ZigBee

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

28th May 2020

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

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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.
Smart Cities

CO\textsubscript{2} sensor
Fill-level sensor
Luminosity level sensor
Flow traffic sensor

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

...
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)
Market data and forecast future IoT trends

Spending on Internet of Things worldwide by vertical in 2015 and 2020
(Statista, March 2020)
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?
Standard solutions for wireless networks

**IEEE 802.15.4/ZigBee**

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

**Short range**
Outdoor < 100 m (LoS)
Drastical decrease indoor → Multi-Hopping is needed!
Standard solutions for IoT

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

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

Short-range technologies will dominate IoT

- 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
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**

![Diagram](image.png)
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

IEEE 802.15.4

- Well established standards
- In building coverage
- Battery Life
- Provisioning
- Network Cost & Dependencies

Low Power Wide Area (LPWAN)

- Low Power Consumption
- Low cost
- Positioning
- Security
- High Data Rate
- Emerging Standards

Local Area Network

- Automated Coverage
- High Data Rates
- Autonomy
- Total Cost of Ownership

Wireless communications standards:
- Bluetooth 4.0
- LoRa
- SIGFOX
- neul
- 3G
- 4G
- 5G
3. Wireless Sensor Networks – Main features
Wireless Sensors Networks – *State of Art*

- First releases of commercial products based on standards
- Proprietary solutions available
- Releases of commercial products based on “stable” standards
- Large-scale networks deployment

# Scientific Publications

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<th>Year</th>
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How does a WSN look like

Other Nets (e.g. Internet)

Gateway

Users

Sensor nodes

Monitored Area
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)

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**)
Connectivity

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

Reference values of a *freescale* device

<table>
<thead>
<tr>
<th>Compliant 802.15.4</th>
<th>Clock</th>
<th>Flash</th>
<th>RAM</th>
<th>Receiver Sensitivity</th>
<th>RF Power Min</th>
<th>RF Power Max</th>
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<td>128K</td>
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<td>-96 dBm</td>
<td>-30 dBm</td>
<td>+4 dBm</td>
<td>$150</td>
<td>USA</td>
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</table>

**Transmit Power**

**Power Loss through the Radio Channel**

**Received Power**
## Connectivity

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</table>

Reference values of a *freescale* device

### Power Loss

\[
\text{Power Loss} \ [\text{dB}] = \text{Tx Power} \ [\text{dBm}] - \text{Receiver Sensitivity} \ [\text{dBm}]
\]

### Max. Loss

\[
\text{Max. Loss} \ [\text{dB}] = \text{Max. Tx Power} \ [\text{dBm}] - \text{Receiver Sensitivity} \ [\text{dBm}]
\]

*freescale* \(\Rightarrow\) **Max. Loss** \(\ [\text{dB}] = 4 \ [\text{dBm}] - (-96) \ [\text{dBm}] = 100 \ [\text{dB}]\)
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**)

Monitored Area

Gateway

Users
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.
Elements of a node

- Sensor
- Transceiver
- Microcontroller
- Memory

All these parts are responsible of energy consumption
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
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.
Where does the energy is spent?

Power consumption [mW]

The transceiver is the most energy consuming!

Generally nodes are battery charged while sink might need to be plugged-in, as it receives data from the sensors of the entire networks.
When does the energy is spent?

\[ T_R = D + S + T + I \]

**Round duration**

**Energy spent / Round**

\[ E_R = P_{\text{rec}} \cdot D + P_{\text{sens}} \cdot S + P_{\text{transm}} \cdot T + P_{\text{idle}} \cdot I \quad \text{[Joule/round]} \]

- **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

Gateway

Monitored Area

Users

Sensor nodes

Router

Sink

1st hop

2nd hop
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
Type of reporting

**Event Detection**  ➔ Req.s on delay

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

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**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 frequency*: in this context it refers to the periodicity with which a sensor takes samples (➔ related to the **Round duration**).
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 aggregation, 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
A WSN based on IEEE 802.15.4 for toilet paper detection
How could we improve the project?

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Multi-hoping!
ZigBee

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Thanks for your attention