Reliable Distributed Systems - Technological Backbone for the Cyber-Physical-Metaverse

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Bosch Research

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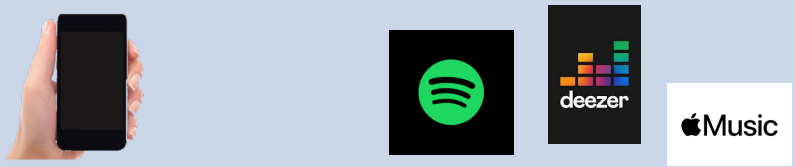
Reliable Distributed Systems
Impact of cloud in different industries

Industry	Classic	Cloud	Key enabler
Music			Bandwidth
Film			Bandwidth
Navigation			Wireless Coverage
Gaming			Latency

Improving cloud capabilities have already moved applications to cloud

Reliable Distributed Systems

Setting the scene

Distributed Systems
enable

functionality on **off-the-shelf distributed infrastructure** (HW&SW) across all industries

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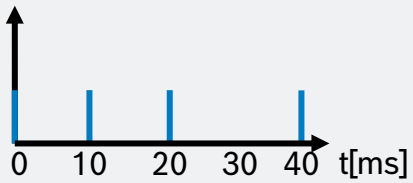
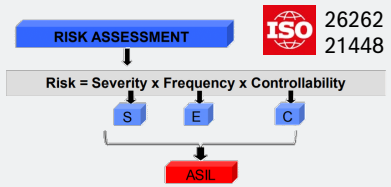
Reliable Distributed Systems

Setting the scene



Ensure proper timing



Ensure proper operation in case of failure

Prevent unauthorized influence

Reliable Distributed Systems enable

- **real-time**,
- **safety-critical**, and
- **secure**

functionality on **off-the-shelf distributed infrastructure** (HW&SW) across all industries

RDS

ISO26268: Functional Safety; ISO/PAS21448: SOTIF (Safety of the Intended Function)

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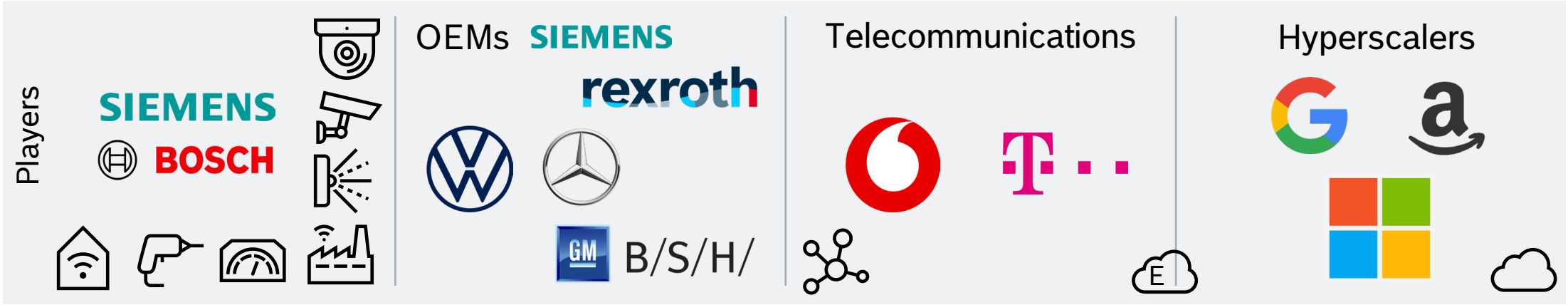
Reliable Distributed Systems

Nobody can build RDS alone – many competencies are needed



- RDS can only be built through partnerships

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Reliable Distributed Systems

Nobody can build RDS alone – many competencies are needed

RDS Applications

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B/S/H/

SIEMENS rexroth

RDS Platform

Domain Knowledge **IT Security**

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Embedded Security **Real-Time** **Safety**

SIEMENS

Systems Integration **Communications** **Cloud Technologies**

Devices & Sensors

Comm

Edge

Cloud

- An integrated RDS technology stack enables standards and broad usage, CPS competencies remain key

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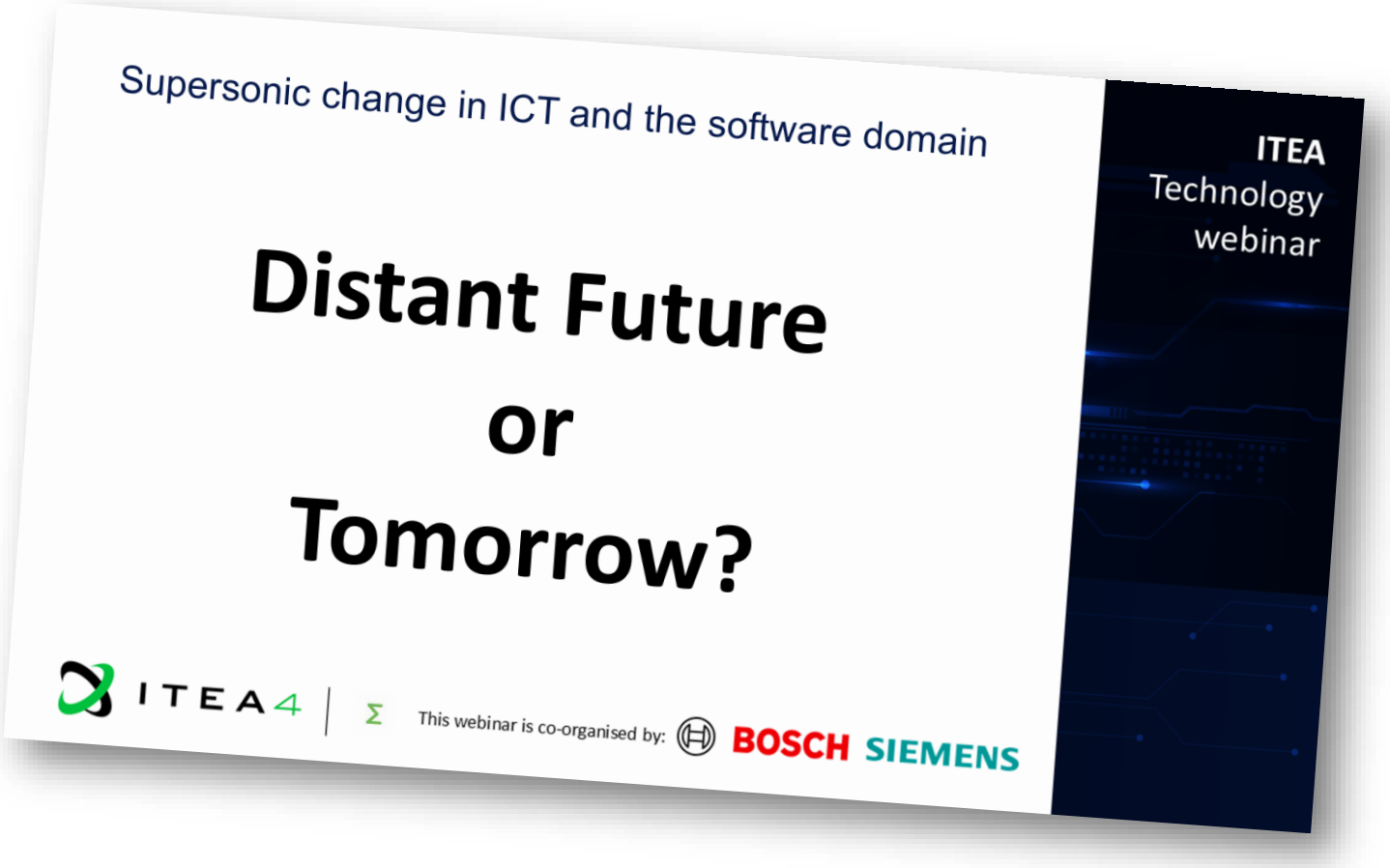
Reliable Distributed Systems



- **NOW!** At least for RDS…

Reliable Distributed Systems
Why now?

Demand & Use Cases

Offboarding Intelligence

Infrastructure-Based AD

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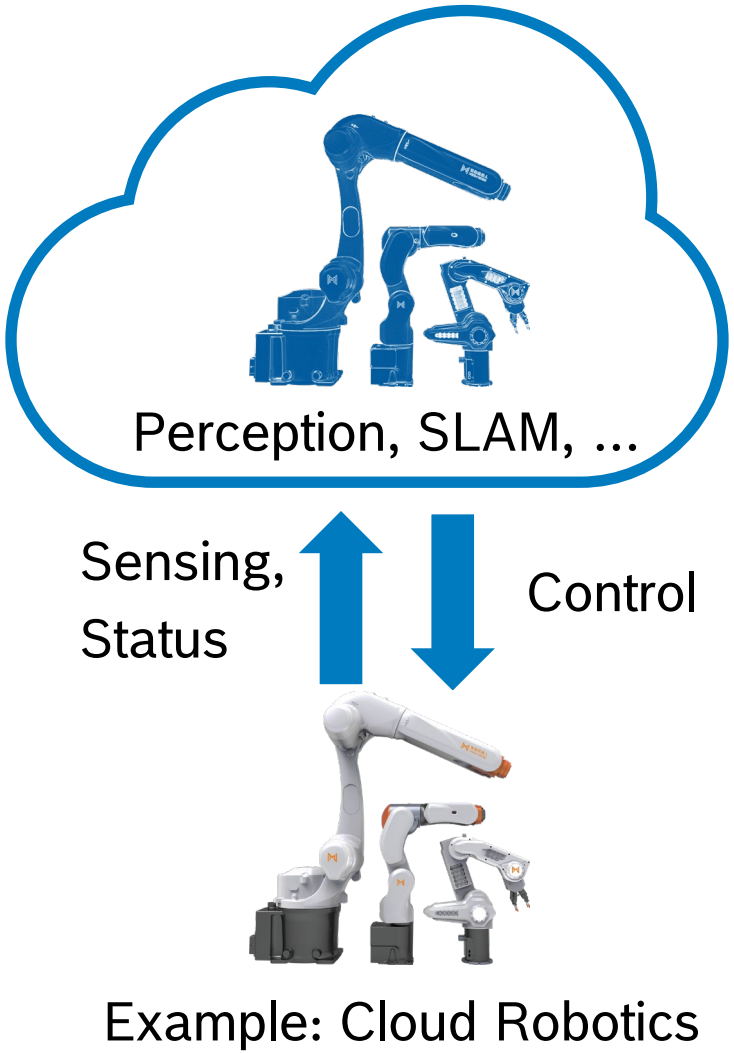
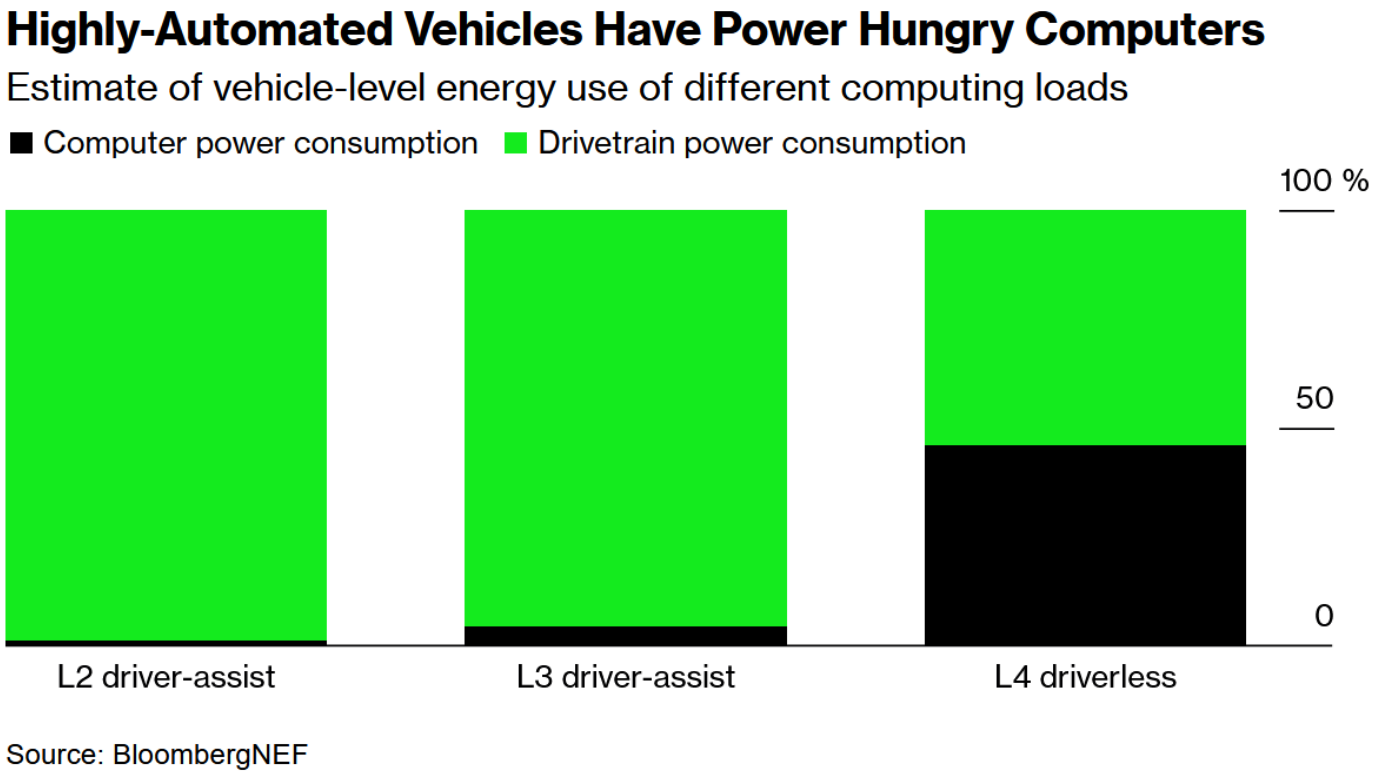
Use Case: Offboarding Intelligence

- Shift intelligence from device to cloud
  - Cheaper devices
  - Easier upgrades
  - Less power consumption
  - More sustainable
- Enable additional functional advantages
  - Fleet learning
  - Remote trouble shooting



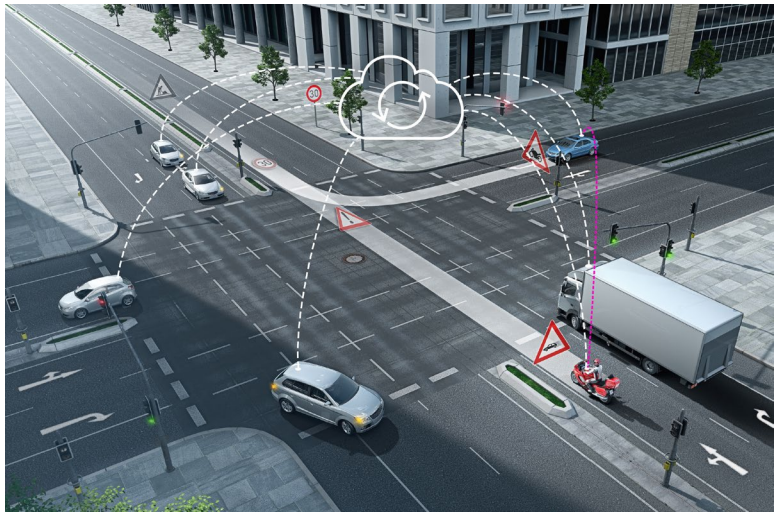
Example: Cloud Robotics

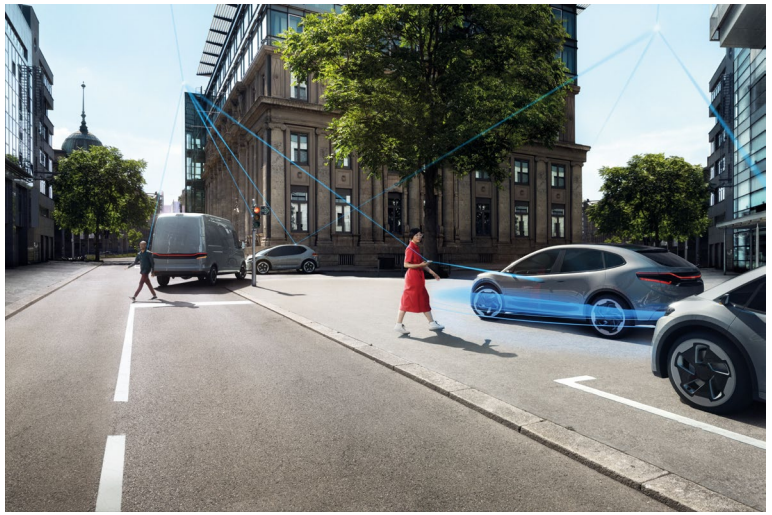
Use Case: Offboarding Intelligence
The energy angle…

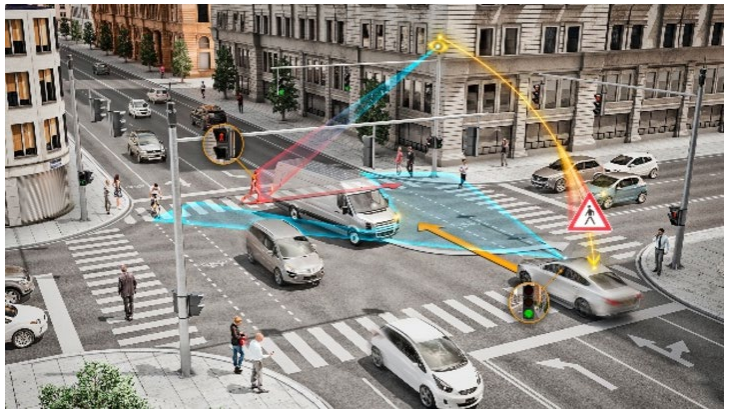


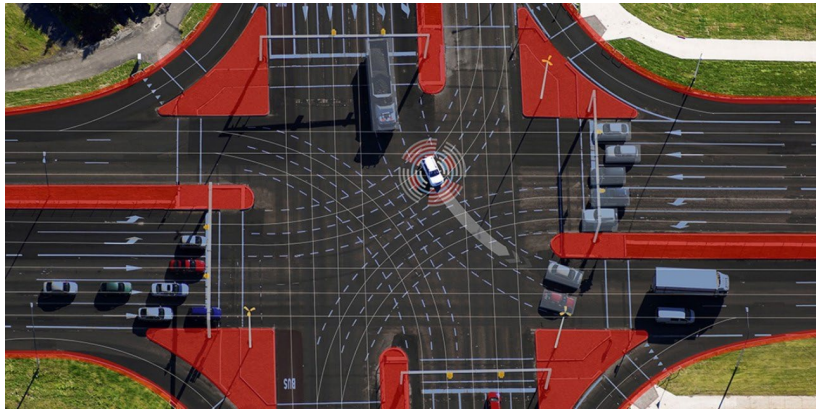
For Robotaxis: automation compute uses almost as much energy as driving

Use Case: Infrastructure-Based Driving









Source: Continental

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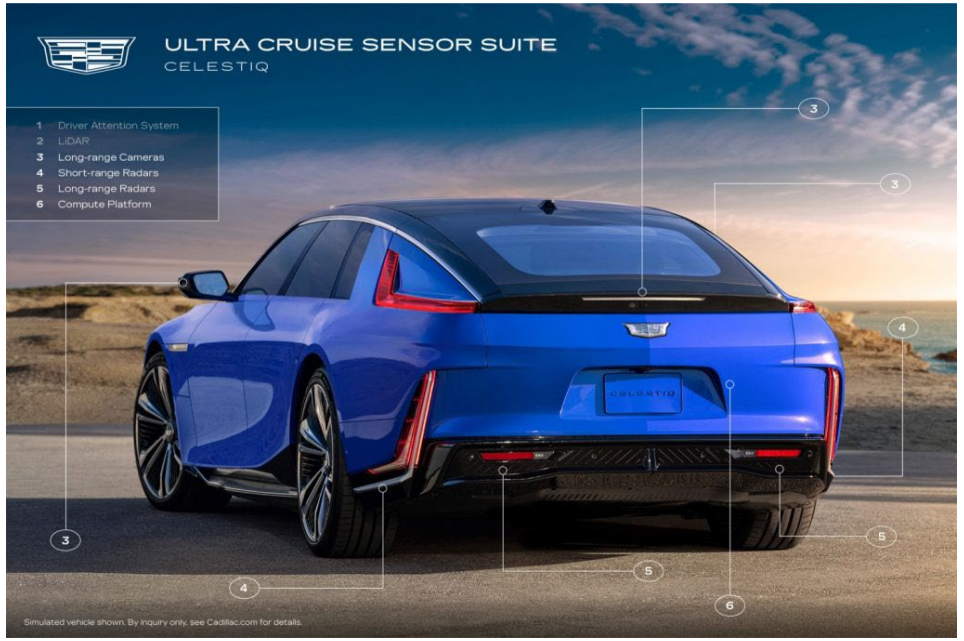
Use Case: Infrastructure-Based Driving



7 long-range cameras, 4 short-range and 3 long-range radars,
1 LiDAR, high-performance onboard compute for L2+ system…

… not being used on average 23h per day.

Infrastructure-Based Driving will democratize Automated Mobility

Reliable Distributed Systems
Why now?

Demand & Use Cases

Offboarding Intelligence
Infrastructure-Based AD

Funding

Large Government Programs
e.g., IPCEI-CIS in Europe

Next Generation Cloud Infrastructure and Services (IPCEI CIS)

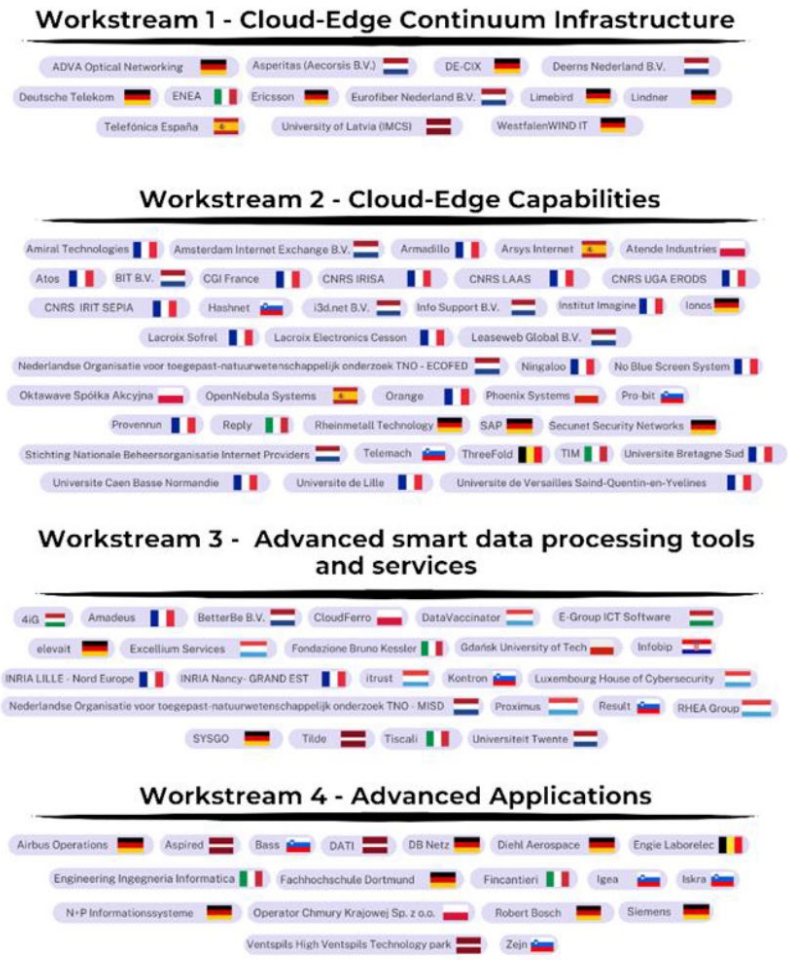
European Publicly Funded Project

- Develop an interoperable European multi-provider cloud-edge continuum

CLOUD·EDGE CONTINUUM

- “Will allow for real-time and low-latency (i.e., a few milliseconds) services by distributed computing resources”

- Facts & Figures
  - ~100 participants from 12 EU member states
  - Up to 1.2 billion EUR funding
  - Up to 1.4 billion EUR private investment
  - started 2023
  - first industrial deployments in 2027



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Reliable Distributed Systems
Why now?

Demand & Use Cases	Offboarding Intelligence Infrastructure-Based AD
Funding	Large Government Programs e.g., IPCEI-CIS in Europe
Technology	Steady Improvements in Bandwidth, Coverage, Latency

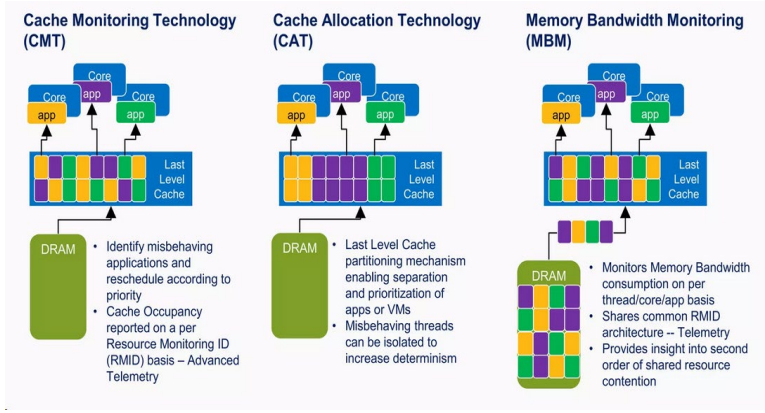
Technology Enablers
Predictable Low Latency

5G

TSN Time Sensitive Networking Powered by IEEE 802

6G

Increased Comm Performance & Isolation

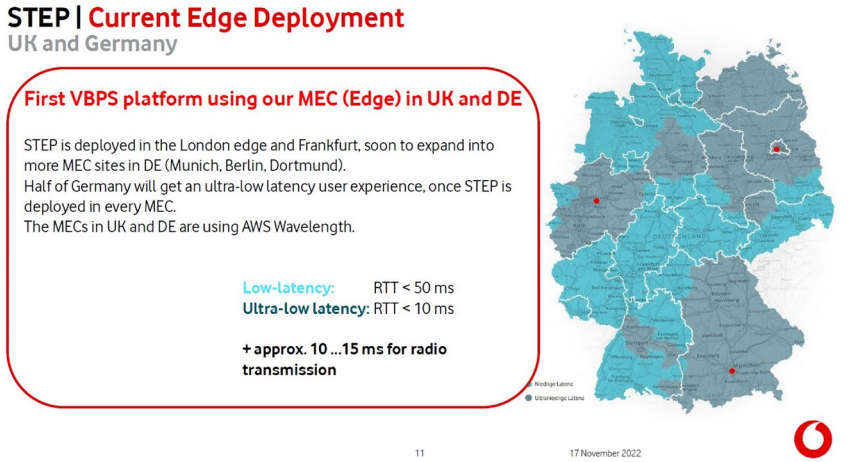


Source: intel

On-Chip Performance Isolation

CAMARA
THE TELCO GLOBAL API ALLIANCE

Network APIs to control Quality on Demand



Source: vodafone

Telco Edge Clouds

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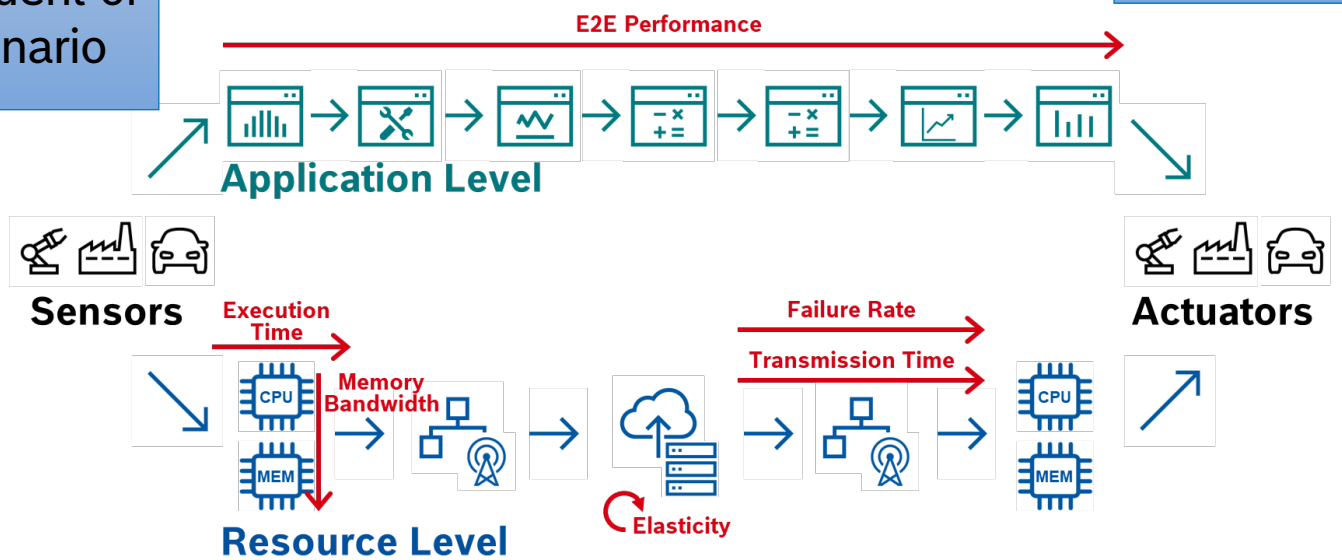
Challenge: Design Implications

Develop independent of deployment scenario

Specify application & generate deployment



Platform mechanisms for controlling RT behavior

Monitor & adapt platform management

[2] P. Pazzaglia et al. "Brief Industry Paper: Delay-Aware Control in Networked Systems Using Smart Actuators." *2024 IEEE 30th Real-Time and Embedded Technology and Applications Symposium (RTAS).*

Reliable Distributed Systems

Challenge: Modern control methods to handle RT uncertainties

Strategy 2: "Be adaptive"

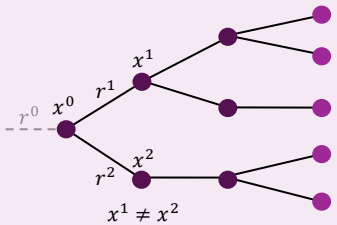
Only at the actuator, the real amount of delay is known!

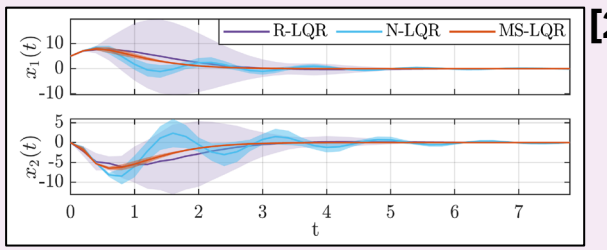
Multi-mode control

→ *compute multiple control modes designed for different delays*

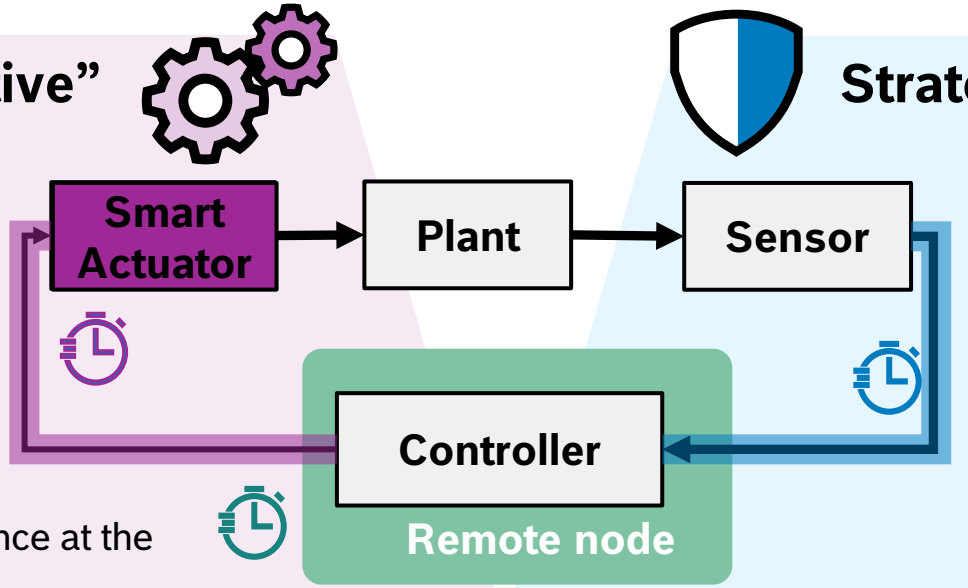
Smart Actuator: add a little intelligence at the actuator level

→ *applies the right control mode at the right time to the plant*





[2]



Strategy 1: "Be robust"

Compensate upstream delays by moving horizon Kalman filtering

→ estimation techniques

However, compute & downstream delays happen after the control was chosen!

→ timing aware **predictive** control with stochastic methods