Evolving Wireless Technology Towards 6G

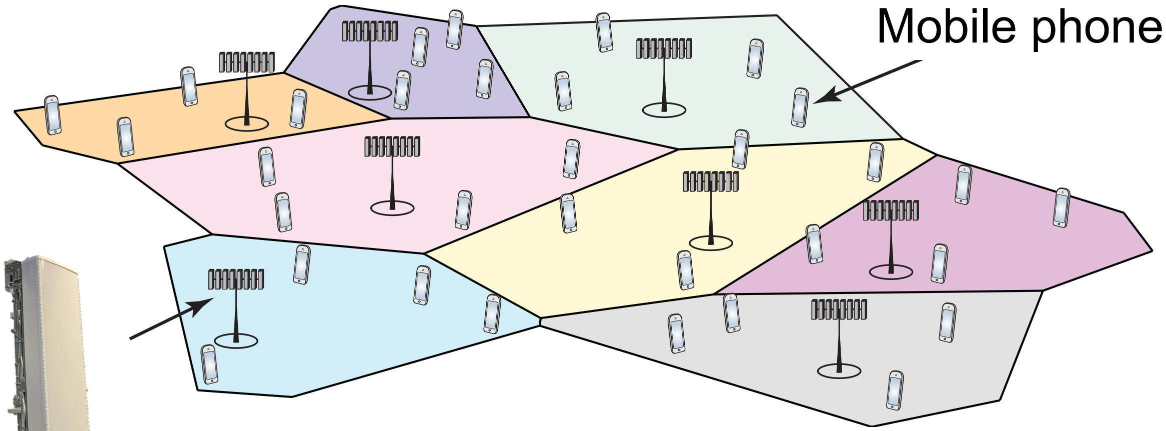
Emil Björnson

Professor of Wireless Communication at KTH

Director of Vinnova Center: Swedish Wireless Innovation Network (SweWIN)

Fellow of IEEE, Digital Futures, and Wallenberg Academy

Mobile/cellular networks

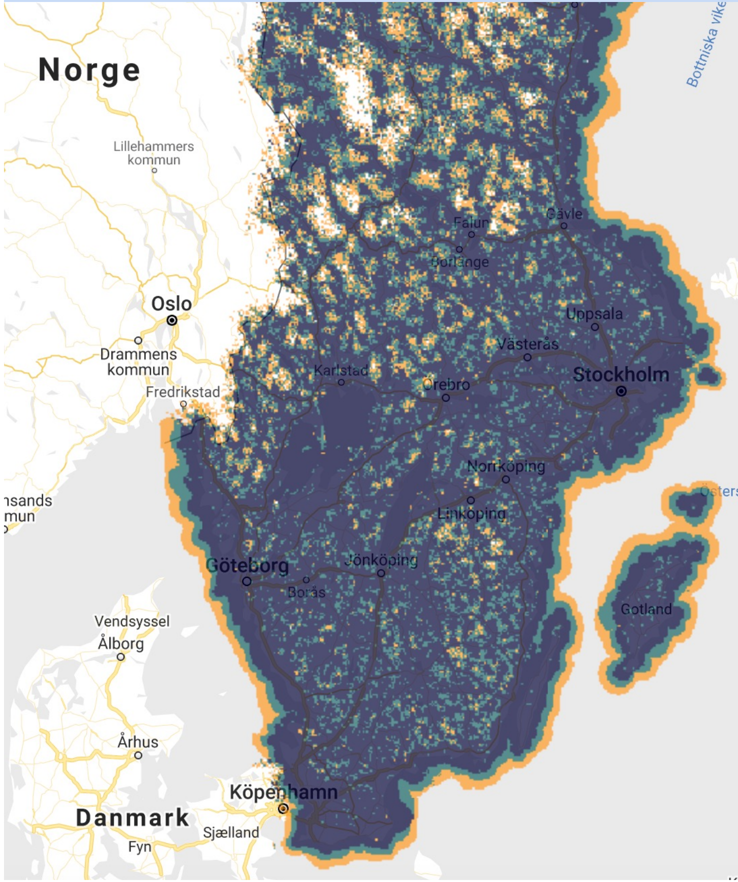


Bit rate: bits per second

Capacity: Total bit rate of all mobiles

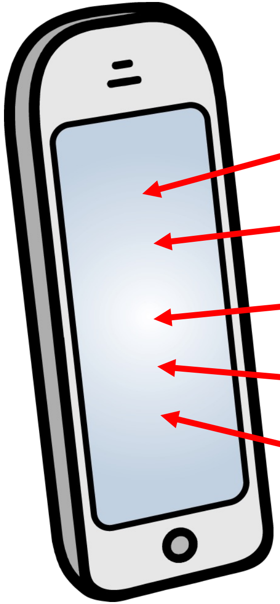
Coverage:

Where mobiles “reach” base stations



How fast bit rates do we need?

Refine technology: Increase capacity



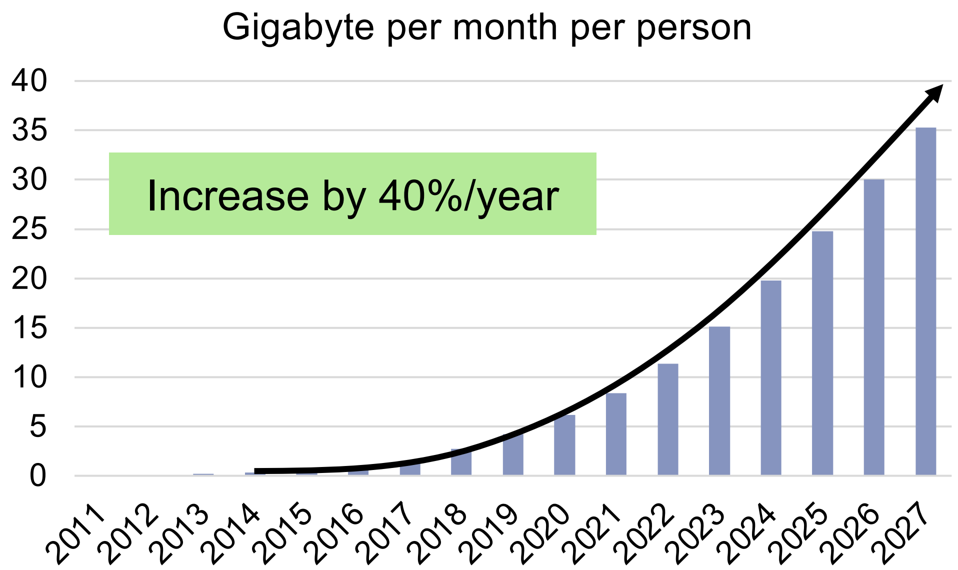
Video streaming [1-25 Mbit/s]

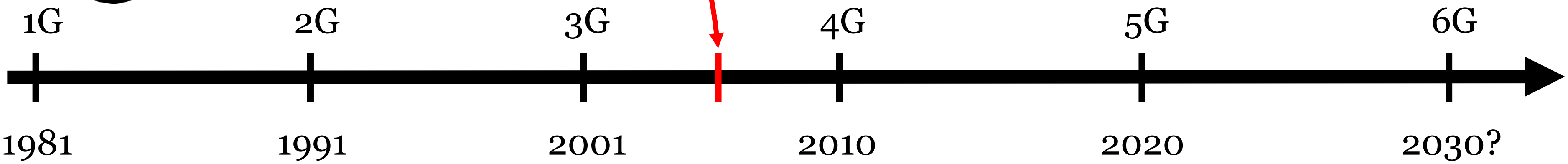
Social media

Gaming

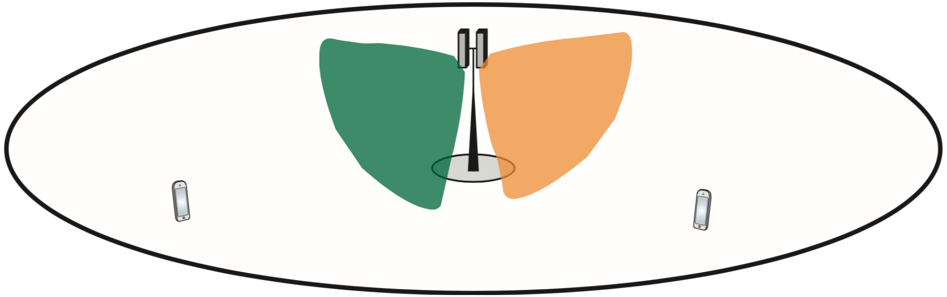
Web, shopping, …

Call, SMS



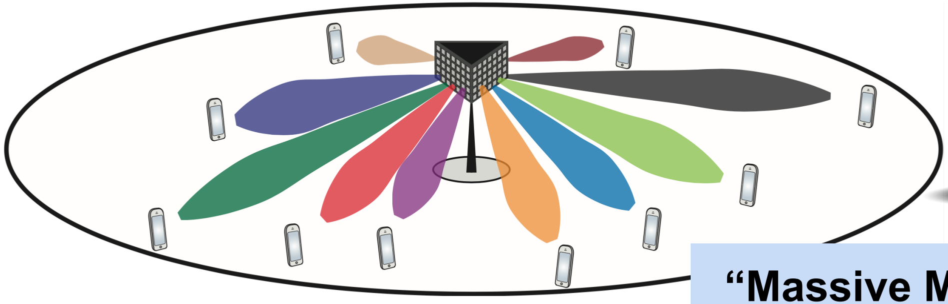


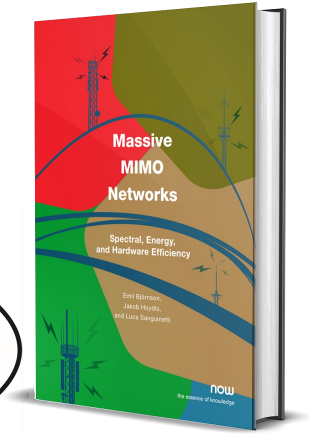
Capacity improvements between 4G and 5G



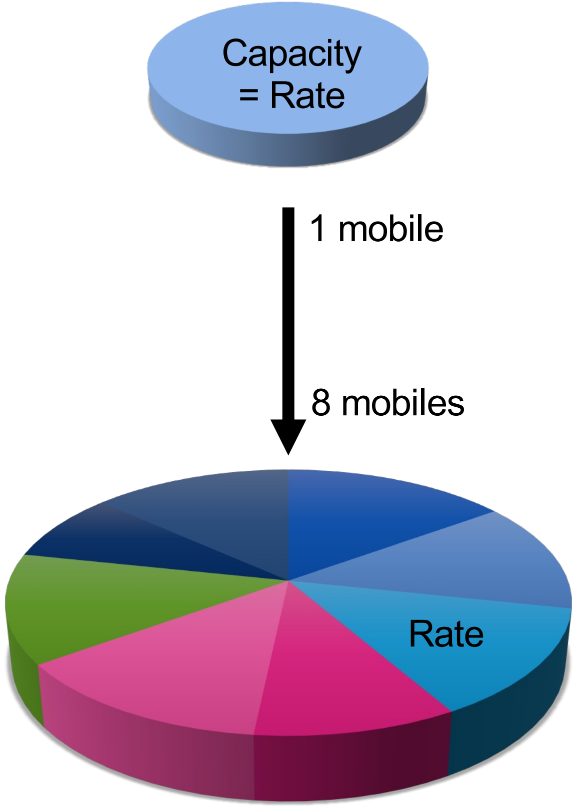
A few broad beams

Many narrow beams



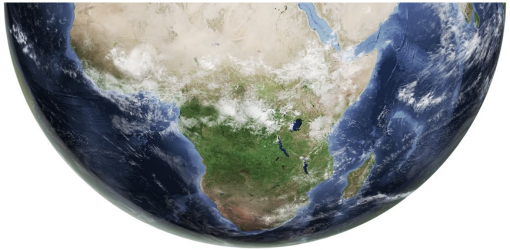


“Massive MIMO”



The global challenge: Sustainability

Use too much resources



Economic growth:
Improved
living standard

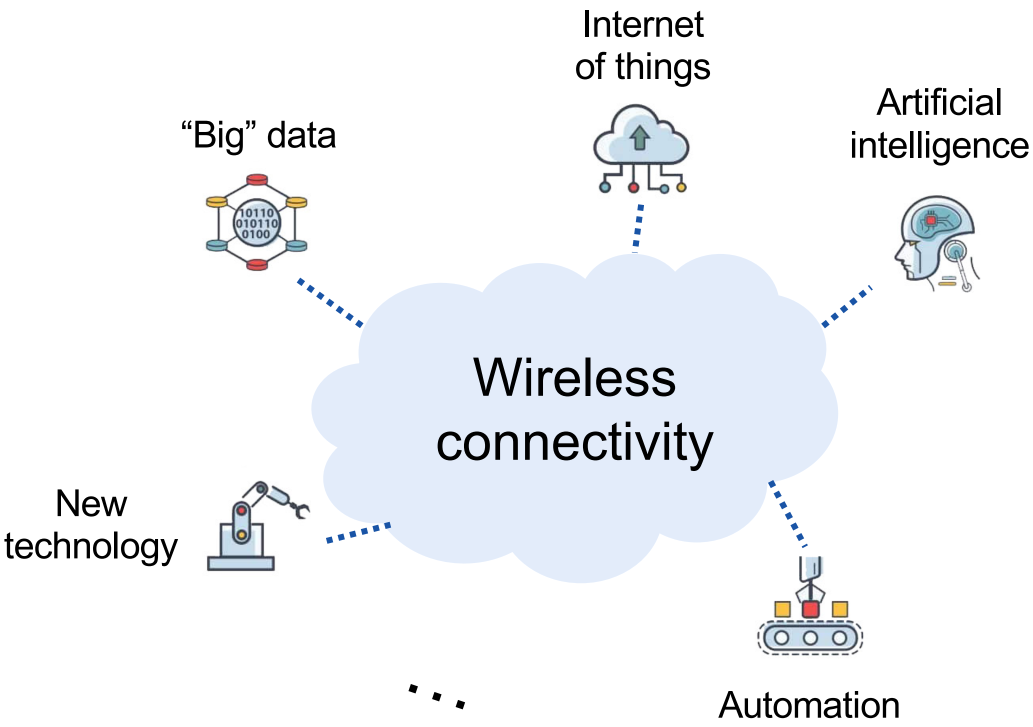
↓

More efficient
resource utilization

↓

Digital transformation?

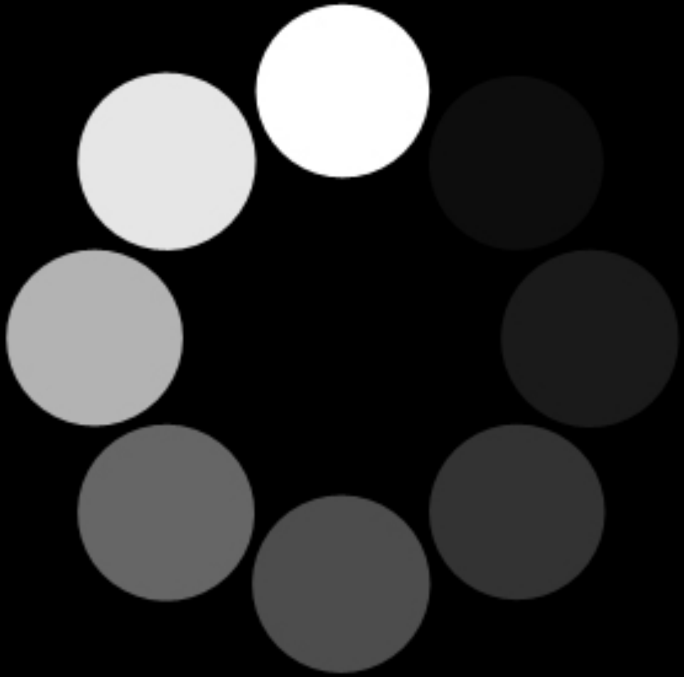
Some components of digital transformation



Requirements on wireless technology will rise!

The digitalized society requires perfect connectivity?

The big challenges



1. Poor availability

2. Trustworthiness

3. Sustainability

Predominant 6G visions

- The high-level message is very much on *sustainability, trustworthiness, availability*

- Actual technical solutions: ***more of the same***
  - Even higher *peak* bit rates
  - Higher *spectral efficiency* for extreme cases
  - Extremely short delays
  - Enormously many user devices

6G Flagship: White Paper on Broadband Connectivity in 6G

KPI	5G
Peak data rate	20 Gb/s
Experienced data rate	0.1 Gb/s
Peak spectral efficiency	30 b/s/Hz
Experienced spectral efficiency	0.3 b/s/Hz
Maximum bandwidth	1 GHz
Area traffic capacity	10 Mb/s/m^2
Connection density	10^6 devices/km^2
Energy efficiency	not specified
Latency	1 ms
Reliability	$1\text{-}10^{-5}$

No sustainability, trustworthiness, availability metrics

The issues with this vision

Best-case performance metrics only relevant in extreme/expensive situations
Buzzwords: No measurable targets for sustainability, trustworthiness, availability

Swedish Wireless Innovation Network (SweWIN)

Vinnova Competence Center, 2024-2028

“Realizing sustainable, resilient, and fair wireless communication and sensing for in the digitalised era”

KTH VETENSKAP OCH KONST

RI. SE Research Institutes of Sweden

ERICSSON

ABB

CellMax

SAAB

BeammWave

NW Northern Waves

SweWIN's vision

- **Shift actual focus** to new key value indicators (KVIs)
  – New performance metrics require new competences
  – Precise goals require careful research!

5G

Performance indicators

Bit rates
Spectral efficiency
Connection density
Bandwidth
Latency

→

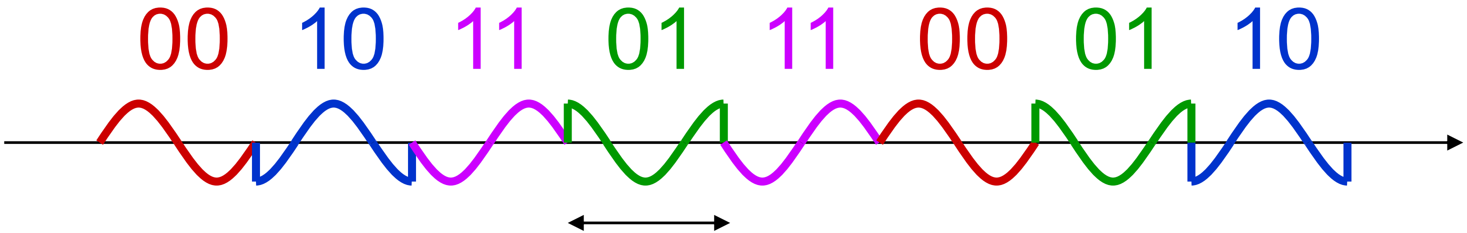
6G

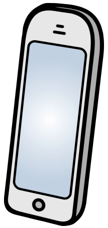
KVIs

Sustainability
Resilience
Fairness

How can 6G achieve a uniform coverage?

Principles for wireless communications



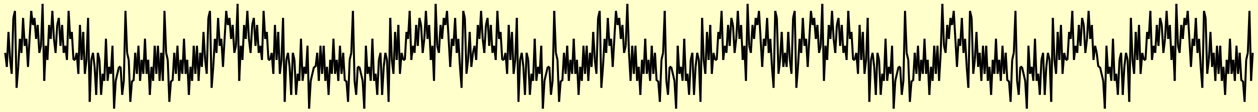


Time for a "symbol" $= \frac{1}{\text{Bandwidth}}$

0010110111000110

0010110111000110

Received signal with noise:



Algorithm

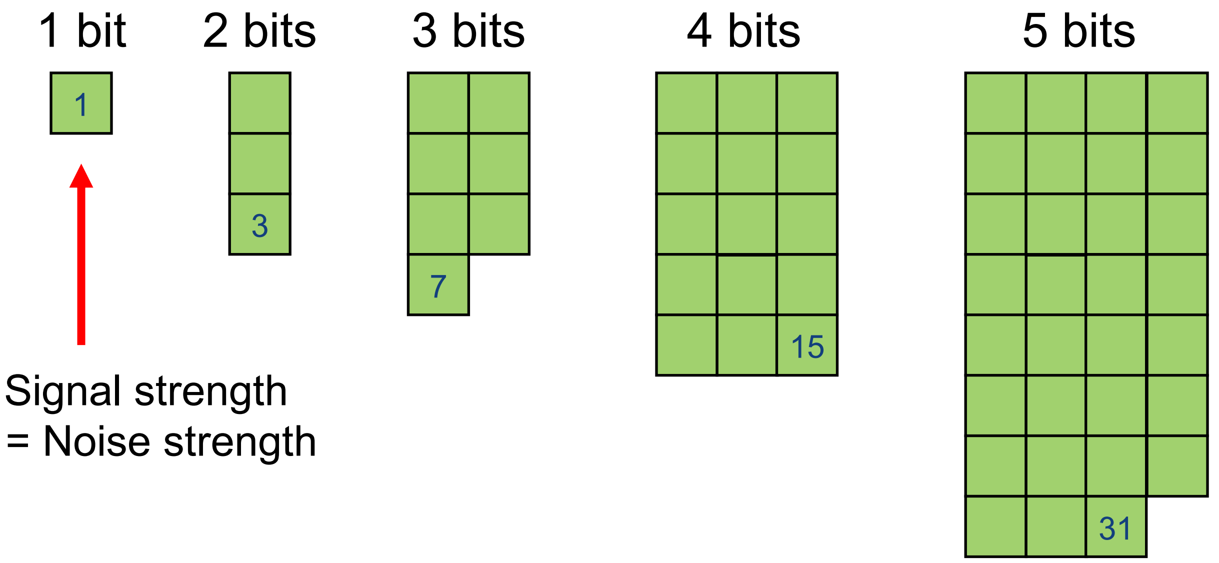
How many bits per symbol?

Depends on the signal strength!

Claude Shannon’s limit

Long sequence of symbols

Send one out of x messages per symbol *without error*
if the signal is $x - 1$ times stronger than the noise



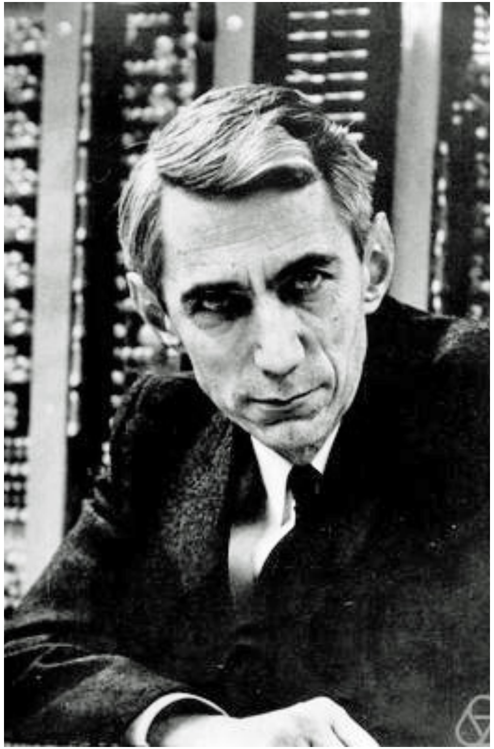
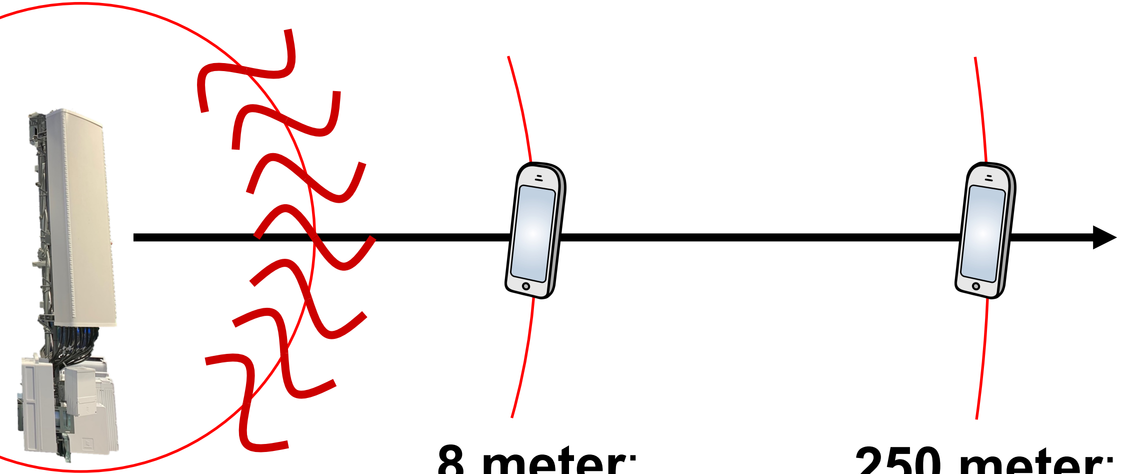


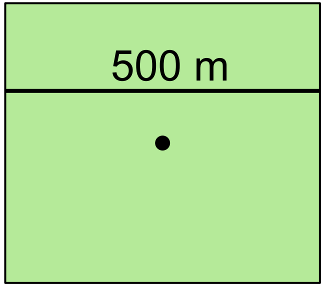
Photo: Konrad Jacobs
(CC BY-SA 2.0 DE)

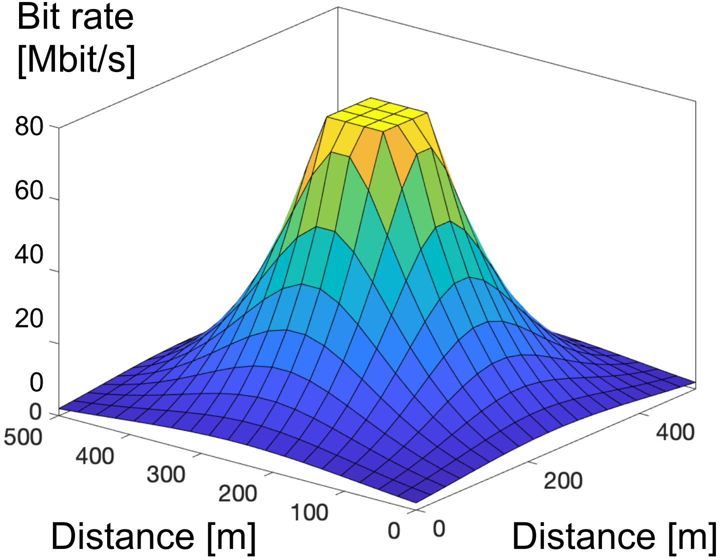
Signal energy vanishes rapidly…



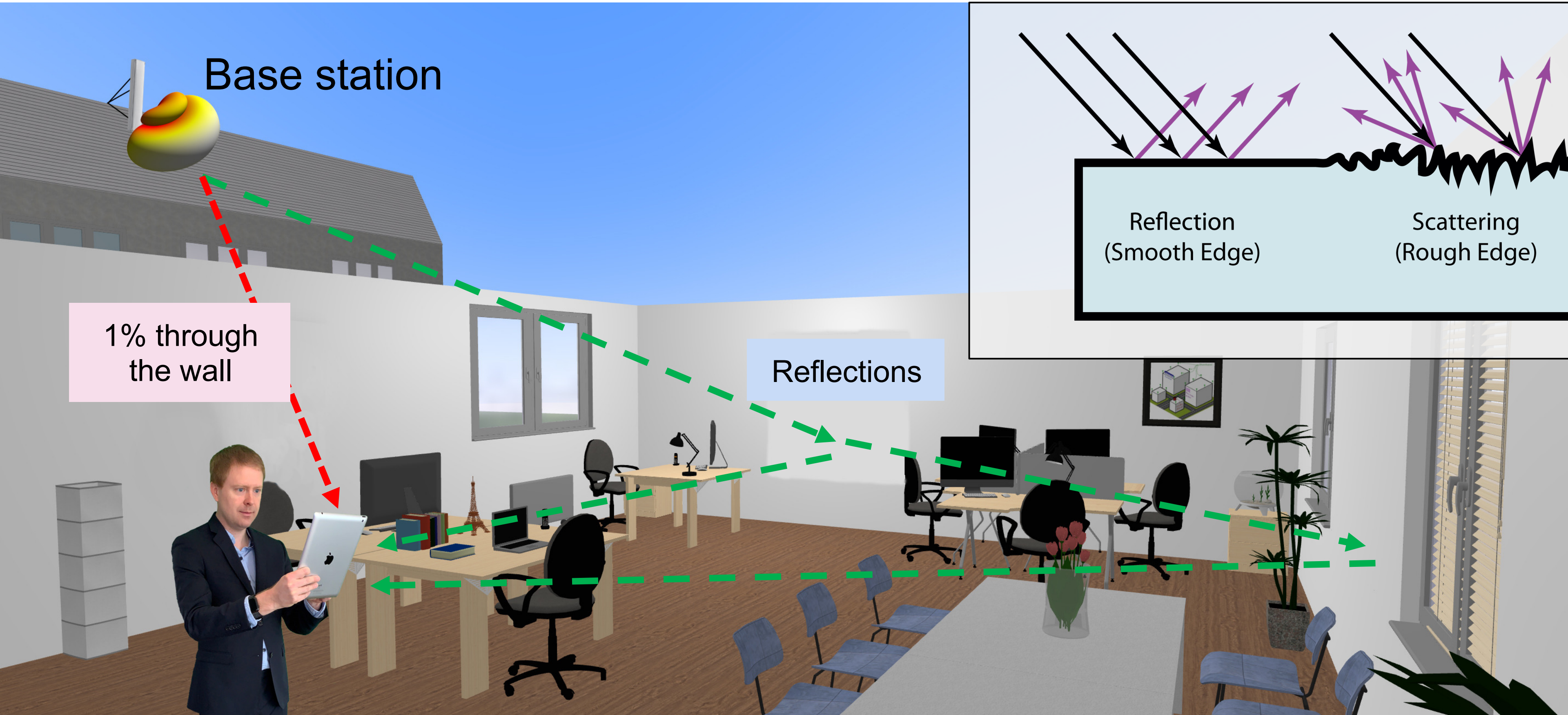
8 meter:
1 million part

250 meter:
1 billion part



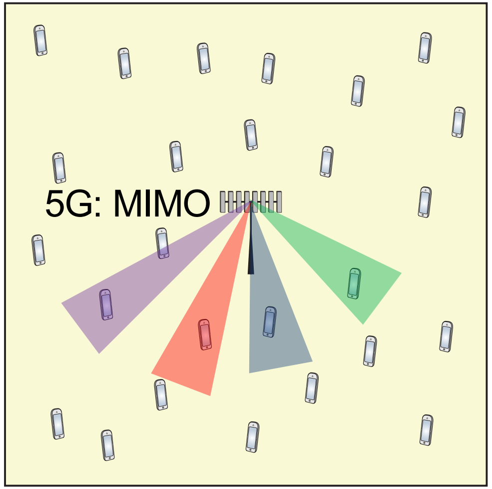


Reflections, penetration losses, blockage, …



Mobile Networks for Uniform Data Speeds

Today

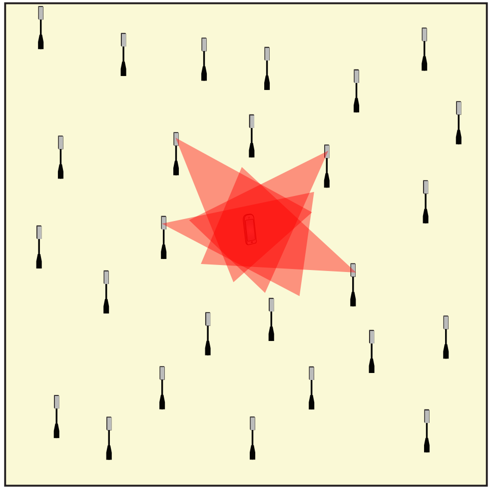


MIMO = Multiple input multiple output

Large distance variations
High power and visible
Sensitive to blocking

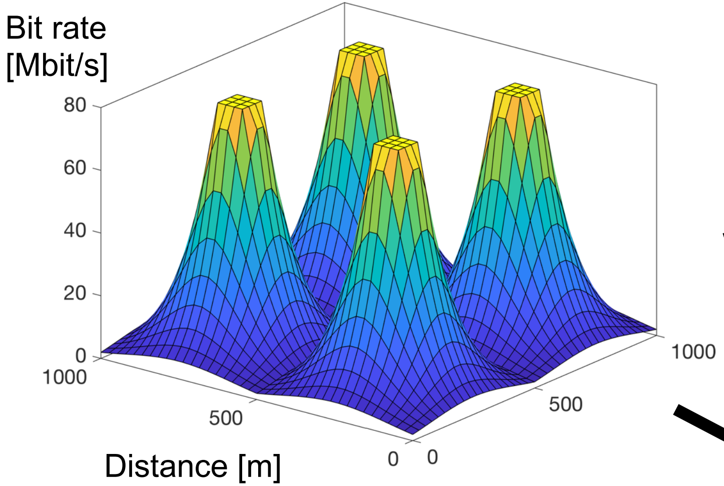
Designed for voice calls!

Future: “Distributed MIMO”

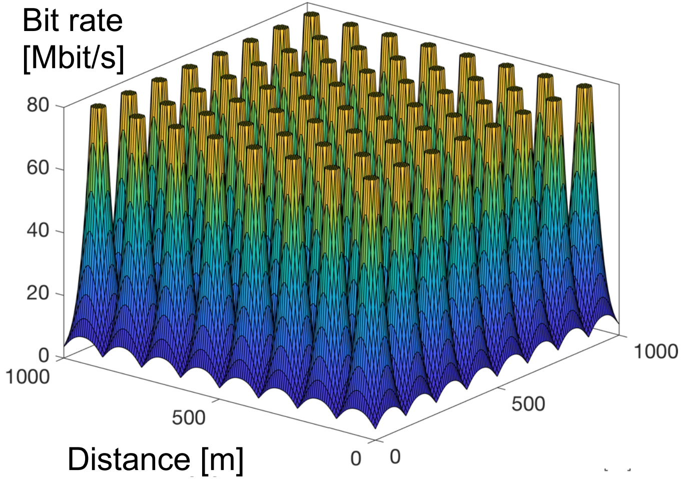


Small distance variations
Low power and invisible
Diversity: Unlikely to block all

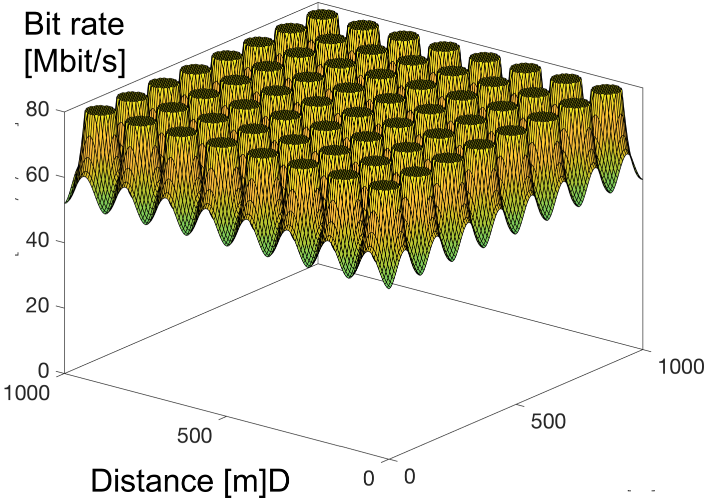
Intelligent densification is key

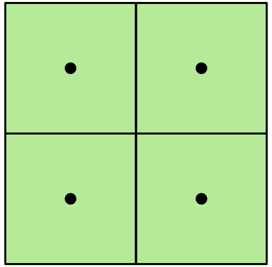


16 times
more masts



Our solution

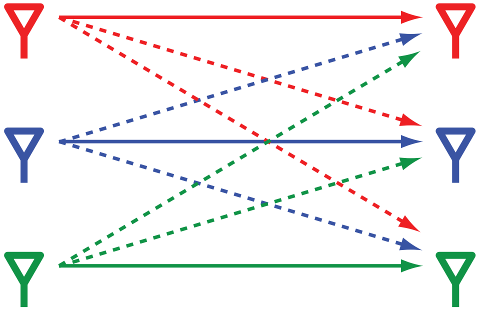




Philosophy of Interference Suppression

Cellular network:

3 desired signals:
One per transmitter

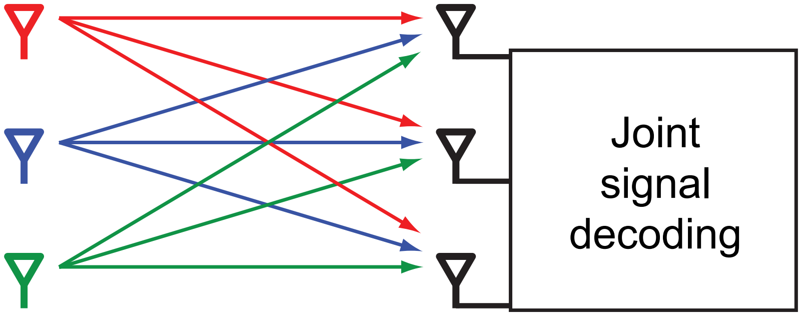


Each receiver:
1 observation
1 desired signal
2 interfering ones

Too few observations to remove interference

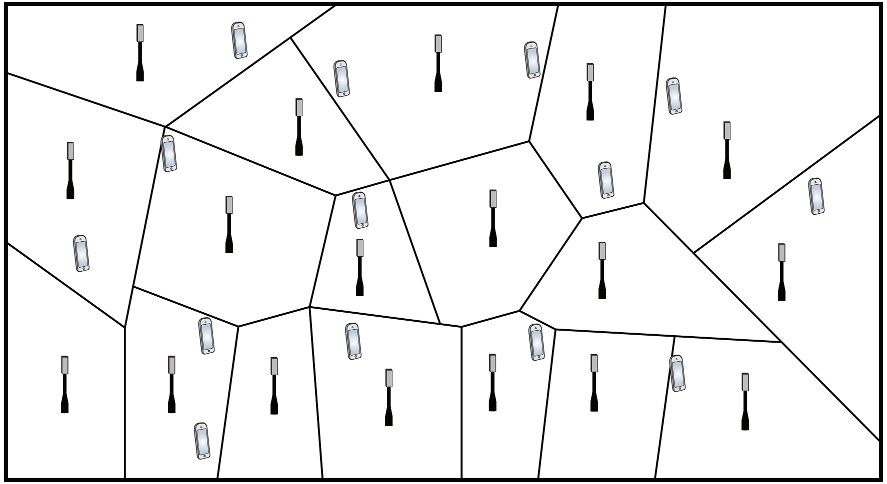
Cell-free network:

3 desired signals:
One per transmitter

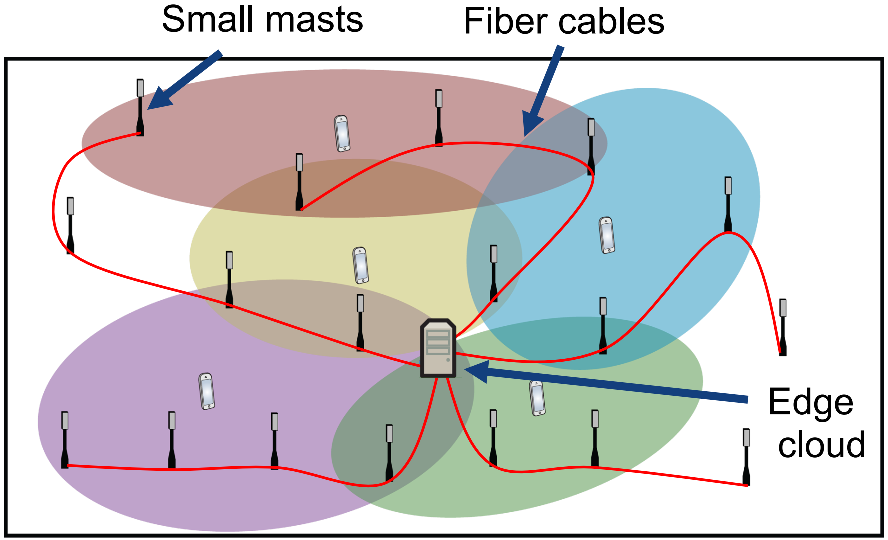


Enough observations:
3 observation
3 desired signal

Future "cell-free" networks

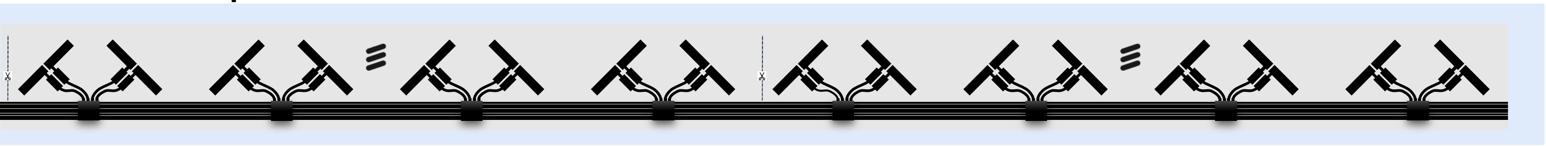


Cellular network

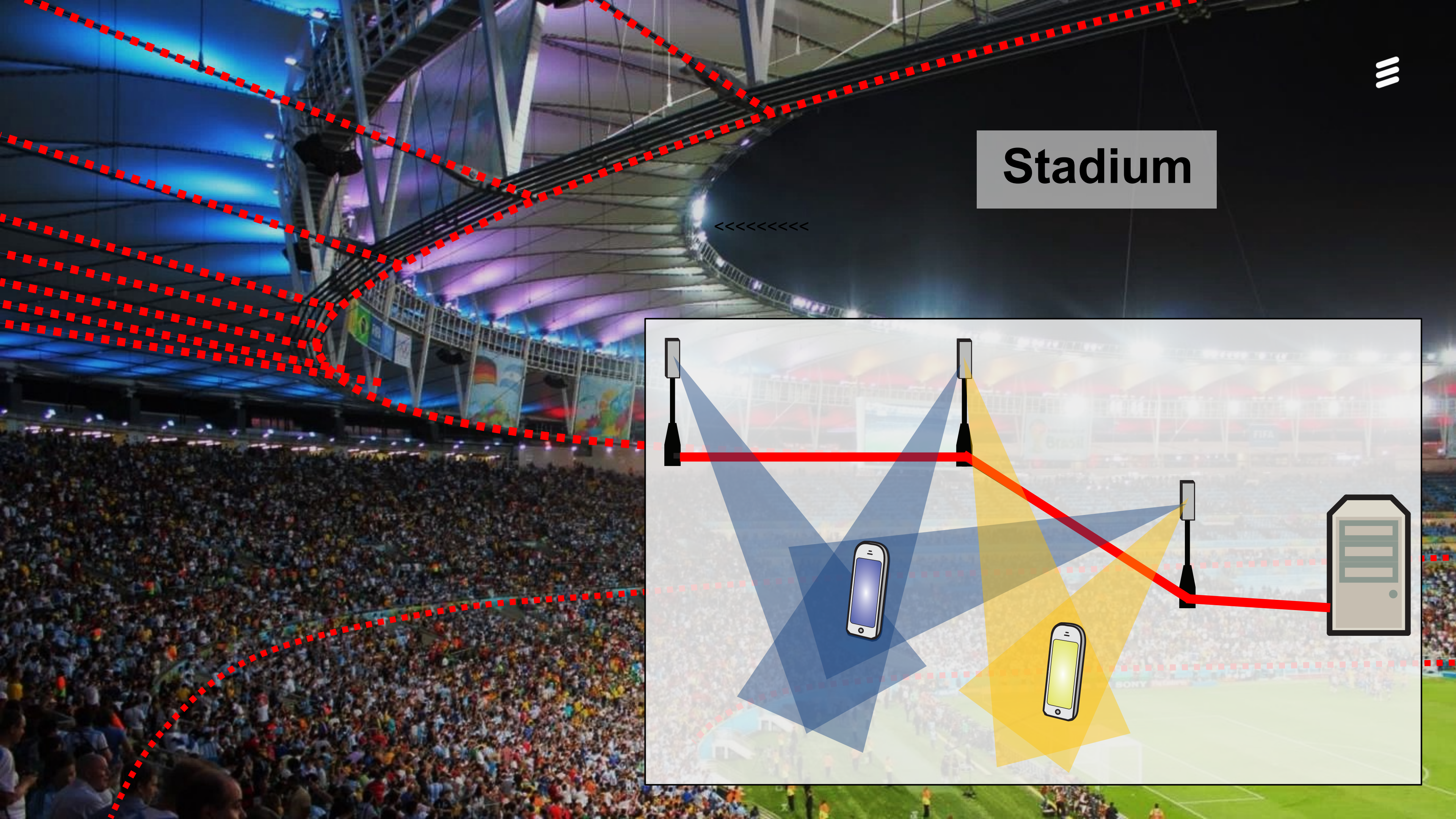


"Cell-free" network

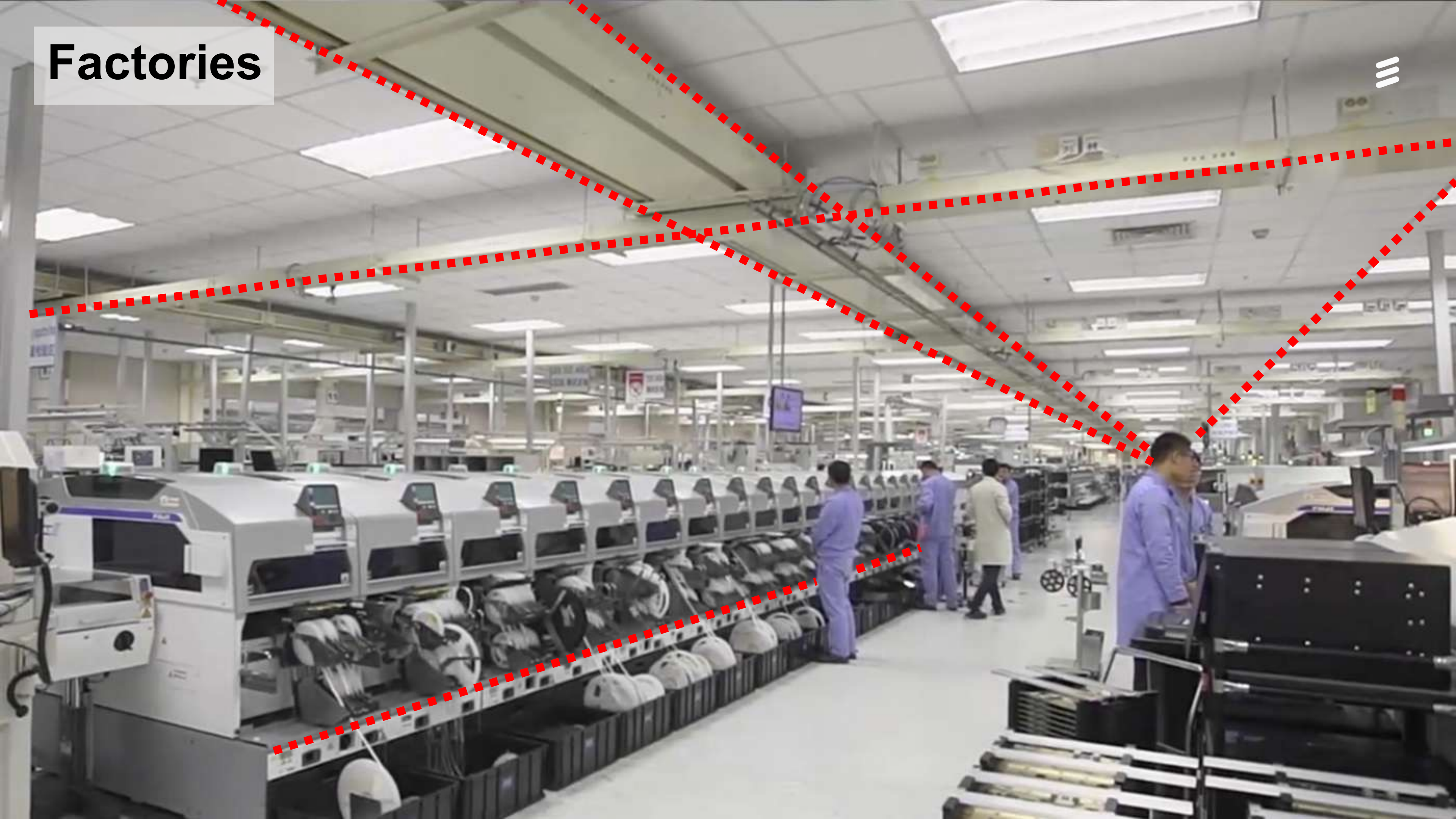
Radio stripes:



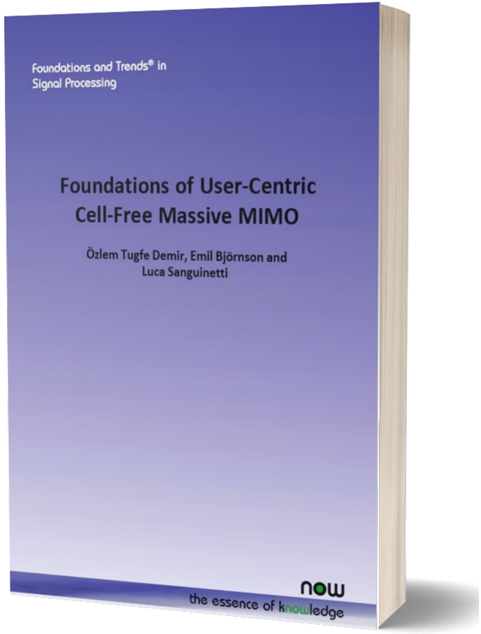
Cultural places


Stadium
<<<<<<<<<<

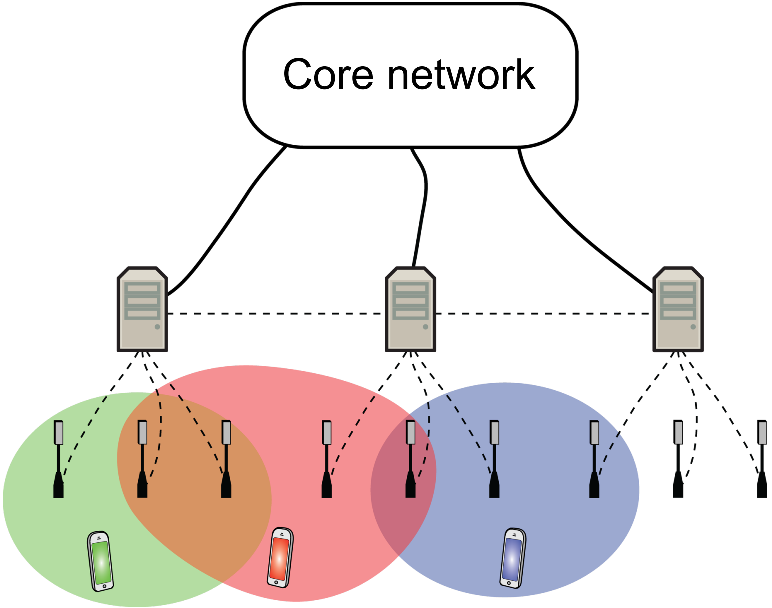
Factories



Where do we stand?



Communication theory
is becoming mature



Challenges

Synchronization, prototyping, standardization of interfaces, radio resource management, …

Samples of recent work

Soft Handover Procedures in mmWave Cell-Free Massive MIMO Networks

Mahmoud Zaher, Emil Björnson, *Fellow, IEEE,* and Marina Petrova, *Member, IEEE.*

***Abstract*—This paper considers a mmWave cell-free massive MIMO (multiple-input multiple-output) network composed of a large number of geographically distributed access points (APs) simultaneously serving multiple user equipments (UEs) via coherent joint transmission. We address UE mobility in the downlink (DL) with imperfect channel state information (CSI) and pilot training. Aiming at extending traditional handover concepts to the challenging AP-UE association strategies of cell-free networks, distributed algorithms for joint pilot assignment and cluster formation are proposed in a dynamic environment considering UE mobility. The algorithms provide a systematic procedure for initial access and update of the serving APs and assigned pilot sequence to each UE. The principal goal is to limit the necessary number of AP and pilot changes, while limiting computational complexity. We evaluate the performance, in terms of spectral efficiency (SE), with maximum ratio and regularized zero-forcing precoding. Results show that our proposed distributed algorithms effectively identify the essential AP-UE association refinements with orders-of-magnitude lower computational time compared to the state-of-the-art. It also provides a significantly lower average number of pilot changes compared to an ultra-dense network (UDN). Moreover, we develop an improved pilot assignment procedure that facilitates massive access to the network in highly loaded scenarios.**

***Index Terms*—Cell-free massive MIMO, handover, cluster formation, pilot assignment, mobility management, spectral efficiency.**

performance gain of massive MIMO, inter-cell interference and large pathloss variations remain inherent in the cell-centric design of conventional networks. Cell-free massive MIMO is a post-cellular architecture that synergistically combines cooperative principles with massive MIMO for seamless connectivity [5]. A cell-free network is composed of a large number of distributed access points (APs) jointly serving the UEs within a given coverage area without creating cell boundaries [6]–[9]. It has become a basis for beyond 5G networks due to its ability to utilize macro diversity and higher resilience to interference [8], [10], allowing for more network densification and providing almost uniform service to the UEs. Despite the gains provided by these technologies, the bandwidth limitation in sub-6 GHz bands remains a serious impediment in mobile networks. Combining cell-free massive MIMO with mmWave network operation can deliver unprecedented data rates with high reliability and improved network coverage.

A hindrance to the cell-free network topology is the computational complexity of signal processing and the fronthaul requirements for information exchange between the APs and central processing unit (CPU) [11]. To mitigate these issues and enable a scalable network operation, previous works have proposed user-centric (UC) clustering in which each UE is served by only a subset of the APs in the network [12]–[14]. This is deemed reasonable as the APs that are relatively

Cell-Free Massive MIMO in O-RAN: Energy-Aware Joint Orchestration of Cloud, Fronthaul, and Radio Resources

Özlem Tuğfe Demir, *Member, IEEE*, Meysam Masoudi, *Member, IEEE*, Emil Björnson, *Fellow, IEEE*, and Cicek Cavdar, *Member, IEEE*

***Abstract*—For the energy-efficient deployment of cell-free massive MIMO functionality in a practical wireless network, the end-to-end (from radio site to the cloud) energy-aware operation is essential. In line with the cloudification and virtualization in the open radio access networks (O-RAN), it is indisputable to envision prospective cell-free infrastructure on top of the O-RAN architecture. In this paper, we explore the performance and power consumption of cell-free massive MIMO technology in comparison with traditional small-cell systems, in the virtualized O-RAN architecture. We compare two different functional split options and different resource orchestration mechanisms. In the end-to-end orchestration scheme, we aim to minimize the end-to-end power consumption by jointly allocating the radio, optical fronthaul, and virtualized cloud processing resources. We compare end-to-end orchestration with two other schemes: 1) "radio-only" where radio resources are optimized independently from the cloud; and 2) "local cloud coordination" where orchestration is only allowed among a local cluster of radio units. We develop several algorithms to solve the end-to-end power minimization and sum spectral efficiency maximization problems. The numerical results demonstrate that end-to-end resource allocation with fully virtualized fronthaul and cloud resources provides a substantial additional power saving than the other resource orchestration schemes.**

***Index Terms*—Cell-free massive MIMO, virtualized O-RAN, joint transmission, end-to-end resource allocation, joint network orchestration.**

New networking and new air interface solutions are the two key enablers to support next-generation wireless systems [1]. The networking technologies include the softwarization, virtualization, and open radio access networks (O-RAN), whereas massive MIMO (multiple-input multiple-output) and cell-free massive MIMO are among the main air interface technologies. This paper studies cell-free massive MIMO in the O-RAN architecture, which brings together two inherently compatible networking and air interface entities of beyond 5G networks.

Cell-free massive MIMO has been proposed as a physical-layer technology that combines ultra-dense networks with joint transmission/reception (JT), and the low-complexity linear processing schemes from massive MIMO [3], [4], [5]. By taking advantage of both joint processing and macro diversity, cell-free massive MIMO reduces the large data rate variations across the coverage area, which solves one of the main drawbacks of the current cellular networks. For joint processing of UEs' signals, it is required to centralize parts of the baseband processing, which constructs the inherent connection between cell-free massive MIMO and the centralized RAN (C-RAN) architecture [6]. The separation of software from hardware not only allows for joint processing in cell-free operation but also creates new energy-saving opportunities with green and agile virtualization [7]. To meet the coordination and signal-

Summary

New technology needed

Higher capacity needs

Availability, trustworthiness, sustainability

Part of the solution

Many small base stations

Algorithms for cooperation

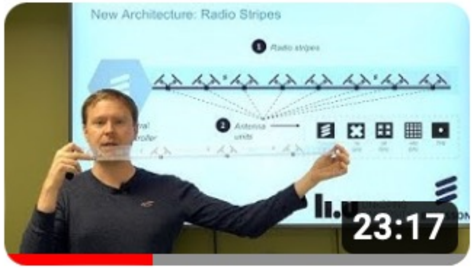
Low cost and energy

QUESTIONS?

Blog
Podcast
YouTube

youtube.com/wirelessfuture

WIRELESS FUTURE



Reinventing the Wireless Network Architecture Towards 6G: Cell-free Massive MIMO and Radio Stripes

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