IEEE International Smart Cities Conference (ISC2) September 2021

Title: # AI for IoT and Smart Cities

Presenters: Kamal Singh and Guillaume Muller

Affiliation: University Jean Monnet, St-Etienne, France

IEEE Smart Cities

UNIVERSITÉ JEAN MONNET SAINT-ÉTIENNE

LABORATOIRE HUBERT CURIEN

IEEE Advancing Technology for Humanity

Presenters

Kamal Singh

Guillaume Muller

Plan

- Session 1: IoT Landscape, AI
- Session 2: Federated Learning
- Session 3: Exercises
  - Installation instructions to follow in advance
  - https://github.com/GMTSE/isc2-IoT-AI-smart-tutorial/blob/main/README.md
  - If you do not have python3.6 or above and cannot install it
    - then please download the VM
    - when VM starts then please do not select factory reset

Session 1 Plan

- IoT Landscape
- AI for IoT and Smart Cities
  - Applications
  - AI
  - Opportunity and challenges

IoT Landscape

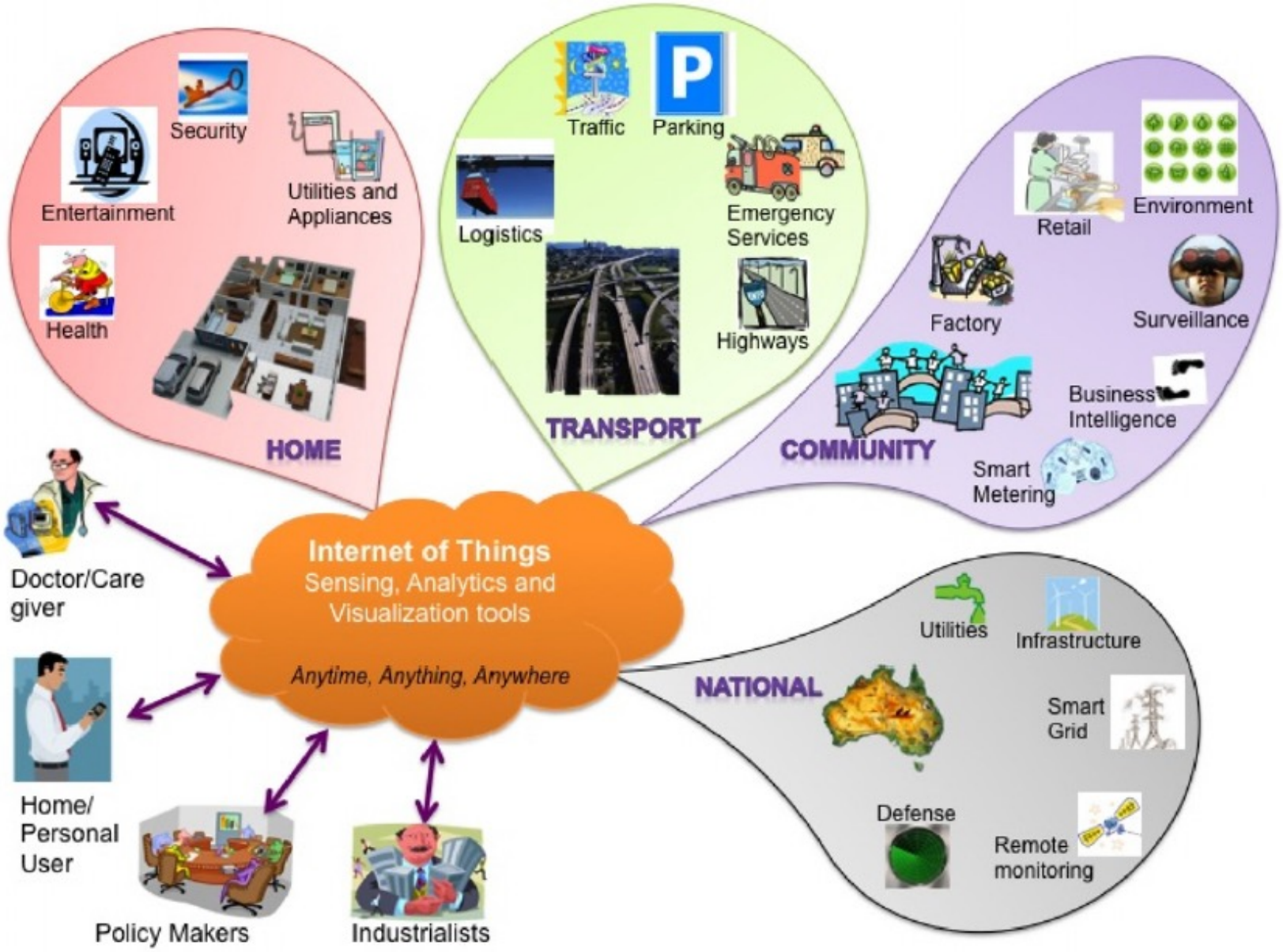
Introduction

- IoT combines different domains, the physical and digital world

- Challenge and opportunities are to create Intelligent services for our society and environment

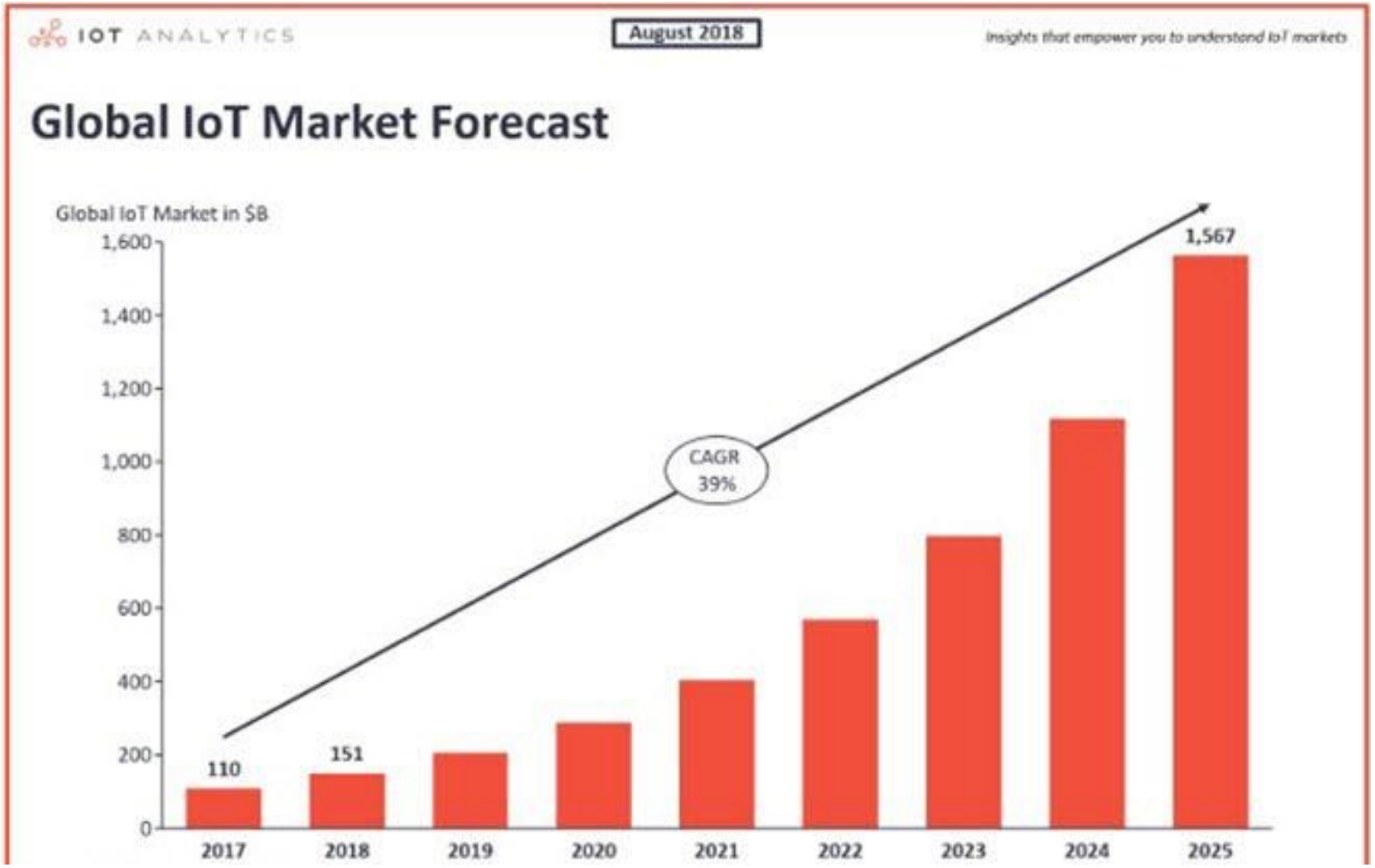
Ref: Al-Fuqaha et al., ‘’Internet of Things: A Survey on Enabling Technologies, Protocols and Applications’’

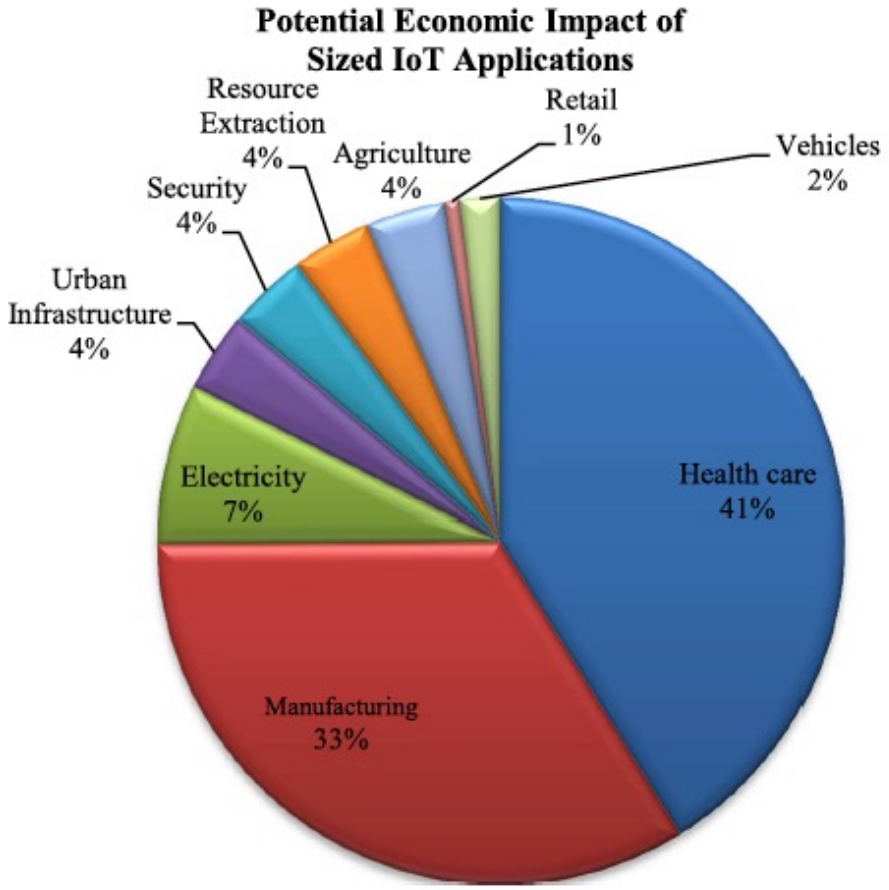
Applications



Ref: Gubbi et al., “Internet of Things (IoT): A vision, architectural elements, and future directions”

Market



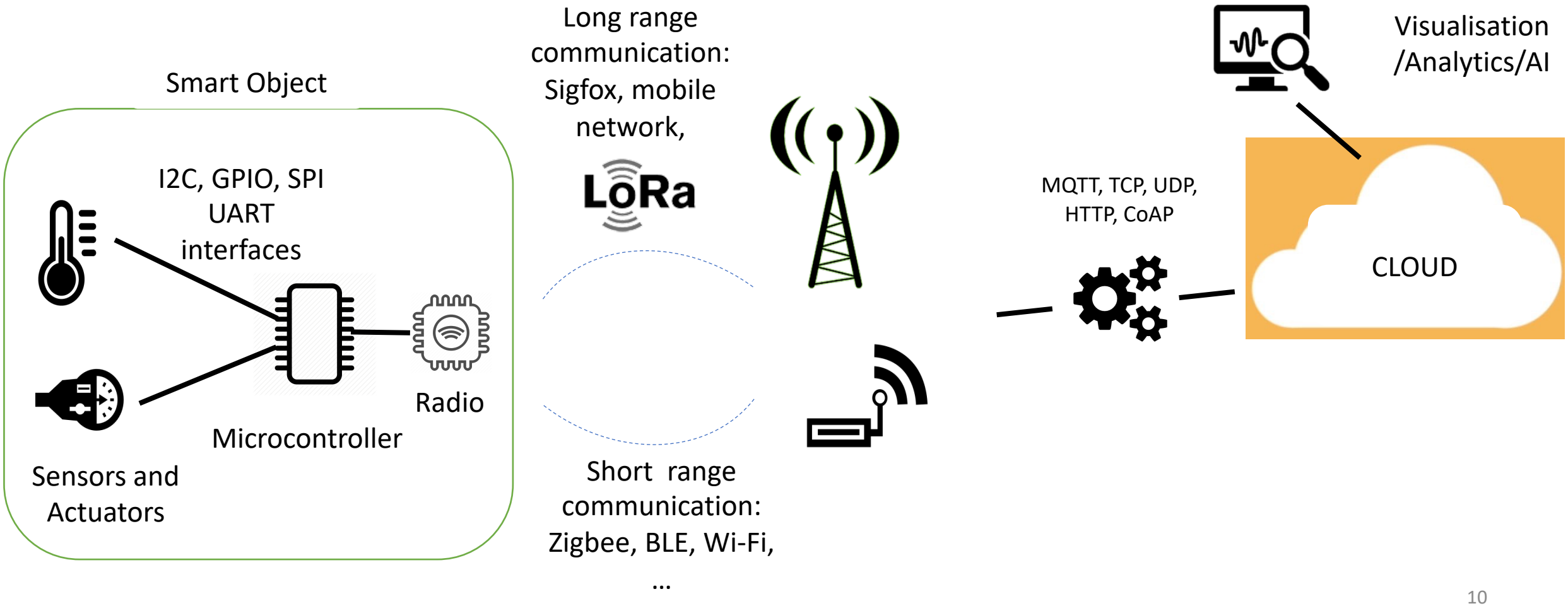


Source: IoT Analytics Research 2018

Challenges and Opportunities

- Power consumption
- Device constraints
- Latency
- Privacy
- Security

Chain


Smart Object
I2C, GPIO, SPI
UART
interfaces
Radio
Microcontroller
Sensors and
Actuators
Long range
communication:
Sigfox, mobile
network,
LoRa
Short range
communication:
Zigbee, BLE, Wi-Fi,
…
MQTT, TCP, UDP,
HTTP, CoAP
CLOUD
Visualisation
/Analytics/AI

IoT Landscape

- Device capabilities
- Communication protocols
- Computing

Plan

- IoT Landscape
  - **Device capabilities**
  - Communication protocols
  - Computing
- AI for IoT and Smart Cities
  - Applications
  - AI
  - Opportunity and challenges

Range of Boards and Microcontrollers

- Raspberry Pi
- Pycom
- Arduino
- ESP8266, ESP32
- Particle
- …

1.5GHz, 2-8 GB RAM

Pycom: 160 MHz, 520 KB RAM, 4 MB external

ESP32: 160 MHz, 520 KB RAM

Particle: 120 MHz, 128 KB RAM

Arduino Nano 33 IoT: 48 MHz, 32 KB RAM

Range of Boards and Microcontrollers …

- Memory, MCU, Power consomption, Price (ESP32: 1 to 4$!)
- AI and Image/audio based applications: Nvidia Jetson Nano, GPU with 128 CUDA cores
- AI accelarators: NPUs (Neural processing unit), ISPs (Image signal processor), and VPU (Vision processing unit, Video processing unit)

OS

	Contiki	TinyOS	FreeRTOS	Zephyr	Mbed	RIOT
Characteristics	Event Driven	Event Driven	Multi-threading, RTOS	Multi-threading, RTOS	Event Driven	Multi-threading, RTOS
Programming	C	nesC	C	C	C, C++	C, C++
License	BSD	BSD	Modified GPL	Apache 2.0	Apache 2.0	LGPLv2

Some other OS allow programming using microPython and circuitPython.

Plan

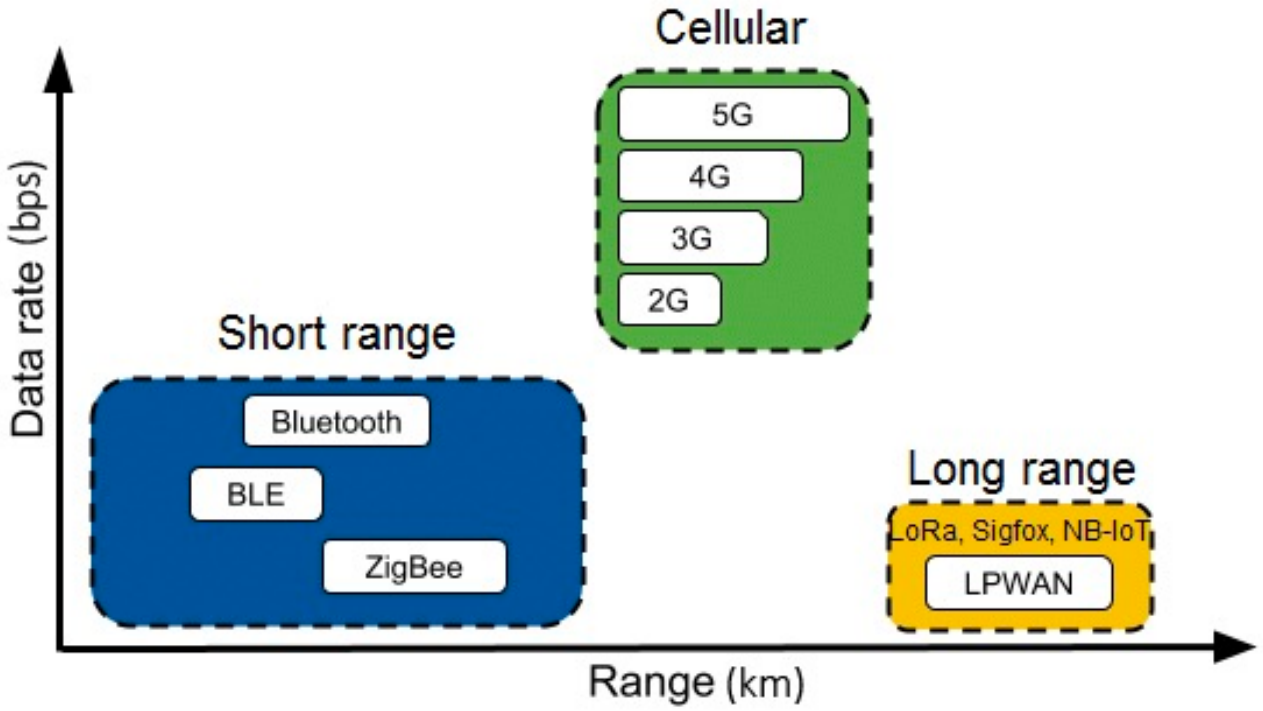
- IoT Landscape
  - Device capabilities
  - **Communication protocols**
  - Computing
- AI for IoT and Smart Cities
  - Applications
  - AI
  - Opportunity and challenges

Short Range vs Long Range Communication

Source: pngegg.com

Data rate vs distance

- Choose a technology as a function of the application



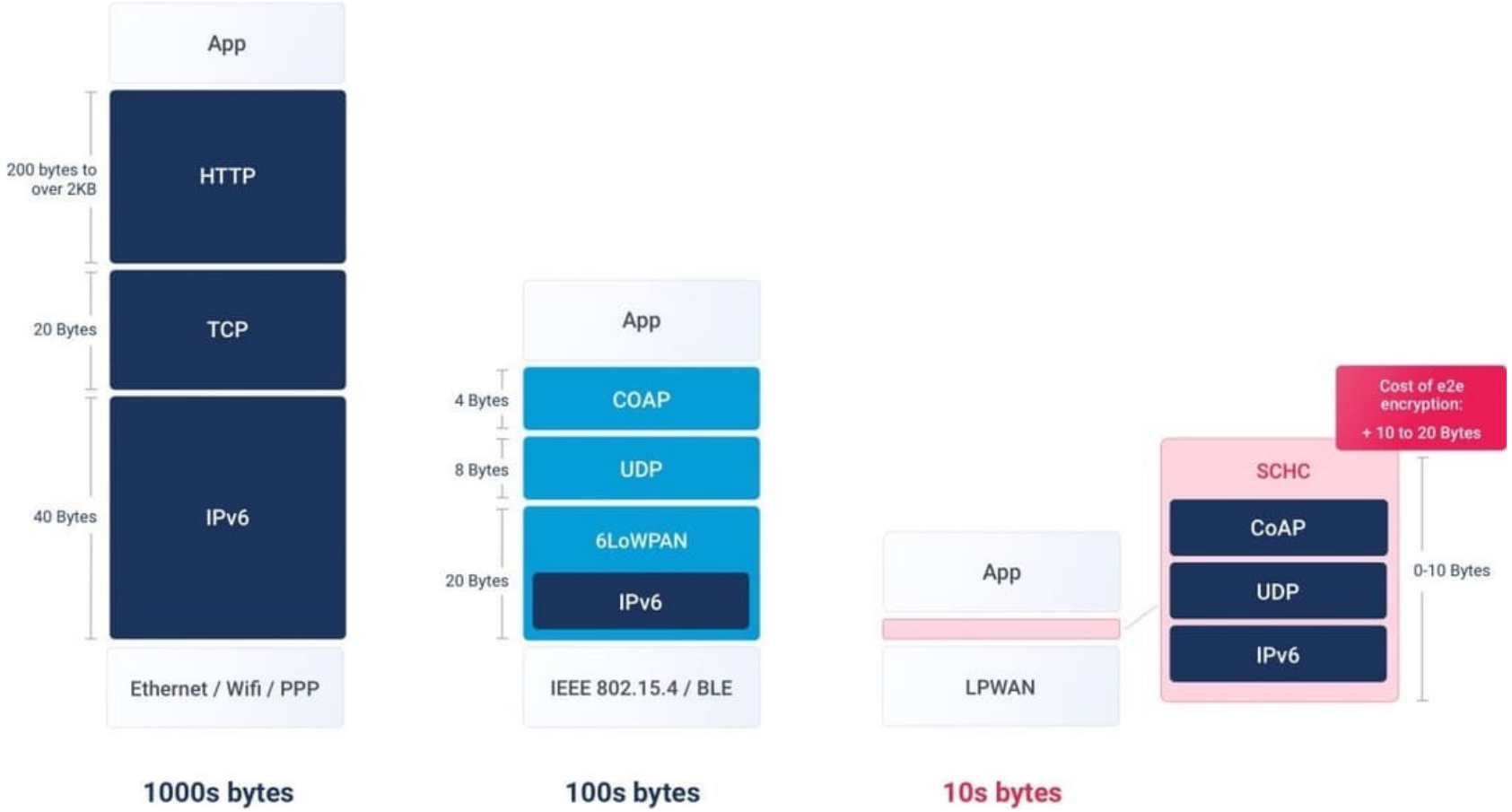
Ref: https://www.researchgate.net/figure/Range-and-data-rate-of-different-communication-technologies_fig1_332187524

LoRAWAN: open business model

- Possible to deploy a private network as well as an operator network
- An international opensource LoRAWAN network: TTN https://www.thethingsnetwork.org/

LoRAWAN, Sigfox, …: whats next?

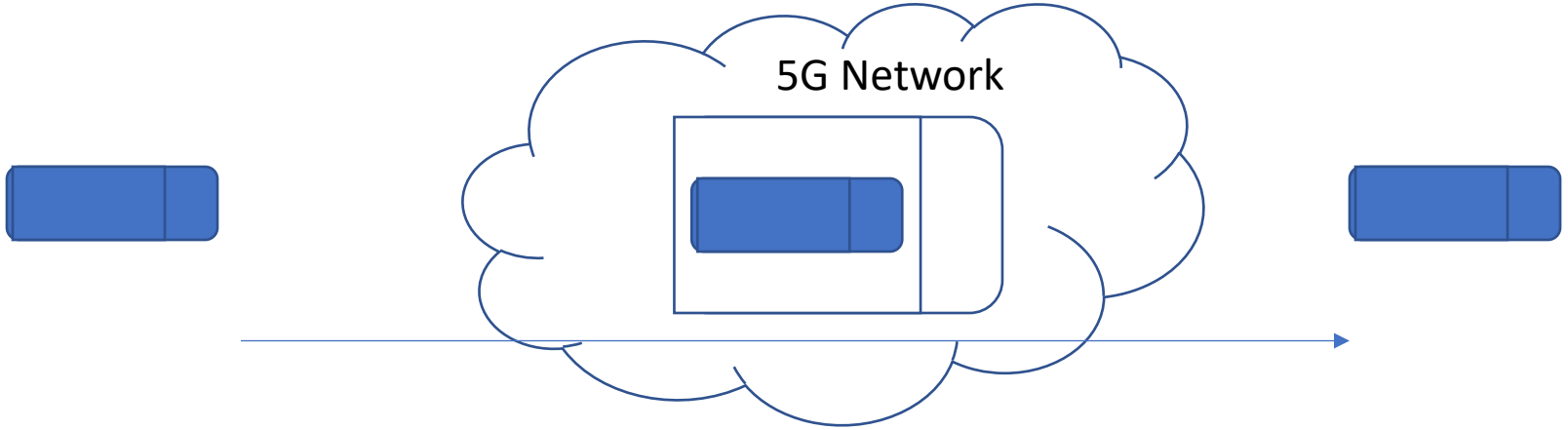
- Higher bitrates?
- IP connectivity?Header compression, RFC 9011 for LoRAWAN, a draft for sigfox, …



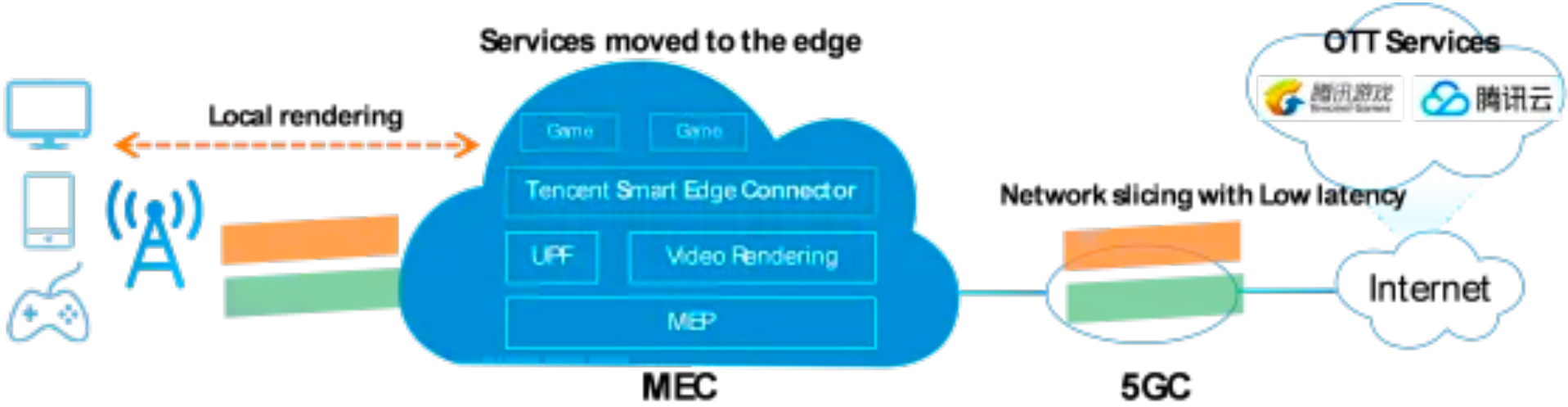
Source: www.ackl.io

What does 5G bring to IoT and Smart Cities?

- Private 5G networks
- Transport of other network protocols: Ethernet, CAN
- eURLLC for TSN (Time Sensitive Networking)
- Flexibility with the help of virtualisation and disaggregation
- Low latency with the help of Edge computing



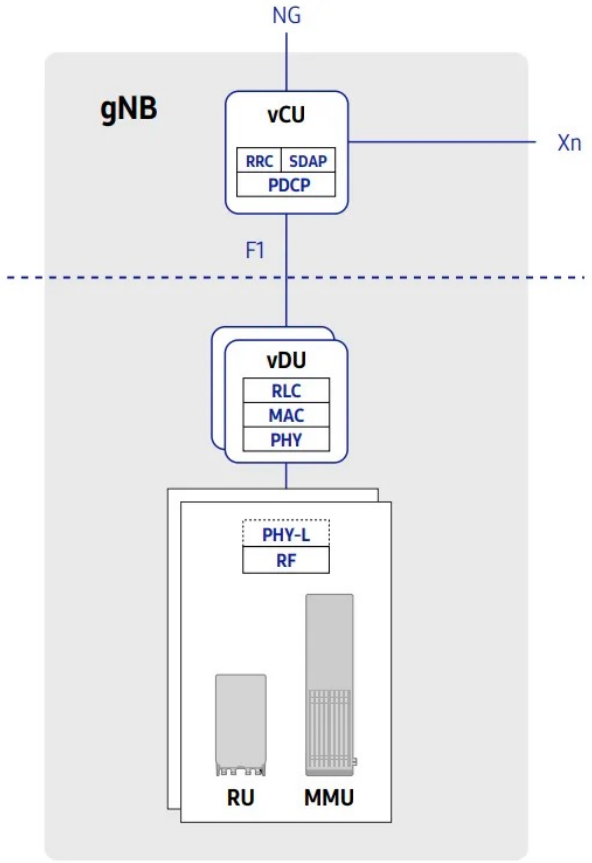
Multi-Access Edge Computing (MEC)

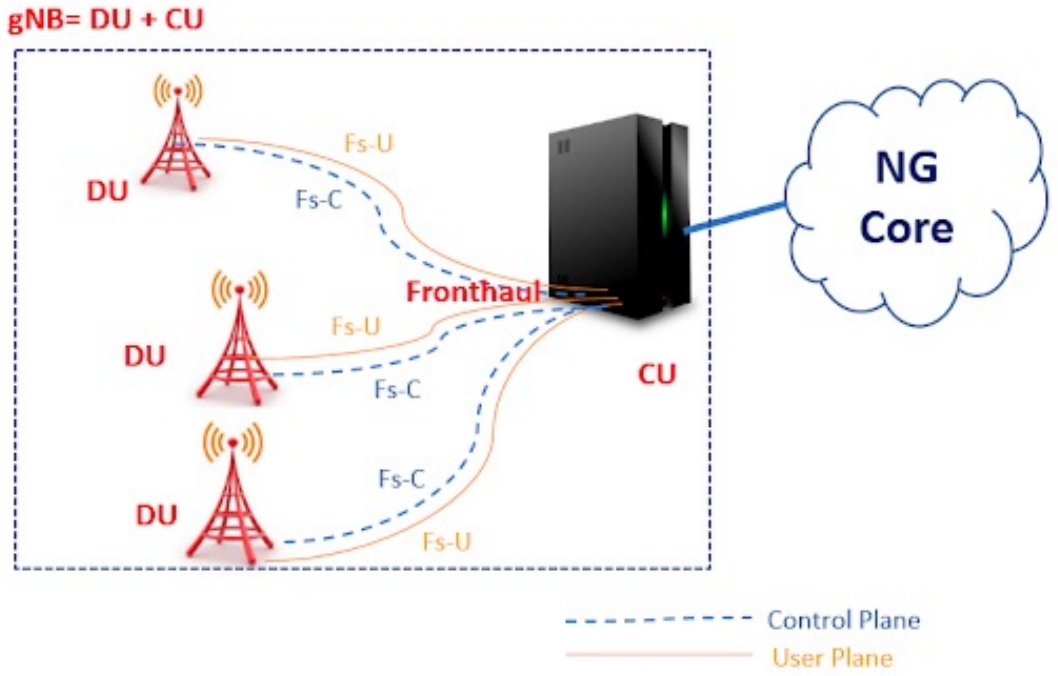


Ref: https://www.gsma.com/futurenetworks/wiki/5g-mec-based-cloud-game-innovation-practice/

Disaggregation in 5G

- gNB can be cut
- Further CU can be cut into CU-CP and CU-UP
- …



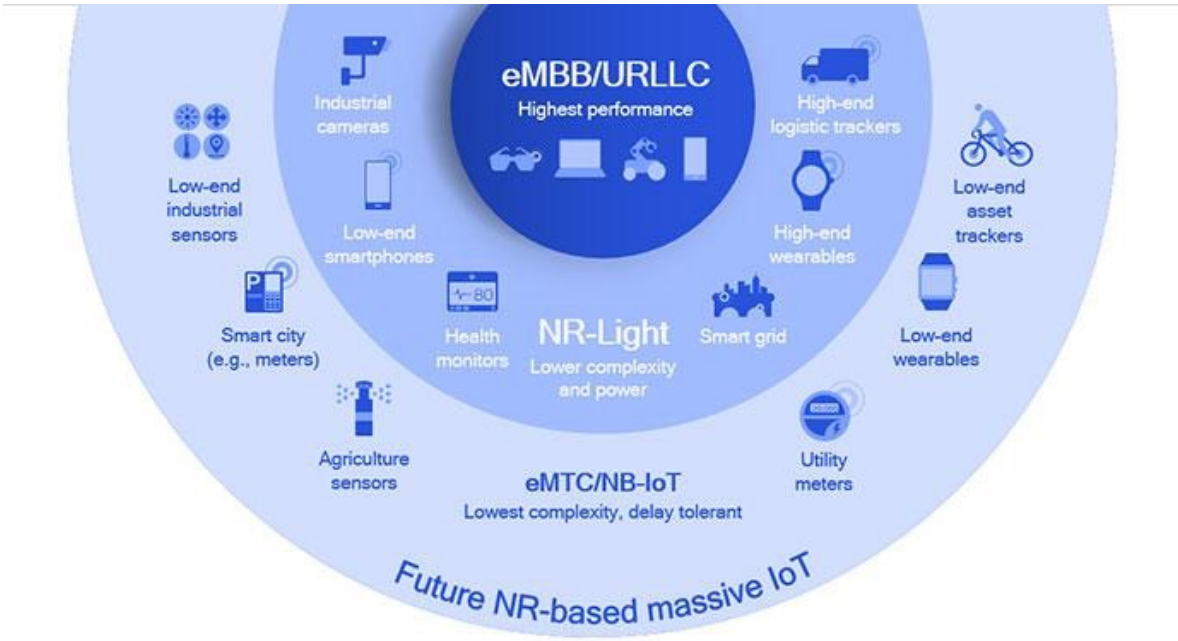


Ref: techplayon.com

Ref: https://www.5g-networks.net/5g-technology/virtualised-and-disaggregated-5g-nr-vran-architecture/

What is next for IoT and 5G/Beyond5G?

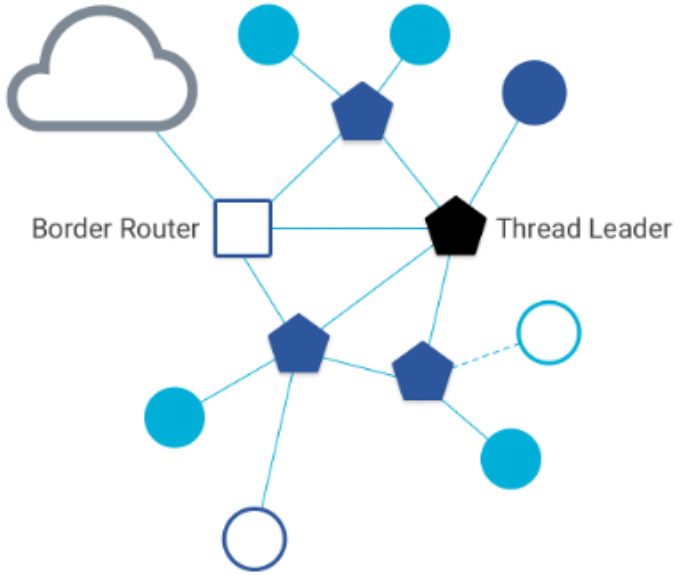
- New Radio Light (NR Light) for energy efficiency
- Massive IoT
- Support for AI applications
- eURLLC
- Precise localisation



Ref: https://www.qualcomm.com/news/onq/2020/05/12/5g-here-whats-next-internet-things

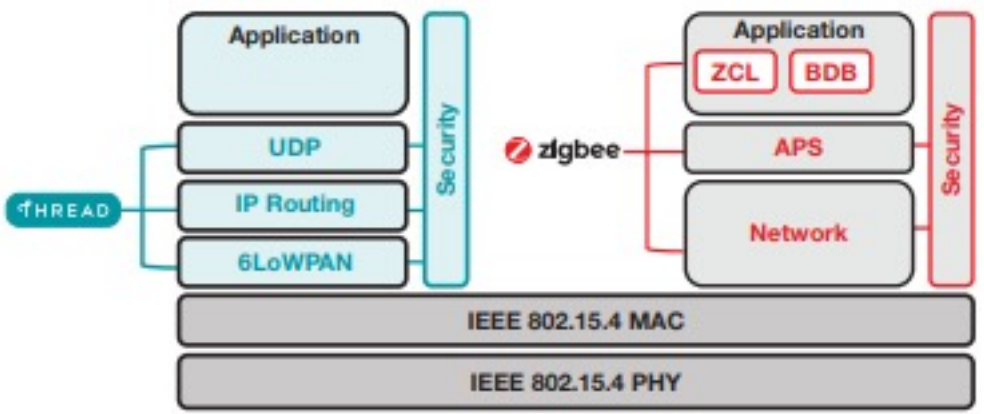
Short Range Communications

- Zigbee, Bluetooth Low Energy (BLE), Zwave, ANT, NFC …
- Relatively new protocol: Thread



Thread

- Launched in 2014 and open source in 2016. Thread group alliance includes Google, Samsung, Nest, Freescale et ARM, NXP, etc.
- Native support for IP. In comparison, Zigbee should translate its address to IP using an intelligent gateway
- Ease of authentication based on smartphone

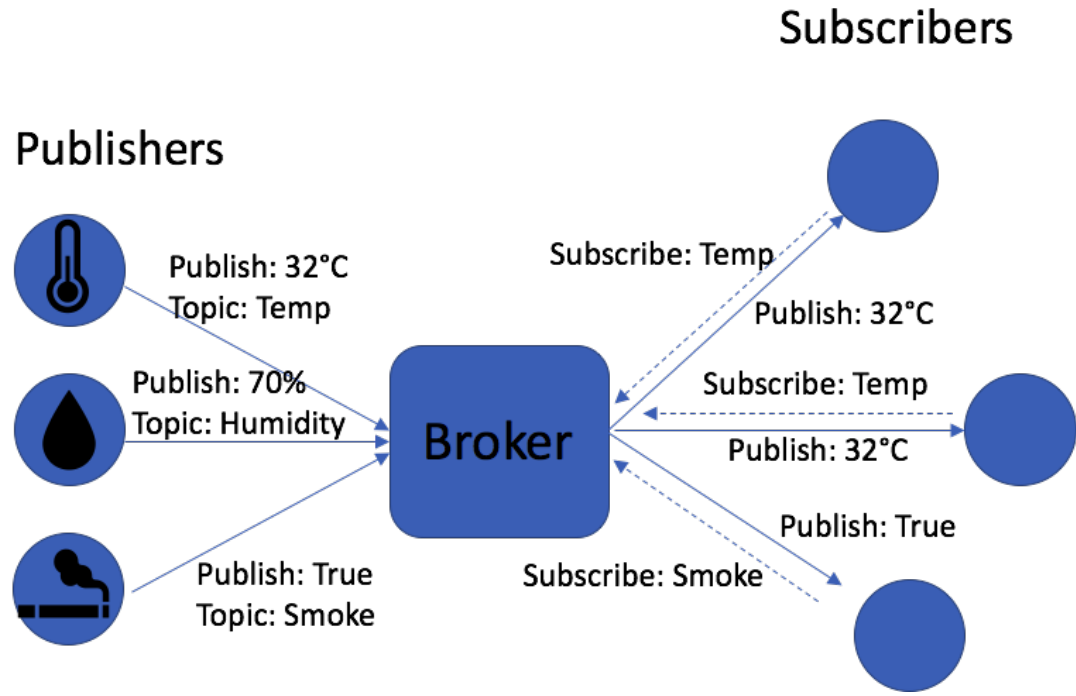


Ref: https://e2e.ti.com/blogs_/b/process/posts/thread-vs-zigbee-what-s-the-difference

Publish-Subscribe and REpresentational State Transfer(REST)

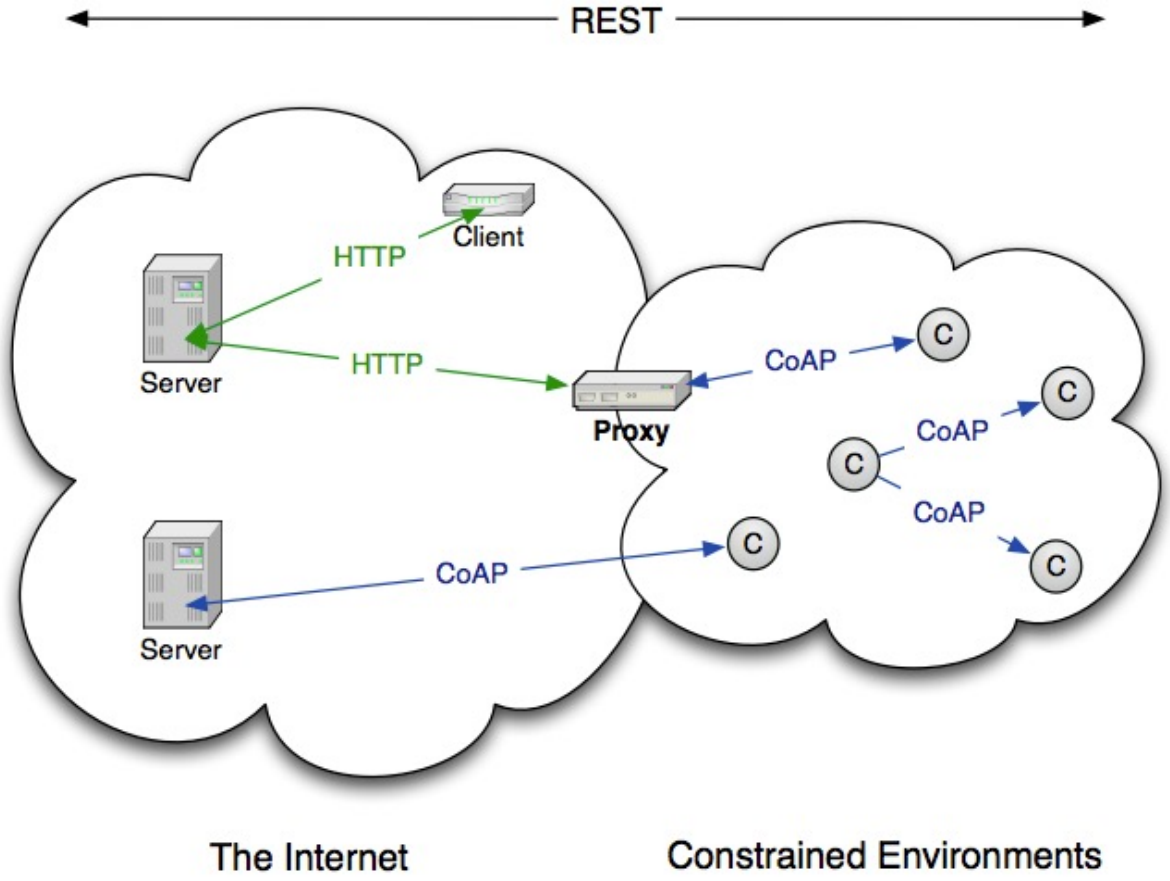
MQTT (Message Queuing Telemetry Transport)

- Publish to Topics: myhome/firstfloor/room1/tempsensor
- Subscribe using wildcards (+ or #)
  - All sensors: myhome/#
  - All tempsensors on firstfloor: /myhome/firstfloor/+/tempsensor
- Advantages/disadvantages
  - Sender and receivers are decoupled
  - Needs TCP which can be heavy for some sensors
  - A variant MQTT-SN uses UDP



CoAP (Constrained Application Protocol)

- REST APIs are very popular
- 4 bytes header, UDP, SMS (TCP)
- Security with DTLS
- Discovery
- Option Observe: useful for asynchronous observations



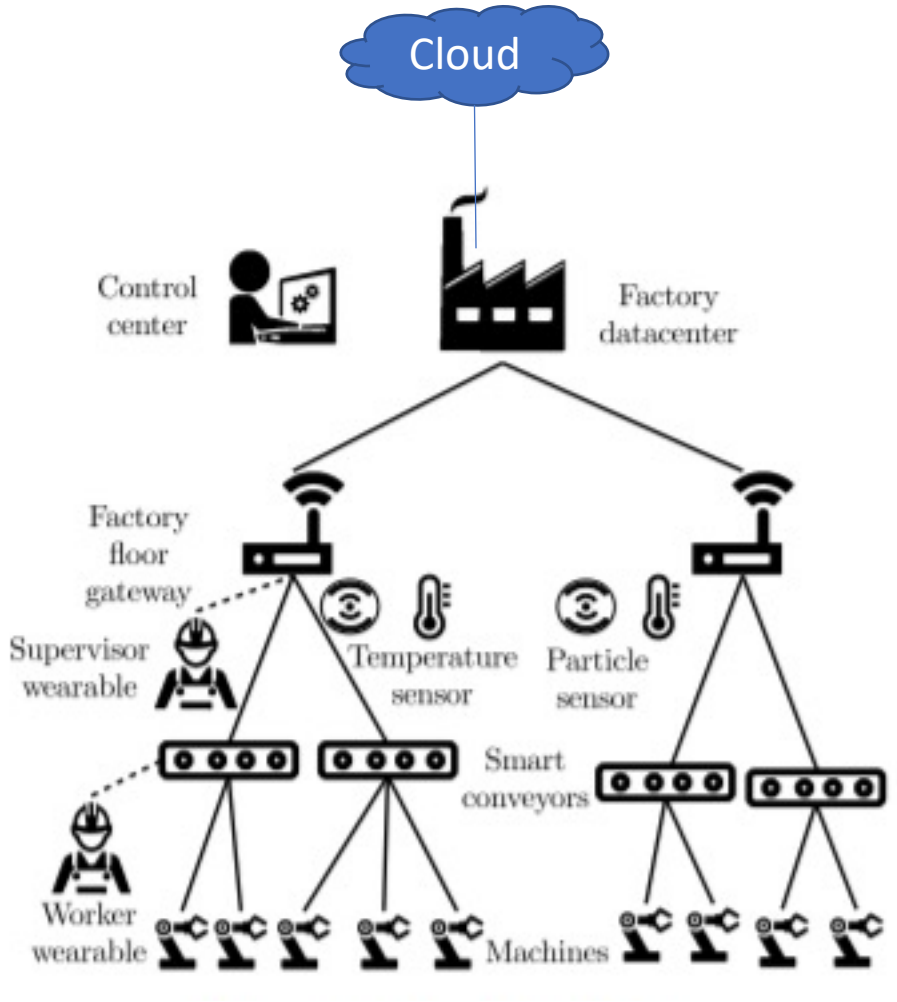
Source: ARM CoAP tutorial

Plan

- IoT Landscape
  - Device capabilities
  - Communication protocols
  - **Computing**
- AI for IoT and Smart Cities
  - Applications
  - AI
  - Opportunity and challenges

Edge Computing

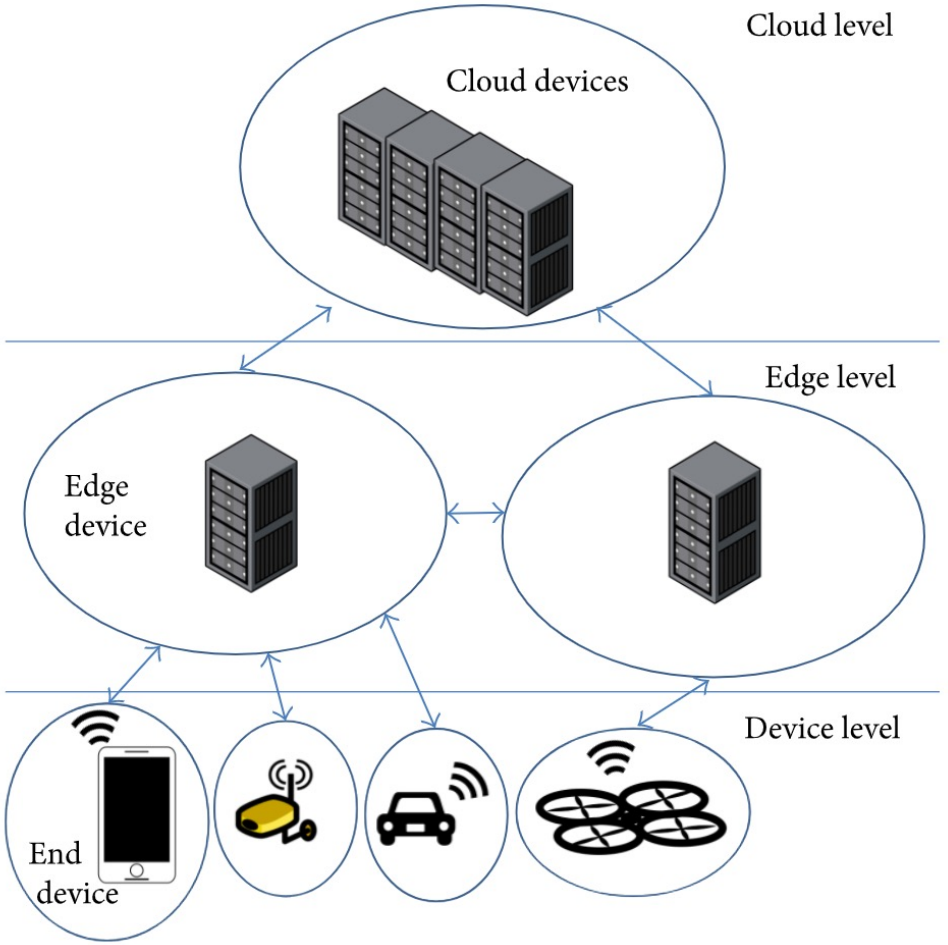
- Need for lower latency
- Local intelligence is needed
  - Instead of messages travelling to and fro from cloud



Ref: EDR: A Generic Approach for the Distribution of Rule-Based Reasoning in a Cloud-Fog continuum

Edge Computing Research challenges

- Heterogeneous environments
- Resource management
- Scalability
- Reliability, Fault tolerance
- Security, Trust



Ref: Toczé et al. “A Taxonomy for Management and Optimization of Multiple Resources in Edge Computing”

Plan

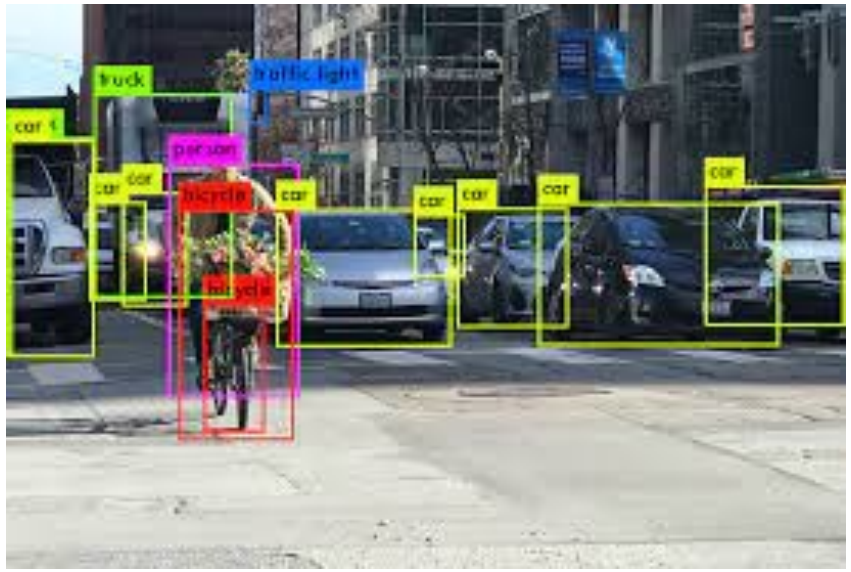
- IoT Landscape
  - Device capabilities
  - Communication protocols
  - Computing
- **AI for IoT and Smart Cities**
  - Applications
  - AI
  - Opportunity and challenges

Plan

- IoT Landscape
  - Device capabilities
  - Communication protocols
  - Computing
- AI for IoT and Smart Cities
  - **Applications**
  - AI
  - Opportunity and challenges

AI based Applications

- Camera
  - Crowd density estimation, cooling depending on no. of persons or weather, social distancing
  - Urban emergency, traffic management, driver attention
  - Face mask detection
  - Activity detection
- Audio
  - Detecting running equipment
  - Anomaly detection (car engine, machine going bad, elevator)
- Accelerometer
  - Anomaly detection, activity detection
- …



Source: YOLO software

Plan

- IoT Landscape
  - Device capabilities
  - Communication protocols
  - Computing
- AI for IoT and Smart Cities
  - Applications
  - **AI**
  - Opportunity and challenges

AI

- Symbolic
  - High level symbolic representation, semantics, human readable, logic
  - Expert systems, reasoners, etc.
- Statistical
  - Statistical and mathematical tools, data mining
  - Machine learning

Recently statistical approaches have shown good performances, i.e., deep learning

Nevertheless both are needed

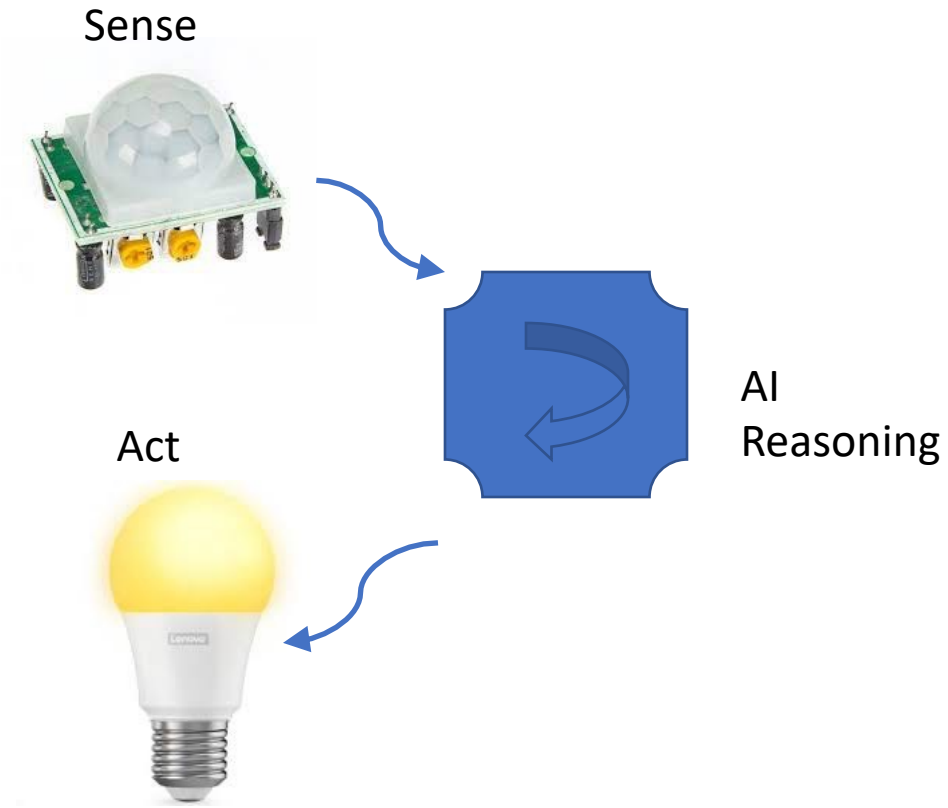
- Shifting away from symbolic AI may be a shift from explainable AI – Noam Chomski

Plan

- IoT Landscape
  - Device capabilities
  - Communication protocols
  - Computing
- AI for IoT and Smart Cities
  - Applications
  - **AI**
    - **Symbolic**
  - Opportunity and challenges

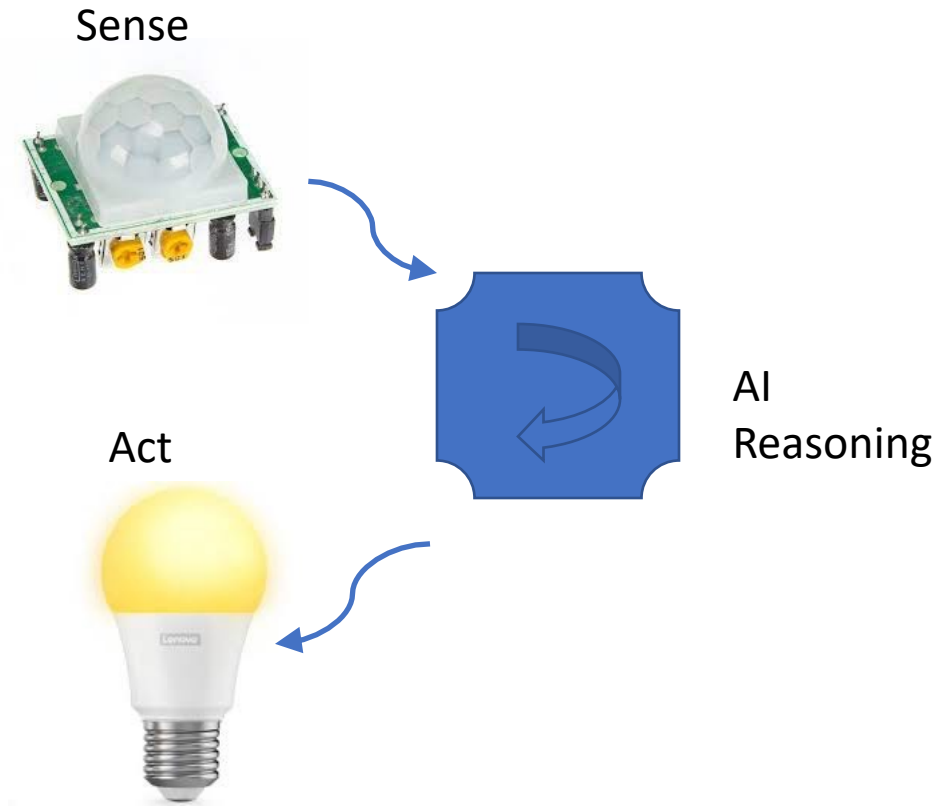
Symbolic AI: Rule based reasoning

- Example: If luminosity < 50 and presence == 1 then light the lamp



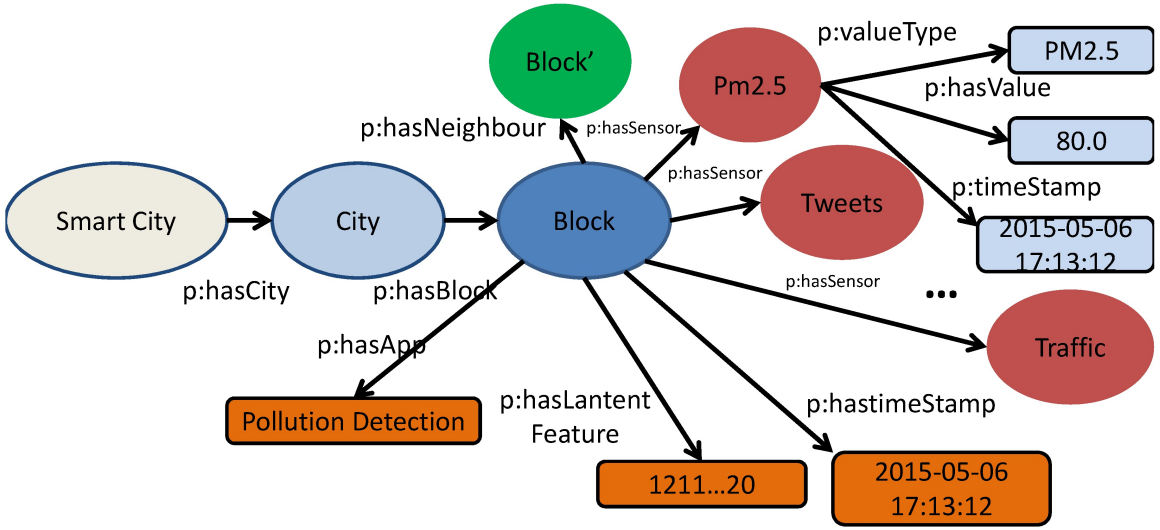
Problems to make it automatic

- How will AI recognise required concepts?
  - luminance, Presence, etc.
- Semantic interoperability between different devices?
  - pir or presence sensor?
  - Will my definitions work with other AI?
- Context?
  - Is the presence detected in the same room?



Knowledge representation, Semantics

- Ontologies: specify the concepts and relations of concepts within a domain
  - machine understandable and human readable specifications
  - being largely adopted in the industry for ***interoperability and federation***
- Knowledge graphs: using ontology as framework, we can build a graph of real data
- Reasoning and Querying can be done on graph data



Ref: Zhang et al. Semantic Framework of Internet of Things for Smart Cities: Case Studies

Some technologies and concepts

- REST allows loose coupling between devices and applications

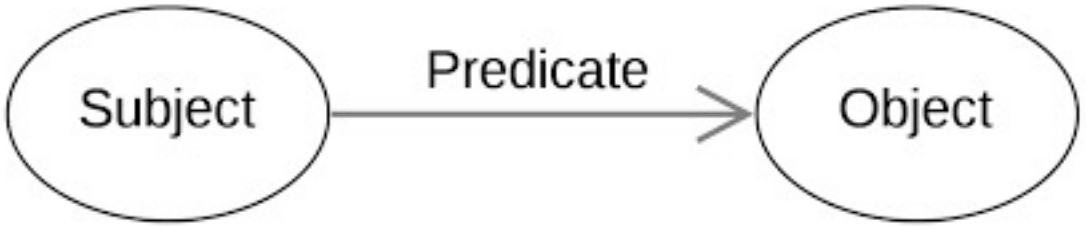
- URI: Uniform resource identifier to reference a resource

coap://192.168.1.52/capteur1/temperature?max value&date=20131206

- JSON, JSON-LD data formats

{ ”temperature” : 25} a JSON object

Resource Description Framework (RDF)



- W3C standard data model
- Triple: subject, predicate (property), object

Paris is capital of France (p:Paris p:Capital p:France .)

p: is prefix abbreviation for “http://example.org/data.ttl#”

- Multiple triples can be combined to form a graph

SPARQL (SPARQL Protocol And RDF Query Language)

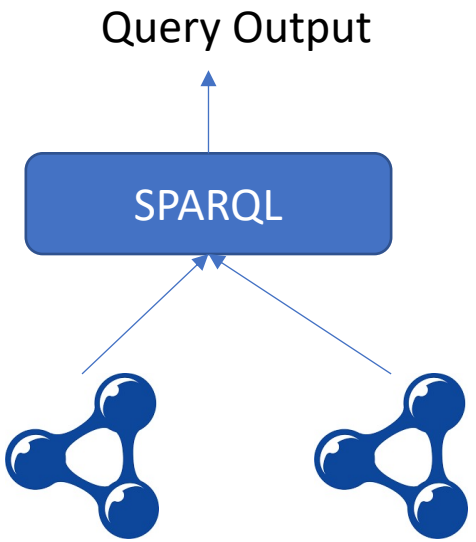
```
PREFIX p: <http://example.org/data.ttl#>
SELECT ?city
FROM <http://example.org/data.ttl>
WHERE {
        (Some conditions for example city marked as polluted)
}
```

Prefix declarations

Result saught

Dataset

Query pattern



You can test different queries on a big pubic knowledge graph: https://dbpedia.org/sparql

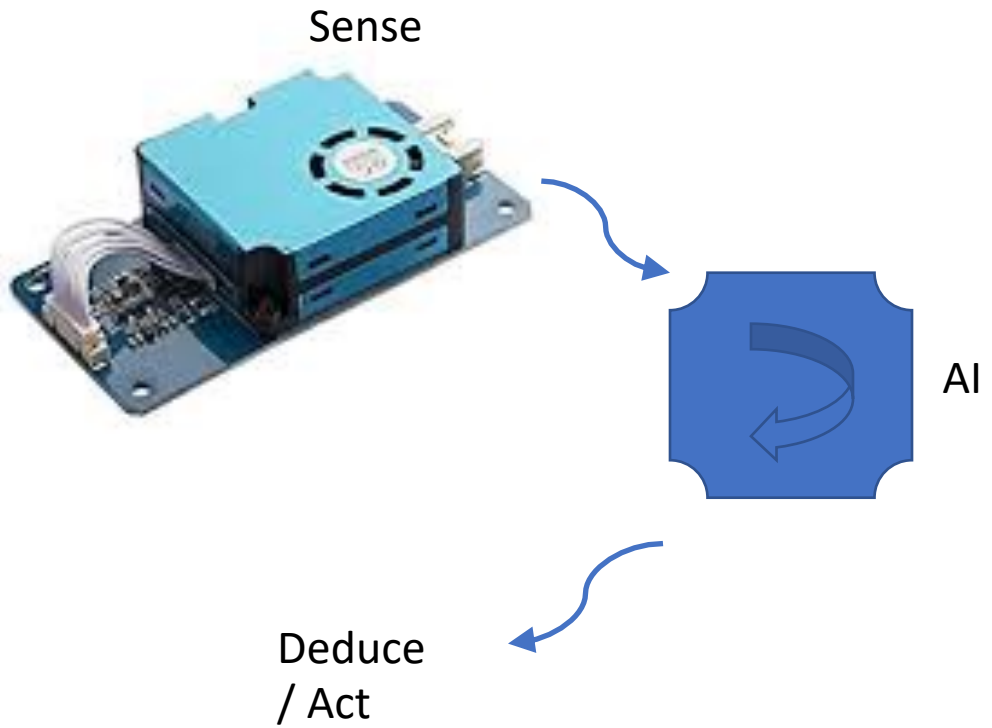
Rule based reasoning for inference and deductions

If PM2.5 is more than 50

then city is polluted

IF PM2.5 is more than 150

then city is very polluted



Reasoners: RETE, RDFox, Hermit, Jena (contains many modules)

Constrained semantic web of things (CoSWoT)

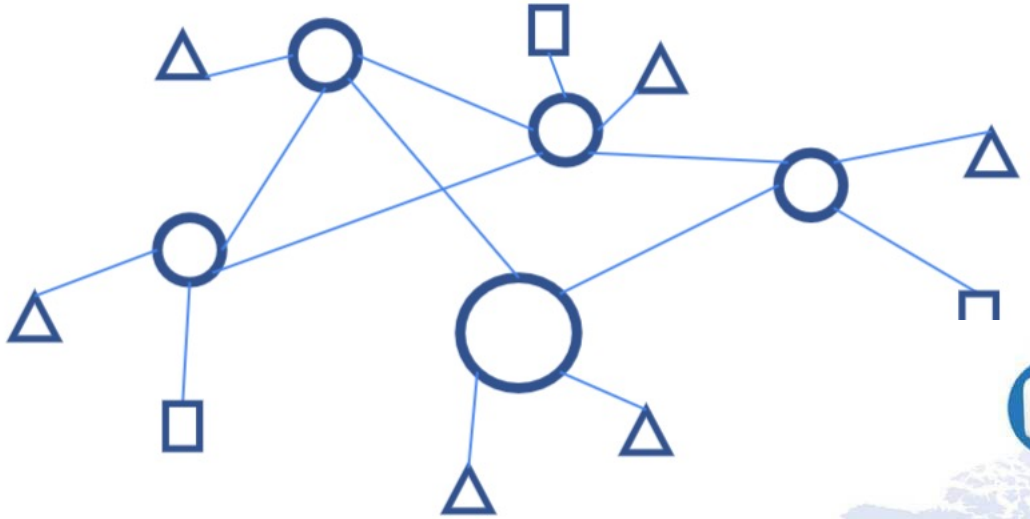
French national project to design WoT application platform able to:

(1) use graph-based **knowledge models**
(2) distribute and process **reasoning** tasks among heterogeneous nodes, including **constrained devices**

Will enable the development and execution of traceable and decentralised smart WoT applications despite the heterogeneity of devices

Use cases

- Smart buildings
- Agriculture

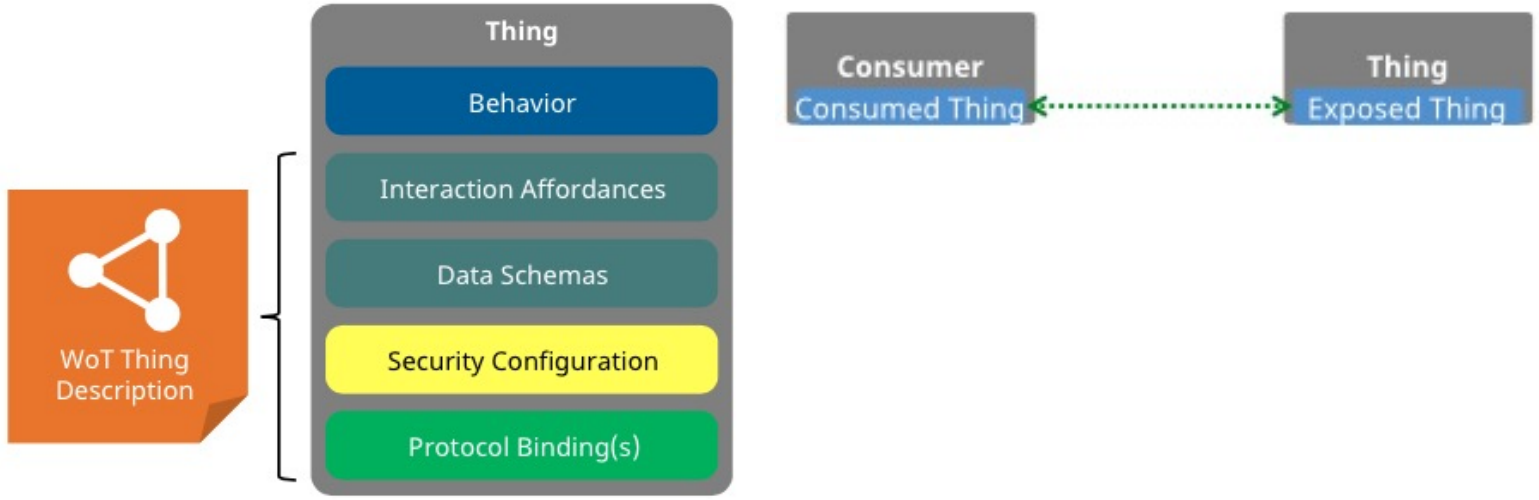


CoSWoT

- **We are Hiring!** Postdoc on distributed reasoning for web of things
  - Requirements: PhD in computer science
- Email: kamal.singh@univ-st-etienne.fr
- For info on the project:
- https://coswot.gitlab.io/

Frameworks and ontologies

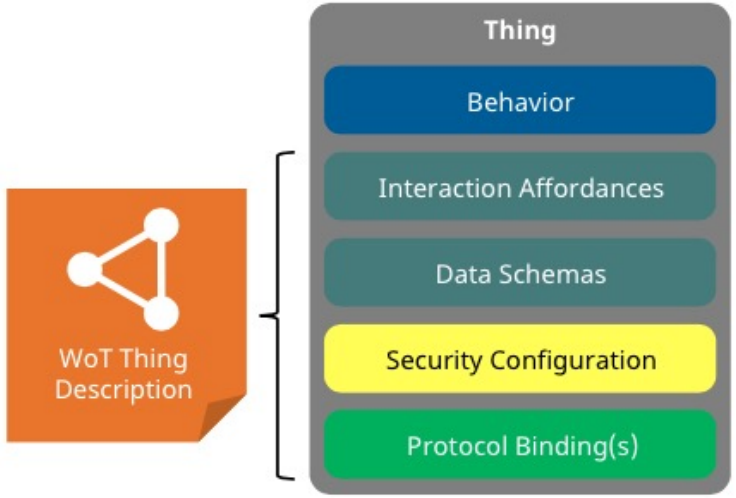
W3C
Web of things

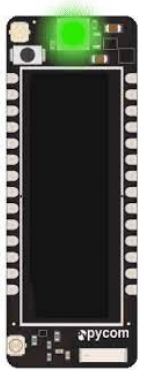


- **WoT vs IoT**: WoT works on application layer while IoT on Network Layer.
- The **Web of Things (WoT)** is application layer software that allows real-world objects to be a part of the Web.
- WoT architecture standardised by W3C: thing, Things Description, consumer, ...

Web of Things: Things Description (TD)

- A formal description of meta-data and interfaces of a Thing.
- Defines ways of interactions with a thing:
  - properties
  - actions
  - events
- Example - a thing (1 RGB LED, a temperature sensor)
  - properties: temperature, RGB LED color
  - action: change color …





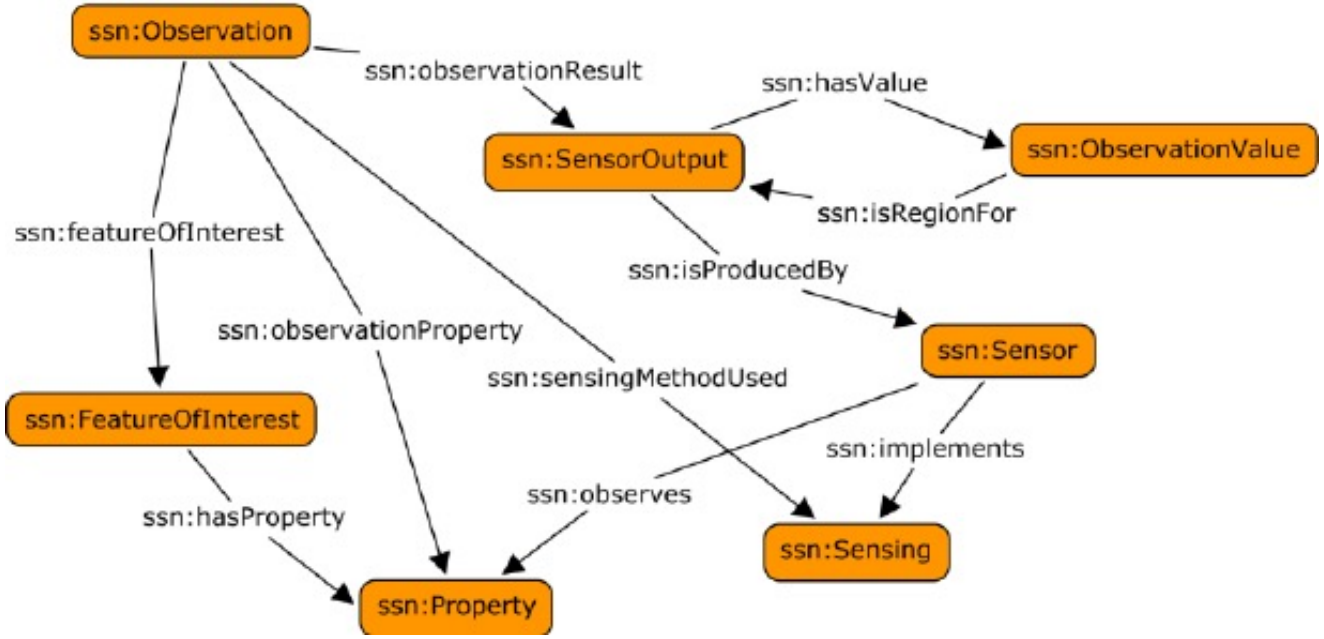
Web of Things: Things Description (TD)


```
{
  "@context": "https://www.w3.org/2019/wot/td/v1",
  "id": "urn:dev:ops:pysense-rgb-led-1234",
  "title": "PYSENSE-RGB-LED",  "description": "RGB LED on Pysense",
  "securityDefinitions": {"nosec_sc": {"scheme": "nosec"}},
  "security": ["nosec_sc"],
  "base": "http://192.168.0.17/"
  "properties": {
     'color": {
        "title": "Color", "description": "The color of the LED",
        "links": [{"rel": "property", "href": "/properties/color"}],
        "@type": "ColorProperty",  "type": "integer"
      },
       "temperature": {
        "title": "Temperature",  "description": "The temperature sensor value",
        "links": [{"rel": "property", "href": "/properties/temperature"}],
        "@type": "Temperature", "type": "number"
      },
  "actions": {
     "changecolor": {
        "title": "Change Color",  "description": "Change the color of LED",
        "links": [{"rel": "action", "href": "/actions/changecolor"}],
        "input": {"required": ["color"],
        "properties": {"color": {"minimum": 0, "maximum": 16777215, "type": "integer"}},
        "@type": ["ColorControl"], "type": "object"
     },
```


HTTP GET or PUT to http://192.168.0.17/properties/color

Other frameworks and ontologies

- oneM2M (machine to machine)
- SAREF (devices, sensors, actuators)
- OPC Unified Automation (architecture for industrial automation)
- SSN/SOSA (sensors, observations)



Plan

- IoT Landscape
  - Device capabilities
  - Communication protocols
  - Computing
- AI for IoT and Smart Cities
  - Applications
  - **AI**
    - **Machine learning**
  - **Opportunity and challenges**

Machine Learning

- Supervised, unsupervised, semi-supervised
- Traditional: SVM, RF, Xboost, Reinforcement learning, etc.
- Neural Networks
  - Deep Learning,
  - Auto-encoders, VAE
  - Deep Reinforcement learning
- Distributed learning, Federated learning

ML details in session 2

Plan

- IoT Landscape
  - Device capabilities
  - Communication protocols
  - Computing
- AI for IoT and Smart Cities
  - Applications
  - AI
  - **Opportunity and challenges**

Research challenges for Knowledge Representation and Reasoning

- Embedded reasoning
  - RDF, Reasoners, SPARQL can be heavy for embedded devices
  - For the moment they are realised on the cloud
- Edge computing platforms are needed
- Can they be implemented on embedded devices?
  - Project CoSWoT
- Can we do efficient reasoning on streams and real time data?
  - Project CoSWoT

Embedded ML Challenges

- How to fit ML models into embedded devices?
  - Quantisation / sometimes floating point is not supported
  - For example see Microsoft Research: https://github.com/microsoft/EdgeML
- Problem of obtaining labels
  - Semi-supervised or unsupervised techniques
  - VAE, anomaly detection
- Privacy
  - Federated learning

Thanks!