

# Multiple Antenna Communications

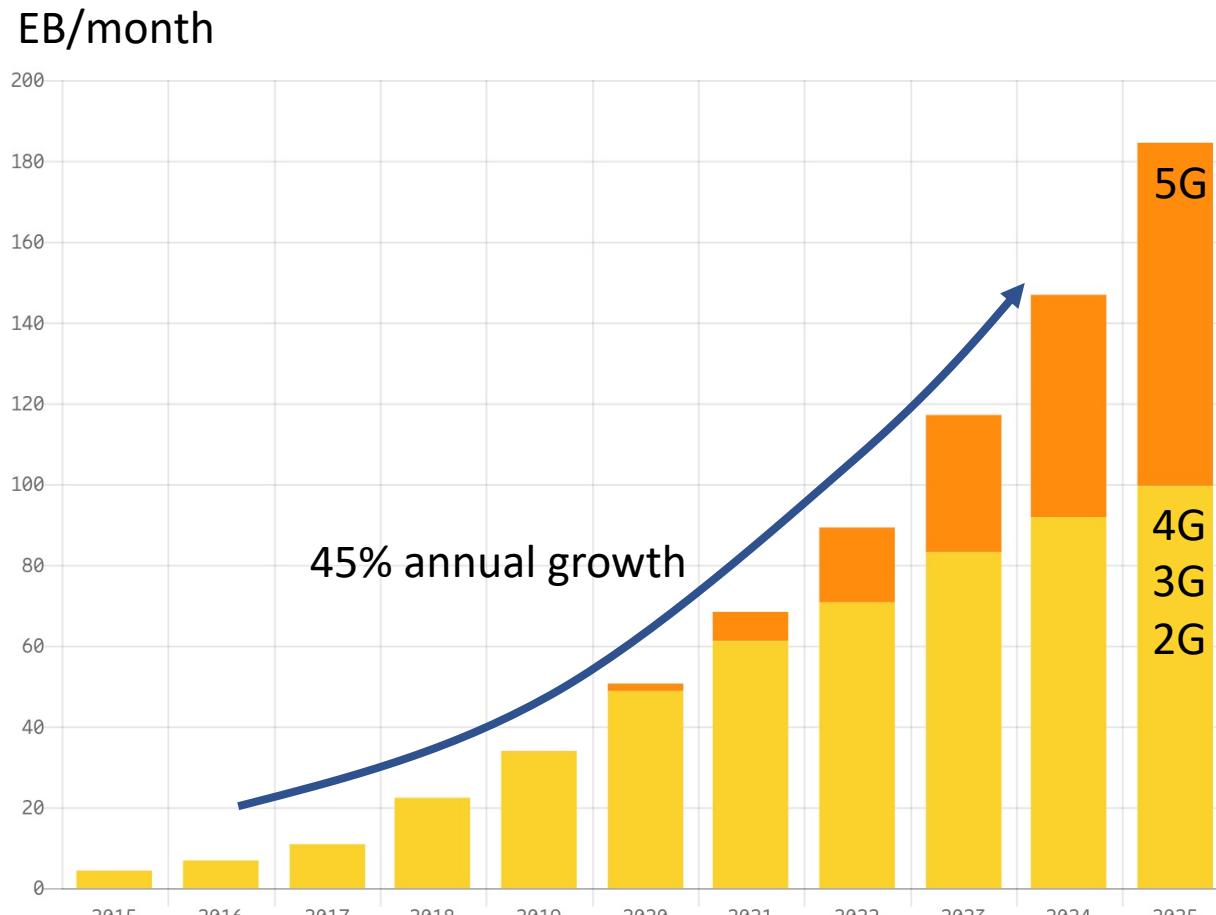
Lecture 14:  
Practical Aspects and Outlook

*Emil Björnson*

# Outline

- Role of multiple antenna communications
  - Enhanced data rates
  - Reliability and coverage
- Practical aspects
  - Analog, digital, hybrid beamforming
  - Polarization, subarrays, 3D beamforming
- Outlook towards the future

# Data traffic grows exponentially

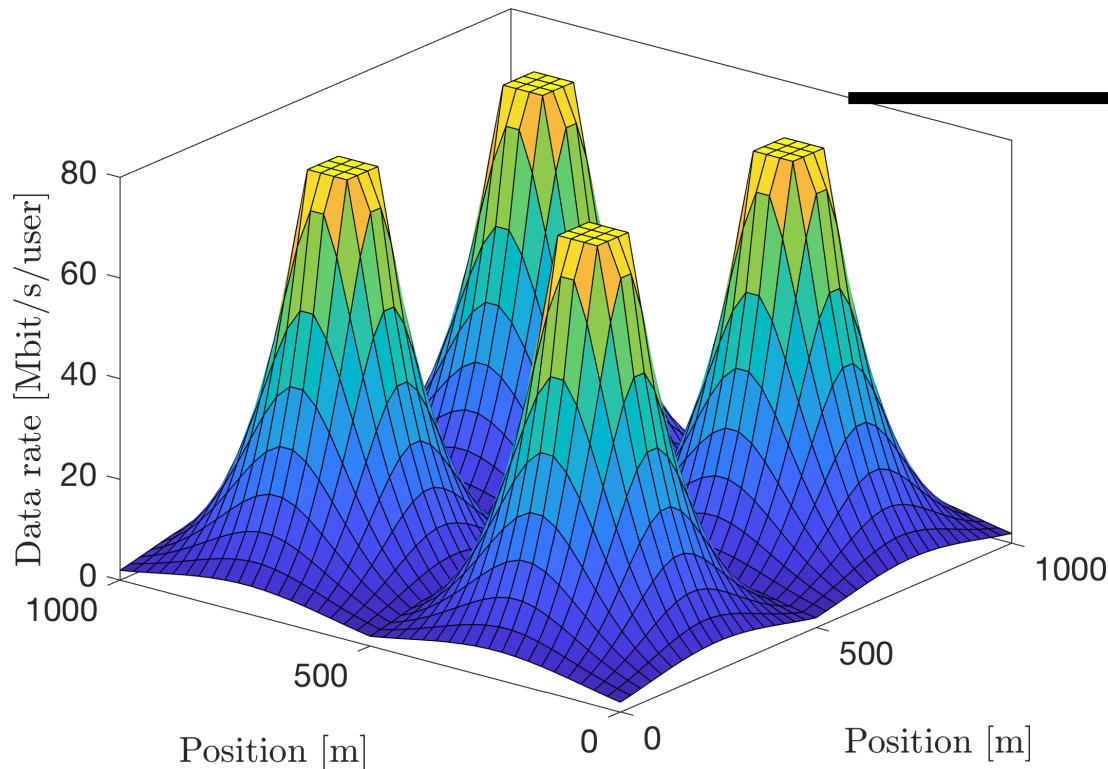


Data: Ericsson Mobility Report 2021

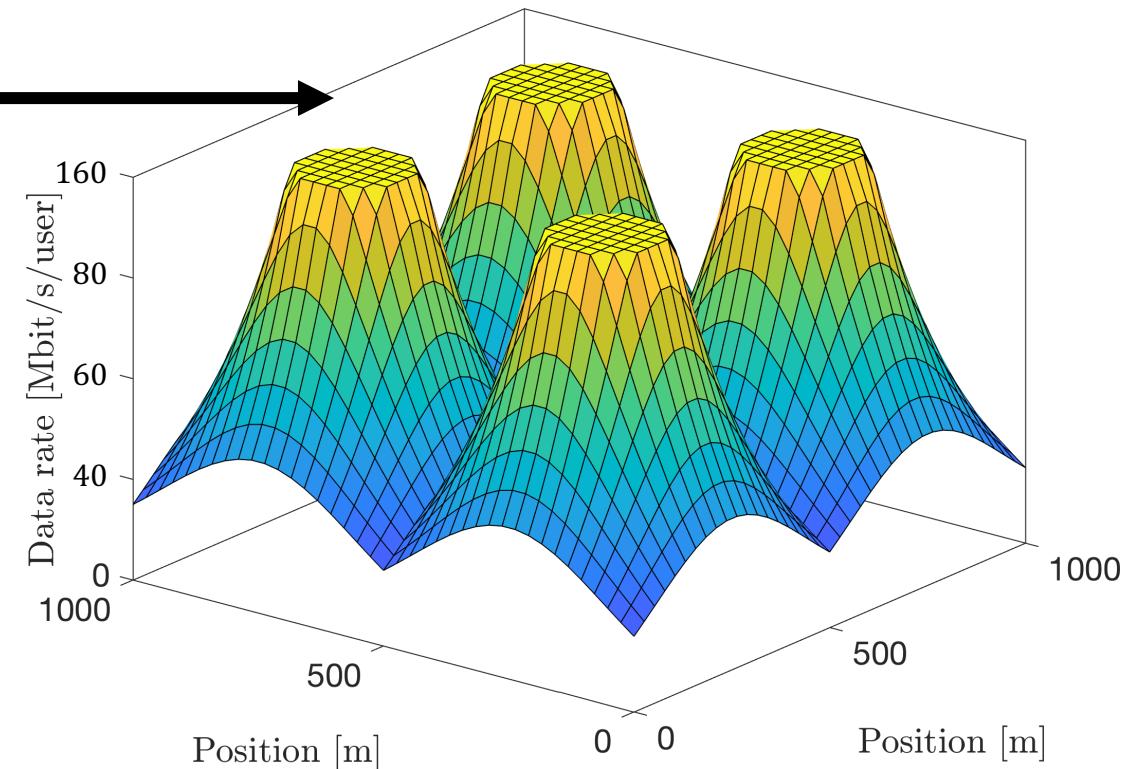
**More traffic per device**  
Require higher data rate  
Users active more often

**Impact of multiple antenna communications?**

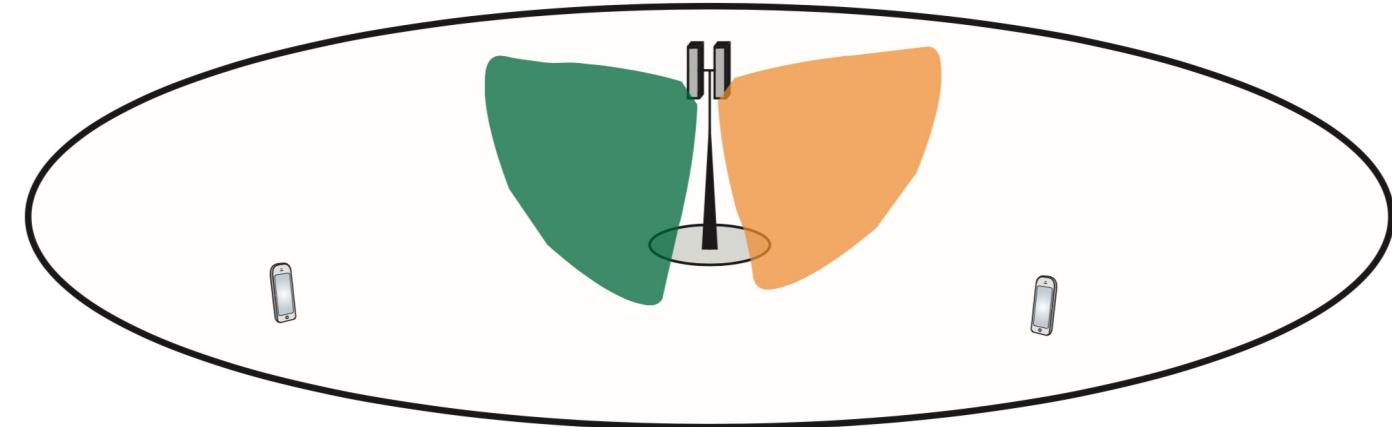
# Point-to-point MIMO: Better user performance



Beamforming and multiplexing gain



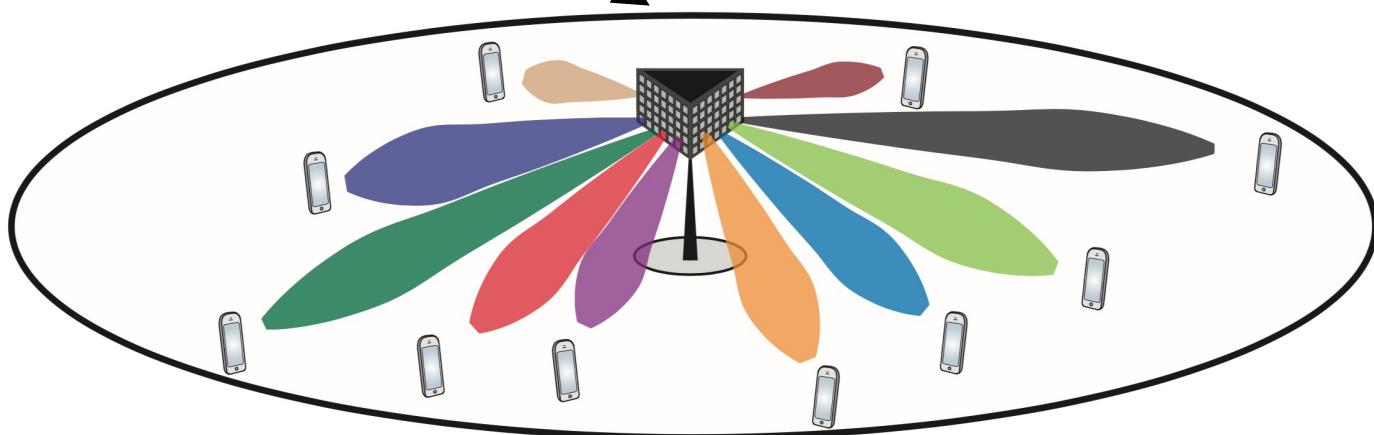
# Multi-user MIMO: Spatial multiplexing of users



Few antennas (elements): Broad beams

Serve many users at same time/frequency resource

Narrow beams limit interference

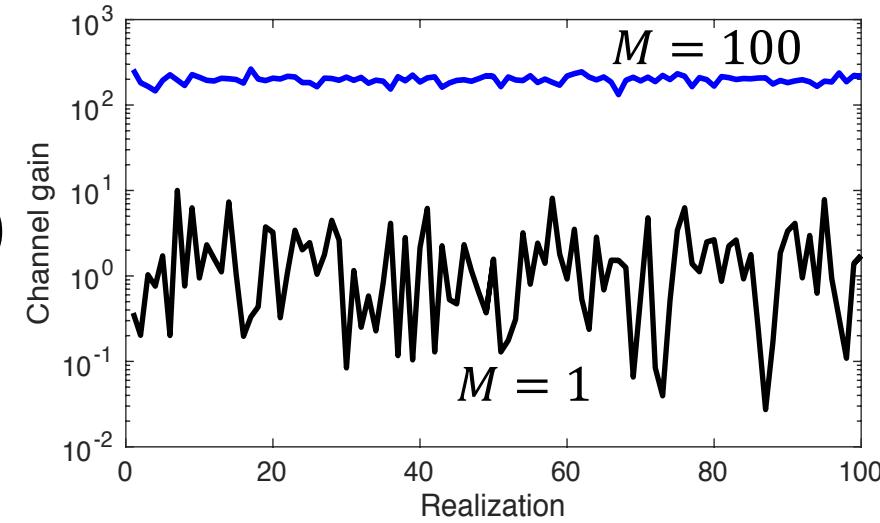


Massive number of antennas: Narrow beams

# Beyond enhanced data rate

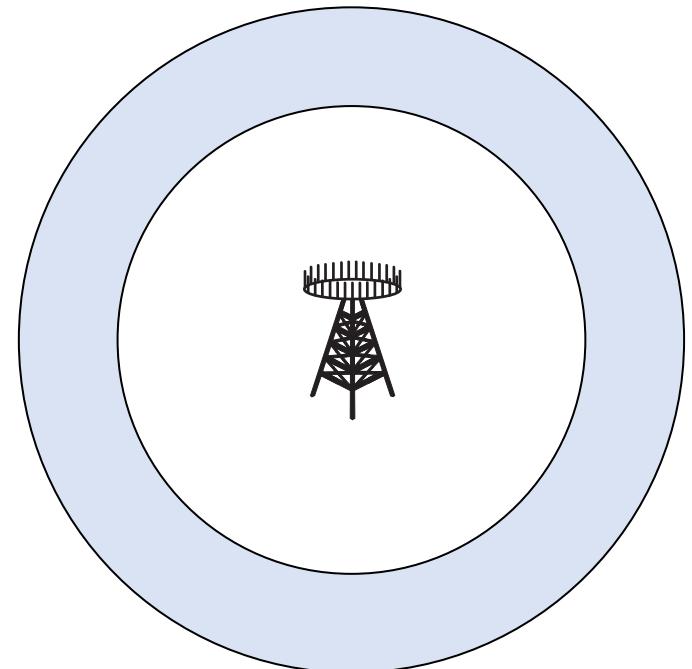
## Ultra-reliable low-latency communication (URLLC)

- *Channel hardening* alleviates channel fading
- Fewer retransmissions, predictable performance

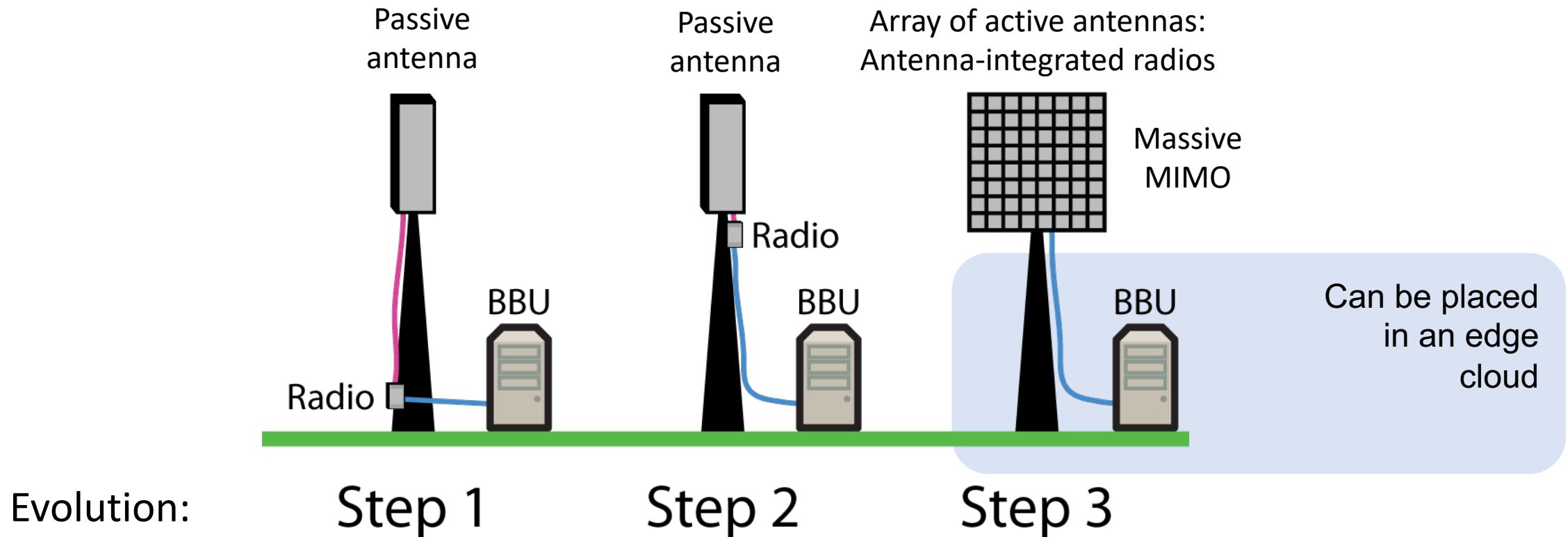


## Massive machine-type communication (mMTC)

- *Extend coverage*, more cost-efficient deployment
- *Reduce transmit power* for battery-power devices



# Passive and active antennas



Radio = Also called transceiver chain  
BBU = Baseband unit

# Beamsteering and (generalized) beamforming

## Beamsteering

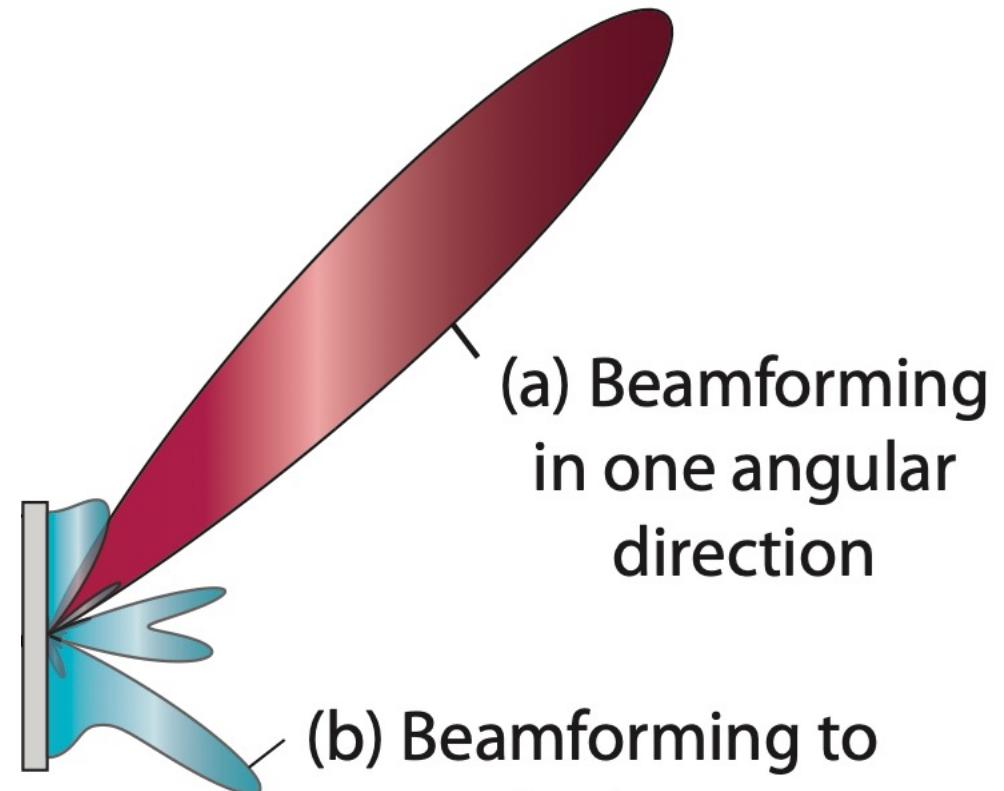
Beam in one angular direction  
*Not associated with any user*

## Beamforming

Beam in one angular direction  
*Designed for line-of-sight user*

## Generalized beamforming

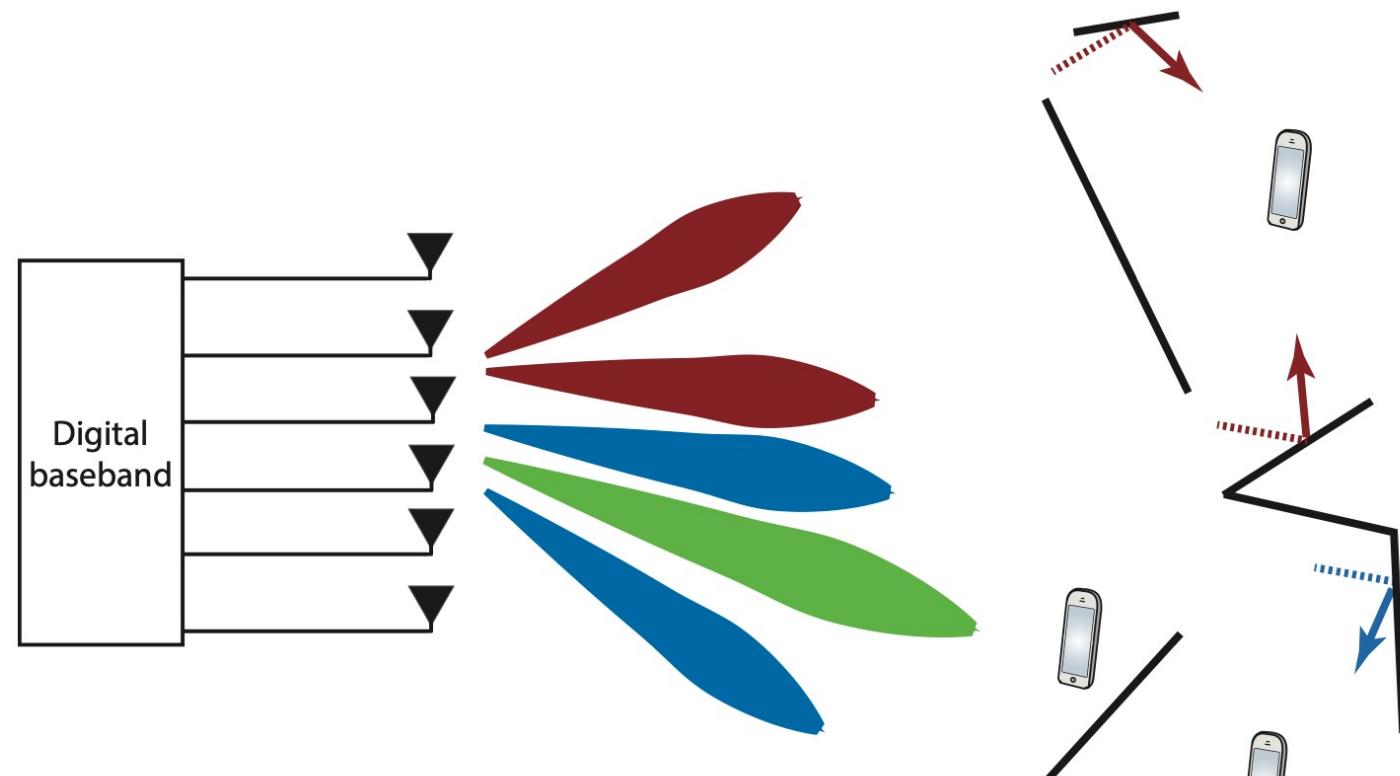
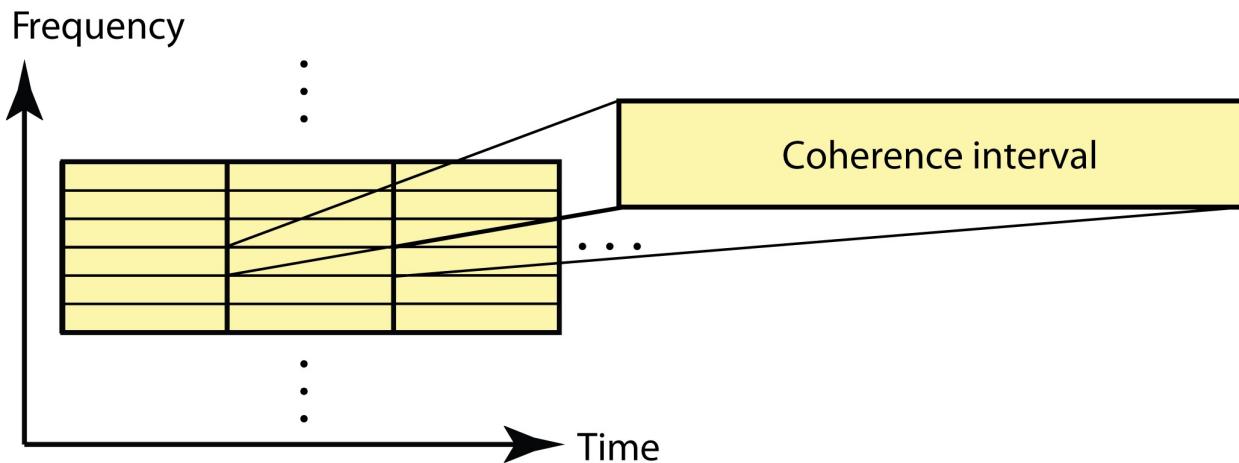
Superposition of beams  
*Designed for a non-line-of-sight user*



# Digital beamforming

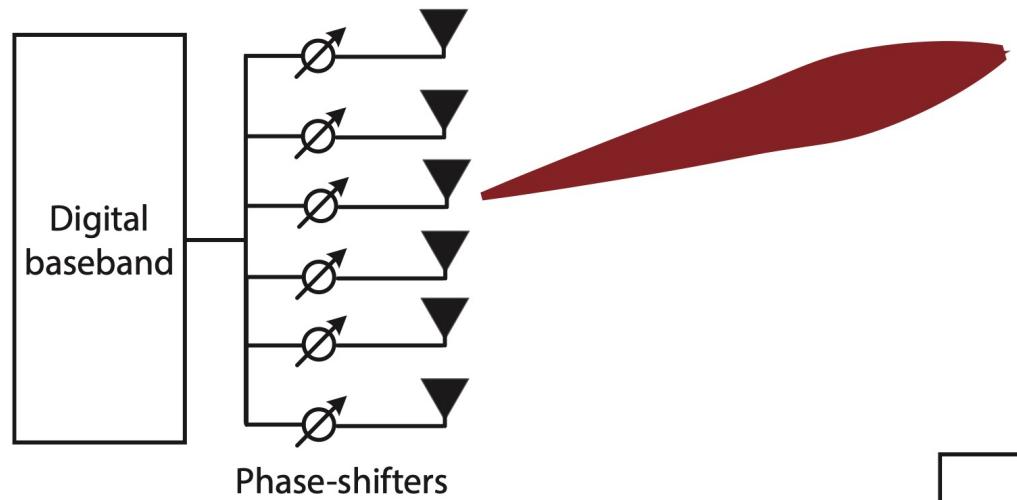
Full flexibility to create a superposition of beams

- Adapt to multipath
- Vary power over antennas
- Vary over frequency domain

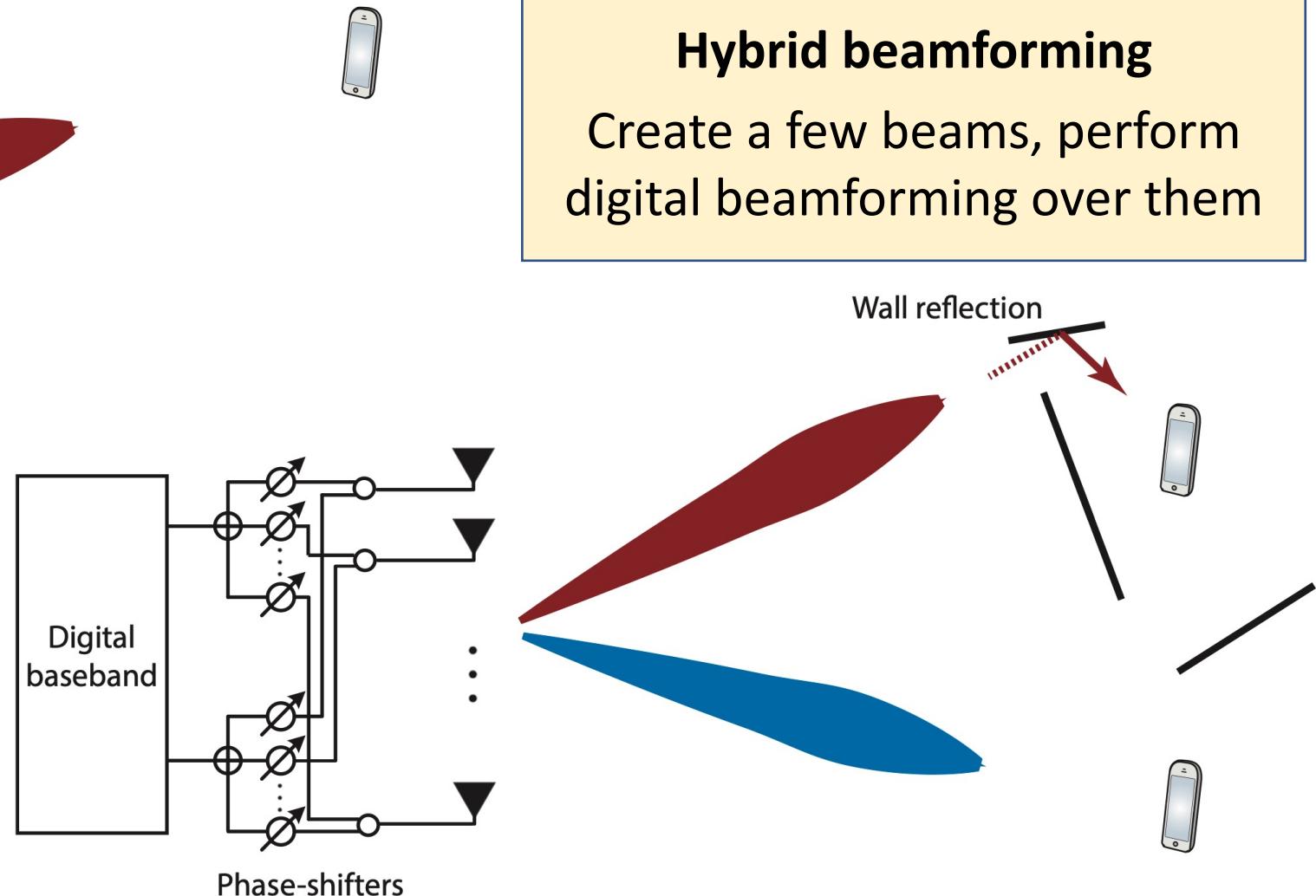


**Precoding**  
Multi-user/layer beamforming

# Analog and hybrid beamforming



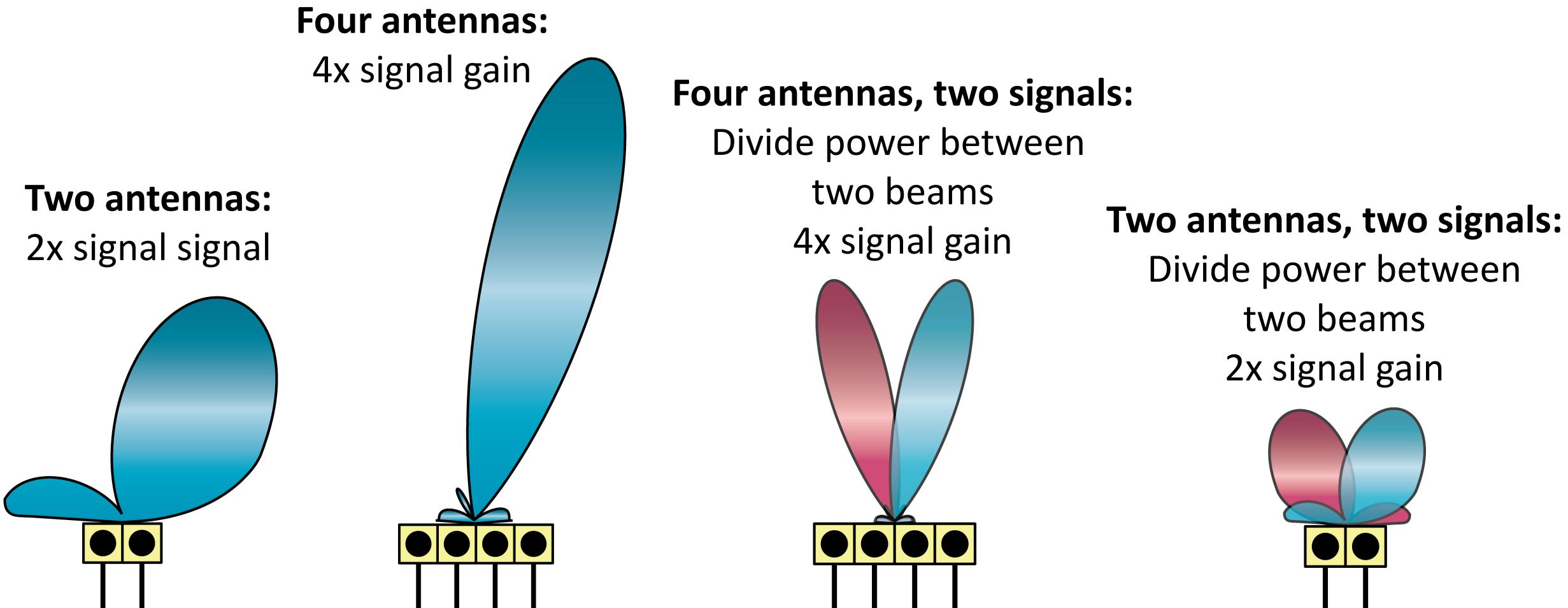
**Analog beamforming**  
One signal, different phase shifts  
Same over frequency domain



## Hybrid beamforming

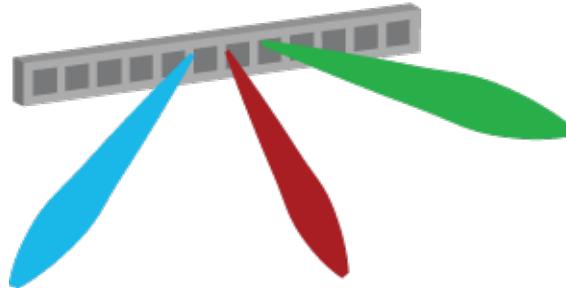
Create a few beams, perform digital beamforming over them

# Beamforming and multiplexing gains

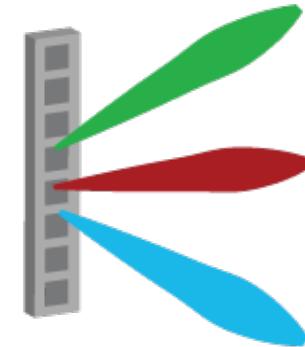


# Three-dimensional beamforming

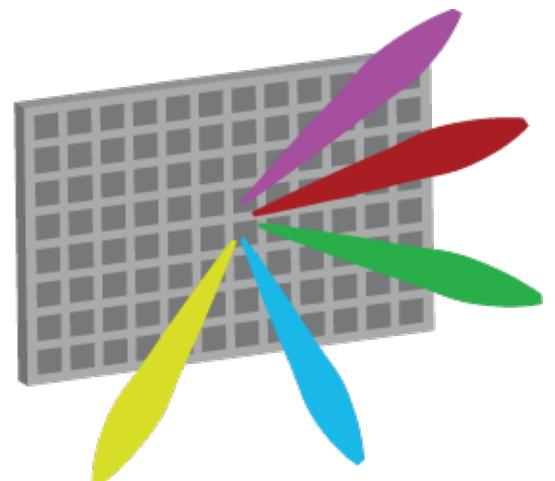
- Array geometry determines possible beam directions



**Horizontal linear array**  
Azimuth beamforming

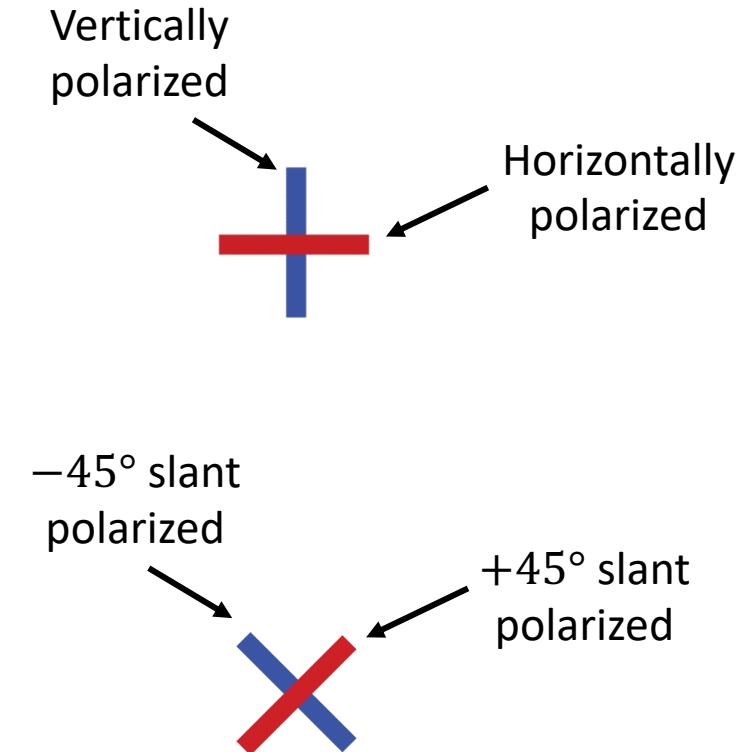
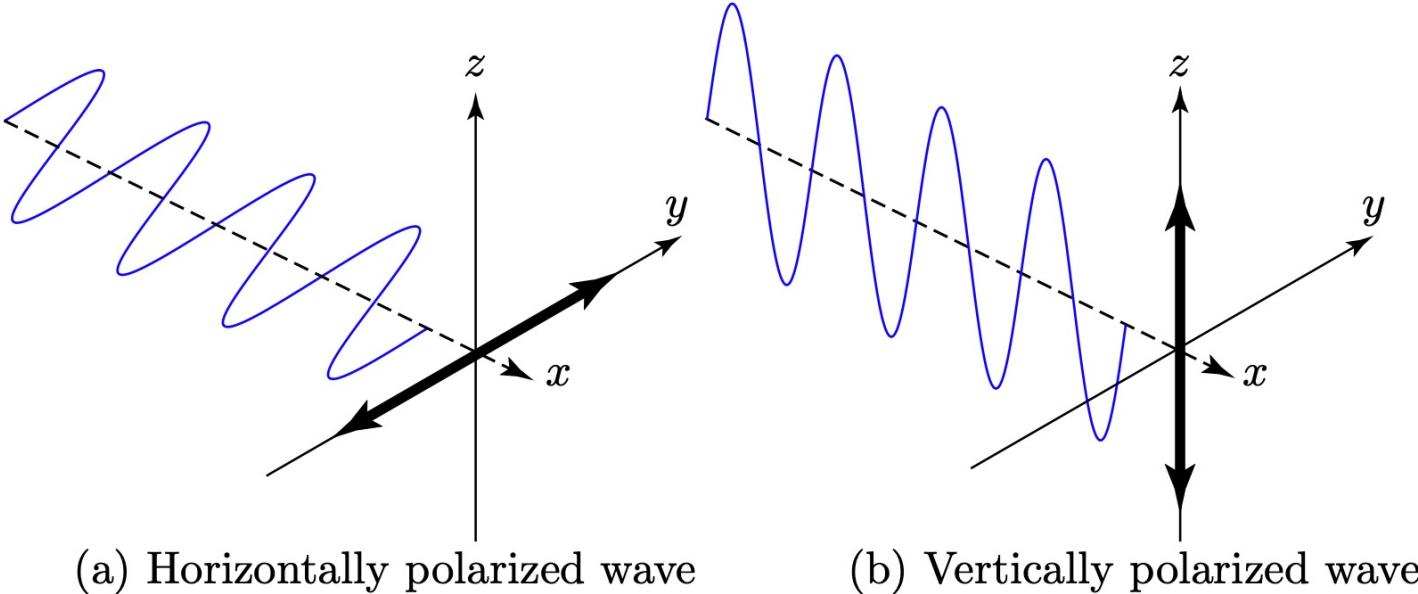


**Vertical linear array**  
Elevation beamforming



**Planar array**  
3D beamforming

# Polarization of waves and antennas



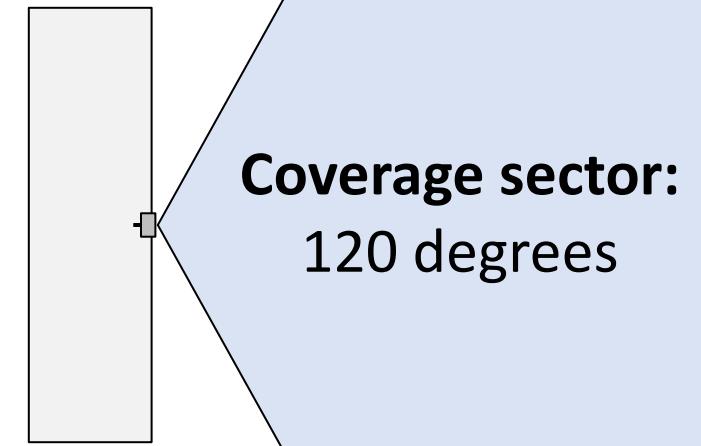
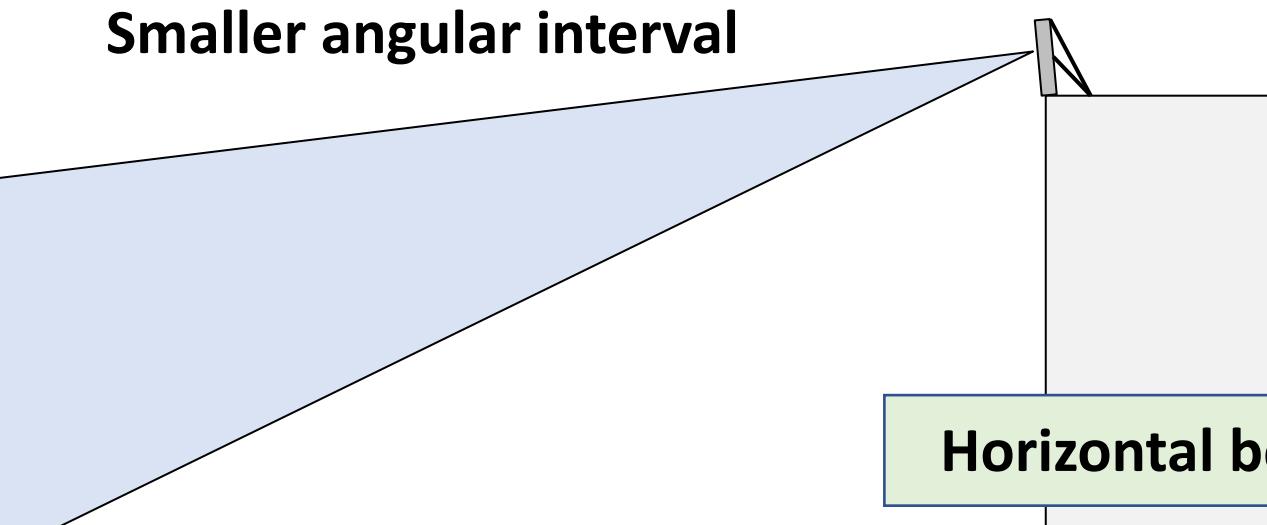
**Channel is changing the polarization**

Anyway creates an extra dimension

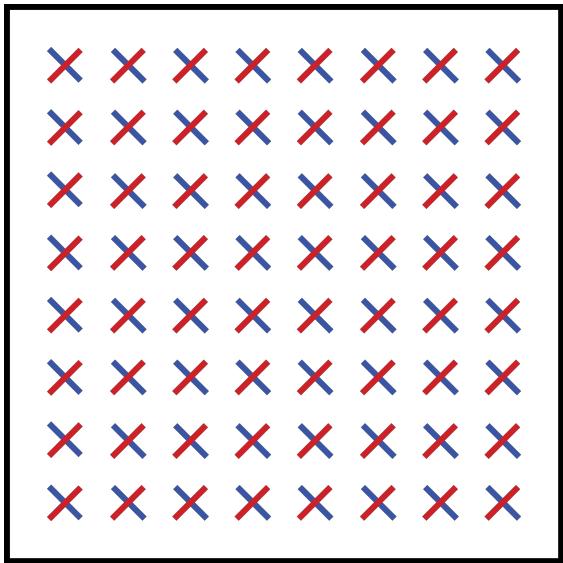
Often used in point-to-point MIMO

# Typical channel properties

- People live on the ground
  - Builds have limited height



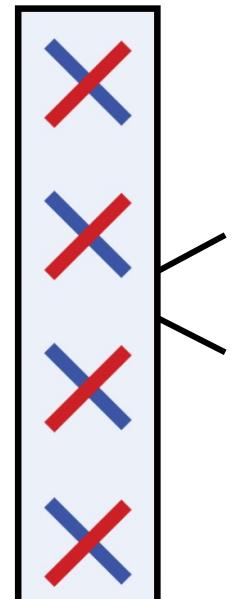
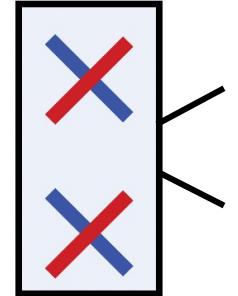
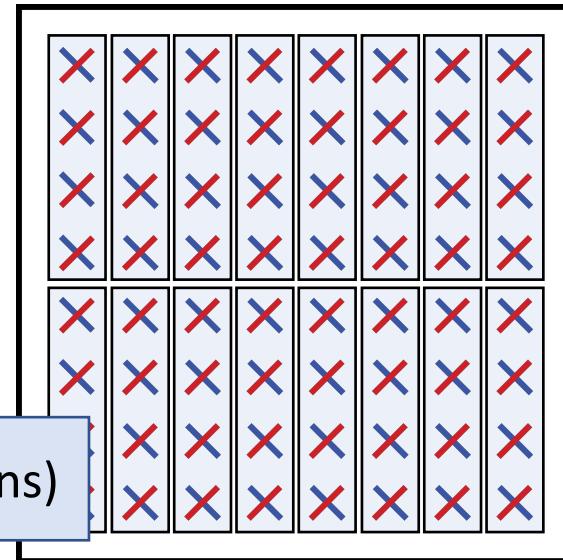
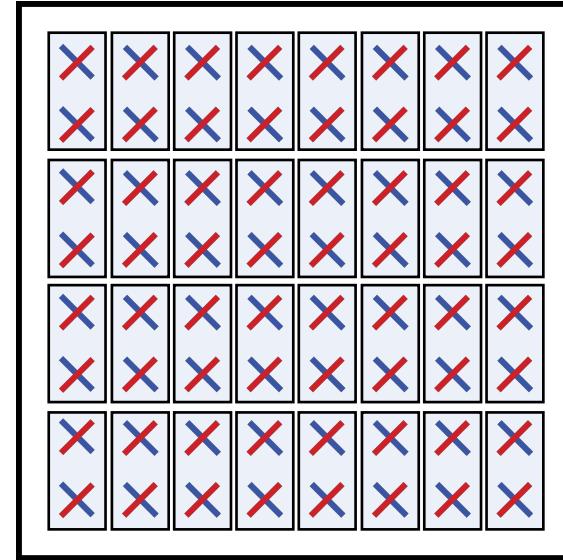
# Planar arrays and subarrays



**128 antenna elements**  
How many radios?

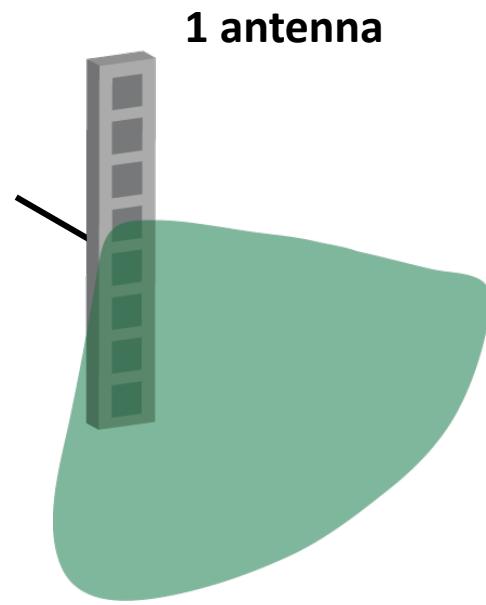
**64 radios**  
(64T64R)

**32 radios**  
(32T32R)

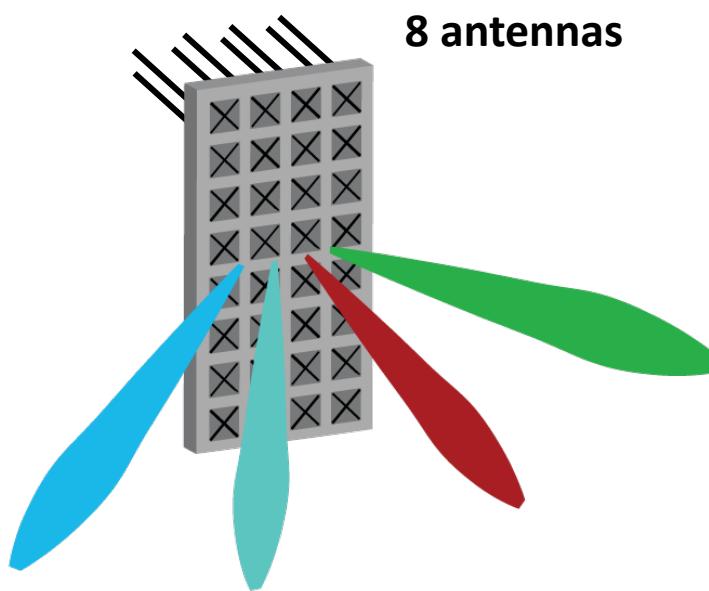


“Antenna” = Group of elements sharing one radio (transceiver chains)

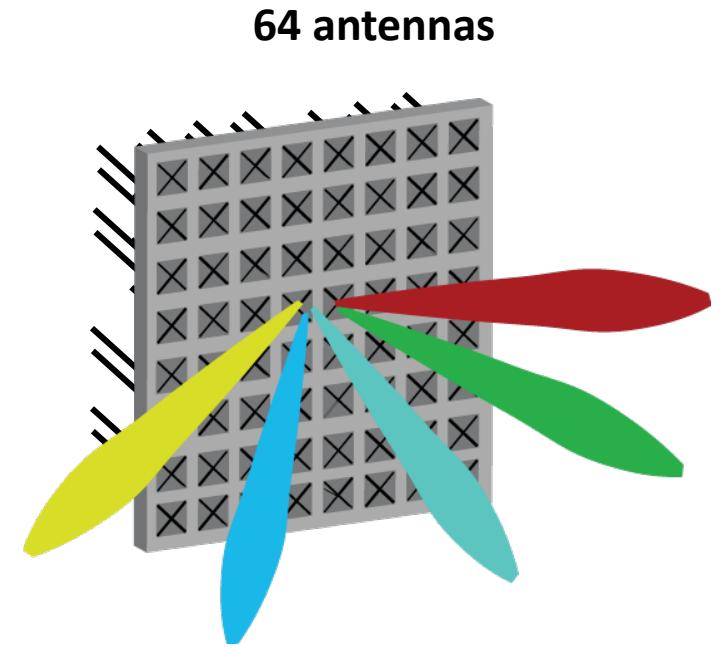
# Evolution of active antenna technology



**Passive sector antenna**  
8 elements (7 dBi each)  
1 transceiver chain  
Fixed beam 16 dBi



**Classical antenna array**  
64 elements (32 per polarization)  
8 transceivers (2 per column)  
Up to 8 horizontal beams



**Massive antenna array**  
128 elements (64 per polarization)  
64 transceiver  
Up to 64 3D beams

# Massive MIMO in 5G

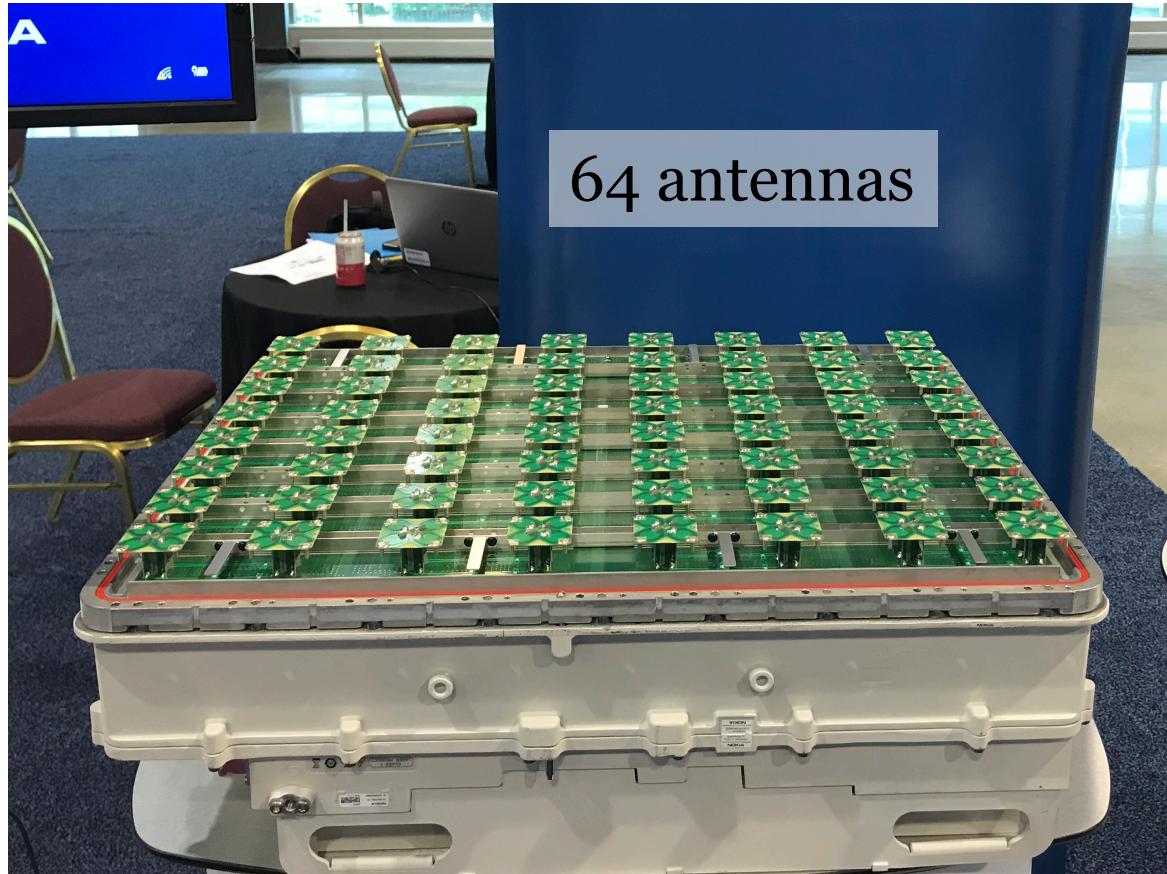


Photo: Erik G. Larsson, May 2018

# Massive MIMO in 5G: Evolution



## Ericsson Street Macro 6705

Millimeter-wave band  
Complete base station

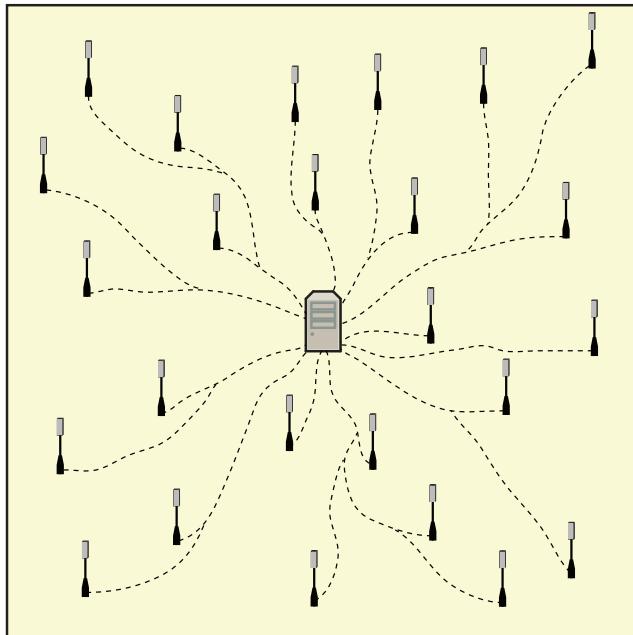
## Ericsson AIR 3268

3.5 GHz band  
32 antennas  
(128 elements)  
12 kg  
200 W over 200 MHz  
Integrated circuitry

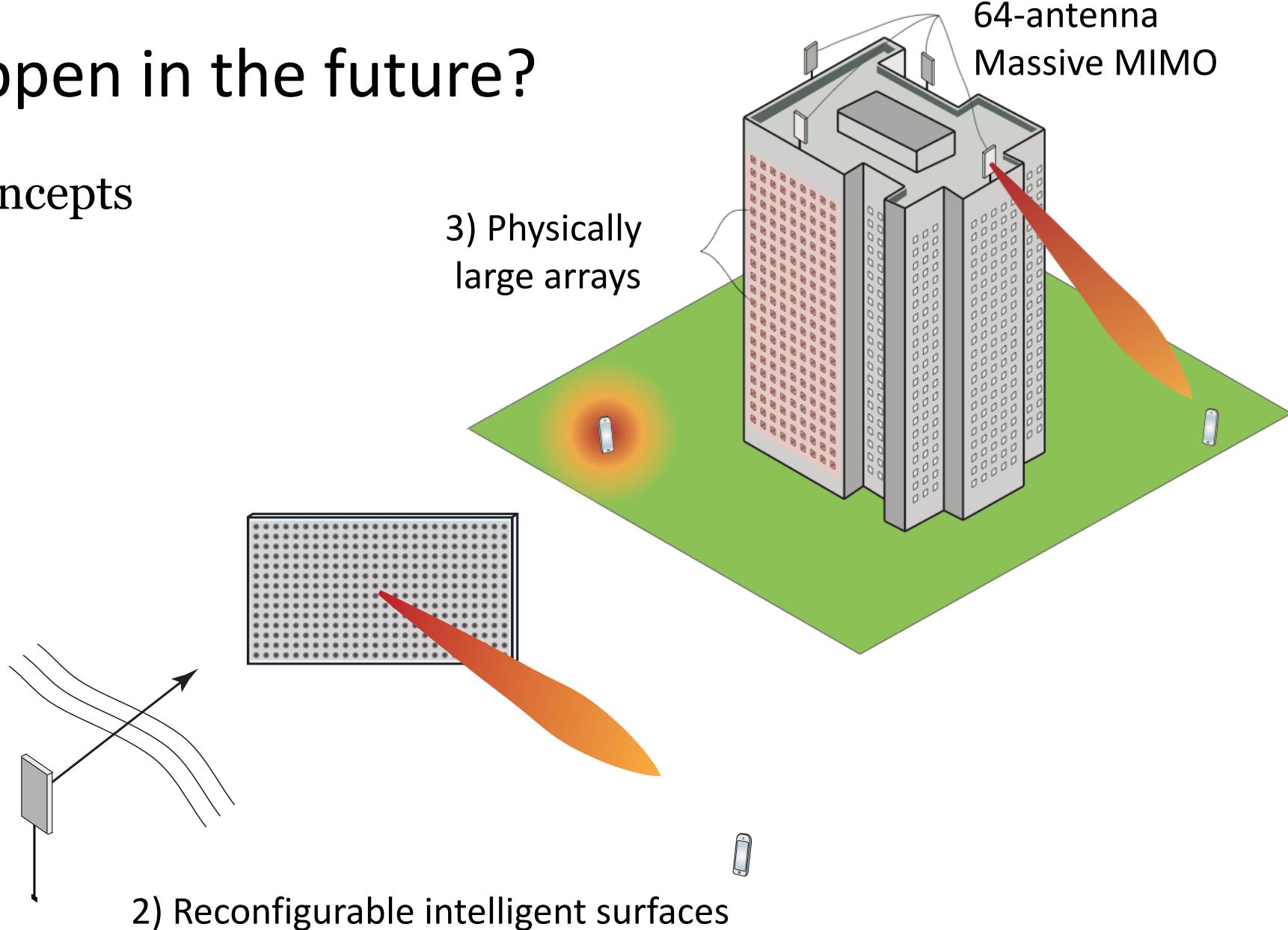


# What might happen in the future?

- New deployment concepts



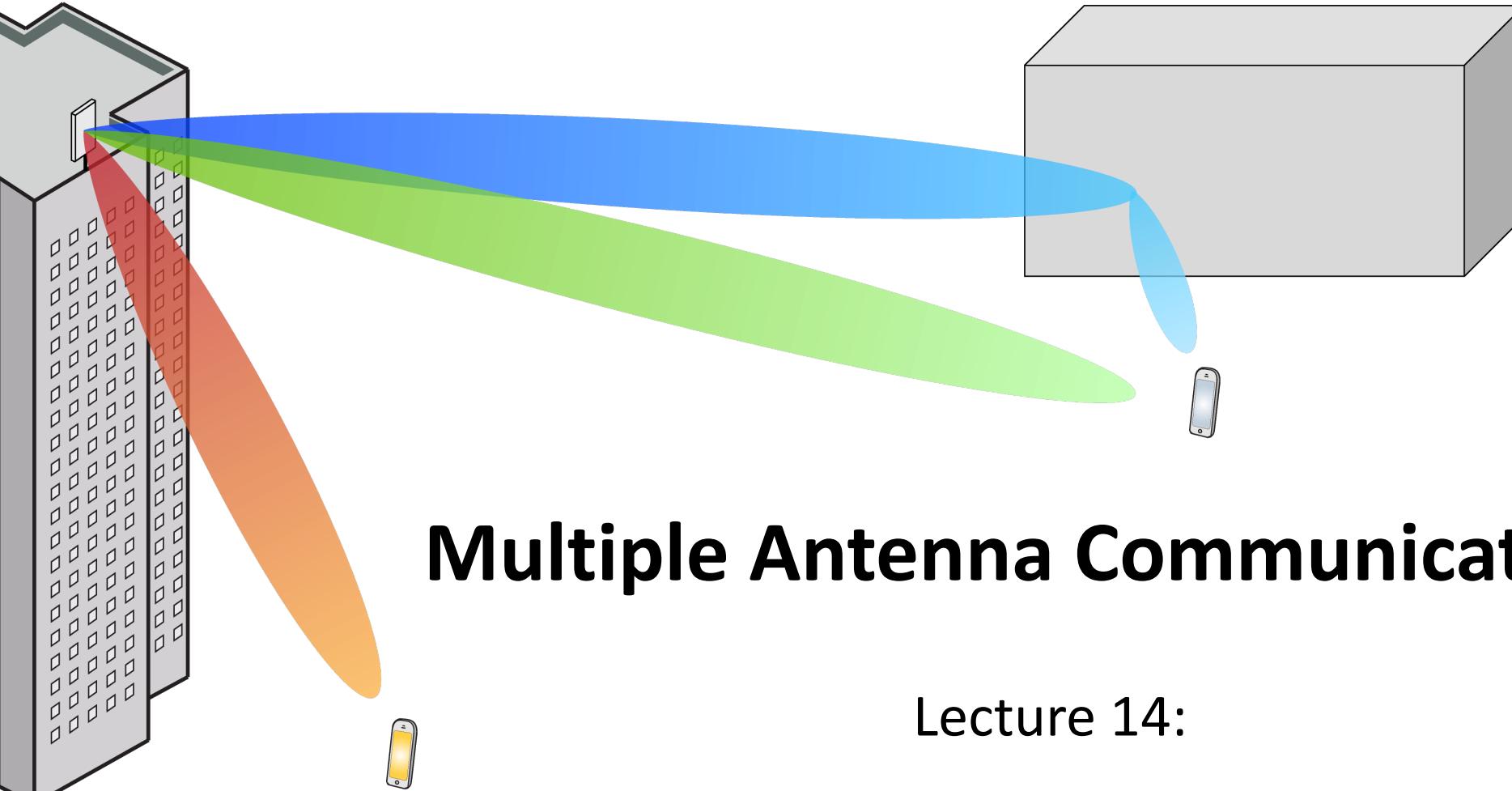
1) Distributed Massive MIMO  
(Cell-free)



2) Reconfigurable intelligent surfaces

# What have we not covered in the course?

- Point-to-point MIMO
  - Cases with imperfect channel knowledge
- Massive MIMO
  - Advanced processing (multi-cell, MMSE)
  - More realistic channels  
(e.g., correlated Rayleigh fading)
- Fading channels
  - Gradual variations, channel tracking and prediction



# Multiple Antenna Communications

Lecture 14:

## Practical Aspects and Terminologies

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