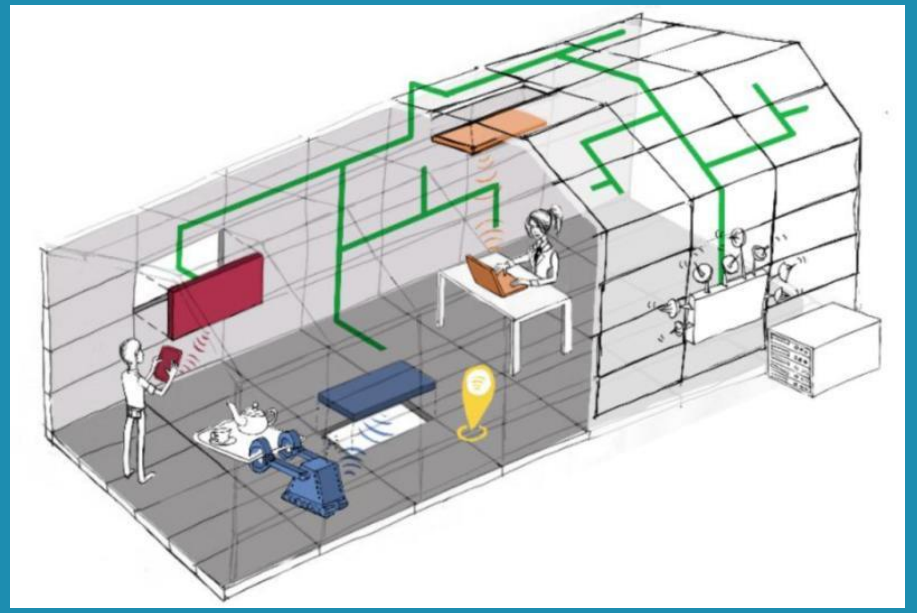
KU LEUVEN

Scaling up massive MIMO: can progress be made sustainably?



Liesbet Van der Perre, ELLIIT - 6G Symposium, Nov. 8th 2023

Special thanks to KU Leuven - DRAMCO,
Liang Liu (ULund), REINDEER & 6GTandem partners

REINDEER

www.reindeer-project.eu

6GTandem

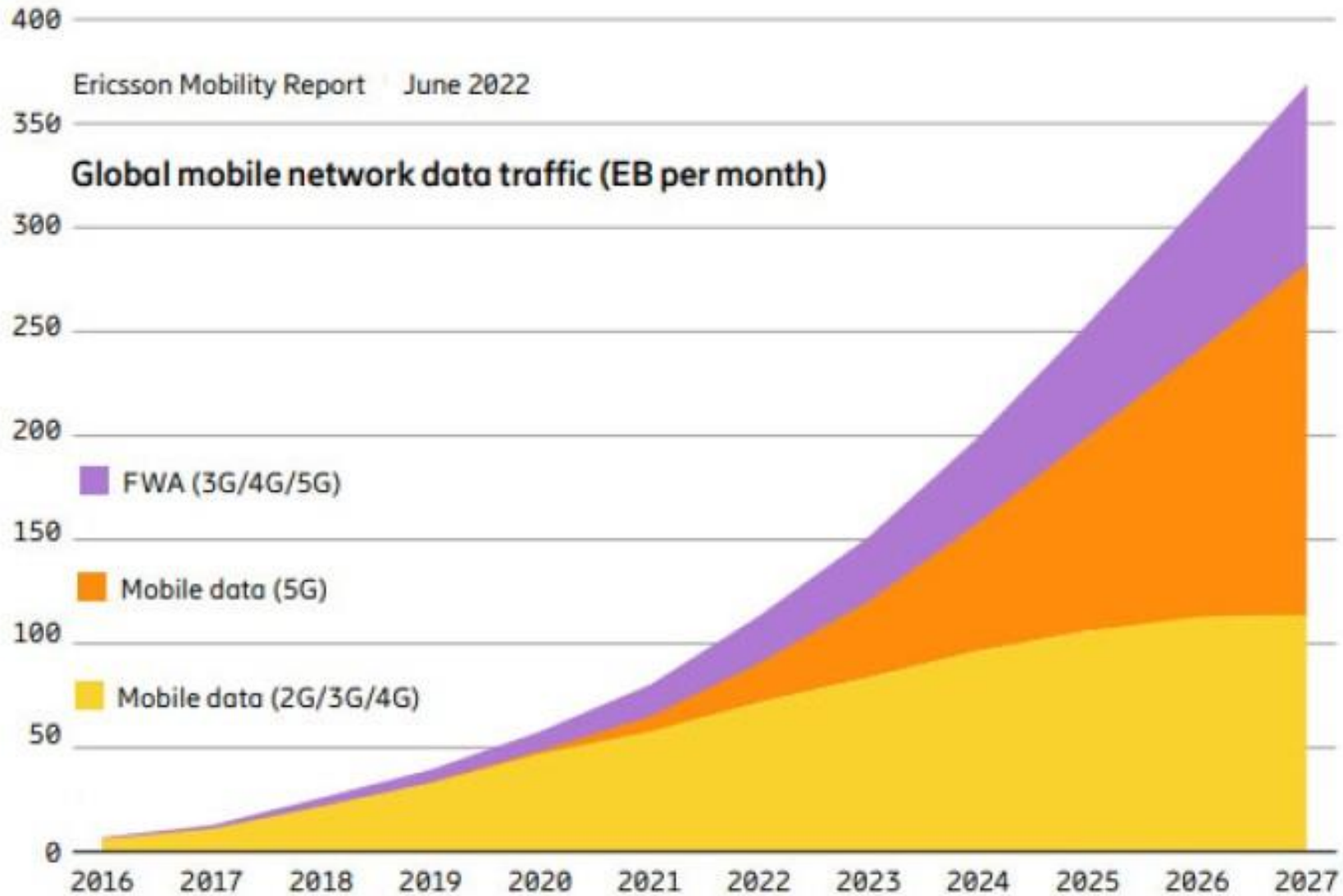
horizon-6gtandem.eu

A story of 3 hockey sticks:

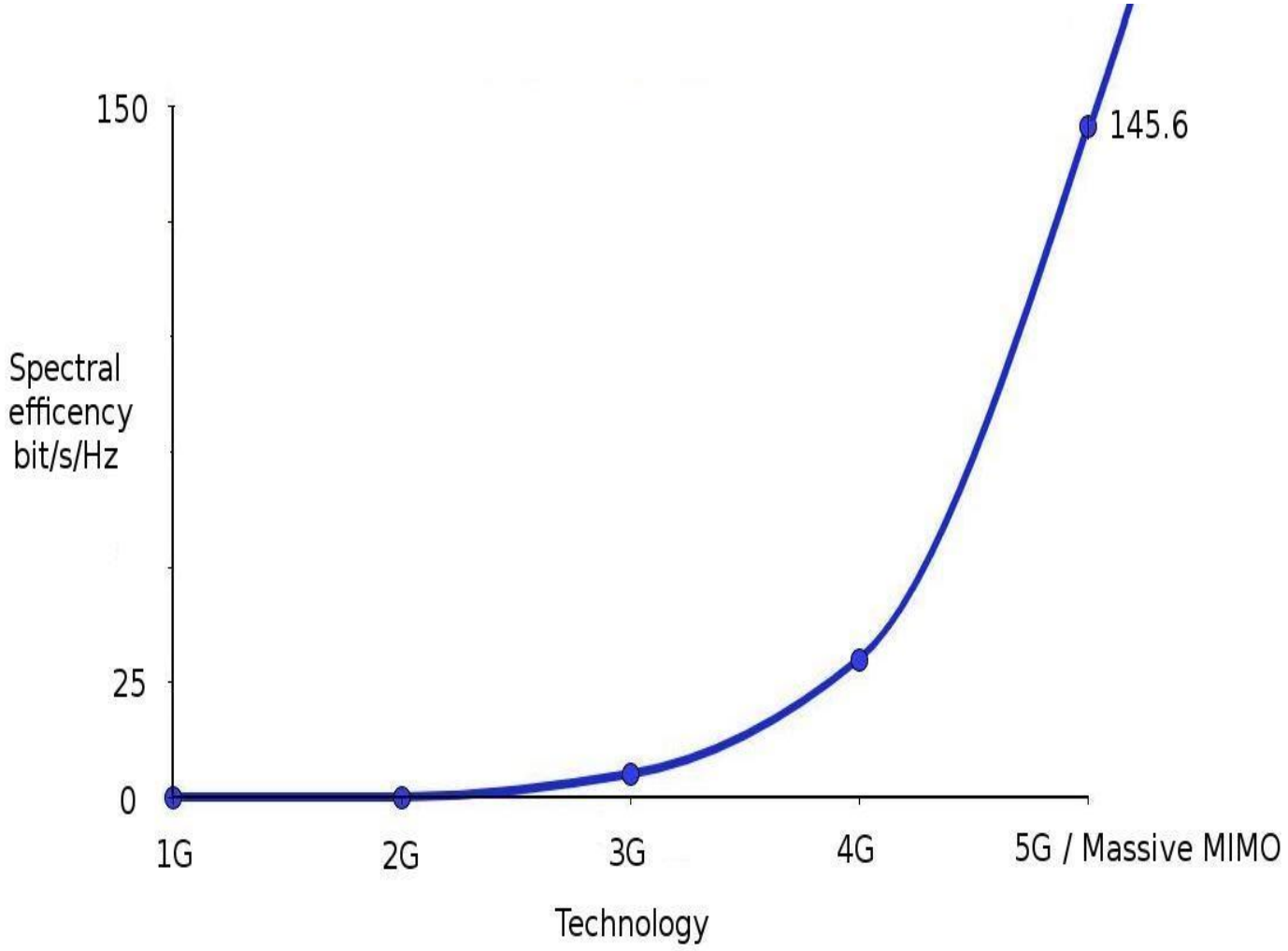
Traffic – the bad

Technology – the good

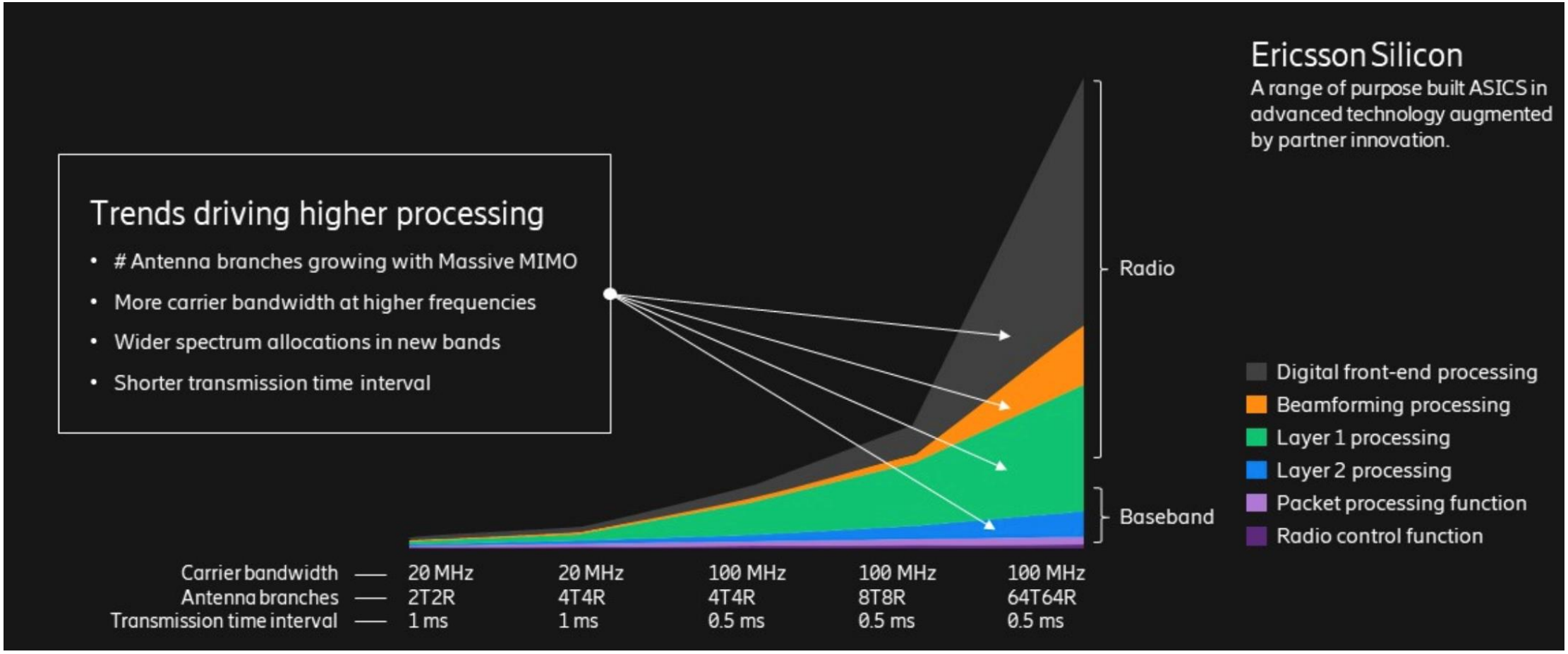
Implementation – the ugly?


Ericsson Mobility Report June 2022
Global mobile network data traffic (EB per month)
400
350
300
250
200
150
100
50
0
FWA (3G/4G/5G)
Mobile data (5G)
Mobile data (2G/3G/4G)
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027

Massive MIMO achieved record spectrum efficiency



Power consumption challenges with more antennas and larger BW



E. Ekudden. "5G Drives Exponential Increase in Processing Needs Across all Industries." In 2023 IEEE International Solid-State Circuits Conference (ISSCC), pp. 33-35.

Superfast but not so clean: China’s 5G network is causing its carbon emissions to soar

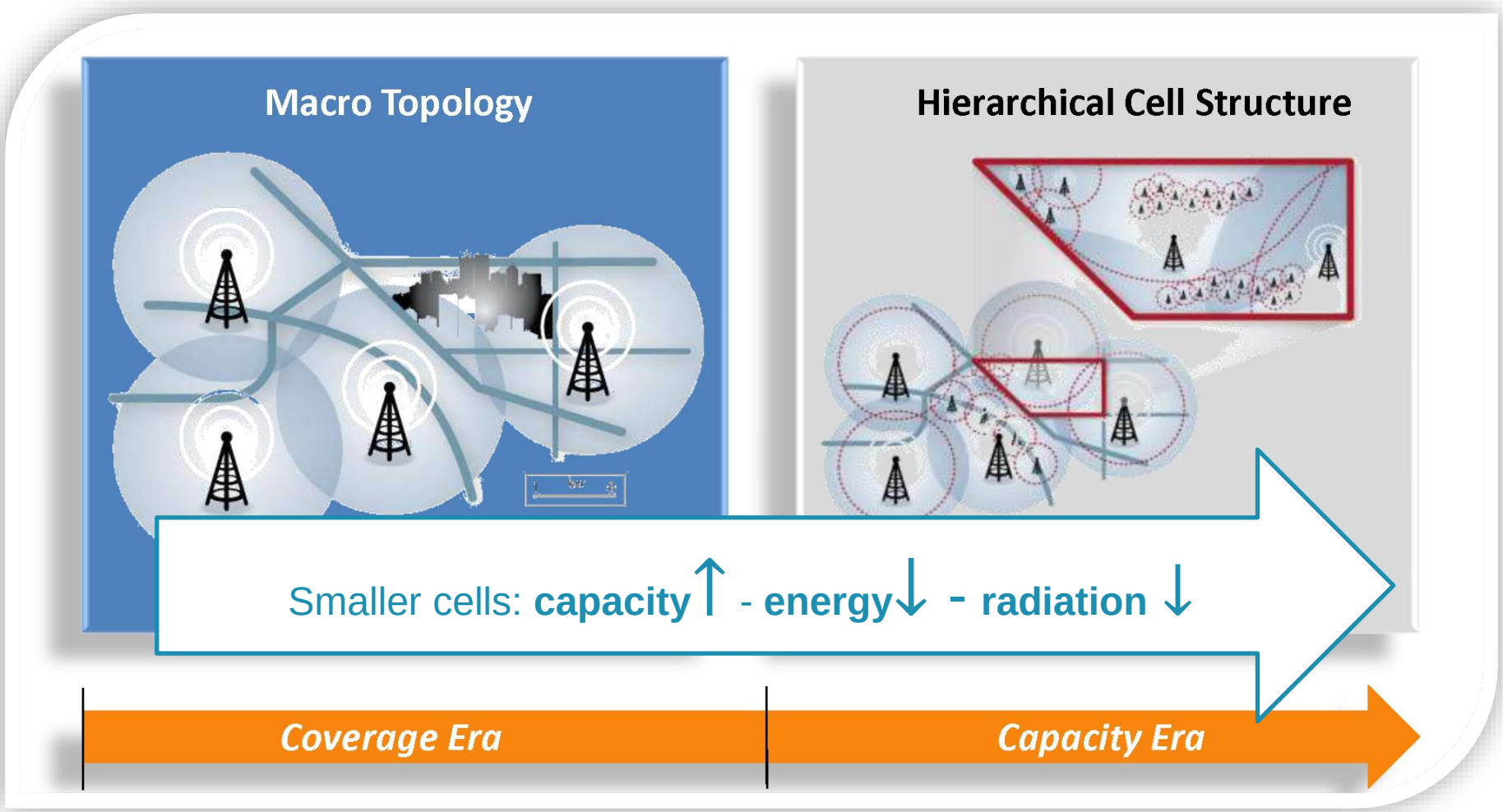
‘China's digital sector will use nearly three times as much energy by 2035 thanks to 5G.’
Euronews June 2021

Fast backward to ≤ 4G: why was/is massive MIMO the preferred technology for 5G?

How was spectacular capacity growth realized – up to 5G?
More spectrum and better spectrum efficiency (bits/s/Hz)

Link Capacity	5X	Closing the gap with Shannon's bound
More Bands	25X	Conquering the spectrum
Spatial reuse	1600X	Densifying the network
Frequency Division	5X	Improving the hardware

Small cells: a great idea for capacity and energy



WILL DENSIFICATION BE THE DEATH OF 5G?

The Death of 5G?

IEEE ComSoc Technology News, May 5th 2015

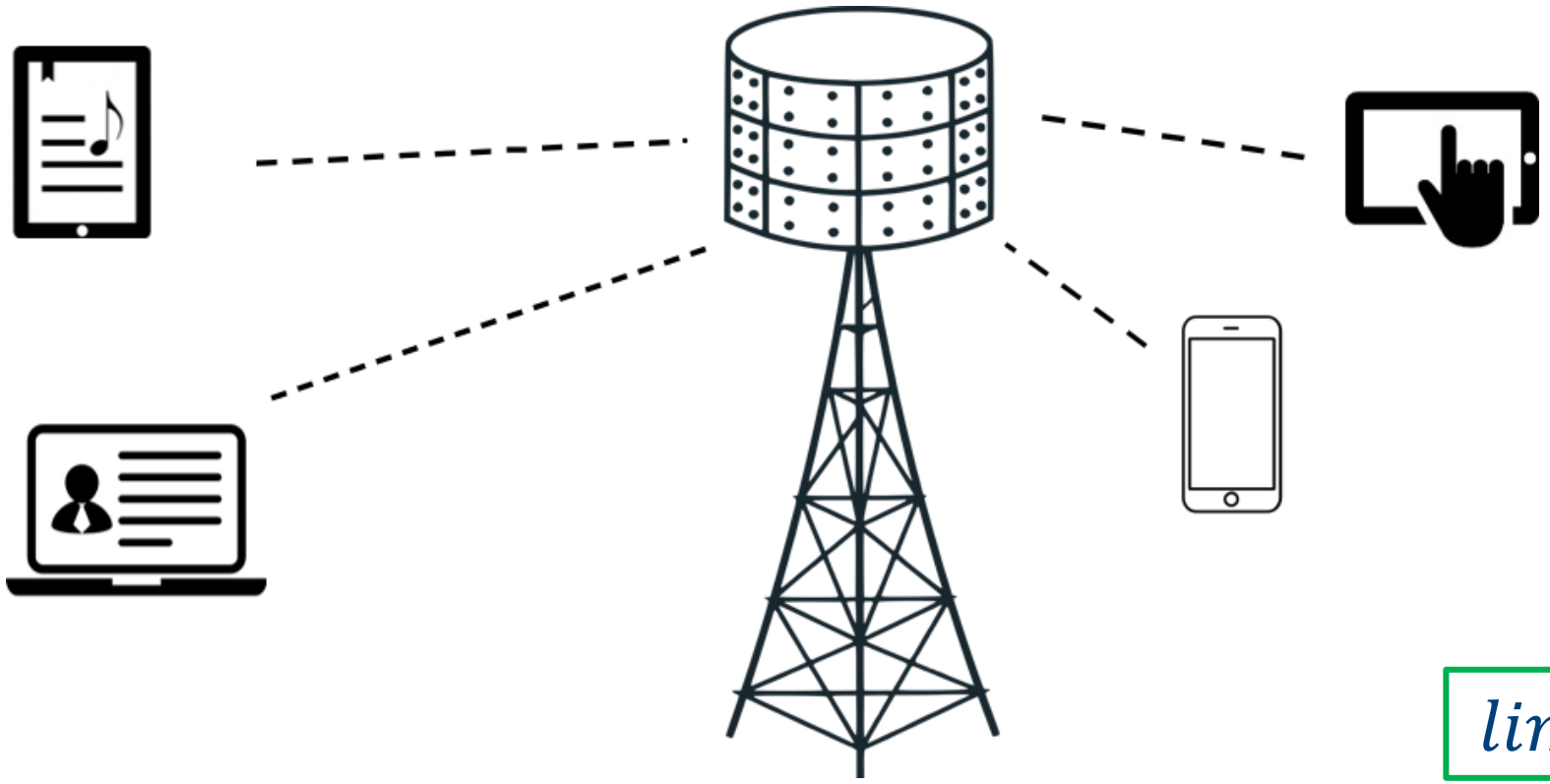
…. a vast majority of capacity increases has been enabled by ever denser and denser cell deployment.
Will this law continue to get us towards the promised land of 5G data rates or will it end up in a messy patchwork?

physical limits:
interference

traffic constraints:
scheduling complexity

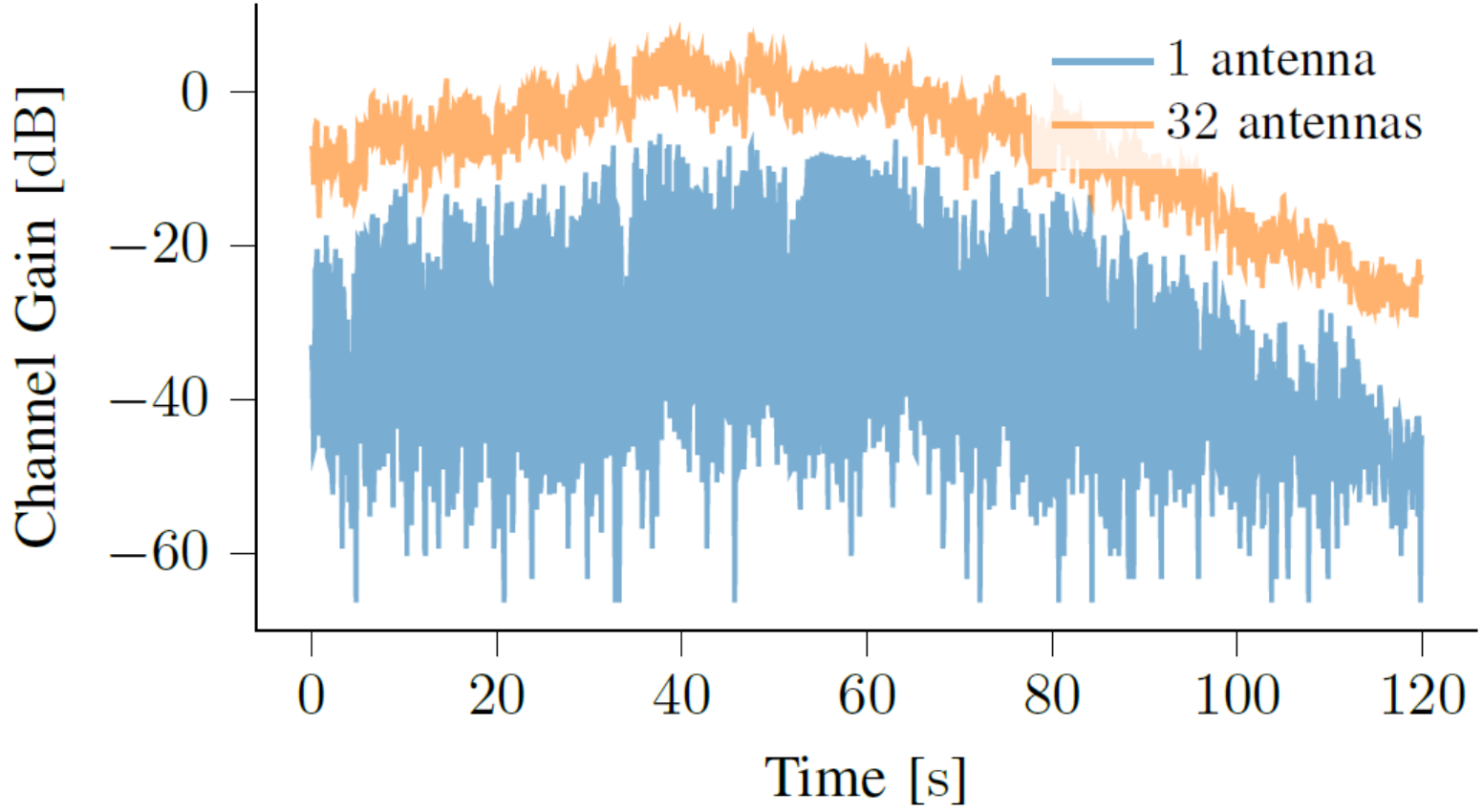
Telefonica Sept 2015: “The small cell debate”
Theoretical research: small cells best to increase area capacity (bps/Hz/km2), they are hardly seen.
Reasons: mixture of technical, economic, spectrum & deployment

Massive MIMO concept:
boosting spectral efficiency through spatial multiplexing



$$lim_{M\to\infty} H.H^H \to I_K$$

Impressive energy reduction and reliability gains validated



Callebaut, G. Gunnarsson, S., Guevara, A.P., Tufvesson, F., Pollin, S., Van der Perre, L., & Johansson, A. (2020). Massive MIMO goes Sub-GHz: Implementation and Experimental Exploration for LPWANs. Asilomar Conference on Signals, Systems, and Computers 2020, *arXiv: Signal Processing*.

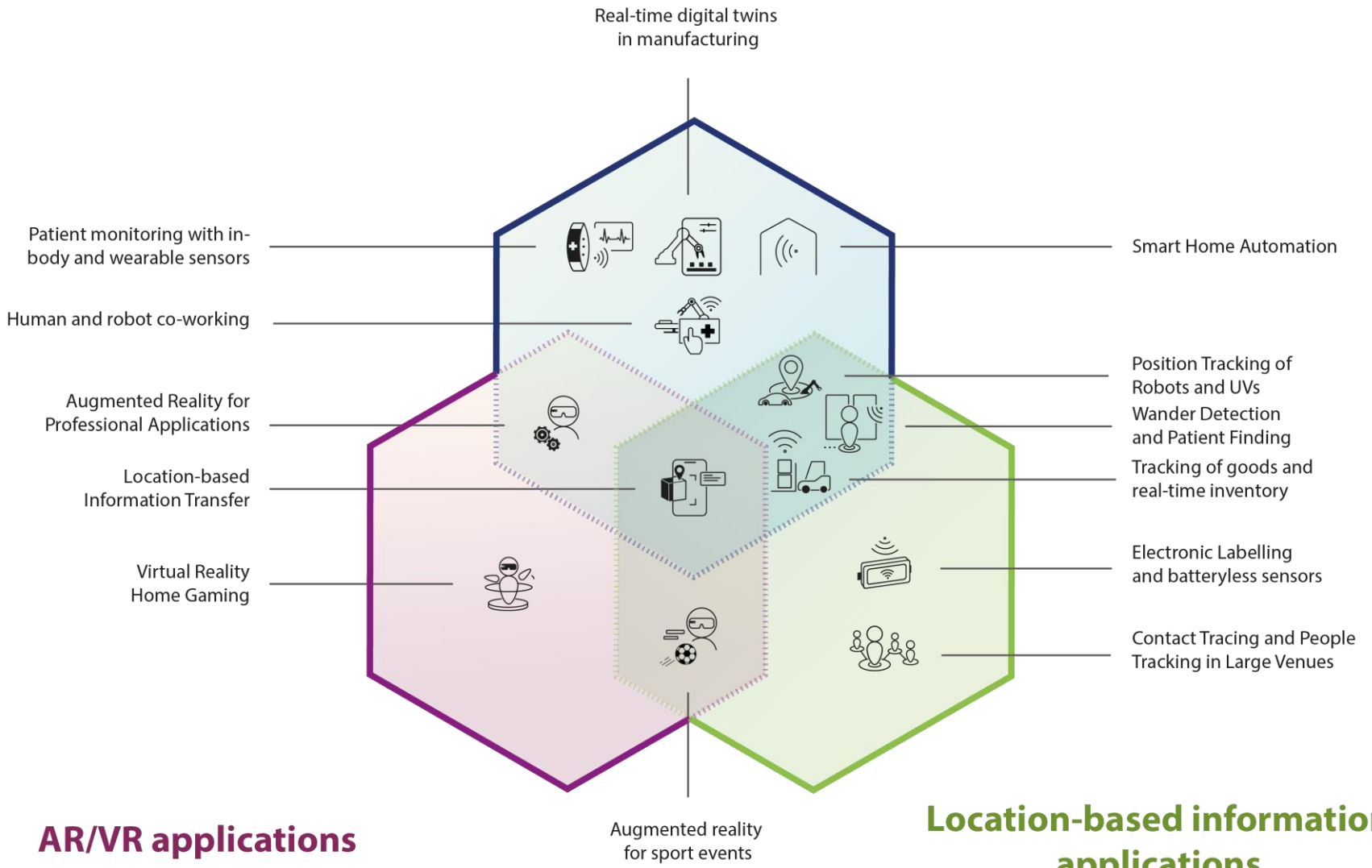
From 5G to 6G:
More hockey-sticks?

REINDEER

www.reindeer-project.eu

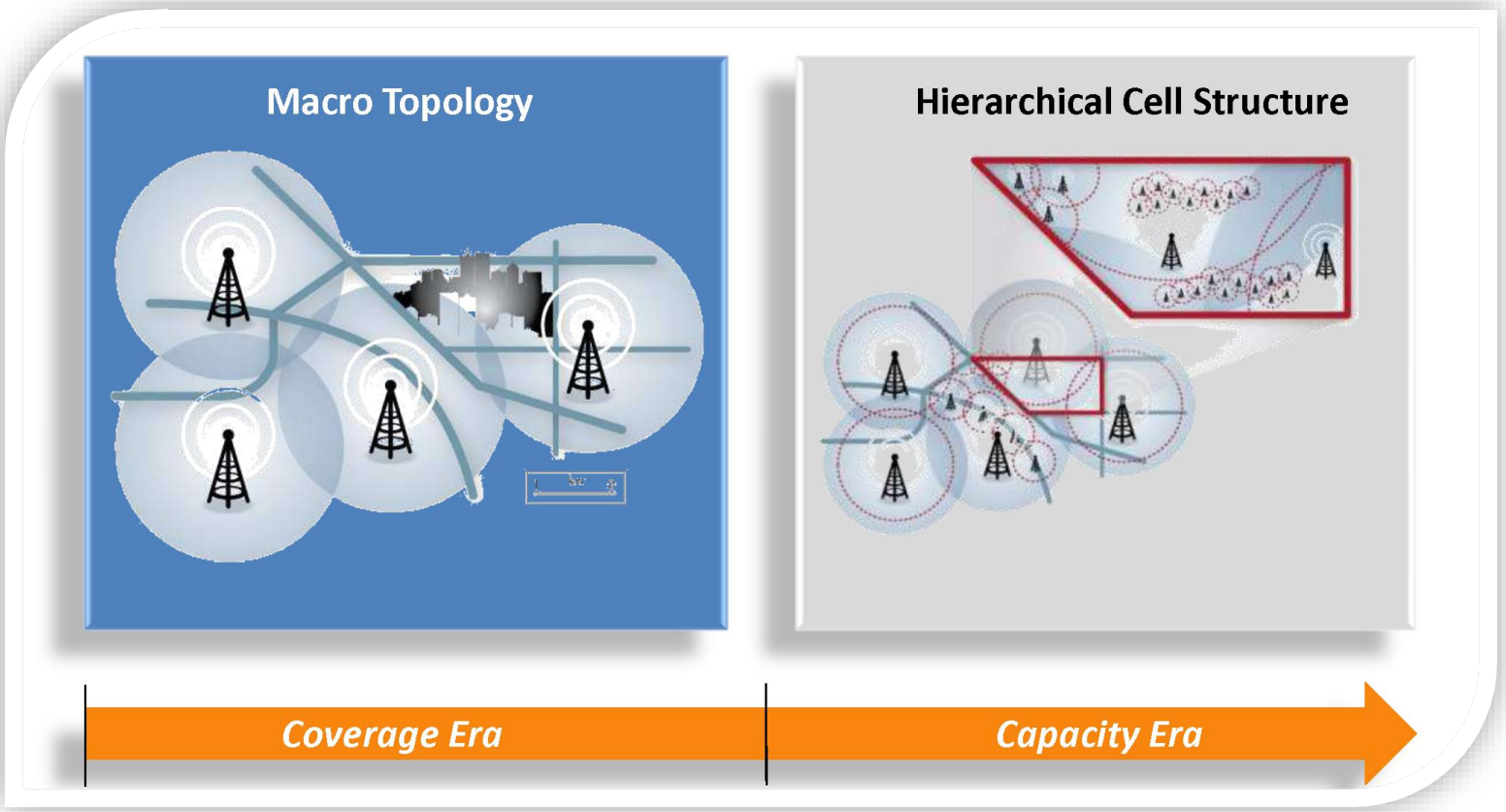
Project deliverable D1.1 available online

Monitoring and real-time applications



AR/VR applications

Location-based information applications



2000

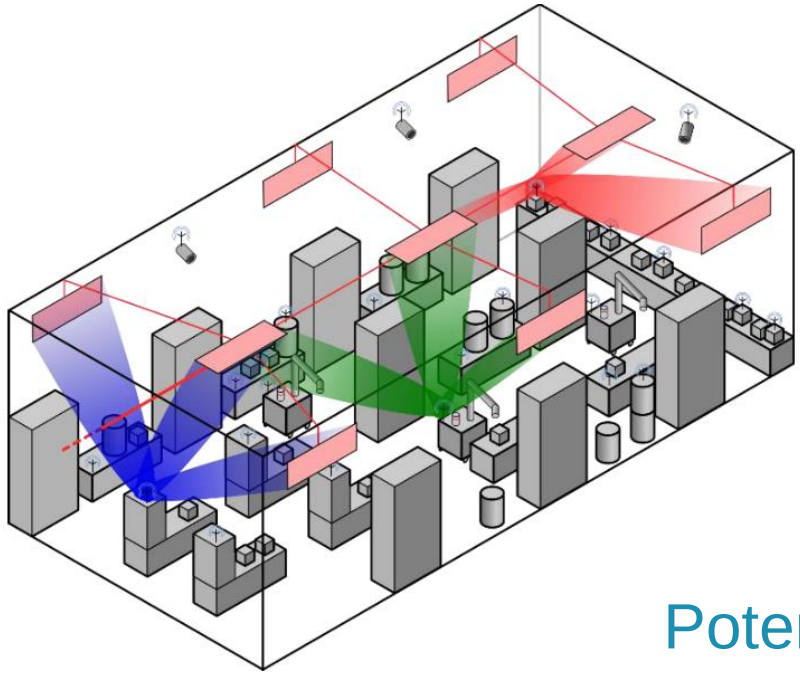
2010
4G

2020
5G

Coverage & capacity & Compute era

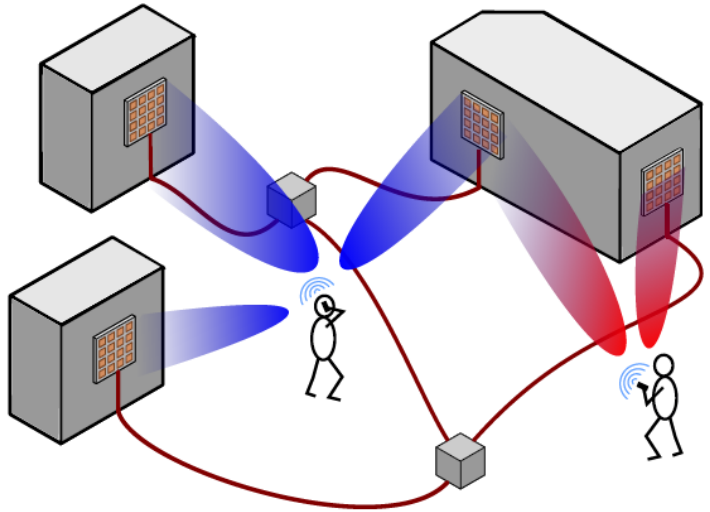
2030
6G

Novel decentralized cell-free network infrastructure: distributed radio and computation resources



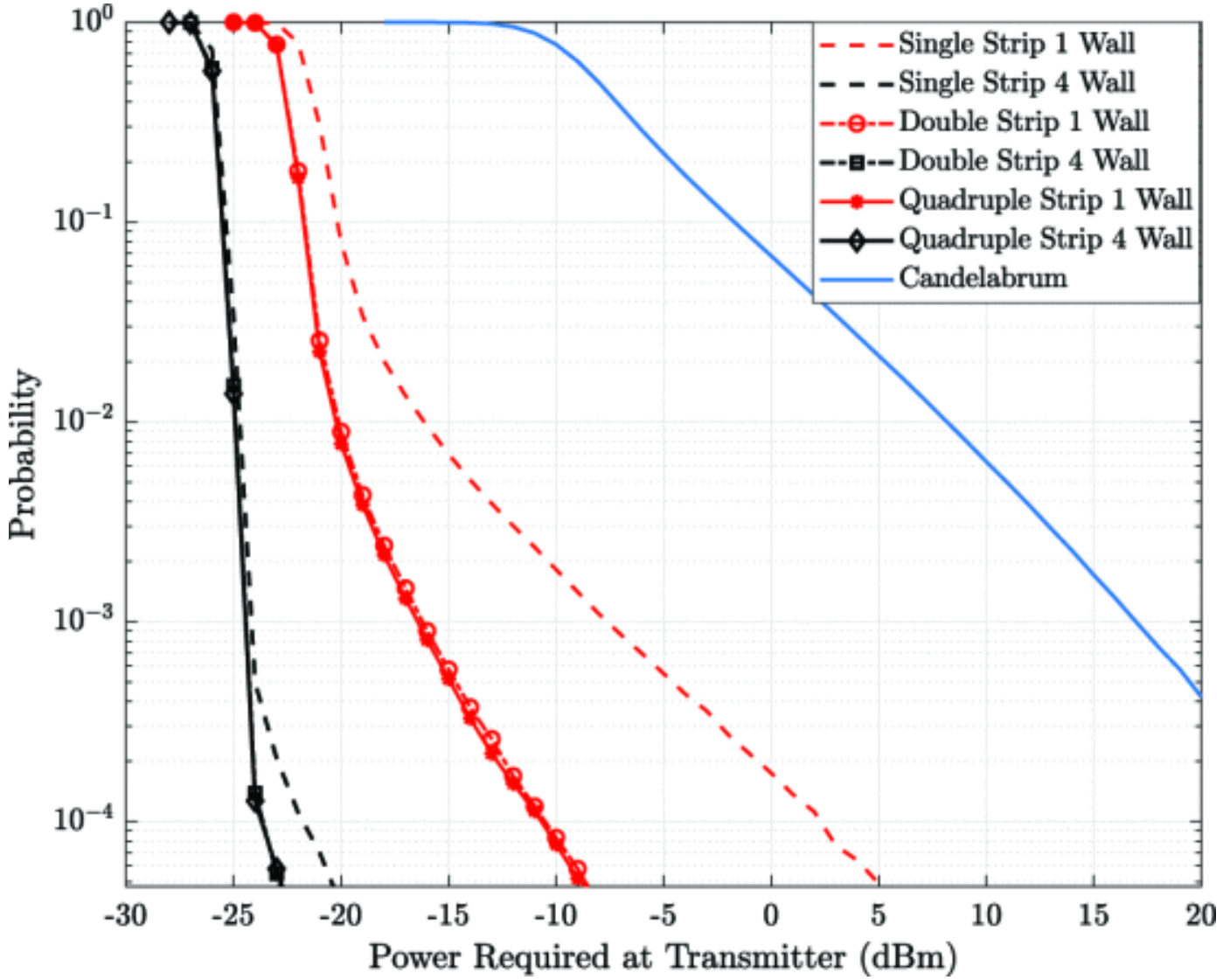
Smart factory

Potential to scale up performance,
with efficient usage
of energy and bandwidth



Crowded environments

Courtesy O. Edfors, EU-REINDEER project



REINDEER D3.1 & references therein

U. K. Ganesan, E. Björnson and E. G. Larsson, "RadioWeaves for Extreme Spatial Multiplexing in Indoor Environments," *2020 54th Asilomar Conference on Signals, Systems, and Computers*, 2020, pp. 1007-1011.

From 5G to 6G:
what could make all the difference?

Could sustainable scalability be the primary ambition?

The potential in cell-free massive MIMO for sustainable scalability

Mind losses!

Distributed/cell-free deployments: Opportunities and R&D challenges to scale up massive MIMO

Scaling up massive MIMO sustainably: observations and R&D questions

O1. Distributed deployment: potential for improving energy performance.

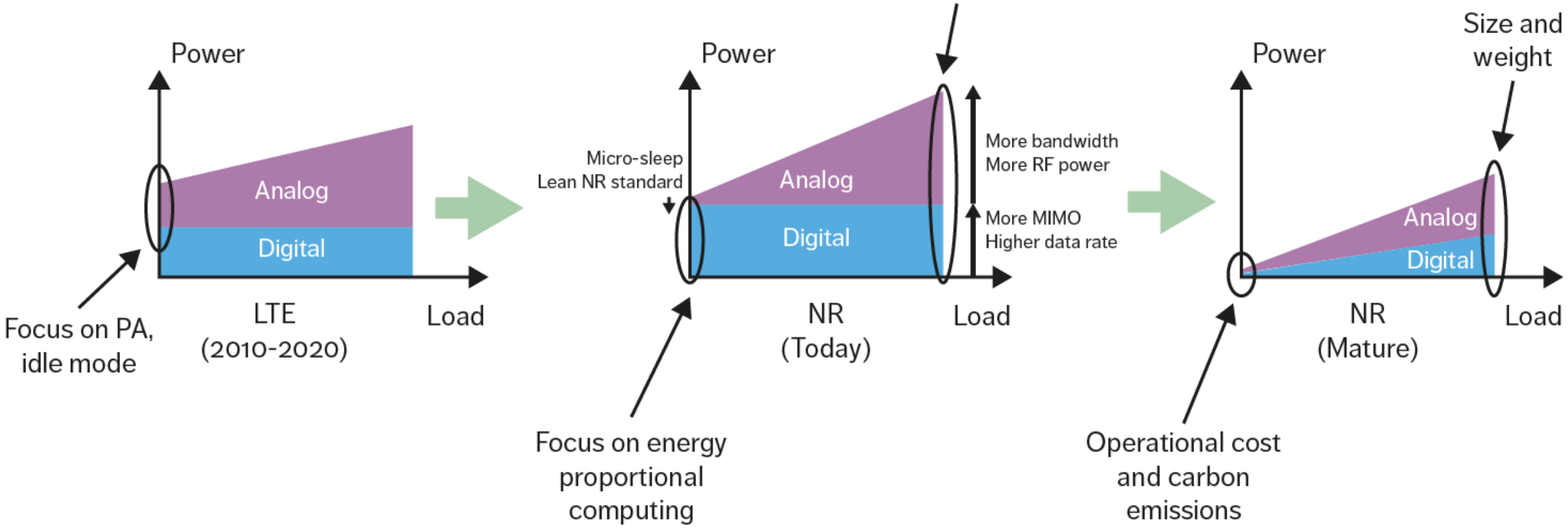
O2. From micro to macro sleep: adaptive operation in scalable architecture.

Q1. Implementation: PAs, DSP complexity, synchronization and calibration, information exchange in distributed architectures, the beauty?

Q2. Can massive MIMO scale up in frequency sustainably?

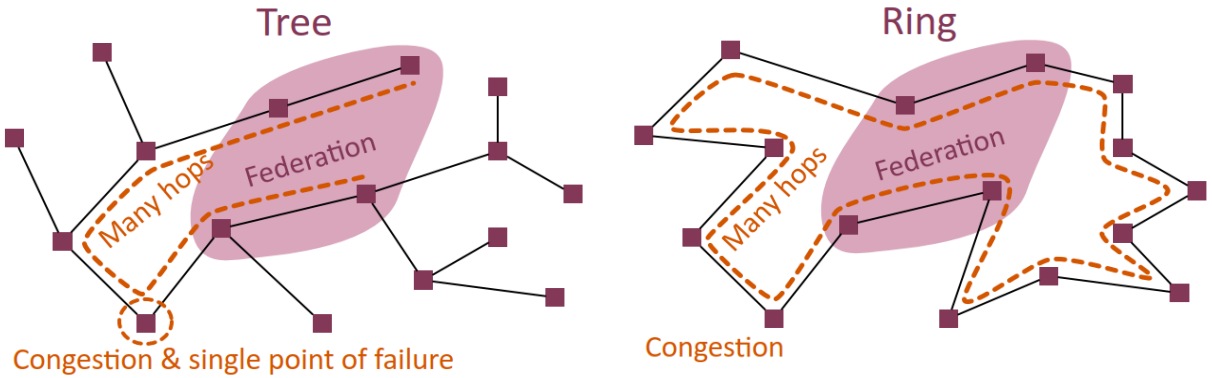
Q3. Can 6G serve SDGs in the broad sense?

Focus on total energy performance, beyond transmit energy and energy per bit

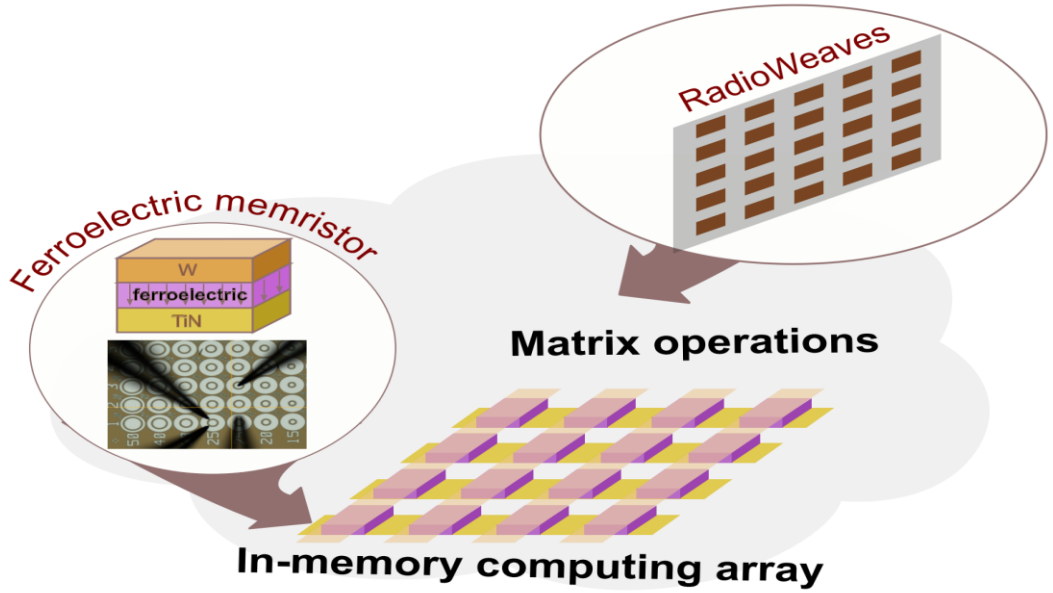


Source: Improving energy performance in 5G networks and beyond, Ericsson CTO Erik Ekudden's view on network energy performance

Opportunities at different levels: networking and computing



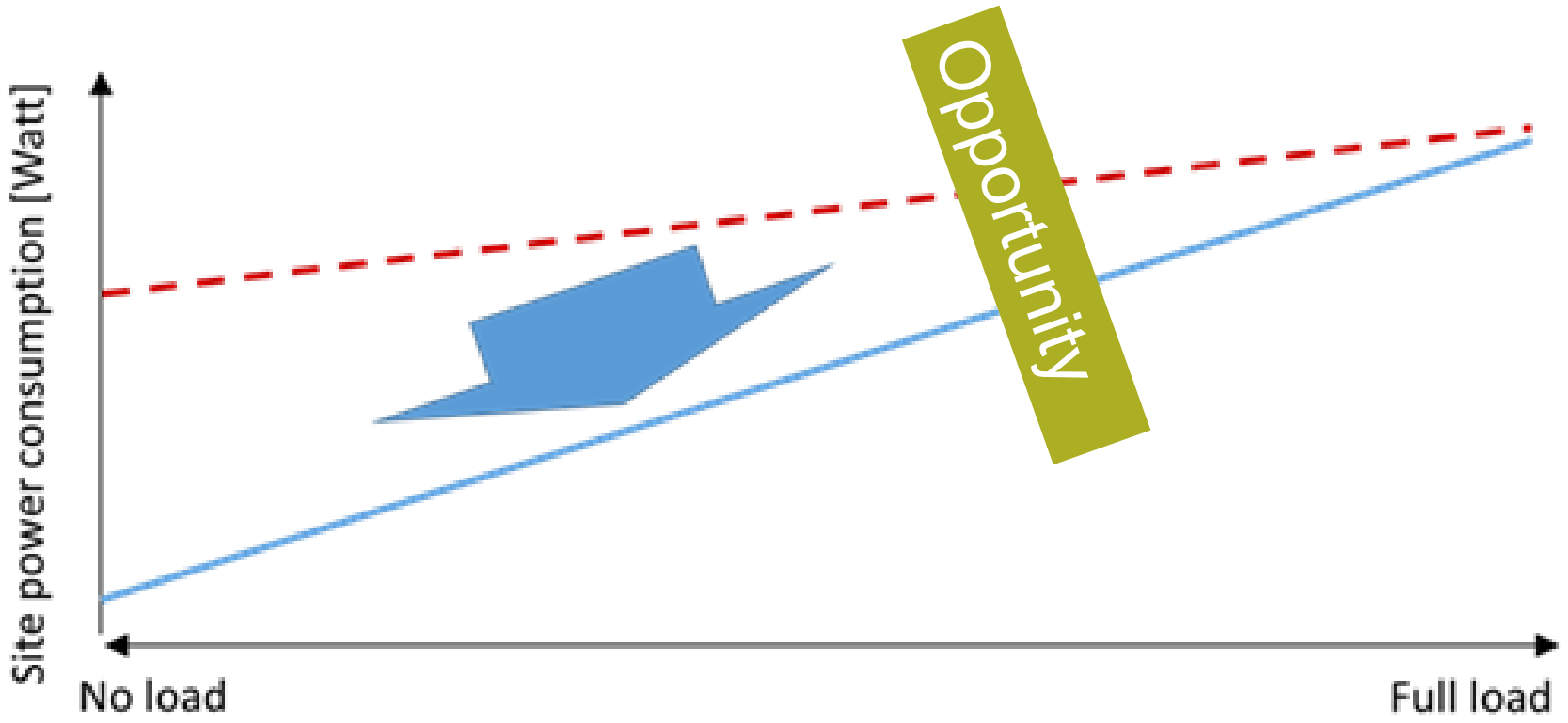
Distributed near-antenna processing:
10X reduction in data movement



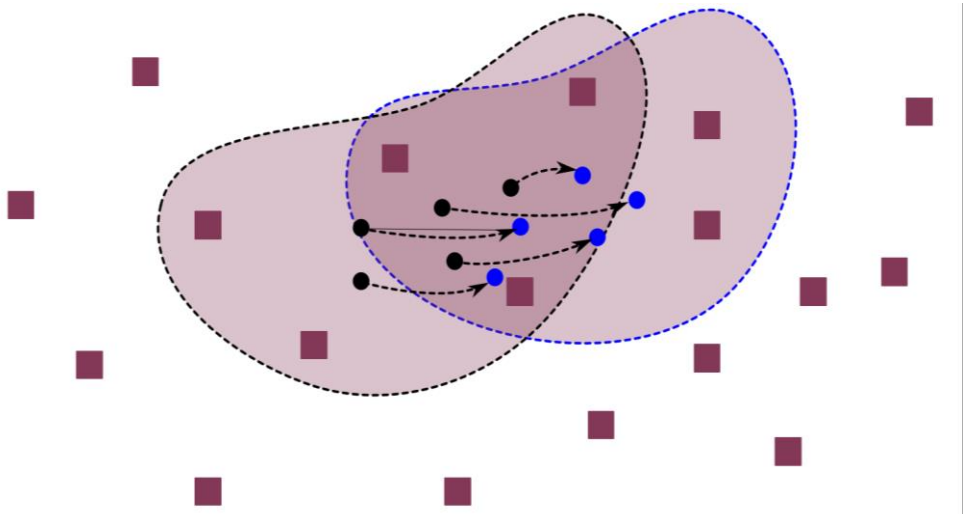
In-memory computing:
100X power reduction for matrix operations

Source: Reindeer D 2.1

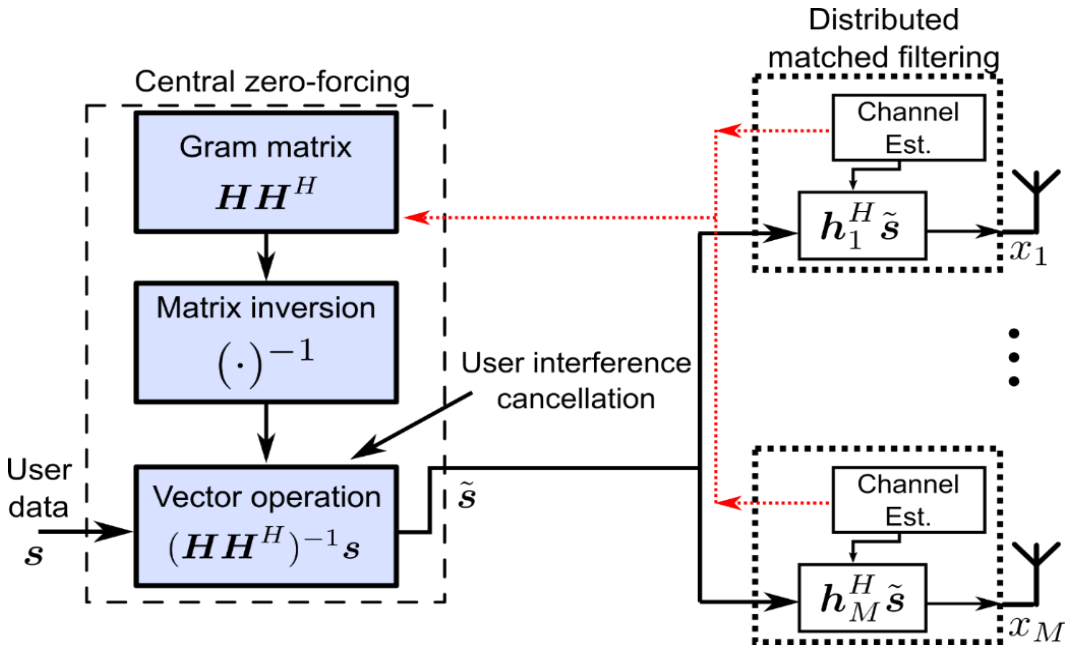
Lean energy performance can be achieved in inherent scalable distributed architectures.



From macro sleep to micro and nano sleep



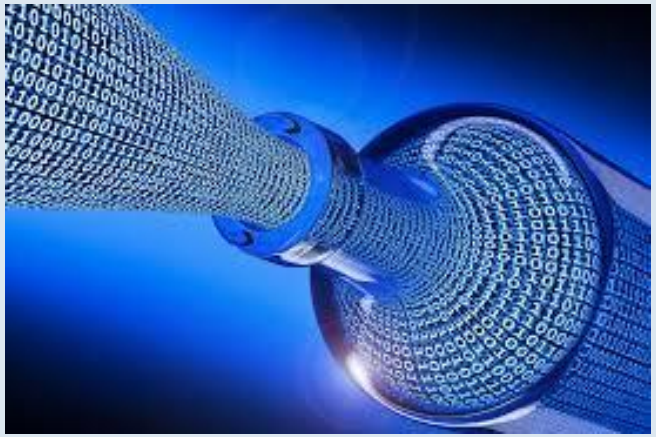
Source: Reindeer D 3.1

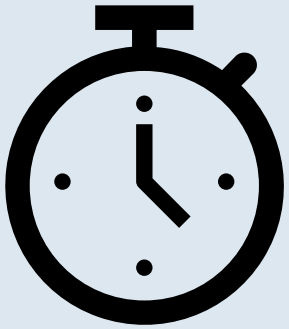


Activate ONLY parts of the infrastructure adaptive to the movement of users and the traffic load

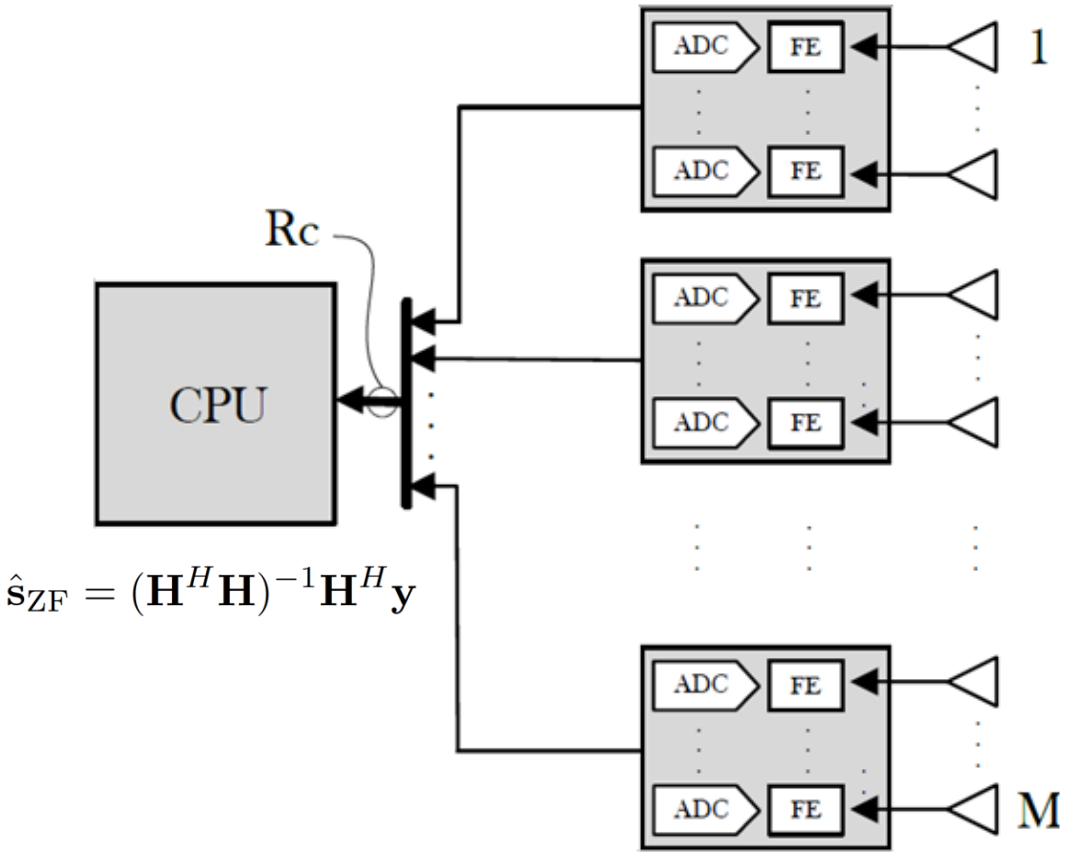
Module DSP design with power/clock gating and DVFS adaptive to algorithms needed

Q1: Implementation complexity – and beauty?





Aggregated Interconnect bandwidth and memory capacity

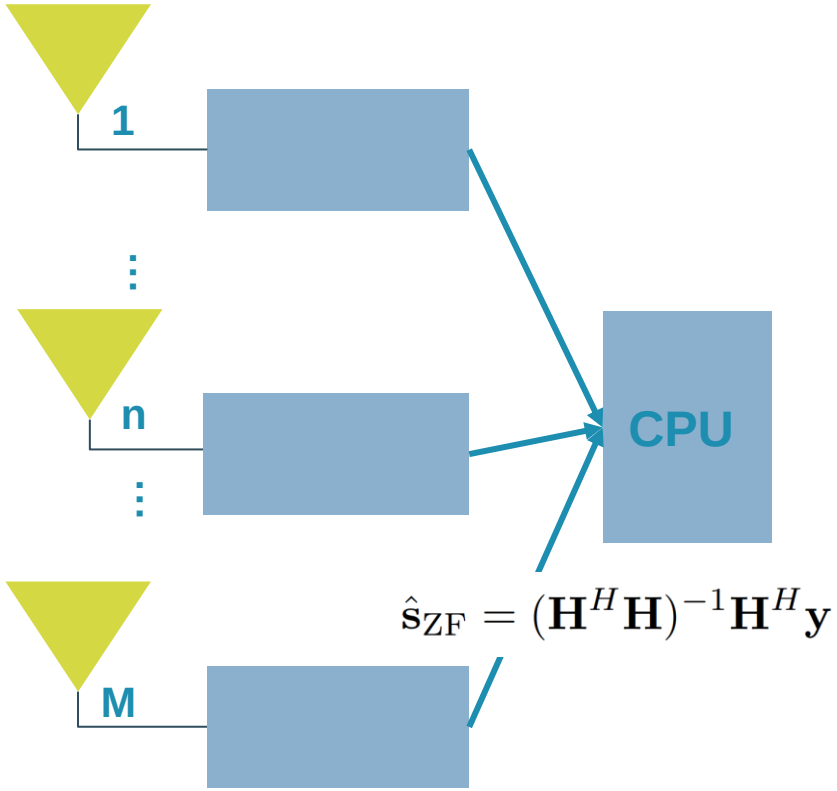


Simple example with approximate calculation

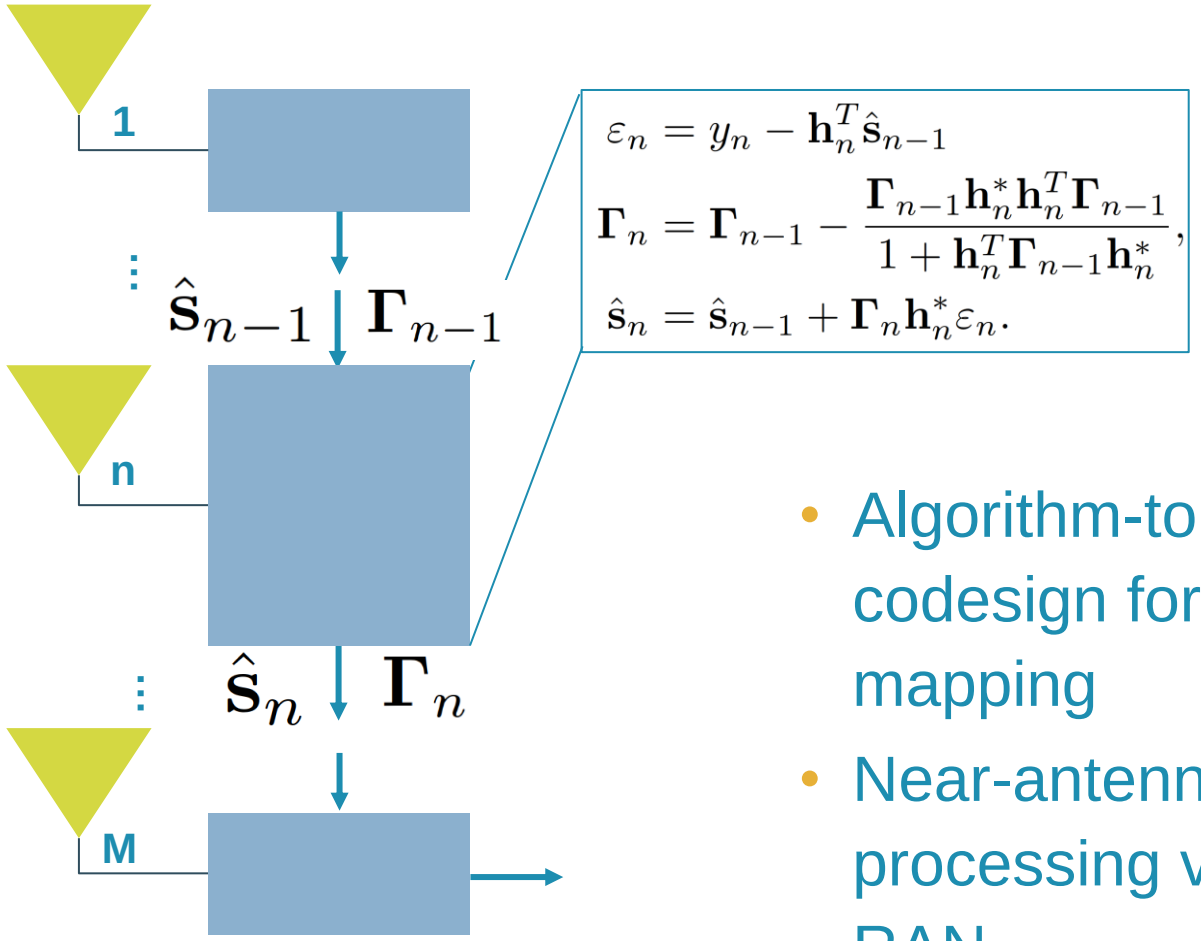
	Massive MIMO	Radio Weaves
# antennas	128	1024
# users	10	100
Signal BW	20MHz	100MHz
Inter. BW[1]	61.4Gb/s	2.5Tb/s
Mem. Size[2]	3.7Mb	1.5Gb

1. 12*2 bits for a complex sample
2. Memory size for only channel matrix of one OFDM symbol

Solutions: co-design distributed algorithms and architectures



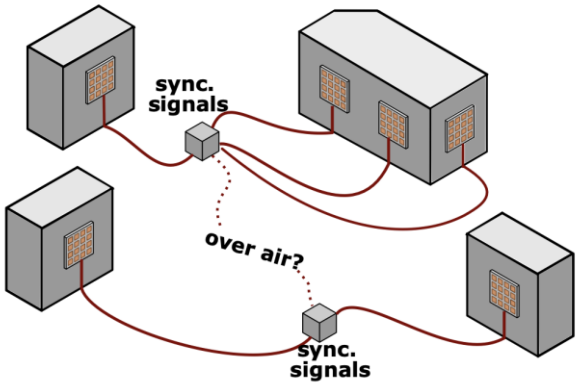
Least square in centralized processing unit



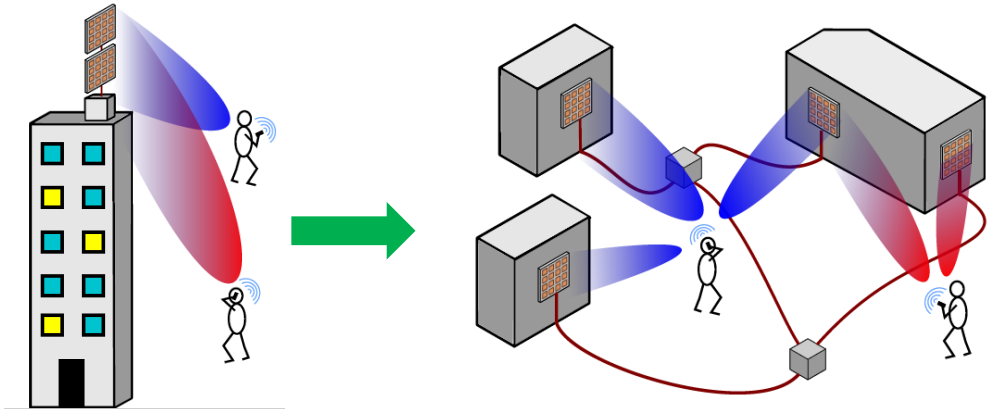
Recursive least square in a distributed daisy-chain

- Algorithm-topology codesign for optimized mapping
- Near-antenna processing vs. cloud RAN

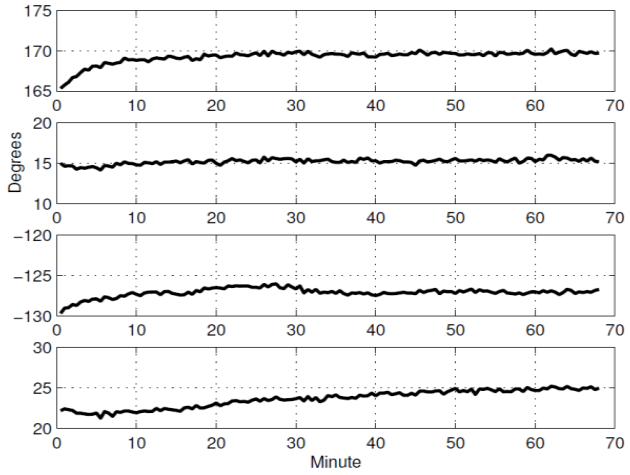
What keeps us busy all day[1]: synchronization and calibration



Frequency sync: More difficult to distribute the LO/Ref



Timing sync: from BS centric to UE centric

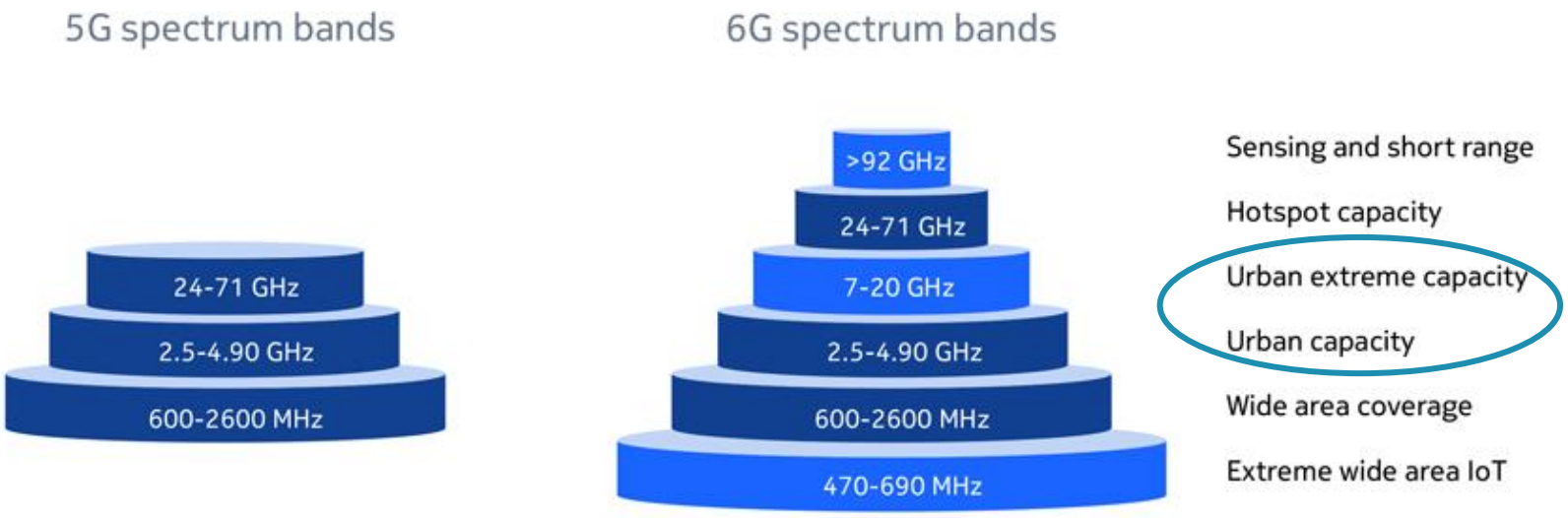


Phase coherency: Challenging when operating in dynamic enviroments

[1] and sometimes sleepless at night

Q2: Can massive MIMO scale up in frequency sustainably?

Scaling up massive MIMO for mmwave & sub-THz, sustainably? Mind physics and propagation[1]



"The 6G era's enormous capacity demands will require new spectrum and extreme massive MIMO", Nokia Bell Labs

- sub-6 GHz PA (@ 6 dB back-off): power added efficiency (PAE) up to >30 %.
- mmWave CMOS PAs PAE (at 6 dB back-off) < 10%.

[1] E. Bjornson, L. Van der Perre, S. Buzzi and E. G. Larsson, "Massive MIMO in Sub-6 GHz and mmWave: Physical, Practical, and Use-Case Differences," in *IEEE Wireless Comm*, vol. 26, no. 2, pp. 100-108, April 2019

The 6GTandem approach: dense deployment at the rescue?

6GTandem co-designs

novel dual-frequency operation

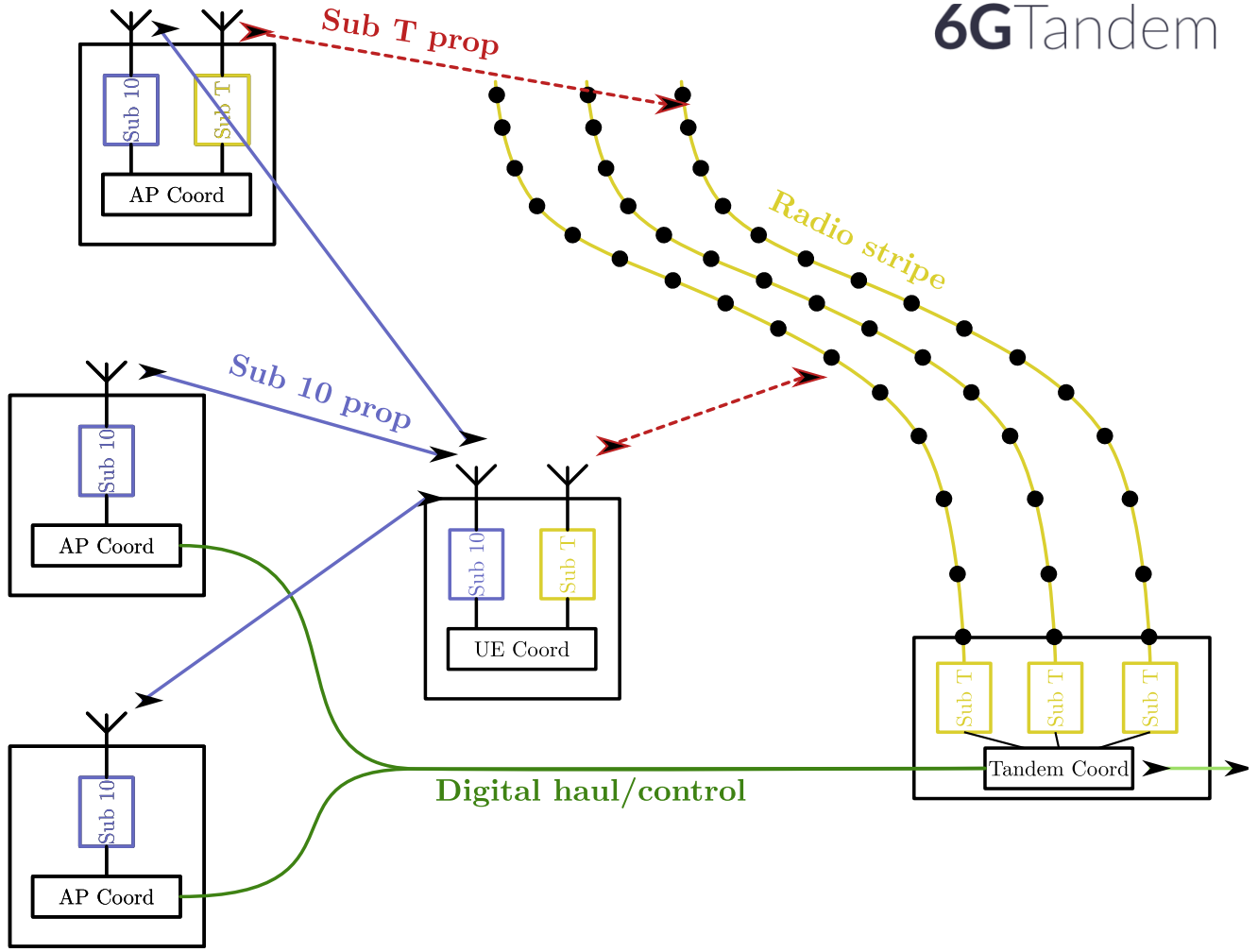
at sub-10 GHz & sub-THz frequencies

& a highly integrated and distributed

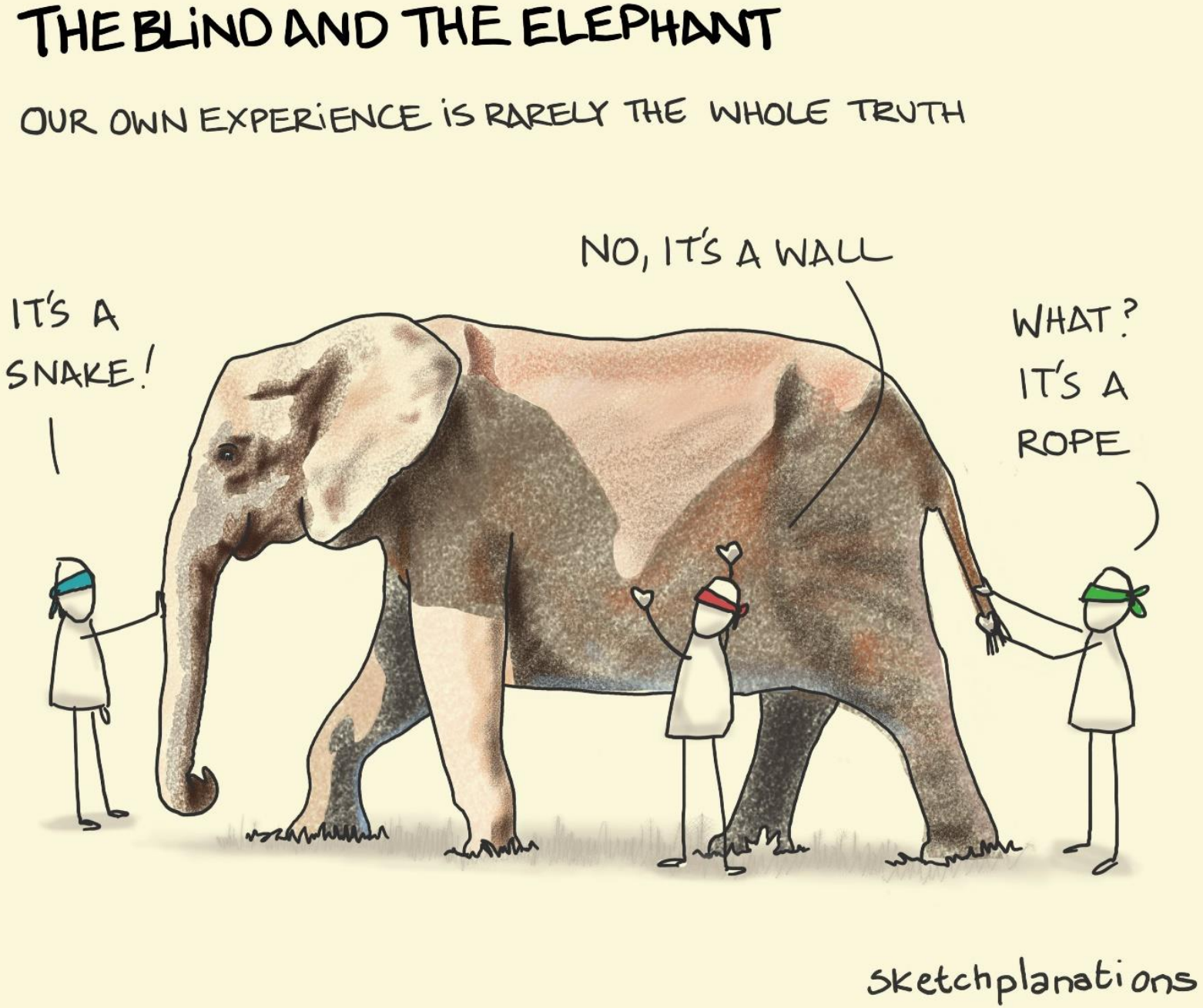
radiostripe & transceiver architecture

to deliver high-performance

energy-efficient services for 6G.

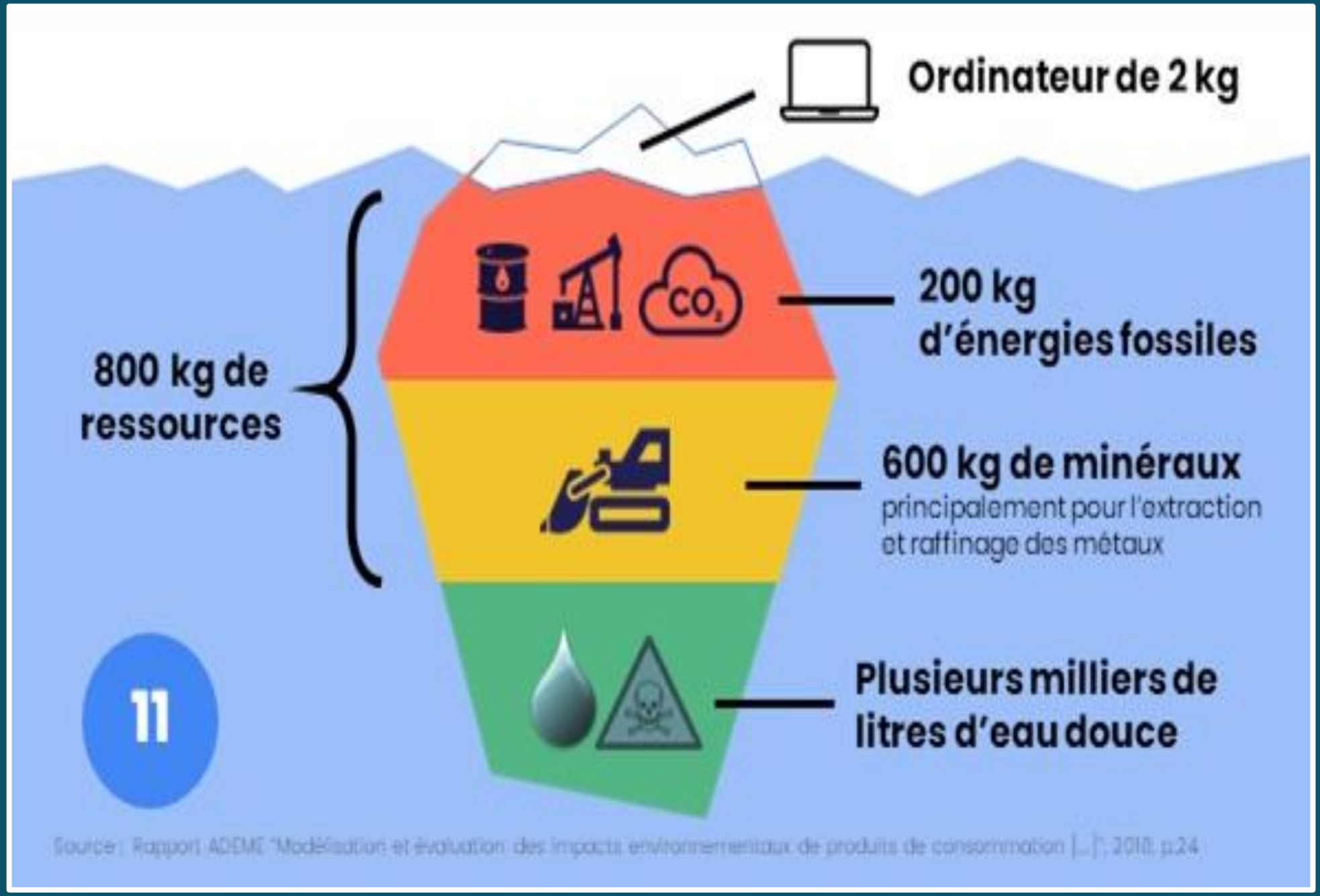


Q3: serve diverse SDGs?



The story of the elephant and the blind men - could be the story of 6G/a reindeer for sustainability?

Moreau, N. et Al.
Could Unsustainable Electronics Support Sustainability?
Sustainability 2021, 13, 6541. https://doi.org/10.3390/ su13126541


Ordinateur de 2 kg
800 kg de ressources
200 kg d'énergies fossiles
600 kg de minéraux
principalement pour l'extraction et raffinage des métaux
Plusieurs milliers de litres d'eau douce
11
Source : Rapport ADEME "Modélisation et évaluation des impacts environnementaux de produits de consommation [...]", 2018, p.24

6G for sustainability? criticial assessment needed

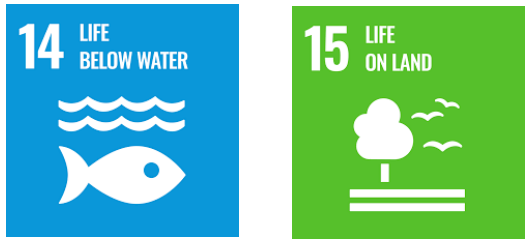
‘Empathy for technology?’

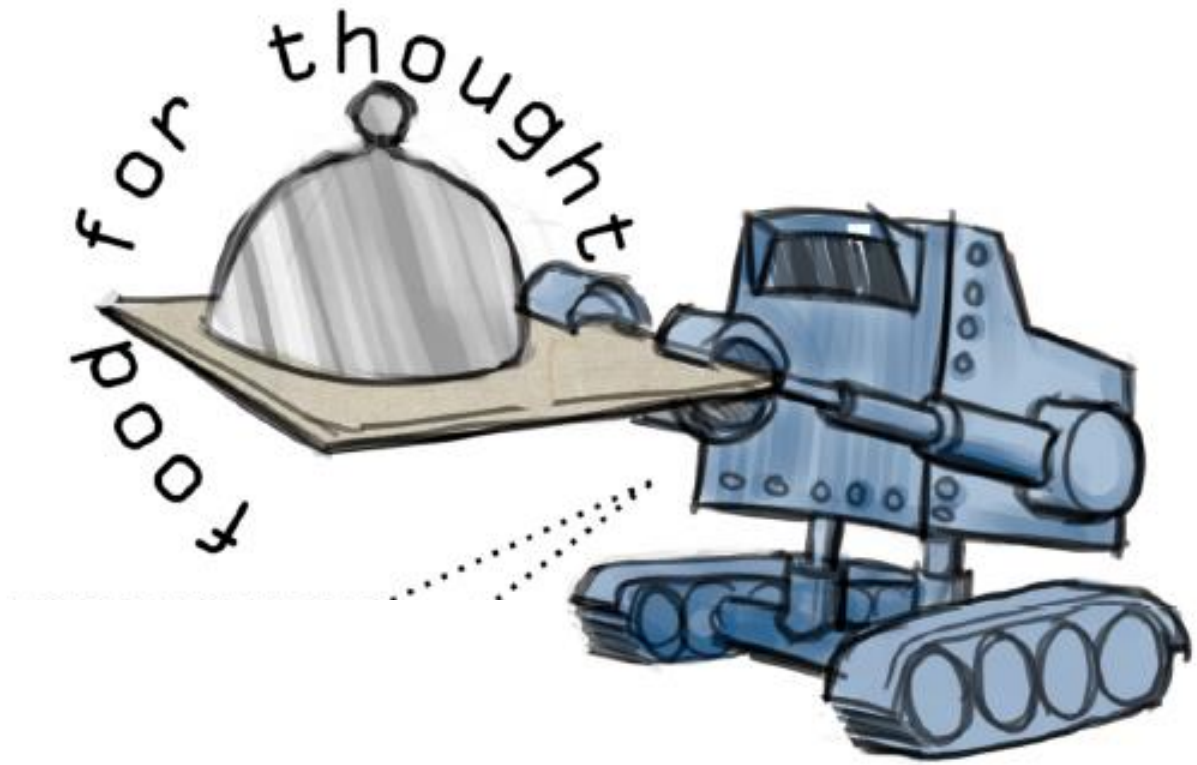
Avoid the ‘eco-trap’:
can 5G equipment cooperate
in 6G concepts?

Towards a human-centric 6G on the road to the SDGS: How can we help?

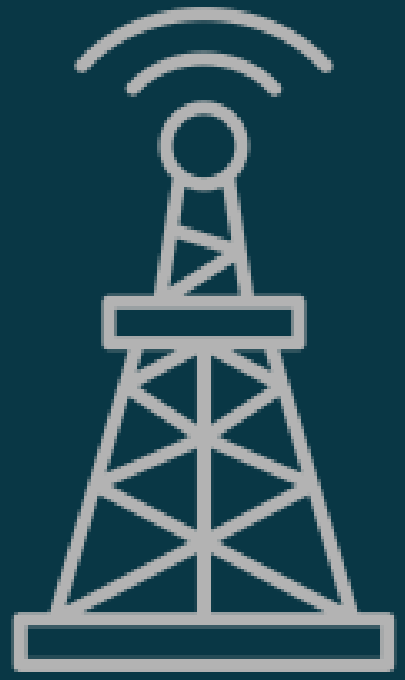
- Environmental monitoring: will 6G offer more/better support?

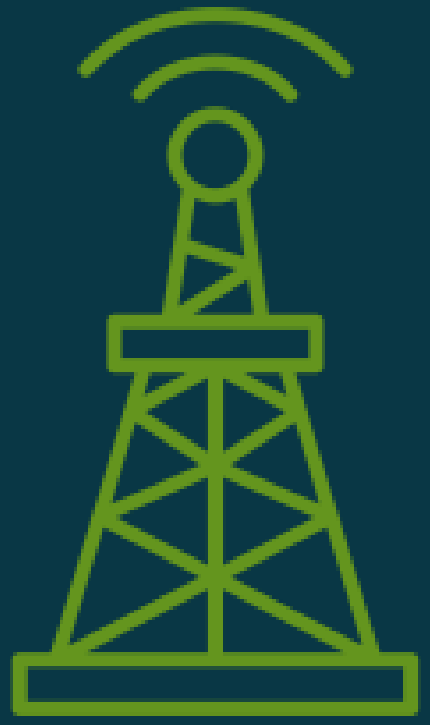
- The divers set of SDGs: how will we contribute?




food for thought

From 5G to 6G: what may be the difference?

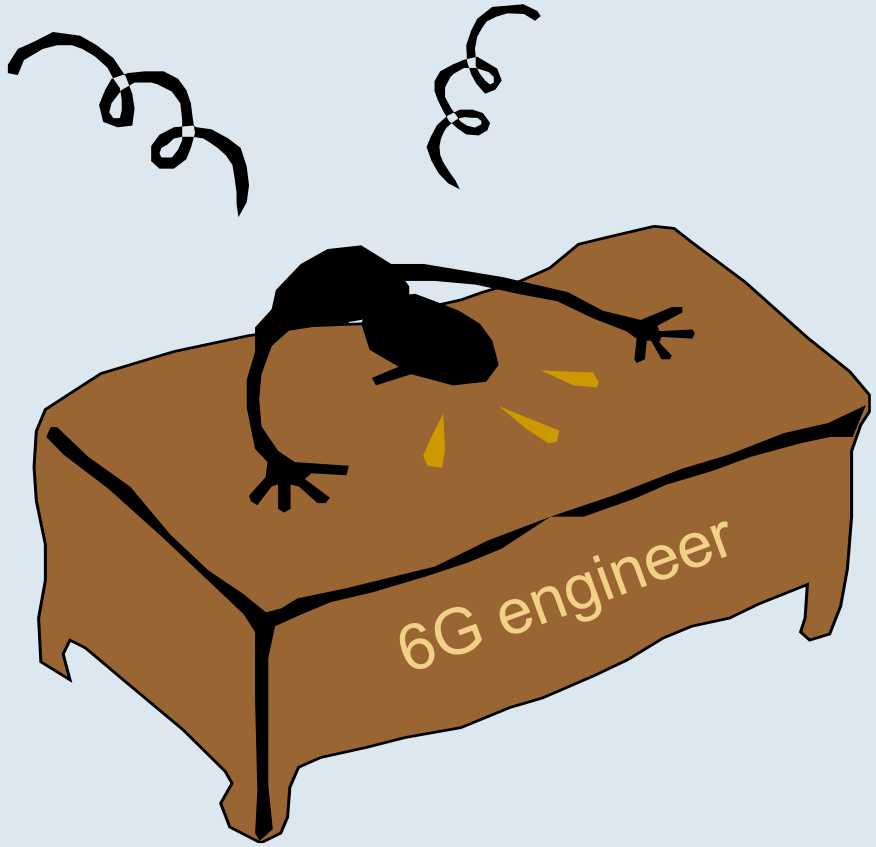




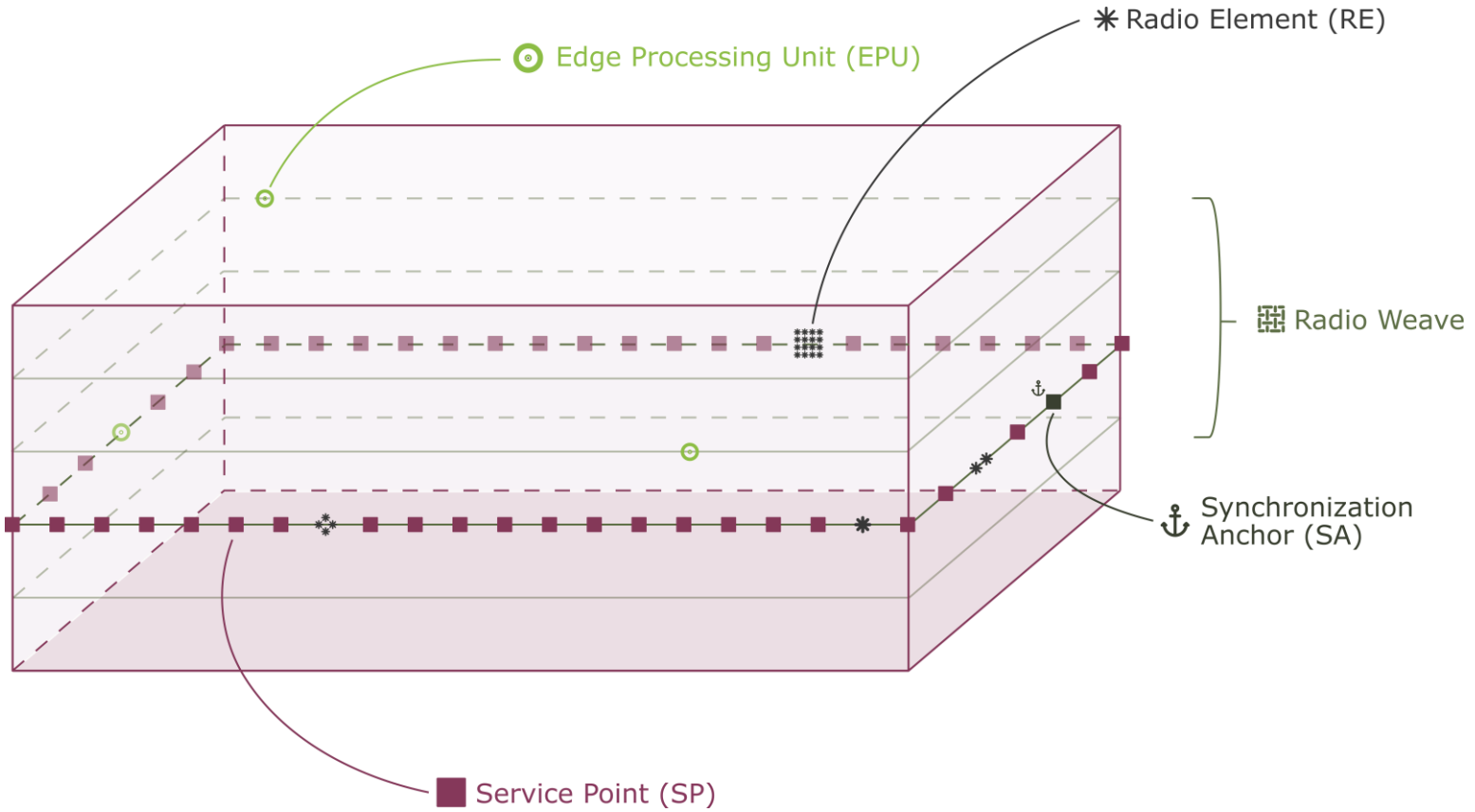
‘refurbish’

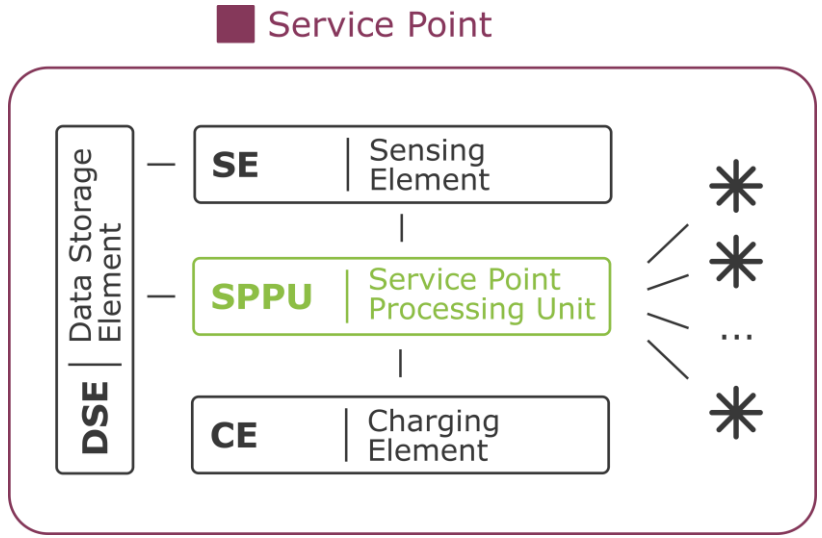
O2. From micro sleep to macro sleep, adaptive operation with scalable architecture –
and hardware support?

Coordination challenges

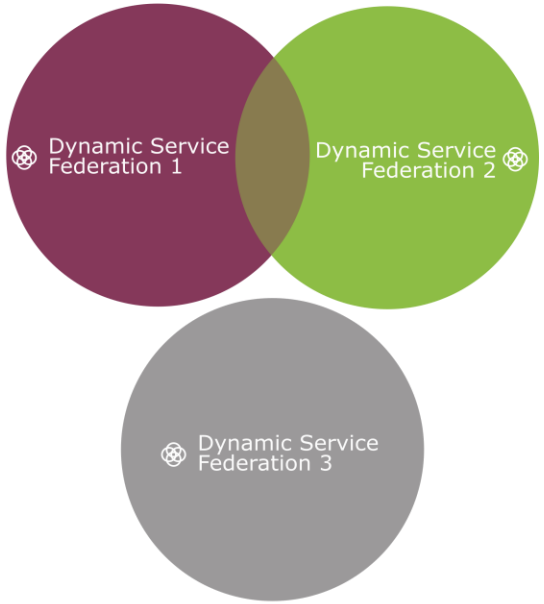


Terminology and concepts introduced to denote and manage the distributed resources

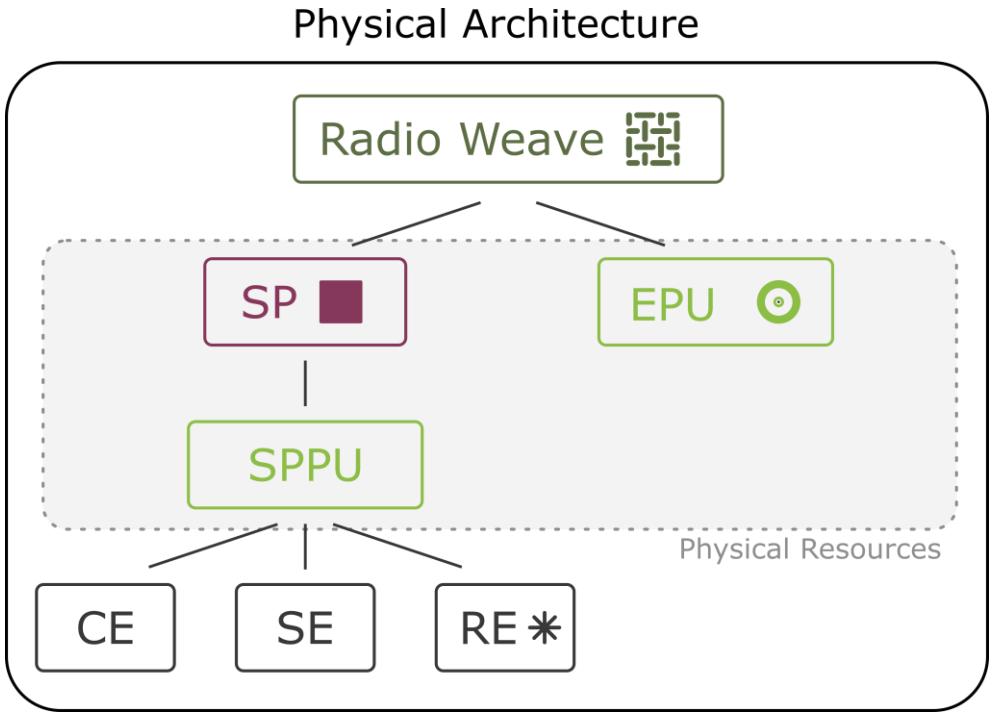


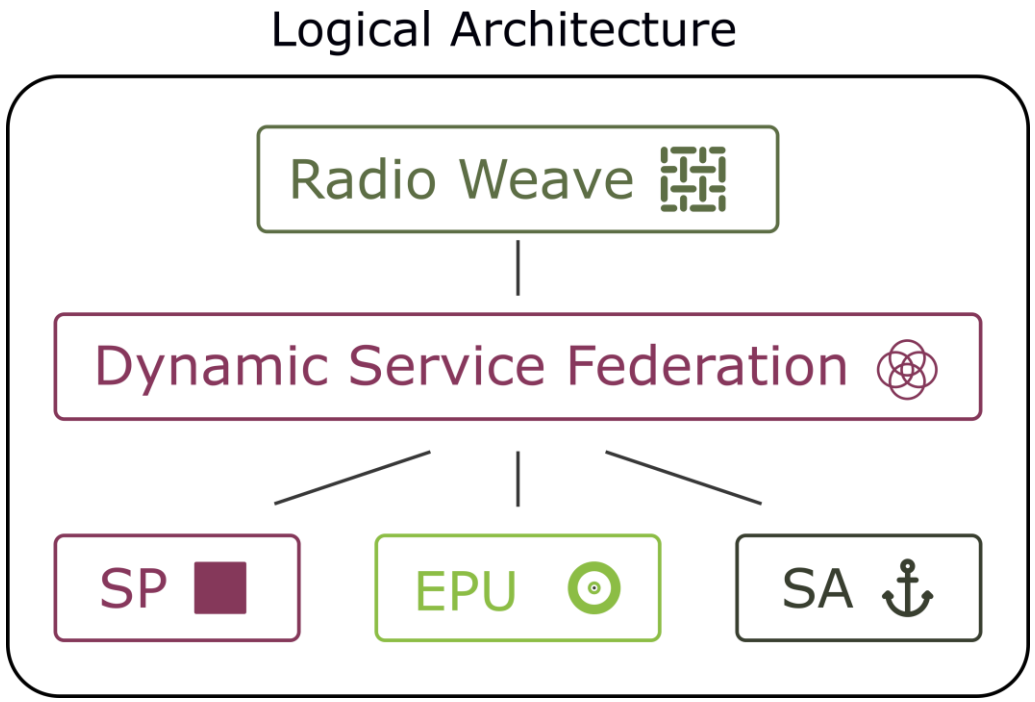


Introducing dynamic federations to cope with heterogeneity and control complexity



A federation establishes a logical architecture in the physical architecture





Sharing ‘one RadioWeave’ and pool of resources
Adapting and co-designing (federation) architecture & algorithms to application cluster needs