

Beyond the Cellular Paradigm

Cell-Free Architectures with Radio Stripes

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Outline

1. Cellular communications
 - Properties and weaknesses
2. Beyond the cellular paradigm
 - Basics of cell-free networks
 - Ways to deal with interference
 - Implementation aspects: Radio stripes
 - Deployment examples

The Cellular Architecture was Proposed in the 1950s

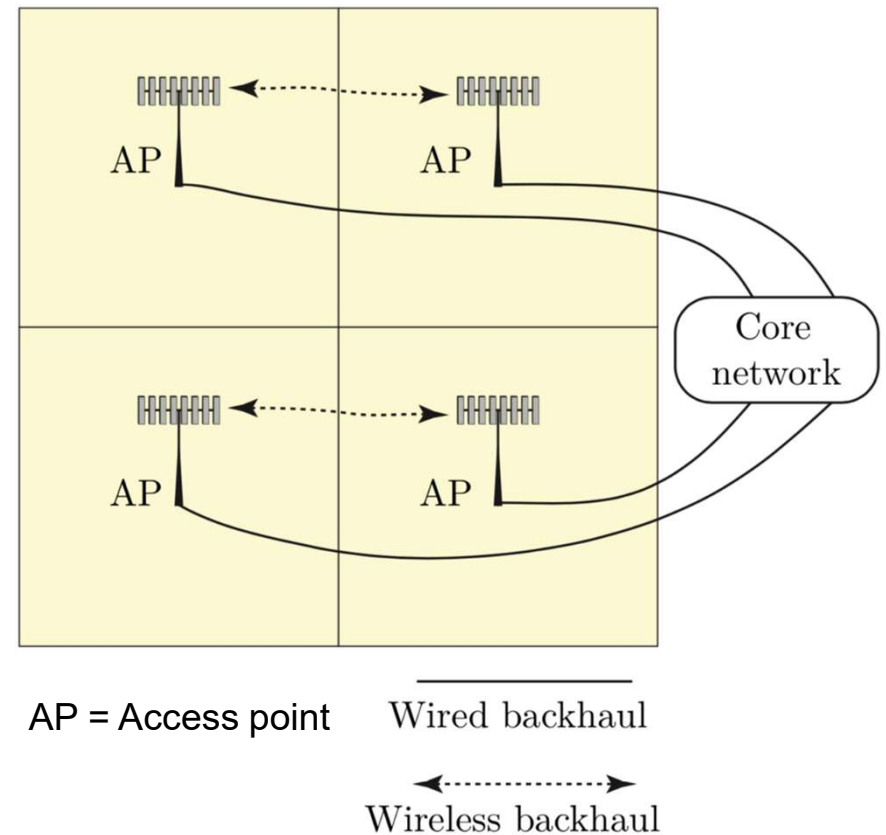
Designed for mobile telephone systems

Bullington, K. (1953). "Frequency economy in mobile radio bands". *The Bell System Technical Journal*.

Schulte, H. J. and W. A. Cornell (1960). "Multi-area mobile telephone system". *IEEE Trans. Veh. Technol.*

Reuse of spectrum in space:
Densify as usage increases

Control interference by fractional
spectrum reuse, reduce power



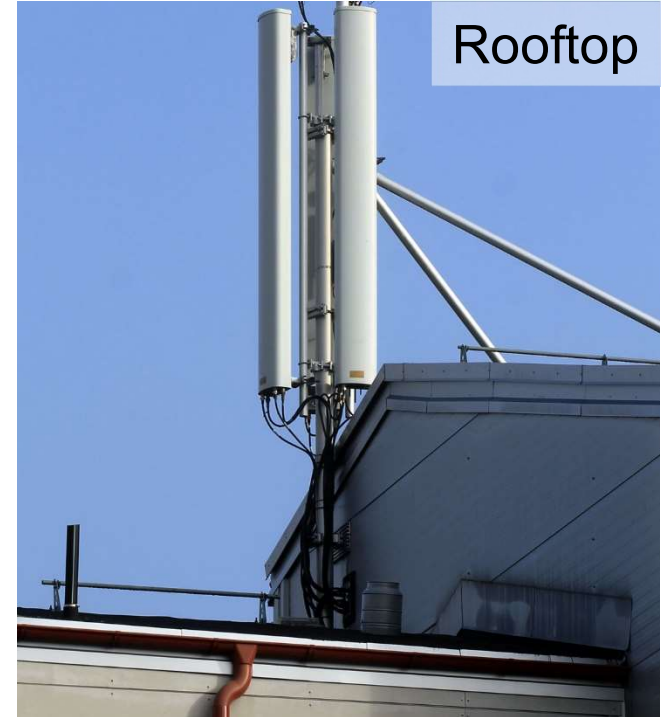
Sparse Deployment of Access Points

Tower



Sensitive to blocking

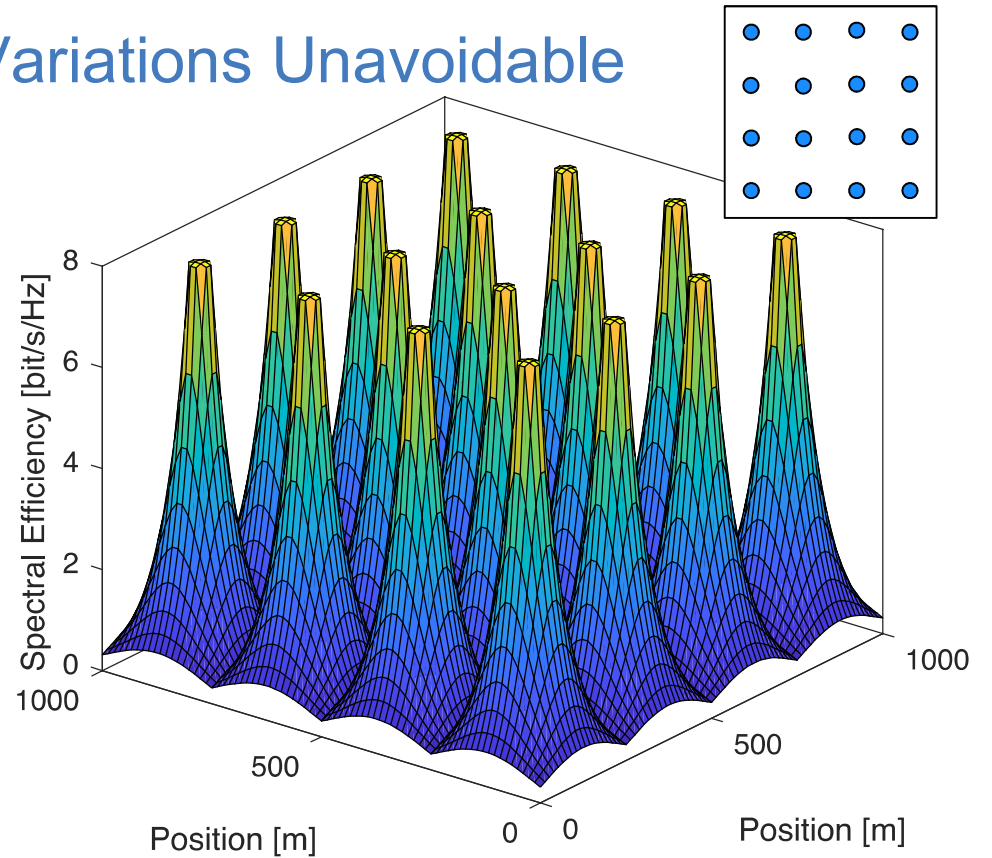
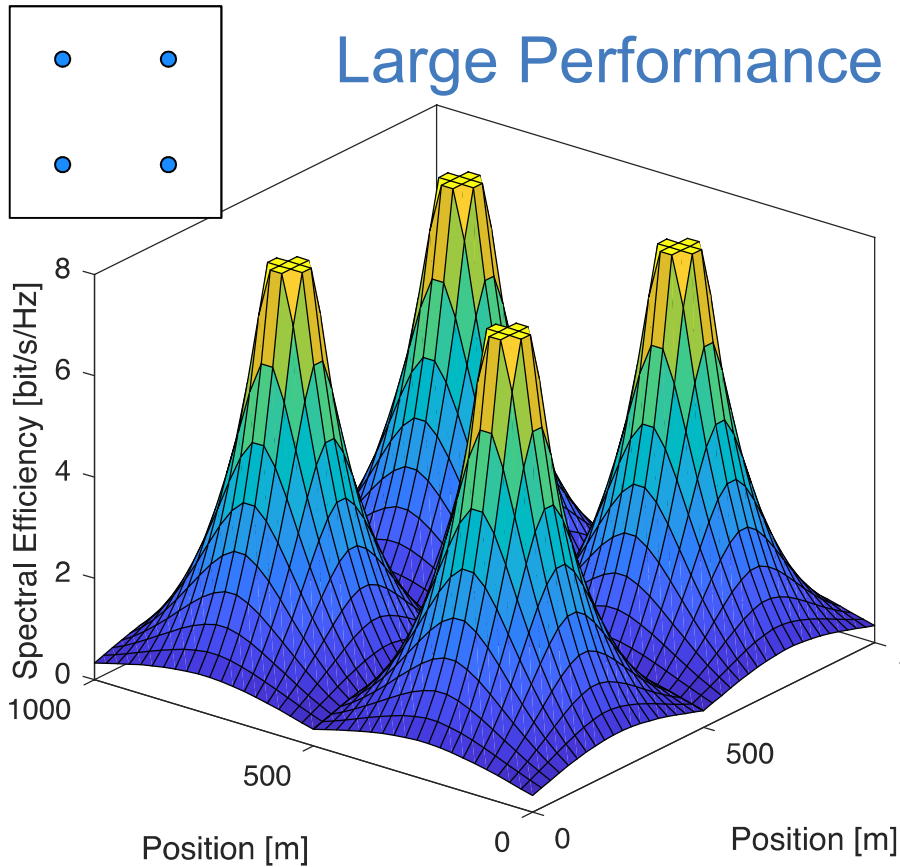
Rooftop



Visible installation

Large variation in distance to users →
Large signal strength variations

Large Performance Variations Unavoidable



Most users get mediocre performance

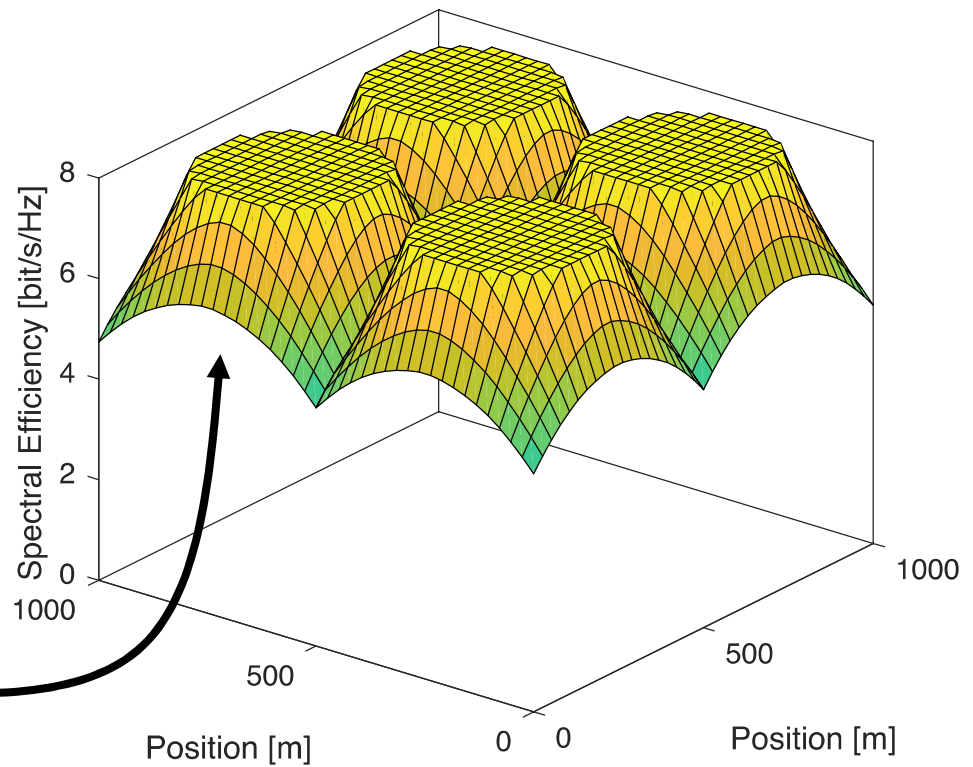
Enough for voice calls, not for data!

*Pathloss exponent: 3
5-10 dB at cell edge*

Wireless Dream: (Almost) Uniformly Good Service Quality

Users request same service everywhere

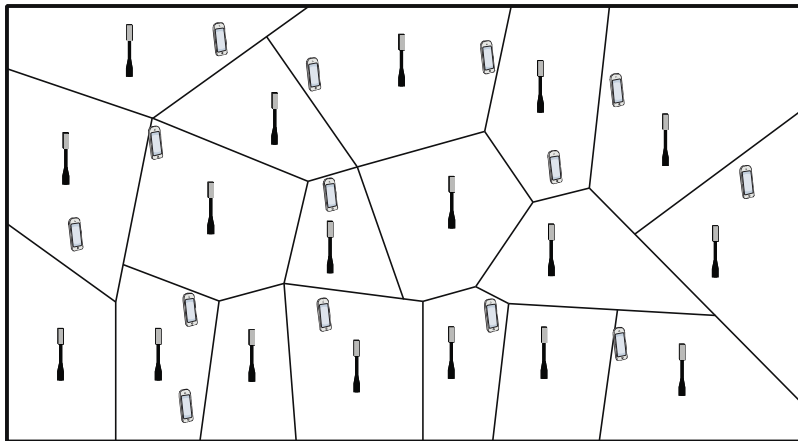
Easy to serve users in cell center
Most *active users* are at cell edge!



Can we deliver this somehow?

Coordinated Multipoint Transmission

A 4G attempt to solve the issue within the cellular paradigm

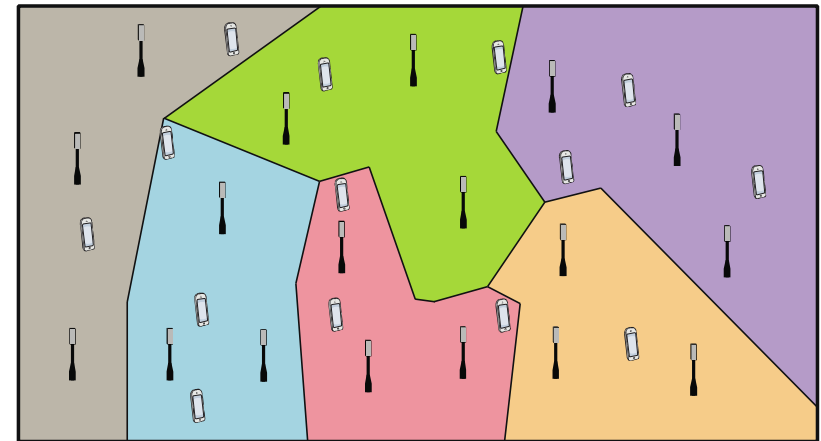


Conventional cellular network

Not a successful solution

A lot of backhaul signaling

Hard to standardize



Cellular with cooperation clusters

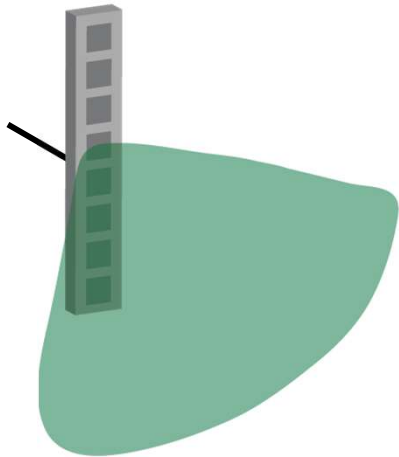
Coordinated scheduling

Coordinated spatial beamforming

Joint transmission

Massive MIMO: 5G Attempt to Improve Spectral Efficiency

1 high-gain antenna

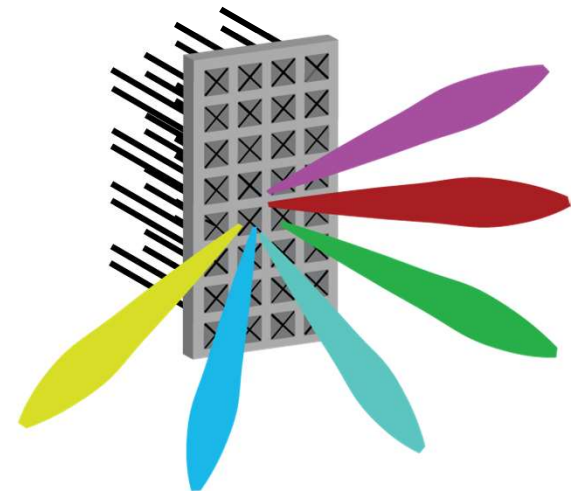


Classical antenna

Always the same directivity



64 low-gain antennas



“Massive MIMO”

Strong, adaptive directivity

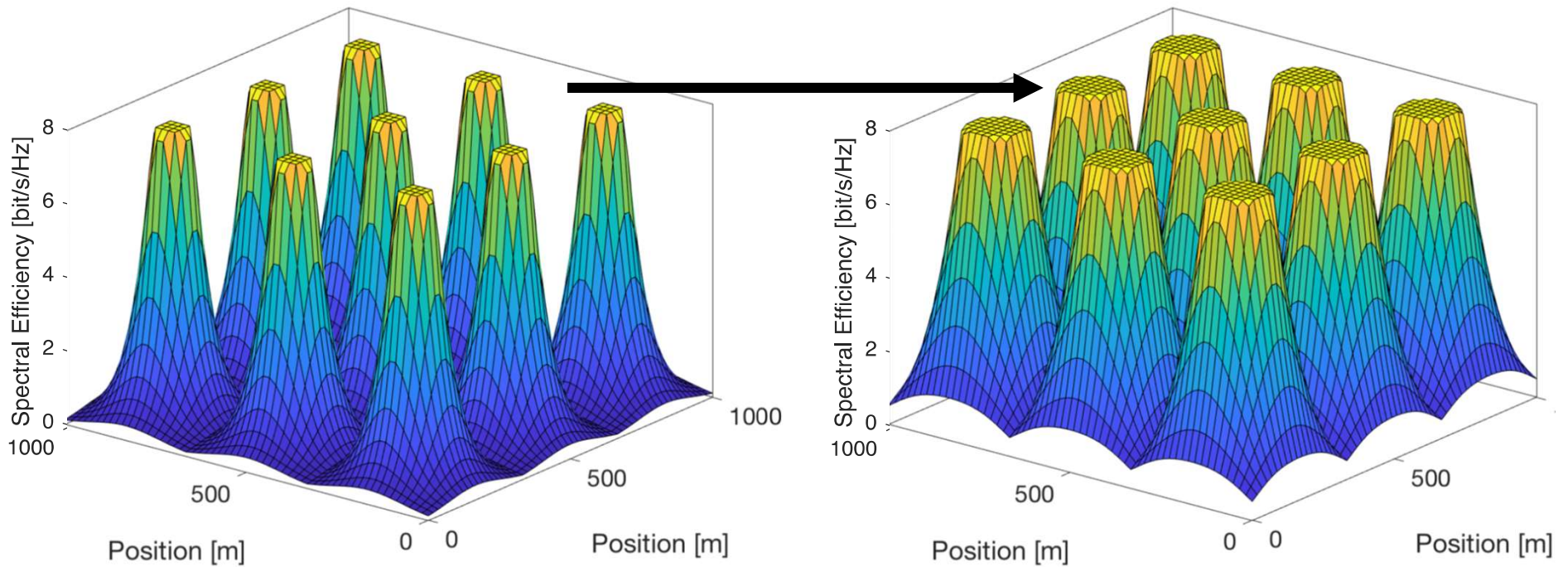
Separate users in space

Reduce interference

Massive MIMO
(multiple-input multiple-output):
 M antennas \gg K users

Can 5G Deliver Uniformly Good Service Everywhere?

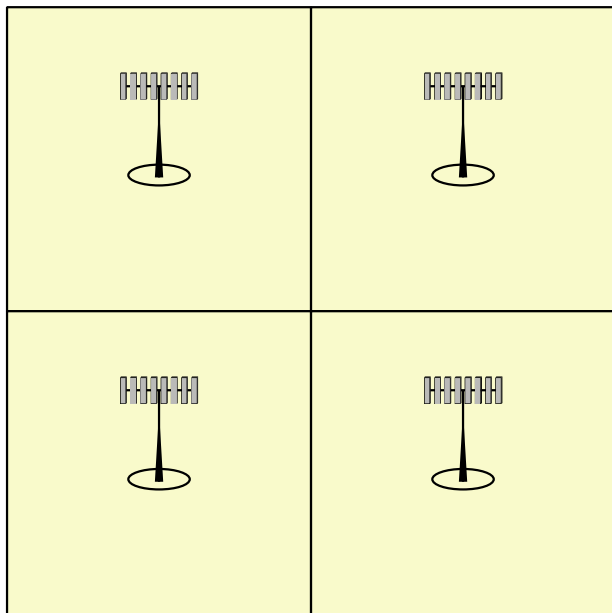
Handles more users and give stronger signals, but problems remain!



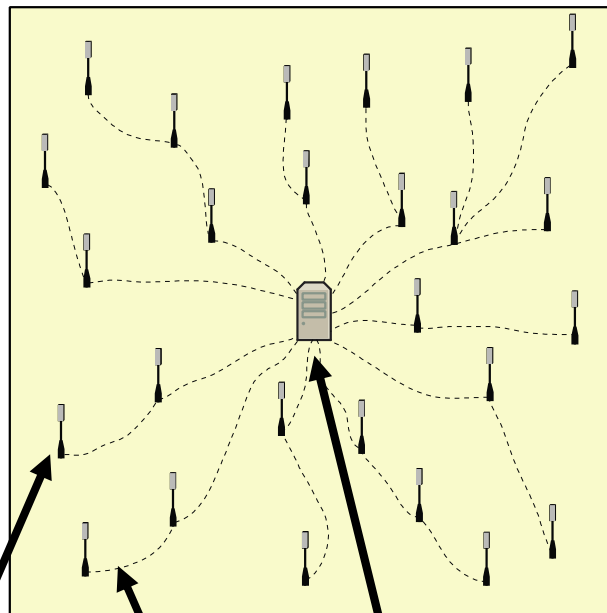
mmWave bands: Worse signal variations!

Moving Beyond the Cellular Paradigm

Cellular network



Cell-free network



Massive number of distributed antennas:

Short distance from user to some antennas

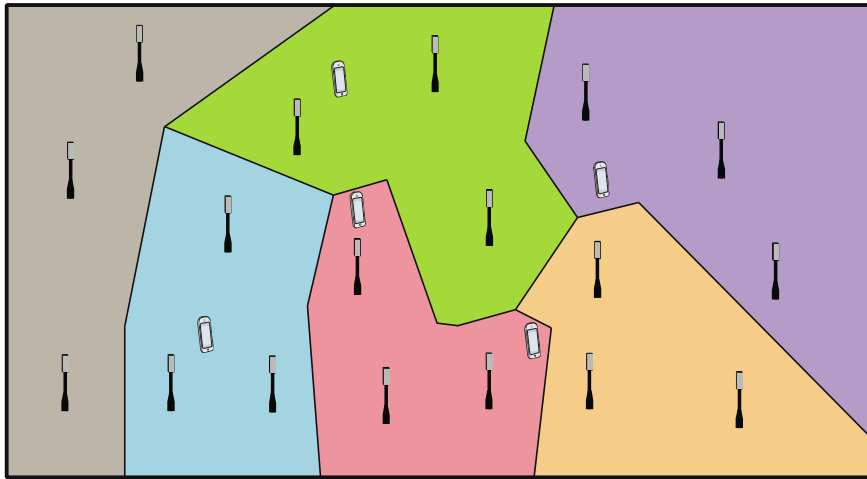
Connection to Massive MIMO:

$$M \gg K$$

M antennas, K users

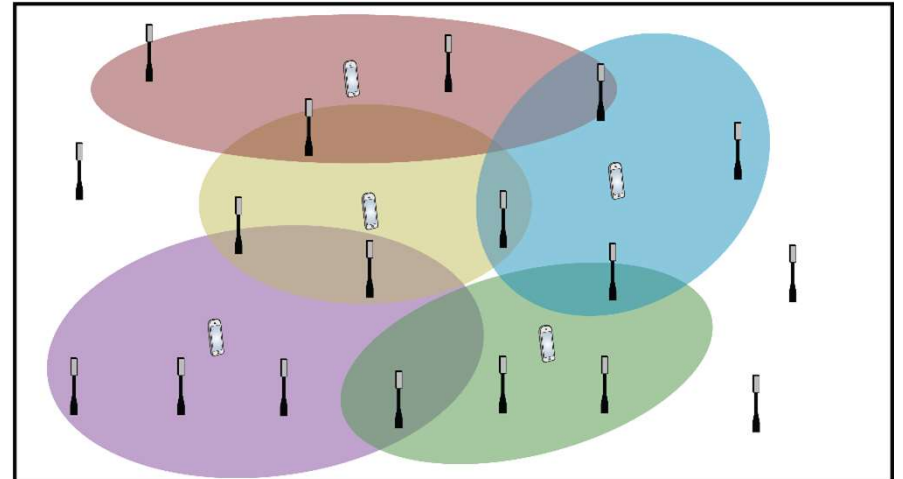
Access point Fronthaul Central processing unit

Difference from 4G Coordinated Multipoint



Cellular: Coordinated multipoint

Network-centric design



Cell-free: Each user served by all AP in its area of influence

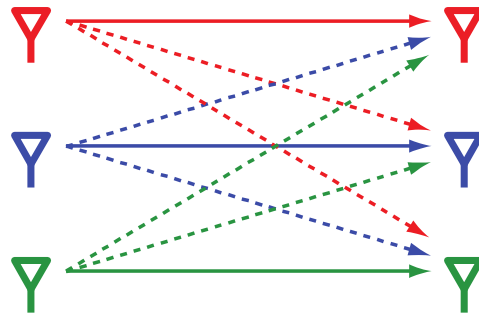
User-centric design



Uplink: Philosophy of Interference Rejection

Cellular network:

3 desired signals:
One per transmitter

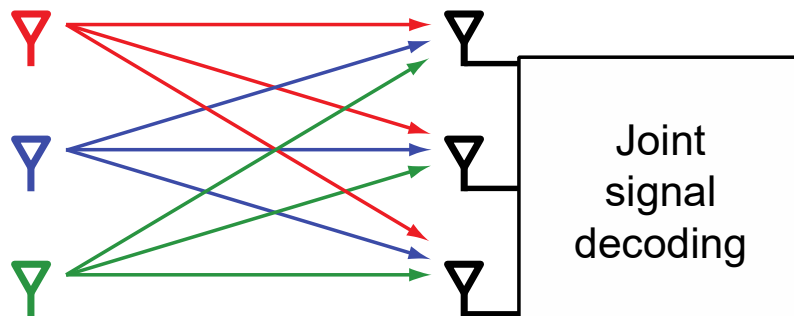


Each receiver:
1 observation
1 desired signal
2 interfering ones

Too few
observations
to reject
interference

Cell-free network:

3 desired signals:
One per transmitter



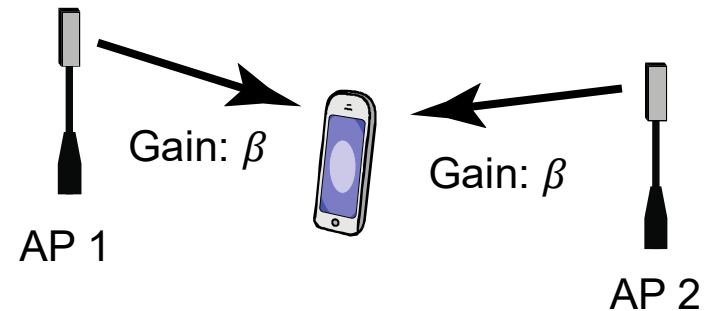
Enough observations:
3 observation
3 desired signal

Downlink: Why Transmit From More Than One AP?

- **Example:** Two APs
 - Total transmit power P

1. Transmit from AP 1:

- Received power: $P\beta$



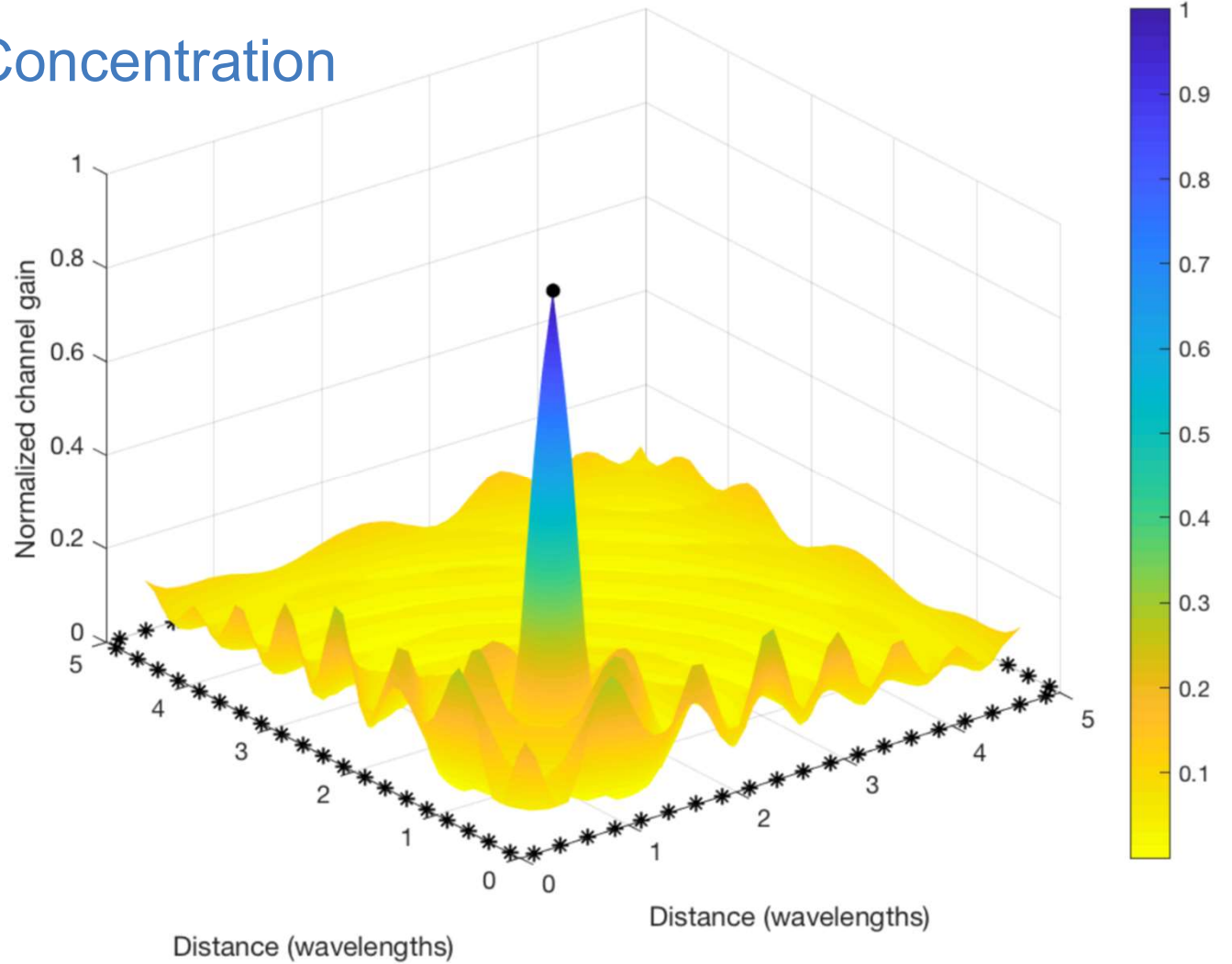
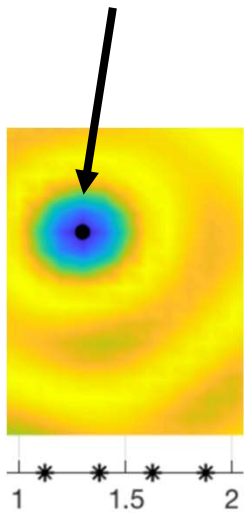
2. Transmit from both APs: $P/2$ from each AP

- Received power: $\left(\sqrt{\frac{P}{2}} \cdot \sqrt{\beta} + \sqrt{\frac{P}{2}} \cdot \sqrt{\beta}\right)^2 = 2 \cdot P\beta$

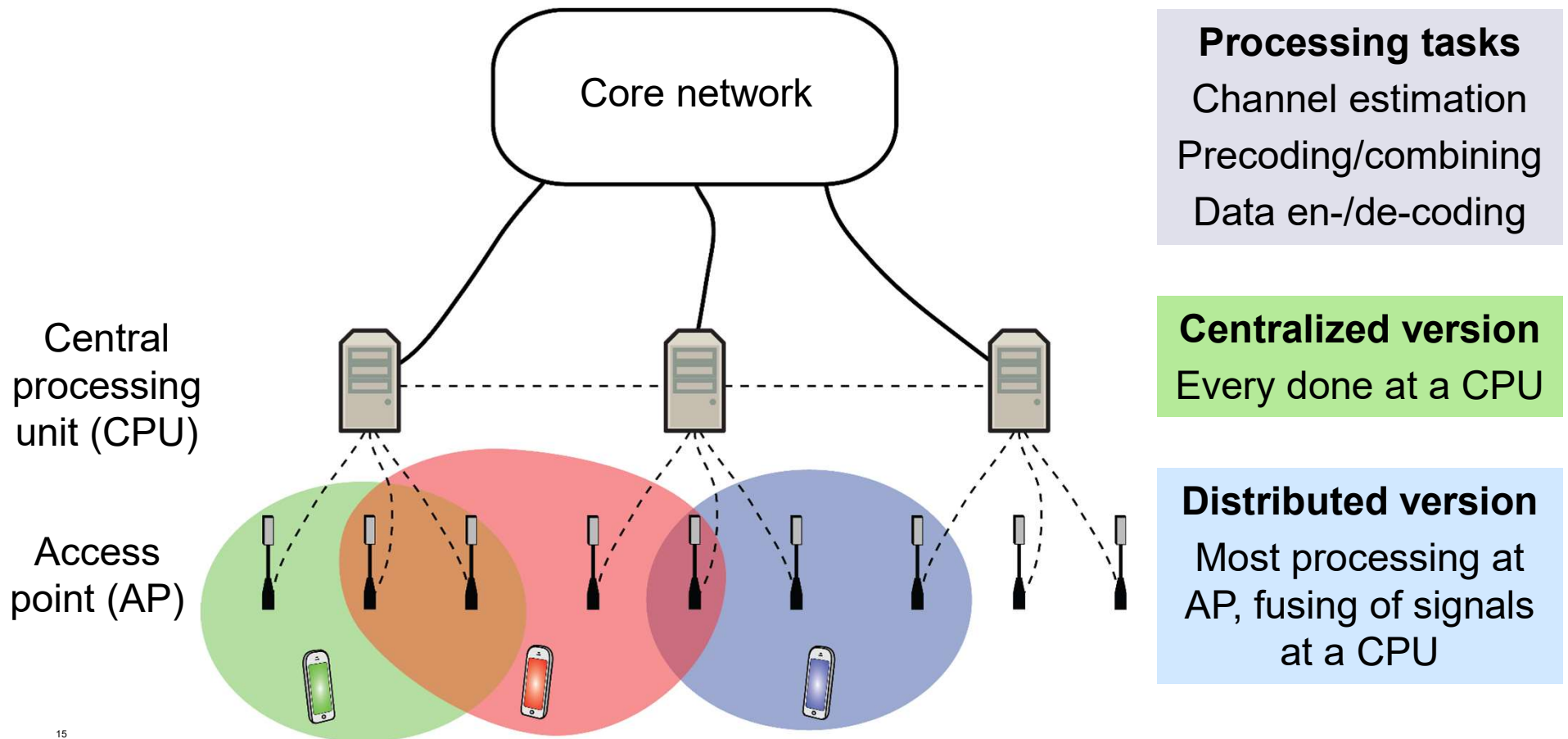
Coherent combination!

Downlink Power Concentration

Strong signal:
Ball with diameter $\lambda/2$

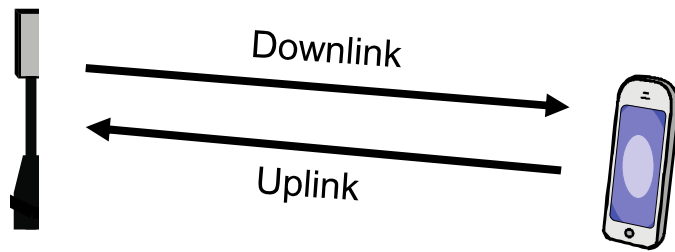


Signal Processing: Centralized versus Distributed



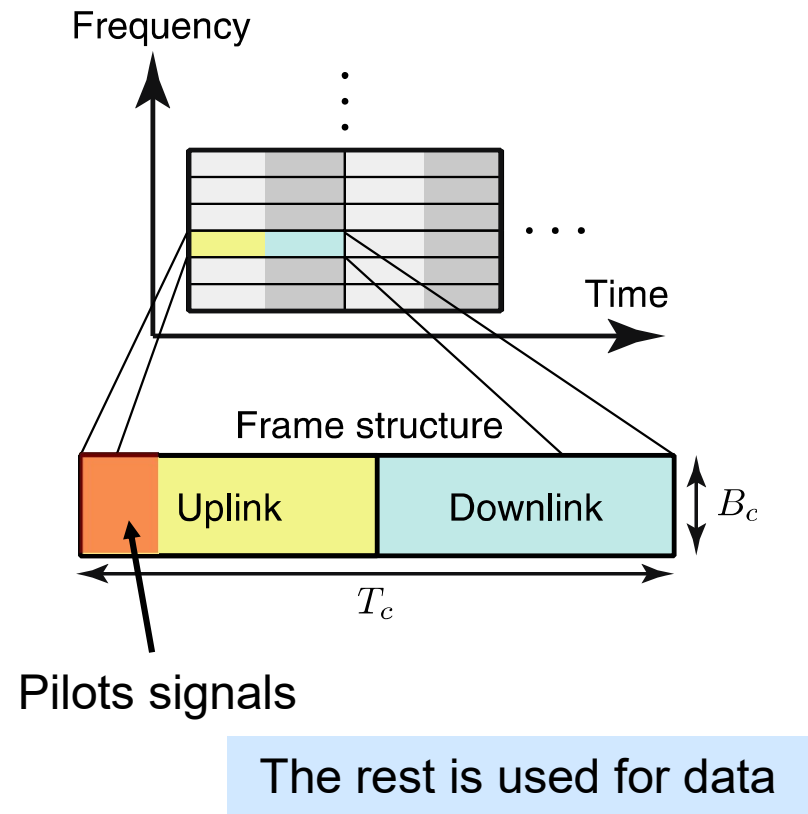
Efficient Channel Estimation – No Feedback is Needed!

Time-division duplex
Downlink and uplink on same frequency



Estimate channels at AP
from uplink pilots

No need to share between APs



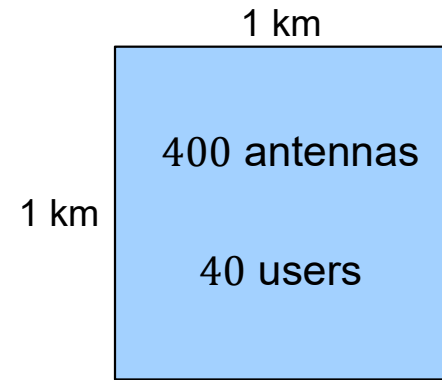
Simulation Setup

- **Cell-free setups**

- 400 APs on a square grid
- Centralized or distributed processing

- **Cellular setups**

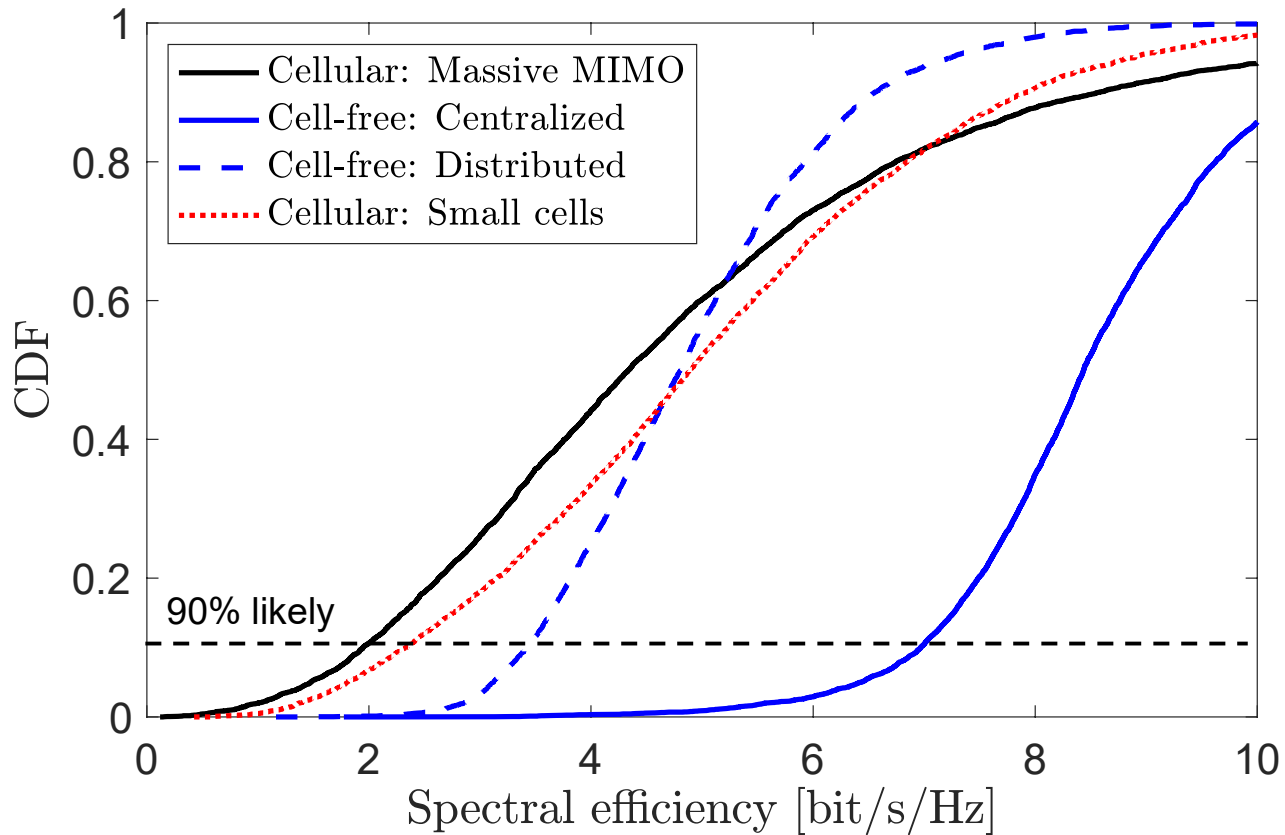
- Massive MIMO: 4 APs, 100 antennas each
- Small cells: Same AP locations in cell-free case



3GPP Urban Microcell model
Uplink, 20 MHz, 100 mW power

Reference: E. Björnson, L. Sanguinetti, "Making Cell-Free Massive MIMO Competitive With MMSE Processing and Centralized Implementation," IEEE Trans. Wireless Communications, January 2020.

Uplink Simulation Results

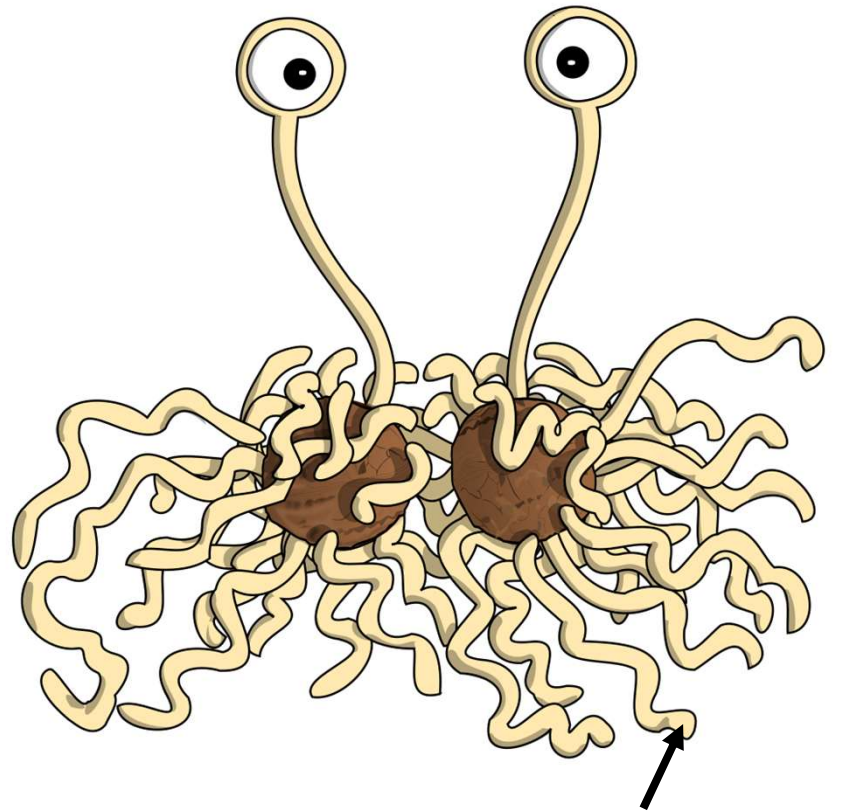


Cell-free
Improves 90% likely performance

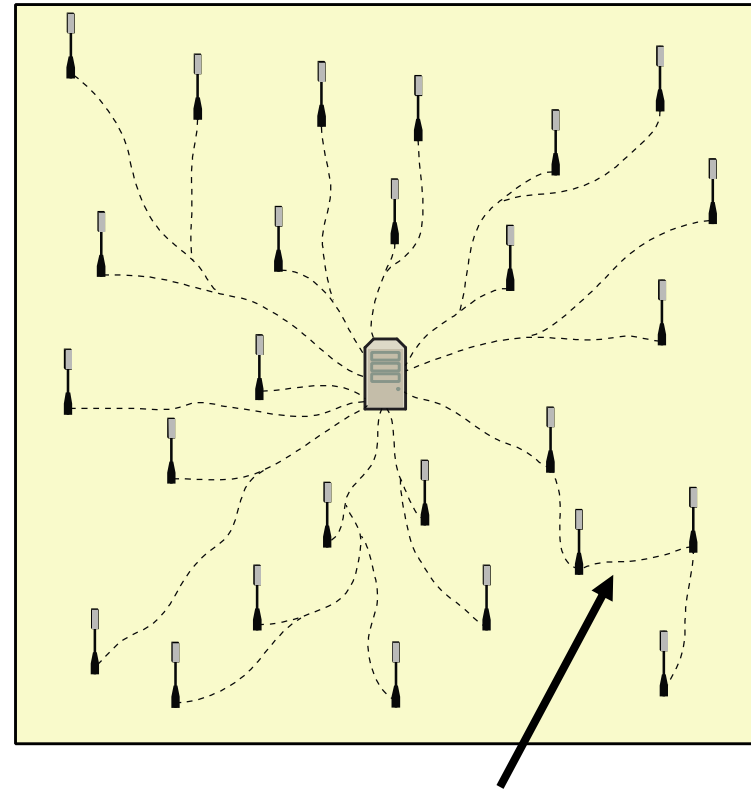
Centralized version
Best performance

Distributed version
Increases worst-case performance

Practical Convenience: Avoid Creating a Spaghetti Monster

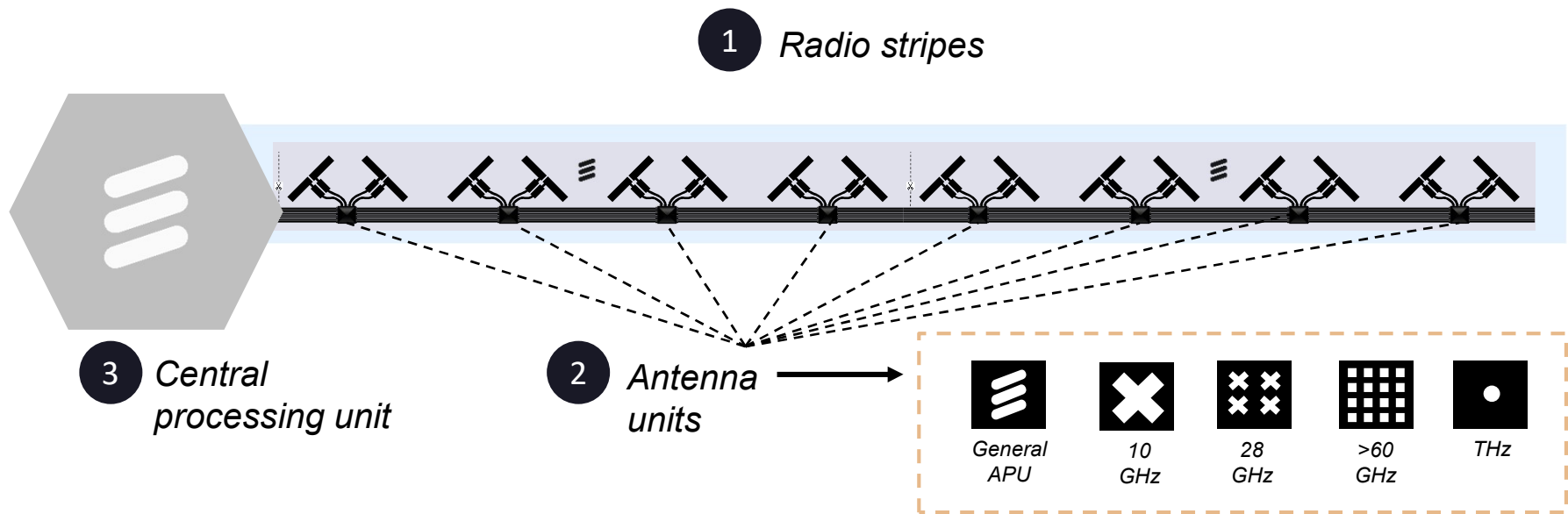


Dedicated fronthaul



Alternative: Serial fronthaul

Implementation Architecture: Radio Stripes

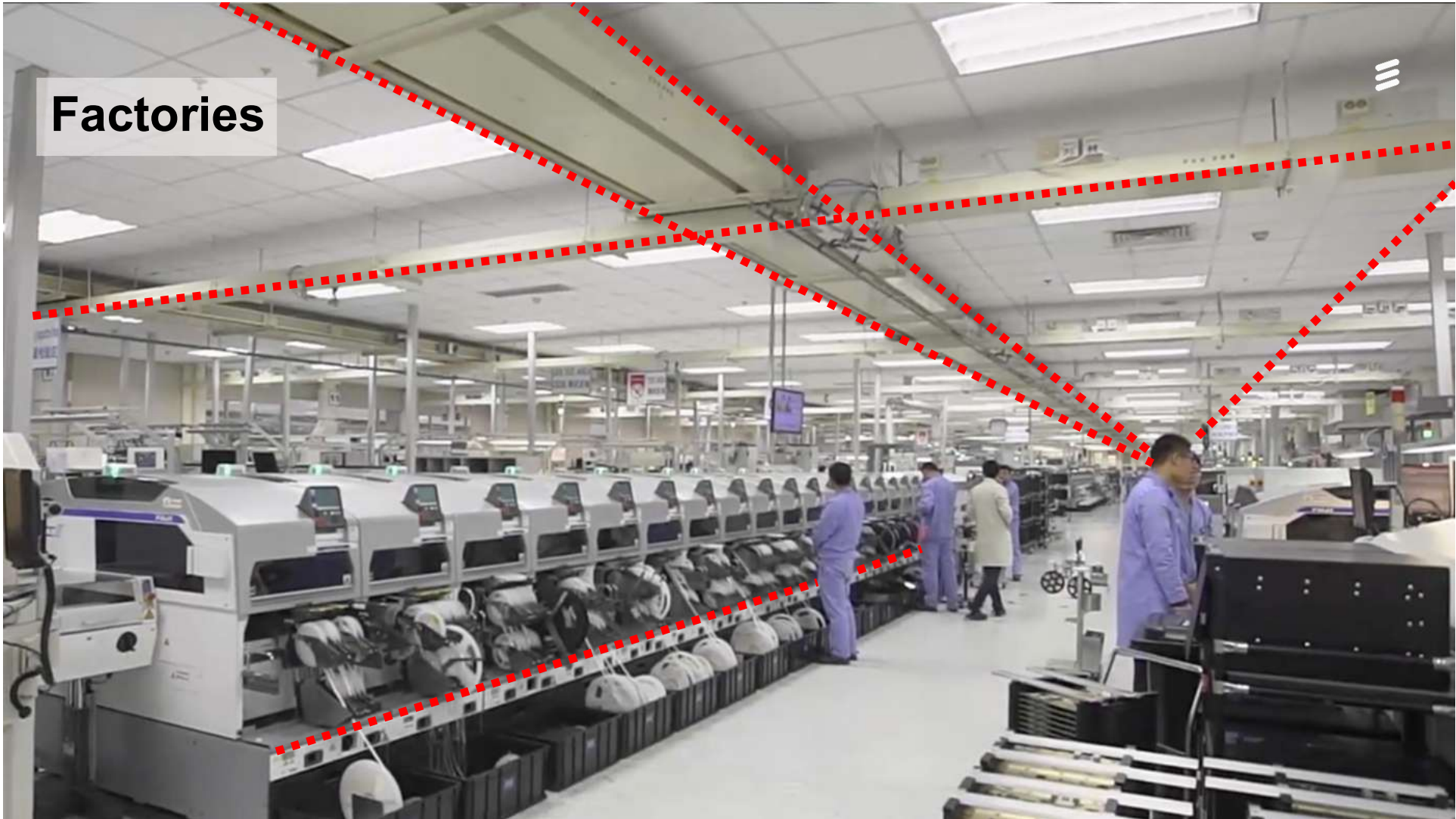


Can create as long stripes as we need

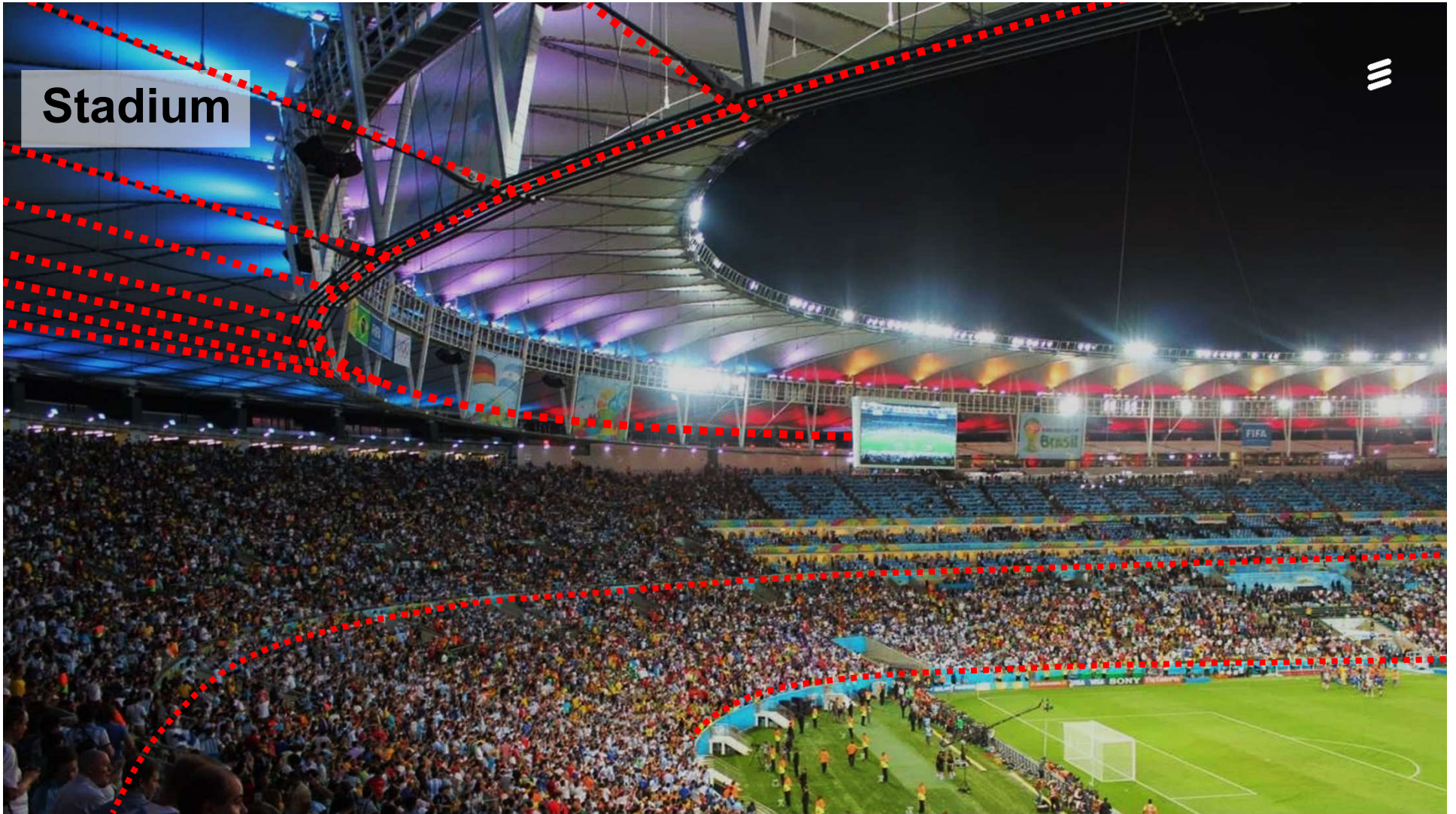
Cultural places



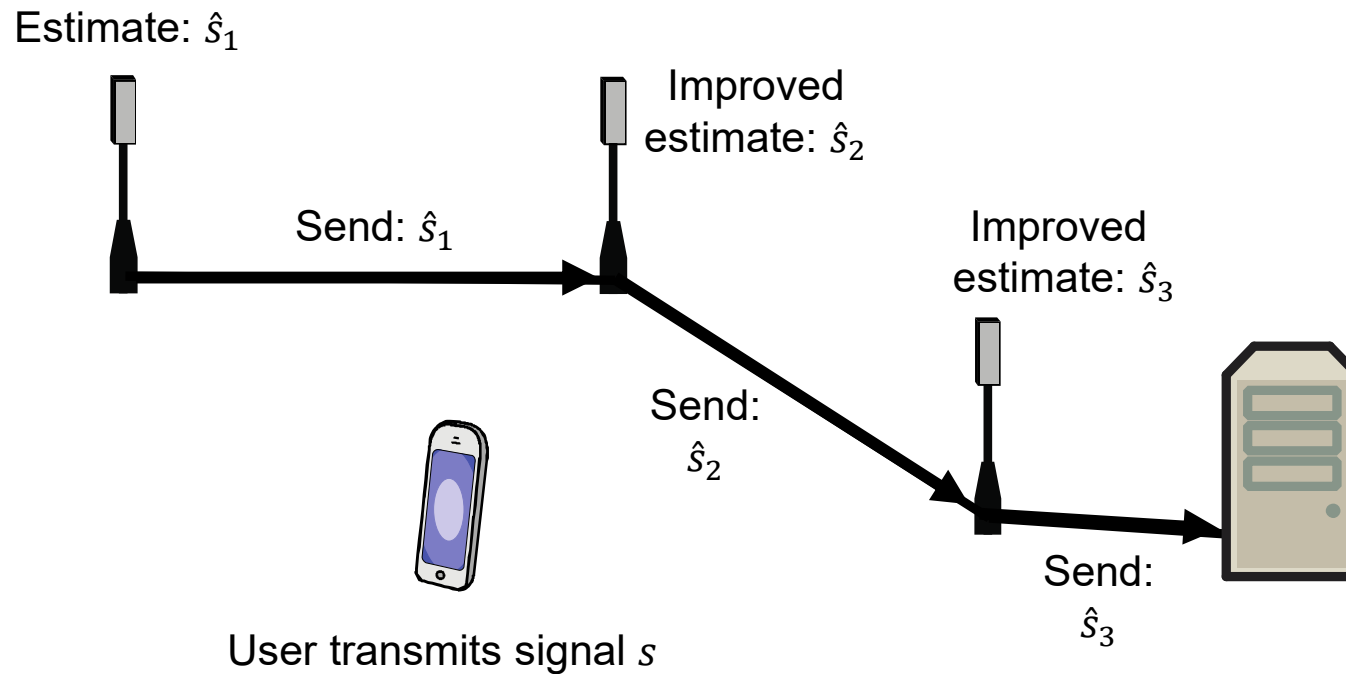
Factories



Stadium



Making Use of Serial Fronthaul: Sequential Processing



Fewer cables

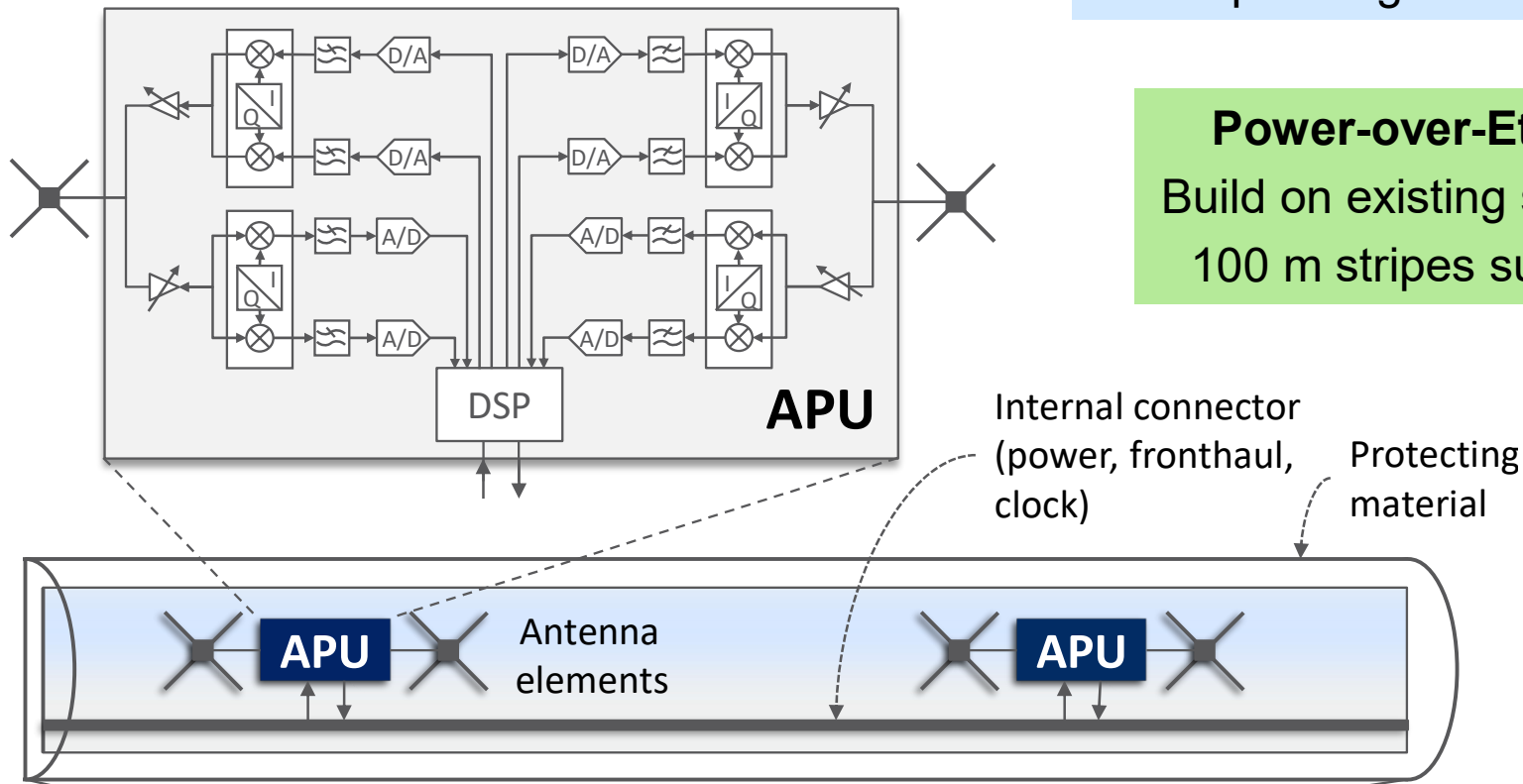
Fronthaul capacity per cable does not grow with number of APs

Reference: Z. H. Shaik, E. Björnson, E. G. Larsson, "Cell-Free Massive MIMO With Radio Stripes and Sequential Uplink Processing," IEEE ICC 2020.

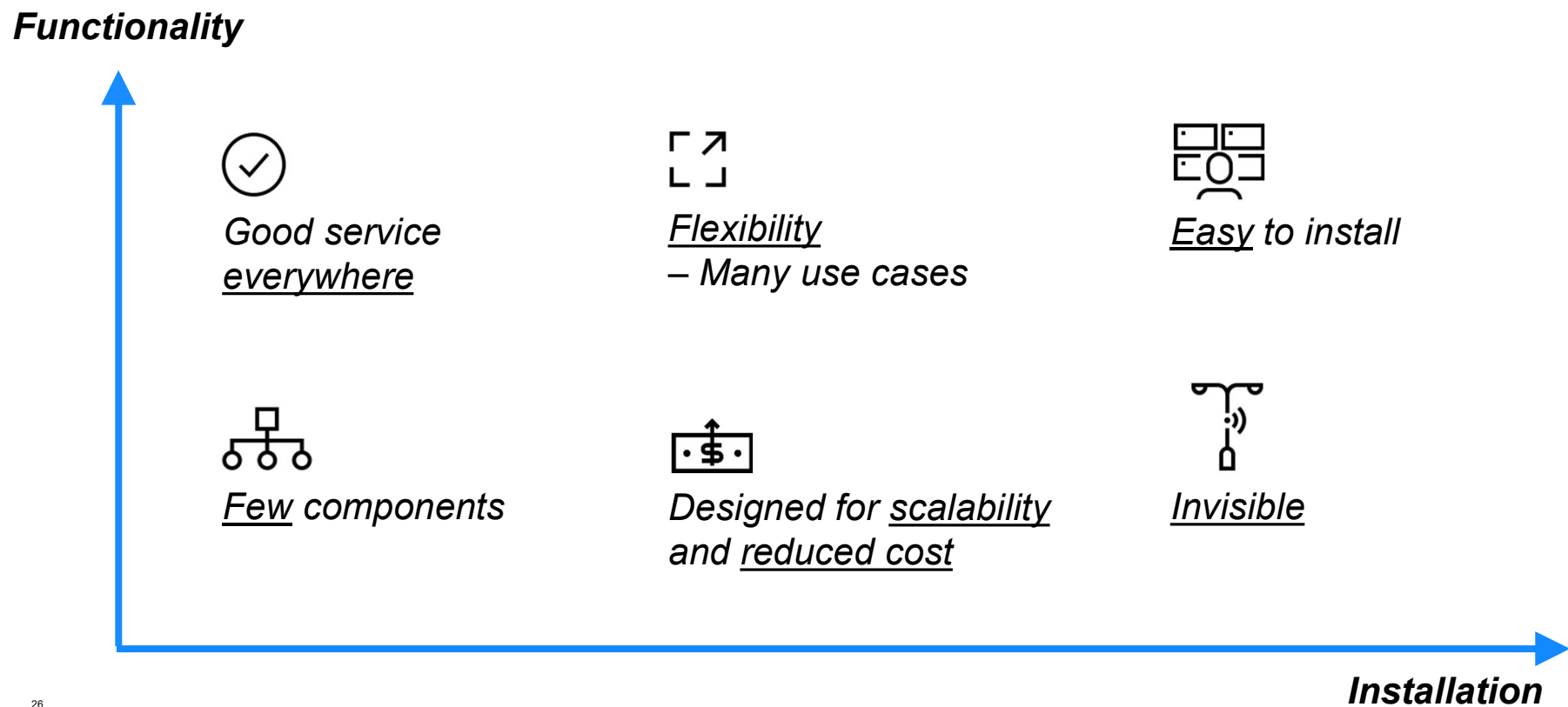
Radio Stripe: Implementation Details

Low power
Cell-phone grade components

Power-over-Ethernet
Build on existing standards
100 m stripes supported



Summary: Many Benefits of Cell-free Architecture and Radio Stripes



Key References

1. H. Q. Ngo, A. Ashikhmin, H. Yang, E. G. Larsson, T. L. Marzetta, “Cell-free Massive MIMO versus small cells,” IEEE Trans. Wireless Commun., 2017.
 2. G. Interdonato, E. Björnson, H. Q. Ngo, P. Frenger, E. G. Larsson, “Ubiquitous Cell-Free Massive MIMO Communications,” EURASIP Journal on Wireless Communications and Networking, 2019.
 3. E. Björnson, L. Sanguinetti, “Making Cell-Free Massive MIMO Competitive With MMSE Processing and Centralized Implementation,” IEEE Trans. Wireless Commun., 2020.
 4. Z. H. Shaik, E. Björnson, E. G. Larsson, “Cell-Free Massive MIMO With Radio Stripes and Sequential Uplink Processing,” IEEE ICC 2020.
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Acknowledgements

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