5th IEEE Internet of Things (IoT)
Vertical and Topical Summit at RWW2022

Sustainable Sensor Systems for IoT

10-15 January // Las Vegas, NV, USA

IoT and Digitalization as Key Technological Enablers for Achieving the UN Sustainable Development Goals

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Researcher, Instituto de Telecomunicações, Aveiro, Portugal
IEEE Senior Member, Portuguese Section

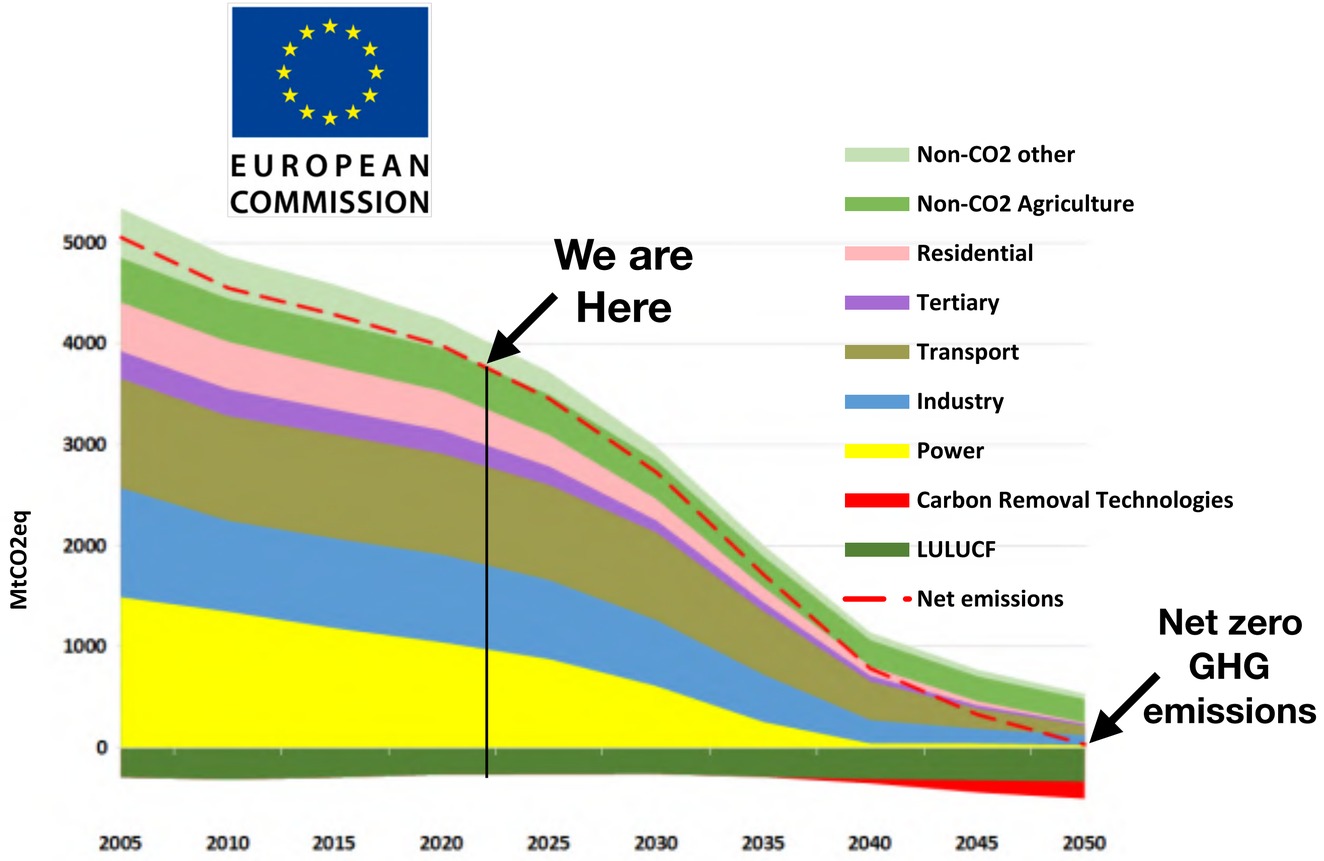
Organization:

Agenda

- A clean planet by 2050
- Sustainable Development in a Nutshell
- SDGs and IoT: Key Technological Enablers
- Designing (some) IoT-driven applications:
  - RnMonitor: IoT-Based Indoor Radon Gas Management
  - CoViS: IoT-Based Contactless Health Monitoring
  - IPVC S2S: Towards a Smart & Sustainable Campus
    - Refill_H20: Plastic Consumption Reduction on Campus;
    - BIRA: Bicycle Real-Time Tracking on Campus;
    - CrowdMonitor: Crowd Quantification with Flow Direction Estimation
- Final Remarks

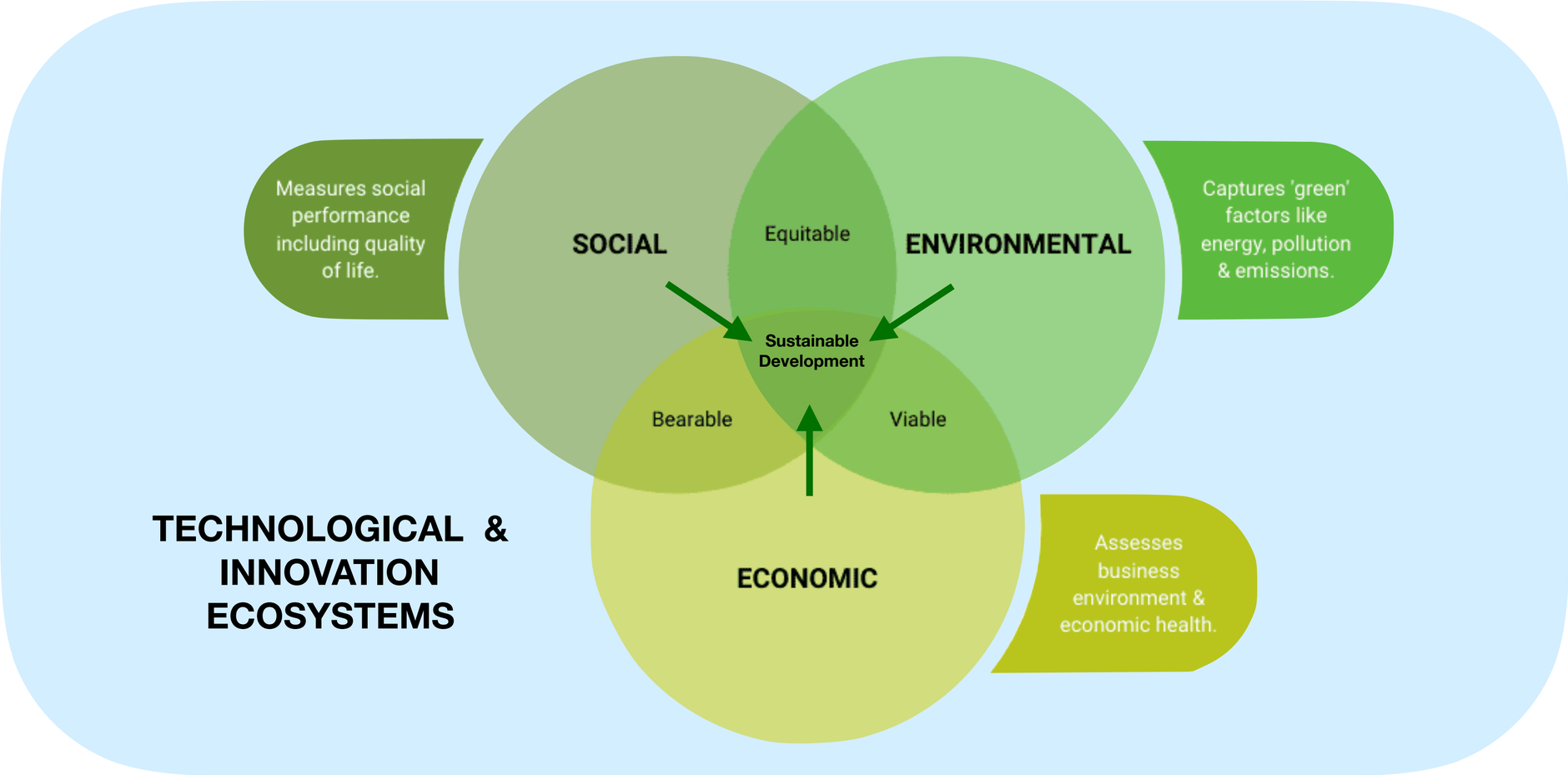
EU Vision for a clean planet by 2050

- **EU long-term strategy**: become climate-neutral by 2050 (net zero GHG emissions);
- **Radical transformations needed:** clean energy, efficient buildings, sustainable transportation, circular economy…
- There are four challenging perspectives: **technological**, **economical**, **environmental** and **social**.

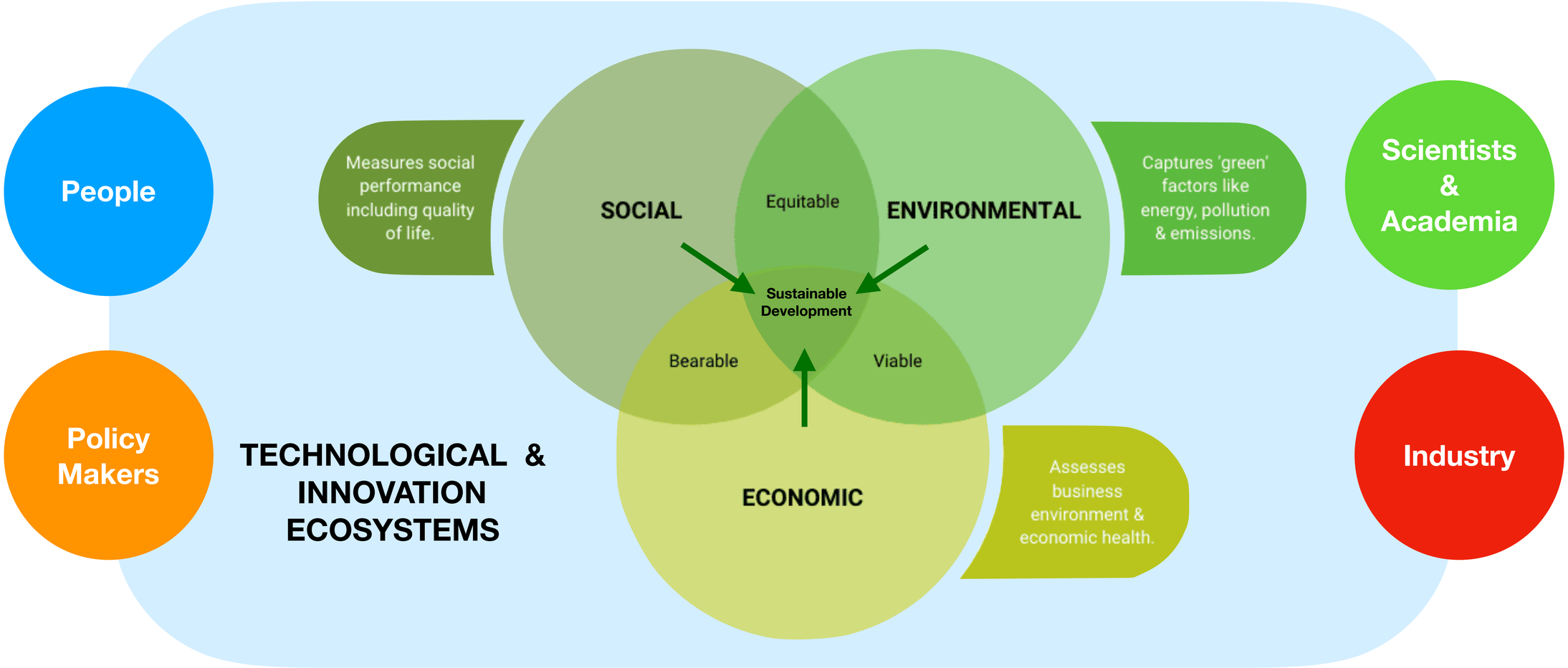


Source: World Economic Forum, "The EU wants to be carbon neutral by 2050", 2018, url: https://www.weforum.org/agenda/2018/12/european-union-aims-to-be-first-carbon-neutral-major-economy-by-2050

Sustainable Development in a nutshell



Sustainable Development in a nutshell



SDGs and IoT

WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

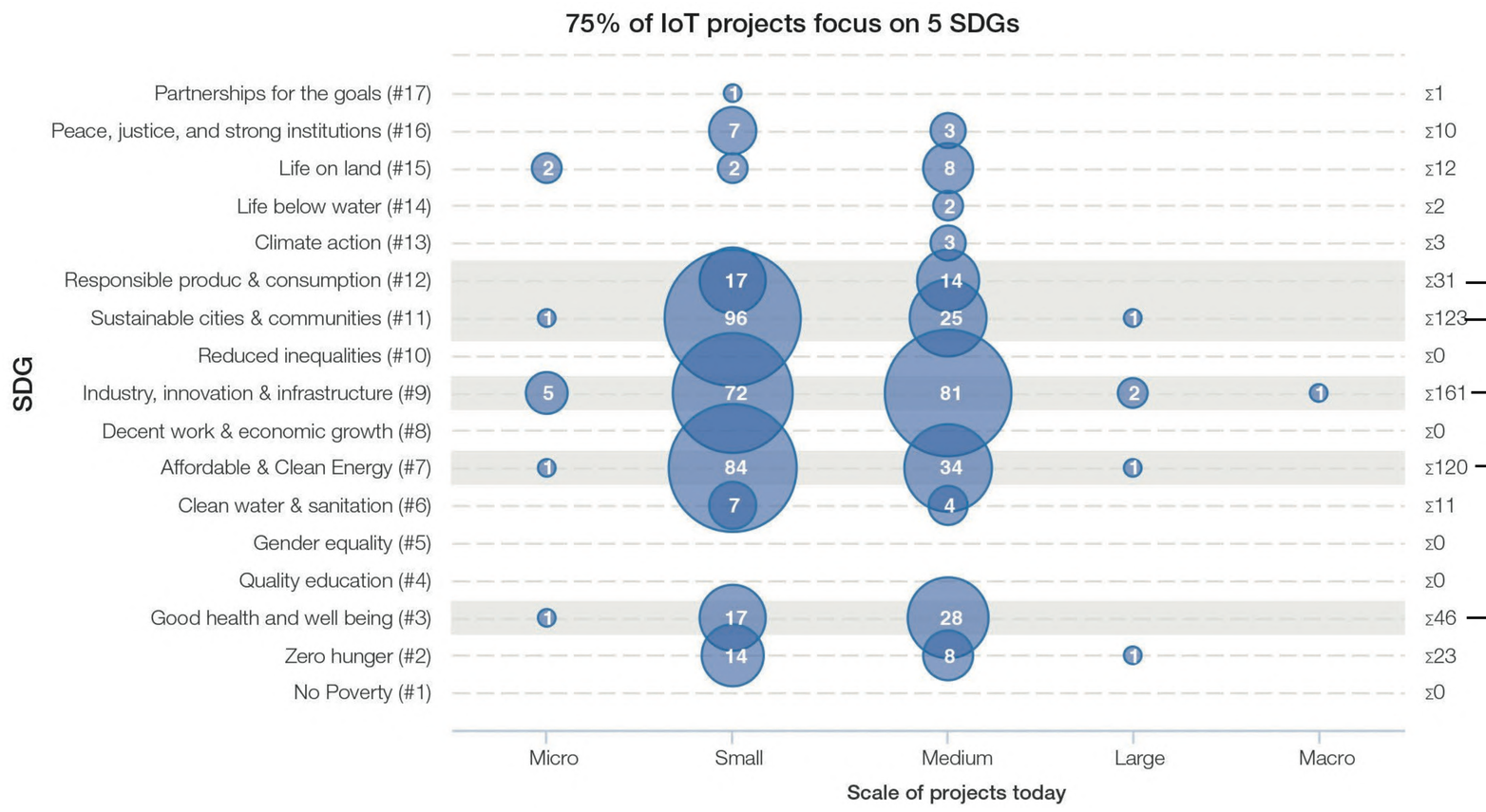
Future of Digital Economy and Society System Initiative

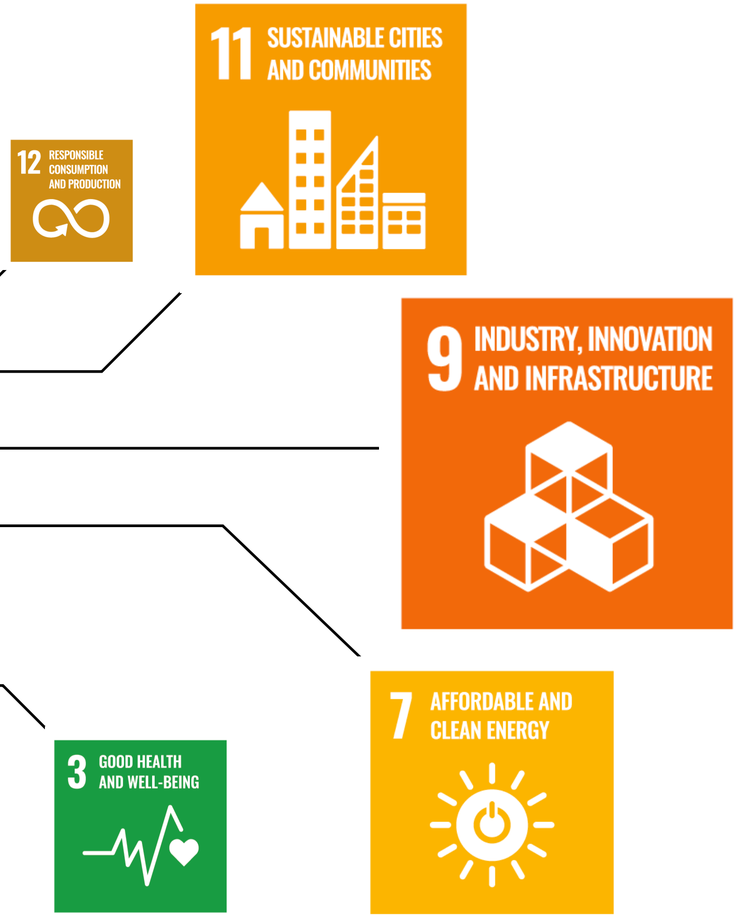
Internet of Things
Guidelines for Sustainability

*"The objective of these guidelines is to encourage the **prioritization of sustainability goals** as part of the **design of commercial projects** to **maximize social impact** while still **delivering, and potentially also increasing, commercial value**."*

January 2018

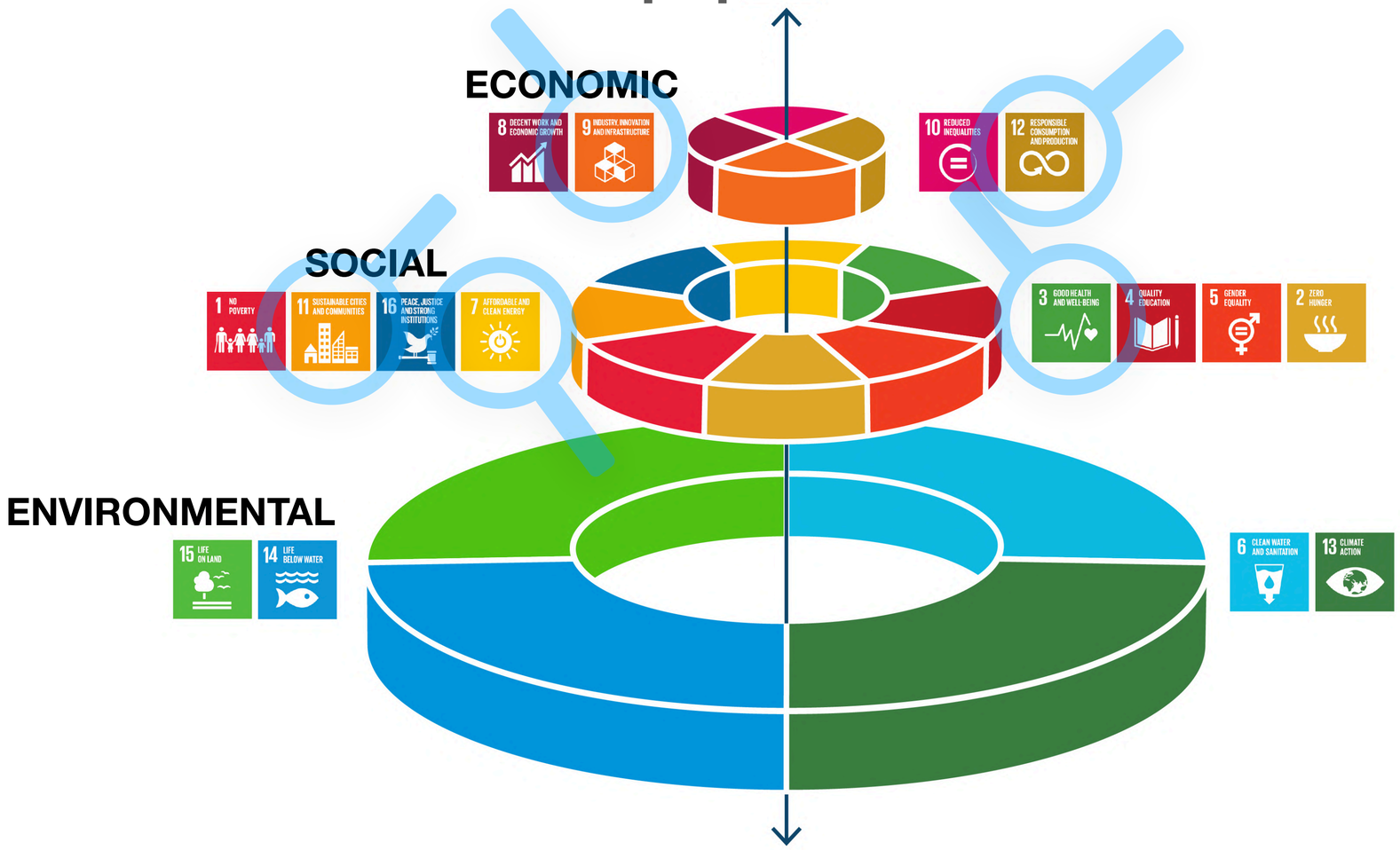
Common IoT Applications for SDGs





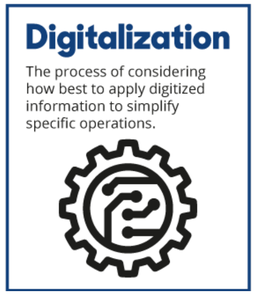
Source: World Economic Forum Annual Meeting, "The effect of the Internet of Things on sustainability", 2018
https://www.weforum.org/agenda/2018/01/effect-technology-sustainability-sdgs-internet-things-iot/

Common IoT Applications for SDGs



Key Technological Enablers

DIGIT… & IoT

			
Operational Focus	**Transformation of Data**	**Processing of Data**	**Taking Advantage of Information**
Goal	**Convert Processes from Analog to Digital**	**Automate Business Processes**	**Change the way organizations operate and think**
Activity	**Digitizing physical resources like paper documents, photos and videos**	**Creating a fully digital workflow process**	**Creating a new digital organization Holistic process of change**
Tools	**Internet of Things** Edge Computing and other technologies for converting	**Internet of Things** Fog/Cloud Computing AI, ML, DLTs IT systems and Applications	Digital Twins New Digital Technologies
Challenge	**Material**	**Financial**	**Human Resources**

Key Technological Enablers

DIGIT… & IoT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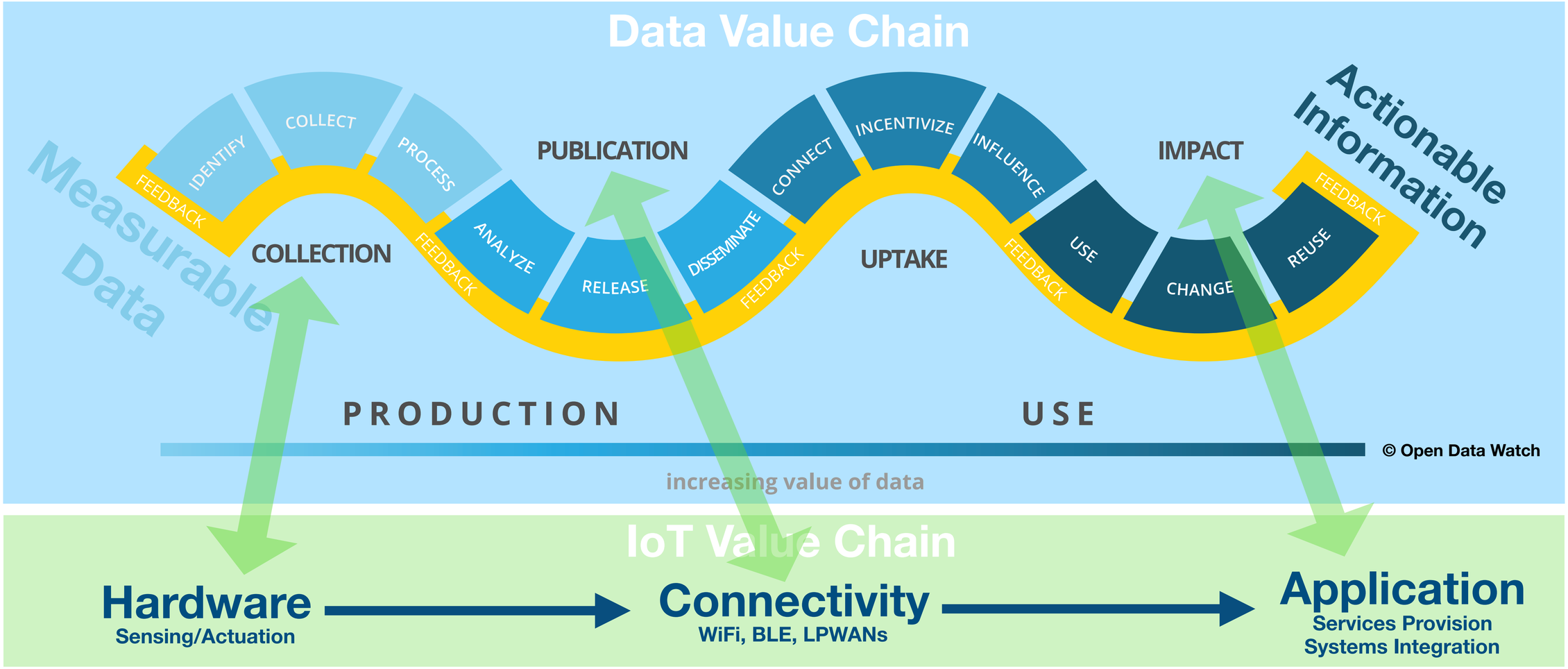
	Technological Enablers		

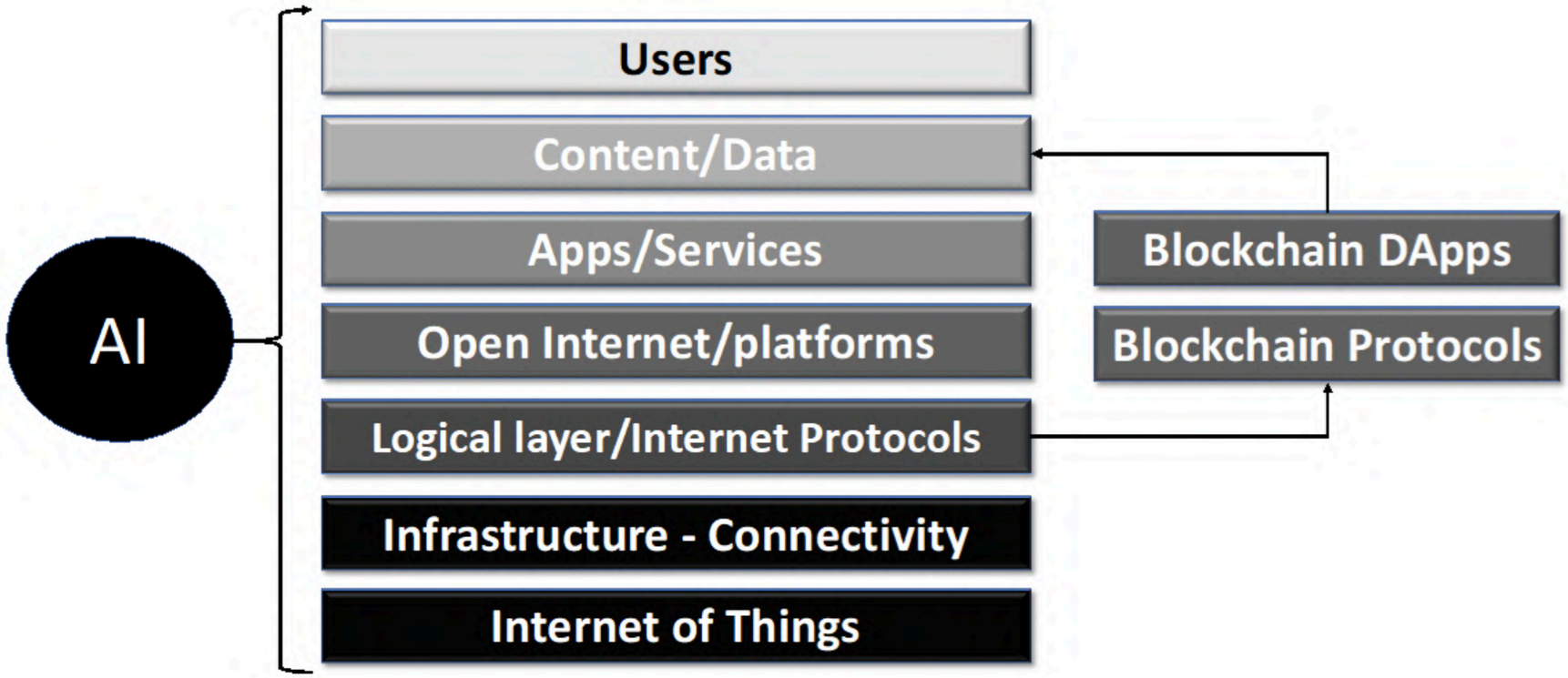
Key Technological Enablers

Data Value Chain & IoT



Key Technological Enablers

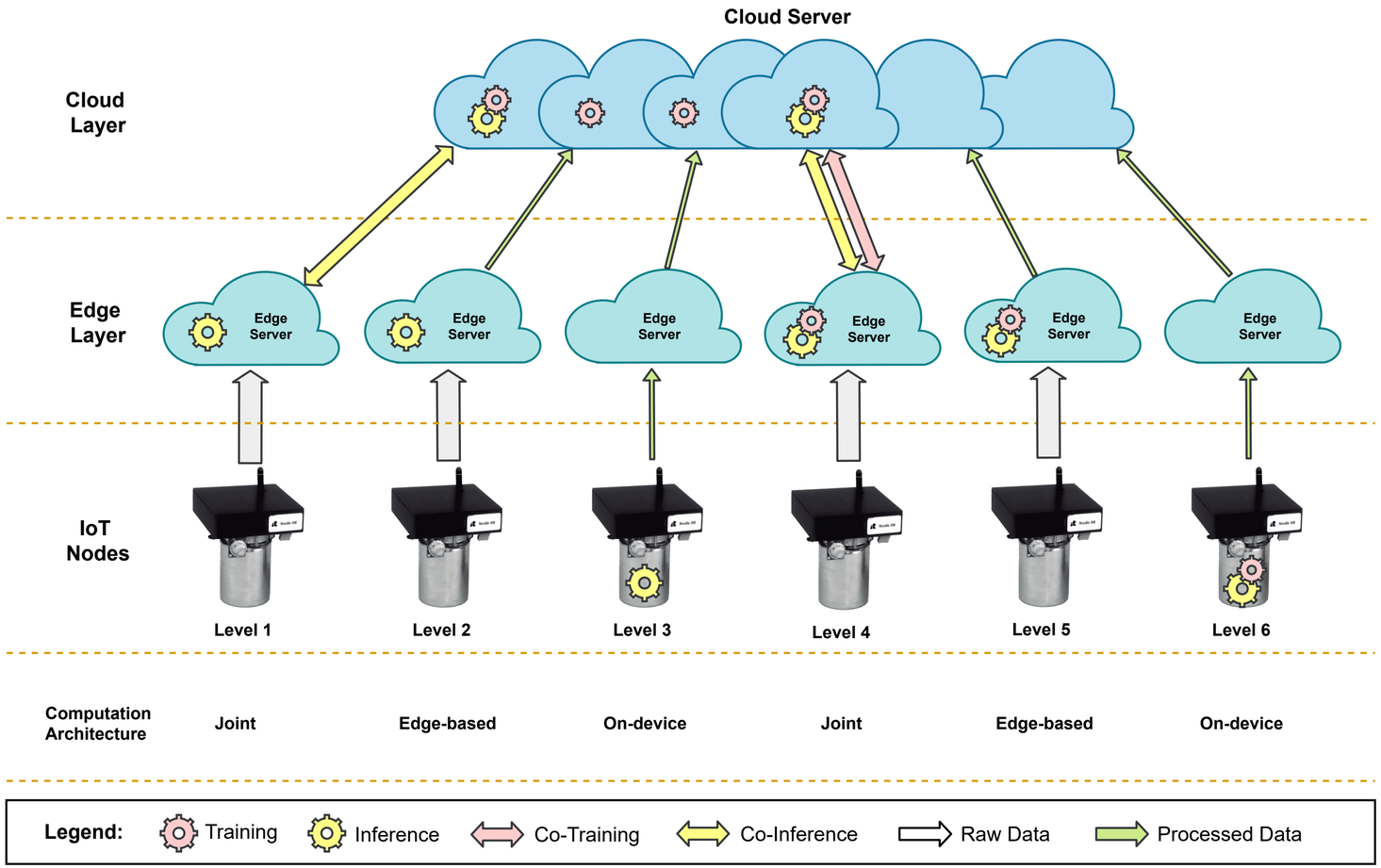
The New Digital Stack



Source: Andrea Renda and Moritz Laurer, "IOT 4 SDGS - WHAT CAN THE DIGITAL TRANSFORMATION AND IOT ACHIEVE FOR AGENDA 2030?", CEPS, MARCH 2020.

Key Technological Enablers

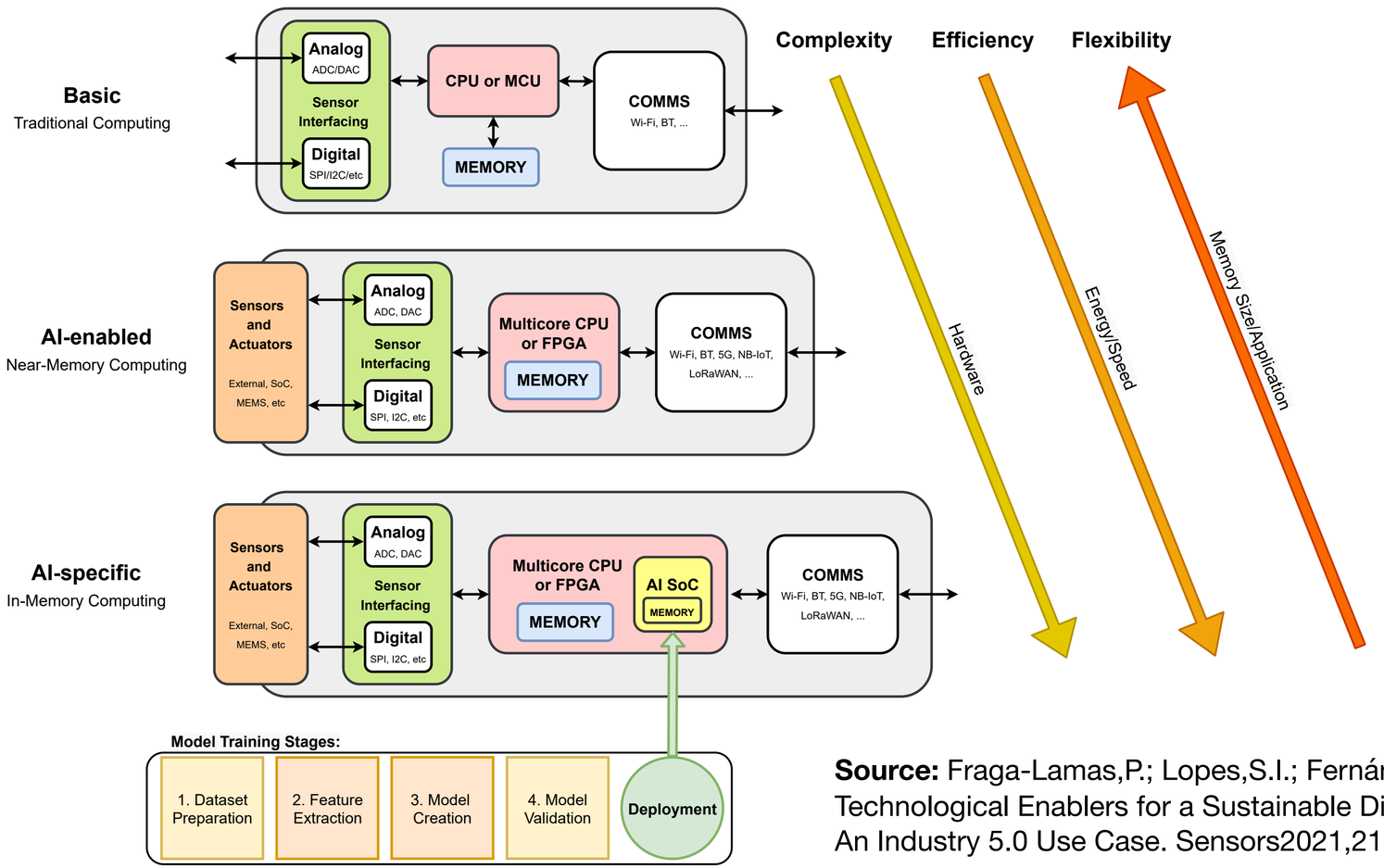
IoT & AI Convergence



Source: Fraga-Lamas,P.; Lopes,S.I.; Fernández-Caramés, T.M., Green IoT and Edge AI as Key Technological Enablers for a Sustainable Digital Transition towards a Smart Circular Economy: An Industry 5.0 Use Case. Sensors2021,21,5745. https:// doi.org/10.3390/s21175745

Key Technological Enablers

AIoT Device Architectures



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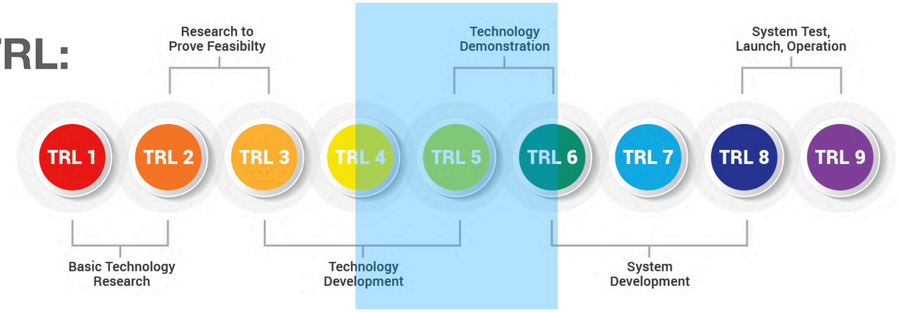
Designing IoT-Driven Applications

Designing IoT-driven applications

Indoor Air Quality Management

SDGs:

TRL:



RnMonitor

- **Funding:** POCI-01-0145-FEDER-023997

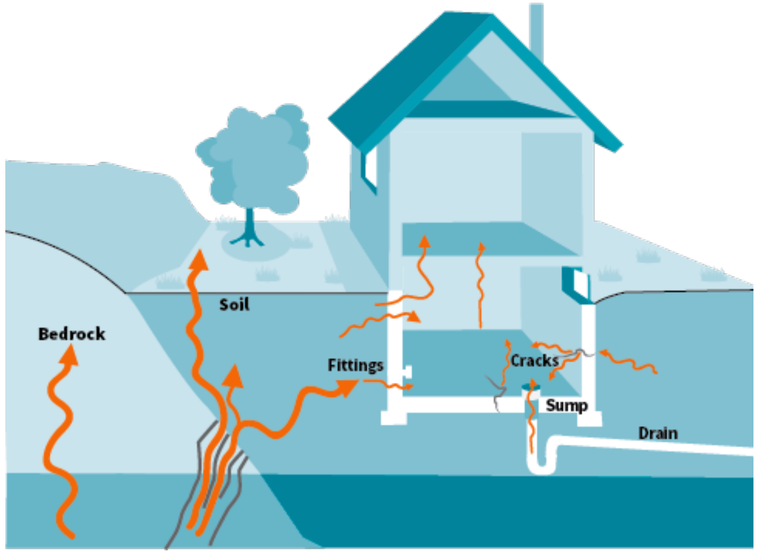
Cofinanciado por:

COMPETE 2020 — PROGRAMA OPERACIONAL COMPETITIVIDADE E INTERNACIONALIZAÇÃO
PORTUGAL 2020
UNIÃO EUROPEIA — Fundo de Coesão

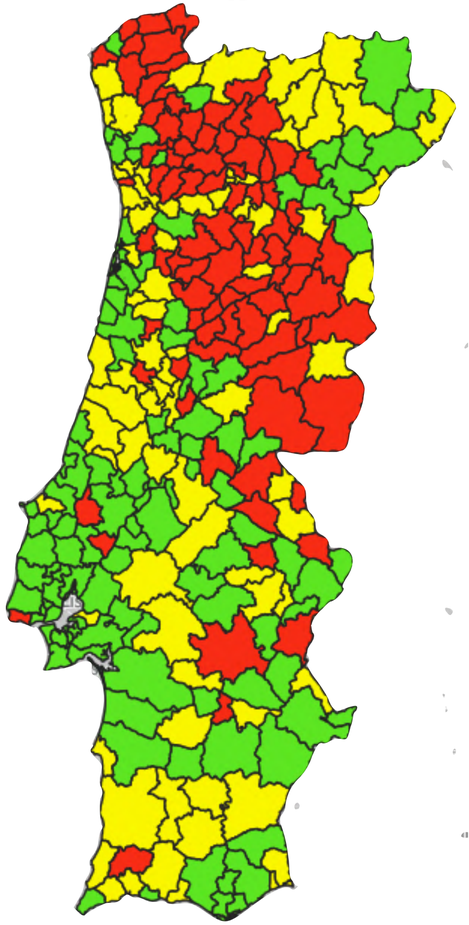
- **Website:** http://rnmonitor.ipvc.pt
- **Goals:**
  - Design a low-cost IoT-based Radon Gas Probe;
  - Design and develop a Cloud-based WebSIG platform for online radon monitoring and management.

What is Radon

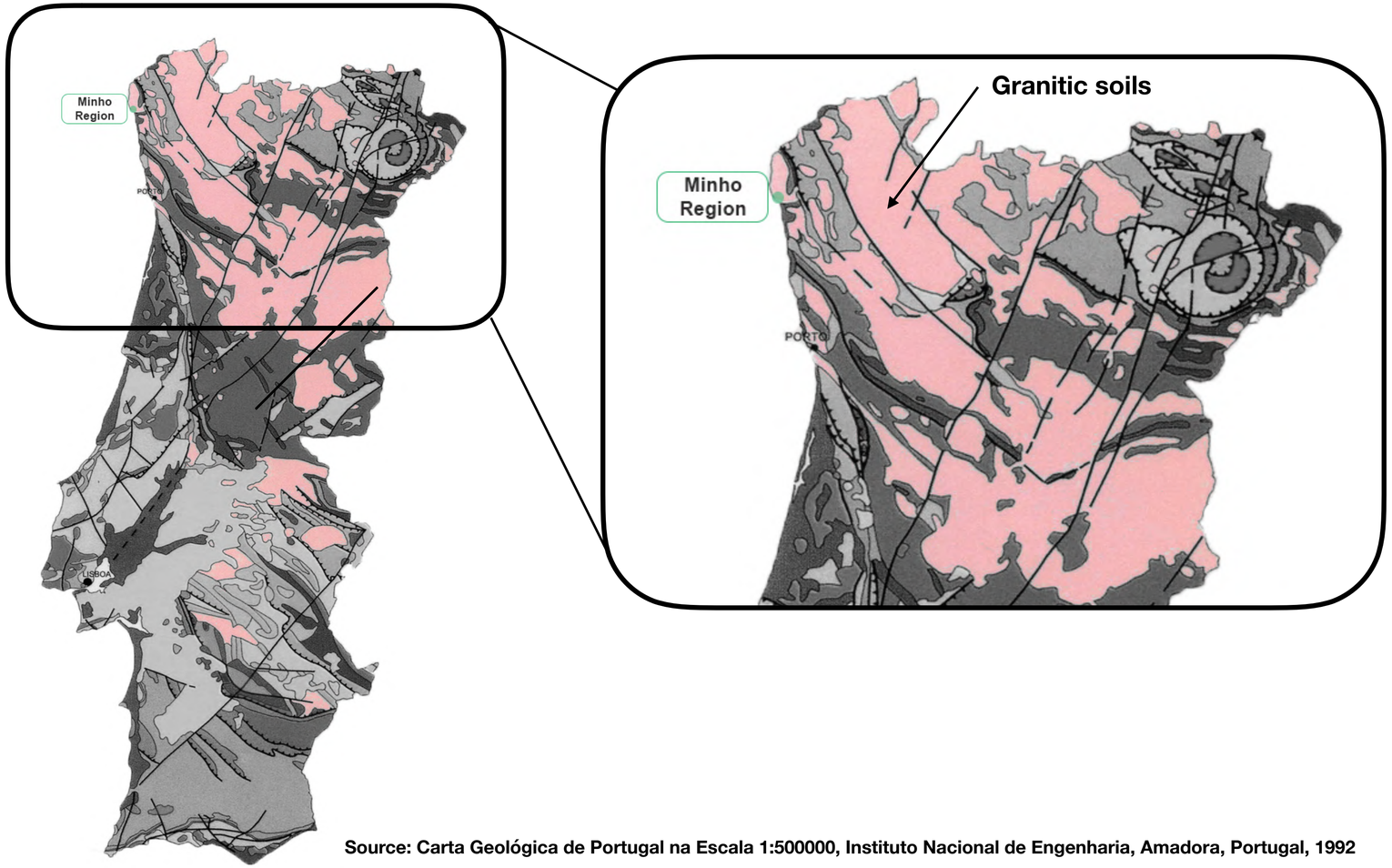
- Radon is a naturally occurring radioactive gas;
- It is continuously produced by the decay of uranium, which occurs naturally in soils and rocks;
- Once produced, Radon escapes into the open air unless it enters a building or enclosed space.
- WHO estimates that Indoor Radon is responsible for 20.000 lung cancer deaths per year.
- Indoor Radon is the 2nd leading cause of lung cancer, after tobacco.



Portugal: Geology and Radon Potential

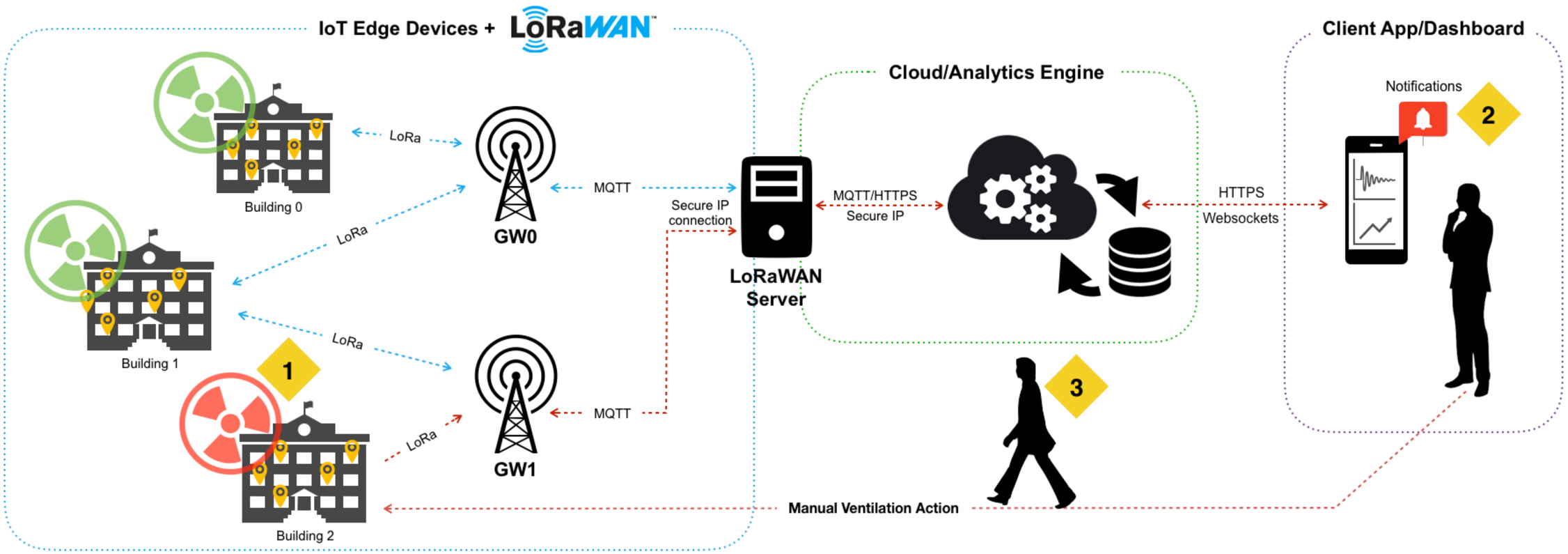


Source: Mapa de Risco de Radão, Instituto Tecnológico Nuclear, Portugal



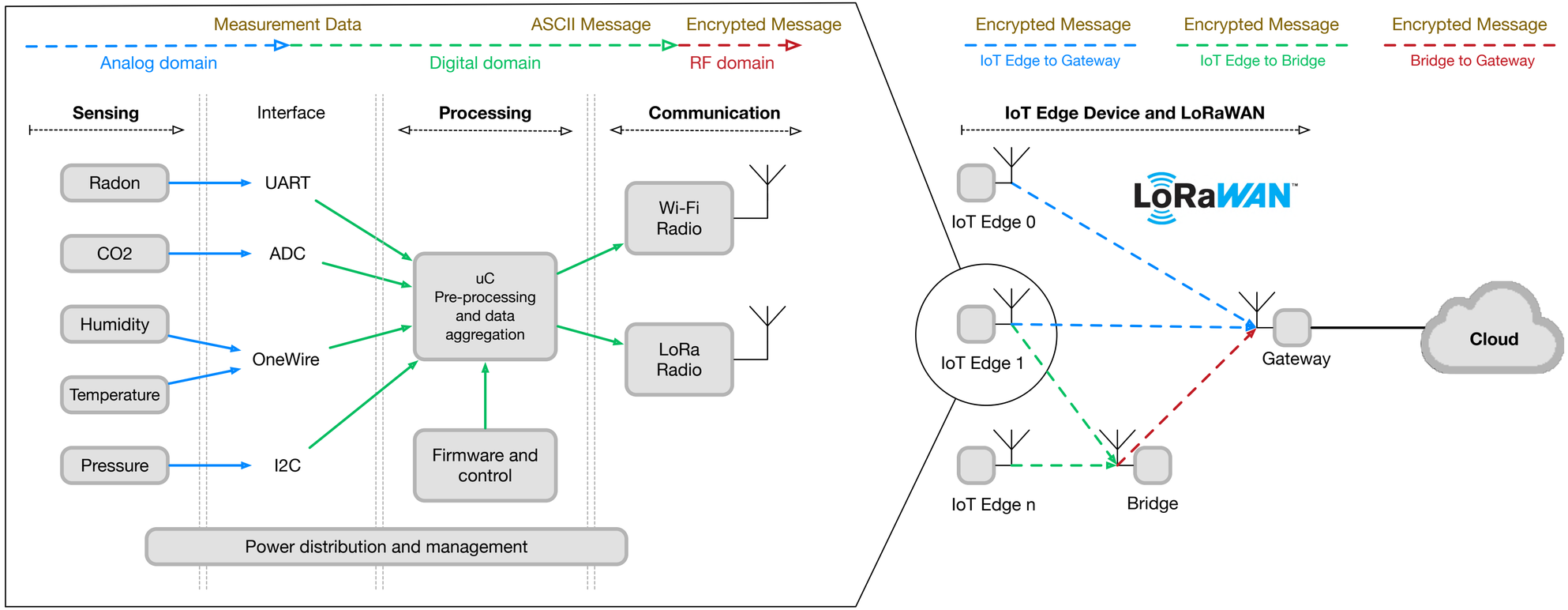
Source: Carta Geológica de Portugal na Escala 1:500000, Instituto Nacional de Engenharia, Amadora, Portugal, 1992

RnMonitor: How it Works?



Source: S.I. Lopes, A. Cruz, P.M. Moreira, C. Abreu, J.P. Silva, N. Lopes, J. Vieira and A. Curado, "On the design of a Human-in-the-Loop Cyber-Physical System for online monitoring and active mitigation of indoor Radon gas concentration," 2018 IEEE International Smart Cities Conference (ISC2), Kansas City, MO, USA, 2018, pp. 1-8, DOI: 10.1109/ISC2.2018.8656777

RnProbe - IoT Device Architecture



Source: F. Pereira, S.I. Lopes, N.B. Carvalho and A. Curado, "RnProbe: A LoRa-Enabled IoT Edge Device for Integrated Radon Risk Management", in IEEE Access, vol. 8, pp. 203488-203502, 2020, DOI: 10.1109/ACCESS.2020.3036980

RnProbe - Prototype Validation

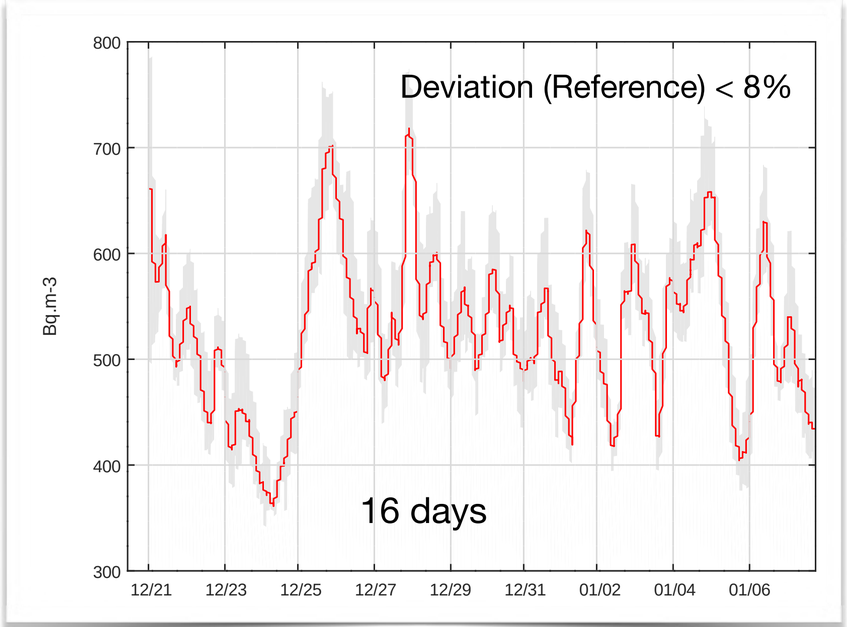
Prototype

Experimental Apparatus

Reference Instrument

Experimental Validation

	D03	D07	D09	D12	Reference
Arith. Mean ($Bq.m^{-3}$)	537	534	477	550	509
Stand. Dev. ($Bq.m^{-3}$)	72	79	66	80	112



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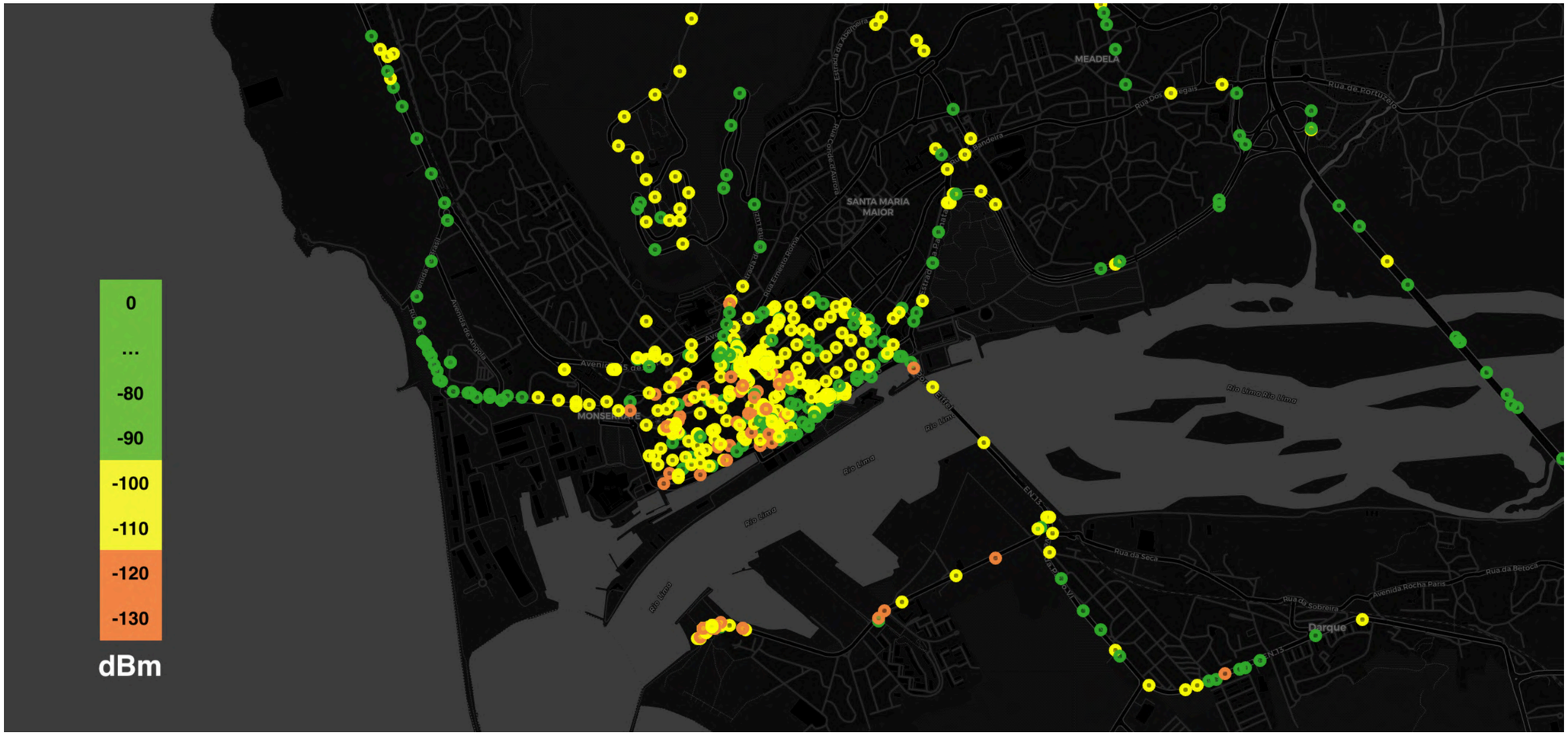
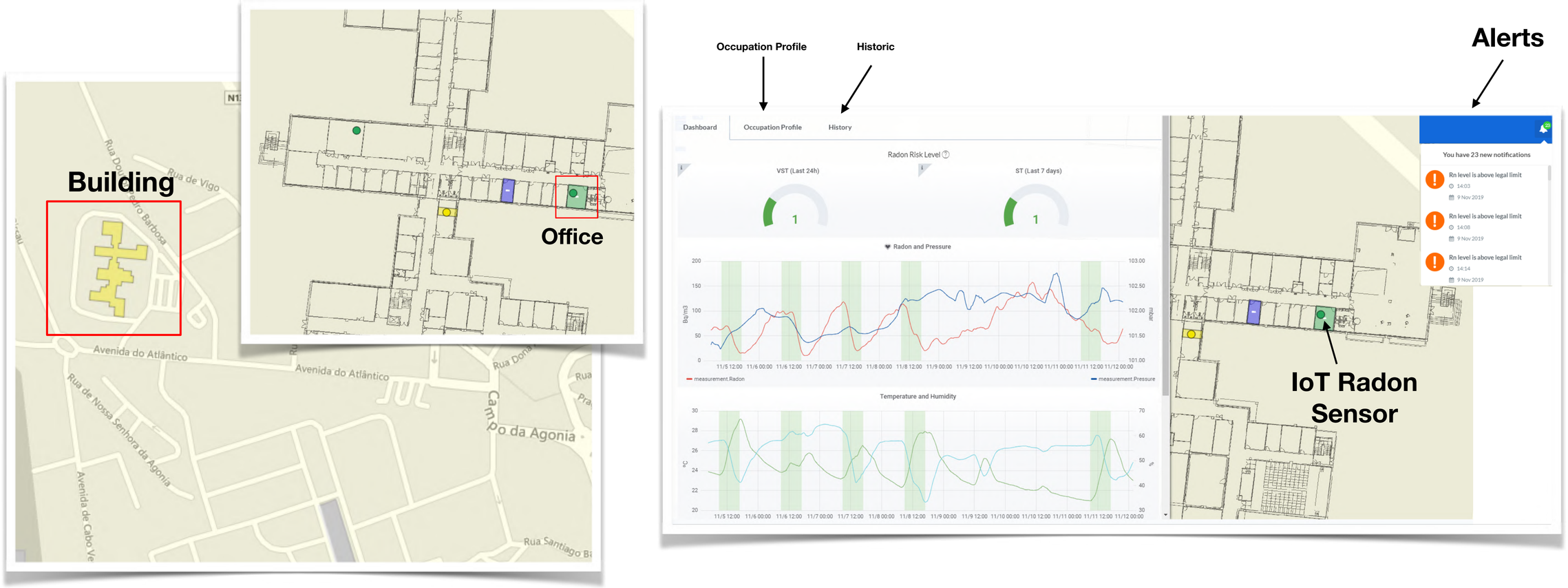
Connectivity

LoRaWAN @ Viana do Castelo



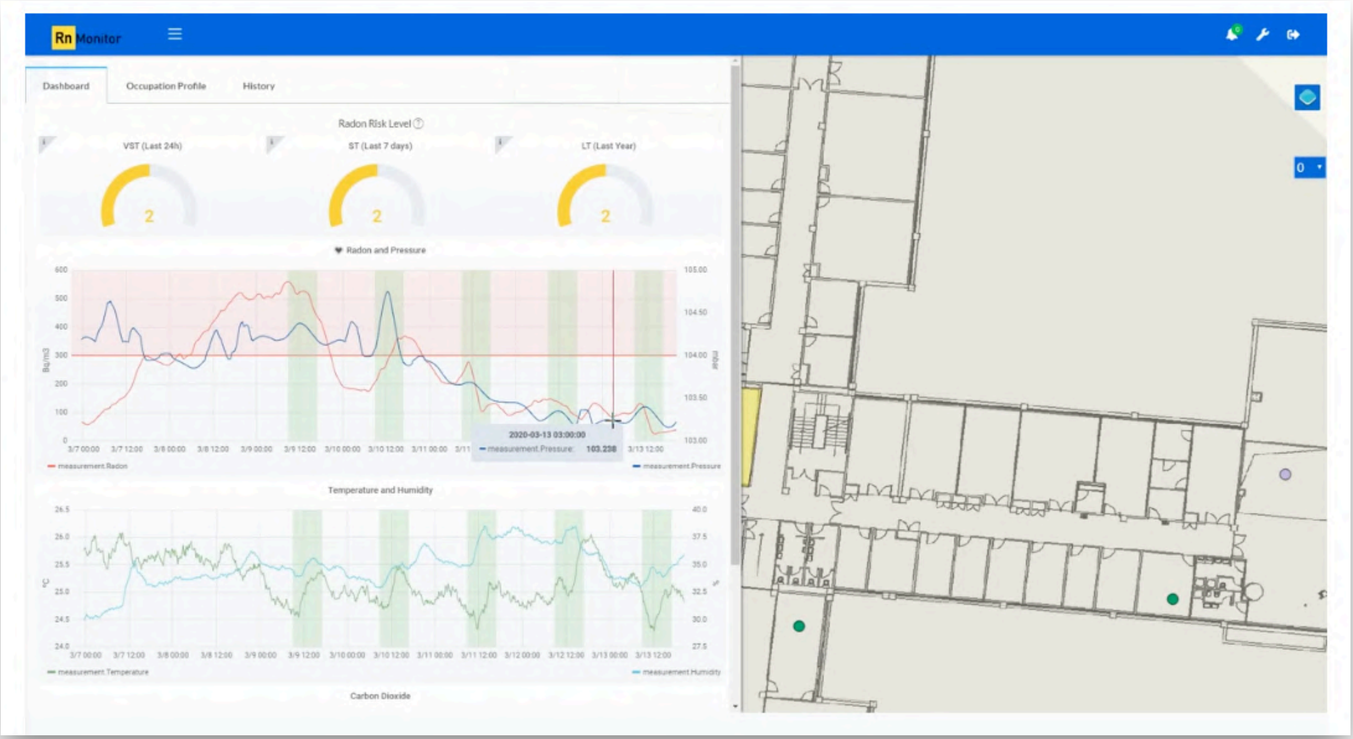
RnMonitor: WebGIS Client App



The RnMonitor Ecosystem

IoT-based Sensor RnProbe

RnMonitor IoT Platform

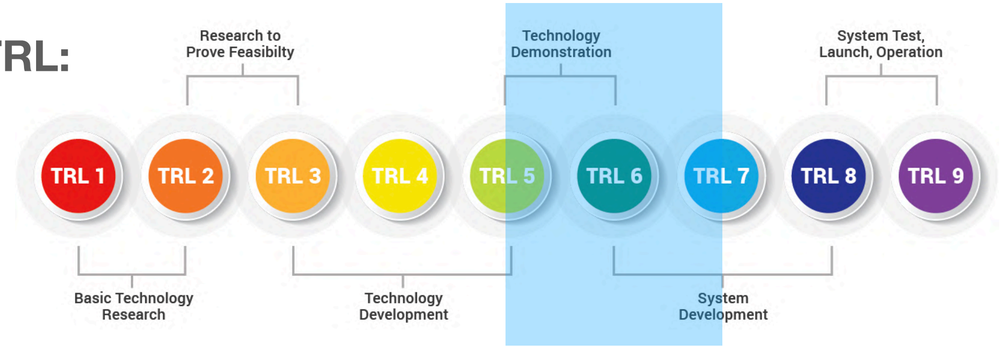


Designing IoT-driven applications

Contactless Health Monitoring

SDGs:

TRL:



- **Project Name:** Contactless Vital Signs Monitoring in Nursing Homes using a Multimodal Approach
- **Funding:**

COMPETE 2020 | PORTUGAL 2020 | UNIÃO EUROPEIA Fundo Europeu de Desenvolvimento Regional

- **Website:** https://covis.wavecom.pt
- **Partners:**

wavecom | instituto de telecomunicações | ipvc | ISEL

- **Goals:**
  - Develop a low-cost IoT device for contactless vital signs monitoring;
  - Development of a digital platform to track the patient's health status to assist healthcare professional on their job;
  - Not for diagnostic purpose;

Designing IoT-driven applications

Conventional Vital Signs Monitoring

Respiratory Rate

Pulse

Body Temperature

- **Conventional methods** contact-based:
  - require the use of contact sensors; properly placed by a health professional;
  - inconvenient for regular measurements and impractical for long-term monitoring.
- **Respiratory Rate:**
  - Stethoscope + Medical Practice
- **Pulse (Heart Rate):**
  - ECG, Medical Practice
- **Body Temperature:**
  - Contact-based thermometers
  - Proximity IR sensors

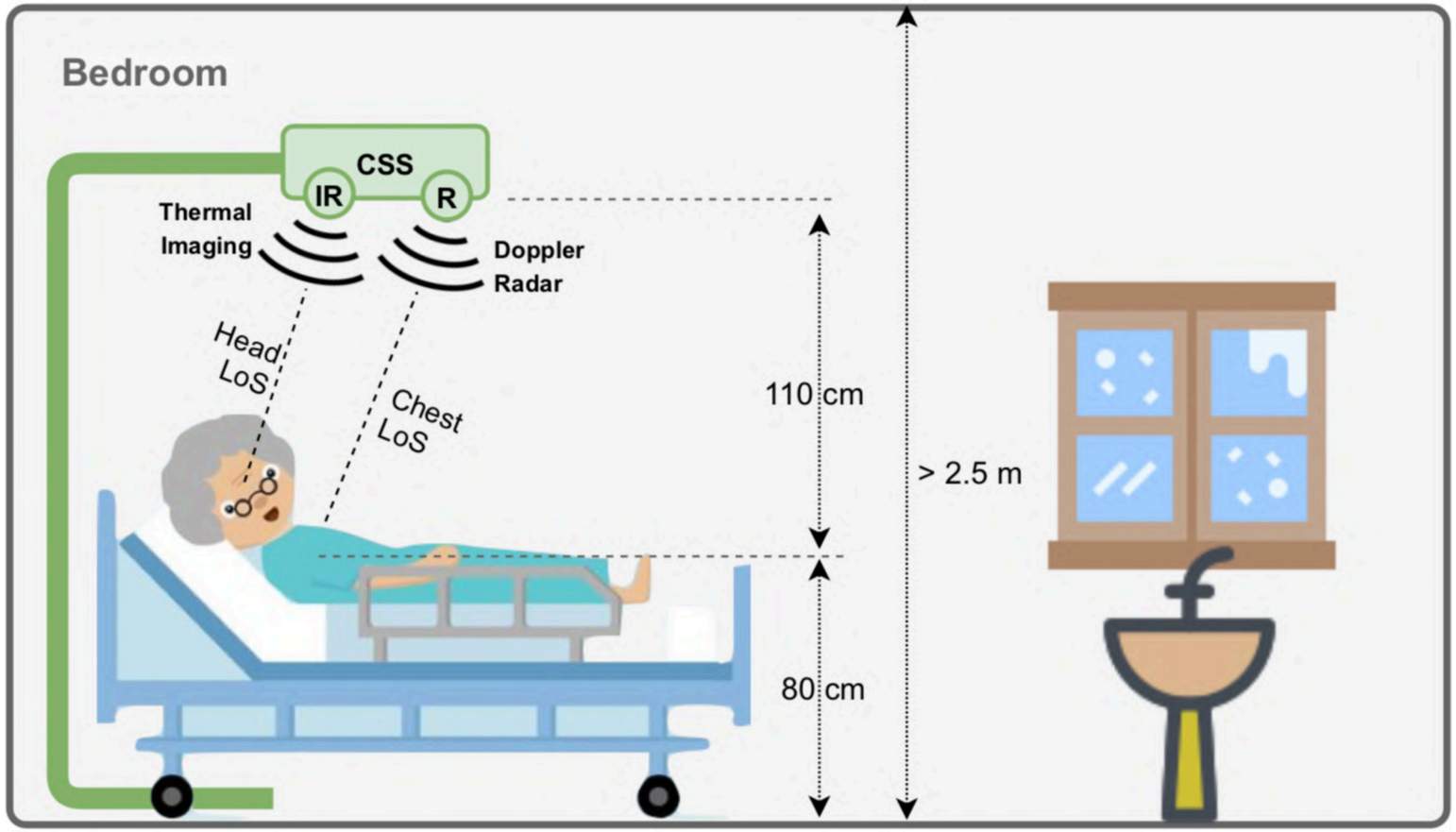
Designing IoT-driven applications

Contactless Vital Signs Monitoring (VSM)

- do not require physical attached electrodes;
- eliminates restrictions on the person's movement;
- more comfortable;
- less invasive for patients;
- relevant for remote acquisition > minimizes contact with health professionals;
- reduces the probability of infection.

Designing IoT-driven applications

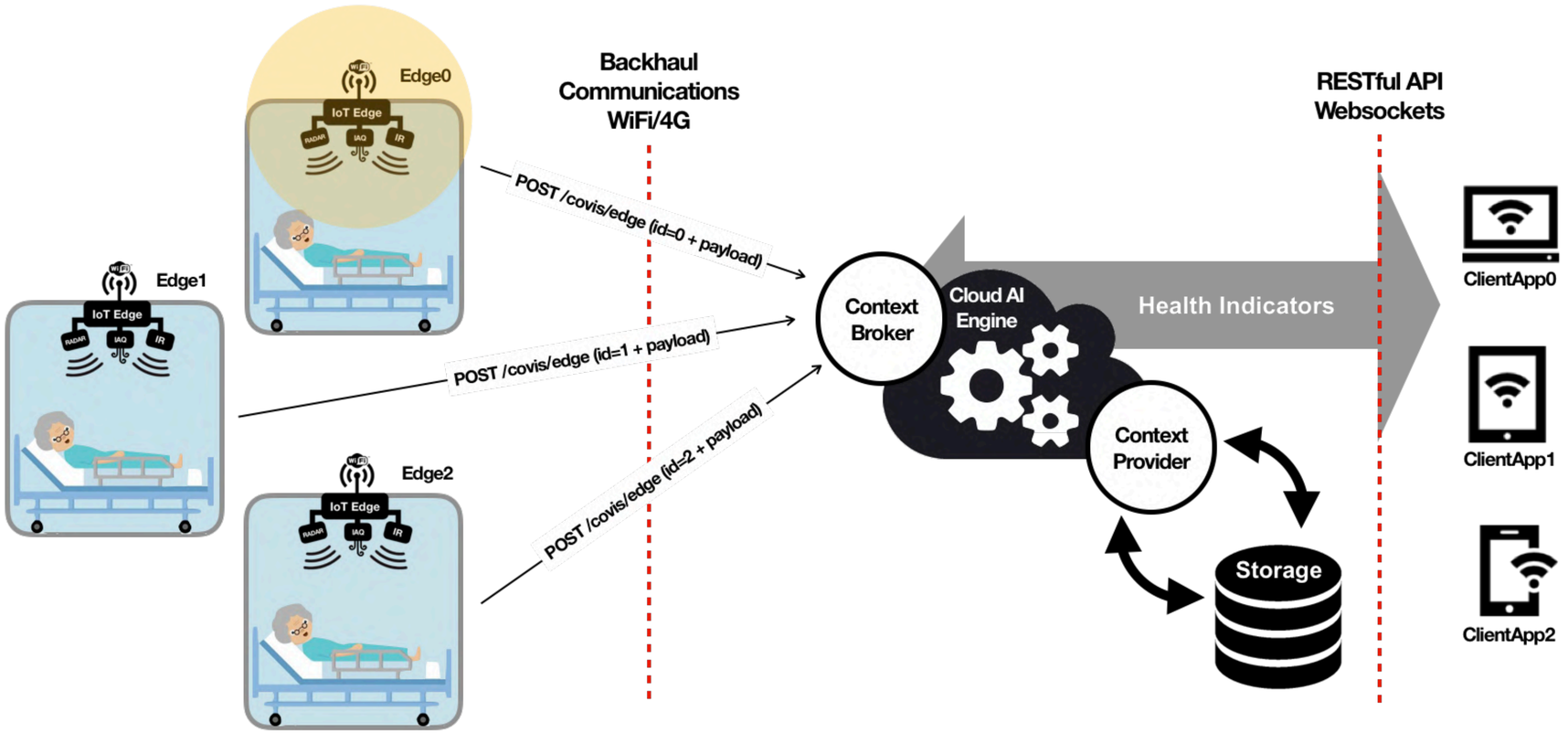
Contactless Vital Signs Monitoring (VSM)

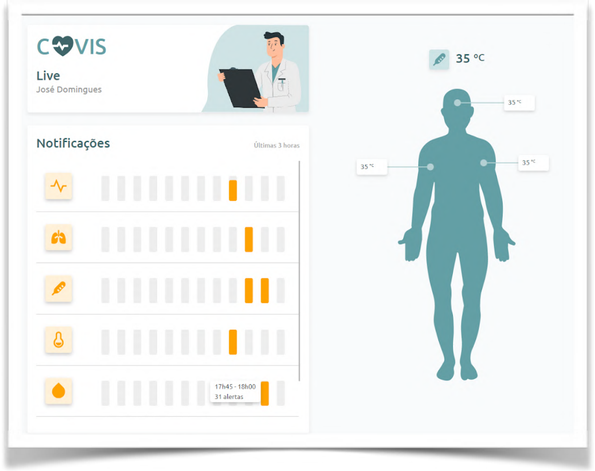


Low-Cost Thermal Imaging + Doppler Radar

Designing IoT-driven applications

System Architecture

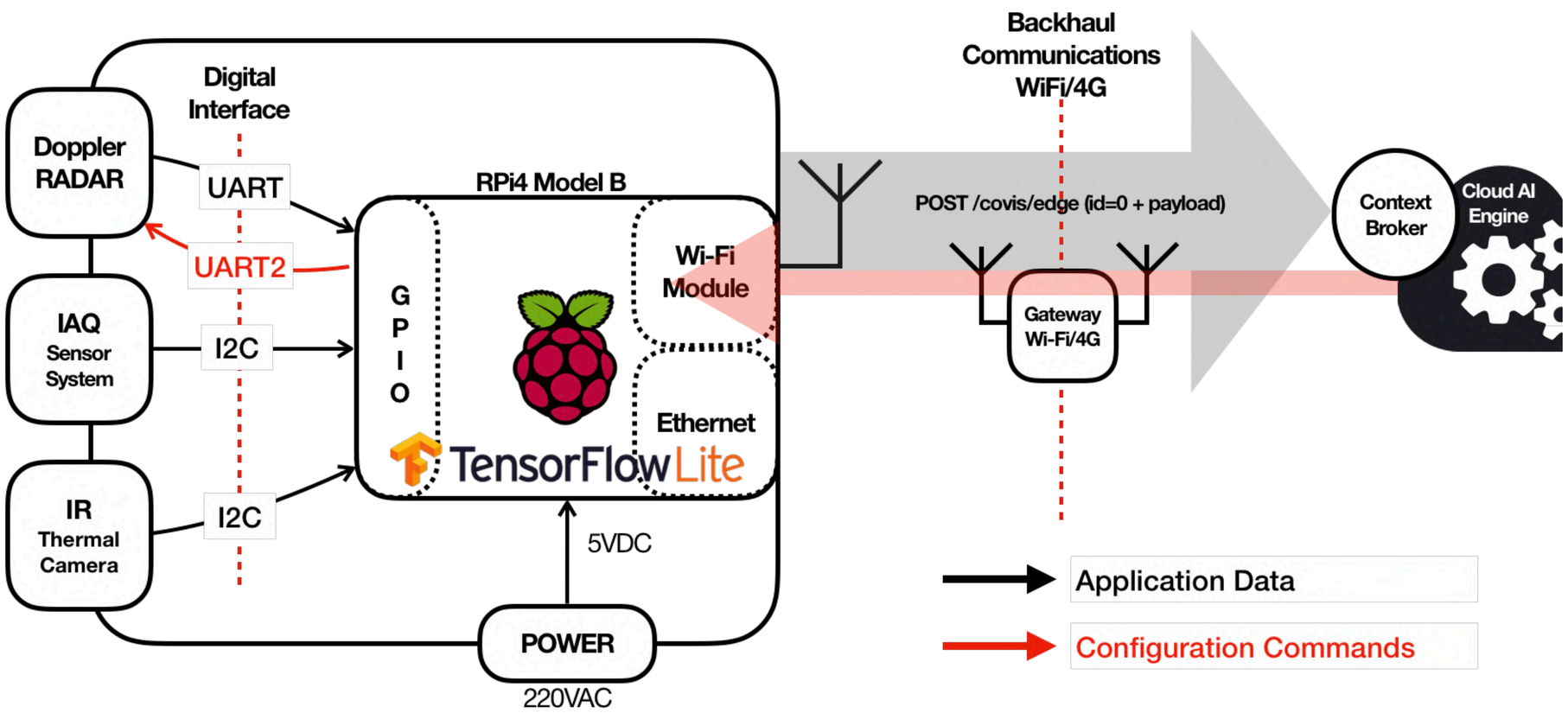




Source: S. I. Lopes, P. Pinho, P. Marques, C. Abreu, N. B. Carvalho and J. Ferreira, “Contactless Smart Screening in Nursing Homes: an IoT-enabled solution for the COVID-19 era,”, 17th IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), 2021, pp. 145-150,

Designing IoT-driven applications

IoT Edge Architecture



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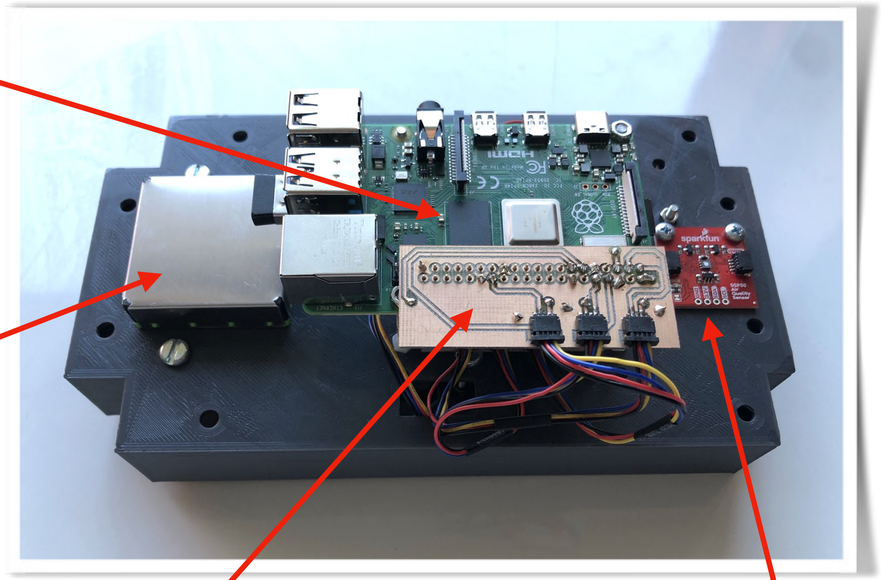
Designing IoT-driven applications

IoT Edge Prototype

Top View



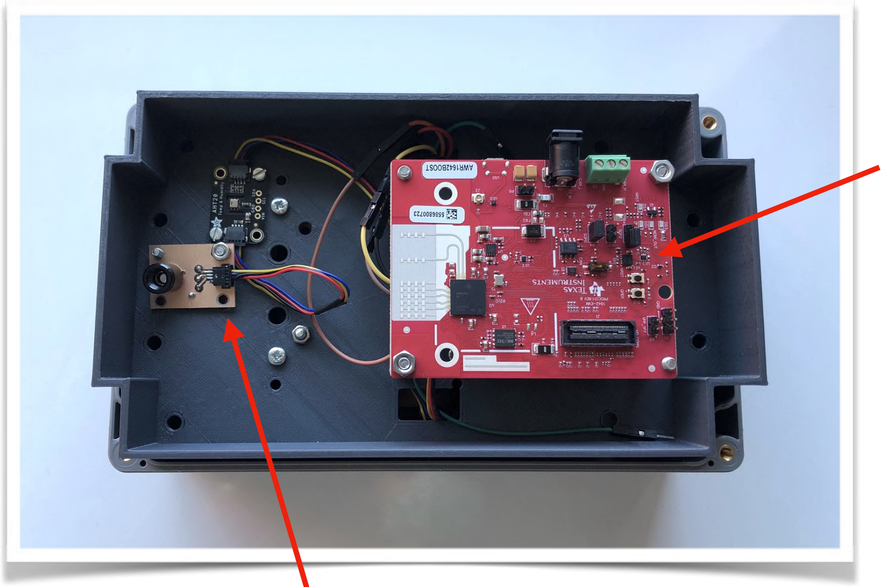
RPi 4

SPS30
PM Sensor

Sensor Interfacing PCB
AHT20 Sensor + I2C/UART

SGP30
TVOC, eCO2 Sensor

Bottom View

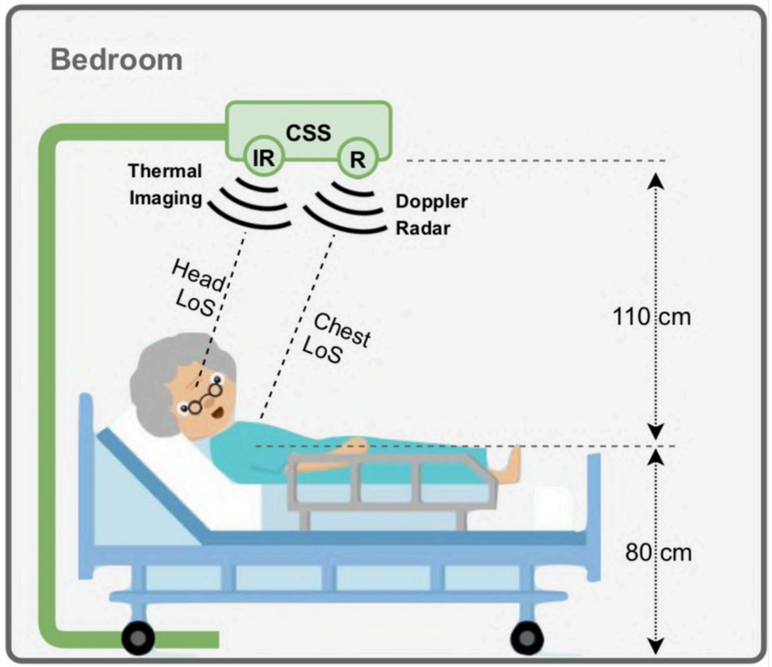


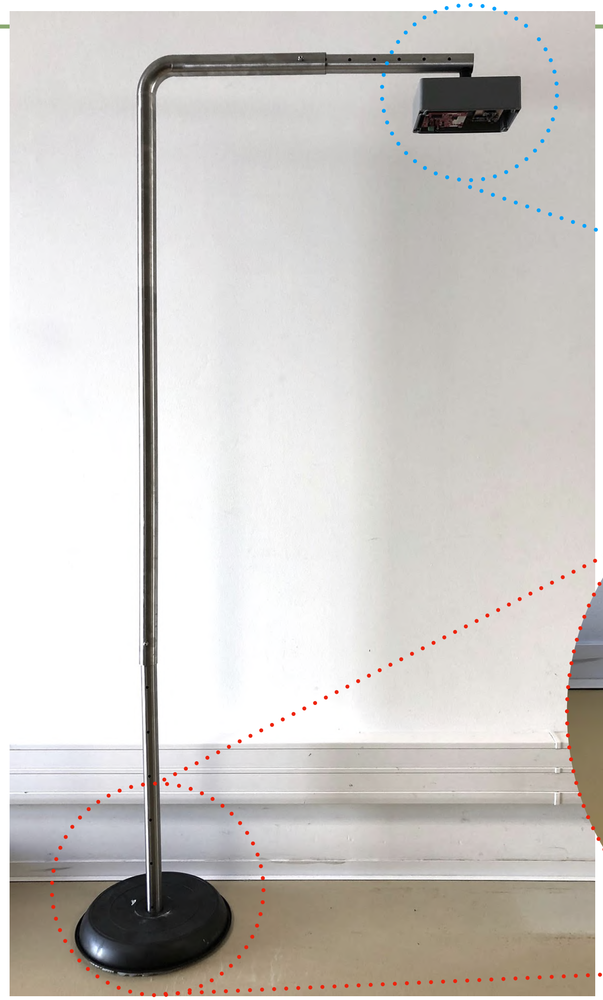
Doppler Radar

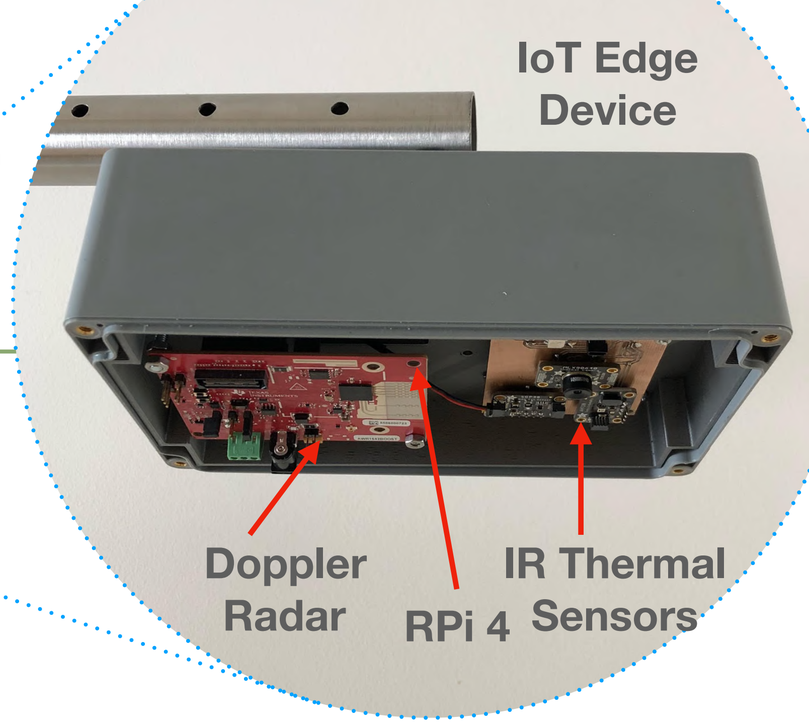
IR Thermal Sensors

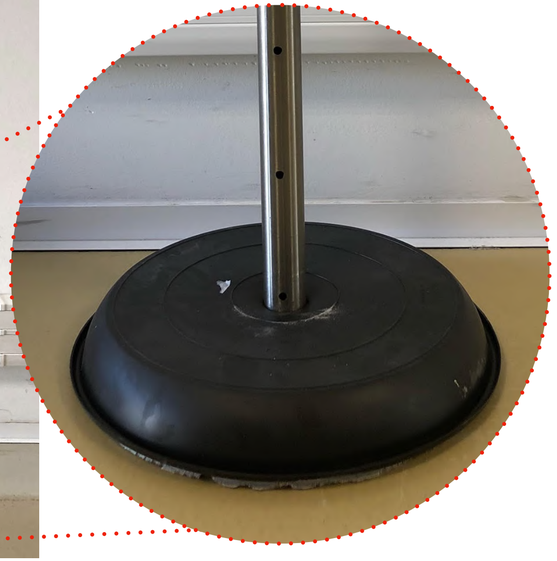
Designing IoT-driven applications

Prototype







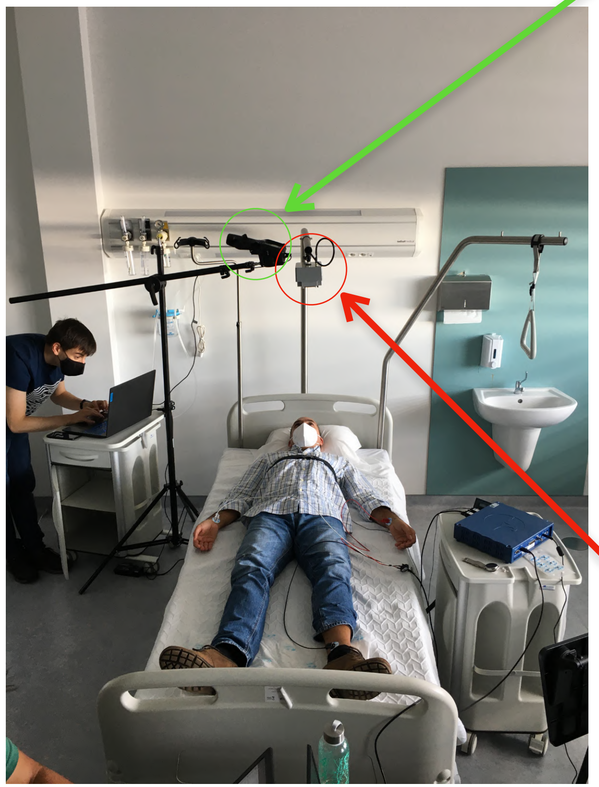


Concrete base

Designing IoT-driven applications

CVSM System Validation

FLIR E54 Reference Thermal Camera



Contactless VSM IoT Device

Biopac Reference Instrument

Designing IoT-driven applications

CVSM System Validation - Relative Error

- 5 distinct users where evaluated in three distinct positions (Tilted Bed, Lying Up, and Laying Sideways);
- Each experiment took 5 minutes and were taken with users at rest (immobilized);
- Average values have been obtained in each experiment;
- Relative Error obtained in comparison with the reference instruments.

Heart Rate			
Rehearsal	Tilted bed	Lying up	Lying sideways
3	6.724%	6.791%	0.695%
4	5.84%	1.651%	4.343%
5	1.323%	9.644%	6.683%
6	7.384%	11.11%	4.062%
7	5.154%	4.542%	19.339%

Error < 10% in 87.5% of the cases

Error < 5% in 37.5% of the cases

Respiratory Rate			
Rehearsal	Tilted bed	Lying up	Lying sideways
3	4.236%	1.533%	12.211%
4	1.865%	9.392%	1.214%
5	5.97%	6.776%	0.989%
6	1.91%	0.827%	1.223%
7	2.849%	12.073%	7.283%

Error < 10% in 85% of the cases

Error < 5% in 56,3% of the cases

Body Temperature			
Rehearsal	Tilted bed	Lying up	Lying sideways
3	6.946%	7.082%	5.993%
4	4.52%	5.493%	2.966%
5	nan%	1.662%	5.005%
6	0.242%	0.066%	1.028%
7	3.258%	2.254%	3.519%

Error < 10% in 93.8% of the cases

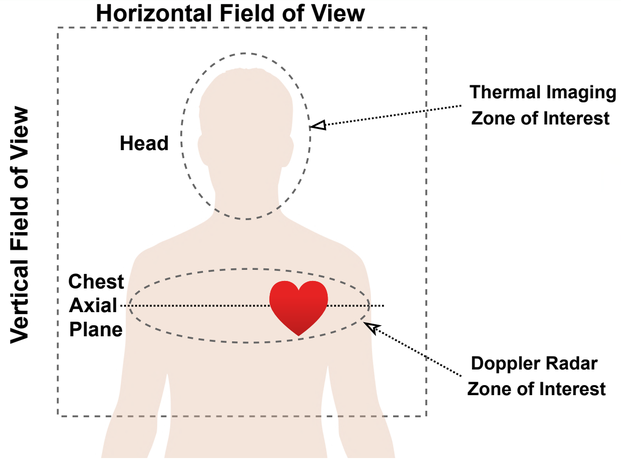
Error < 5% in 56.3% of the cases

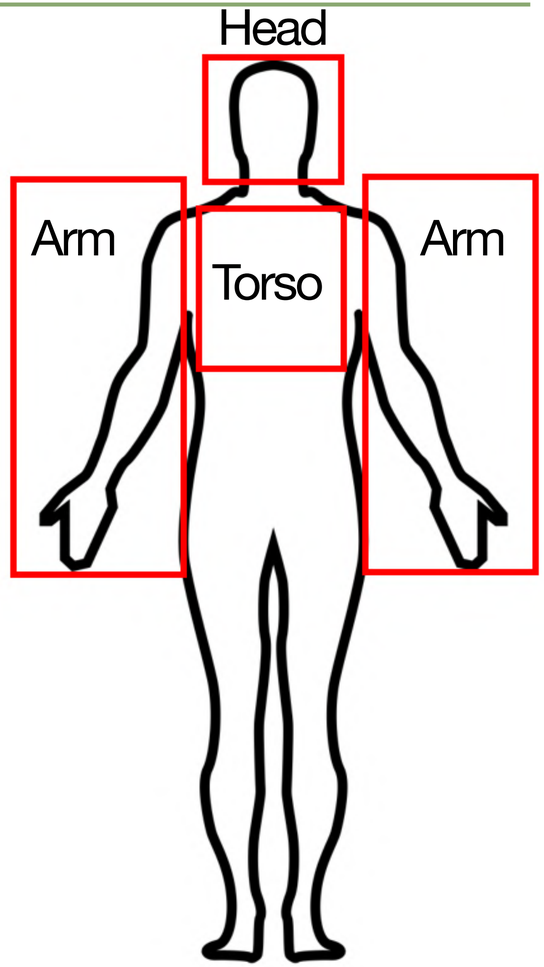
Errors outside medical grade scale > focus on assisting Healthcare professionals, not on diagnosis.

Designing IoT-driven applications

EdgeAI for Body Parts Identification

- Relevant for RoI Identification:
  - Head
    - Thermal Imaging RoI
  - Chest Axial Plane
    - Doppler Radar RoI
- Evaluated with FLIR E-54:
  - Thermal Images
  - RGB Images
- <u>Future evaluation with FLIR Lepton</u>

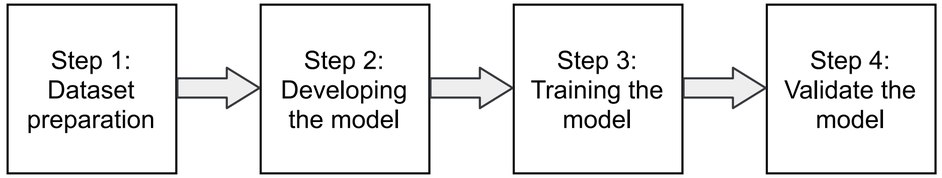


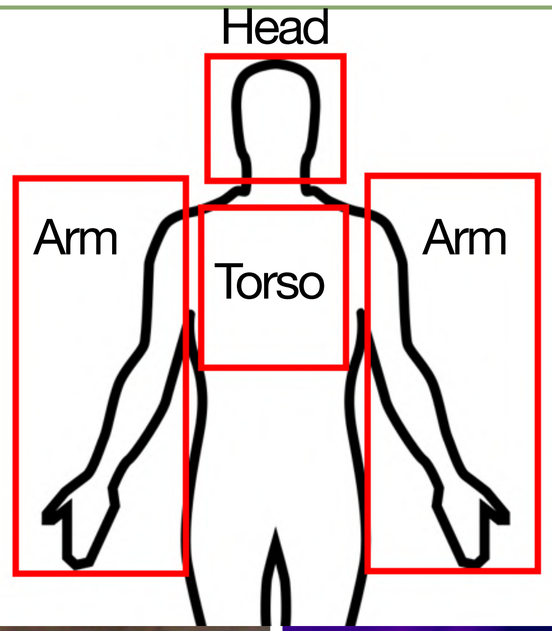


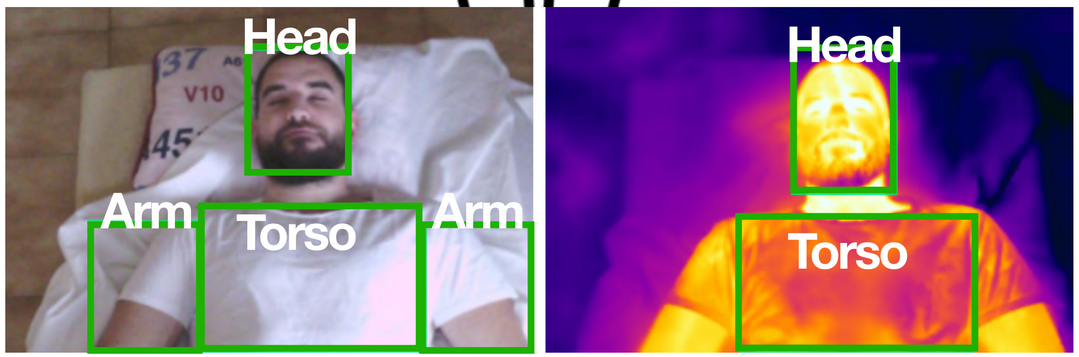
Designing IoT-driven applications

EdgeAI for Body Parts Identification

- Two models have been trained using a pre-defined object detection algorithm in Tensorflow:
  - SSD MobileNet V2 FPNLite model > TensorFlow Lite
    - RGB 640x640
    - Thermal 320x320
- Methodology:

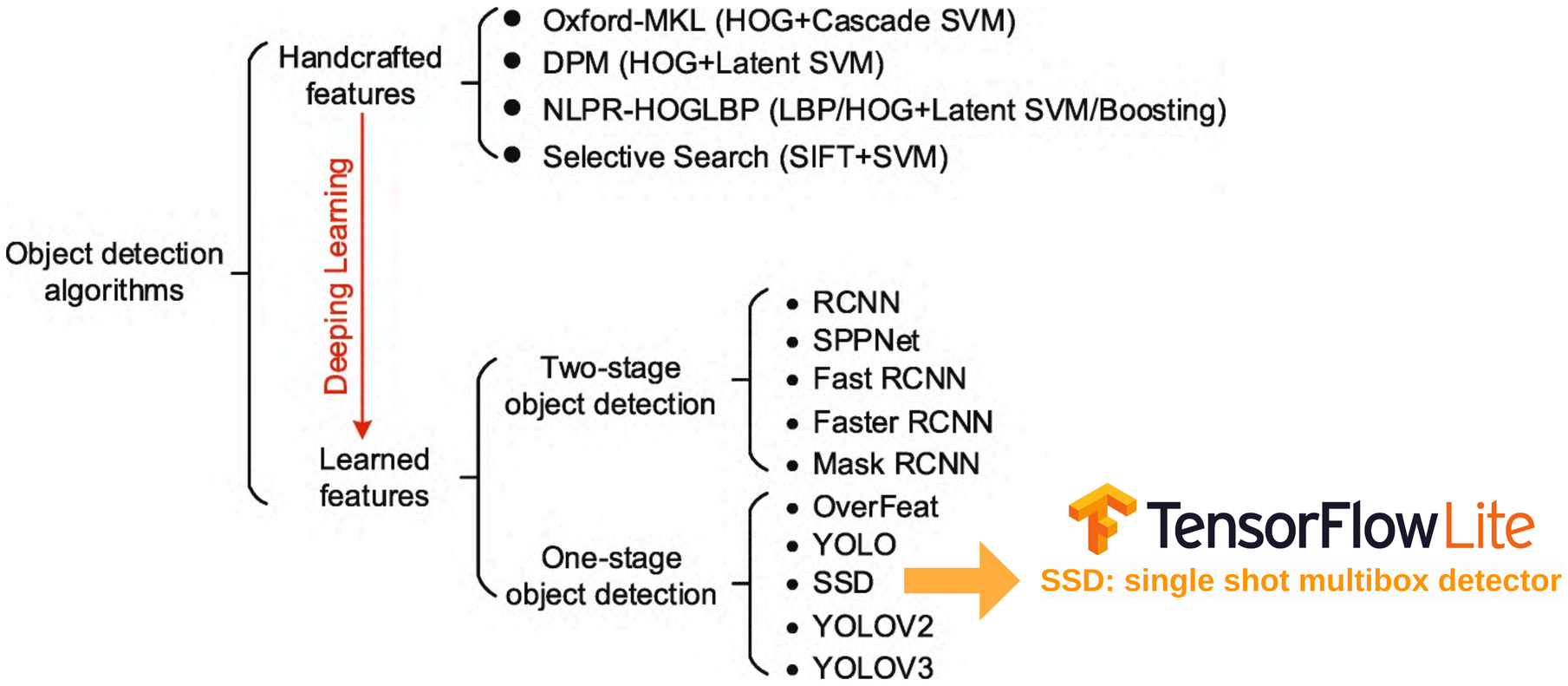






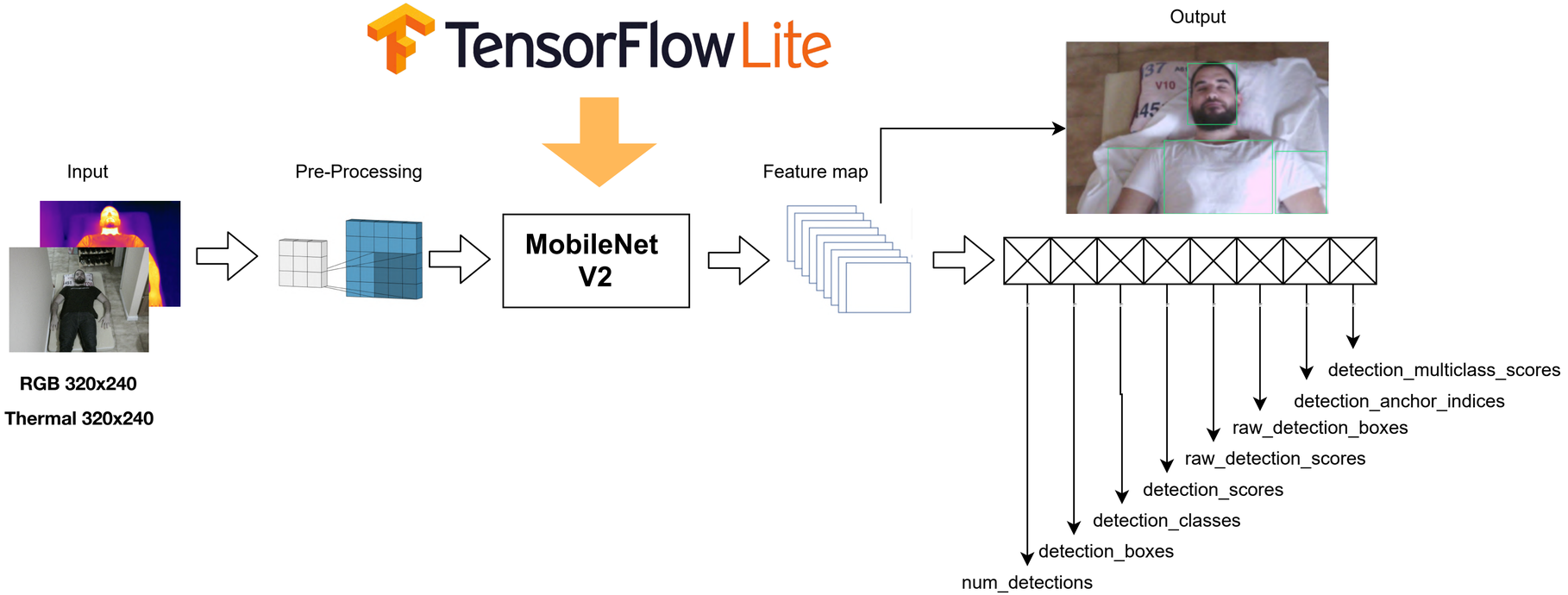
Designing IoT-driven applications

EdgeAI for Body Parts Identification



Designing IoT-driven applications

EdgeAI for Body Parts Identification



Source: D. Rocha, P. Rocha, J. Ribeiro, and S.I. Lopes, "Identification and Classification of Human Body Parts for Contactless Screening Systems: an Edge-AI Approach", Edge-IoT 2021 – 2nd EAI International Conference on Intelligent Edge Processing in the IoT Era, Virtual, November 24-26, 2021.

Designing IoT-driven applications

EdgeAI for Body Parts Identification

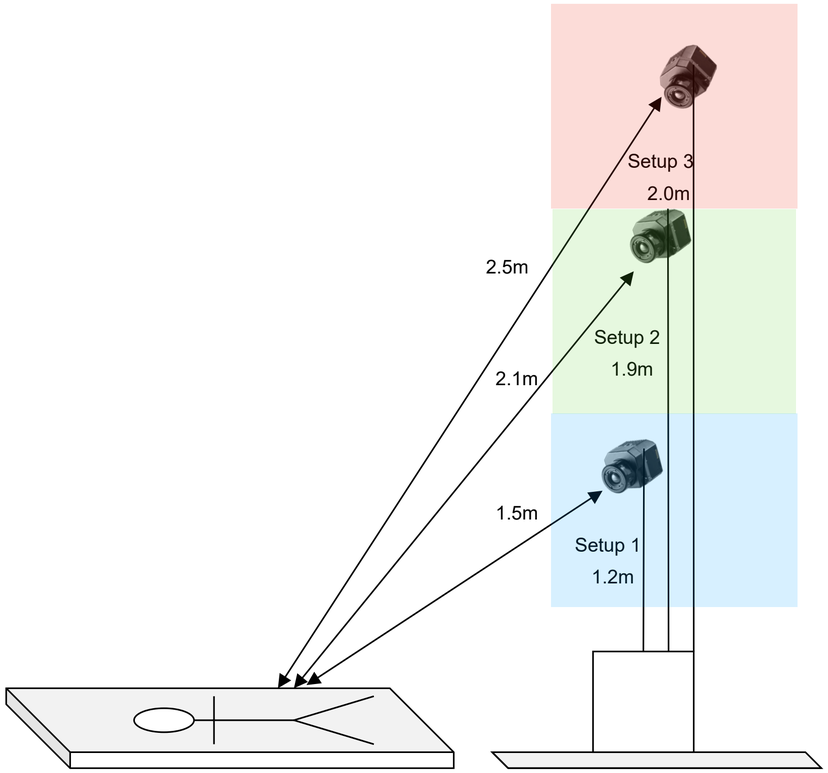


Table 1. Results summary for the three evaluated setups.

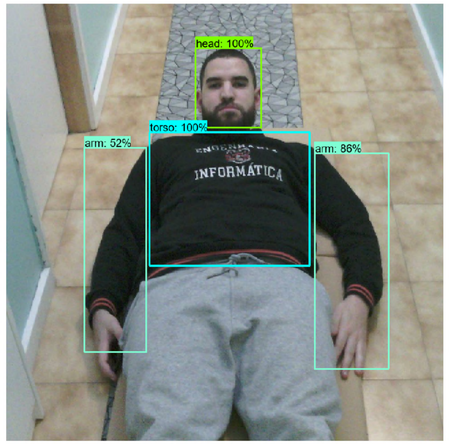
	Setup 1		Setup 2		Setup 3		Total	
	RGB	Thermal	RGB	Thermal	RGB	Thermal	RGB	Thermal
Accuracy					> 97%			
Head	95.51%	90.69%	97.82%	97.78%	99.97%	96.93%	98.97%	96.70%
Torso	90.50%	46.99%	77.19%	41.54%	94.45%	42.10%	89.42%	42.64%
Arms	38.87%	-	46.41%	-	63.27%	-	56.39%	-
Confidence					> 95%			
Head	95.23%	88.89%	95.76%	96.88%	100.00%	95.05%	98.40%	95.18%
Torso	83.33%	37.78%	61.86%	33.59%	92.45%	31.45%	83.33%	32.89%
Arms	22.62%	-	19.49%	-	52.34%	-	40.87%	-
Number of Images	42	45	118	128	278	283	438	456

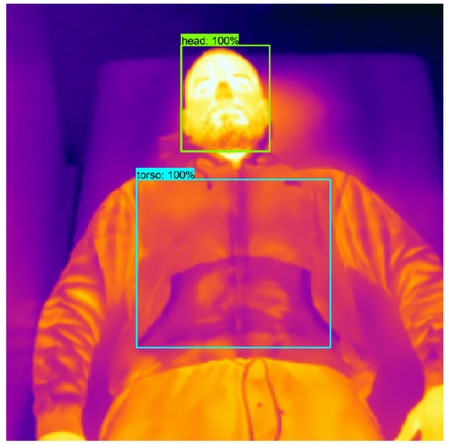
Source: D. Rocha, P. Rocha, J. Ribeiro, and S.I. Lopes, “Identification and Classification of Human Body Parts for Contactless Screening Systems: an Edge-AI Approach”, Edge-IoT 2021 – 2nd EAI International Conference on Intelligent Edge Processing in the IoT Era, Virtual, November 24-26, 2021.

Designing IoT-driven applications

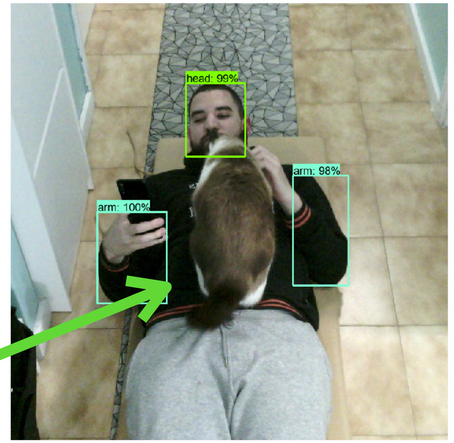
EdgeAI for Body Parts Identification

- Examples of results obtained with normal images (setup 3):



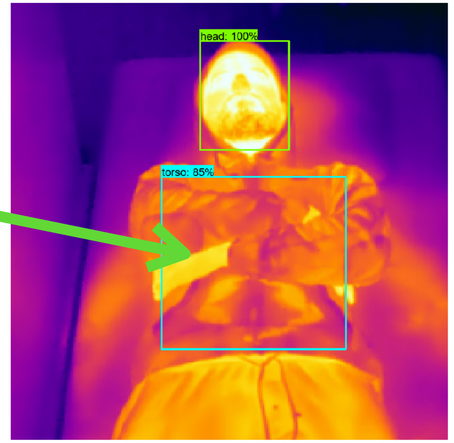


- Results obtained with images with artefacts (setup 3):



Cat

Arms crossed



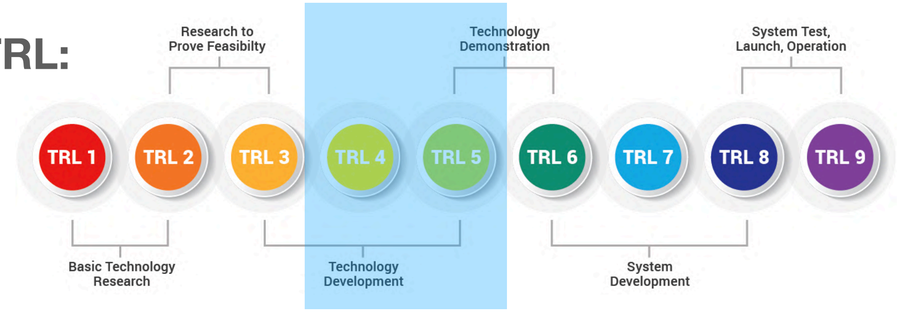
Designing IoT-driven applications

IPVC-S2C: Towards a Smart & Sustainable Campus

Instituto Politécnico de Viana do Castelo

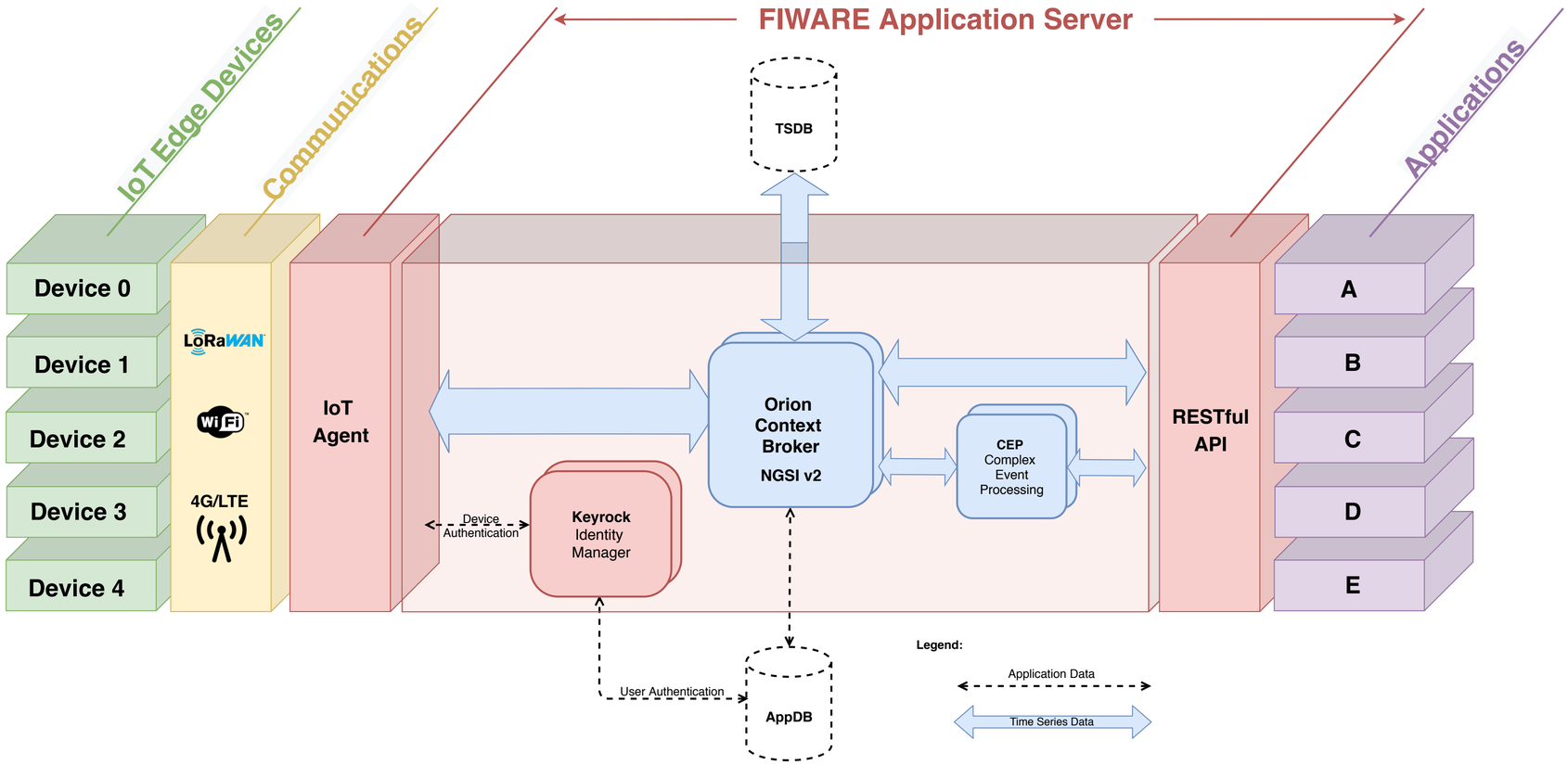
SDGs:

TRL:



- **Goals**:
  - Think the campus as a “small” City;
  - Aggregate IoT projects within the same platform;
  - Share IT and IoT resources;
  - Create awareness towards sustainable practices by integrating:
    - IoT technologies;
    - Learning activities, i.e. Project-based Learning;
    - R&D activities

IPVC-S2C: Towards a Smart & Sustainable Campus



Source: P. Martins, S.I. Lopes, A. M. R. Cruz and A. Curado, "Towards a Smart & Sustainable Campus: An Application-Oriented Architecture to Streamline Digitization and Strengthen Sustainability in Academia", Sustainability 2021, 13, 3189, DOI: 10.3390/su13063189.

Designing IoT-driven applications

IPVC-S2C

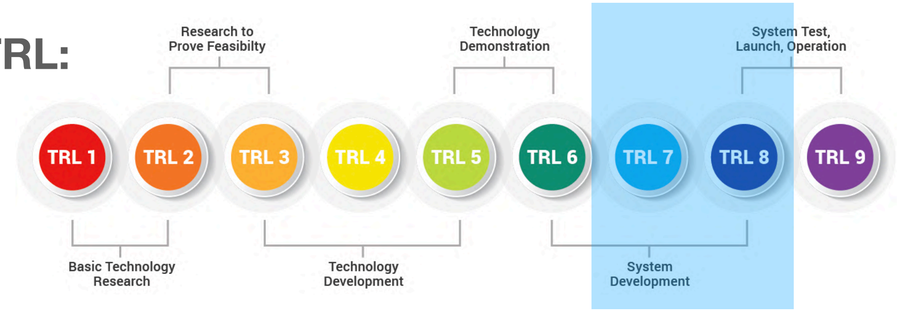
IEEE Internet of Things

Refill_H2O: Plastic Reduction on Campus

ipvc
Instituto Politécnico de Viana do Castelo

SDGs:

TRL:



- **Facts**:
  - 51.000 bottles (500 ml) + 15.000 bottles (1500 ml), are consumed annually at the IPVC campus.
  - This is equivalent to 1215 kg of plastic
- **Goals**:
  - Stop selling disposable plastic water bottles on campus
  - Create awareness towards sustainable practices on campus
- **Funding**:

Iceland Liechtenstein Norway grants

EEA Grants Portugal
Mecanismo Financeiro do Espaço Económico Europeu
European Economic Area Financial Mechanism
Unidade Nacional de Gestão
National Focal Point

Designing IoT-driven applications

IPVC-S2C

IEEE Internet of Things

Refill_H2O: System Architecture

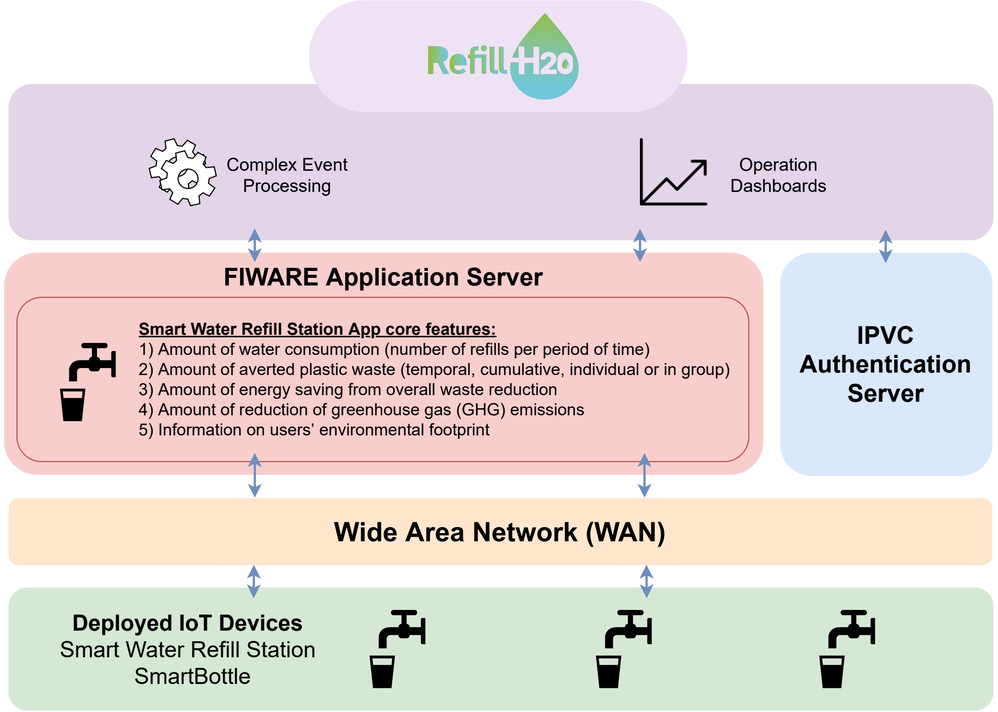
IoT Water Refill Station

Bottle Refill Zone

Display User Interface

ATM Payment

RFID Reader



IoT connected bottle

RFID Tag

Reusable IPVC Smart Bottle

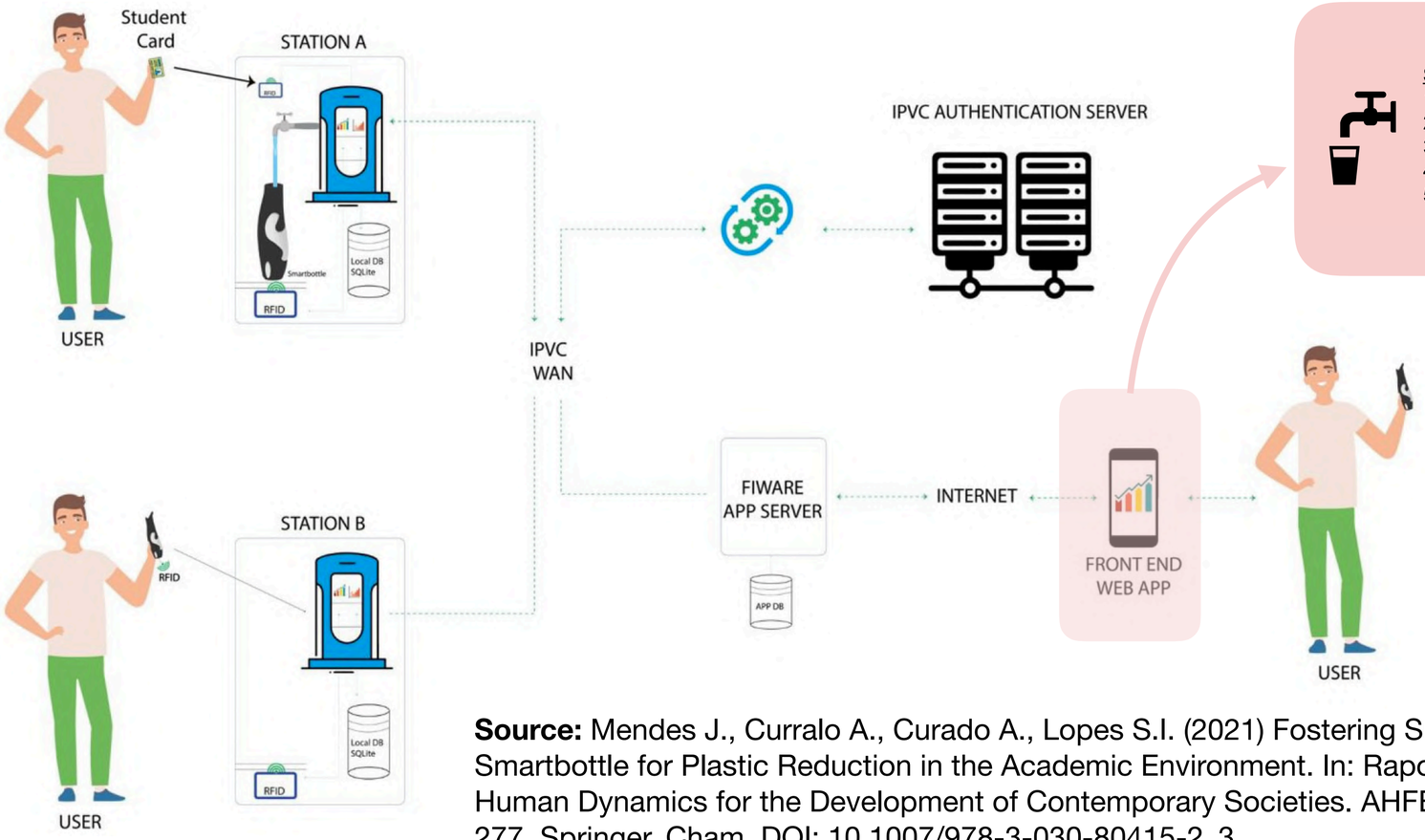
Source: Mendes J., Curralo A., Curado A., Lopes S.I. (2021) Fostering Sustainability on Campus: Design of an IoT-Enabled Smartbottle for Plastic Reduction in the Academic Environment. In: Raposo D., Martins N., Brandão D. (eds) Advances in Human Dynamics for the Development of Contemporary Societies. AHFE 2021. Lecture Notes in Networks and Systems, vol 277. Springer, Cham. DOI: 10.1007/978-3-030-80415-2_3

Designing IoT-driven applications

IPVC-S2C

IEEE Internet of Things

Refill_H2O: How it Works



Smart Water Refill Station App core features:

1) Amount of water consumption (number of refills per period of time)
2) Amount of averted plastic waste (temporal, cumulative, individual or in group)
3) Amount of energy saving from overall waste reduction
4) Amount of reduction of greenhouse gas (GHG) emissions
5) Information on users' environmental footprint

Source: Mendes J., Curralo A., Curado A., Lopes S.I. (2021) Fostering Sustainability on Campus: Design of an IoT-Enabled Smartbottle for Plastic Reduction in the Academic Environment. In: Raposo D., Martins N., Brandão D. (eds) Advances in Human Dynamics for the Development of Contemporary Societies. AHFE 2021. Lecture Notes in Networks and Systems, vol 277. Springer, Cham. DOI: 10.1007/978-3-030-80415-2_3

Designing IoT-driven applications

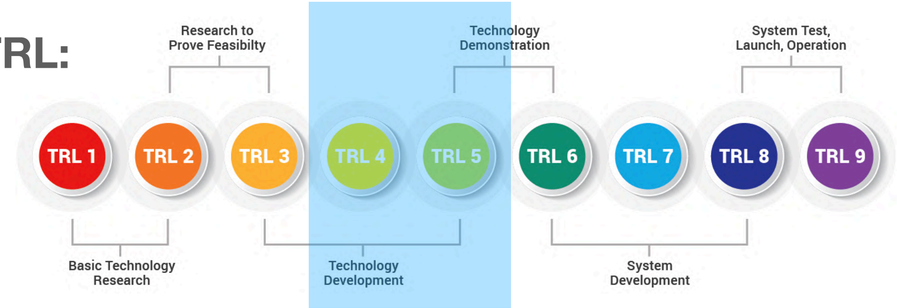
IPVC-S2C

IEEE Internet of Things

BIRA Bicycle Real-Time Tracking

SDGs:

TRL:



ipvc

Instituto Politécnico de Viana do Castelo

- **Facts**:
  - The BIRA Bicycle is accessible to the academic community (students, professors, staff, and researchers);
  - Bicycles are re-assigned annually to the users that have performed more Kms and thus contribute more to the reduction of CO2 Emissions.
- **Goals**:
  - Track Bicycles and effectively count user Kms;
  - Create awareness towards sustainable practices on campus:
- **Funding**:

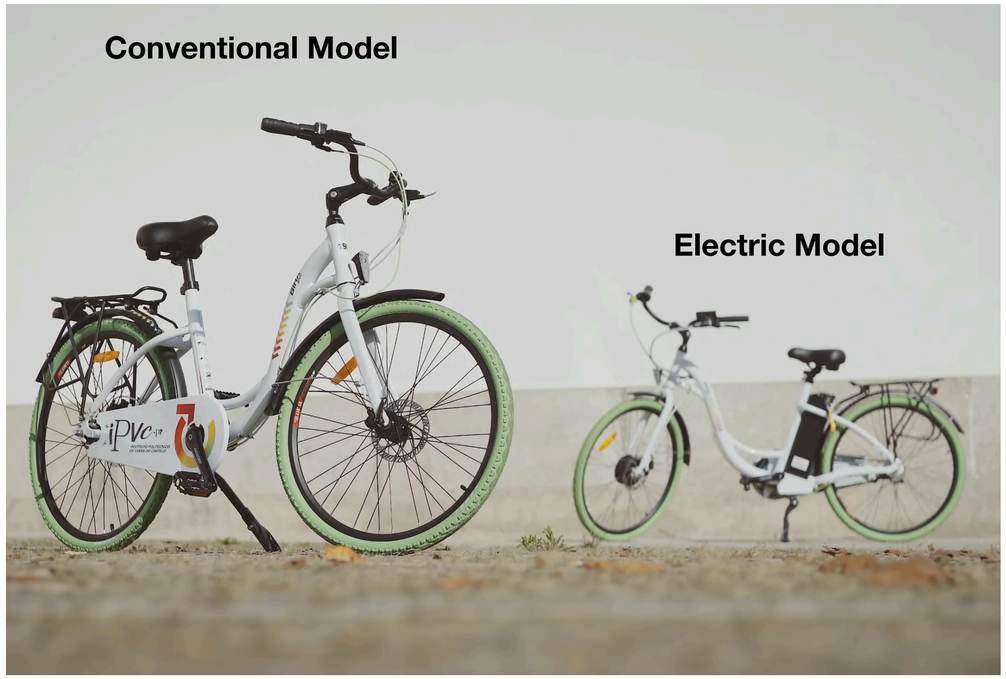
POSEUR PROGRAMA OPERACIONAL SUSTENTABILIDADE E EFICIÊNCIA NO USO DE RECURSOS 2014 20 · PORTUGAL 2020 · UNIÃO EUROPEIA Fundo de Coesão

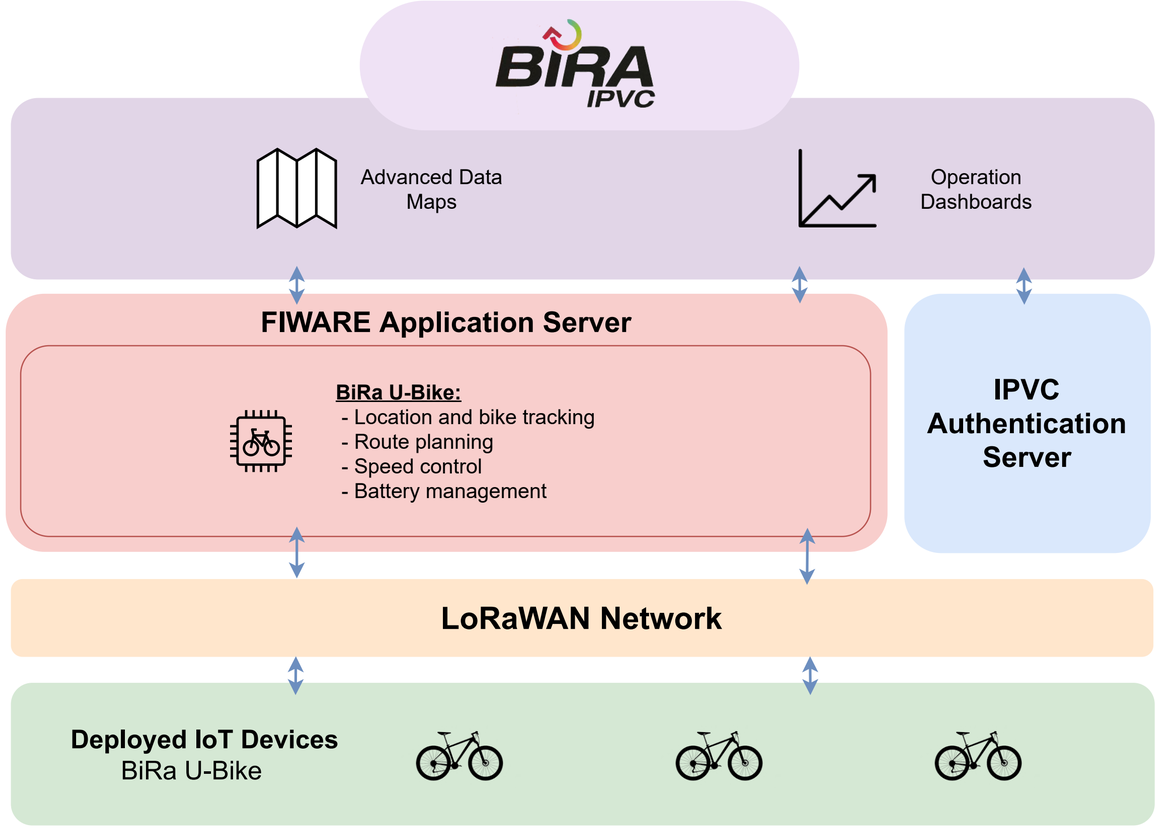
Designing IoT-driven applications

IPVC-S2C

IEEE Internet of Things

BIRA Bicycle Real-Time Tracking





Source: N. Torres, P. Martins, P. Pinto and S. I. Lopes, “Smart & Sustainable Mobility on Campus: A secure IoT tracking system for the BIRA Bicycle,” 2021 16th Iberian Conference on Information Systems and Technologies (CISTI), 2021, pp. 1-7, DOI: 10.23919/CISTI52073.2021.9476495.

Designing IoT-driven applications

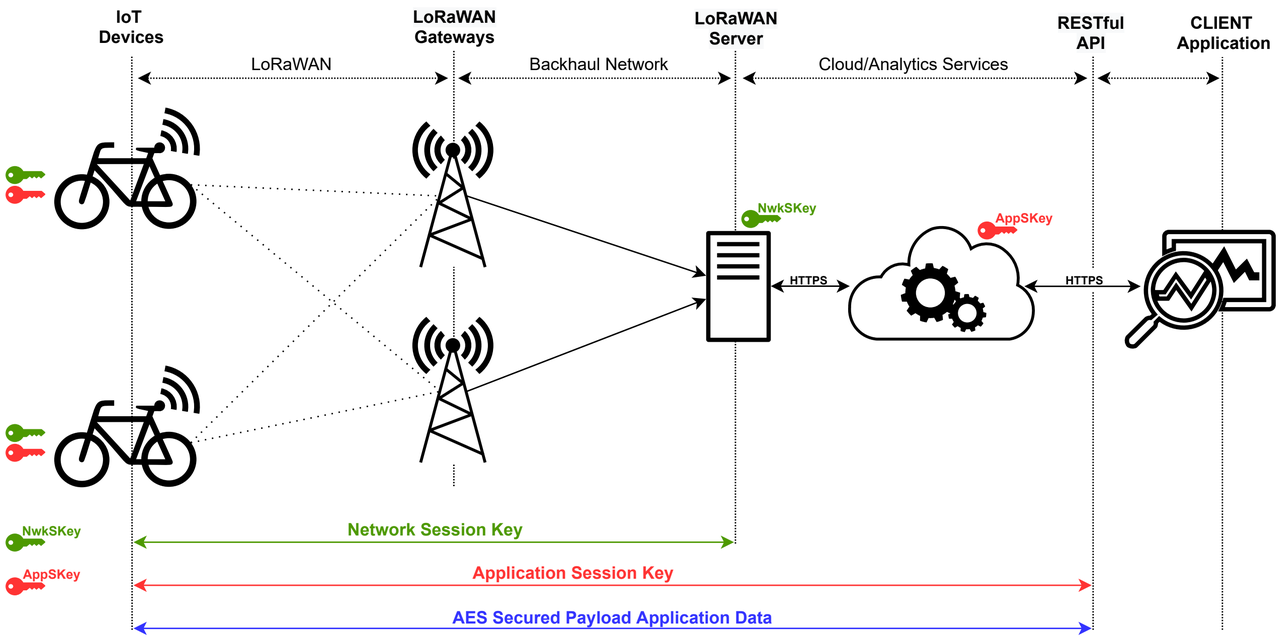
IPVC-S2C

IEEE Internet of Things

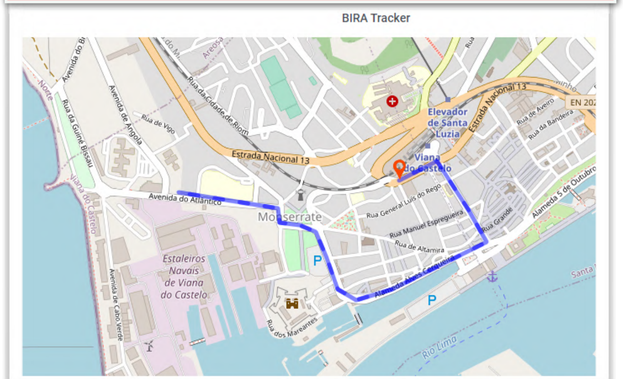
BIRA Bicycle Real-Time Tracking

IoT-Tracker with LoRAWAN Connectivity

IoT-Enabled BiRa Bicycle



BiRa U-Bike:
- Location and bike tracking
- Route planning
- Speed control
- Battery management



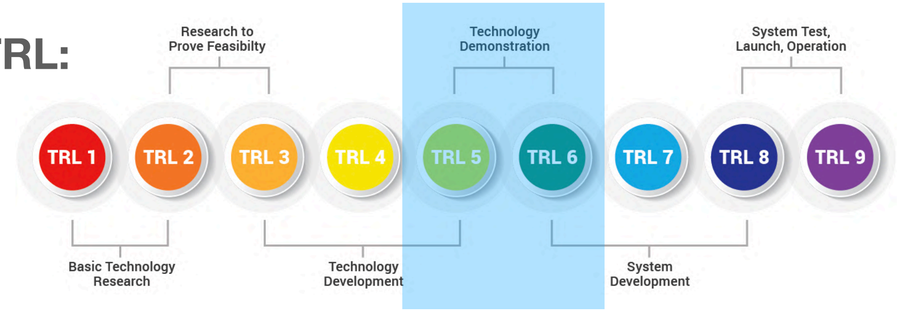
Source: N. Torres, P. Martins, P. Pinto and S. I. Lopes, “Smart & Sustainable Mobility on Campus: A secure IoT tracking system for the BIRA Bicycle,” 2021 16th Iberian Conference on Information Systems and Technologies (CISTI), 2021, pp. 1-7, DOI: 10.23919/CISTI52073.2021.9476495.

Designing IoT-driven applications

Crowd Quantification with Flow Direction Estimation

SDGs:

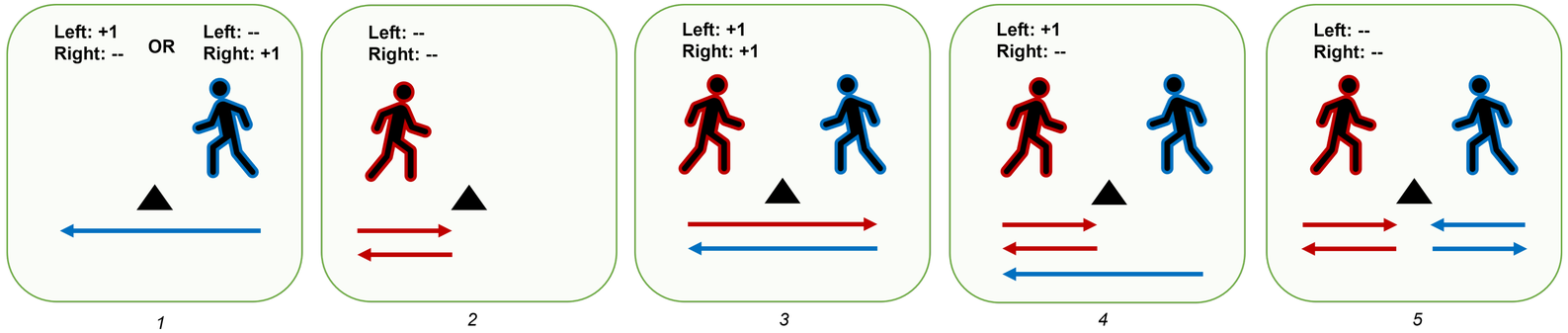
TRL:

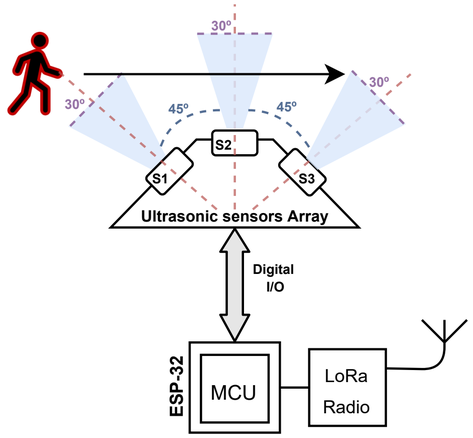


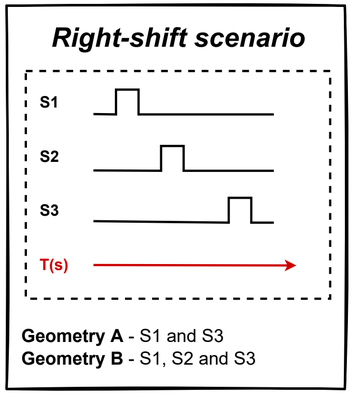
- Monitoring crowds in public environments is of great value for understanding human routines and managing crowd routes indoors or outdoors;
- Crowd quantification and flow direction estimation may help to:
  - Ensure Social Distancing Practices;
  - Improve Energy Efficiency & Comfort;
  - Streamline Cleaning/Janitorial Services;
  - Enhance Indoor Air Quality;
  - Deliver Additional Security.

Designing IoT-driven applications

Crowd Quantification with Flow Direction Estimation





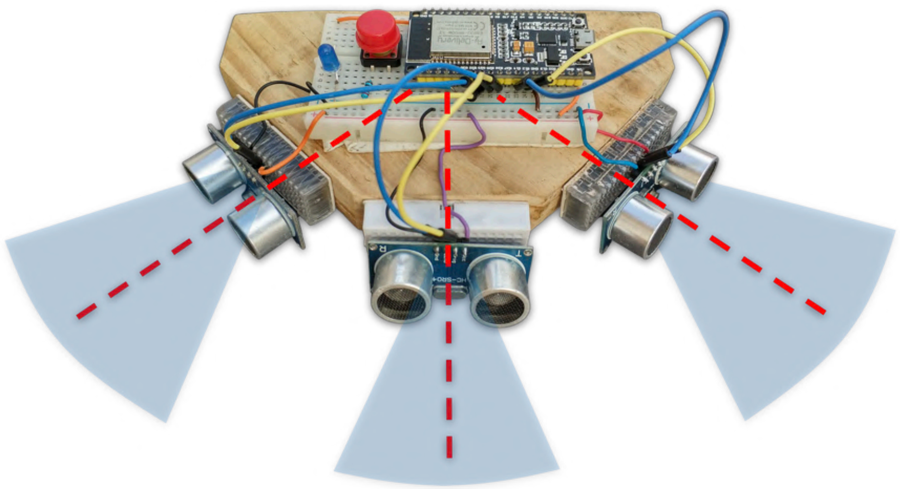


Source: R. Santil, B. Gomes, S. Paiva, S.I. Lopes, "Crowd Quantification with Flow Direction Estimation: A Low-Cost IoT-Enabled Solution", IEEE GCAIoT2021, 2021 IEEE Global Conference on Artificial Intelligence and Internet of Things (GCAIoT), Expo 2020, Dubai, 13 – 16 December, 2021.

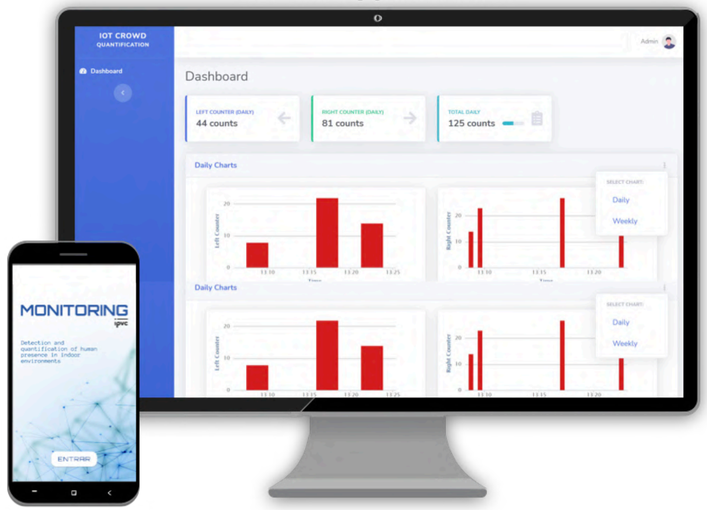
Designing IoT-driven applications

Crowd Quantification with Flow Direction Estimation

Ultrasonic Sensor Array



Client Applications



Source: R. Santil, B. Gomes, S. Paiva, S.I. Lopes, “Crowd Quantification with Flow Direction Estimation: A Low-Cost IoT-Enabled Solution”, IEEE GCAIoT2021, 2021 IEEE Global Conference on Artificial Intelligence and Internet of Things (GCAIoT), Expo 2020, Dubai, 13 – 16 December, 2021.

Final Remarks

- IoT **has a great potential to foster digitalization** and act as a **driving force for achieving the SDGs**;
- **Increasing awareness among citizens regarding sustainability** also promotes a more **sustainable citizenship**;
- Hands on experience has shown that the **deployment of such technologies is still costly**, and the **outcomes need to be considered in a mid-long term**;
- **Deployment is not the end** > **is the beginning of a new stage** > i.e. **resource exploration**;
- **IoT-as-a-Service** (**IoTaaS**) **Business Models** are flexible and may be applied by adding pieces of functionality that may be charged accordingly:
  - To enable this, things/products **need to become "network-native"** and thus allowing **over-the-air SW or FW** updates, **online support and diagnostics**, or able to **apply the latest security patches**;
  - We are still waiting for a **big wave of disruption on the business side towards IoTaaS**.

5th IEEE Internet of Things (IoT)
Vertical and Topical Summit at RWW2022

Sustainable Sensor Systems for IoT

10-15 January // Las Vegas, NV, USA

Thank you!

Sérgio Ivan Lopes (sil@estg.ipvc.pt)

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Researcher, Instituto de Telecomunicações, Aveiro, Portugal

Organization: