Preliminary Concepts

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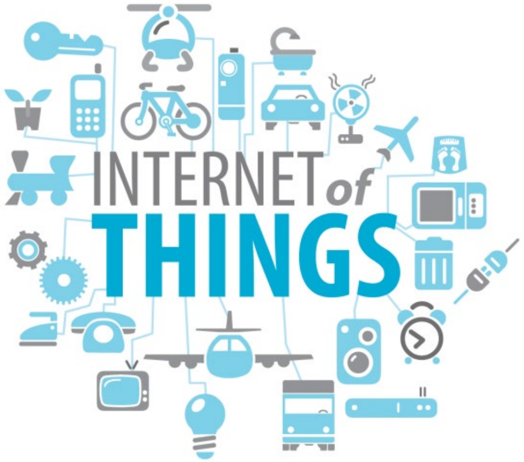

Internet of Things

"The next logical step in the technological revolution connecting people anytime, anywhere is to connect inanimate objects. This is the vision underlying the **Internet of Things: anytime, anywhere, by anyone and anything"**

(ITU, Nov. 2005)

Internet of Everything

- computers and communication devices
- cars, robots, machine tools
- persons, animals, and plants
- processes
- data

IoT in Italy

Connected IoT Objects (end 2023)

- 140 millions
- 2.4 objects per inhaitant

Cellular Connections

- 41 millions
- +5%, compared to 2022

Other communication technologies

- 100 millions
- +17%, compared to 2022

Low Power Wide Area (LPWA)

- 3 millions
- +25%, compared to2022

IoT in Enterprises

- ***18%*** *of large companies have initiated Industrial IoT projects in the past year*
- ***60%*** *of machinery manufacturers are familiar with connected systems*

Source
Internet of Things Observatory
School of Management, Politecnico di Milano

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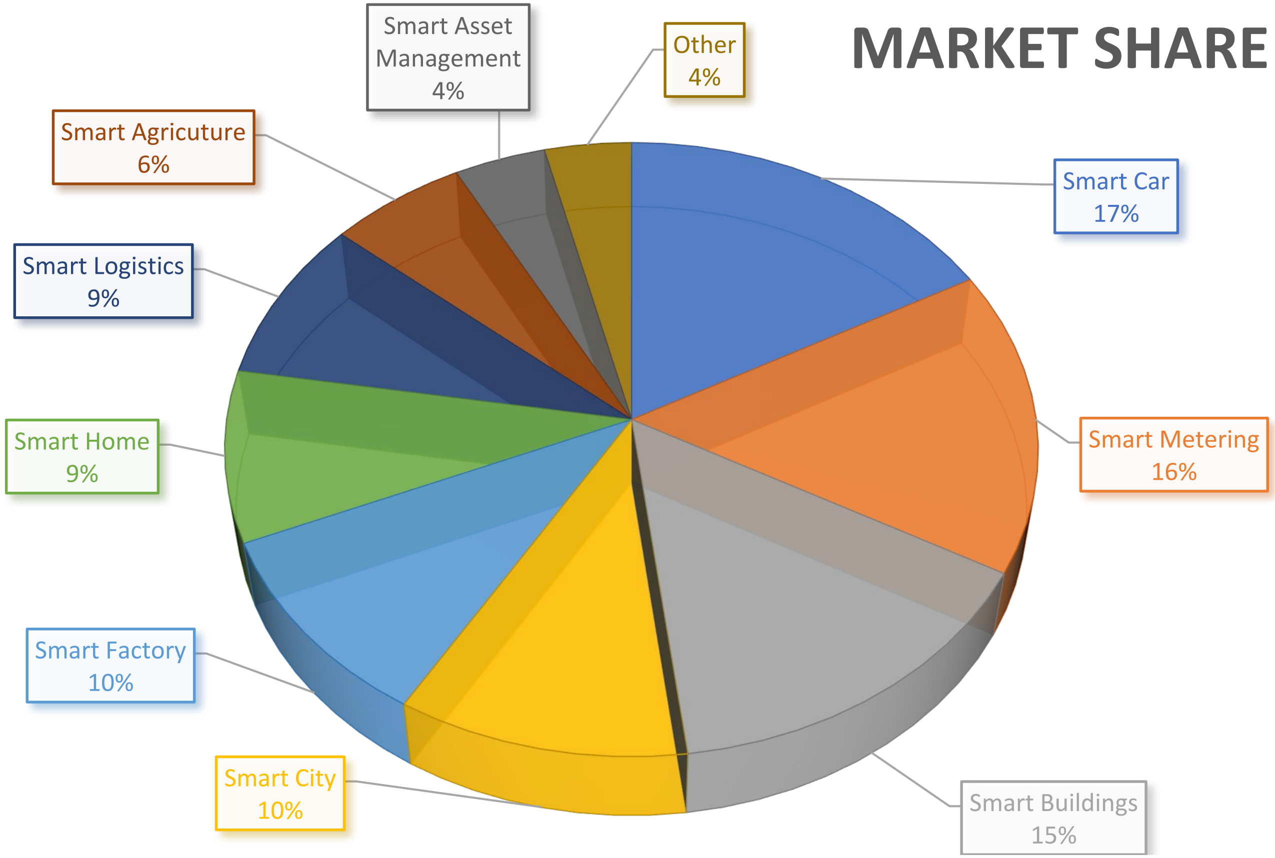
IoT in Italy

Some Figures (2023)

140 Millions of connected devices

2.4 IoT devices per inhabitant

9 Billions market (+ 9%, wrt 2022)

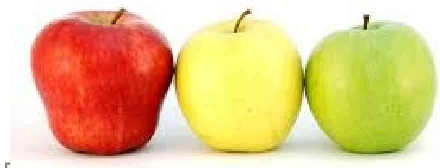


https://www.osservatori.net/it/ricerche/comunicati-stampa/internet-of-things-italia-mercato

Smart Object

Any real-world object empowered with

- Communication capabilities
  - Allow the smart object to communicate
- Computing capabilities
  - Give the smart object its behavior
- Sensing/Actuating capabilities
  - Allow the smart object to interact with the physical world
- Power Source
  - Needed to feed electronic circuits



Smart Object

Real-world Object

Instrumenting Device

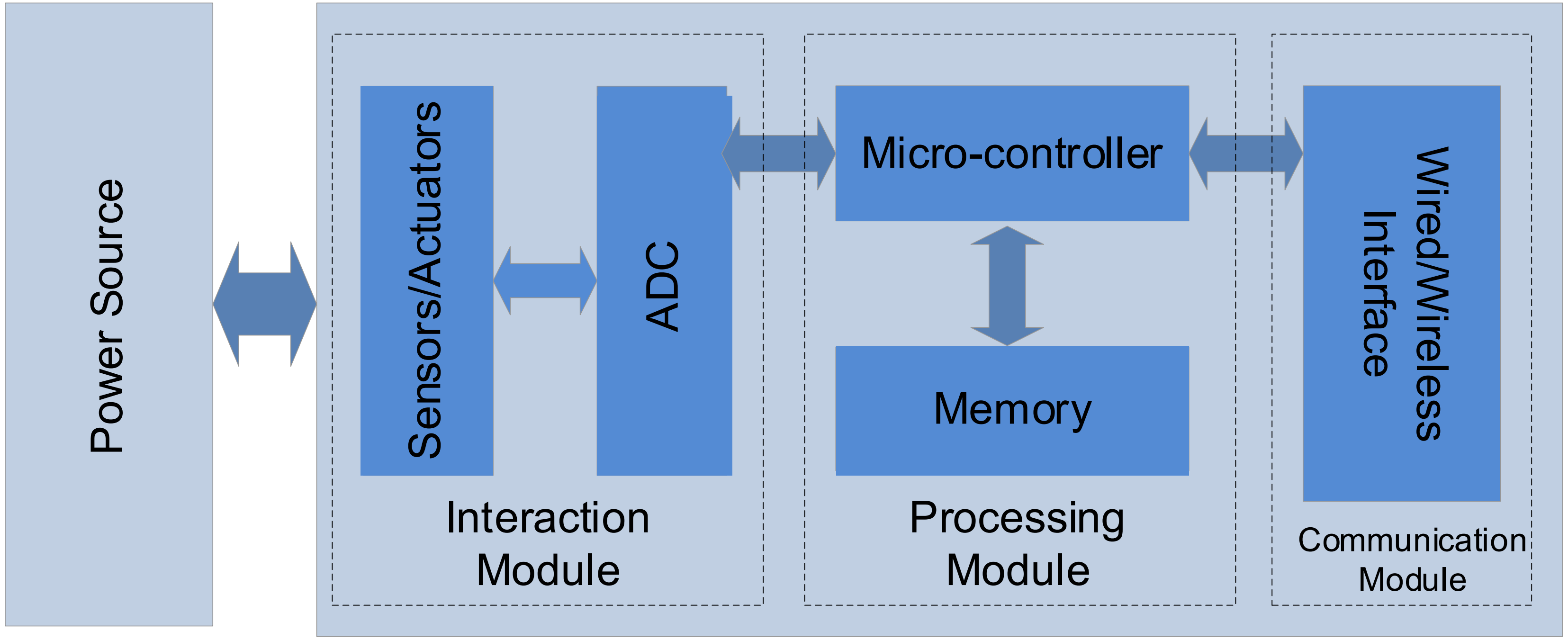
Low-cost device embedded to the object

Communication capabilities

Computing capabilities

Sensing/Actuating capabilities

Instrumenting Device



Instrumenting Device

RFID Taggs

- Only connectivity
- Reader required for communication

Instrumenting Device

RFID Taggs

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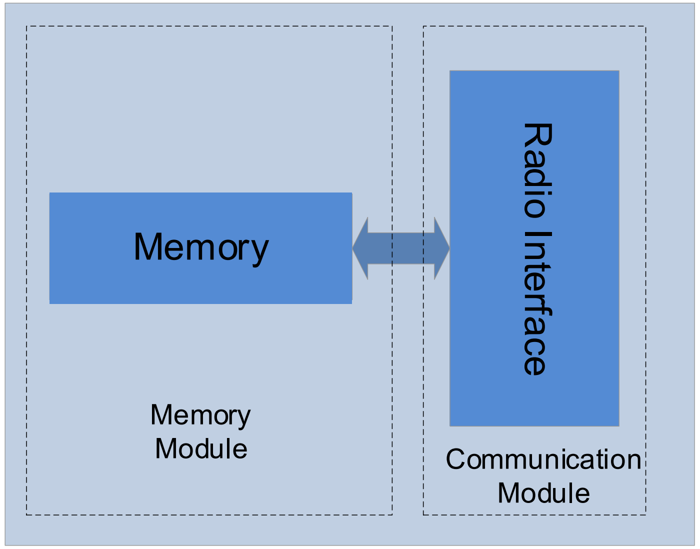
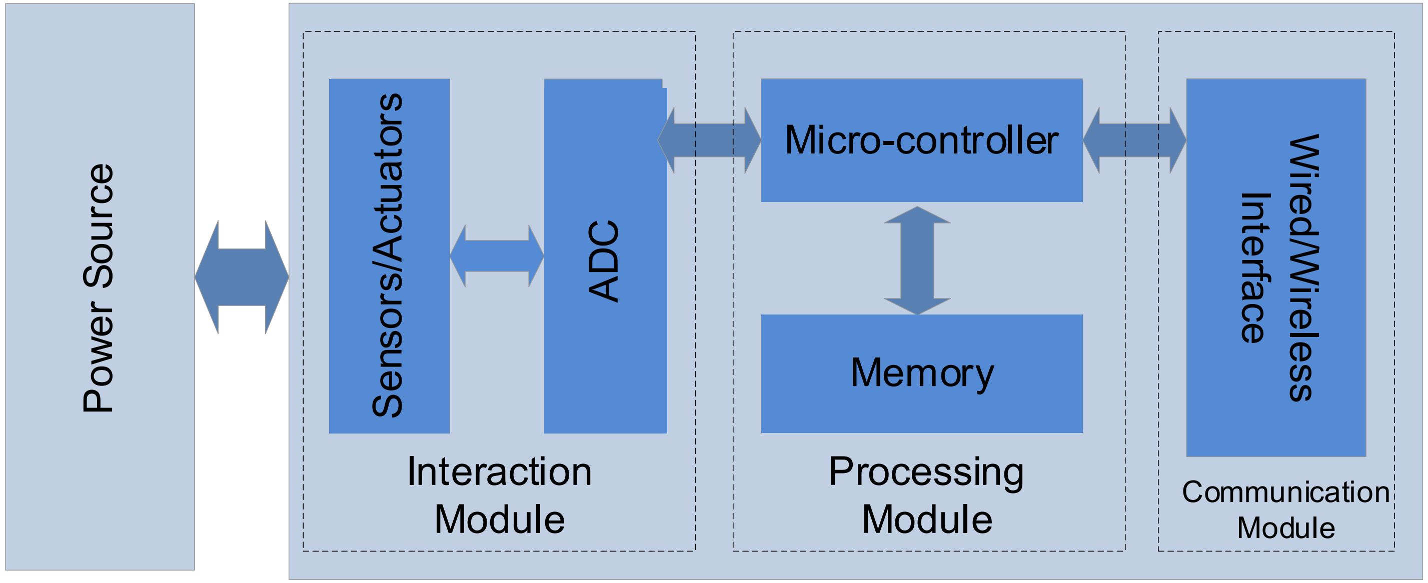


Instrumenting Device

Sensor Actuator Node

- Sensing
- Processing
- Communication
- Actuation

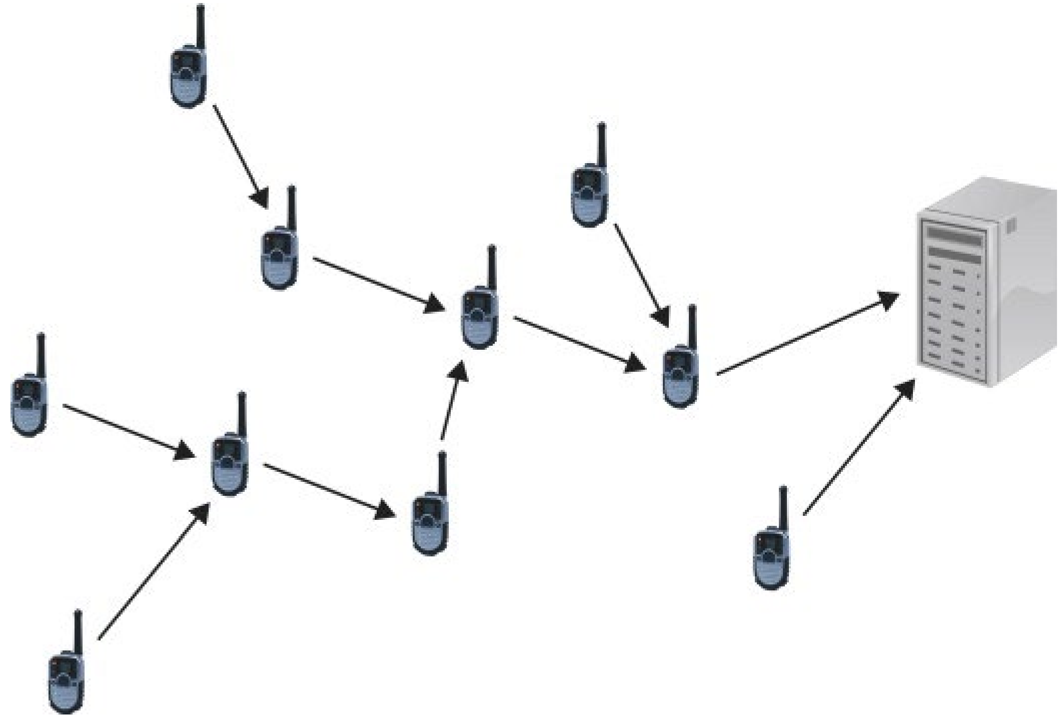


Smart Object Network

Smart Objects typically are part of a network

Different smart objects cooperate to perform a specific task

Wireless/Wired communication



Smart Environments

Smart Environment

- A place where human activities are assisted and supported by ICT
- through cooperating smart objects
- Most of the environments where we live, work, and spend our time are smart, or can be made smart

- Smart Cities
- Smart Mobility
- Smart Parking
- Smart Lighting
- Smart Energy (Smart Grid)
- Smart Waste/Water Management
- Smart Buildings
- Smart Healthcare
- Smart Factory (Smart Industry)
- Smart Manufacturing
- Smart *

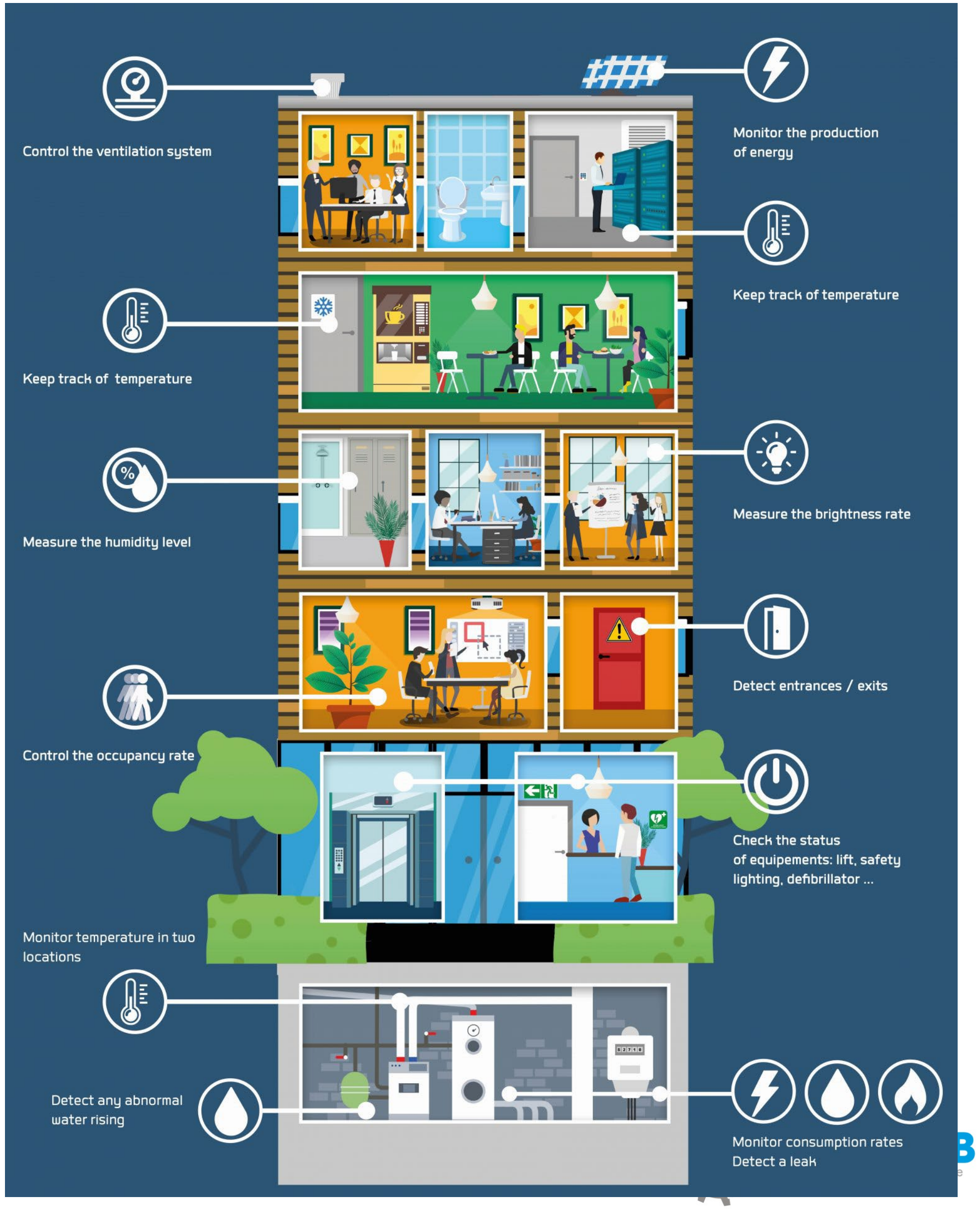
Smart Home

A lot of networked embedded sensors and actuators that monitors and automatically control all the home activities

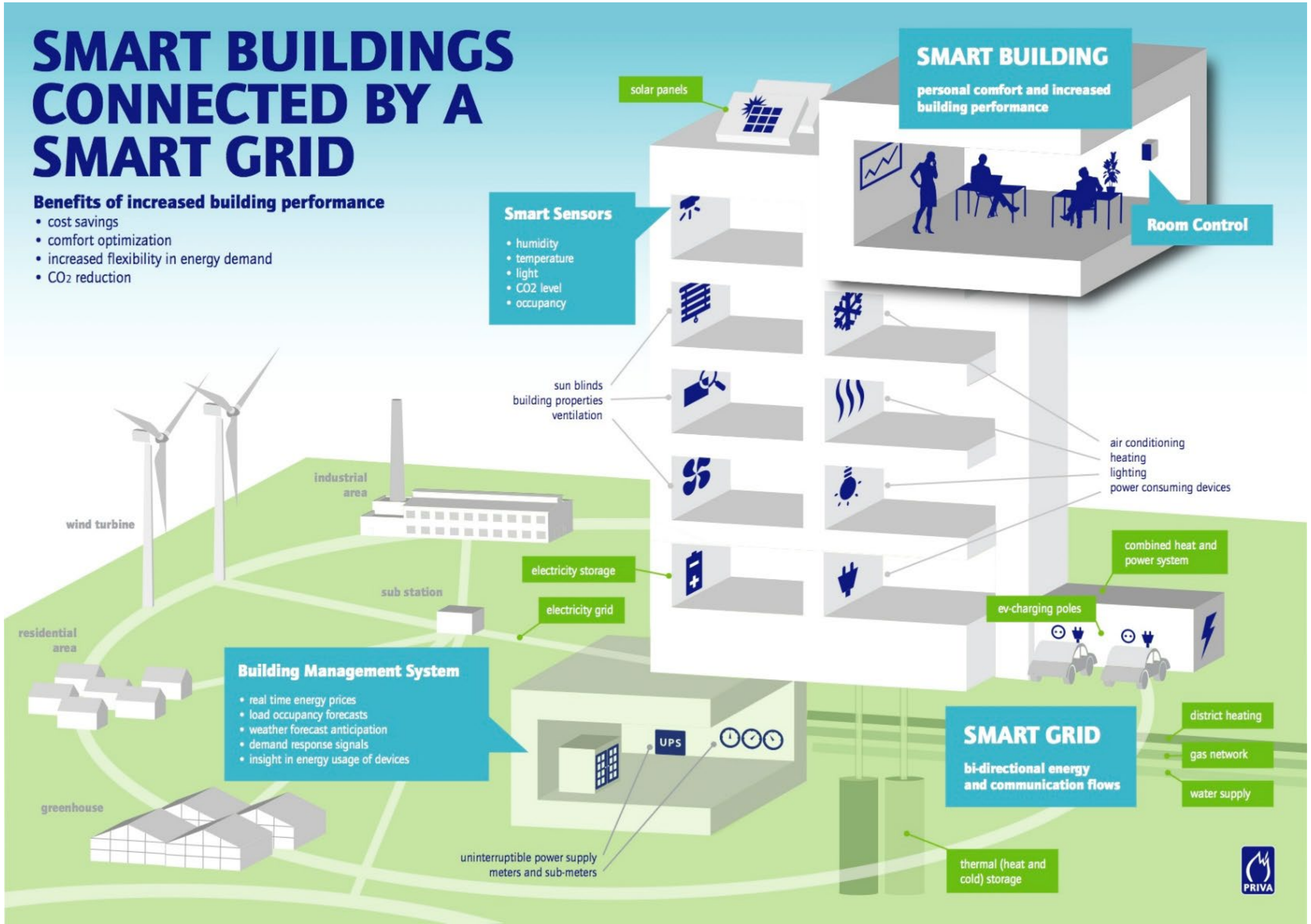
Smart Home/Building

Smart Home

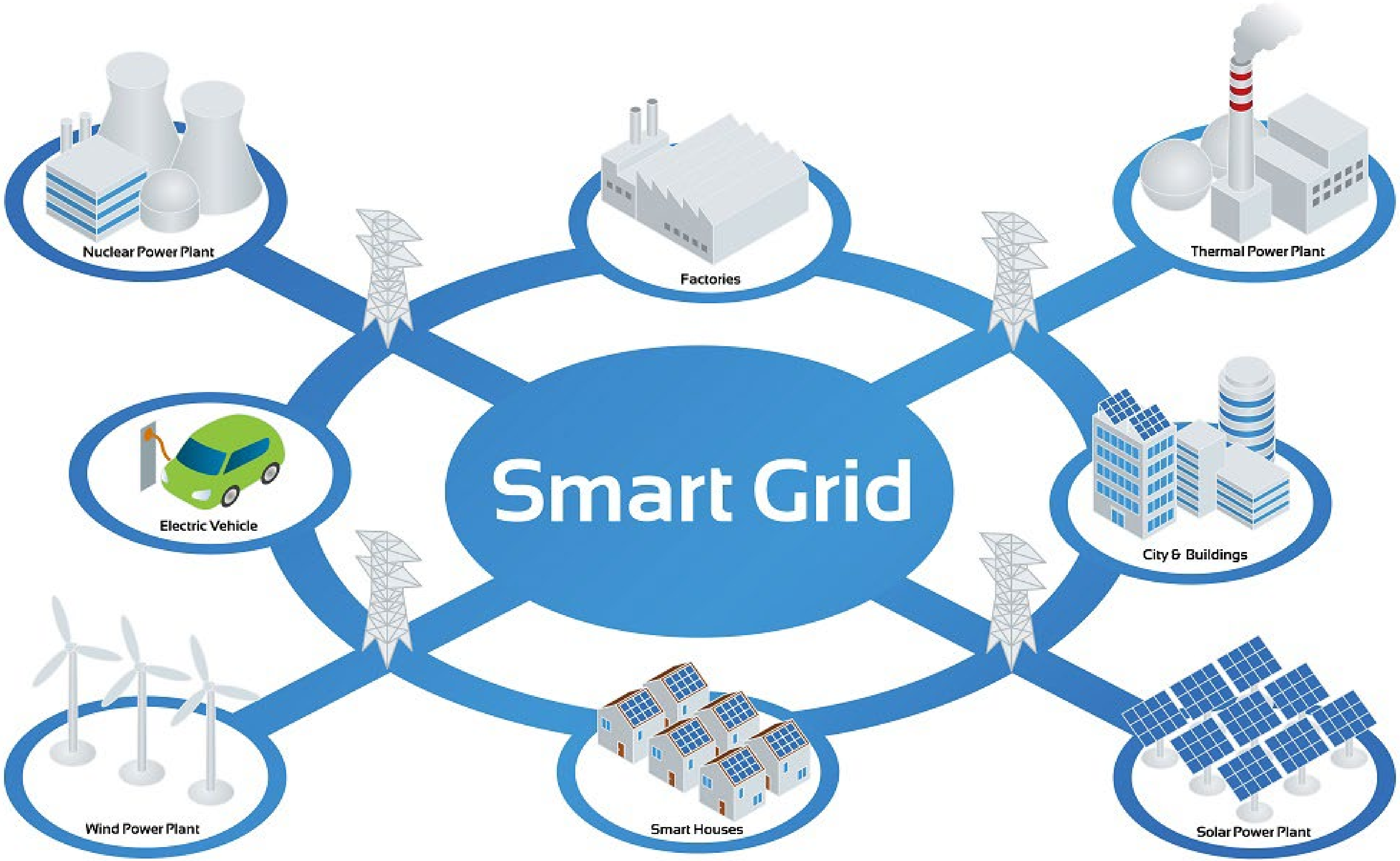
Environmental Sensors	Temperature Humidity Brightness Occupancy …
Smart Meters	Energy produced by local generator Energy consumption (electrical appliances) Water consumption Gas consumption …
Data Collection Center	Data stored for further analysis
Data Analysis	Monitors consumptions Detects leaks Detects abnormal situations Predicts possible faults
Control Center	Analyze collected data Takes decisions
Actuators	Execute decisions taken by the control center Act on the external environment



Smart Home/Building



Smart Grid

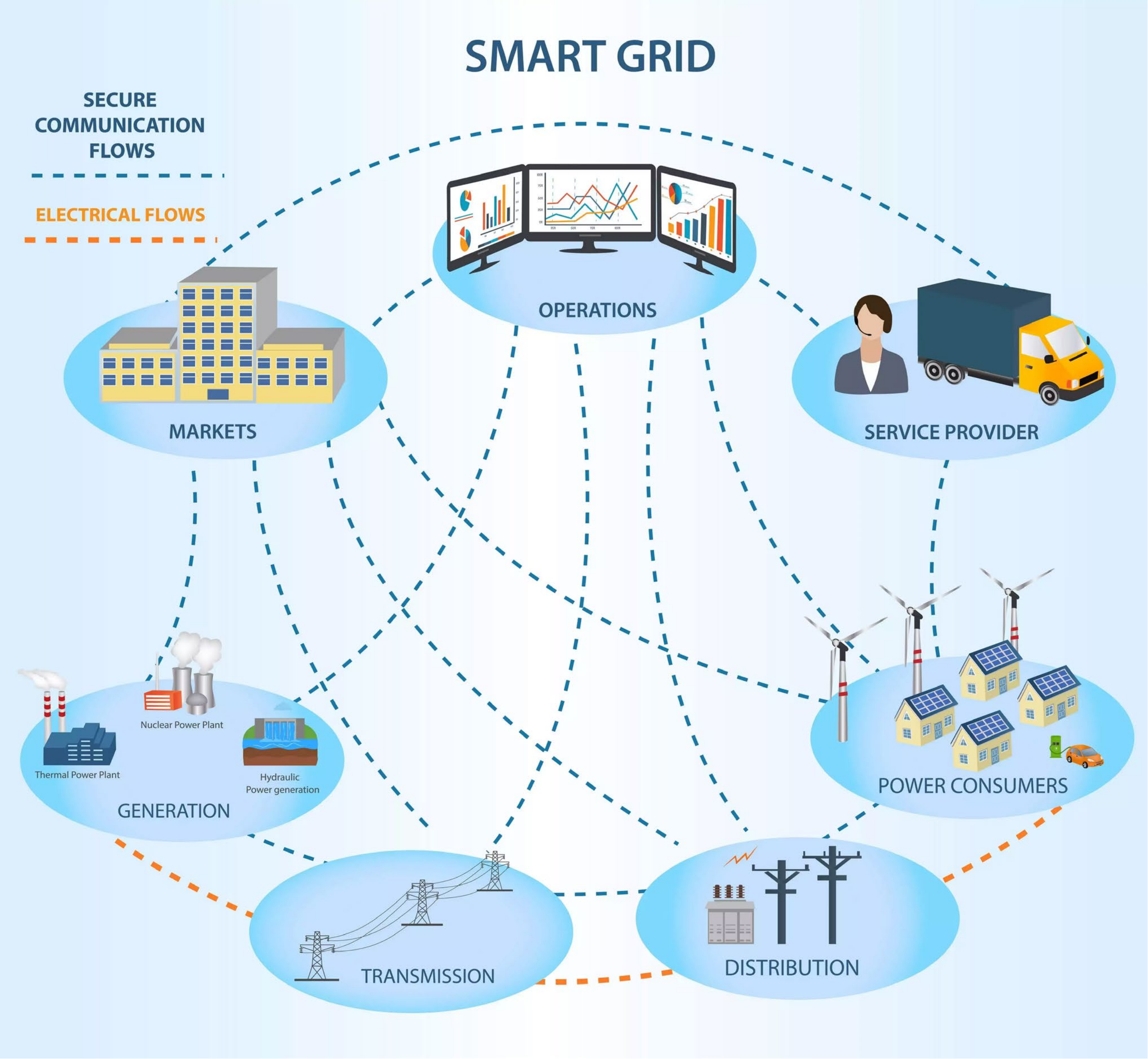


- Local Power Generation
- Energy Storage Devices
- Energy Distribution Networks
- Digital Sensors and Controls
- Real-time Data
- Broadband Communication

Smart Grid

Electrical Flow

Data Flow



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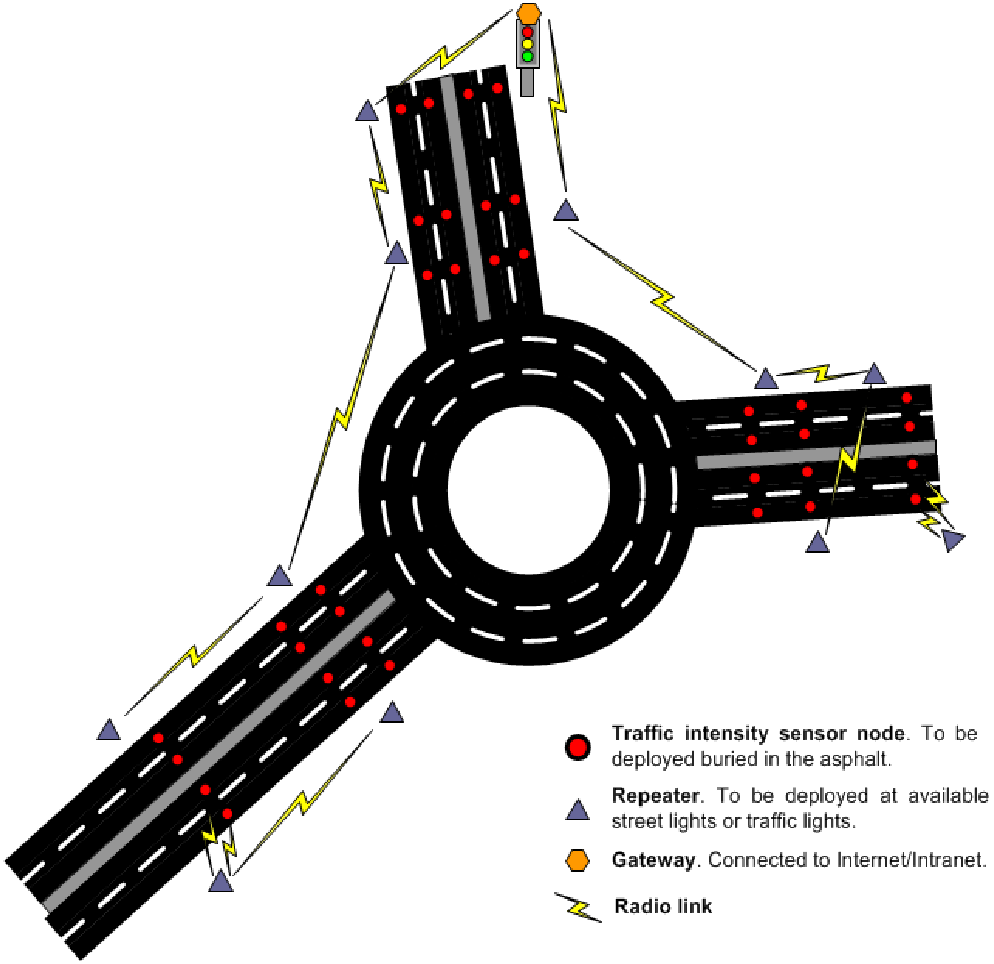
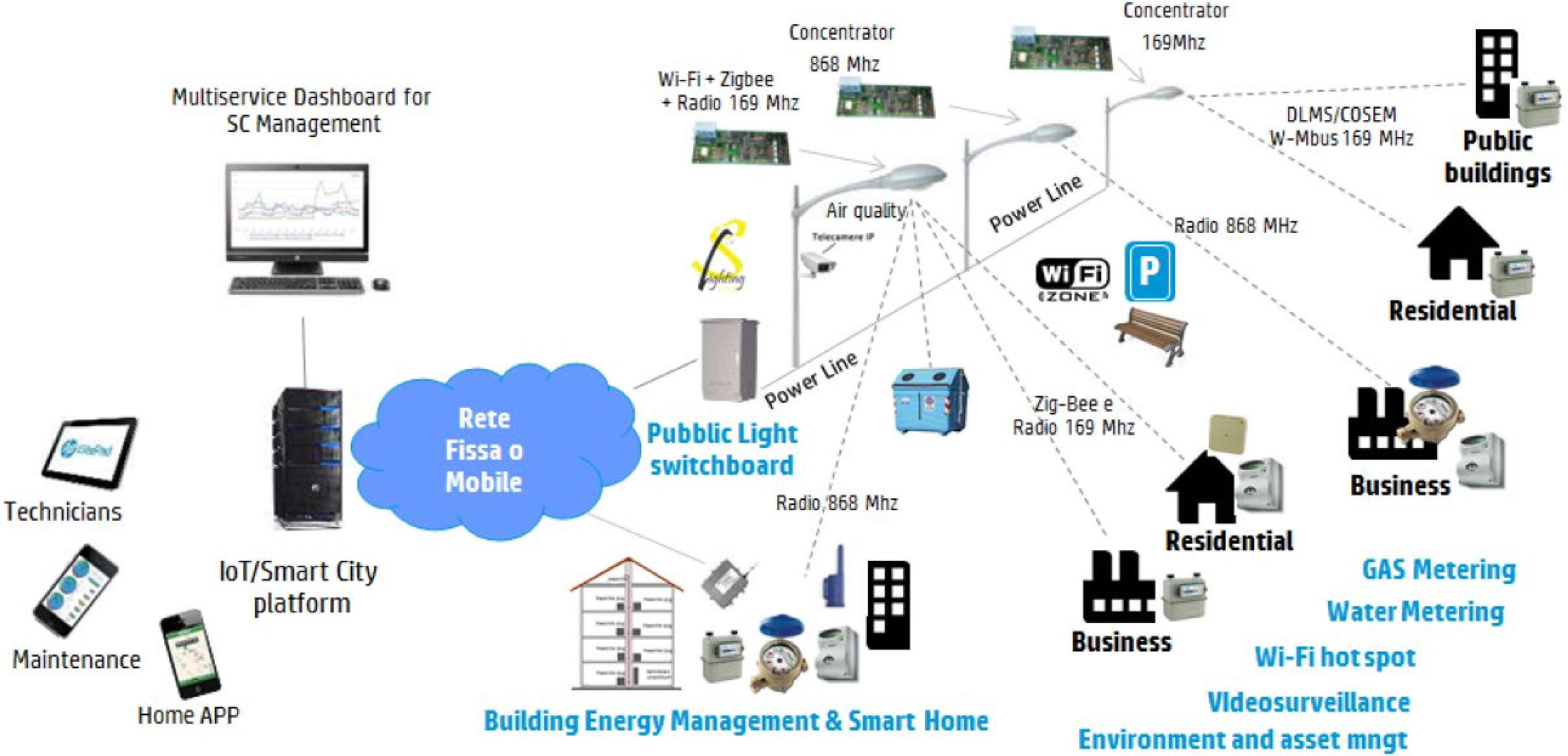
Smart Mobility

Sensors deployed at the main entrance of the city for real-time monitoring of urban traffic

Allows to take timely and appropriate decision



Smart City Services



Smart City

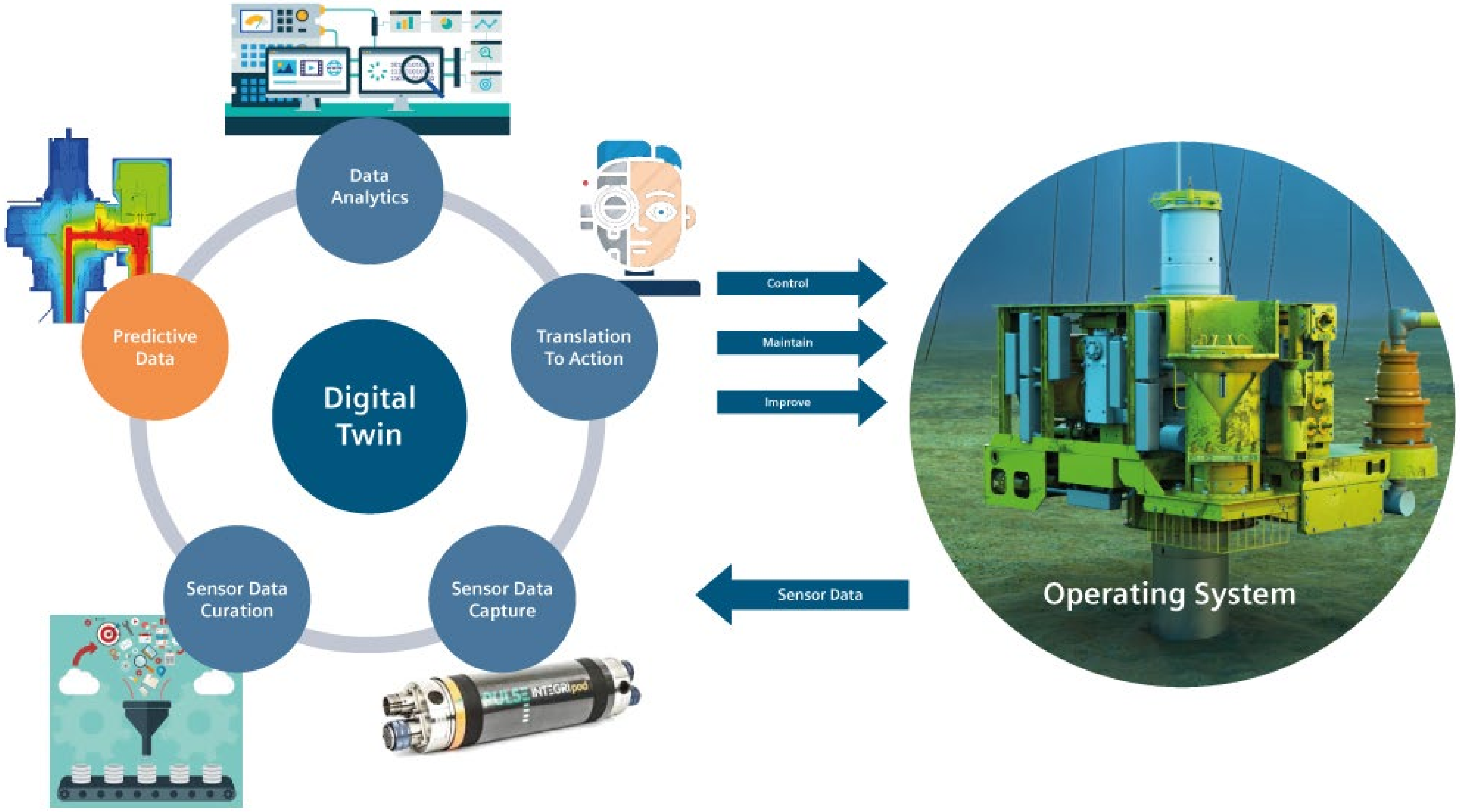
Smart Factory

Real-time networking of human beings, machines, and smart objects for intelligent factory management

- Emergency actions
- Process control
- Alerting
- Logging & monitoring
- Predictive maintenance
- Intra-logistics
- …

Digital Twins

Digital twin for operations – the full loop



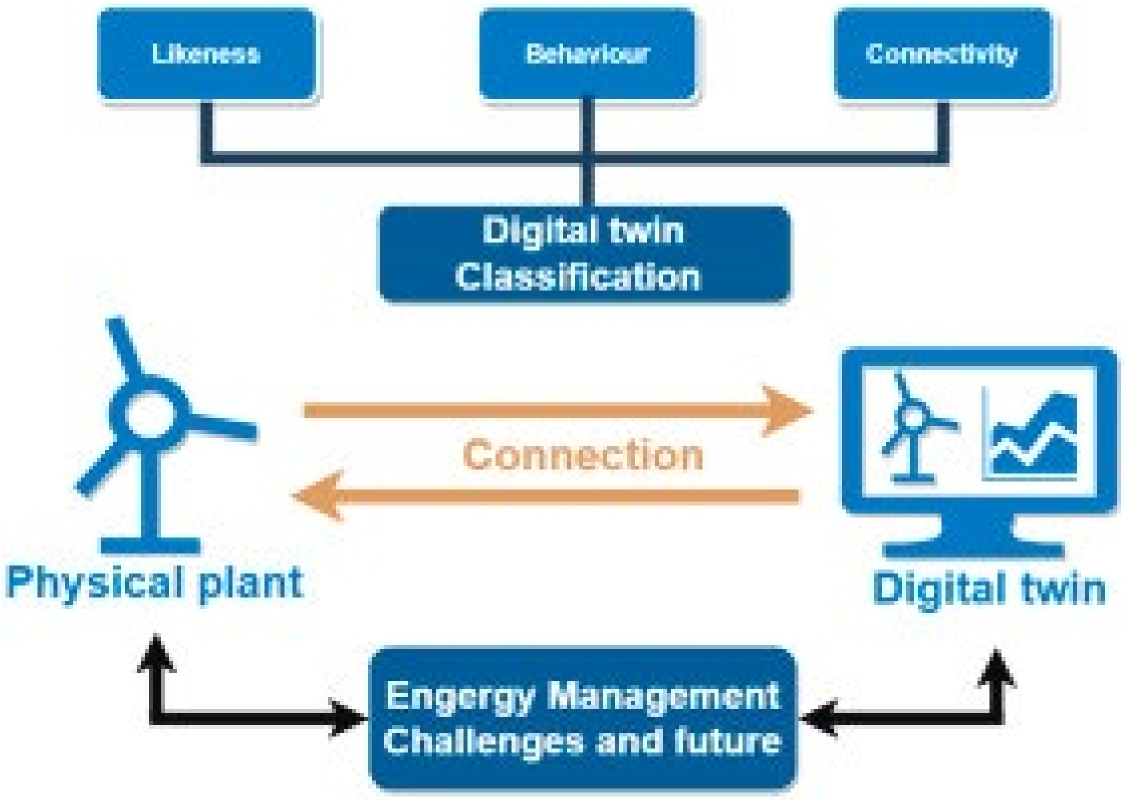
Digital Twins

A DT is the digital replica of a real system

- operates in the cloud platform
- simulates the health condition with an integrated knowledge from both data-driven analytical algorithms as well as other available physical knowledge

A DT contains three main parts

- physical system in the real space
- virtual copy in the cyberspace
- the connections of data and information that ties the virtual and real copies together



W. Yu, P. Patros, B. Young, E. Klinac, T. Gordon Walmsley, «Energy digital twin technology for industrial energy management: Classification, challenges and future»,*Renewable and Sustainable Energy Reviews*, Volume 161, 2022. https://doi.org/10.1016/j.rser.2022.112407.

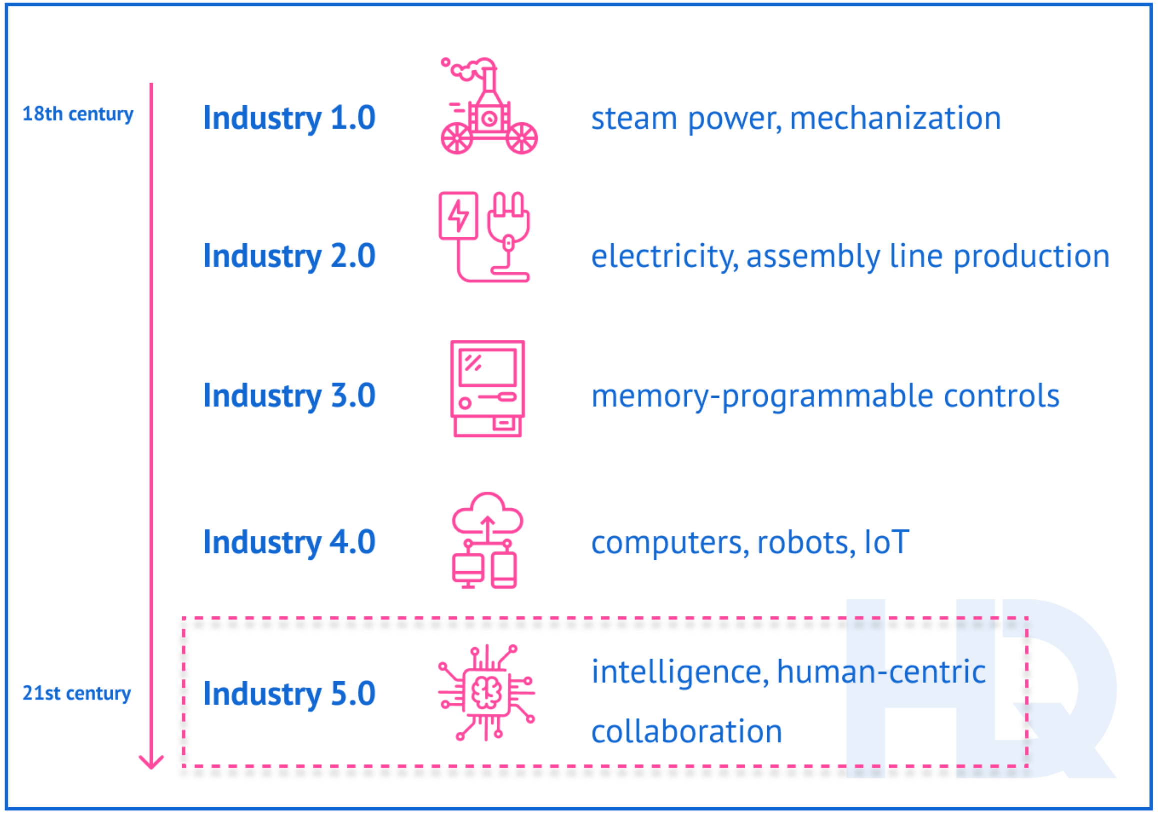
Evolution of Industrialization

Industry 4.0

- Introduction of connected device (IoT), artificial intelligence and data analytics to automate processes
- **Digitalization**

Industry 5.0

- Cooperation between man and machine, as
- Human-centric, sustainable, resilient solutions
- **Personalization**

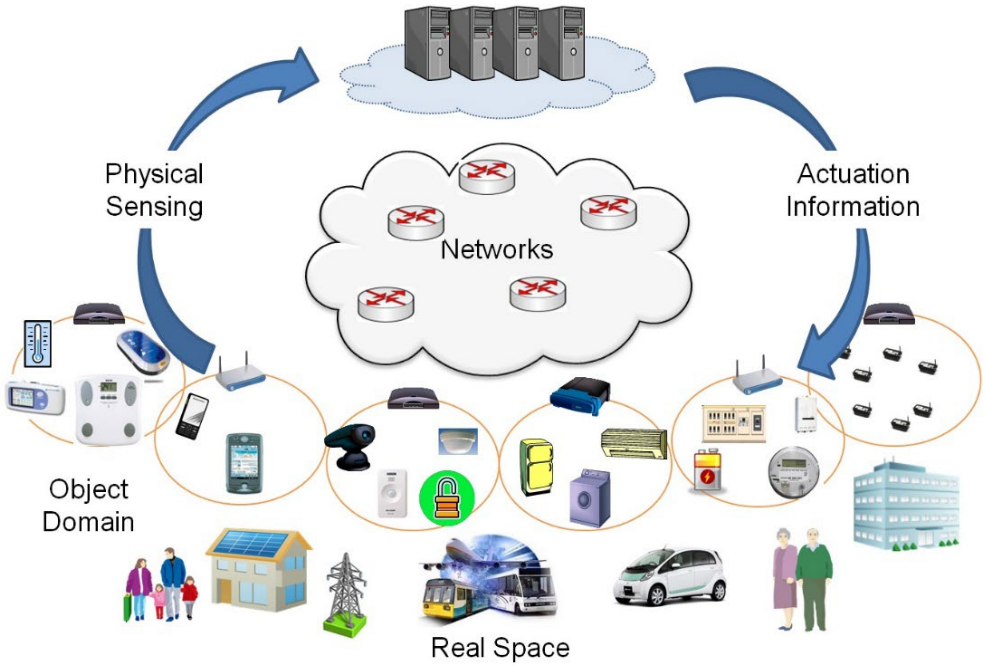


Cyber-Physical System (CPS)

Lots of smart objects with embedded sensors and/or actuators …

… pervasively deployed

... and wirelessly connected



Real space

- Energy Production/Distribution Systems
- Electrical Appliances
- (Autonomous) Vehichles
- Machine tools
- Medical devices
- People
- Animals
- ….

Cyber-space

- Hardware
- Software
- Algorithms
- Data

Cyber-Physical System (CPS)

Lots of smart objects with embedded sensors and/or actuators …

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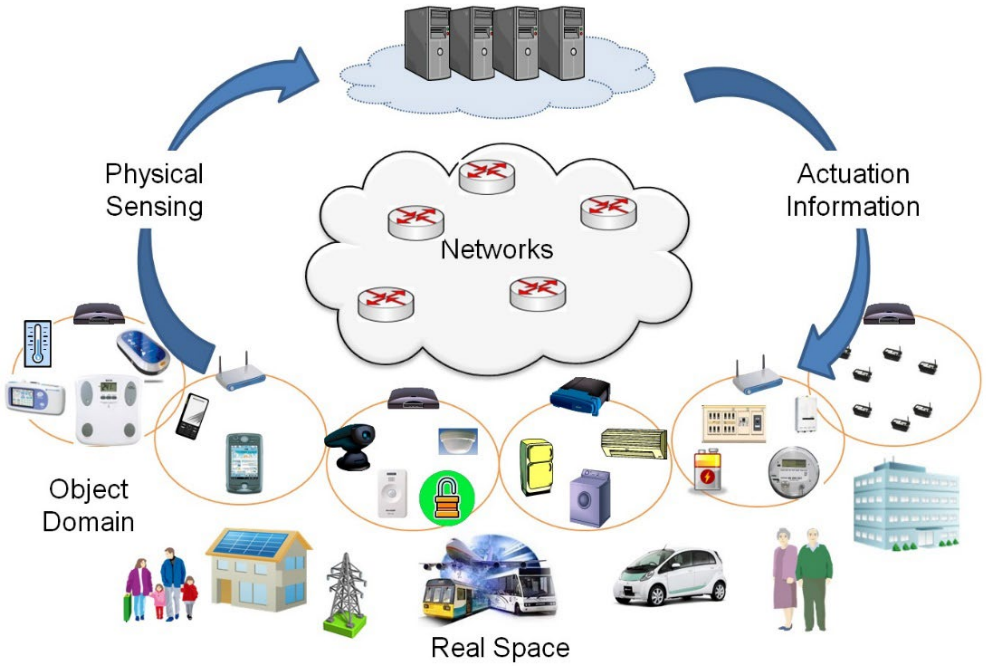


Data collection → Data Transportation → Data Storage → Data Processing → Actuation

Data Processing:
- *services*
- *intelligent decision making*

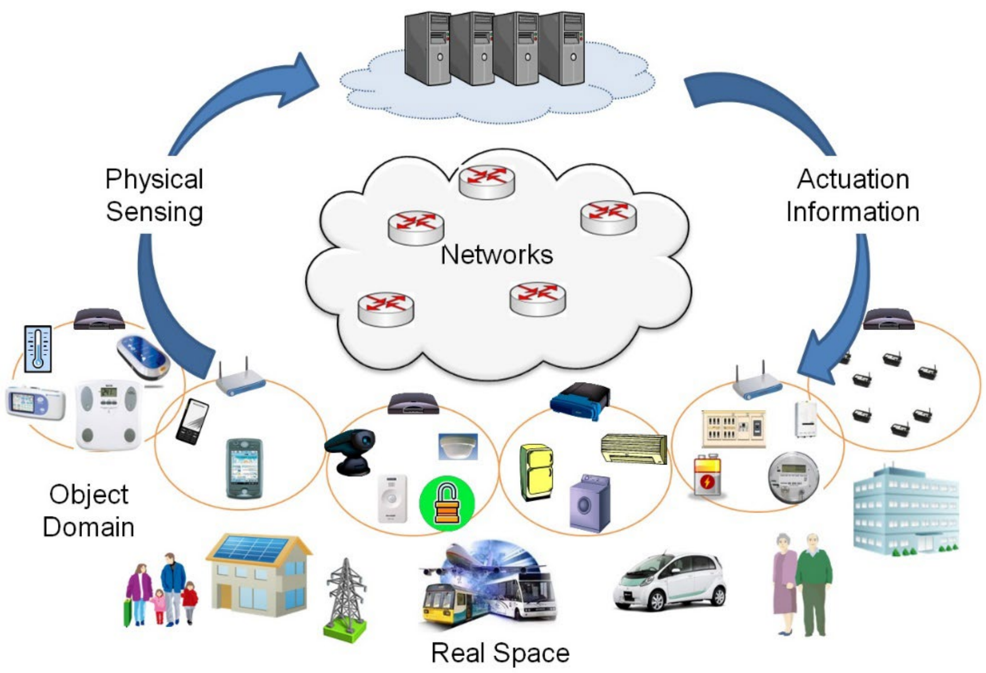
Actuation:
- actuators
- people

Cyber-Physical System (CPS)

Lots of smart objects with embedded sensors and/or actuators …

… pervasively deployed

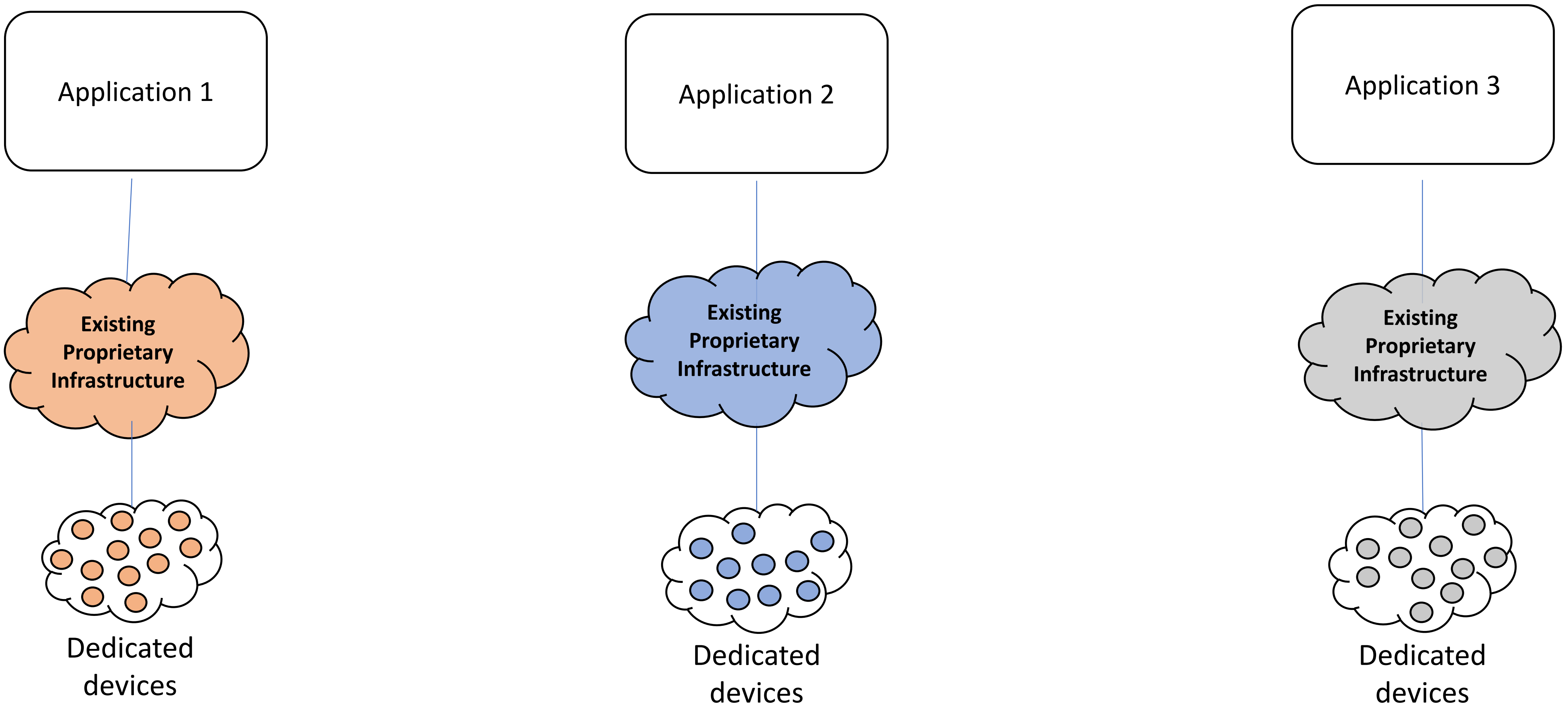
... and wirelessly connected



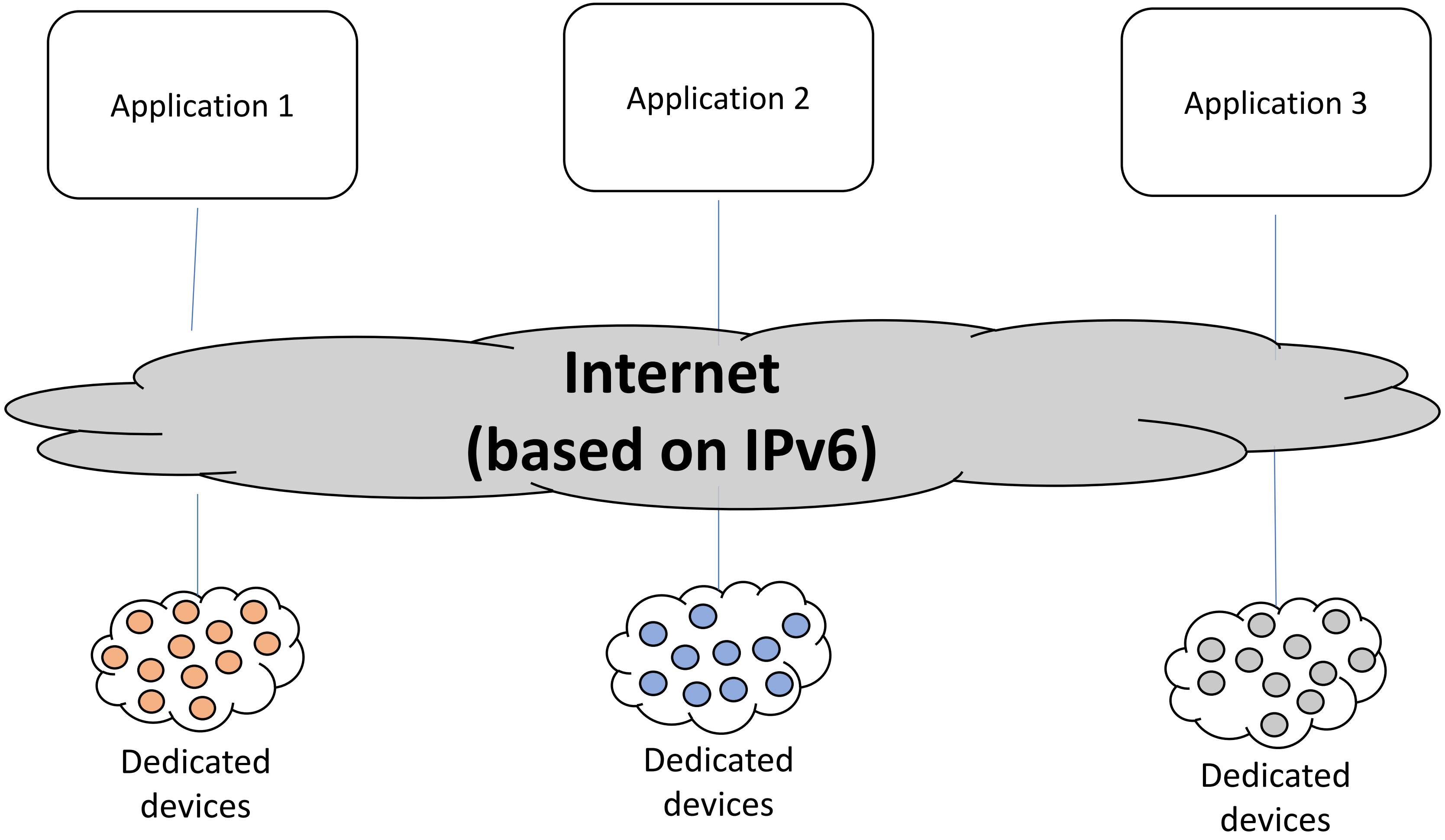
People in the loop as

- users
- sensors
- actuators

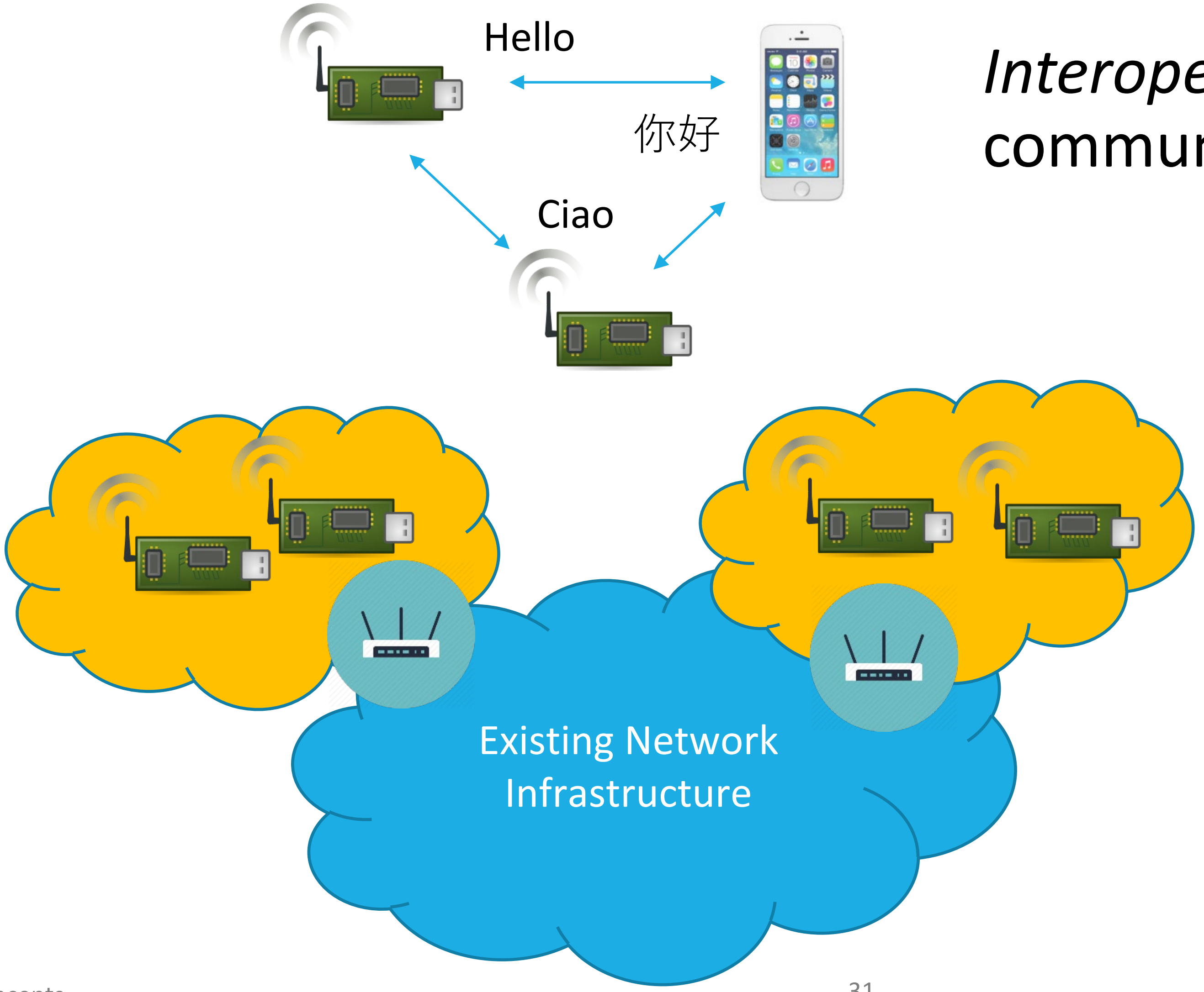
Current Solutions for IoT



Desired Solution for IoT



Communication Standards



Interoperable and *open* communication standards

Standardization Bodies

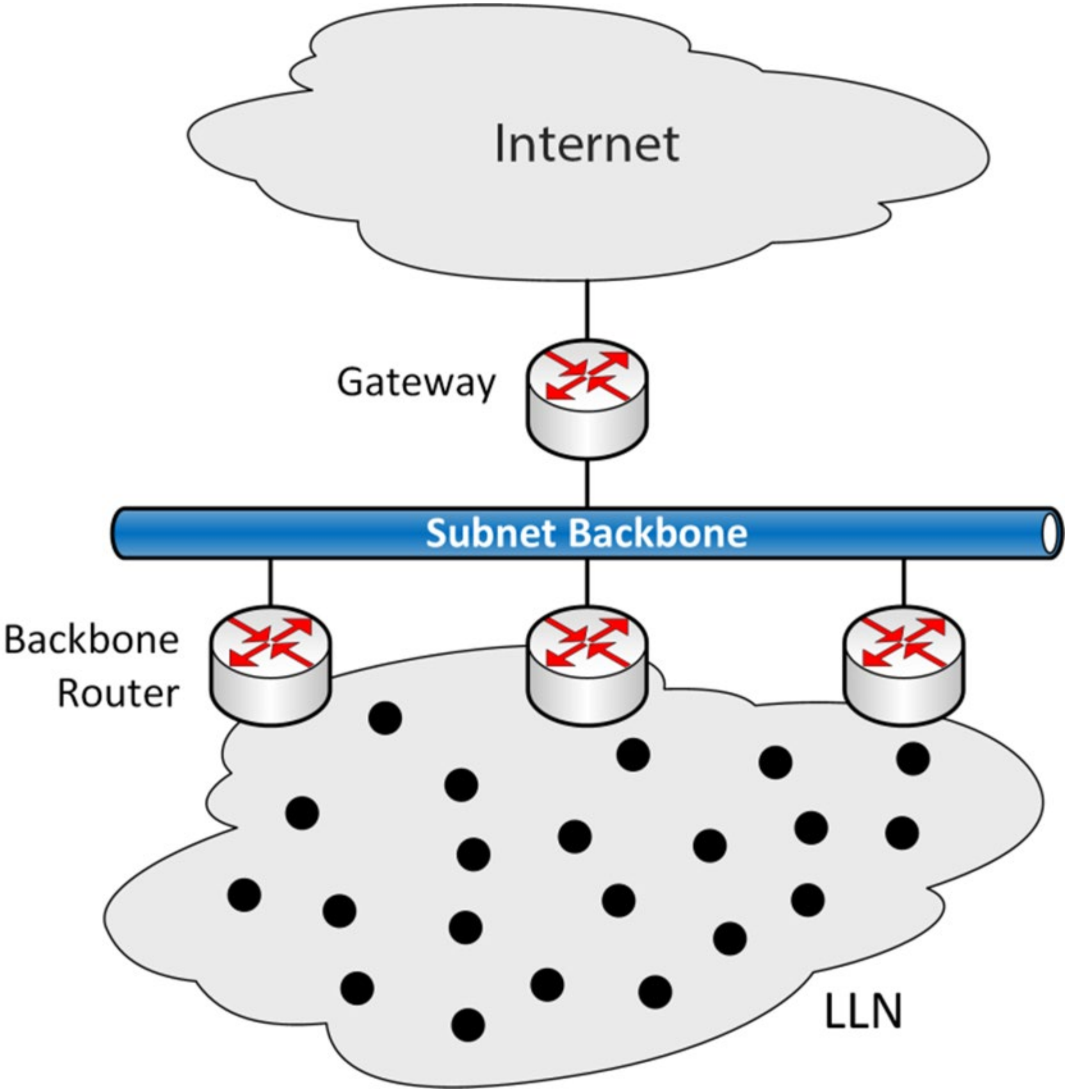
IP for Smart Objects

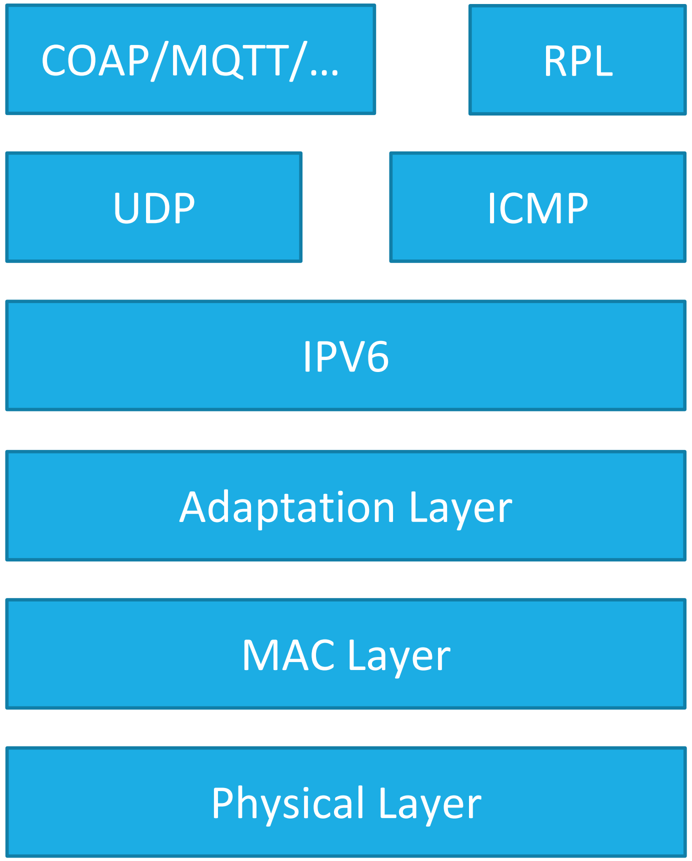
- Set of IPv6-based solutions defined (or under definition) by IETF
- Supported by the IPSO alliance

Machine-to-Machine (M2M)

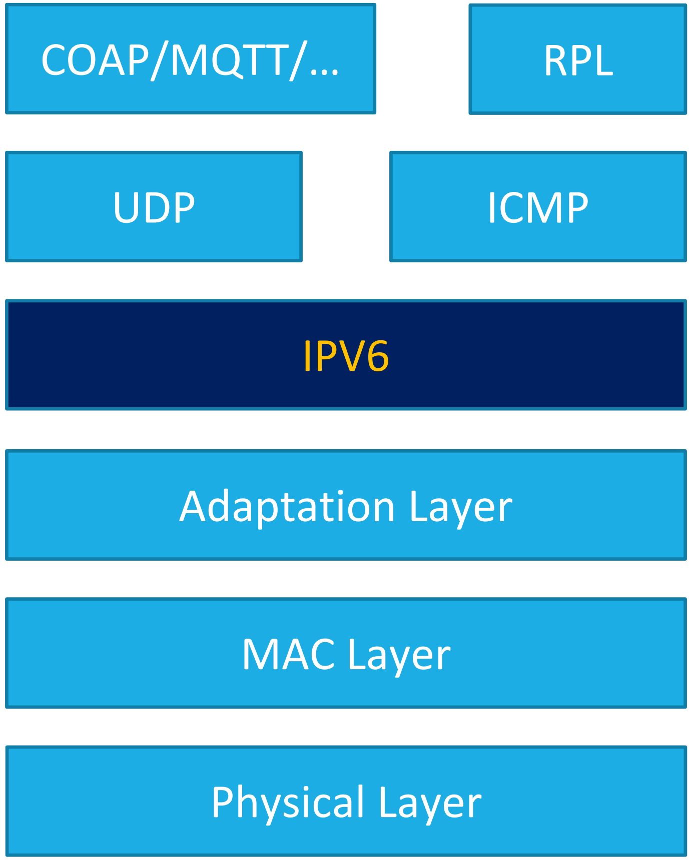
- Service architecture defined by the ETSI M2M Technical Committee

IETF Reference Architecture for IoT





IETF Protocol Stack for IoT



Protocol stack built around the IPv6 protocol

IPv6 is the common “language” in communication networks nowadays

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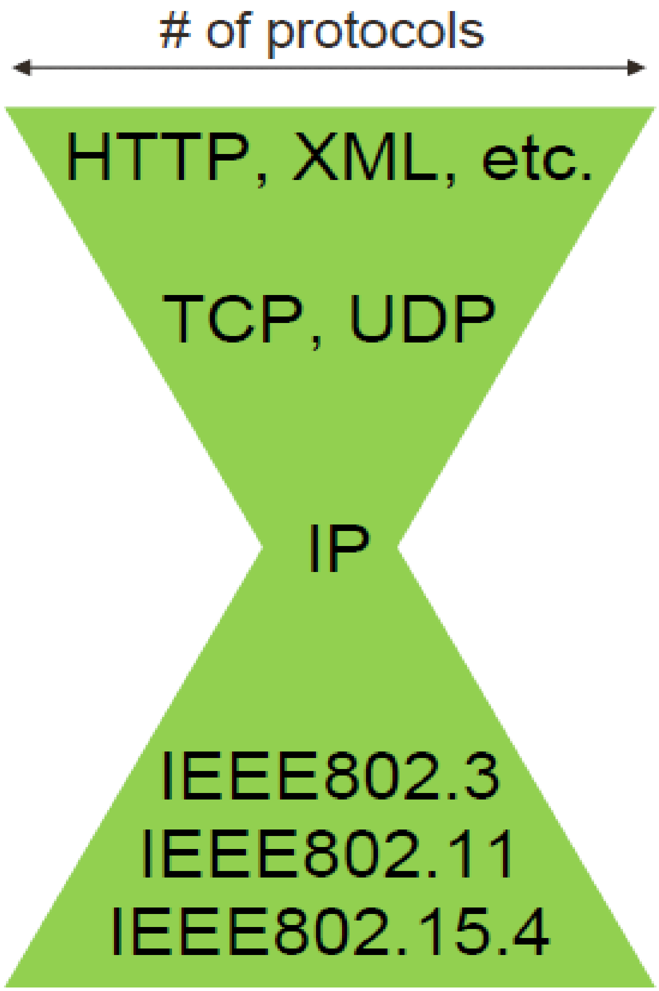
Why IPv6 for Smart Objects?

Interoperability
- Layered approach for independence of underlying technologies

Scalability
- Survived the current Internet evolution
- Unique (IPv6) addressing
- Direct support for self-configuration and management

End-to-end
- No multi-protocol intermediate gateways that:
  - Are expensive and difficult to manage
  - Lack of QoS end-to-end
  - Have security holes



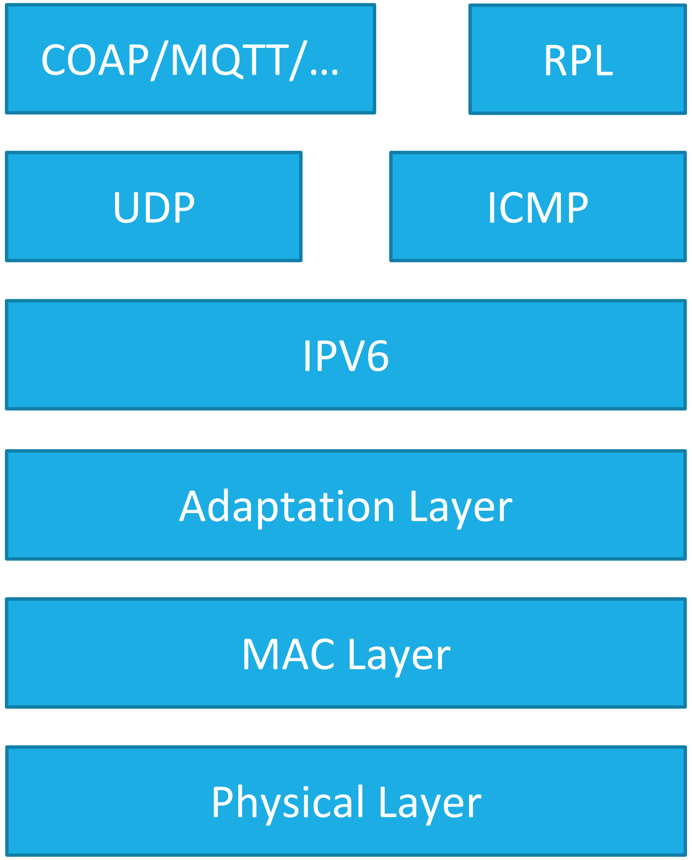
IoT vs. Cyber-Physical Sistems

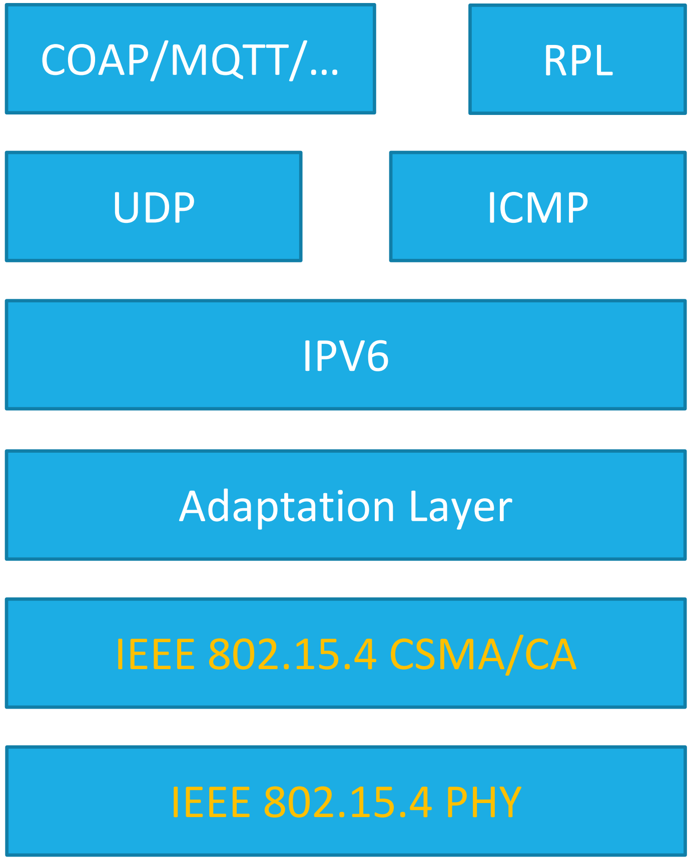
Cyber component + physical component

- The cyber component receives data from the physical world …
- … processes the received data
- … takes intelligent decisions and
- … communicates to actuators
- Smart object interact with the physical world

In IoT smart objects are connected to the Internet and communicate through IoT protocols

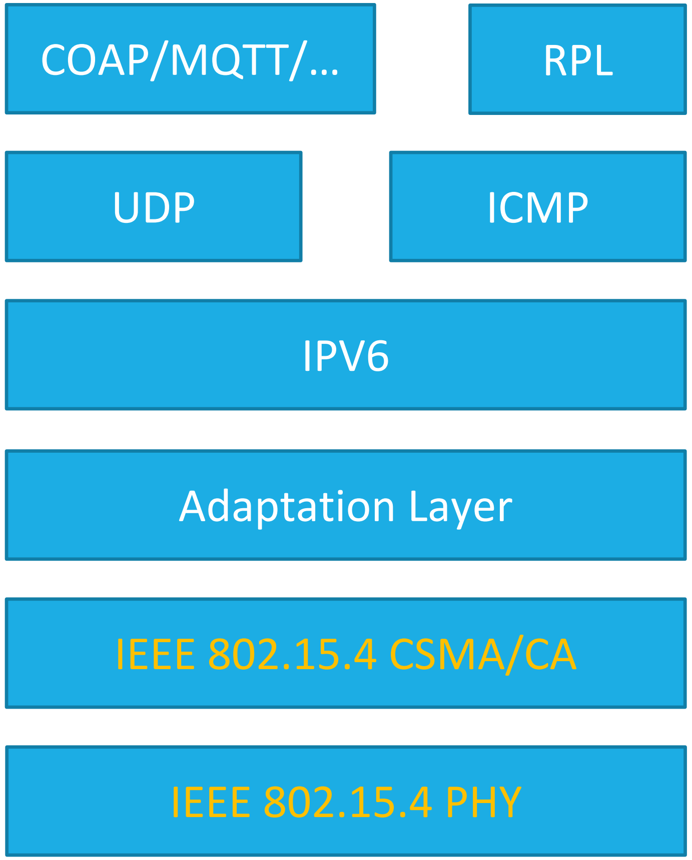
IoT Protocols defined by IETF





MAC protocol

- The IEEE802.15.4 standard has been designed for low-power communications
- CSMA/CA MAC protocol
- Small frames, up to 127 bytes!
- IPv6 assumes a minimum frame size of 1280 bytes

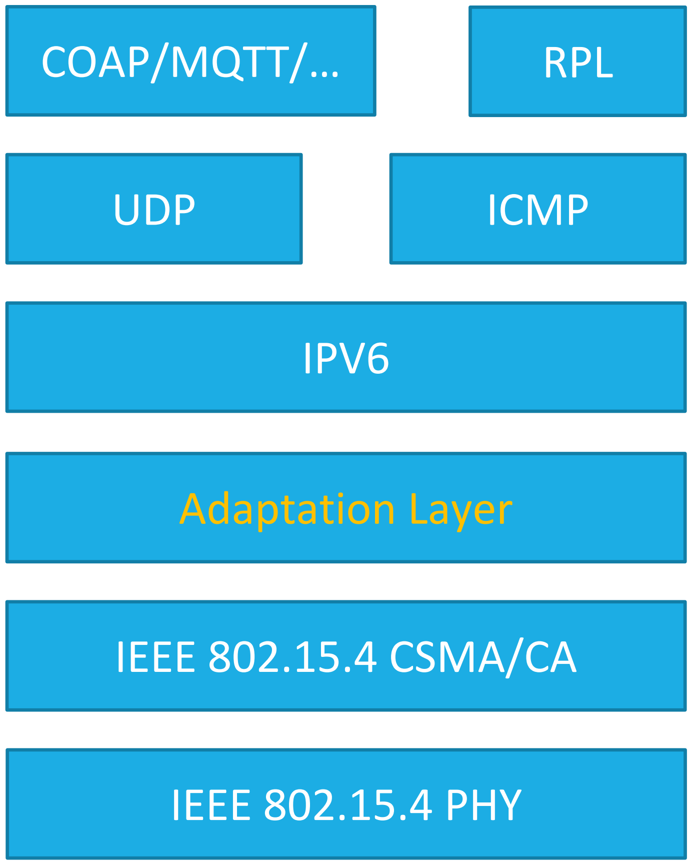


6LowPAN Adaptation Layer

Adaptation Layer allows the transmission of IPv6 datagrams on IEEE 802.15.4 frames

6LowPAN defines the operations to be performed to transmit IPv6 packets in such networks

- How compress/translate the header
- How fragmentation can be performed
- How discovery is performed



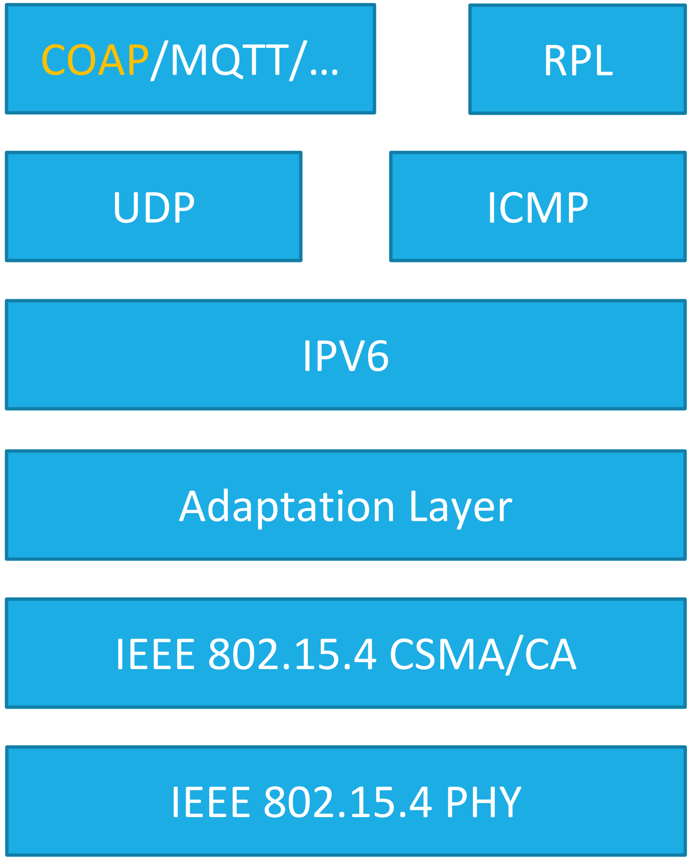
Application Layer Protocol

In principle smart objects could use HTTP as application-layer protocol

In practice, they do NOT have enough memory to implement such a complex protocol

The *Constrained Application Protocol* (CoAP) to fulfill their needs

Simplified version of HTTP with specific features for the IoT

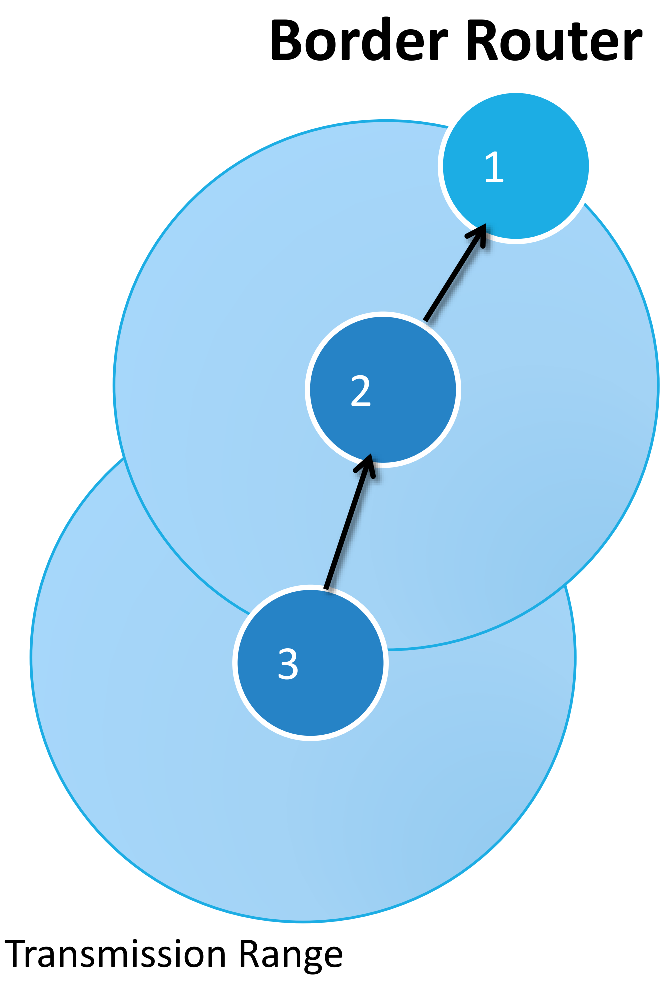


Routing Protocol

Wireless technologies for IoT devices are typically low-power

The transmission range of devices is limited

Multi-hop communication used to reach the destination when it is outside of the transmission range of the sending device



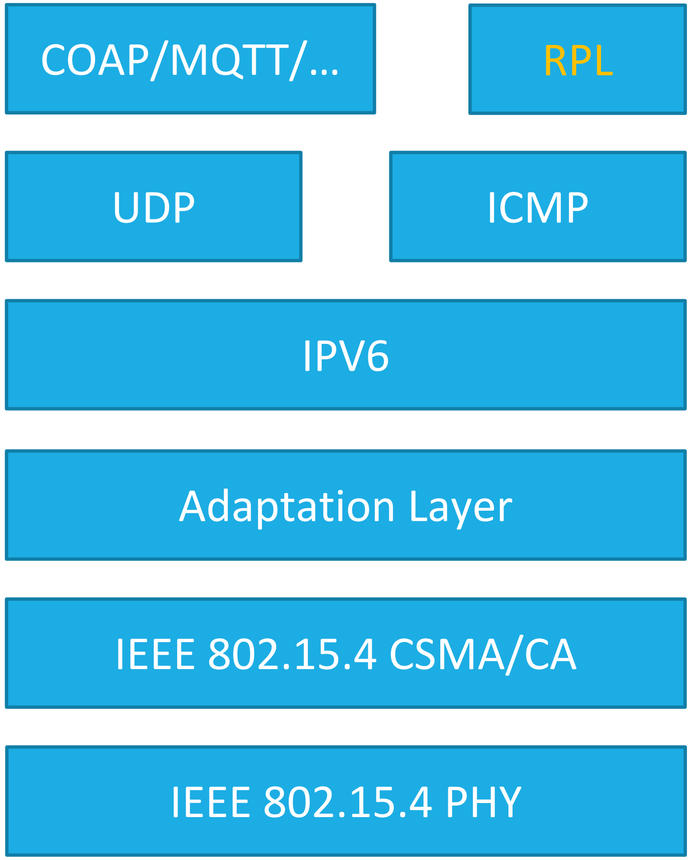
Routing Protocol

RPL: Routing Protocol for Low-power and Lossy Networks (LLN)

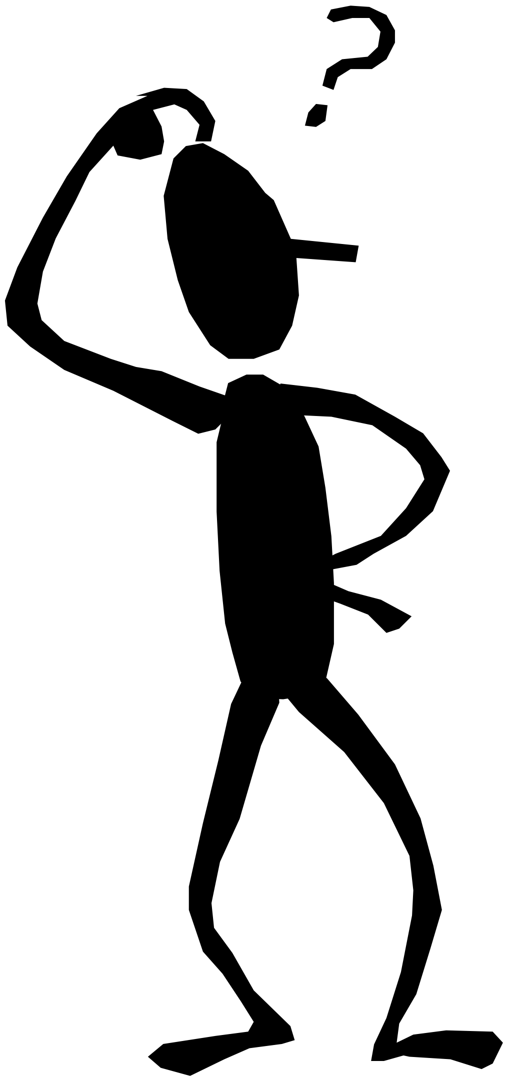
Collects information on the network topology

Computes the multi-hop routes

Populates the routing table of IoT nodes



Questions



Future IoT

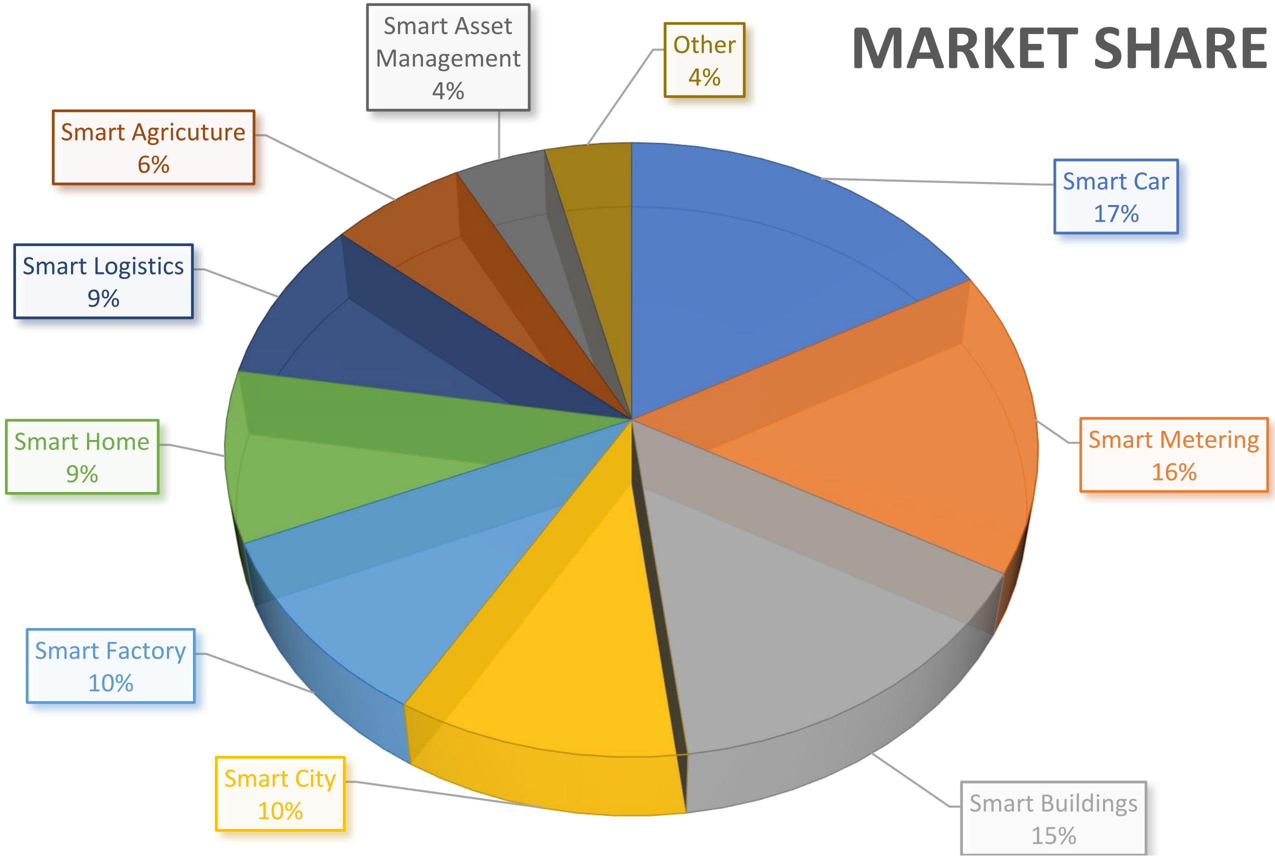
IoT is already a reality

IoT in Italy (2023)

140.000.000 connected devices

2.4 IoT devices per inhabitant

9 billions market (+ 9%, wrt 2022)



https://www.osservatori.net/it/ricerche/comunicati-stampa/internet-of-things-italia-mercato

Next Step: Pervasive IoT

Extremely large number of connected devices

- 1 billion of connected devices
- Up to 100 millions of IoT device per Km^2

Diversity of connected devices

- From wearable devices to UAV
- Constrained vs. Unconstrained
- Static vs. Mobile

Heterogeneus communication technologies

- Wired (Ethernet, PLC, ...)
- Wireless (5G/6G, WiFi, LoRa, TSCH, BLE, UWB, ...)

Beyond the Edge

- Functionalities embedded into users and IoT devices (beyond the edge)
- Integration of sensing, computing, and communication functionalities
- AI along the Cloud-to-Things Continuum (C2TC)

Cloud-to-Things Continuum (C2TC)

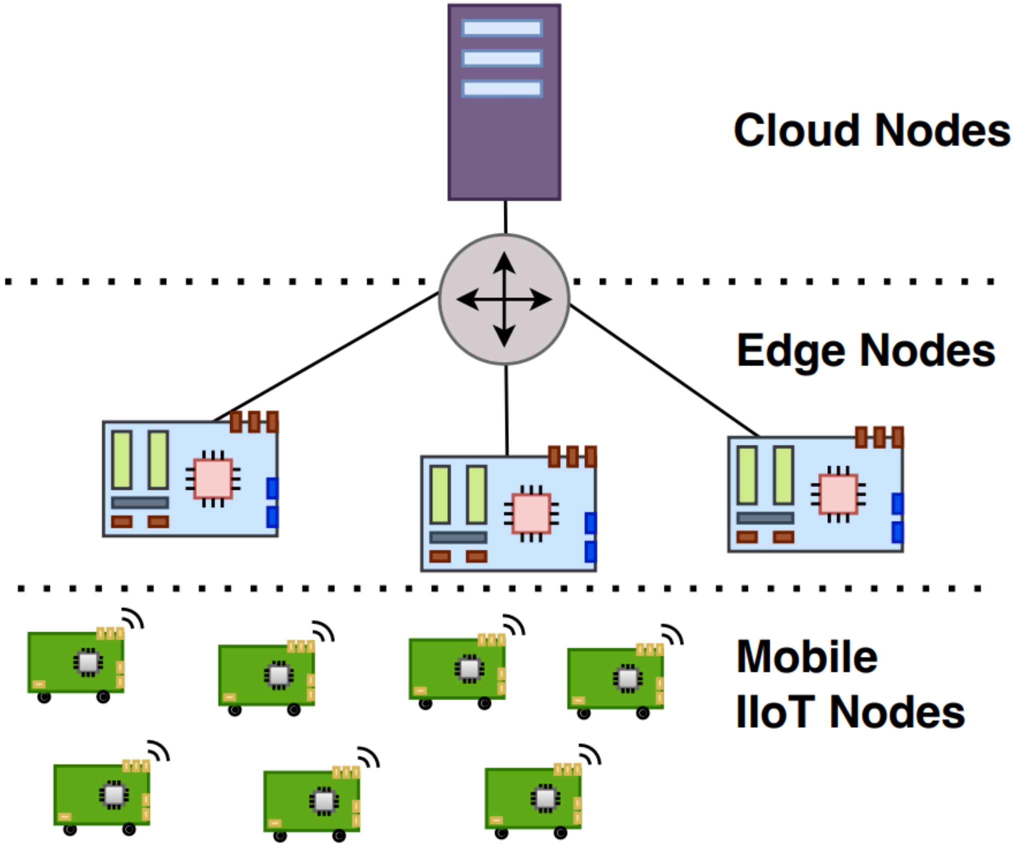
Cloud computing support for computationally intensive tasks

Edge computing support for

- Delay-sensitive tasks
- Privacy
- Security
- Reduced data transfer

AIoT: Artificial Intelligence of Things

- AI along the C2TC
- Beyond the edge



Heterogeneity

Heterogeneous Applications

- Different QoS requirements
- Different Traffic Patterns

Heterogeneous computing resources

- IoT devices
- Edge/Fog nodes
- Cloud

Heterogeneous network technologies

- Ethernet, PLC, …
- 5G/B5G, WiFi, 6TiSCH, LoRA, …

Heterogeneous IoT devices

- Constrained/Unconstrained Devices
- Static/Mobile Nodes

Challenges

Sustainability

- Energy consumption
- Device management and disposal

AI of Things (AIoT)

- AI distributed along the C2TC

QoS Support

- Delay, Reliability, Security, …
- Mobility
- Reconfigurability

Novel solutions required

Novel solutions for sustainability

- Batteryless IoT and intermittent computing
- Energy efficiency in the *Cloud-to-Things Continuum*

Novel computing and communication paradigms

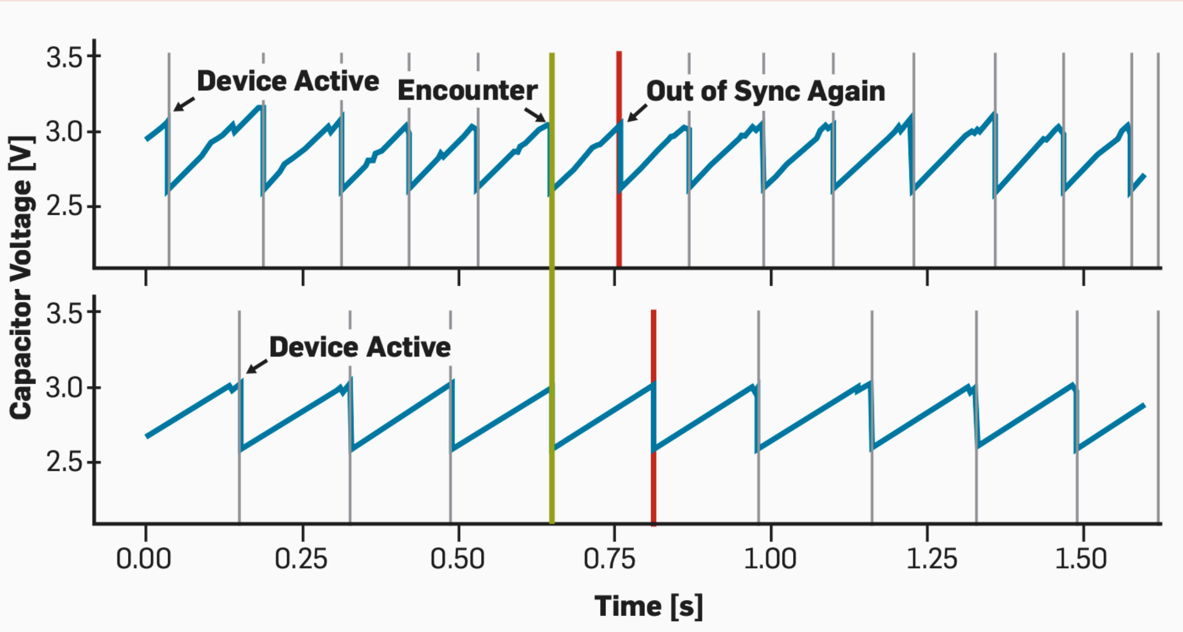
- Ensure the required QoS in the presence of
  - resource heterogeneity
  - node mobility
  - system reconfigurations

Novel solutions for Sustainability

Batteryless IoT

Reduction in environmental impact by eliminating the need for batteries, which are difficult to dispose and harmful to the environment

- **Energy Harvesting**
  - New technologies to collect energy from sources like sunlight, heat, vibrations, or radio waves
- **Prediction of available energy**
  - In spatial and temporal dimensions
- **Network of batteryless IoT device**
  - Single batteryless IoT device already used
  - Coordination of a network of batteryless devices not trivial
- **Intermittent computing**



Novel solutions for Sustainability

Energy efficiency in the C2TC

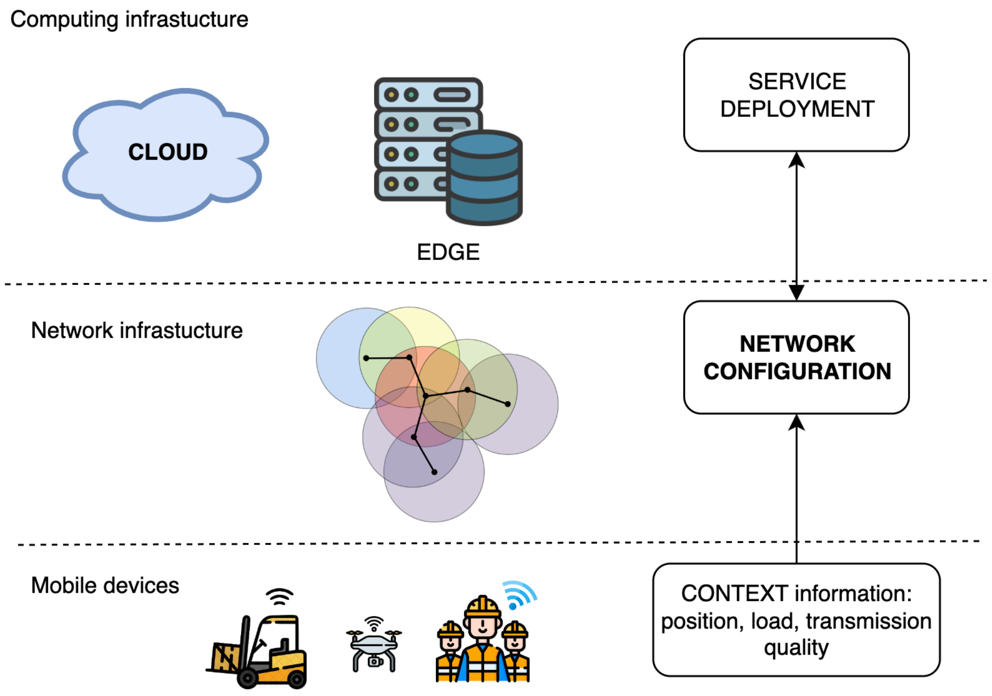
- **Energy-Aware Task Offloading**
  - Definition of algorithms to dynamically decide where process tasks (cloud, edge, or device) based on energy consumption and latency requirements
  - Definition of algorithms that consolidate the load in the minimum number of nodes to reduce the energy consumption still satisfying latency requirements

- **Energy-Aware Resource Allocation**
  - Definition of resource allocation algorithms that prioritize energy efficiency, such as scaling down resource usage during low-demand periods

Novel Computing/Communication Paradigms

(Real-time) IoT deployments based on the C2TC paradigm

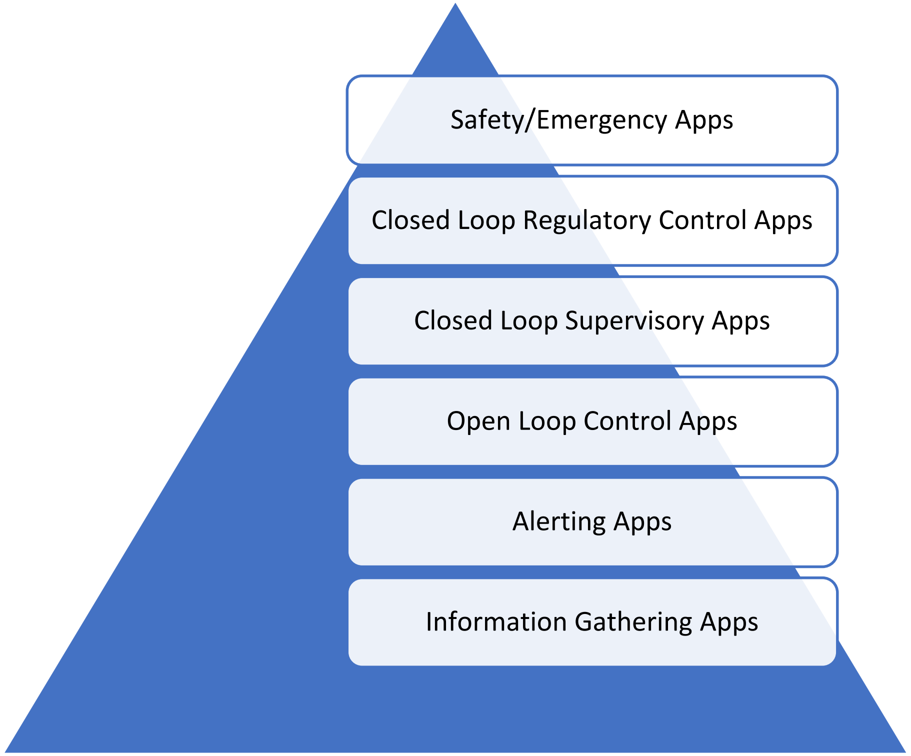
- Heterogeneous computing resources
  - Cloud, Fog, Edge, IoT nodes
- Heterogeneous network technologies
  - Ethernet, PLC, …
  - 5G/B5G, WiFi, LoRA, TSCH, …
  - LiFi
- Heterogeneous IoT devices
  - Constrained, Unconstrained Devices
  - Static, Mobile Nodes



QoS provisioning in C2TC

- **Stringent QoS requirements**
  - Maximum delay
  - Minimum reliability
  - Security
  - Energy Efficiency
- **Node Mobility**
  - Linear
  - Random
  - …
- **System Reconfigurability**
  - New applications
  - Variable QoS requirements
  - New (Mobile) Nodes

Classification of Industrial Applications



M. Raza *et al.*, "A Critical Analysis of Research Potential, Challenges, and Future Directives in Industrial Wireless Sensor Networks", *IEEE Commun. Surveys & Tutorials*, vol. 20, no. 1, 2018, pp. 39–95

Question

How to allocate computing and network resources in the C2TC continuum to minimize energy consuption, while satisfying the QoS requirements?

- Maximum Delay
- Minimum Reliability
- System reconfiguration

On-going Projects

C^2ASPER

Computing, **C**ommunication, **A**nd **S**ensing in the **Per**vasive IoT Era

Developing foundations and concrete technological enablers for the future pervasive and sustainable Preliminary Concepts

PNRR PESCO Cascade Call

UniPI, UniCampania, UniTN, UniME, SmartME

CAVIA

Cloud-to-**A**utonomous-**V**ehicles continuum for future **I**ndustrial **A**pplications

Resource allocation, algorithms for service composition, for efficient orchestration of AVs management services, considering QoS requirements and reconfiguration

PRIN 2022

UniPI, UniMi, UnivAQ

JOULE

JOint ResoU**r**ce Management in Reconfigurab**LE** I4.0 Factories

Optimal resource allocation and dynamic orchestration in the C2TC to support time-critical industrial applications deployment, enabling reconfigurability

PRIN 2022

UniBO, UniME, UniPI