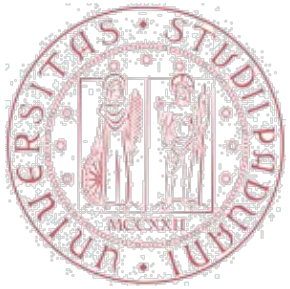

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Internet of Things for Smart Cities: vision and reality

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SIGnals processing &
NETworking research group

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The reason why I'm here…

- In the top-100 most downloaded papers in IEEEXplore since May 2014
- 1st ranked till May 2016

What's the reason of such a great success?

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Honey for bees

Internet of Things for Smart Cities

Andrea Zanella, *Senior Member*, *IEEE*, Nicola Bui, Angelo Castellani,
Lorenzo Vangelista, *Senior Member*, *IEEE*, and Michele Zorzi, *Fellow*, *IEEE*

***Abstract*—The Internet of Things (IoT) shall be able to incorporate transparently and seamlessly a large number of different and heterogeneous end systems, while providing open access to selected subsets of data for the development of a plethora of digital services. Building a general architecture for the IoT is hence a very complex task, mainly because of the extremely large variety of devices, link layer technologies, and services that may be involved in such a system. In this paper, we focus specifically to an urban IoT system that, while still being quite a broad category, are characterized by their specific application domain. Urban IoTs, in fact, are designed to support the Smart City vision, which aims at exploiting the most advanced communication technologies to support added-value services for the administration of the city and for the citizens. This paper hence provides a comprehensive survey of the enabling technologies, protocols, and architecture for an urban IoT. Furthermore, the paper will present and discuss the technical solutions and best-practice guidelines adopted in the Padova Smart City project, a proof-of-concept deployment of an IoT island in the city of Padova, Italy, performed in collaboration with the city municipality.**

sensors, actuators, displays, vehicles, and so on, the IoT will foster the development of a number of applications that make use of the potentially enormous amount and variety of data generated by such objects to provide new services to citizens, companies, and public administrations. This paradigm indeed finds application in many different domains, such as home automation, industrial automation, medical aids, mobile healthcare, elderly assistance, intelligent energy management and smart grids, automotive, traffic management, and many others [2].

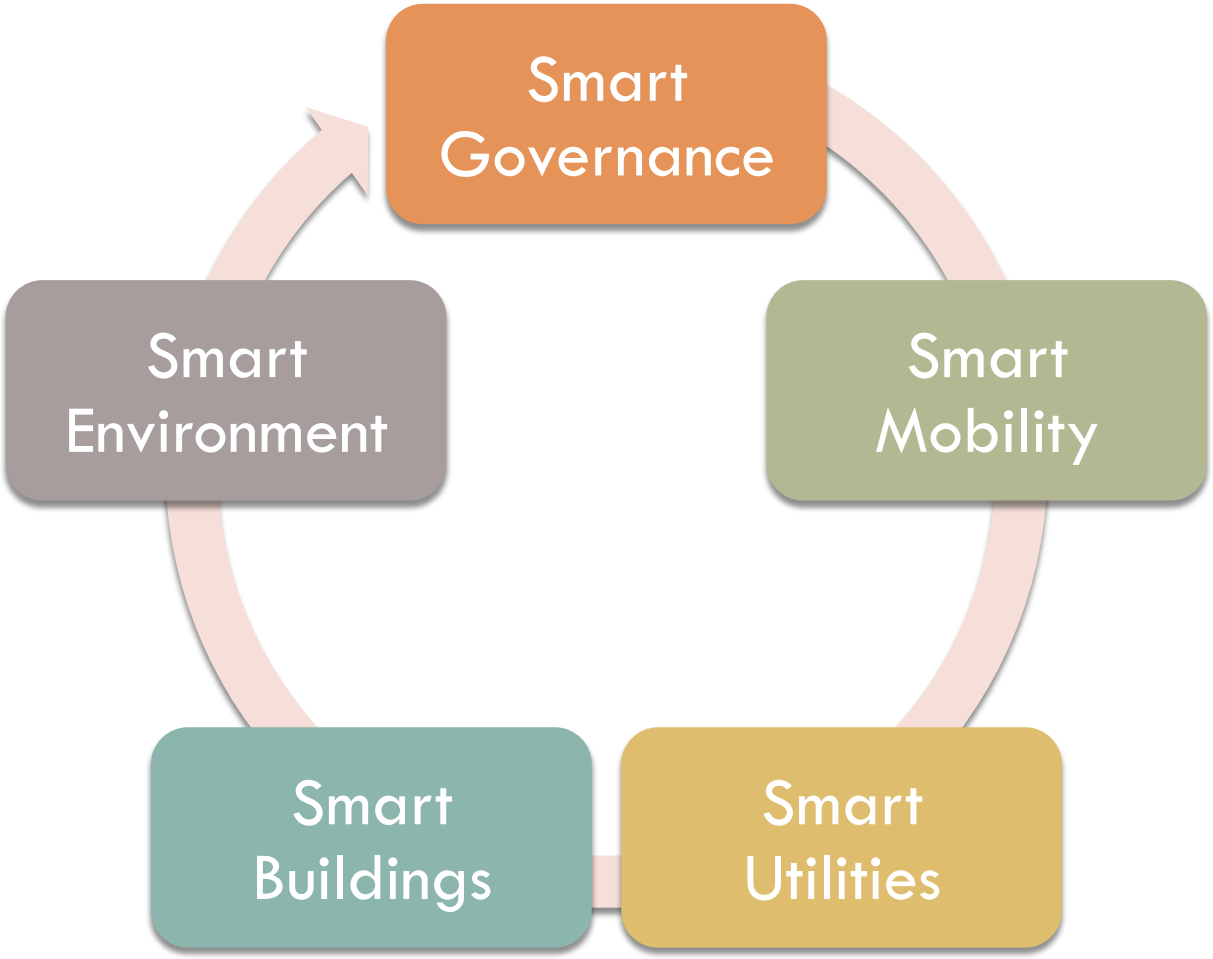
However, such a heterogeneous field of application makes the identification of solutions capable of satisfying the requirements of all possible application scenarios a formidable challenge. This difficulty has led to the proliferation of different and, sometimes, incompatible proposals for the practical realization of IoT systems. Therefore, from a system perspective, the realization of an IoT network, together with the required backend network services and devices, still lacks an established best practice because

The Business Perspective

- **Cisco**
  - The estimated market of $**14.4 Trillion** up for grabs in the coming decade
- **Intel**
  - IoT brought about $**2 billion** of the company's $12.8 billion in revenue in 2013, which equated to 32% growth year over year
- **IBM**
  - Since 2003 IBM spent over $**50 billion** on acquisitions and R&D in preparation for a radical shift in IBM's business

Smart Cities concept

Smart city ecosystem



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Smart City services

A few examples

Smart buildings

- Monitoring of conditions of (historical) building
  - Polluting levels
  - Humidity/temperature
  - Vibrations
  - Tension sensors in the structure

- Improve energy efficiency
  - Control temperature, humidity, lighting to enhance comfort while reducing costs
- Keep an eye on structural health of the building
  - E.g., schools…

Waste management

- Intelligent waste containers
  - Detect level of load
  - Check quality of garbage
  - Communicate with Internet
- Optimize collector trucks route
  - Reduce costs
  - Improve efficiency
  - Reduce pollution

Environmental monitoring

- The 20-20-20 European Union directive targets:
  - 20% reduction of greenhouse gas emissions by 2020
  - 20% cut of energy consumption
  - 20% increase of use of renewable energy sources
- Sensors can monitor
  - Air quality
  - Climate conditions (temperature, humidity, wind speed, solar lighting,…)
  - Noise level

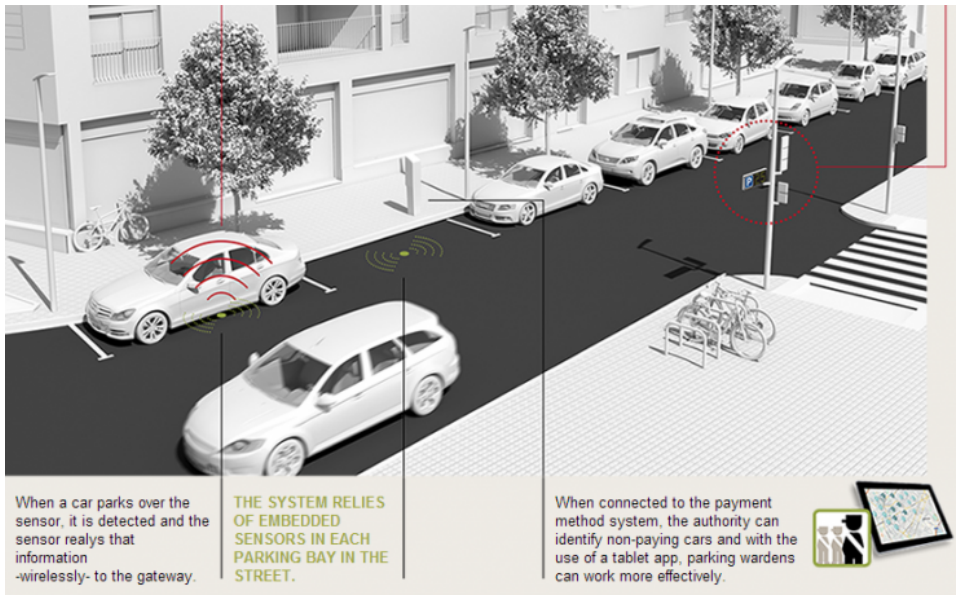
Traffic monitoring

- Many cities already use traffic monitoring cameras in critical points
- Real time accurate traffic monitoring can help
  - administration to discipline traffic and better public transport services
  - citizens to better plan their trip to office
  - street police to promptly detect anomalies in traffic
- Furthermore, traffic flows tell a lot about the city
  - Number and origin of inbound/outbound commuters
  - Crossing traffic
  - City night life…

Smart Parking

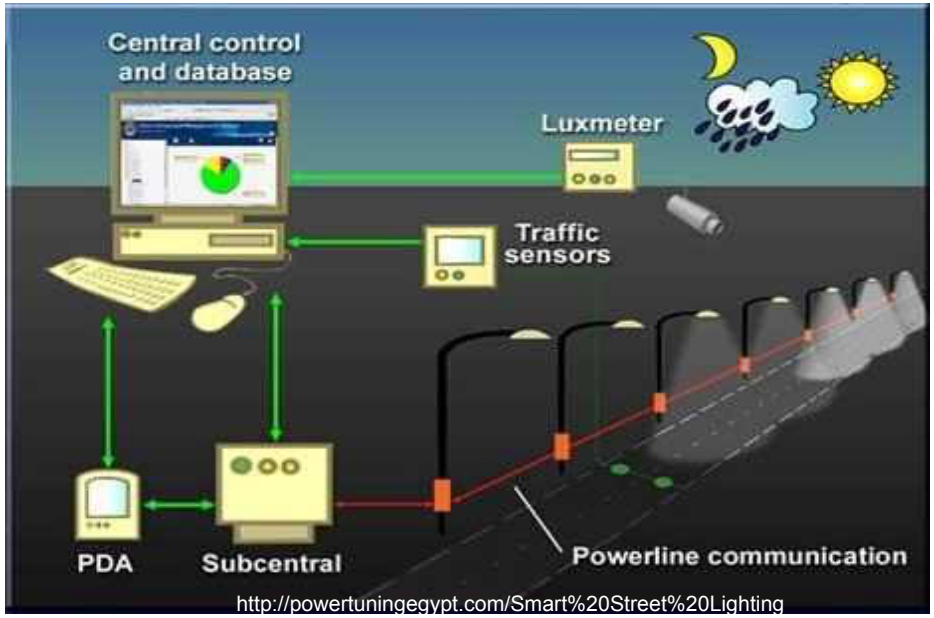
Images taken from worldsensing.com webpage

- Smart parking
  - Place sensors on each parking lot
  - Place intelligent boards along the streets
  - Provide app for smartphones



Smart lighting

- Place sensors on street lamps along the road
- Optimize the light intensity according to
  - Time of the day
  - weather conditions
  - presence of people
- Automatically find burned bulbs
  - Reduce replacement time
  - Reduce costs
- Provide WiFi access



Smart City Service Requirements

- **Place-&-Play**
  - Ubiquitous coverage
  - Zero-configuration
- **Low Cost**
  - Simple Hardware
  - Massive production
- **Little maintenance**
  - Very long battery life
  - Very low fault rate
  - Remote control/ reprogramming

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Technologies

http://www.keepcalmstudio.com/gallery/poster/L90JKS

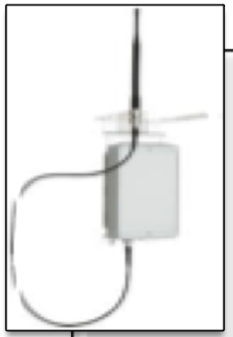
Three main approaches

Short-range multihop

- ZigBee
- WiFi low energy
- RFID

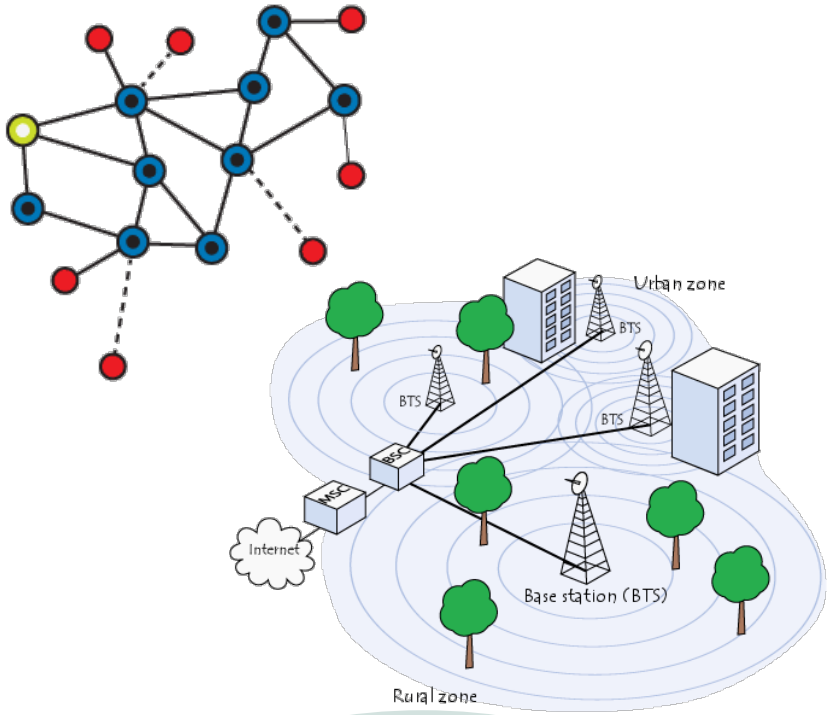
Cellular

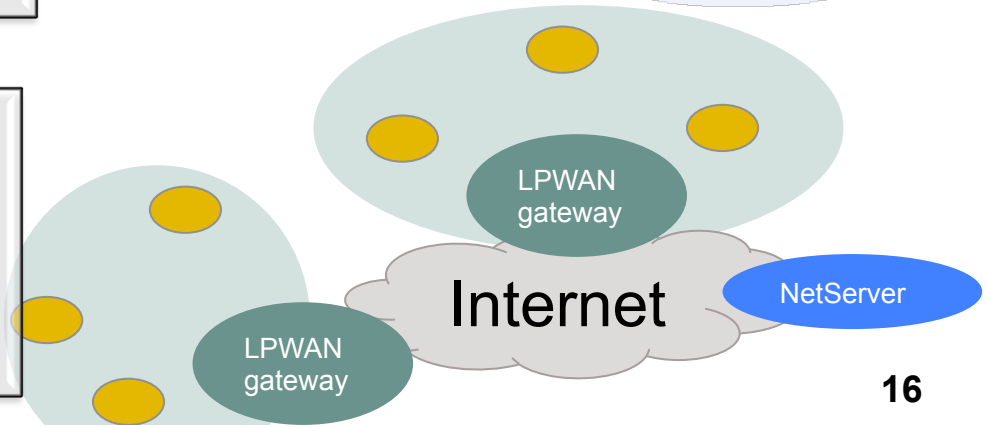
- GSM
- LTE-A
- 5G



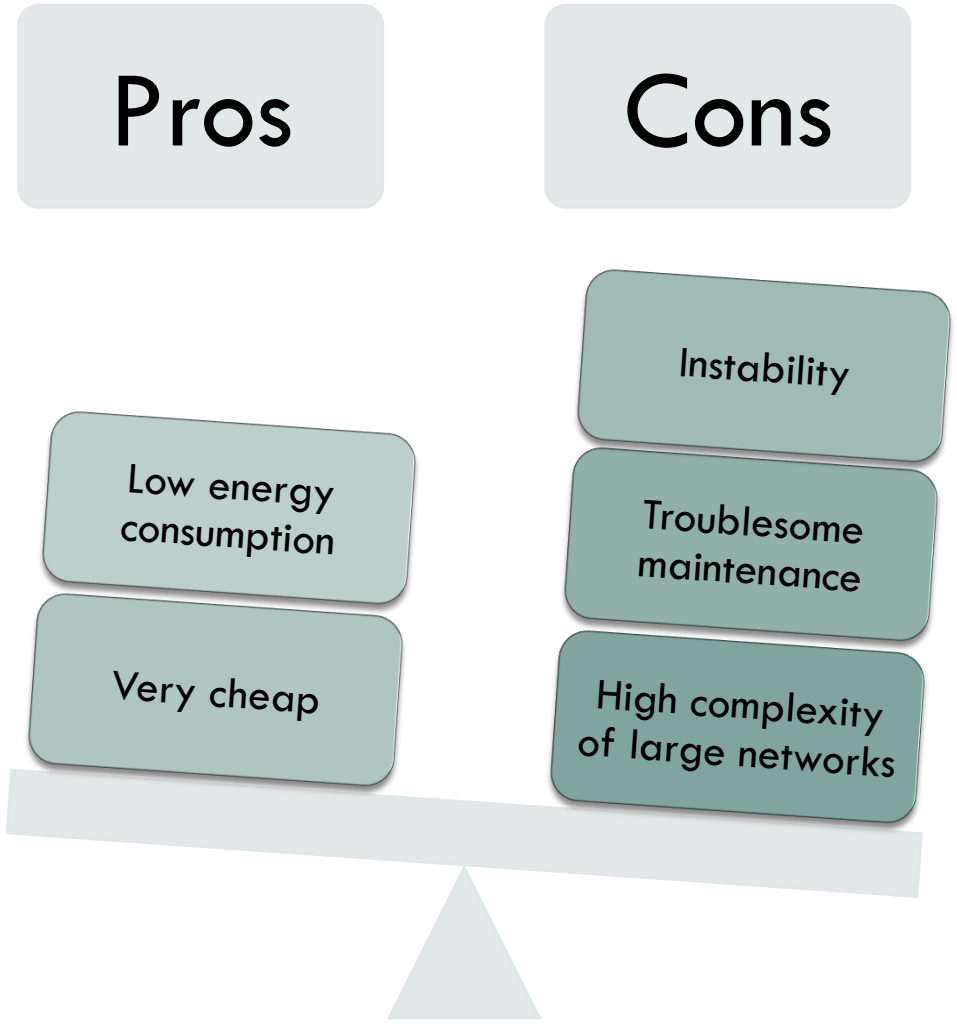
Low Power Wide Area Networks (LPWAN)

- SIGFOX
- Neul
- LoRa

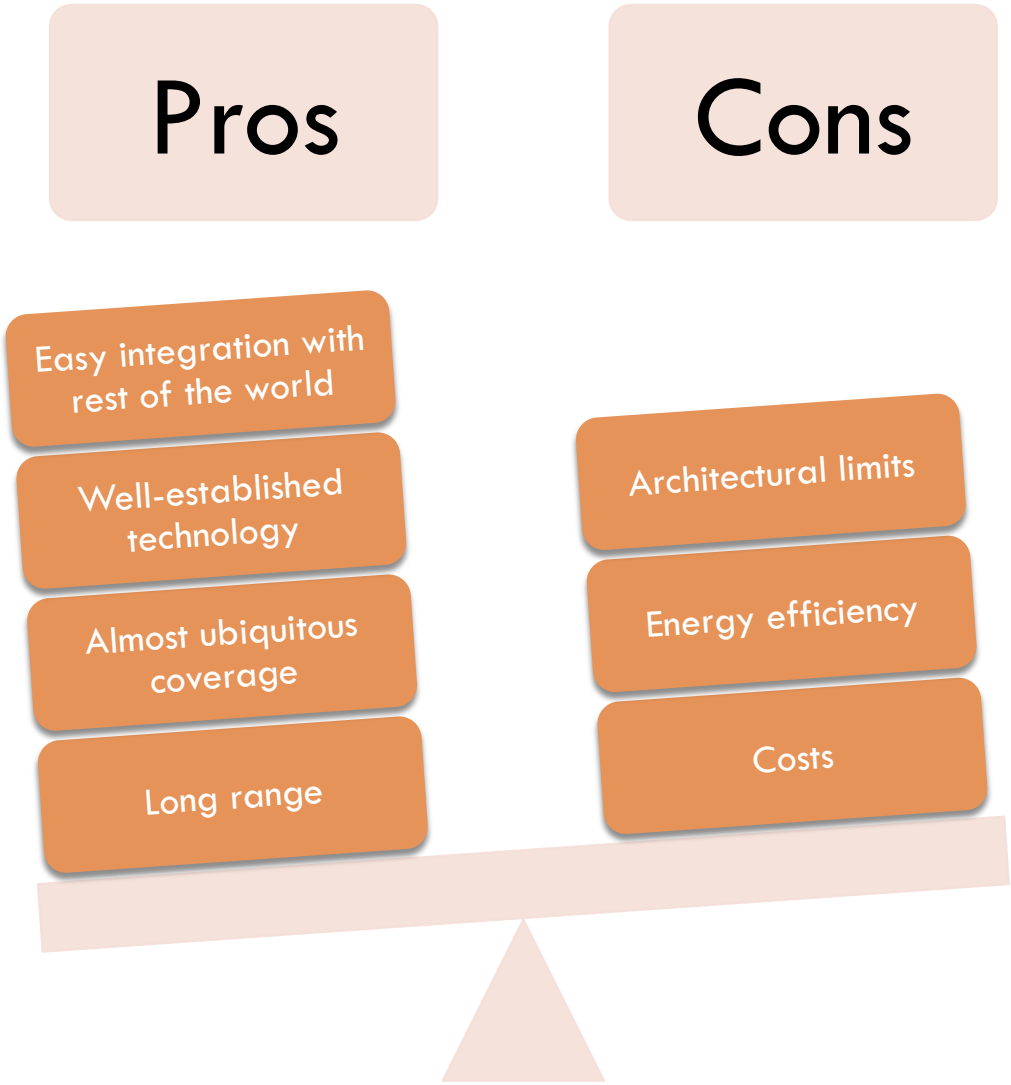




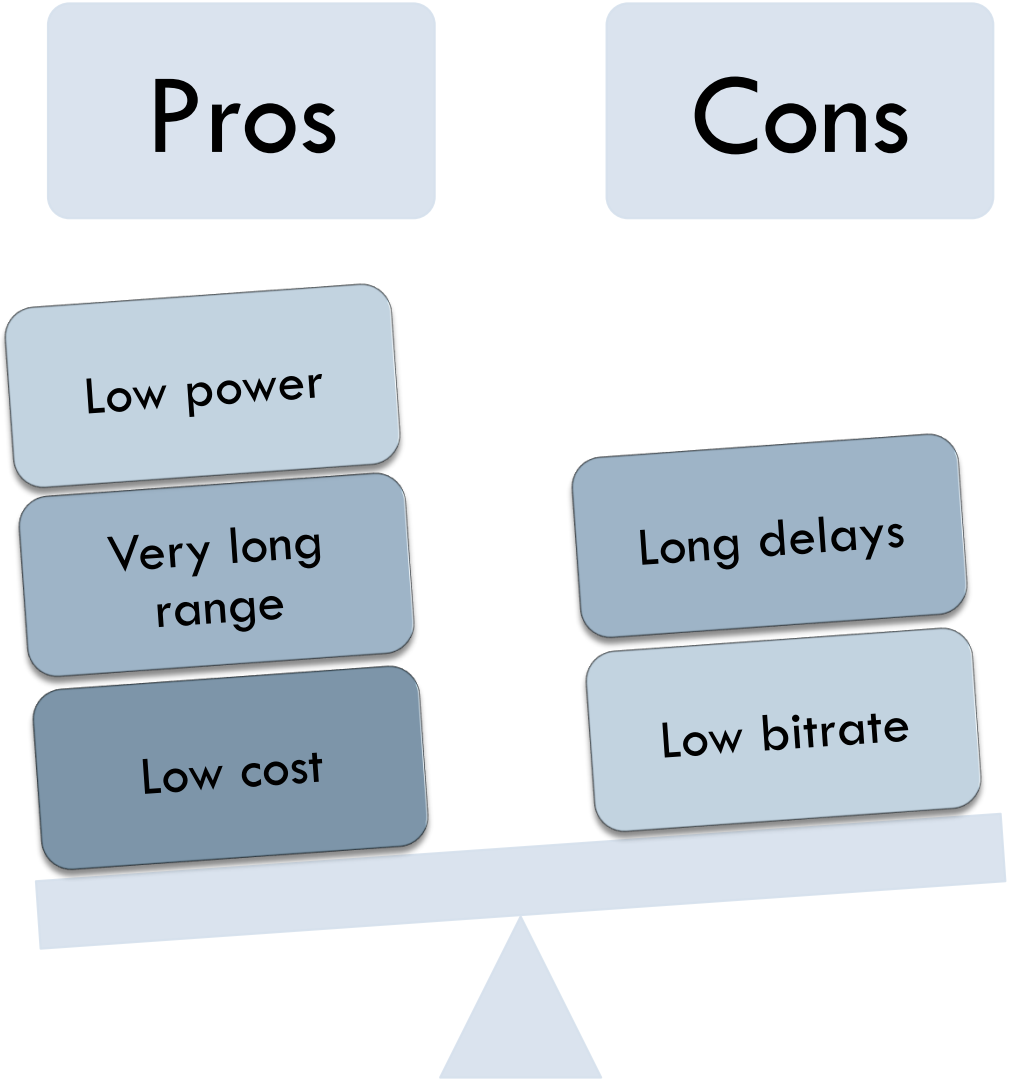
Short range multihop



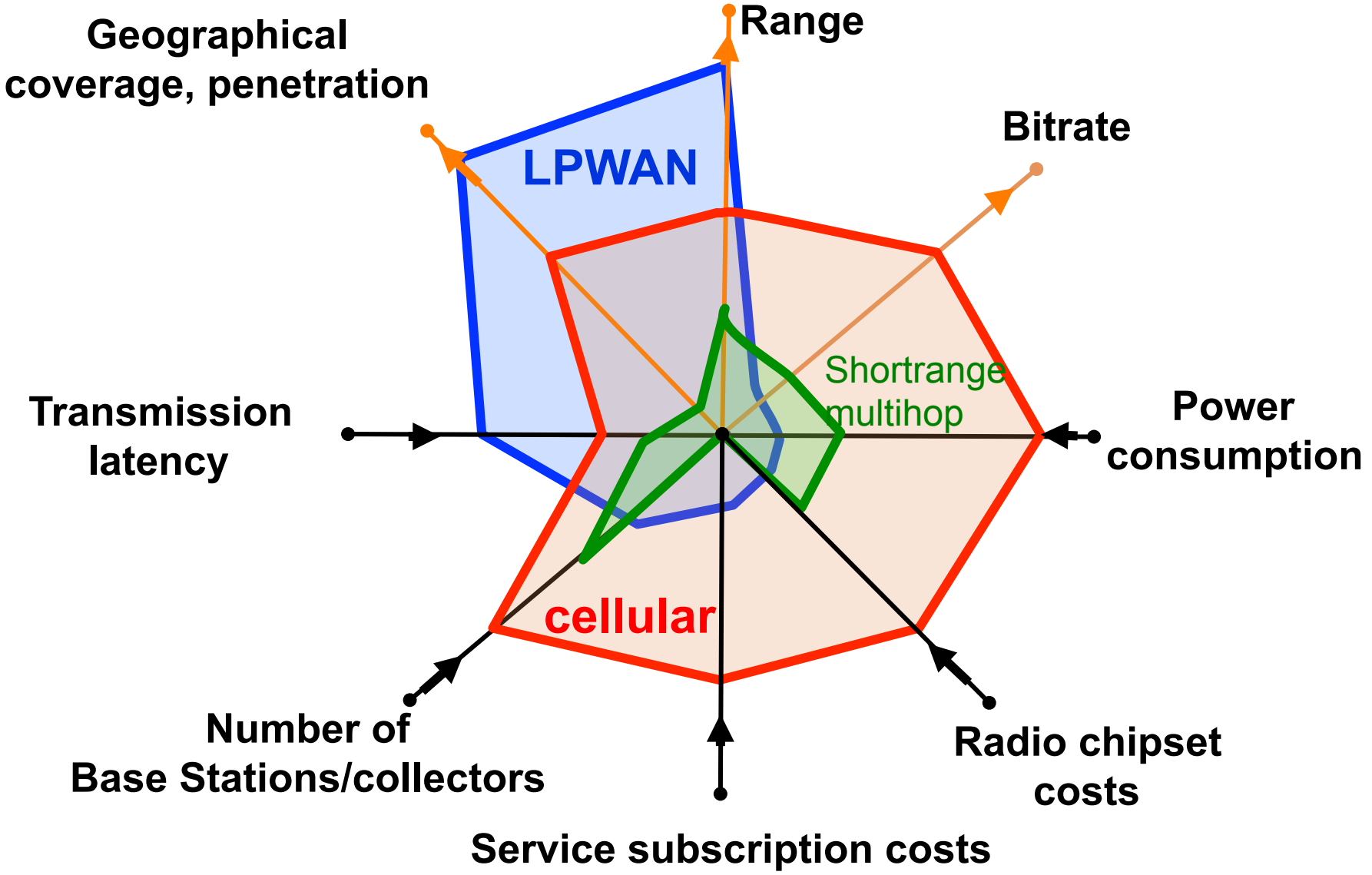
Cellular-based solutions



LPWAN


Pros
Cons
Low power
Very long range
Low cost
Long delays
Low bitrate

Quick comparison



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Pilots and trials

http://www.keepcalmstudio.com/gallery/poster/L90JKS

Three examples

PT ThingSpeak project

- Indoor monitoring

Padova Smart City project

- Outdoor monitoring

RAMSES II project

- Active environments

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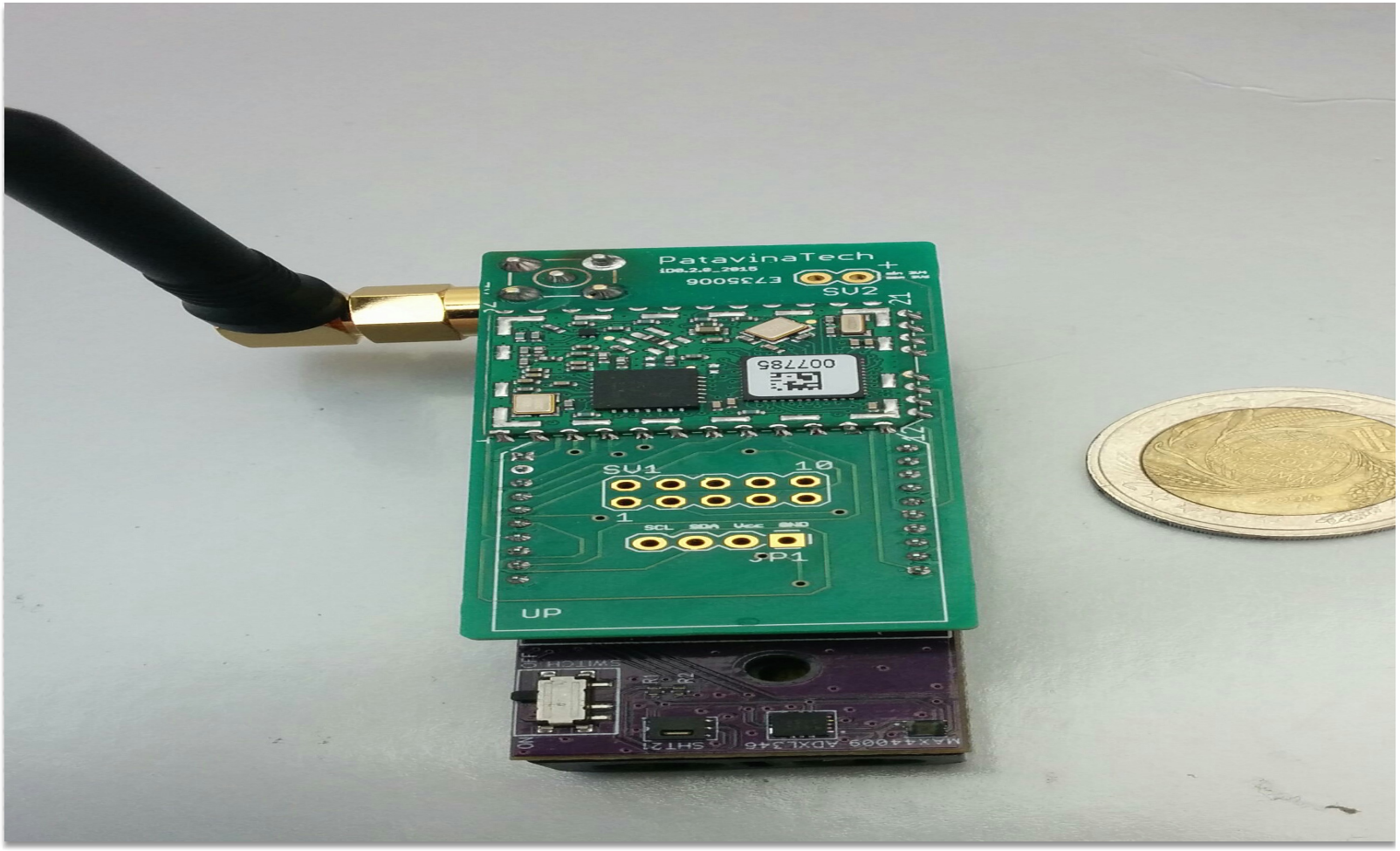

PT ThingSpeak Project

Objectives

- **What**: collect environmental measurements from a building
  - Temperature, humidity, light intensity,…
- **Why**: control the conditions, act if needed
  - Check ambient conditions in museums/historical buldings
  - Check comfort level in working places
  - Check light/heating systems usage
- **How**: battery-powered sensors + LoRa + WebApp
  - A few, cheap sensors powered by AA batteries
  - LoRa wireless connectivity → a single collector (gateway)
  - Open and free web visualization tool

LoRa™

- Origin:
  - Chipset patented by SemTech (France)
  - LoRaWAN being developed by the LoRa Alliance
    - https://www.lora-alliance.org
    - Cisco, IBM, SemTech, …
- Secret sauce:
  - Wideband CIRP-like PHY layer with adaptive rate
  - Simple but effective LoRA WAN MAC protocol
- Capacity & Coverage
  - From order of 10^2 to 10^4 bit/s over up to 1-3 km in EU

COVERAGE


SF12
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SF12
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SF11
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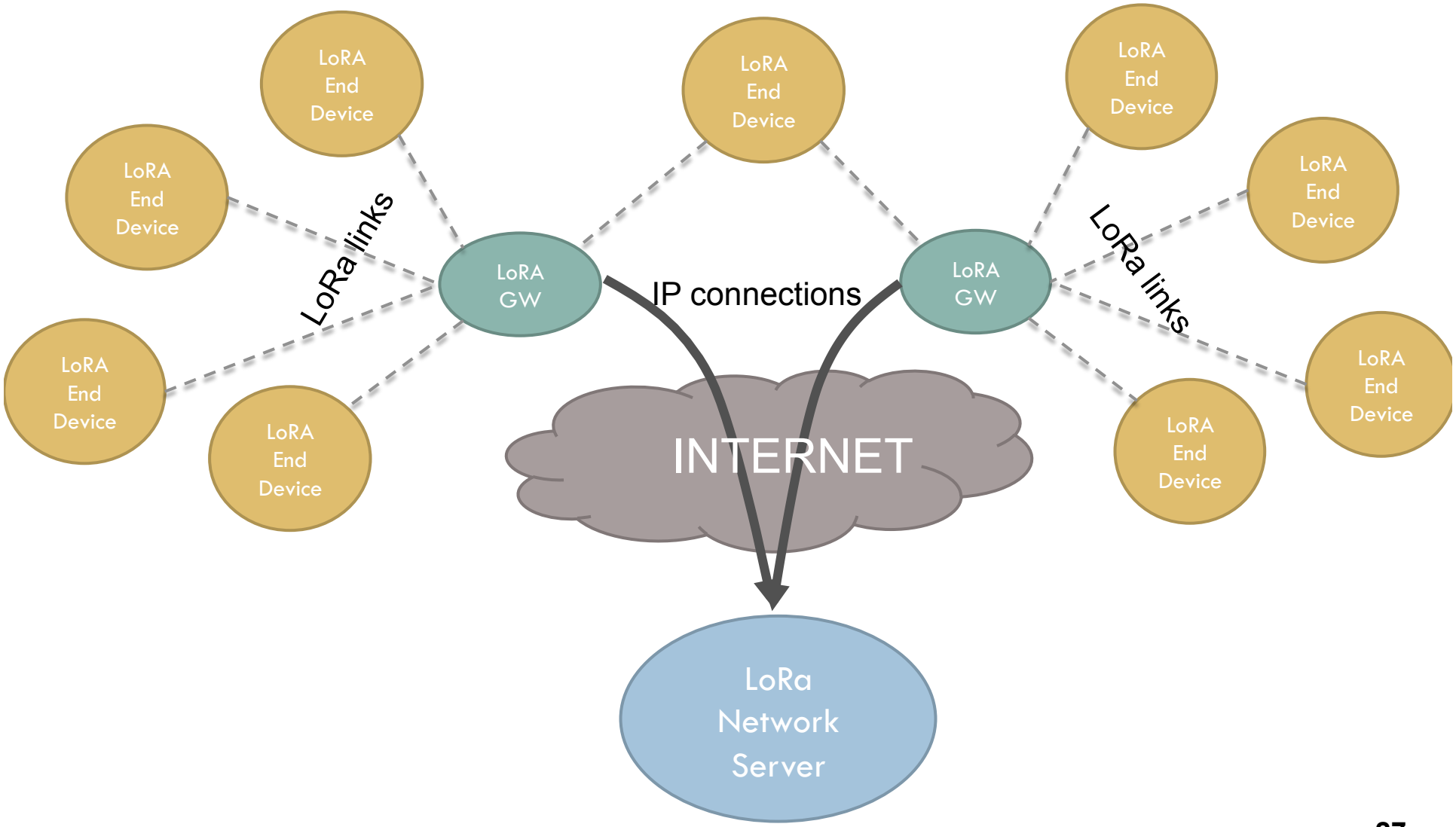
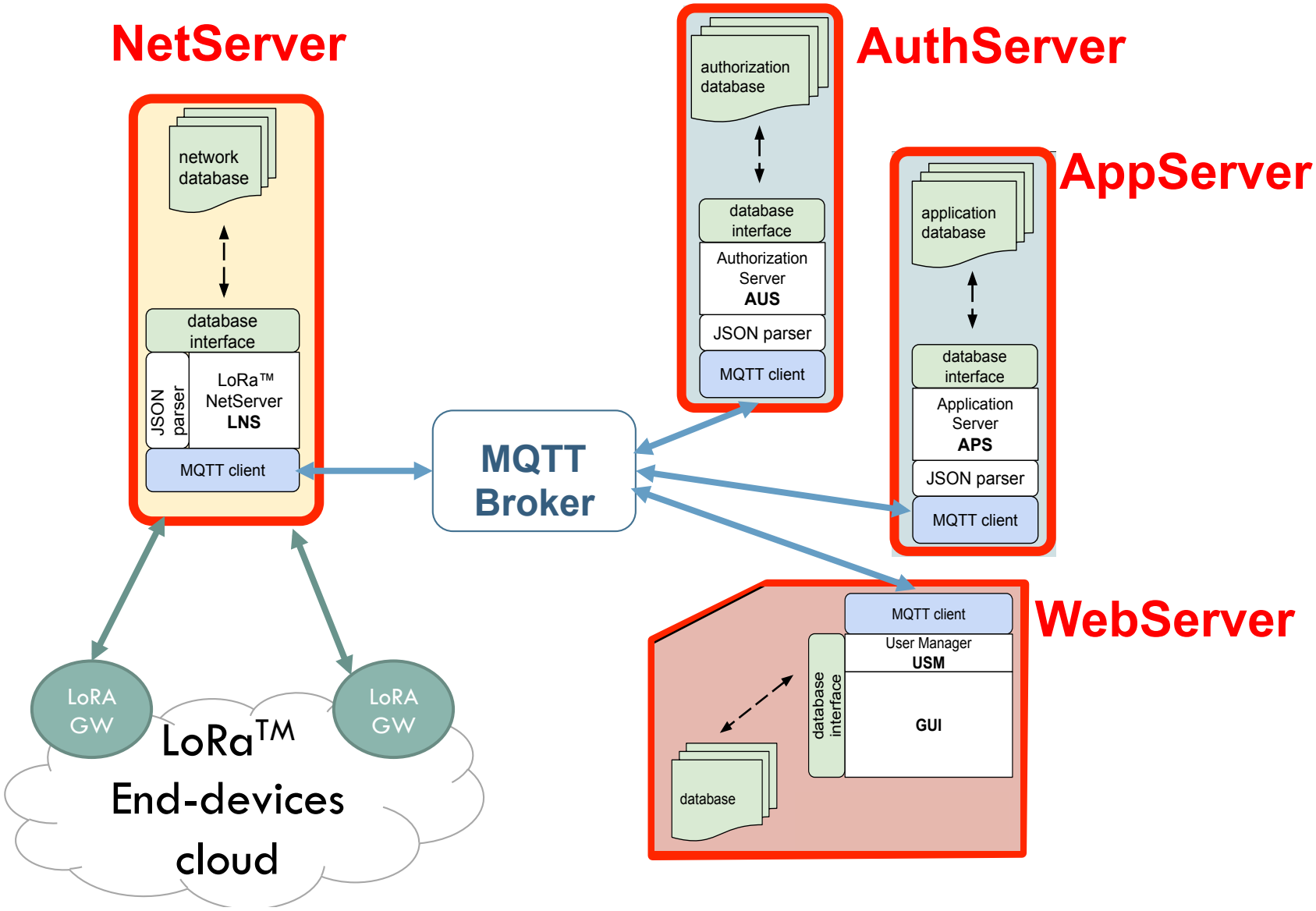
GW
1Km
2Km

LoRa™ system architecture



PT' LoRa™ system architecture



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Snapshot of deployment time

My request

zanellandrea 3:21 PM ☆

Ciao a tutti. martedì sera sarò a Mantova per un evento "Smart City". Sono interessati a soluzioni per illuminazione pubblica, musei e parcheggi. Io ho il compito di presentare le tecnologie abilitanti e un po' di esperienza pratica. Mi piacerebbe far vedere, magari "live", una possibile applicazione di LoRa per musei, tipo quella che si era discussa con MZ tempo fa. Se possibile, si potrebbe mettere 3-4 dei sensori che avete fabbricato in giro per PT e creare una pagina web con i dati, accessibile dall'esterno, sicche' io possa collegarmi in remoto e mostrare un po' di valori di temperatura. Pensate si possa fare? Grazie mille! AZ

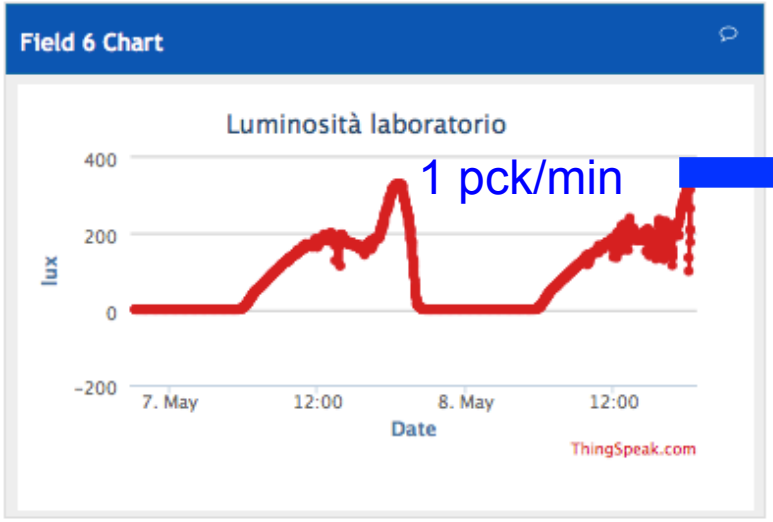
Done!

moreno 5:53 PM ☆

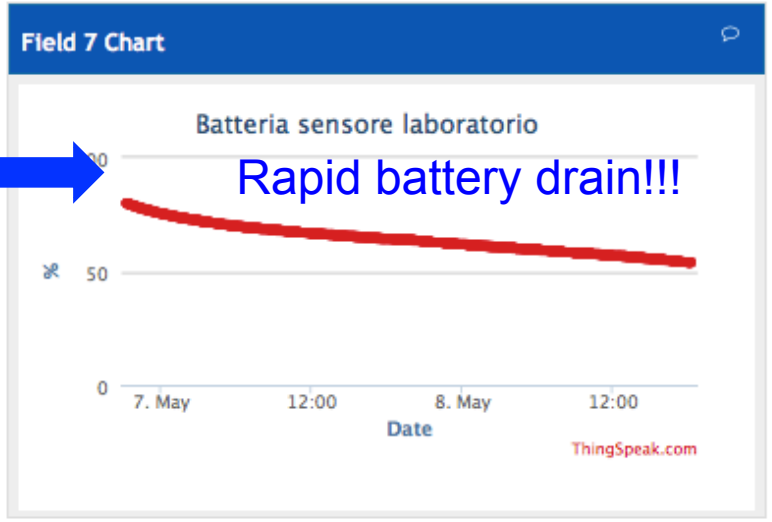
I dati saranno visibili qui: https://thingspeak.com/channels/114287

> **PatavinaTech Lab - ThingSpeak**
> PatavinaTech Lab on ThingSpeak: Open source data platform and API for the Internet of Things.

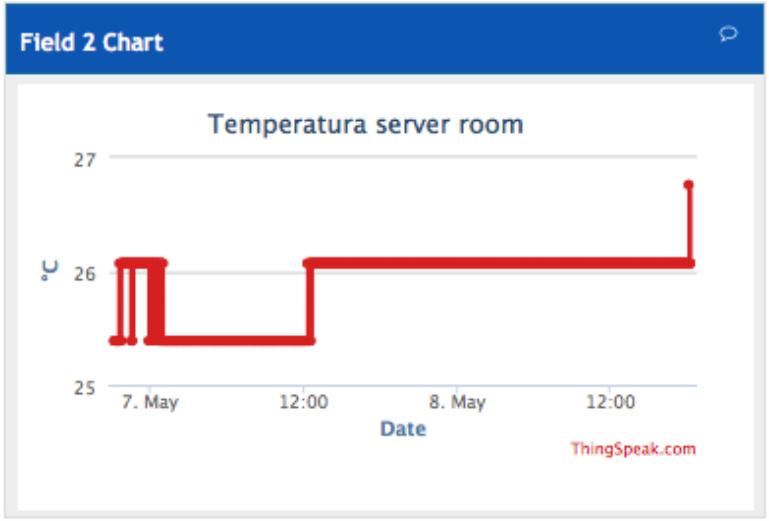
Snapshot of results

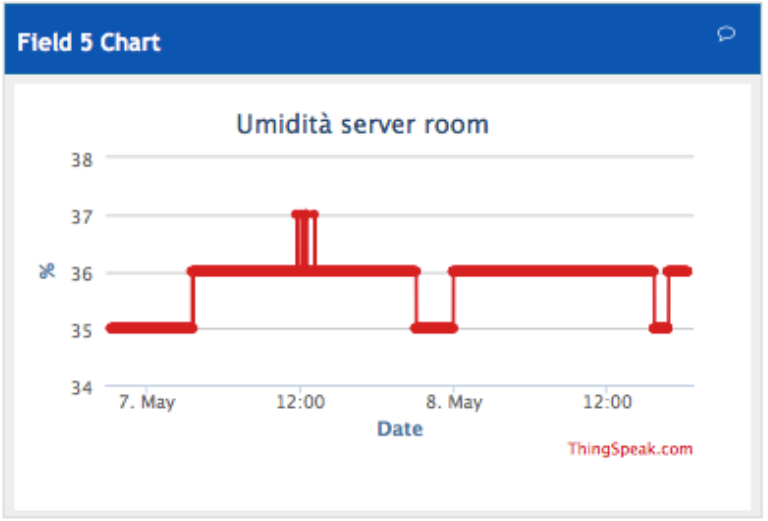


1 pck/min



Rapid battery drain!!!





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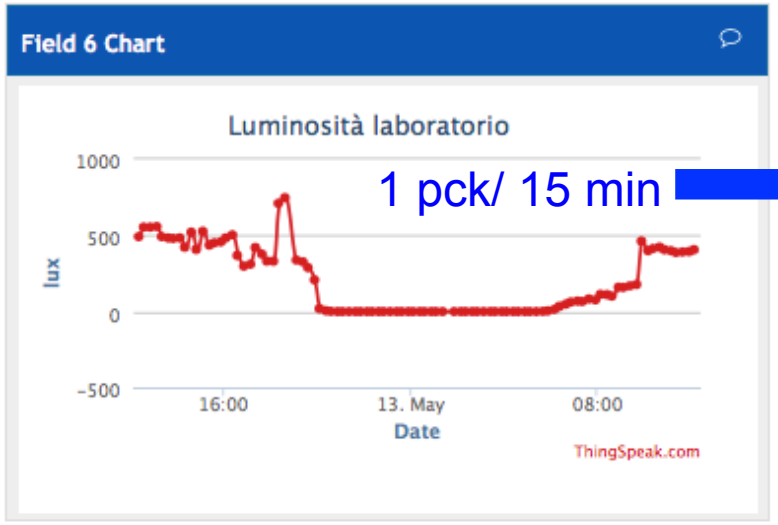
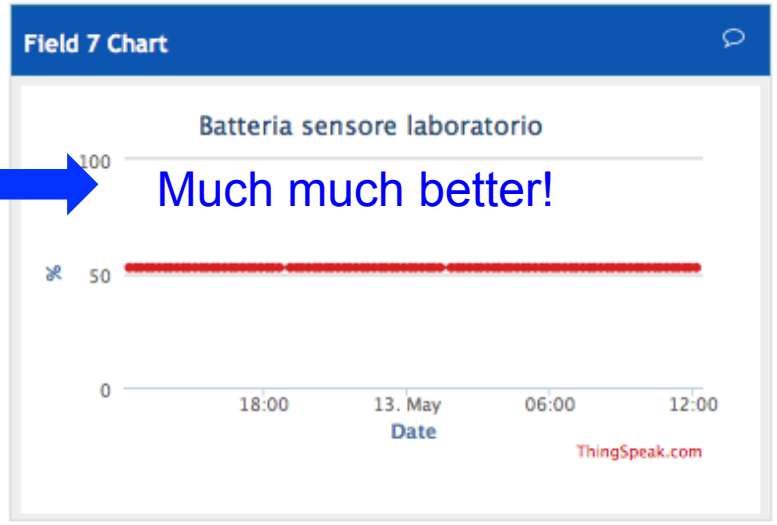
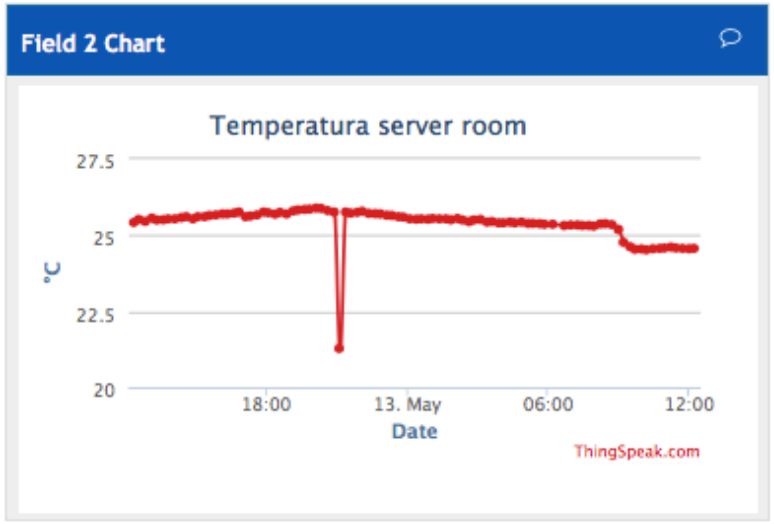
Adjusting the parameters…

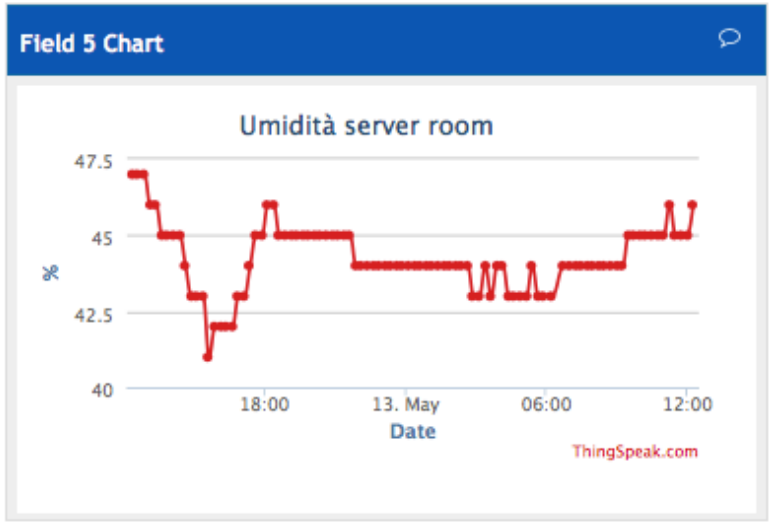


1 pck/ 15 min



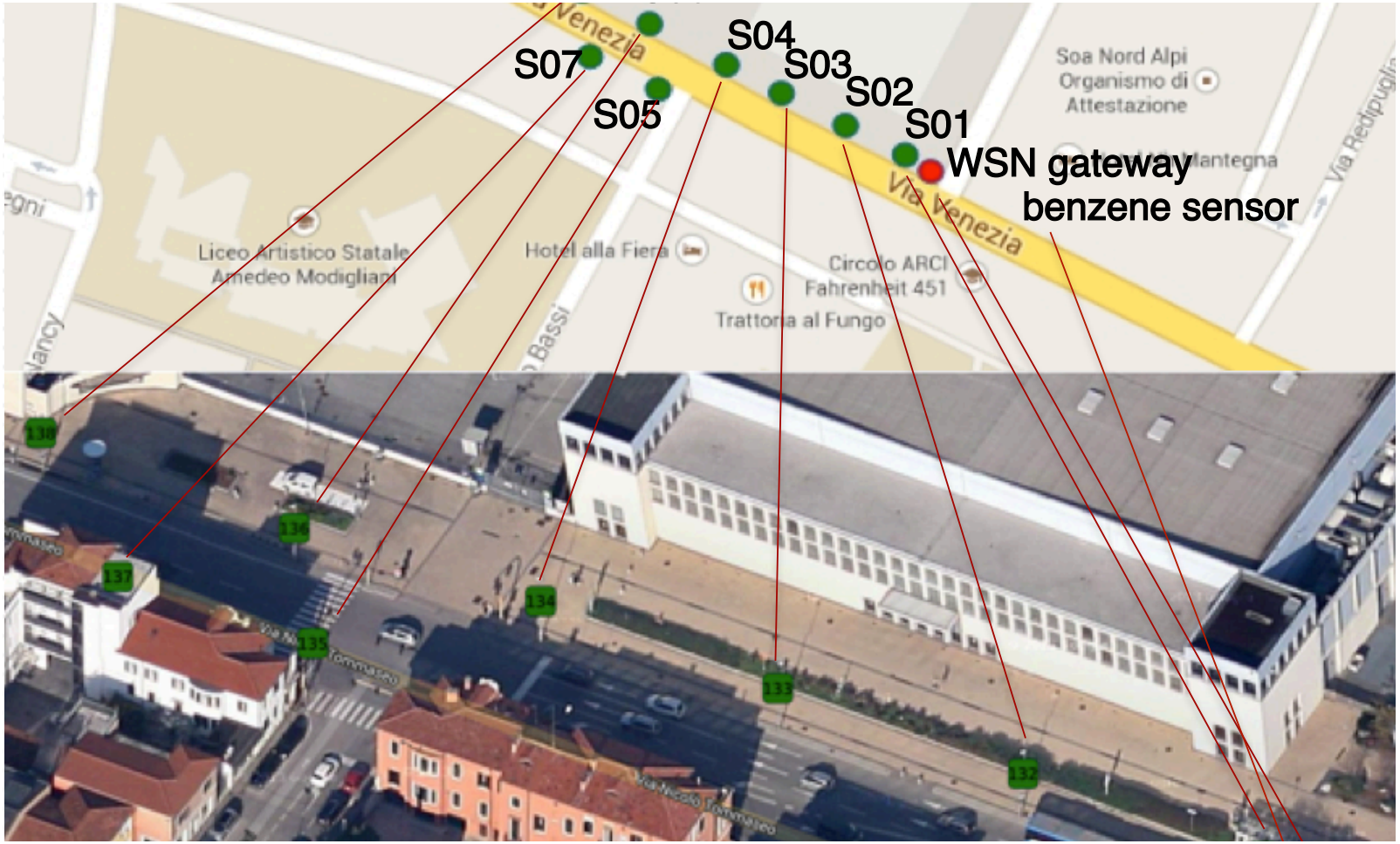
Much much better!





Lesson learned

- Simple architecture → rapid deployment!
- Data reporting frequency is critical for energy consumption
  - No more than few pcks per hours to preserve battery charge
  - Online parameters adjustment is fundamental
- Environmental data can reveal human behaviors



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Padova Smart City

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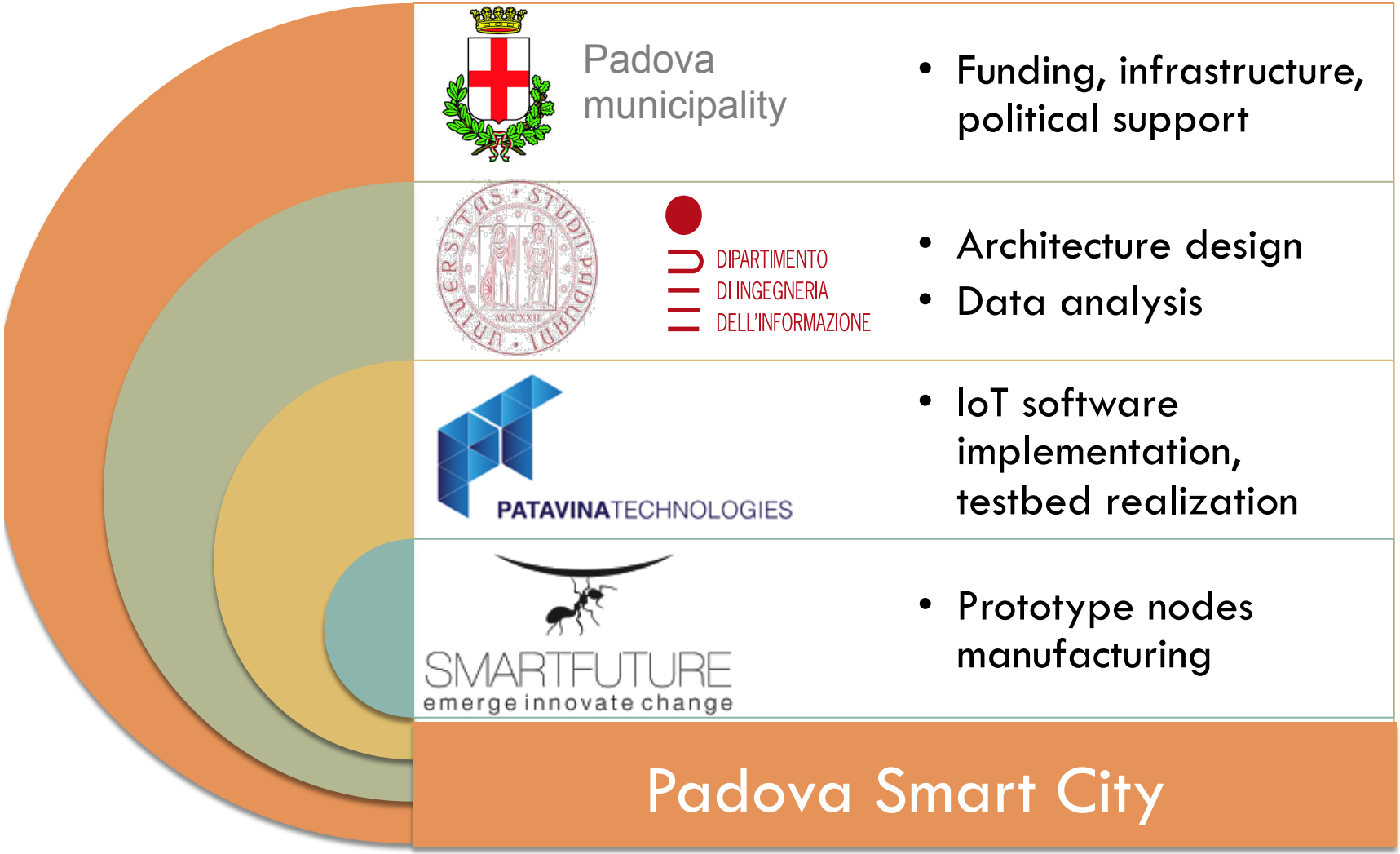
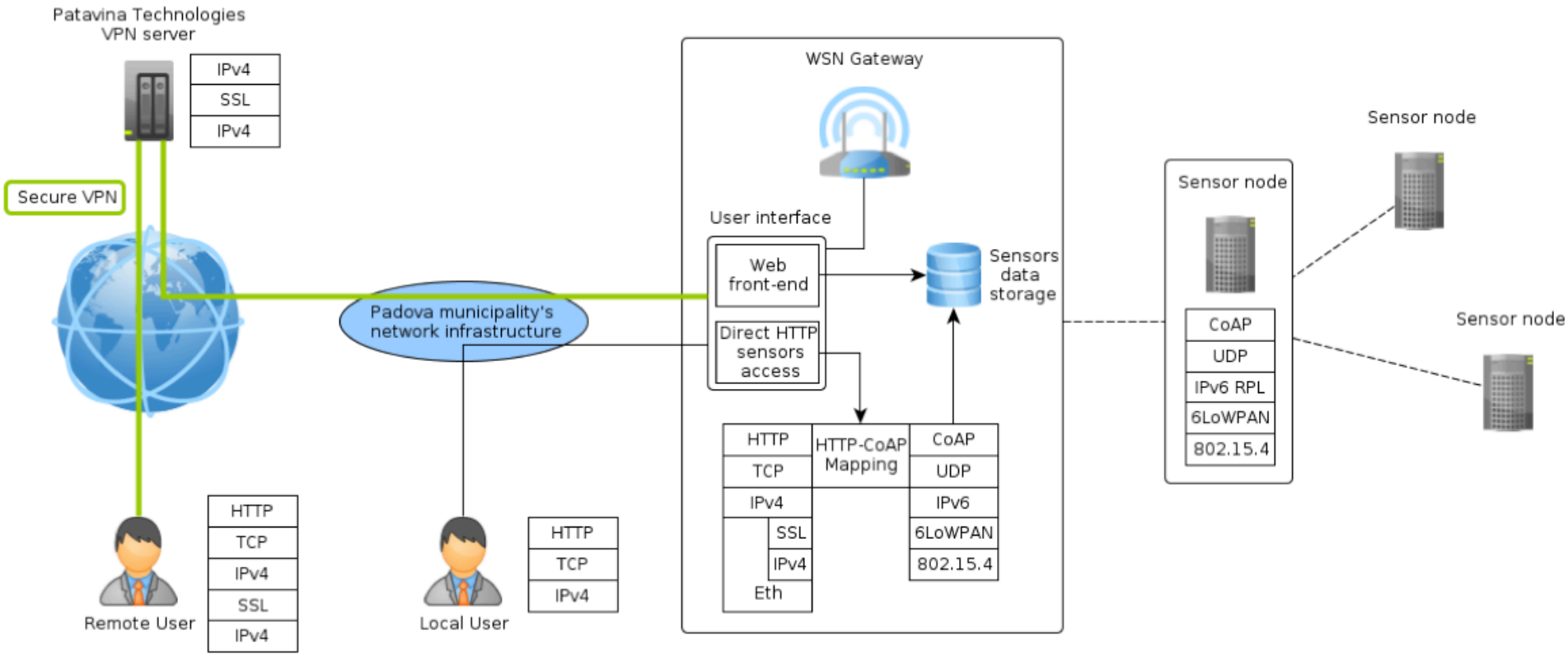
PSC: the players



PSC: architecture



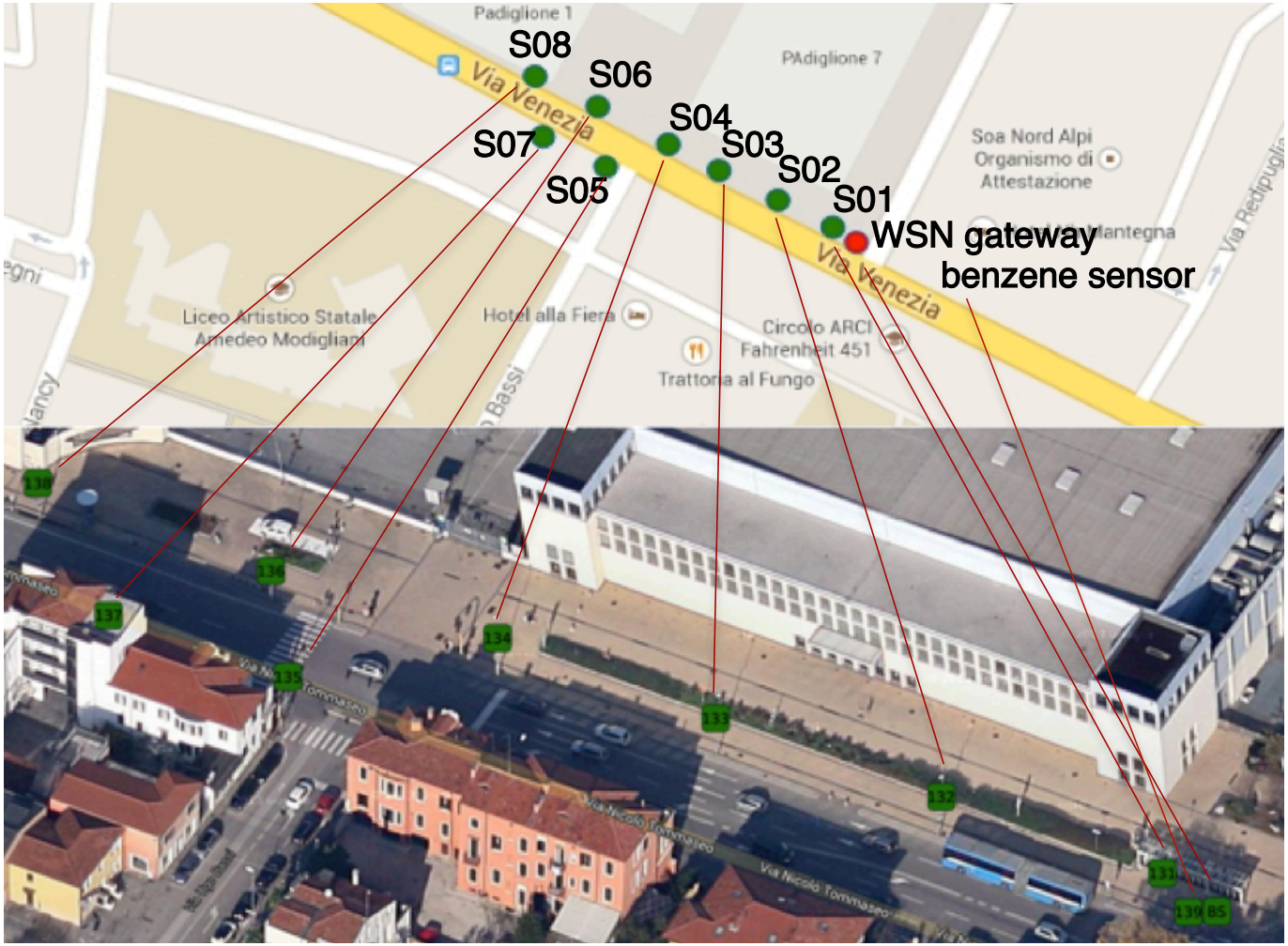
Objectives

- **What:** apply sensors to public light poles
  - Collect light measurements
  - Collect other environmental measurements
- **Why:** exemplify potential of IoT for Smart City services
  - Reduce management cost
  - Provide environmental data
- **How:** TmoteSky sensors + 6lowPAN + basic web app
  - Mostly battery powered sensors placed on the poles
  - Multihop wireless communication to the gateway
  - Wired connection from gateway to the control center

Nodes placement

Sensor node protected by transparent plastic shield that permits air circulation

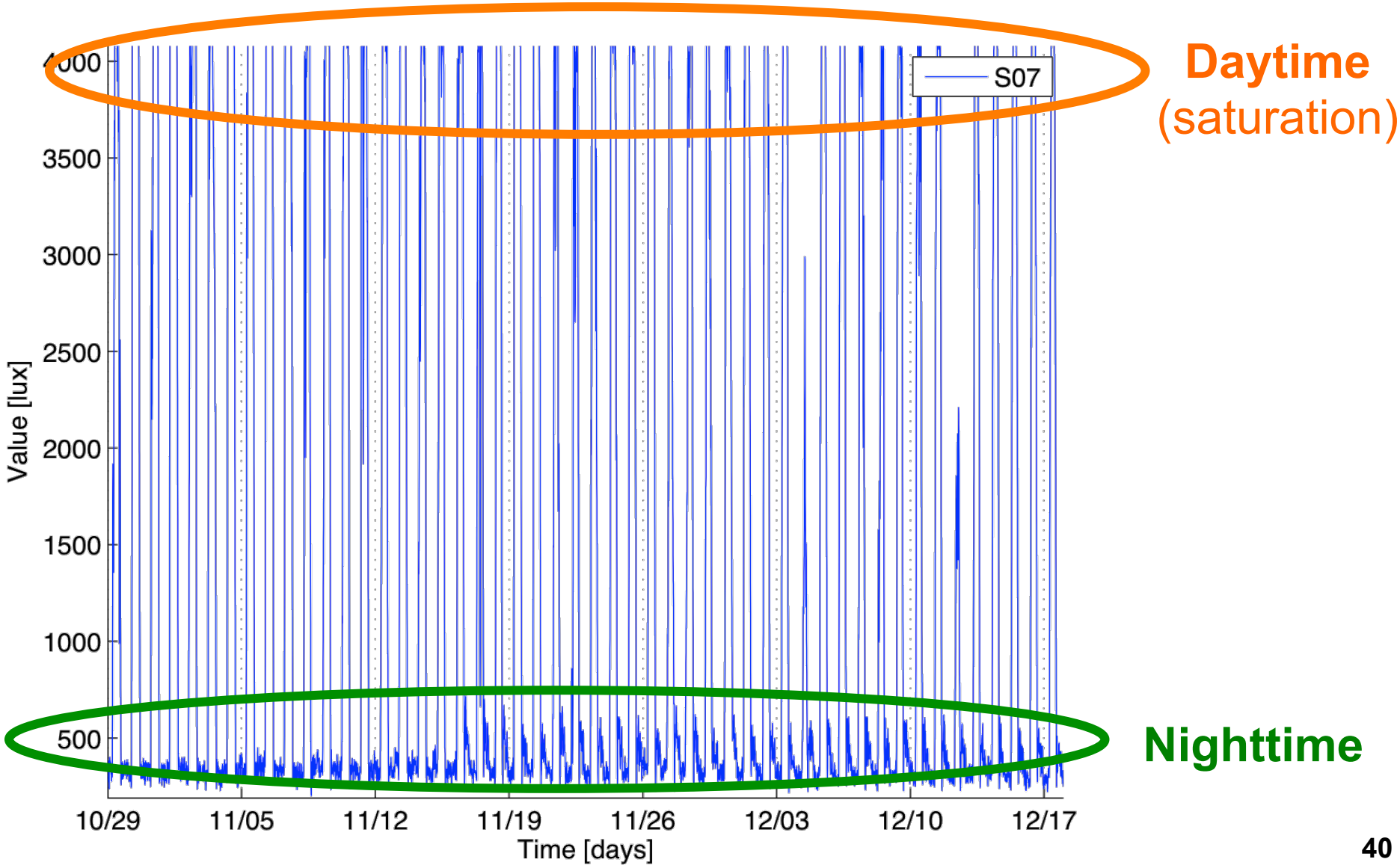
Nodes' location on the map



Data collection and reporting

- Each node reads sensors data every 5 minutes
- The average of three readings is stored in a buffer
  - 1 average value every 15 minutes
- A packet can carry 7 (averaged) values for each of the four sensors
  - One full packet transmitted every 7x15=105 min to the gateway

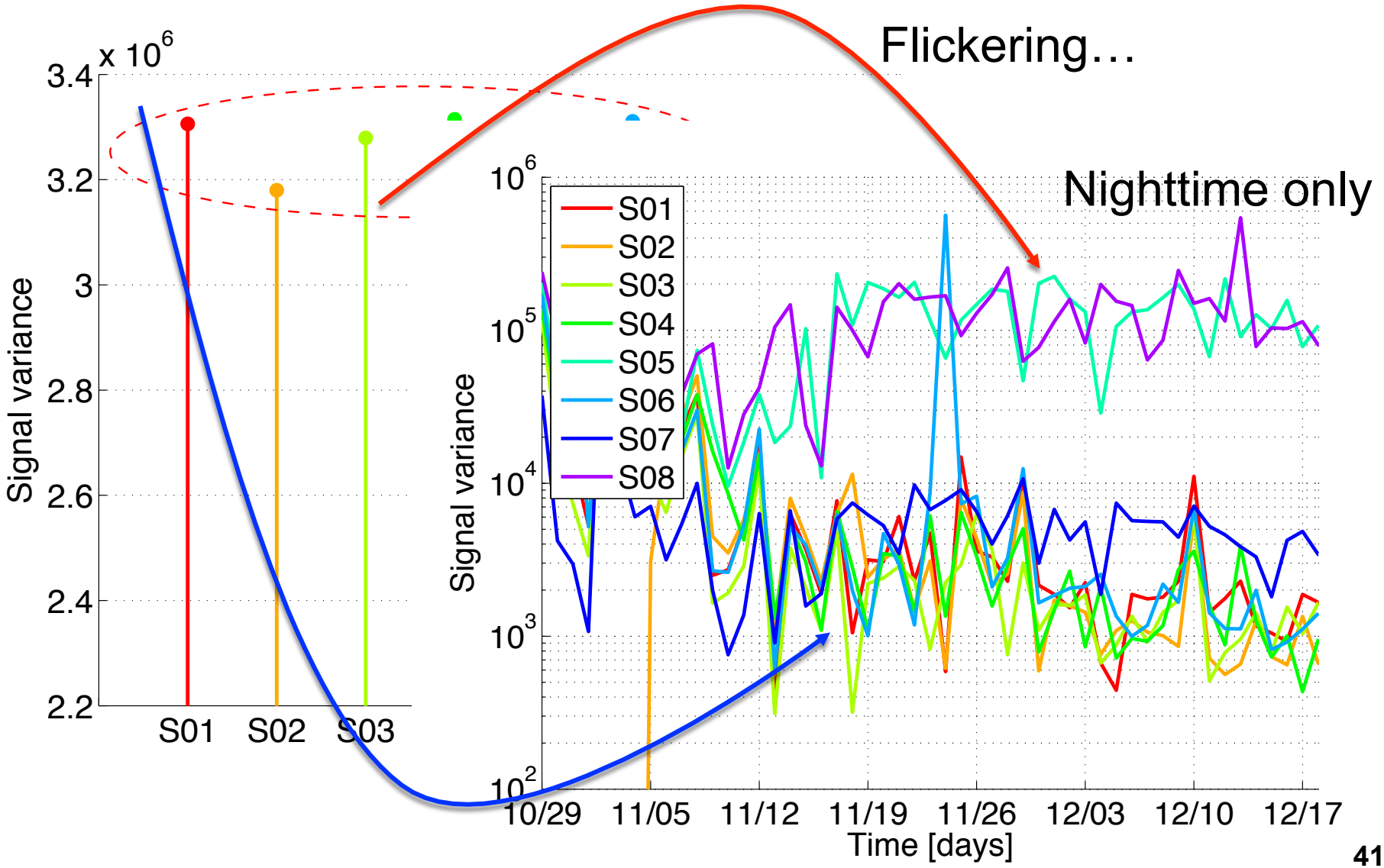
Example of light readings



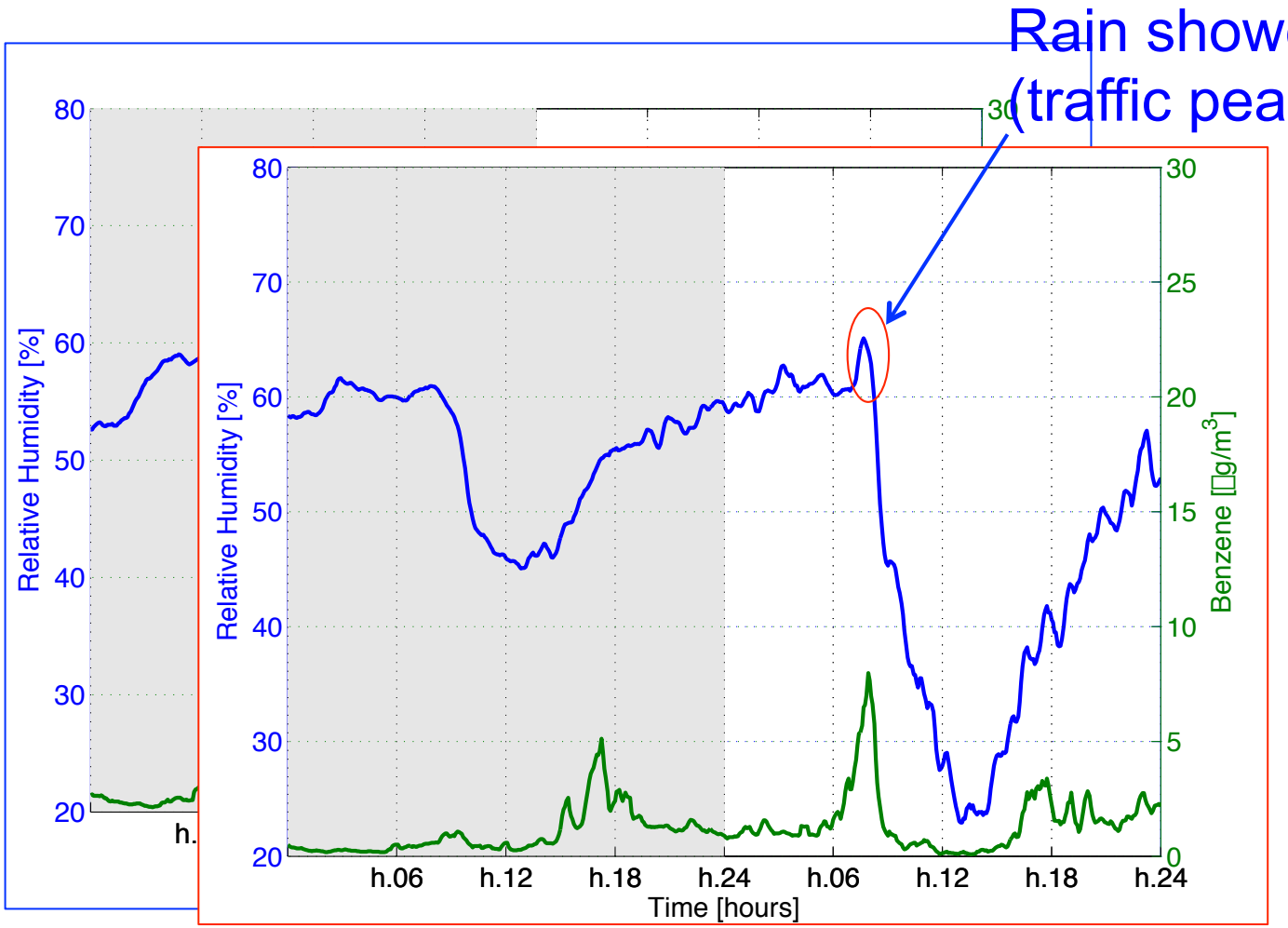
Daytime
(saturation)

Nighttime

Variance analysis



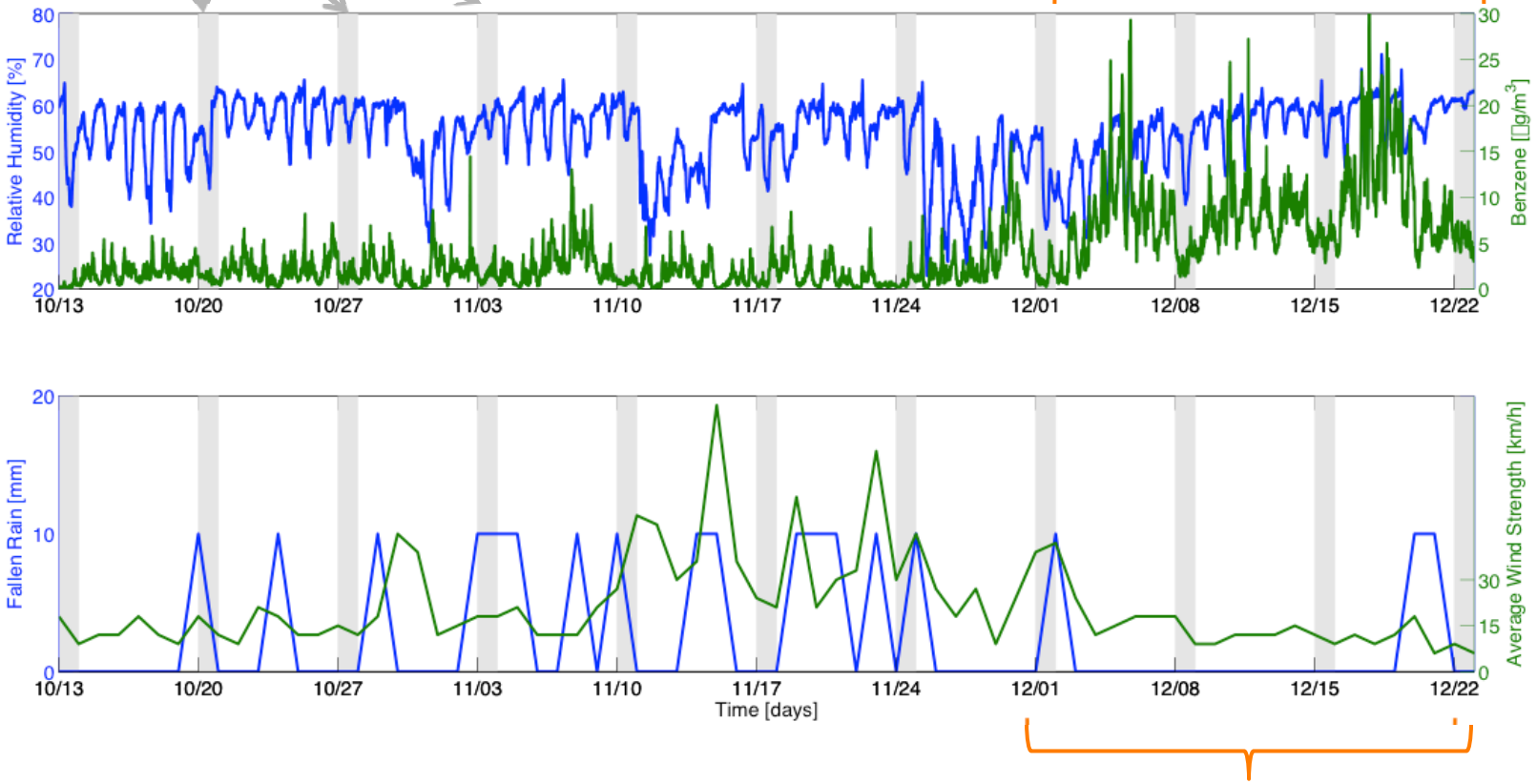
Pollution and weekdays…



Benzene analysis

Sundays

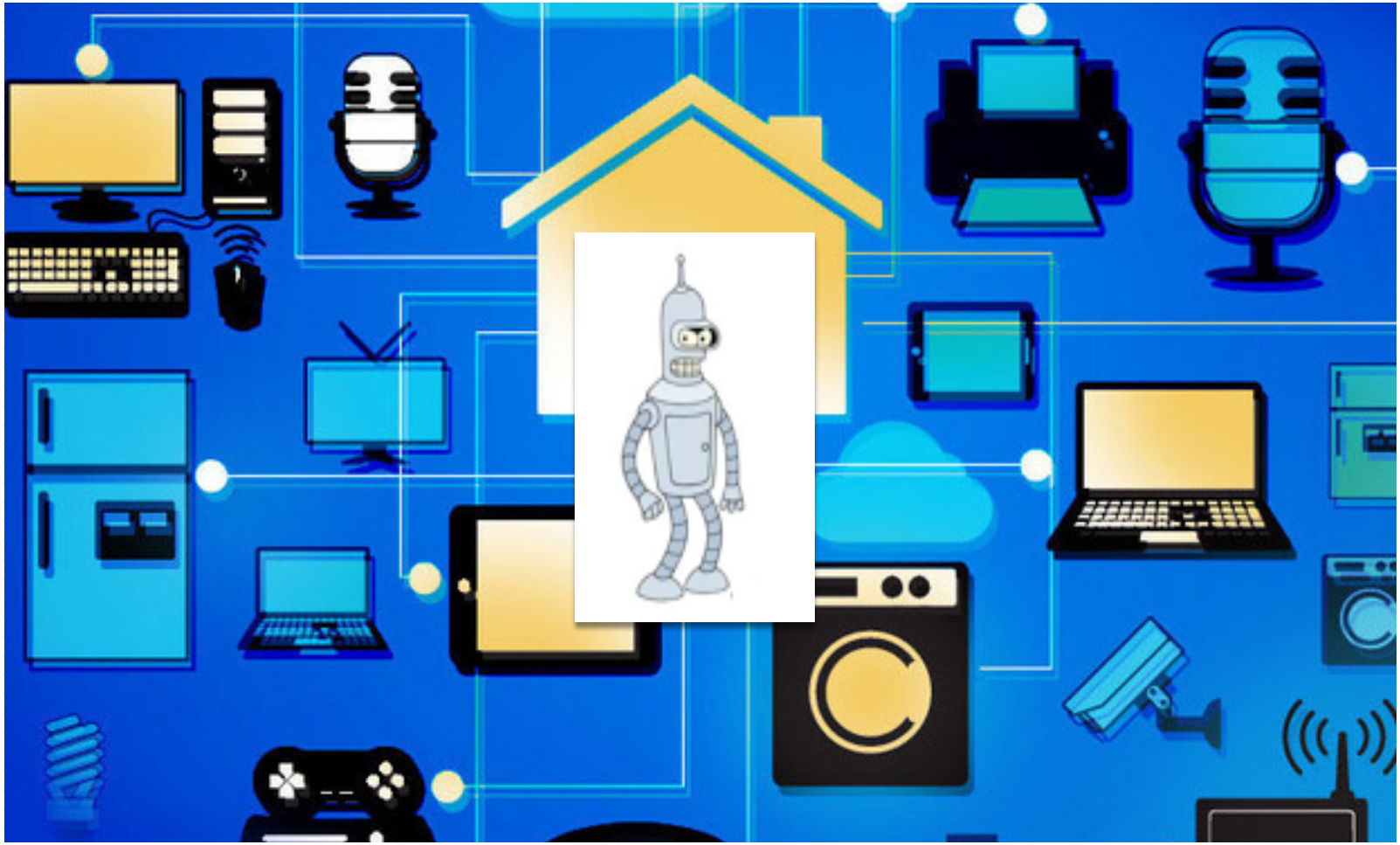
More pollution….



Nice weather….

Lesson learned

- Multihop works… but it is critical
- Over-the-air software updating is essential!
- Environmental data can reveal useful information regarding air conditions, traffic management, citizens habits… particularly useful if combined with other data
  - Bike/car sharing, traffic monitoring, city events calendar, pollution monitoring stations,…



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RAMSES II Project

Objectives

- **What:** make the environment "active"
  - Able to interact with humans or machines
  - Able to self-adapt to context changes
- **Why:** new services & improved quality of life
  - Augmented reality
  - Assisted leaving for impaired people
  - Autonomous robot navigation in unknown environments
- **How:** TmoteSky sensors + stereo camera + software
  - Heterogeneous sensors in the environments
  - Wireless communication
  - Suitable signal processing techniques and algorithms

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A practical example: smart objects

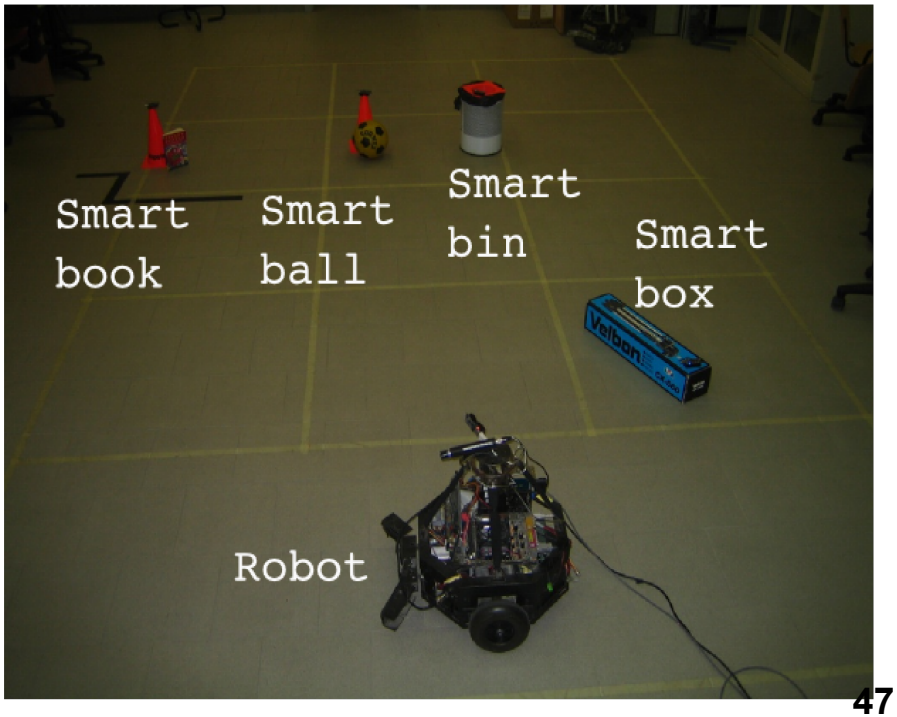
Vision

- AMR equipped with
  - odometers for self-localization
  - on-board camera
  - RF transceiver

- Smart Objects (SOs), i.e., common objects tagged with WSNs that provide
  - Computational/communication capabilities
  - data storage
  - self-management features

Goal

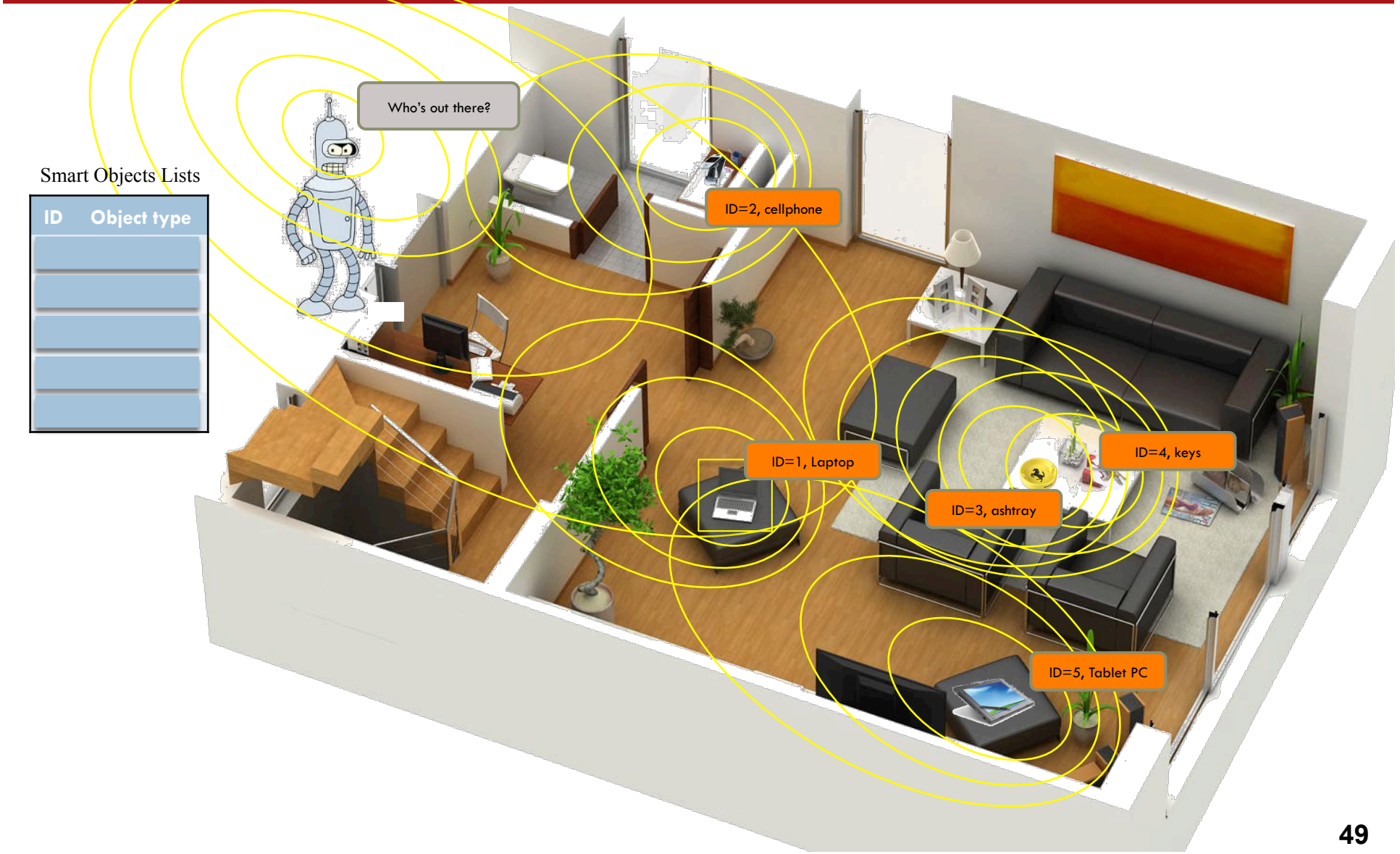
- Autonomous **exploration** of **unknown environments** and **interaction** with SOs
  - No prior info about the number or kind of SOs



System's building blocks

1. Smart Object Identification
   - The AMR gets a list of close by SOs, but does not know their location
2. Smart Object Mapping
   - The AMR builds a map of the area estimating SOs' location
3. Smart Object Recognition
   - The AMR gets close to a selected object and, then, visually recognizes it in the image taken by the on-board camera

1. Identification



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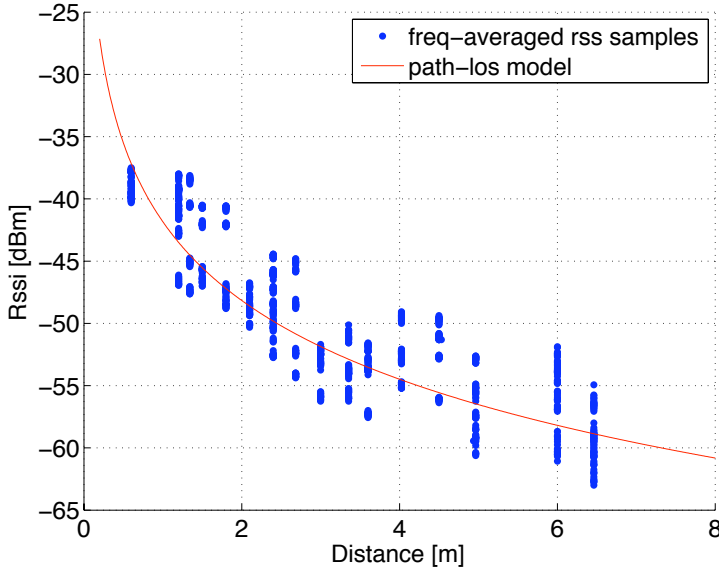
2. Mapping: our solution

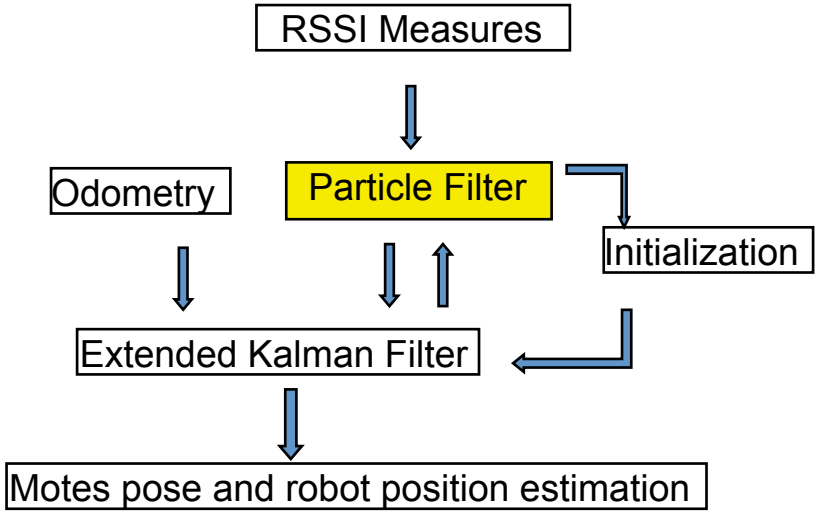
WSN-wise

- Multi-channel RSSI averaging



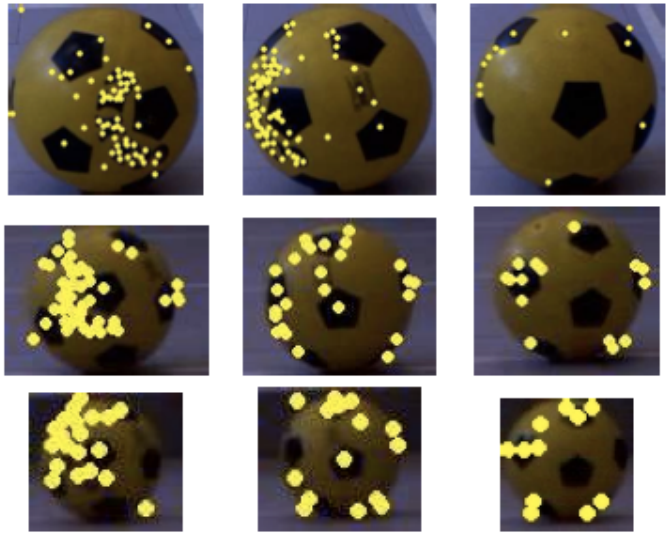
AMR-wise

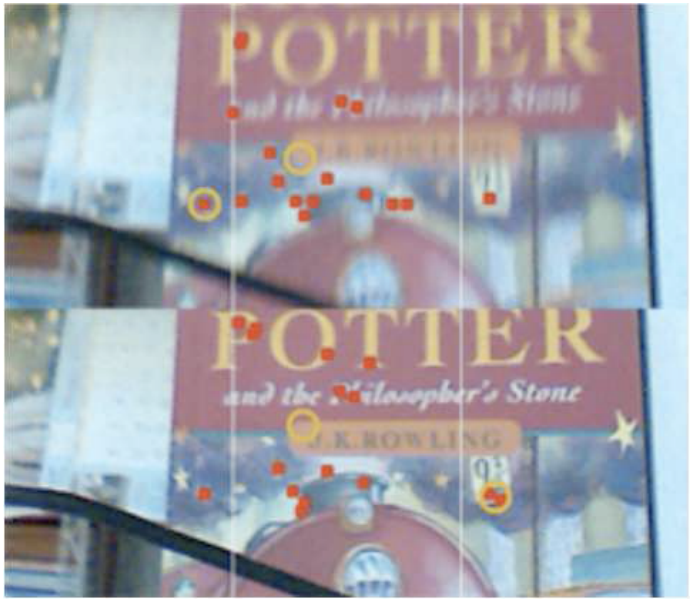
- SLAM: Simultaneous Localization (of the AMR) And Mapping (of the SOs)



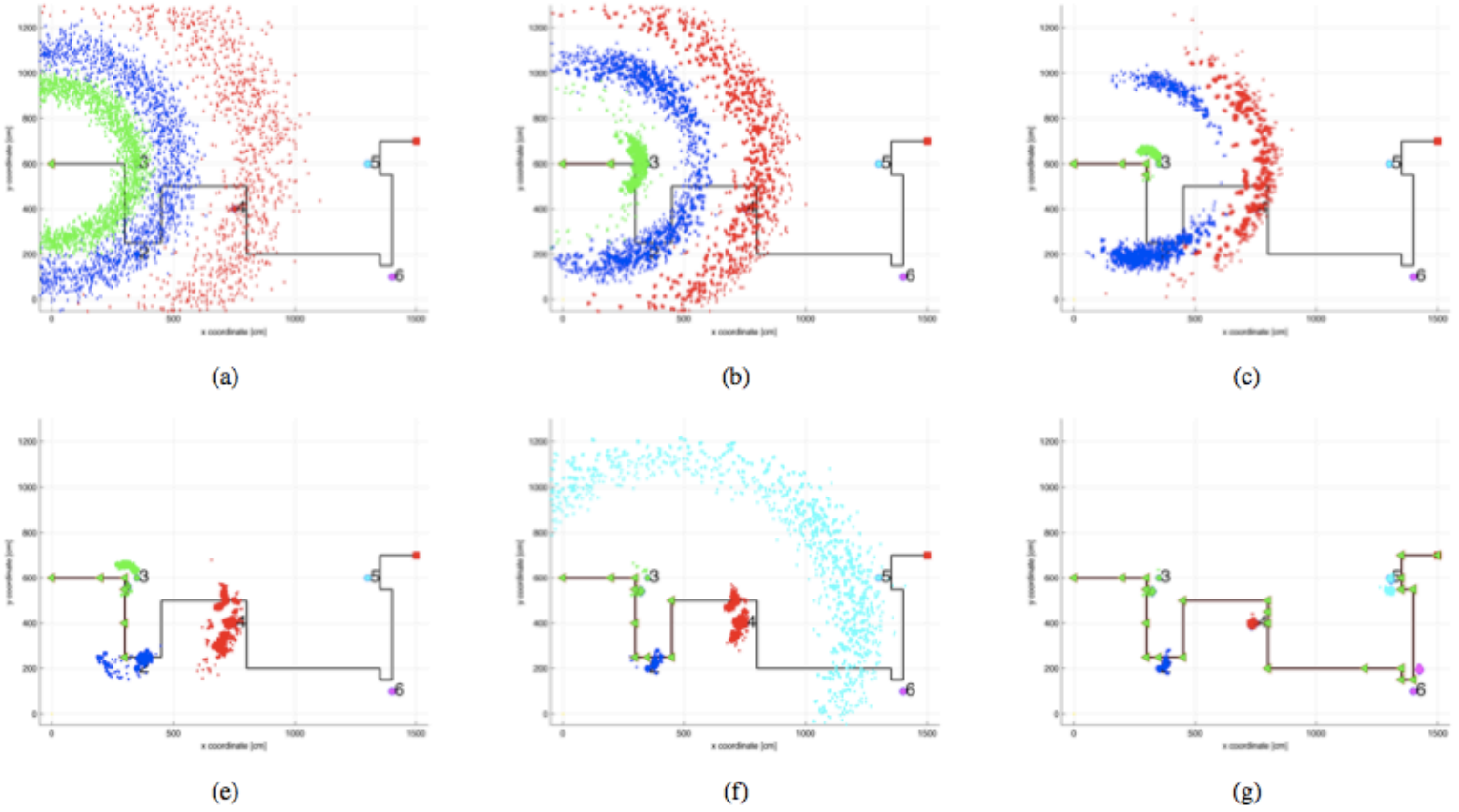
3. Recognition

- Object appearance is stored inside the object (in the motes)
- The appearance is coded by scale invariant feature descriptors robust also to motion blur (MoBIF)



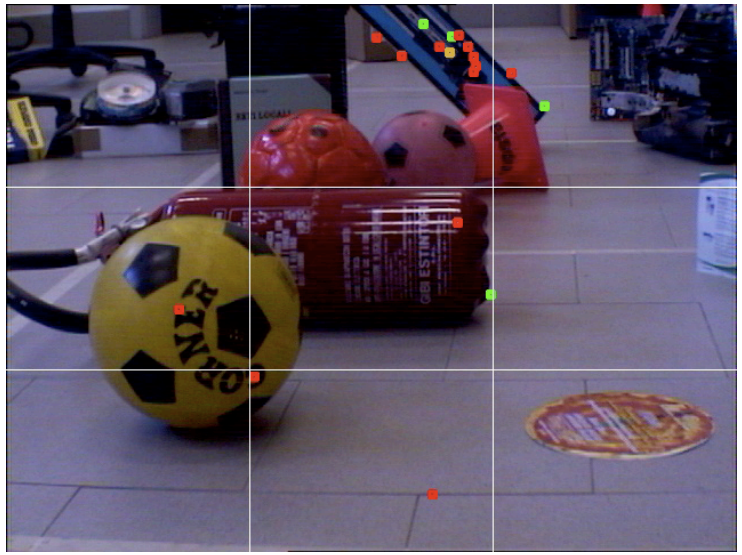


Delayed Initialization based on Particle Filter



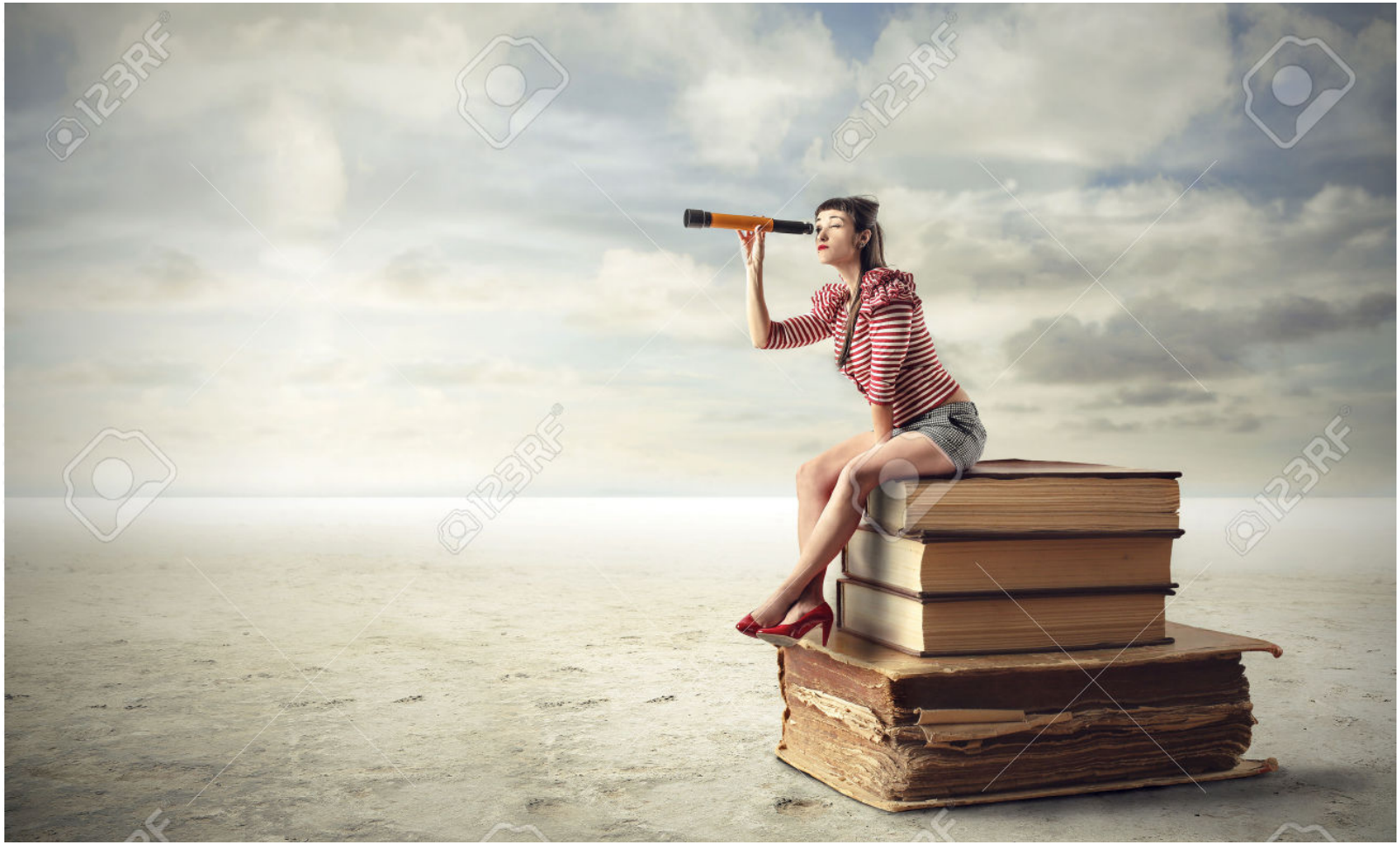
MoBIF Matching

- The AMR requires the selected SO to send its MoBIF descriptors
- The AMR dynamically extracts MoBIF descriptor from the image taken by onboard camera
- When MoBIF descriptors matching exceeds a threshold the SO is recognized



Lesson learned

- RSS is critical for localization… but still worth!
  - Circuits that provide accurate RSS reading would be VERY welcome
- Advanced services can be obtained by combining signals from heterogeneous sensors
  - Design of multisensor devices



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Looking forward

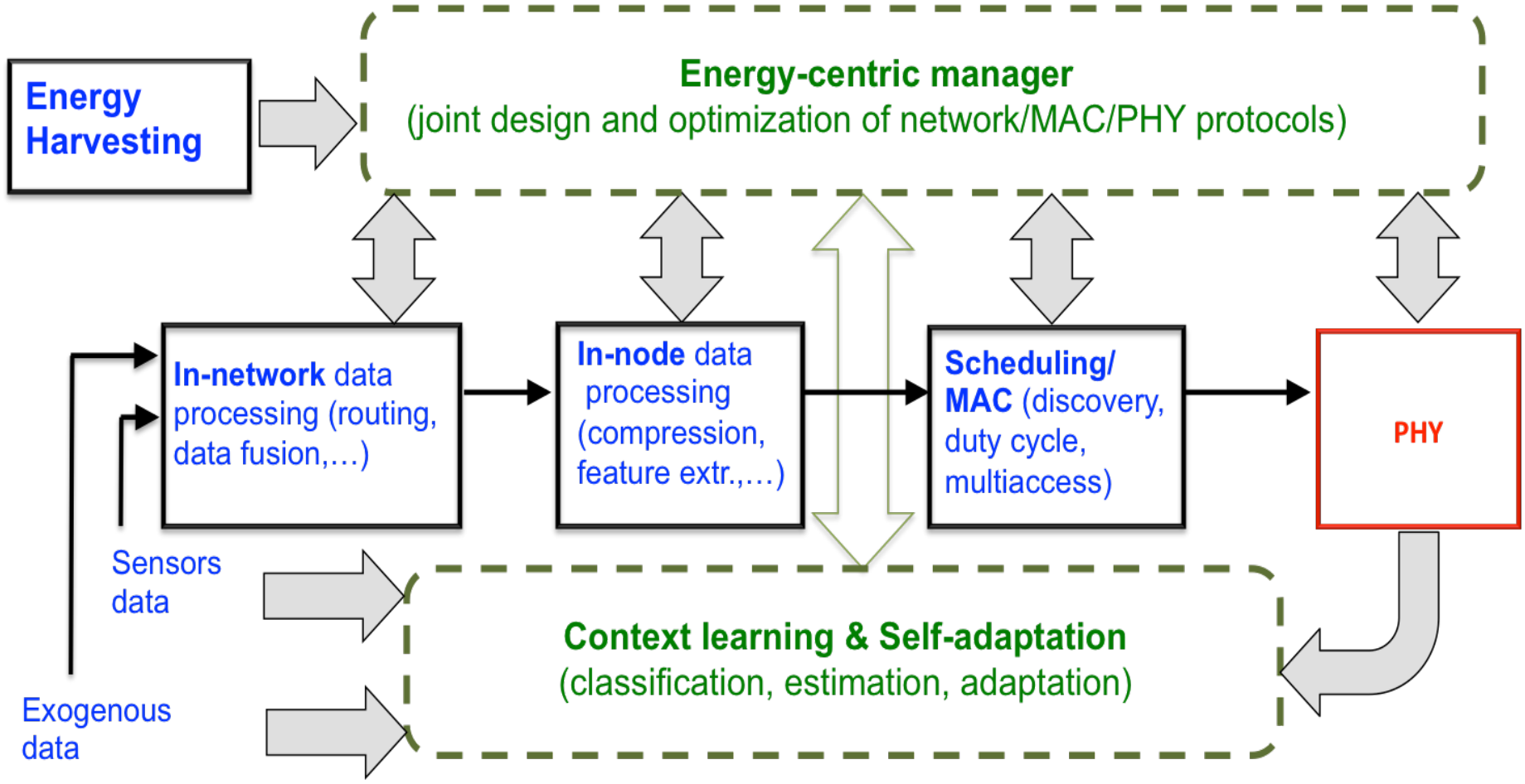
Image source: http://www.123rf.com/stock-photo/looking_far_away.html

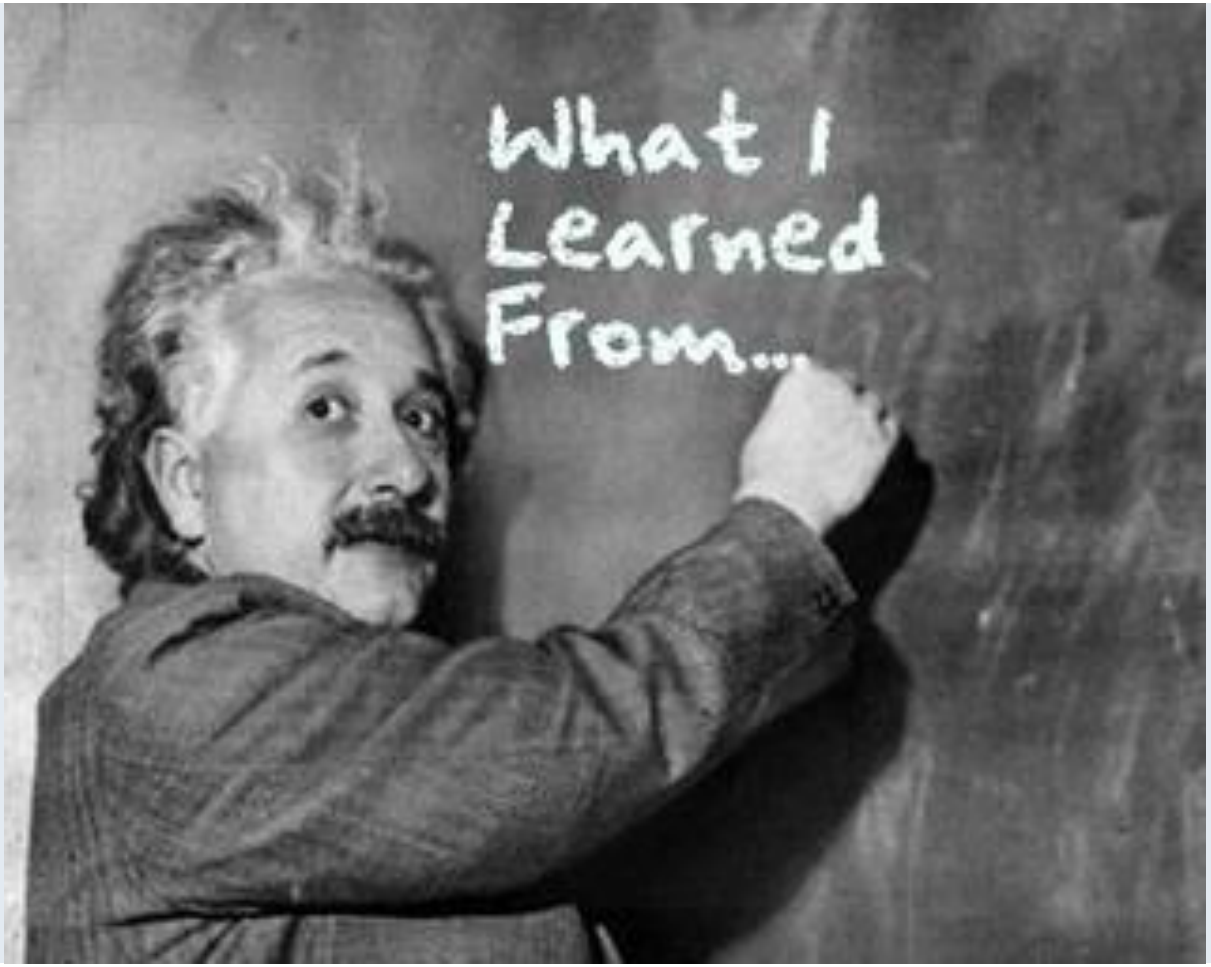
Our point

- In future networks
  - Functionalities & algorithms will be injected as new software
  - Software Defined Networking
- Signal statistics depend on
  - What is being measurer
  - When
  - Where
- Statistics may change as a function of time

⇒ Classification, estimation, adaptation

E-centric building blocks





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Take home message

Wrapping up

- Smart City
  - a nice promise… but still to come!
- Why?
  - Many enabling technologies… not yet a clear winner
  - Many data… not clear what to do with them
  - Many players… not clear who leads the play

Wrapping up

- Then, what?
- Keep working!!!
- On what?
  - Sensor/battery design
  - Service/protocol design
  - Data/signal processing
  - Experimentation: 1 test teaches more than 1000 simulations!

The key to success

Choose a cool title for your paper!!!

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