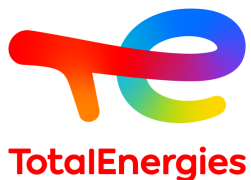


# Understanding the Technologies and Challenges of the Internet of Things

sensors, hardware, radios, clouds, protocols, ...



Innovation  
Accelerator

IoT Capsule 2026

Prof. Congduc Pham  
<http://www.univ-pau.fr/~cpham>  
Université de Pau, France  
[Congduc.Pham@univ-pau.fr](mailto:Congduc.Pham@univ-pau.fr)



Horizon 2020  
European Union funding  
for Research & Innovation



IoT – from idea to reality



Paving for the next 10 years  
of innovation in IoT and AI



Intel-IrriS RESILINK

Advanced and disruptive IoT/AI technologies targeting  
the smallholder community for increased resilience



AgriFutur

Wireless Sensors Made Simple  
for agroecology & sustainable agriculture

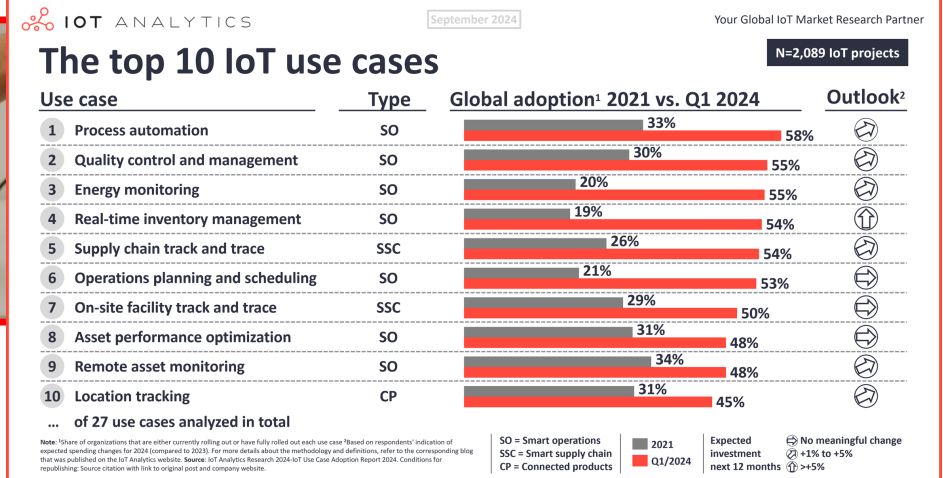
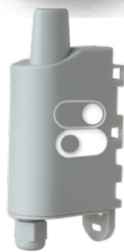
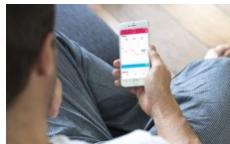
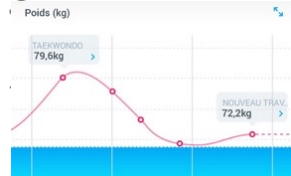
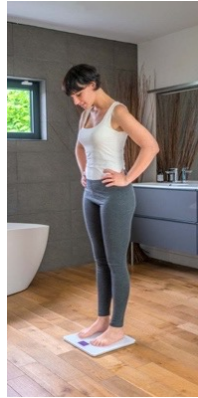


2



# 2026: A very mature ecosystem!

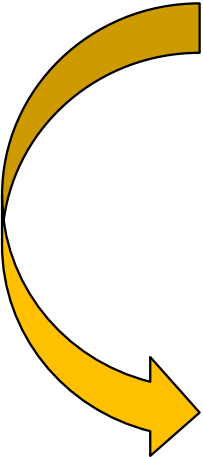
Pr. Congduc Pham  
http://~cpham



# Quick definitions of IoT

## Some definitions

- IoT is about making **ordinary objects “smart”** by giving them the ability to **sense, communicate, and act via the internet** [ChatGPT]
- IoT refers to any system of **physical devices that receive and transfer data over wireless networks** with limited human intervention [RedHat]
- Internet of things (IoT) refers to **devices with sensors, processing ability, software, and other technologies that connect and exchange data with**

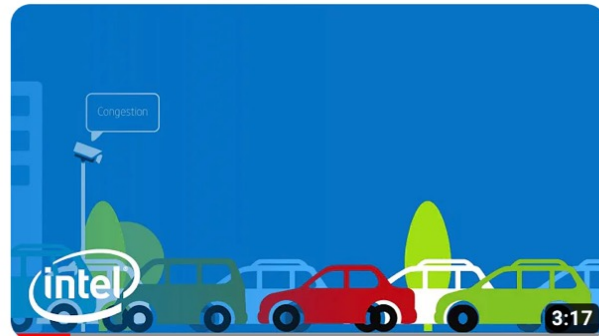


**Implementing IoT can be considered as deploying a whole ecosystem**

- The Internet of things (IoT) refers to devices with embedded sensors, processing ability, software and other technologies that allows to connect and exchange data with **other devices and systems** over the internet or other communications networks [EU Commission]



# IoT teaser & tutorial videos!



## Intel IoT – What Does The Internet of Things Mean?

591 k vues • il y a 8 ans



Fun, animated video answers: What does the Internet of Things mean? The Internet of Things (IoT) is an evolution of mobile, home ...



Intro | What is IoT | Transform our lives | Big picture | Example | Big Possibilities | Intelligent Traffic |... 9 chapitres ▾



## IOT Tutorial | IOT Tutorial For Beginners | IOT - Internet Of Things | IOT Course |

Simplilearn

25 k vues • il y a 1 an

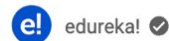


This IoT tutorial video introduces you to IoT Technology and how it is revolutionizing the world today. Internet of things or IoT ...



## Internet of Things (IoT) | What is IoT | How it Works | IoT Explained | Edureka

2,1 M de vues • il y a 4 ans

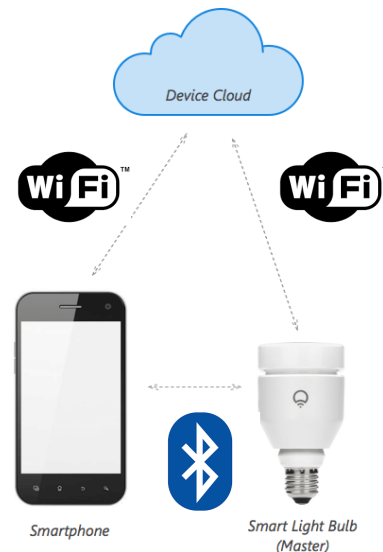


Subscribe to our channel to get video updates. Hit the subscribe button above. #Edureka #EdurekaIoT #InternetOfThings ...

Sous-titres

# Example: the smart light bulb

- Smart light bulbs are becoming very popular: ease of installation, centralized control, many configurations are possible, e.g. dimmable, scheduling & timers, integration with voice control, ...



What's Inside a Smart Bulb? | SYSKA LED Teardown & Full Breakdown!

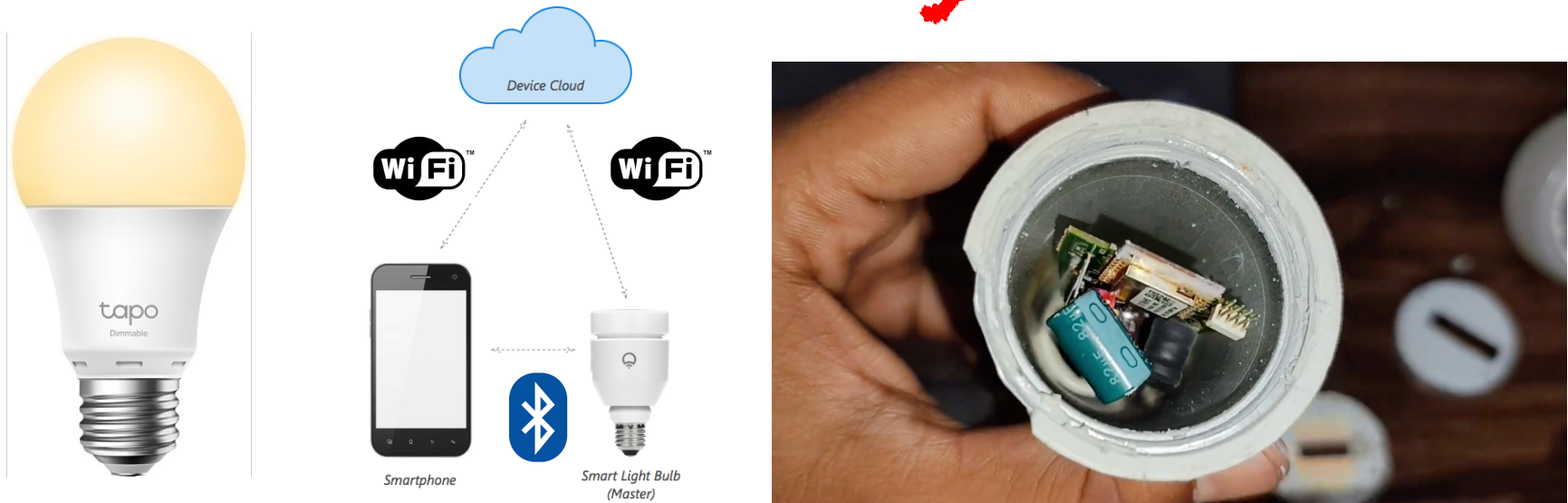
[https://www.youtube.com/watch?v=PvH3tj4\\_kWo](https://www.youtube.com/watch?v=PvH3tj4_kWo)



# Example: the smart light bulb

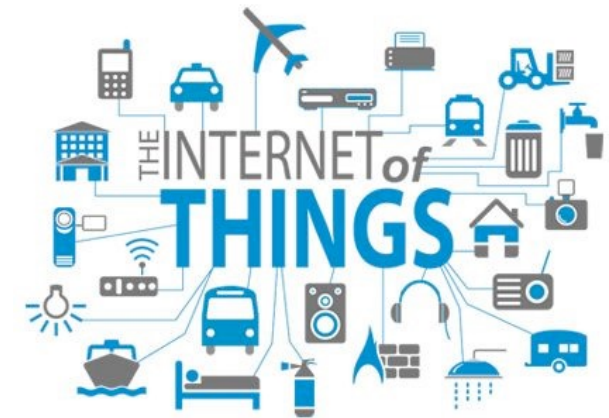
Implementing IoT can be considered as deploying a whole ecosystem

**Q: What is the ecosystem here?**

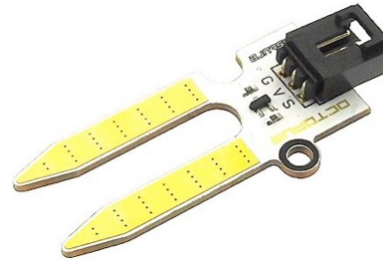
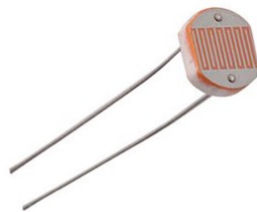


What's Inside a Smart Bulb? | SYSKA LED Teardown & Full Breakdown!

[https://www.youtube.com/watch?v=PvH3tj4\\_kWo](https://www.youtube.com/watch?v=PvH3tj4_kWo)



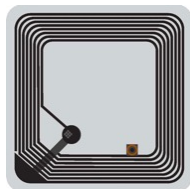
# Interaction? With sensors!





# Interaction: active or passive sensors?

- Powering sensors may be impossible in some cases
  - Radio-Frequency Identification (RFID)
  - Near Field Contact (NFC)
  - Even printed QR code on stickers!

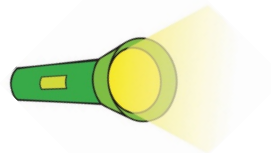


# Interaction: active or passive sensors?

- Powering sensors may be impossible in some cases
  - Radio-Frequency Identification (RFID)
  - Near Field Contact (NFC)
  - Even printed QR code on stickers!



**Q: How RFID works without batteries?**





# IoT? What for? A simple example...



**Soil  
Monitoring**



**Connected  
Agriculture**



ALL EQUIPMENTS ARE  
TRACKED (AVAILABILITY,  
LOCATION, SPEED)

OPTIMIZE HOW THEY  
WORK ALTOGETHER: E.G.  
HARVEST IN LESS TIME!

OPTIMIZATION GIVE TIME  
TO HELP NEIGHBOR  
FARMS AS WELL !



# IoT, a new concept?

**~1850:** The term **telemetry** (Greek: tele = remote, metron = measure) emerged: telegraphs sending weather/river level data over wires, remote monitoring of electrical power networks. **This was the first step — collecting data at one place and transmitting it to another.**

**1970s-1990s:** Shift from analog to digital electronics and computers: industrial plants, oil & gas, weather stations, military. **SCADA** systems (Supervisory Control and Data Acquisition) connected sensors, machines, and computers. **Early “machine-to-machine” (M2M) communication — precursor to IoT**

**A large majority of IoT are basically modern telemetry at massive scale!**

**1920s:** Wireless **radio telemetry** enabled **monitoring from far away** (e.g. aircraft).

**1950s–60s:** NASA and space agencies monitor spacecraft (temperature, pressure, velocity) from Earth. **→ Large-scale remote monitoring & control — a concept central to IoT.**

**1990s-2000s:** Telemetry started using cellular networks (GSM, GPRS, 3G) for remote monitoring (e.g., vehicle tracking, utility meters). **Devices began sending data not only to control centers but also to the internet/cloud**

**2010s-present:** Explosion of **cheap sensors, microcontrollers, Wi-Fi, Bluetooth, LPWAN (LoRa, NB-IoT)**. Devices became small, low-power, affordable

# IoT, a new concept?

~1850: The term telemetry (Greek: tele = remote, metron = measure) emerged: telegraphs sending weather/river level data over wires, remote electrical power networks.

first step — collecting and transmitting it to a central location.

1970s-1990s: Shift from analog to digital electronics and computers: industrial plants, oil & gas, weather stations, military. SCADA systems (Supervisory Control and Data Acquisition) connected sensors, machines, and computers.

IoT is the evolution of telemetry from specialized, limited systems into a global, everyday network of smart, connected devices!

are basically massive scale!

1920s: Wireless monitoring

1950s-60s: NASA and space agencies monitor spacecraft (temperature, pressure, velocity) from Earth. → Large-scale remote monitoring & control — a concept central to IoT.

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of cheap sensors, Bluetooth, LPWAN became small, low-

# IoT ? Simple telemetry?



Internet of Things (IoT) | What is IoT | How it Works | IoT Explained | Edureka

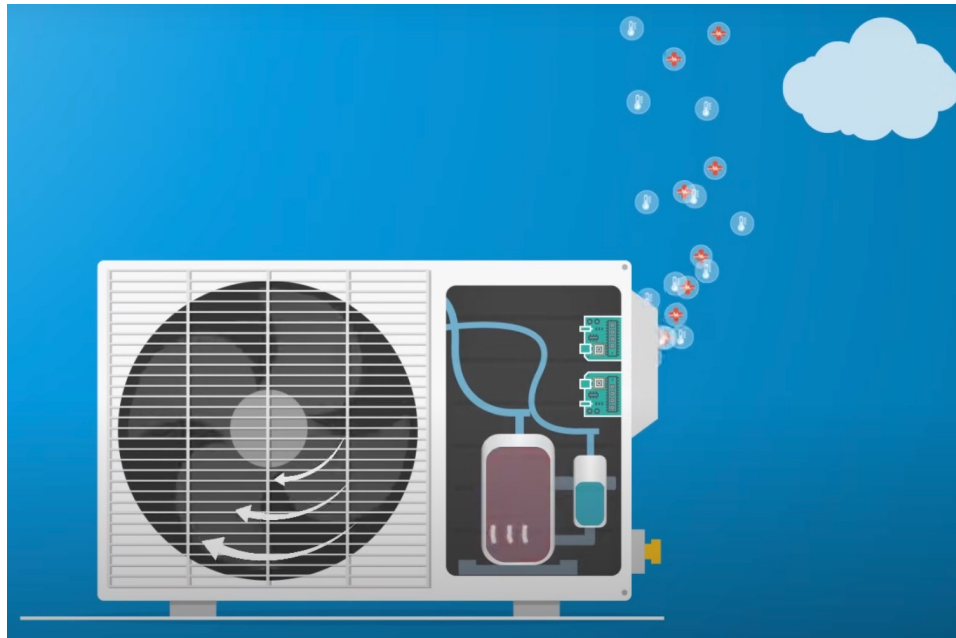
2,1 M de vues • il y a 4 ans



Subscribe to our channel to get video updates. Hit the subscribe button above. #Edureka #EdurekaIoT #InternetOfThings ...

Sous-titres

**Cited as IoT example in the video**



The air conditioner unit can communicate whether its compressor is running smooth or shows some sign of failure.

**Is it IoT or Telemetry?**



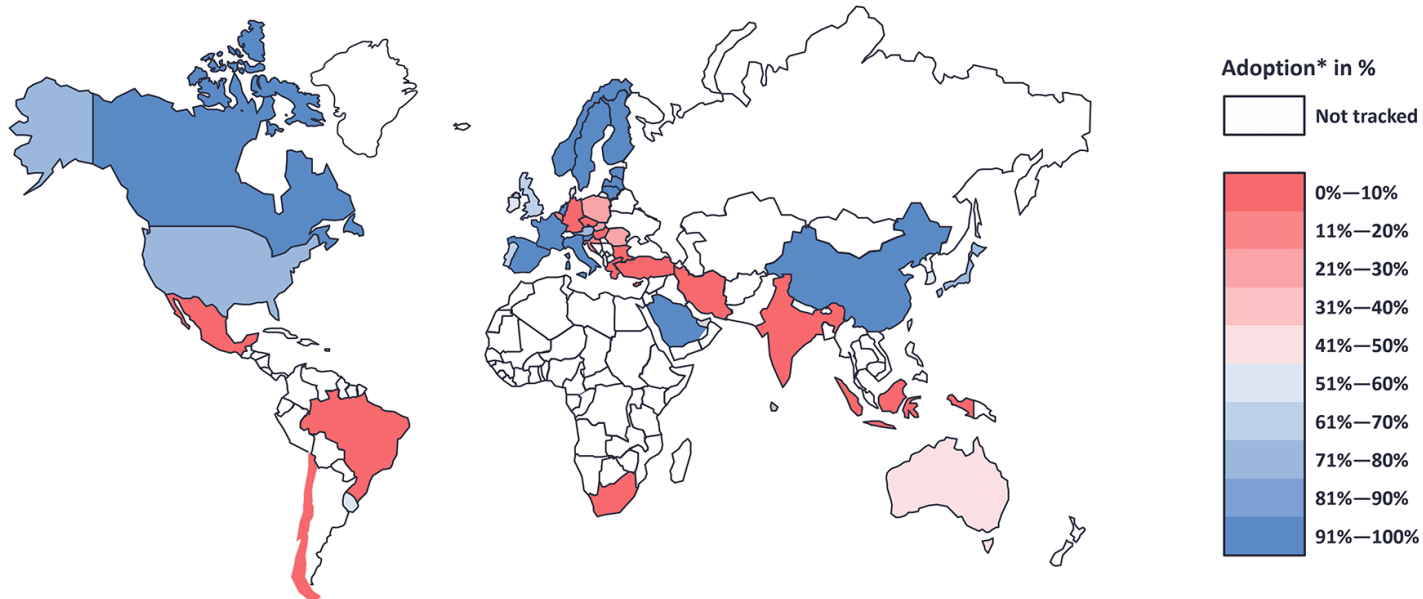
# IoT for Smart Metering – Telemetry?

**IOT ANALYTICS**

February 2024

Your Global IoT Market Research Partner

## Global smart electricity meter adoption 2024



\* =Smart meter adoption (as of Q4 2023) = The share of smart (AMI) electricity meters installed as a share of the total number of metering points that includes residential, commercial, and industrial segments.  
Source: IoT Analytics Research 2024 – Global Smart Meter Market Tracker 2020-2030. We welcome the republishing of images but ask for source citation with a link to the original post or company website.



# IoT for Smart Agriculture – Going IoT!



Soil Monitoring

**MORE  
TELEMETRY  
ORIENTED**

Connected  
Agriculture

**TO REALLY TRUE IOT!**

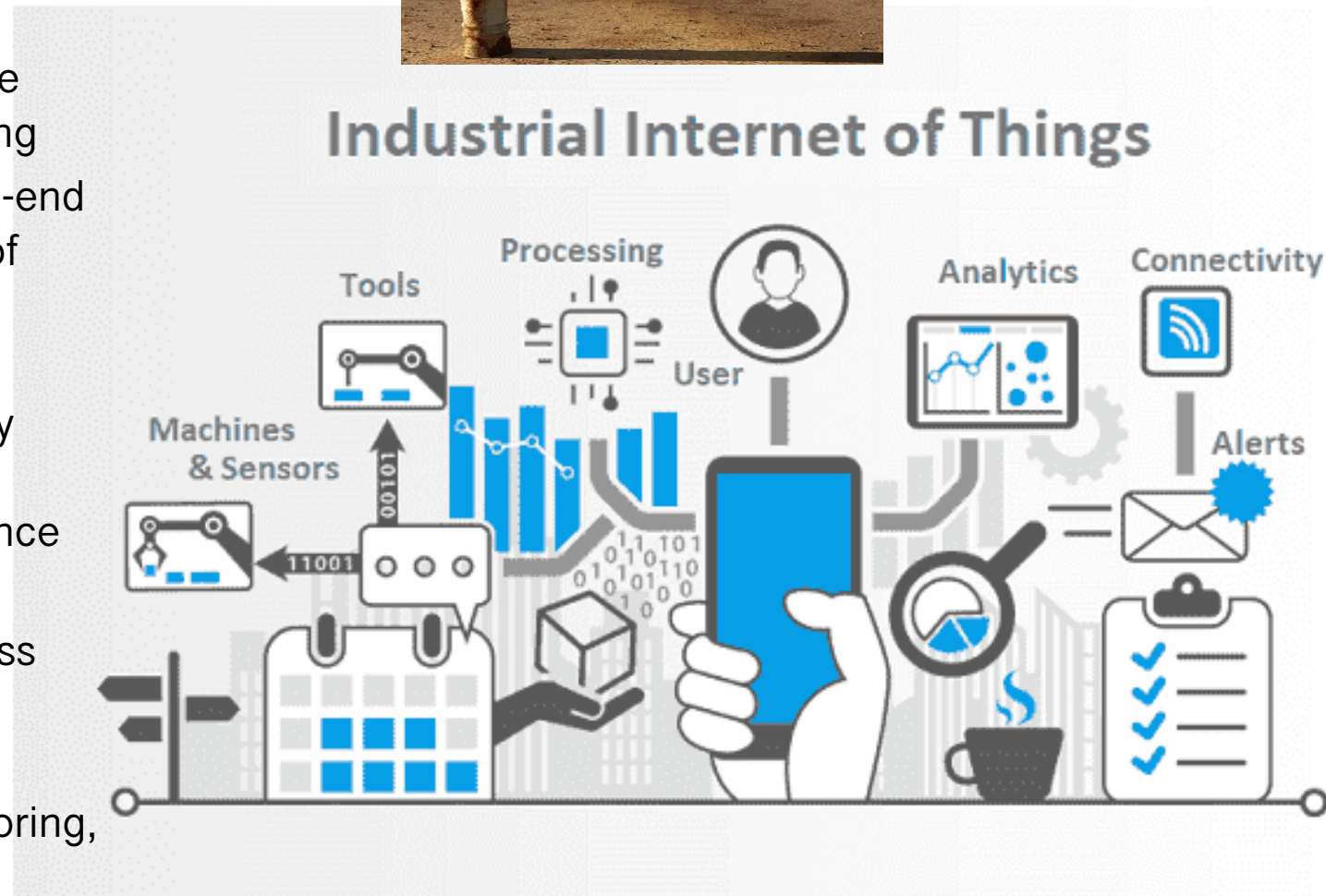


# IoT in industry

## *Industry 4.0*



- Smart logistics management, remote management, tracking
- Connectivity to back-end system, integration of smart tools, Interoperability
- Data analysis, Supply Chain Optimization, Predictive maintenance
- Continuous process improvement, Process automation, Process optimization
- Infrastructure monitoring, Security & Safety

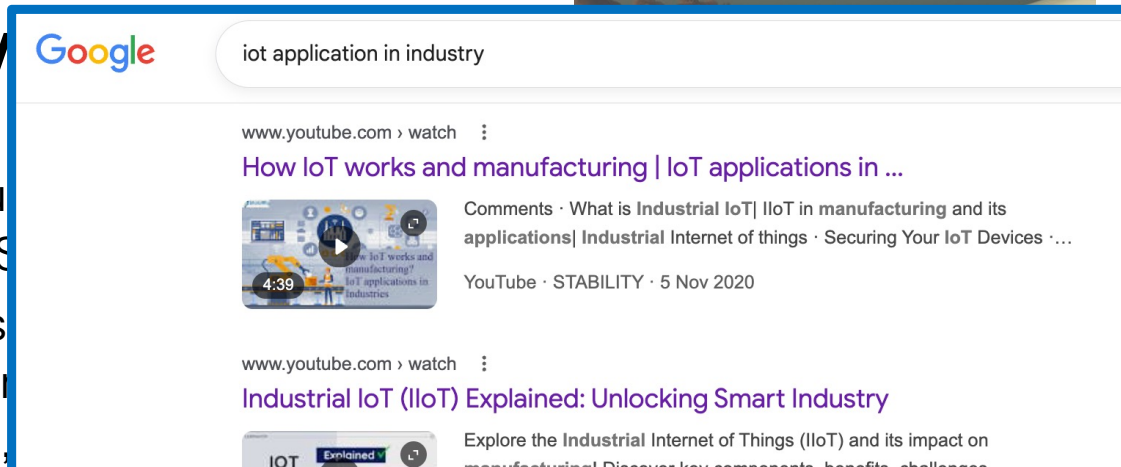




# IoT in industry

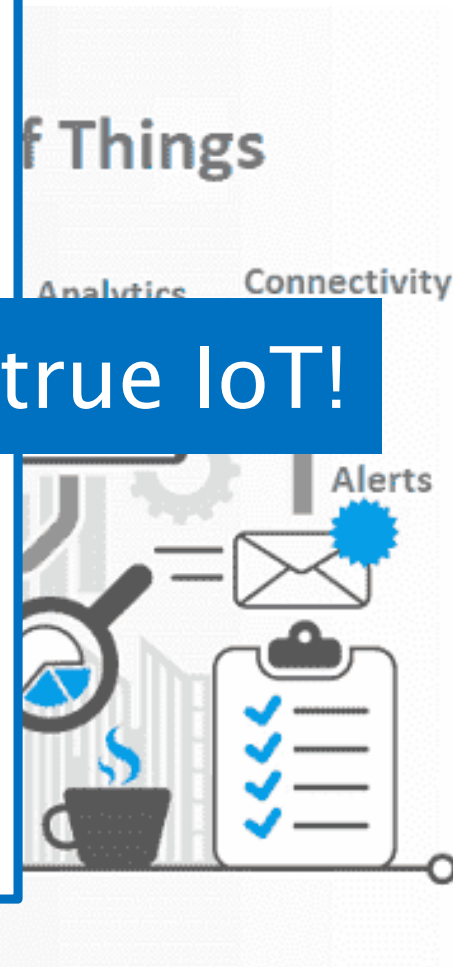
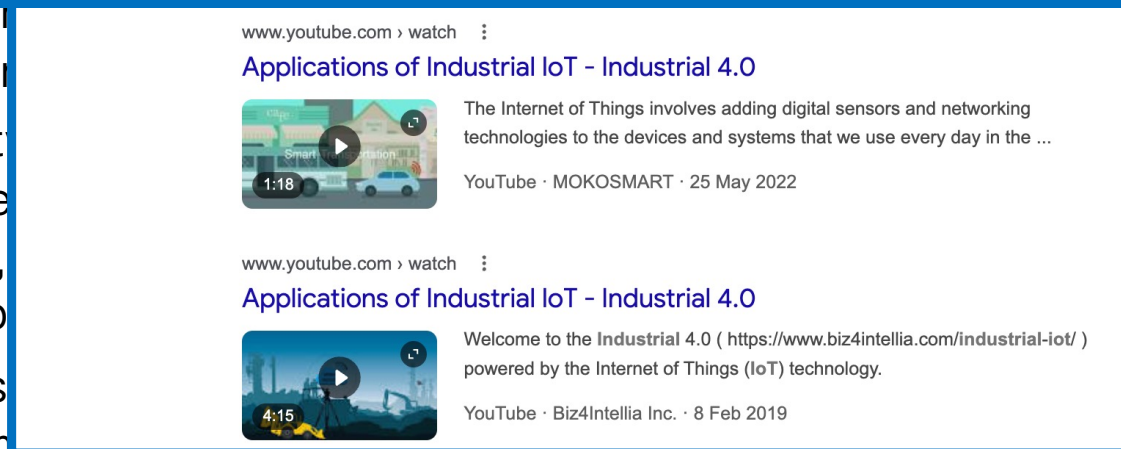
## Industrial

- Infrastructure
- Security & S
- Continuous
- improvement
- automation,



Think critically, not all examples are true IoT!

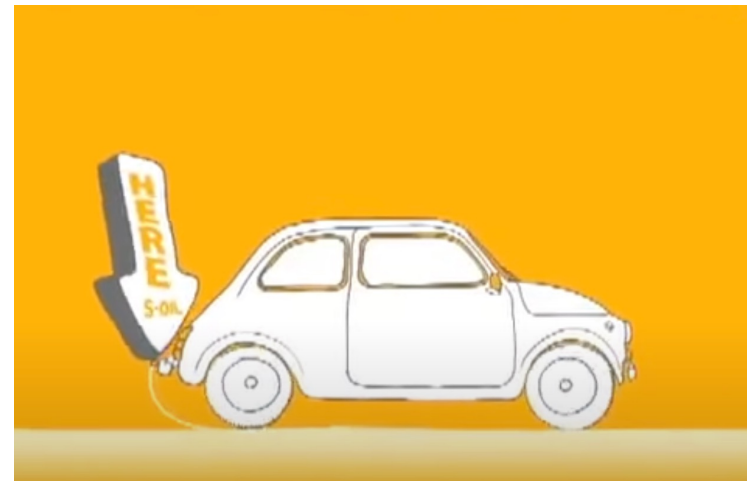
- Connectivity
- system, inte
- smart tools,
- Interoperab
- Data analys
- Chain Optim
- Predictive maintenance



# IoT: All communicating objects?



# IoT: Always complex interactions?



From <https://youtu.be/ccM8RLLKasw>



# IoT: Let's be creative!

Q: How to enable municipal street sweepers to report illegal dumping, leaking pipes and emergencies?



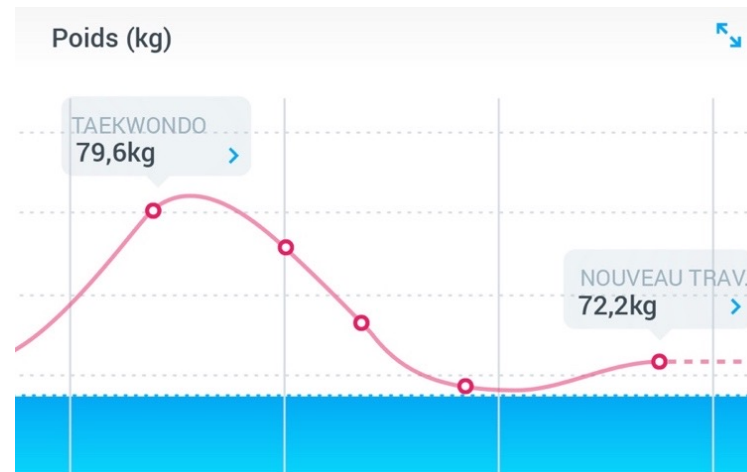
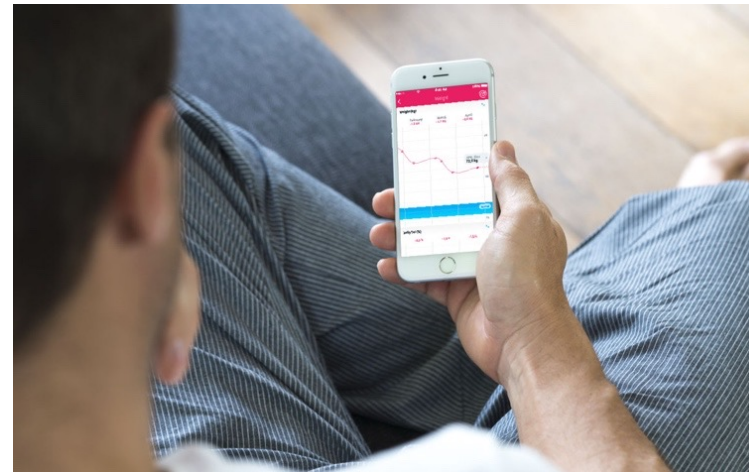
"smartphone"  
Hum, they only  
have 2 hands...



ITU Telecom World 2018  
Phathwa Senene at MTN booth

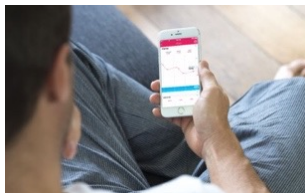


# Home/Consumer IoT products



Pictures from WiThing, <https://www.withings.com/eu/fr/products/body>

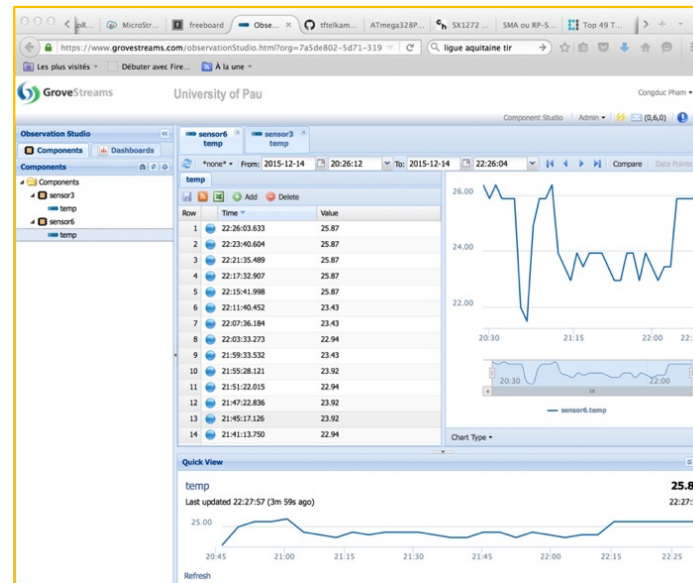
# Local interaction is possible...



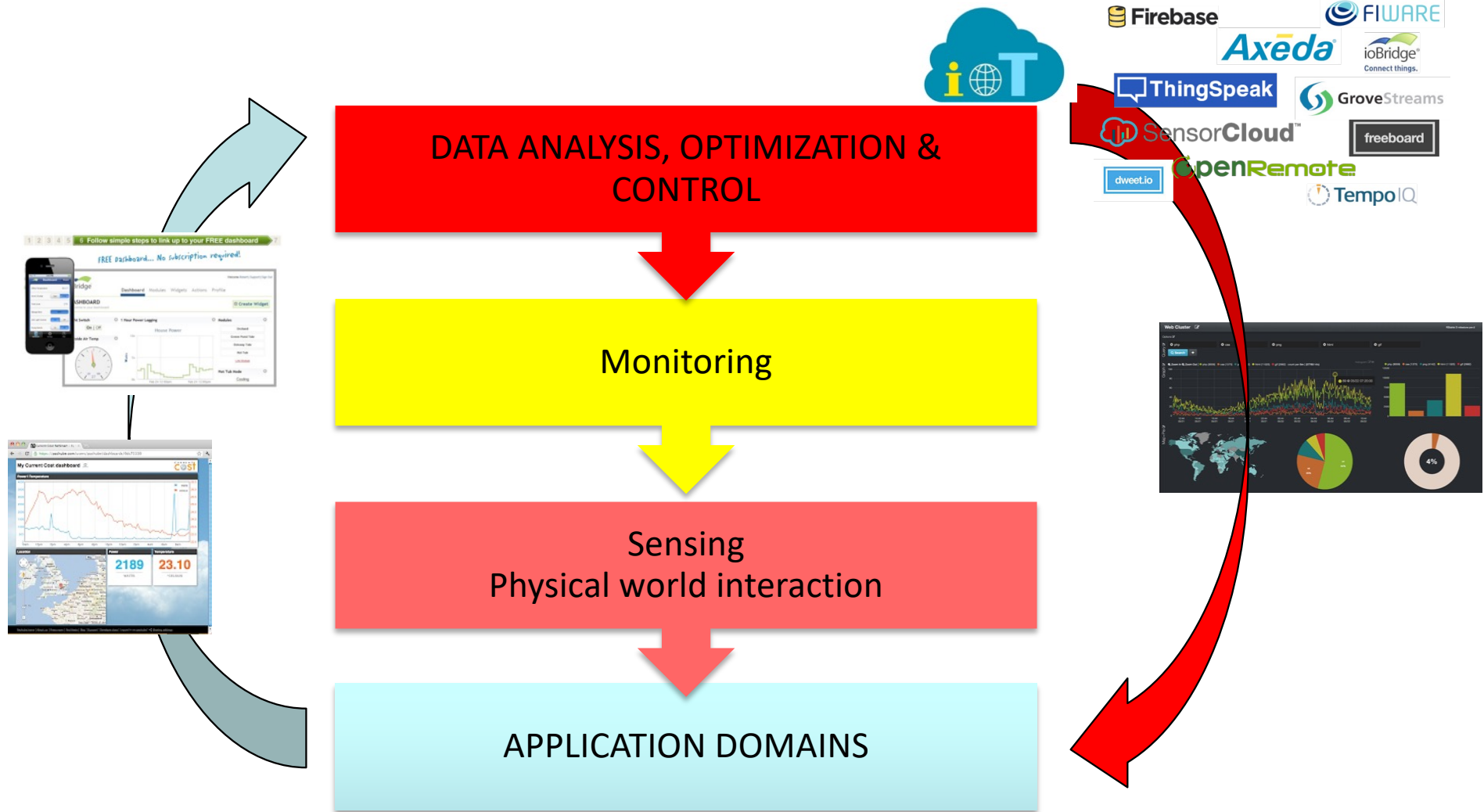


# ...but IoT added-values come from interactions & linked data!





# Sense, Monitor, Optimize & Control

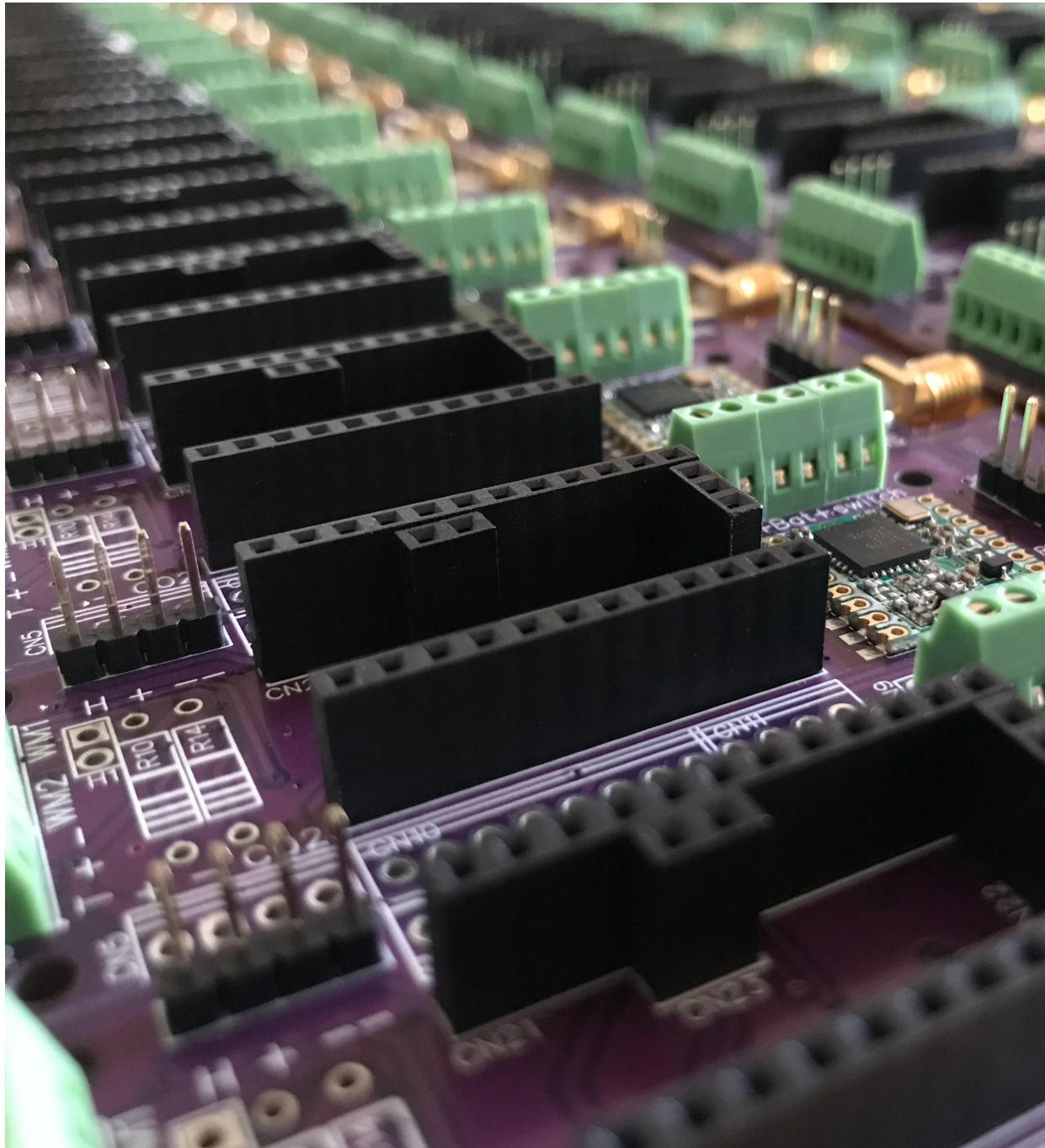




# WHAT DID WE LEARN? QUESTIONS?

- ⦿ IOT IS THE EVOLUTION OF TELEMETRY
- ⦿ IOT=INTERACTIONS WITH PHYSICAL WORLD
- ⦿ INTERACTION → WITH PHYSICAL SENSORS!
- ⦿ IOT ADDED-VALUES COME FROM CLOUD DATA
- ⦿ CLOUD DATA ALLOW FOR DATA CORRELATION



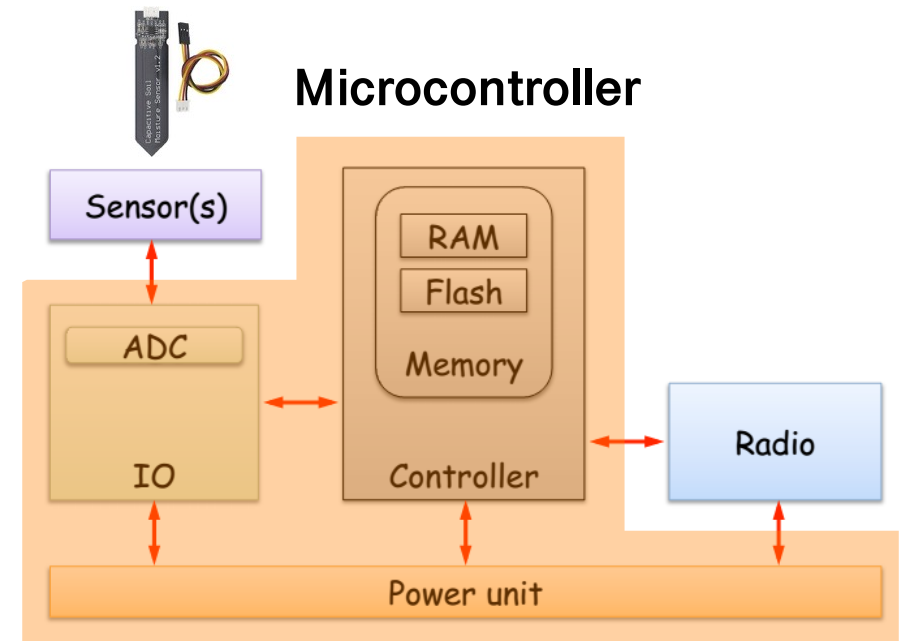
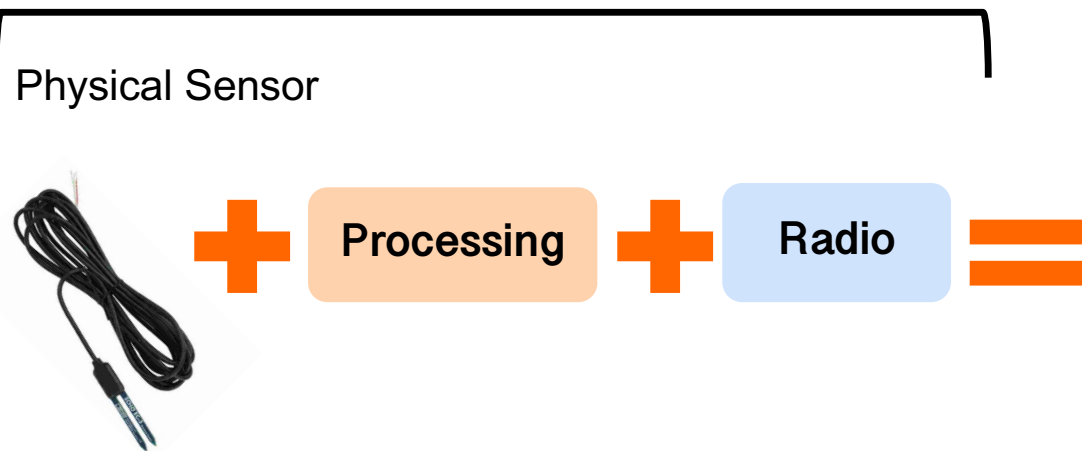
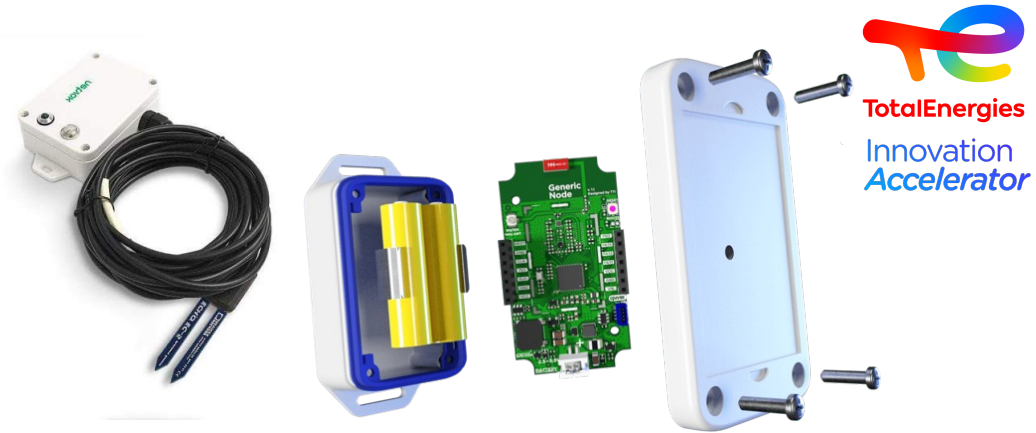


# IOT

## CORE TECHNOLOGIES & CHALLENGES

# Typical IoT device

- IoT device can be viewed as a simple Embedded System
- Designed for a single, specific task



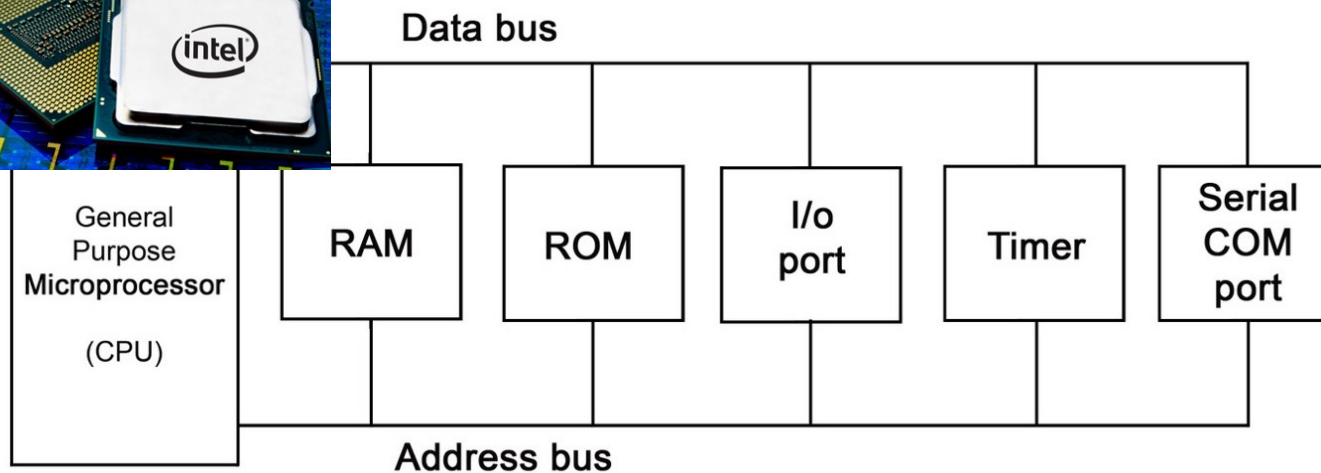
Q: uprocessor vs ucontroller?



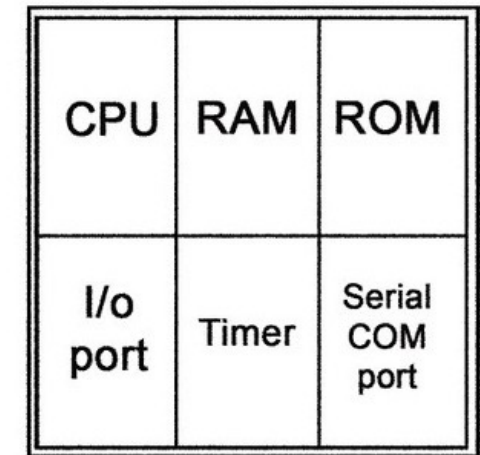
# Microprocessors & Microcontrollers

- ⦿ A microprocessor unit (MPU) is a processor on one silicon chip
- ⦿ A microcontroller unit (MCU) is a microprocessor with some added circuitry on one silicon chip
- ⦿ Most IoT devices are based on microcontrollers

Pham  
tr/~cpham



VS



(Single chip)



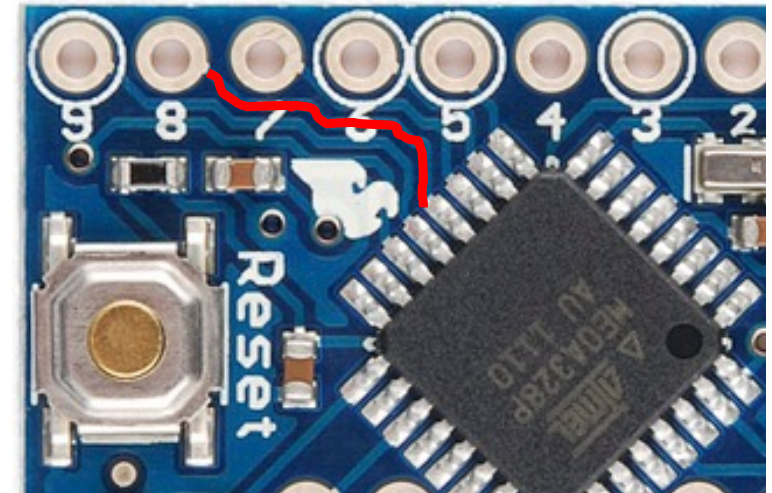
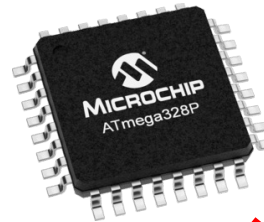
From "An Embedded System Overview" by Dr. Eng. Amr T. Abdel-Hamid

# From $\mu$ controller to $\mu$ controller board

- A  $\mu$ controller (MCU) can be standalone

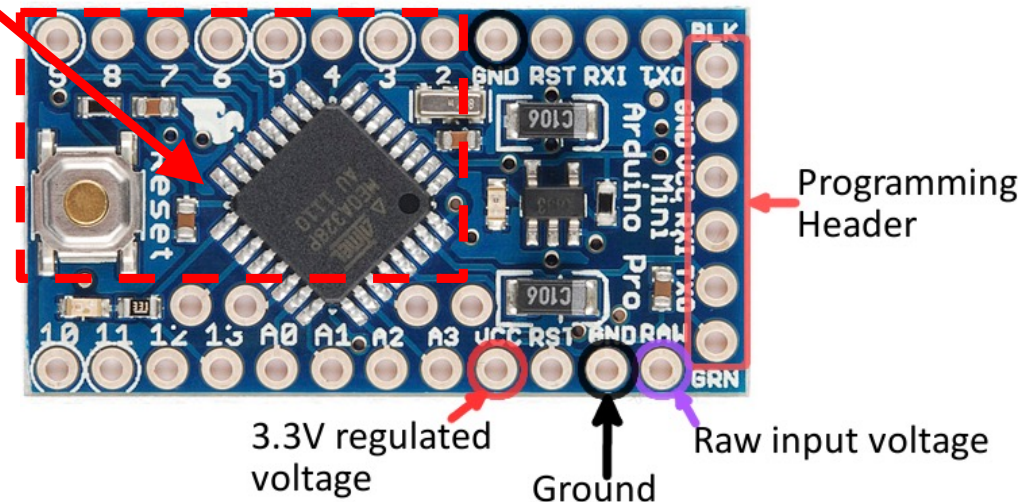
|          |       |                 |
|----------|-------|-----------------|
| CPU      | RAM   | ROM             |
| I/o port | Timer | Serial COM port |

(Single chip)

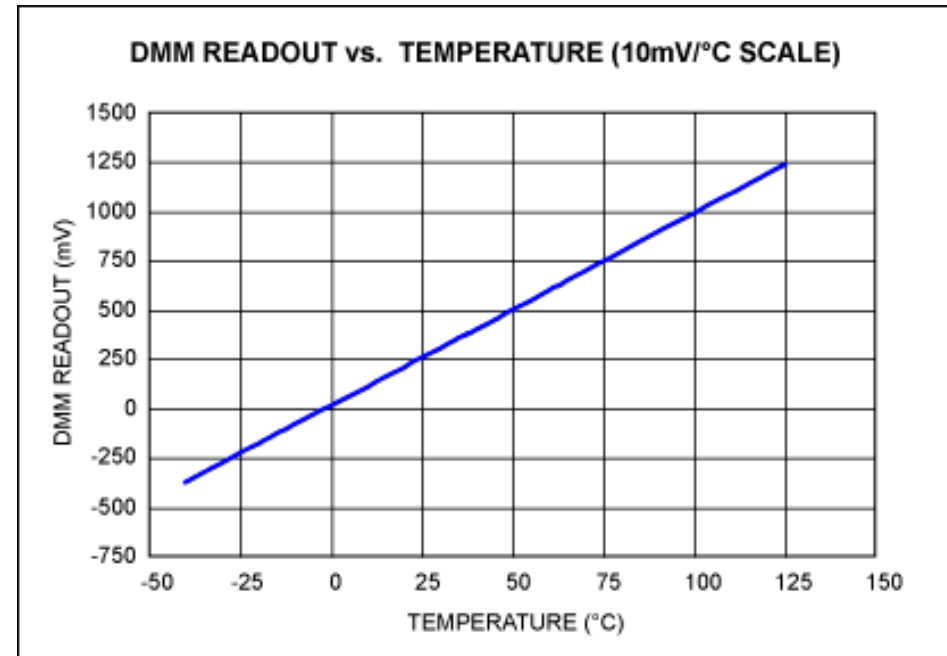


- But, it is usually mounted on a board with additional electronics parts

- Leds, Voltage regulators
- Easy access to pins
- Reset button
- Serial-USB interface

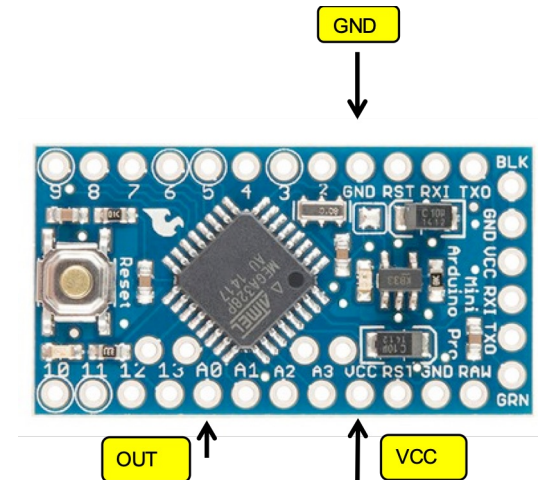
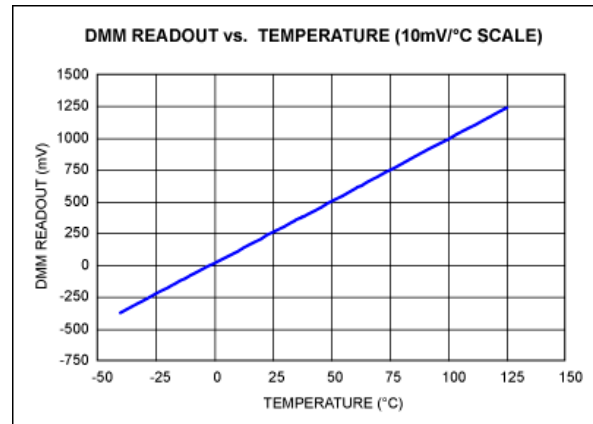


- ⦿ Taking the simple analog sensors example
- ⦿ Analog sensors provides a voltage output that varies according to a physical parameter, e.g. temperature, humidity, luminosity,...





# Digitalizing the physical world!



Microcontrollers have Analog/Digital (A/D) converter to map a voltage to a numerical value. **A/D with 10-bit resolution give numerical values in  $[0, 2^{10}-1] = [0, 1023]$**

V<sub>cc</sub> usually refers to the operating voltage of a given microcontroller. V<sub>cc</sub> is typically 3.3V.

If 0=0V and 1023=3300mV then  **$3300\text{mV}/1024=3.22\text{mV}$  is the granularity of the measure**

**Reading a digital value of 100 means  $100 \times 3.22\text{mV} = 322\text{mV}$**

**If the sensor output is 10mV/1°C then the physical temperature is  $322\text{mV}/10\text{mV} = 32.2^\circ\text{C}$**

# Arduino's success story starting in 2005



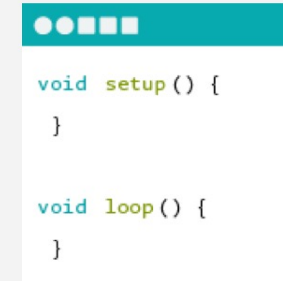
## WHAT IS ARDUINO?

Arduino is an open-source electronics platform based on easy-to-use hardware and software. It's intended for anyone making interactive projects.



## ARDUINO BOARD

Arduino senses the environment by receiving inputs from many sensors, and affects its surroundings by controlling lights, motors, and other actuators.



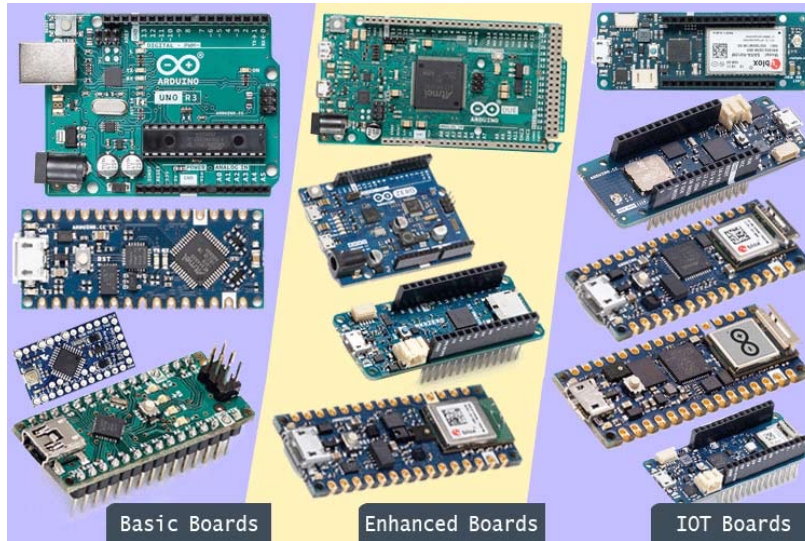
## ARDUINO SOFTWARE

You can tell your Arduino what to do by writing code in the Arduino programming language and using the Arduino development environment.





# 20 years later: the incredibly large microcontroller board ecosystem!



STM32 Nucleo-32



Teensy 3.2



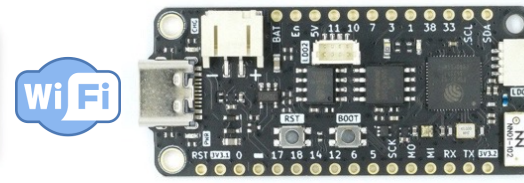
Adafruit Feather



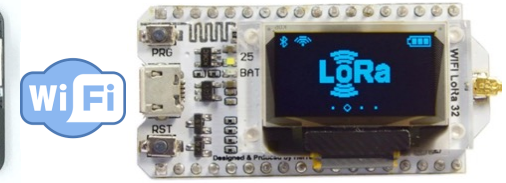
uPesy ESP32



ePulse Feather Low Power ESP32



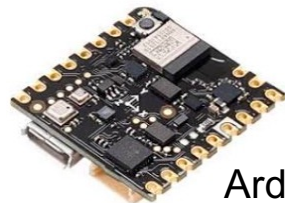
FeatherS3 – ESP32-S3



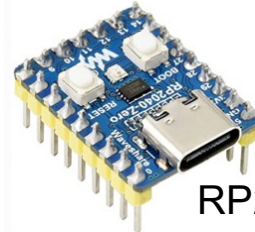
Heltec ESP32



XIAO SAMD21



Arduino Nicla  
Sense ME



RP2040  
zero



DFRobot  
Beetle



QT Py ESP32-C3

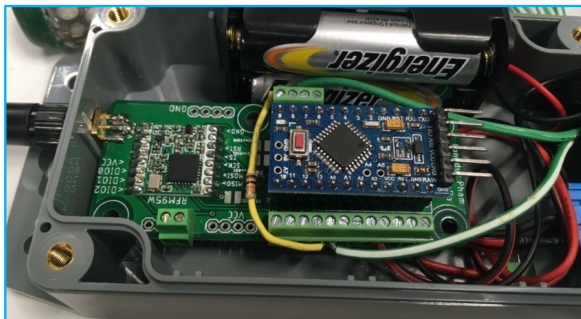
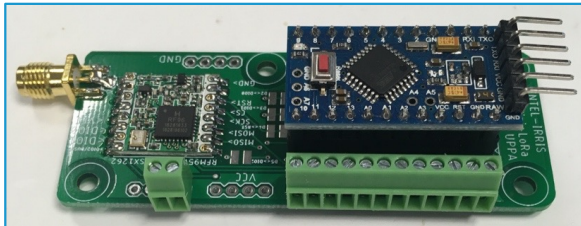
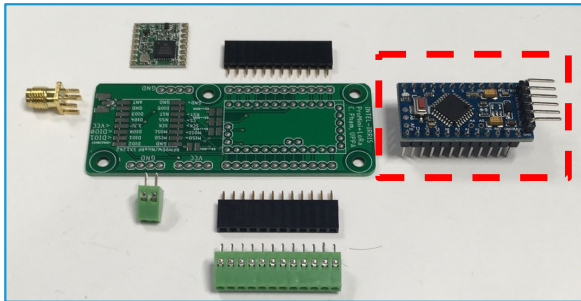


# Major MCUs manufacturers

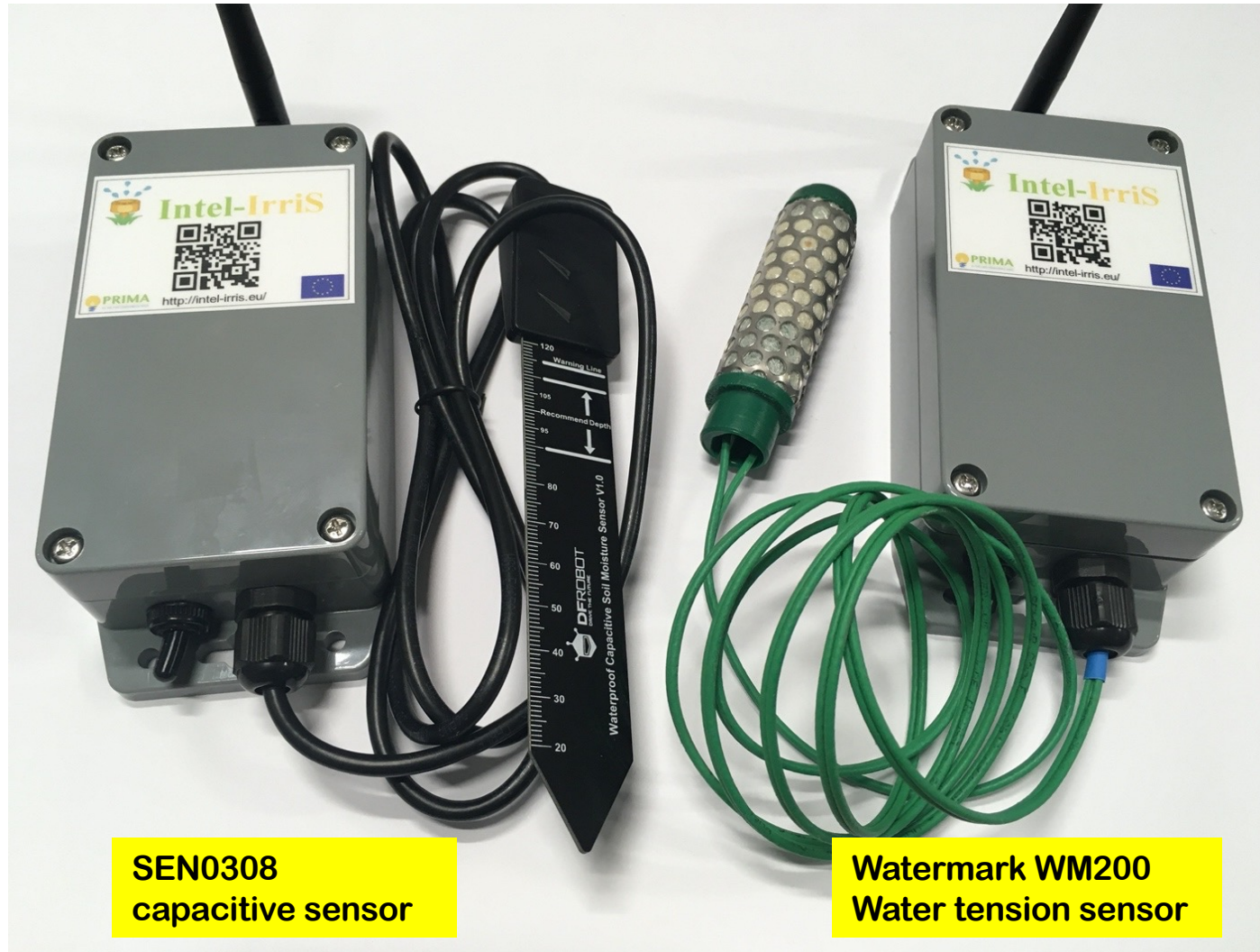
- **STMicroelectronics** – STM32 series
    - Widely used in IoT sensors, wearables, and industrial devices
  - **Espressif Systems** – ESP8266, ESP32
    - Extremely popular for Wi-Fi + Bluetooth IoT (esp8266.com)
  - **Microchip Technology** (formerly Atmel)
    - Backbone of Arduino Uno, AVR, PIC, SAM, etc.
  - **Texas Instruments** (TI)
    - Known for sensors and industrial apps
  - **NXP Semiconductors** – Kinetis series, LPC series, etc.
    - Strong in automotive IoT, smart cards, industrial control
  - **Renesas Electronics** – RX, RA, RL78 series
    - Big in automotive IoT, industrial, and healthcare devices
  - **Nordic Semiconductor** – nRF51, nRF52, nRF53 (BLE)
    - Dominates wearables and wireless IoT sensors
  - **Silicon Labs** – EFM32 (Gecko), Wireless Gecko (BLE, Zigbee, Thread)
    - Used in smart home, energy management, medical devices

# Enabling Do-It-Yourself IoT!

- Simple integration of off-the-shelves components



# Low-cost soil moisture device



Pr. Congduc Pham  
<http://www.univ-pau.fr/~cpham>





# Piloting in Algeria & Morocco

Pr. Congduc Pham  
<http://www.univ-pau.fr/~cpham>



**ADDITIONAL DEPLOYMENT IN GREECE,  
PANAMA, LAOS, THAILAND, TUNISIA**

# Going beyond irrigation

- Use the same approach of cost-efficiency and out-of-the-box deployment, expanding the sensor ecosystem
- Complementarity & Adaptability: high-end, low-end, innovative, ...
- Target **Agroecology, Nature-Based Solutions & sustainable agriculture practices**
- With the objective to better Qualify & Quantify the impact of these new practices
- More data = more correlation in agroecological system**

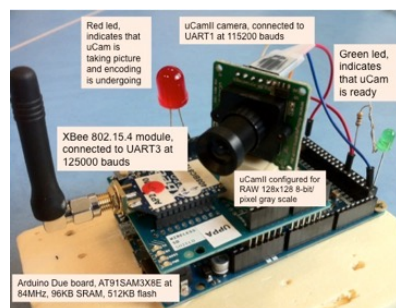




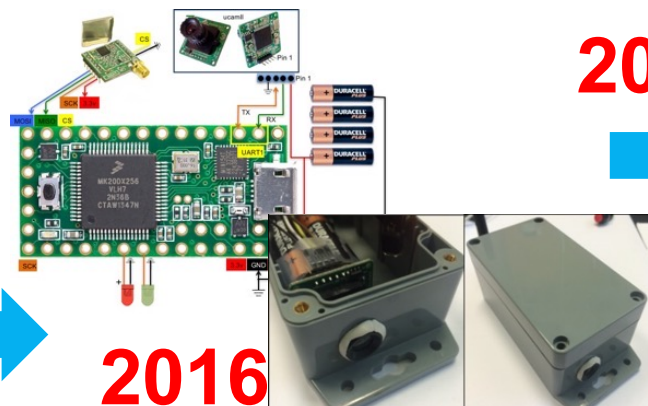
# More Advanced Sensing Systems?



Many applications need visual information → Image Sensing IoT

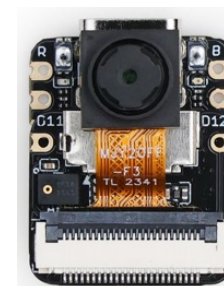


2012



2016

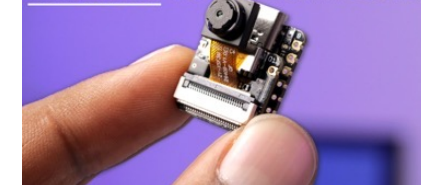
2024



ESP32S3 32-bit, dual-core, up to 240 MHz

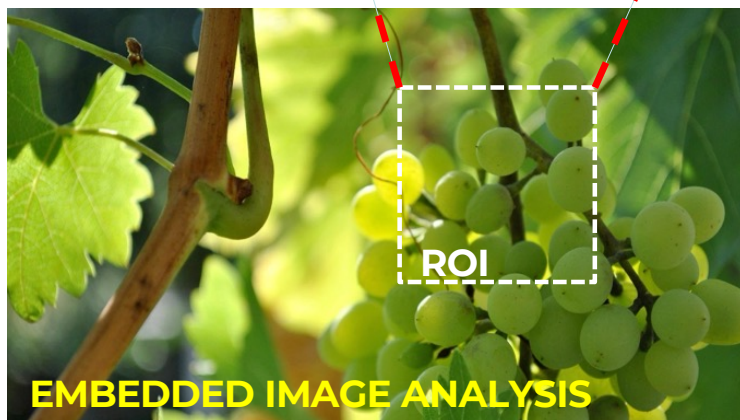
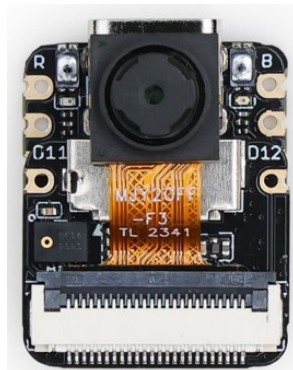
XIAO  
ESP32S3  
Sense

Smallest ESP32 Cam Board





# Image Sensor? Quite a challenge!



**Agriculture**  
**Biodiversity**  
**Environment**

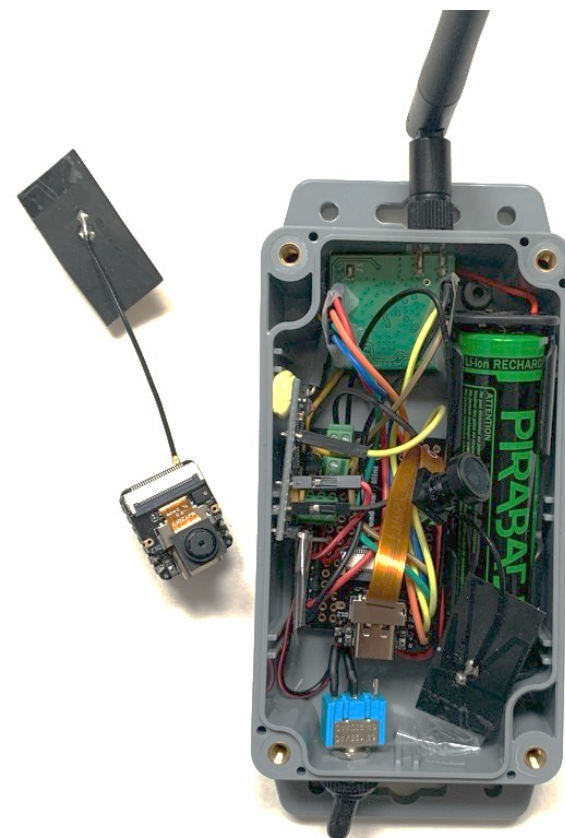
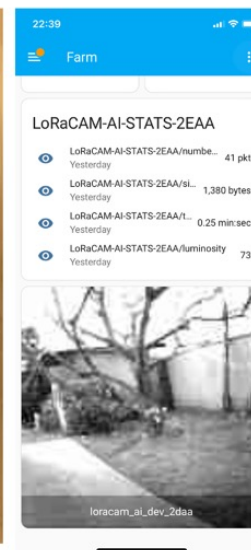
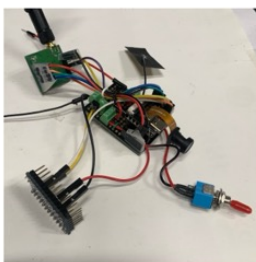
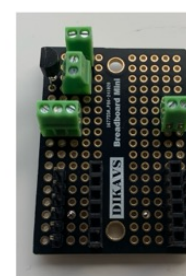
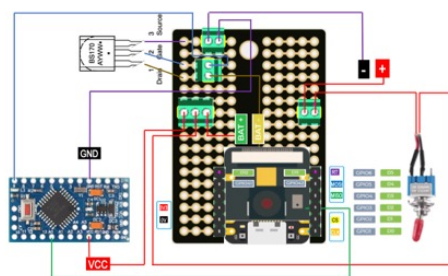
**Wildlife**  
**Agroecology**  
**Surveillance**

- Low Power
- Plug-and-Sense, out-of-the-box
- Embedded AI processing
- Versatile AI learning framework
- Application-specific AI models
- Robust image encoding against losses
- Long-range radio transmissions
- Efficient usage of radio resources



# Proof-of-concept: LORACAM-AI

UPDATED VERSION IN 2025 FOR THE PEPR AGRIFUTUR PROJECT



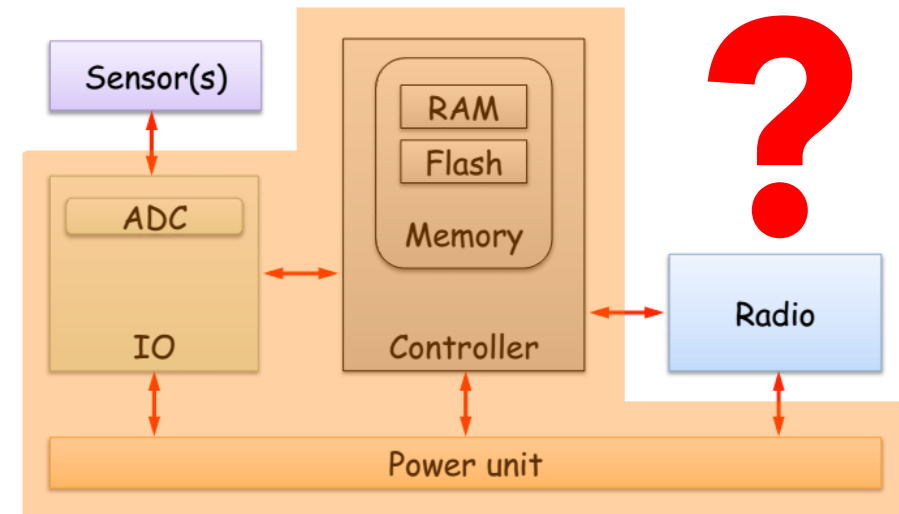
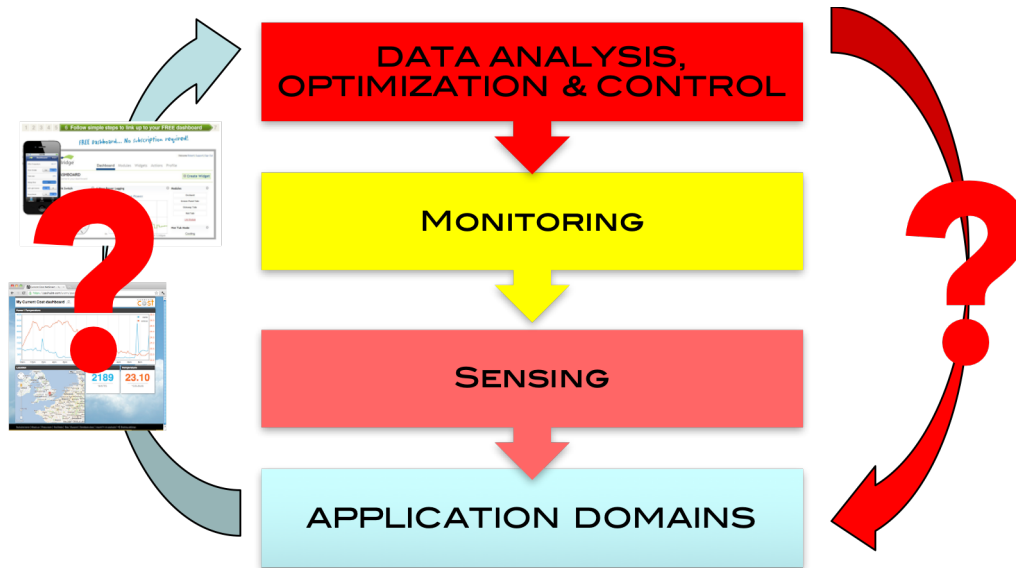
# WHAT DID WE LEARN? QUESTIONS?

- ⦿ NO IOT WITHOUT MICROCONTROLLERS !
- ⦿ VERY POWERFULL MICROCONTROLLERS ARE AVAILABLE
- ⦿ ENABLING DIY IOT FOR MAKERS & HOBBYIST & RESEARCH
- ⦿ SUFFICIENTLY POWERFUL FOR EMBEDDED AI !
- ⦿ MATURE ECOSYSTEM → INNOVATIONS EVERY DAY !





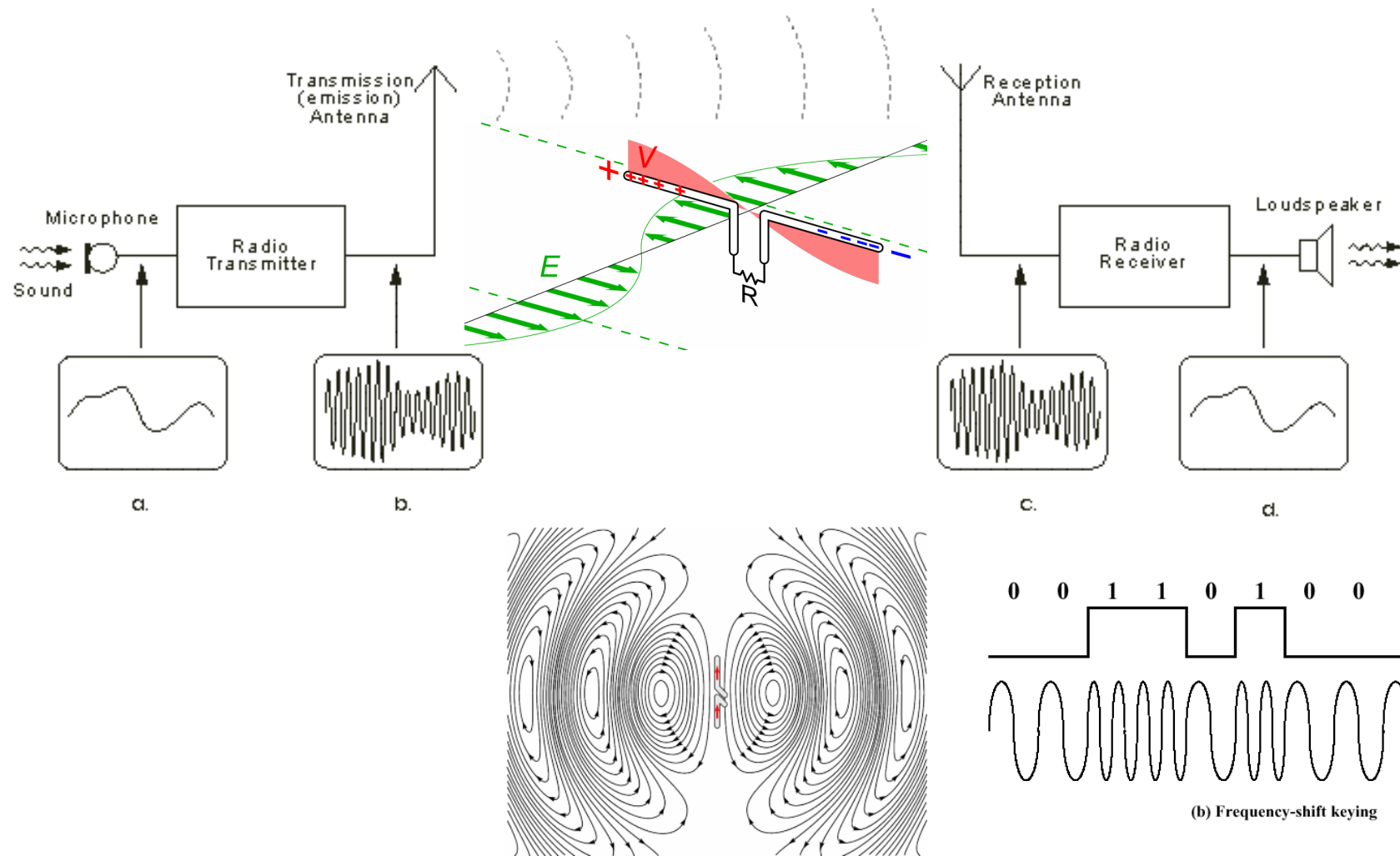
# You said IoT? OK, how to collect data?



Microcontroller

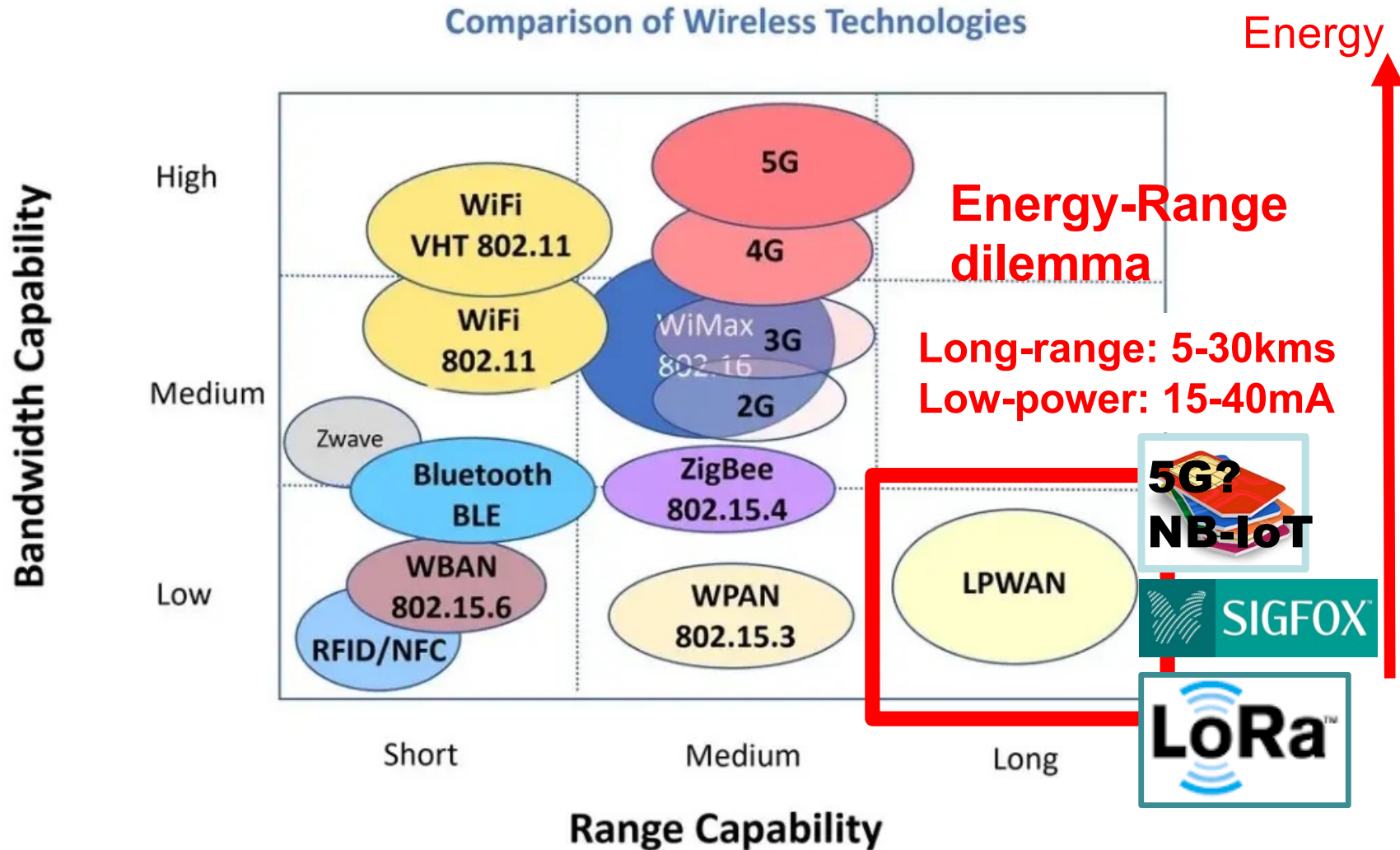


# Wireless (radio) transmission basics



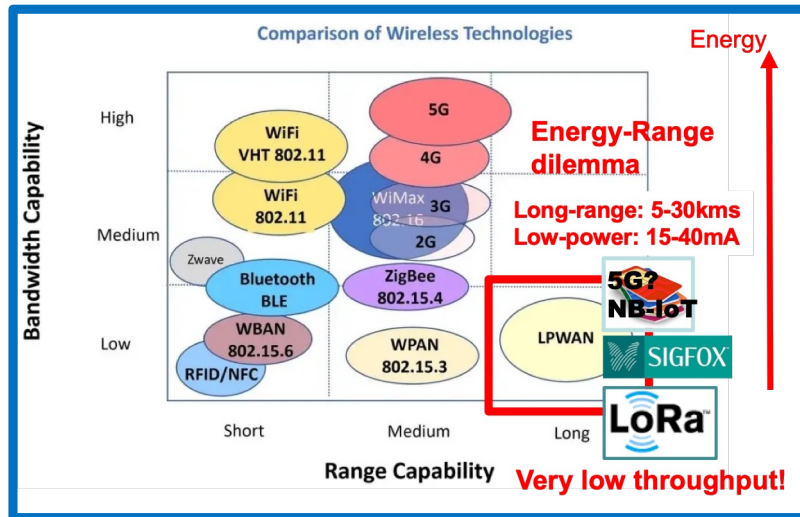
Q: Can we have Gbps in wireless?

# Low-power & long-range radios





# Energy consumption comparison



| 2G        | 3G         | LAN               | ZigBee           | Lo Power WAN  |
|-----------|------------|-------------------|------------------|---------------|
| N/A       | N/A        | O: 300m<br>I: 30m | O: 90m<br>I: 30m | Same as 2G/3G |
| 200-500mA | 500-1000mA | 100-300mA         | 18mA             | 18mA-40mA     |
| 2.3mA     | 3.5mA      | NC                | 0.003mA          | 0.001mA       |

TX power: 500mA. Mean consumption:  $(4s \times 500 + 3596s \times 0.005) / 3600 = 0.56mA$

$2500 / 0.56 = 4464h = 186 \text{ days} = 6 \text{ months} \text{ ☹️}$

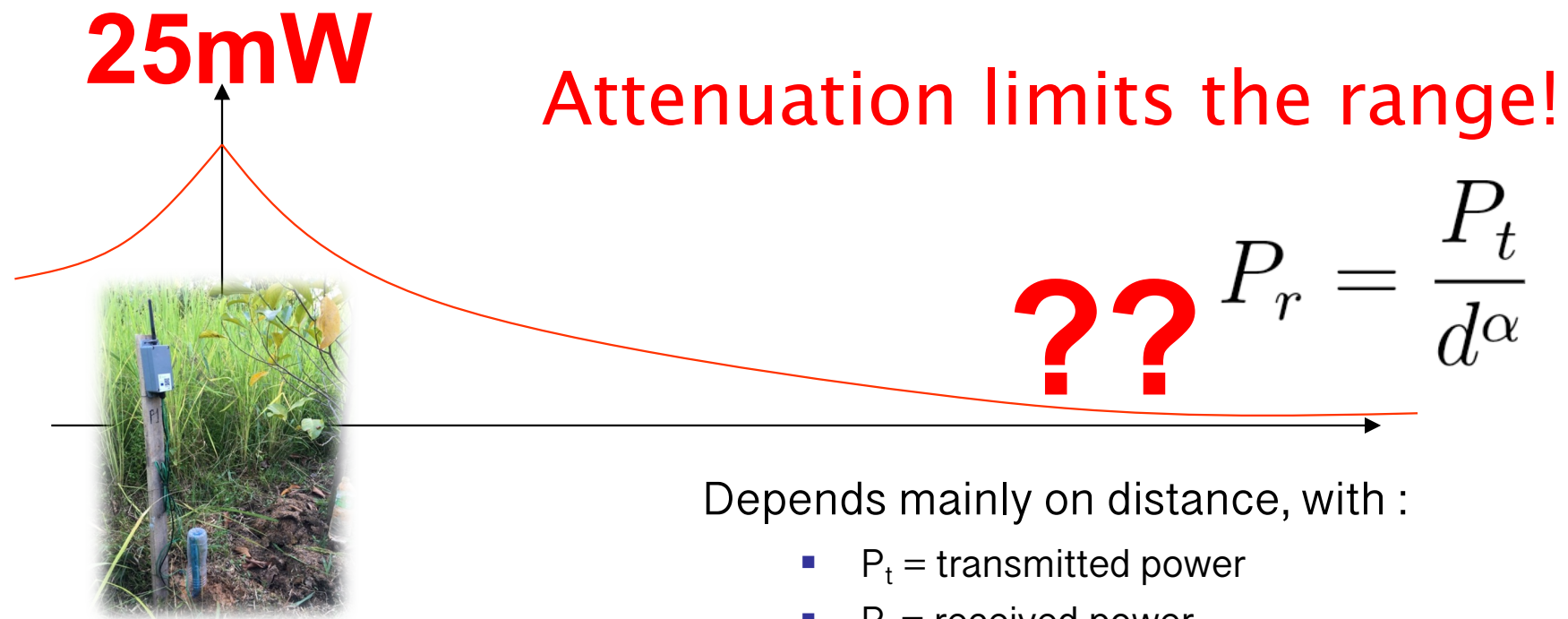
In most cellular networks, the device is still maintaining communication with BS even if it is inactive

TX power: 40mA. Mean consumption:  $(4s \times 40 + 3596s \times 0.005) / 3600 = 0.049mA$

$2500 / 0.049 = 51020h = 2125 \text{ days} \sim 6 \text{ y.} \text{ ☺️}$

Most LPWAN does not need to maintain connection if not in used

# 1st challenge: signal attenuation



Depends mainly on distance, with :

- $P_t$  = transmitted power
- $P_r$  = received power
- $d$  = distance between antennas
- $\alpha$  from 2 to 4

<https://vexlio.com/math-equation-writer/>

# Attenuation for wireless signals

- ⦿ For an ideal antenna (theoretic)

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

**Only f and d are variables!**

- $P_t$  = transmitted power
- $P_r$  = received power
- $P_t / P_r$  is high when  $P_r$  is small → high attenuation
- d = distance between antennas
- c = light speed in space  $3 \cdot 10^8$  m/s
- $\lambda$  = wave length of the signal =  $c/f$
- Higher frequencies f means higher attenuation!



# Attenuation, values in watts

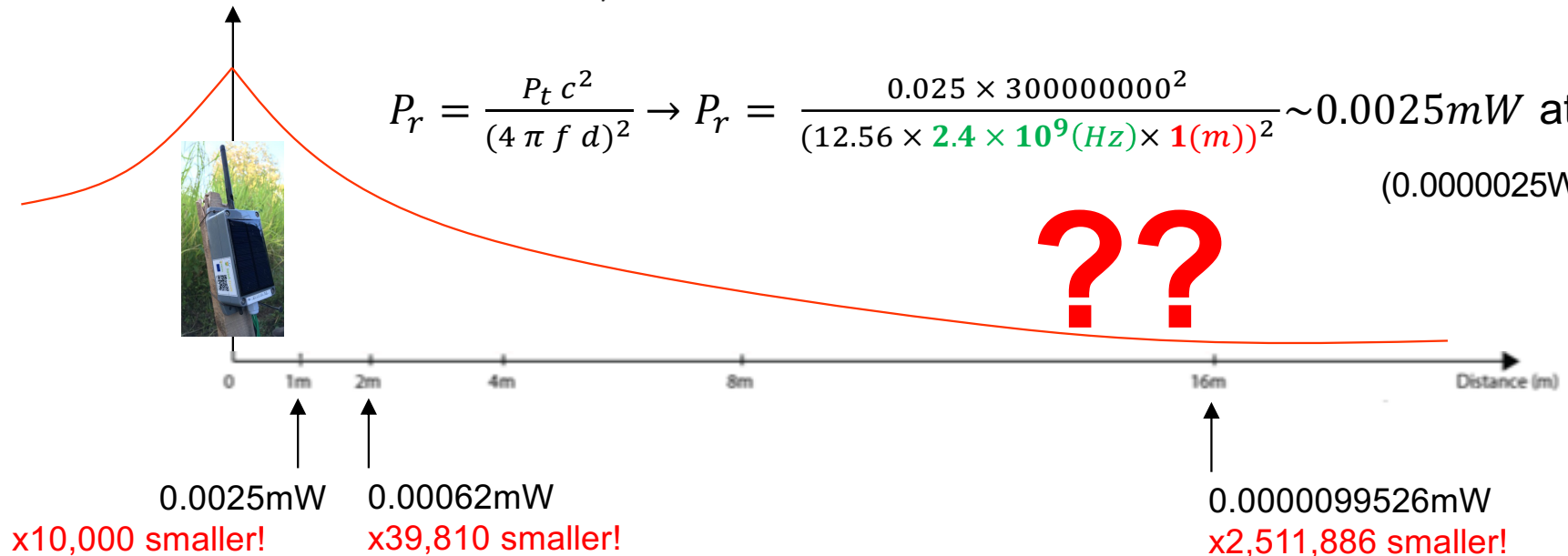
## Free Space Path Loss model

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

**25mW**

$$P_r = \frac{P_t c^2}{(4\pi f d)^2} \rightarrow P_r = \frac{0.025 \times 300000000^2}{(12.56 \times 2.4 \times 10^9 (Hz) \times 1(m))^2} \sim 0.0025mW \text{ at } 1m$$

(0.0000025W)

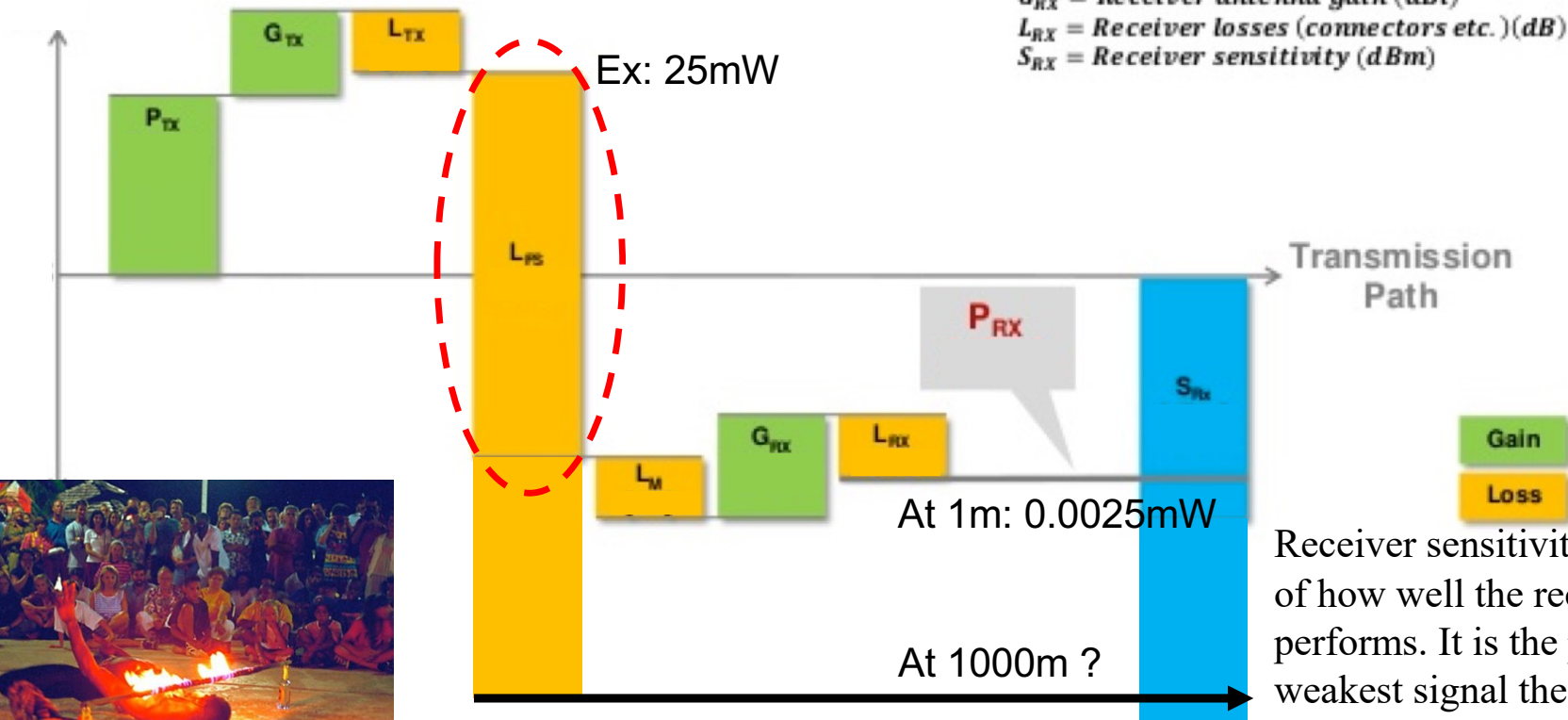


# Link budget in wireless system – (simplified)

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX}$$

Adapted from Peter R. Egli, INDIGOO.COM

$P_{RX}$  = Received power (dBm)  
 $P_{TX}$  = Sender output power (dBm)  
 $G_{TX}$  = Sender antenna gain (dBi)  
 $L_{TX}$  = Sender losses (connectors etc.)(dB)  
 $L_{FS}$  = Free space loss (dB)  
 $L_M$  = Misc. losses (multipath etc.)(dB)  
 $G_{RX}$  = Receiver antenna gain (dBi)  
 $L_{RX}$  = Receiver losses (connectors etc.)(dB)  
 $S_{RX}$  = Receiver sensitivity (dBm)



Receiver sensitivity is a measure of how well the receiver performs. It is the power of the weakest signal the receiver can detect

How low can you go?



# Attenuation, in decibel (dB)

- ⊙ Since attenuation is high, received power  $P_r$  is very small compared to transmitted power  $P_t$  : from 25mW to 0.0025mW
- ⊙ **Decibel uses logarithmic scale** to express attenuation in a more "simple" way:  $P_t/P_r = 10^{\text{dB}/10}$
- ⊙ An attenuation of 40dB means  $P_t/P_r = 10^{40/10} = 10,000$
- ⊙ To simplify even more it would be great to easily add or subtract transmitted power with attenuation= 25mW – 40dB?
- ⊙ We need to also **express transmitted power in logarithmic scale**. We use dBm to express power relatively to 1mW
- ⊙  $P(\text{mW}) = 10^{\text{dBm}/10}$
- ⊙ A transmit power of 14dBm means  $P_t = 10^{14/10} \sim 25\text{mW}$
- ⊙ Now, we can do 14dBm-40dB=-26dBm  $\rightarrow P_r = 10^{-26/10} = 0.0025\text{mW}$



# Attenuation and how far can we go?

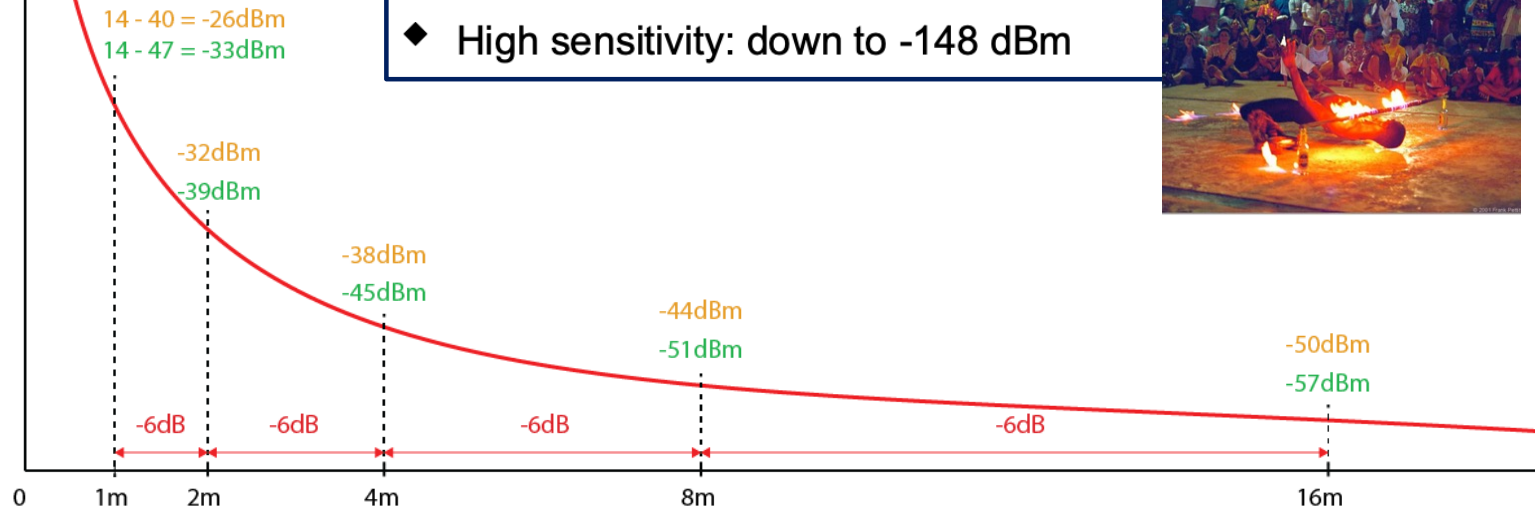


2.4GHz EIRP = 14dBm  
5GHz EIRP = 14dBm

Amplitude  
(dBm)

## KEY PRODUCT FEATURES

- ◆ LoRa® Modem
- ◆ 168 dB maximum link budget
- ◆ +20 dBm - 100 mW constant RF output vs. V supply
- ◆ +14 dBm high efficiency PA
- ◆ Programmable bit rate up to 300 kbps
- ◆ High sensitivity: down to -148 dBm



|      |         |
|------|---------|
| -26  | 1       |
| -32  | 2       |
| -38  | 4       |
| -44  | 8       |
| -50  | 16      |
| -56  | 32      |
| -62  | 64      |
| -68  | 128     |
| -74  | 256     |
| -80  | 512     |
| -86  | 1024    |
| -92  | 2048    |
| -98  | 4096    |
| -104 | 8192    |
| -110 | 16384   |
| -116 | 32768   |
| -122 | 65536   |
| -128 | 131072  |
| -134 | 262144  |
| -140 | 524288  |
| -146 | 1048576 |
| -152 | 2097152 |

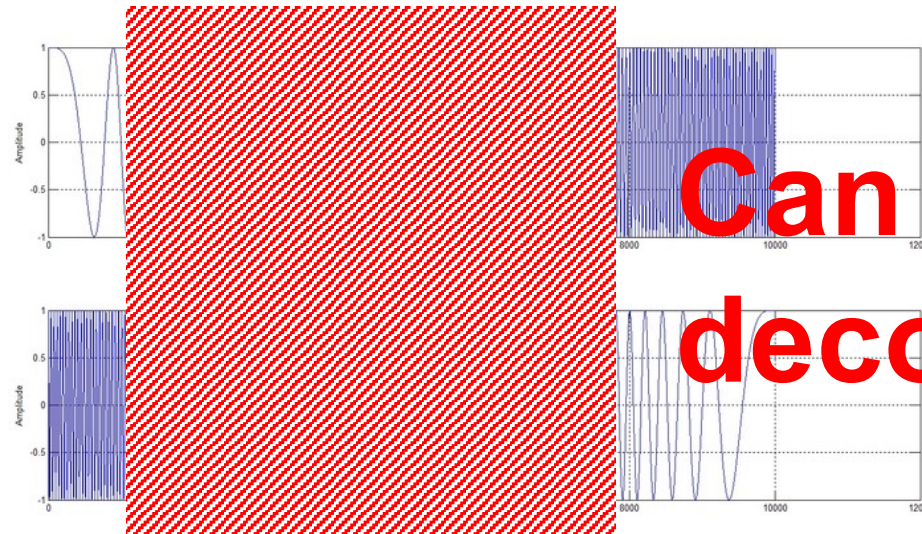
# How can we increase range?



- ⦿ Increase TX power and/or improve RX sensitivity
- ⦿ RX sensitivity (decoding capability~robustness) can be increased when transmitting slower – like speaking slower!
- ⦿ → LPWAN have low data rates
- ⦿ Ex: LoRa technology. Spreading Factor defines how long is a symbol. Longer duration → more robustness

**up chirp → Binary 0**

**down chirp → Binary 1**



**Can still  
decode!**

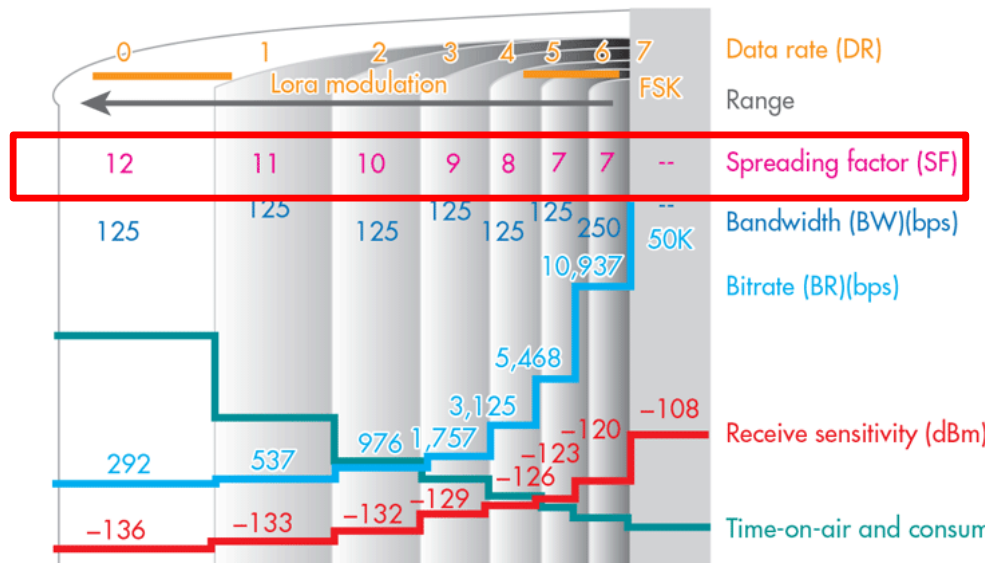
# The price to pay!



HopeRF RFM series



- ⦿ **The price to pay for LPWAN**
- ⦿ LoRa radio has **very low** throughput  
200bps – 37500bps  
→ 0.2kbps – 37.5kbps!

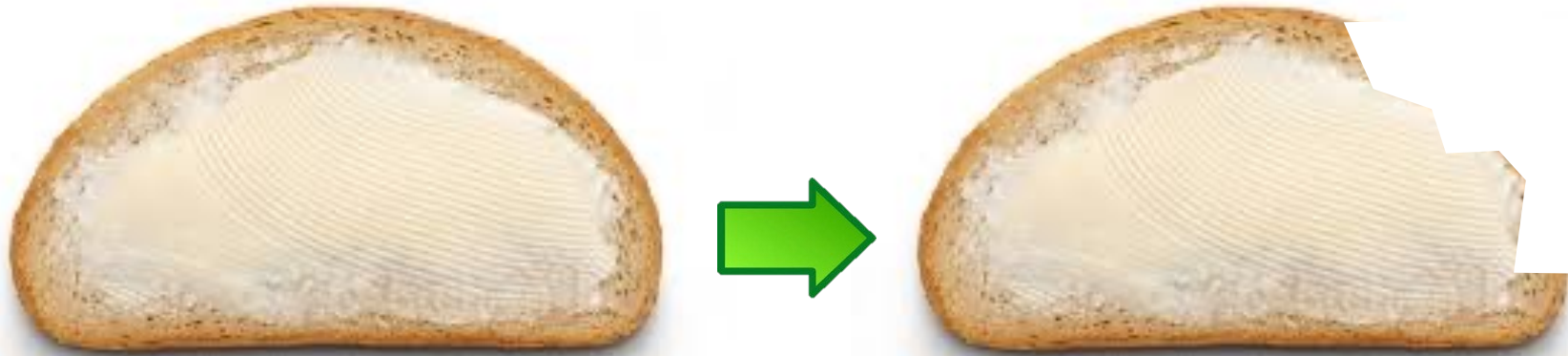


WiFi 802.11n: 450 000 000 bps (450Mbps)  
 WiFi 802.11g: 54 000 000 bps (54Mbps)  
 Bluetooth3&4: 25 000 000 bps (25Mbps)  
 Bluetooth BLE: 2 000 000 bps (2Mbps)  
 3G/4G : 20Mbps-200Mbps  
**LoRa** : 200bps – 37500bps (0.0002 –0.0375Mbps)  
 3G/LoRa ratio: 20,000,000bps/200bps = 100000!



# DISTRIBUTE to be more robust!

## The buttered toast analogy



- ⦿ Assuming you could get back ALL your butter, how much butter did you lose?
- ⦿ This is the idea behind "spread spectrum" techniques: the more you "spread", the more it is robust to interferences

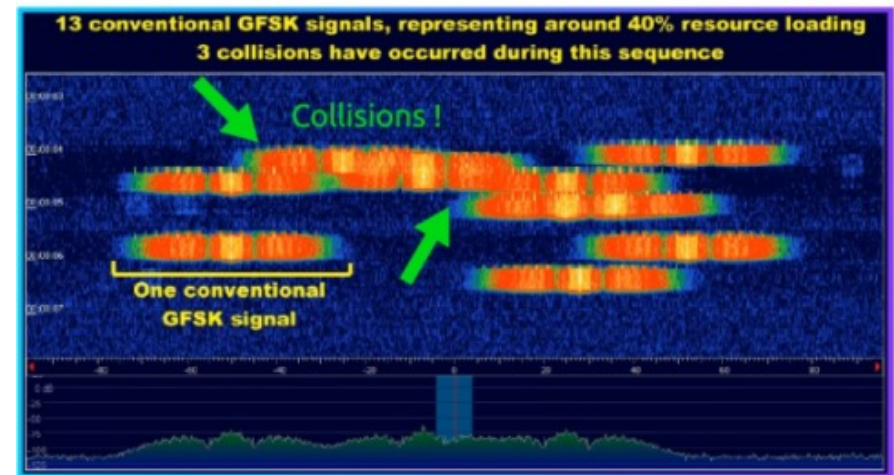
# Another solution: BE INVISIBLE!

- Ultra-narrow band (UNB) of about only 100Hz (e.g. SigFox) 
- High frequency diversity from one message to another
- Narrowband reduces noise and increases transmission quality
- But decoding is much more complex...**

|                         |  |  |
|-------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Frequency band          | 868/915 MHz                                                                         | 868/915 MHz                                                                          |
| Physical layer          | CSS - Chirp Spread Spectrum                                                         | UNB – Ultra Narrow Band                                                              |
| Spreading factor        | $2^7 - 2^{12}$                                                                      | NA                                                                                   |
| Channel bandwidth       | 125 kHz to 500 kHz                                                                  | 100 Hz (UL)<br>600 Hz (DL)                                                           |
| UL (upload) data rate   | 29-50 kbps                                                                          | 100 bps                                                                              |
| DL (download) data rate | 27-50 Kbps                                                                          | 600 bps                                                                              |
| Efficiency (bit/s/Hz)   | 0.12                                                                                | 0.05                                                                                 |
| Doppler sensitivity     | Up to 40 ppm                                                                        | Unconstrained                                                                        |
| Max Tx power            | EU: +14 dBm<br>US: +23 dBm                                                          | EU: +14 dBm<br>US: +23 dBm                                                           |
| Max link budget         | 156 dB                                                                              | 156 dB                                                                               |

More than 1000 times smaller!

Conventional Wireless systems



Sigfox Ultra Narrow Band

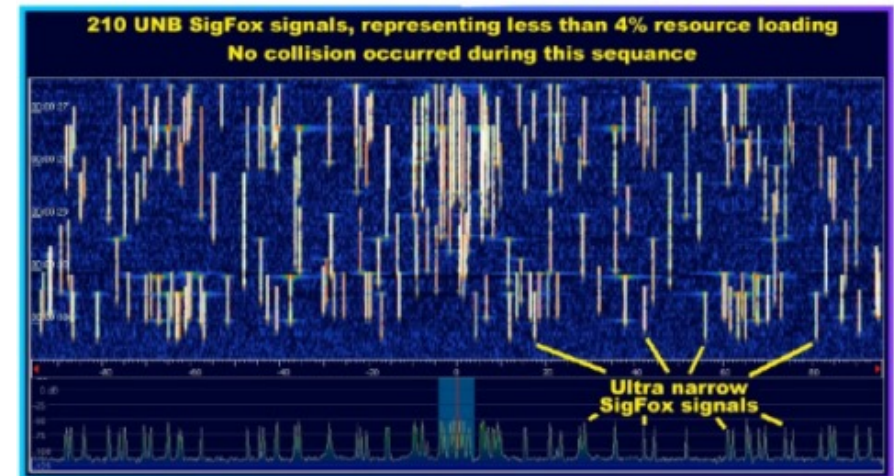
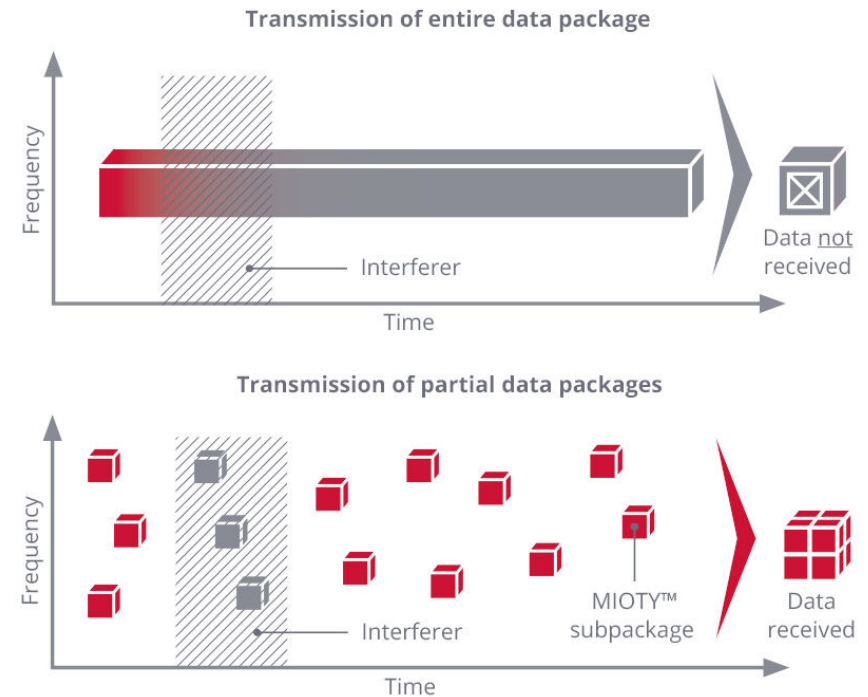
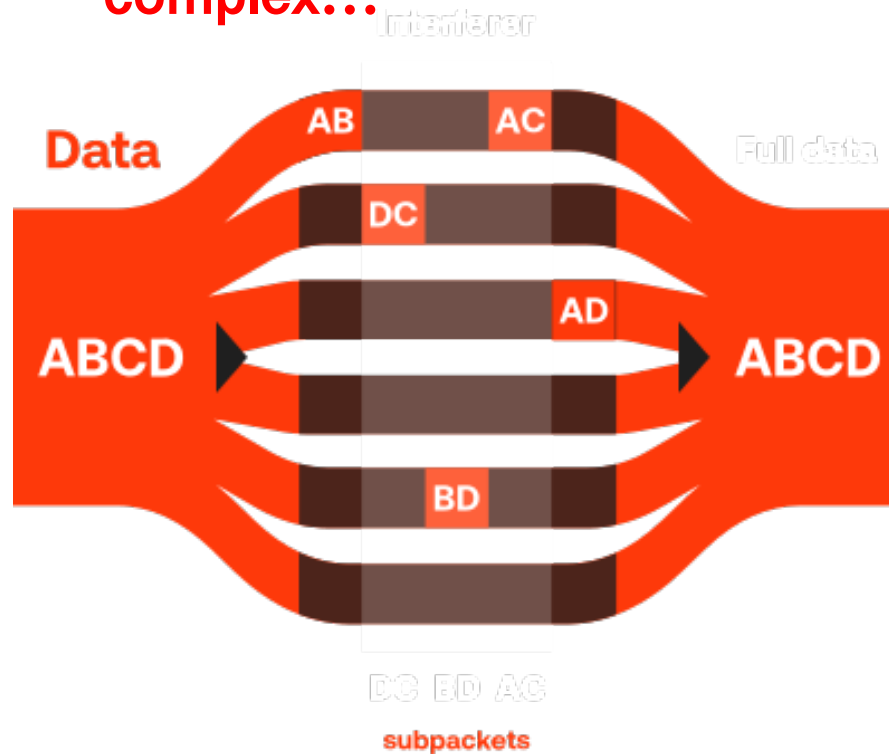


Image credit: <https://www.linuxembedded.fr/2020/03/introduction-a-sigfox>

# Distribute AND try to be invisible!

- A new comer: mioty technology based on Telegram-Splitting
- **Again, decoding is much more complex...**





# The LPWAN revolution... and battle!

Tata Communication  
world's largest IoT n  
India



LoRa™ technology to be  
integrated into FLASHNET's street  
lighting management solution



From intelli  
" Brasov,  
2015

SIGFOX and Glen Canyon Corp. to  
Connect 1 Million Smart Meters to  
Internet of Things

Semtech and STMicroelectronics  
Collaborate to Scale LoRa  
Technology to Meet High-Volume Demands of  
Internet of Things Applications

LoRa® IoT Ecosystem

From www.st.com - December 14,  
2015 7:27 AM

ST to offer complete line of  
solutions including LoRa systems  
on chips (SOCs) to  
accelerate deployments of  
low-power wide-area networks by  
mobile network operators (MNOs)

Cofely Services, a subsidiary of  
ENGIE (SUEZ group), integrates  
SIGFOX solution to expand services it  
provides for buildings

COFELY Services  
GDF SUEZ

SIGFOX  
One network A billion dreams

From m  
2:26 PM  
" Cofe  
in driv  
buildi  
conne  
the SI  
cost-e  
this n  
revisi

Sogedo et Sigfox lancent les  
compteurs d'eau intelligents



From www.sudouest.fr - December  
16, 2015 2:24 PM

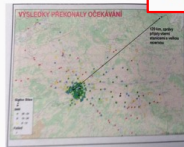
" Gestionnaire de réseaux dans  
les Landes, en Gironde et en  
Dordogne, Sogedo utilise les  
ondes radio de Sigfox pour relever  
les compteurs et surveiller l'état

des canalisations  
Le compteur..."

METERING &  
SMART ENERGY

determ

T-Mobile to cover  
Republic with the  
for the Internet of



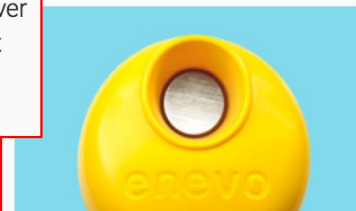
September 10, 4:41 PM

Following a pilot opera  
Czech Republic that ex  
expectations, T-Mobile  
SimpleCell Networks v  
SIGFOX's Internet of T  
network throughout th



" French MNO and ISP Bo  
Telecom has chosen Sem  
LoRa radio technology for its own  
domestic IoT and M2M network."

ance at Mobile World Congress in  
Barcelona - Enevo

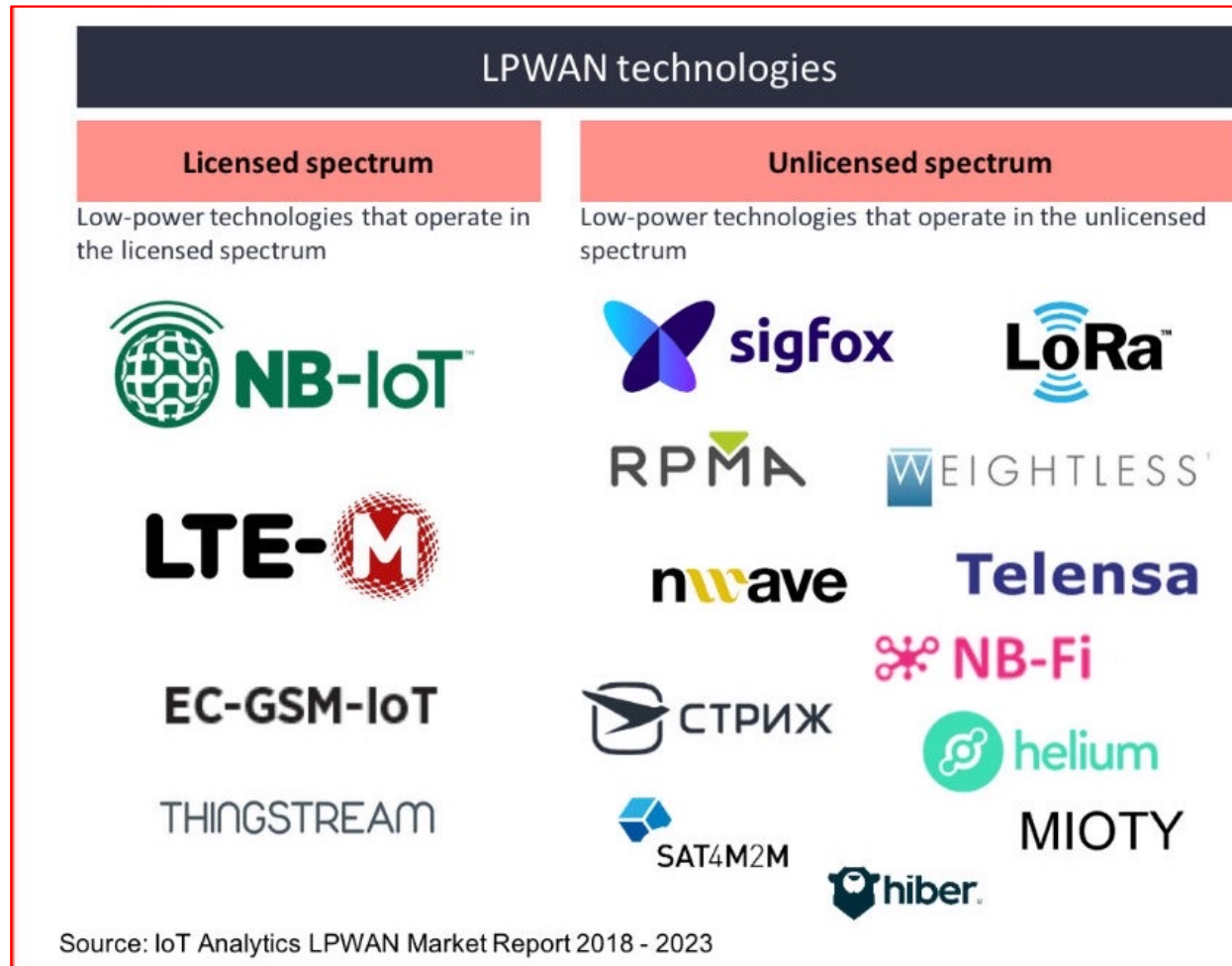


From www.enevo.com - March 6, 4:12  
PM

orange guarantees connectivity at a reduced energy  
consumption rate and at a lower cost. Orange has  
chosen to rely on LoRa (Long Range) technology  
to deploy this network that will cover the whole of metropolitan France.

Image credit: scoop.it

# The competitors – other technologies



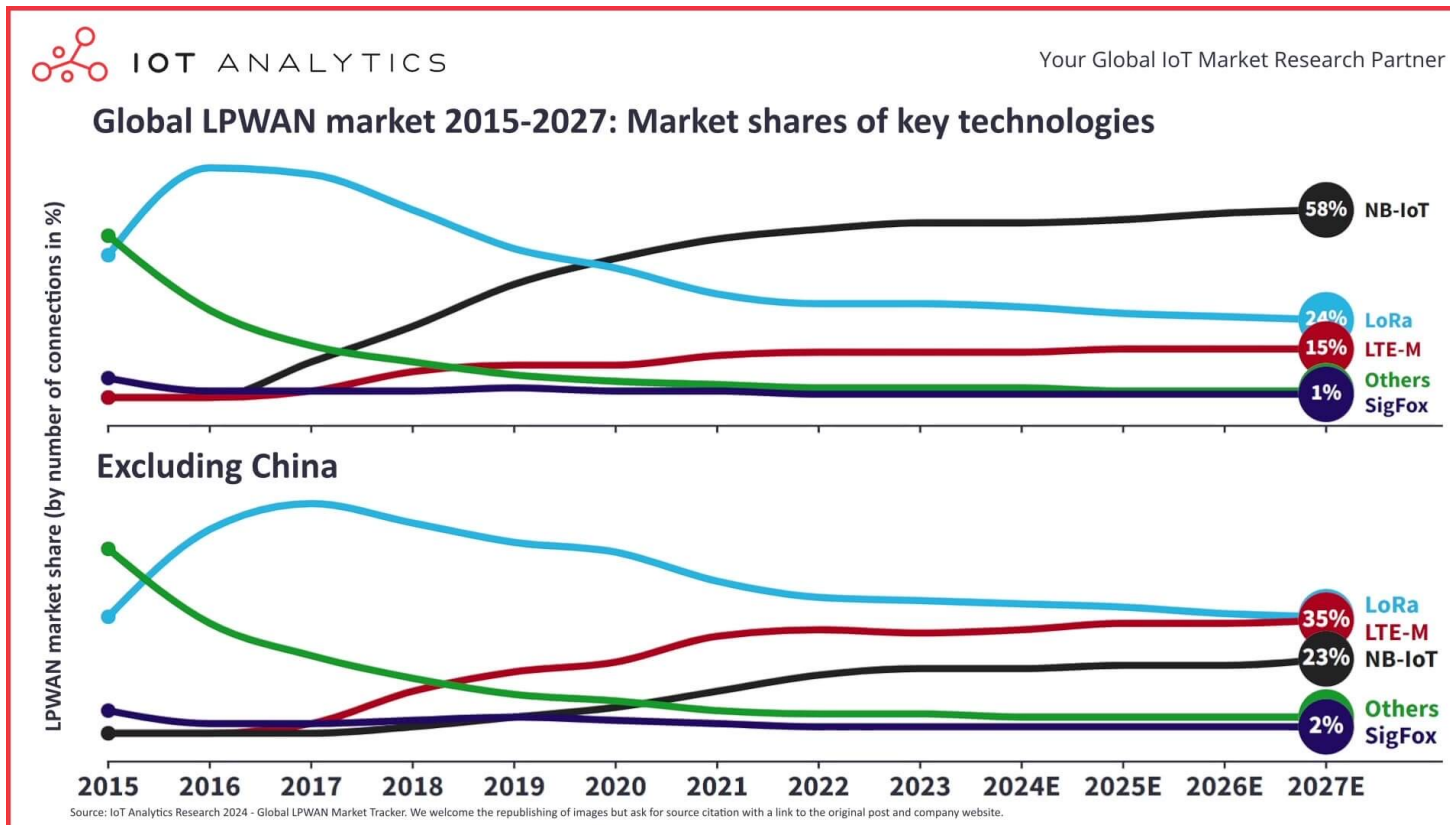
# 2026: the 4 (3?) that counts!

LoRa

LTE-M  
(Cat-M1)

NB-IOT

SigFox





# LPWAN=star topology, gateway centric

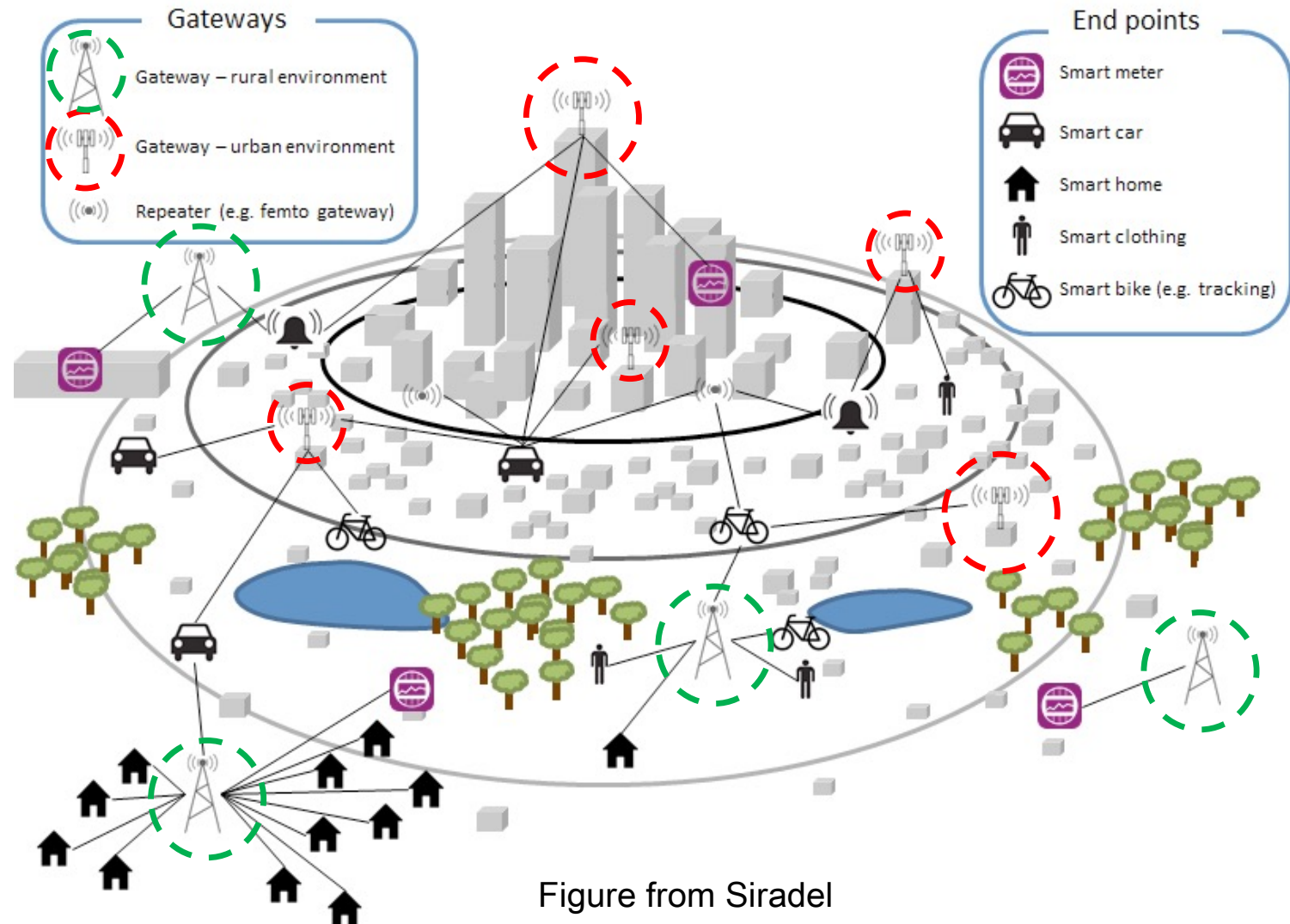
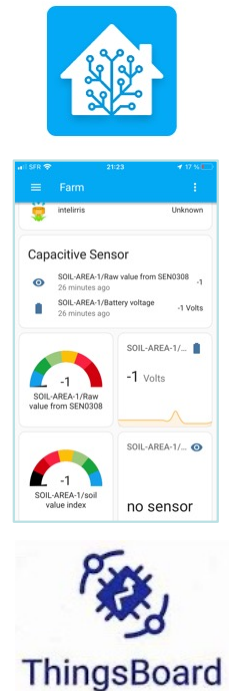
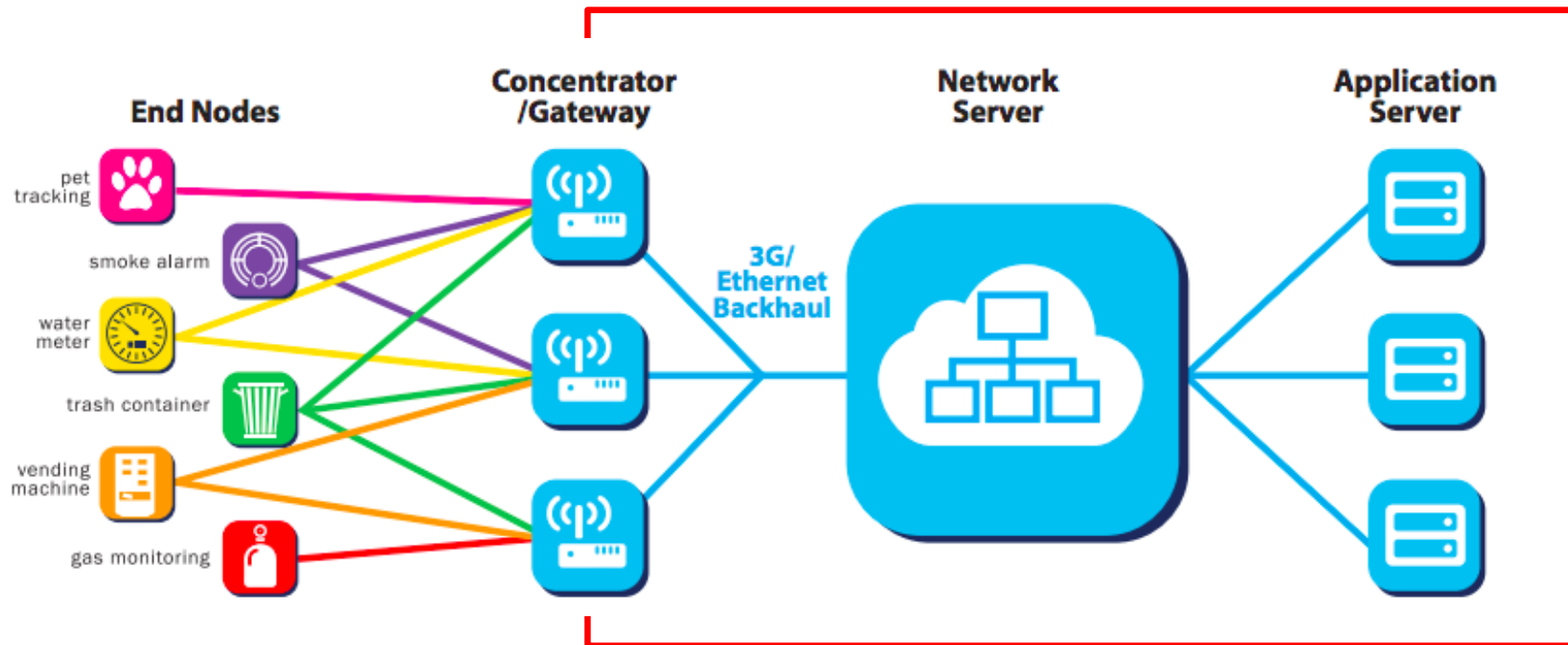


Figure from Siradel

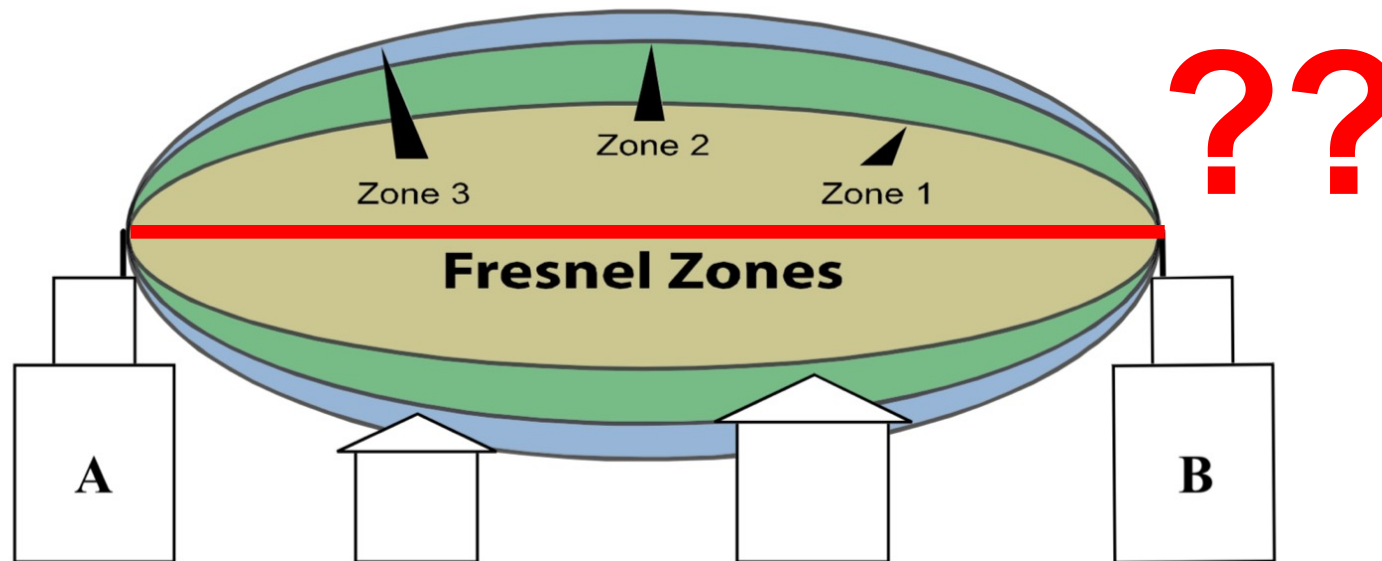
# LPWAN: example with LoRaWAN

- LoRaWAN specifications/protocols run on top of LoRa physical networks. It is defined and managed by the [LoRa Alliance](#)
- Make possible to run large-scale, public LoRa networks



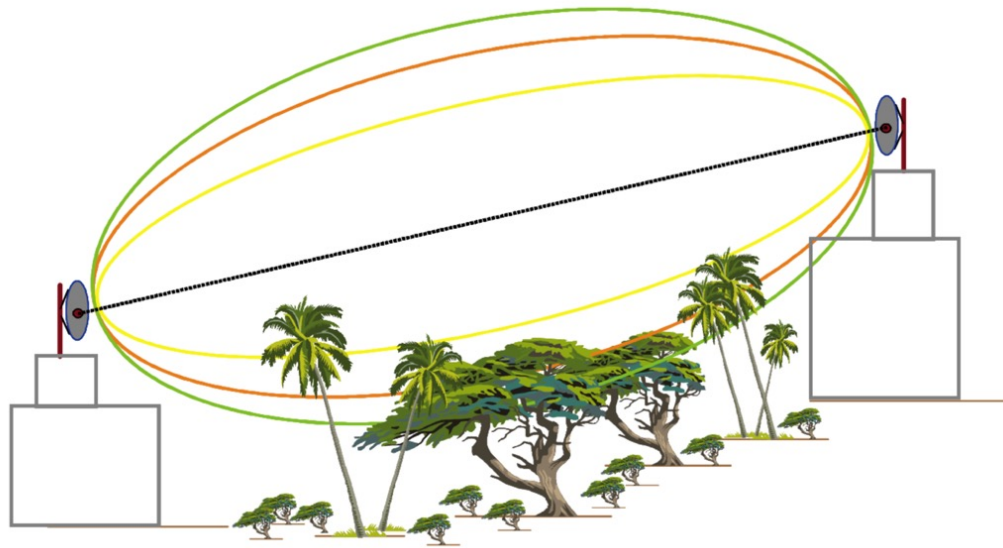
# Line-of-Sight & Fresnel zone

- LoS means clear Fresnel zone
- Football (american) shape
- Acceptable = 60% of zone 1 + 3m



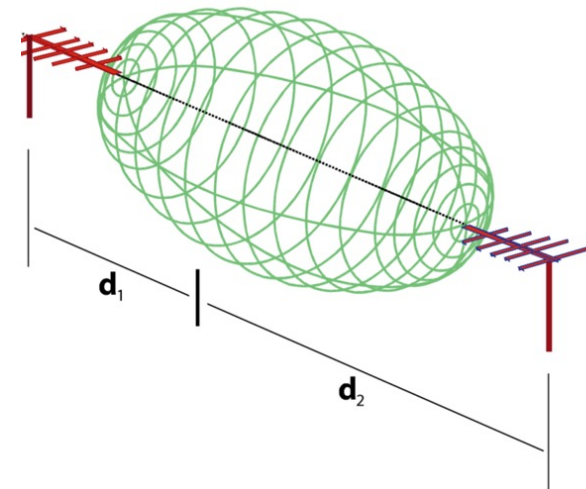


# Clearing the Fresnel zone? Raise antennas!



$$r_n = \sqrt{\frac{n \lambda d_1 d_2}{d_1 + d_2}}$$

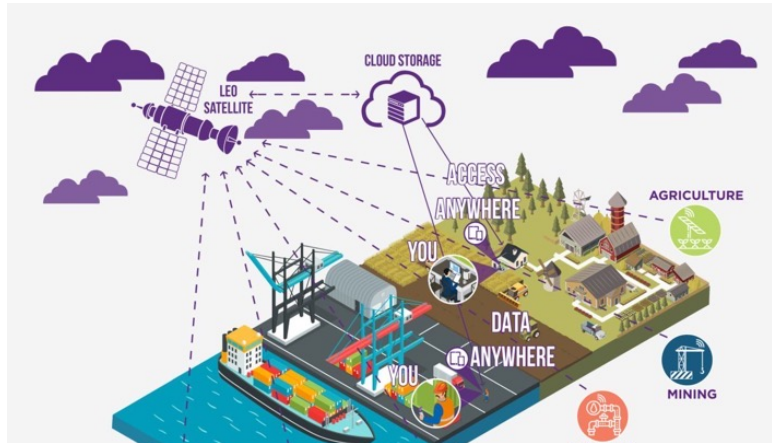
| Range Distance   | 900 MHz Modems<br>Required Fresnel Zone<br>Diameter | 2.4 GHz Modems<br>Required Fresnel Zone<br>Diameter |
|------------------|-----------------------------------------------------|-----------------------------------------------------|
| 1000 ft. (300 m) | 16 ft. (5 m)                                        | 11 ft. (3.4 m)                                      |
| 1 Mile (1.6 km)  | 32 ft. (10 m)                                       | 21 ft. (6.4 m)                                      |
| 5 Miles (8 km)   | 68 ft. (21 m)                                       | 43 ft. (13 m)                                       |
| 10 Miles (16 km) | 95 ft. (29 m)                                       | 59 ft. (18 m)                                       |



# Going beyond terrestrial network!

With no obstacle, we can reach a satellite!

<https://www.everythingrf.com/community/what-is-satellite-iot-connectivity>



<https://www.smartsight.in/industry-insights/iot-for-wildlife-conservation-and-environmental-monitoring/>

EchoStar XXI satellite

Formerly TerreStar 2, launched in 2017

Geostationary satellite, S-band 2GHz

Huge transponder of 18 meters!

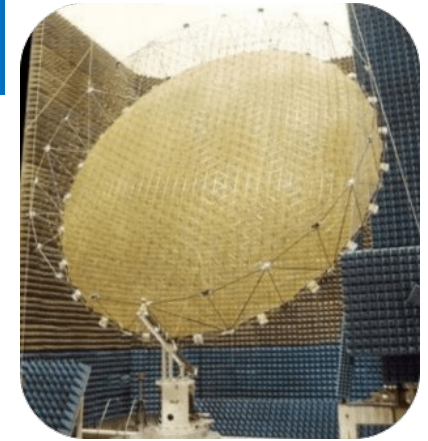
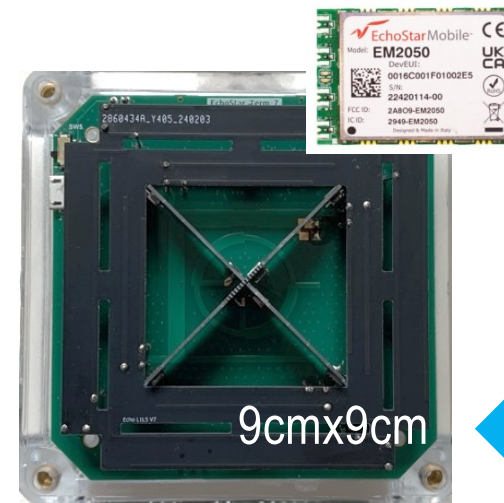


Image credit: EchoStar

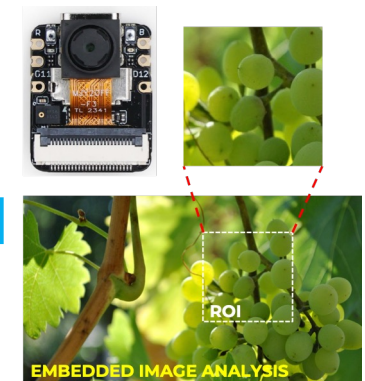


Low-cost satellite IoT

F. Ferrero & M. T. Nguyen

LEAT laboratory, University of Nice, France

<https://github.com/nguyenmanhthao996tn/LEAT-EchoStar-Terminal-BSP>

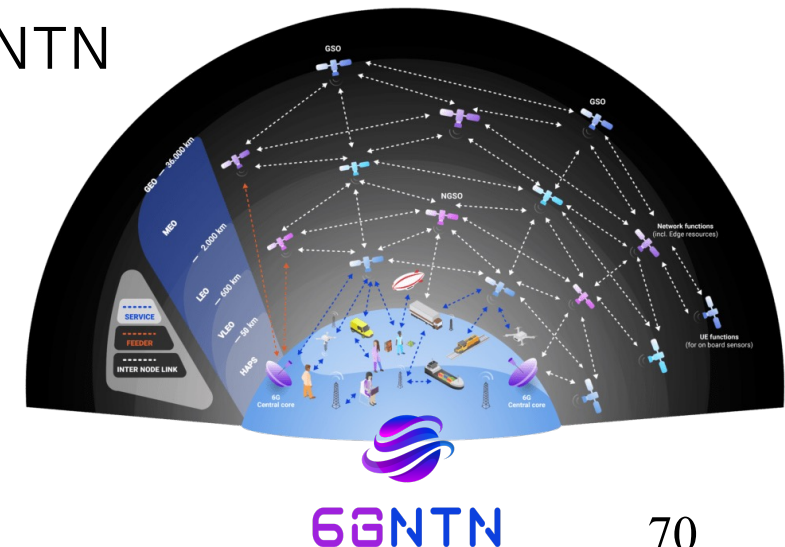
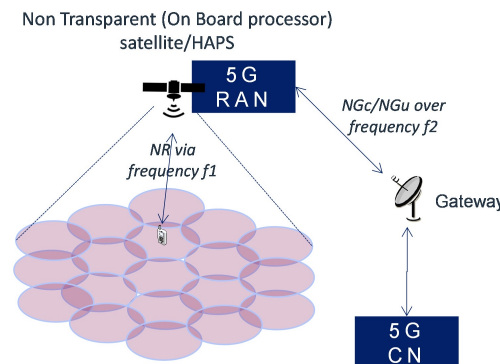
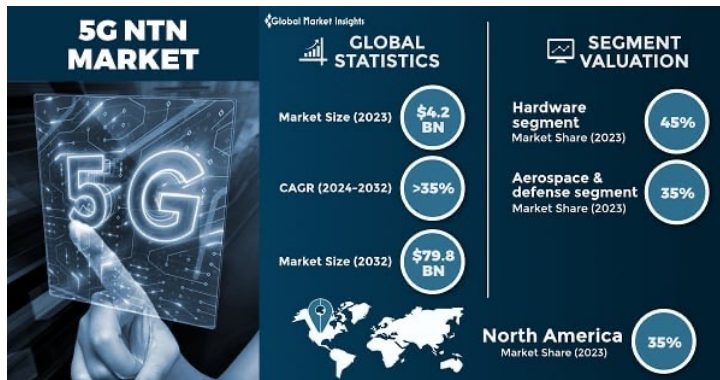


# IoT connectivity battle going to space!

- ⦿ Non-Terrestrial Networks (NTN) & Direct-to-Satellite (DtS) IoT communication
- ⦿ DtS version of the LoRa PHY modulation for increased robustness → LR-FHSS
- ⦿ Mioty can be extended to DtS communication

**BUT TRADITIONAL CELLULAR ACTORS WANT THEIR SHARE!**

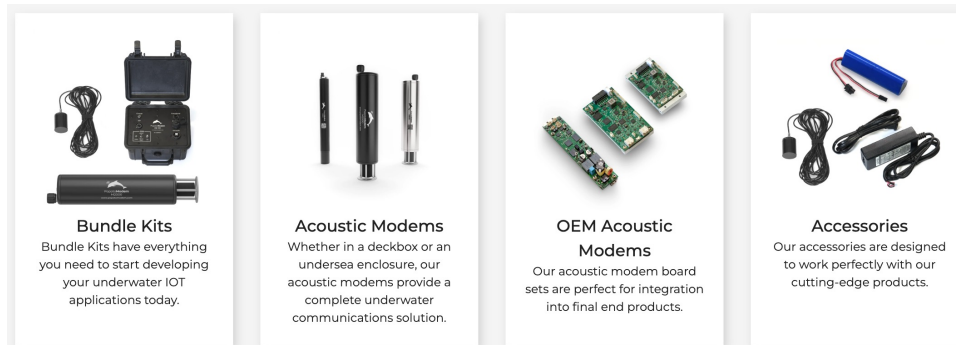
- ⦿ Cellular Network standards such as 5G NTN and future 6G with **native** NTN support



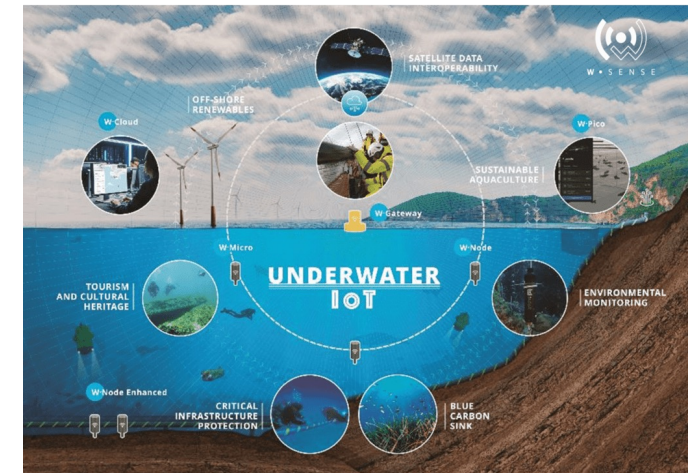


# What about underwater IoT?

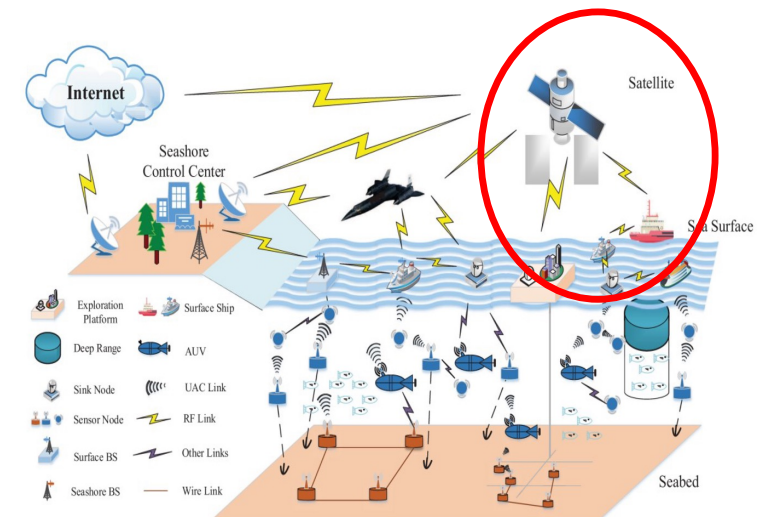
- Radio waves can not be used in water
- Only acoustic waves can cover long distances underwater
- Underwater IoT (IoUT) is possible but still a niche market
- Last link may be satellite IoT links**
- Example of manufacturer/provider



PopotoModem



<https://www.codemotion.com/magazine/iot/underwater-iot/>



**Internet of Underwater Things: A Survey on Simulation Tools and 5G-Based Underwater Networks**

by Lewis Nkenyereye <sup>1,\*</sup>, Lionel Nkenyereye <sup>2,†</sup> and Bruce Ndiranje <sup>3</sup>

# WHAT DID WE LEARN? QUESTIONS?

- ⦿ WIRELESS TRANSMISSION: ENERGY-RANGE DILEMMA
- ⦿ 1ST CHALLENGE: SIGNAL ATTENUATION!
- ⦿ RX SENSITIVITY INCREASED WHEN SENDING SLOWER
- ⦿ → LPWAN RADIOS HAVE VERY LOW THROUGHPUT
- ⦿ IOT CONNECTIVITY IS A TRUE BATTLE!



# IOT

## UNLEASH THE POWER OF IOT DATA !







**2026, billions of IoT devices  
are deployed worldwide !**



# Integrating multiple data sources

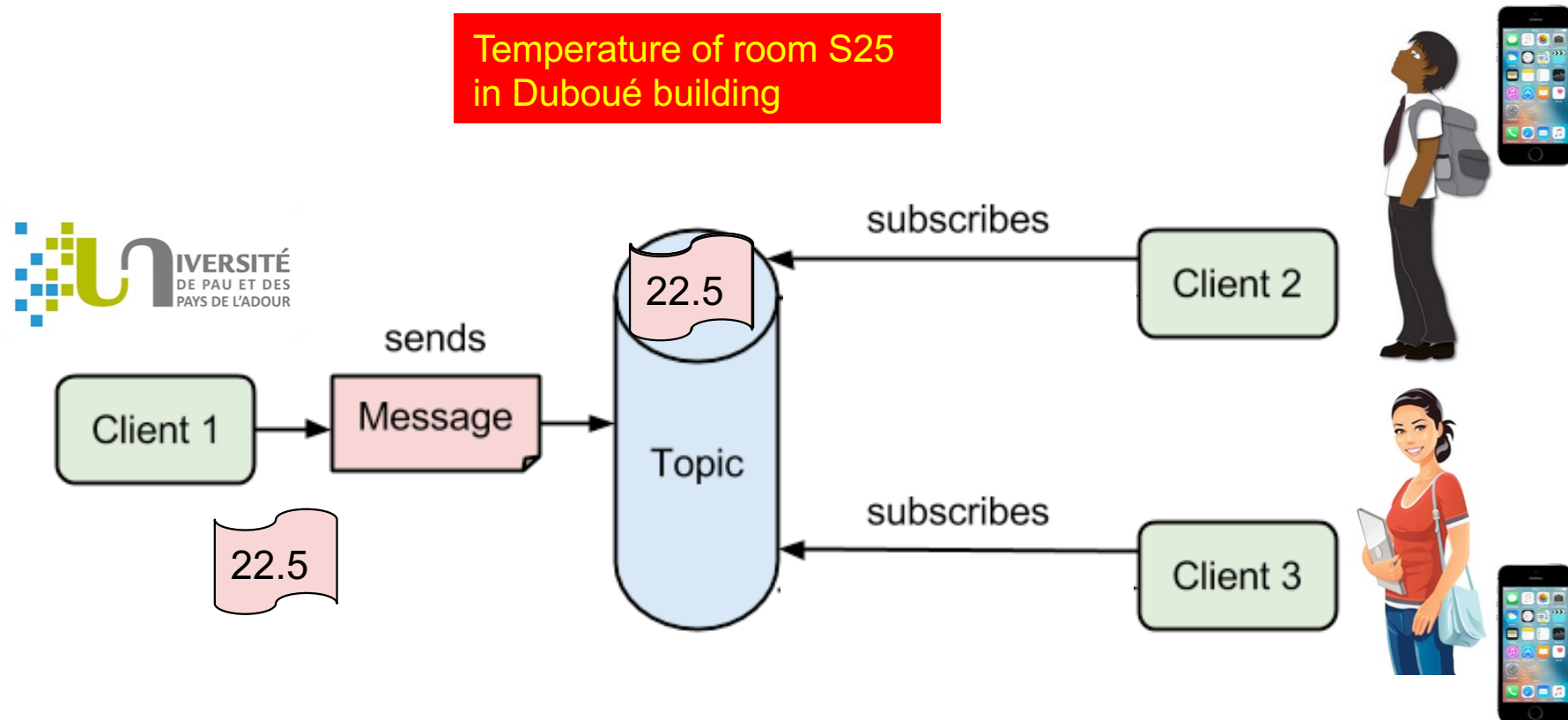
Pr. Congduc Pham  
http://www.univ-pau.fr/~cpham



## 2<sup>nd</sup> challenge: searching for IoT data

From "search for info" to "receive the info"

- Use the PUBLISH/SUBSCRIBE model

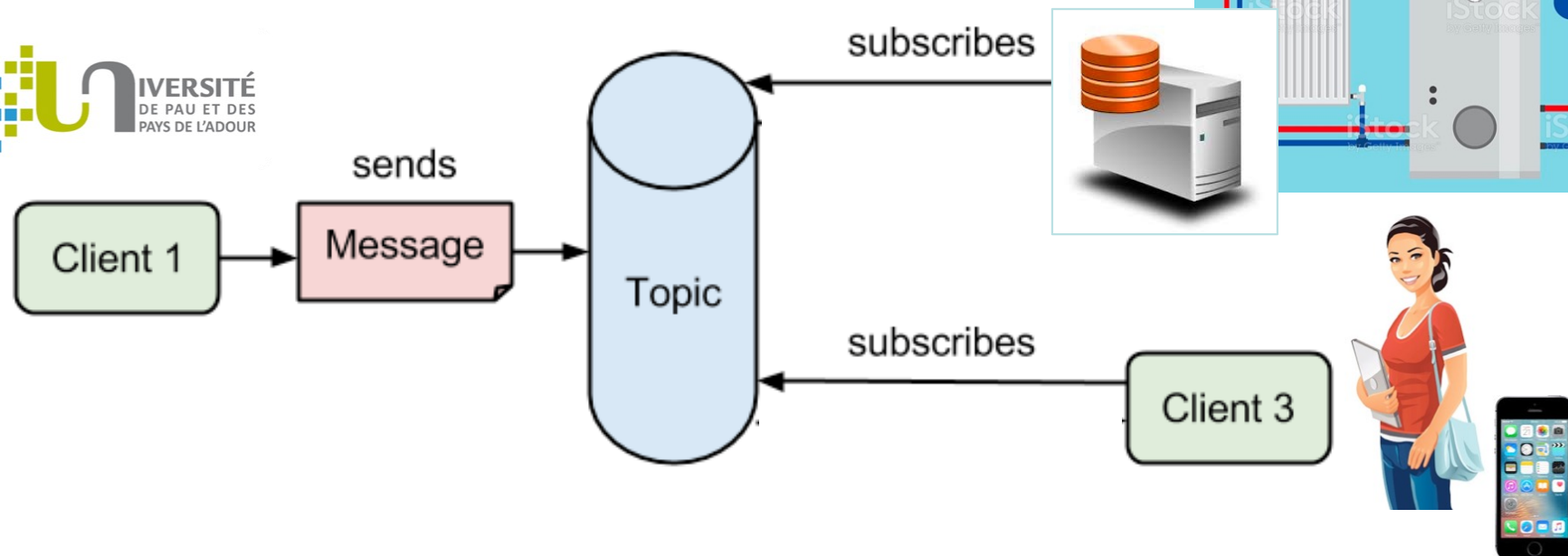




# Automatization made simpler

- Use the PUBLISH/SUBSCRIBE model

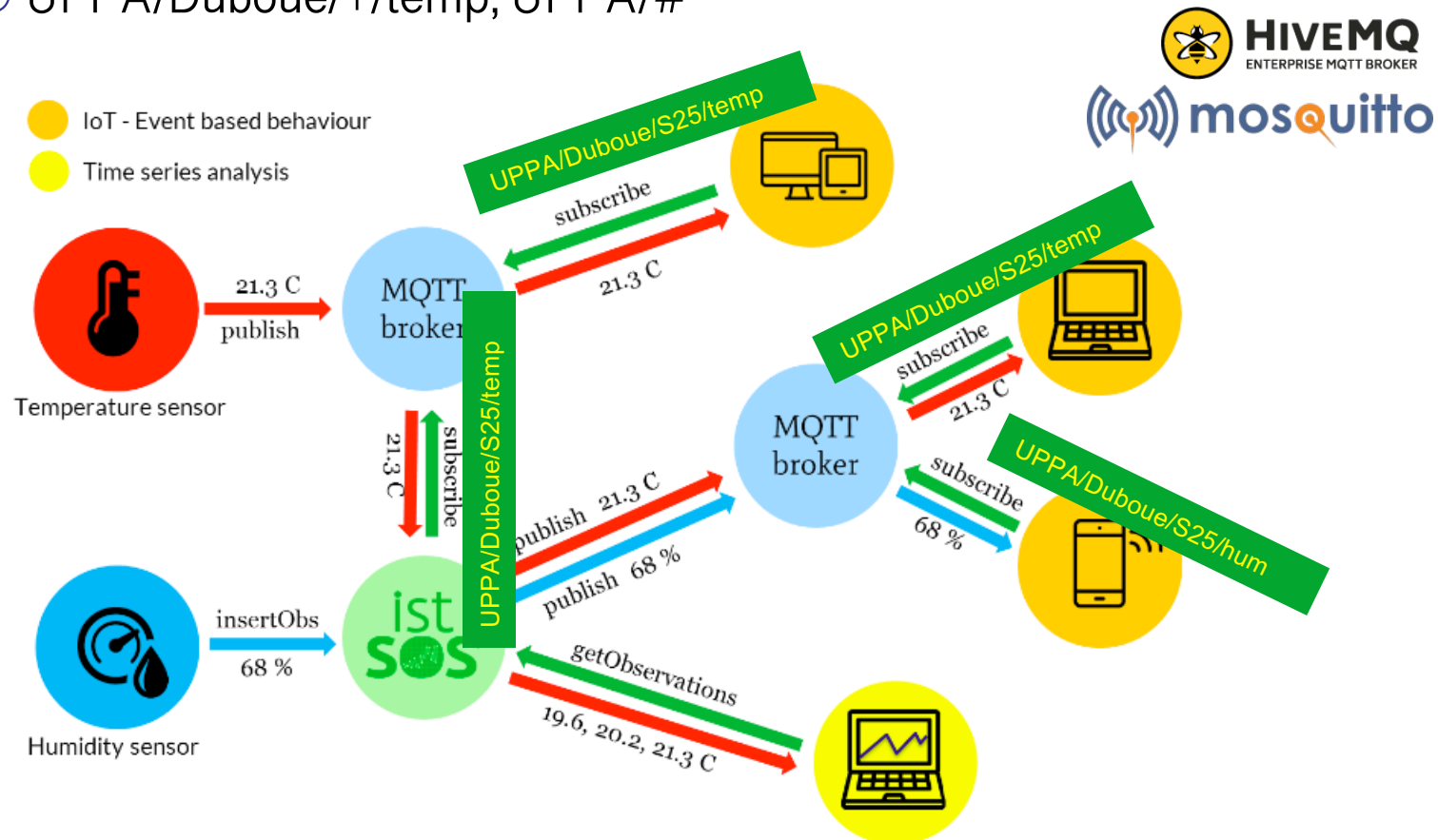
Temperature of room S25  
in Duboué building



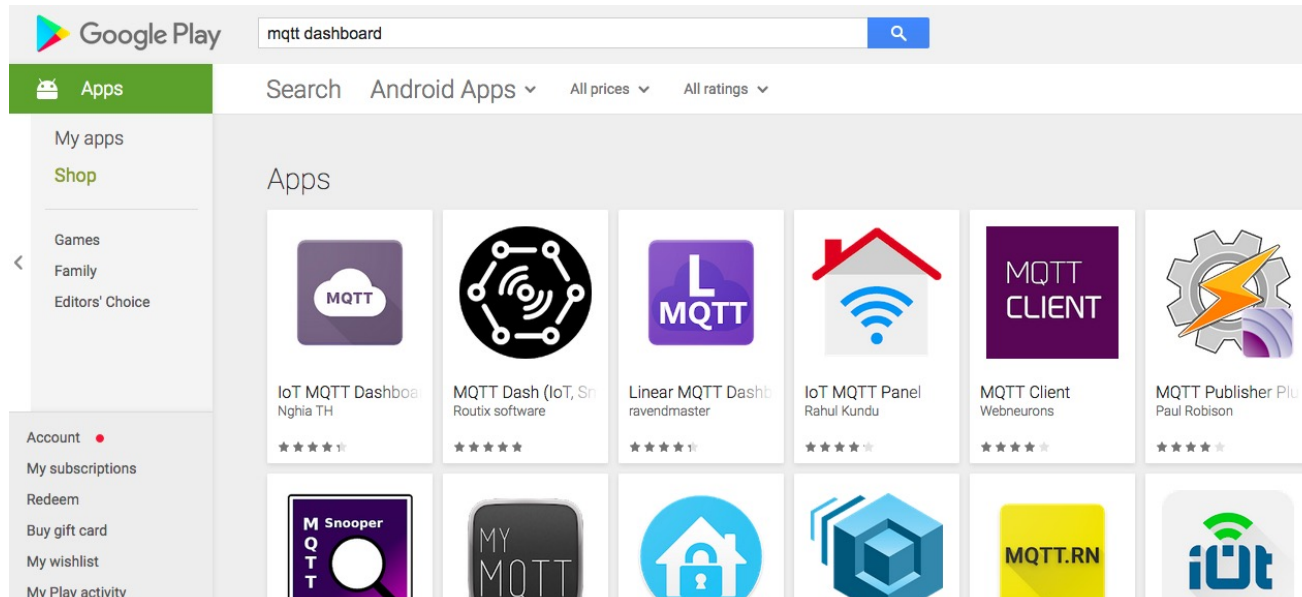
# MQTT

Message Queue Telemetry Transport, 1999 by IBM for SCADA system

- Use **broker** nodes to manage **topics**
  - UPPA/Duboue/S25/temp, UPPA/Duboue/S25/hum
  - UPPA/Duboue/+/temp, UPPA/#



# MQTT+smartphone=



**GET YOUR IOT DATA EVERYWHERE**

→ Easier access to open data

□ UPPA/ROOMS/#

□ UPPA/CONGRESS/#

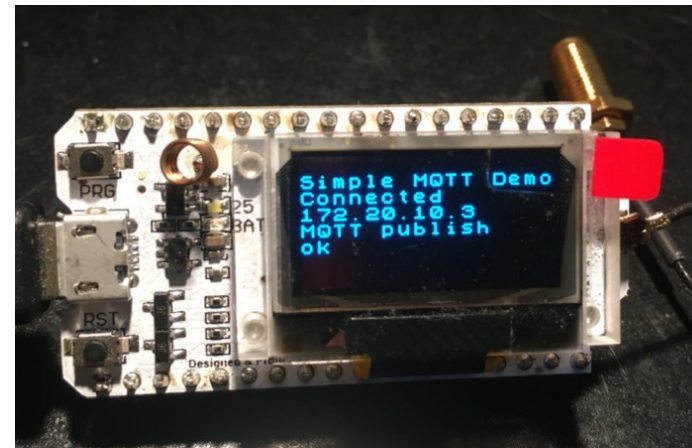
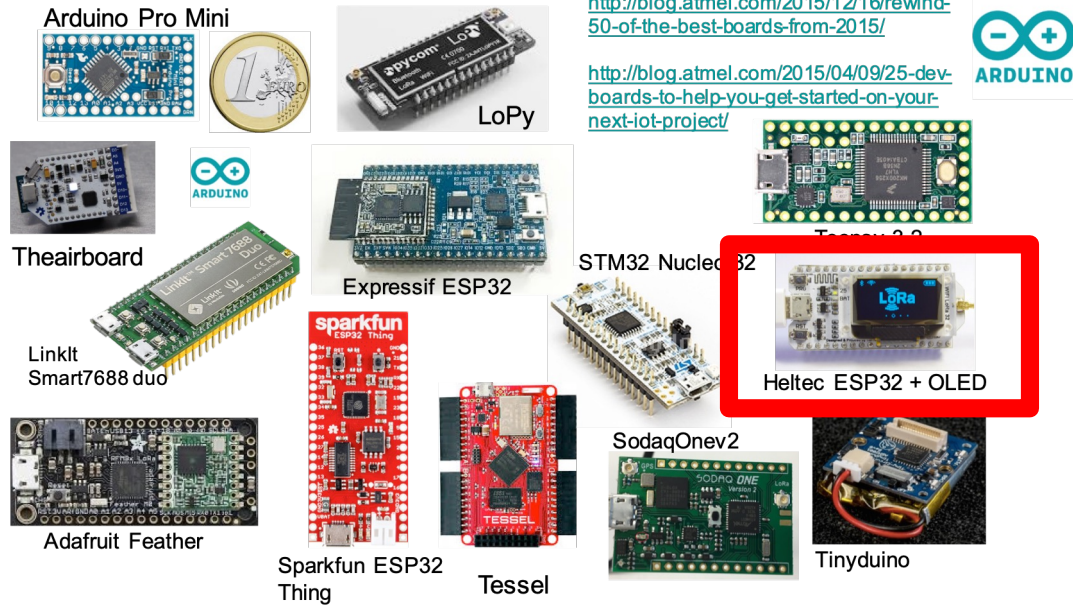
□ PAU/WEATHER/#





# MQTT is very lightweight

- MQTT can run on small IoT devices
- Heltec WiFi ESP32
  - Device connects to WiFi network
  - Then will publish data to an MQTT broker & topic



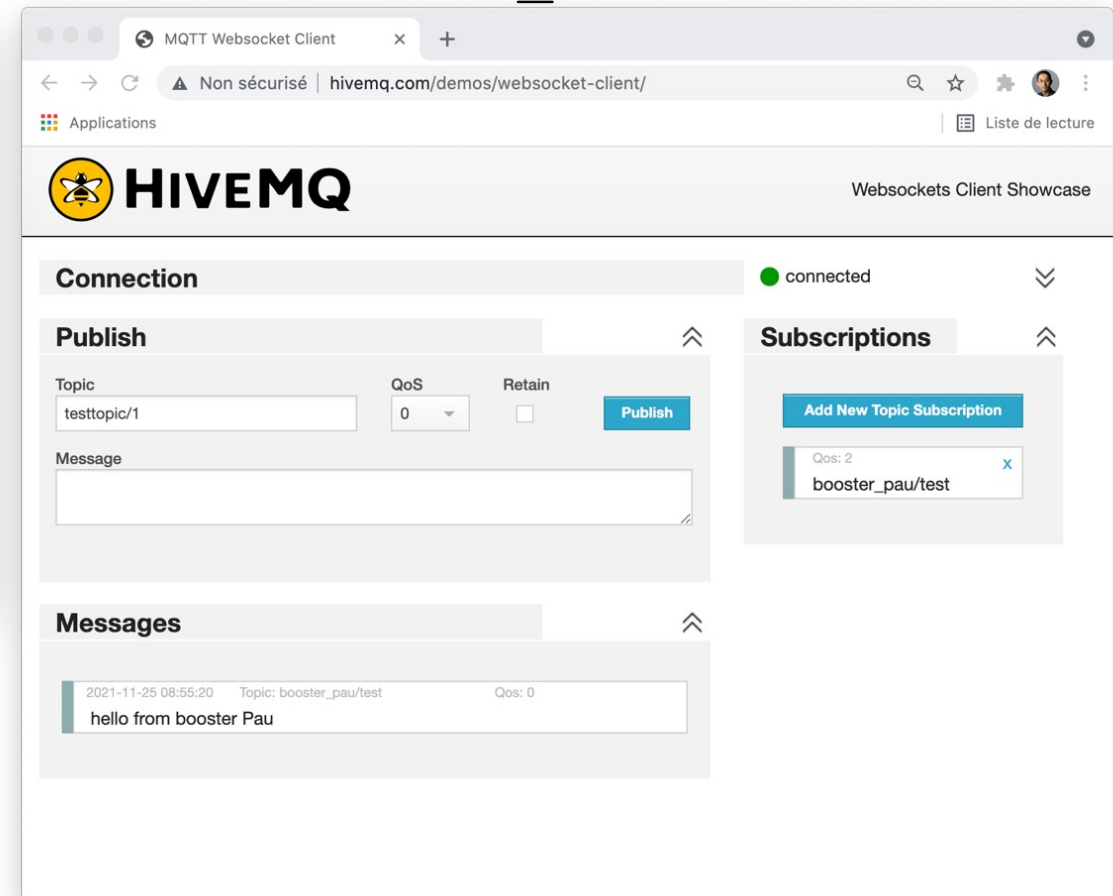
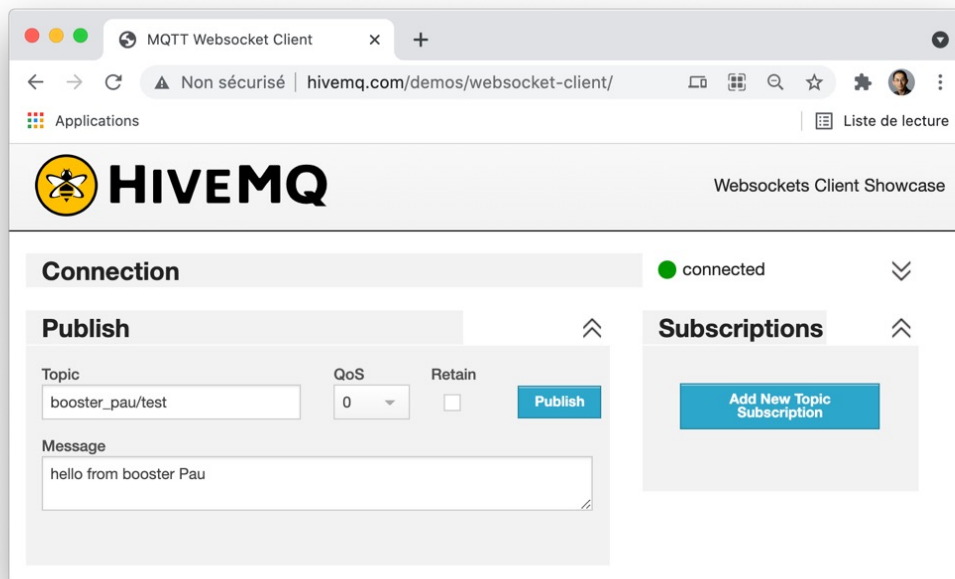
# Ex: Mosquitto MQTT broker



- ⦿ Eclipse Mosquitto is an open-source MQTT broker
- ⦿ MQTT test broker: `test.mosquitto.org`
- ⦿ IoT device will publish to topic **UPPA/Duboue/S25/temp**
- ⦿ On a computer, use `mosquitto_sub` to subscribe
  - ⦿ `mosquitto_sub -v -h test.mosquitto.org -t UPPA/Duboue/#`
  - ⦿ `-v` ➡ to display information in detailed mode
  - ⦿ `-h` ➡ the MQTT broker: `-h test.mosquitto.org`
  - ⦿ `-t` ➡ the MQTT topic: `-t UPPA/Duboue/#`

# Ex: HiveMQ broker on websocket

- ⦿ <http://www.hivemq.com/demos/websocket-client/>
- ⦿ use "-h mqtt-dashboard.com" with `mosquitto_sub`



**DEMO**



# MQTT in real IoT deployment

## Sensor part



Simple IoT devices have NO WiFi

Use LPWAN radios, e.g. LoRa

Send to IoT gateway



## Control part – IoT gateway



MQTT

Connected to Internet



# MQTT implementing social media

- It is very easy to implement a social media app using MQTT
- WhatsApp-like example
  - Define MQTT topic per phone number
    - Alice: myWhatsApp/0655667788
    - Bob: myWhatsApp/0611223344
  - To receive/send message
    - Alice publishes to myWhatsApp/0611223344
    - Bob publishes to myWhatsApp/0655667788
    - Both subscribe to their own topic
  - To create a group
    - Alice creates a group showcase-iot
    - myWhatsApp/0655667788/showcase-iot
  - To join(publish) on(to) the group
    - Subscribe(publish) to myWhatsApp/0655667788/showcase-iot



0655667788



Alice



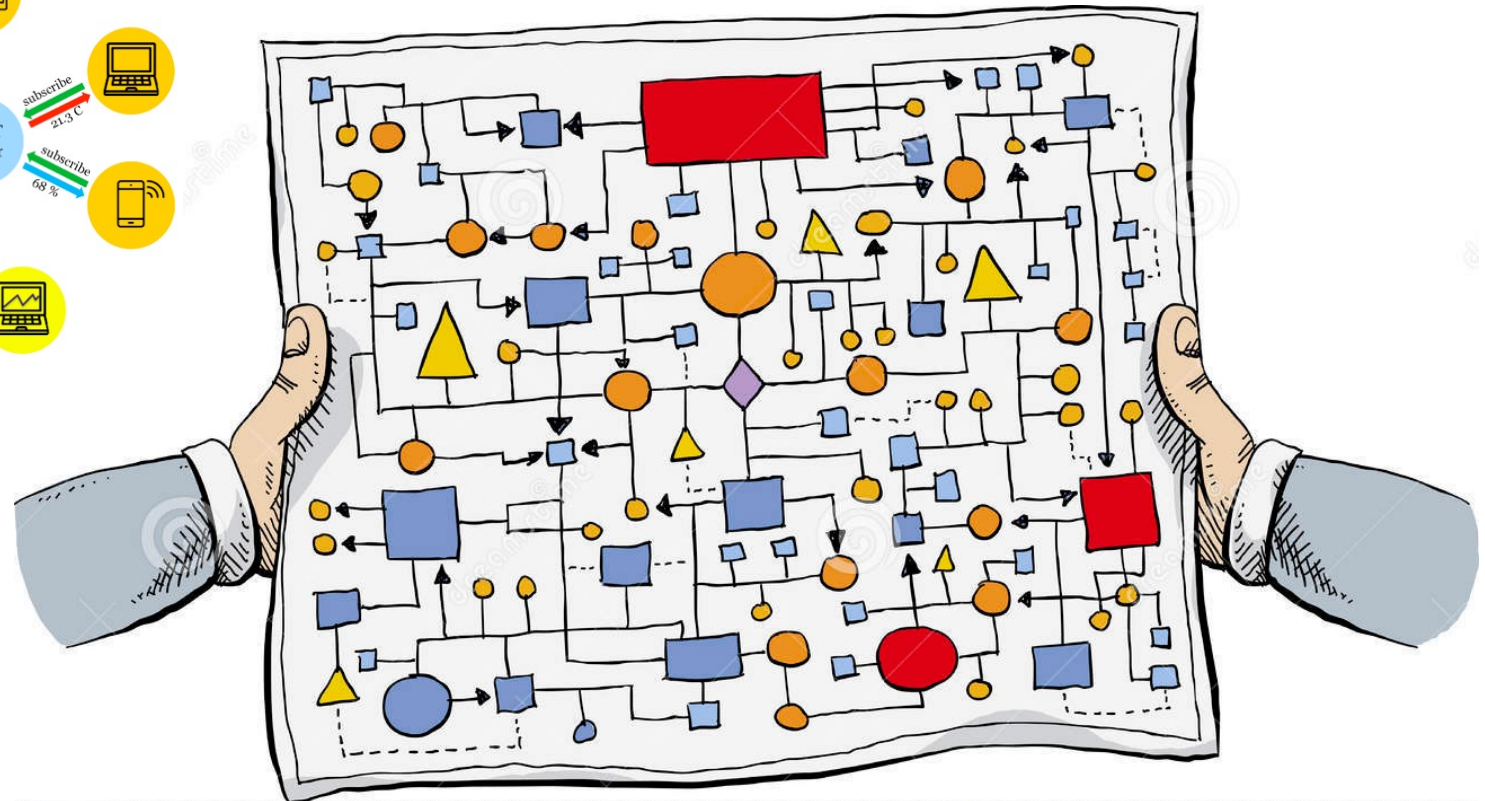
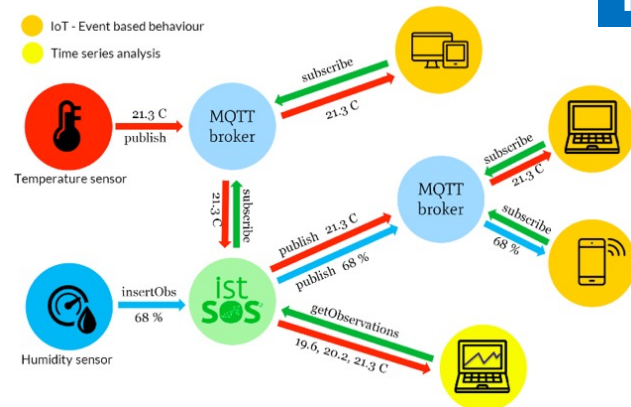
0611223344



Bob

# Creating complex data flows?

Intuitive connection from IoT data producers to IoT data consumers?





# ...without programming?

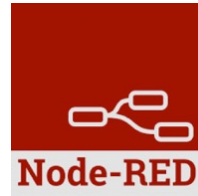


- End-users are not necessarily computer science experts nor high-skilled programmers!

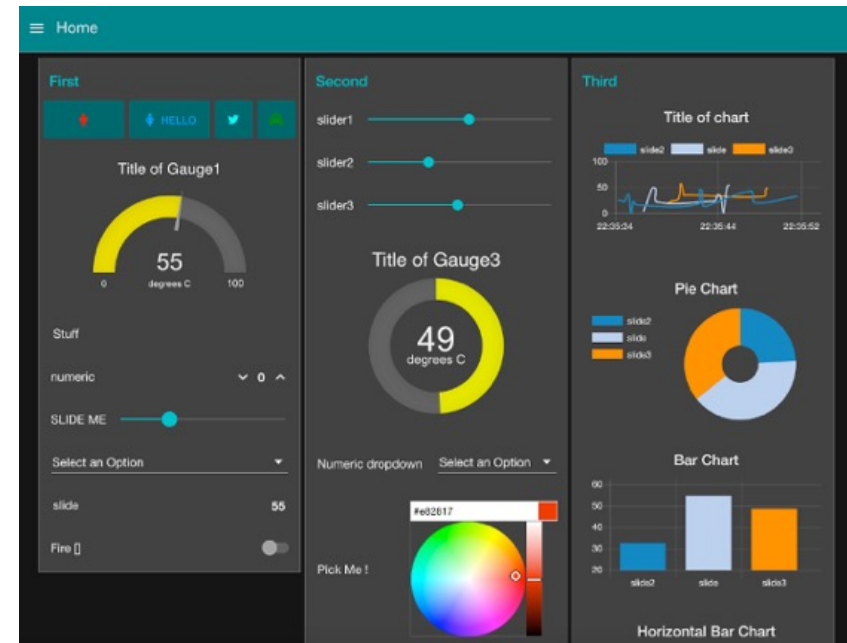
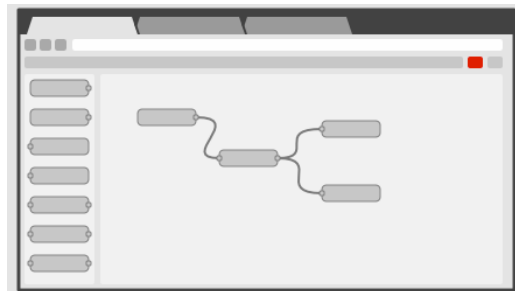
- Building data processing flows with a low-code approach?



# Node-RED



- Tool for graphically wiring together hardware devices, APIs and online services, e.g. clouds of various types
- Browser-based flow editor to wire together flows with a wide range of nodes



- Increasing number of Node-RED blocks



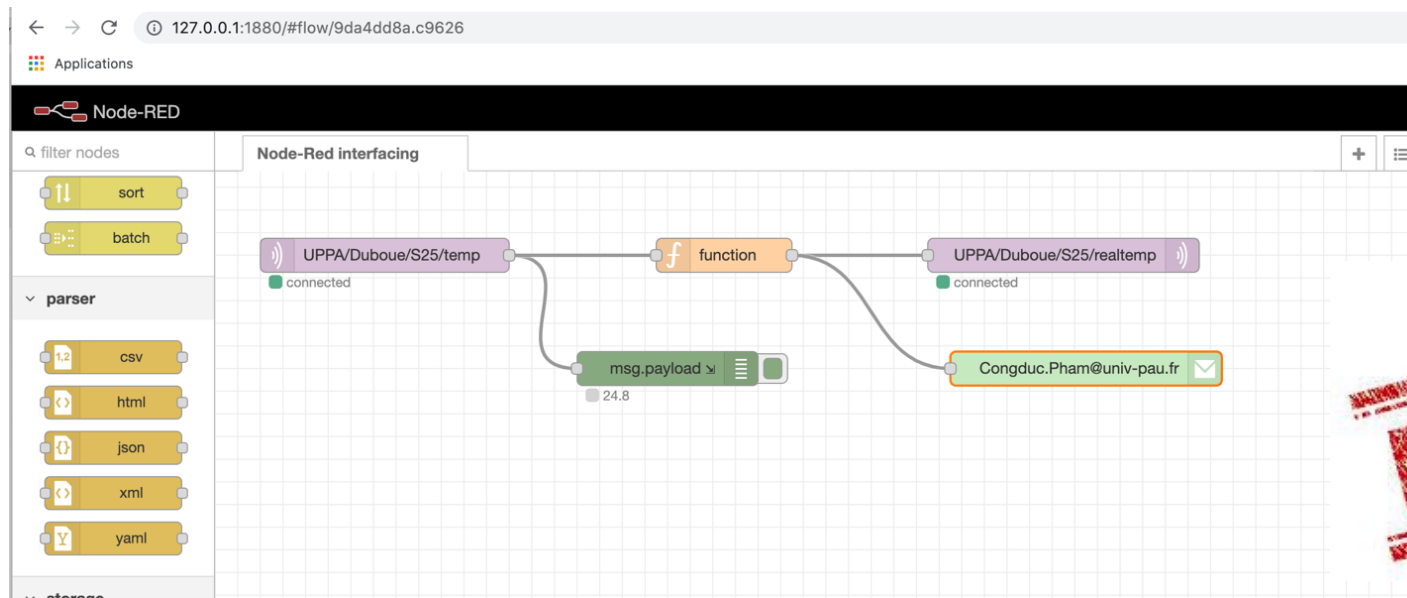
Nodes represent reusable pieces of code and logic. Node-RED comes with a core set of useful nodes, but there are a growing number of additional nodes available to install from both the Node-RED project as well as the wider community or you





# Simple MQTT Node-RED flow

- MQTT in-broker: `test.mosquitto.org`
- "MQTT in" node listens on `UPPA/Duboue/S25/temp`
- "Function" node to rectify temperature by  $-1.8^{\circ}\text{C}$
- MQTT out-broker: `mqttdashboard.com`
- "MQTT out" node publishes on `UPPA/Duboue/S25/realtemp`
- "Mail" node sends rectified temp to `Congduc.Pham@univ-pau.fr`



**DEMO**

# Simple MQTT Node-RED flow

MQTT Websocket Client

Non sécurisé | hivemq.com/demos/websocket-client/

Applications | Liste de lecture

 Websockets Client Showcase

**Connection** connected

**Publish**

Topic: testtopic/1 QoS: 0 Retain: ☐ **Publish**

Message:

**Subscriptions**

**Add New Topic Subscription**

Qos: 2

Qos: 2

**Messages**

| Timestamp           | Topic                    | QoS | Message                |
|---------------------|--------------------------|-----|------------------------|
| 2021-11-25 09:18:14 | UPPA/Duboue/S25/realtemp | 0   | 20.7                   |
| 2021-11-25 09:18:11 | booster_pau/test         | 0   | hello from booster Pau |
| 2021-11-25 09:18:04 | UPPA/Duboue/S25/realtemp | 0   | 20.7                   |
| 2021-11-25 09:17:57 | UPPA/Duboue/S25/realtemp | 0   |                        |

Node-RED

filter nodes

sort batch

parser

csv html json xml yaml

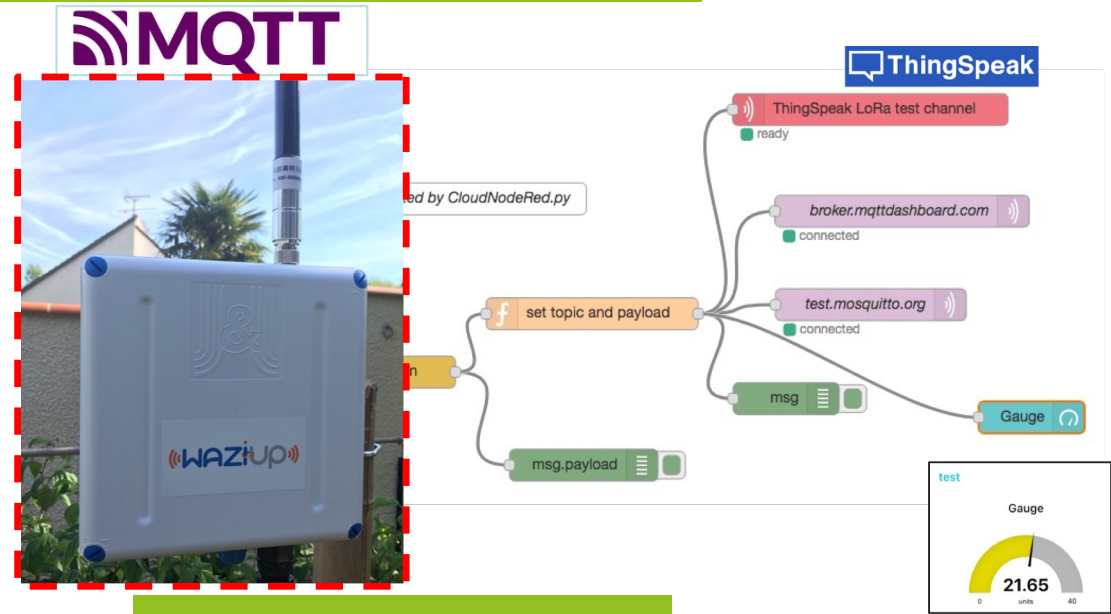
etrange

5/realtemp

am@univ-pau.fr

**DEMO**

## Control part – IoT gateway



## Connected to Internet

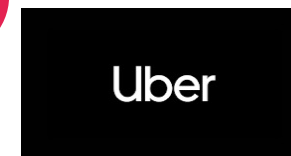




# Generalizing interactions?

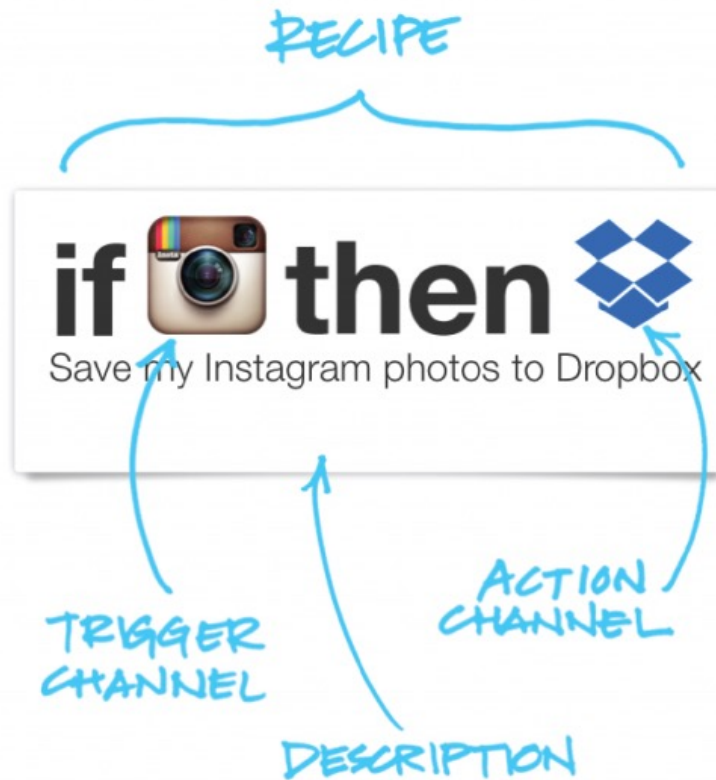


# Adding interactions?



# IF THIS THEN THAT applets

## Some example Recipes



**if**  **then**   
 Nearly home? Direct message  
 the person who should know

**if**  **then**   
 Email your new iPhone photos  
 to yourself

**if**  **then**   
 Backup your contacts to a Google  
 Spreadsheet



# IoT landscape

IOT ANALYTICS

## IoT Startup Landscape 2024 – 3,000+ companies

July 2024

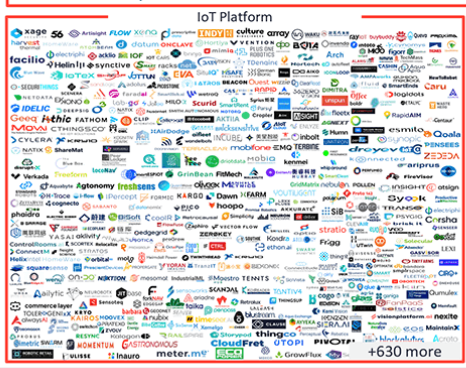
Your Global IoT Market Research Partner

### IoT Software

Data & Analytics



### IoT Platform



### IoT Security



© Matt Turck (@mattturck), Demi Obayomi (@demi\_obayomi) & FirstMark Capital (@firstmarkcapital)

### IoT Hardware

Devices (incl. Sensors)



Processors / Semiconductors



Note: For companies to be included in IOT Analytics IoT startups database they must be founded in or after January 2016, focus on building solutions for the Internet of Things and providing services. Companies can offer more than one technology layer. Source: IOT Analytics Research 2024 – IoT Startup Landscape with a link to the original post and our source database.

IOT ANALYTICS

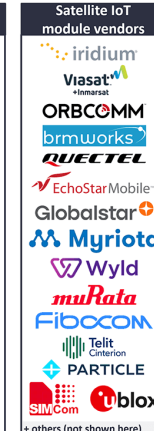
## Satellite IoT vendor landscape 2025

July 2025

Satellite IoT operators



Satellite IoT module vendors



Satellite IoT equipment vendors



Note: The total of all three categories adds up to more than 100 because some vendors appear in several categories. Source: IOT Analytics Research 2025-Satellite IoT Market Report 2025-2030. Conditions for republishing: Source citation with link to original post and company website.

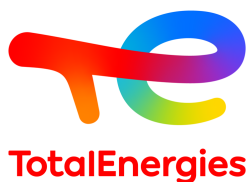
<https://mattturck.com/iot2018/>



- Internet-of-Things provides the unique feature to make things "talk" to us: localisation, surrounding environmental conditions, particular events, ...
- Next gen sensors such as cameras, spectrometers, hyperspectral cameras, etc, will provide possibilities to further optimize a number of complex processes

# Understanding the Challenges and Opportunities

sensors, ... protocols, ...



Innovation  
Accelerator

## IoT Capsule 2026

Prof. Congduc Pham  
<http://www.univ-pau.fr/~cpham>  
Université de Pau, France  
[Congduc.Pham@univ-pau.fr](mailto:Congduc.Pham@univ-pau.fr)



Horizon 2020  
European Union funding  
for Research & Innovation



Paving for the next 10 years  
of innovation in IoT and AI



Intel-IrriS RESICO LINK

Advanced and disruptive IoT/AI technologies targeting  
the smallholder community for increased resilience



AgriFutur

Wireless Sensors Made Simple  
for agroecology & sustainable agriculture