EUCNC | 6G Summit
Gothenburg, Sweden ▪ 6-9 June 2023

# Future deterministic programmable networks for 6G

6 June 2023 - from 14:00 to 17:30

**Organized by:**

PREDICT-6G DETERMINISTIC6G DESIRE6G

Funded by the European Union

# Workshop scope and supporting EU Projects

- The Workshop introduces new technologies towards improving the programmability and determinism of 5G/6G networks.

- 6G-IA SNS programme has funded three projects in this area:
  - DETERMINISTIC-6G: Deterministic end-to-end communications with 6G
  - DESIRE6G: Deep programmability and secure distributed intelligence for real-time end-to-end 6G networks
  - PREDICT-6G: Programmable AI-enabled deterministic network for 6G

# Agenda

**14:00 - 14:05** Workshop introduction

**14:05 - 14:25** DESIRE6G introduction (Chrysa Papagianni)

**14:25 - 14:45** DETERMINISTIC6G introduction (Dhruvin Patel)

**14:45 - 15:05** PREDICT-6G introduction (Antonio de la Oliva)

**15:05 - 15:30** Coffee Break

**15:30 - 16:00 Keynote** “5G-ACIA: learnings on 5G for industries” (Afif Osseiran)

**16:00 - 16:20** End-to-end data plane abstraction for supporting deep slicing in 6G (Sandor Laki)

**16:20 - 16:40** Data driven aspects for 6G deterministic communication (James Gross)

**16:40 - 17:00** Can TSN be the standard communication protocol for robotics? (Milan Groshev)

**17:00 - 17:30 Panel** with audience involvement (Chair Valerio Frascolla)

DESIRE6G

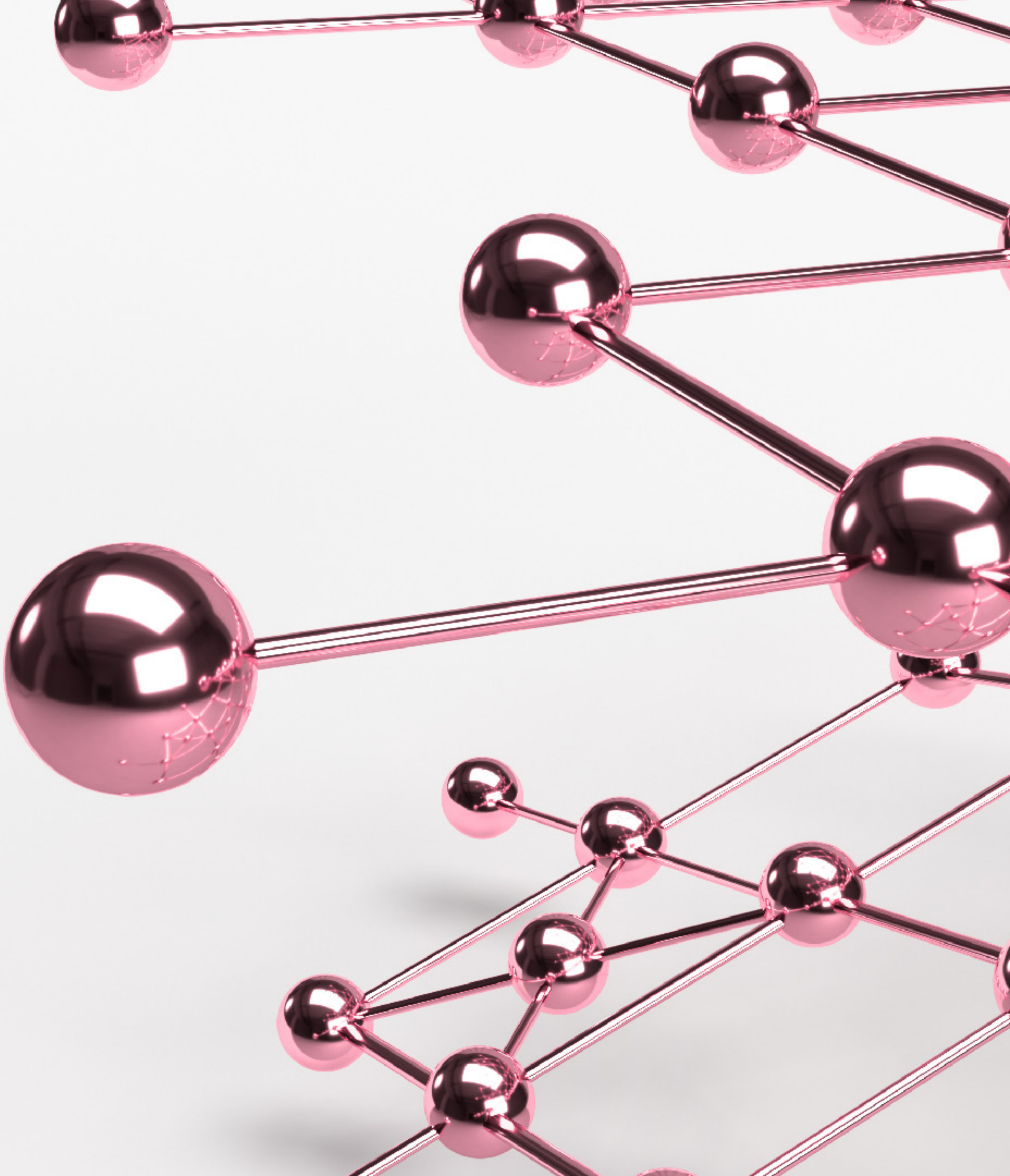
# EMPLOYING DEEP PROGRAMMABILITY AND DISTRIBUTED INTELLIGENCE FOR REAL-TIME 6G NETWORKS

Chrysa Papagianni, assistant professor

Multi-scale Networked Systems, Informatics institute, University of Amsterdam

Co-funded by the European Union

6GSNS



# DEEP PROGRAMMABILITY & SECURE DISTRIBUTED INTELLIGENCE FOR REAL-TIME END-TO-END 6G NETWORKS

**Project coordination:**
University of Amsterdam

**Technical coordination:**
Ericsson Hungary

**Duration:**
01/01/2023 - 31/12/2025

**Total Cost:**
6.227.919€

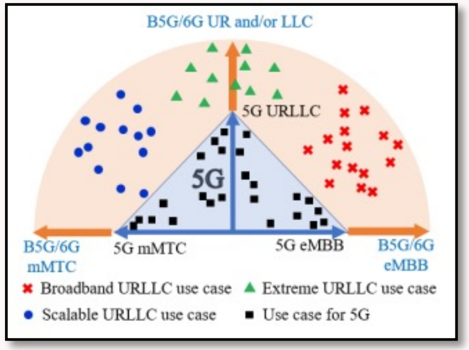
Universiteit van Amsterdam
NUBIS
Universitat Politècnica de Catalunya BarcelonaTech
Ericsson
NEC
University of Oulu
CNIT
Telefónica
ELTE Eötvös Loránd University
NVIDIA
uc3m Universidad Carlos III de Madrid
Accelleran
Sant'Anna Scuola Universitaria Superiore Pisa
Solid Shield

**Follows us on:** desire6g.eu @DESIRE6G_EU @DESIRE6G

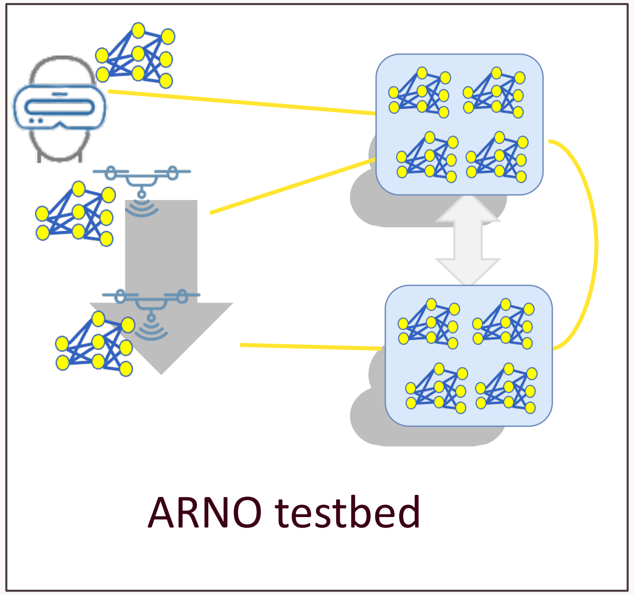
# PROJECT SCOPE & OBJECTIVES

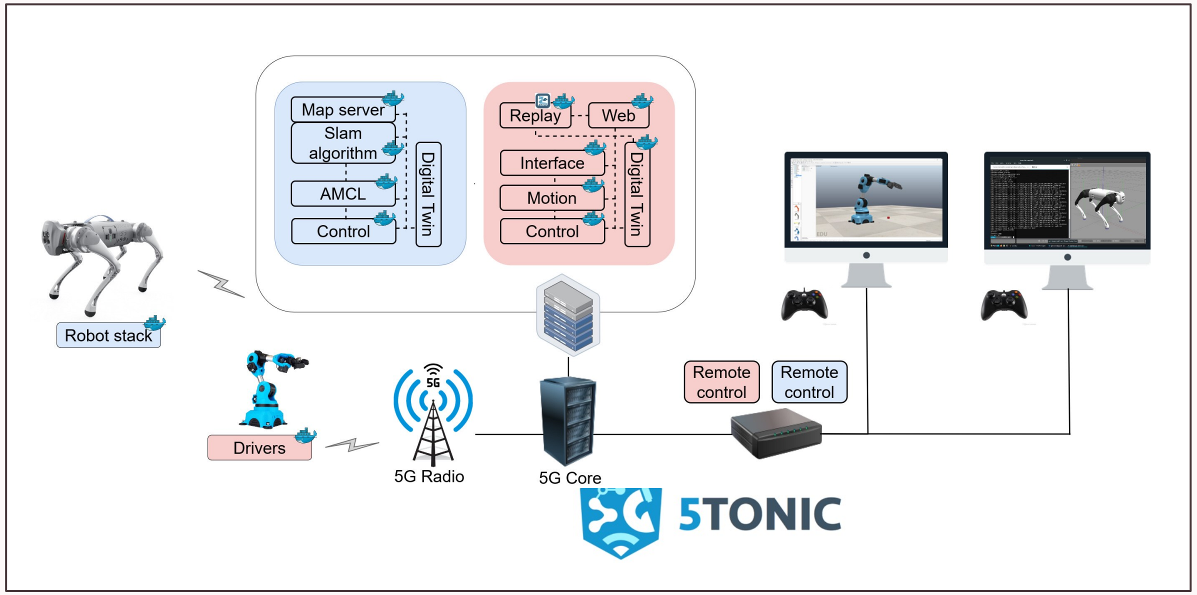
- Zero-touch control, management & orchestration platform, with native integration of AI, to support eXtreme URLLC requirements over a performant, measurable & programable data plane.

- Use cases: AR and a Digital Twin application at two distinct experimental infrastructures.



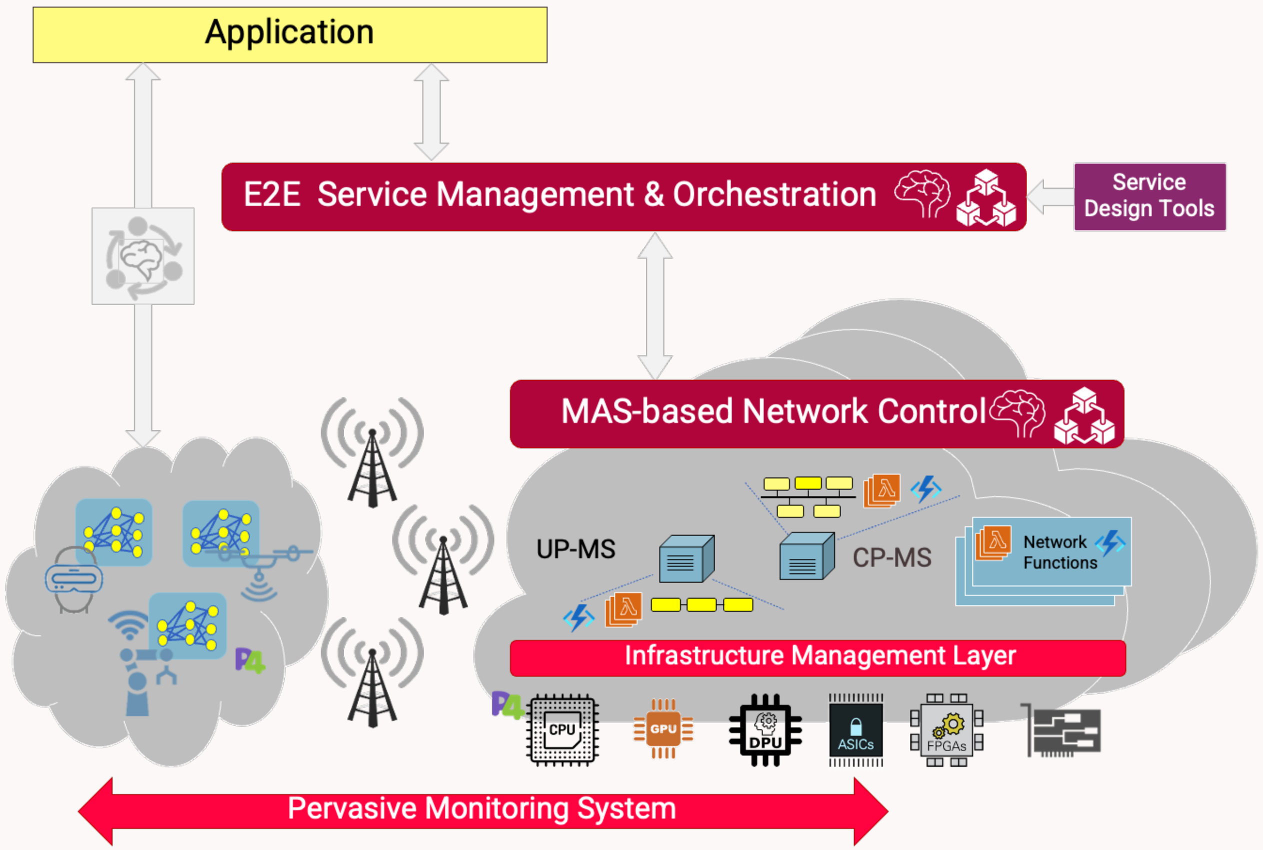

URLLC evolution and new service classes [1]




[1] Alves H. et al. "Beyond 5G URLLC evolution: New service modes and practical considerations." ITU Journal on Future and Evolving Technologies, 2022.

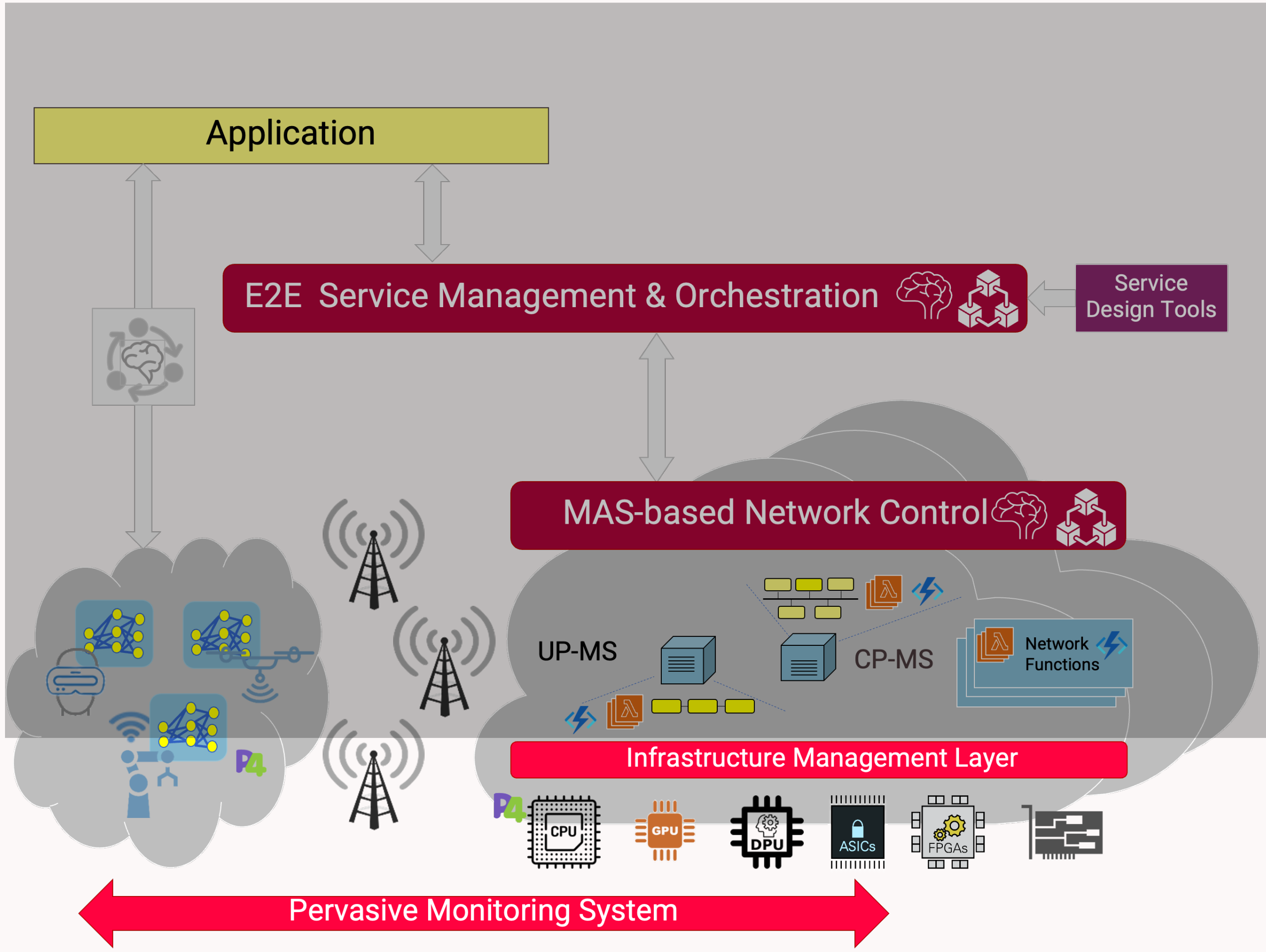
# D6G KEY INNOVATIONS




Innovation

- xURLLC services
- Edge Intelligence
- Intent-based orchestration
- Blockchain-based federation
- Secure distributed intelligence
- RAN-core convergence
- Edge-to-Cloud continuum
- Serverless architecture
- E2E programmable data plane
- Multi HW acceleration
- E2E network telemetry

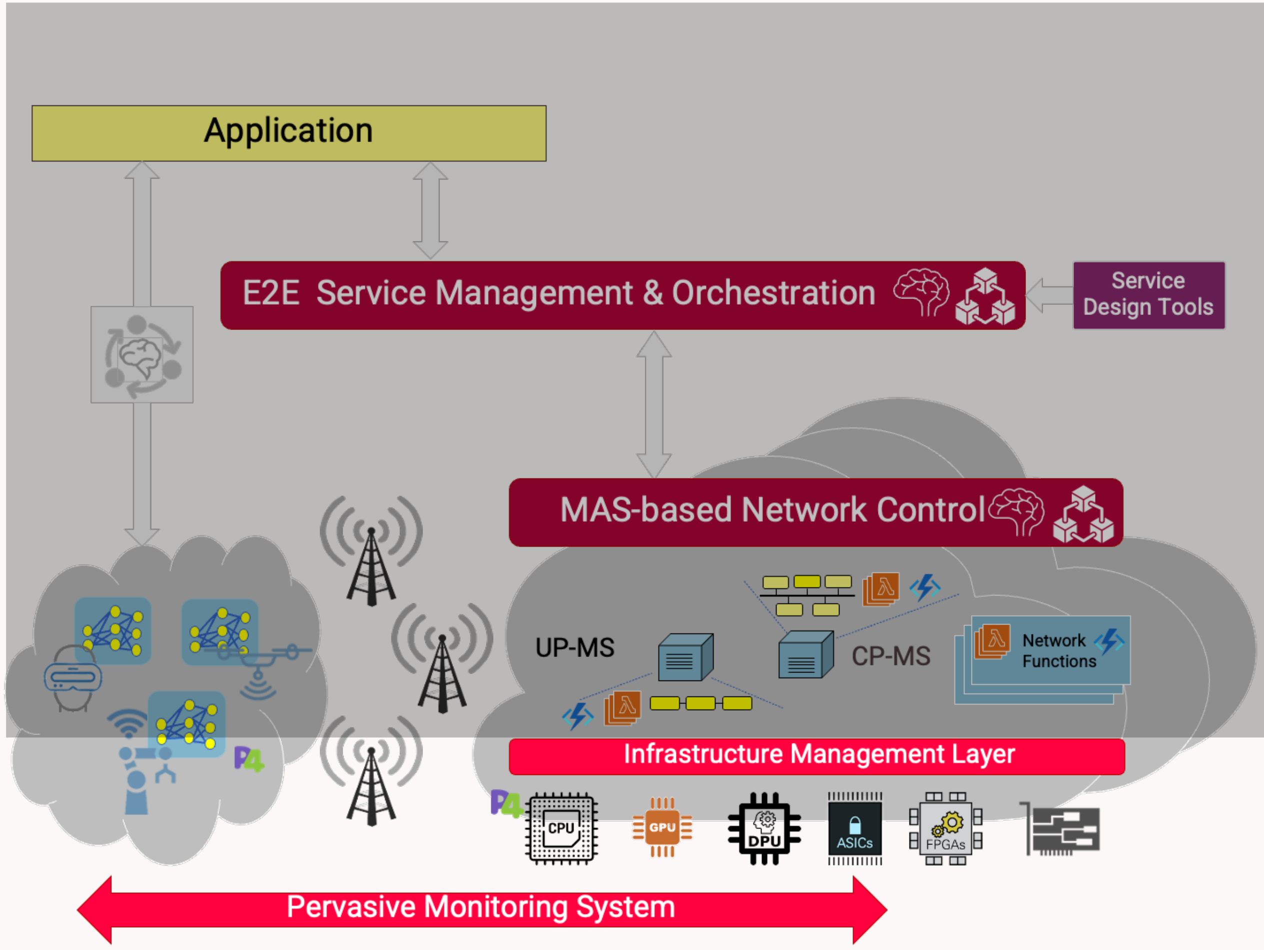
# DEEP PROGRAMMABILITY




Innovation

- xURLLC services
- Edge Intelligence
- Intent-based orchestration
- Blockchain-based federation
- Secure distributed intelligence
- RAN-core convergence
- Edge-to-Cloud continuum
- Serverless architecture
- **E2E programmable data plane**
- **Multi HW acceleration**
- E2E network telemetry

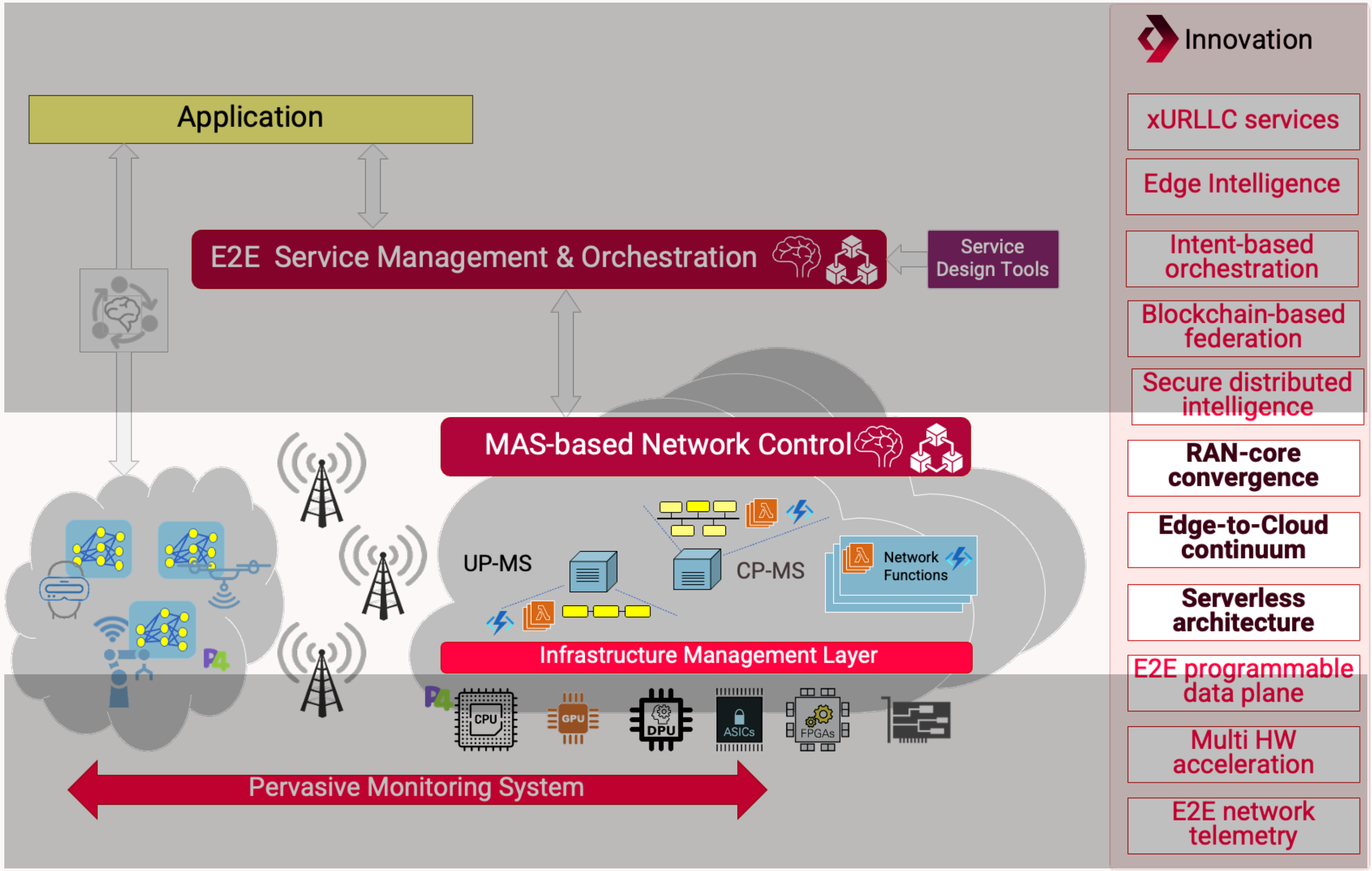
# E2E NETWORK VISIBILITY



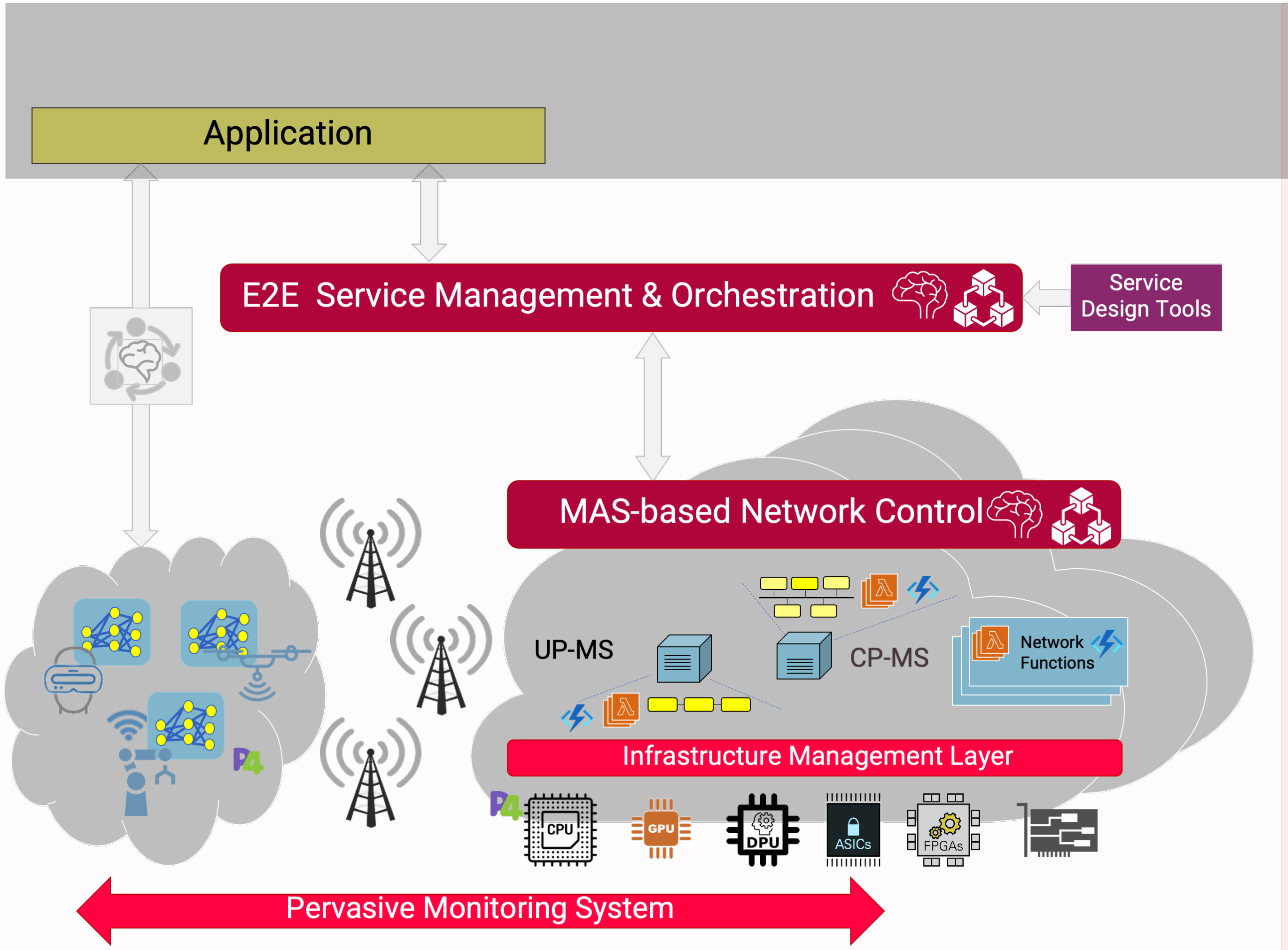

Innovation

- xURLLC services
- Edge Intelligence
- Intent-based orchestration
- Blockchain-based federation
- Secure distributed intelligence
- RAN-core convergence
- Edge-to-Cloud continuum
- Serverless architecture
- **E2E programmable data plane**
- Multi HW acceleration
- **E2E network telemetry**

# CLOUD NATIVE



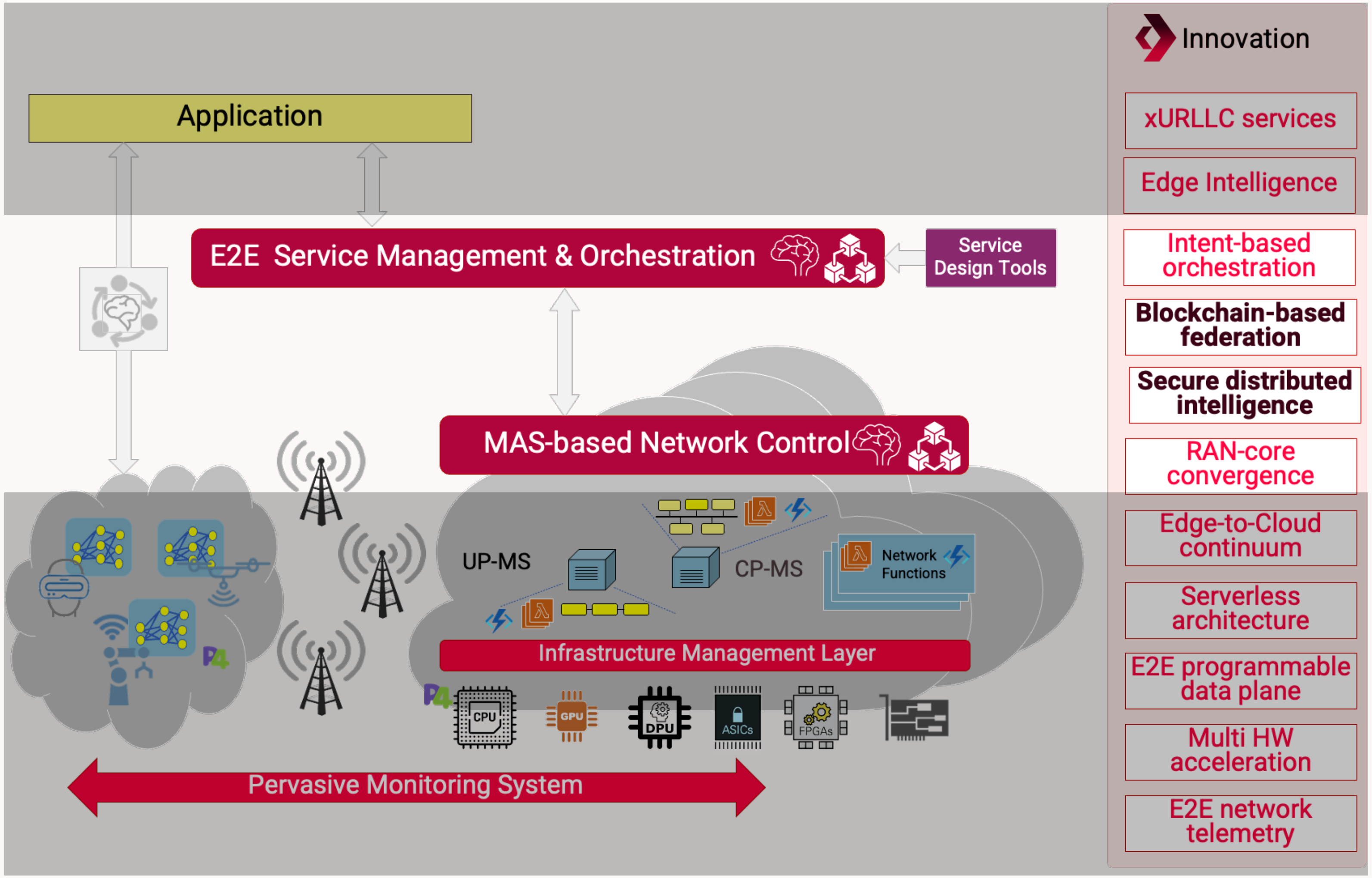
# AI-NATIVE




Innovation

- xURLLC services
- Edge Intelligence
- **Intent-based orchestration**
- Blockchain-based federation
- **Secure distributed intelligence**
- RAN-core convergence
- Edge-to-Cloud continuum
- Serverless architecture
- E2E programmable data plane
- Multi HW acceleration
- E2E network telemetry

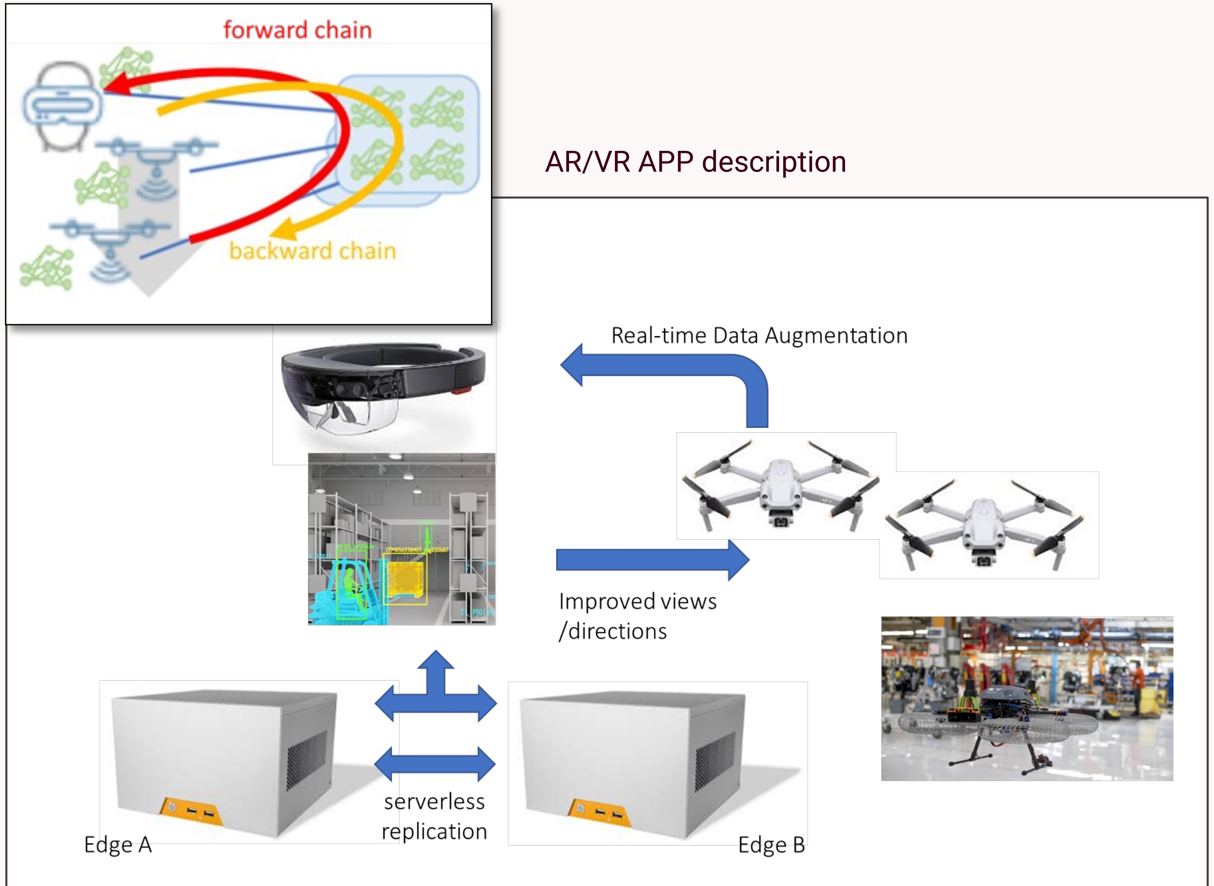
# DLT FOR ZERO-TRUST ARCHITECTURE



# INTELLIGENT AND RESILIENT AR APPLICATION WITH PERCEIVED ZERO LATENCY

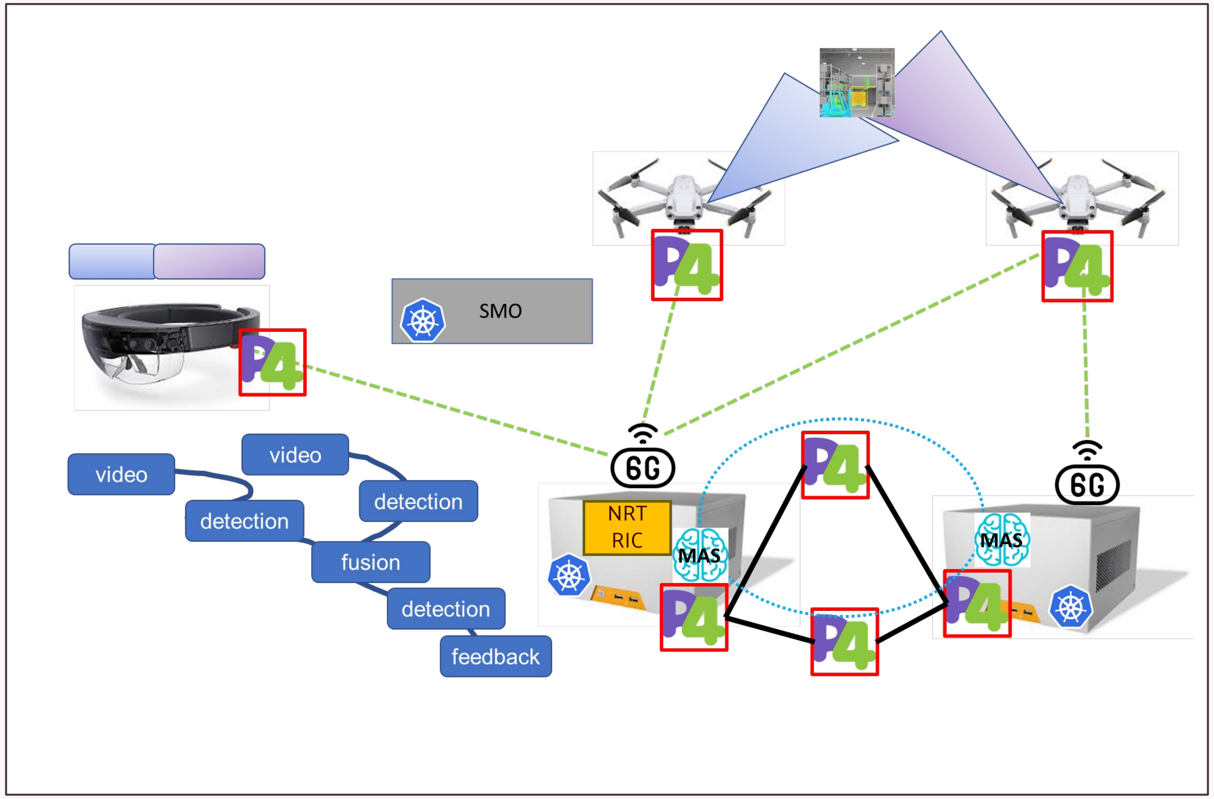
›DESIRE6G‹

AR/VR APP description




$d_{e2e}$<20ms
Thr : 50-100Mbps ,130-960Mbps

AR/VR application deployment in D6G



# TAKE-AWAY

**What is the difference between D6G and the other 6G projects**?

We answer the following questions:

- How (i) end-to-end network programmability and (ii) pushing decision-making closer to the infrastructure, helps addressing challenging use cases / KPIs [2]?
- Can we solve the scalability/complexity/performance problems of centralized control and optimization with a distributed agent-based system?
- Can we address the inherent challenges posed by multiagent systems(dynamicity, coordination and cooperation, security etc.)?[3]
- And how can we put this together as simply as possible with other innovative methods, like AI-driven telemetry [2] or blockchain-based federation?

[2] D6G: "Pervasive monitoring and distributed intelligence for 6G near real time operation". EUCNC Poster
[3] D6G: "Securing Multi-Agent Systems for Near Real-Time Control of 6G Services". EUCNC Poster

DESIRE6G

# THANKS!

Chrysa Papagianni

email: c.papagianni@uva.nl

Co-funded by
the European Union

6GSNS

DESIRE6G has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101096466.
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Commission. Neither the European Union nor the granting authority can be held responsible for them.

DETERMINISTIC6G

# Introduction to Deterministic End-to-End communication with 6G

Dhruvin Patel

EuCNC'23, 6th June

The DETERMINISTIC6G has received funding from the European Union's Horizon Europe programme under grant agreement No 10109504.

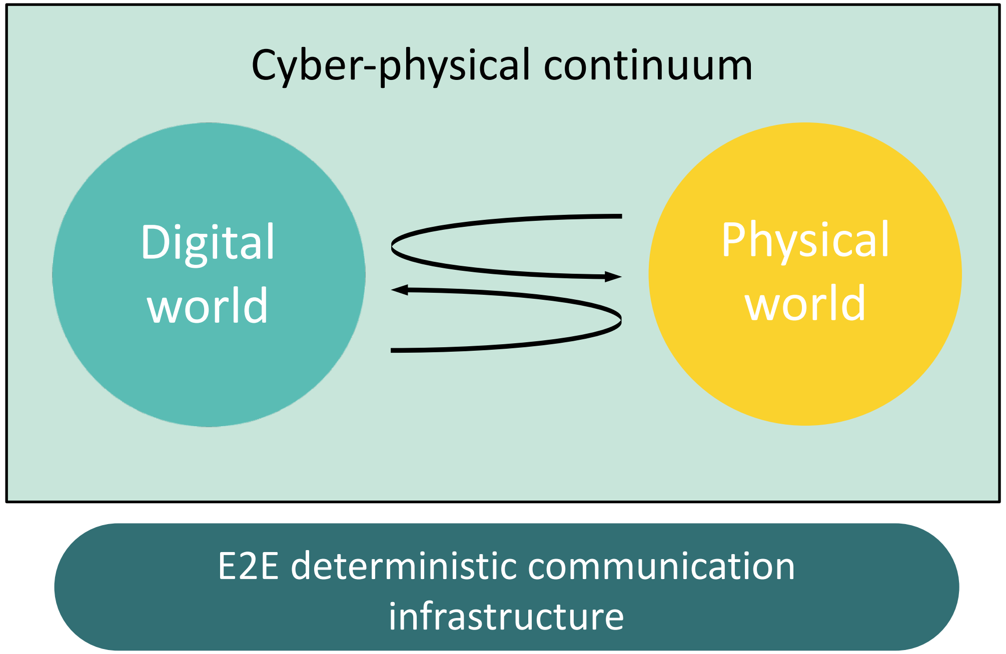
DETERMINISTIC6G

# Outline

- Introduction
- Vision
- Objective
- Consortium
- Use case
- Architecture
- Summary

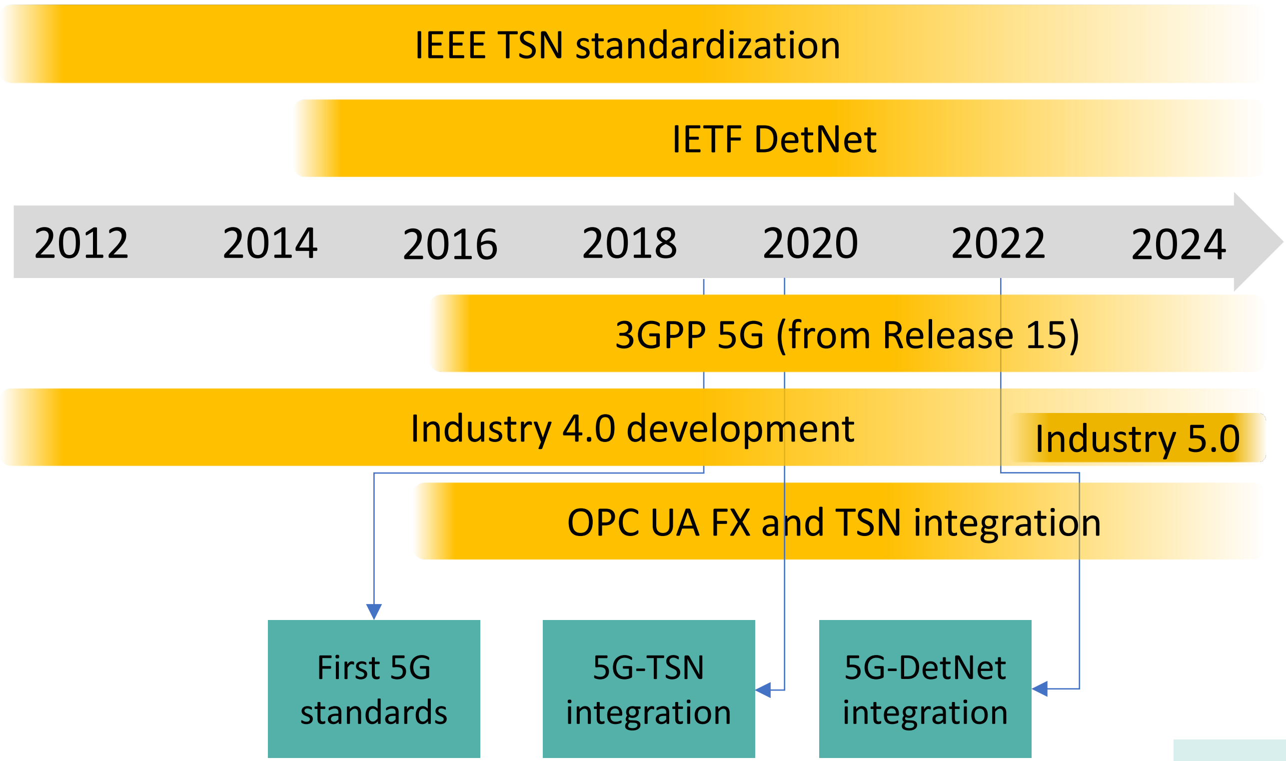
# Moving towards a Cyber-Physical Continuum

- The digitalization is driving the transformation of the society and industries
- New forms of interactions will lead to a converged cyber-physical continuum spanning different communication technologies
- End-to-End (E2E) deterministic communication infrastructure is a necessary requirement to support such interactions



# Today's Deterministic Communications Arena

- Over the last decade, the major pivot of the communications community has been towards low-latency and reliability
  - Digitalization of automation systems as a main driver
- Several communication technologies (TSN, DetNet, 5G, OPC UA) are independently evolving towards the support for wired/wireless deterministic communication
  - So far only limited interworking (e.g., recent 5G-TSN integration architecture)

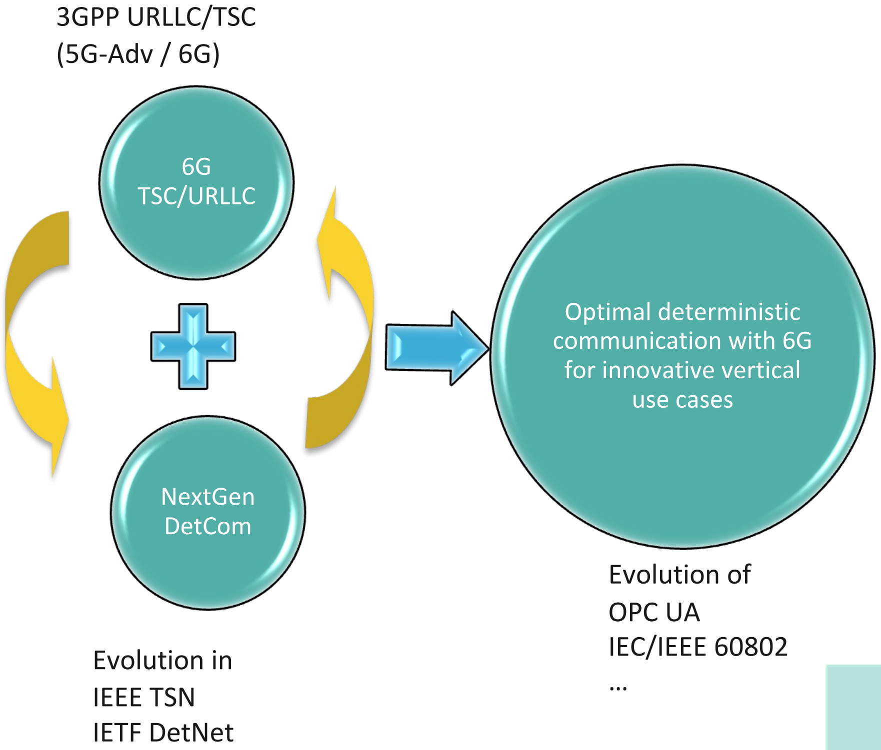



TSN : Time-Sensitive Networking
OPC UA : OPC Unified Architecture
DetNet: Deterministic Networking

# DETERMINISTIC6G Vision

The DETERMINISTIC6G vision is to set the foundation for future global communication standards enabling 6G deterministic communication for visionary use cases

- New concepts, features and solutions to
  - Evolve TSN (&DetNet) to become more wireless-friendly
  - Improve 5G-Advanced/6G to be better suited for deterministic communication
  - Align with the main application middleware for deterministic communication:  OPC UA (with its features on OPC UA FX (Field eXchange) and the usage of TSN)




URLLC: Ultra-reliable and low-latency communications
5G-Adv: 5G-Advanced
TSN : Time Sensitive Networking
TSC: Time Sensitive Communication
DetNet: Deterministic Networking

DETERMINISTIC6G

# DETERMINISTIC6G objectives

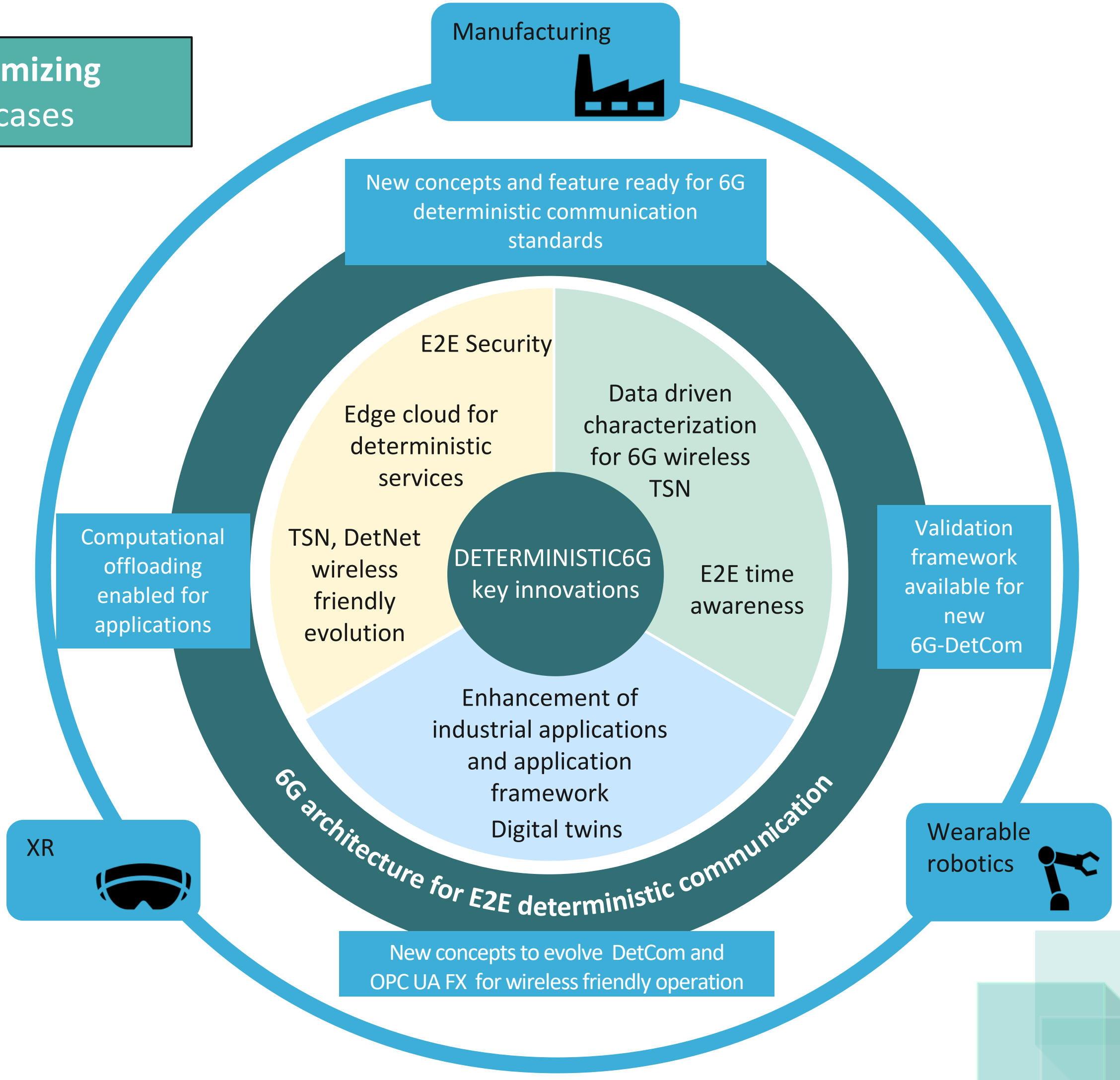
**The DETERMINISTIC6G objective is to develop a new architecture optimizing deterministic E2E communication with 6G to enable innovative use cases**

- The three pillars of DETERMINISTIC6G:

Architectural aspects for E2E deterministic communication

Awareness for providing E2E deterministic communication performance

Anticipation for assurance and control of E2E deterministic performance guarantees




TSN : Time-Sensitive Networking
OPC UA : OPC Unified Architecture
DetNet: Deterministic Networking

# DETERMINISTIC6G Consortium

Scuola Superiore Sant'Anna Pisa · IUVO (Wearable technology, uplifted life) · B&R (A member of the ABB Group)

Industrial application players bringing 6G visionary use cases

Ericsson · orange™ · montimage · Cumucore

Key industrial players in 6G research and development

KTH Vetenskap och Konst · University of Stuttgart Germany · SAL Silicon Austria Labs

Key university and research institutes at the forefront for 6G fundamental research

- 12 partners (Coordinator: Ericsson GmbH)
- Jan 2023 – Jun 2025 (30 months)
- € 5.8 M€

DETERMINISTIC6G

# Project overview

## E2E deterministic system architecture

### System aspects for deterministic E2E communication

- 6G use cases requiring deterministic communication
- Deterministic service definition (KPI/KVI)
- Security analysis

### Deterministic communication technology enablers

- Deterministic 6G wireless transmission design
- Data driven characteritization for 6G wireless system
- E2E time synchronization
- Deterministic communication standards (TSN DetNet) Evolution
- Edge computing solution for deterministic communication
- Situational awareness via digital twins
- Security countermeasures

### Validation framework

- System level modelling
- Data driven model evaluation and validation
- System level simulations

KPI : Key Performance Indicators
KVI : Key Societal Value indicators

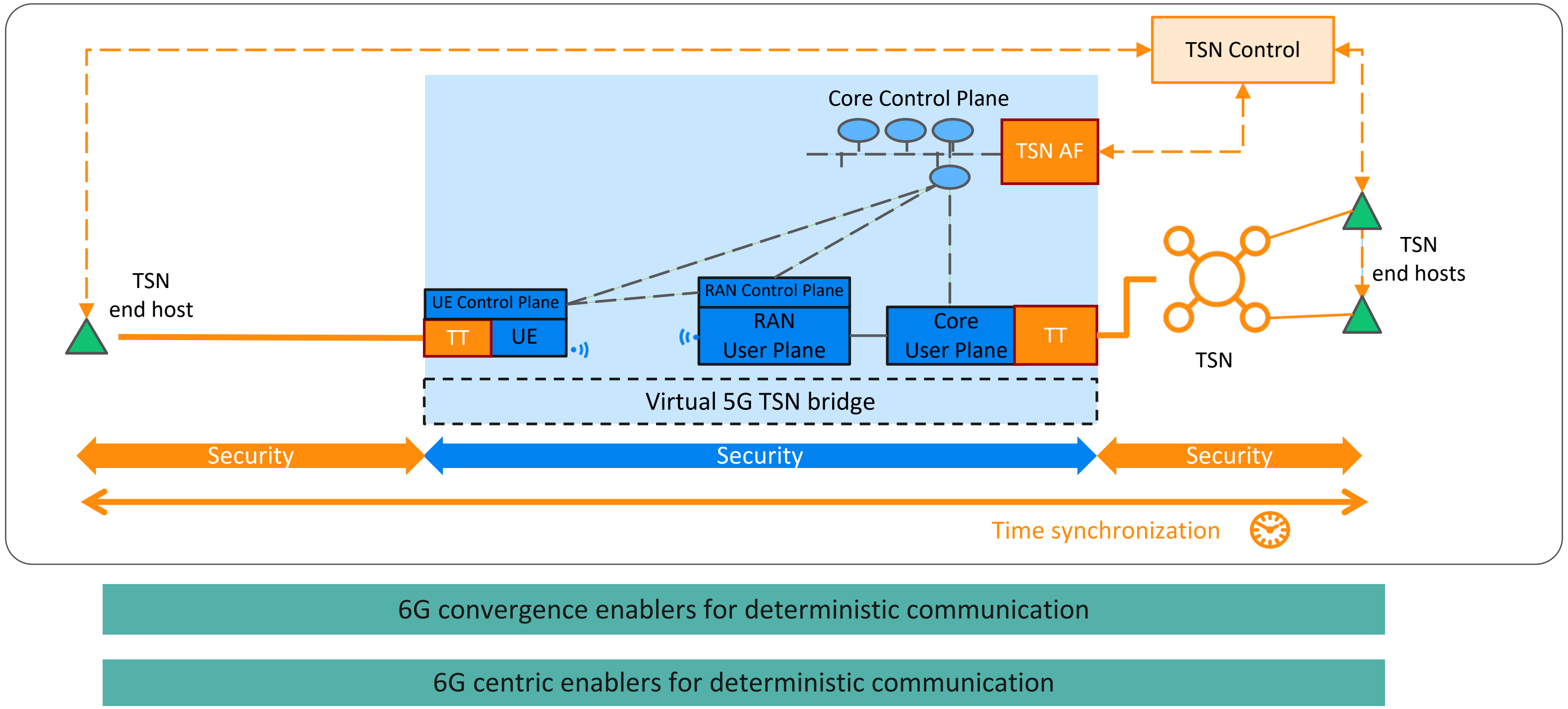
# Use Cases and Service Definitions

- Selected use cases for the evaluation of concepts
  - Extended reality
  - Occupational exoskeletons
  - Wireless industrial automation
- Definition of specific **KPIs** and **KVIs** for deterministic communication (DetCom) based on selected use cases


KPI: Key Performance Indicator
KVI: Key Value Indicator

# E2E 6G deterministic communication architecture

- Enhancements are needed for the existing 5G-TSN integration model for seamless integration




UE : User Equipment
RAN: Radio Access Network
CNC: Centralized Network Configuration
TT: TSN Translator
AF: Application Function

# E2E 6G deterministic communication architecture

DETERMINISTIC6G

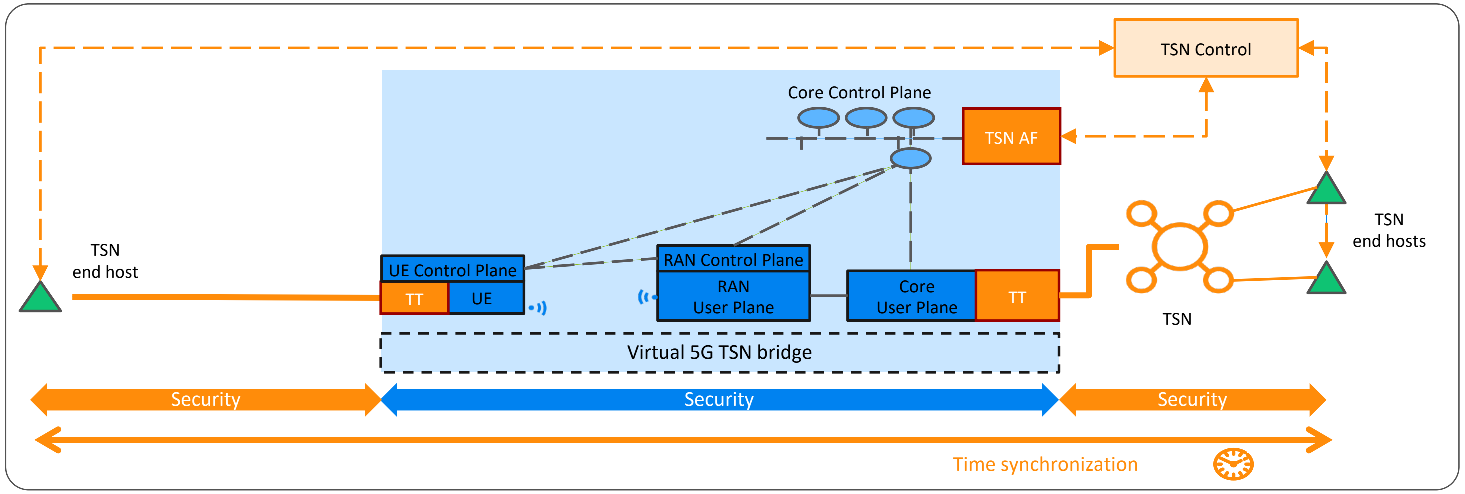
- ❑ DETERMINISTIC6G's enablers for E2E deterministic communication
  - ❑ Data driven approached
  - ❑ Digital twinning
  - ❑ OPC UA enhancement
  - ❑ Wireless friendly evolution of TSN and DetNet
  - ❑ Edge computing for deterministic communication services
  - ❑ E2E security and time synchronization
  - ❑ Deterministic 6G wireless transmission

Data-driven characterization for 6G wireless systems
deterministic 6G wireless transmission

Situational awareness by digital twining

Enhancing application framework (OPC UA)

Edge cloud solution for deterministic communication services




Seamless interworking (e.g. wireless friendly E2E schedules) of 5G-Adv/6G with TSN/DetNet

E2E security & time synchronization

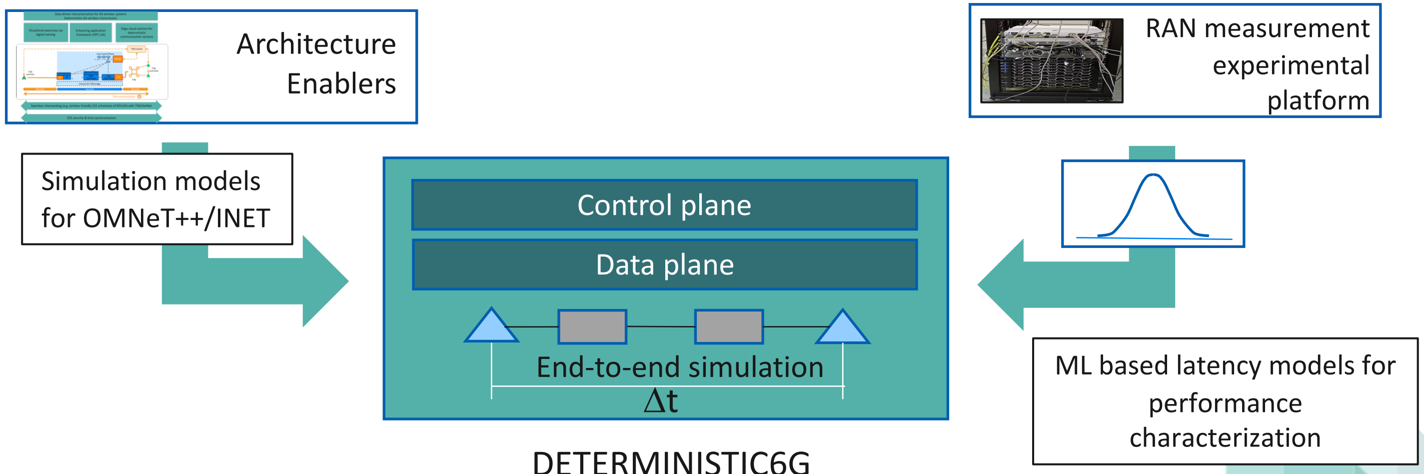
# Validation

Validation through **simulation**

- ❑ Simulation of **end-to-end communication**
  - ❑ Extension of OMNeT++/INET simulator (open-source release)
- ❑ Simulation models for
  - ❑ wired and wireless data plane
  - ❑ wireless-friendly control plane
  - ❑ Edge cloud
  - ❑ Security concepts
  - ❑ Time synchronization concepts

Validation through **experiments in RAN**

- ❑ Measurements of **wireless RAN** timing characteristics
  - ❑ Analysis of RAN latencies
  - ❑ Realistic latency models of wireless components for end-to-end simulation




DETERMINISTIC6G validation framework

# Impact creation towards 6G

- Technological impact
- Economic impact
- Societal and environmental impact
- Scientific impact

DETERMINISTIC6G Objectives

DETERMINISTIC6G Results

6G Technical KPIs

KVIs

**Impact areas**

- Reinforcing European leadership in global 6G development (economic impact)
- Drive Industry standards and Scientific Research (scientific impact )
- Enablement of innovative time critical applications (technological impact)
- Joint collaboration with sister SNS projects, seminars, media, etc (societal impact)

# DETERMINISTIC6G Grant Agreement No. 101096504

The DETERMINISTIC6G project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No. 101096504.

If you need further information, please contact the coordinator:

Dhruvin Patel, ERICSSON

E-Mail: coordinator@deterministic6g.eu

or visit: www.deterministic6g.eu

@DETERMINISTIC6G    DETERMINISTIC6G

# Summary

DETERMINISTIC6G vision is to set the foundation for future deterministic communication technology standards by developing

- ❑ Deterministic service definition that includes KPI and KVI for innovative 6G use case
- ❑ E2E deterministic system architecture built upon new DETERMINSITIC6G enablers
- ❑ Open-source validation framework

KPI: Key Performance Indicator
KVI: Key Value Indicator

DETERMINISTIC6G

# Deterministic E2E communication with 6G

Project coordination: Ericsson, Technical coordination: KTH, Project start: January 2023, Project duration: 30 months, Contact: coordinator@deterministic6g.eu, deterministic6g.eu

## E2E deterministic system architecture

6G challenges and vision

### System aspects for deterministic E2E communication

- 6G use cases requiring deterministic communication
- Deterministic service definition (KPI/KVI)
- Security analysis

### Deterministic communication technology enablers

- Deterministic 6G wireless transmission design
- Data driven characterization for 6G wireless system
- E2E time synchronization

- Deterministic communication standards (TSN, DetNet) Evolution
- Edge computing solution for deterministic communication
- Situational awareness via digital twins
- Security countermeasures

### Validation framework

- System level modelling
- Data driven model evaluation and validation
- System level simulations

Beyond DETERMINISTIC6G

DETERMINISTIC6G has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under grant agreement No.101096504. The SNS JU receives support from the European Union's Horizon Europe research and innovation programme

ERICSSON · KTH · B&R · SAL SILICON AUSTRIA LABS · IUVO · University of Stuttgart Germany · montimage · Cumucore · orange

PREDICT 6G

# PREDICT-6G

## The importance of ~~predictability~~ determinism in 6G networks

Antonio de la Oliva (aoliva@it.uc3m.es)
EuCNC WS10: Future deterministic programmable networks for 6G

Funded by the European Union

This project was awarded funding by the European Union's Horizon Europe Research and Innovation programme under grant agreement N° 1101095890.

# The vision

## Building a deterministic 6G network

### RELIABLE

Availability
Low packet
Failure resilient

### TIME SENSITIVE

Bounded latency
Low jitter

### PREDICTABLE

Use of AI to predict events, states, demands, resources
Autonomous proactive actions based on predictions

# The mission

PREDICT-6G aims to **design, create and validate end-to-end (E2E) 6G solutions providing deterministic services over multiple interconnected domains and technologies** (incl. wired and wireless).

## 3 pillars

- To **extend the reliability and time sensitiveness features** of IEEE 802.11 and 3GPP networks, including APIs for the monitoring and control of such capabilities, enabling predictability.
- To **develop a multi-technology multi-domain Data-Plane** jointly with an AI-driven multi-stakeholder inter-domain Control-Plane (AICP)
- To **enhance the predictability** of the network through artificial intelligence, enabling the forecasting of the occupancy of network resources and the effect of accepting a new flow into the network

## 3 use cases

1. **Smart manufacturing**
2. **Multi-domain deterministic communications**
3. **Critical communications**

# Innovations

## Specific innovations

1. Improvement of L2 deterministic capabilities of IEEE 802.11 and 3GPP
2. Emulate deterministic network capabilities on top of non-deterministic network segments
3. Data-plane integration of multiple deterministic and non-deterministic domains
4. User, resource, and function mobility under deterministic constraints
5. Highly configurable monitoring platform for multi-technology deterministic networks
6. Cross-domain E2E deterministic service management automation
7. Predictability through Network Digital Twinning

# Architecture overview

PREDICT-6G management scope

Networks (e.g., PM/CM)

Network services within one network (e.g., connectivity, det. SLA)

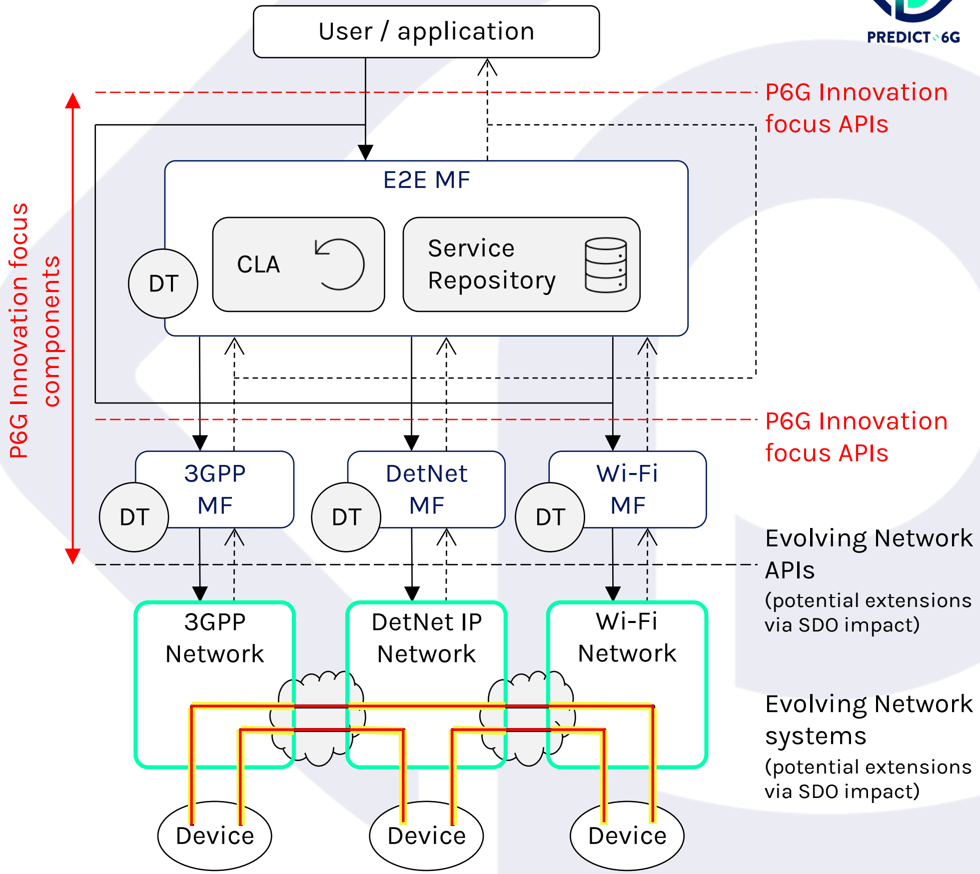
E2E services over multiple networks (e.g., between devices attached to different networks)

These are **Managed Entities (ME)** for the PREDICT-6G framework.

E2E deterministic service flow (MDP)

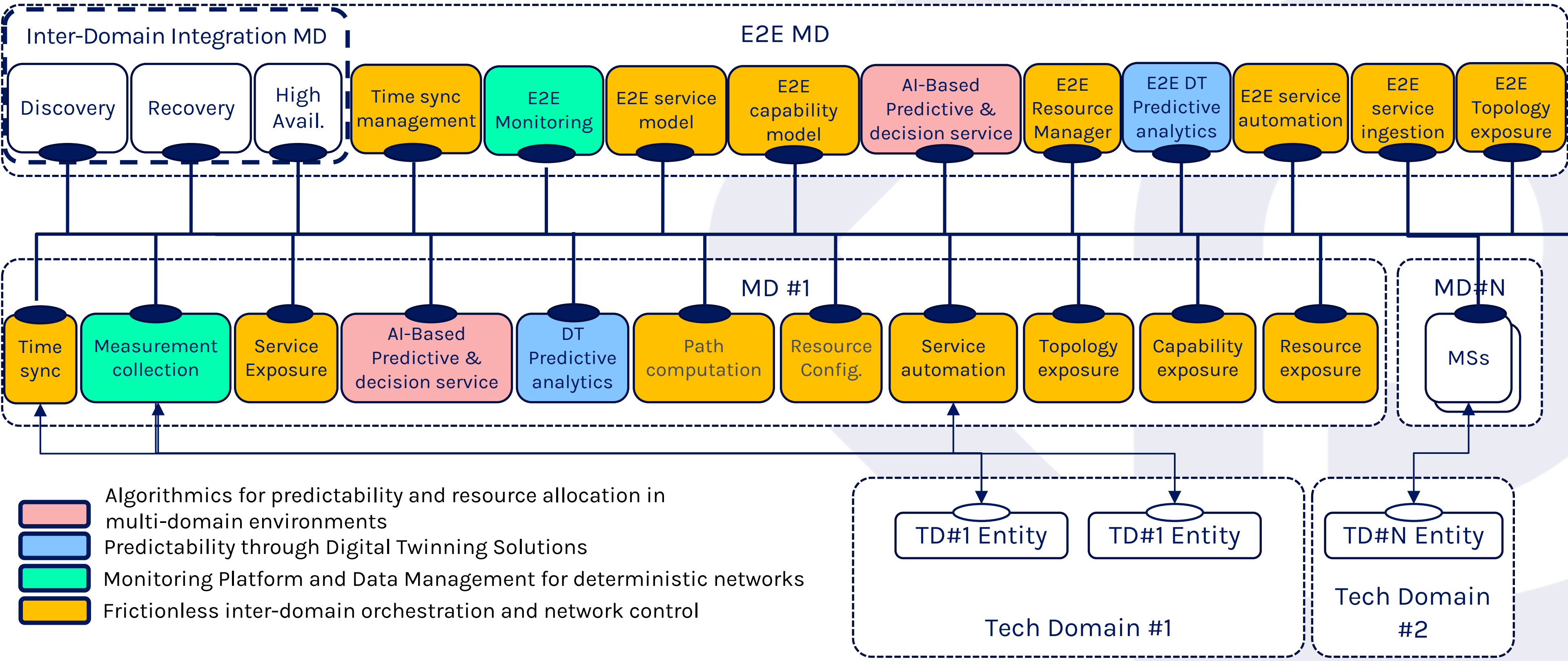
Request / configuration (AICP)

Measurement / status / insight (AICP)



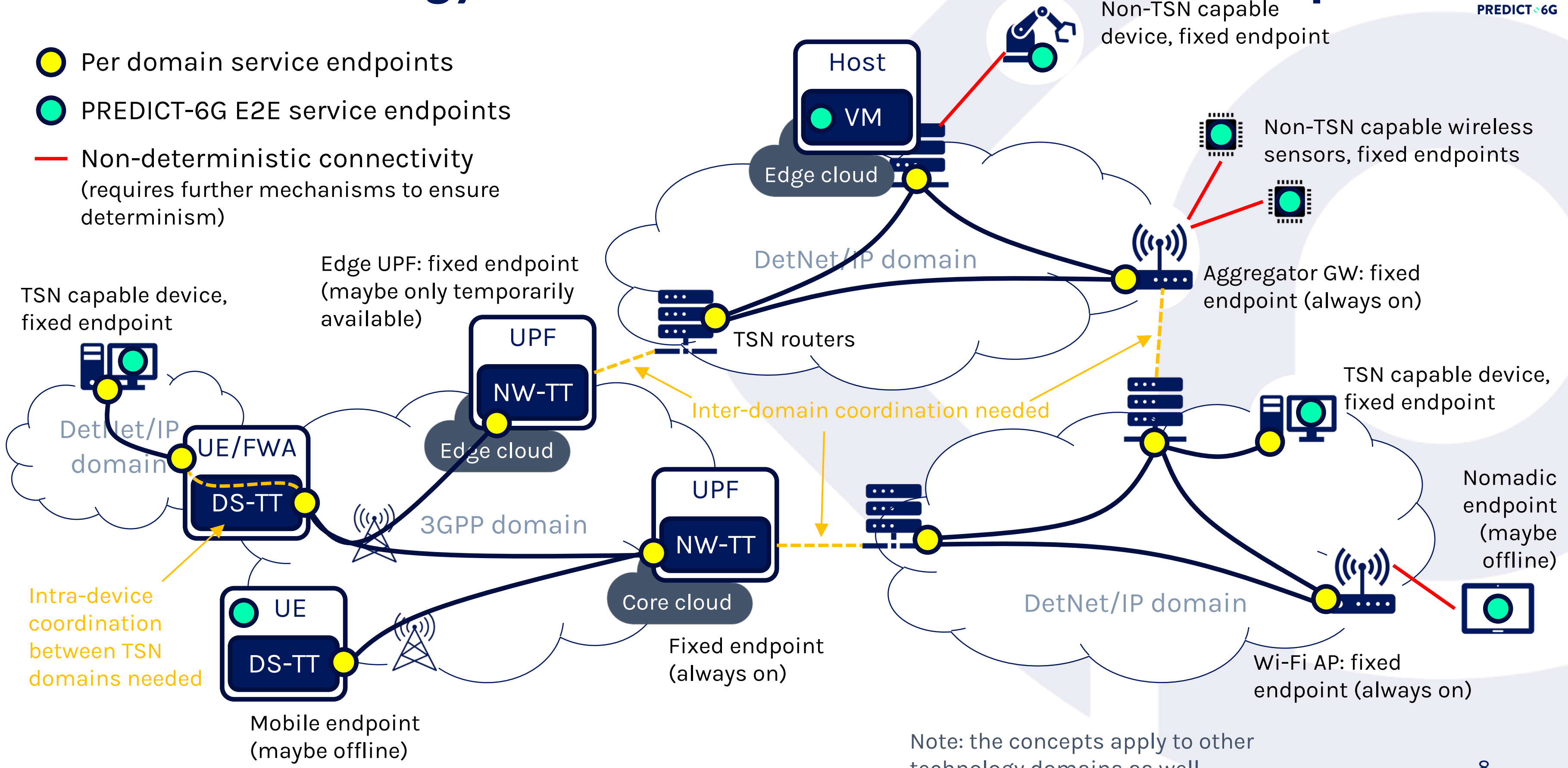
# AICP Architecture

Represents all management capabilities of the corresponding MS



# Multi-technology multi-domain DP architecture concepts

- Per domain service endpoints
- PREDICT-6G E2E service endpoints
- Non-deterministic connectivity (requires further mechanisms to ensure determinism)




Note: the concepts apply to other technology domains as well.

# MDP

## The integration concept within PREDICT-6G

- PREDICT-6G Integrates multi-domain layer-2 islands of deterministic technologies through layer-3 mechanisms (DetNet, RAW).

**Fundamental research**

Wireless Dynamic Scheduling

**Standalone demos**

Determinism for Localization & Sensing

**Integrated demos**

Non-deterministic devices and networks

Industrial cross-domain TSN

Technological solutions for TSN on Wi-Fi

Objectives

Articles

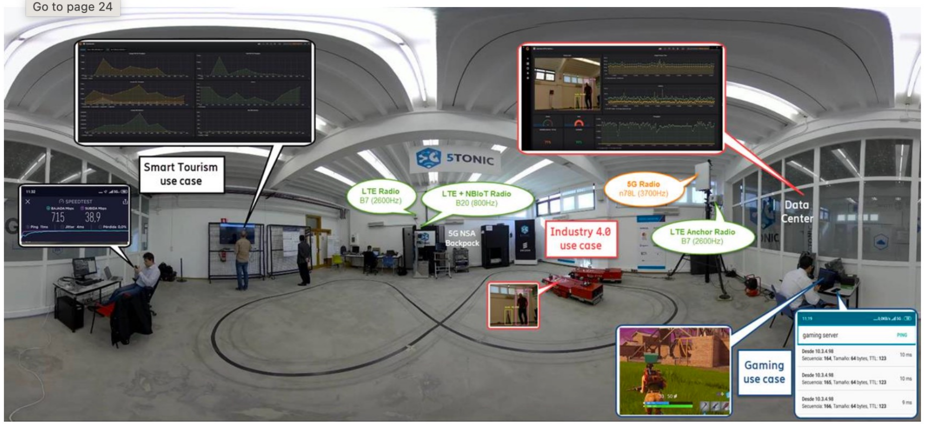
SDOs

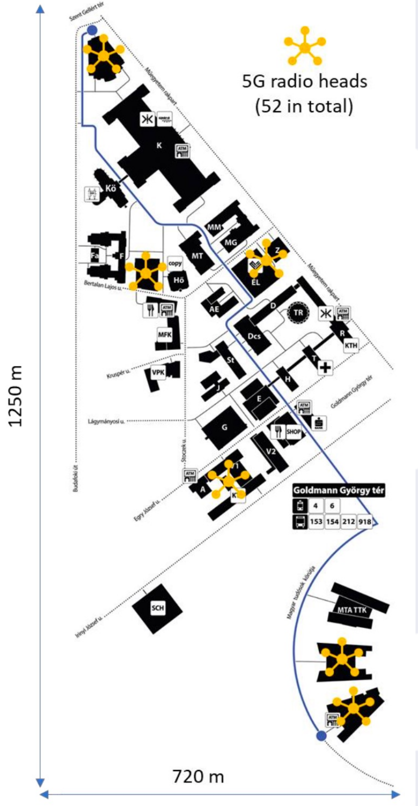
PoCs

# Experimentation plans and testbeds

- 3 key use cases
  - Deterministic services for critical communications
  - Multi-domain deterministic communication
  - Smart Manufacturing
- 2 main testsites
  - Budapest Open Lab
  - Madrid Open Lab (5TONIC)

Go to page 24



# Summary

- PREDICT-6G considers networks need to be enhanced to become more deterministic (i.e., predictable, reliable and time sensitive) to cope with emerging use cases
- The 6G network will be composed of multiple heterogeneous networks merged together
  - Not a single L2 solution will solve the problem
- PREDICT-6G proposes two main innovations in this area:
  - Multi-technology multi-domain Data-Plane (MDP)
    - Enhance L2 technologies
    - Integrate them into a single E2E data plane
    - Expose APIs for control and monitoring
  - AI-driven Multi-stakeholder Inter-domain Control-Plane (AICP)
    - AI-based network control plane framework
    - Network digital twins for predictability
    - Monitoring platform

# Meet our team

PREDICT 6G

## 17 partners from seven EU countries have joined forces

uc3m | Universidad Carlos III de Madrid

ERICSSON

intel

Gestamp

interdigital

Atos

SIMAVI Software Imagination & Vision

Telefónica

NOKIA

Politecnico di Torino 1859

NEXTWORKS HEADING THE FUTURE

Consiglio Nazionale delle Ricerche

UPC UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

PREDICT-6G

# Thank you!

@Predict6G predict-6g.eu PREDICT-6G Project

Funded by
the European Union

This project was awarded funding by the European Union's Horizon Europe Research and Innovation programme under grant agreement N° 1101095890.

EUCNC| 6 June 2023

# Industrial 5G / 5G-ACIA: Lessons Learned & State of the Union

**Dr. Afif Osseiran** (Ericsson)
General Vice-Chair of 5G-ACIA

Part I

# Looking Back

# 5G-ACIA | Recap: Major Objectives

## OT Industry

## ICT Industry

5G-ACIA

1. Establish a common language btw. ICT & OT
2. Reflect OT needs in standardization & regulation
3. Analyze how 5G may enhance the Industrial IoT
4. Identify relevant certification & testing needs
5. Develop a sustainable Industrial 5G ecosystem
6. Promote Industrial 5G worldwide

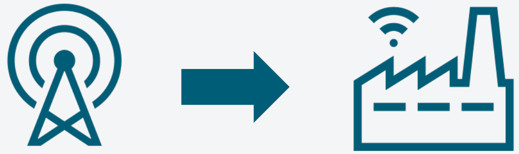
**5G-ACIA as the globally leading organization for driving and shaping Industrial 5G**

# 5G-ACIA | Overview of Major Achievements

## Use Cases & Requirements

Solid understanding of
Industrial 5G use cases & requirements

## Private Networks



Suitable deployment & operating
models of private 5G networks

## Shopfloor Integration

OPC UA

DetNet

TSN

Profinet

Integration of 5G with other
important OT technologies

## IT Integration

Enterprise IT

Capability exposure

Private Network

Integration of 5G in existing
enterprise IT environments

## Education

Creating awareness for Industrial 5G
all around the world

## Collaboration

Establishing a unique network
of global collaboration partners

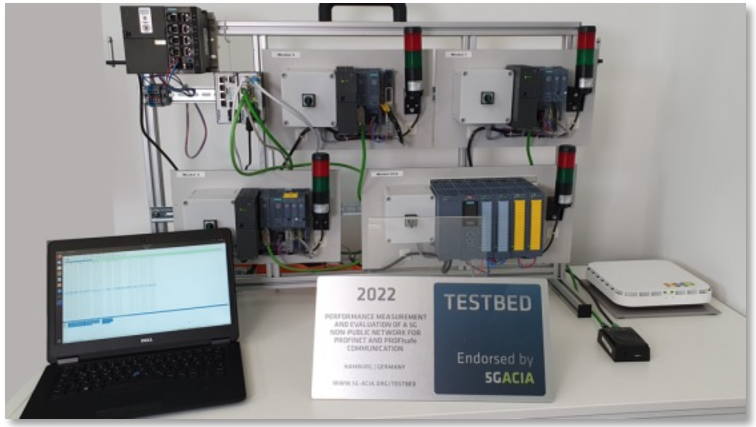
# 5G-ACIA | Overview of Major Achievements – Testbeds


5G-SMART Testbed in Semiconductor Factory


5G Industry Campus Europe


5G Open RAN Commun. & Positioning Testbed

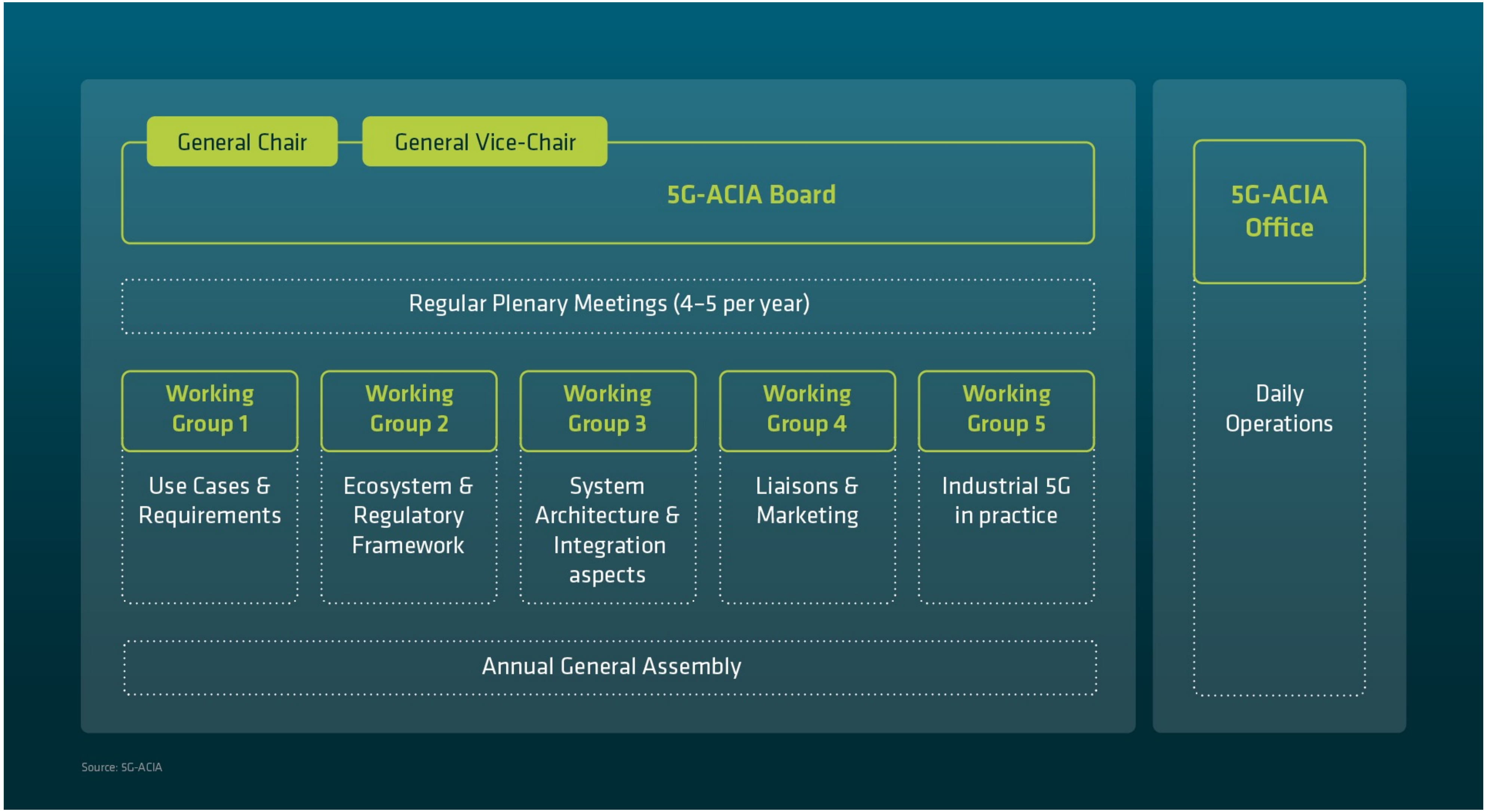
5G Performance Evaluation for Material Handling




5G for PROFINET and PROFIsafe

**…and many more exciting 5G-ACIA testbeds by different member companies**

# 5G-ACIA | Working Group Structure



# 5G-ACIA | 5th Anniversary at Hannover Messe 2023


**Public Kick-Off of 5G-ACIA**
Hannover Messe, April 2018
26 Members


**5th Anniversary of 5G-ACIA**
Hannover, April 2023
99 Members

# 5G-ACIA | Member Overview

5GACIA

5G to go, Aalborg University Denmark, ABB, AI-LINK, ASKEY, asmote, ASOCS, ATAYA, ATHONET, BASLER, BAYFU, BECKHOFF

BOSCH, Capgemini engineering, cellnex, celona, 中国移动 China Mobile, CISCO, CONGIV, Dassault Systèmes, DEMAG, DENSO, Deutsche Messe, DFKI

CATAPULT Digital, docomo, Druid, EMERSON, Endress+Hauser, ERICSSON, ETRI, FESTO, firecell, flex, Fraunhofer, GHMT

HARTING, HIRSCHMANN A BELDEN BRAND, HMF smart solutions, HMS, HUAWEI, IDLab Internet & Data Lab, ifak, ifm, III, infineon, inIT, intel

ITRI Industrial Technology Research Institute, KETI, KEYSIGHT TECHNOLOGIES, Lenovo, LS telcom, MAVENIR, MC TECHNOLOGIES, MITSUBISHI ELECTRIC, MOXA, MUGLER TELCO NETWORKS, Nitto, NOKIA

NXP, OMRON, ONELAYER, orange, Panasonic, PEPPERL+FUCHS, PHOENIX CONTACT, Qualcomm, RELIABLE REAL-TIME RADIO, Radisys, Rockwell Automation, ROHDE&SCHWARZ

S&T ISKRATEL, SAL SILICON AUSTRIA LABS, salzburgresearch, Schneider Electric, SICK, SIEMENS, SINTEF, SoftBank, SONY, ST life.augmented, Telefónica, T··

telent, TRUMPF, 財團法人電信技術中心 TELECOM TECHNOLOGY CENTER, ublox, UNIBERG, UPLINK, verizon, VIAVI Solutions, vodafone, VOLKSWAGEN AKTIENGESELLSCHAFT, WAGO, Weidmüller

XITASO, YOKOGAWA, ZTE

axians, brown-iposs, CAMPUS GENIUS

Joined in May

Status: May 2023

Part II

# (Industrial) 5G Today

# 5G in numbers

**249**
Live 5G networks
(GSA Apr. 2023)

**41**
Live 5G standalone networks
(GSA Apr. 2023)

**43%**
Population coverage by the end of 2023
(Ericsson November 2022)

**15GB**
Monthly mobile data traffic per sub
Global (2022)


**1000+**
Private Networks based on 4G / 5G in 2022

**13500**
Private Networks in 2026

**13.2 Bn**
IoT Connections in 2022

**30+ Bn**
IoT Connections in 2027

# 3GPP 5G standard addresses industrial needs

Rel-15

**Key URLLC (Ultra Reliable Low Latency) features**
First 5G release
Key features for low latency and high reliability

Rel-16

**Industrial IoT**
Support for IEEE time sensitive networking (TSN)
Non-public network enhancements, positioning, time-sync, exposure

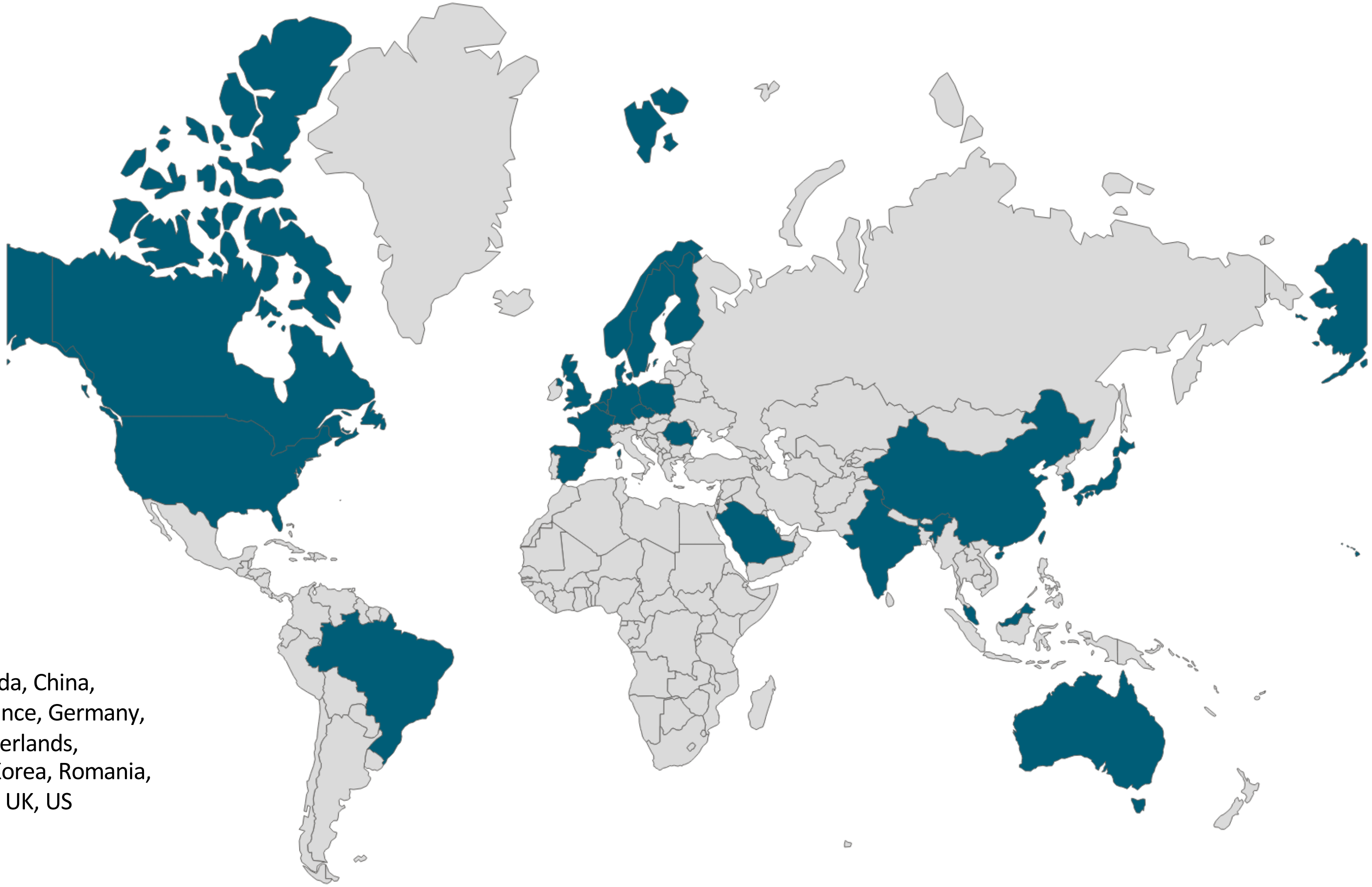
Rel-17

**Efficiency and scale**
Enhanced efficiency and capacity for URLLC
Improvements for positioning and time sync

Rel-18

**Expand use cases**
Addressing AR/VR, remote control, media production
Further enhancement of time synch, NPN, exposure

# Spectrum for Industries – Decided or Ongoing discussions



**High band**
Australia, Brazil, Canada, China, Denmark, Finland, France, Germany, Japan, Malaysia, Netherlands, Norway, Republic of Korea, Romania, Saudi, Spain, Sweden, UK, US

**Status Quo in Germany**

**>293** Granted licenses in 3.7 – 3.8 GHz band

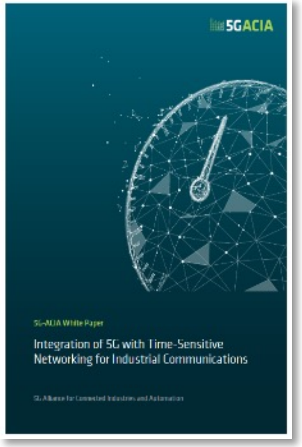
**16** Granted licenses in 26 GHz band

Part III

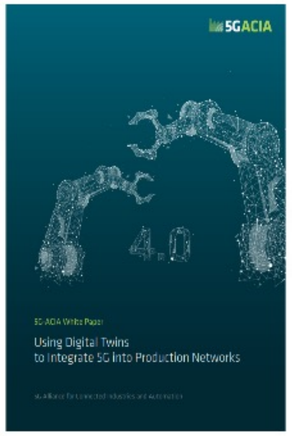
# Industrial 5G Shopfloor Integration in Detail

# 5G-ACIA | Overview of Recent Activities

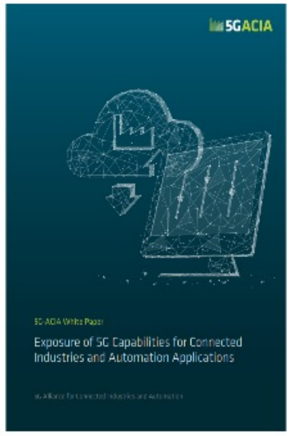

Edge Cloud



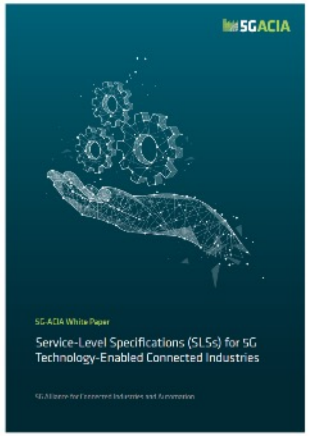

TSN-over-5G



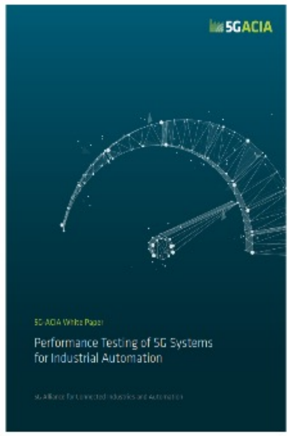

5G Digital Twins



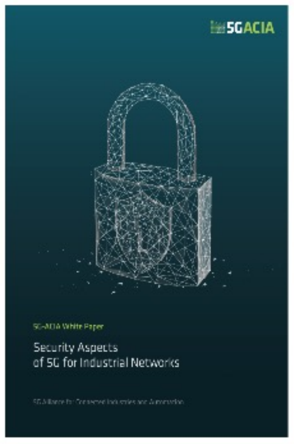

5G Exposure Interface



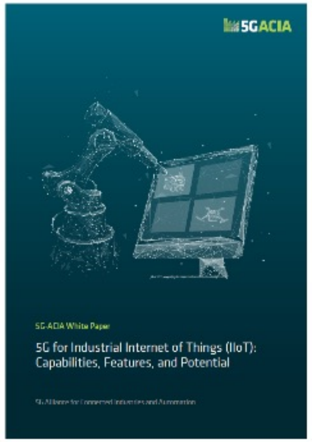

Service-Level Specifications



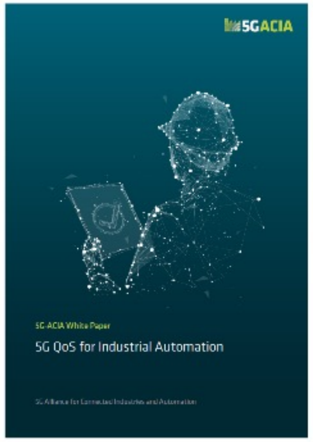

Performance Testing




Security




5G IIoT Capa.




5G QoS

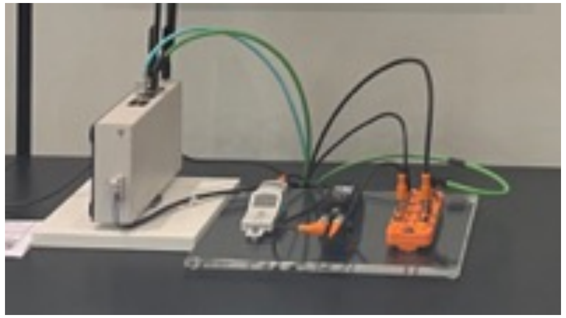

6G Position Paper


5G Industrial Devices

# Industrial 5G Devices | Examples

Gateway for IP67 sensor [Weidmuller]

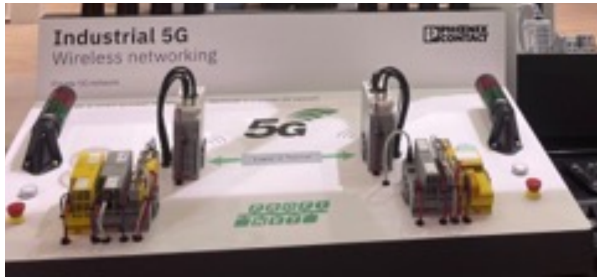

I/O Device [ifm]



Controller [Wago]

Mobile Panels [ABB]

Level Sensor [Endress+Hauser]




Router [Phoenix Contact]

Gateway for brownfield [Endress+Hauser]


Drones [ABB]

# Edge Cloud | Use Case Requirements and Benefits

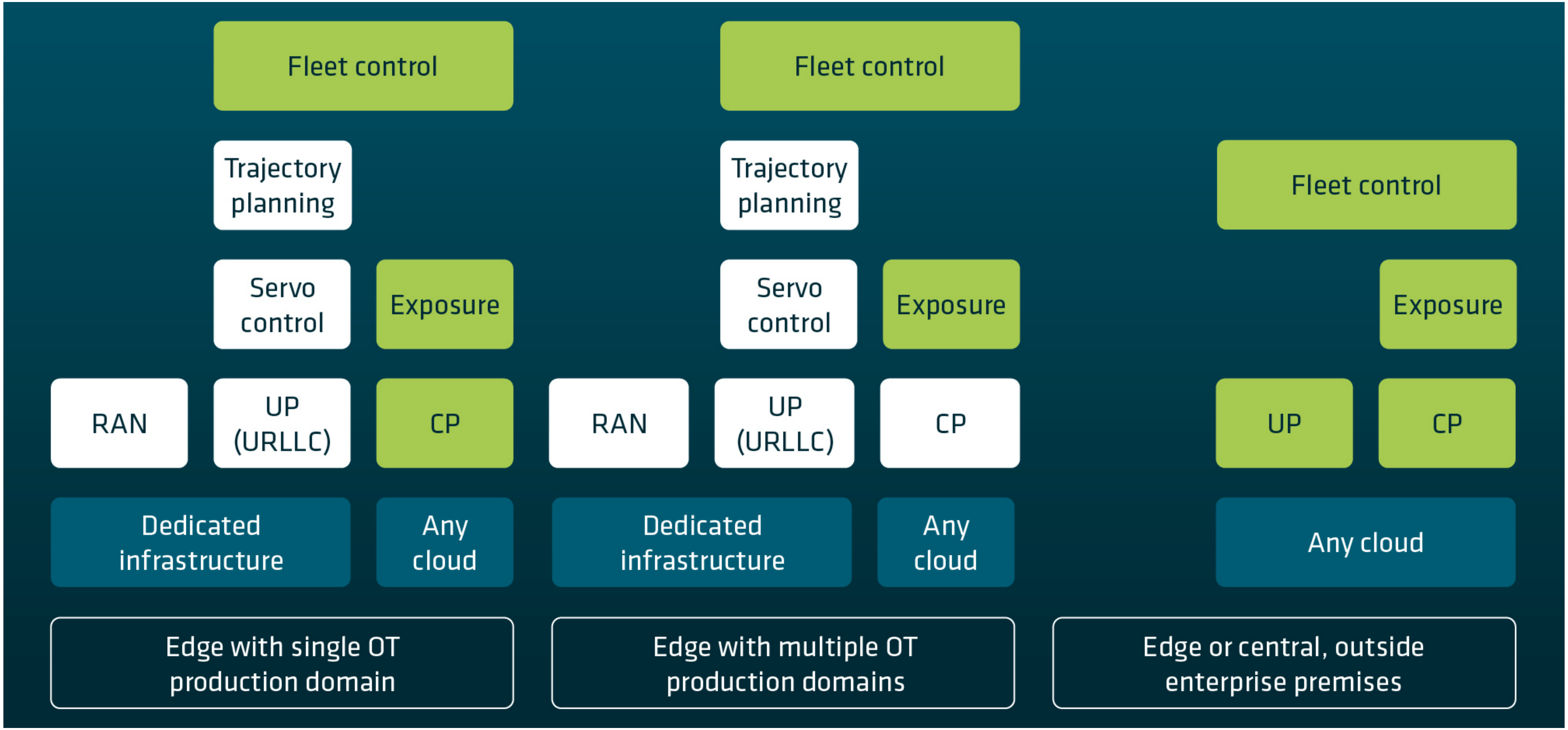
5GACIA

Mapping use cases to edge location

| Group | Requirements | Use cases | Edge Location |
|---|---|---|---|
| Group 1 | Latency-sensitive<br>High Reliability and availability<br>Data must be stored locally<br>**Single OT Domain** | 1. Closed-loop control<br>2. Mobile robots<br>3. Evolved collaborative robots | On-Premise Edge cloud single OT domain |
| Group 2 | Latency-sensitive<br>High Reliability and availability<br>Data must be stored locally<br>**Multi-OT Domain** | 1. Mobile robots<br>2. Evolved collaborative robots<br>3. Remote access & maintenance<br>4. Video surveillance service | On Premise Edge Cloud multiple OT domain |
| Group 3 | Latency-torelant<br>No need to store Data locally<br>**Mobility among locations** | 1. Remote access & maintenance<br>2. Video surveillance service<br>3. Mobile positioning & asset Tracking | Off premise Edge cloud (Near the Premise or regional, Central ) |

# Edge Cloud | Example deployments for use cases

Mobile Robots

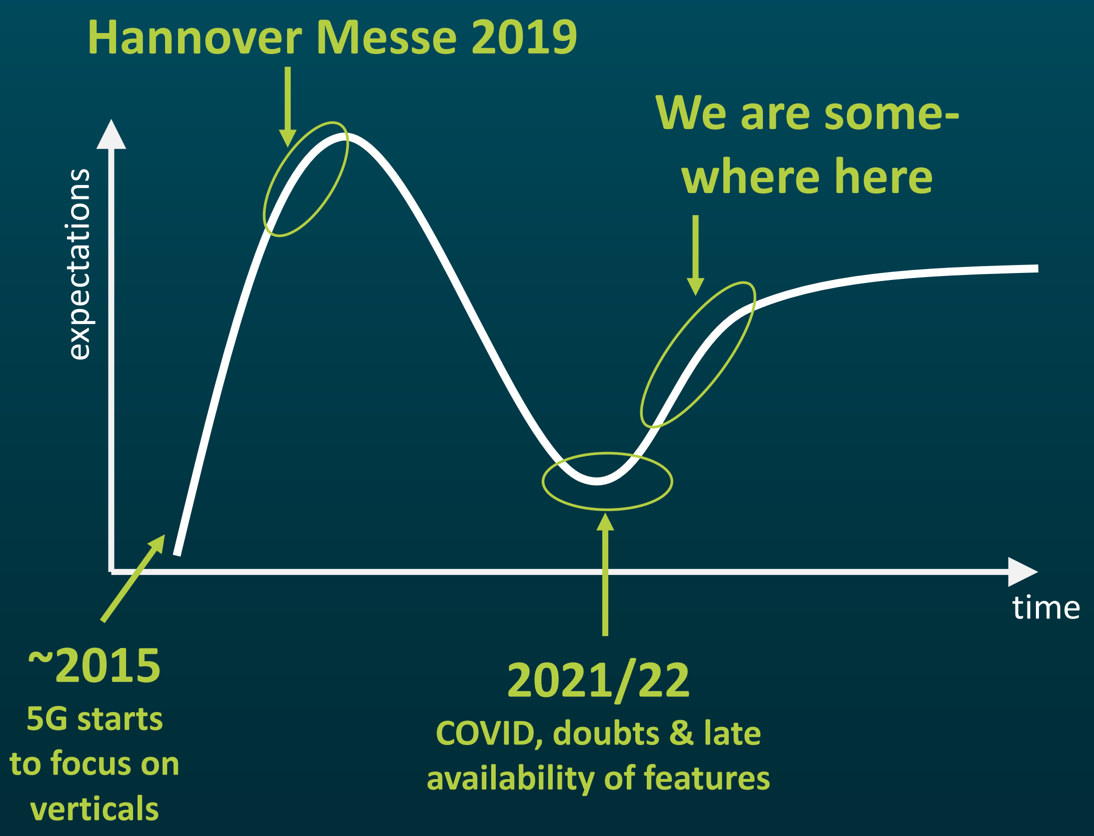


Part VI

# Industrial 5G: Where are we heading?

# 5G-ACIA | Quo Vadis, Industrial 5G?

## The Industrial 5G Hype Cycle




## From Theory to Practice

1. Significant adoption of private 5G for addressing coverage challenge already today (e.g., mining, ports, chem. plants)
2. Increasing availability of IIoT features (e.g., NR RedCap)
3. Increasing device ecosystem available, targeting particularly at industrial users
4. Significant activities of many industry leaders ongoing, esp. in areas such as car or aircraft manufacturing
5. Significant momentum and investments all around the world, incl. in the US, Japan, China and Korea

**Industrial 5G is coming later than originally expected, but it is coming!**



[1] Ultra-reliable low-latency communication [2] Time-sensitive networking [3] 5G New Radio Reduced Capability Mode [4] Non-public networks

# 5G-ACIA | Selected Topics of Current Interest

**Advanced Use Cases & Requirements**

**Advanced Shopfloor Integration**

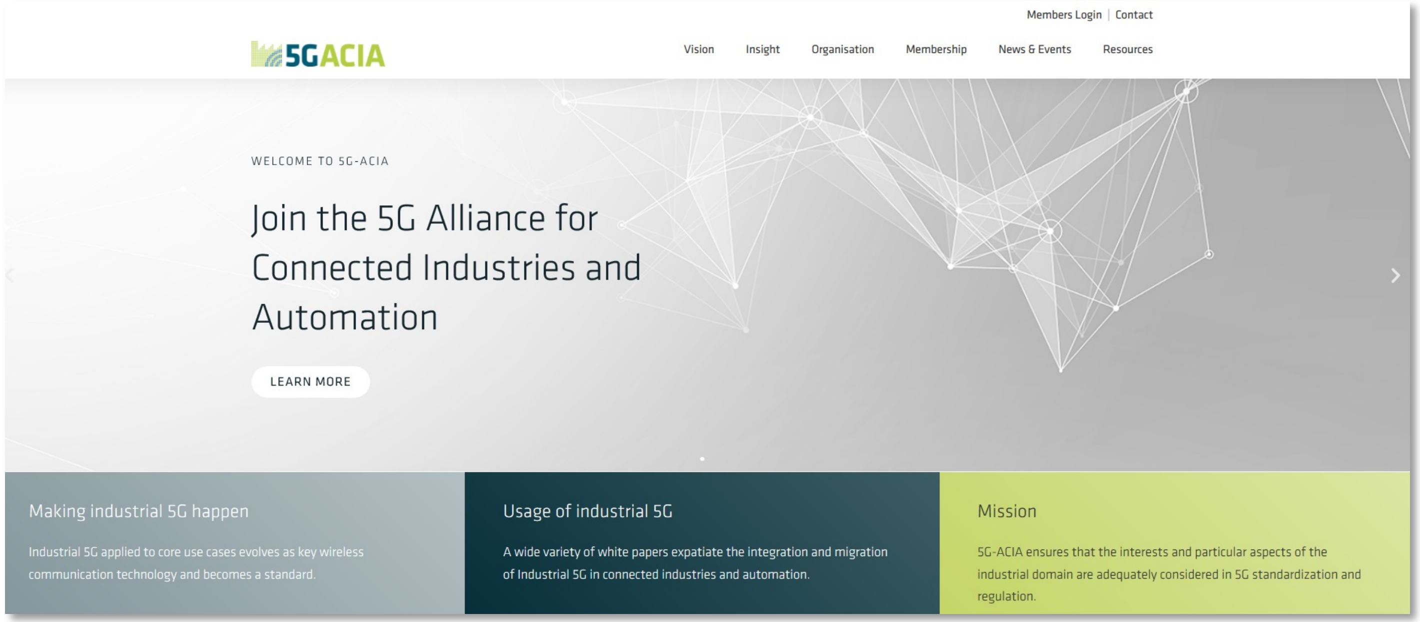
**Open RAN for Industrial 5G**

**Market Tracking & Forecasting**

**Hands-On Guidelines & Best Practices**

**+ many more exciting and important topics**

# 5G-ACIA | Further Information




www.5g-acia.org


Free white papers

**Join us today to unlock the full potential of Industrial 5G and to pave the way for its further evolution towards B5G and 6G in future!**

# Thank you!

Afif Osseiran (Ericsson), Director Industry Engagements & Research
General Vice-Chair of 5G-ACIA

Afif.Osseiran@ericsson.com

5G Alliance for Connected Industries and Automation
Lyoner Strasse 9
60528 Frankfurt am Main
Germany

www.5g-acia.org

5G ACIA

DESIRE6G

# END-TO-END DATA PLANE ABSTRACTION FOR SUPPORTING DEEP SLICING IN 6G

**Sándor Laki**, assistant professor

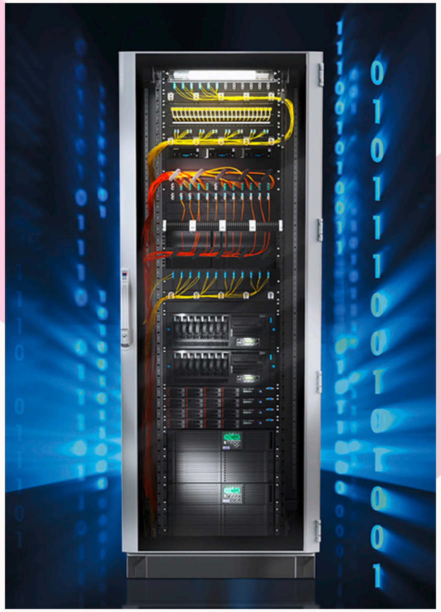
Communication Networks Laboratory
Faculty of Informatics
ELTE Eötvös Loránd University
Budapest, Hungary

Co-funded by
the European Union

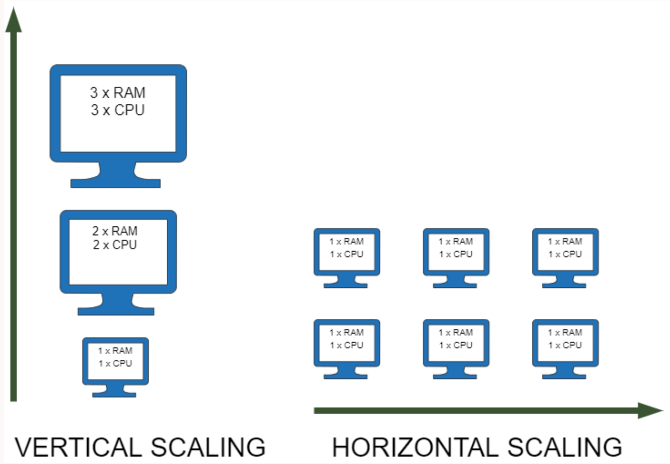
6GSNS

06/06/2023

# SOFTWARIZATION TREND IN PACKET CORE NETWORKS



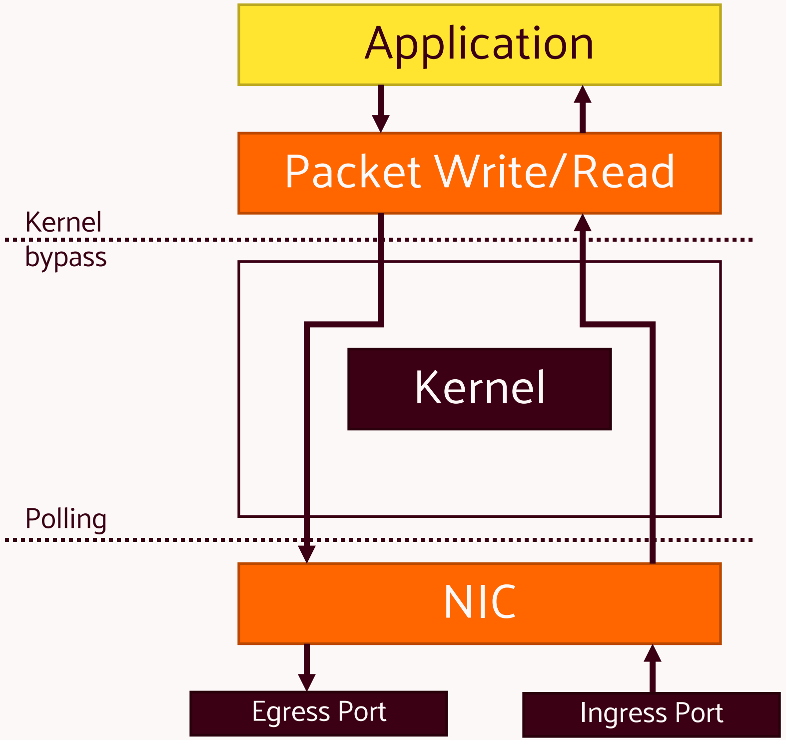
- Delivering new functionalities
  - Timely and customized way
- Softwarized packet core
  - Packet processing in software
  - Running on commodity servers
- High flexibility and good scalability
  - Software instances can be scaled up or down
  - Network Function Virtualization



# DRAWBACKS

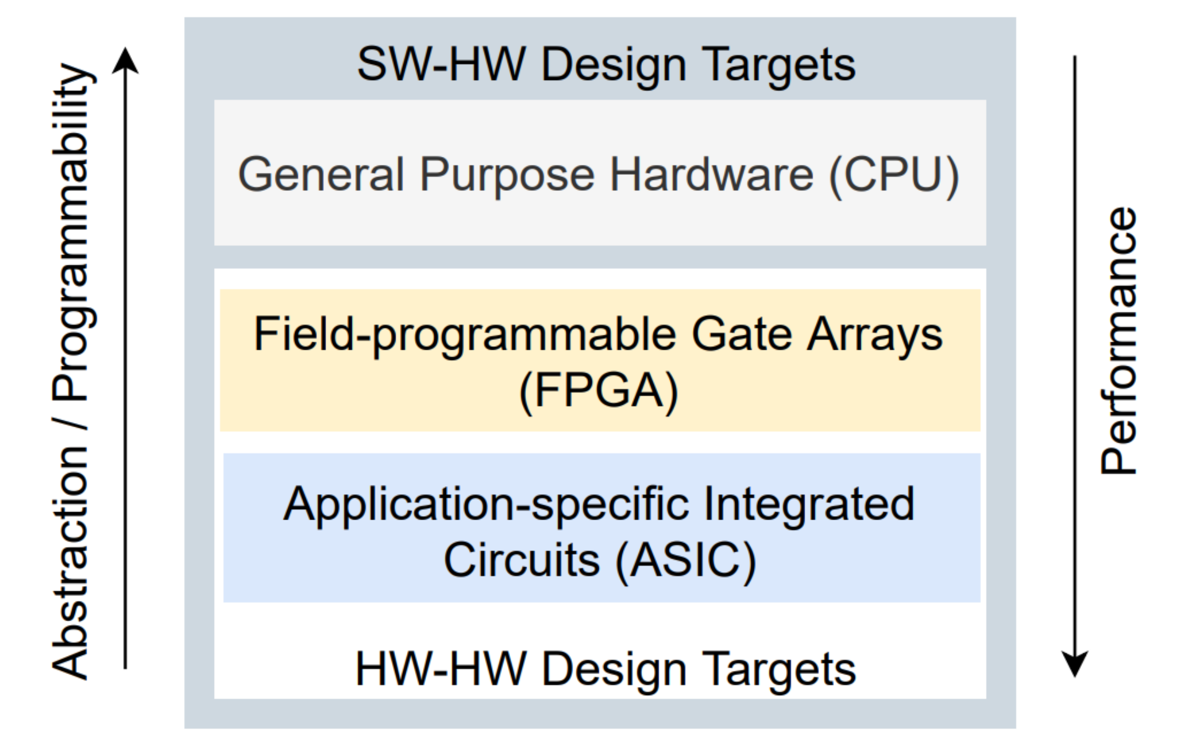
- Unpredictable latency and problems with low latency guarantees
  - Commodity hardware not designed for packet processing
- Throughput limits
  - Several bottlenecks: PCIe speed, cache misses, memory access, etc.

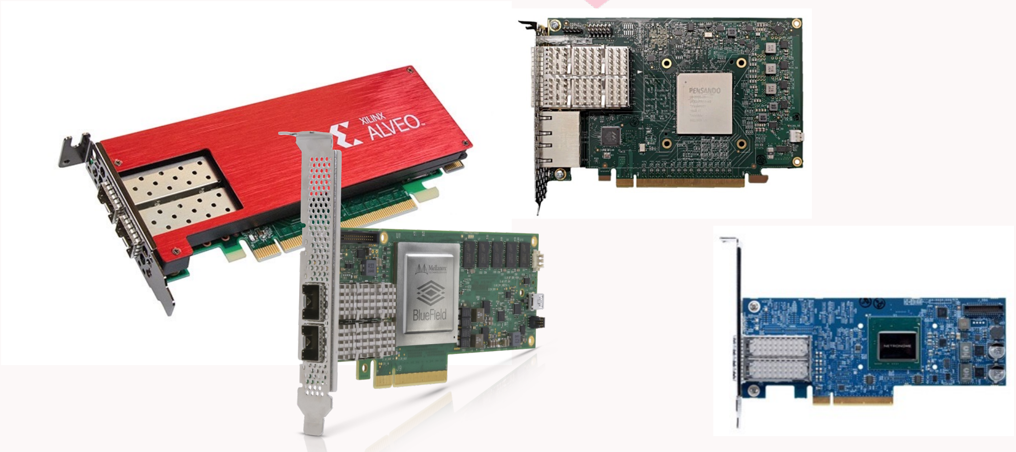

- Kernel-bypass techniques
  - High performance packet processing
  - Needed for good througput
  - Fully utilized CPU cores
  - Constantly polling NICs
- High energy consumption
  - W/pps
  - Increasing OPEX




DESIRE6G

# PROGRAMMABLE NETWORK DEVICES AS NF(V) BACKENDS

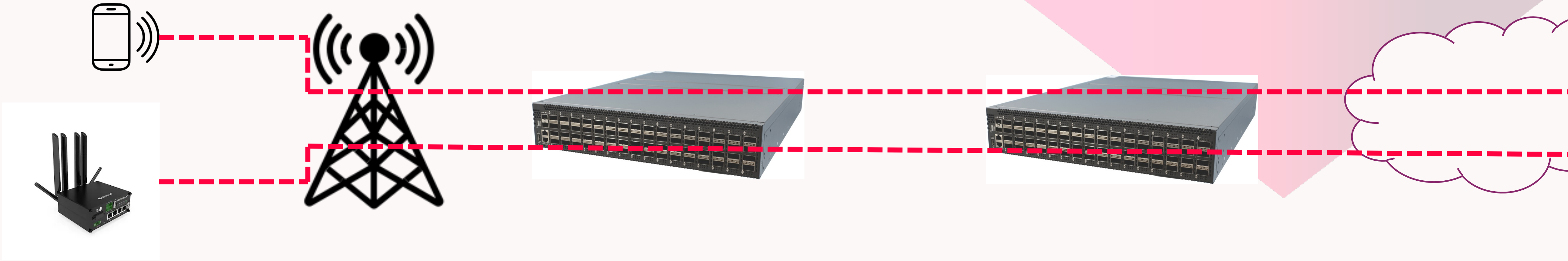


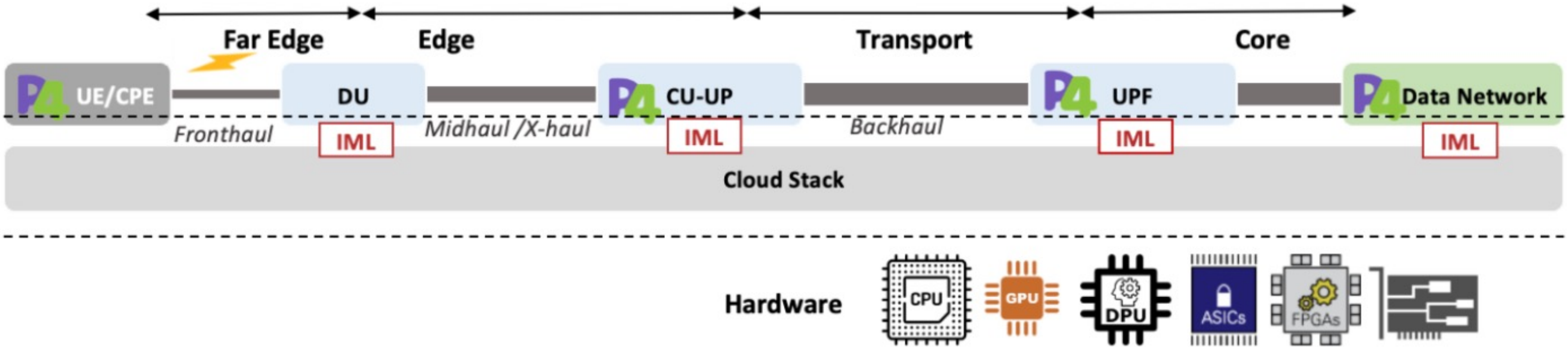




DPDK eBPF P4

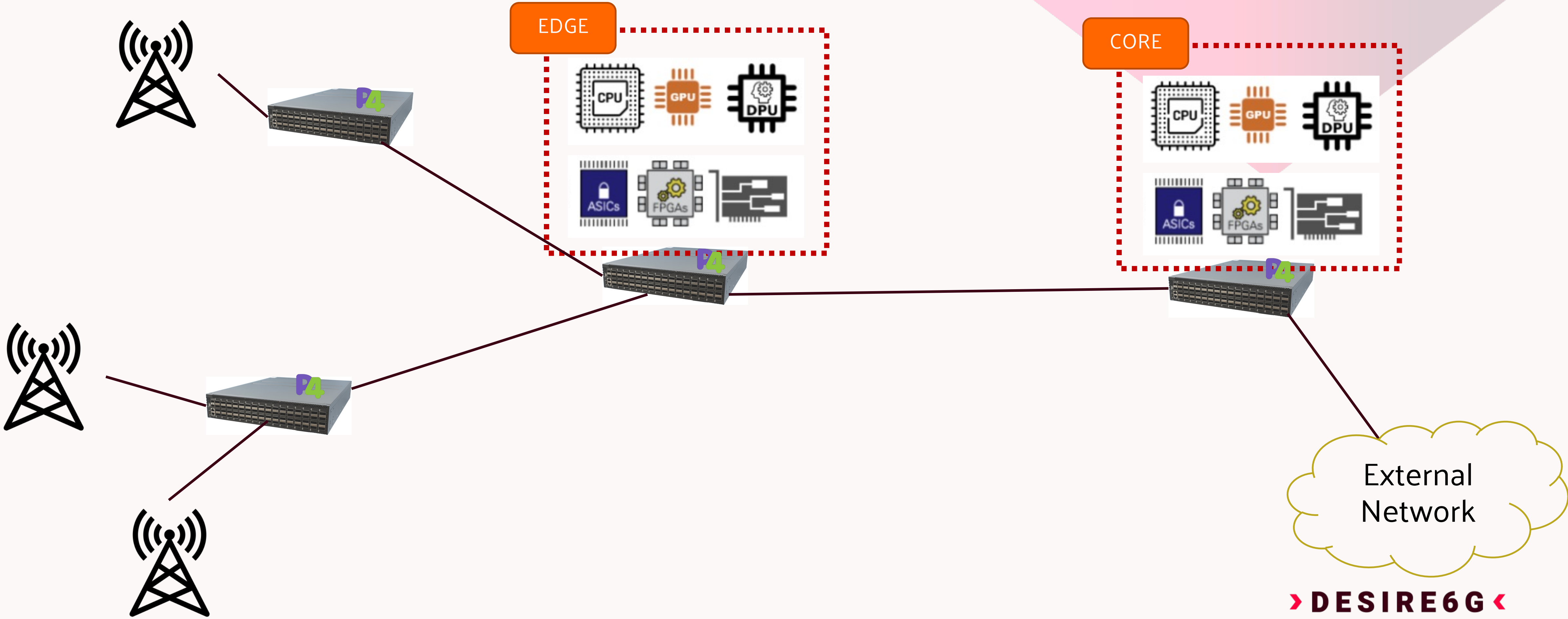
DESIRE6G

# E2E PROGRAMMABILITY VISION



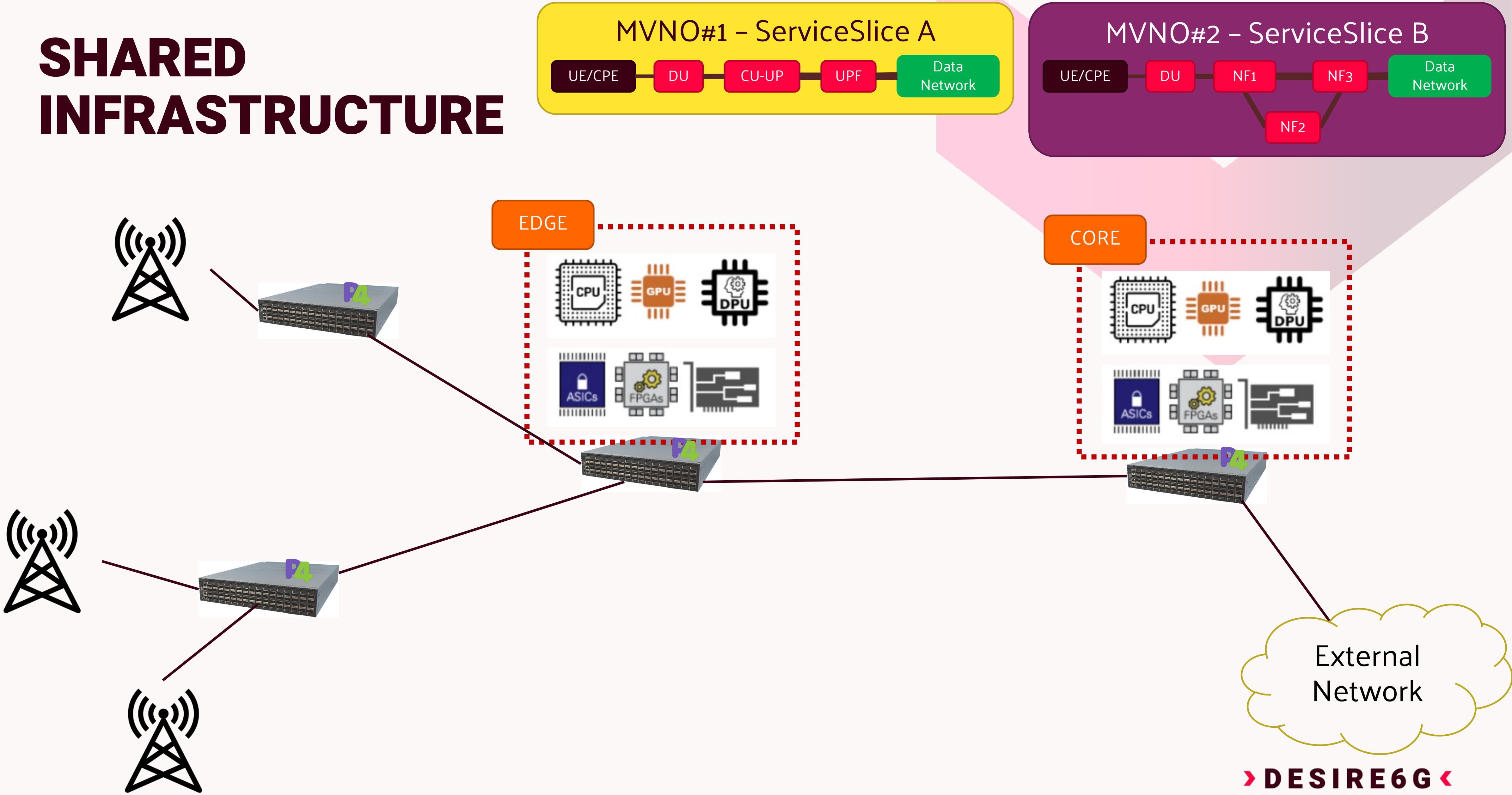


# SHARED INFRASTRUCTURE



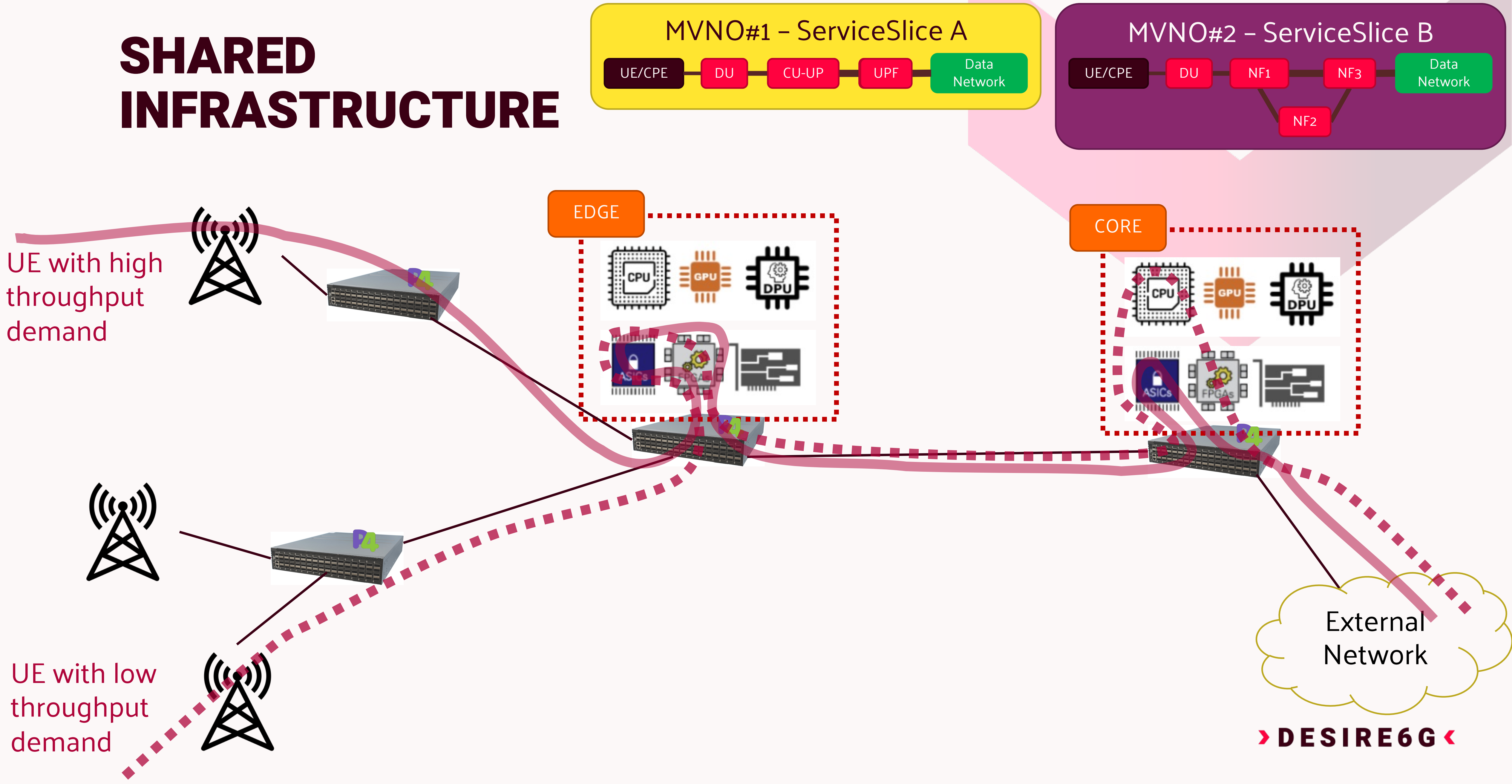

DESIRE6G

# SHARED INFRASTRUCTURE




DESIRE6G

# SHARED INFRASTRUCTURE

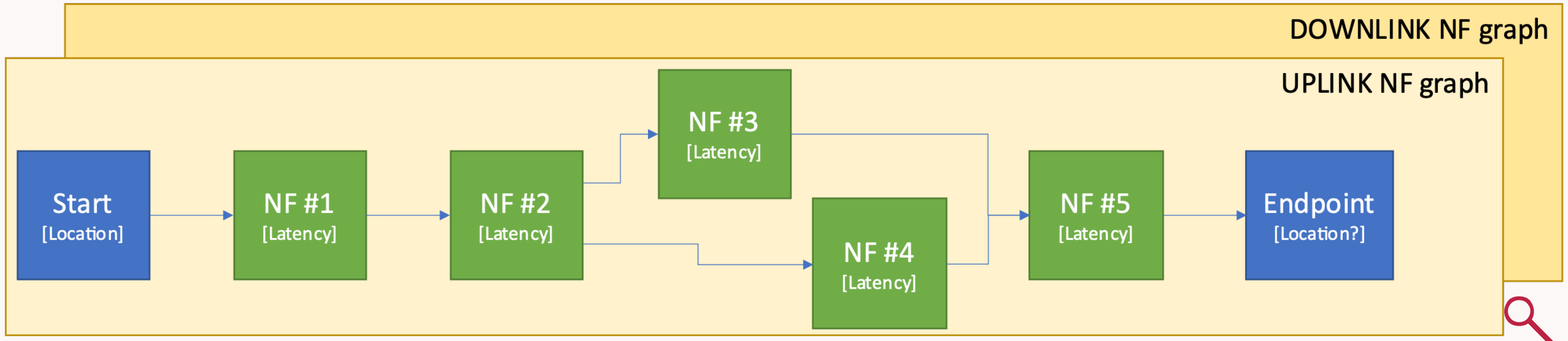



DESIRE6G

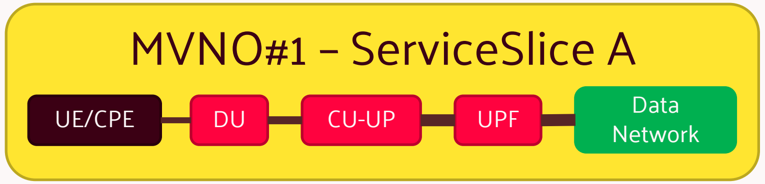
# SERVICE SLICE: INSTANCE OF A NETWORK FUNCTION GRAPH TEMPLATE

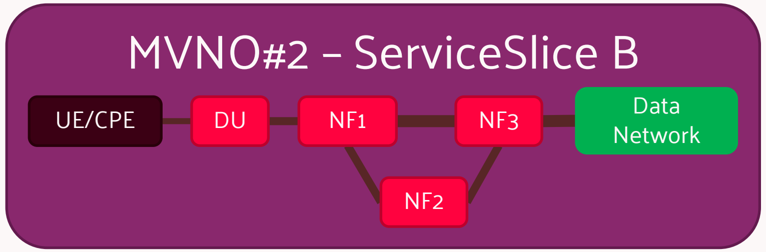
Abstract NF (or service) graph

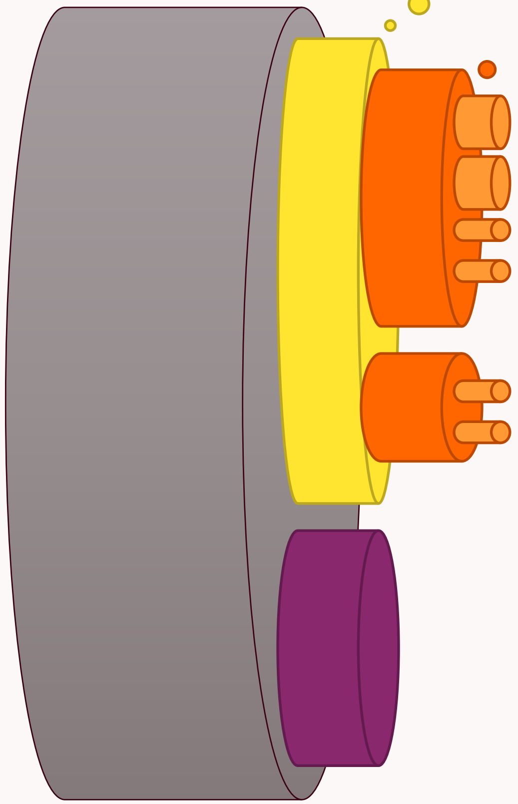
- Describes the end-to-end packet processing logic of one service
  - e.g., Internet access, robot control @MEC
- A user/application can join a network service (i.e., the slice implementing it) by instantiating the template between the end points
  - Done by mostly configuration, but redeployment of NFs may also be required
- One graph per direction (UL/DL) – the functionality is not always the same

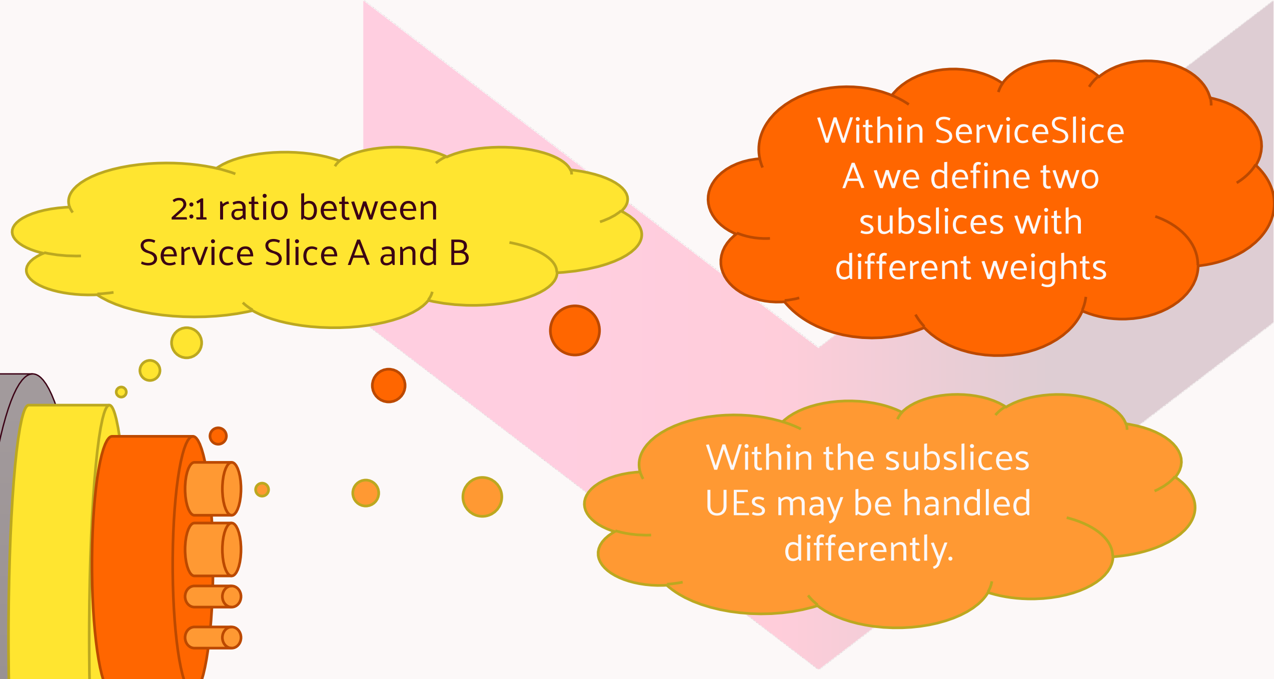


# QOS SLICES





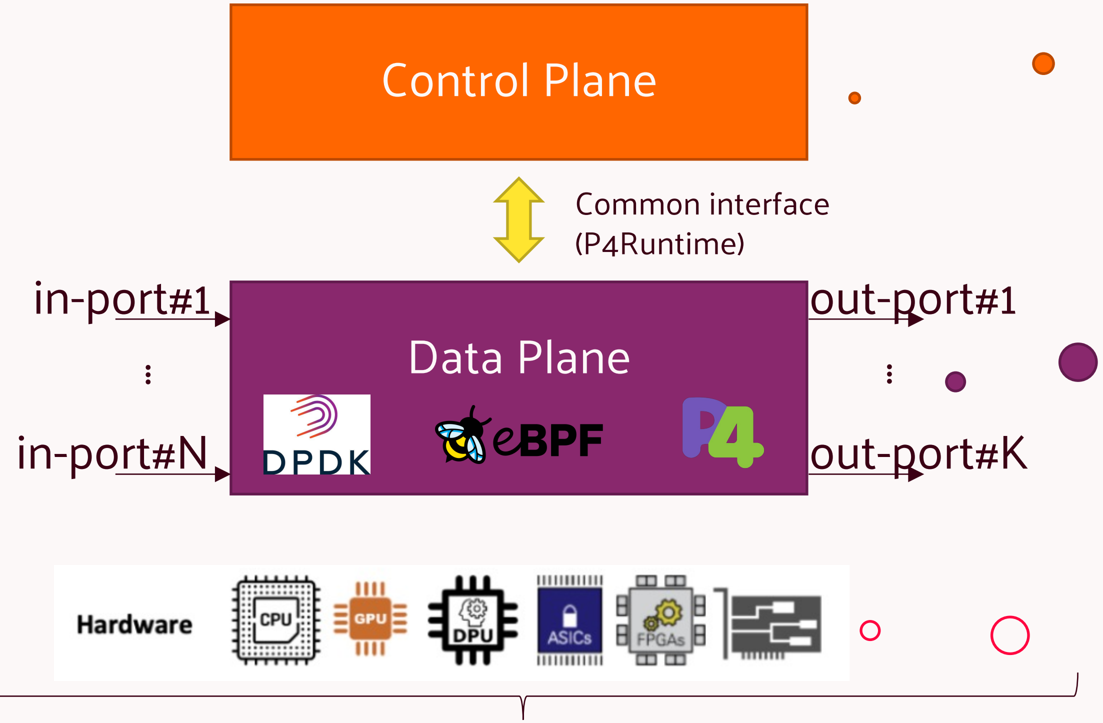

QoS requirements include

- Resource sharing requirements
  - i.e., HQoS
- E2E Latency requirements
- Guaranteed throughput demand

# DEEP SLICING REQUIREMENTS AGAINST DATA PLANE

- Resource isolation between service slices
  - Requires multi-tenant support for NF deployment on dedicated PDP HW
- Security isolation
  - Access control between data plane objects and control plane components
- Performance isolation between slices and subslices
  - Includes routing, traffic management and load balancing implemented by PDP
  - Fine grained and on demand settings
  - SLA enforcement with runtime optimization
- Pervasive monitoring for SLA assurance
  - Fast reaction to failures and performance degradation

# PACKET PROCESSING NETWORK FUNCTIONS: CP+DP




Running on CPU

Different equivalent NF-DP implementations (e.g., P4, eBPF/XDP, DPDK ) for the same DP functionality

Different implementations can be executed on various targets

NFs are stored in an NF repository and instantiated by Service Slices
NF-DP implementation properties include

- Execution latency on specific target config
- Max. bitrate/packet rate capacity
- Max. number of Ues to be handled
- …

# DEEP SLICING REQUIREMENTS AGAINST DATA PLANE

- Resource isolation between service slices
  - Implemented by P4 program aggregation and slice-based traffic classification in PDP
- Security isolation
  - Implemented by a Proxy between the Aggregated Data Plane and Control Plane instances

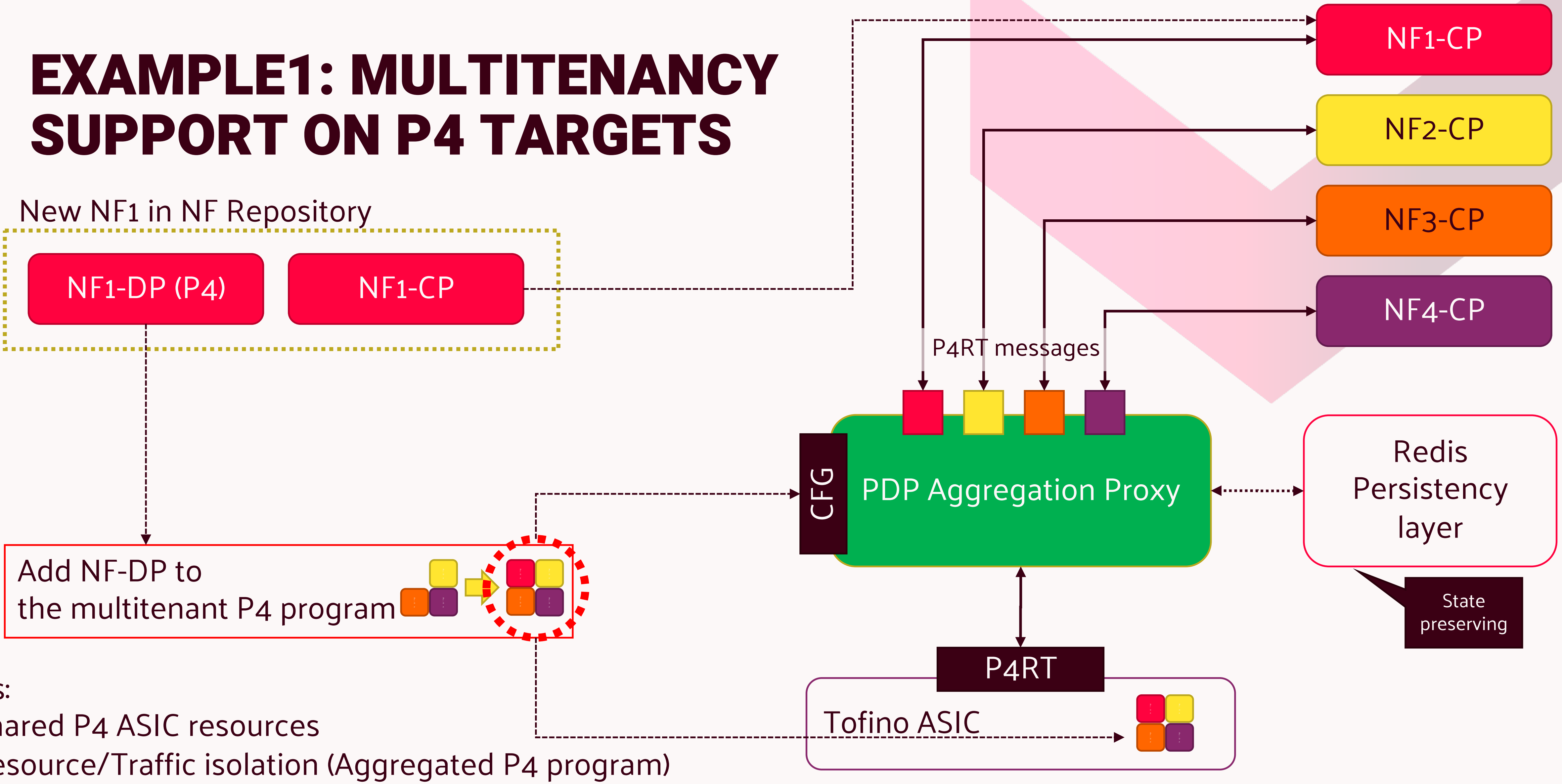
**EXAMPLE#1**

- Performance isolation between slices and subslices
  - Implemented by so called InfraNFs: routing, traffic management and load balancing
  - Reconfigurable traffic management and load balancing, self-driving pure data plane solutions

**EXAMPLE#2**

- Pervasive monitoring for SLA assurance
  - Implemented as an in-band network telemetry solution, can notify higher layers if needed
  - QoS/SLA measurement techniques for continous monitoring of the provided services

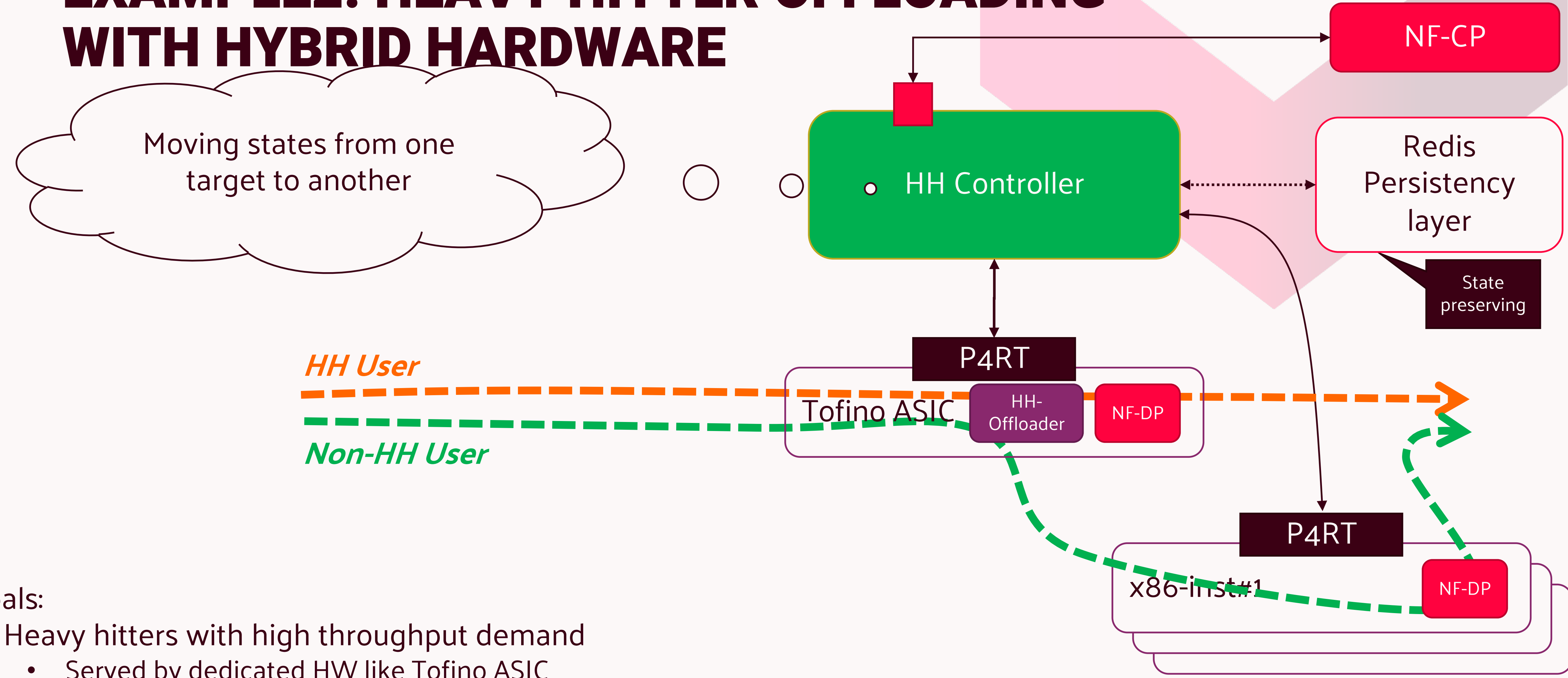
# EXAMPLE1: MULTITENANCY SUPPORT ON P4 TARGETS




Goals:

- Shared P4 ASIC resources
- Resource/Traffic isolation (Aggregated P4 program)
- Security isolation (PDP Aggregation Proxy)

# EXAMPLE2: HEAVY HITTER OFFLOADING WITH HYBRID HARDWARE



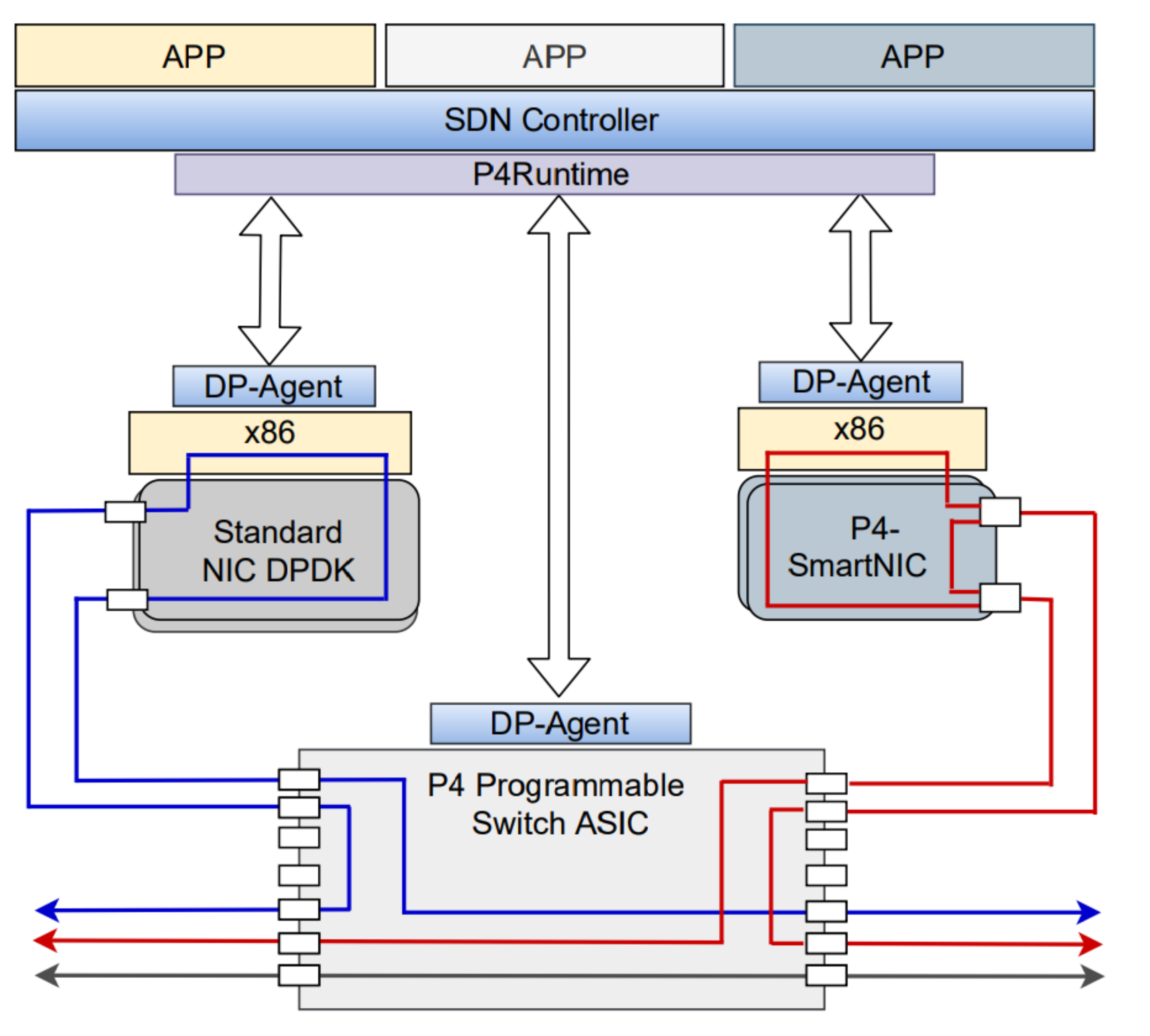

Goals:

- Heavy hitters with high throughput demand
  - Served by dedicated HW like Tofino ASIC
- Non-heavy hitters not requiring dedicated high-speed HW
- Run-time optimization needed

# CASE STUDY [1]: UPF ON HYBRID HW

- Key functions
  - L2 switching/virtualization
  - QoS support
  - Firewall
  - GTP decap/encap
  - L3 routing

- Disaggregation of the pipeline
  - Horizontal split
    - Identical logic, but the traffic is split
  - Vertical split
    - Chain of basic functional blocks

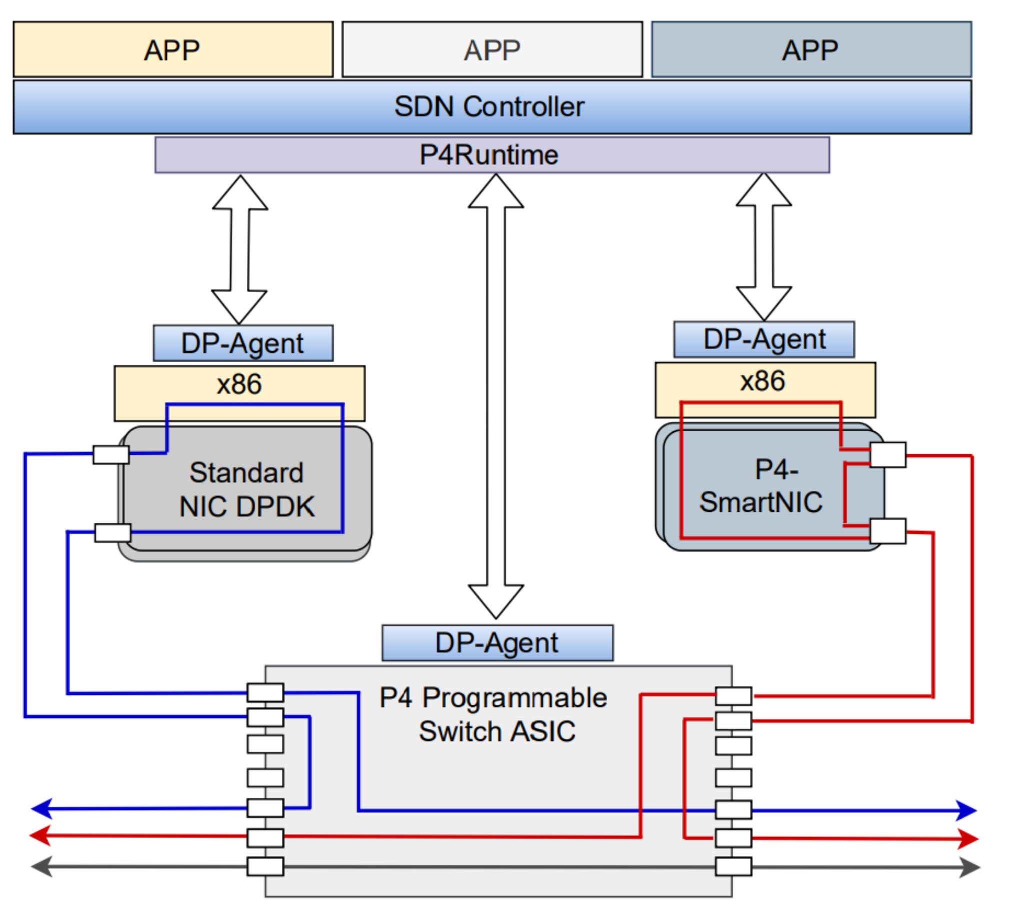



DESIRE6G

[1] S. Kumar Singh et al., "Hybrid P4 Programmable Pipelines for 5G gNodeB and User Plane Functions," in IEEE Transactions on Mobile Computing, 2022, doi: 10.1109/TMC.2022.3201512.

# CASE STUDY [1]: UPF ON HYBRID HW

- Tofino ASIC
  - Guaranteed low and bounded per packet delay
  - >6.5 Tbit/sec forwarding capacity
  - Limited SRAM resources - 10000s of UE matches only
  - Good target for crucial control functions like ACL
- Solutions
  - Option 1 – Scaling out to multiple switches
  - Option 2 – Differentiate between UEs
    - 90-95% of UEs are inactive or non-heavy-hitters
    - Only 5-10% have high throughput demand (heavy-hitters (HH))
    - E.g., 5M UEs: 5-10% smart phones (HH), 10-20% wideband IoT (HH), 70-85% narrowband IoT (non-HH)
    - Deploying HHs on Tofino, while non-HHs on x86

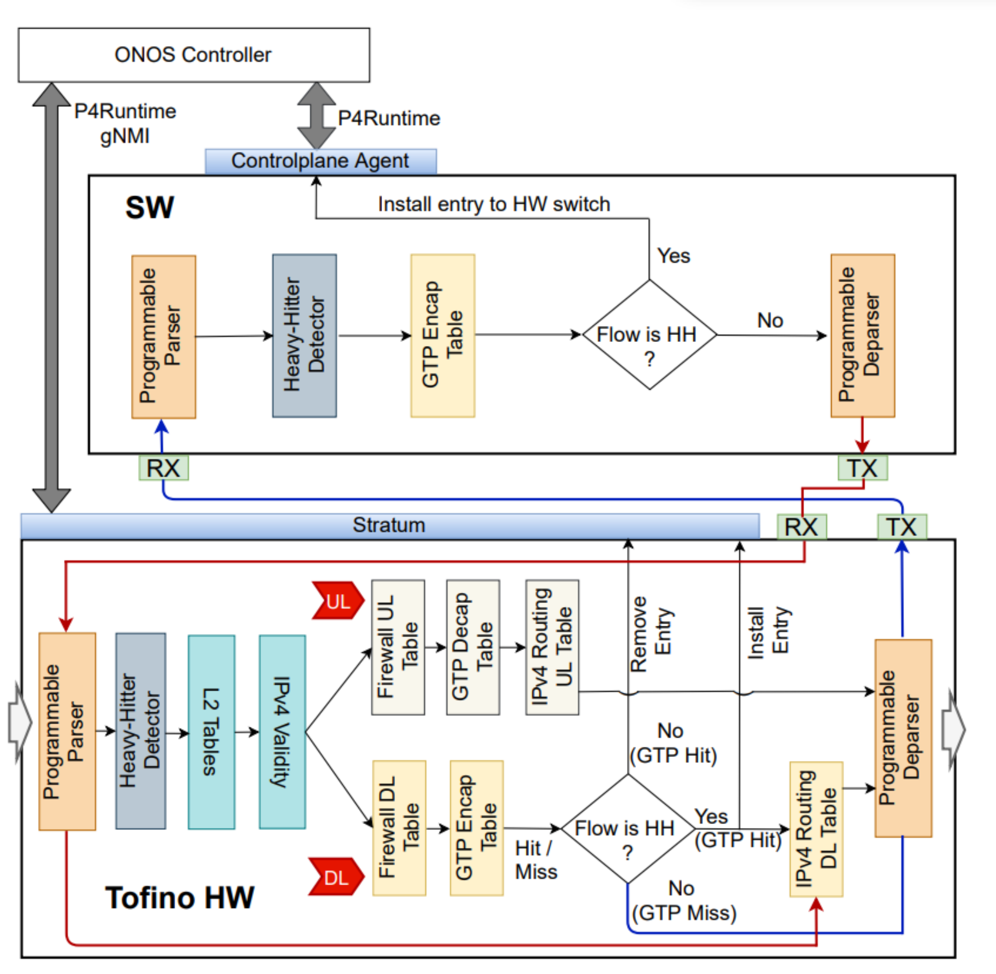





[1] S. Kumar Singh et al., "Hybrid P4 Programmable Pipelines for 5G gNodeB and User Plane Functions," in IEEE Transactions on Mobile Computing, 2022, doi: 10.1109/TMC.2022.3201512.

# CASE STUDY [1]: UPF ON HYBRID HW

- Upstream on Tofino only
- Downstream on both
- Heavy hitter detection-based switching
  - Inter Packet Gap-based HH detection
  - High detection accuracy
  - Notification to the control plane
  - Autonomous operation
- Exceptions can be added
  - Low latency flows
  - Slices with low latency requirements



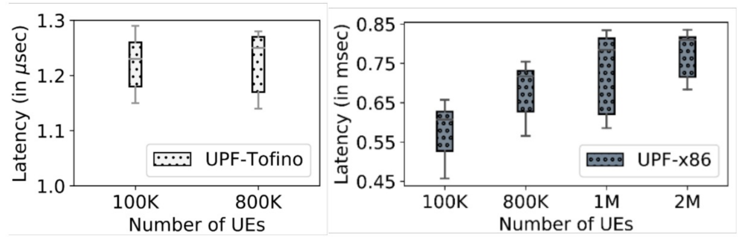

DESIRE6G

[1] S. Kumar Singh et al., "Hybrid P4 Programmable Pipelines for 5G gNodeB and User Plane Functions," in IEEE Transactions on Mobile Computing, 2022, doi: 10.1109/TMC.2022.3201512.

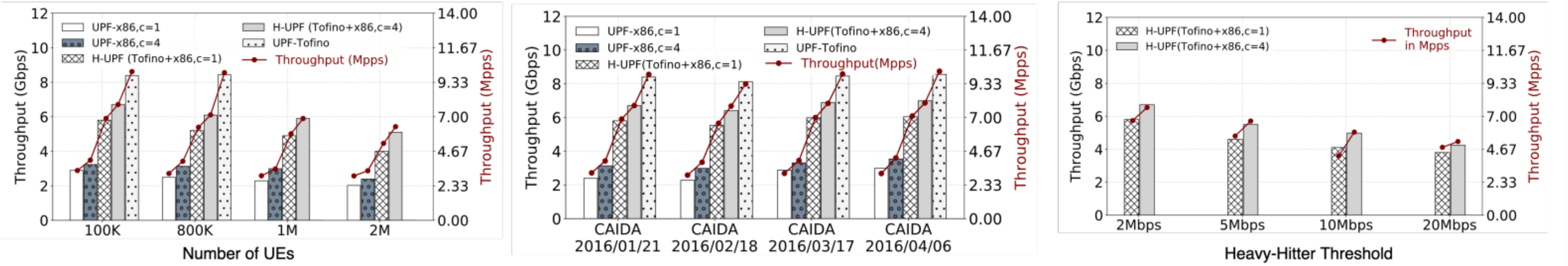
# CASE STUDY [1]: UPF ON HYBRID HW

**Testbed settings:**
- Tofino switch: Edgecore Wedge 100BF-32X
- X86 server: Intel Xeon D-1518 (4C, 2.2GHz) 10G SFP+ ports
- Traffic generator: NetFPGA SUME 10G
- Traffic: CAIDA 2016 ISP traces

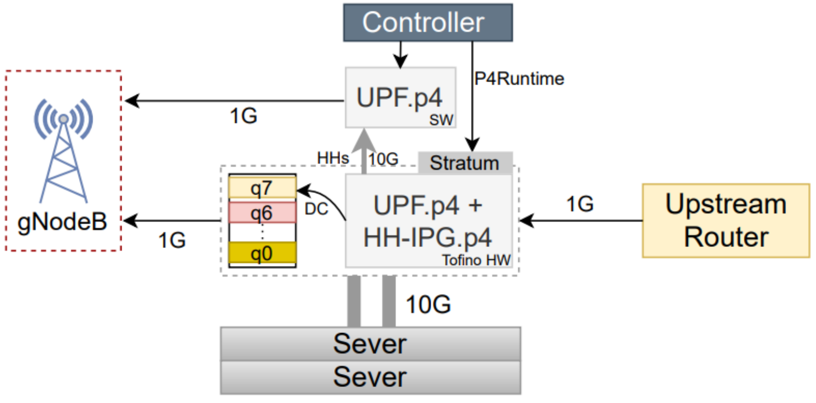
| | UPF-Tofino | H-UPF(Tofino+x86) |
|---|---|---|
| SRAM | 60% | 34.4%(Tofino) |
| UEs | 850K | 430K(Tofino)+15M(x86) |



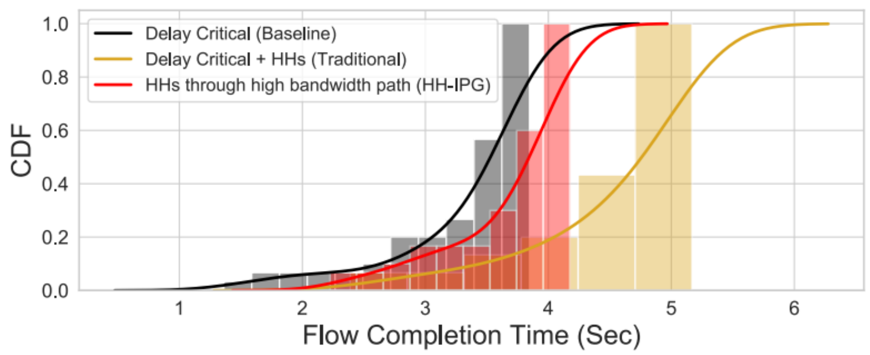
(a) UPF-Tofino Latency (b) UPF-x86 Latency



(a) TP for the number of UEs (b) TP for 4 days of CAIDA trace data (c) TP based on different HH thresholds



(a) QoS-HH Use-case Scenario



(b) Flow completion time with and without HHs offloading

› DESIRE6G ‹

[1] S. Kumar Singh et al., "Hybrid P4 Programmable Pipelines for 5G gNodeB and User Plane Functions," in IEEE Transactions on Mobile Computing, 2022, doi: 10.1109/TMC.2022.3201512.

# TAKE-AWAY

- **Programmable data planes as Technology enablers**
  - Accelerating customized packet processing
  - Quasi deterministic, ultra-low packet processing latency
  - InfraNFs can do runtime optimization at packet processing time-scale
    - Non-traditional traffic management – fine-grained resource sharing
    - Routing/Fast Rerouting
    - Load balancing including heavy hitter offloading can improve scalability – less load on CPU resources
  - Pervasive monitoring via in-band network telemetry
    - Fast notification and reaction to unexpected situations, failures and performance issues
- **Challenges**
  - HW PDPs are not shared resources by default
  - HW PDPs have numerous limitations and many restrictions
  - Migration of stateful NF-DPs
  - Dealing with non-programmable node in the transport

DESIRE6G

# THANKS!

Sandor Laki

lakis@inf.elte.hu

Co-funded by the European Union

6GSNS

DESIRE6G has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101096466.
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Commission. Neither the European Union nor the granting authority can be held responsible for them.

# Workshop on *Future deterministic programmable networks for 6G*, EuCNC 2023, June 6th, 2023

DETERMINISTIC6G

## Data driven aspects for 6G deterministic communication

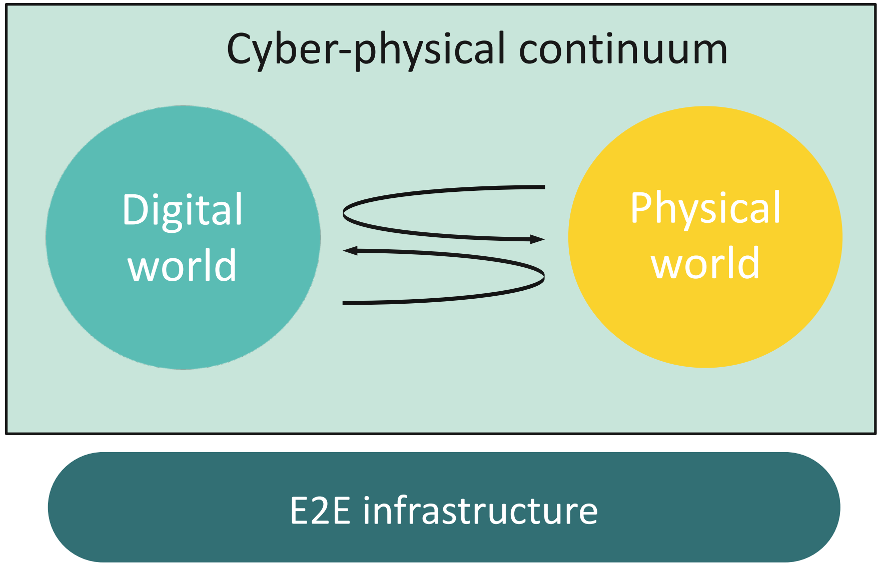
Prof. James Gross (KTH)
*jamesgr@kth.se*

KTH VETENSKAP OCH KONST

The DETERMINISTIC6G has received funding from the European Union's Horizon Europe programme under grant agreement No 10109504.

# Cyber-Physical Continuum Pull

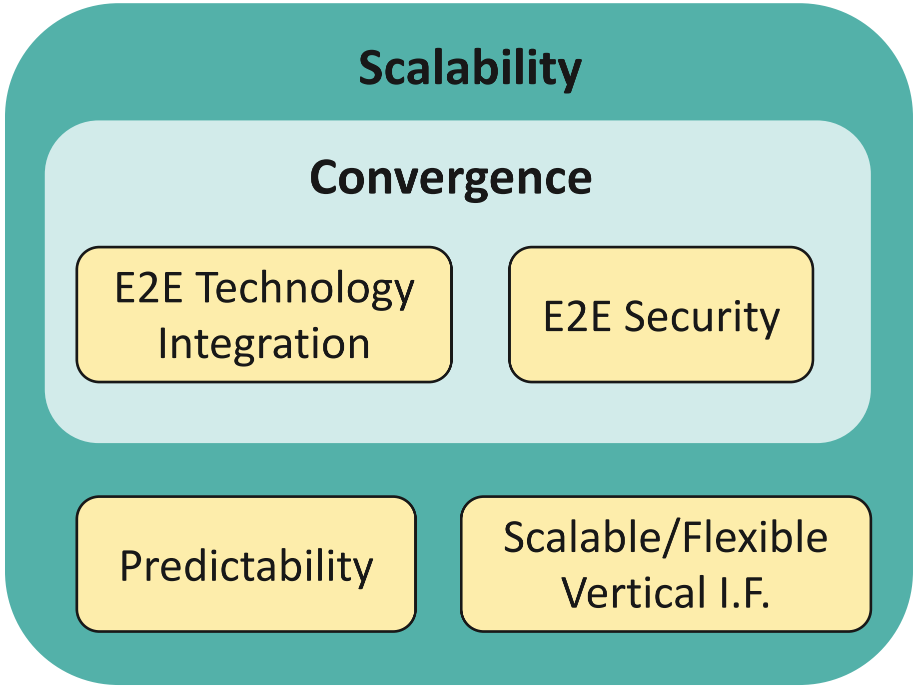
- Digitalization continues to drive transformation in industry & society
- Community expects an increasingly meshed deployment of (heterogeneous) CPS applications, leading to a cyber-physical continuum.
- Cyber-physical continuum challenges todays communication "islands": Existing technologies are not ready for massive CPS deployment.



# Central Goals of Next-Generation Cyber-Physical Networks



- Meeting cyber-physical continuum demands requires next-generation systems to attain 2 key system goals:
  - Convergence among different technologies and infrastructures to provide end-to-end guarantees for CPS applications
  - Scalability of communication and compute infrastructure to support CPS applications with diverse workloads and requirements
- Leads to four fundamental challenges!




Sharma et al. “Towards Deterministic Communications in 6G Networks: State of the Art, Open Challenges and the Way Forward”, *arXiv preprint arXiv:2304.01299*

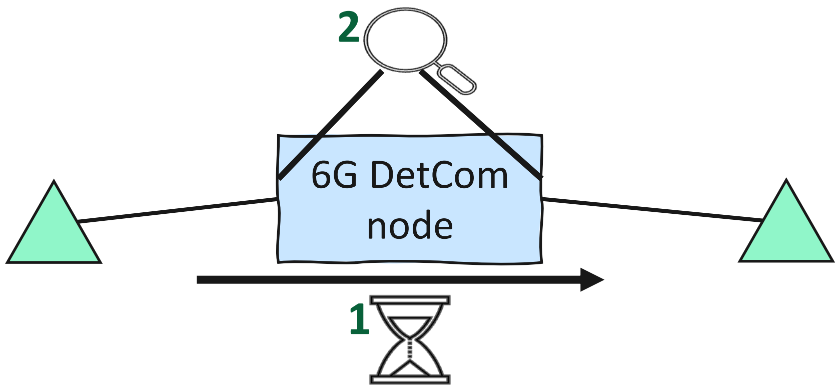
# 6G Cyber-Physical Networking Enablers

| E2E Technology Integration | Predictability | Flexible/scalable Vertical Interfaces | E2E Security |
|---|---|---|---|
| Deterministic communications & compute integration | Digital Twinning and Awareness | | Security-by-design Architecture |
| | | OPC UA Extensions | |
| Wireless-friendly Integration of TSN & DetNet | | | |

- 6G System Evolution
- ML-based System Characterization
- E2E Time Synchronization

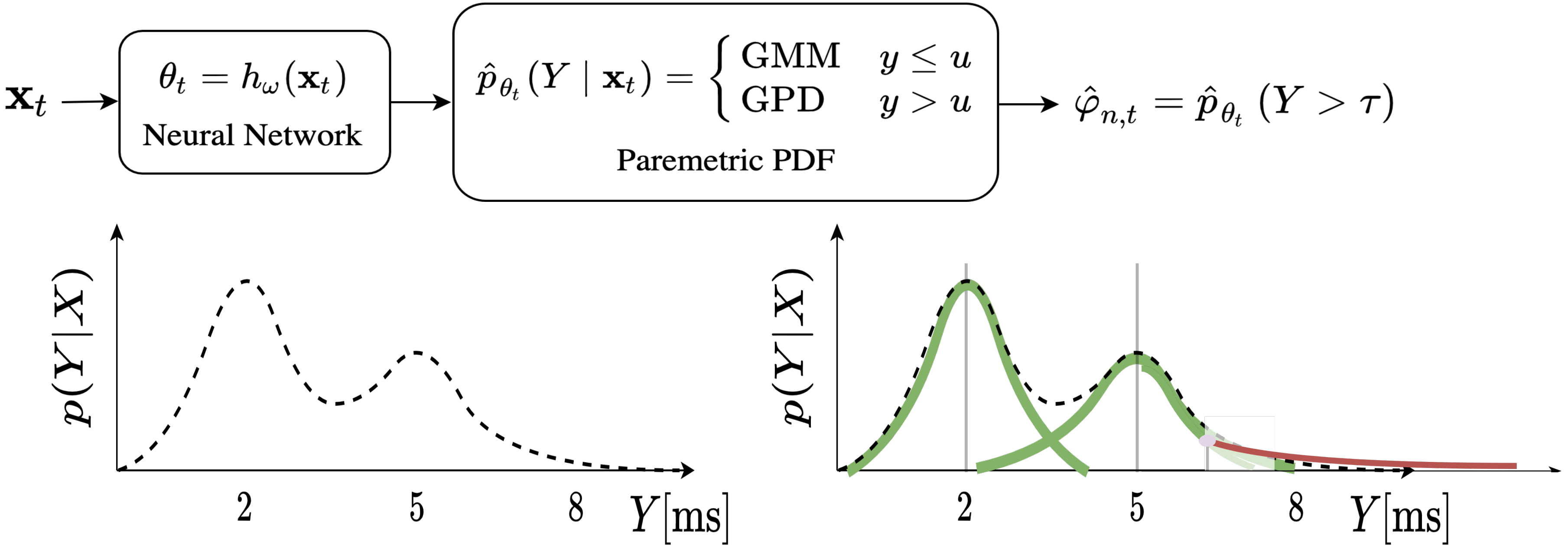
# Predictability for 6G Deterministic communications

- Predictability is the ability to accurately predict parameters of stochastically evolving KPIs of a given communication system over a given time interval at run-time.
- For example, average throughput of UE, likelihood of next m/n packet reception within deadline *d* ms, tail latency probability, etc
- Q*: Can future 6G systems be built with sufficient predictability to ensure seamless operation of diverse applications?*
- Predictability of a system can be influenced during
  1. System design phase -> URLLC, PDC, …
  2. Runtime phase -> AI/ML system ckt



# Data-driven latency characterization

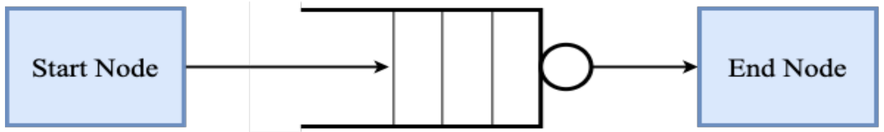
- Problem: To fit a parametric density function $\hat{p}_\theta$ with parameter $\theta$ to the conditional data set:

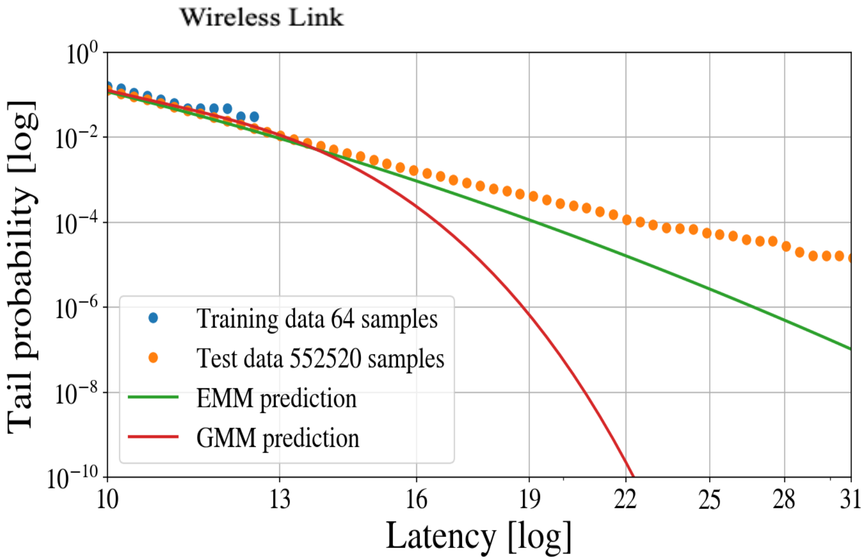



GMM: Gaussian Mixture Model
GPD: Generalized Pareto Distribution

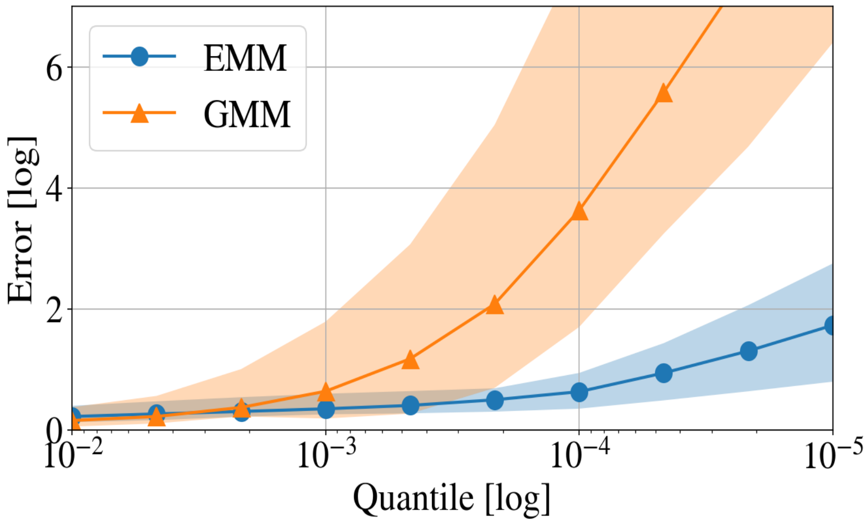
# Previous work: Queuing-theoretic system

Service: heavy-tailed Gamma distributions ($\mu = 1$ )
Arrival: deterministic ($\lambda = 0.9$)




- Dataset creation: Simple stationary one-hop queuing model in simulator
  - Time stamp the packet at the ingress and the egress
  - Record e2e delay and conditions




GMM: Gaussian Mixture Model
EMM: Extreme Mixture Model

S. S. Mostafavi, G. Dán and J. Gross, "Data-Driven End-to-End Delay Violation Probability Prediction with Extreme Value Mixture Models," *2021 IEEE/ACM SEC.*

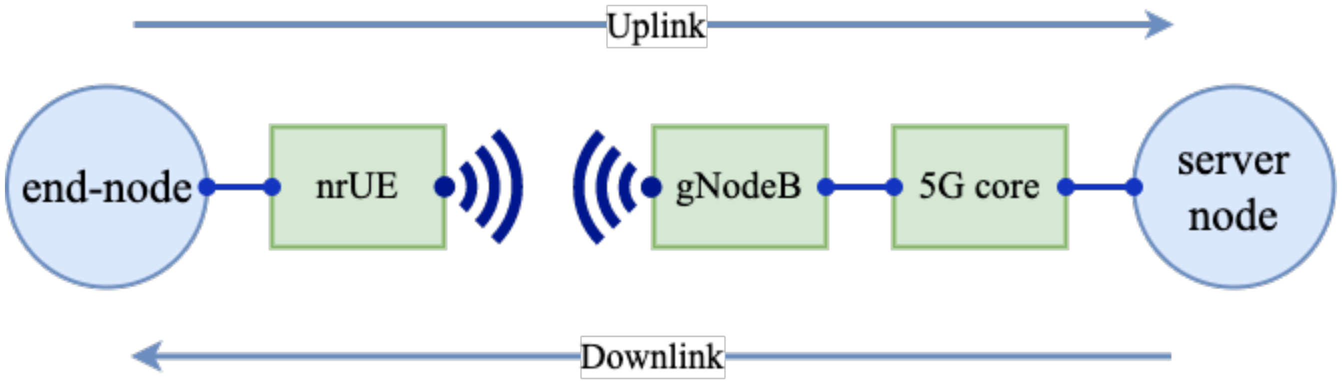
# Goal

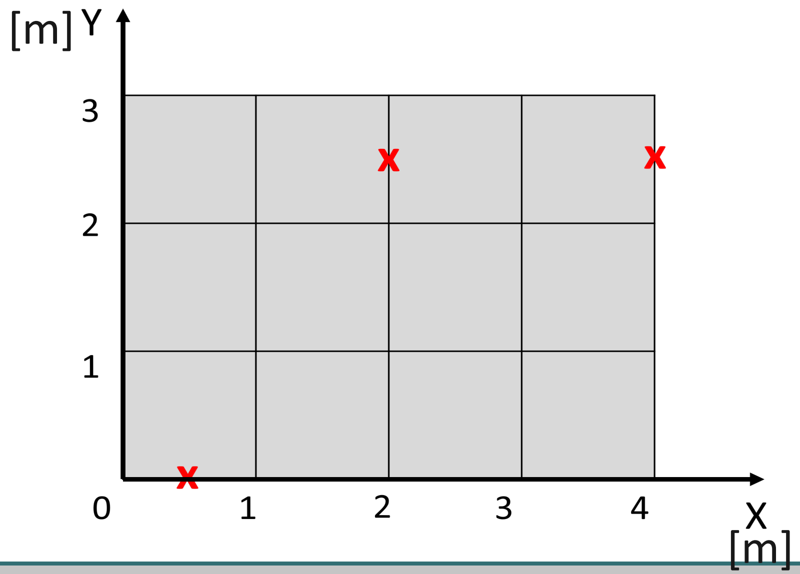
- The goal of this work is to investigate if data-driven approaches (w/ EVT) can be leveraged to characterize the latency of (real) wireless systems
- We characterize the latency distribution of two technologies- i) COTS 5G and ii) OAI 5G
- Study the generalization capability of predictors and the impact of the number of training samples on the accuracy of predictors

COTS: Commercial-off-the-shelf
OAI: OpenAirInterface

# Methodology

- Measurements taken on COTS and OAI 5G setups
- Latencies (UL, DL and RTT) measured between the end node and the edge server via IRTT
- UE position on a 4x3 grid and RSRP measured for the COTS 5G setup
- MCS observed in the OAI 5G setup



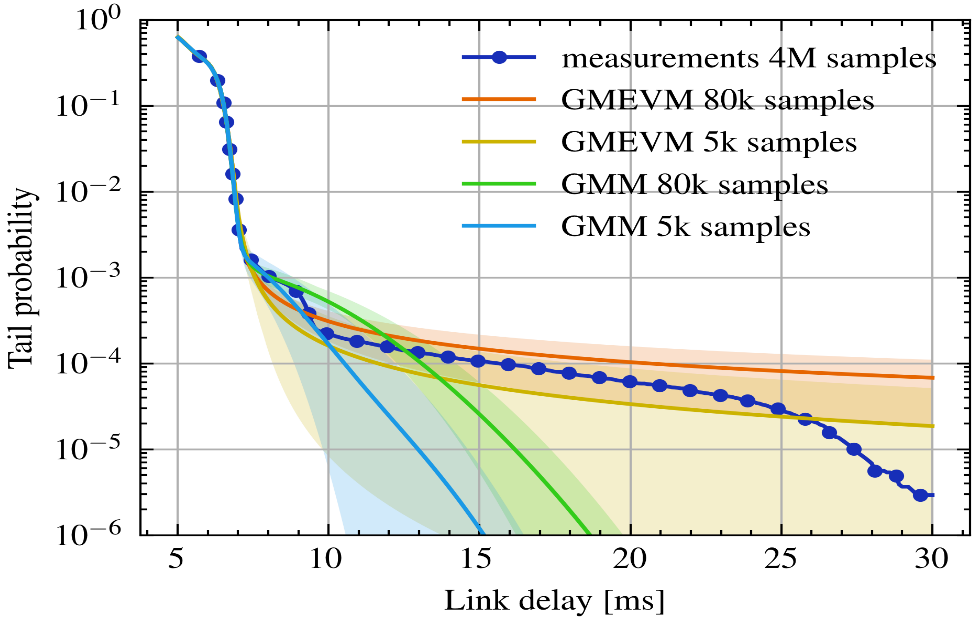




nrUE: New Radio User equipment
gNodeB: Next Generation Node B
RSRP: Reference-Signal-Receive-Power

# COTS 5G: Non-conditional latency estimation

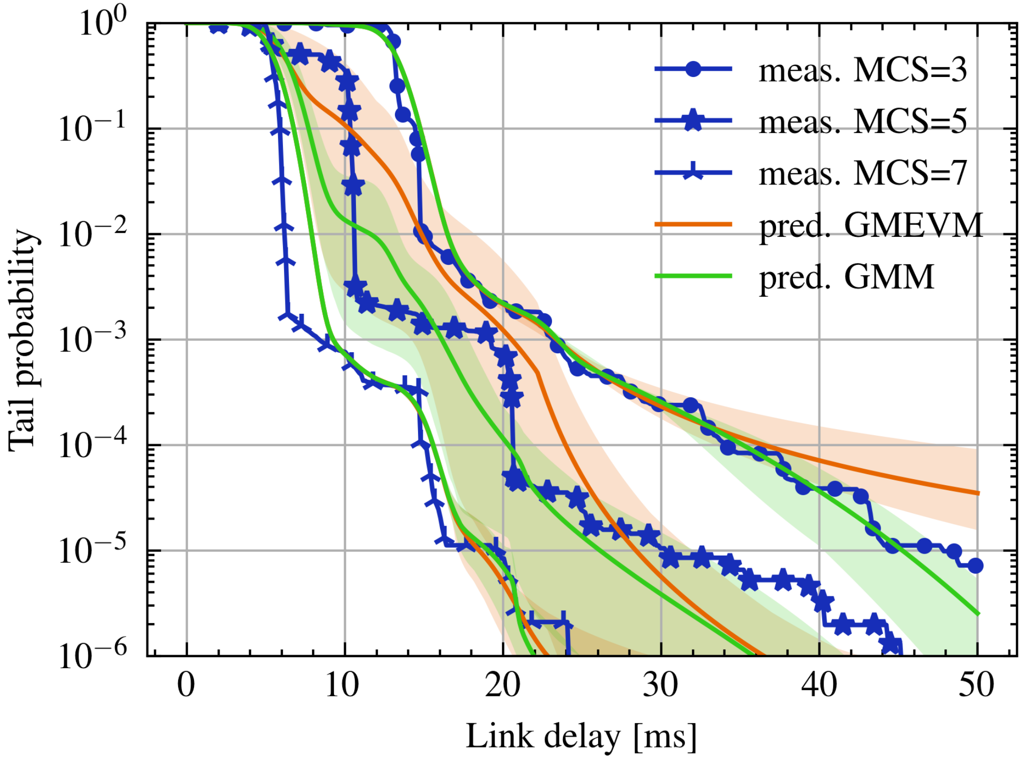
| | |
|---|---|
| MDN | Gaussian Mixture Model (GMM) and Gaussian Mixture Extreme Value Model (GMEVM) |
| Neural Network | 4 hidden layers ([10, 50, 50, 40])), 15 Gaussian centers |
| Training samples | 4M samples (66 min), 80k (17 min) and 5k (5 min) |
| Platform (OS, hardware) | Intel(R) Core(TM) i9-10980XE CPU @ 3.00GH, 125GB RAM, 28 cores assigned |

Training parameters




*Non-conditional latency probability prediction for COTS 5G is improved by incorporating EVT with GMM!*

# OAI 5G: Generalization wrt MCS




0.6 M training samples

- Increasing MCS results in reduced latency in general due to increase in link capacity
- Models trained on the datasets for only MCS=3 and MCS=7 and predictions produced for MCS=5
- Gaussian noise of 1ms std added to the training data for regularization

# Conclusions

- Deterministic communications in 6G require predictability of wireless systems
- Data-driven latency characterization: MDN combined with EVT could be leveraged to accurately characterize latency of different wireless technologies
- Proposed predictors can i) perform well with a relatively smaller training dataset and ii) can generalize, i.e., estimate latency probabilities for conditions not seen during the training phase
- Next step is to investigate the system states (e.g., MCS, frequency band) and factors (e.g., UE position) that majorly influence latency (blackbox -> whitebox)
- Compare different latency prediction architectures (centralized and distributed)

DETERMINISTIC6G

# DETERMINISTIC6G Grant Agreement No. 101096504

The DETERMINISTIC6G project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No. 101096504.

If you need further information, please contact the coordinator:

Dhruvin Patel, ERICSSON

E-Mail: coordinator@deterministic6g.eu

or visit: www.deterministic6g.eu

@DETERMINISTIC6G

DETERMINISTIC6G

# Can TSN be the standard communication protocol for robotics ?

Milan Groshev (mgroshev@pa.uc3m.es)
EuCNC WS10: Future deterministic programmable network for 6G

Funded by
the European Union

Visit us at predict6g.eu

# About me

- Researcher at UC3M (~5 years).
    - Telematics department, part of NETCOM research group
- PhD in the field of Networked robotics
- Current research interests: JCAS, Semantic orchestration, TSN
- Background
    - AI for teleoperated robots
    - DLT for mobile robot services
    - Robot as a Network Service

# Outline

- Provide a brief introduction of Networked robotics
- Present the current Networked robotics communication protocols
- Time Sensitive Networking for robotics

# Outline

- Provide a brief introduction of Networked robotics
- Present the current Networked robotics communication protocols
- Time Sensitive Networking for robotics

# Industrial revolutions

**Industry 1.0**
**Mechanization,**
*water and steam powers*
1800

**Industry 2.0**
**Mass production,**
*electric power, assembly line*
1900

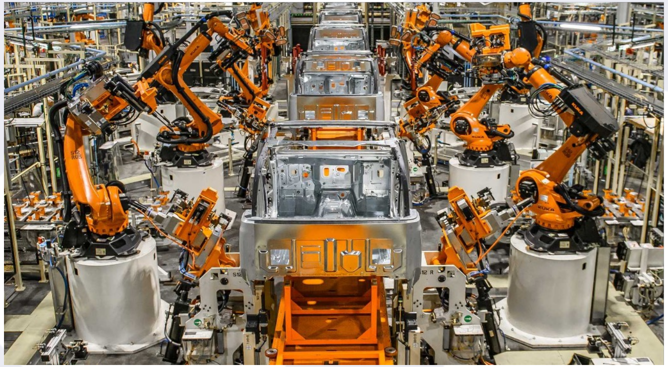
**Industry 3.0**
**Automation,**
*electronics, IT and robotics*
2000

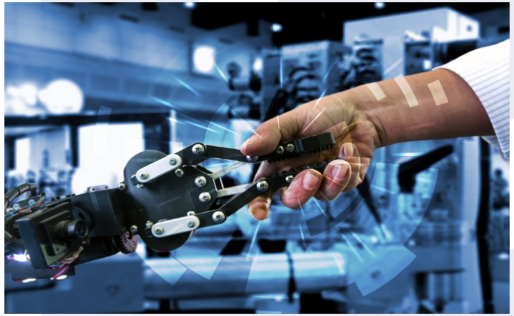
**Industry 4.0**
**Connectivity,**
*Cyber-physical systems, ML*
2010

**Industry 5.0**
**Customization,**
*human-robot collaboration*
2020

# Robotics in manufacturing

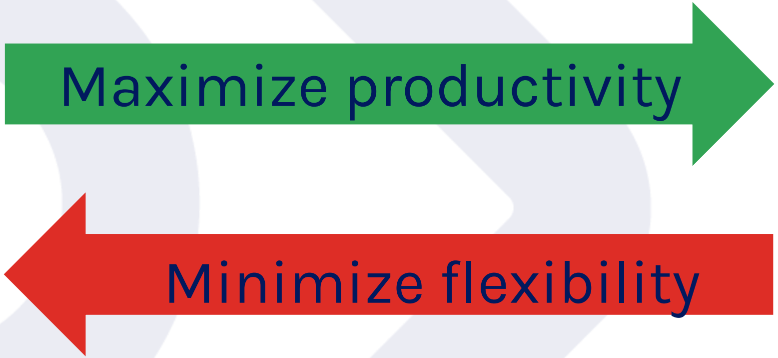
- In 2018, < 10% of the US manufacturing firms used robots
- In 2020 this number even decreased
- China is estimated to be roughly the same as in US





# Productivity limits flexibility

1. Automation technologies are not adaptable to changes in external environment
2. Require specific, deep technical skills to program and repair them
3. Black boxes operating without the human feedback

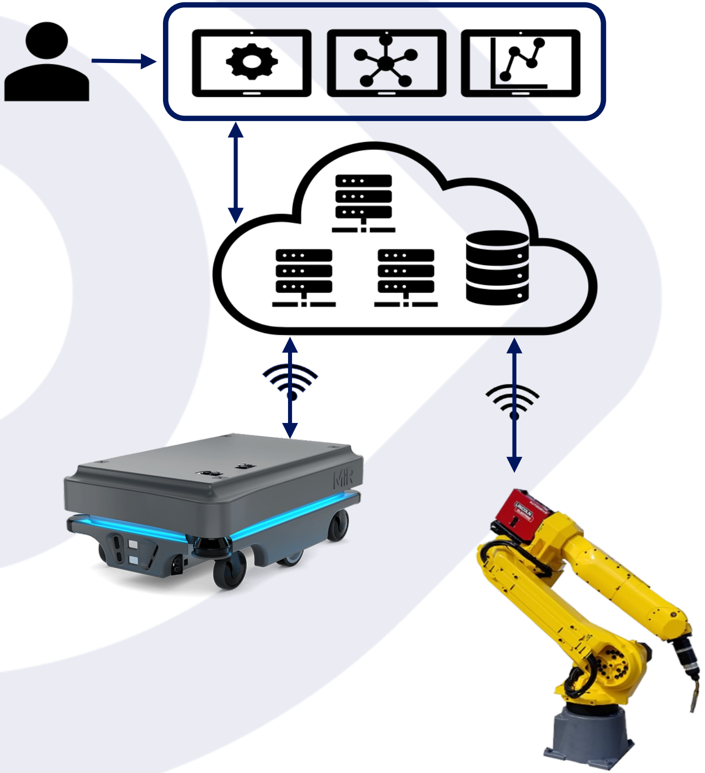


# What is networked robotics?

- Set of evolving **Information and Communication Technologies (ICT)** that allow, at different levels of granularity to model a robot system as a set of individual components that are glued together.
  - Started from Online robot systems (Internet robots)
  - Allows for OT and IT to co-exist
- Provides flexibility by making robots:
  - Service oriented
  - Interoperable
  - Distributed
  - Programmable
- Target different use cases:
  - Industrial robots, telepresence robots, social robots, etc

# Cloud robotics example

- Robots
  - Joint states
  - Multiple sensors
    - Camera
    - Lidar
    - Mics
- Control
  - Robot config
  - Monitoring
  - Cooperation and coordination
- Why networked robotics?
  - Optimize automation
  - Availability
  - Reduce costs



# Outline

- Provide a brief introduction of Networked robotics
- Present the current Networked robotics communication protocols
- Time Sensitive Networking for robotics

# Current infrastructure behind networked robotics

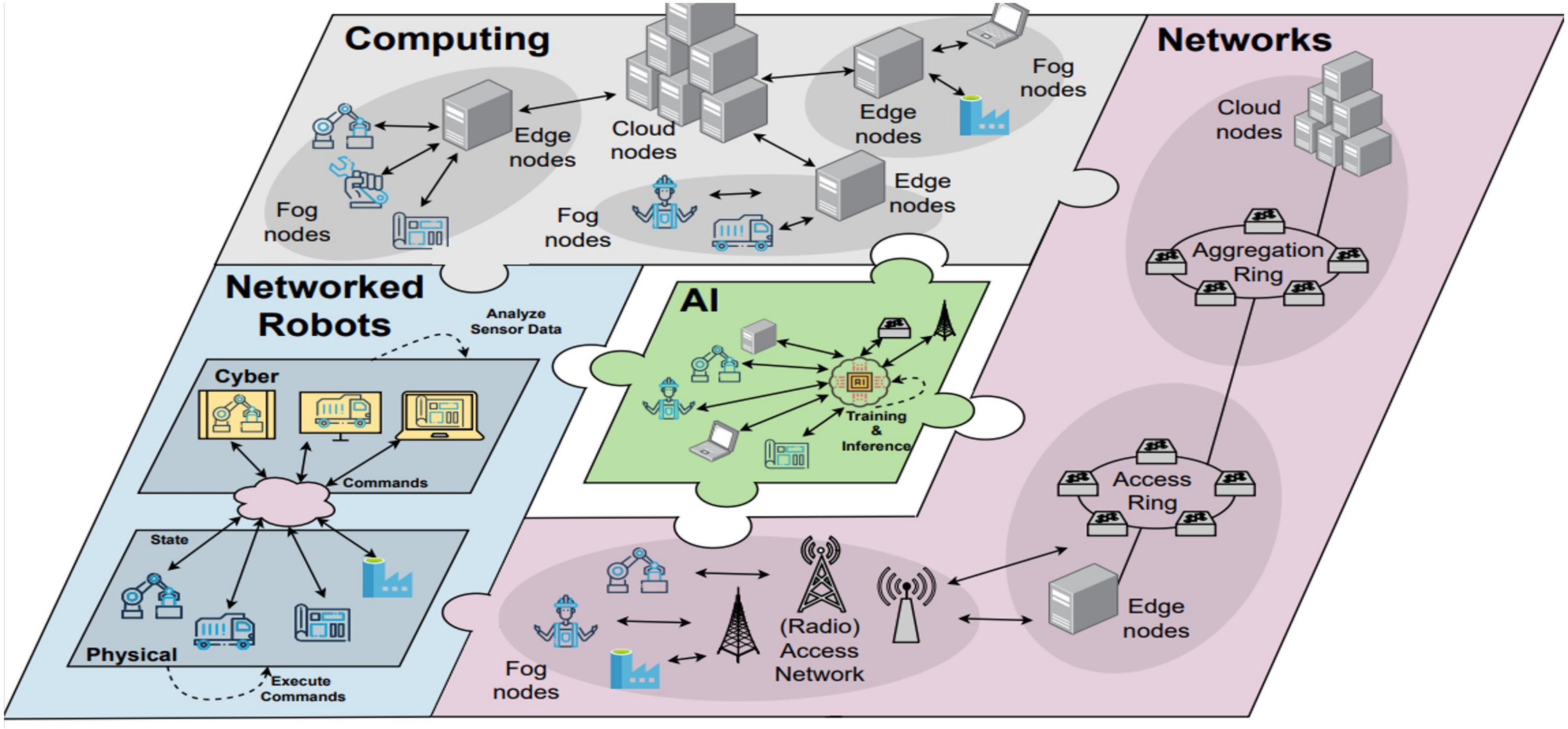



Figure 1: The computing and communication infrastructure [1].

[1] M. Groshev et. al., "Toward Intelligent Cyber-Physical Systems: Digital Twin Meets Artificial Intelligence," in *IEEE Communications Magazine*

# Robots traffic profile connectivity requirements

| Application | Traffic Profiles | Throughput | Latency | Reliability | Mobility | Availability |
|---|---|---|---|---|---|---|
| Remote control and navigation; Control loops; Visual analytics; | Isochronous flows; Asynchronous messages; | Low (isoc./ async.) Low to High (video) | 100 - 0.1 ms<br>100 – 10 ms | 99.9 to 99.99999% | Low mobility (mostly indoor) | High |

Table 1: Robot traffic flows and connectivity requirements [2]

[2] D. Cavalcanti et al., "WiFi TSN: Enabling Deterministic Wireless Connectivity over 802.11," in *IEEE Communications Standards Magazine*

# Robots traffic profile connectivity requirements

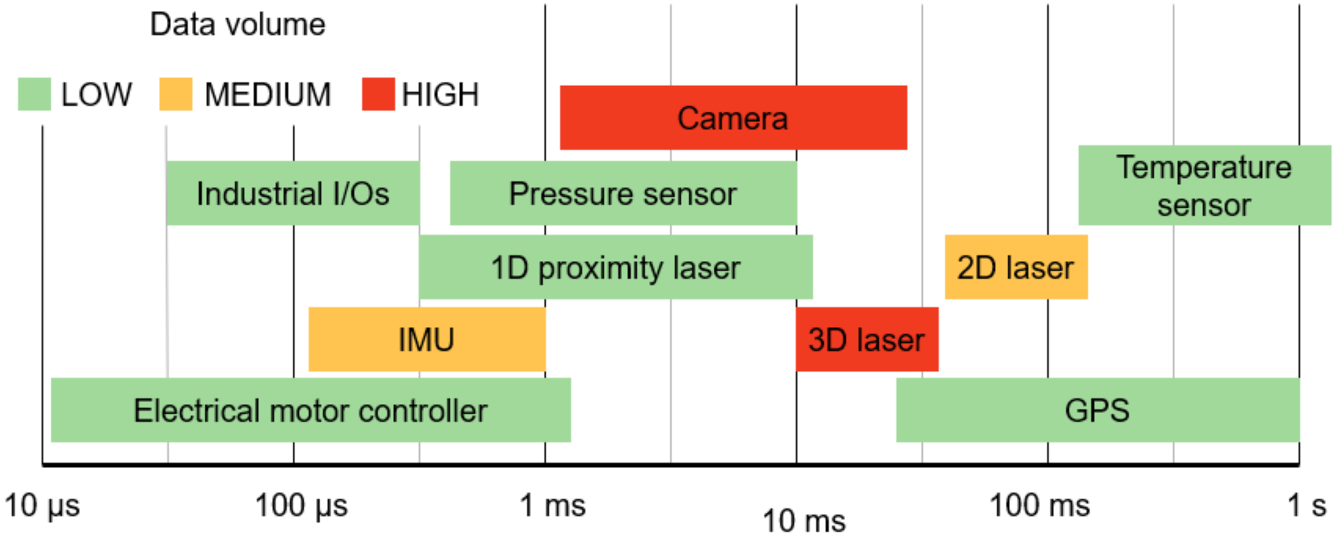



Figure 2: Typical response-time of common robotic components

# Networks

- Wired technologies
  - Serial-based field busses
    - RS-485, CAN
  - Ethernet-based field-busses
    - IEEE 802.3
- Wireless technologies
  - Licensed spectrum
    - 3GPP
  - Unlicensed spectrum
    - IEEE 802.11

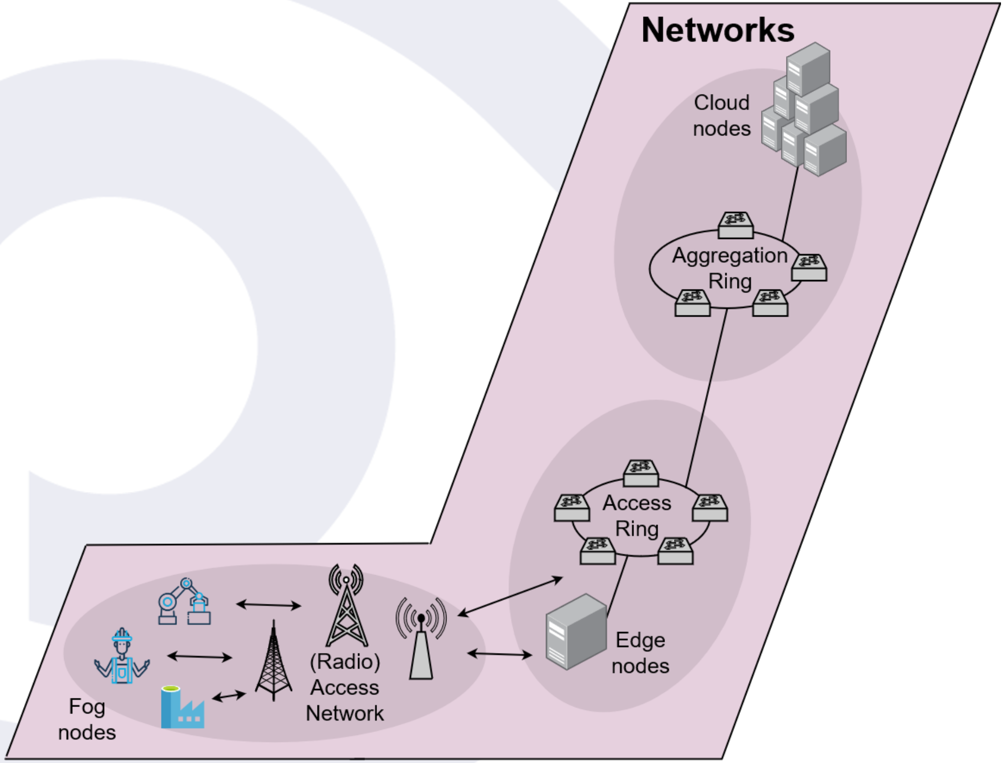



Figure3: Different network segments that the robot flows need to travers

# Industrial communication protocols today

- Natively designed for local connections or other applications (e.g., IoT, Web).
- Can not meet all the requirements of different robot applications.
- Interoperability.
- Difficulties to cope with the unreliable and interface prone wireless channel.

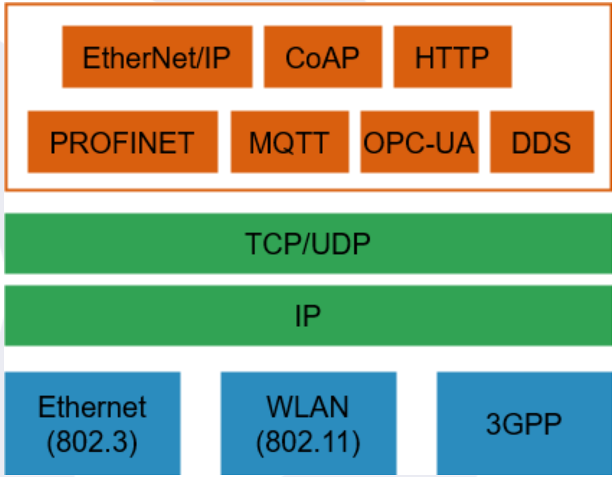



Figure4: Classification of real-time industrial protocols for robotics

# Outline

- Provide a brief introduction of Networked robotics
- Present the current Networked robotics communication protocols
- Time Sensitive Networking for robotics

# TSN reference model

- Set of evolving standards developed by IEEE to allow for time-sensitive traffic on Ethernet, WiFi and 5G.
- Provides time synchronization and bounded latency.
  - Determinism is prioritized over throughput
- TSN tools include time synchronization (802.1 AS), scheduled traffic (802.1Qbv) and network management (802.1Qcc)
- Bring to robotic systems:
  - Scalability, **flexibility**, interoperability, coexistence, latency guarantees, reliability

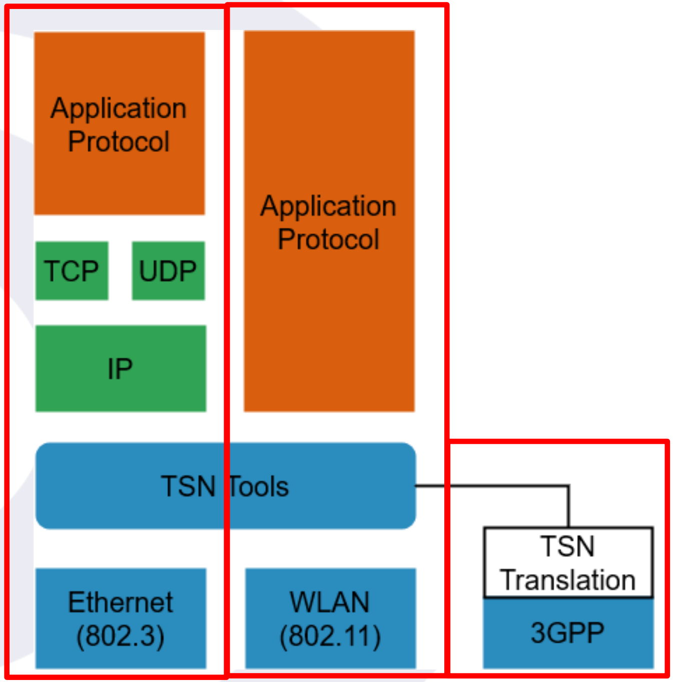



Figure5: Wired and Wireless TSN Reference Protocol Stack [2]

[2] D. Cavalcanti et al., "WiFi TSN: Enabling Deterministic Wireless Connectivity over 802.11," in *IEEE Communications Standards Magazine*

# IEEE 802.11 TSN for robotics

- **Time Synch over 802.11**
  - **802.11AS**
- Time-Aware Scheduling for missing-critical robotics flows over 802.11
  - 802.1Qbv
- Redundancy to improve reliability
  - FRER (IEEE 802.1 CB)
- Network Management Models to meet the end-to-end robotics requirements
  - IEEE 802.1Qcc
- IEEE 802.11bf (WiFi7)
  - Multi-link Operation
  - rTWT for scheduling

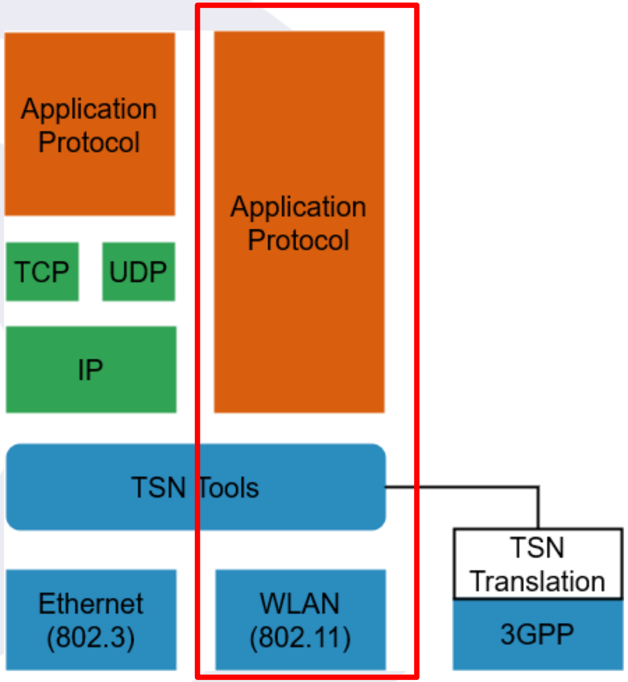



Figure5: Wired and Wireless TSN Reference Protocol Stack [2]

[2] D. Cavalcanti et al., "WiFi TSN: Enabling Deterministic Wireless Connectivity over 802.11," in *IEEE Communications Standards Magazine*

# IEEE 802.11 TSN for robotics

- Time Synch over 802.11
  - 802.11AS
- **Time-Aware Scheduling for missing-critical robotics flows over 802.11**
  - **802.1Qbv**
- Redundancy to improve reliability
  - FRER (IEEE 802.1 CB)
- Network Management Models to meet the end-to-end robotics requirements
  - IEEE 802.1Qcc
- IEEE 802.11bf (WiFi7)
  - Multi-link Operation
  - rTWT for scheduling

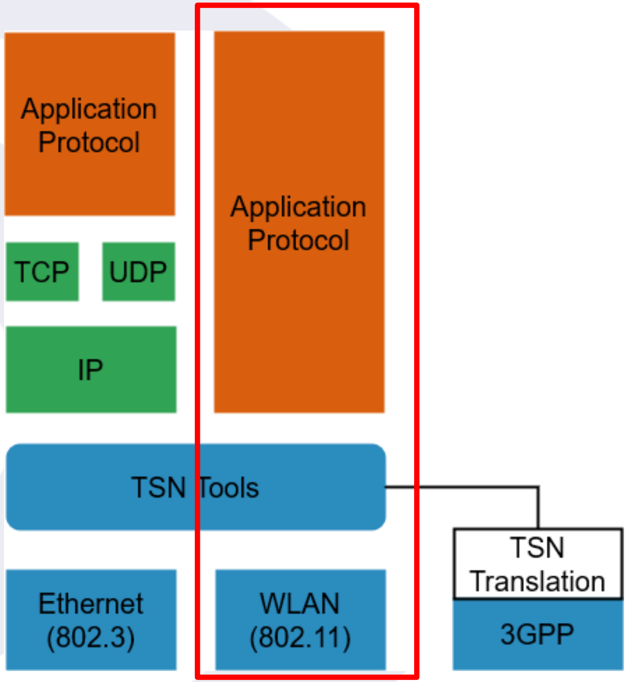



Figure5: Wired and Wireless TSN Reference Protocol Stack [2]

[2] D. Cavalcanti et al., "WiFi TSN: Enabling Deterministic Wireless Connectivity over 802.11," in *IEEE Communications Standards Magazine*

# IEEE 802.11 TSN for robotics

- Time Synch over 802.11
  - 802.11AS
- Time-Aware Scheduling for missing-critical robotics flows over 802.11
  - 802.1Qbv
- **Redundancy to improve reliability**
  - **FRER (IEEE 802.1 CB)**
- Network Management Models to meet the end-to-end robotics requirements
  - IEEE 802.1Qcc
- IEEE 802.11bf (WiFi7)
  - Multi-link Operation
  - rTWT for scheduling

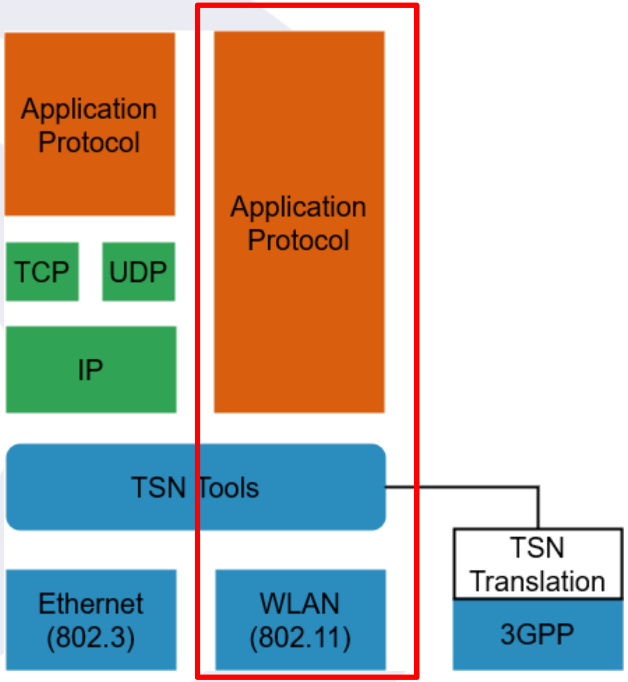


Figure5: Wired and Wireless TSN Reference Protocol Stack [2]

[2] D. Cavalcanti et al., "WiFi TSN: Enabling Deterministic Wireless Connectivity over 802.11," in *IEEE Communications Standards Magazine*

# IEEE 802.11 TSN for robotics

- Time Synch over 802.11
  - 802.11AS
- Time-Aware Scheduling for missing-critical robotics flows over 802.11
  - 802.1Qbv
- Redundancy to improve reliability
  - FRER (IEEE 802.1 CB)
- **Network Management Models to meet the end-to-end robotics requirements**
  - **IEEE 802.1Qcc**
- IEEE 802.11bf (WiFi7)
  - Multi-link Operation
  - rTWT for scheduling

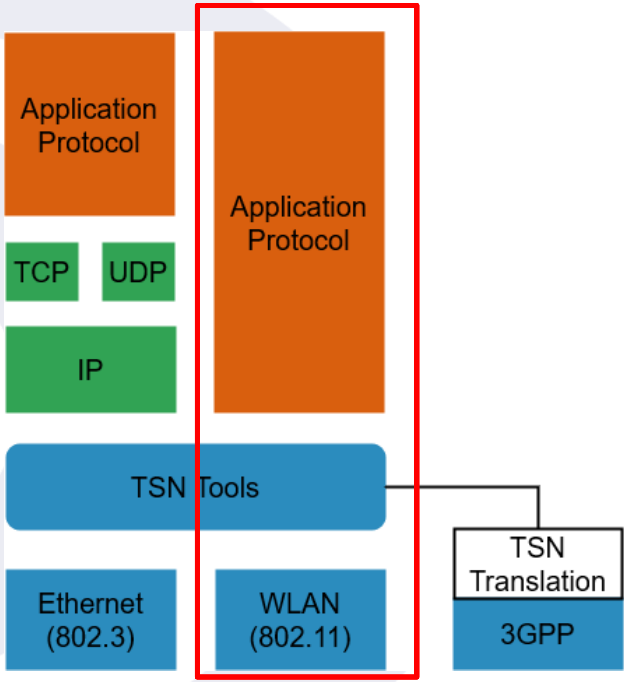


Figure5: Wired and Wireless TSN Reference Protocol Stack [2]

[2] D. Cavalcanti et al., "WiFi TSN: Enabling Deterministic Wireless Connectivity over 802.11," in *IEEE Communications Standards Magazine*

# IEEE 802.11 TSN for robotics

- Time Synch over 802.11
  - 802.11AS
- Time-Aware Scheduling for missing-critical robotics flows over 802.11
  - 802.1Qbv
- Redundancy to improve reliability
  - FRER (IEEE 802.1 CB)
- Network Management Models to meet the end-to-end robotics requirements
  - IEEE 802.1Qcc
- **IEEE 802.11bf (WiFi7)**
  - **Multi-link Operation**
  - **rTWT for scheduling**

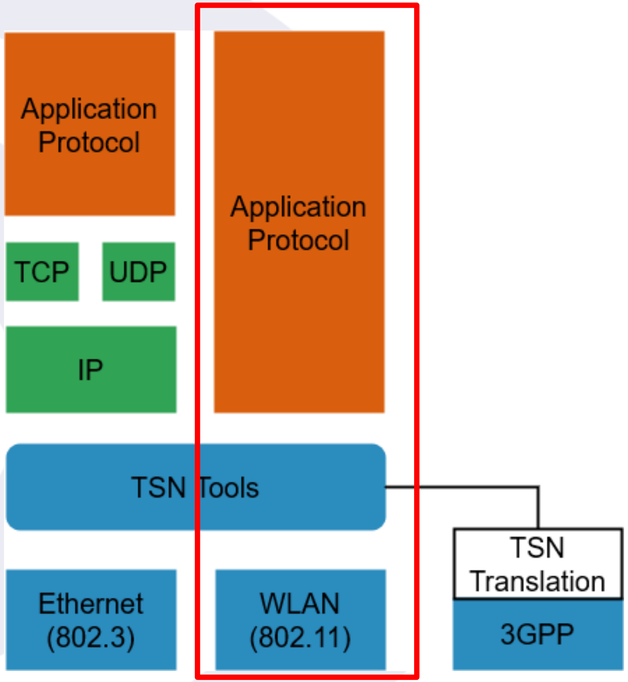



Figure5: Wired and Wireless TSN Reference Protocol Stack [2]

[2] D. Cavalcanti et al., "WiFi TSN: Enabling Deterministic Wireless Connectivity over 802.11," in *IEEE Communications Standards Magazine*

# Challenges ahead

- Ultra-low latency.
- Time-synchronization and TSN flows
- Coexistence with other non-time-sensitive traffic.
- Bounded latency when robots are roaming between APs.
- Integration of hybrid TSN networks that guarantee end-to-end latency over shared wired and wireless infrastructure.
- Performance tradeoffs and interference issues
- Integration, testing and validation

# Wrap up

- Robotic systems must improve flexibility.
- In robotics, the lack of a real standard protocol burdens the component integration or robot to infrastructure communications
- TSN aims to provide bounded latency on Ethernet, WLAN and 3GPP.
- Current TSN tools for WLANs are suitable for Robotics traffic.
- Multiple challenges ahead related to:
  - Ultra-low latency
  - Interoperability with non-time-sensitive flows
  - Mobility
  - Interference

This project was awarded funding by the European Union's Horizon Europe Research and Innovation programme under grant agreement No:  1101095890.

PREDICT 6G

Visit us at predict6g.eu

# Thanks!

Funded by
the European Union