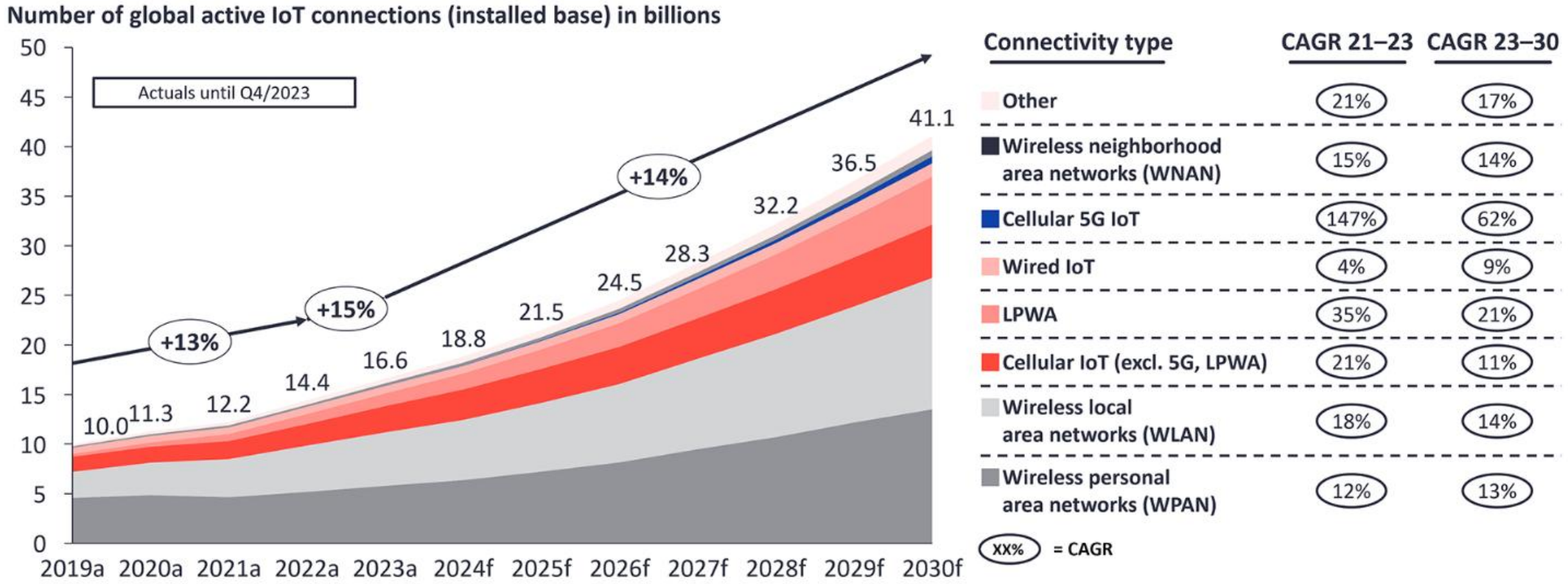
Mastering IoT Orchestration with Cloud-Native Technologies

REMARKABLE TECHNOLOGY, EASY TO USE

July 2025

Fraunhofer PORTUGAL

Context
IoT Growth



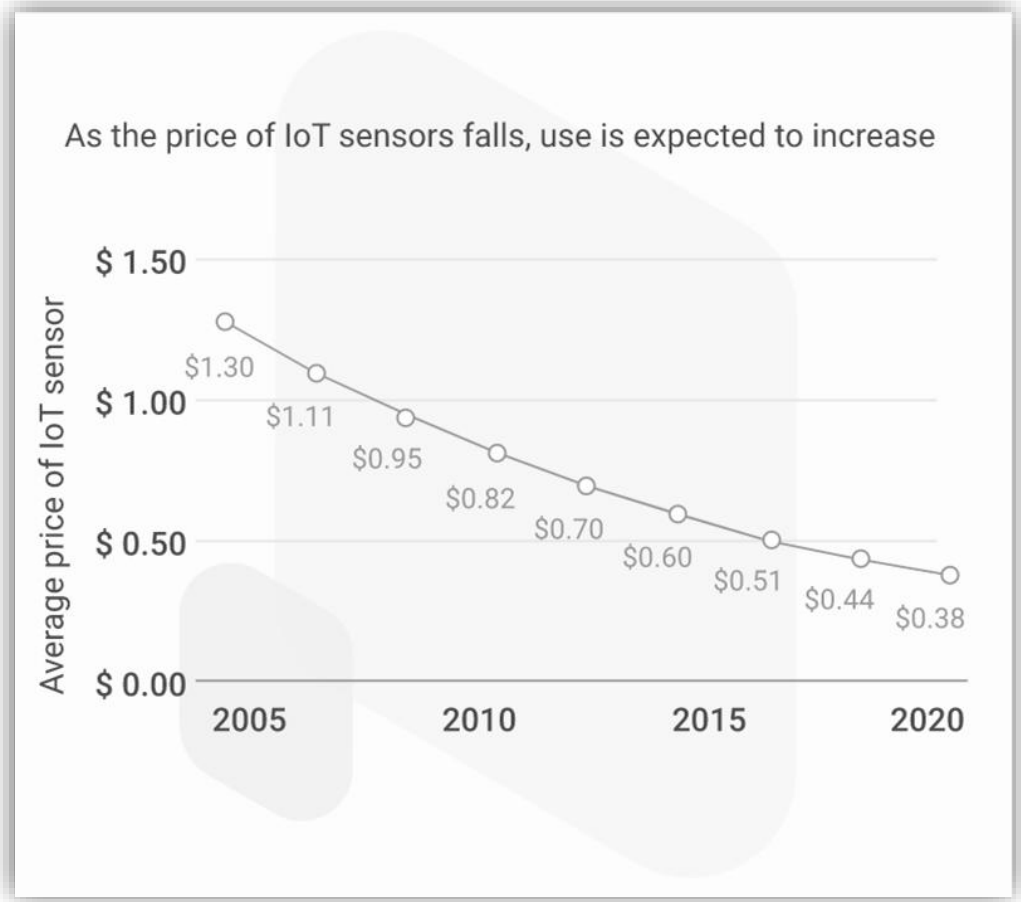
Source: IoT Analytics Research 2024-State of IoT Summer 2024 (https://iot-analytics.com/number-connected-iot-devices/).

© Fraunhofer Portugal

Context

Why IoT now?

- Lower (and falling) technology prices
  - Cost of hardware
  - Cost of connectivity
  - Technology evolution
- Advanced connectivity
  - Wi-Fi and Bluetooth
  - 4G and 5G
  - Low-power wide area networks
- Advanced analytics
  - Big Data
  - Artificial Intelligence



Source: Microsoft, 2019 Manufacturing Trends Report.

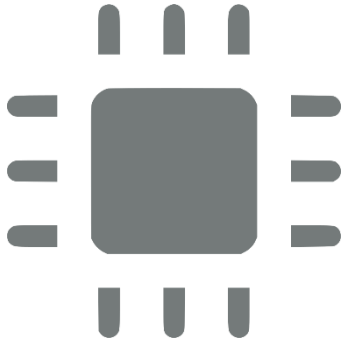
© Fraunhofer Portugal


AIA
LIPPO
HUGE OPPORTUNITY

IoT

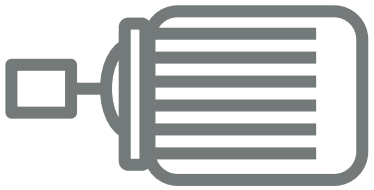
Tear down

Sensors



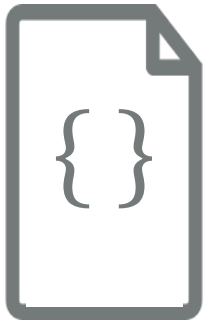
MCU/MPU

Energy



Actuators

Network Interface



Firmware

© Fraunhofer Portugal

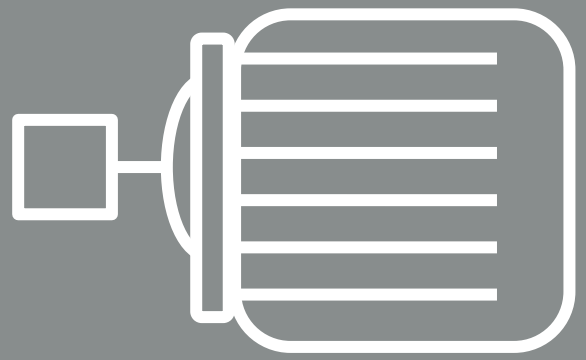
Fraunhofer PORTUGAL

IoT
Sensors

- Temperature, Humidity, Atmospheric Pressure
- Luminosity (light)
- Vibration
- Air Quality: CO_2, VOC
- Noise
- Dust
- GPS
- IMU: Accelerometer, Magnetometer, Gyroscope
- Indoor Location
- Cameras/CCD
- Movement

© Fraunhofer Portugal

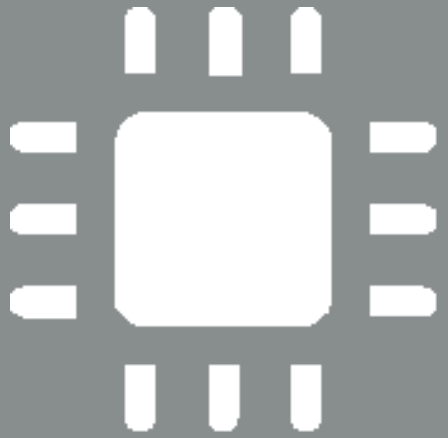
IoT
Actuators



- Comb drive
- Electro valve
- Electric motor
- Piezoelectric actuator
- Servomechanism
- Solenoid
- Stepper motor
- Screw jack

© Fraunhofer Portugal

IoT
MCU/MPU



MCU can be viewed as a single-chip computer

MPU has surrounding chips that support various functions like memory, interfaces, and I/O

© Fraunhofer Portugal

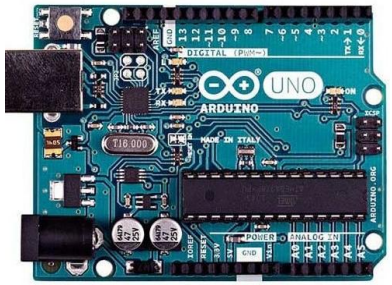
IoT

MCU/MPU & Dev Boards

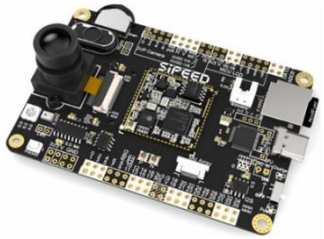
Jetson Nano

Jetson AGX Xavier

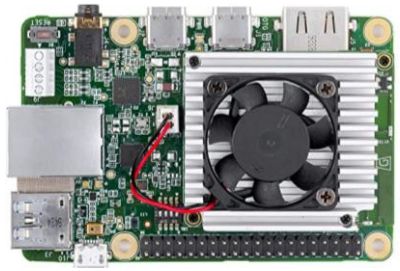
Intel Neural Compute Stick 2



Arduino

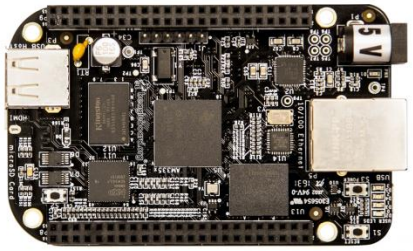


Sipeed MAIX GO



Google Edge TPU Coral

Raspberry Pi



Beaglebone

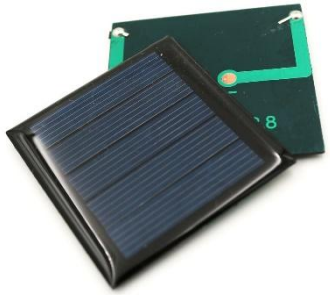
© Fraunhofer Portugal

Fraunhofer PORTUGAL

IoT
Energy

Battery

Power Plug (AC)



Harvesting

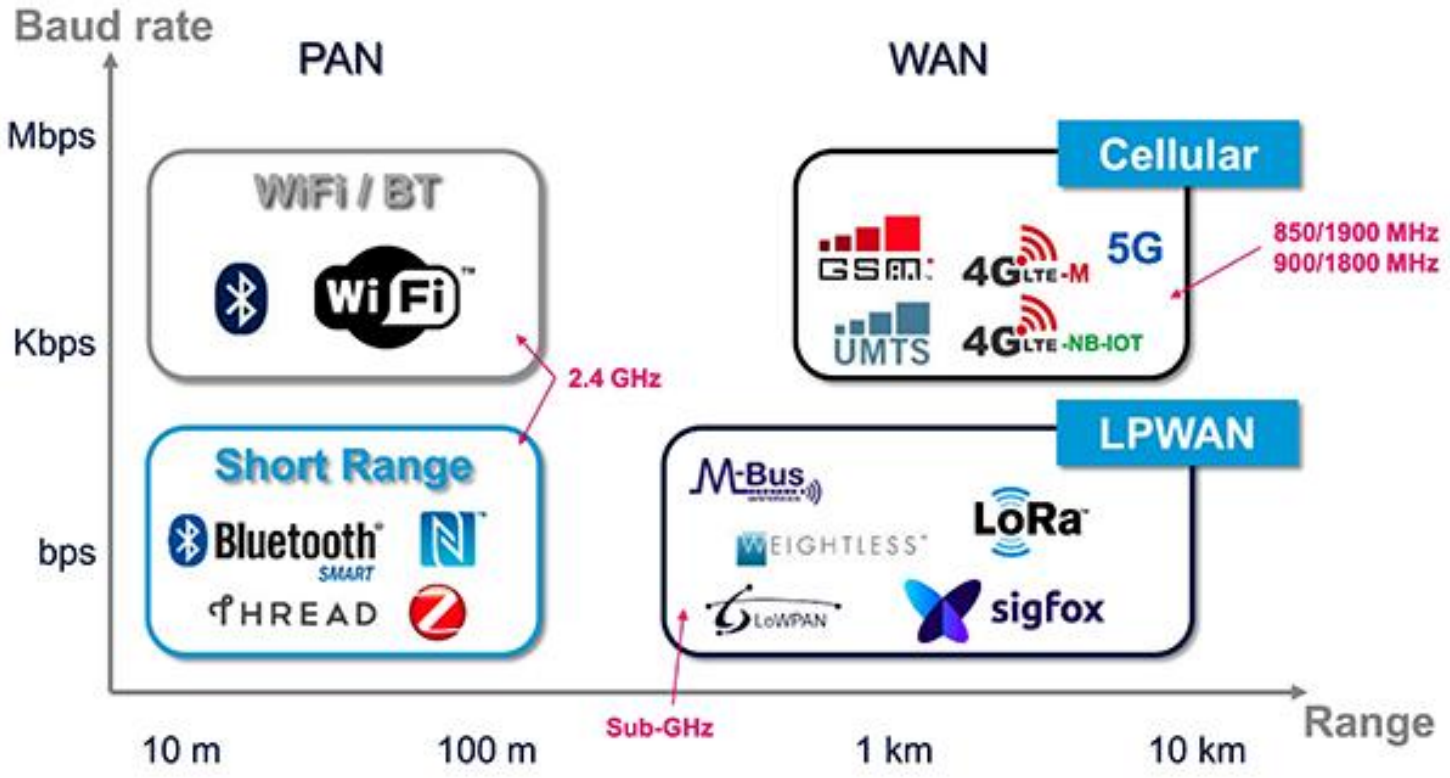
© Fraunhofer Portugal

IoT
Energy Harvesting

- Kinetic
- Photovoltaic
- Thermoelectric
- Piezoelectric crystal
- Micro wind turbine
- Radio Waves
- Vibration
- Fluid flow

© Fraunhofer Portugal

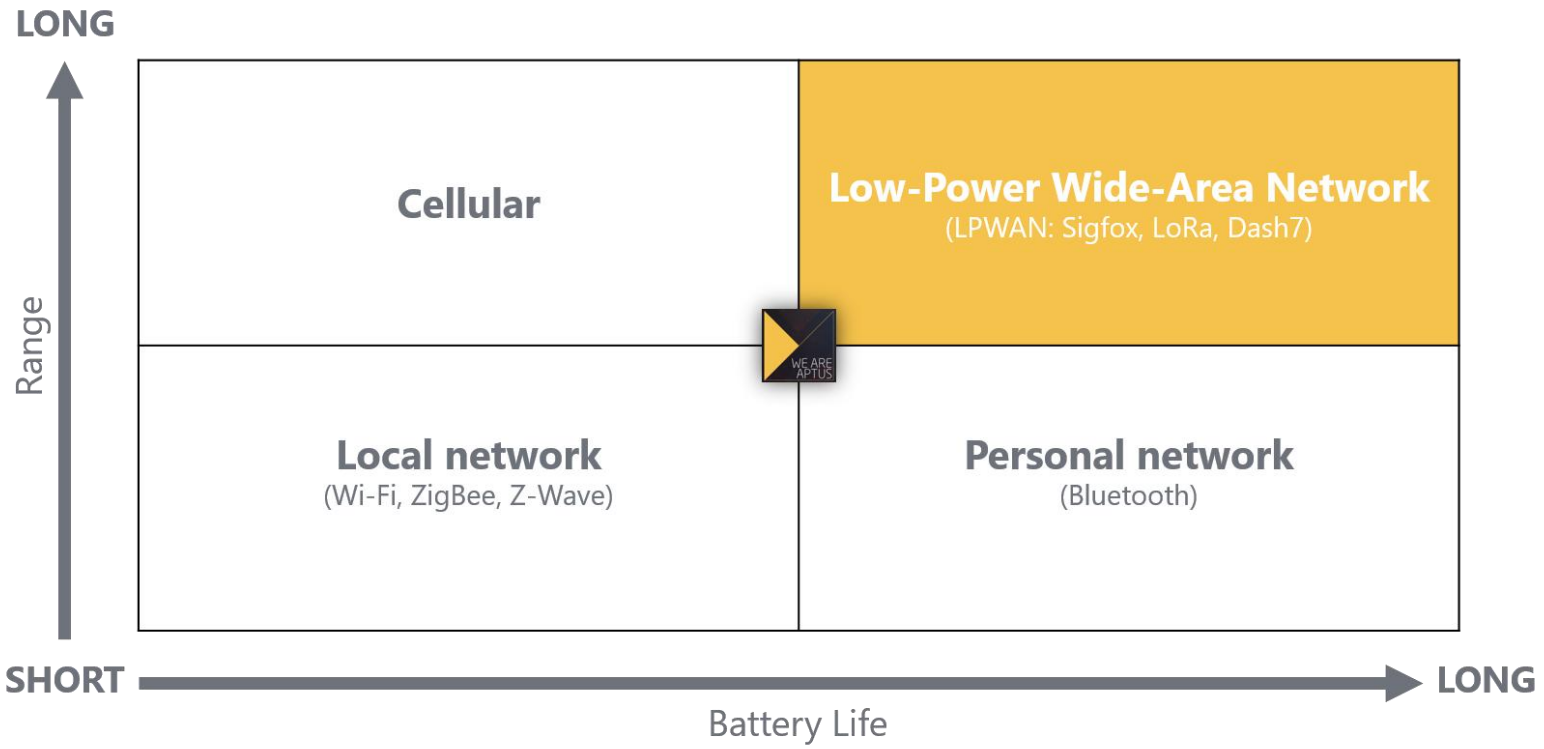
IoT
Network Interface



Source: STMicroelectronics

© Fraunhofer Portugal
Fraunhofer PORTUGAL

IoT
Network Interface



Source: Long-range radios will change how the Internet of Things communicates, Nov 2016

© Fraunhofer Portugal

IoT
Network Interface

LPWA

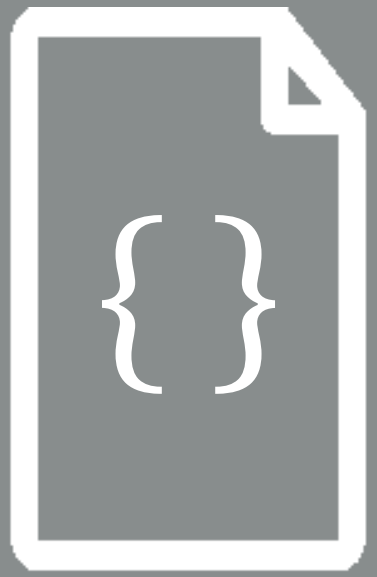
- Low Power, Wide Area Networks
- Low data throughput = High sensitivity = Long range
- Relatively low cost
- Multiple Access = One-to-Many Architecture
- Using Licensed or Unlicensed Spectrum

License-free/Unlicensed Spectrum

Licensed Spectrum

© Fraunhofer Portugal
Fraunhofer PORTUGAL

IoT
Firmware

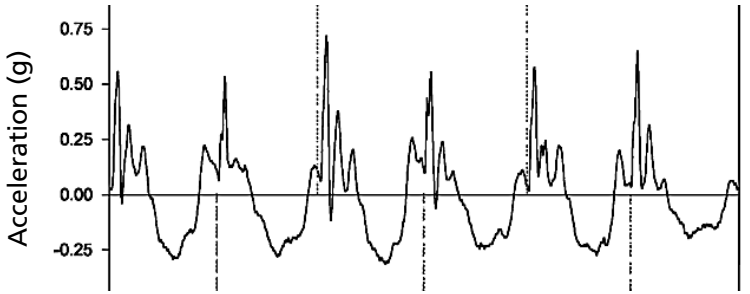


- Firmware is a specific class of computer software that provides the low-level control for a device's specific hardware
- Contain basic functions of a device, and may provide hardware abstraction services to higher-level software such as operating systems
- Updating firmware requires ROM integrated circuits to be physically replaced, or EPROM or flash memory to be reprogrammed through a special procedure

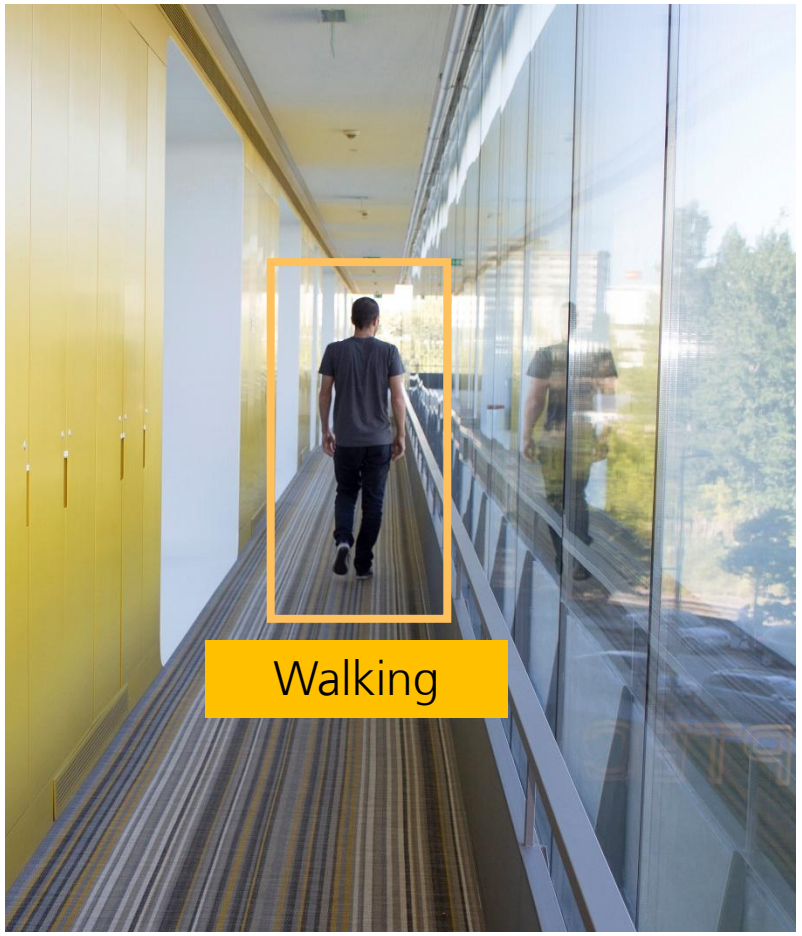
© Fraunhofer Portugal

IoT Use Case

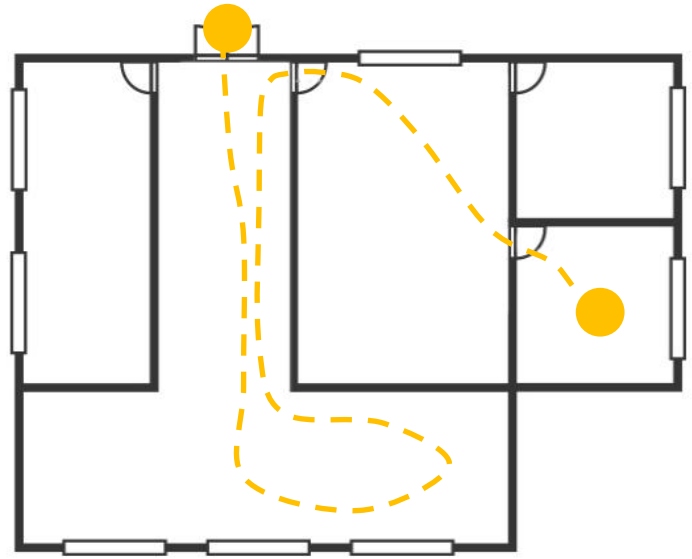
Motion Tracking



Inertial measurement



Activity recognition/Events detection



Indoor tracking

© Fraunhofer Portugal

Fraunhofer PORTUGAL

IoT Use Case

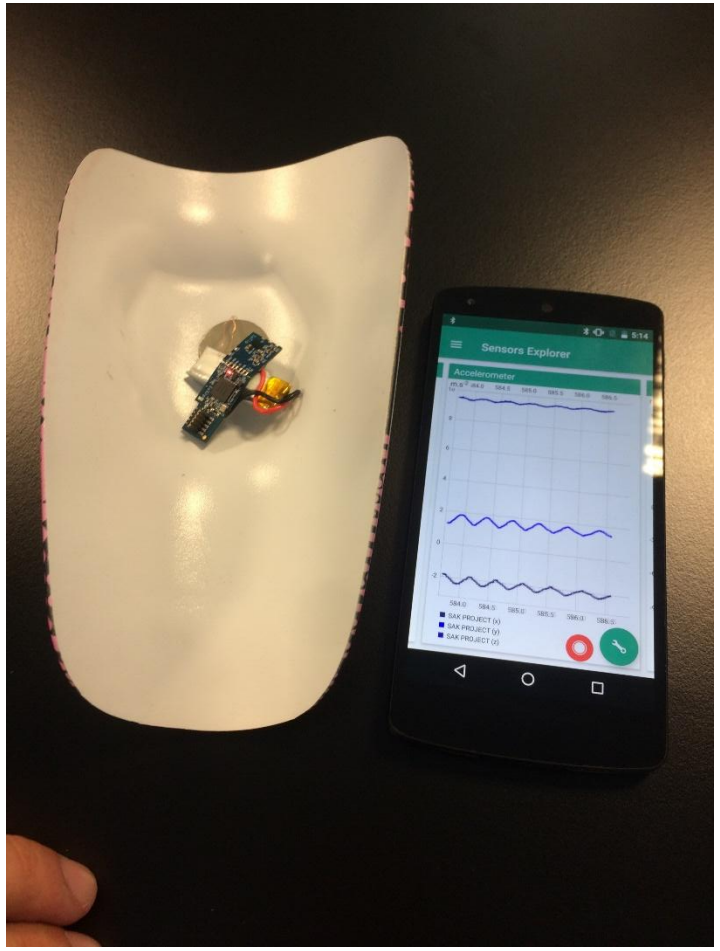
Wearable Device

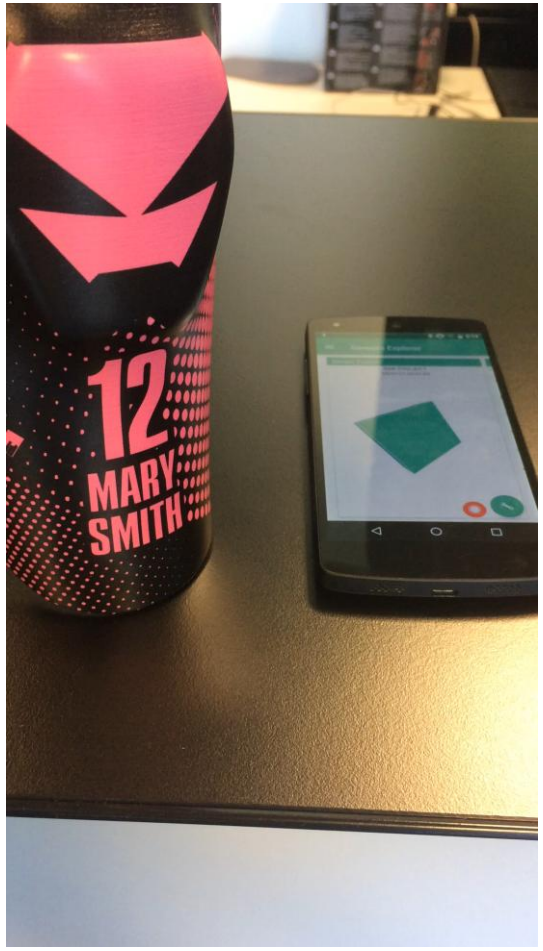
Rate	Direction	Matching	Axis
Plane	Profiling	Range-of-motion	Posture

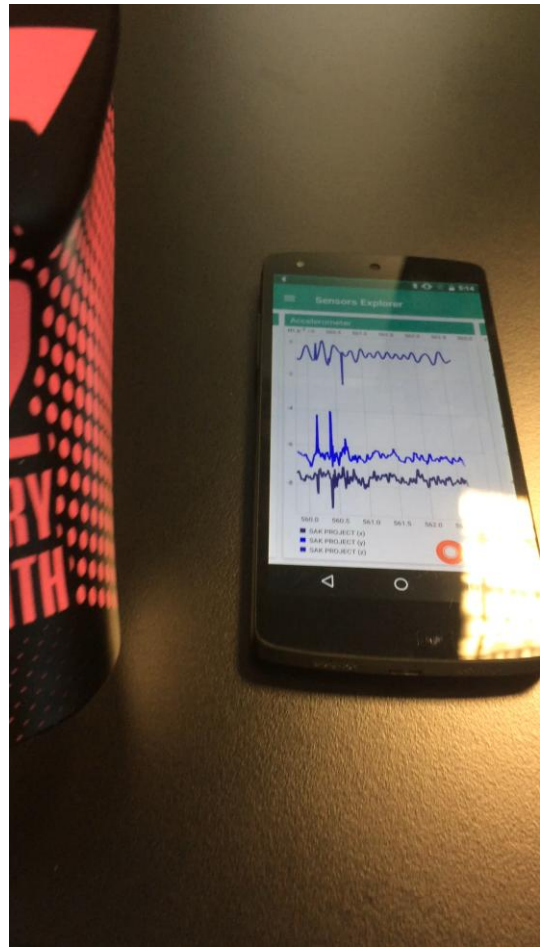
© Fraunhofer Portugal

Fraunhofer PORTUGAL

IoT Use Case
Wearable Device



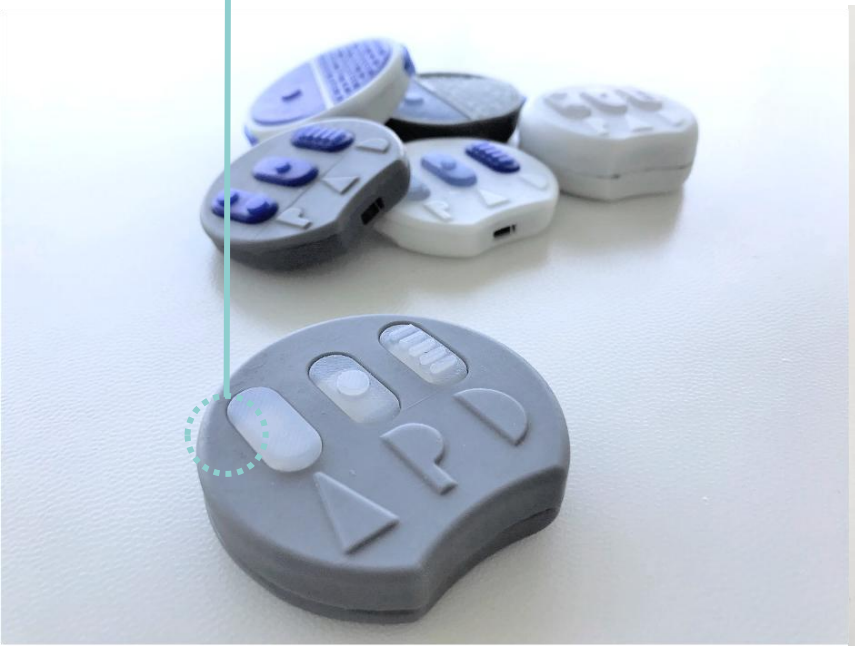




© Fraunhofer Portugal
Fraunhofer PORTUGAL

IoT Use Case
Industrial Worker

Social Support
Pressure
Pain



Temperature
Humidity
Illuminance
Noise

Productivity Rate
Motion Similarity

Ergonomic Risk
(EAWS, RULA)

Self-report | **Environment** | **Ergonomics/Productivity**

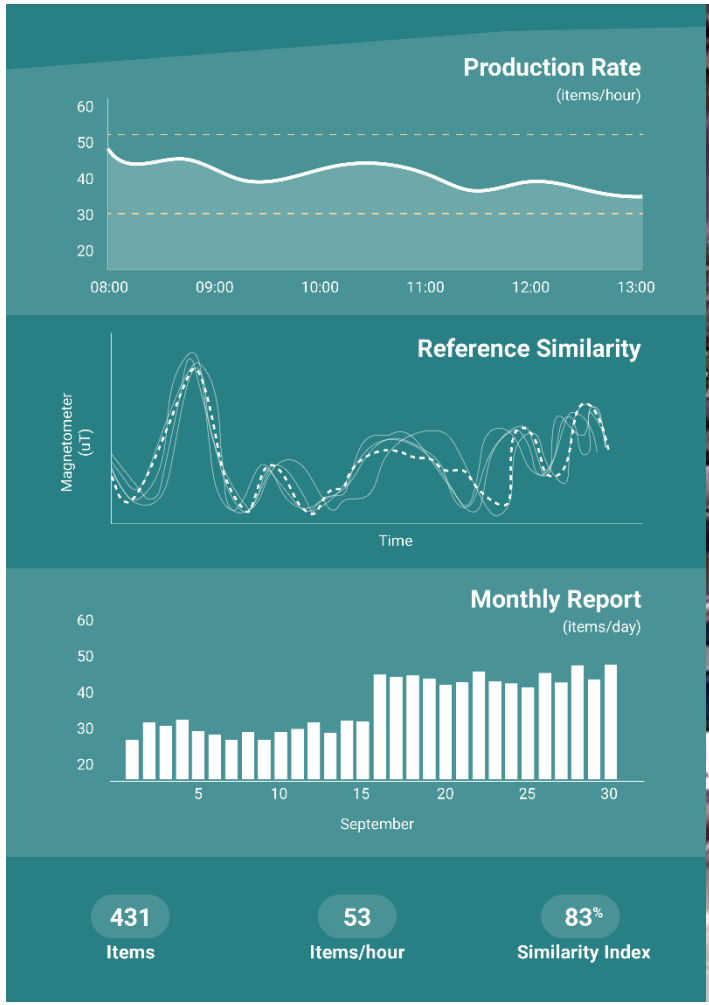
© Fraunhofer Portugal

Fraunhofer PORTUGAL

IoT Use CAse

Ergonomics in Manufacturing

- Repetitive tasks are identified as a risk factor associated with labor activity
- Productivity
  - Number of pieces
  - Overall workstation efficiency
  - Downtime
- Ergonomics
  - Rapid Upper Limb Assessment (RULA)
  - Ergonomic Assessment Work-Sheet (EAWS)
  - Strain Index (SI)



© Fraunhofer Portugal

Fraunhofer PORTUGAL


CITY
SPEED
LIMIT
25
7 Ave
SLOW ZONE
BUSES
ONLY
ONE WAY
W 41 ST
ONE WAY
NO STANDING
ANYTIME
M7
M20
MTA
South Ferry
Express Buses
Stop On Only
GLEASON'S
TAVERN
McDonald's

IoT Application Areas

Key Application Areas

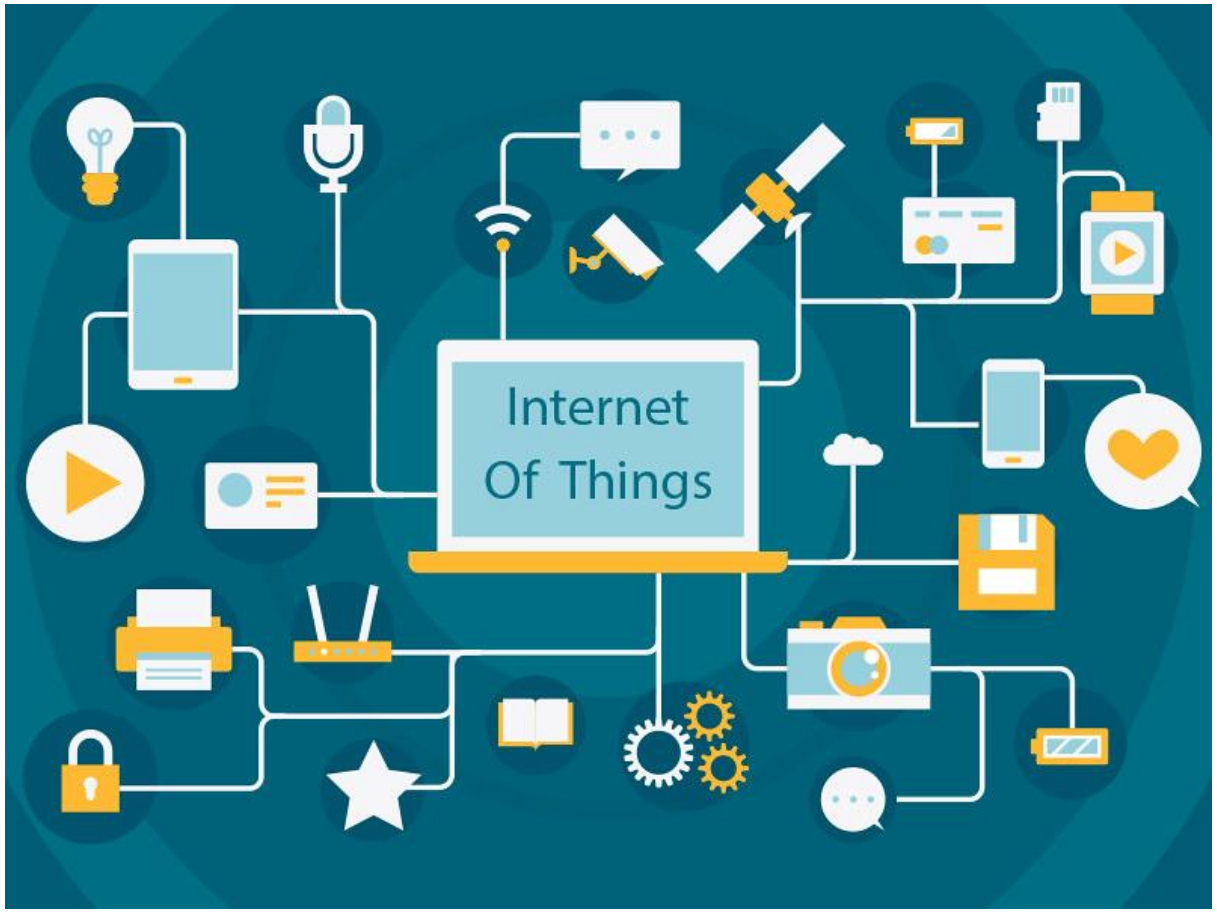
- Industrial & Manufacturing
  - Predictive maintenance, asset tracking, digital twins
  - Product Quality and production optimization
- Smart Cities
  - Traffic management, energy usage, air quality
  - Detection of incidents
- AI on Edge
  - Real-time analytics on cameras, sensors, and drones

© Fraunhofer Portugal

IoT Challenges

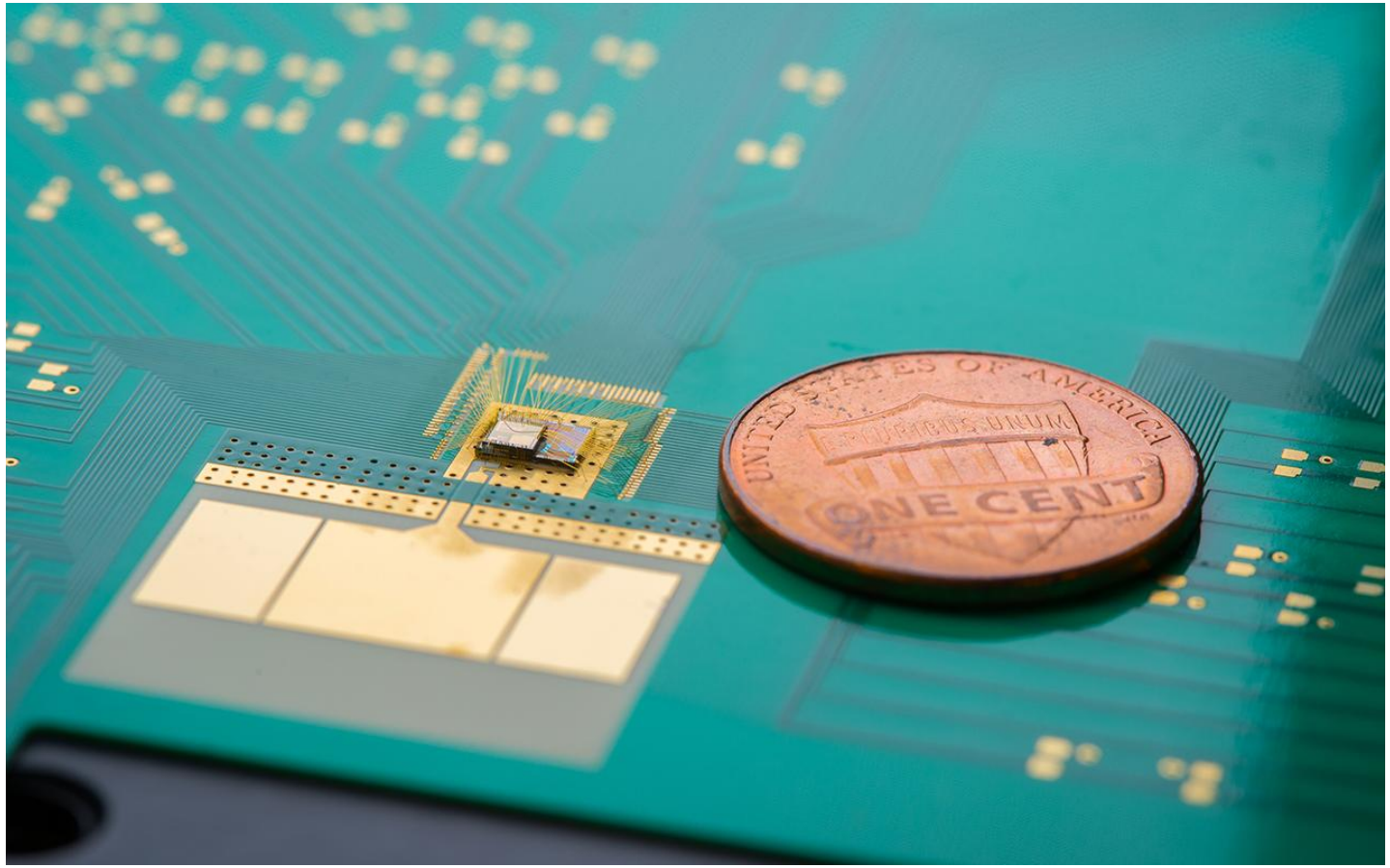
Heterogeneous Devices

- Different types of hardware specifications and Operating Systems
- Communication Protocols (Wi-Fi, BLE, Zigbee, LoRa, NB-IoT)
- Management of devices with different architectures, resource limits, and platforms



© Fraunhofer Portugal

IoT Challenges
Resource Constraints



- Limited Resources
  - Constrained CPU, memory, power, and storage
- Unreliable Connectivity
  - Intermittent or low-bandwidth network connections.
- Energy Efficiency
  - Battery-powered devices require low-energy operation

© Fraunhofer Portugal

IoT Challenges

Scalability and Interoperability

- Massive Device Management
  - Difficulties in updating, monitoring, and maintaining a growing number of IoT devices.
- Data Overload and Network Strain
  - High volumes of data can overwhelm storage, processing systems, and communication networks.
- Security and Interoperability Challenges
  - Scaling secure access and ensuring compatibility among diverse devices and protocols.

© Fraunhofer Portugal

IoT Challenges
Security

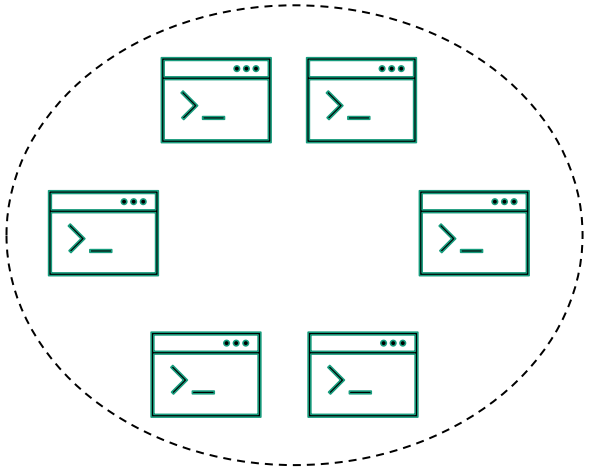
- Device-Level Attacks
  - Physical tampering
  - Firmware exploits
- Network-Level Attacks
  - Man-in-the-middle (MitM)
  - Packet sniffing
  - Denial-of-Service (DoS)
- Cloud/Backend Attacks
  - Unauthorized API access
  - Data breaches
  - Malware in cloud services

© Fraunhofer Portugal

CLOUD NATIVE CONCEPTS

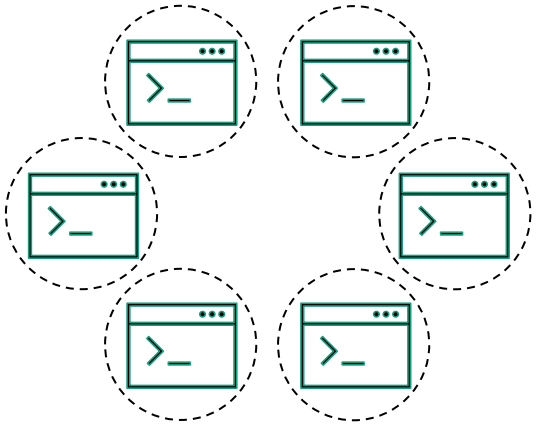
Cloud native concepts

Micro-services and its paradigms



Monolithic

VS.



Microservices

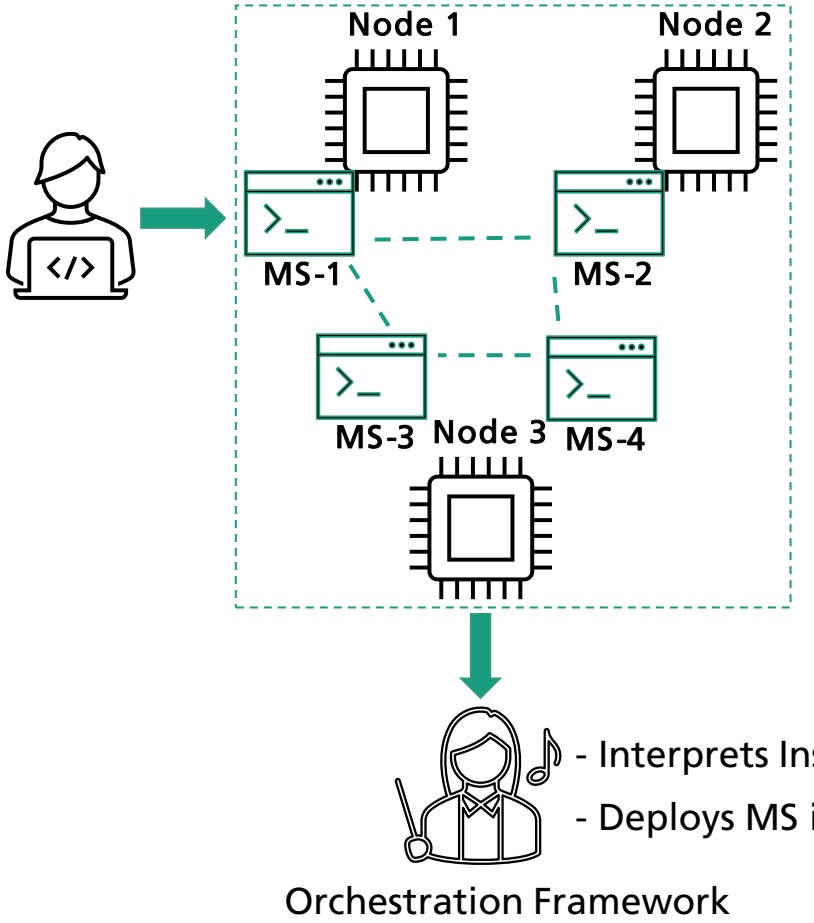
- Microservices characteristics:
  - Separation of concerts
  - Asynchronous communication
  - Scalability
  - Potentiates distributed computing
  - Potentiates/eases the automation of software development and deployment

© Fraunhofer Portugal

Cloud native concepts

Automation of Software Deployment - Specification Language

Imperative

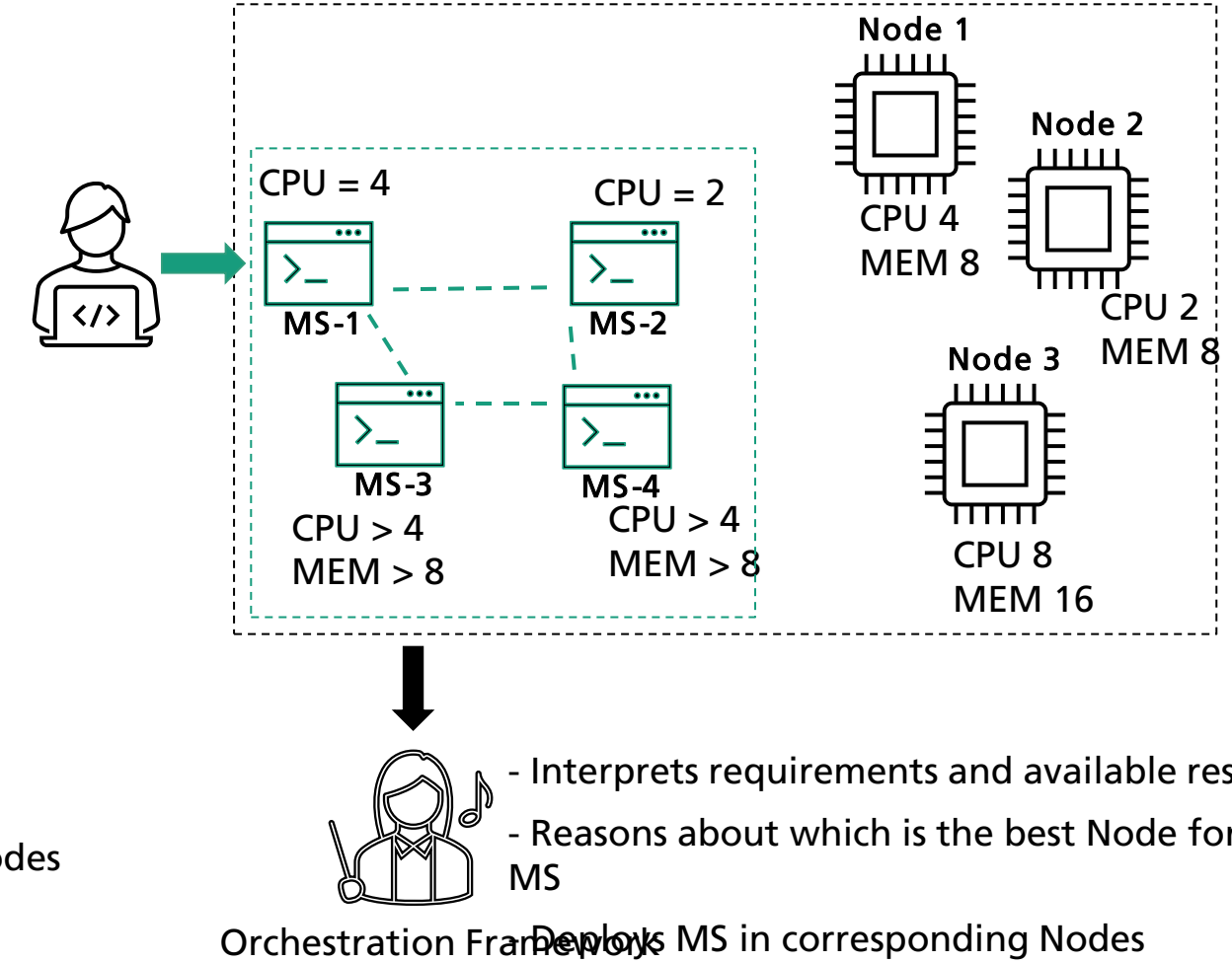


- Interprets Instructions
- Deploys MS in corresponding Nodes

Orchestration Framework

VS.

Declarative



- Interprets requirements and available resources
- Reasons about which is the best Node for each MS
- Deploys MS in corresponding Nodes

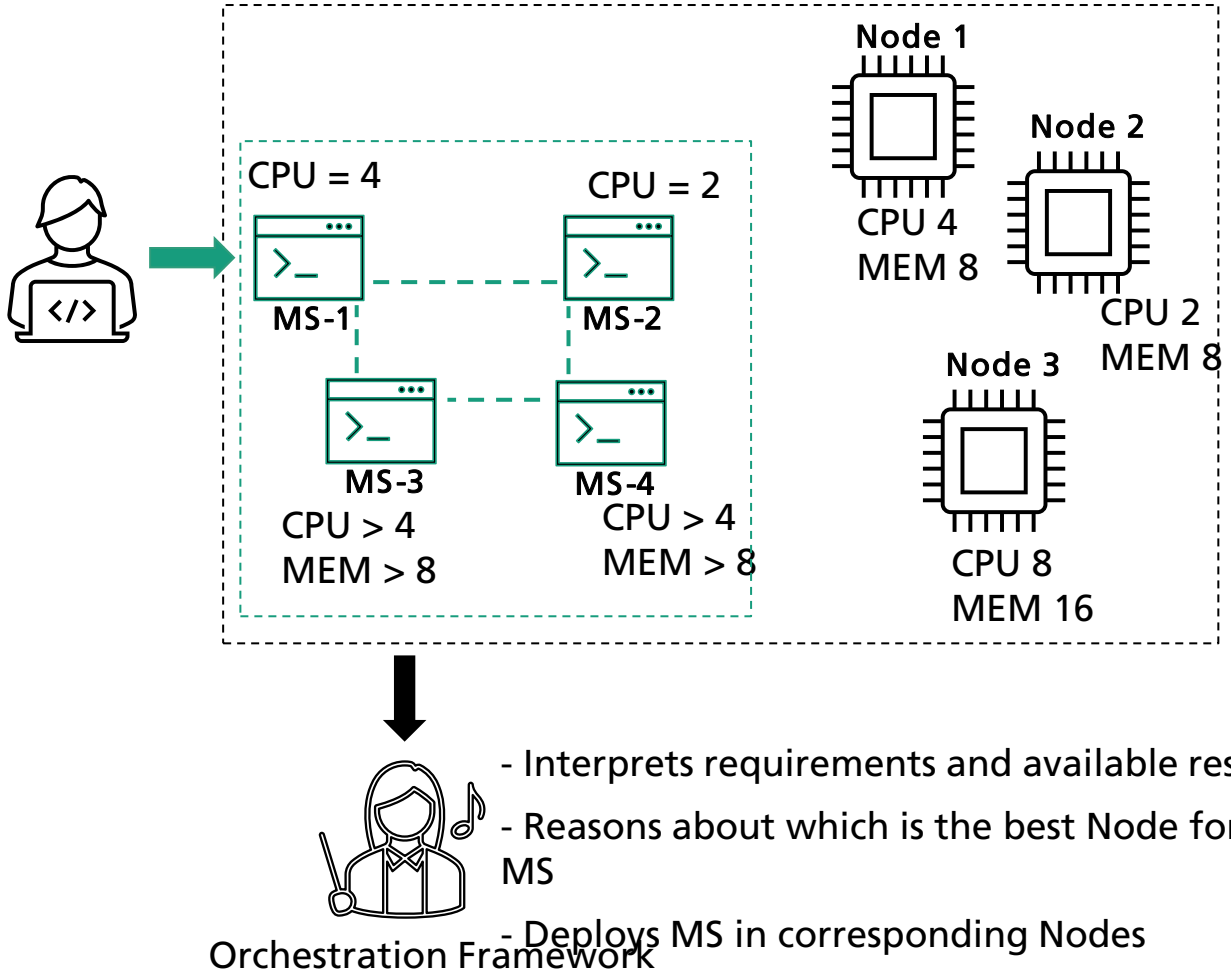
Orchestration Framework

© Fraunhofer Portugal

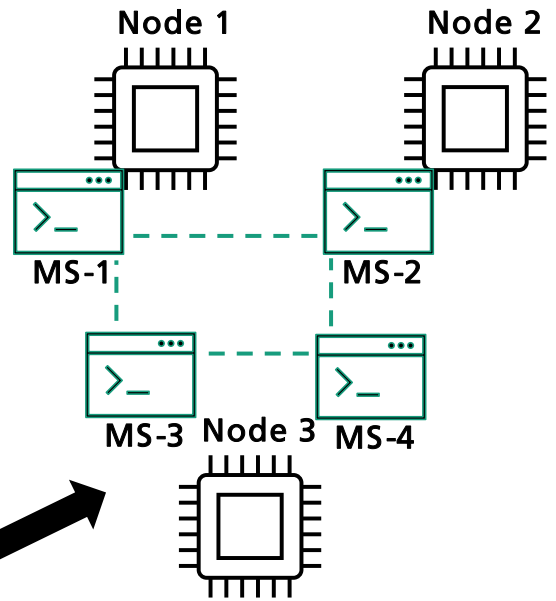
Fraunhofer PORTUGAL

Cloud native concepts

Declarative Specification Language



- Interprets requirements and available resources
- Reasons about which is the best Node for each MS
- Deploys MS in corresponding Nodes

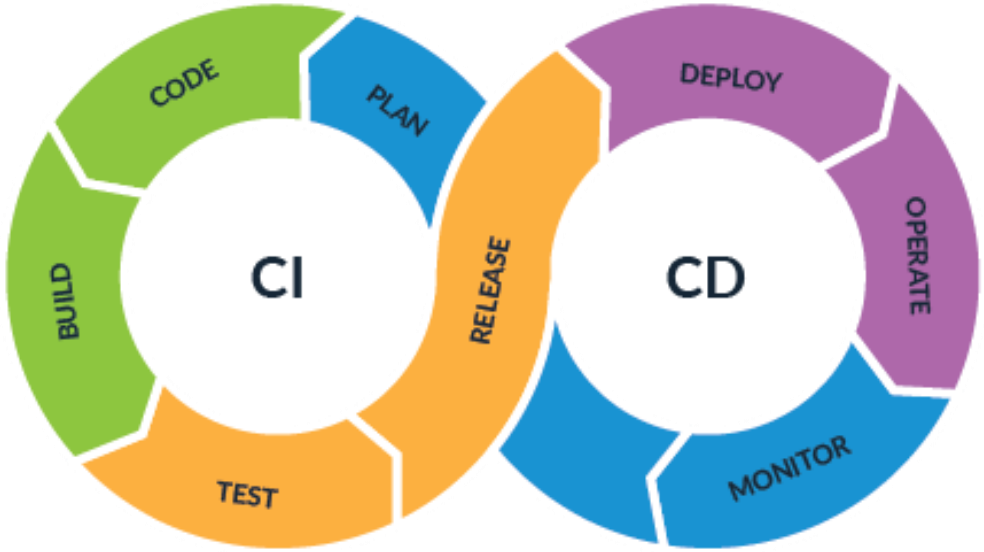


© Fraunhofer Portugal

Fraunhofer PORTUGAL

Cloud native concepts

Automation with DevOps CI/CD

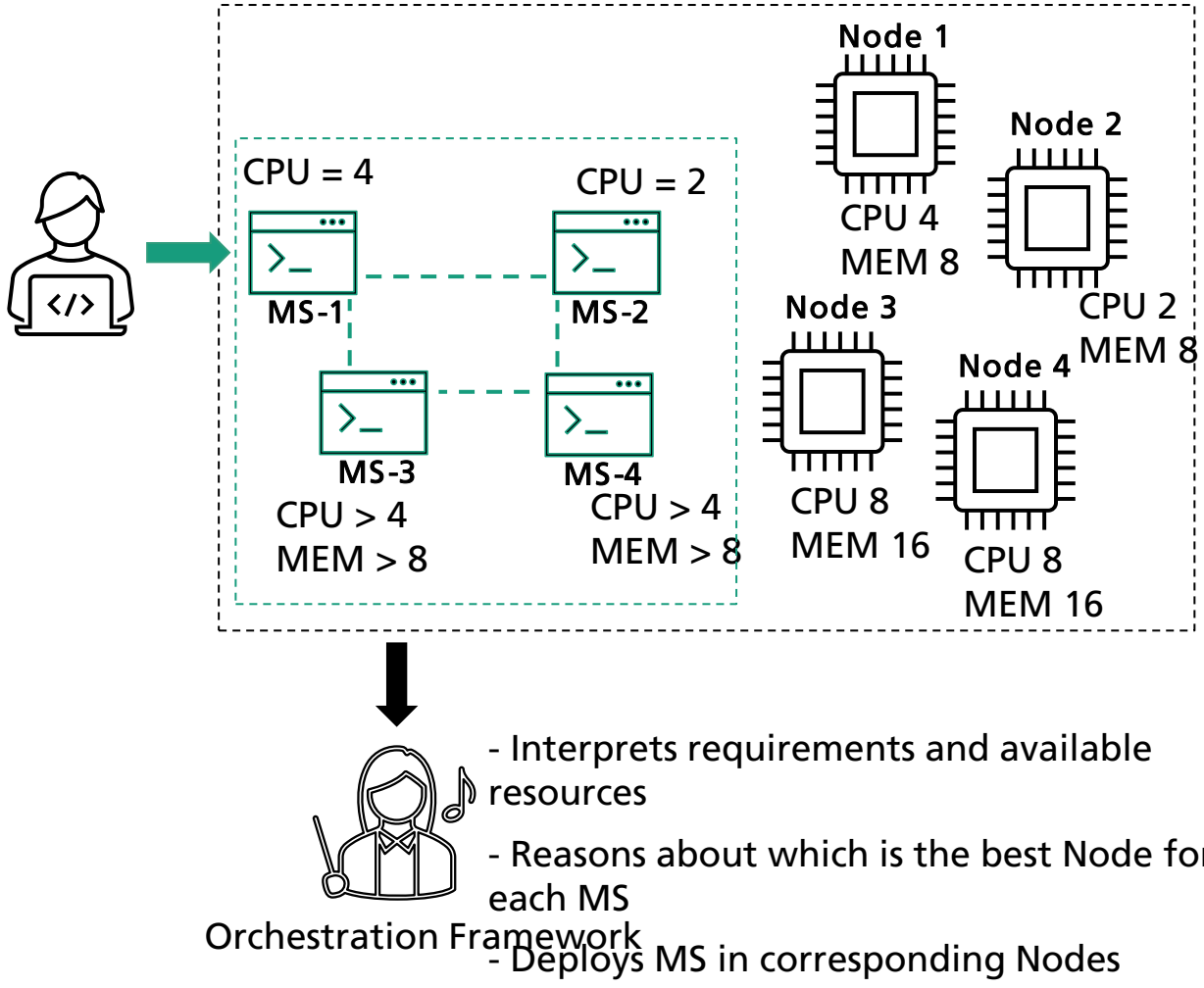


© Fraunhofer Portugal

Fraunhofer PORTUGAL

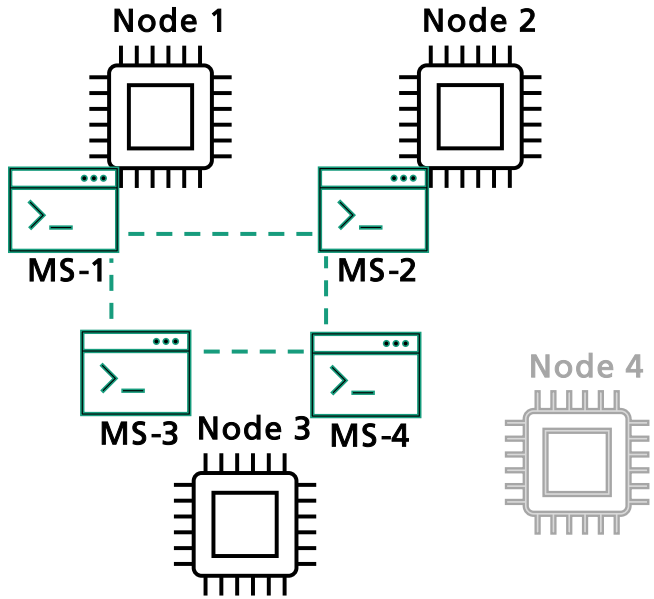
Cloud native concepts

Better infrastructure utilization



Orchestration Framework

- Interprets requirements and available resources
- Reasons about which is the best Node for each MS
- Deploys MS in corresponding Nodes

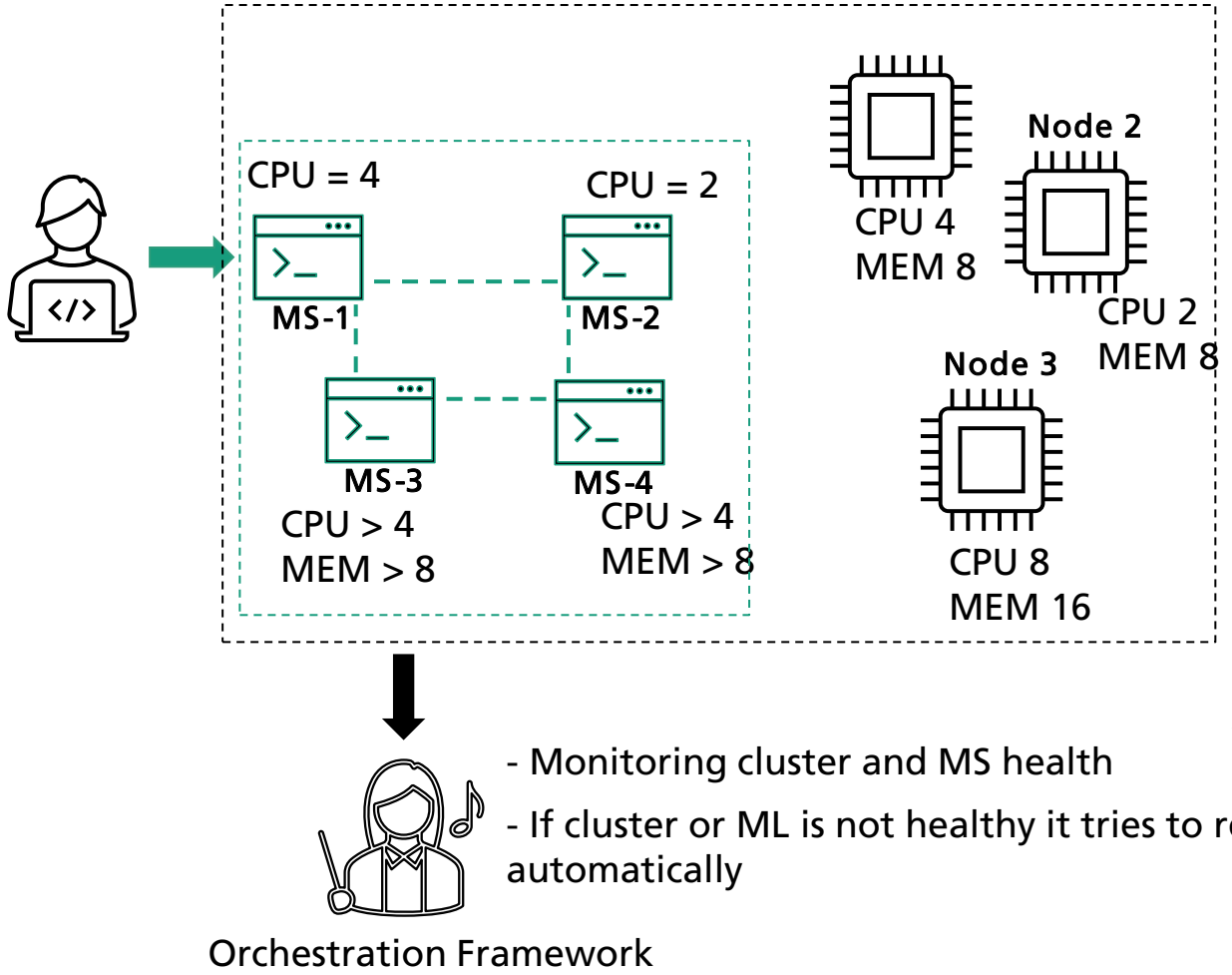


© Fraunhofer Portugal

Fraunhofer PORTUGAL

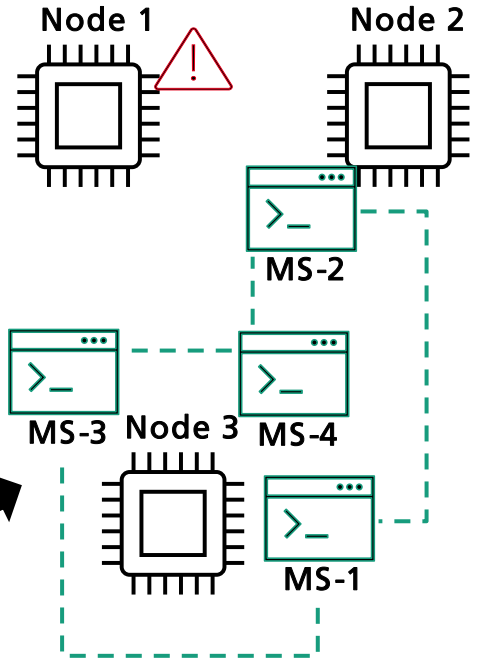
Cloud native concepts

Fault tolerance and Observability



- Monitoring cluster and MS health
- If cluster or ML is not healthy it tries to recover automatically

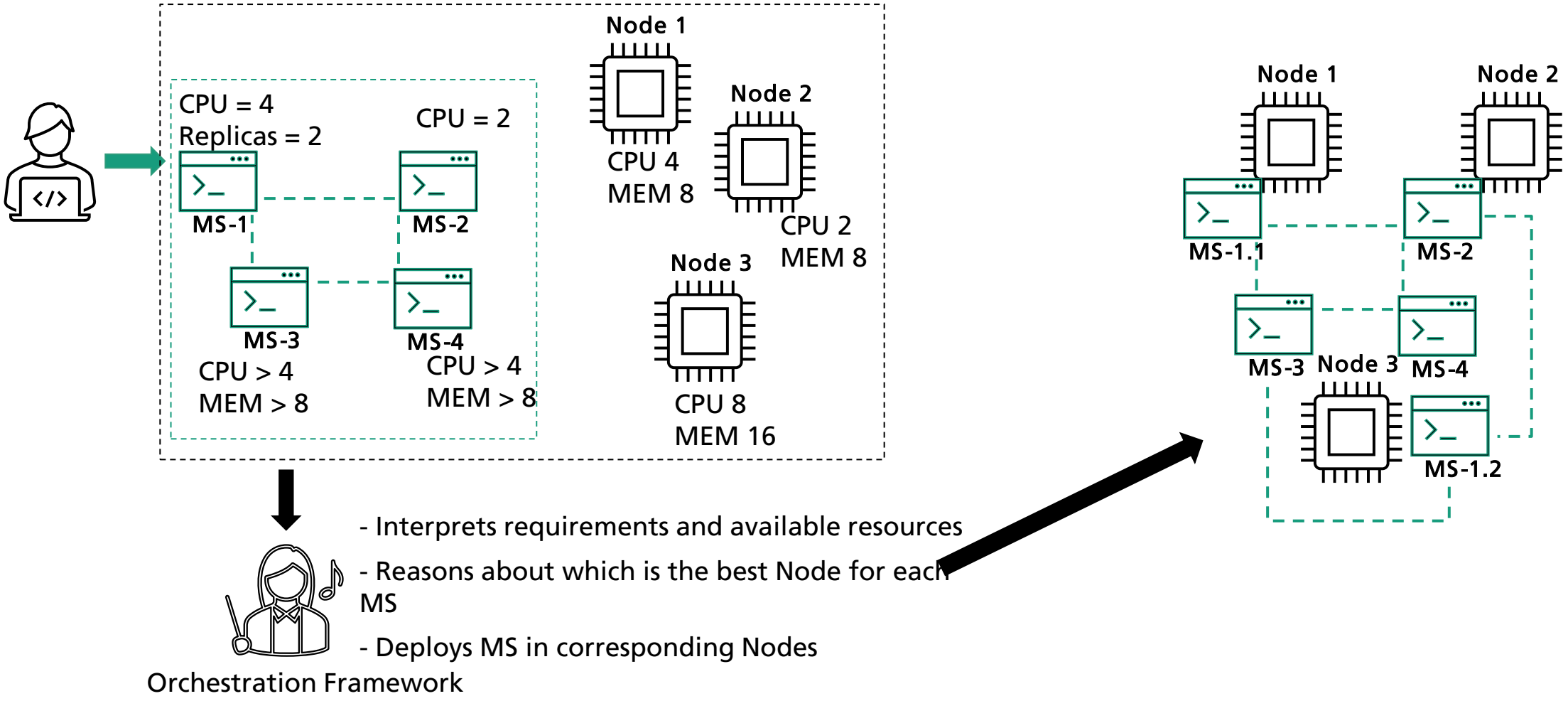
Orchestration Framework



© Fraunhofer Portugal

Cloud native concepts

Replication

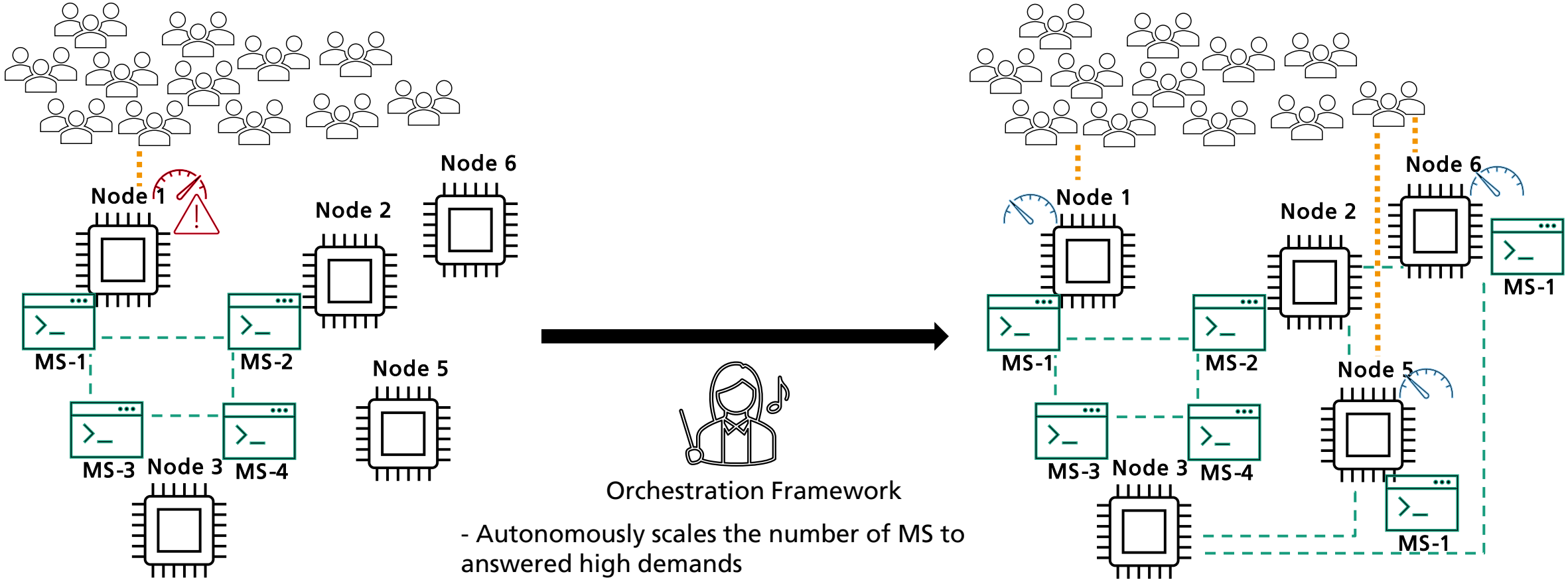


© Fraunhofer Portugal

Fraunhofer PORTUGAL

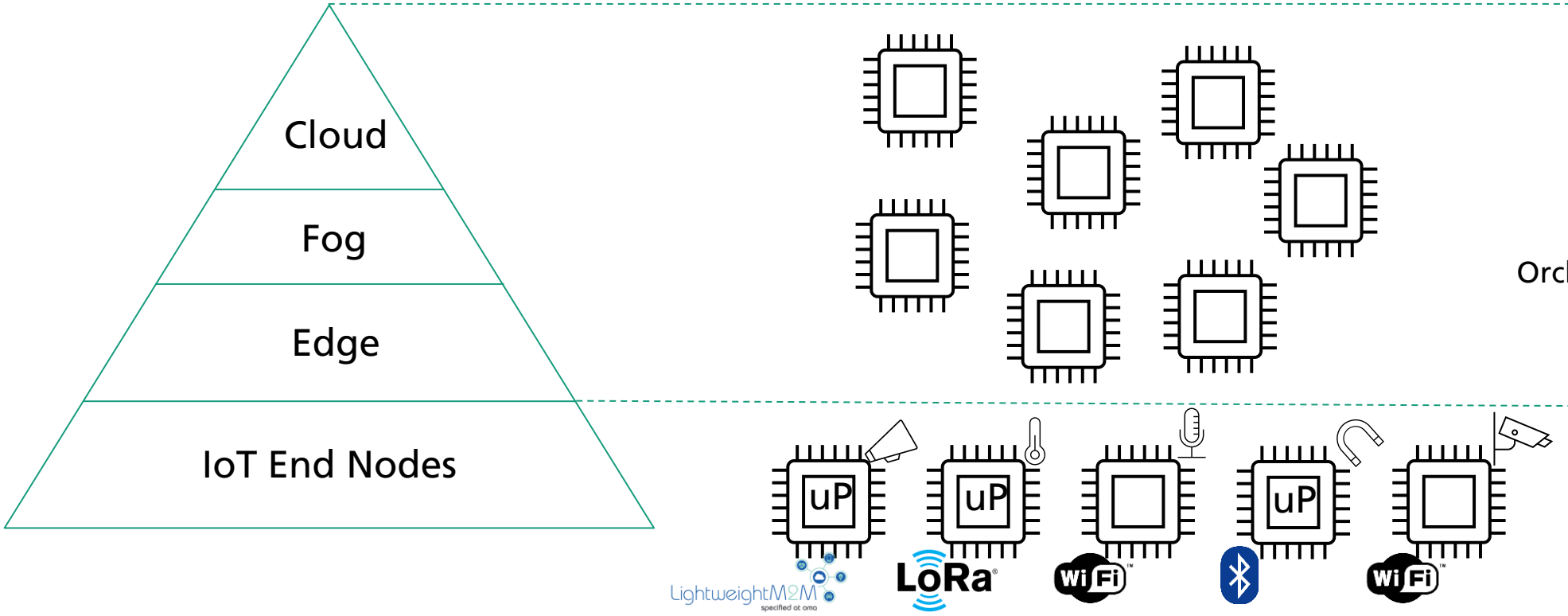
Cloud native concepts

Scalability



Cloud native concepts

Continuum

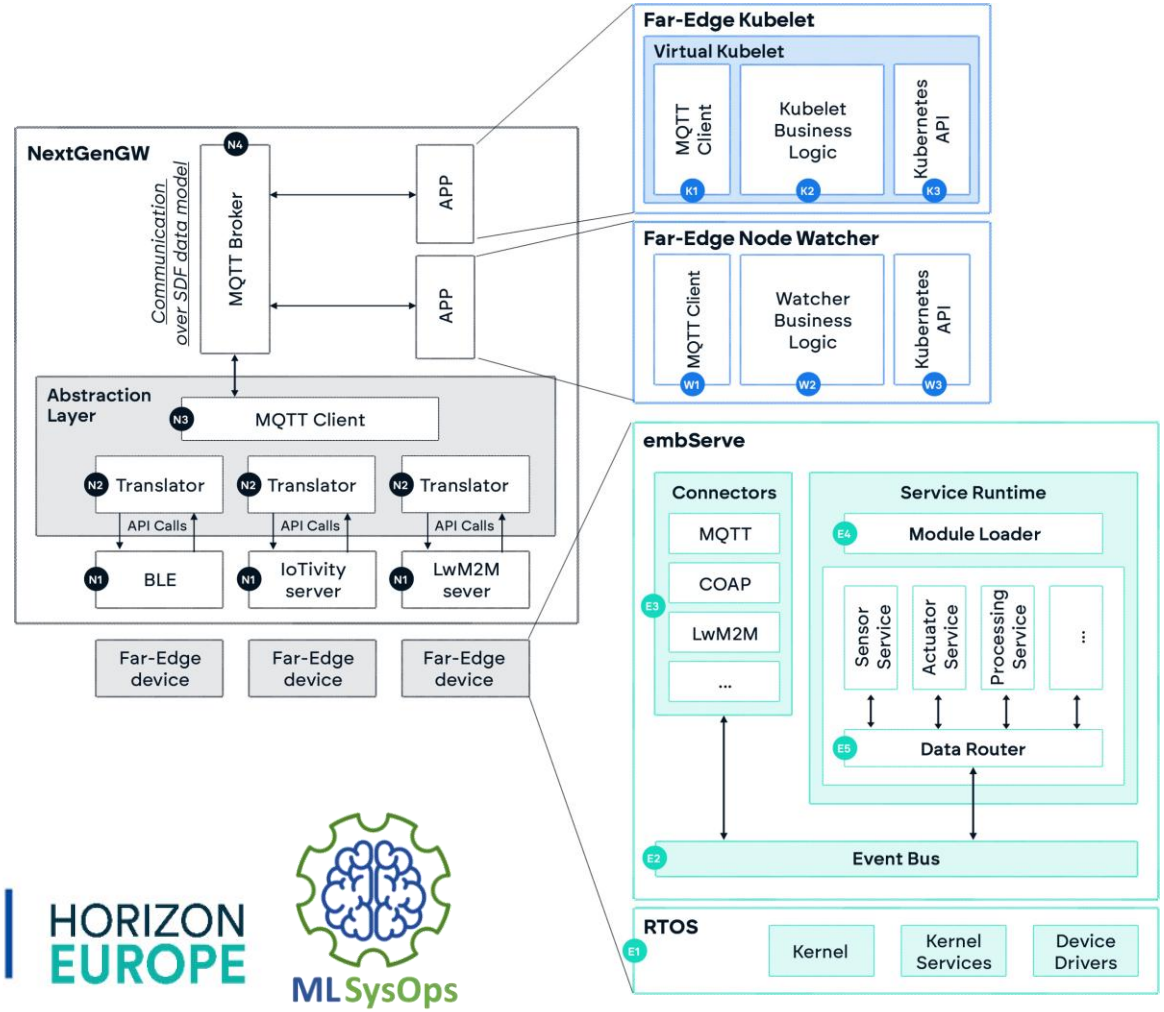


© Fraunhofer Portugal
Fraunhofer PORTUGAL

CLOUD NATIVE CONCEPTS & IOT

Applying cloud native concepts to IoT device and workload management

FITA – Integrating Resource Constrained IoT devices in Kubernetes



European Commission | HORIZON EUROPE

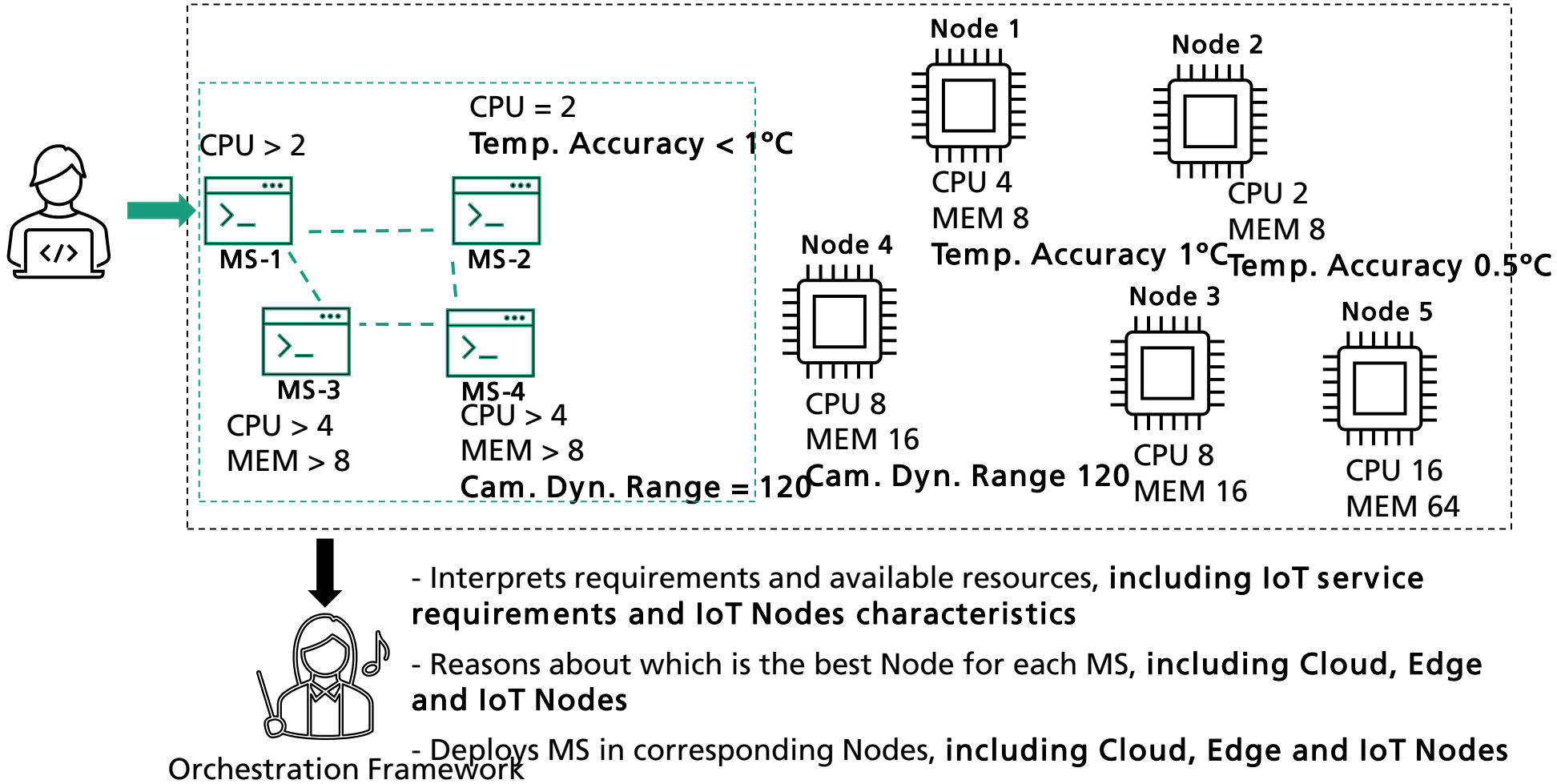
MLSysOps

© Fraunhofer Portugal

Fraunhofer PORTUGAL

Applying cloud native concepts to IoT device and workload management

Shared configuration across all computing layers - managing cloud, edge and IoT with the same tools

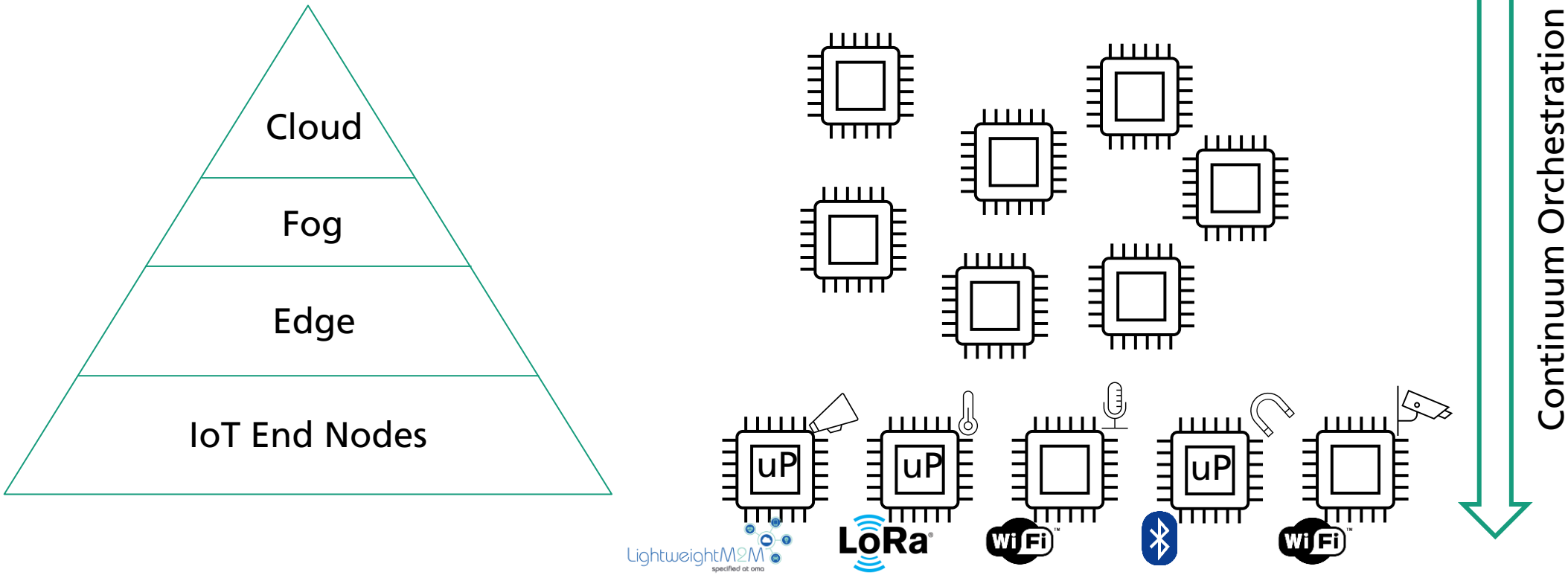


- Interprets requirements and available resources, **including IoT service requirements and IoT Nodes characteristics**
- Reasons about which is the best Node for each MS, **including Cloud, Edge and IoT Nodes**
- Deploys MS in corresponding Nodes, **including Cloud, Edge and IoT Nodes**

© Fraunhofer Portugal

Cloud native concepts

Continuum



© Fraunhofer Portugal
Fraunhofer PORTUGAL

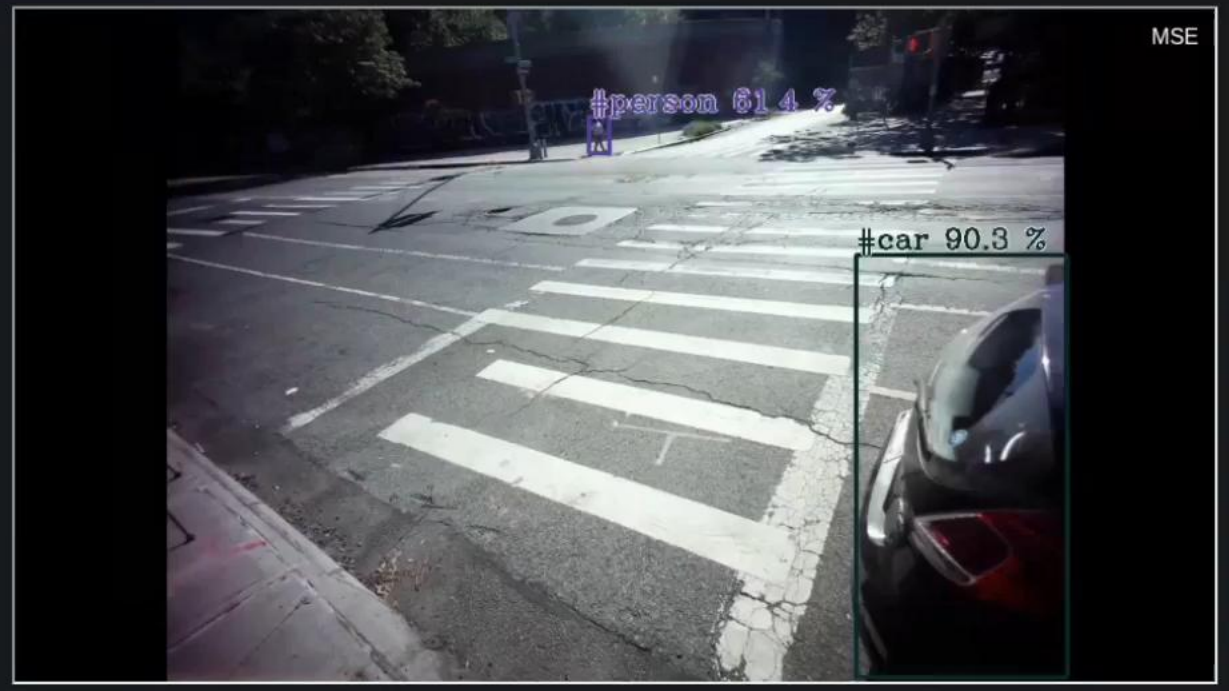
DEMO - OBJECT RECOGNITION

Nodes

labnuc01

labnuc01-b1-node1

No data



aicos@labnuc01: ~/fita-demos/demos/mlsysops_use_case

```
aicos@labnuc01:~/fita-demos/demos/mlsysops_use_case$
```

DEMO – DISTRIBUTED INFERENCE

Edge Node - FITA

fita-fita-78768fc86b-wxklj

far-edge-kubelet-labnuc01-b1-node6

far-edge-kubelet-labnuc01-b1-node2

far-edge-kubelet-labnuc01-b1-node4

far-edge-kubelet-labnuc01-b1-node5

far-edge-kubelet-labnuc01-b1-node1

far-edge-kubelet-labnuc01-b1-node3

Edge Node - TinyKubeML

femlm-fita-femlm-operator-7586d44f5

Far-edge Node 1 - 512kB

No data

Far-edge Node 3 - 128kB

No data

Far-edge Node 5 - 128kB

No data

Far-edge Node 2 - 256kB

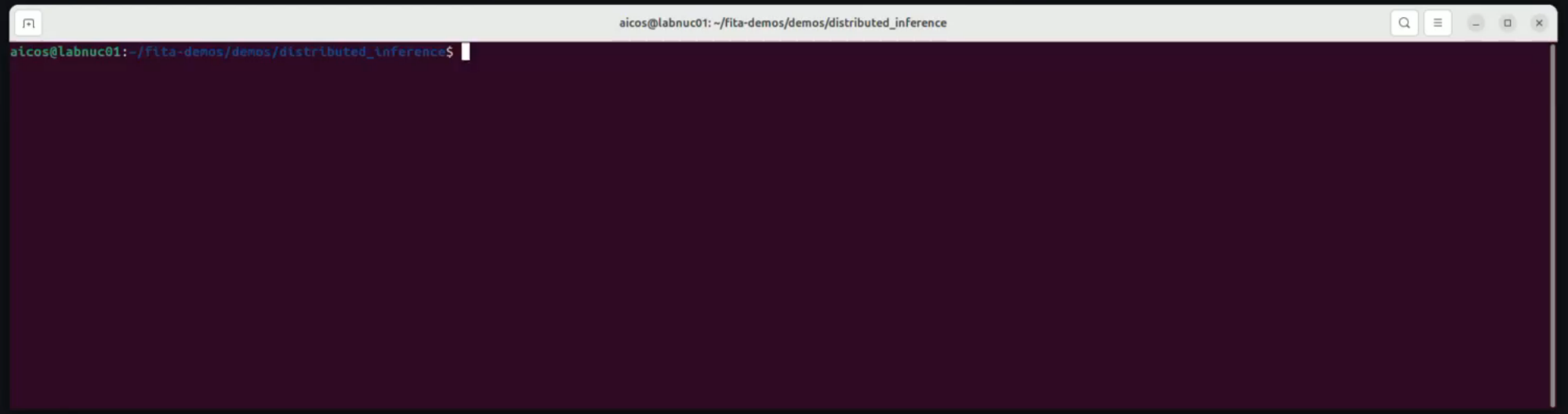
No data

Far-edge Node 4 - 128kB

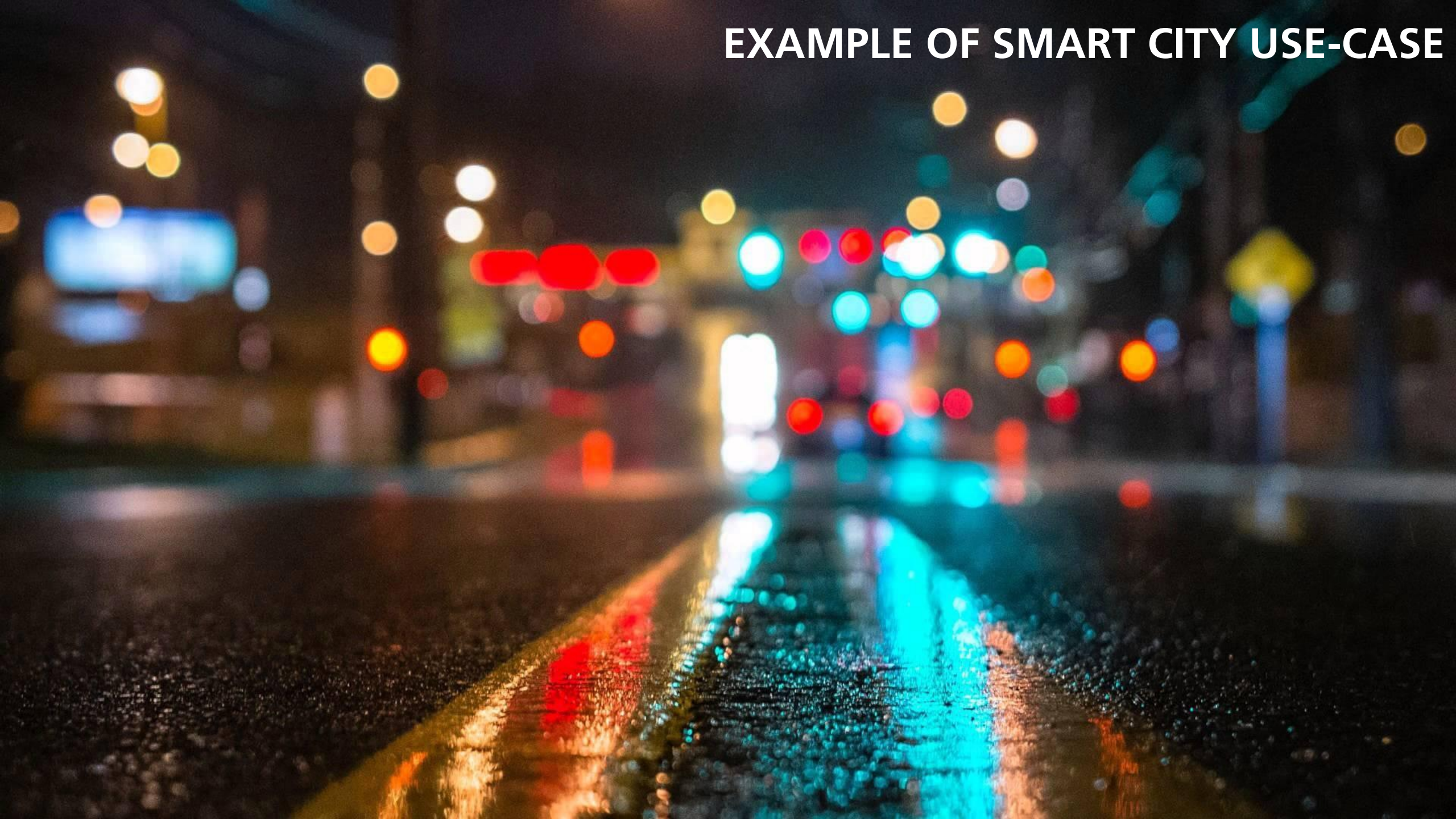
No data

Far-edge Node 6 - 128kB

No data



EXAMPLE OF SMART CITY USE-CASE

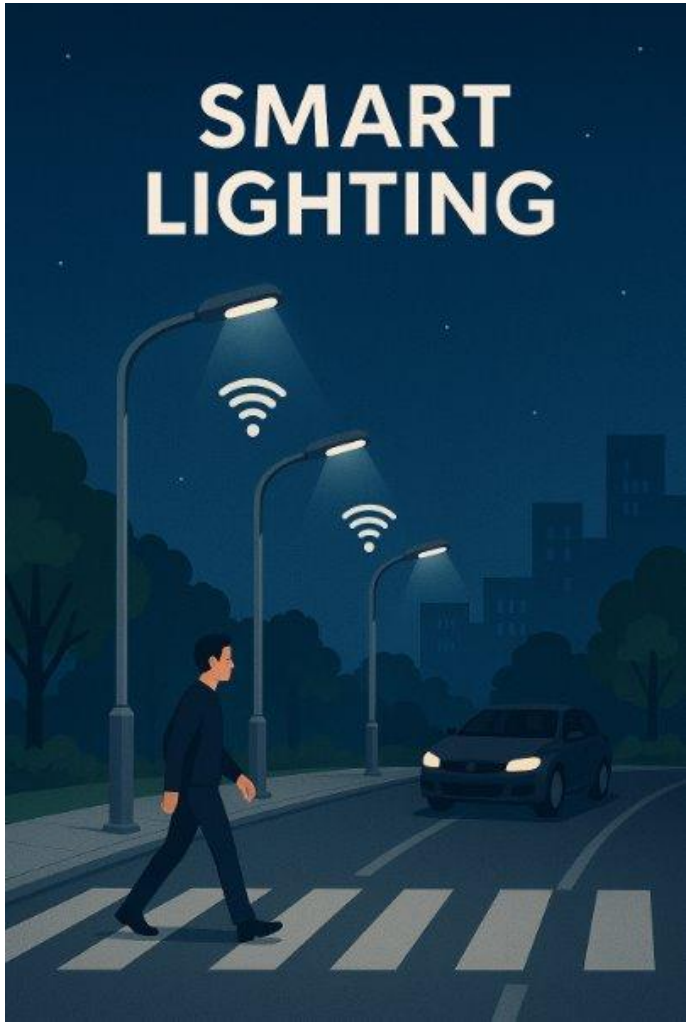


Example of Smart City Use-Case

Smart Lighting

- A service provided by Smart Street Lighting
  - Enhances the functionality of the lighting infrastructure with a connectivity and IoT infrastructure

- Smart Lighting is a service provided by Smart Street Lighting
  - Aims to reduce energy consumption, with expected savings between 50% and 70%[1]
  - Envisioned as the future of lighting in Smart Cities:
    - Annual market growth of 22.7% per year.[2]
    - Expectation to reach 63.8 million connected street lights in 2027 and market value estimated in USD 50 billion by 2028. [2]



1. TÜV SÜD. 2024. Smart cities and intelligent lighting. https://www.tuvsud.com/en/press-and-media/2024/january/smart-cities-and-intelligent-lighting

2. Graham Colclough, Leen Peeters, Christina Protopapadaki, and Judith Borsboom. 2021. Smart Lighting in Cities: Factsheet. Technical Report. Smart Cities Marketplace. https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2021-06/Smart%20Lighting%20Factsheet_0.pdf

© Fraunhofer Portugal

Fraunhofer PORTUGAL

Example of Smart City Use-Case

Smart Lighting

- Potentiated by Cloud Native
  - Control the distribution of the dimming application through the continuum and the Smart Street Lighting infrastructure
  - Fault tolerance
    - Automate the identification of faults in the infrastructure (lampposts and its sensors and actuators) and migrate application components to working lampposts
  - Are there other infrastructure and application management problems that could be solved with orchestration?

© Fraunhofer Portugal

Future

- Support intermittent devices
- Distribute AI across the continuum
- Harden security through IoT components

© Fraunhofer Portugal

THANK YOU

PORTO – Headquarters

Address: **Rua Alfredo Allen 455/461**

4200-135 Porto | Portugal

Phone: **+351 220 430 300**

LISBON – Branch office

Address: **Avenida Prof. Gama Pinto, 2**

1649-003 Lisboa | Portugal

Phone: **+351 220 430 300**

Website: **www.aicos.fraunhofer.pt** | E-mail: **info@fraunhofer.pt**

Filipe Sousa filipe.sousa@aicos.fraunhofer.pt

José Costas jose.costa@aicos.fraunhofer.pt

Fraunhofer PORTUGAL