Alliance for
Internet of Things
Innovation

IoT and Edge Computing Research and Innovation: Priorities and Synergies with SNS Partnership

Juergen Sturm - AIOTI Management Board Chair

SRIA preparation – Visions for Future Communication Summit – Lisbon 24 & 25 November 2021

AIOTI and 6GIA: Common research topics

- IoT related topics proposed and contributed to NetWorld Europe SRIA 2020 via joint document developed by 6G IA and AIOTI in 2019:
  - ✓ Smart Networks and IoT: Common topics for research and innovation in Horizon Europe
- Additional relevant topics (from draft AIOTI SRIA):
  - ✓ IoT and X-Continuum Paradigm, applied in 6G
  - ✓ Decentralized Distributed IoT Edge Systems applied in 6G infrastructures
  - ✓ Federated Learning and AI for IoT Edge, applied in 6G infrastructures
  - ✓ Digital Twin applied in 6G

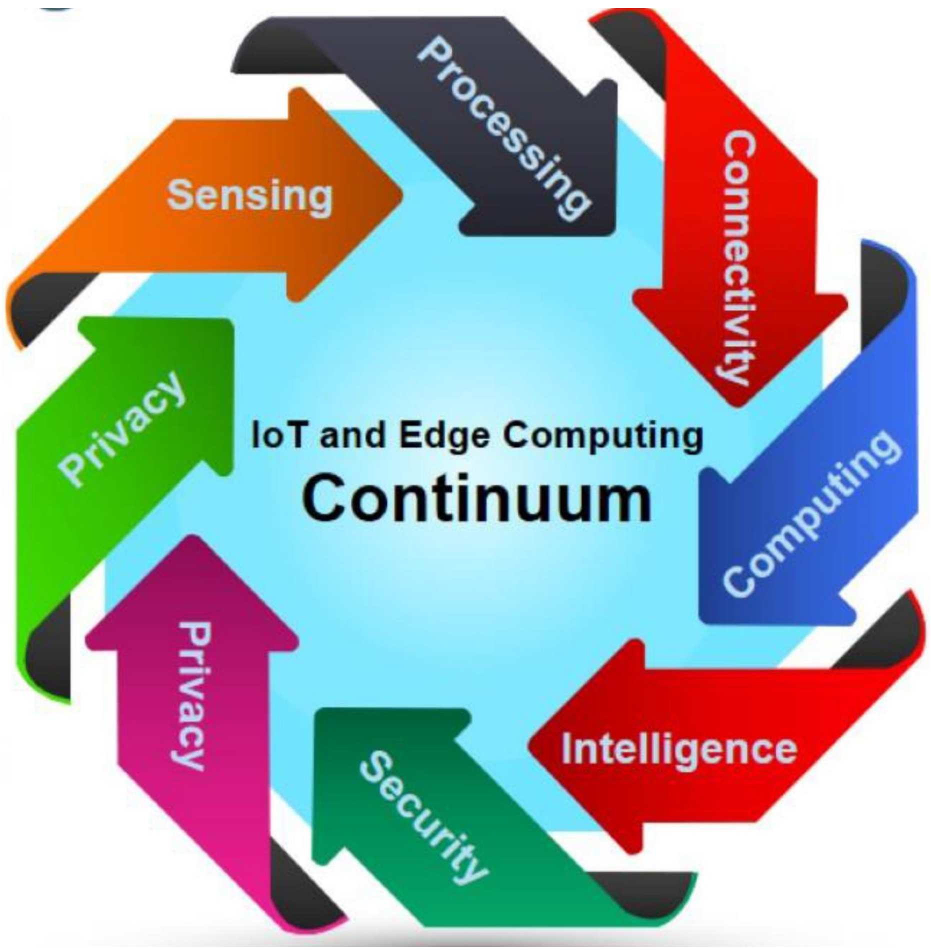
AIOTI

Intelligent Connectivity

- IoT connectivity continuum
- Combination of wireless/cellular, AI and IoT technologies
- Context-awareness capability
- Intelligent device management
- Optimised low and ultra-low latency and faster response
- Optimised bandwidth for real-time data collection and exchange.
- New edge processing approaches for scaling, lower response time and extended coverage.

IoT and X-Continuum Paradigm applied in 6G

- Research on addressing the end-to-end capabilities of IoT technologies across the edge granularity and beyond connectivity, gateways, edge processing, robotics, platforms, applications, AI and analytics
- Continuum of intelligence and IoT edge capabilities
- Continuum of IoT and edge applications across vertical sectors and seamless integration



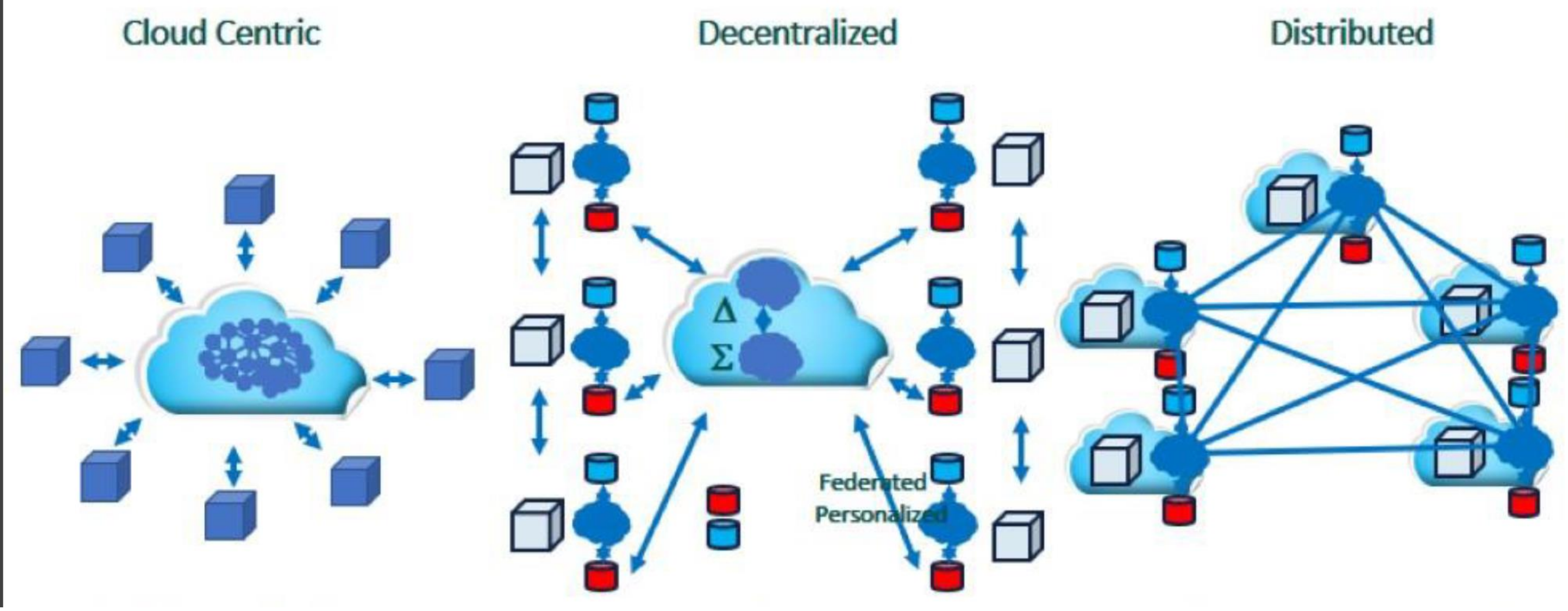
AIOTI

Decentralized Distributed IoT Edge Systems, applied in 6G infrastructures

- IoT architectures applied in 6G, considering the requirements of distributed intelligence at the edge, cognition, artificial intelligence, context awareness, tactile applications, heterogeneous devices, end-to-end capabilities
- Research on distributed intelligence at the edge, cognition, context awareness, tactile applications and integration of heterogeneous.
- Autonomies and distributed intelligence in IoT towards the Internet of Autonomous Things

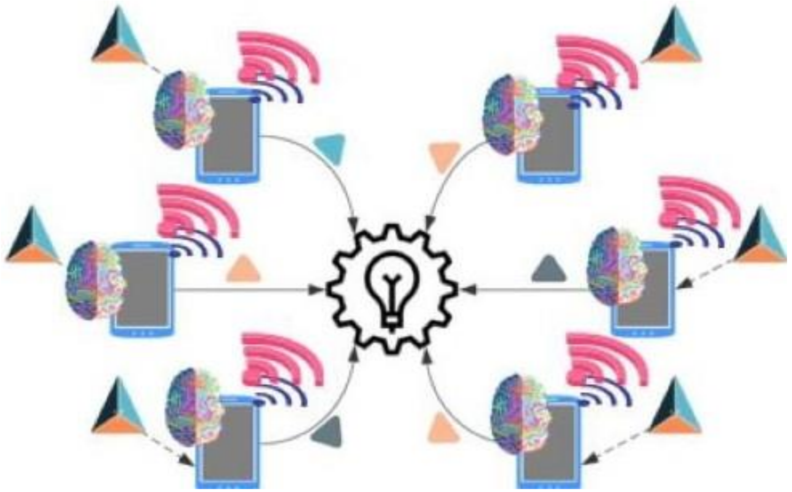
AIOTI

Decentralized Distributed IoT Edge Systems, applied in 6G infrastructures



Federated Learning and AI for IoT Edge, applied in 6G infrastructures

- Federated Learning and Artificial Intelligence for IoT Edge Systems applied in 6G
- Federated Learning brings AI models close to the edge to enhance data protection, improve inference reliability, and increase autonomy of end clusters (e.g., end IoT/IIoT devices, on-premises servers, etc.)
- The cloud plays a federation role for aggregating insights from different IoT edge dîstributed clusters to generate a federated model shared with each individual cluster
- Collaborative work for IoT devices and services discovery, applied in 6G
- Challenges-workflow standardization, interfaces edge/cloud, orchestration, model contamination, and pipes for handling distributed traffic
- Distributed IoT model at horizon, applied in 6G, with embedded AI enabling the shift



Digital Twin applied in 6G

- Virtual representation of IoT devices mirroring the relevant dynamics, characteristics, critical components and important properties of an original physical abject throughout its life cycle. Real-time update based on reliable multi-sense wireless sensing, cyber-physical interaction and reliable wireless control over interaction points where wireless devices are embedded
- Technique for mesh and multi point over the air (OTA) updates/upgrades
- Simulation and modelling tools for large scale of real-time, robust and seamless interactions among, IoT digital twins, humans, machines and environments

Thank you for your attention

Alliance for Internet of Things Innovation

@aioti_eu
www.aioti.eu

ROBUST AND SUSTAINABLE AI FOR 6G NETWORKS

Jordi Serra
PhD, Researcher
CTTC/CERCA

Visions for Future Communications Summit, Lisbon, November 24,25 2021.

Outline

- AI for 6G networks: motivation and pitfalls.
- Sustainable AI for 6G networks
- Robust AI for 6G networks
- Conclusions

AI for 6G networks: motivation and pitfalls.

- AI a key ingredient of the future 6G networks. WHY?
- Stringent KPIs of multiple vertical services increase network complexity

	4G	5G	6G
Peak data rate	1 Gb/s	20 Gb/s	≥1 Tb/s
User-experienced data rate	10 Mb/s	100 Mbit/s	1 Gb/s
Spectrum efficiency	1×	3×	15 – 30×
Mobility	350 km/h	500 km/h	≥1,000 km/h
Latency	10 ms	1 ms	≤100 μs
Connection density (devices/km^2)	10^5	10^6	10^7
Network energy efficiency	1×	100×	100–10,000×
Area traffic capacity	0.1 Mb/s/m^2	10 Mbit/s/m^2	≥1 Gb/s/m^2

KPIs 4G, 5G, 6G [Debbah_2020].

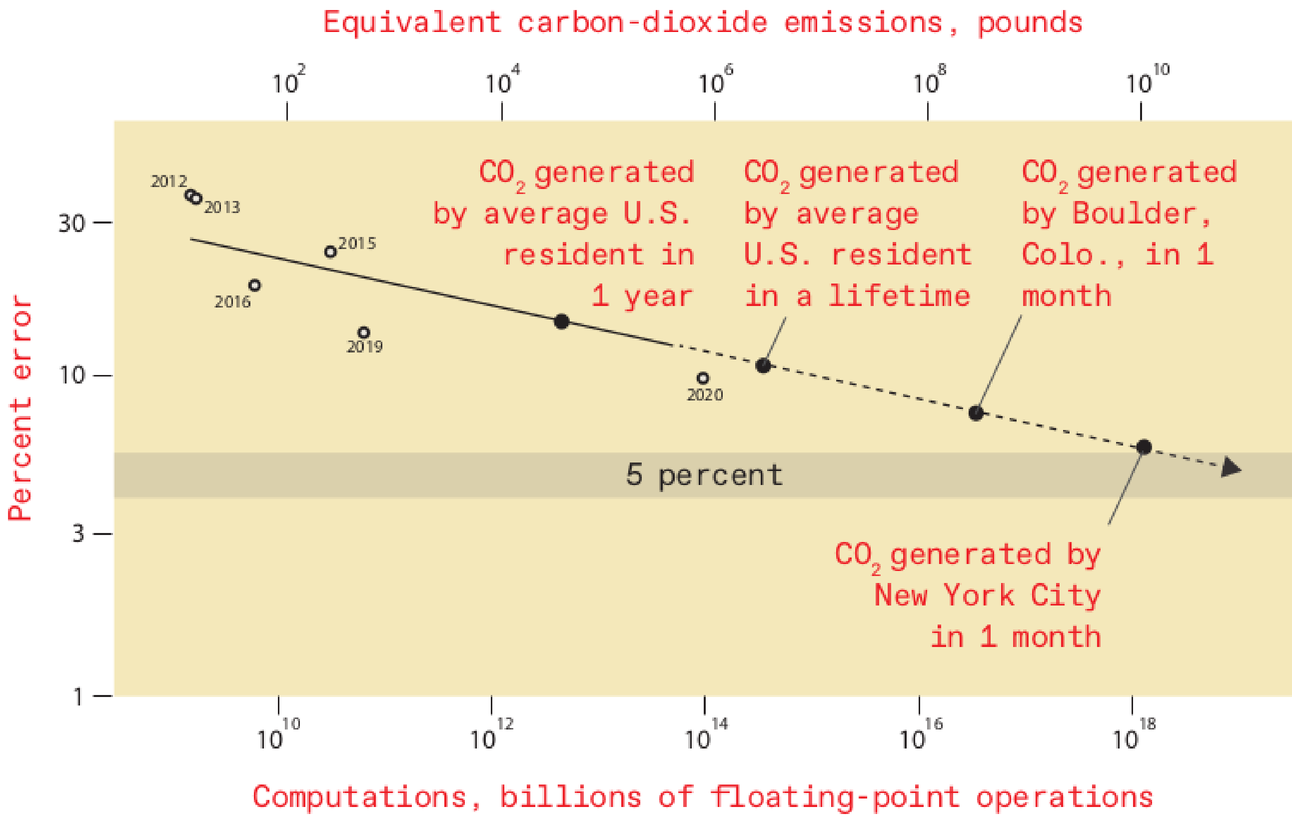
AI for 6G networks: motivation and pitfalls (contd.)

- Model-based approach in 6G too complex.
- Need for self-x networks to reduce CAPEX, OPEX.
- That is the motivation for AI.

- Advantages:
  - Alleviate model complexity
  - Compared to conventional model-based approach:
    - Improved Performance, increase computational efficiency
- Drawbacks:
  - Data-inefficient. **NEED FOR SUSTAINABLE AI**
  - Unstable Performance. **NEED FOR ROBUST AI**
  - Generalization**. NEED FOR SUSTAINABLE, ROBUST AI**

Sustainable AI for 6G networks

- Motivation: SoTA AI require huge amount of data for model training.
- Cost of improving SoTA ML is becoming unsustainable:



Performance improvement vs computation increase [Thompson_2021].

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Research directions for sustainable AI

- Federated learning:
  - Training leverages distributed set of nodes.
  - Each node only uses local samples.
  - [Qiu_2021] FL can be greener than centralized learning (CL):

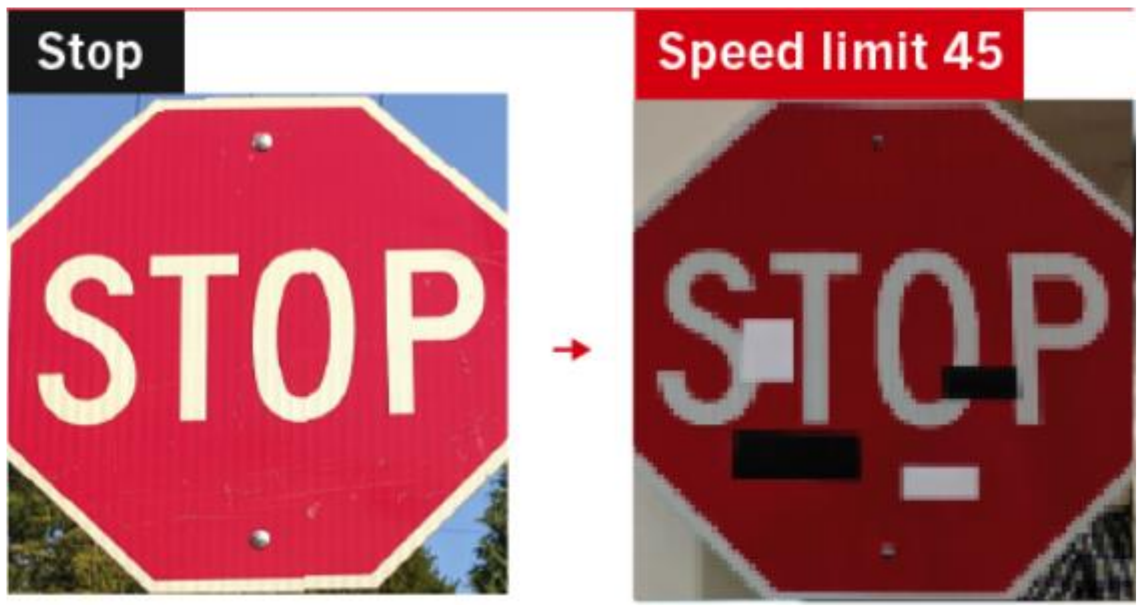
Country/CO2(g)	V100 $PUE = 1.67$	K80	V100 $PUE = 1.11$	K80	FL IID	FL non-IID
USA	1.6	5.2	1.1	3.5	0.5	1.0
China	2.9	9.2	1.9	6.2	0.9	1.7
France	0.2	0.8	0.2	0.5	0.1	0.1

CL vs FL for ResNet-18 on FashionMNIST [Qiu_2021].

- Meta-learning:
  - Learn to generalize with less training samples.
  - Flexible to learn new tasks with few samples.

Robust AI for 6G networks

- Adversarial attacks have shown to degrade SoTA deep learning methods [Heaven_2019].



- Security app in B5G DARLENE

Robust AI for 6G networks

- In 6G may compromise network security / reliability.
- E.g. Adversarial attack on Massive-MIMO CSI feedback [Liu_2020].
- Robustness to adversarial attacks hot topic: e.g. Non-Convex min-max optimization [Hong_2020].

$$\min_{\mathbf{w}} \sum_{i=1}^{N} \max_{\boldsymbol{\delta}: \|\boldsymbol{\delta}_i\| \le \varepsilon} \ell(p(\mathbf{u}_i + \boldsymbol{\delta}_i; \mathbf{w}), t_i).$$

Conclusions

- AI a key ingredient in 6G
- Challenges: Sustainability, robustness
- Seminal research in AI, hot topic for 6G

Thanks for your kind attention!

- Questions?

Jordi Serra
PhD, Researcher
CTTC/CERCA
Email: jserra@cttc.es

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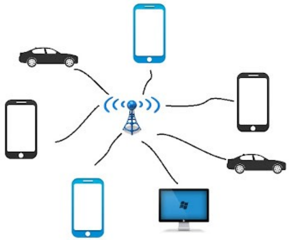
The enablers towards 6G and B6G (Joint Communications & Sensing): materials, electronics and circuits

André Bourdoux

3rd Visions for Future Communications Summit

24-25 November 2021, Lisbon

Key Radio Technologies for wireless communications and active sensing



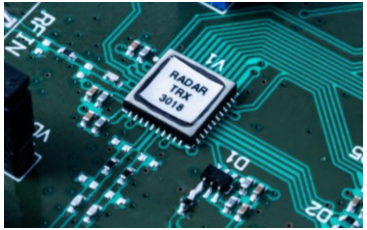
sub-THz

Cell-free massive MIMO

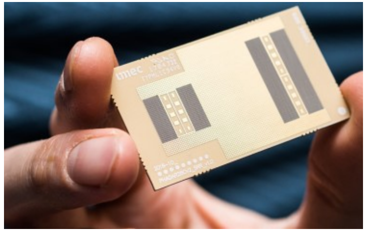
→ Wireless communications

→ Active sensing (= radar)

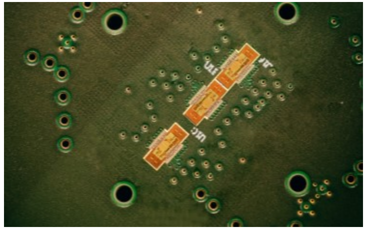
8GHz UWB (CMOS)



79GHz (CMOS)



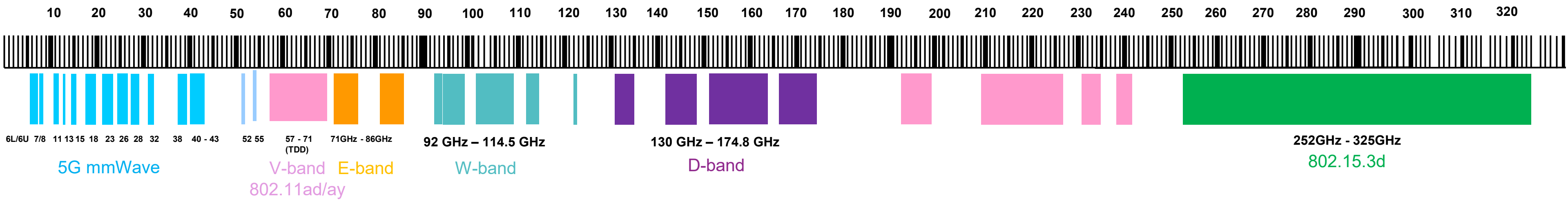
140GHz (CMOS)



sub-THz

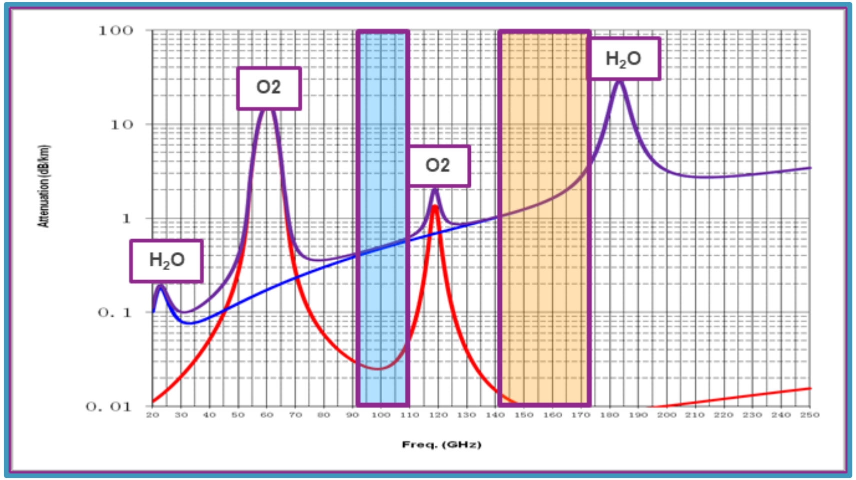
New radio spectrum to meet the 6G capacity Demand

Towards THz frequencies for Tbps wireless connectivity and high-resolution sensing/radar



- Wide bandwidths available at higher frequencies
  - W-band: > 17GHz
  - D-band: > 30GHz
  - 802.15.3d: > 50GHz

$$C = B \cdot log_2\left(1 + \frac{S}{N}\right) \qquad R_{res} = \frac{c}{2B}$$



6G/B6G high capacity applications

Towards wide bandwidth wireless connectivity and high-resolution sensing/radar

Kiosk, automotive data, D2D

vital sign sensing, user tracking

Multi-user AR/VR, holographic display

proximity sensing, people counting and tracking

Fixed wireless access

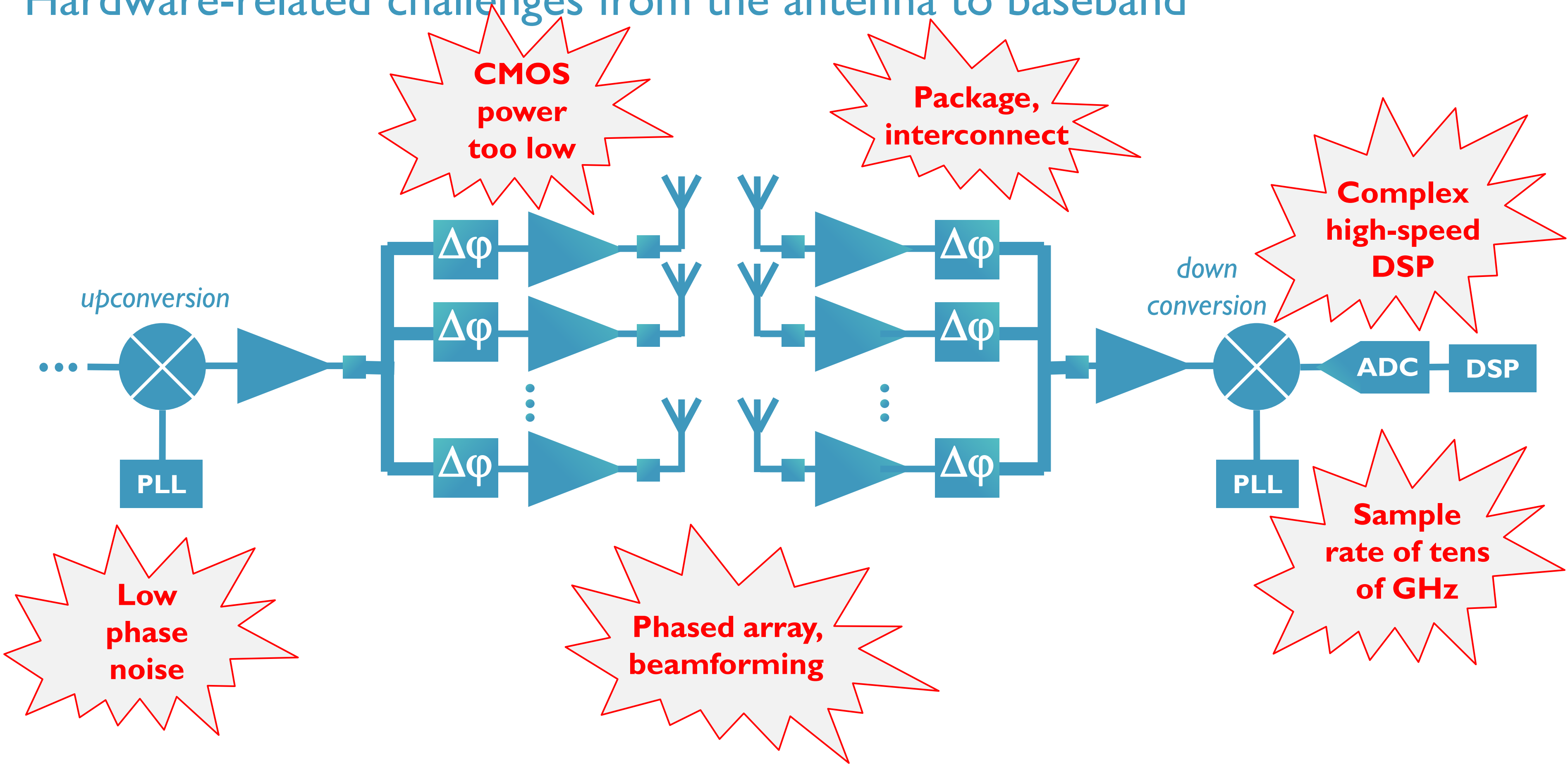
radar detection, terrain mapping

Wireless Backhaul/Fronthaul

Fixed point-to-point links for cellular networks

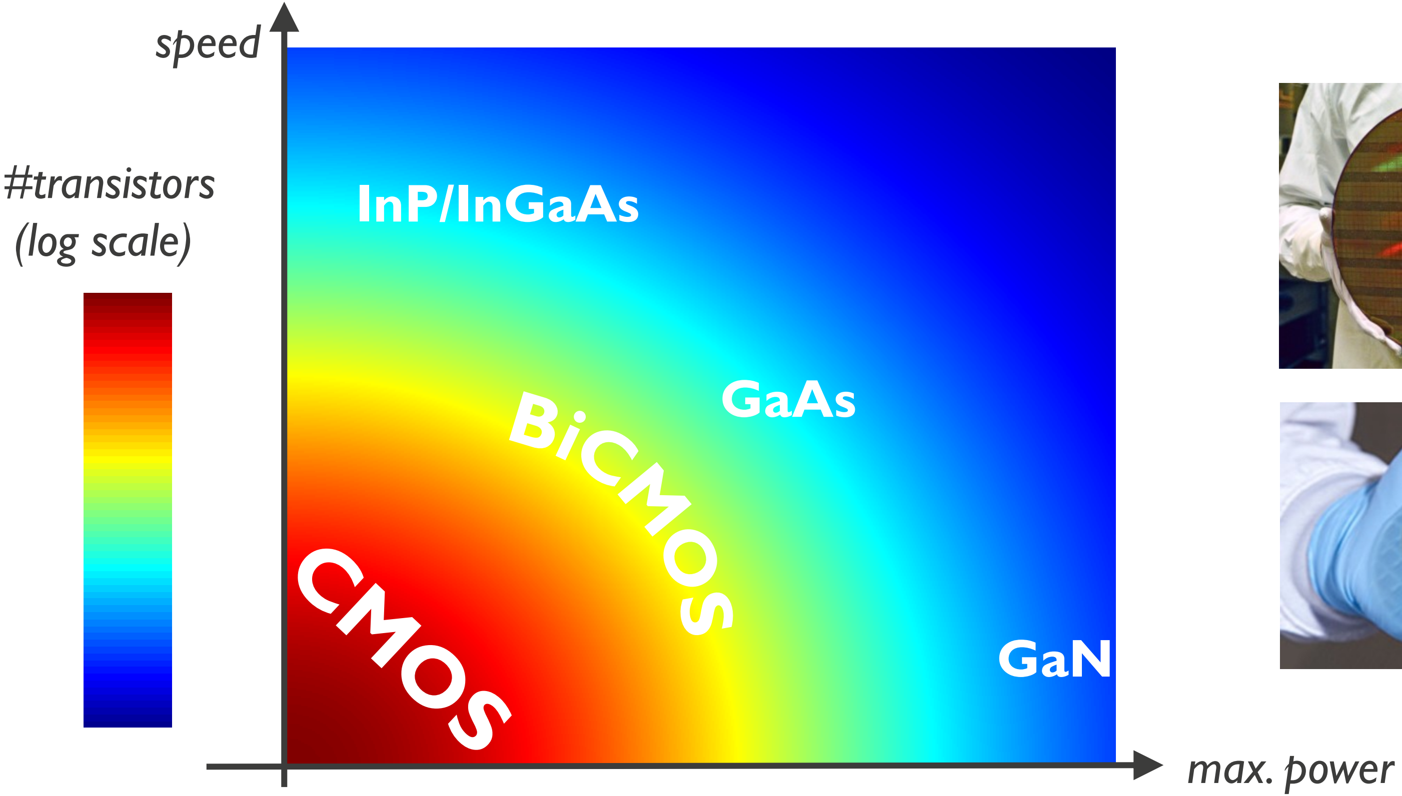
1m — 10m — 100m — >100m

Hardware-related challenges from the antenna to baseband

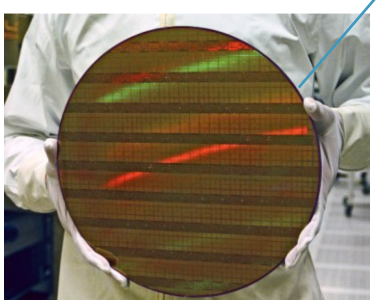


Current landscape in foundry technologies

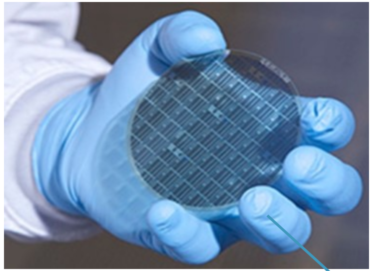
CMOS = density champion, GaN = power champion, InP = RF frequency champion



300 mm wafer



CMOS



III-V

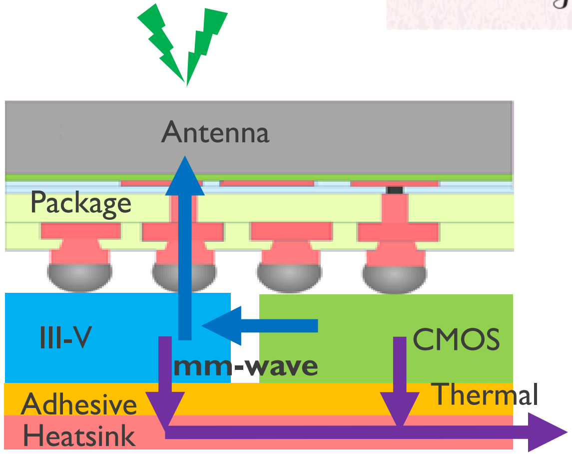
10 or 15 mm wafer

III-V technologies use very few metals (gold)

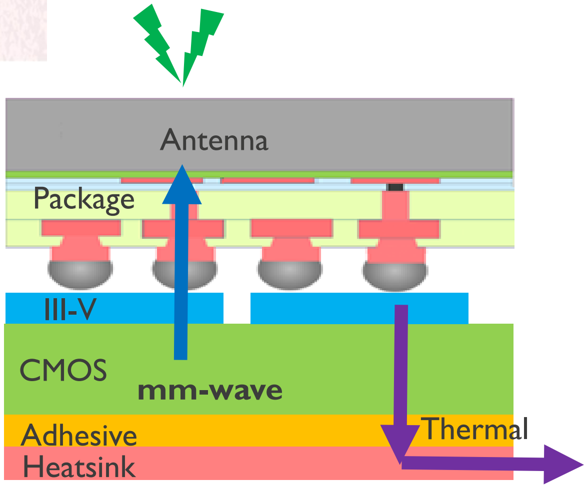
CMOS & InP Integration challenges

- Three dedicated paths needed:
  - Radiation from top
  - Heat removal from bottom
  - Signal routing in between

- Common Challenges > 100 GHz
  - Dimensions below 50-100 µm (bumps, vias, interconnect traces/spacing, ...)
  - Routing of large number of connections (RF/DC/IF/Digital)



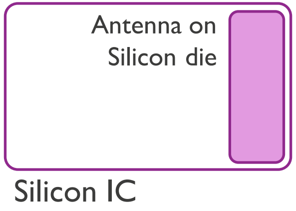
- 2D chip integration
  - 1D Beam-steering
  - Thermal solution using bottom contact



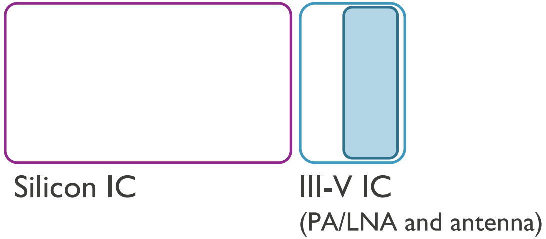
- 3D chip integration
  - 2D Beam-steering
  - Complex packaging
  - Thermal design more challenging

Chip-antenna co-design above 100GHz

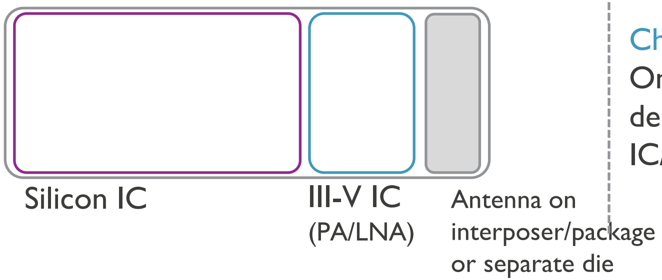
EM and thermal challenges



Challenge:
On-chip antenna design in CMOS

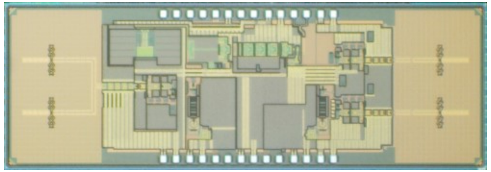


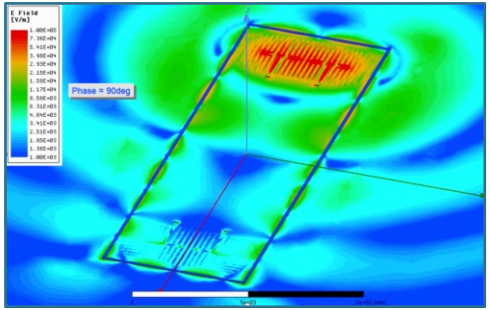
Challenge:
On-chip antenna design & low-parasitics IC/IC interconnect



Challenge:
On-interposer antenna design & low-parasitics IC/IC interconnect

140 GHz FMCW radar, 10GHz BW, with antenna on chip, in standard 28 nm CMOS (3 dB gain, 11dBm EIRP, 1 mm^2 area)





ADCs

- Baseband bandwidths grow to tens of GHz
  - ADCs in the tens of Gsps range are needed
  - Initially low spectral efficiency is required
  - But eventually move to ~64QAM or so → ~7 to 9 bits

Cell-free massive MIMO

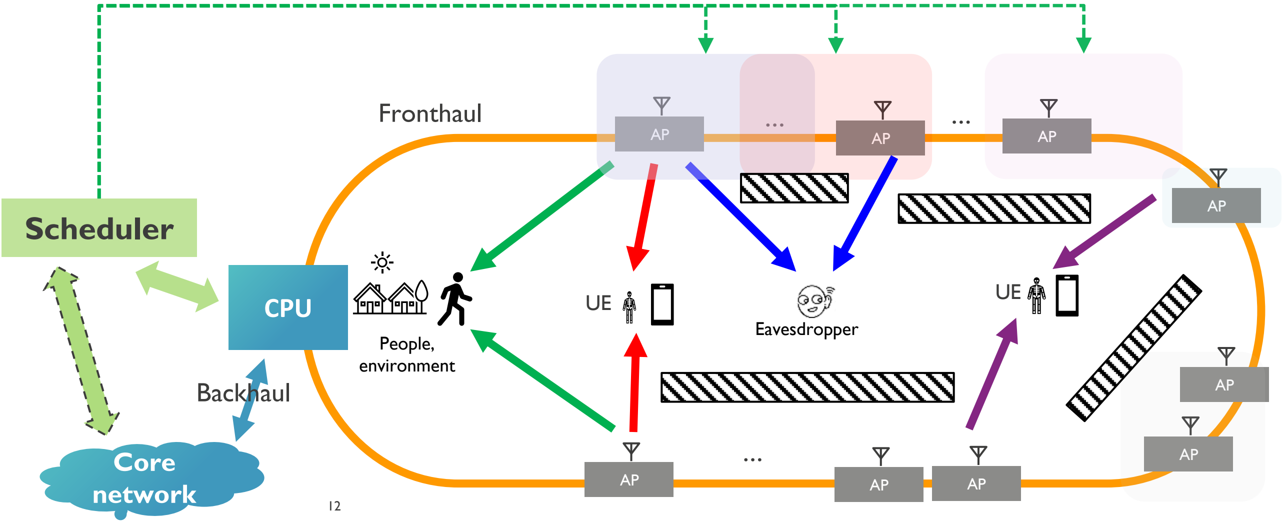
Distributed or cell free massive MIMO

From "BS-centric" to "User-centric" → Deterministic wireless!

- Large number of access points (AP) or base stations (BS) distributed in the environment
  - High reliability and availability
  - Extreme coverage, no cell edges, no inter-cell interference
  - Versatile operating modes
  - Frequency can be from sub-10GHz to sub-THz

Radio access slicing determines the operating mode(s) of each AP/BS:
Connectivity
Security
Radar
Positioning (ToF, AoA,…)
…

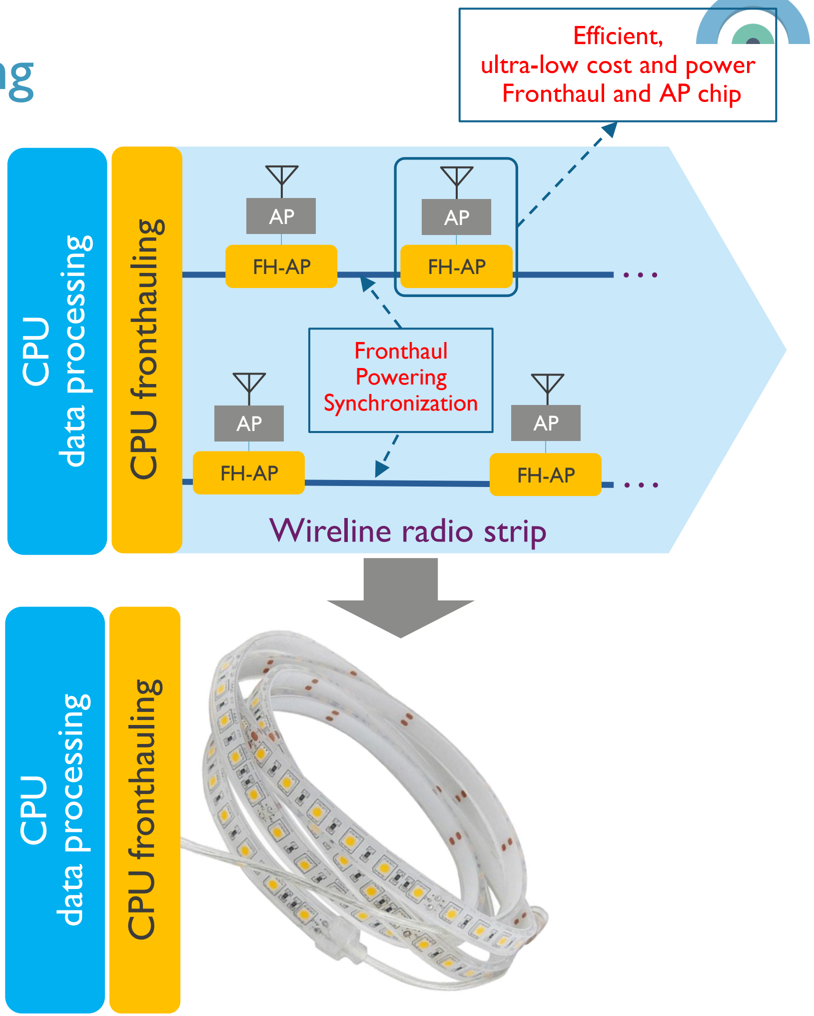
- Challenges:
  - Carrier and clock synchronization
  - CPU complexity
  - Accurate AP/BS localization
  - Large trade-off space: slicing, scheduling, complexity
  - Power consumption and power distribution
  - Moving to mm-wave/sub-THz
  - Cost



umec

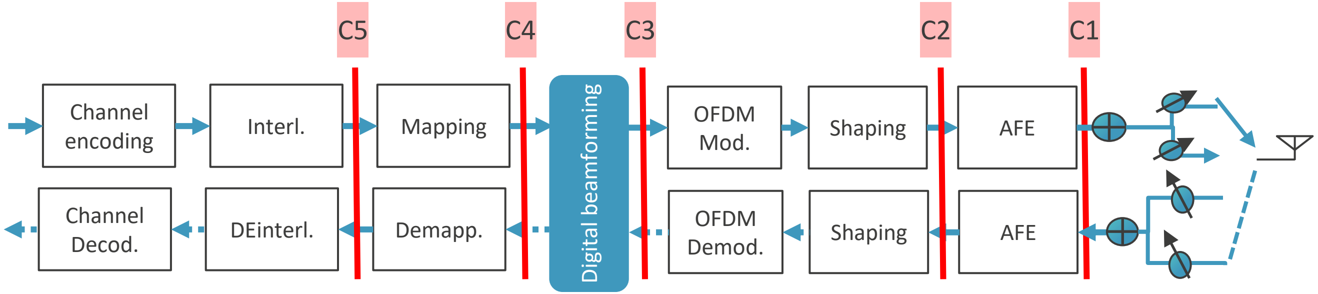
Cell-free massive MIMO APs and fronthauling

- Ultra low cost, low power AP Front-end (CMOS)
- High-speed fronthauling:
  - Optical vs wireline
  - Time-sensitive fronthauling
  - Power distribution
  - Multi-AP synchronization



CF-mMIMO Functional Split

Slicing has profound impact on hardware requirements!



Trade-offs

Low — Fronthaul bandwidth/complexity/cost — High

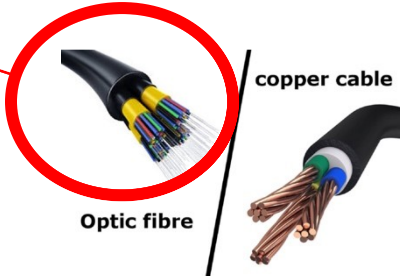
High — AP complexity/cost — Low

Fast (real-time) — Processing delay — non-ideal delay

Low — Synchronization accuracy — High

Low — CPU Complexity — High

X TCMACs in CPU
Memory requirements



Complexity

Complexity: some orders of magnitude

- Cell-free massive MIMO:
  - Serial Fronthaul: multi-Terabit/s
  - CPU: multi-TeraCMAC/s
- Sub-THz connectivity:
  - DSP: several tens of TeraCMAC/s
- Radar imaging or range-Doppler-angle processing:
  - DSP: several TeraCMAC/s

We need high-performance, energy-efficient, low-cost
CPUs, GPUs, TPUs, DSPs, ASICs, SoCs
… and storage (memories)

Conclusions

Key research areas for sub-THz and cell-free mMIMO

Materials, electronics and circuits

- Sub-THz
  - High carrier frequency, wide bandwidth using CMOS + InP
  - Phased arrays, beamforming
  - Chip-interposer-antenna technologies
  - Tens of Gsps ADCs
- Cell-free massive MIMO:
  - AP front-end (integrating Fronthaul & Wireless functionality)
  - Serial fronthaul (high capacity, tight synchronization)
- For both
  - High-performance processing and storage

Low power
Low cost
Mass-producible

embracing a better life

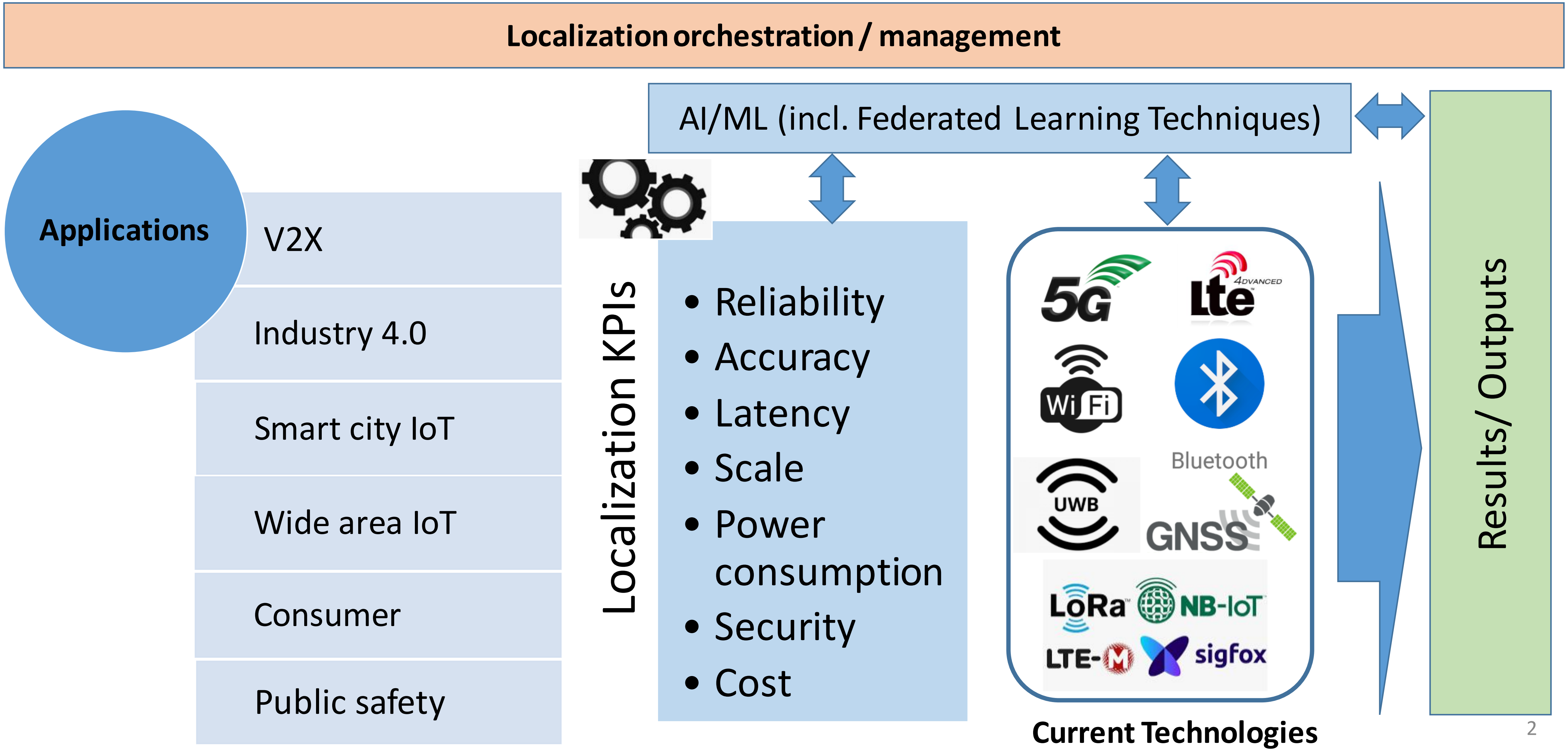
LOCUS 5G

Multi-dimensional Optimization of Localization in 6G

Mythri Hunukumbure - SAMSUNG (LOCUS - WP3 lead)

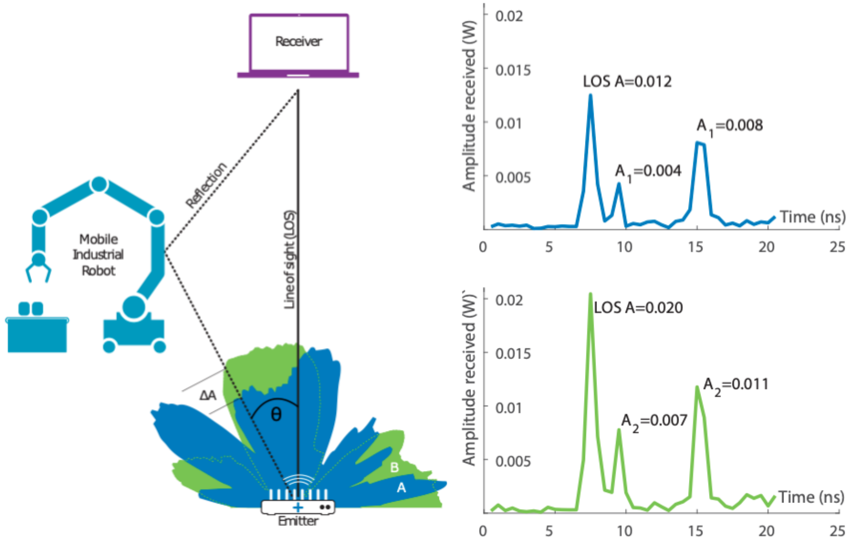
https://www.locus-project.eu/

Multi-dimensional Orchestration for Localization



New Localization Research areas for 6G

- Device Free Localization
  - Use of ‘radar-like’ sensing with mm-wave and THz bands.
  - Use of wider bandwidths and pencil beams for precision.
  - Imaging capabilities of THz enables accurate sensing.
- Phase based localization methods
  - Used traditionally in Sat Com but prone to larger delays.
  - NLOS paths in Cellular and other land based comms - a major obstacle.



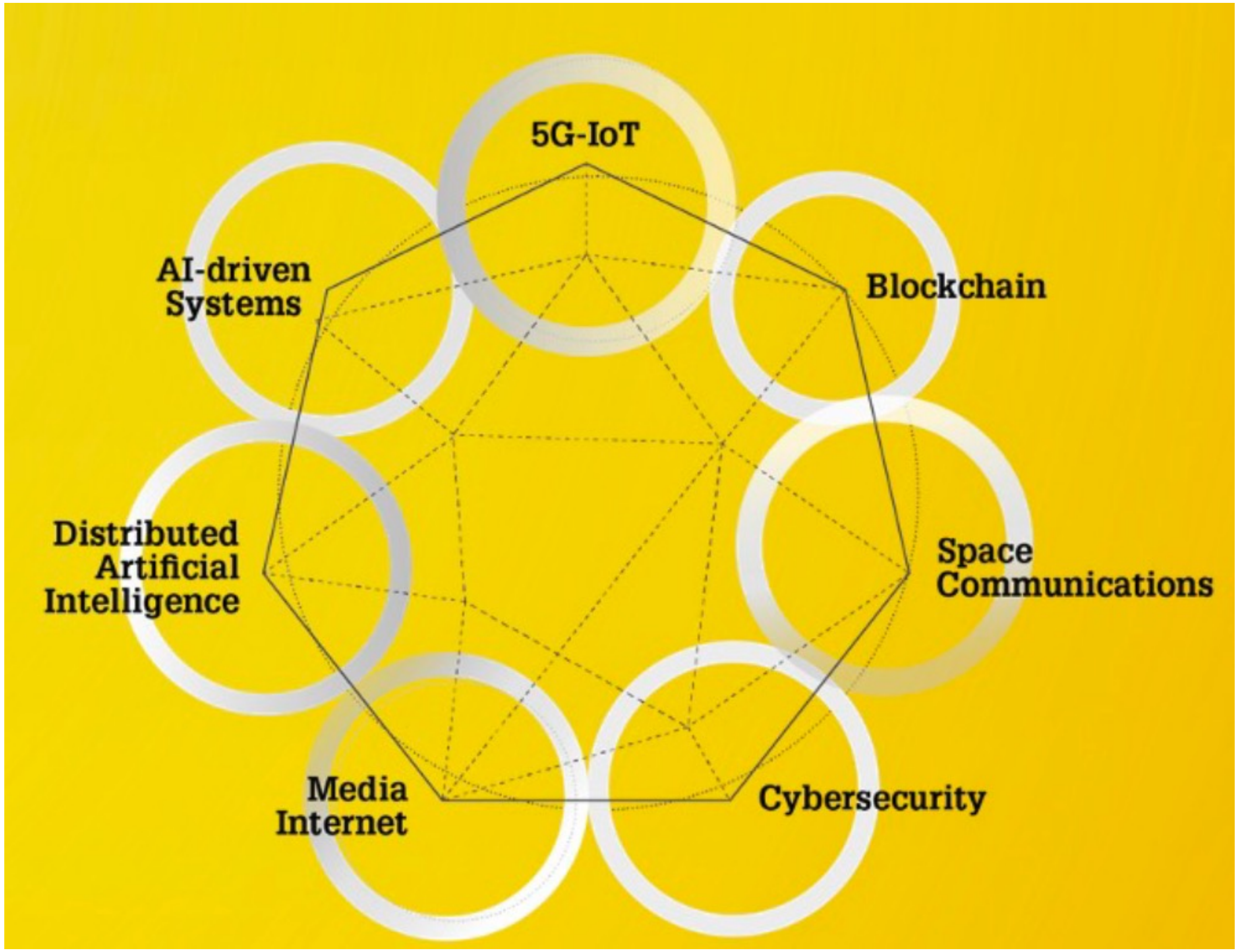
  - Use of NR-sidelink and RIS (Reconfigurable Intelligent Surfaces) potentially can overcome these.
- AI/ML techniques in multiple domains
  - From improving accuracy in estimates (post-processing) to extracting more knowledge from the radio environments to aid multiple other applications and processes (eg: network management, slice configuration).

6G Enabling Technologies: An i2CAT's perspective

November 2021

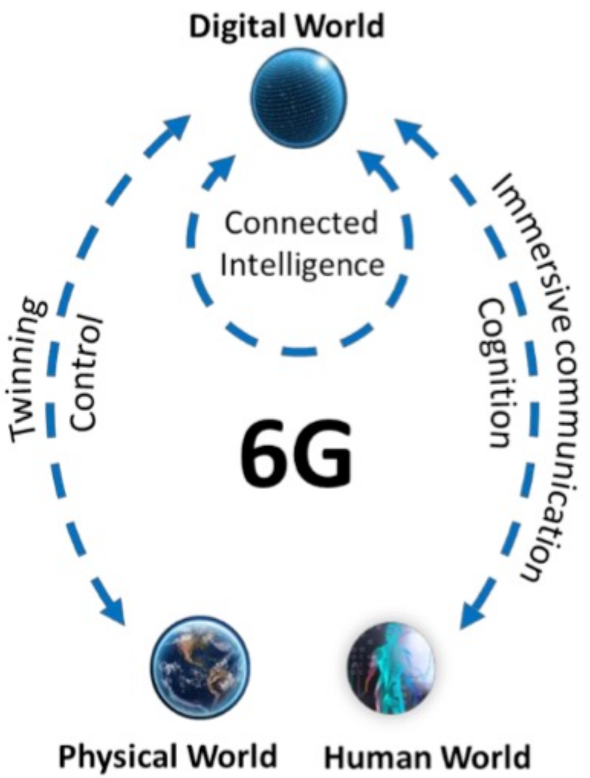
Jesus Alonso-Zarate, PhD, MBA
Deputy Director
EC Research & Innovation Policy and Strategy

www.i2CAT.net


5G-IoT
Blockchain
Space Communications
Cybersecurity
Media Internet
Distributed Artificial Intelligence
AI-driven Systems

Convergence of 3 Worlds: Connecting Intelligence(s)

- 6G will be about bringing the physical objects to the digital world through creating **digital twins** that allow real-time control and monitoring of everything.
- 6G will be about **bringing human beings to the digital world** through truly immersive experiences that create a parallel reality for humans; the so-called **metaverse**.
- 6G will be about **connecting all intelligent objects and people**, creating a network of intelligences and allowing technology to “disappear” from our lives and become part of them.



Source: https://5g-ppp.eu/wp-content/uploads/2021/06/WhitePaper-6G-Europe.pdf

6G: Strategic Technology Areas

OBJECTIVE: Satisfy the needs of society by 2030

Human and Evironmental-Centric Approach: Digital Social Technology

- Cyber Security & Trust
- Cloud Continuum: Intelligence Everywhere
- Intelligent Open Networks: networks which can learn
- Disruptive Wireless Technologies: ex: smart surfaces.
- Non-Terrestrial Networks: massive coverage
- Optical Networks
- Devices and Components

New Use Cases

Co-Creation with Users and Vertical Industries

6G: The Essential Vision

Human-Centric Technology Design

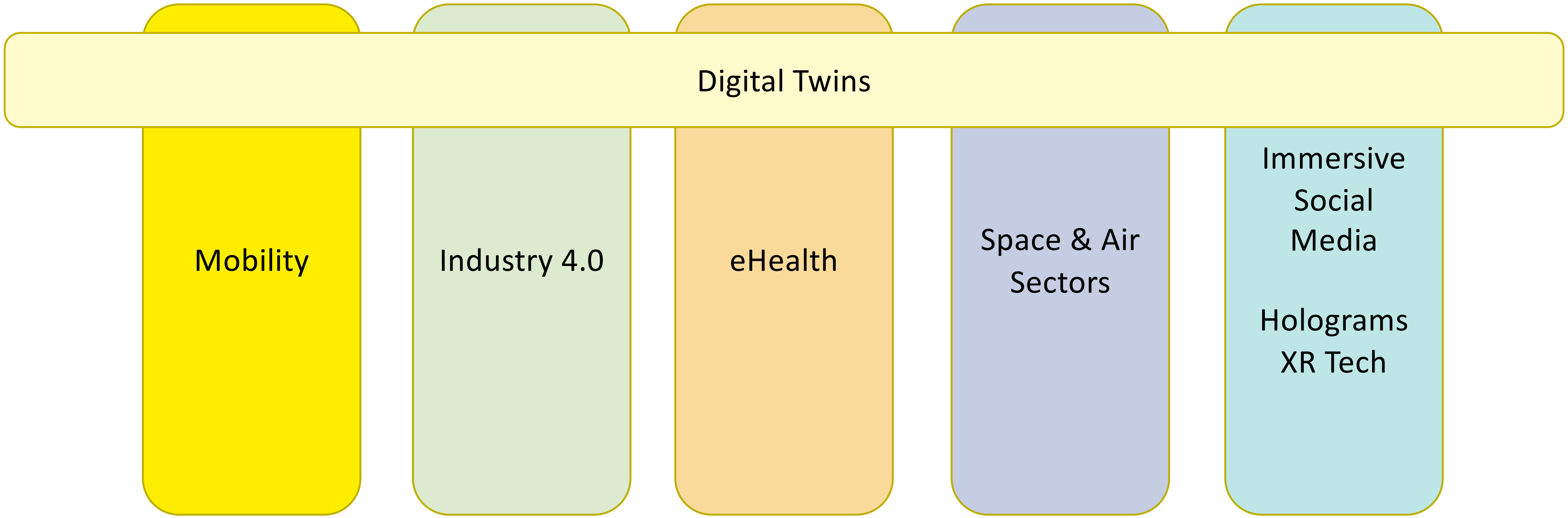
Security by Design

Artificial Intelligence by Design

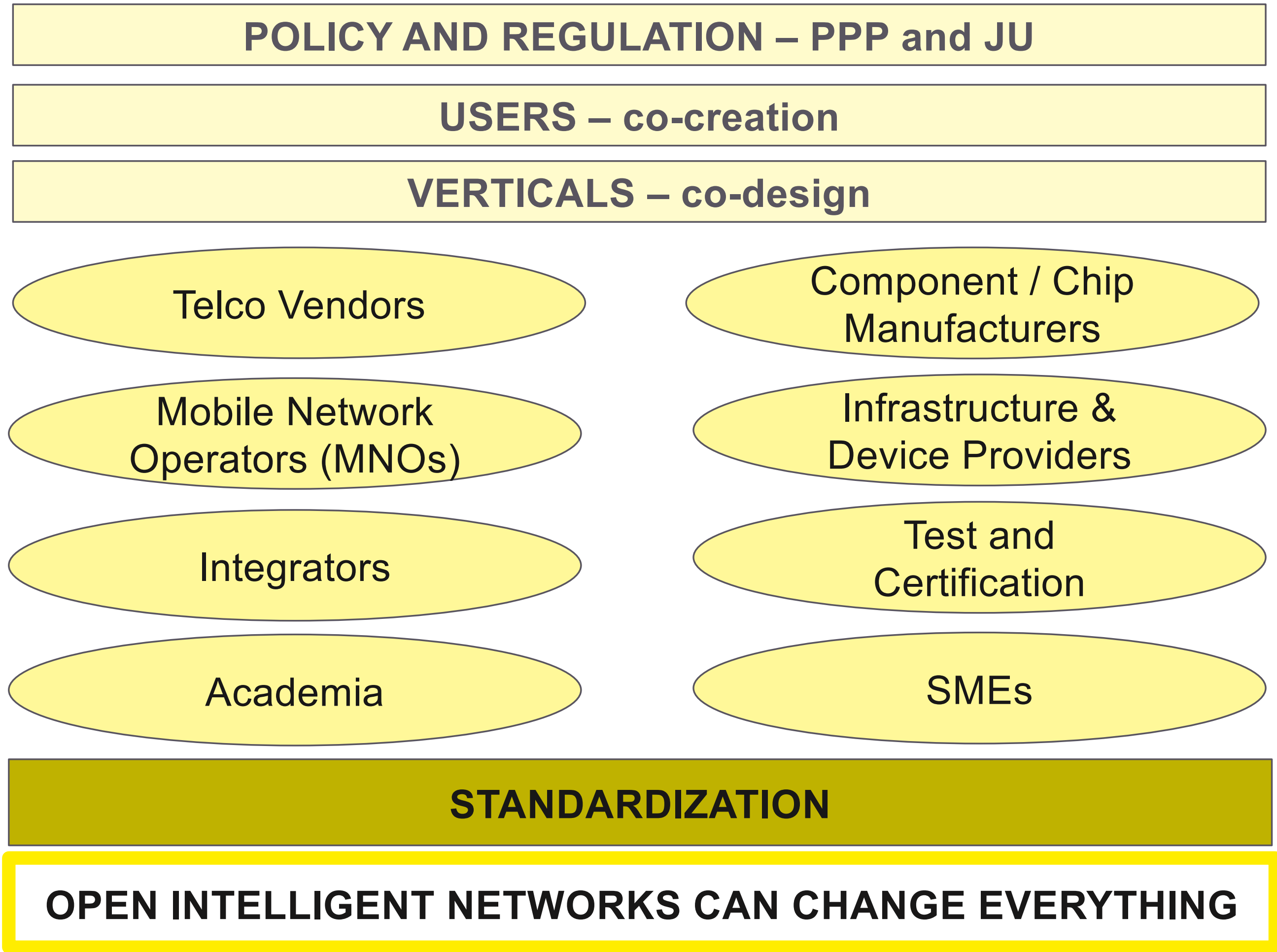
Ubiquitous Coverage: everyone and everything connected

Merge of physical and digital worlds

6G: Some Key Verticals



The Players


POLICY AND REGULATION – PPP and JU
USERS – co-creation
VERTICALS – co-design
Telco Vendors
Component / Chip Manufacturers
Mobile Network Operators (MNOs)
Infrastructure & Device Providers
Integrators
Test and Certification
Academia
SMEs
STANDARDIZATION
OPEN INTELLIGENT NETWORKS CAN CHANGE EVERYTHING

Call for action

Let’s build the future together.

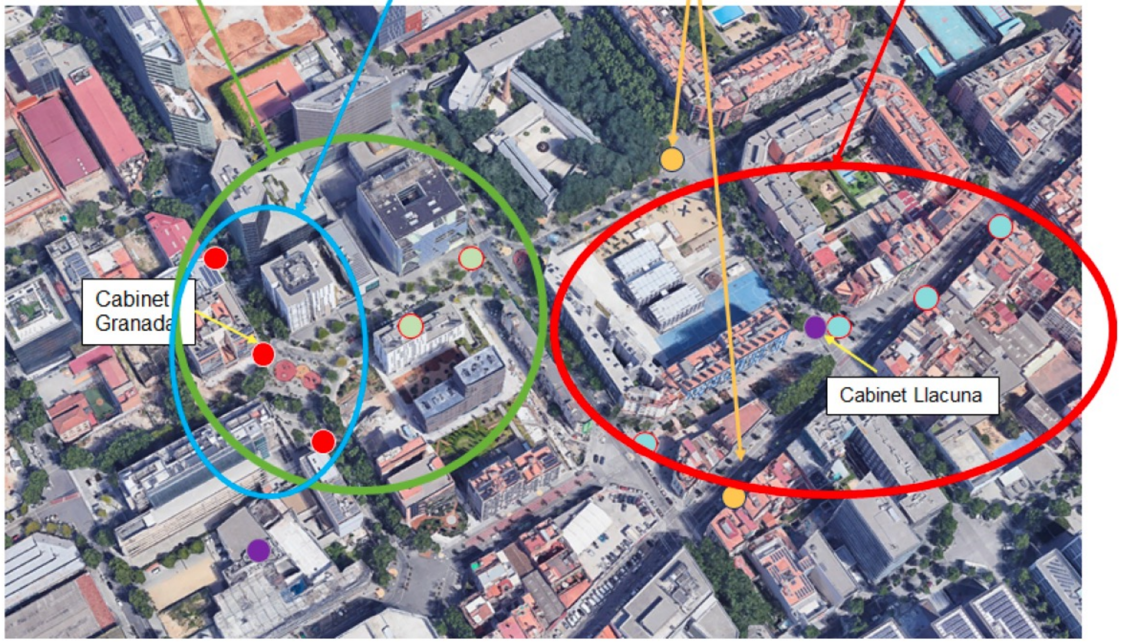
If we don’t build the future, others will do.

Test in Barcelona: CCAM Projects, edge computing, cybersecurity, orchestration, etc.

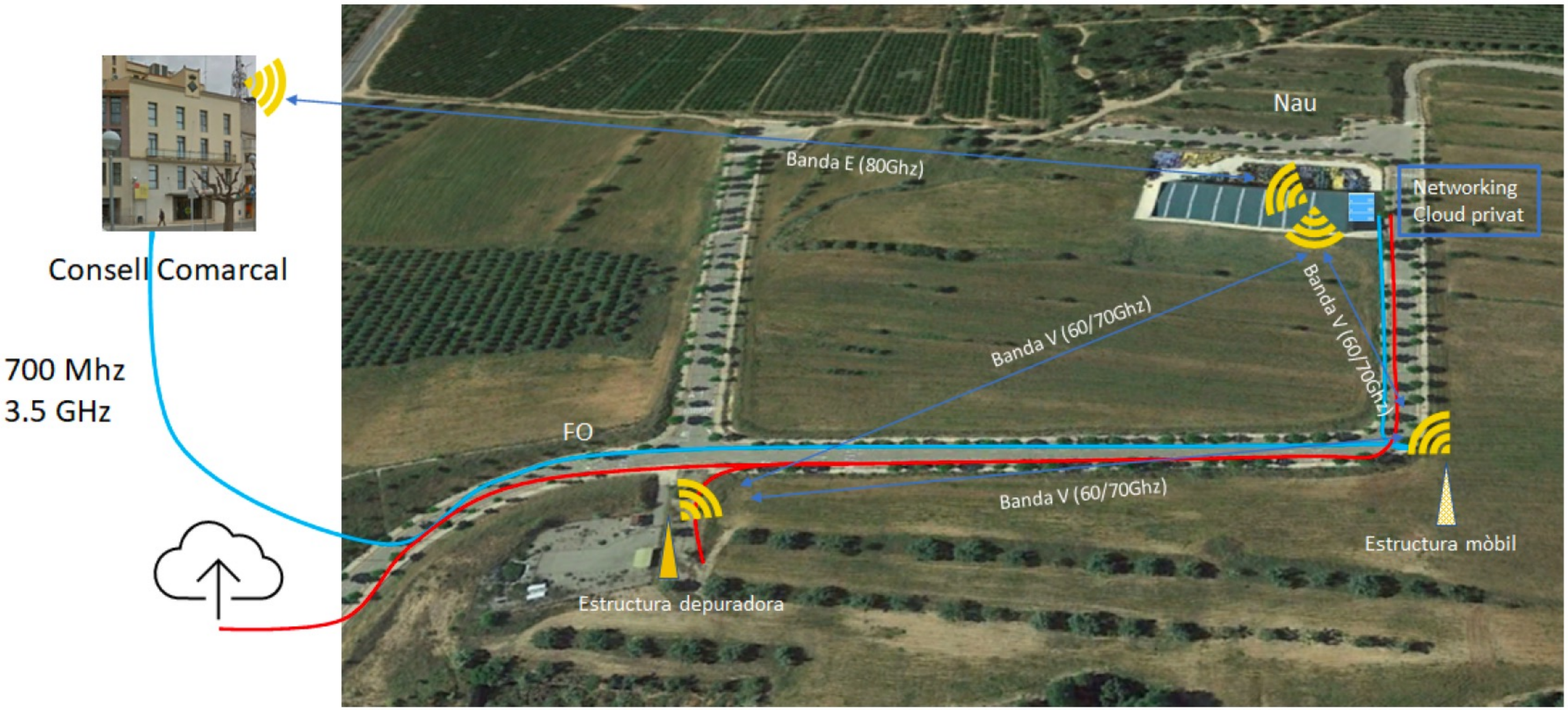
i2CAT Cloud Servers

Edge Server

- Small Cell (5G)
- Wi-Fi6
- Empty Post, available
- Empty, not in use
- Edge Compute



Test in rural areas: NTN networks and a free area for all kind of 6G testing



Test in the Space: access to cubesats with own infrastructure

Test in the metaverse

Jesus Alonso-Zarate, PhD, MBA

Deputy Director

EC Research & Innovation Policy and Strategy

i2CAT Foundation

http://www.jesusalonsozarate.com

@jalonsozarate