ZigBee

One among many: a wireless enabling technology for the IoT world

28th May 2020

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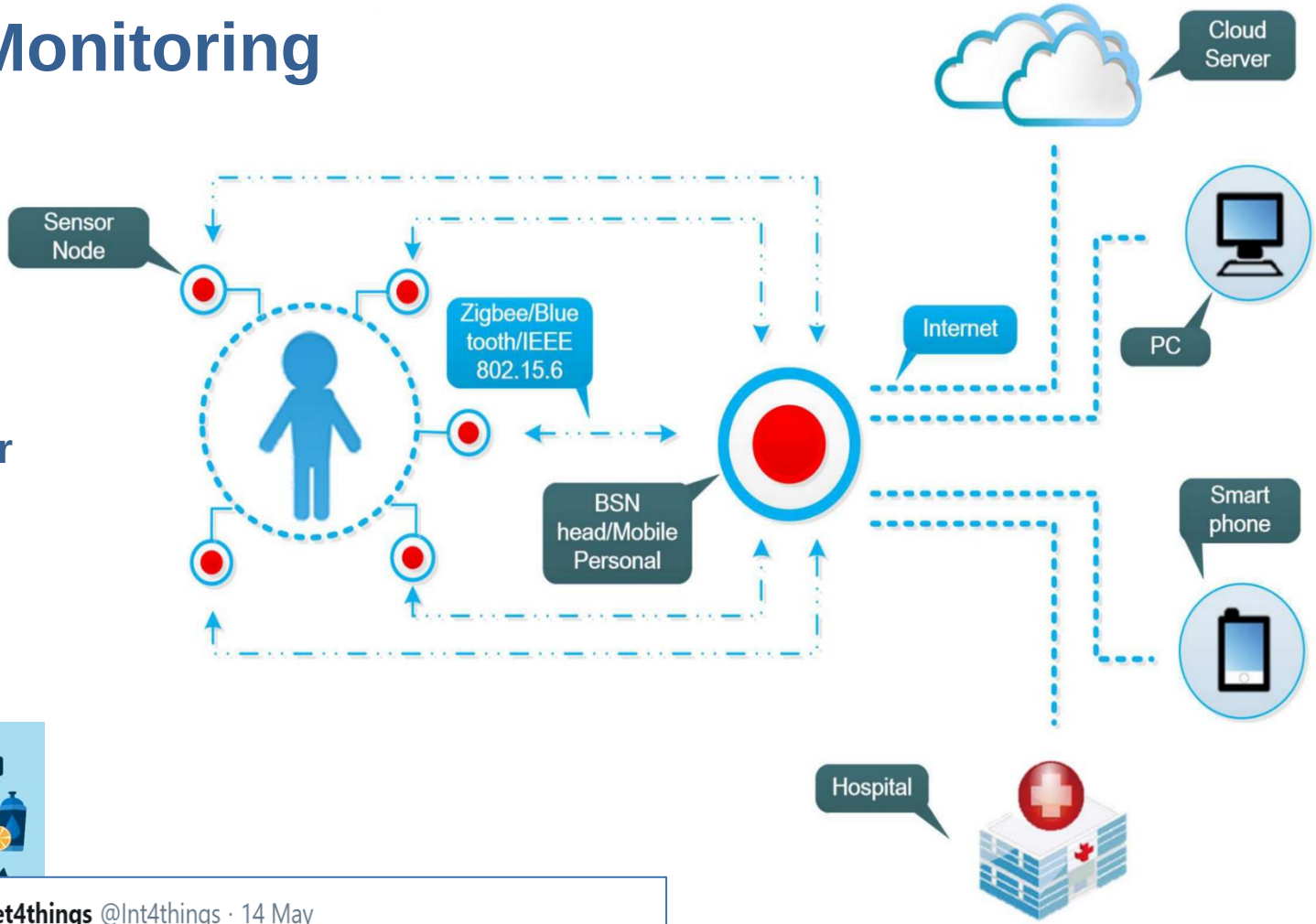
Outline

1. **IoT ecosystem – A brief overview**
2. **Wireless Technologies – Which one?**
3. **Wireless Sensor Networks – Main features**
4. **Requirements – Through the protocol stack**
5. **To sum up – A very «practical» example of WSN**

1. IoT ecosystem – A brief overview

Smart Health Monitoring

EEG Sensor
ECG Sensor
Pressure Sensor
Temperature Sensor
Inertial Sensor
Blood saturation sensor
Blood pressure sensor
…



Internet4things @Int4things · 14 May
La telemedicina, grazie all'utilizzo di sensori biometrici e dispositivi indossabili, si diffonde sempre più rapidamente nell'emergenza #Covid19: alcuni casi italiani.

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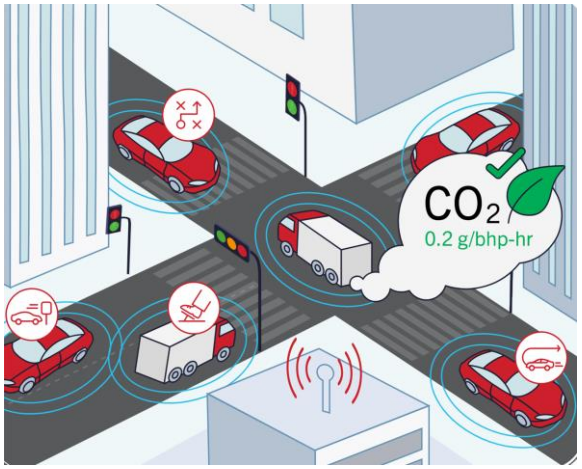
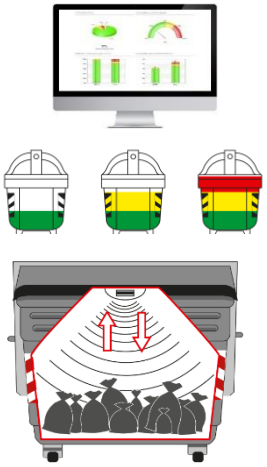
Smart Cities





CO_2 sensor
Fill-level sensor
Luminosity level sensor
Flow traffic sensor
…

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Smart Manufacturing
Environmental Monitoring
Smart Agricolture
Smart Farming/Animal Tracking
Smart Building
…

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Market data and forecast future IoT trends

Sensors offer their **detection capabilities** to the Big Network

- To **modify**, **adapt**, **prevent**, **predict**, whatever kind of process within our ecosystem
- Leading to: **new services**, new value for the user, **companies transformation**, (**constructive**) **competition** among **verticals**

«How Smart, Connected Products Are Transforming Companies»
(Harward Business Review HBR, 2015)

«How Smart, Connected Products Are Transforming Competition»
(Harward Business Review HBR, 2014)

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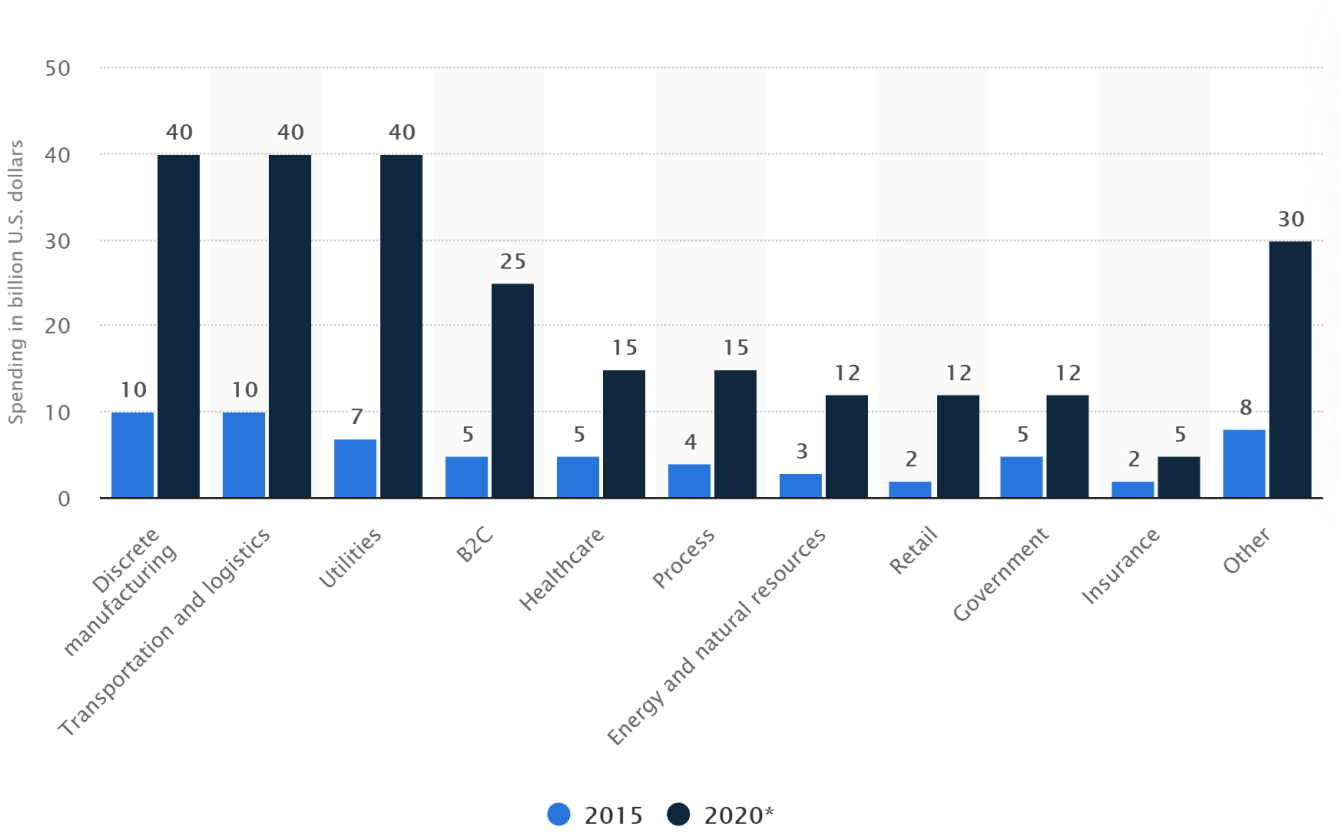
Market data and forecast future IoT trends



Spending on Internet of Things worldwide by vertical in 2015 and 2020

(Statista, March 2020)

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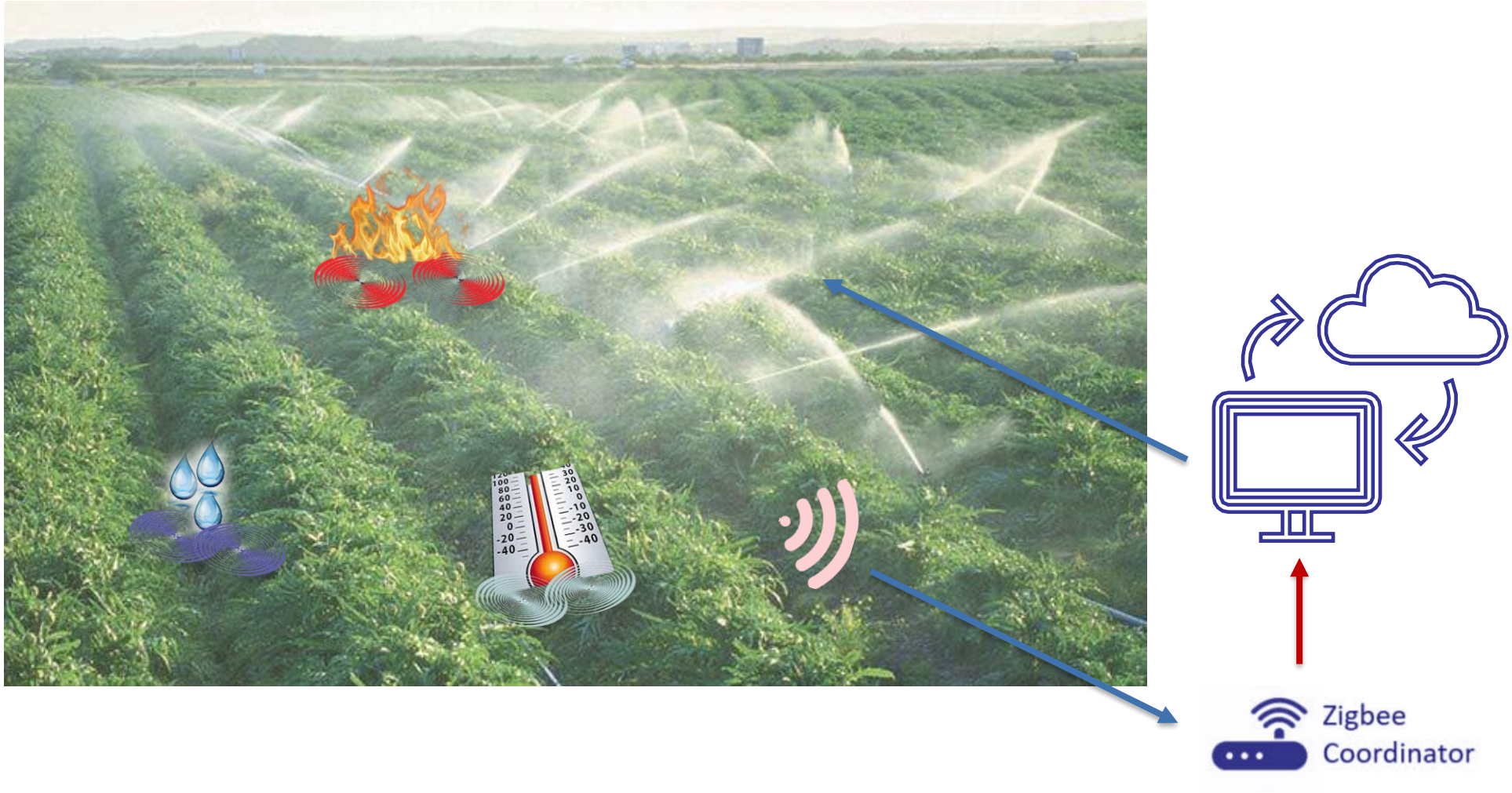
Use case



Two key aspects

Coordination

Wireless Sensor Network

Common set of rules

Wireless Technology

Wireless Sensor Network based on
***IEEE* 802.15.4/ZigBee**

2. Wireless Technologies – Which one?

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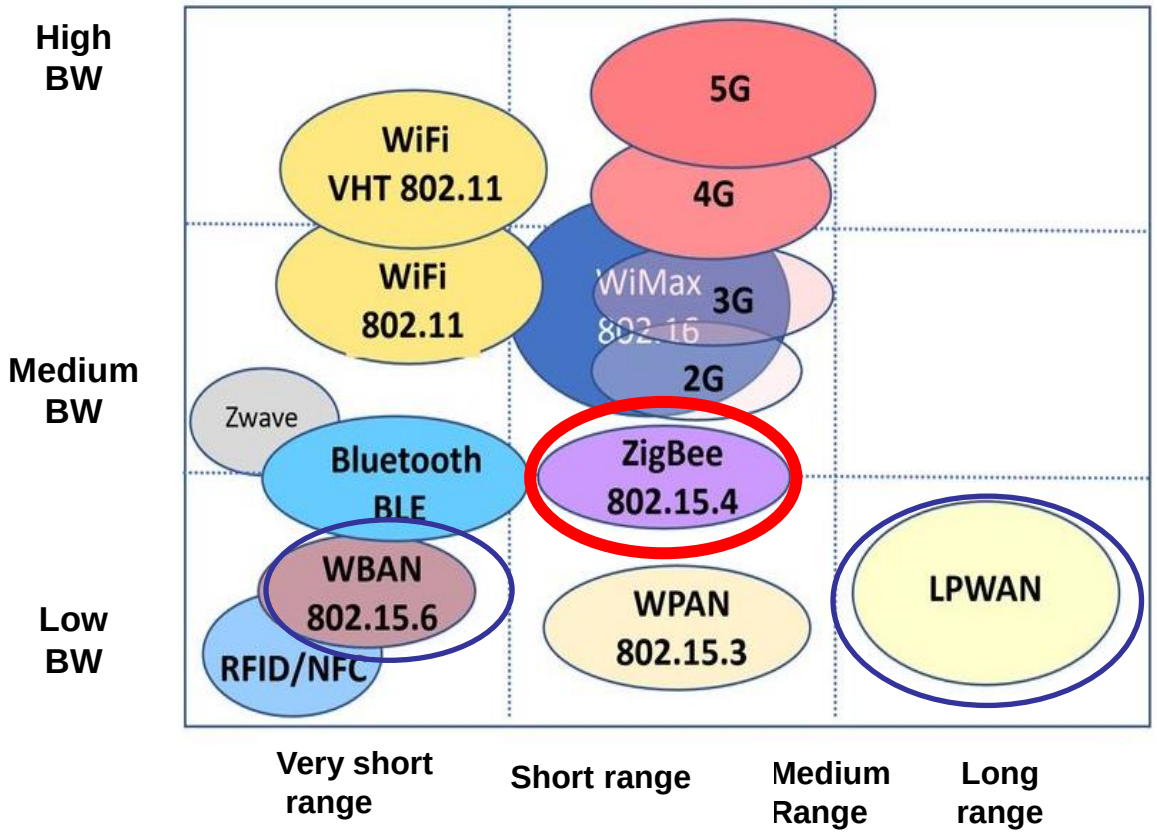
Standard solutions for wireless networks



IEEE 802.15.4/ZigBee

Low/Medium Bandwith
Bc= 5 MHz Bit Rate = 250Kbit/sec

Short range
Outdoor < 100 m (LoS)
Drastical decrease indoor → *Multi-Hoping* is needed !

Short range < 100 m
Very Short Range (typically) < few m

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Standard solutions for IoT

- **Heterogenous** set of requirements for IoT applications
- **Standardization** of new wireless solutions

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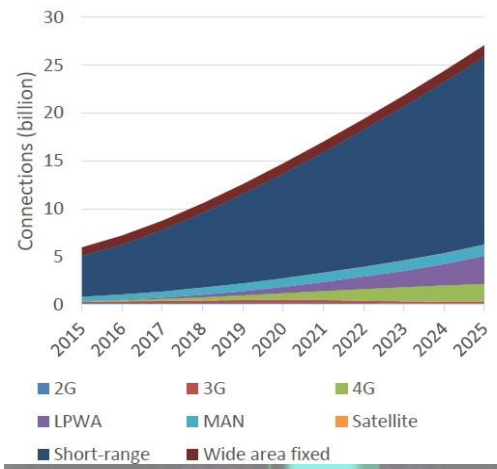
Standard solutions for IoT

- **Heterogenous** set of requirements for IoT applications
- **Standardization** of new wireless solutions
- Tipically **Low Data Rate** & **Short Range**

Short-range technologies will dominate IoT

Global IoT connections 2015-2025 by technology
Source: Machina Research 2016



- **72% of connections in 2025 will be short range (e.g. in-building PLC, WiFi, Zigbee, Z-Wave), up from 71% at the end of 2015**
- **Cellular accounts for 2.2 billion connections in 2025, an increase from 334 million at end of 2015**
  - By 2025 3G takes 7% and 4G/LTE 88%, driven by higher bandwidth requirements and need for future-proofing
- **11% of connections in 2025 will be LPWA, driven by the simplicity of deployment**

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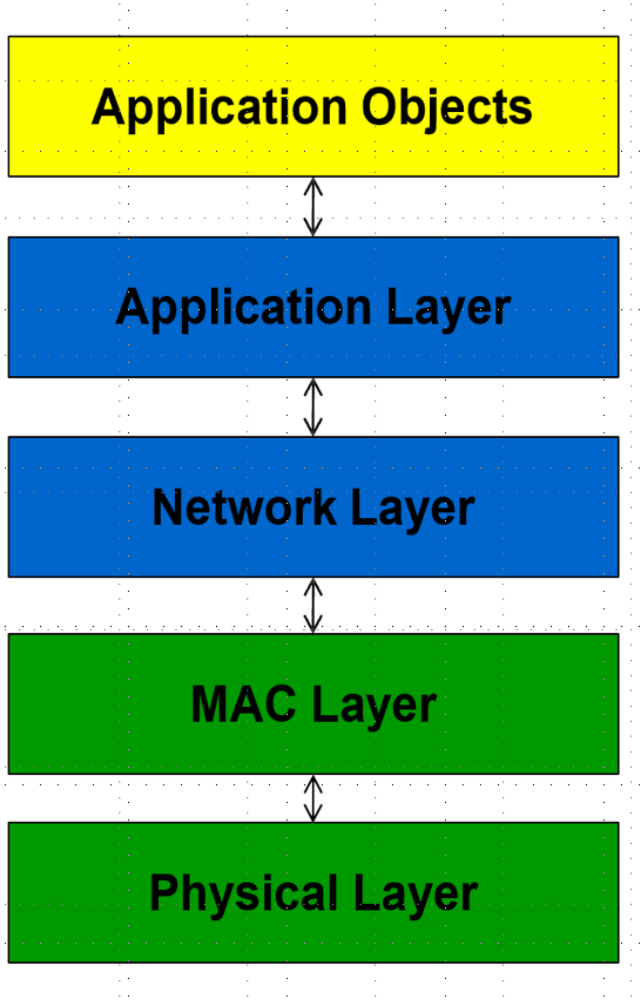
Protocol stack architecture

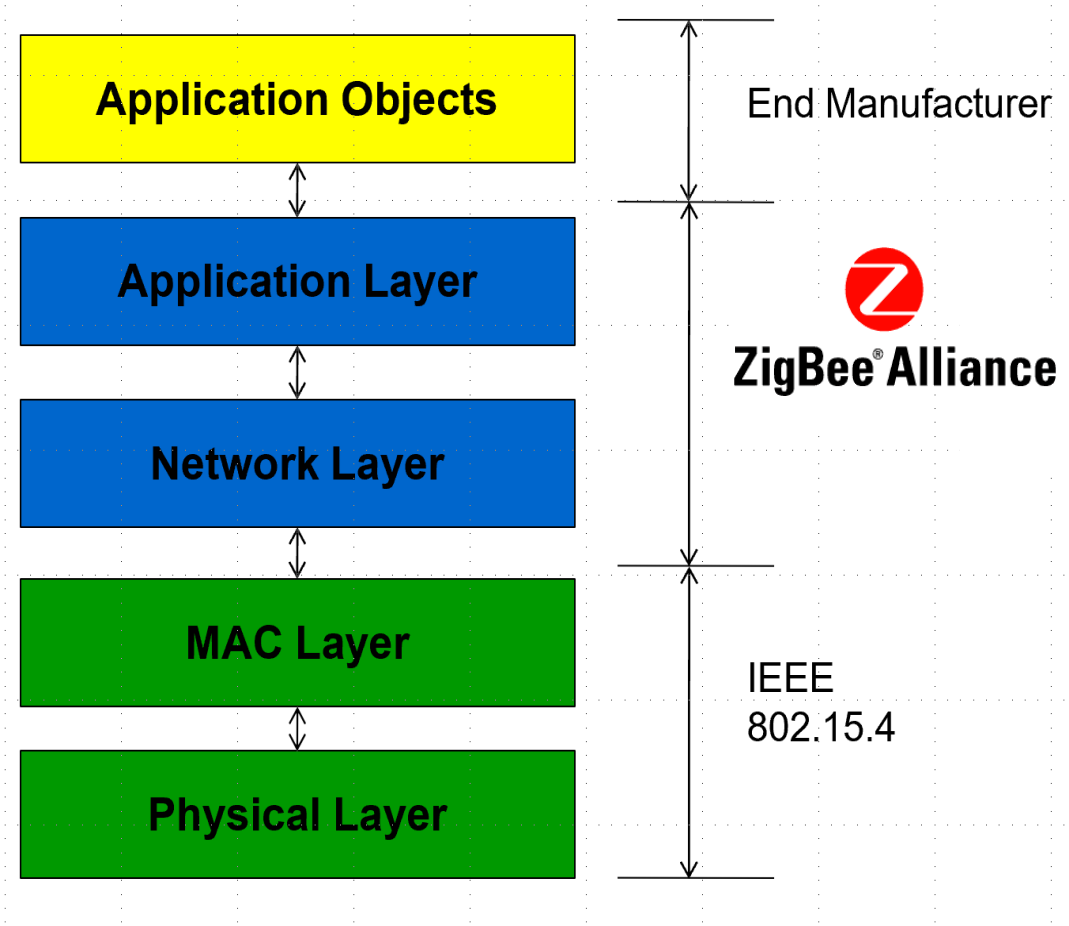
- All the set of **functionalities** performed by a node is **organized in layers**
- Each layer performs tasks in **agreement** with the **corresponding layer** at the **receiver side** according to **communication protocol**
- The **ensemble** of all the communication protocols defines a **protocol stack**



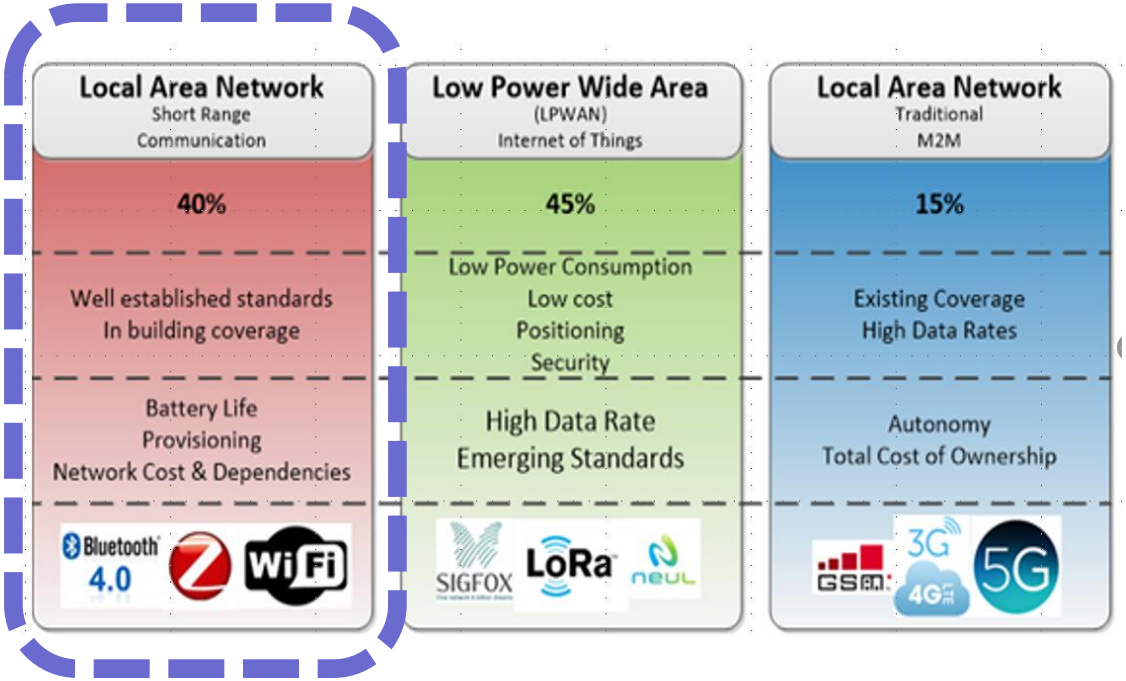
Protocol stack architecture – IEEE 802.15.4/ZigBee

IEEE 802.15.4

- Defines the **PHY** and **MAC** layers protocols
- Standard *de-facto* for **WSNs**



IEEE 802.15.4 – Main features

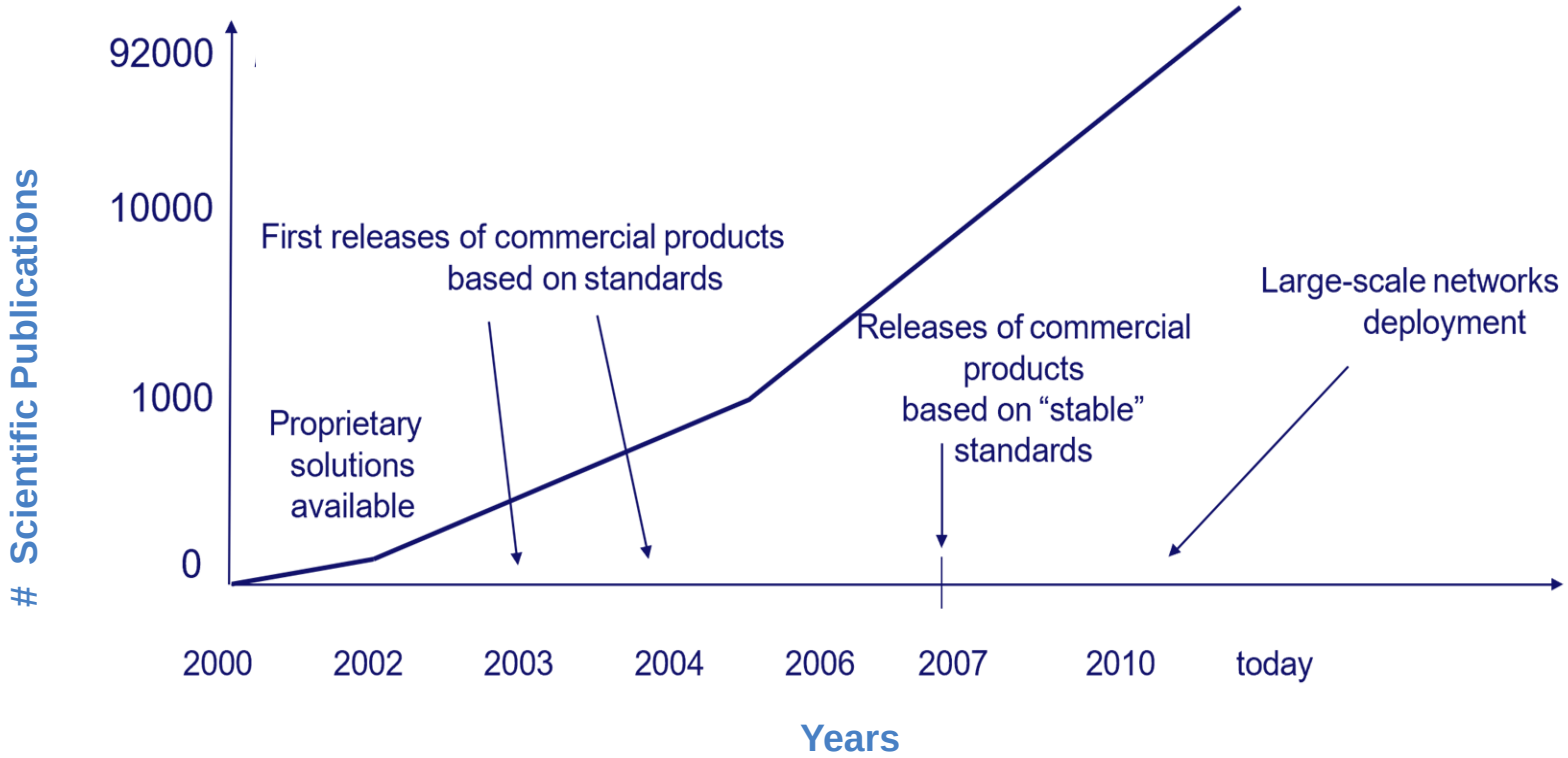


IEEE 802.15.4

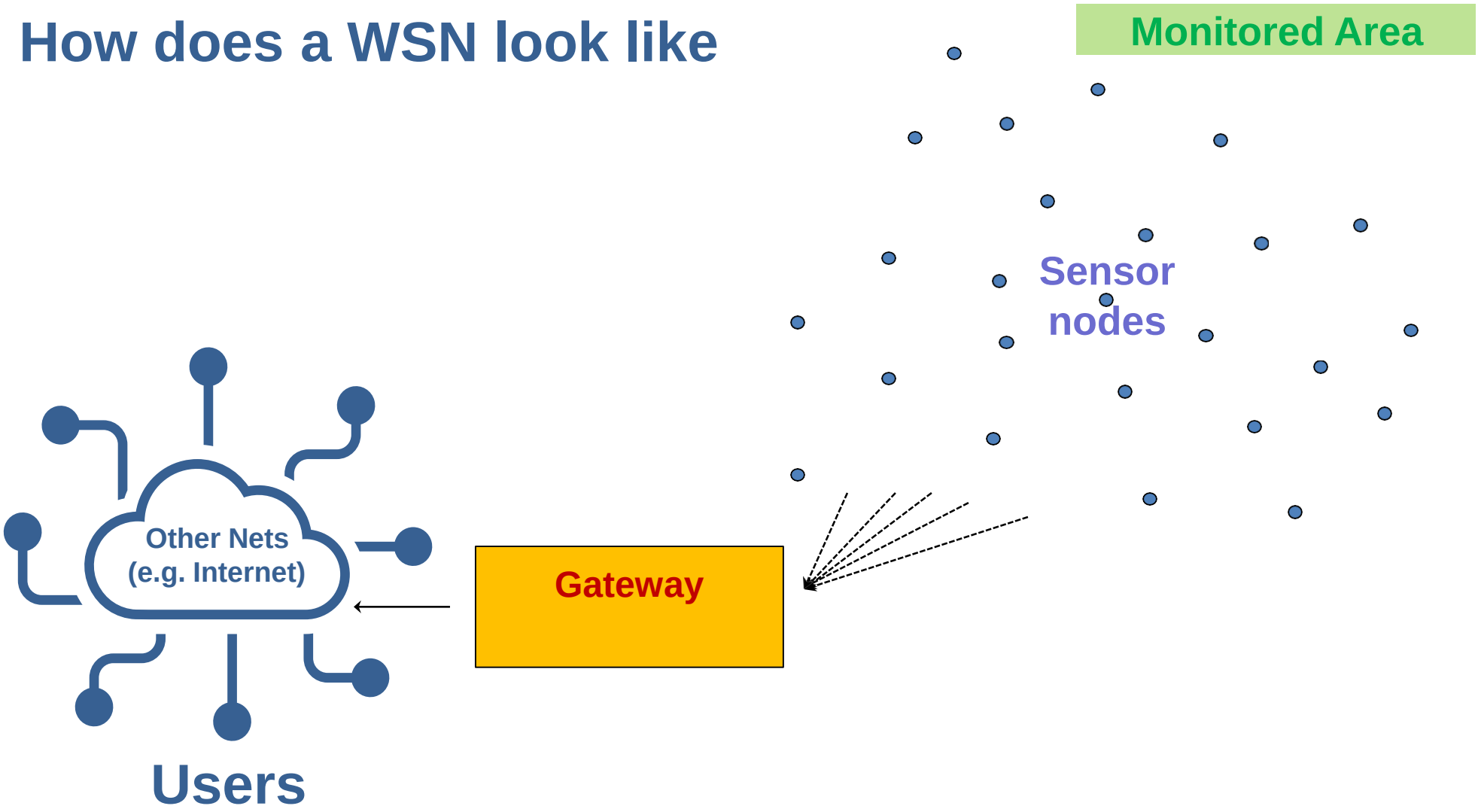
- Defines the **PHY** and **MAC** layers protocols
- Standard *de-facto* for WSNs
- Thought for **low-cost**, **low-rate**, **low-power consumption** wireless communications
- Used for Low Rate W-PAN composed of **battery charged** devices

3. Wireless Sensor Networks – Main features

Wireless Sensors Networks – *State of Art*



How does a WSN look like



Wireless Sensor Networks – Definition

A Wireless Sensor Network (WSN) in its simplest form can be defined as a network of (possibly low-size and low-complex) devices denoted as ***nodes*** *that* ***can sense*** *the* ***environment*** *and* ***communicate*** *the information gathered from the monitored field through* ***wireless*** *links to a* ***gateway****, connected to other networks (e.g. Internet)*

I.F. Akyildiz, Su Weilian, Y. Sankarasubramaniam, E. Cayirci, "A survey on sensor networks,". Communications Magazine, IEEE, vol.40, no.8, pp.102,114, Aug 2002

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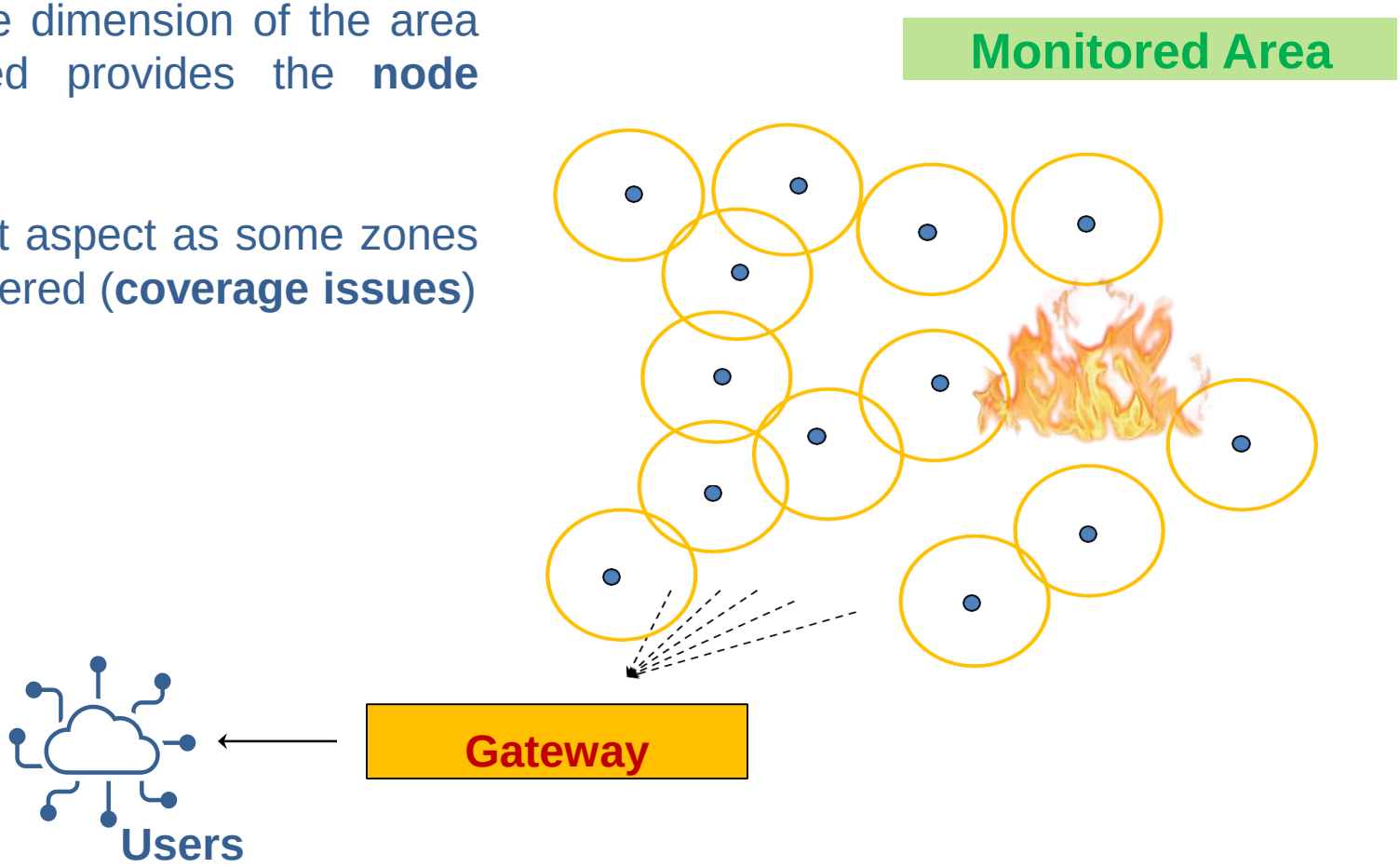
WSNs – 5 key aspects

- Coverage
- Connectivity
- Energy Efficiency
- Self-Organization
- Scalability

Coverage

- The knowledge of the **sensing range** together with the dimension of the area to be monitored provides the **node density**
- It is an important aspect as some zones might be not covered (**coverage issues**)



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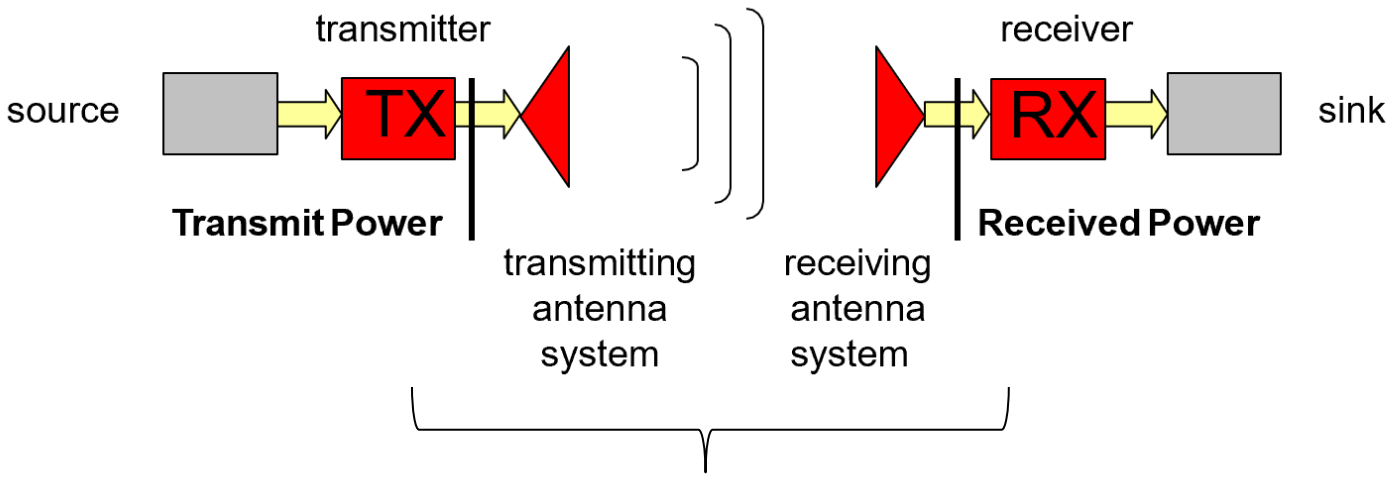
Connectivity

Compliant 802.15.4	Clock	Flash	RAM	Receiver Sensitivity	RF Power Min	RF Power Max	Cost	Country
YES	40 MHz	128K	96K	-96 dBm	-30 dBm	+4 dBm	$ 150	USA

Reference values of a *freescale* device

The **receiver sensitivity** is the lowest power level at which the receiver can detect an RF signal and demodulate it



Power Loss through the **Radio Channel**

Connectivity

Compliant 802.15.4	Clock	Flash	RAM	Receiver Sensitivity	RF Power Min	RF Power Max	Cost	Country
YES	40 MHz	128K	96K	-96 dBm	-30 dBm	+4 dBm	$ 150	USA

Reference values of a *freescale* device

Power Loss [dB] **=** Tx Power [dBm] – Receiver Sensitivity [dBm]

Max. Loss [dB] **=** Max. Tx Power [dBm] – Receiver Sensitivity [dBm]

freescale → **Max. Loss** [dB] = 4 [dBm] - (-96) [dBm] = 100 [dB]

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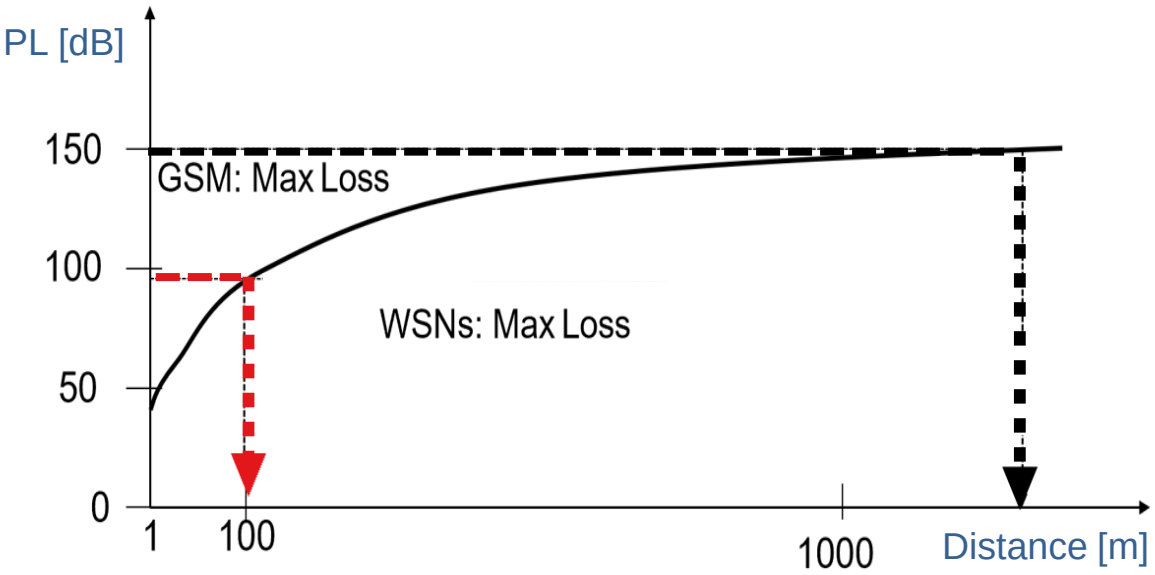
Transmission Range



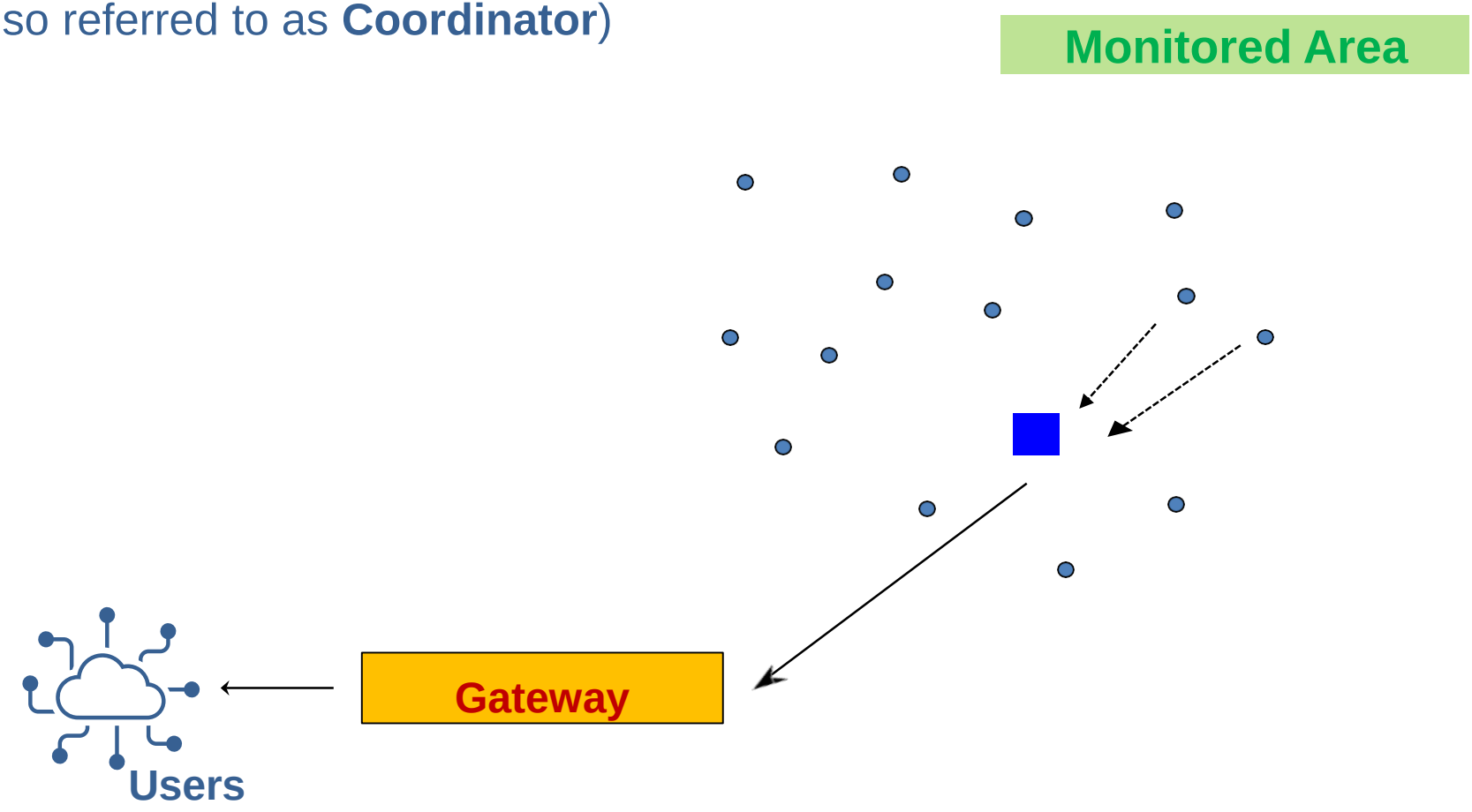
- The **maximum transmission range** is the maximum distance at which two nodes can **communicate**
- From the PL [dB] → **Max. Transmission Range**
- The curve holds in **LoS** Conditions (Outdoor)

freescale →
Max. Loss [dB] = 4 [dBm] - (-96) [dBm] = 100 [dB]
Max Transmission range ≈ 100 m (Outdoor!)

The transmission range plays a crucial role in the design of a WSN

WSN – Single Sink

- Sensor nodes
- **Sink** (also referred to as **Coordinator**)



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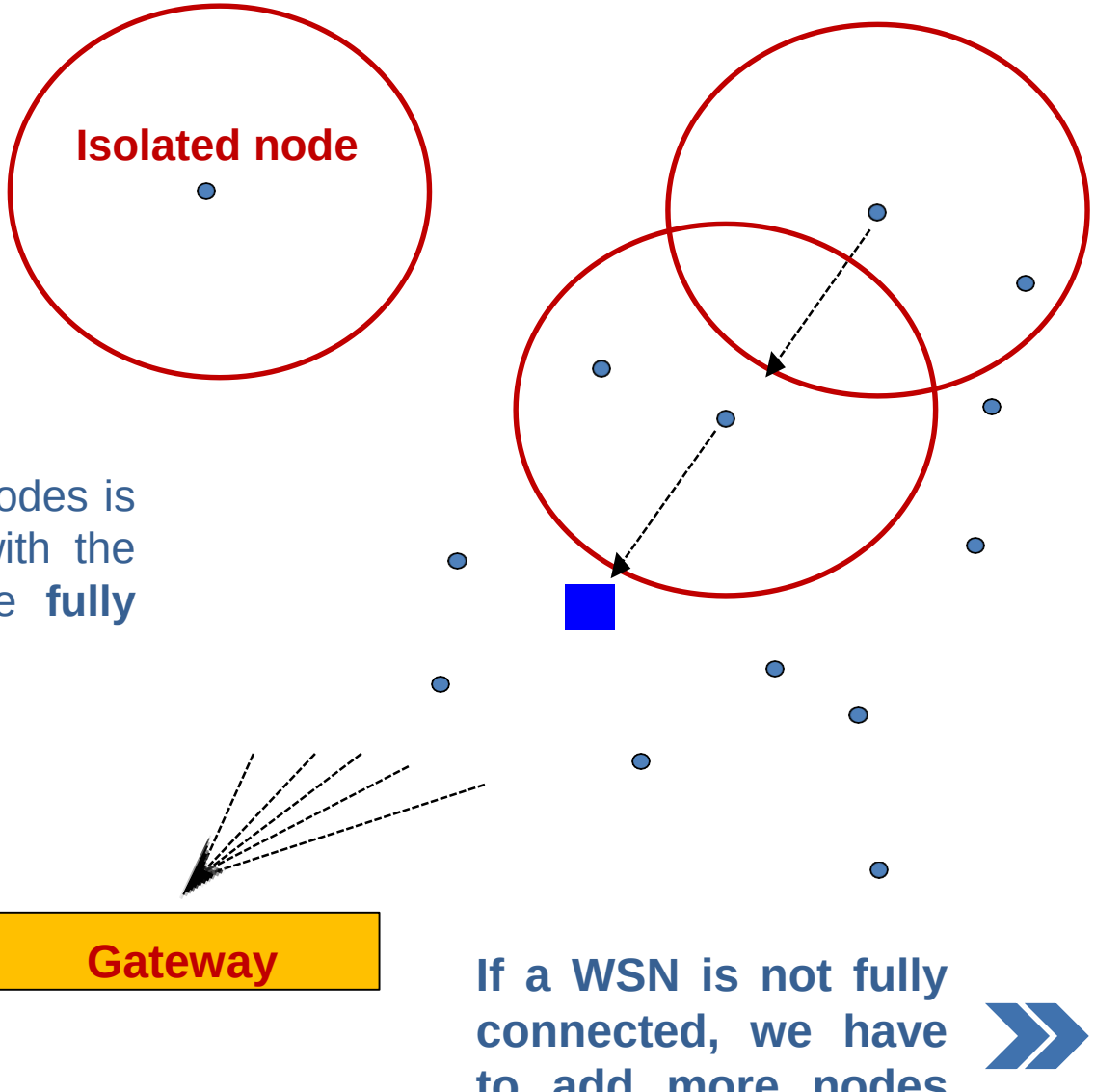
Fully Connectivity

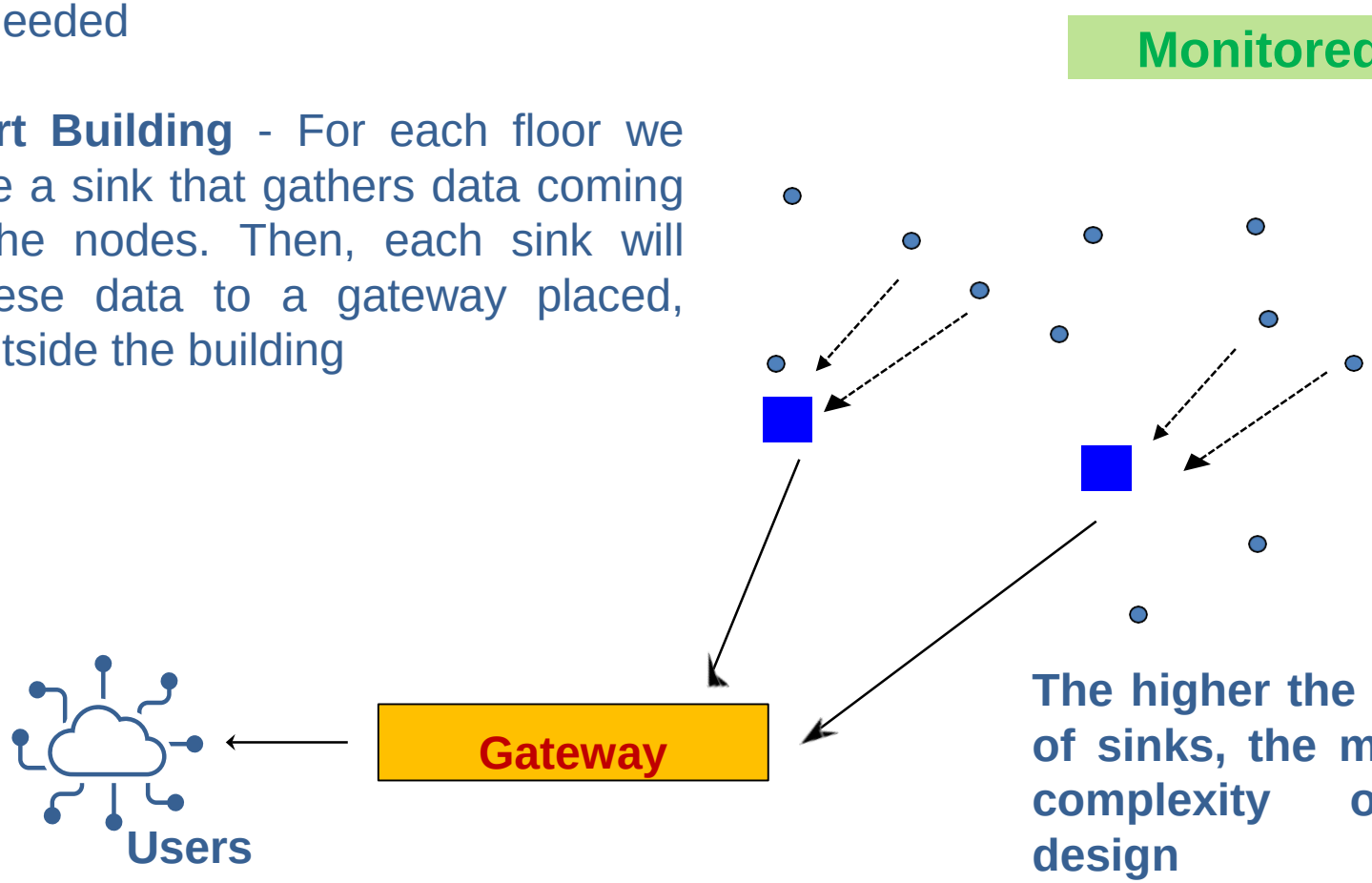
- **Connectivity** and **transmission range** are strictly related
- If the transmission range of all the nodes is such that they can communicate with the sink, then the WSN is said to be **fully connected**



If a WSN is not fully connected, we have to add more nodes or sinks !

WSN – Multiple sinks

- In some situations more than a single sink might be needed
- **E.g. Smart Building** - For each floor we could have a sink that gathers data coming from all the nodes. Then, each sink will deliver these data to a gateway placed, maybe, outside the building



The higher the number of sinks, the more the complexity of the design

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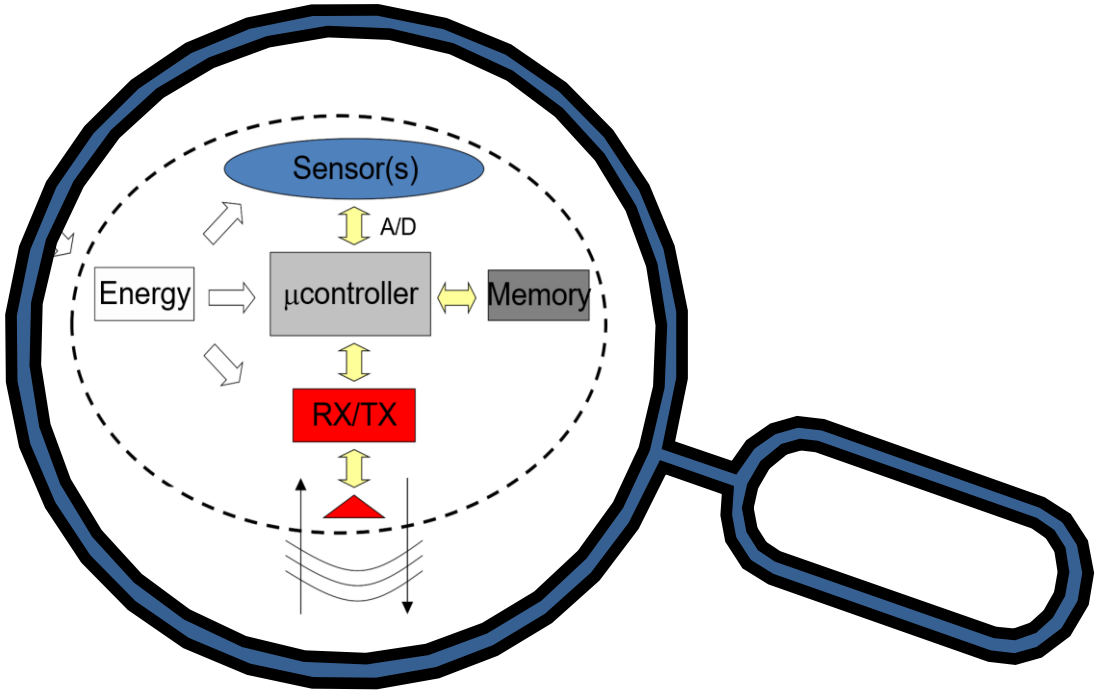
Elements of a node

- Sensor
- Transceiver
- Microcontroller
- Memory

» All these parts are responsible of **energy consumption**



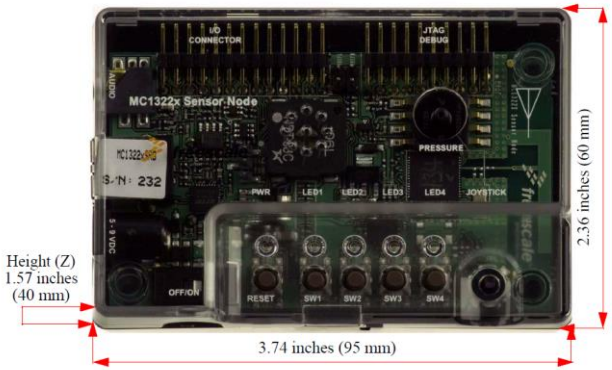


Figure 2-1. 1322x Sensor Node

1322x Sensor Node Reference Manual, Rev. 1.5

Freescale Semiconductor 2-1

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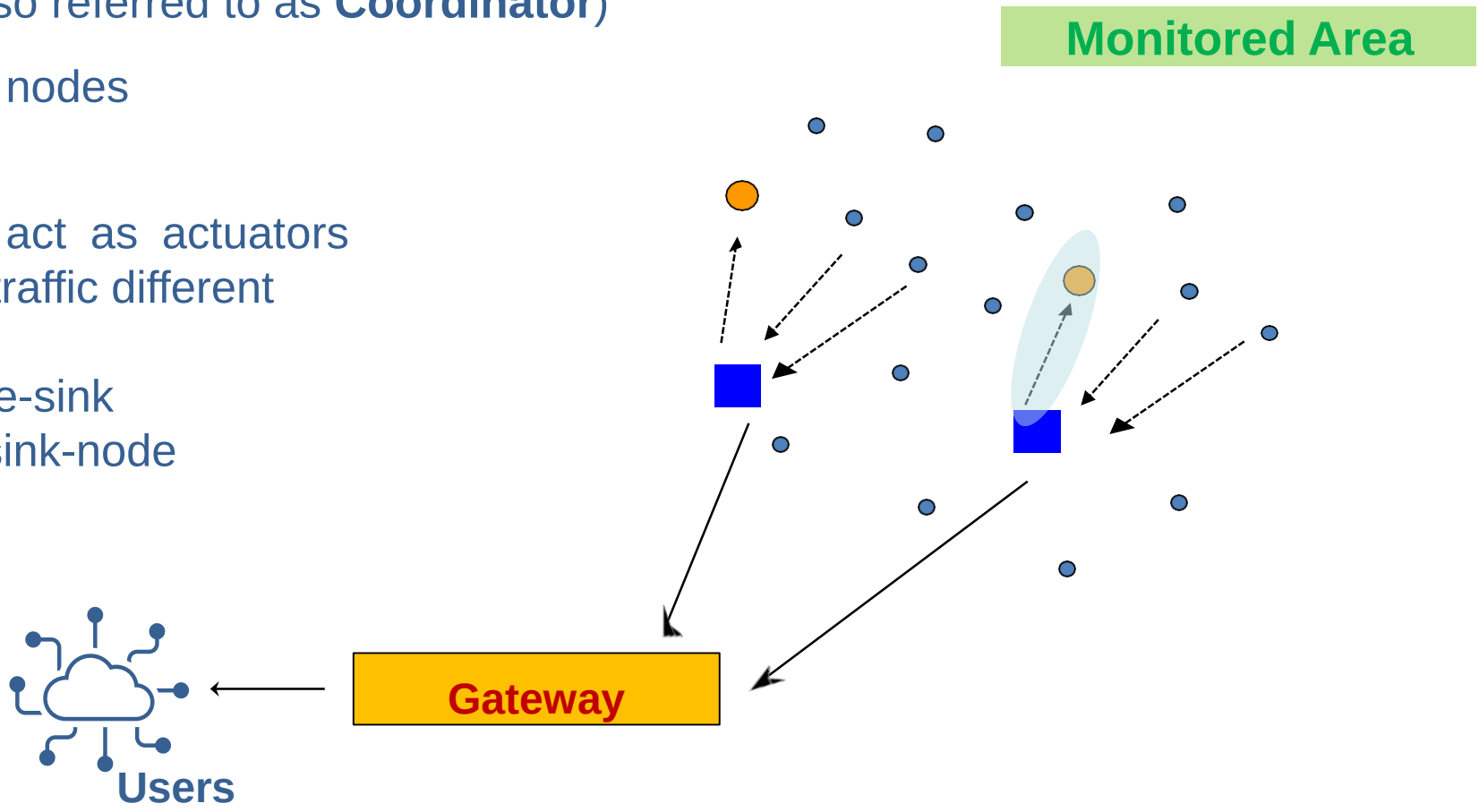
WSNs with actuators

- Sensor nodes
- **Sink** (also referred to as **Coordinator**)
- Actuator nodes

Nodes can act as actuators making the traffic different

Uplink: node-sink
Downlink: sink-node



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Energy Efficiency

- Nodes *generally* cost few money, have low sizes as well as a **low energy consumption → Network lifetime** is a typical requirement in WSNs.

- Understanding ***where*** and ***when*** a node consumes energy is crucial in order to let the network live as much as possible.

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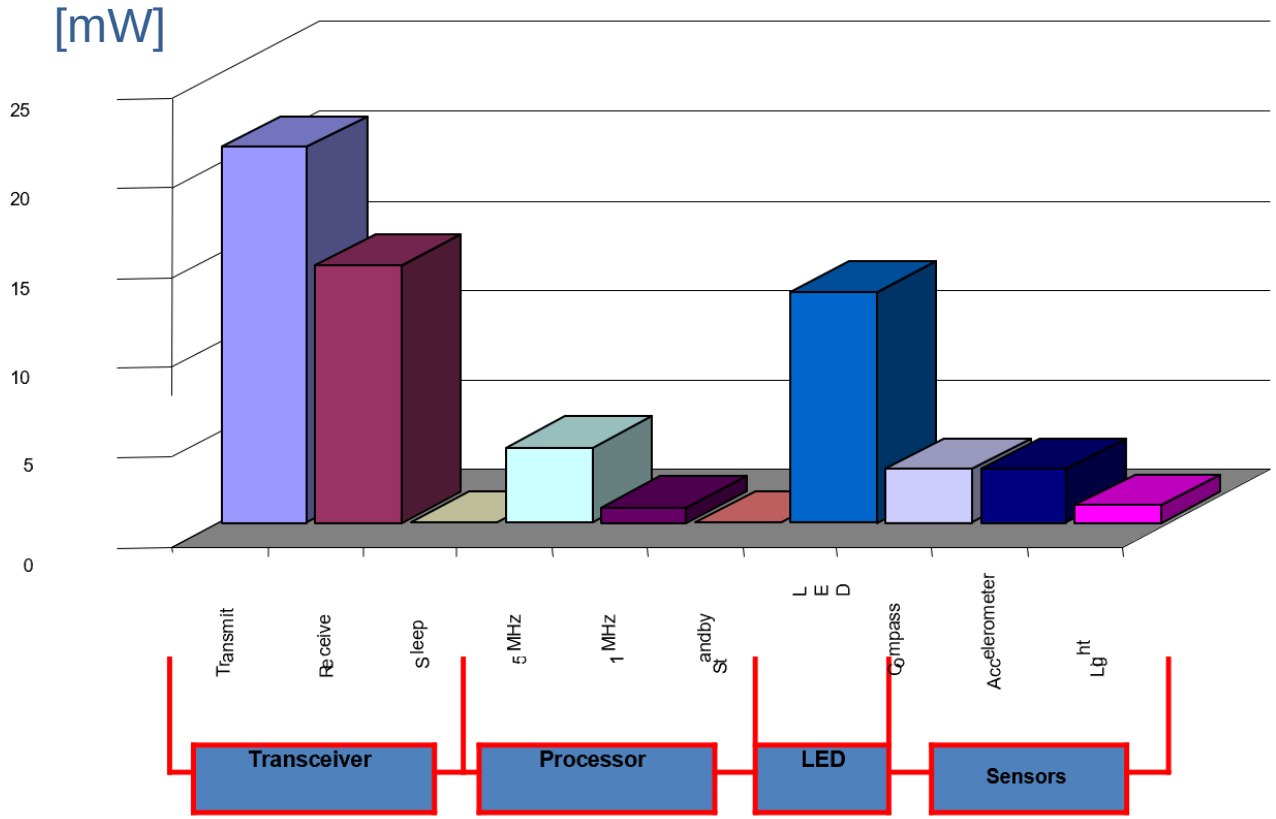
Where does the energy is spent?

Power consumption [mW]



Generally **nodes** are **battery charged** while **sink** might need to be **plugged-in**, as it receives data from the sensors of the **entire networks**

The transceiver is the most energy consuming!

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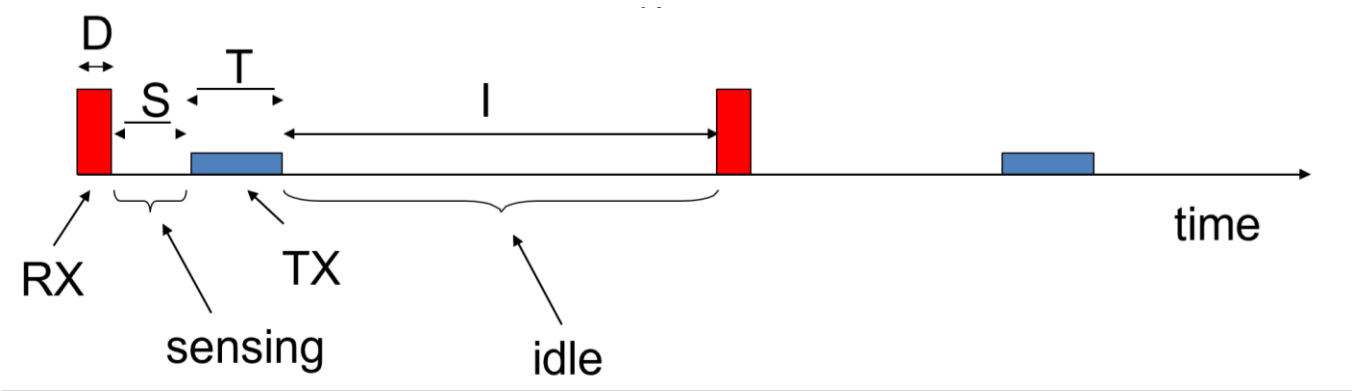
When does the energy is spent?



Round duration

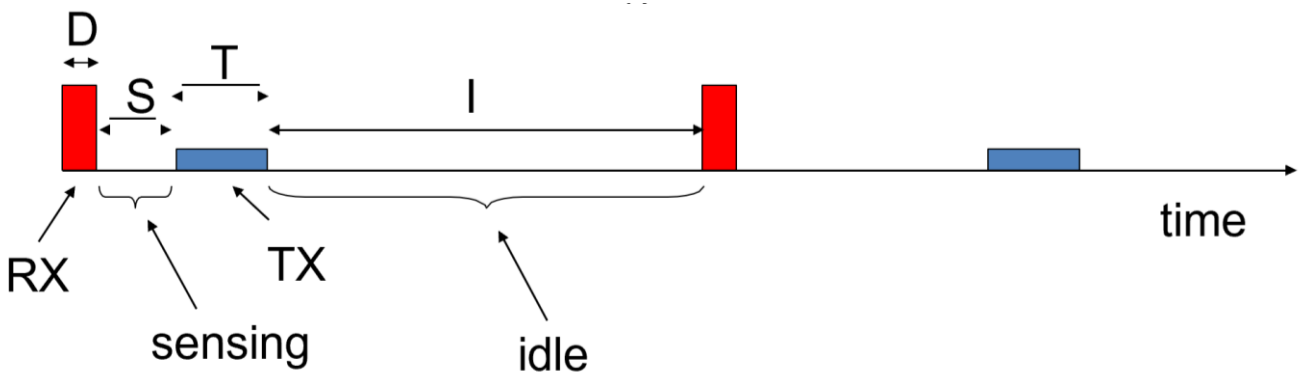
$T_R = D + S + T + I$

Energy spent / Round

$E_R = P_{rec} * D + P_{sens} * S + P_{trasm} * T + P_{idle} * I$ [Joule/round]

- **Reception mode**: the node receives the indication (*query*) to take measures by the sink
- **Sensing**: the node performs measures
- **Transmitting mode**: the node sends the data to the sink
- **Idle state**: the node can switch-off the TX/RX waiting for the next query

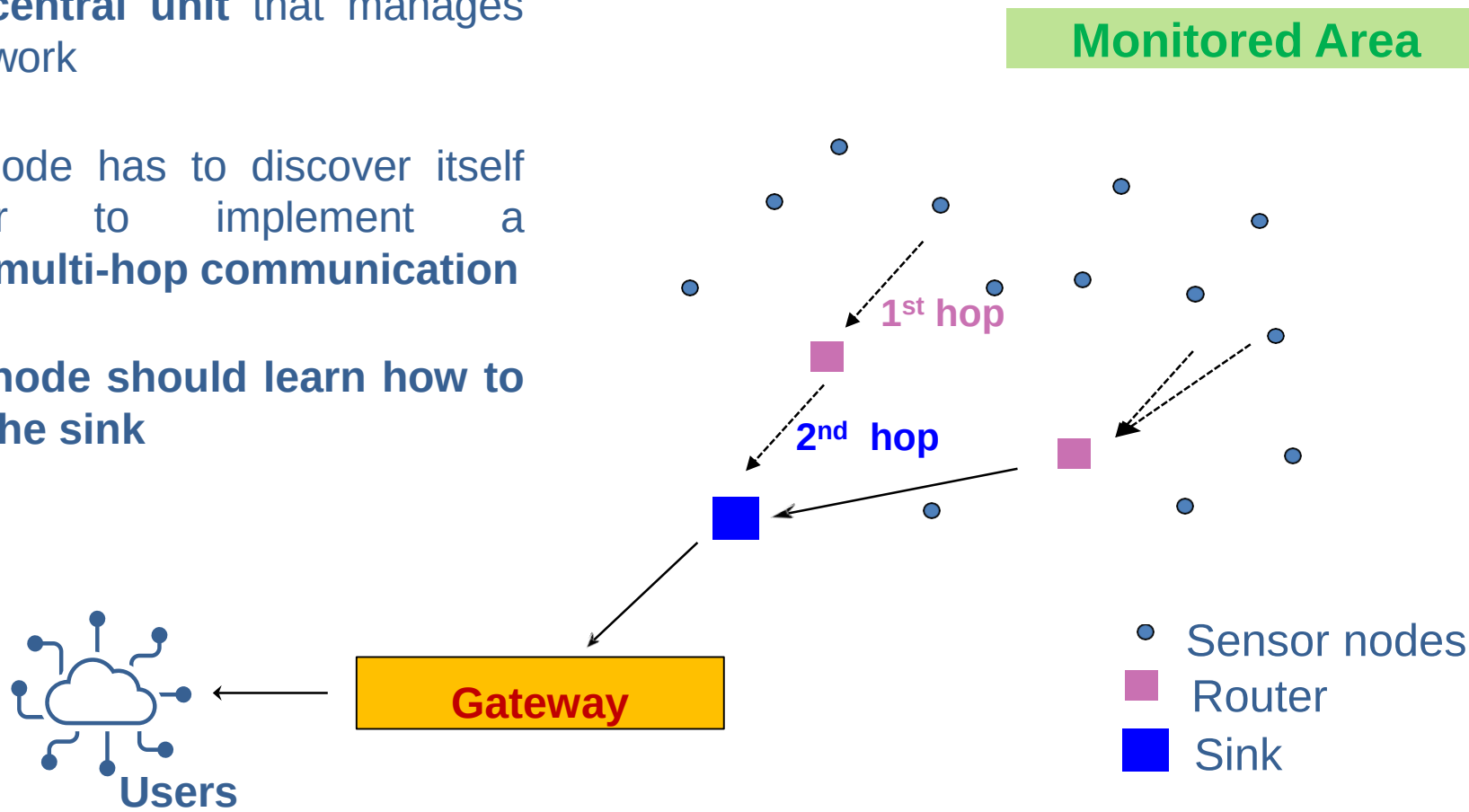
Energy Efficiency



- All phases of the **communication protocol** must be designed to minimise **energy consumption**
- Nodes must **turn off** during inactive periods

Self- Organization

- **None central unit** that manages the network
- Each node has to discover itself whether to implement a **single/multi-hop communication**
- **Every node should learn how to reach the sink**



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Scalability

In many applications the **number of nodes** can be very large as well as the **kind of requirements** to be satisfied (as we will see).

As a consequence, all **protocols** must be:

- Able to work **whatever the number of nodes** within the network
- Very **flexible** and **adaptive** to the different user **requirements**

4. Requirements – Through the protocol stack

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Type of reporting

Event Detection ❯ Req.s on delay

- Probability of false alarm
- Probability of missed detection
- Localization precision
- **Latency**
- **Network lifetime**

Estimation of spatial (and temporal) random processes ❯ Req.s on data losses

- ***Sampling frequency** has to ensure that the process evolution is tracked
- **Network lifetime**

***Sampling frequence**: in this context it refers to the periodicity with which a sensor takes samples (→ related to the **Round duration**)

Requirements – final considerations

- The **wide range of requirements** in terms of node densities, sampling frequencies, latency, network lifetime (energy consumption), etc, makes the design of WSNs extremely **application-dependent**.
- In the design of a WSN, we have to start from the requirements that come from the applications**,** thus the starting point is the **application layer**.

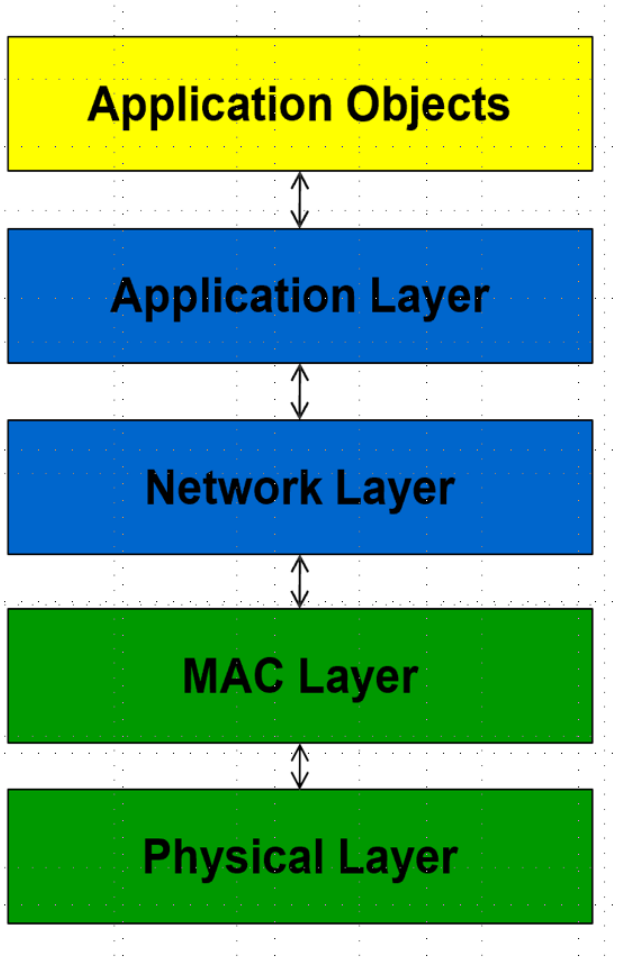
Layers' tasks

Here, bits coming from the sensor are passed to the µprocessor → **data aggragation, security issues**

It finds the **path** to reach the **final destination → forwarding, routing**

Reliable point-to-point communication → **error handling**, **access to the channel** (interference issues), …

Transceiver activation; modulation; amplification; antenna connection



5. To sum up – A very «practical» example of WSN

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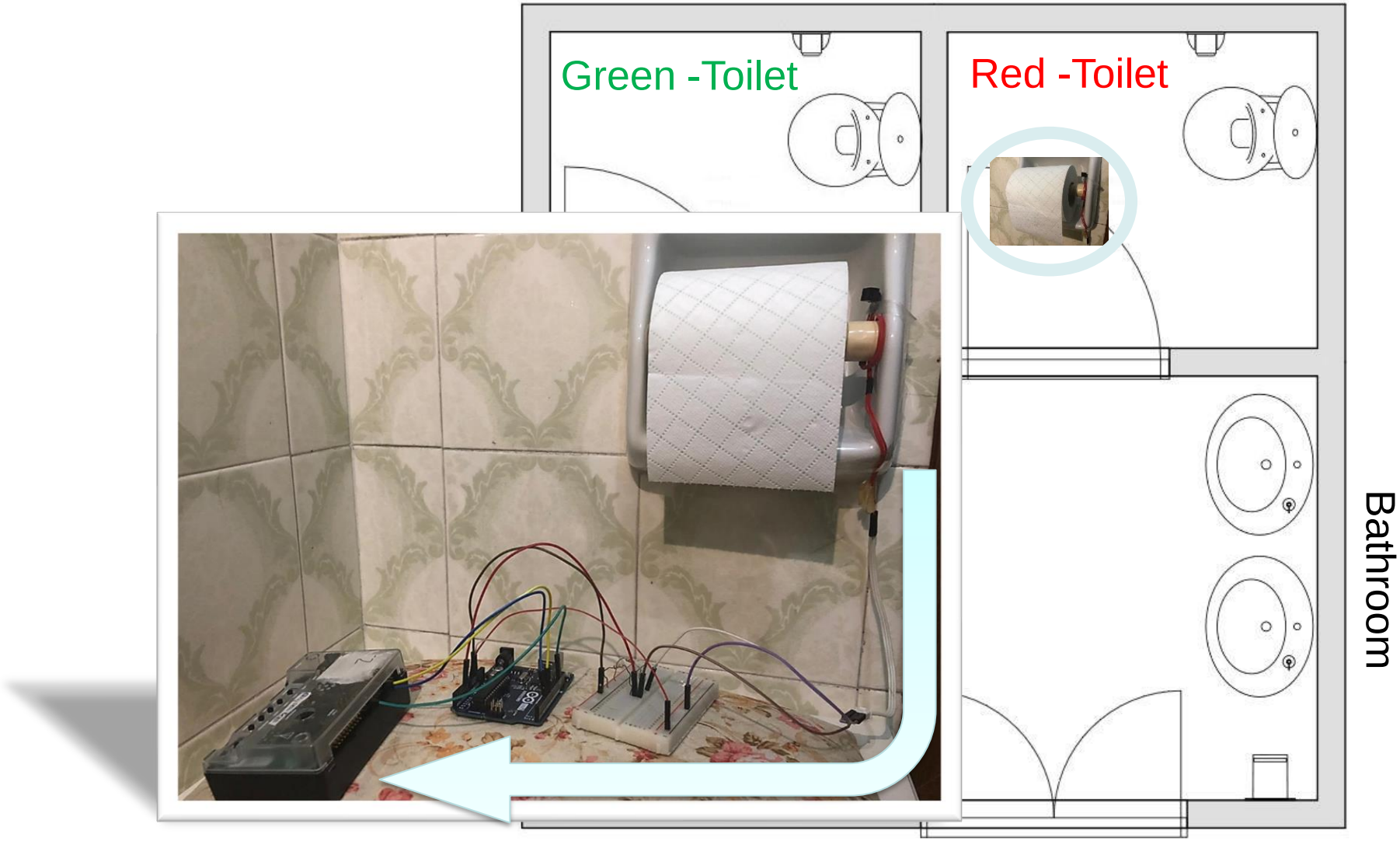
A WSN based on IEEE 802.15.4 for toilet paper detection



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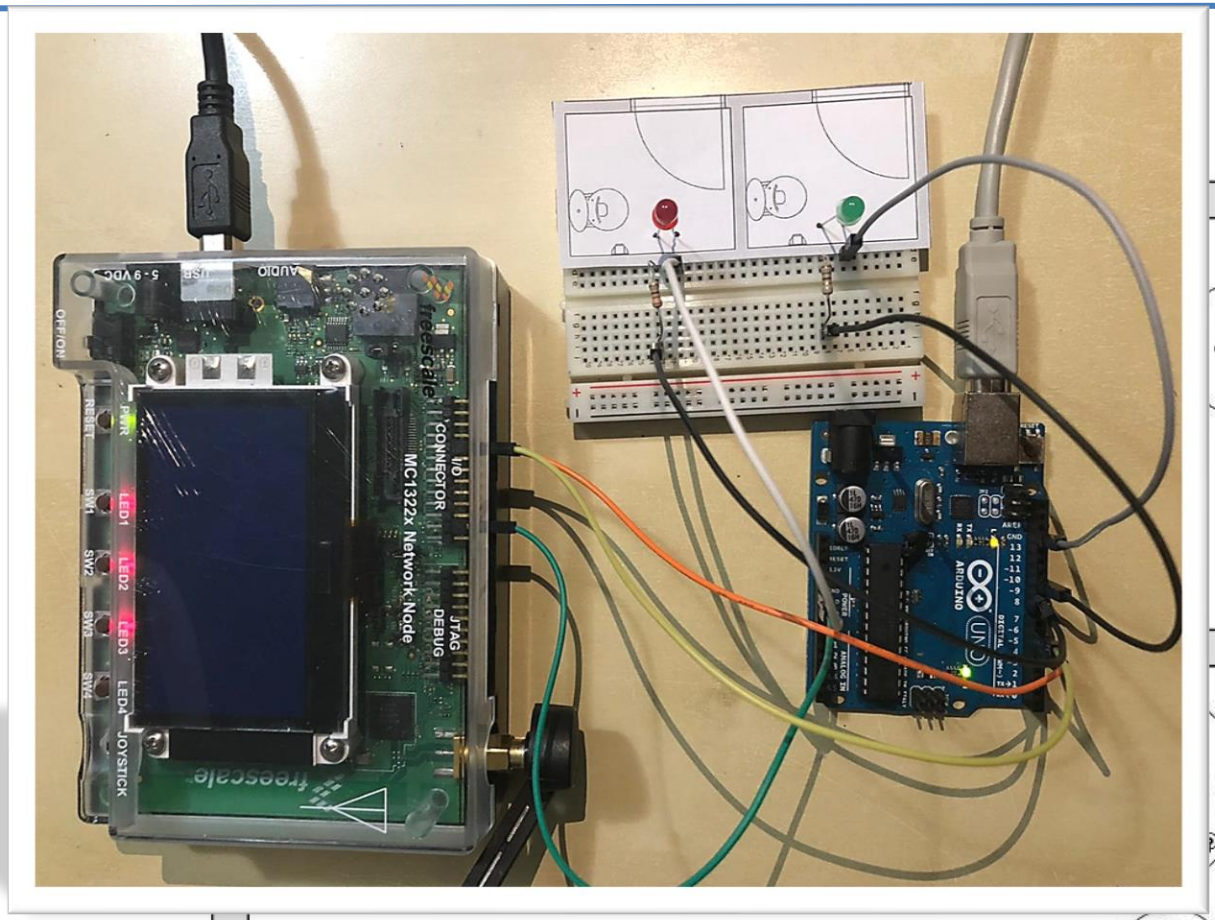

Bathroom

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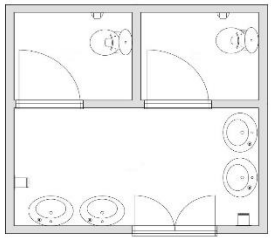
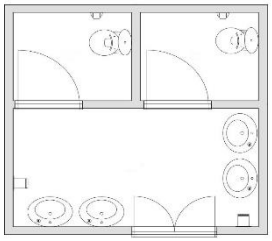
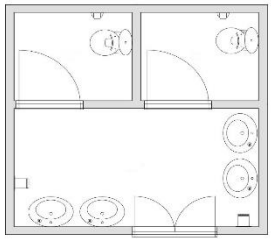
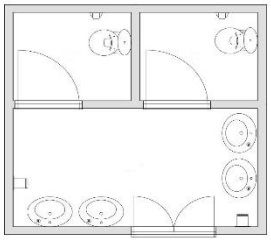
How could we improve the project?



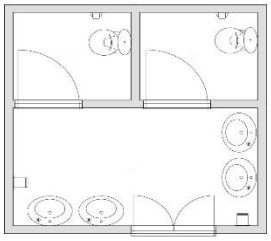


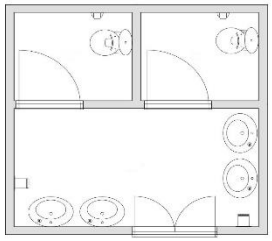


1° floor



Ground floor





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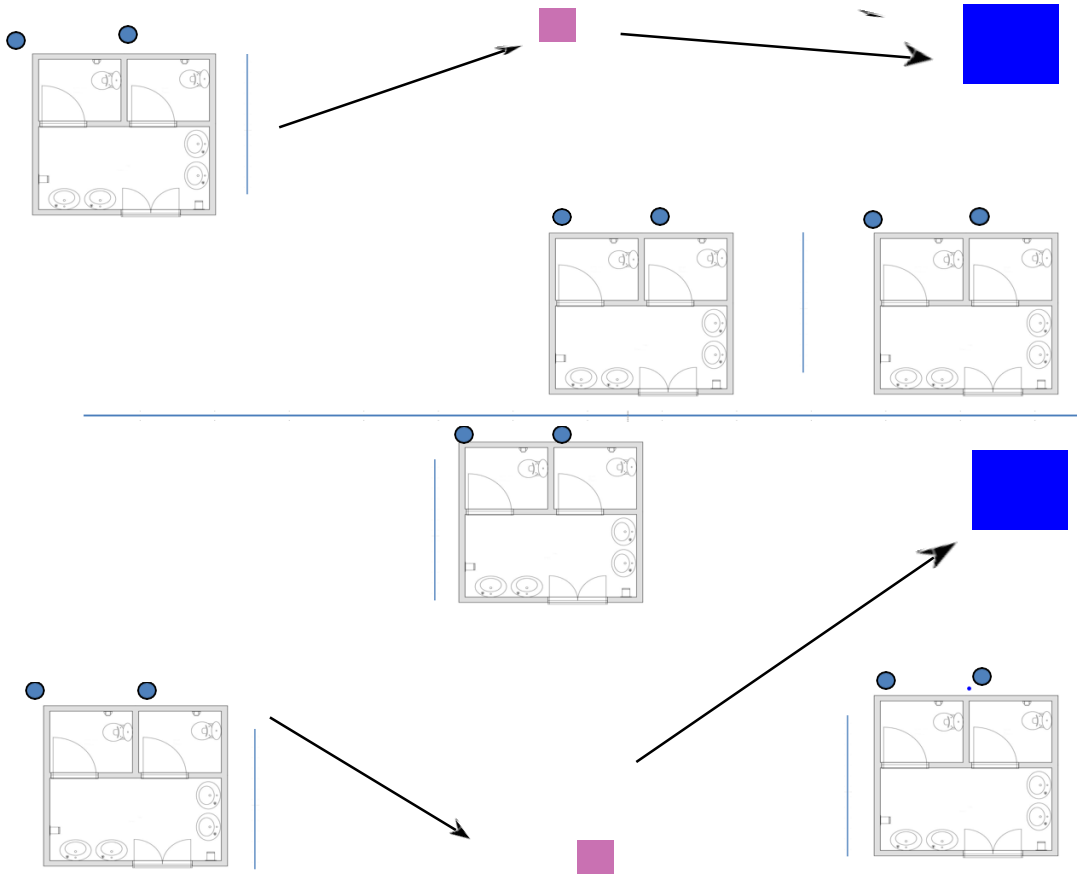

Multi-hoping!

ZigBee

One among many: a wireless enabling technology for the IoT world

28th May 2020

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Thanks for your attention