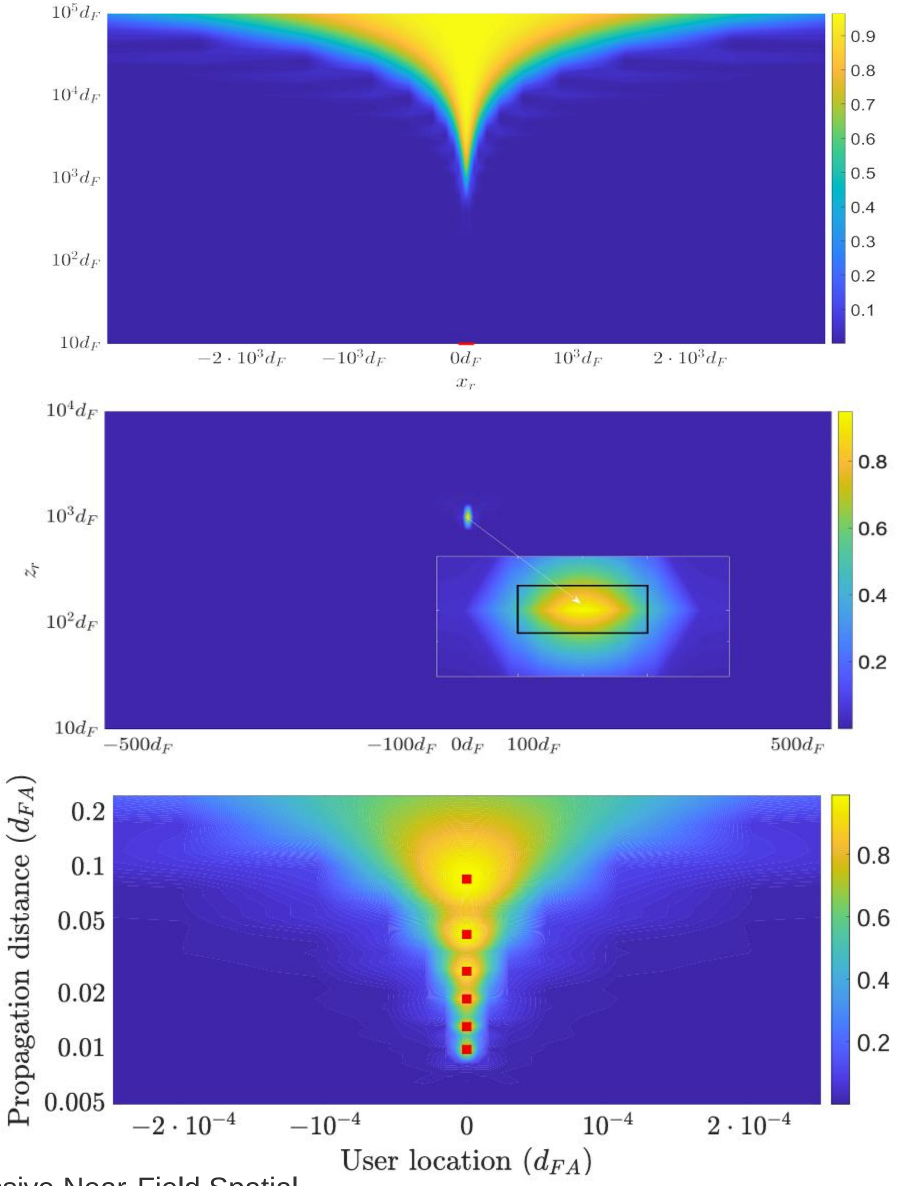


Beamfocusing in the Near-Field

When the transmitter focuses a beam toward a far-field location, the beam spreads out as it travels and the beampattern disperses as a cone across space.

When a beam is focused on a near-field location, the beam focuses its power at a targeted location before rapidly diverging and losing strength beyond that point.

This near-field beamfocusing enables spatial multiplexing in the depth domain [R1].



[R1] P. Ramezani, A. Kosasih, A. Irshad and E. Björnson, "Exploiting the Depth and Angular Domains for Massive Near-Field Spatial Multiplexing," in *IEEE BITS the Information Theory Magazine*, vol. 3, no. 1, pp. 14-26, March 2023

Localization in the Near-Field

The received signal by the antenna array: $\mathbf{y}(t) = \mathbf{a}s(t) + \mathbf{n}(t)$

$$\mathbf{a} = \left[e^{-j\frac{2\pi}{\lambda}(r_1 - r)}, \ldots, e^{-j\frac{2\pi}{\lambda}(r_m - r)}, \ldots, e^{-j\frac{2\pi}{\lambda}(r_M - r)}\right]^{\mathrm{T}}$$

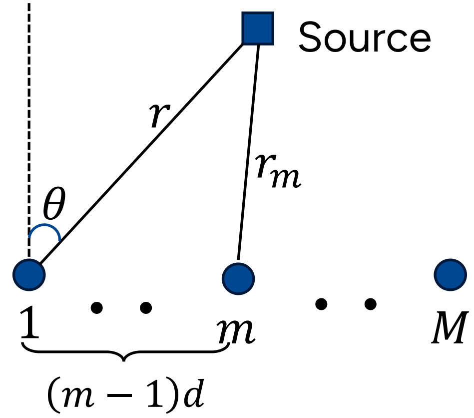
$$r_m = \sqrt{r^2 + (m-1)^2 d^2 - 2r(m-1)d\sin(\theta)}$$
$$= r\sqrt{1 + \frac{(m-1)^2 d^2}{r^2} - 2\frac{(m-1)d}{r}\sin(\theta)}$$

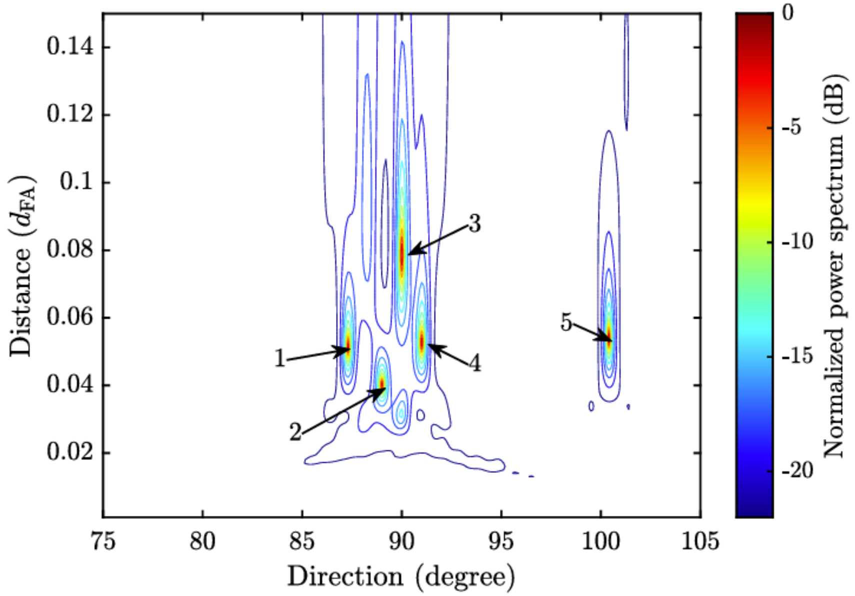
Far-field: first order Taylor approximation $\sqrt{1+x} = 1 + x/2$

$$r_m \approx r - (m-1)d\sin(\theta)$$

Near-field: second order Taylor approximation $\sqrt{1+x} = 1 + x/2 + x^2/8$

$$r_m \approx r - (m-1)d\sin(\theta) + \frac{(m-1)^2 d^2}{2r}\cos^2(\theta)$$





The normalized power spectrum of MUSIC for localizing five near-field sources when $M = 128$, carrier frequency is 28 GHz and the antenna spacing is $\lambda/2$ [R2].

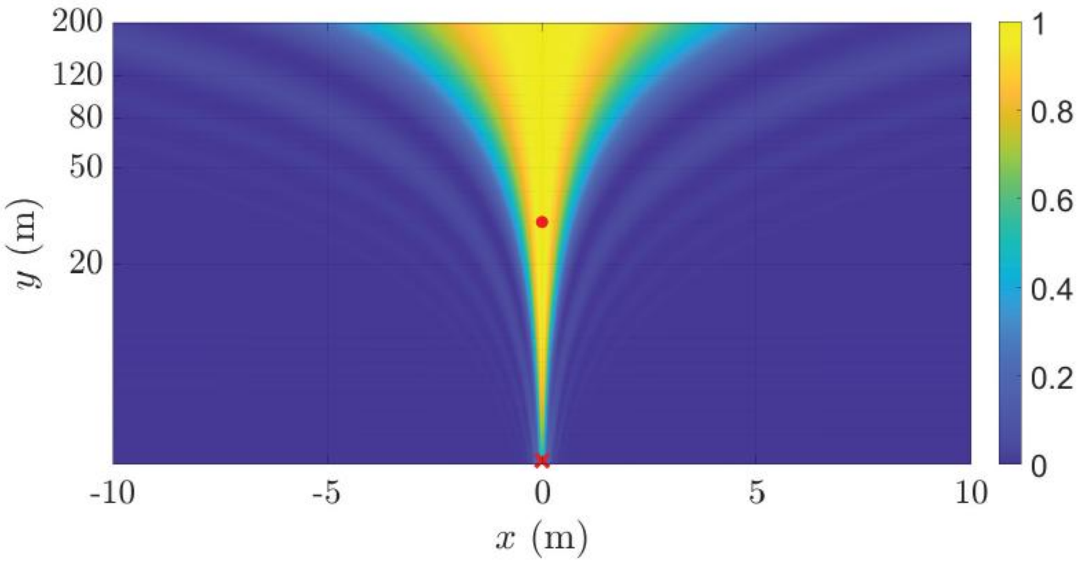
[R2] Z. Wang, P. Ramezani, Y. Liu and E. Björnson, "Near-Field Localization and Sensing With Large-Aperture Arrays: From signal modeling to processing," in *IEEE Signal Processing Magazine*, vol. 42, no. 1, pp. 74-87, Jan. 2025

Will We Have Near-Field Effects in the Upper Mid-Band?

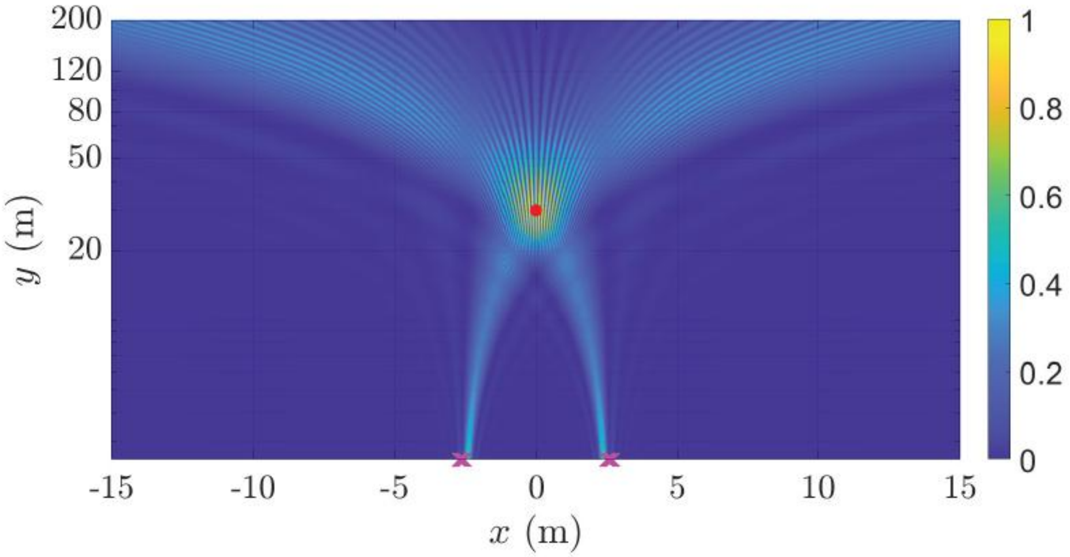
Near-Field Beamfocusing

A **uniform linear array equipped with 48 antennas** with half-wavelength spacing focuses a beam toward a user 30m away in the broadside direction.

Carrier frequency = 15 GHz
Fraunhofer distance = 23 m



The array is divided into **two sub-arrays, each with 24 antennas, and separated by 5m.** They focus the beam toward the same user location as before.

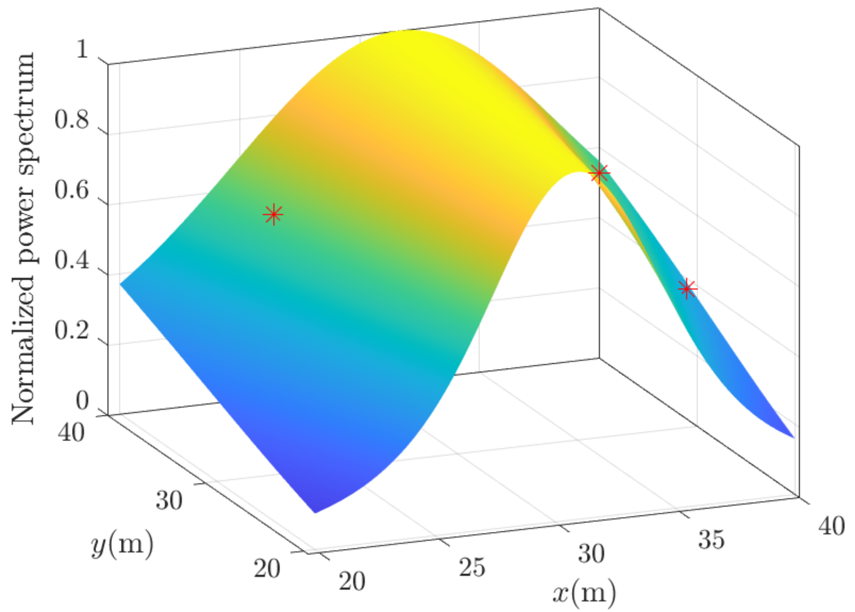


[R3] E. Bjornson, F. Kara, N. Kolomvakis, A. Kosasih, P. Ramezani, and ¨ M. B. Salman, “Enabling 6G performance in the upper mid-band by transitioning from massive to gigantic MIMO,” arXiv preprint arXiv:2407.05630, 2024

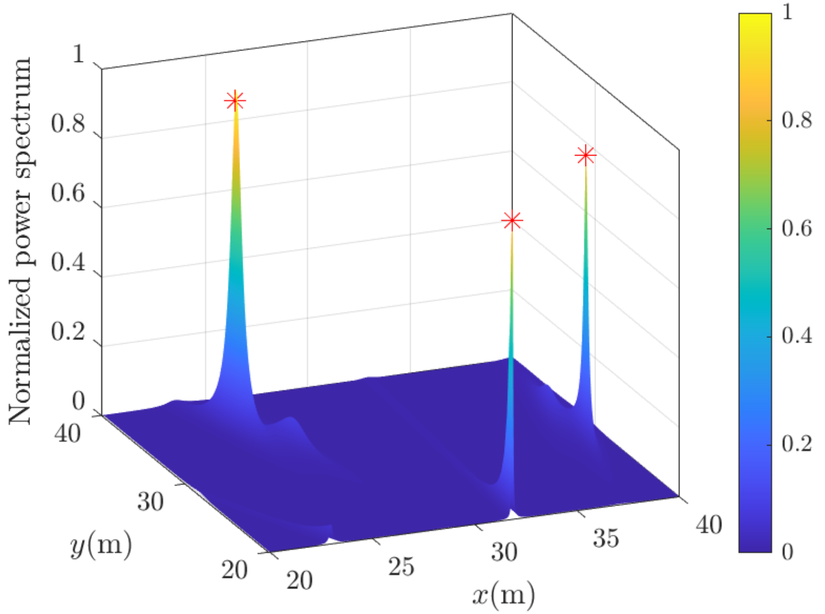
Will We Have Near-Field Effects in the Upper Mid-Band?

Near-Field Localization

A **uniform linear array equipped with 48 antennas** with half-wavelength spacing is used to localize three sources within the region $x \in [20\text{ m}, 40\text{ m}]$ and $y \in [20\text{ m}, 40\text{ m}]$.



The array is divided into **four sub-arrays, each with 12 antennas, and separated by 5m.** They localize the same three sources.



[R3] E. Bjornson, F. Kara, N. Kolomvakis, A. Kosasih, P. Ramezani, and ¨ M. B. Salman, "Enabling 6G performance in the upper mid-band by transitioning from massive to gigantic MIMO," arXiv preprint arXiv:2407.05630, 2024

Will We Have Near-Field Effects in the Upper Mid-Band?

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.**

I. Introduction

The commercialization of massive multiple-input multiple-output (mMIMO) technology has been a cornerstone of 5G networks, enabling substantial improvements in spectral efficiency and energy efficiency compared to 4G [2]. As 5G deployments continue to expand, covering 45% of the world's population by the end of 2023 [3], current research focuses on developing better technology to achieve the ambitious goals of 6G and beyond. Next-generation base stations (BSs) must support even higher cell throughput and new services such as wireless sensing and artificial intelligence (AI) at the edge [4], [5]. The BSs will be equipped with MIMO technology that incorporates significantly larger arrays in the upper mid-band, which might enable significantly higher throughput

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 domain, as with traditional far-field beamforming used in legacy networks. The beamfocusing feature exists when the propagation distance is less than the Fraunhofer distance $2D^2/\lambda$ [9], where D and λ denote the aperture length of the array and the wavelength, respectively. In practice, given a coverage range of $d_{\max}$ and a wavelength of λ, we can calculate the aperture length $D = \sqrt{d_{\max}\lambda/2}$ required to enable beamfocusing. However, filling this aperture with conventional half-wavelength-spaced antennas is challenging: the array will be physically large, requires hundreds or thousands of antennas, and the computational complexity is excessive.

A natural approach to mitigate these issues is to decrease the number of antennas in the array while maintaining its aperture area. There are two main options to achieve this:

1) **Sparse uniform arrays**: Increasing the antenna spacing in the array beyond half a wavelength while maintaining

Thank you for your attention!