TSKS14

Multiple Antenna Communications

Lecture 12, 2020

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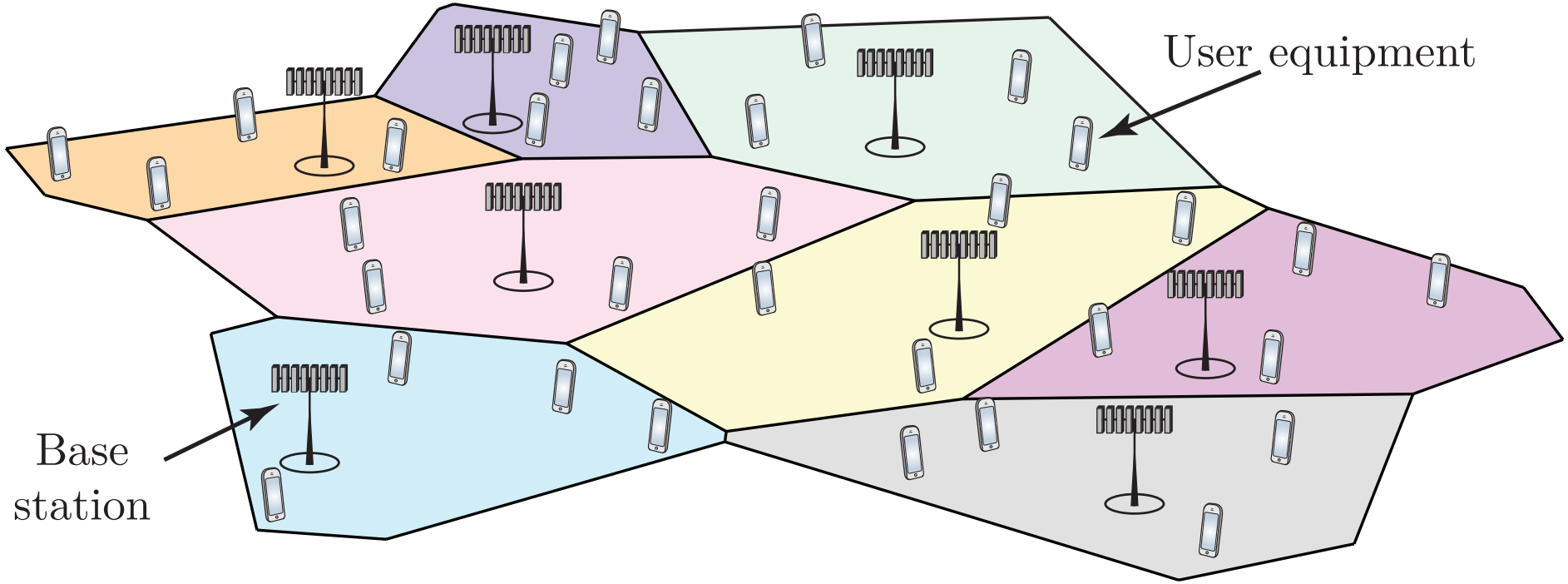
Outline of this lecture

- Evolution of cellular networks
  - Three ways to make improvements
  - The role of multiple antennas
- Summary of main benefits of multiple antenna communications
- Outlook towards the future

Martin Cooper's law

- The number of data connections has doubled every 2.5 years
  - Since beginning of wireless
  - Annual growth: +32%

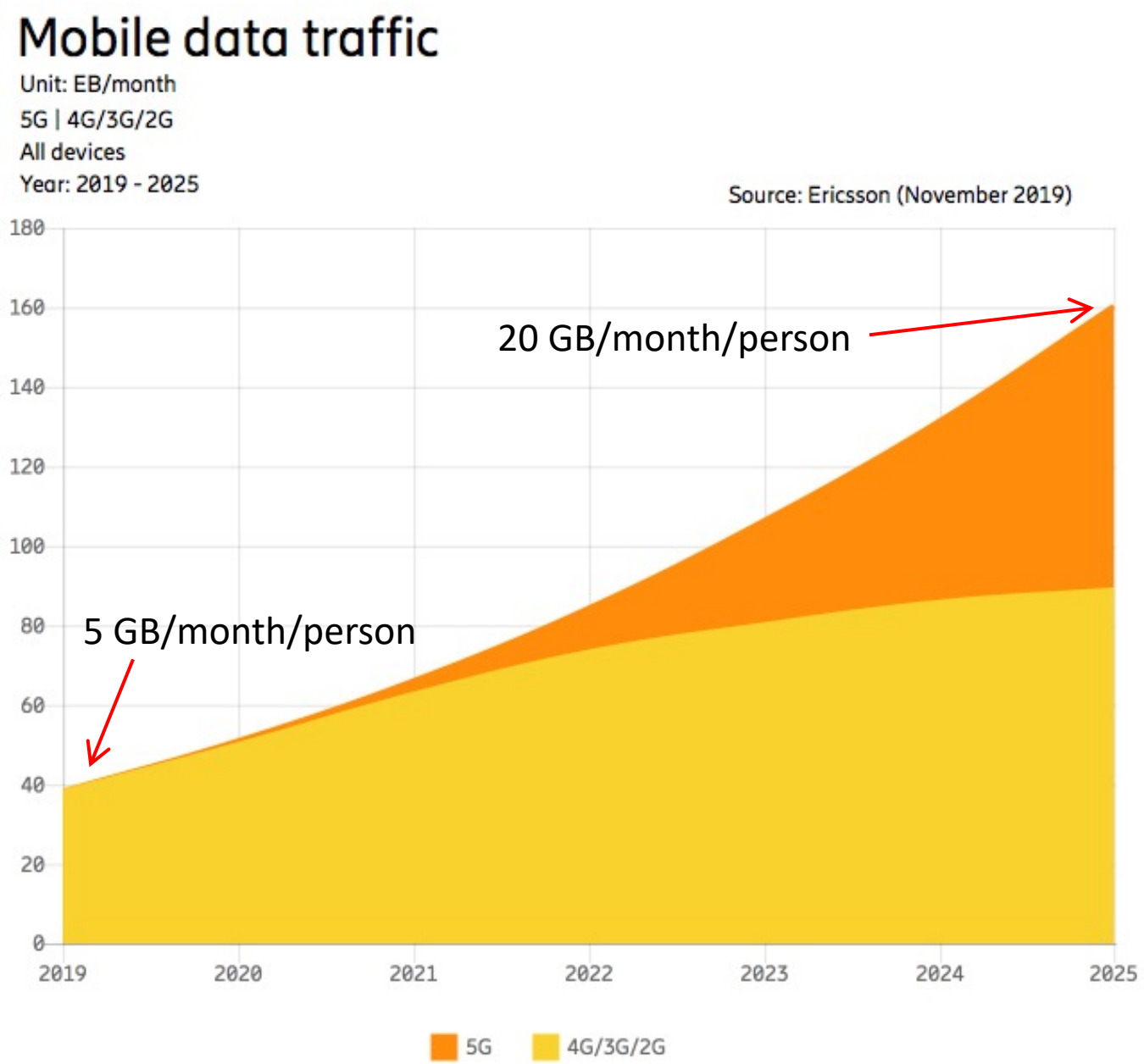
Cellular networks



- Proposed in 1950s
- First deployed in late 1970s

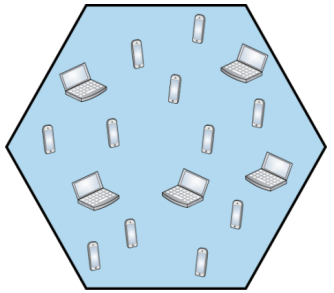
Current trends

- 26% annual growth (slower than in the past)



Evolving cellular networks for higher traffic

- Increase network throughput [bit/s/km²]
  - Consider a given area →



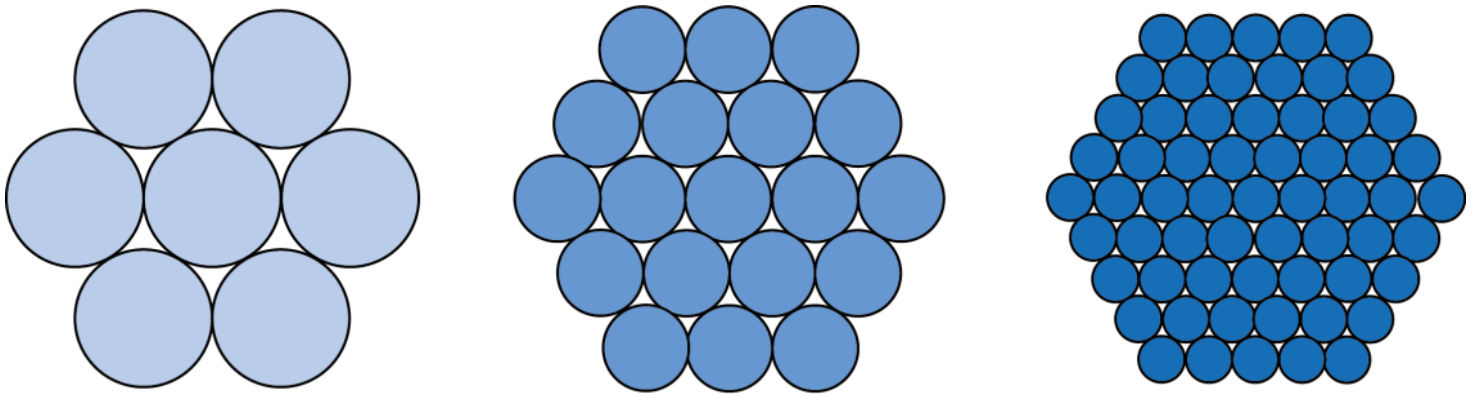
- Simple formula for network throughput:

$$\underbrace{\text{Throughput}}_{\text{bit/s/km}^2} = \underbrace{\text{Cell density}}_{\text{Cell/km}^2} \cdot \underbrace{\text{Available spectrum}}_{\text{Hz}} \cdot \underbrace{\text{Spectral efficiency}}_{\text{bit/s/Hz/Cell}}$$

How to achieve a 100x improvement?

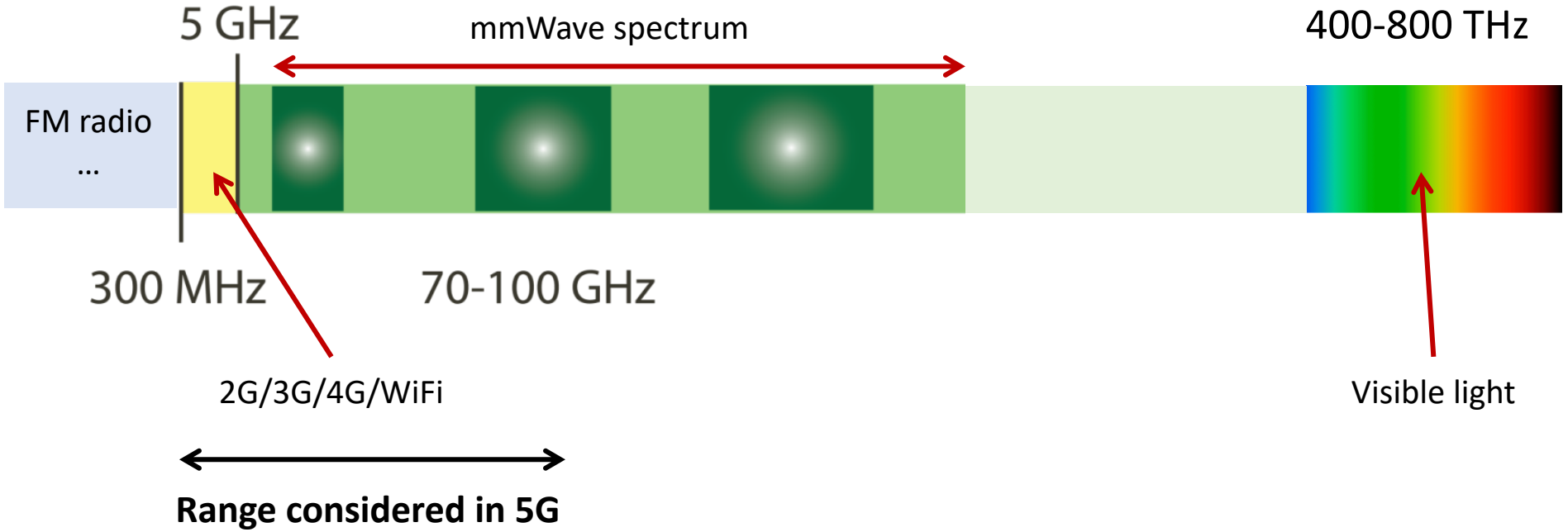
Higher cell density

- Traditional way to improve throughput
- Cut cell radius by z → z^2 times more cells



- Issues: High rent and deployment costs
  Interference is getting worse
  WiFi + Cellular is already dense: *Coverage is the issue*!

More spectrum



- Range suitable for coverage: < 5 GHz
- Far above 5 GHz: High propagation losses → Mainly short-range hotspots

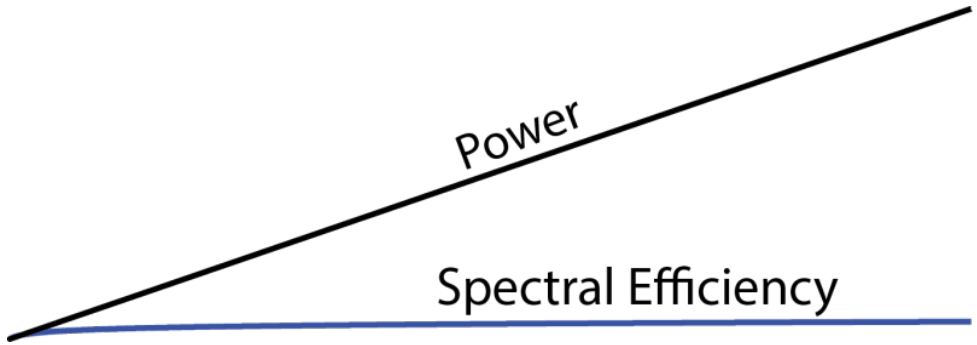
MIMO plays different roles in different bands

Higher spectral efficiency

- Point-to-point spectral efficiency:
  - Governed by capacity limit:

$$\log_2\left(1+\frac{\text{Received Signal Power}}{\text{Interference Power}+\text{ Noise Power}}\right)\ \text{[bit/s/Hz]}$$

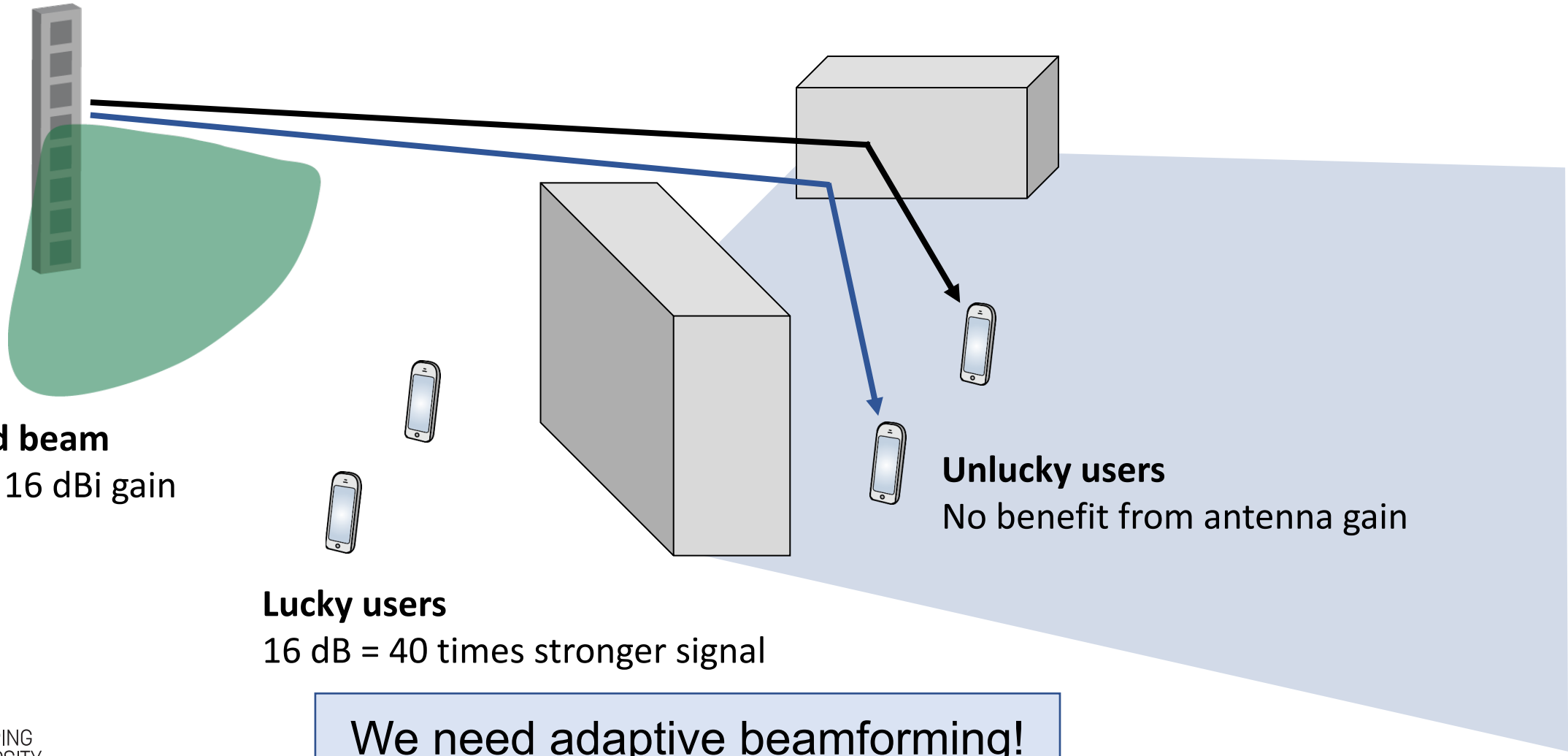
  - Increasing signal power:



4 bit/s/Hz → 8 bit/s/Hz
requires 17× more power!

Use multiple antennas instead!

Fixed beamforming



Fixed beam
with 16 dBi gain

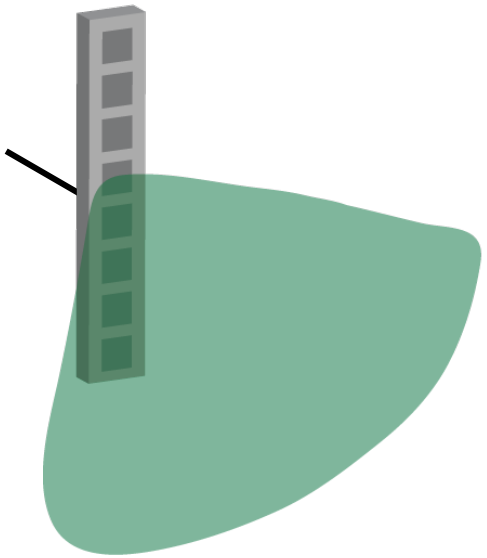
Unlucky users
No benefit from antenna gain

Lucky users
16 dB = 40 times stronger signal

We need adaptive beamforming!

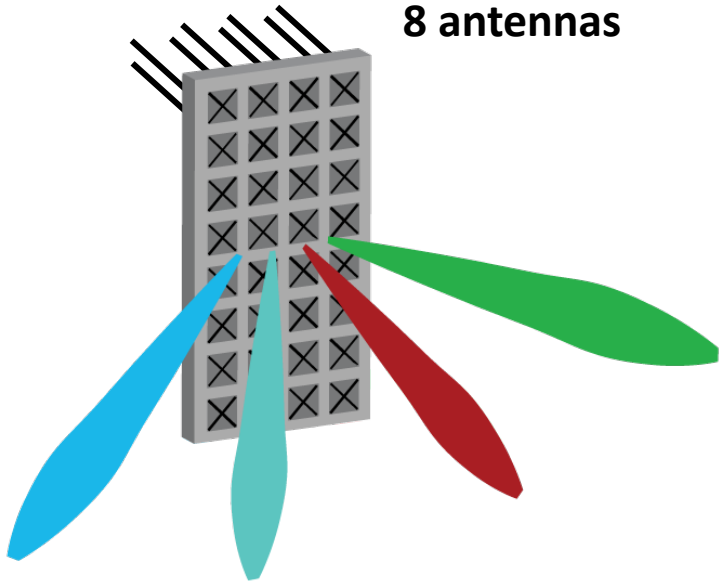
Evolution of “active” antenna technology

1 antenna



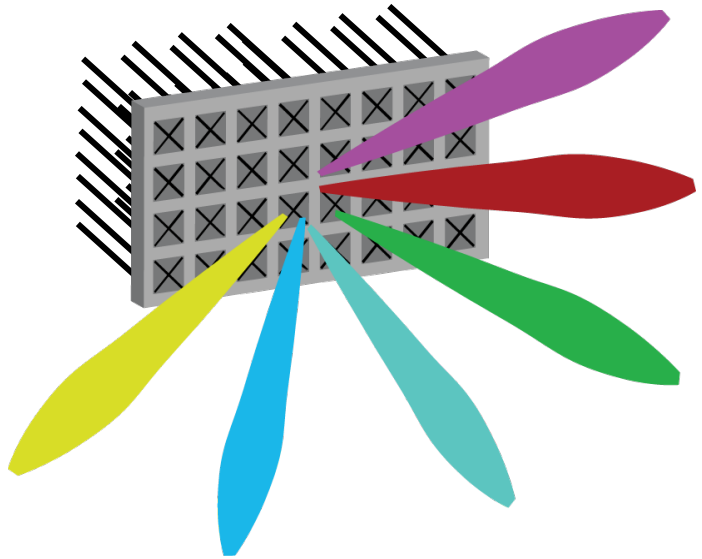
Sector antenna
8 elements (7 dBi each)
1 transceiver chain
Fixed beam 16 dBi

8 antennas



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

64 antennas



Massive antenna array
64 elements
64 transceiver chains
Up to 64 3D beams

Massive MIMO in 5G

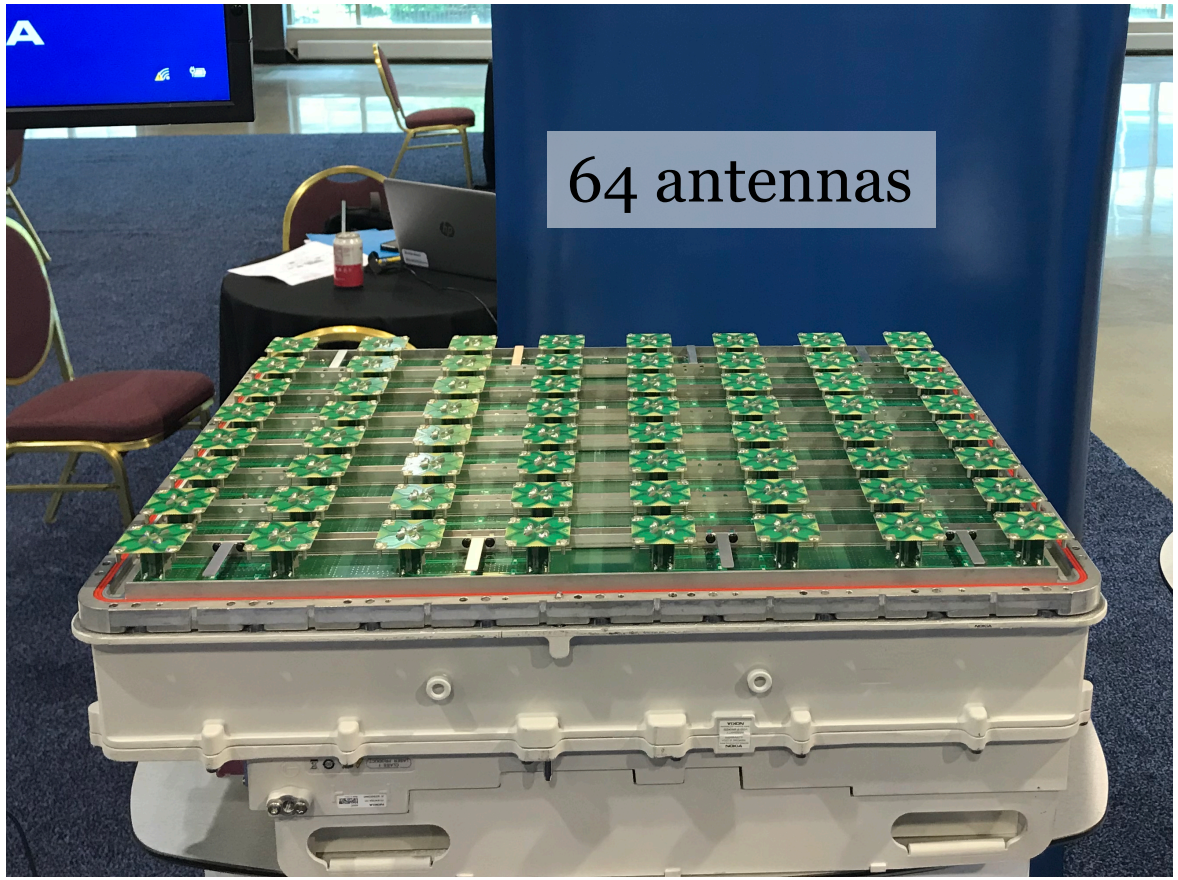
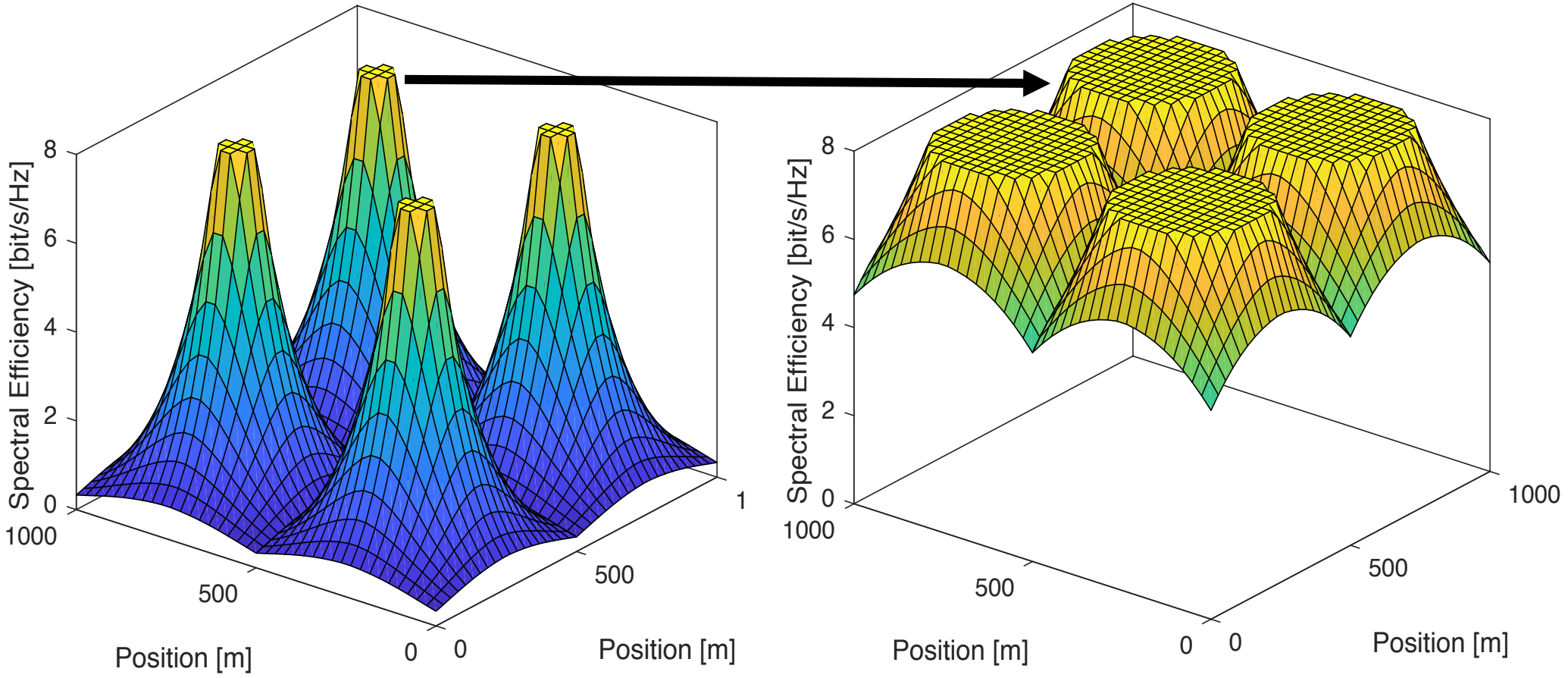


Photo: Erik G. Larsson, May 2018

Different aspects: Multiple antenna communications

- Point-to-point scenario
  - SIMO, MISO, MIMO
- Multi-user scenario
  - M-antenna base station, K single-antenna terminals
- Channel modeling
  - Deterministic and random channels
  - Capacity, outage capacity, ergodic capacity

Point-to-point: Better user performance



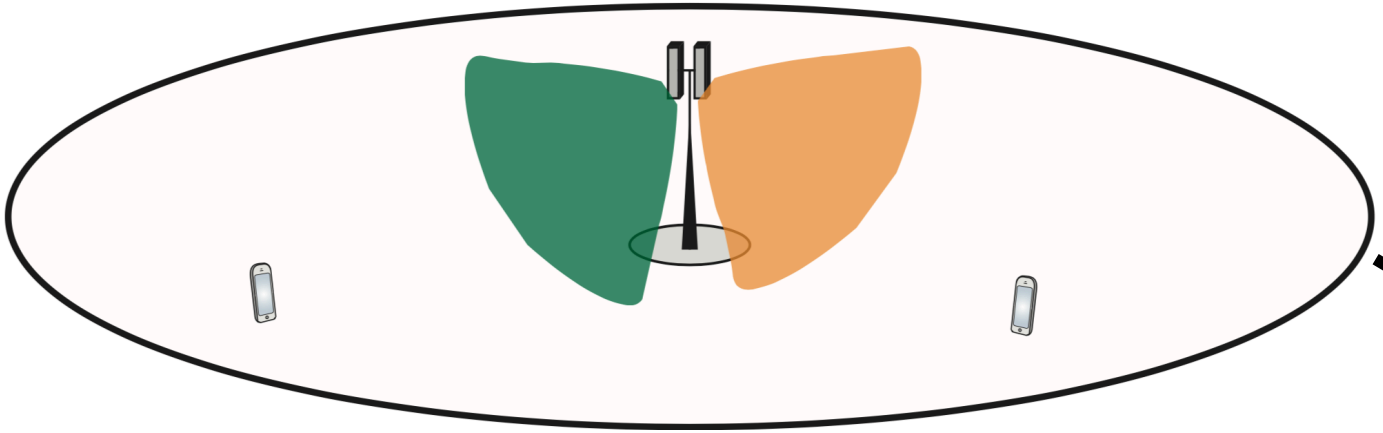
Beamforming and multiplexing gain

Summary: Point-to-point MIMO

- Advantages
  - Multiplexing gain and beamforming gain
  - Increases capacity for a single user
  - Only receiver needs channel state information

- Disadvantages
  - Hard to fit many antennas into a user terminal
  - $\boldsymbol{G}^H\boldsymbol{G}$ might only have a few large eigenvalues

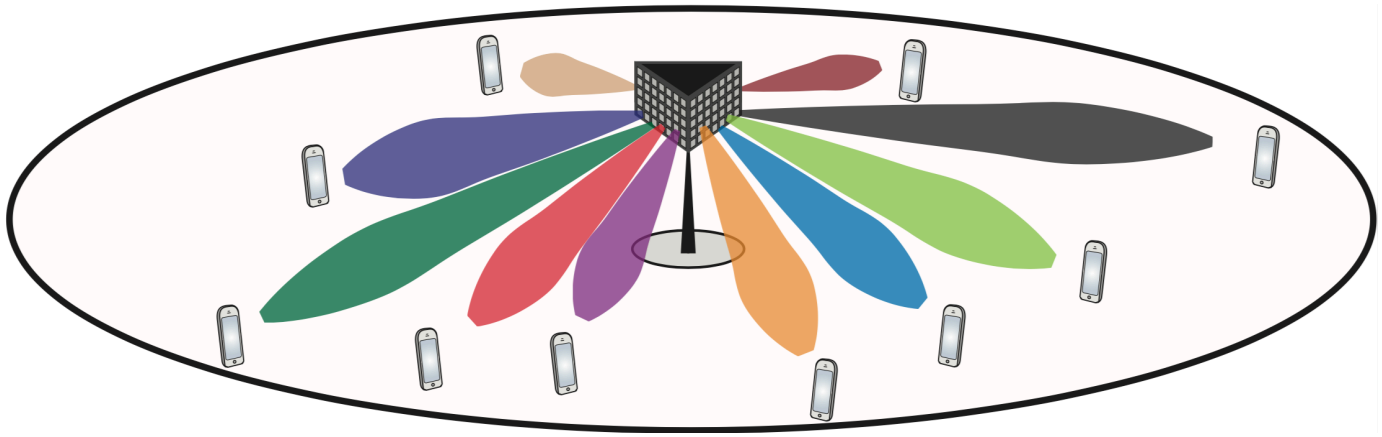
Multi-user MIMO: Spatial multiplexing of users



Few antennas (elements): Broad beams

Serve many users at same time/frequency resource

Narrow beams limit interference



Massive number of antennas: Narrow beams

Summary: Multi-user MIMO

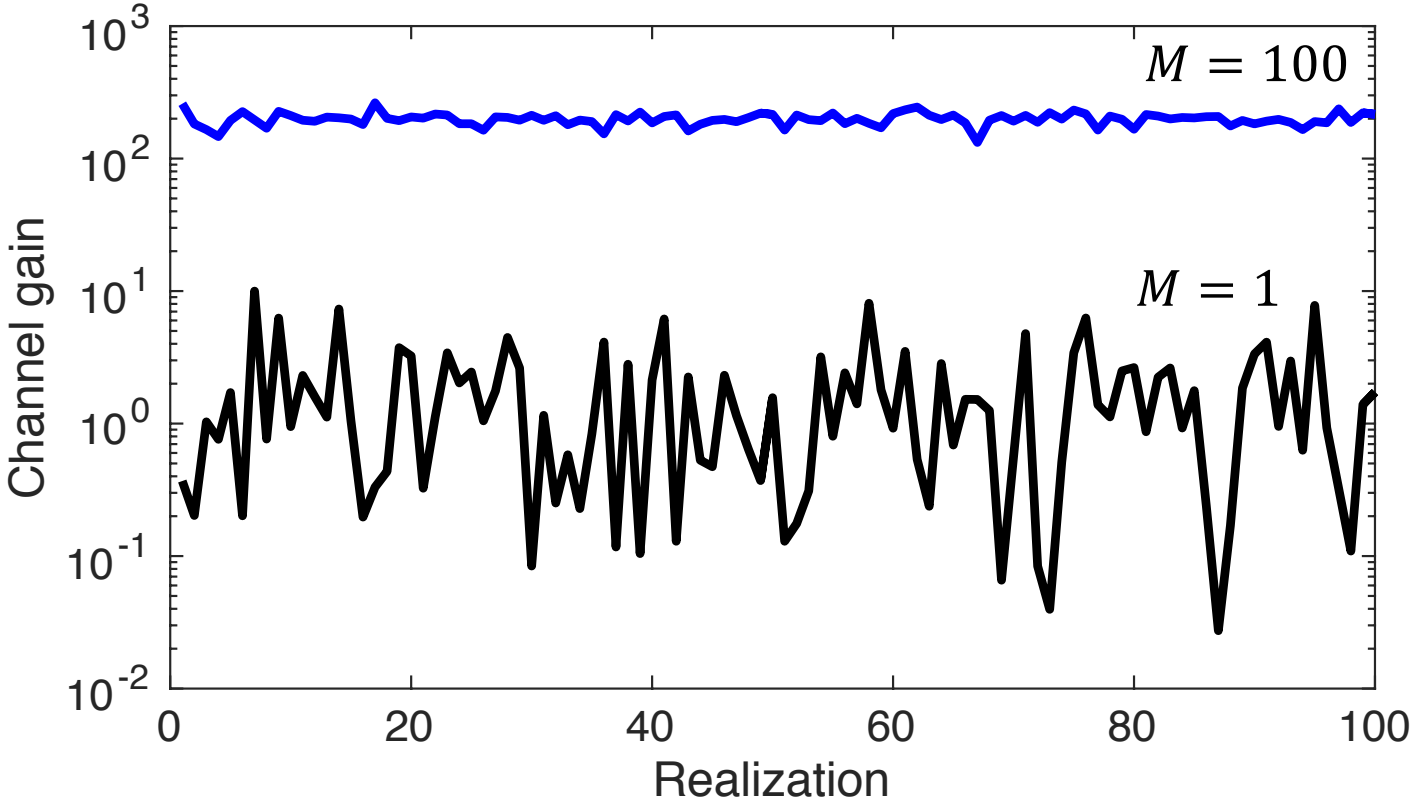
- Advantages
  - Multiplexing gain and beamforming gain: Increases sum capacity
  - Very scalable technology, any number of antennas, tens of users
  - Only base station needs channel state information

- Disadvantages
  - Capacity per user does not grow as fast
  - Require many active users to achieve gains
  - Must be implemented in the right way (TDD, etc.)

Summary: Fading channels

- Slow fading
  - Outage probability
  - Outage capacity
- Fast fading
  - Ergodic capacity
  - Coherence intervals

Diversity gains:

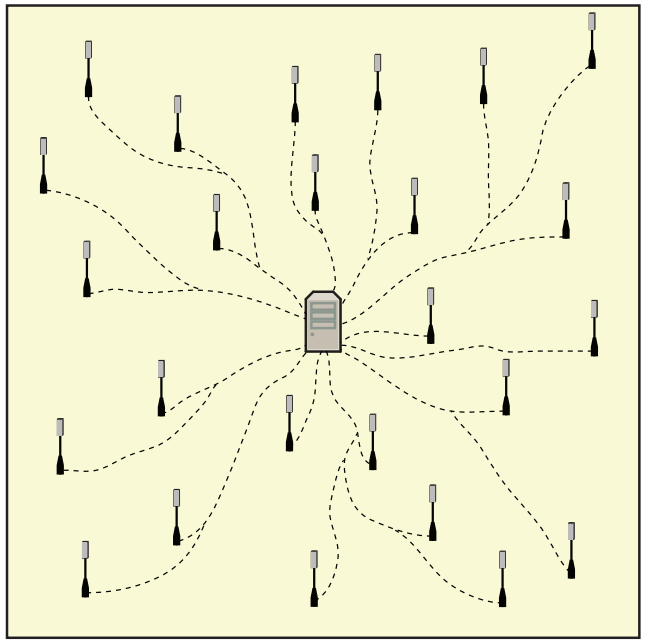


What have we not covered in the course?

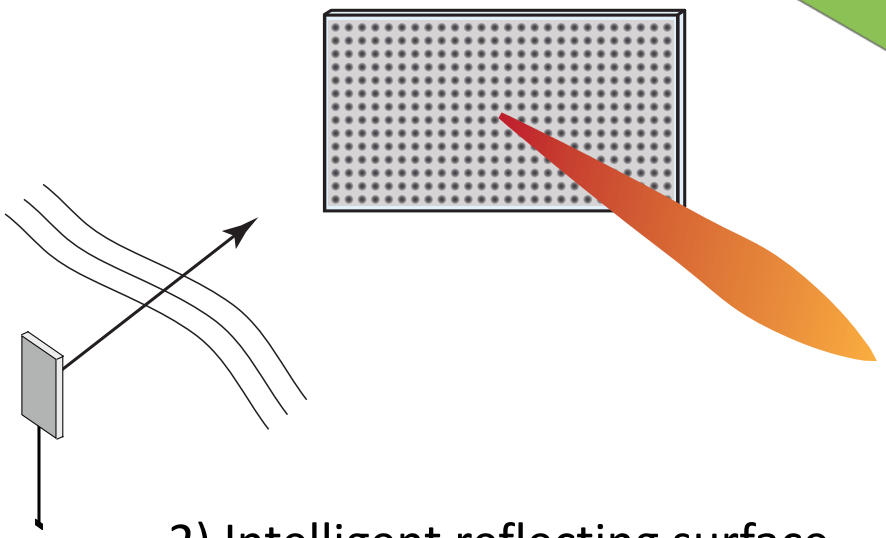
- Point-to-point MIMO
  - Cases with imperfect channel knowledge
- Massive MIMO
  - More advanced processing (zero-forcing, MMSE)
  - More realistic channels (correlated Rayleigh fading)
- Fading channels
  - Gradual variations, channel tracking and prediction

What will happen in the future?

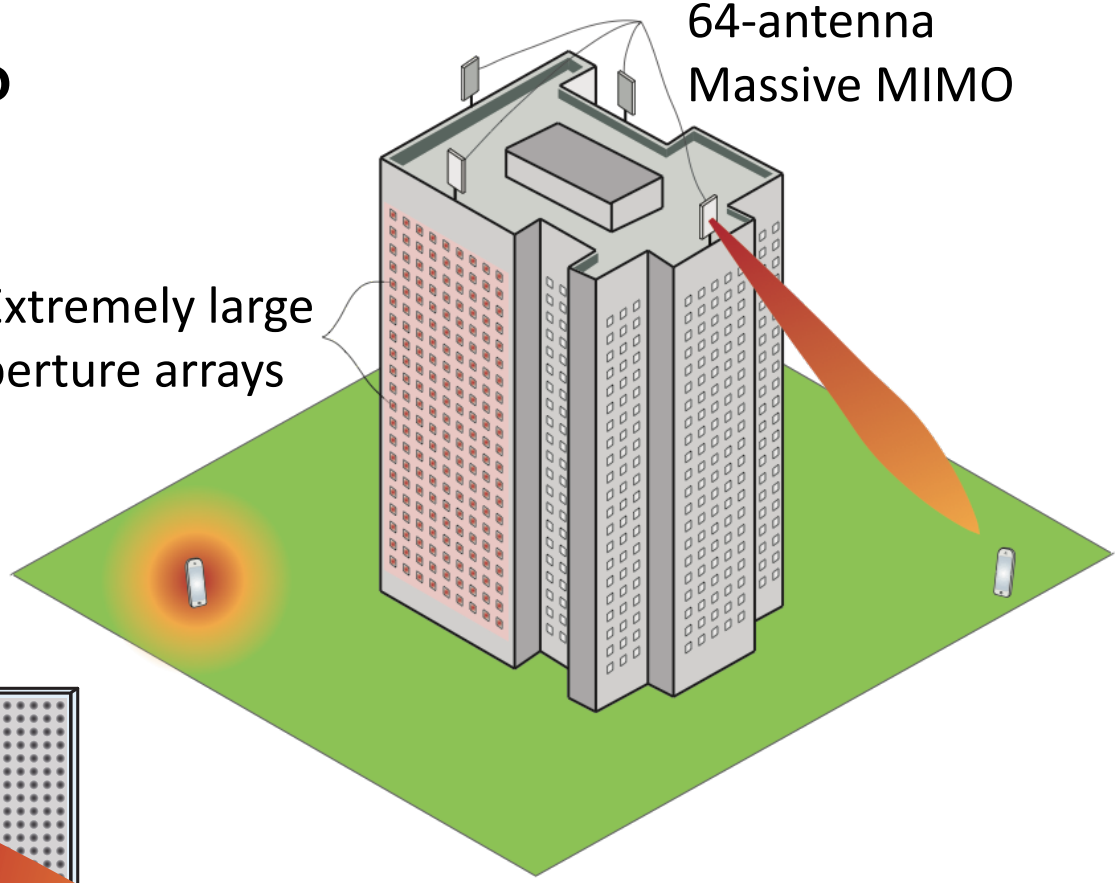
- New deployment concepts



1) Distributed Massive MIMO (Cell-free)



2) Intelligent reflecting surface



64-antenna Massive MIMO

3) Extremely large aperture arrays

End of Lecture 12

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