IOT_1: Understanding IoT technologies

sensors, radios, clouds,...

Booster Pau – Learning Capsule – 2021

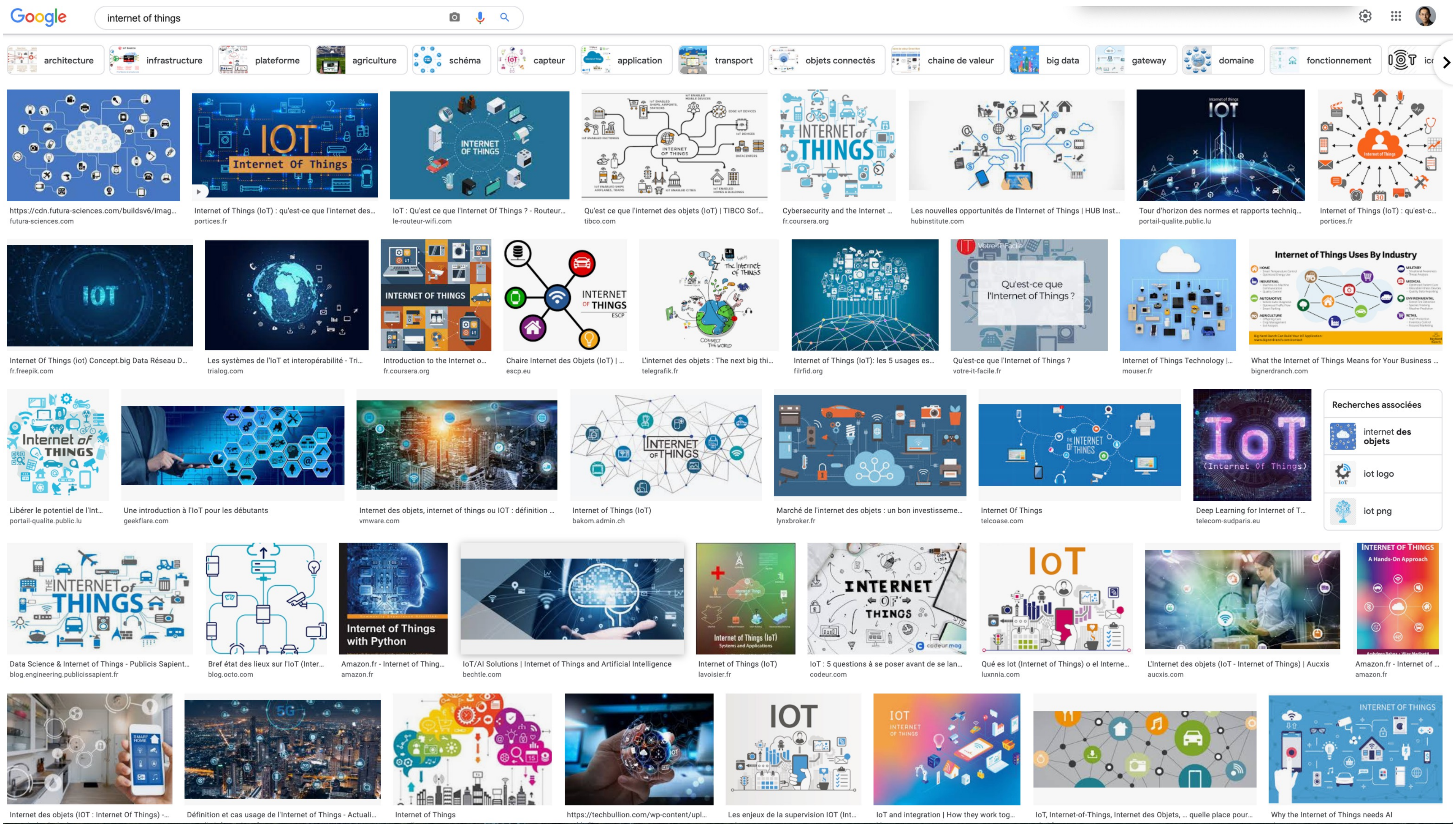
Prof. Congduc Pham
http://cpham.perso.univ-pau.fr

IoT – from idea to reality

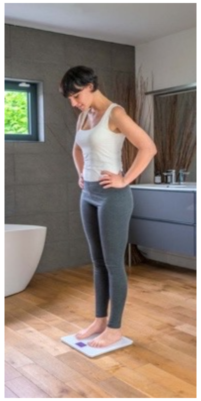
Paving for the next 10 years
of innovation in IoT and AI

BoosterPau program

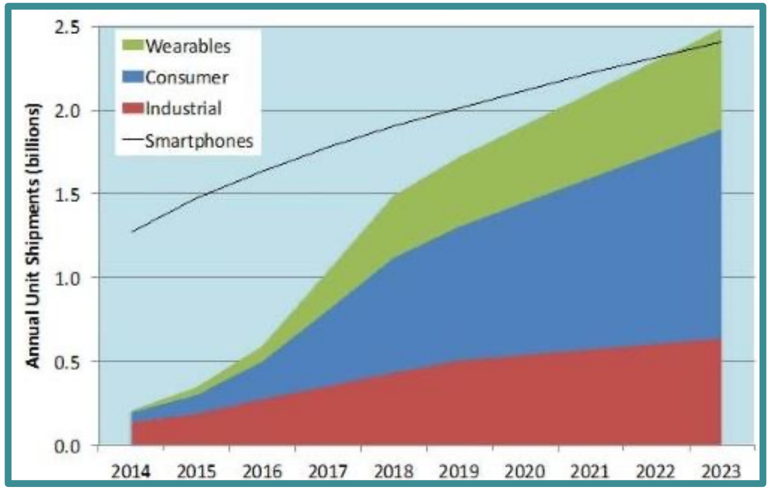
Googling for « Internet of Things »

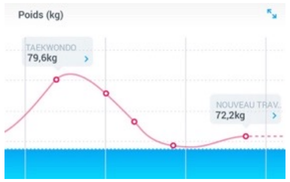


...shows communicating objects

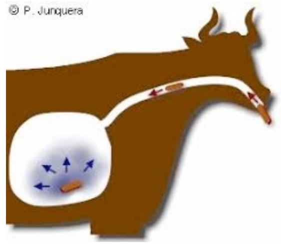




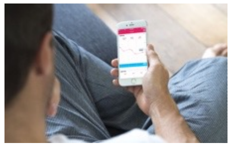









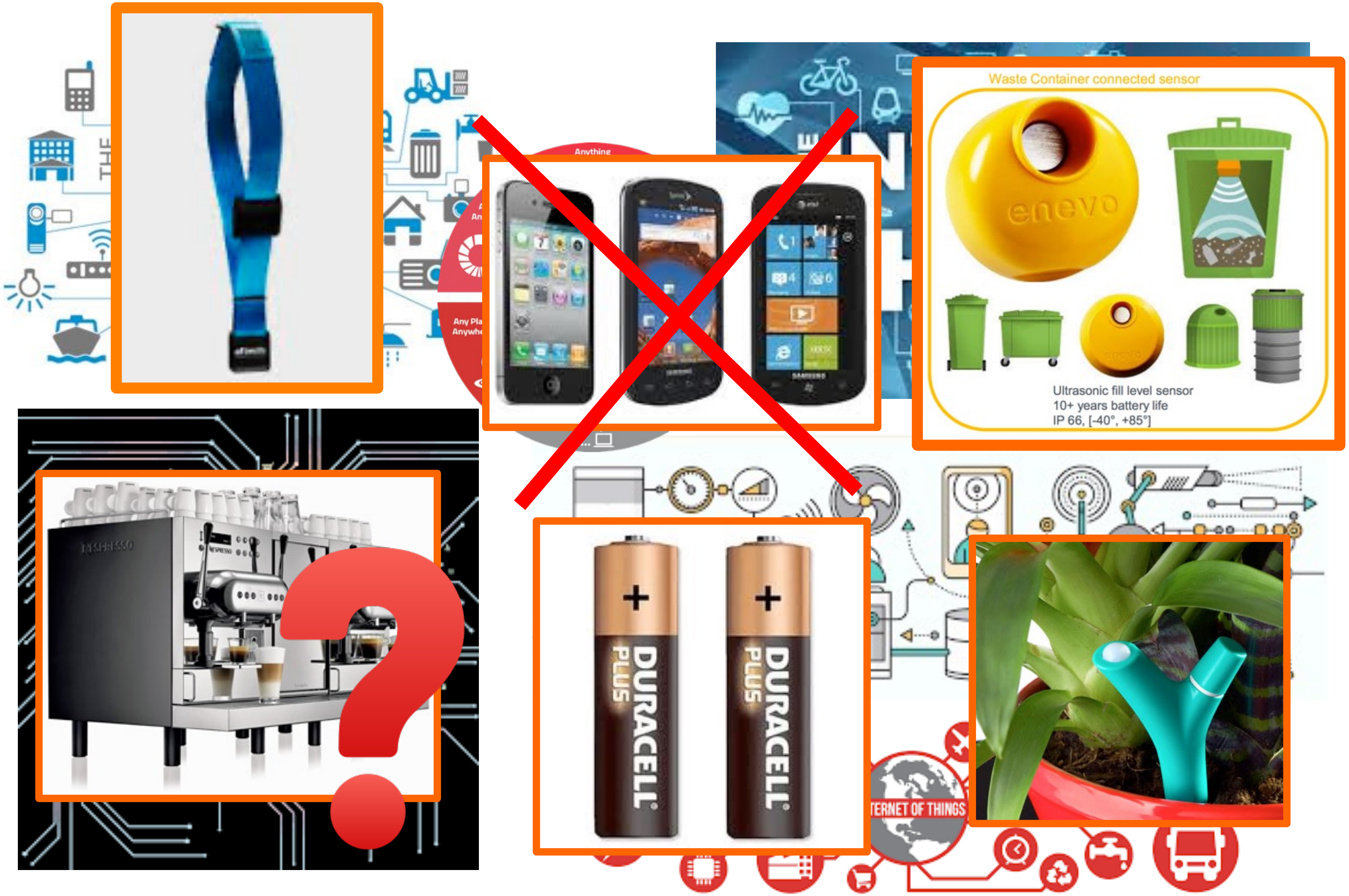










All communicating objects?

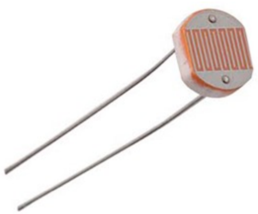


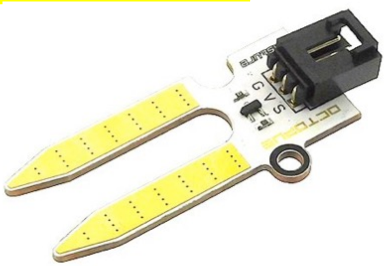
IoT=interactions with physical world

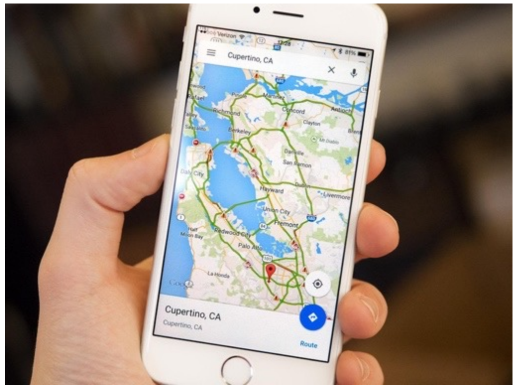
+ IOT =

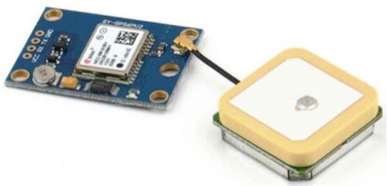
Q: Interactions? How?

Interaction: Sensors



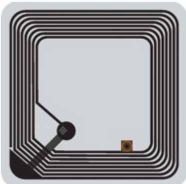






Interaction: RFID, NFC

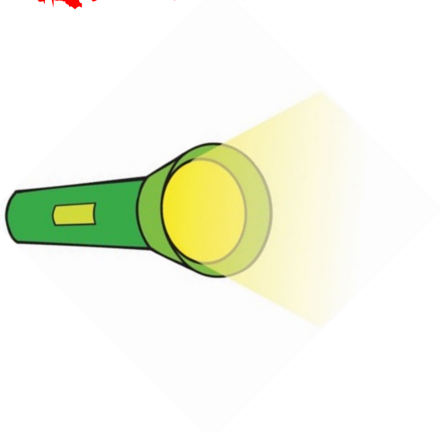
- Radio-Frequency Identification (RFID)
- Near Field Contact (NFC)



Interaction: RFID, NFC

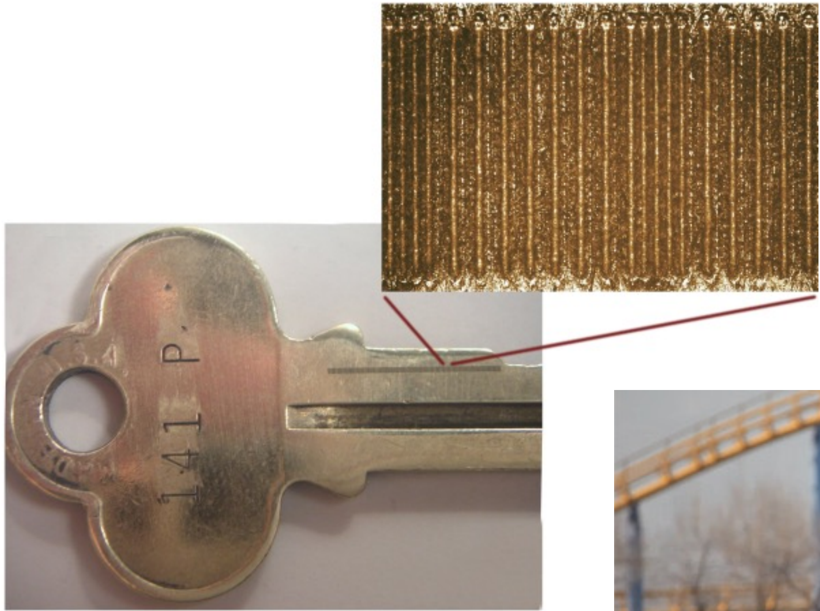
- Radio-Frequency Identification (RFID)
- Near Field Contact (NFC)

Q: How RFID works?

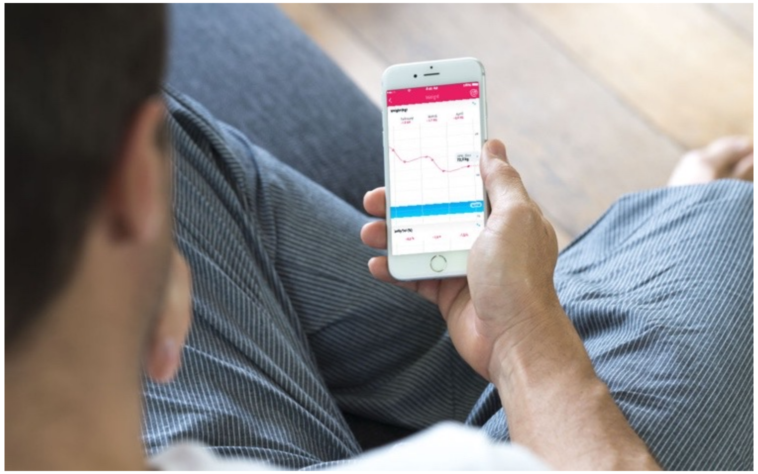


Prof. Congduc Pham
http://www.univ-pau.fr/~cpham

Interaction: always complex?

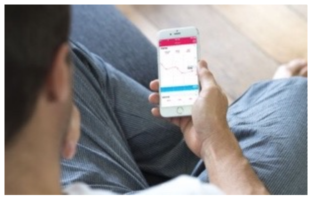


Home/consumer IoT products



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

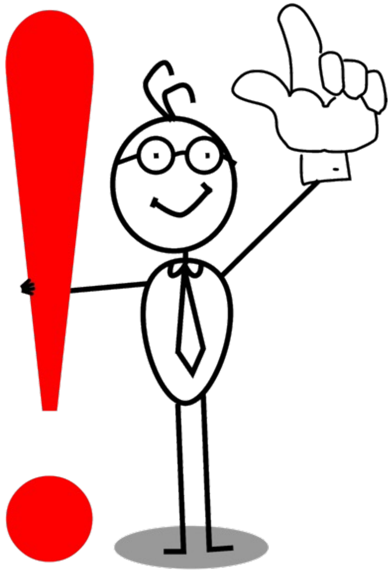
Local interaction is possible…



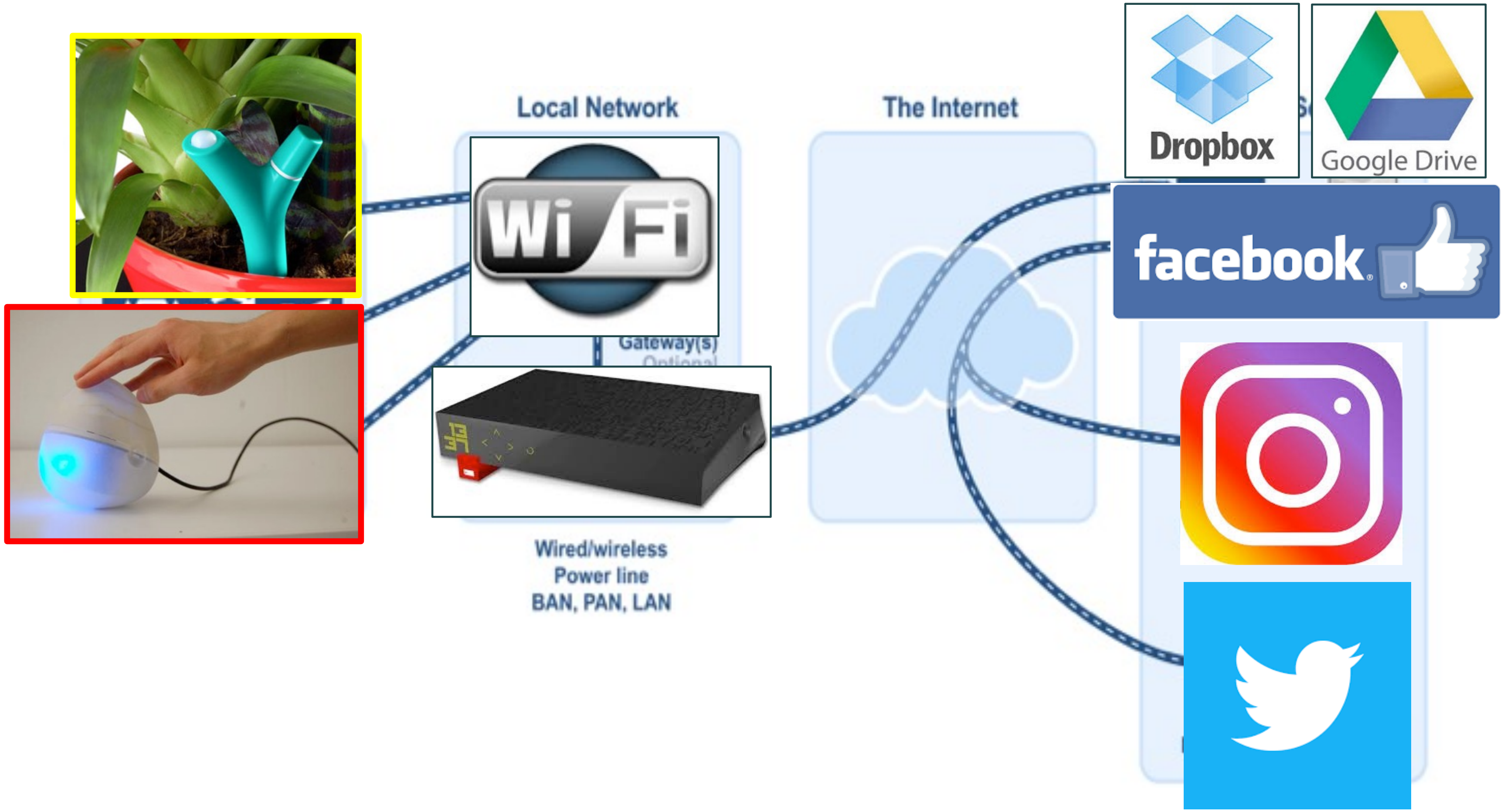
… but IoT usually means cloud data

Lot's of data !

IoT added-values come from interactions and linked data!



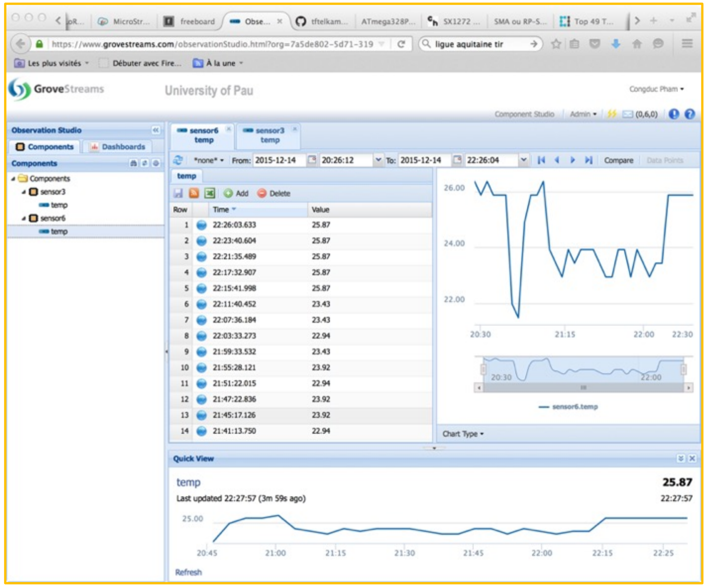
General public IoT architecture



Pictures from ArchitectCorner

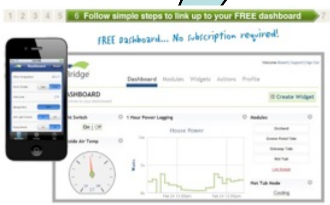
Clouds for IoT

Firebase
FIWARE
Axeda
ioBridge Connect things.
ThingSpeak
GroveStreams
SensorCloud™
freeboard
dweet.io
OpenRemote
TempoIQ



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

Sense, Monitor, Optimize & Control



DATA ANALYSIS, OPTIMIZATION & CONTROL

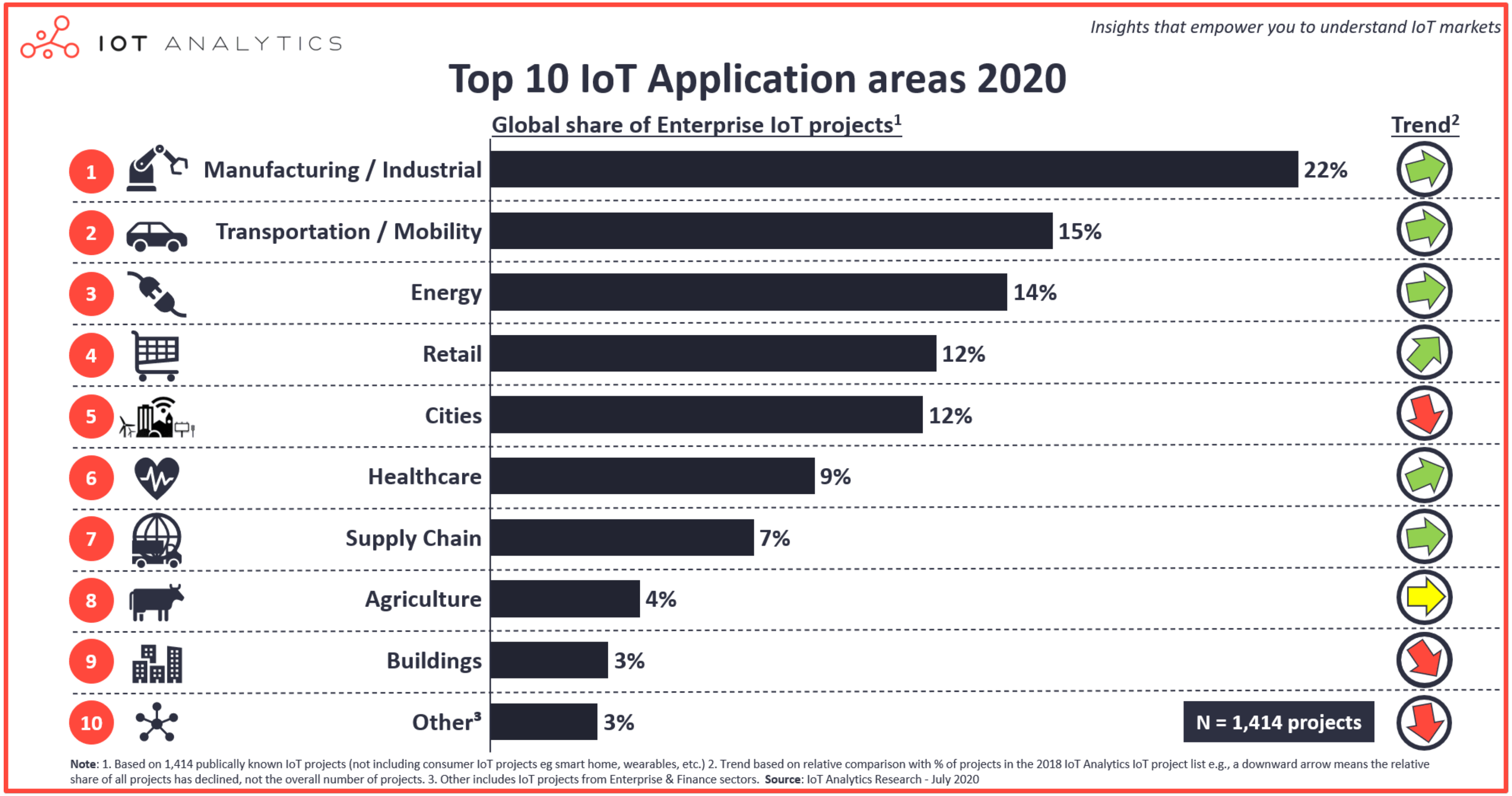
Monitoring

Sensing
Physical world interaction

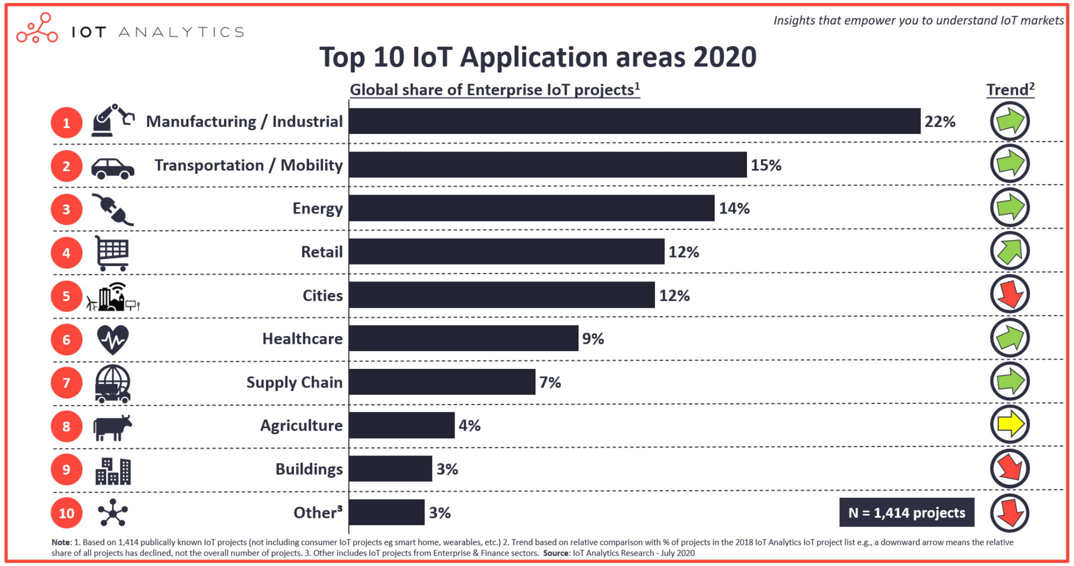
APPLICATION DOMAINS

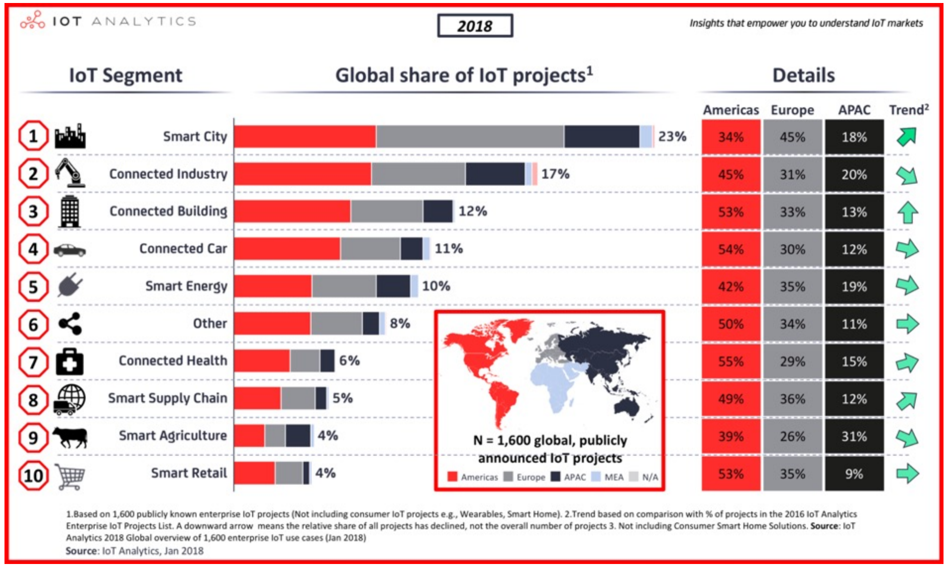
Firebase
FIWARE
Axeda
ioBridge
ThingSpeak
GroveStreams
SensorCloud
freeboard
dweet.io
OpenRemote
TempoIQ

Top IoT applications, 2020



IoT: 2020 vs 2018

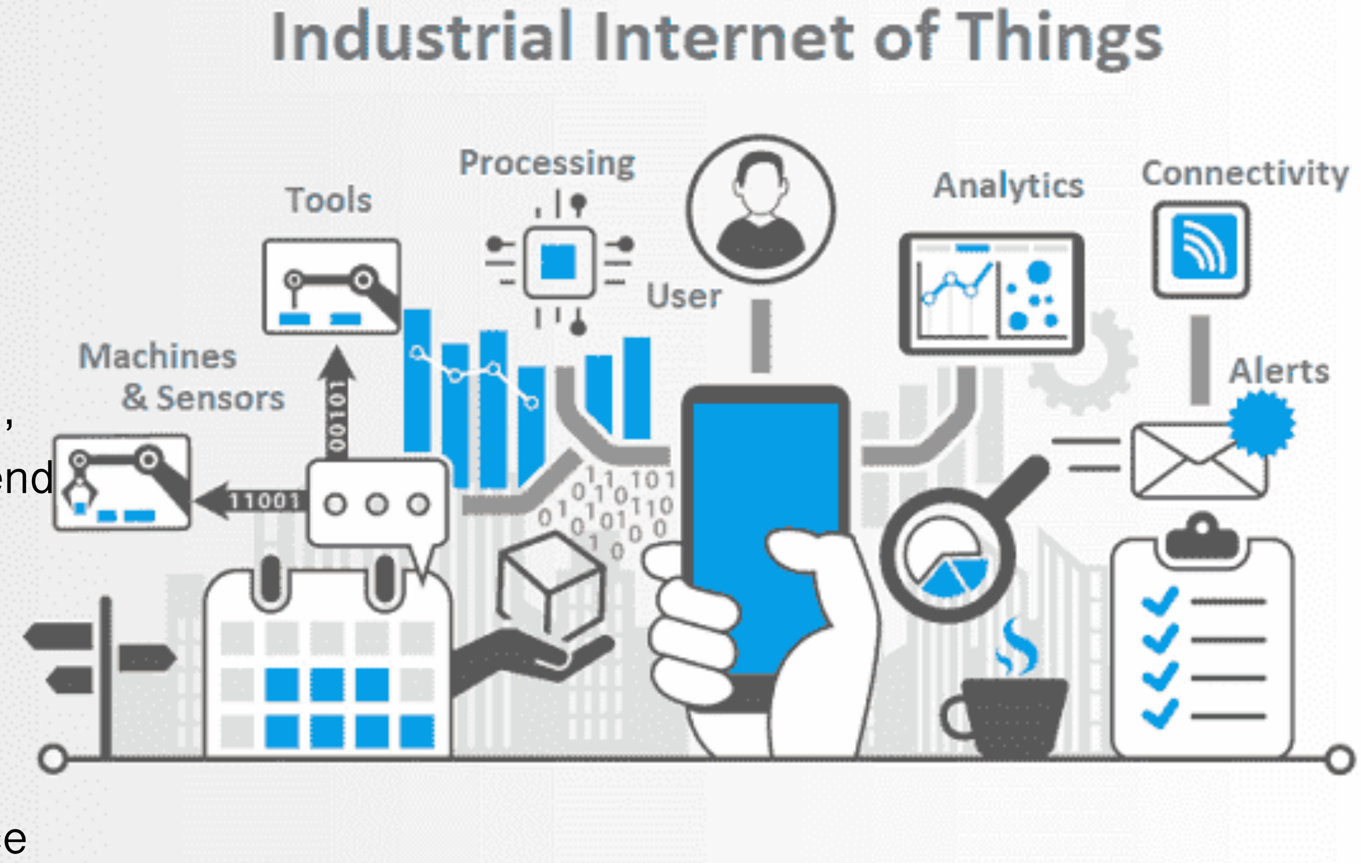




Q: What happen to Smart City?

IoT in industry

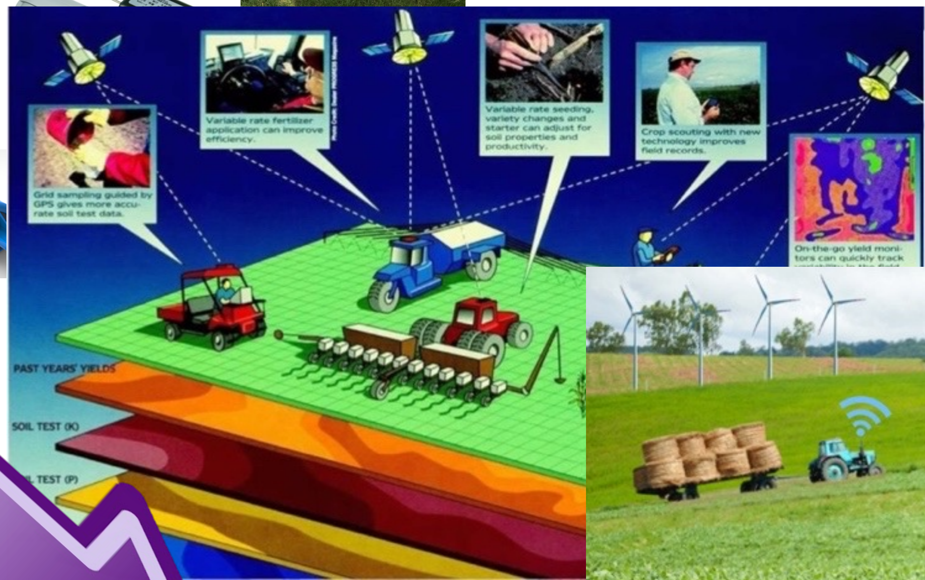
- Infrastructure monitoring, Security & Safety
- Continuous process improvement, Process automation, Process optimization
- Smart logistics management, remote management, tracking,
- Connectivity to back-end system, integration of smart tools, Interoperability
- Data analysis, Supply Chain Optimization,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



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

IoT for Smart Agriculture

Soil Monitoring



Connected Agriculture

IoT for development!


Water saving


Livestock farming


Fish farming & aquaculture


Logistic, Storage, Asset Tracking


Smallholder Agriculture


Water quality & Health

Is IoT the solution for your problem?

Q: How get real-time position of all city buses?

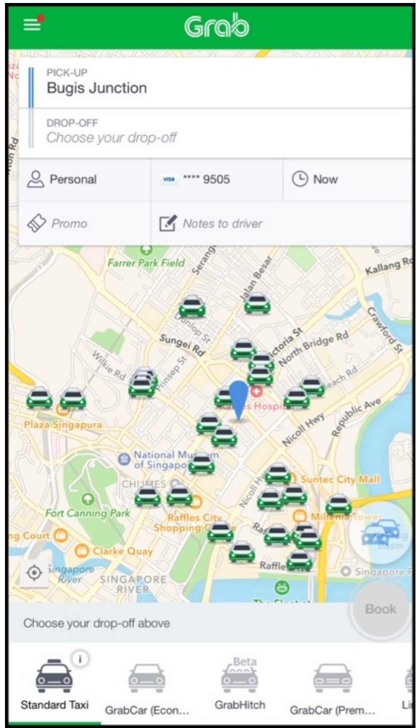
A: Install a GPS + 4G electronic box in each bus to turn the bus into a connected bus!

Q: Is it cost-effective?

Is IoT the solution for your problem?

Q: How get real-time position of all city buses?

"GPS + 4G"
Hum, looks like a smartphone…



Is IoT the solution for your problem?

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

I know! I know !

A: Give them a smartphone and they can use it for reporting!

Q: Is it efficient?

Is IoT the solution for your problem?

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

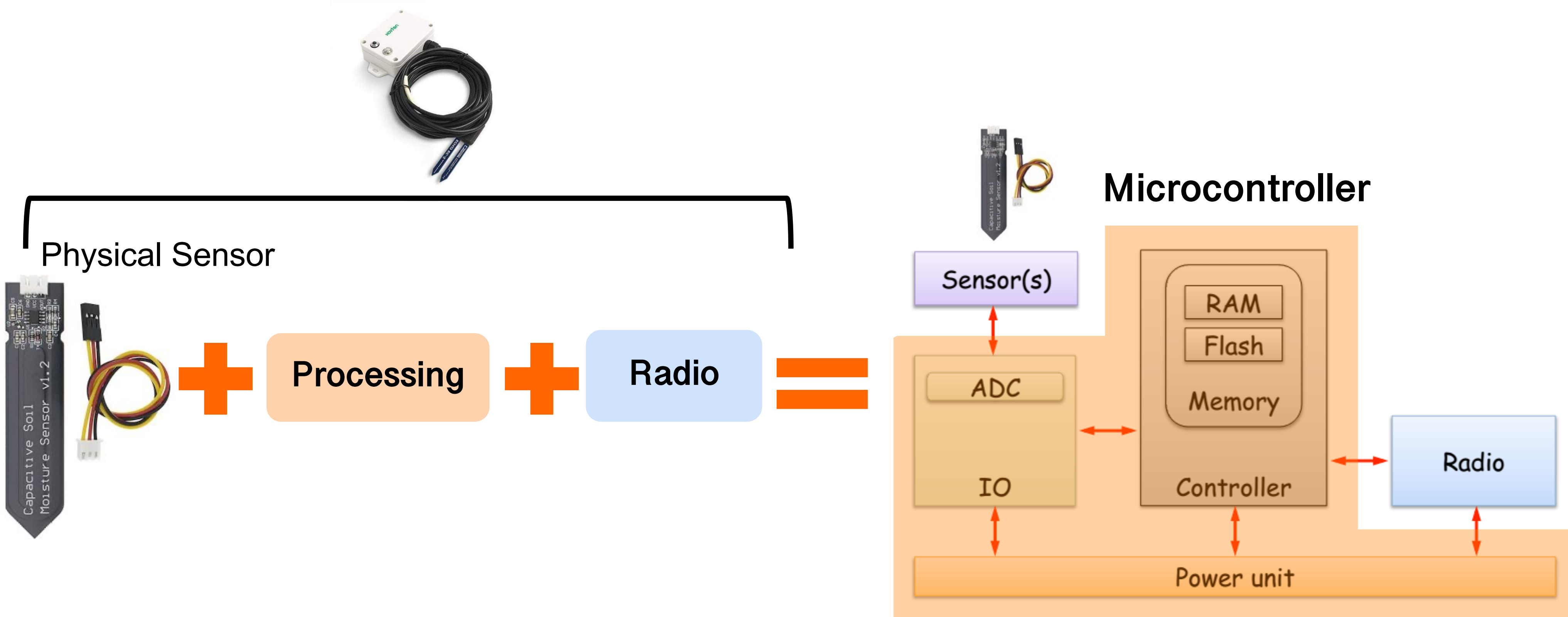
IOT

TECHNOLOGY ?

CONCEPT ?

Typical IoT device

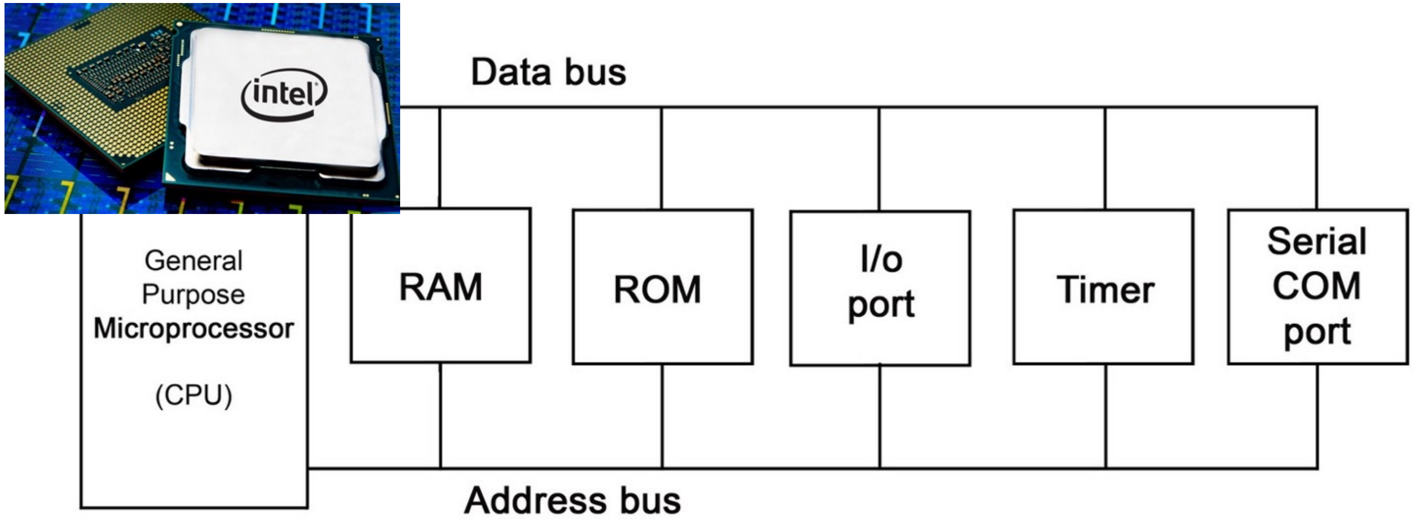
- IoT device can be viewed as a simple Embedded System



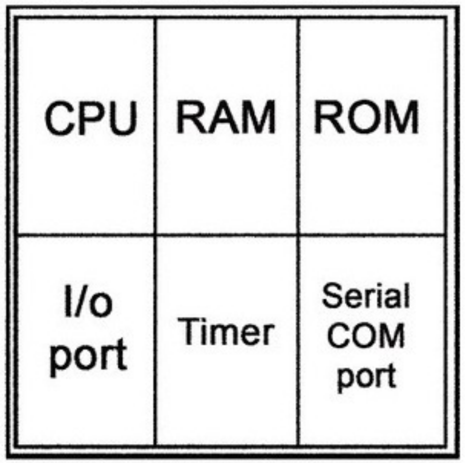
Q: uprocessor vs ucontroller?

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
- Microcontrollers are used in embedded computing and most IoT devices are based on microcontrollers



VS

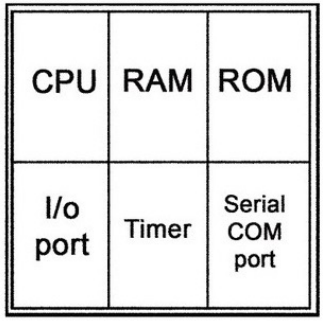


(Single chip)

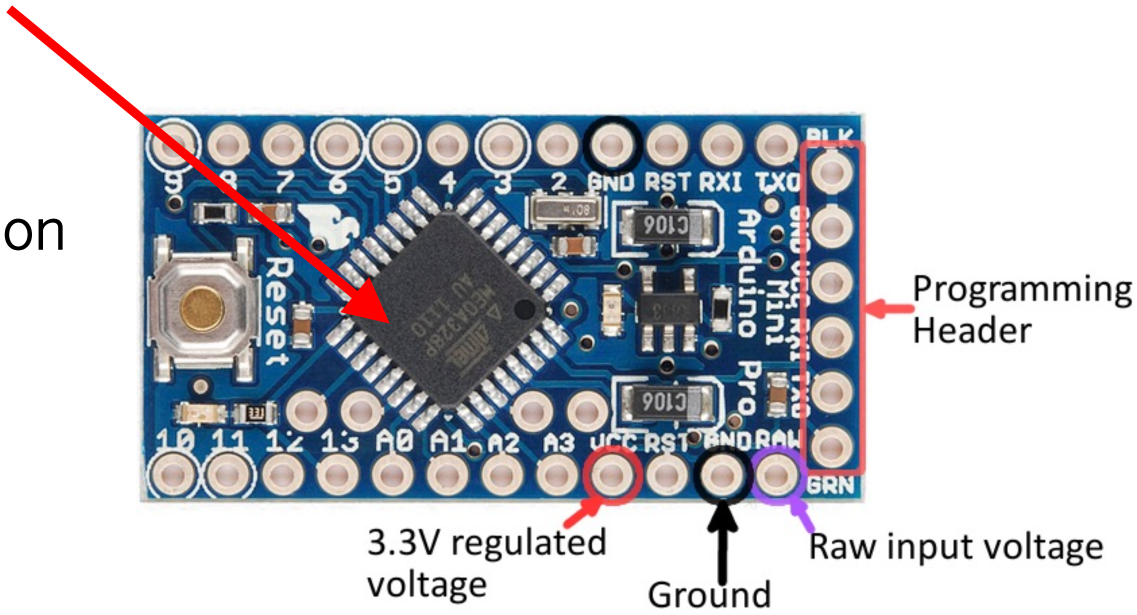
From "An Embedded System Overview" by Dr. Eng. Amr T. Abdel-Hamid

From µcontroller to µcontroller board

- A µcontroller can be standalone…



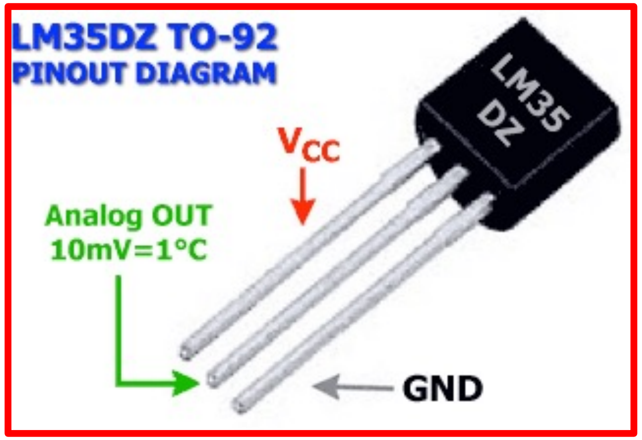
(Single chip)

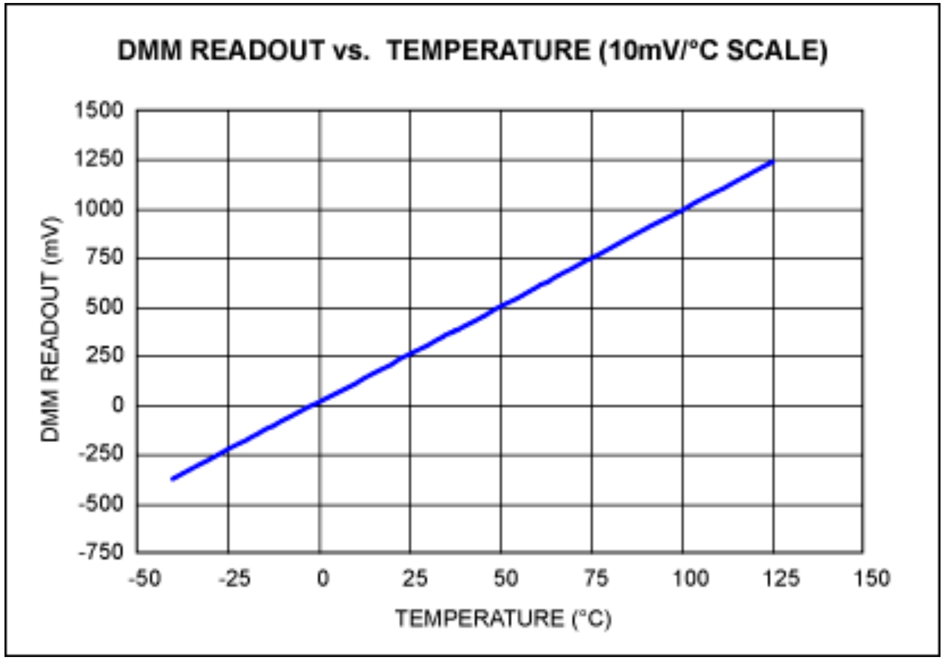


- But, it is usually mounted on a board with additional electronics parts
  - Leds, Voltage regulators
  - Easy access to pins
  - Reset button
  - Serial-USB interface

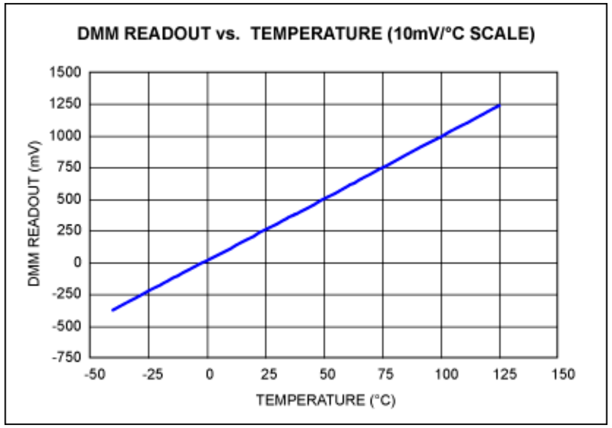
Understanding simple analog sensor

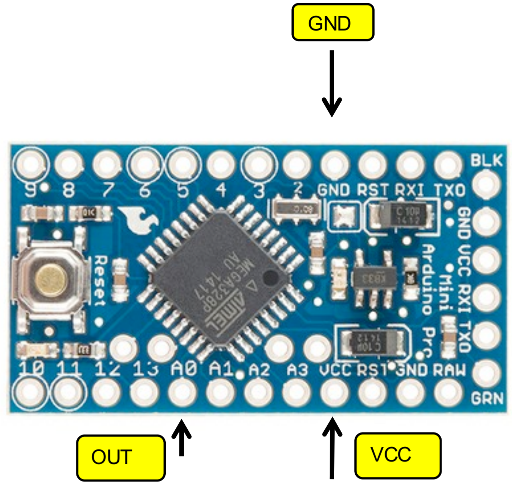
- Analog sensors provides a voltage output that varies according to a physical parameter, e.g. temperature, humidity, luminosity,…





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]**

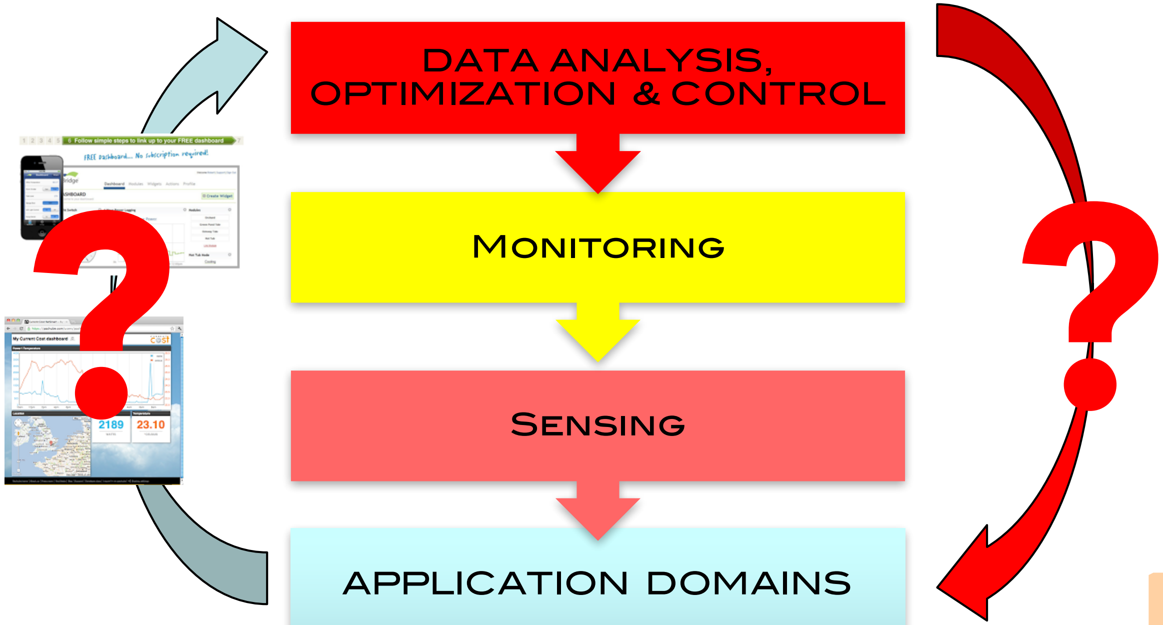
Vcc usually refers to the operating voltage of a given microcontroller. Vcc is typically 3.3V.

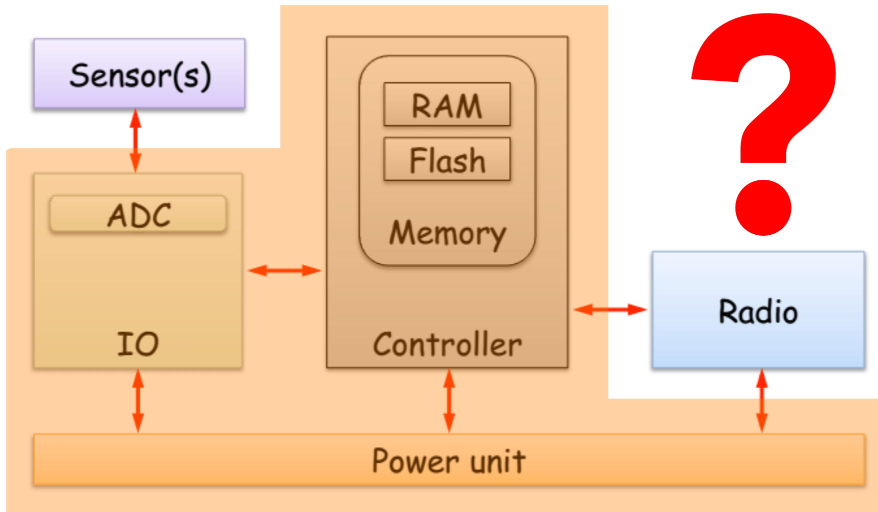
If 0=0V and 1023=3300mV then **3300mV/1024=3.22mV is the granularity of the measure**

Reading a digital value of 100 means 100*3.22mV=322mV

If the sensor output is 10mV/1°C then the physical temperature is 322mV/10mV=32.2°C

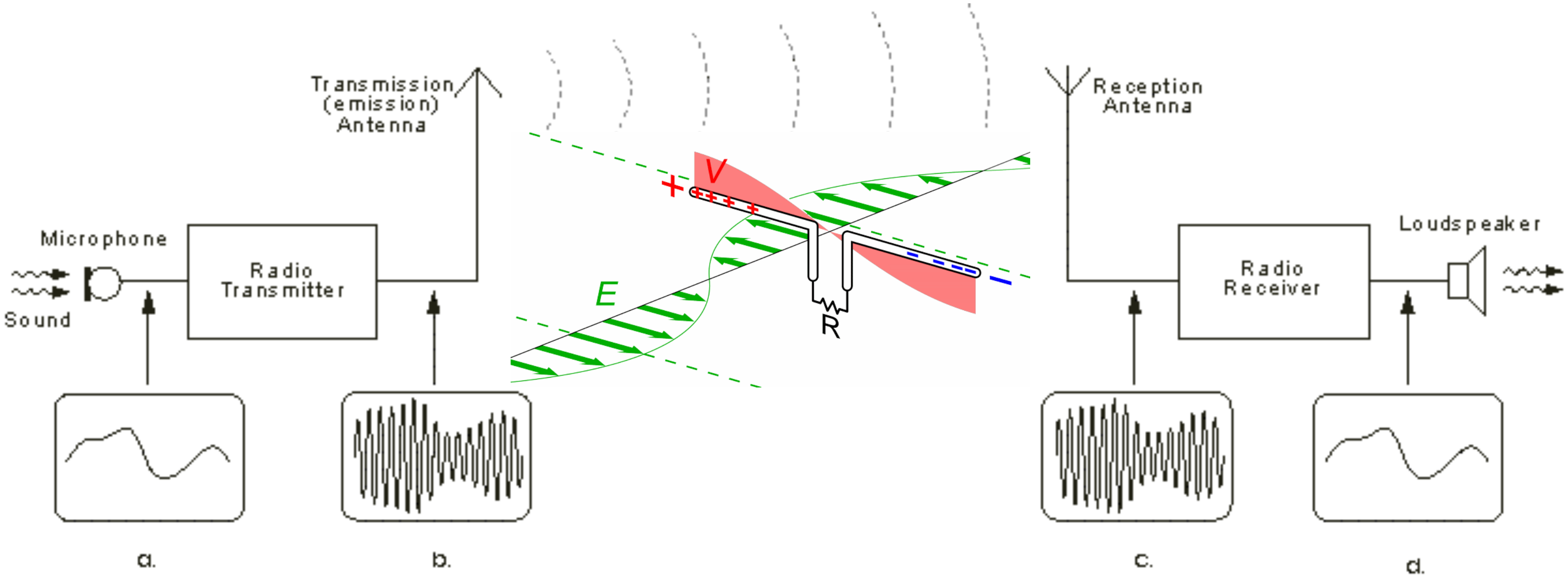
How to collect data?

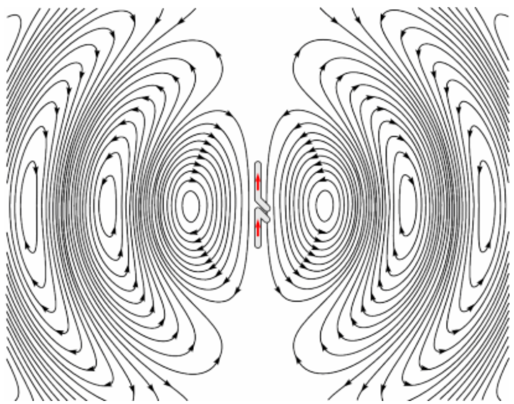


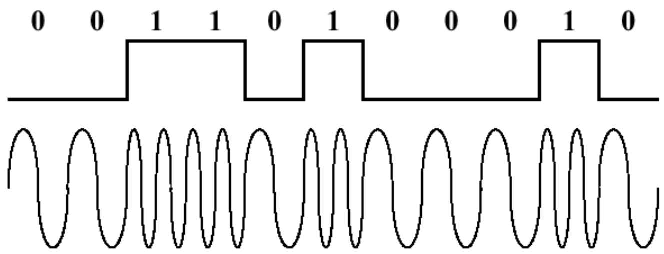


Microcontroller

Wireless (radio) transmission basics



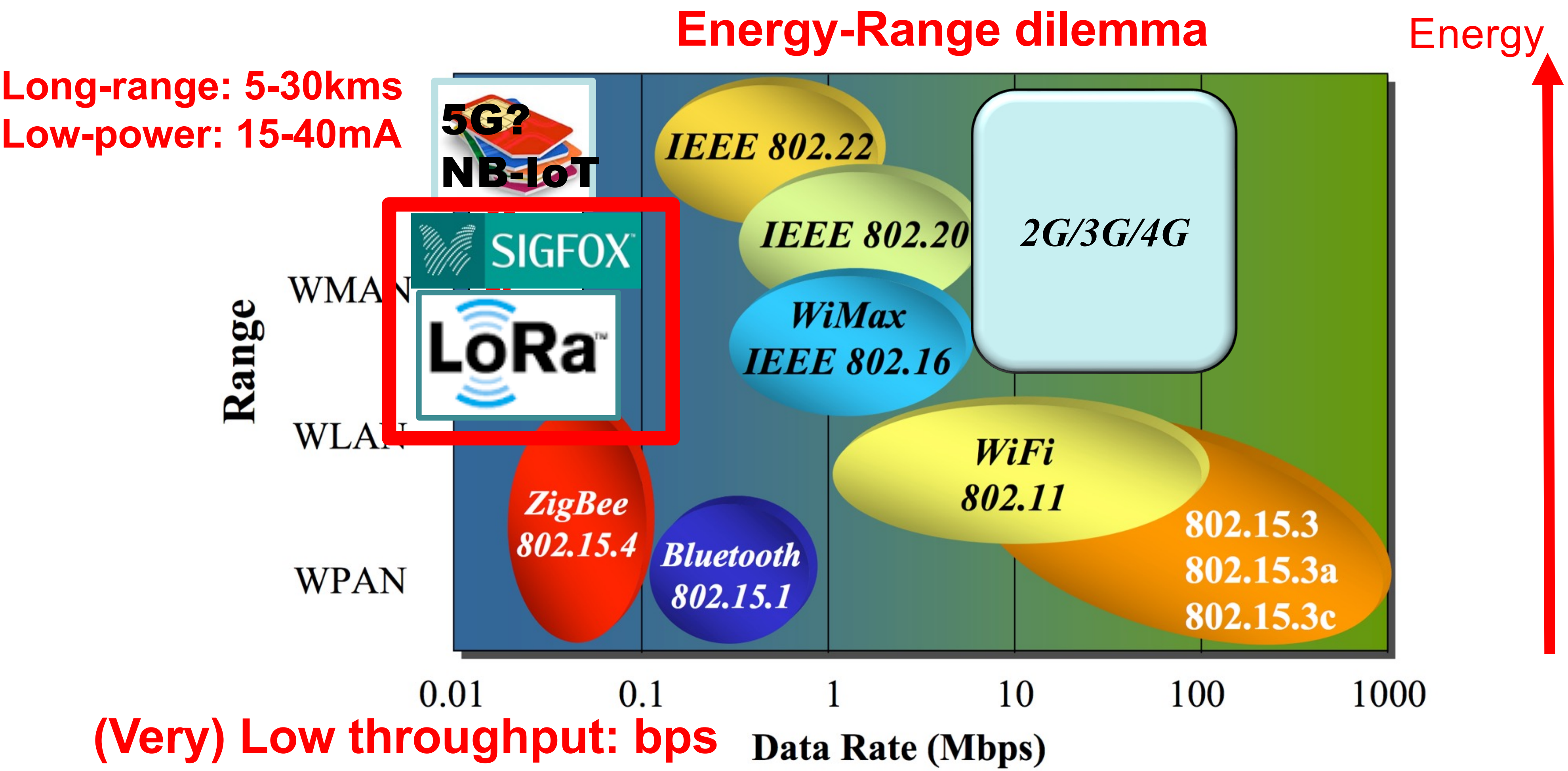




(b) Frequency-shift keying

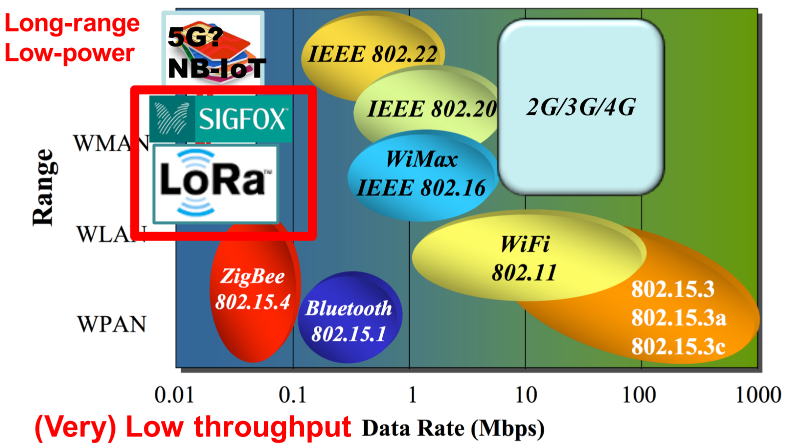
Q: Can we have Gbps in wireless?

Low-power & long-range radios



Energy consumption comparaison

Energy-Range dilemma



Energy ↑

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

2500mA

TX power: 500mA. Mean consumption: (8sx500+3592sx0.005)/3600=1.11mA

2500/1.11=2252h = 93 days = 3 months ☹

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

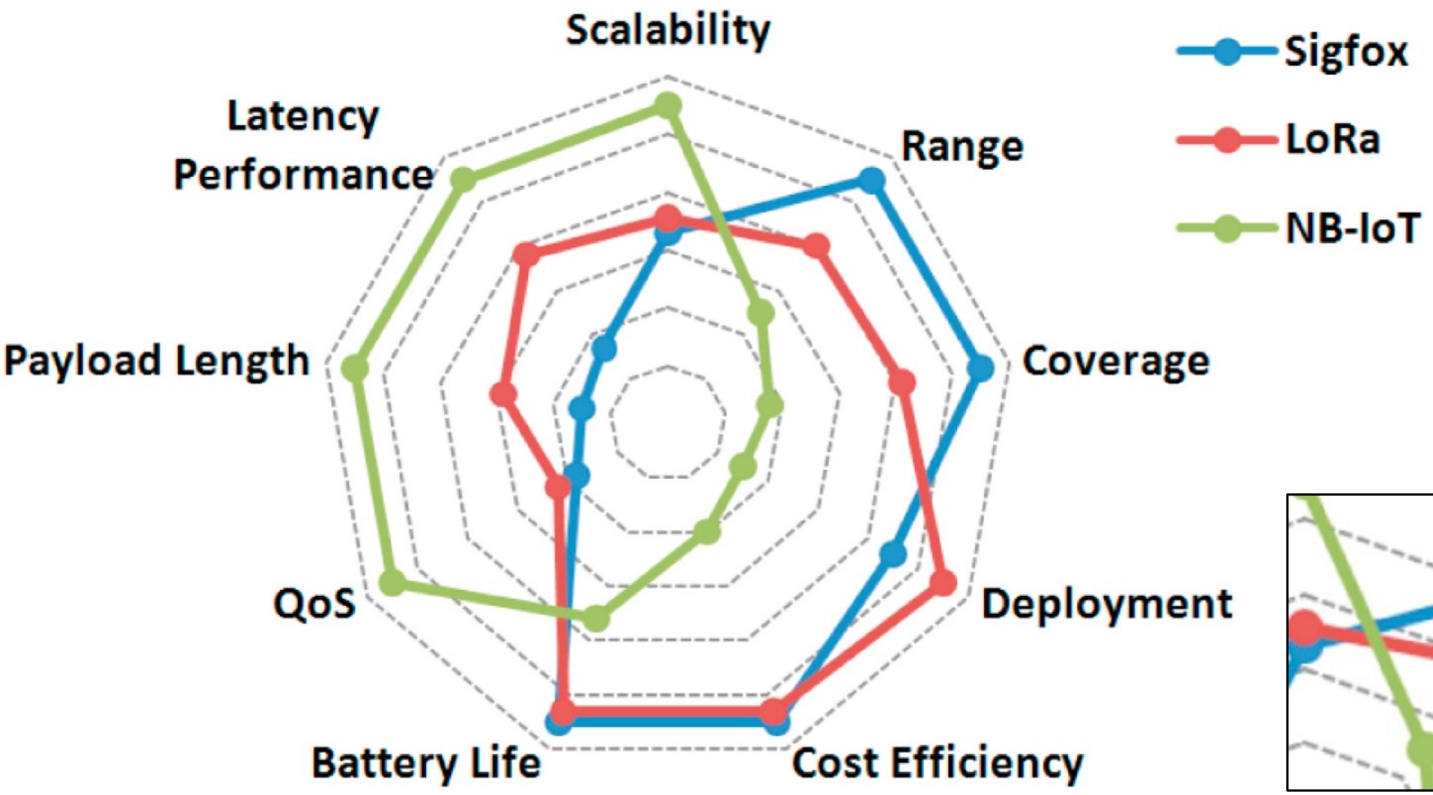
TX power: 40mA. Mean consumption: (2sx40+3598sx0.005)/3600=0.027mA

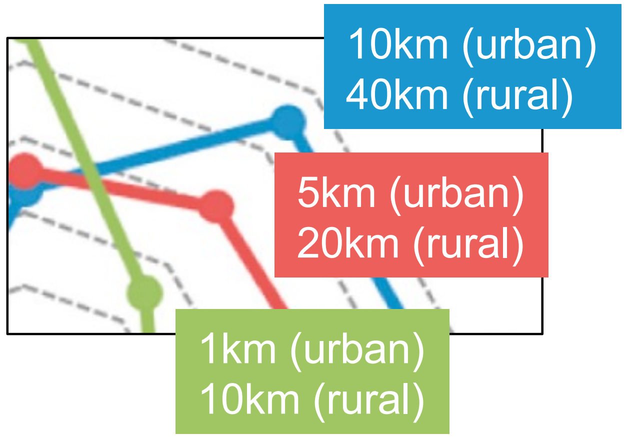
2500/0.027=92592h = 3858 days = 10 y. ☺

LPWAN does not need to maintain connection if not in used

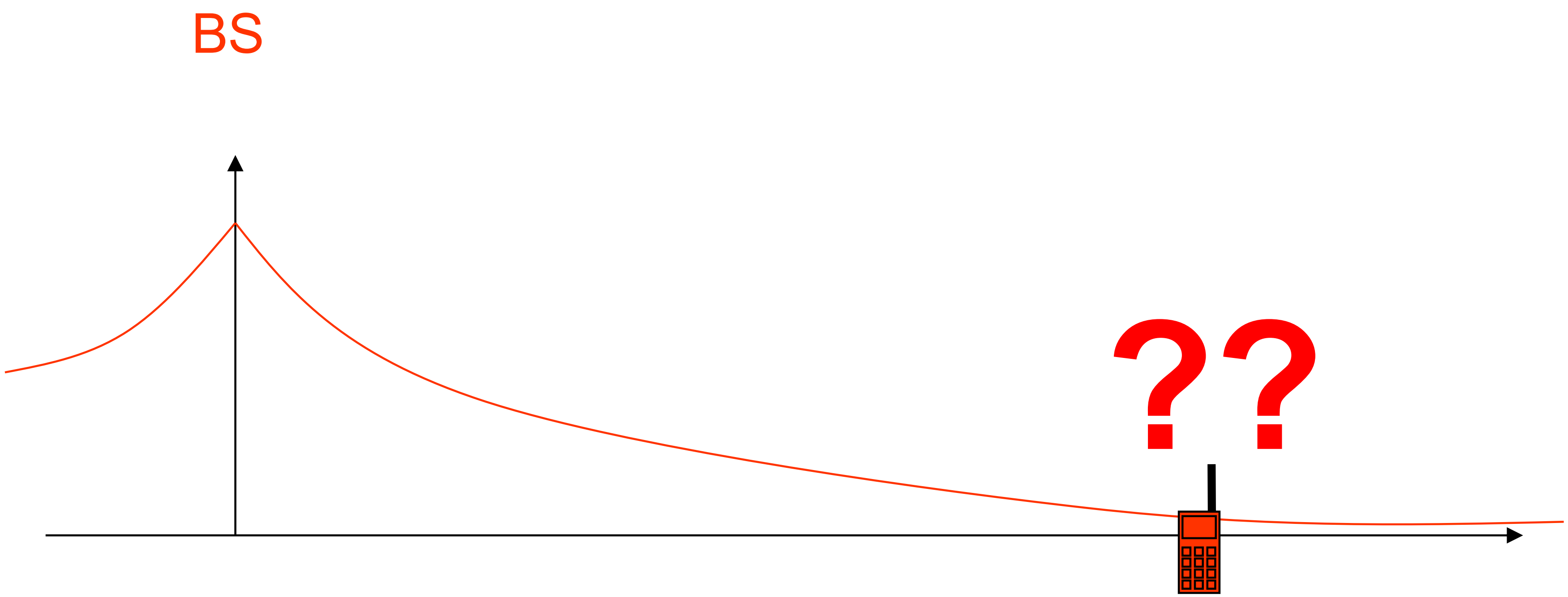
![HORIZON 2020]

LPWAN expected range?





1st challenge: signal attenuation



Attenuation limits the range!

- Depends mainly on distance

$$P_r = P_e d^{-\alpha}$$

- with :
  - P_e = transmitted power
  - P_r = received power
  - d = distance between antennas
  - α from 2 to 4

41

Attenuation in practice

- For an ideal antenna (theoretic)

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

  - P_e = transmitted power
  - P_r = received power
  - P_e / P_r is high when P_r is small → high attenuation
  - d = distance between antennas
  - c = light speed in space 3.10^8 m/s
  - λ= wave length of the signal=c/f
  - Higher frequencies f means higher attenuation!

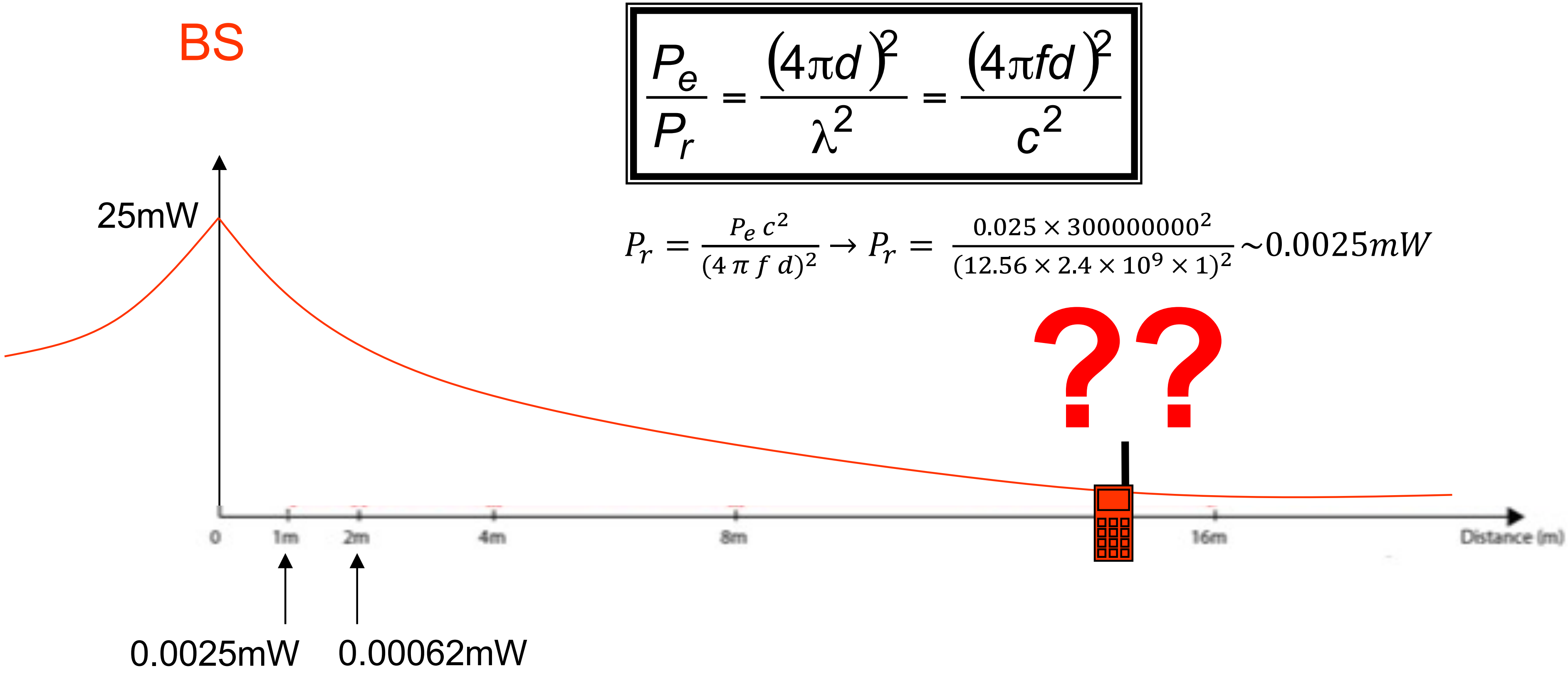
42

Attenuation, value in watts

- Free Space Path Loss model

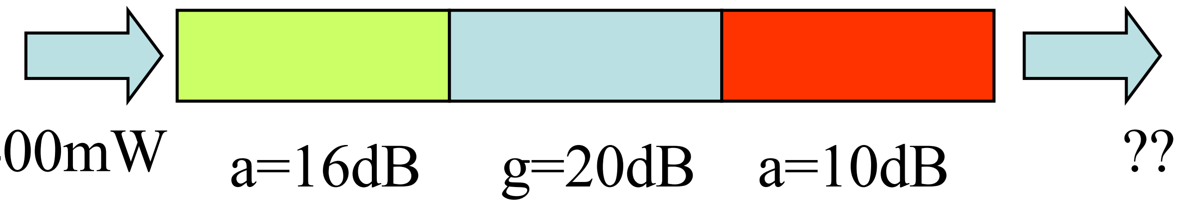
$$\frac{P_e}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

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



Attenuation in decibel (dB)

- Decibel uses logarithmic scale as attenuation values can be very large
- Attenuation in dB: $10\log10(P_e/P_r)$, P_e and P_r in watts
  - So $P_e/P_r = 10^{dB/10}$
  - Difference of 3dB≈half (divided by 2) as $P_e/P_r = 10^{3/10} = 10^{0.3} = 1.99526\ldots$
- ➡Gain = $10\log10(P_r/P_e)$
- We can add various sections with attenuation or gain

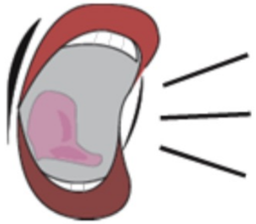


-16dB + 20dB - 10dB = -6dB, so it is an attenuation

$P_e/P_r = 10^{6/10} = 10^{0.6} = 3.98$ ➡ $P_r = P_e/3.98 \approx 100mW$

dB, dBm, …

- Total net output power of transmitter
- Typically measured in dBm or mW



- mW: milliwatts are a measurement of power (1000 mW = 1 Watt).
- dB: decibel is a unit for expressing the ratio of two amounts of signal power equal to 10 times the common logarithm of this ratio. So, a power measurement in dB has to be relative to something.
- dBm: dB(mW) is power relative to 1 milliwatt (mW to dBm = $10Log_{10}(mW/1000) + 30$).

  $P(dBm) = 10 \cdot \log10(P(mW) / 1mW)$
- dBi: dB(isotropic) is the forward gain of an antenna compared to the hypothetical isotropic antenna, which uniformly distributes energy in all directions.

RF Essentials from Digi

45

dBm to mW conversion

$P(dBm) = 10.\log_{10}(P(mW)/1mW)$

$$P(mW) = 10^{\frac{P(dBm)}{10}}$$

Ex:

$$P(mW) = 10^{\frac{14dBm}{10}} = 10^{1.4} = 25.118mW$$

dBm	Watts
0	1.0 mW
1	1.3 mW
2	1.6 mW
3	2.0 mW
4	2.5 mW
5	3.2 mW
6	4 mW
7	5 mW
8	6 mW
9	8 mW
10	10 mW
11	13 mW
12	16 mW
13	20 mW
14	25 mW
15	32 mW

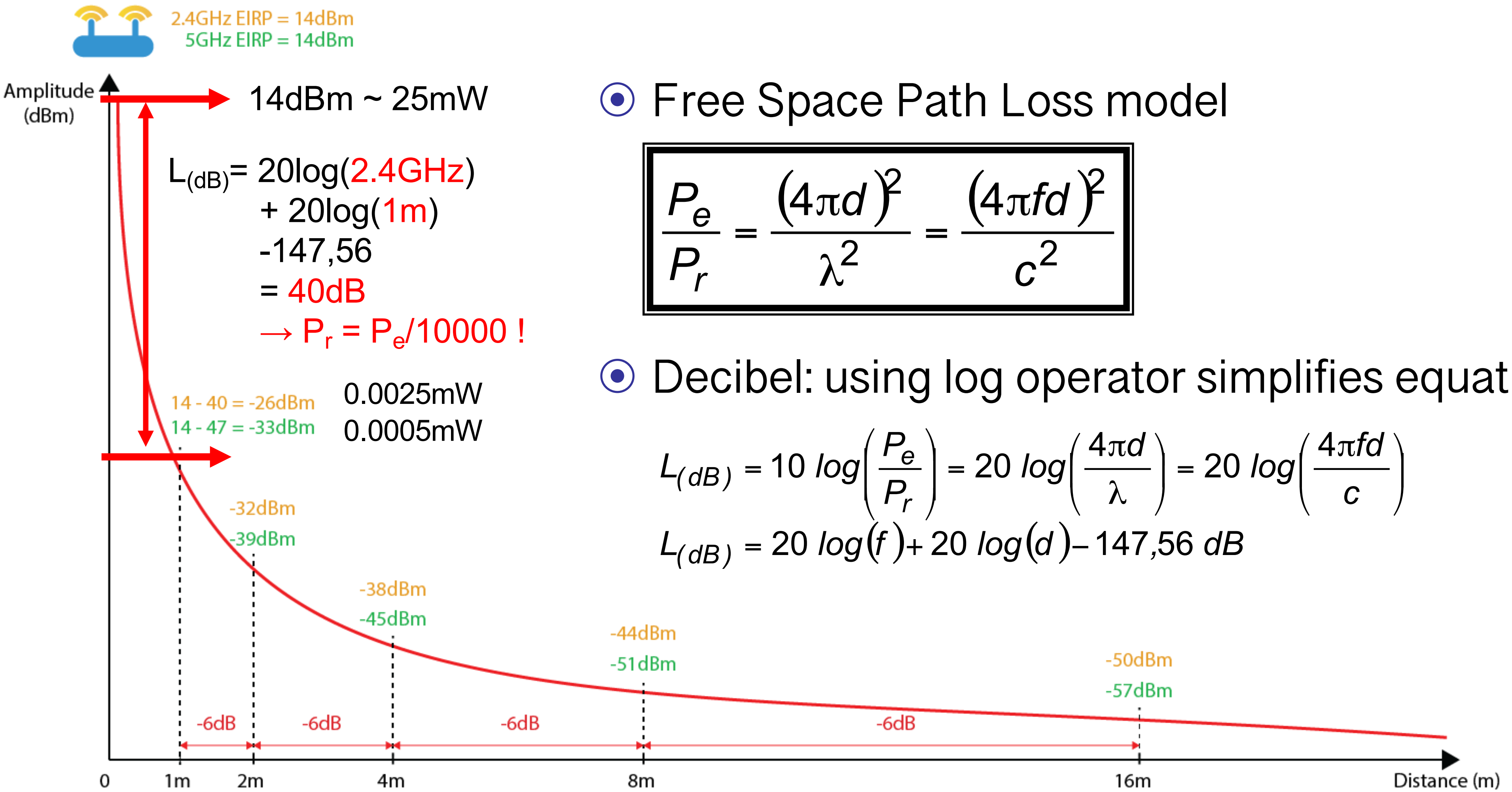
dBm	Watts
16	40 mW
17	50 mW
18	63 mW
19	79 mW
20	100 mW
21	126 mW
22	158 mW
23	200 mW
24	250 mW
25	316 mW
26	398 mW
27	500 mW
28	630 mW
29	800 mW
30	1.0 W
31	1.3 W

dBm	Watts
32	1.6 W
33	2.0 W
34	2.5 W
35	3.2 W
36	4.0 W
37	5.0 W
38	6.3 W
39	8.0 W
40	10 W
41	13 W
42	16 W
43	20 W
44	25 W
45	32 W
46	40 W
47	50 W

RF Essentials from Digi

46

Attenuation in image



- Free Space Path Loss model

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

- Decibel: using log operator simplifies equation

$$L_{(dB)} = 10\ log\left(\frac{P_e}{P_r}\right) = 20\ log\left(\frac{4\pi d}{\lambda}\right) = 20\ log\left(\frac{4\pi f d}{c}\right)$$

$$L_{(dB)} = 20\ log(f) + 20\ log(d) - 147{,}56\ dB$$

$$10^{\frac{-26dBm}{10}} = 10^{-2.6} = 0.0025118mW$$

$$10^{\frac{-32dBm}{10}} = 10^{-3.2} = 0.00063mW$$

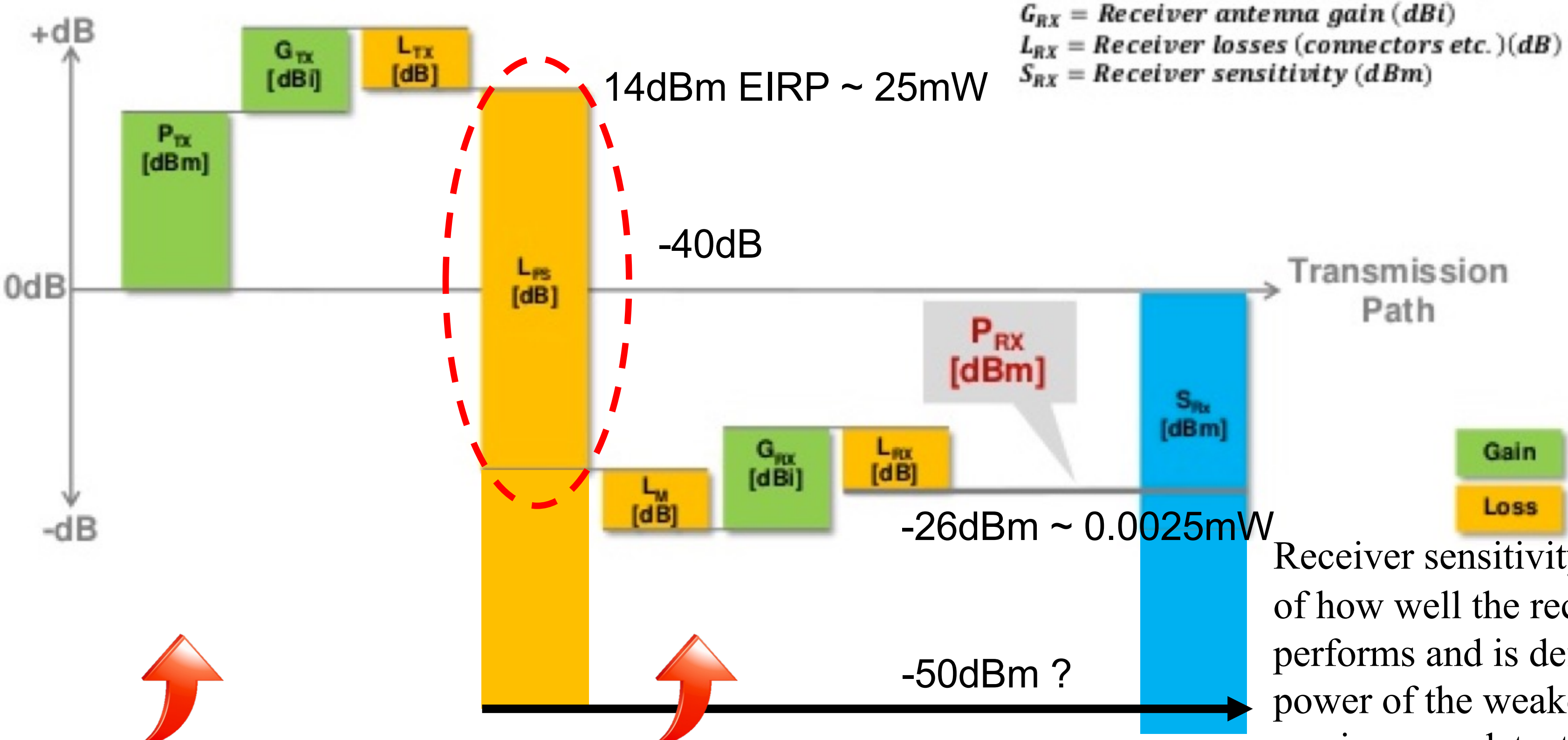
Additional advantage of log scale: very large and very small values can be plotted on the same graph

Link budget in wireless system

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

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)

Adapted from Peter R. Egli, INDIGOO.COM

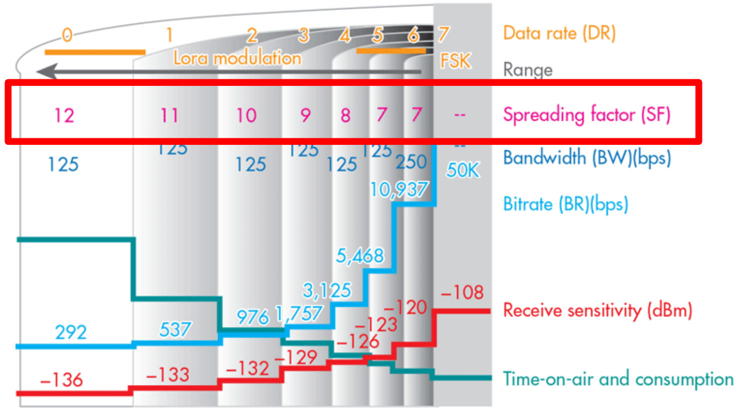


Receiver sensitivity is a measure of how well the receiver performs and is defined as the power of the weakest signal the receiver can detect

$$L_{(dB)} = 20\log(f) + 20\log(d) - 147{,}56\ dB$$

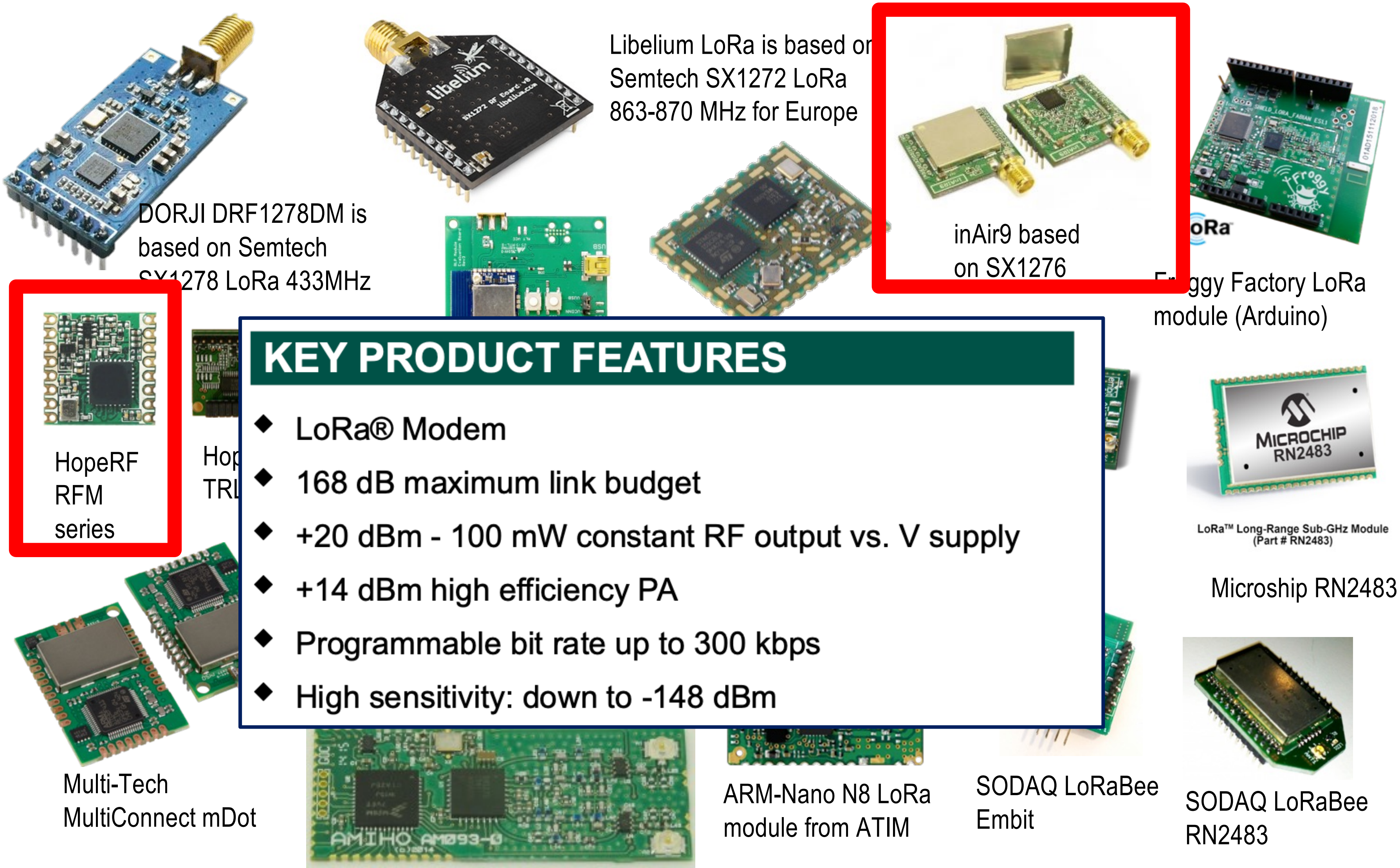
How can we increase range?

- Increase TX power and/or improve RX sensitivity
- Generally, RX sensitivity (~robustness) can be increased when transmitting (much) slower (like speaking slower!)
- LoRa uses spread spectrum approach to increase RX sensitivity
  - Spreading Factor defines how many chips will be used to code a symbol. More chip/symbol=longer transmission time ➠ more robustness
- **The price to pay for LPWAN**
  - LoRa has very low throughput: 200bps-37500bps (0.2-37.5kbps)

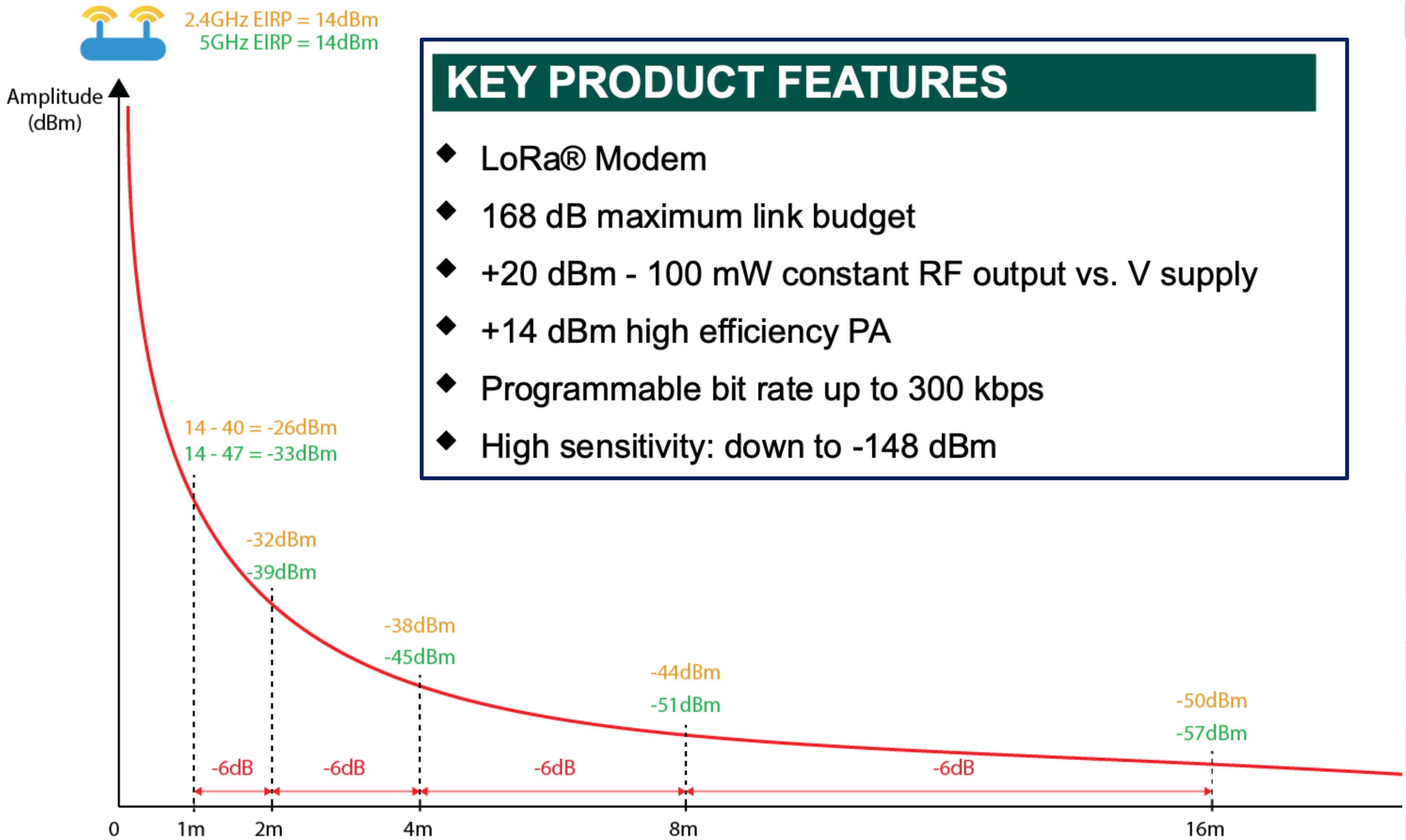


- WiFi 802.11n: 450 000 000 bps (450Mbps)
- WiFi 802.11g: 54 000 000 bps (54Mbps)
- Bluetooth3&4: 25 000 000 bps (25Mbps)
- Bluetooth BLE: 2 000 000 bps (2Mbps)
- 3G/4G : 20Mbps-200Mbps
- LoRa : 200bps-37500bps (0.0002-0.0375Mbps)
- 3G/LoRa ratio: 20,000,000bps/200bps=100000!

LoRa modules with Semtech's SX127x



What distance for -148dBm?



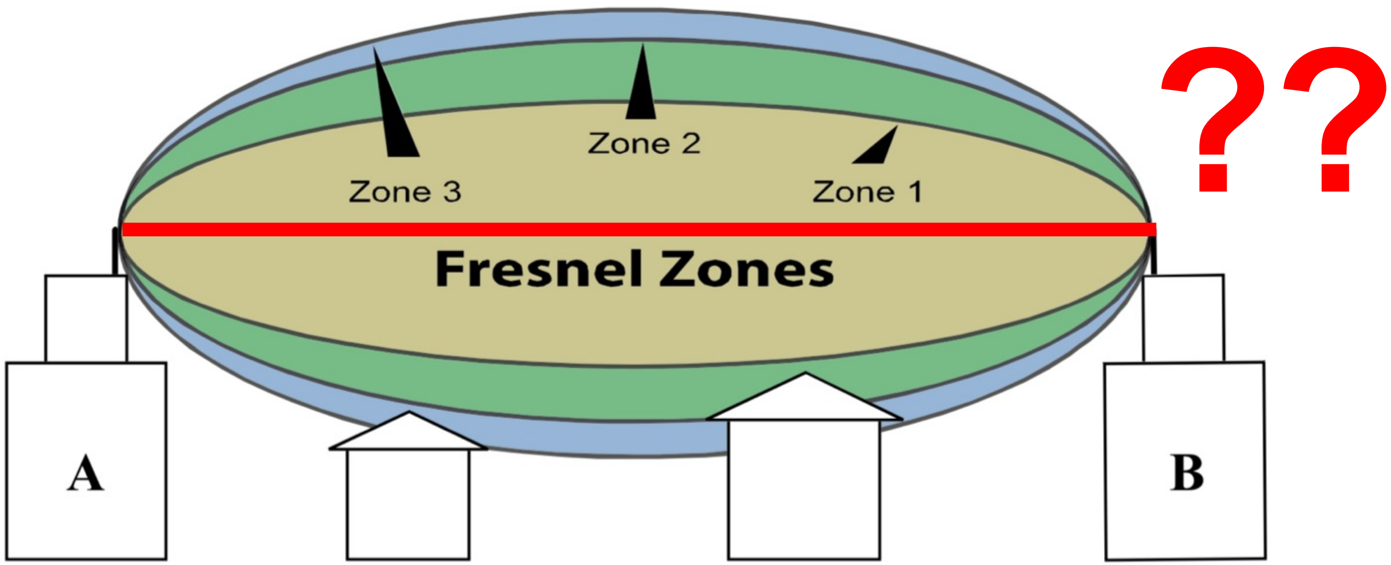
KEY PRODUCT FEATURES

- 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

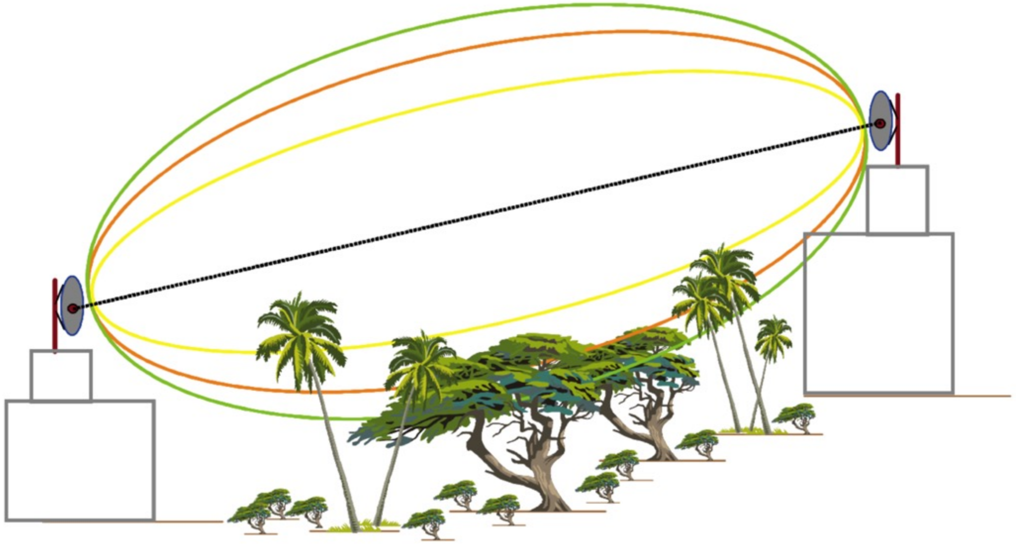
Line-of-Sight & Fresnel zone

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

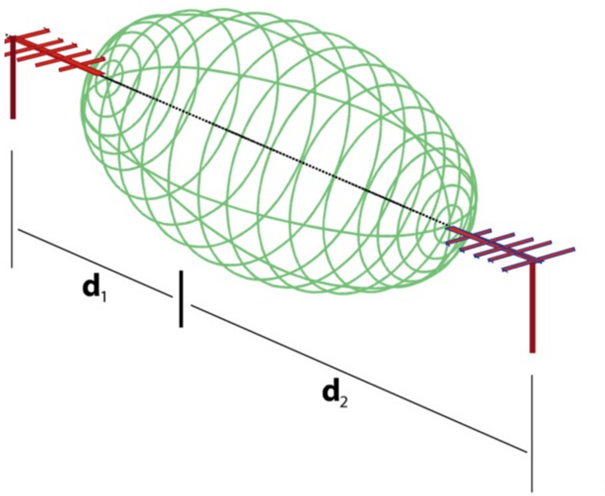


RF Essentials from Digi

Clearing the Fresnel zone? Raise antennas!



$$r_n = \sqrt{\frac{[illegible]}{d_1 + d_2}}$$



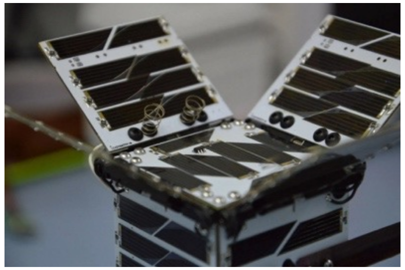
Range Distance	900 MHz Modems Required Fresnel Zone Diameter	2.4 GHz Modems Required Fresnel Zone Diameter
1000 ft. (300 m)	16 ft. (5 m)	11 ft. (3.4 m)
1 Mile (1.6 km)	32 ft. (10 m)	21 ft. (6.4 m)
5 Miles (8 km)	68 ft. (21 m)	43 ft. (13 m)
10 Miles (16 km)	95 ft. (29 m)	59 ft. (18 m)

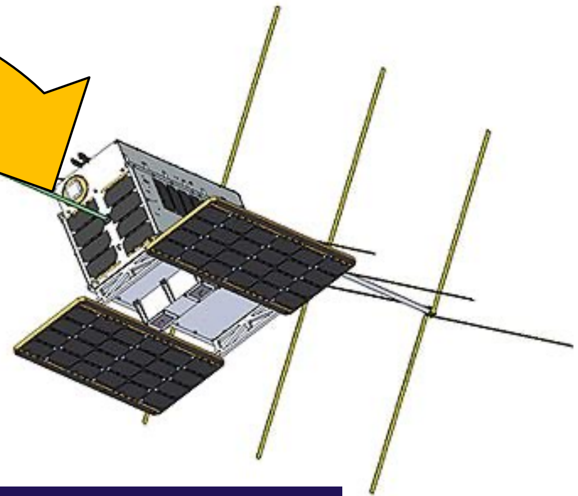
RF Essentials from Digi

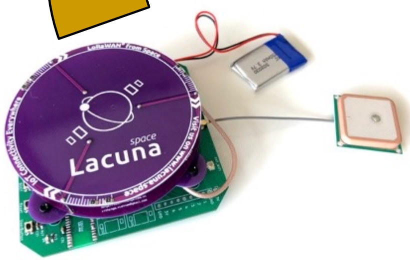
Clearing the Fresnel zone? Let's use satellite!

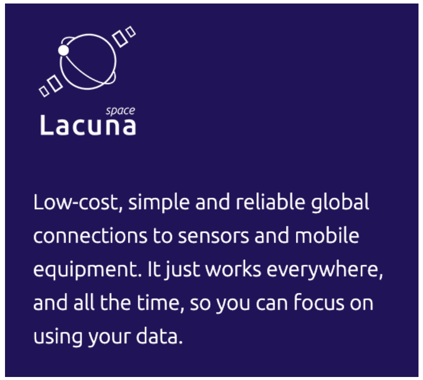
- Low-orbit, low-cost; compact satellite for global coverage

LoRa over 1200kms!



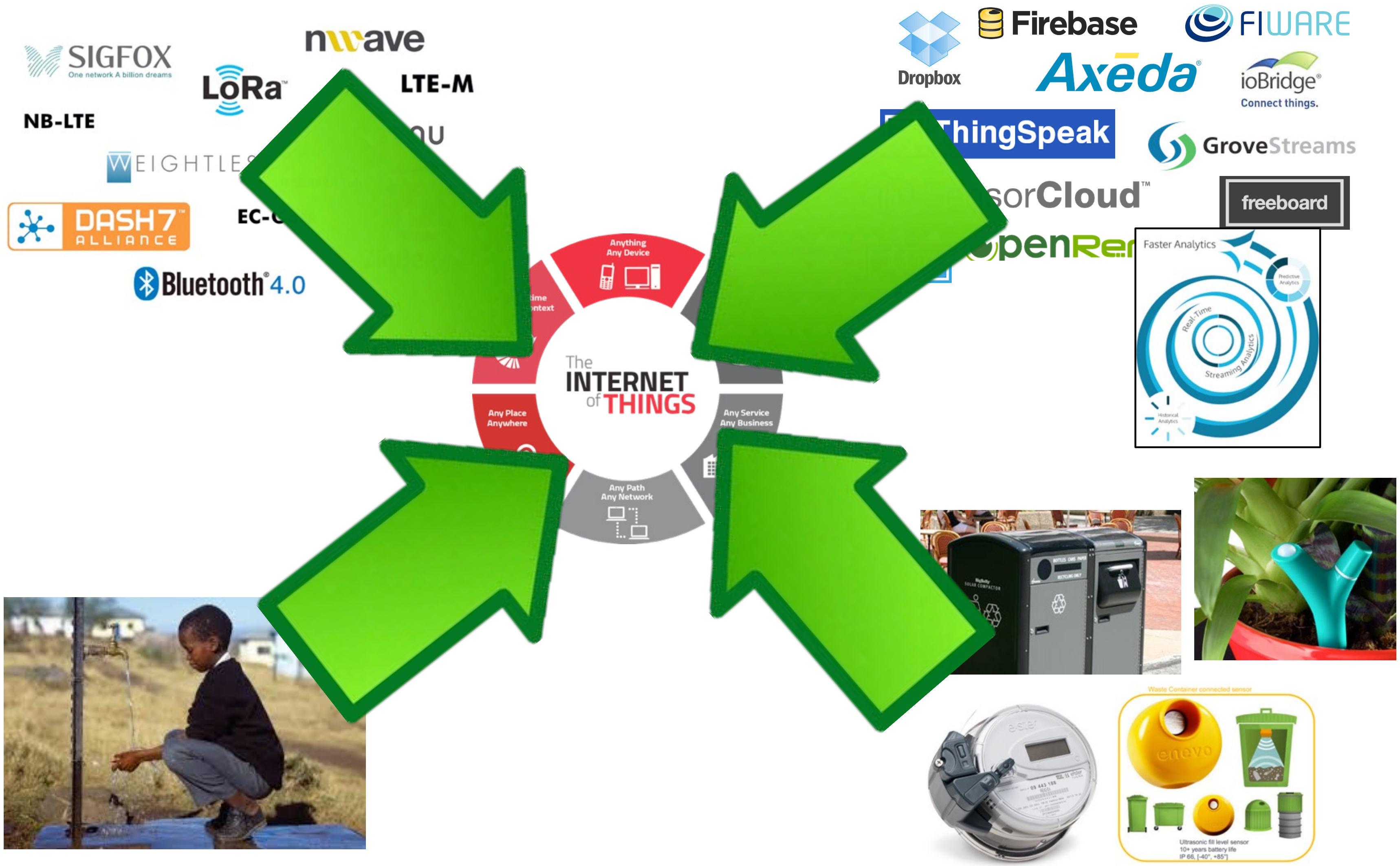






https://lacuna.space/first-successful-lacunasat-launch-in-2021/

IoT becomes reality!



A reality for everybody?

Too expensive
Too integrated
Highly specialized
Difficult to customize
Difficult to upgrade

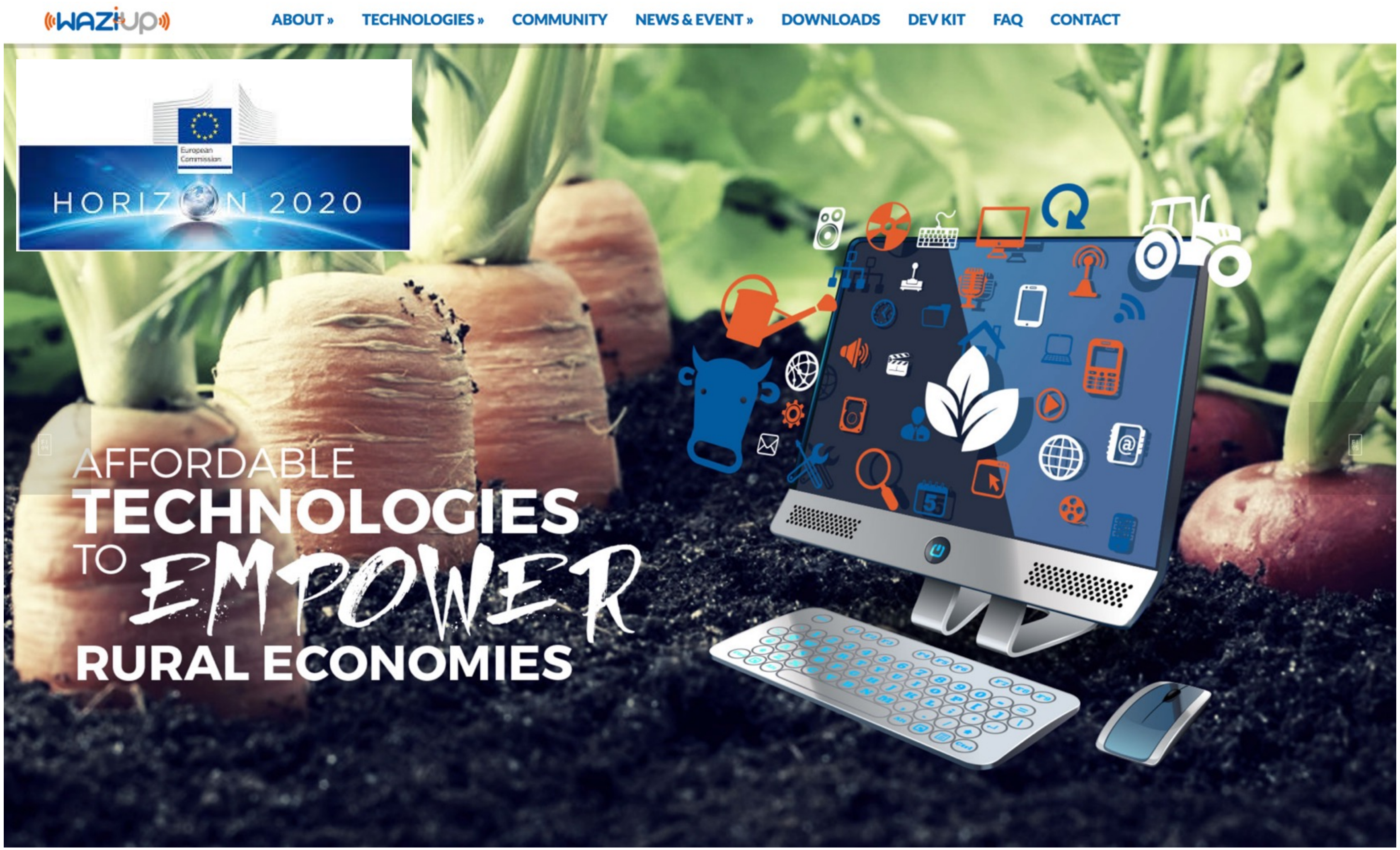
Adapting technological solutions

Many commercial systems are not adapted for developing countries, rural areas, smallholders, …

Needs, cost, design approach, constraints & control mechanisms

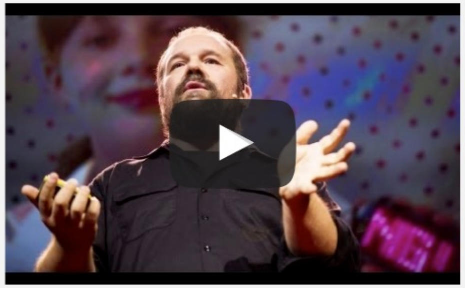
Challenges:
Low-cost, adaptation, digital inclusion, local economy

Low-cost IoT!



ABOUT »
TECHNOLOGIES »
COMMUNITY
NEWS & EVENT »
DOWNLOADS
DEV KIT
FAQ
CONTACT
HORIZON 2020
AFFORDABLE
TECHNOLOGIES
TO EMPOWER
RURAL ECONOMIES

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

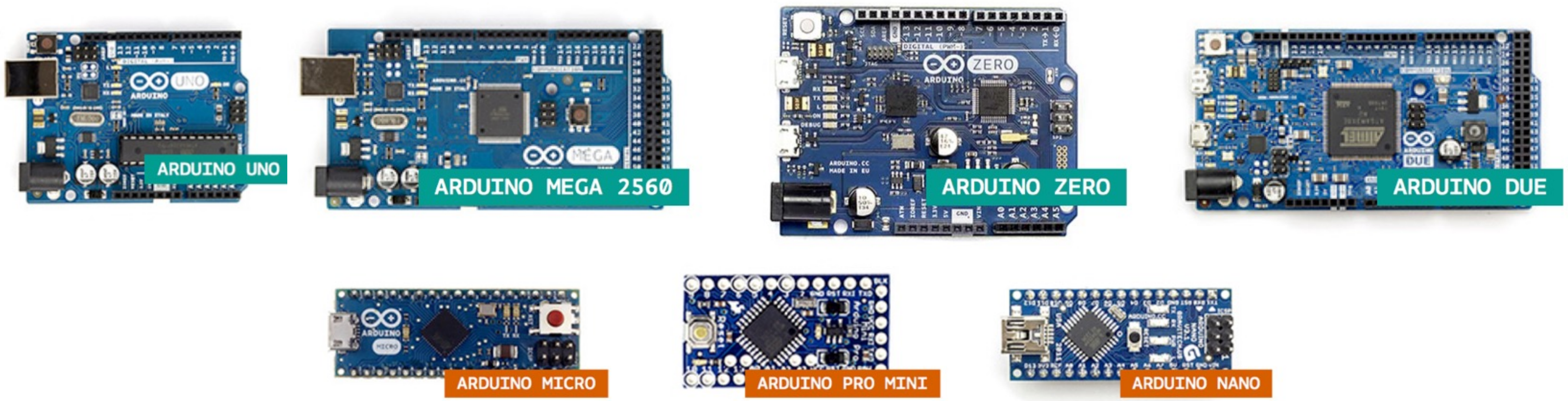
Arduino senses the environment by receiving inputs from many sensors, and affects its surroundings by controlling lights, motors, and other actuators.

```
void setup() {
}

void loop() {
}
```

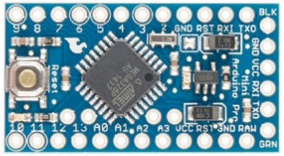
ARDUINO SOFTWARE

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



Low-cost microcontroller boards

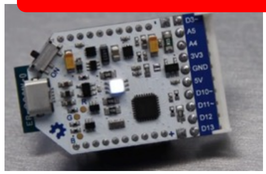
Arduino Pro Mini



LoPy

http://blog.atmel.com/2015/12/16/rewind-50-of-the-best-boards-from-2015/

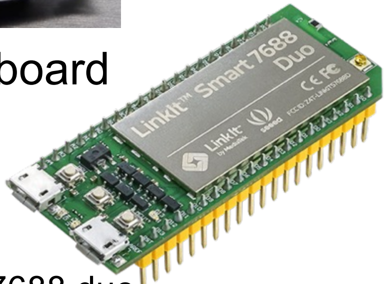
http://blog.atmel.com/2015/04/09/25-dev-boards-to-help-you-get-started-on-your-next-iot-project/



Theairboard

Expressif ESP32

Teensy 3.2

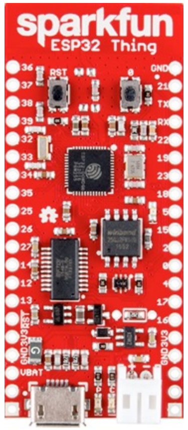


LinkIt Smart7688 duo

STM32 Nucleo-32

Heltec ESP32 + OLED

Adafruit Feather



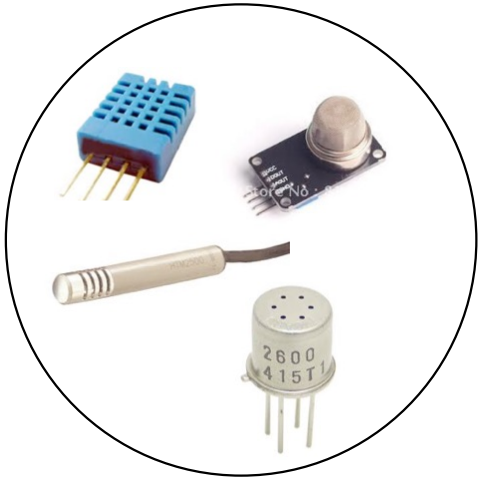
Sparkfun ESP32 Thing

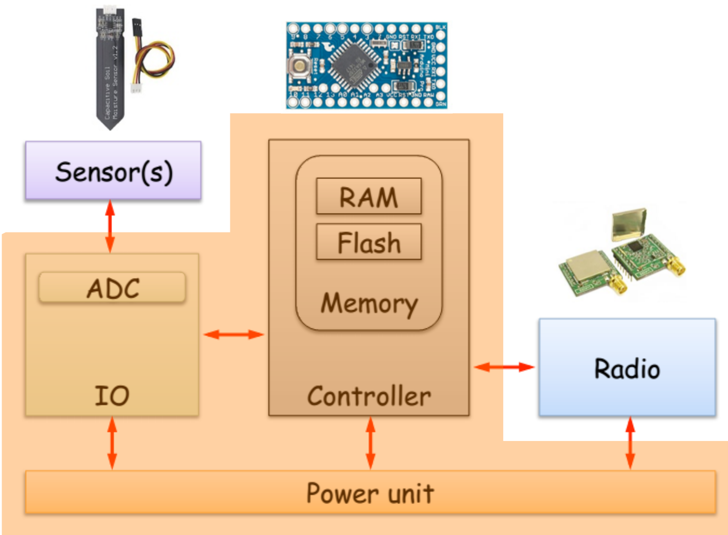
Tessel

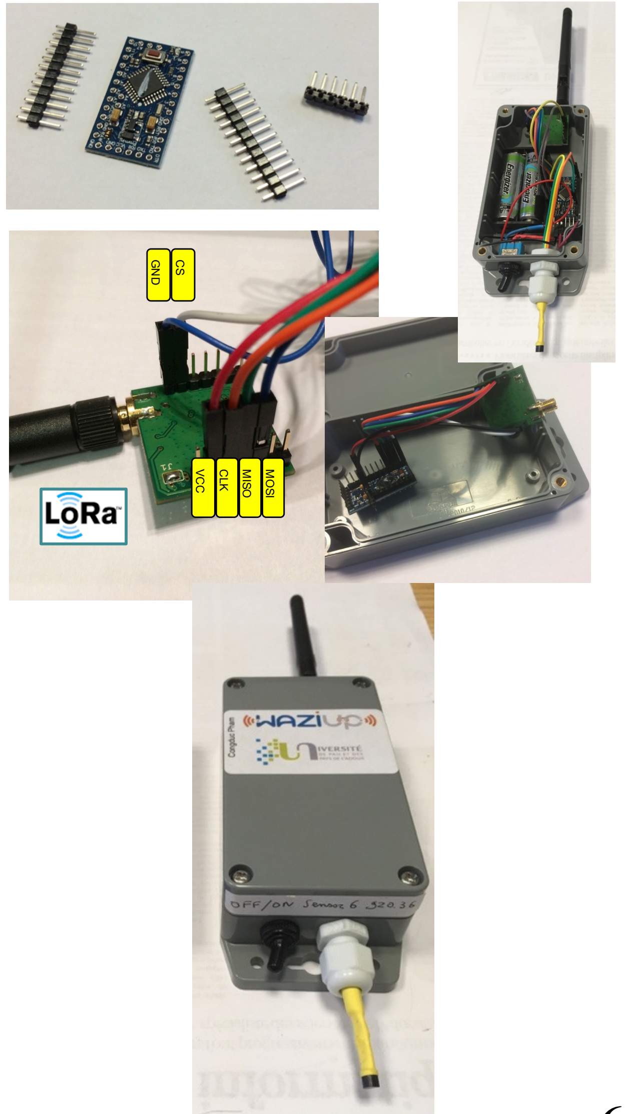
SodaqOnev2

Tinyduino

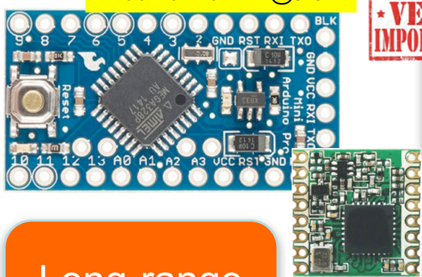
Do-It-Yourself IoT







Arduino Pro Mini @3.3V



Physical sensor mgmt

VERY IMPORTANT

Activity duty-cycle, low power

VERY IMPORTANT

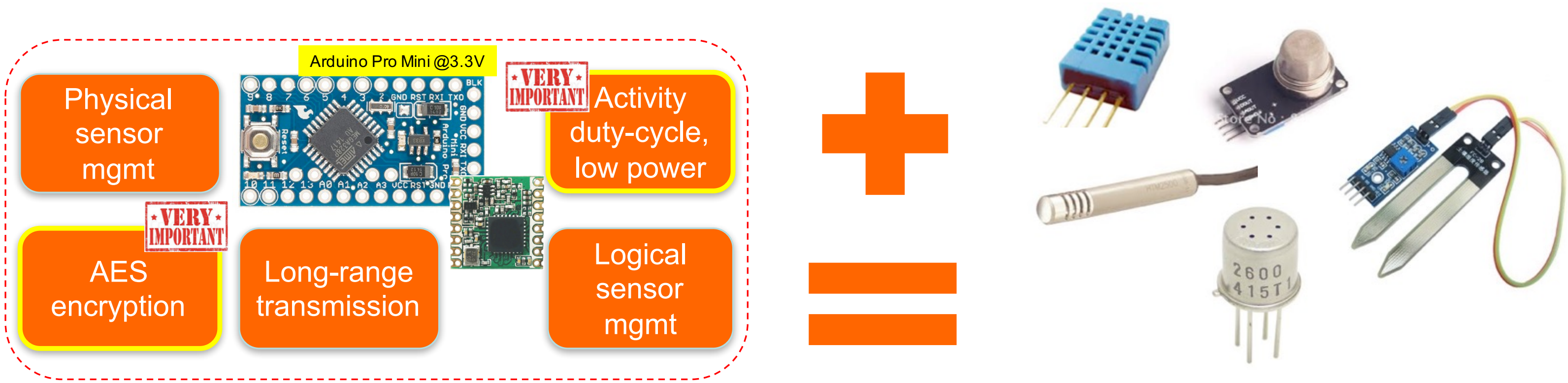
AES encryption

Long-range transmission

Logical sensor mgmt

Generic IoT v.s. highly specialized

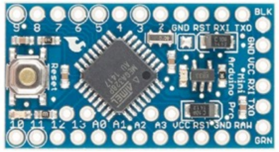
- Build low-cost, low-power, generic IoT platform
- Methodology for low-cost platform design
- Technology transfers to user communities, economic actors, stakeholders,…



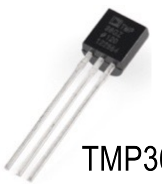
Prof. Congduc Pham
http://www.univ-pau.fr/~cpham

A simple temperature sensor example

Arduino Pro Mini @3.3V

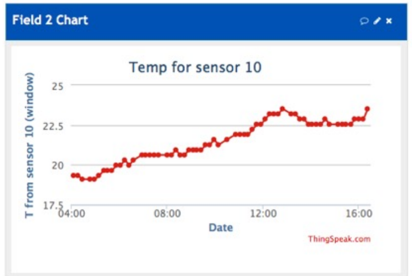


Modtronix inAir9



TMP36

Wakes-up every 10min, take a measure (temp) and send to gateway



5µA in deep sleep mode, about 40mA when active and sending

More than 1 year with 1 measure/10min

Can run several years with 1 measure/1h

Towards IoT vertical domain

PRIMA PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

Intel-IrriS June 2021 – May 2024

Intelligent Irrigation System for Low-cost Autonomous Water Control in Small-scale Agriculture

Dividing the cost by a factor of 10 to 100!

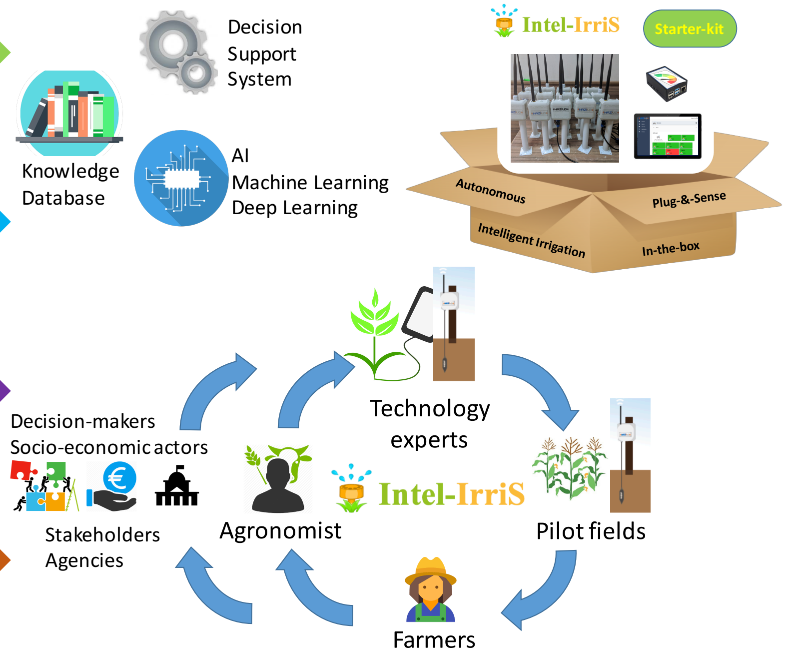
1 Propose low cost but highly efficient water control systems for irrigation optimization

2 Use cutting-edge technologies to propose highly innovative systems yet simple to deploy and adapted to smallholders

3 Seamless integration into existing irrigation system and/or local customs and practices

4 Improve farmer's knowledge on water-related issues, foster local adaptation of technologies, increase local innovation capacity and facilitate technology appropriation

5 Large-scale adoption of low cost smart irrigation system by smallholders, stimulating synergies between various local actors



Low-cost soil moisture device

A soil temperature sensor can be added

INTEL-IRRIS starter-kit

- "Intelligent Irrigation in-the-box", "plug-&-sense"
- From idea to reality!

Conclusions

- 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,… will provide possibilities to further optimize a number of complex processes

Now what?

IOT_2: Unleash the power of IoT data !

So, IoT: Technology or Concept?

IOT_1: Understanding Internet-of-Thing technologies

Booster Pau – Learning Capsule – 2021

Prof. Congduc Pham
http://www.univ-pau.fr/~cpham
Université de Pau, France

IoT – from idea to reality