6G in the Upper Mid-Band:

The Rise of Gigantic MIMO

Emil Björnson

Professor of Wireless Communication

Fellow of IEEE, Digital Futures, and Wallenberg Academy

KTH Royal Institute of Technology, Stockholm, Sweden

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Murat Babek Salman

Nikolaos Kolomvakis

Özlem Tuğfe Demir

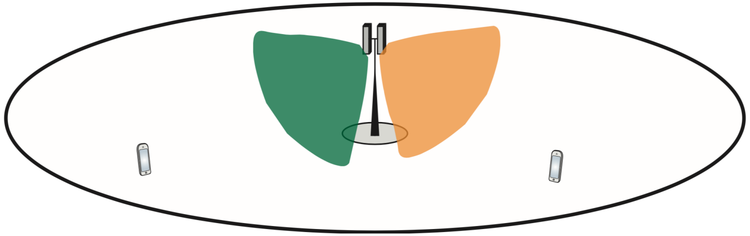
Parisa Ramezani

Alva Kosasih

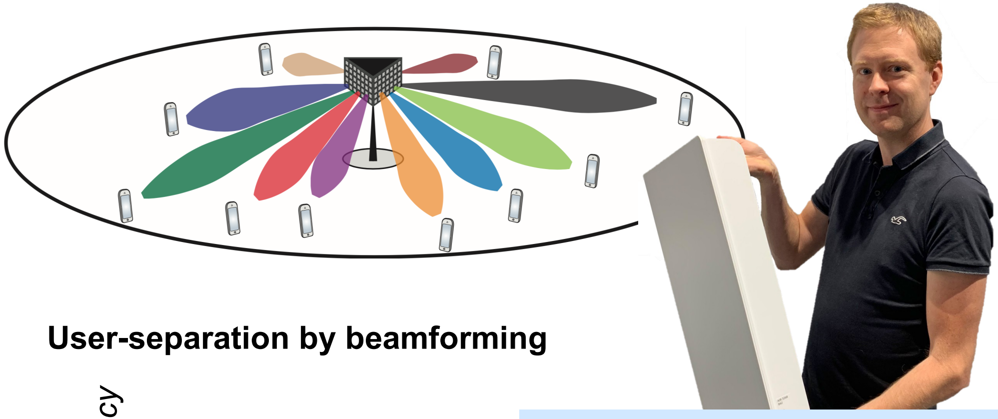
Ferdi Kara

Multiple Access in Wireless Networks

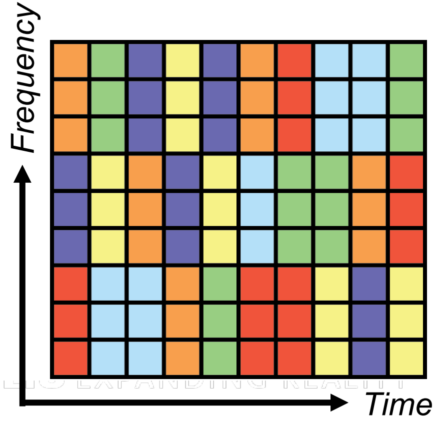
1. Sectorization and frequency reuse



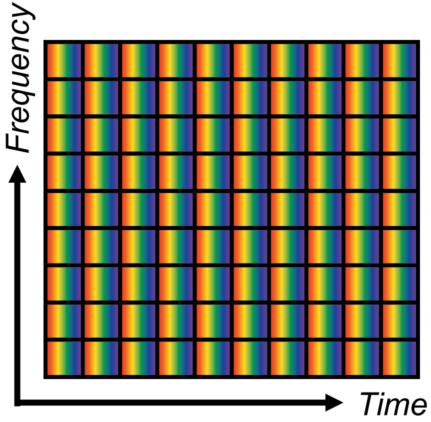
2. Multi-user MIMO (multiple-input multiple-output)



Time-frequency scheduling



User-separation by beamforming



What comes next?

a) 6G frequency bands

b) MIMO functionalities

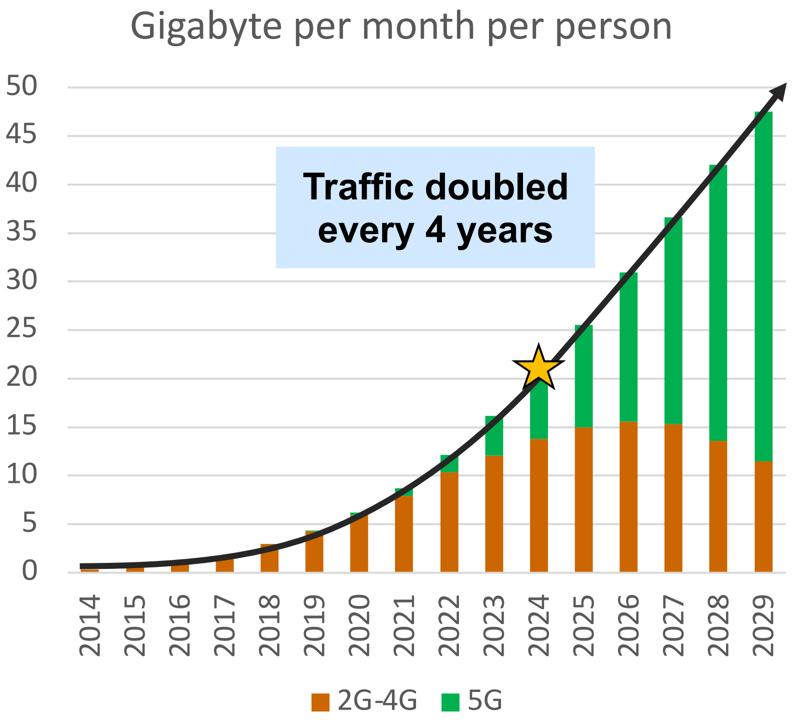
c) Predict “early 6G”

5G: Massive MIMO

64 antennas

The Need for 6G: Network Capacity Growth

Demand



Ericsson Mobility Report, 2024

Supply

Channel capacity (bit/s per access point):

$$C = \text{Bandwidth} \cdot \text{Layers} \cdot \log_2(1 + \text{SNR})$$

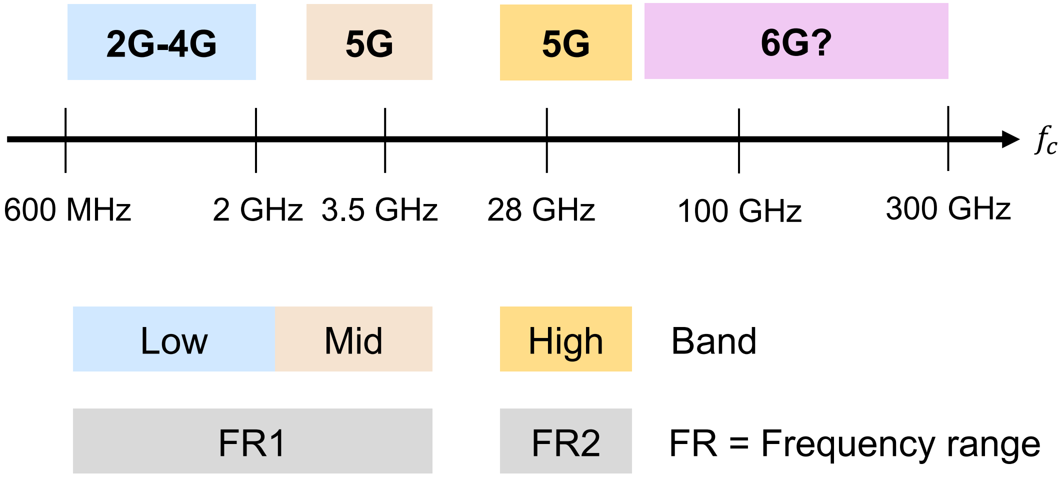
6G: More bandwidth?

6G: Bigger MIMO?

The rise of mmWave…

…and fall?

Rule-of-thumb: Bandwidth $\propto f_c$



South Korea cancels SKT's 28 GHz 5G licence

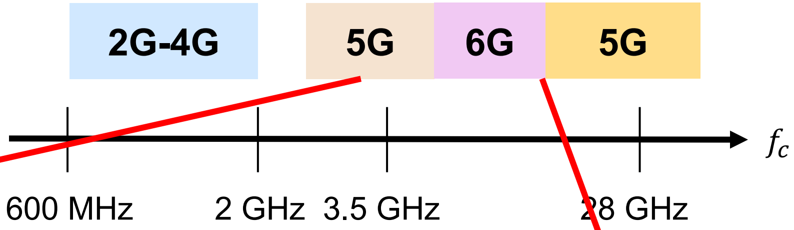
Written by Mary Lennighan 15 May 2023 @ 12:38

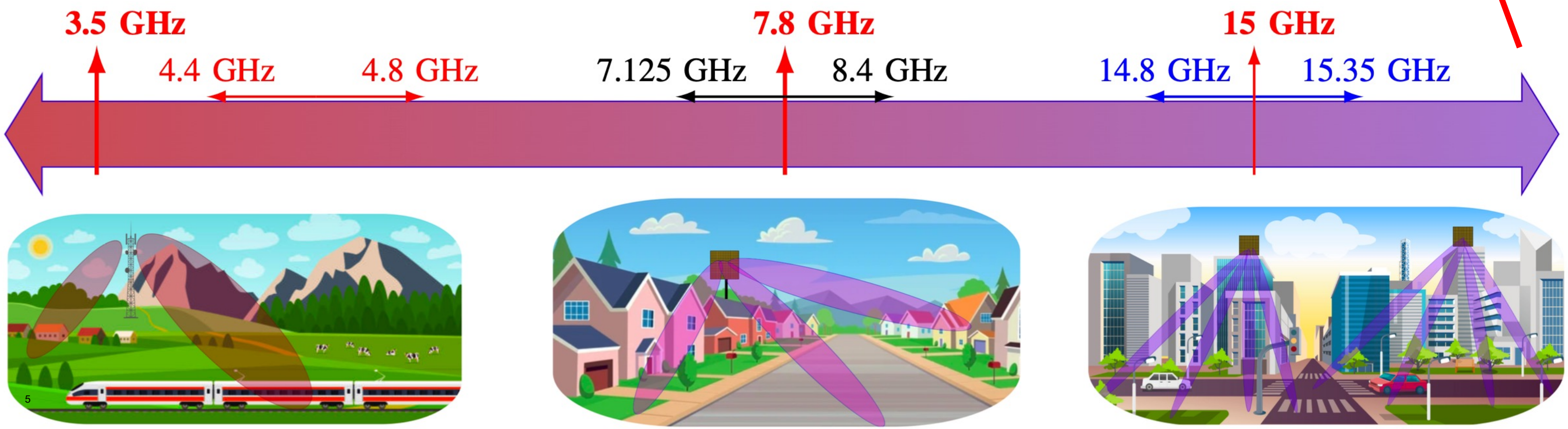
South Korea has withdrawn SK Telecom's licence to operate 5G services in the 28 GHz band, the telco having failed to meet its rollout requirements.

Candidate Bands for 6G

International Telecommunications Union (ITU)

- Sets official 6G performance goals
- Harmonizes worldwide spectrum usage
- Identified candidate bands at WRC-23





6G Spectrum in the **Upper Mid-Band** (7-24 GHz)

6G Candidate bands

- 4.4-4.8 GHz (400 MHz)
- 7.1-8.4 GHz (650-1275 MHz)
- 14.8-15.35 GHz (550 MHz)

Current 5G bands

- 3.3-3.8 GHz (400 MHz)
- 6.4-7.1 GHz (700 MHz, new at WRC-23)

6G will only have slightly more bandwidth than 5G!

Per operator and base station:

4G 20 MHz $\xrightarrow{5\times}$ **5G** 100 MHz $\xrightarrow{2\times - 4\times}$ **6G** 200-400 MHz

Can “bigger MIMO” be the distinguishing 6G factor?

Addressing the Frequency-Dependent Pathloss

Friis' formula: Received power with isotropic antennas, with area $A = \frac{\lambda^2}{4\pi}$

$$P_r = \frac{\lambda^2}{(4\pi d)^2} \cdot P_t$$

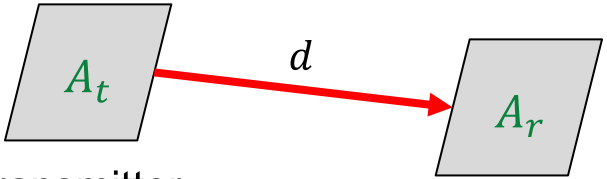
Higher frequency → Less power?

Received power with array areas A_t and A_r:

$$P_r = \frac{A_r A_t}{d^2 \lambda^2} \cdot P_t$$

Higher frequency → More power!

But more antennas needed to fill the area

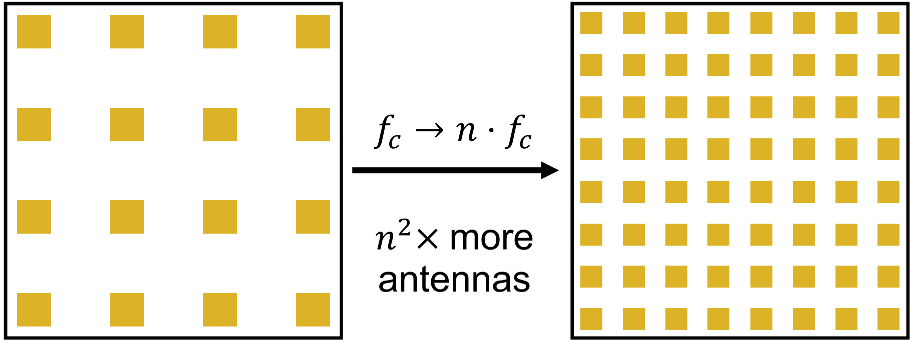


Transmitter array

Receiver array

How Many More Antennas at 6G Base Stations?

Example: Filling the array aperture area



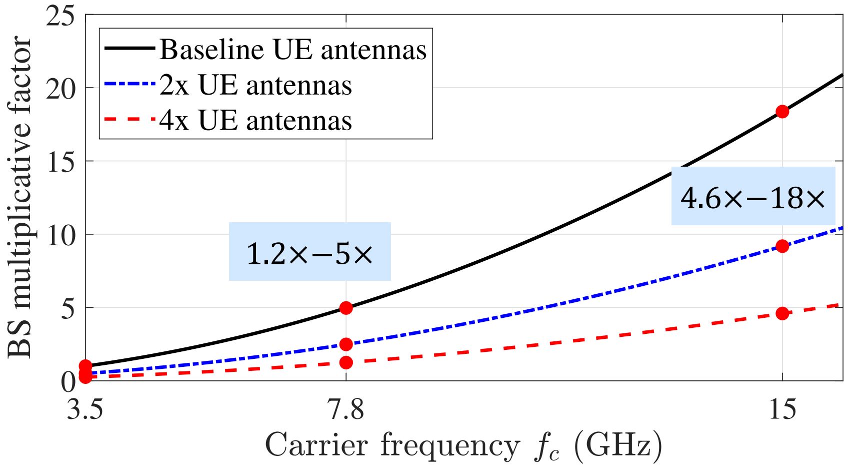
Improves the free-space pathloss!

Margin for non-line-of-sight issues

Bigger penetration losses

Less scattering and diffraction

Example: Maintain free-space pathloss



Tradeoff between adding antennas at base station and users

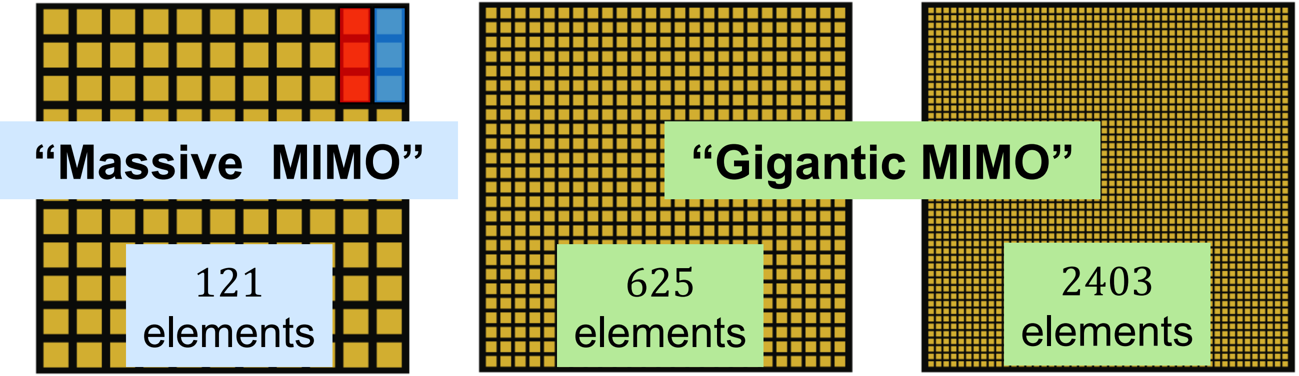
From Massive to Gigantic Numbers

Example: 0.5×0.5 m arrays

Antenna ports

\# elements ≥ # antenna ports

- Fully digital transceivers
- Dual-polarized elements



3.5 GHz: 11×11 array

7.8 GHz: 25×25 array

15 GHz: 48×48 array

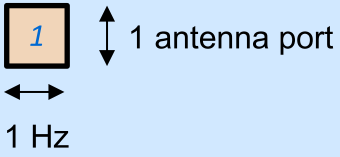
5G base station:

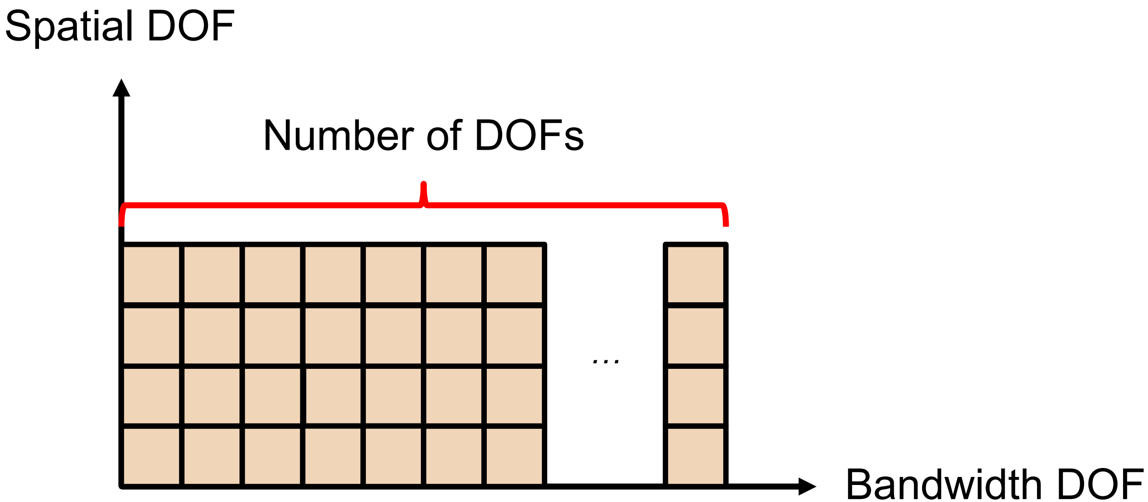
Theoretical Peak Rates per User

Bit rate formula:

$$\text{bit/s} = \text{bit/DOF} \cdot \text{DOF/s}$$

Degree of freedom (DOF)





6G Possibility

($f_c = 7.8$ GHz, $B = 1200$ MHz)

12 bit/DOF (4096-QAM)

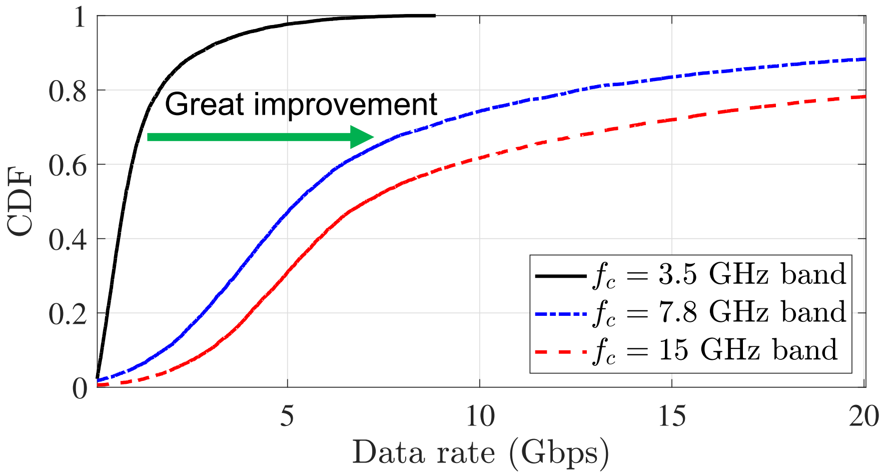
16 spatial DOFs

$1.2 \cdot 10^9$ bandwidth DOFs

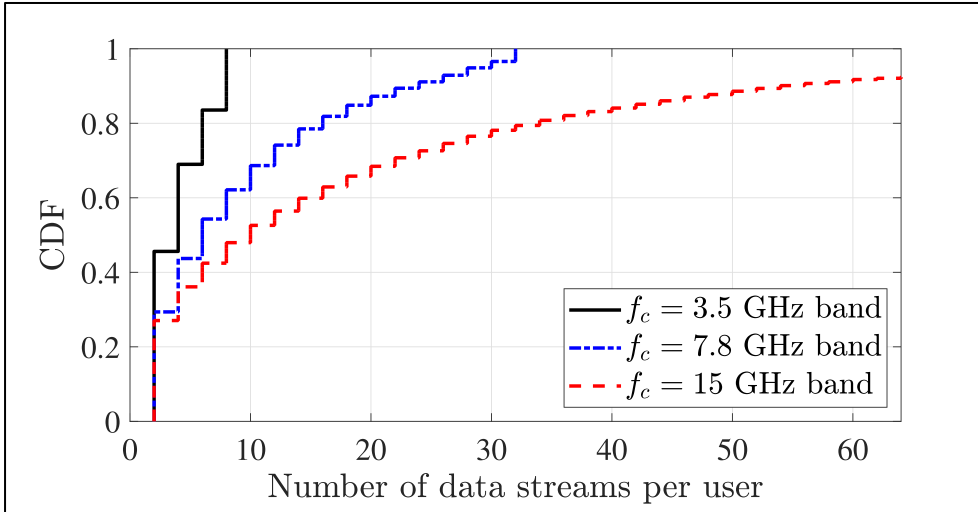
$12 \cdot 16 \cdot 1.2 = 230$ Gbps

ITU 6G vision of
200 Gbps is within reach

Great *Typical* 6G Bit Rates



ITU 6G vision of
0.5 Gbps is within reach

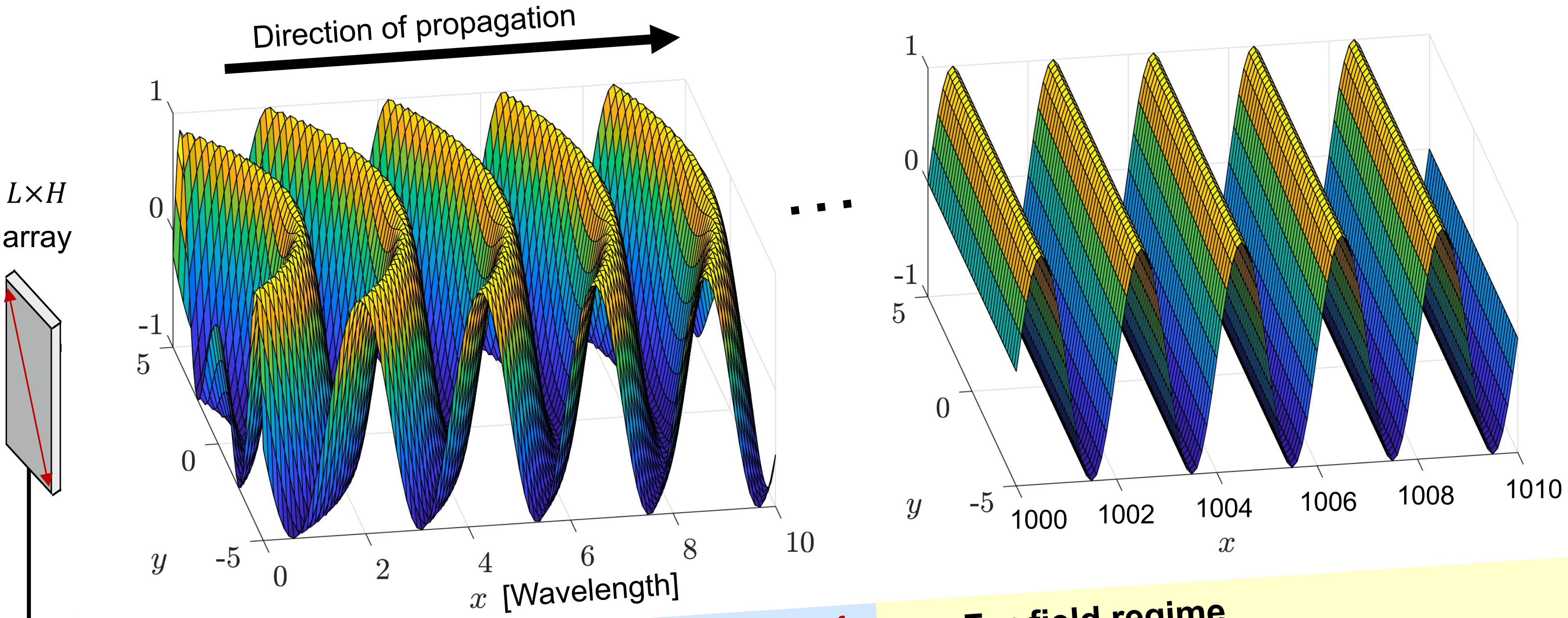


Example: 3GPP Urban Micro Cell LOS

- 1×1 km area, 10 random user locations
- QuaDRiGa simulations
- Block-diagonalization, perfect CSI
- Fixed array areas: 0.5×0.5 m, 4×4 cm
- Spectrum: 100 MHz (5G), 400 MHz (6G)

MIMO is essential
DOF depends on user location
Scales with antenna numbers

From **Spherical** Waves to **Approximately Planar** Waves



Reactive near-field

Radiative near-field

$$\text{User distance} < 2 \cdot \frac{L^2 + H^2}{\lambda}$$

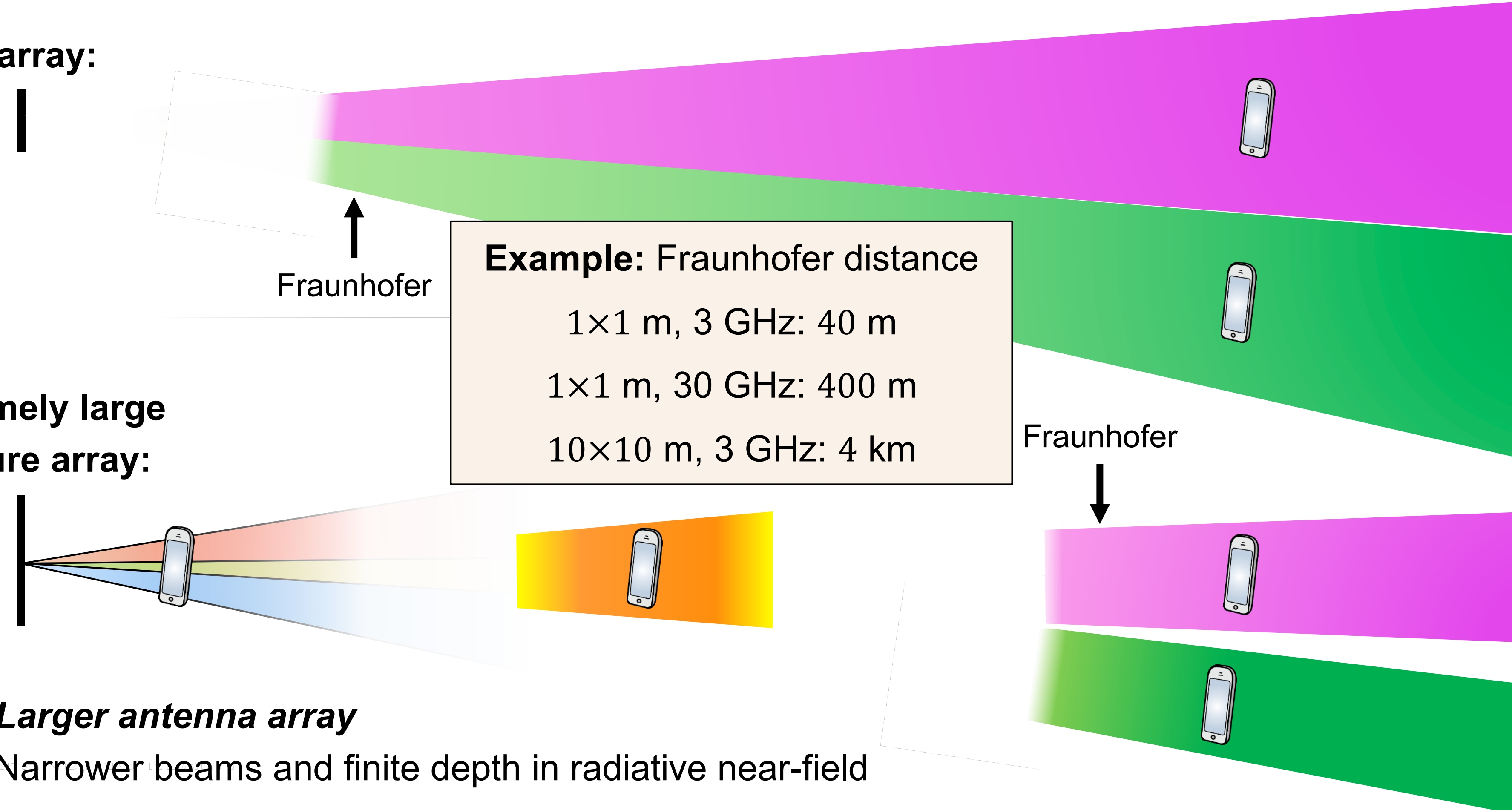
Fraunhofer distance

Far-field regime

Traditional propagation scenario

Spatial Multiplexing in Both **Angle** and **Depth**

5G array:



Example: Fraunhofer distance

1×1 m, 3 GHz: 40 m

1×1 m, 30 GHz: 400 m

10×10 m, 3 GHz: 4 km

Extremely large aperture array:

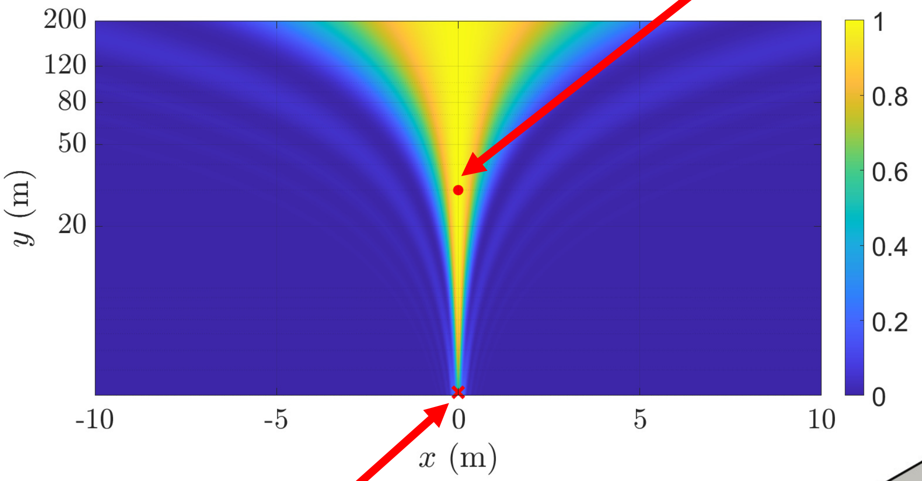
Larger antenna array

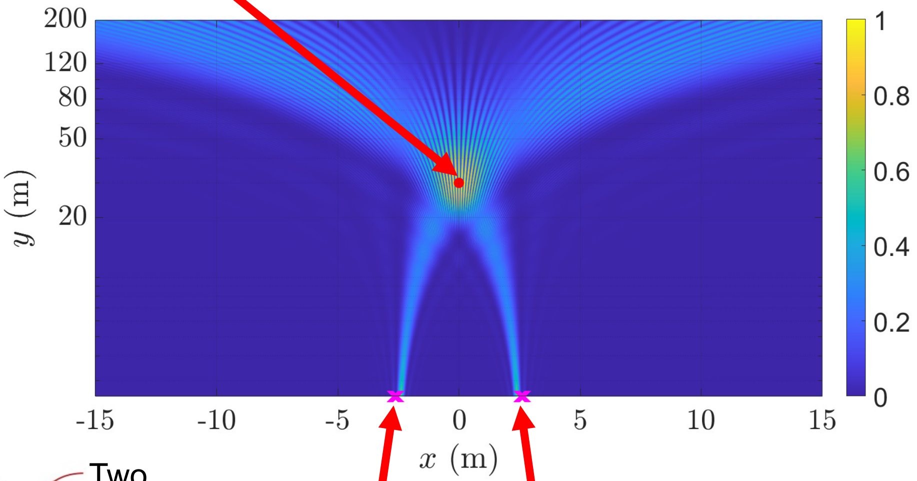
Narrower beams and finite depth in radiative near-field

Will Near-Field Effects Appear in 6G?

Yes, with distributed subarrays

Receiver at 30 m

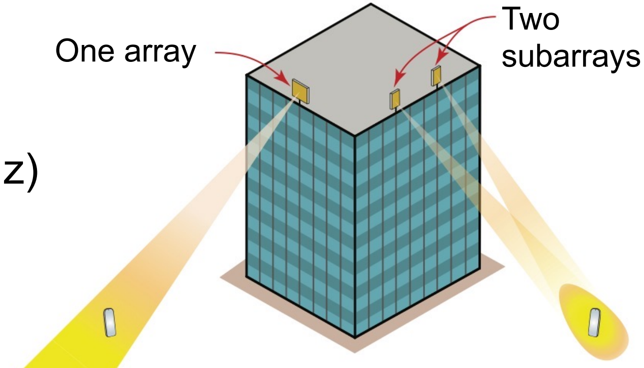




Uniform linear array (ULA)

48 antennas (0.5 m at 15 GHz)

Fraunhofer distance: 23 m

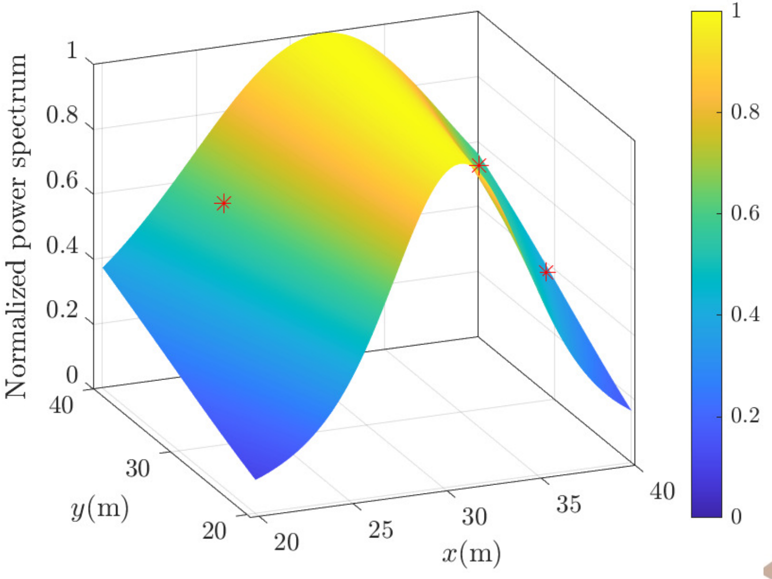


Two 24-antenna ULAs, 5 m apart

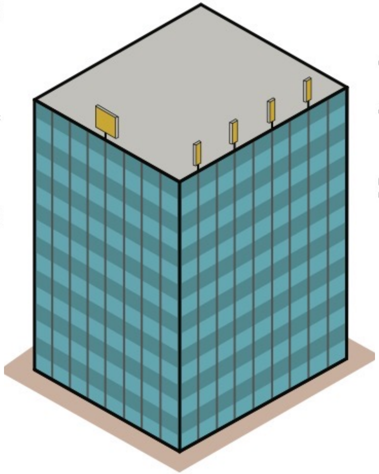
Enabling Precise Localization and Sensing

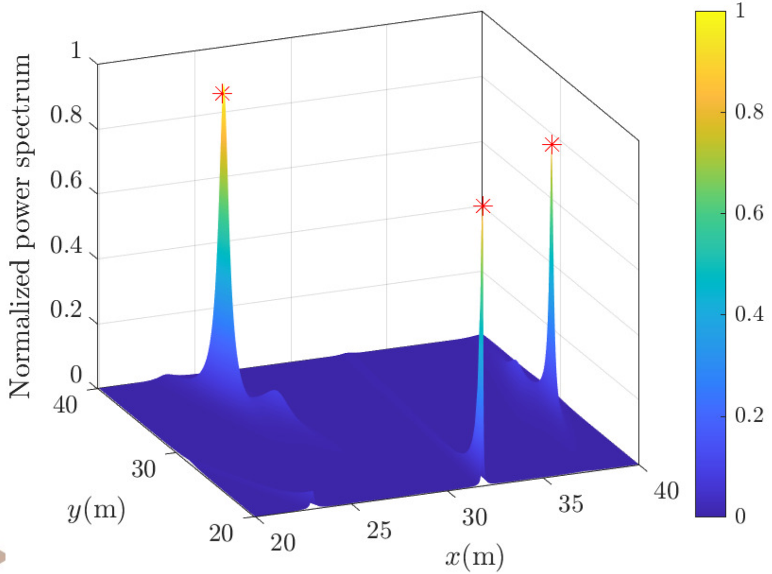
Example: Localization of three targets using *MUSIC algorithm*

Near-field requires subarrays



(a) One array with 48 antennas





(b) Four coordinated subarrays with 12 antennas

Far-field: Estimate angle (Multiple base stations needed)

Near-field: Estimate angle and distance (One is enough)

What do we get in 6G?

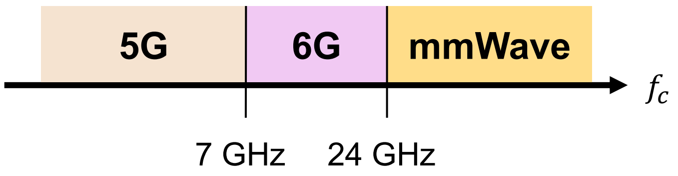
gMIMO: Four Open Research Challenges

1. **Antenna placement strategies**
   - Other array form factors, "movable antennas"
   - Robustness to uncertain array configurations
2. **Near-field-compliant models and algorithms**
   - Industry-accepted models needed
   - Measurements → Ray-tracing, machine learning refinements
3. **Medium-resolution transceivers and computations**
   - Many antenna elements, fewer transceivers, more distortion
   - Better than "*hybrid transceivers*" and "*one-bit resolution*"
   - Reduced resolution in hardware and computations
4. **Resource-efficient channel estimation**
   - Many parameters to estimate, shorter coherence time
   - Exploit non-isotropic structure under pilot contamination

What can we expect in 6G?

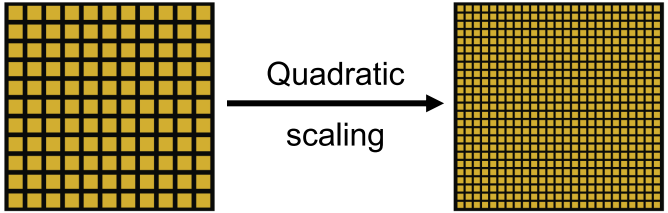
Frequency band: Upper mid-band (7-24 GHz)

- Mediocre bandwidth availability
- Many more antennas in the same form factor



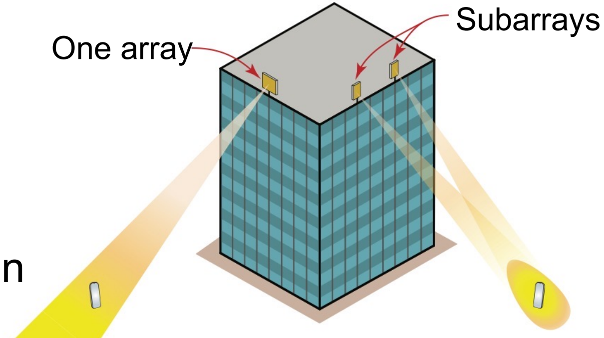
"Gigantic MIMO"

- 512-2048 antenna elements per base station
- Higher rank channels for users
- 200 (peak) and 0.5 Gbps (typical) within reach



Near-field effects

- Requires distributed subarray deployments
- Precise beamfocusing for interference control
- 3D localization and sensing from one base station



Learn more in the paper:

Enabling 6G Performance in the Upper Mid-Band Through Gigantic MIMO

Emil Björnson, Ferdi Kara, Nikolaos Kolomvakis, Alva Kosasih, Parisa Ramezani, and Murat Babek Salman

[cs.IT] 8 Jul 2024

***Abstract*—The initial 6G networks will likely operate in the upper mid-band (7-24 GHz), which has decent propagation conditions but underwhelming new spectrum availability. In this paper, we explore whether we can anyway reach the ambitious 6G performance goals by evolving the multiple-input multiple-output (MIMO) technology from being massive to gigantic. We describe how many antennas are needed and can realistically be deployed, and what the peak user rate and degrees-of-freedom (DOF) can become. We further suggest a new deployment strategy that enables the utilization of radiative near-field effects in these bands for precise beamfocusing, localization, and sensing from a single base station site. We also identify five open research challenges that must be overcome to efficiently use gigantic MIMO dimensions in 6G from hardware, cost, and algorithmic perspectives.**

standardization and technology development. Evidently, 6G must provide more capacity to meet the ever-increasing traffic demands and enable new data-intensive applications such as virtual reality (VR), augmented reality (AR), and ultra-high-definition video streaming. To achieve commercial viability, 6G must also support new use cases and functionalities and ensure connectivity for many more devices with diverse characteristics. Previous general shifts have been associated with wider bandwidths at higher carrier frequencies because more spectrum directly leads to higher rates. In the last decade, it was believed that the millimeter-wave (mmWave) band (24 GHz and above) would be the natural next step due to the abundant spectrum availability. In fact, 5G was co-designed for two frequency ranges (FRs): FR1 with 0.4-7

arXiv:2407.05630