Autonomous Networking

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Some slides in this course are readapted from seminar slides from ***Mauro Piva*** (*Sapienza*)

Google Classroom

- Google Classroom site for Autonomous Networking course
- https://classroom.google.com/c/MTc1OTU1OTAwODc3?cjc=nkayl4e
- Every student enrolled in the master degree can get access by using Sapienza email address
- Notes, videos, news, homeworks, etc. are shared on the classroom site

Today’s plan

- Internet of Things (IoT)
- Battery free IoT environments

What is Internet of Things?

What kind of things?

Everything that is "Smart"

- **Smart objects**: everyday ***physical objects*** with some embedded electronics that allow them to ***compute*** and ***communicate***
- Smart watch, smart phone, smart TV, etc
- But also…
- Smart car, smart home, smart building, smart city
- The conventional concept of the Internet as an *infrastructure network to interconnect end-user devices* leaves space to a notion of **interconnected "smart" objects forming pervasive computing environments**

Internet of Things

The term is broadly used to refer to

1. The **resulting global network** interconnecting smart objects by means of extended Internet technologies
2. The **set of supporting technologies** necessary to realize such a vision
3. The **ensemble of applications and services** leveraging such technologies to open new business and market opportunities

Conceptual point of view

- The IoT builds on three pillars, related to the ability of **smart objects** to:
  1. Be ***identifiable*** (anything identifies itself)
  2. To ***communicate*** (anything communicate)
  3. To ***interact*** (anything interacts) – either among themselves, building networks of interconnected objects, or with end-users or other entities in the network

Single component point of view

Smart object definition: Entity that

- Has a **physical** embodiment and a set of associated physical features (e.g., sixe, shape, etc.).
- Has a minimal set of **communication** functionalities (e.g., the ability to be discovered and to accept incoming messages and reply to them).
- Is associated to at least one **name** and one address.
- Possesses some basic **computing** capabilities (match an incoming message to a given footprint or perform rather complex computations such as network management tasks).
- Possess means to ***sense physical phenomena*** (e.g., temperature, light, motion) or to trigger actions having an effect on the physical reality (actuators).

N.B. The last point is the key one and differentiates smart objects from entities traditionally considered in networked systems (host, terminals, routers)

Smart objects

- include devices considered in RFID research as well as those considered in wireless sensor networks (WSNs) and sensor/actor networks (SANETs)
- RFID
- Sensor and actor networks

Key devices in IoT

- IoT includes devices (in addition to traditional networking devices)
  - With only very basic communication and computing capabilities
  - Do not present a full protocol stack
- IoT is about entities acting as *providers* and/or *consumers* of data related to the *physical world*

System-level point of view

- IoT is a highly dynamic and radically distributed networked system, composed of ***very large number of smart objects producing and consuming information***
- The ***ability to interface with the physical realm*** is achieved
  - through the presence of devices able to sense physical phenomena (**sensors**) and translate them into a stream of information data
  - through the presence of devices able to trigger actions (**actuators**) having an impact on the physical realm
- ***Main issues:***
  - ***Scalability*** - large scale of the resulting system
  - ***self-management*** - smart objects can move and create ad hoc connections with nearby ones

Service-level point of view

- The main issue relate to **how to integrate the functionalities and/or resources** provided by smart objects (in many cases in forms of data streams generated) **into services**
- Requirements:

1. To create a standard representation of smart objects in the digital domain, able to hinder the heterogeneity of devices/resources
2. Methods for seamlessly integrating and composing the resources/services of smart objects into value-added services for end users

User-level point of view

- IoT enables a large amount of **new *always responsive services***, which shall answer to users' needs and support them in everyday activities

Required features (1/2)

Key system-level features that Internet of Things needs to support:

- Devices **heterogeneity** (protocols handling devices with different computational and communication capabilities)
- **Scalability** (naming, communication and networking, information management, service provisioning and management)
- Ubiquitous **data exchange** through proximity wireless technologies (spectrum availability)
- **Energy-optimized** solutions (optimization of energy usage)

Required features (2/2)

Key system-level features that Internet of Things needs to support:

- **Localization** and **tracking** capabilities (many applications require position and movement tracking)
- **Self-organization** capabilities (devices must be able to organize into ad hoc networks)
- **Semantic interoperability** and **data management** (massive data require standardized formats)
- Embedded **security** and **privacy-preserving** mechanisms (key requirement for ensuring acceptance by users and the wide adoption of the technology)

Enabling technologies

- A key issue for IoT is the development of appropriate means for **identifying** smart objects and enabling **interactions with the environment**
- Smart objects must have capabilities of:
  - Identification
  - Communication
  - Computation
  - Direct interaction with the environment
- Key building blocks are:
  - Wireless sensor networks
  - RFID

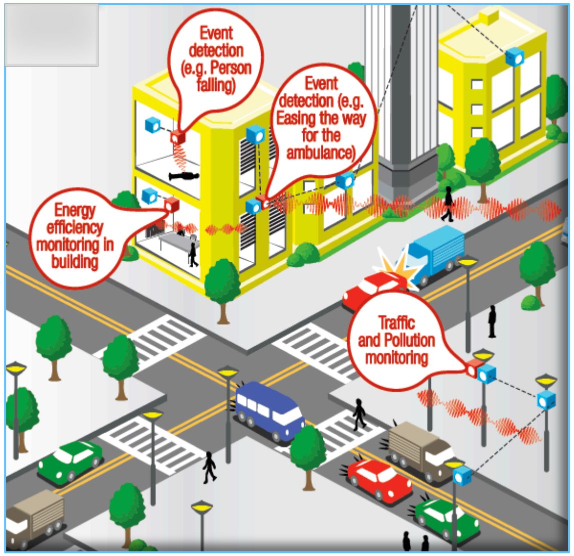
Wireless sensor/actor networks (SANETs)

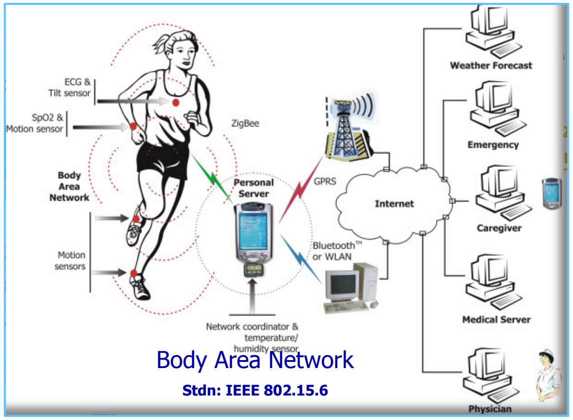
- Sensors passively interface with the physical environment (perform sensing operation)
- Actors actively interface with physical environment (performing actions)
- SANETs are **distributed wireless systems** of **heterogeneous** devices referred to as sensors and actors.
  - Sensors are low-cost, low-power, multifunctional devices that communicate untethered in short distances.
  - Actors collect and process sensor data and consequently ***perform actions on the environment***. In most applications, actors are resource-rich devices equipped with high processing capabilities, high transmission power, and long battery life.

RFID: communication

- Wireless communication
  - Reader to tags
  - Tags to reader
  - ~~Tag to tag~~

IoT Application fields





Communication technologies

- Wi-Fi
- Bluetooth
- cellular

Routing Protocol for Low-Power and Lossy Networks

- The Internet Engineering Task Force (IETF) developed RPL as the routing protocol for low-power and lossy networks (LLNs) and standardized it in RFC6550 in 2012

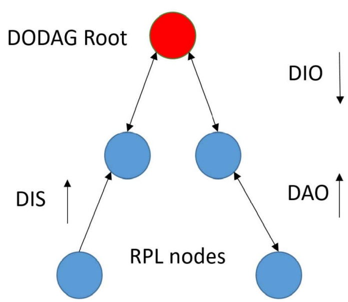
- Proactive protocol based on distance vectors

- RPL created DAG (Directed acyclic graph), similar to a tree (Destination Oriented DAG - DODAG)

- DODAG information object (DIO) is sent from the root node

- The destination advertisement object (DAO) is sent from the child node to its parent

- DIS (information request DODAG): Used to request information



Sensor + RFID

A easy to identify and locate smart object

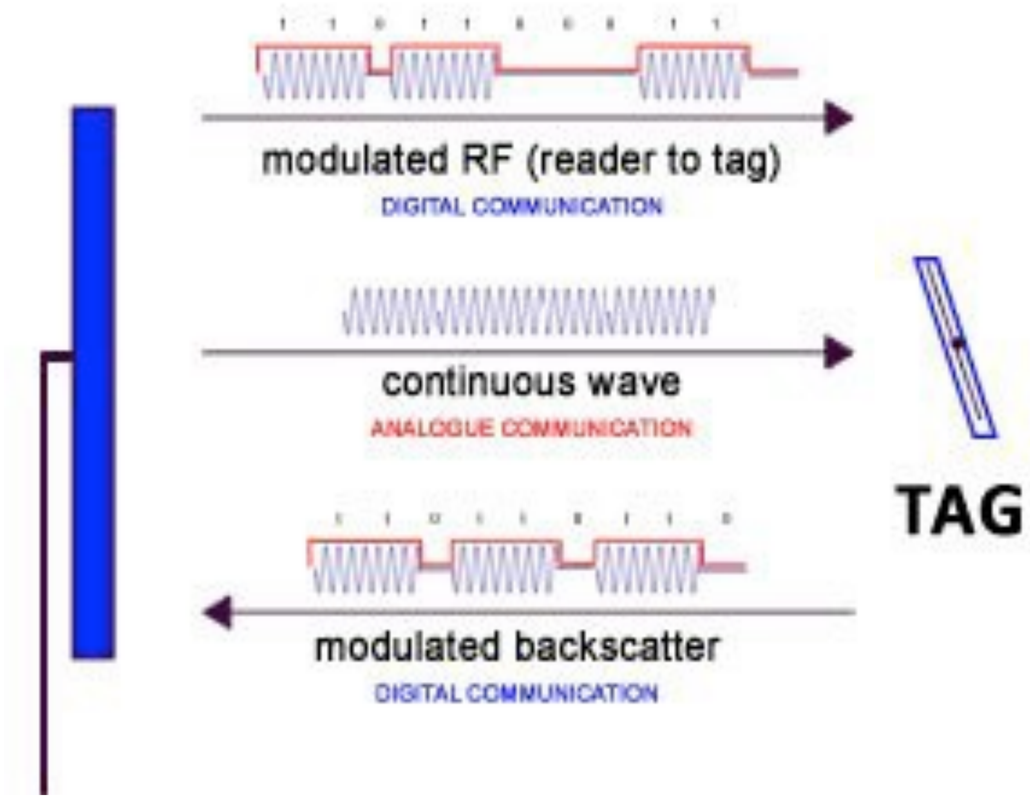
But also…

A new type of device

- Is it possible to re-design smart objects so that they can work without batteries?
- The answer is **backscattering**
- Backscatter (or backscattering) is the reflection of signals back to the direction from which they came

Battery-free smart objects

Backscattering



A new type of device

- Backscattering allows powering of sensor devices and eliminates the need to have any inbuilt batteries at all
- Several low-power devices can use radio frequency (RF) signals as a power source and use them to **sense, compute, and transmit data** via reflecting the RF signal
- Two backscattering techniques
  - Ambient
  - RF identification (RFID)

Ambient backscattering

Devices harvest power from **signals available in the environment** (e.g., TV, cellular, and Wi-Fi transmissions)

The main **advantage** of ambient back-scattering is the use of existing RF signals without requiring any additional emitting device.

Ambient backscattering

Performance drawbacks

- Achieves **low data rate** (below 1 kb/s)
  - applications that need to transmit data only occasionally, for example, to exchange money between smart cards or detect misplaced objects in a grocery store, but cannot support real-time applications, which need continuous communication.
- The **availability** of signals
  - Although TV towers broadcast signals 24 hours a day without interruption, signal ubiquity cannot be guaranteed, with negative effects on the transmission of data in real time.
  - If the signal is weak, smart devices are not able to accumulate the energy necessary to operate.
- Signals **weaken** significantly in **indoor environments**, even in places where they are supposed to be ubiquitous (e.g., TV signals in metropolitan areas located at a distance greater than a few, 8 to 10, Km from the tower).

RFID backscattering

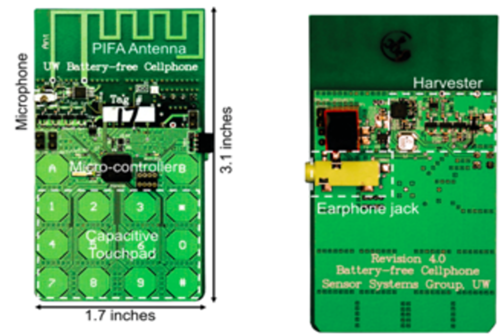
RFID tags harvest power from **signals emitted by the RFID reader**

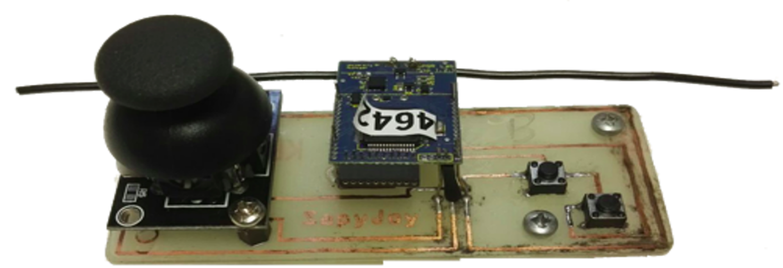
The main advantage is the availability of RFID signal, as the reader is always present in a RFID

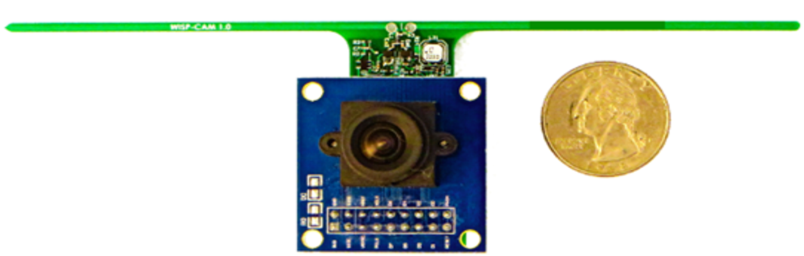
SENSOR-AUGMENTED RFID TAGS

Sensor Augmented RFID Tags

- RFID Tag with sensors embedded:
  - PIR, Camera, Accelerometer…
- No Battery
- Low Power
- Short Distances



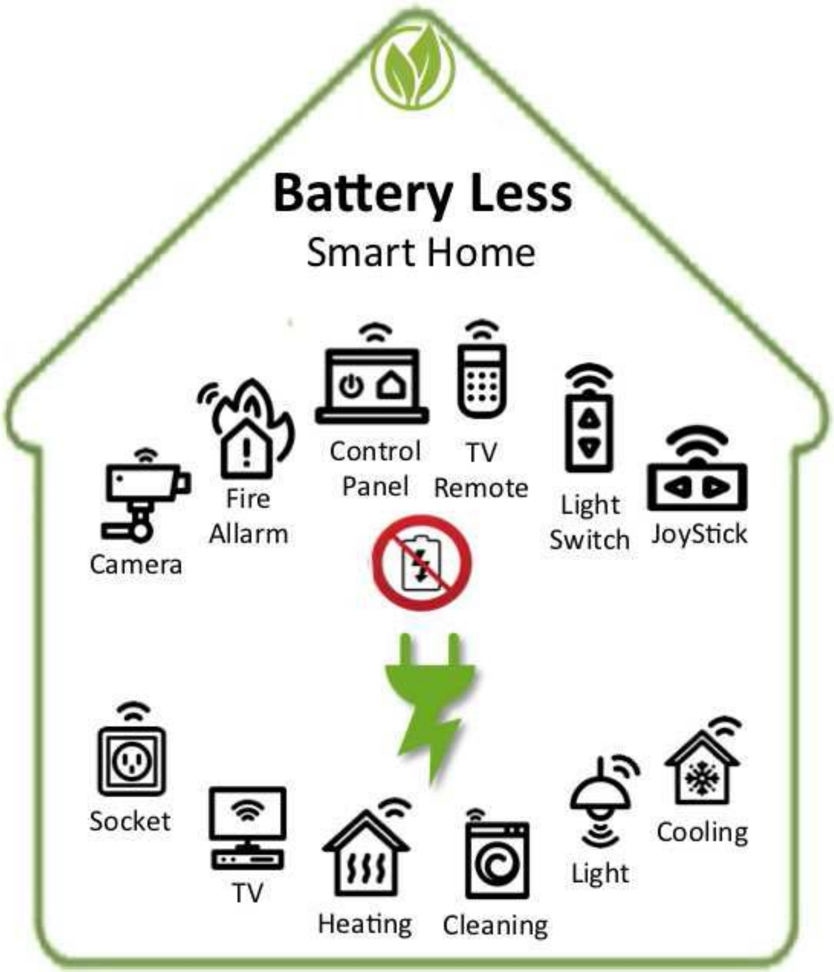




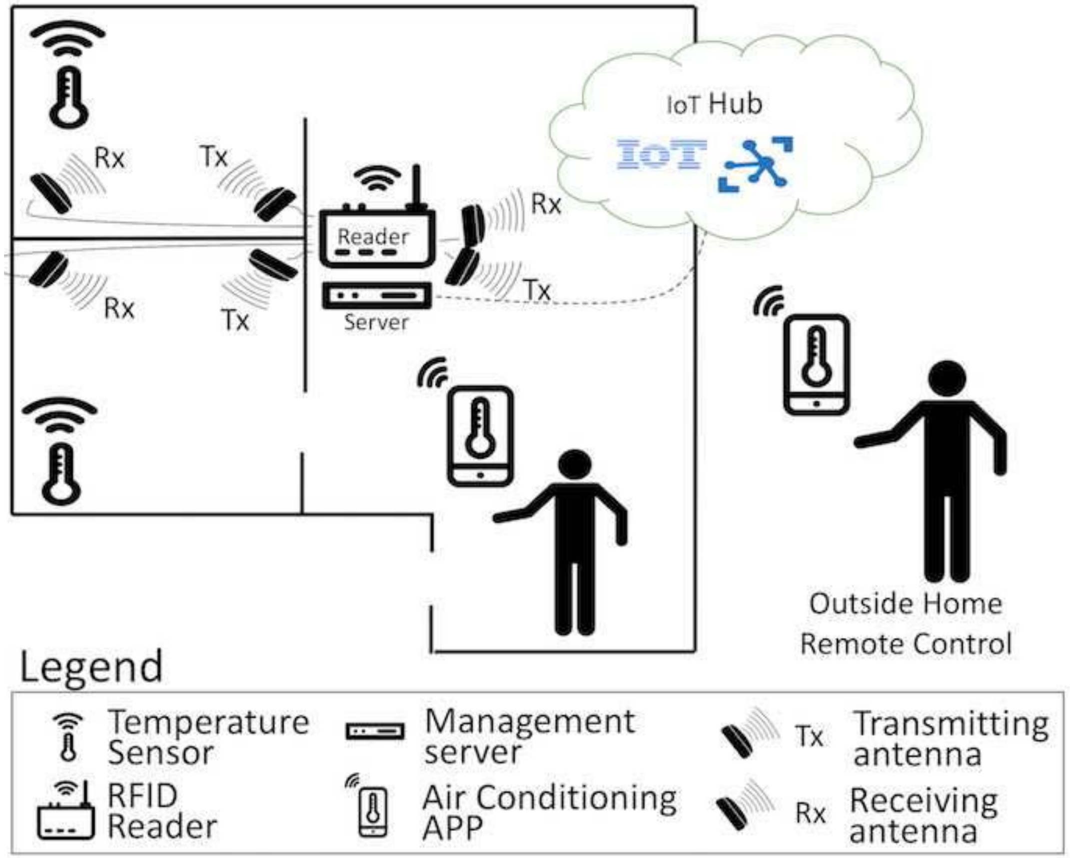
Sensor Augmented RFID Tags: characteristics

- Limited Power
- Limited Operative Range
- Limited Operative Time
- Limited storage
- Low datarate
- **But can run sensors!!!**

Battery free smart home



Deployment



IoT Hub
Rx
Tx
Rx
Tx
Reader
Rx
Tx
Server
Outside Home
Remote Control
Legend
Temperature Sensor
RFID Reader
Management server
Air Conditioning APP
Tx
Transmitting antenna
Rx
Receiving antenna

Developed battery-free devices

Video Game Controller

- Real-time device that is realized by mounting an analog joystick and two buttons on a Moo tag
- Able to interact with several types of video games (e.g., adventure, action, puzzle, and role-playing games)
- a printed circuit board (PCB) connects the analog joystick and the two buttons to the Moo tag, which also has an accelerometer embedded, allowing for complex game experiences.

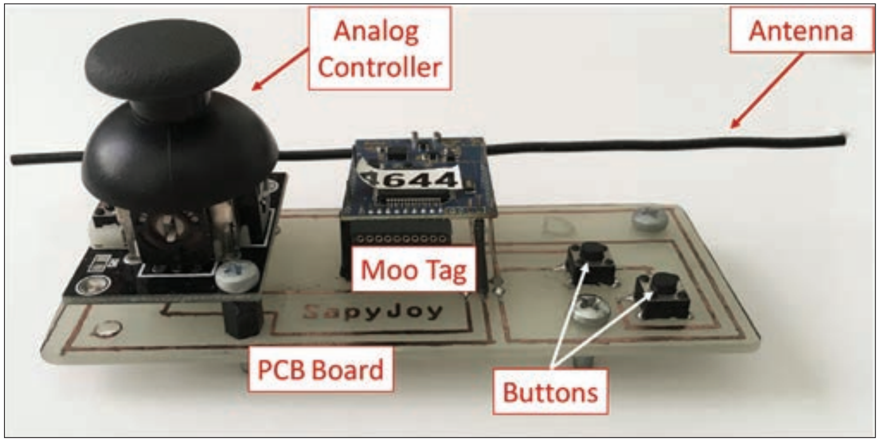


FIGURE 1. SapyJoy videogame controller: A PCB board connects the analog controller and the buttons to the Moo tag.

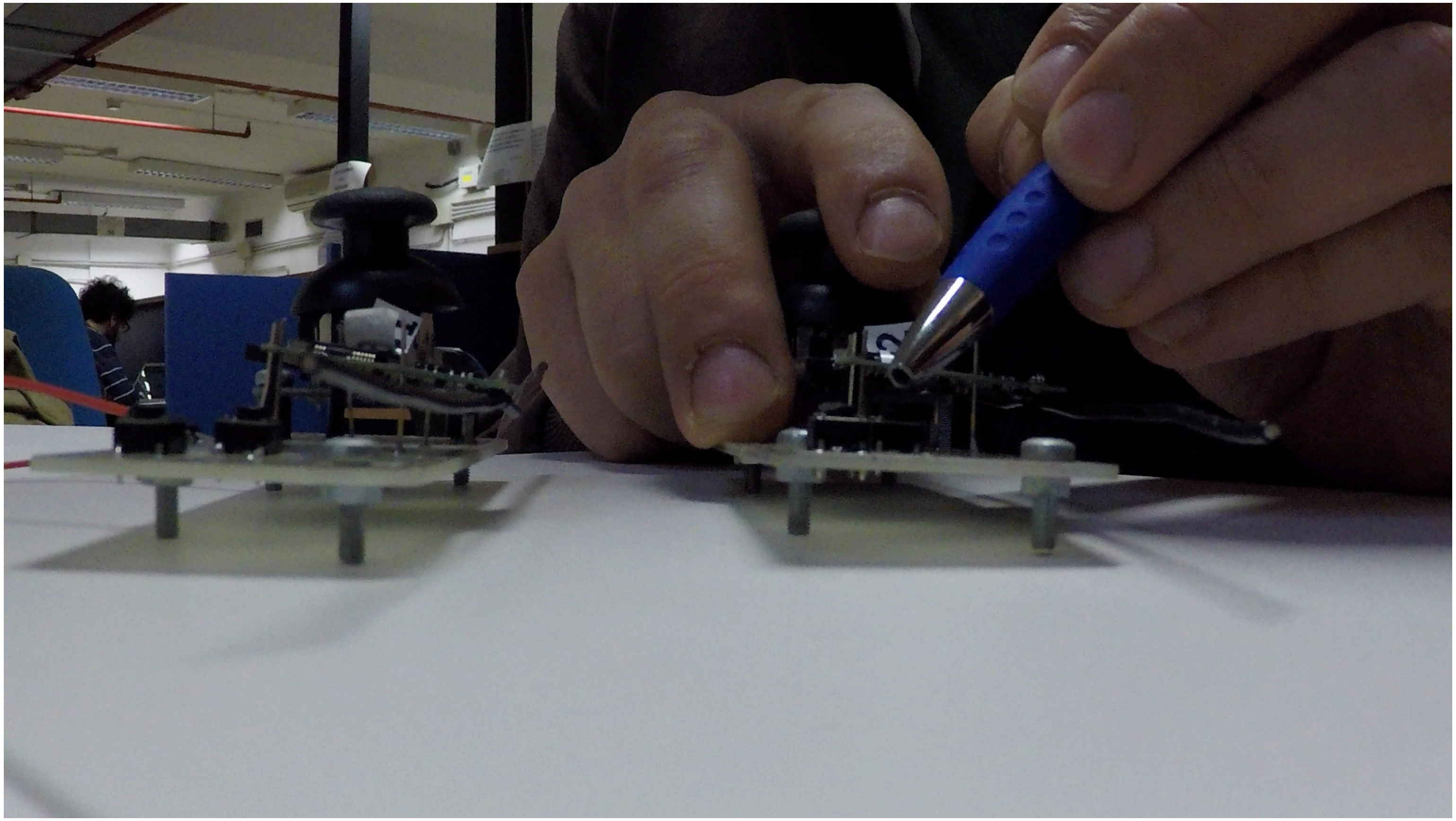
SapyJoy

Developed battery-free devices

Light Switch

- Event-based device, realized by mounting a button on the Moo Tag
- When the user presses the button on the wireless and battery-less light switch, the system switches on an LED on an actuator
- Depending on the application, it is possible to embed multiple buttons on the same Moo tag to control different lights deployed inside a smart building
- The logical connection between the tag switch and the corresponding light is placed inside the server.

Light Switch



Mouse

Mouse: A platform analogous to SapyJoy can work as a wireless and battery-less mouse by interfacing its x and y axes with the pointer on the screen.

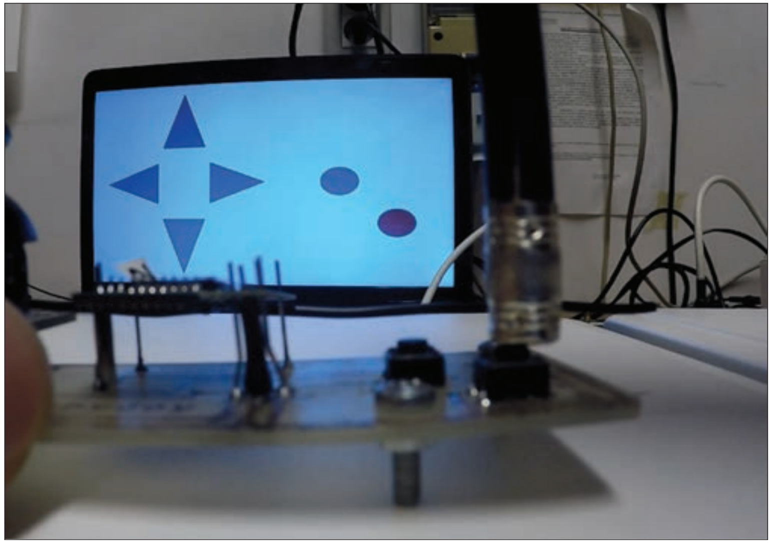


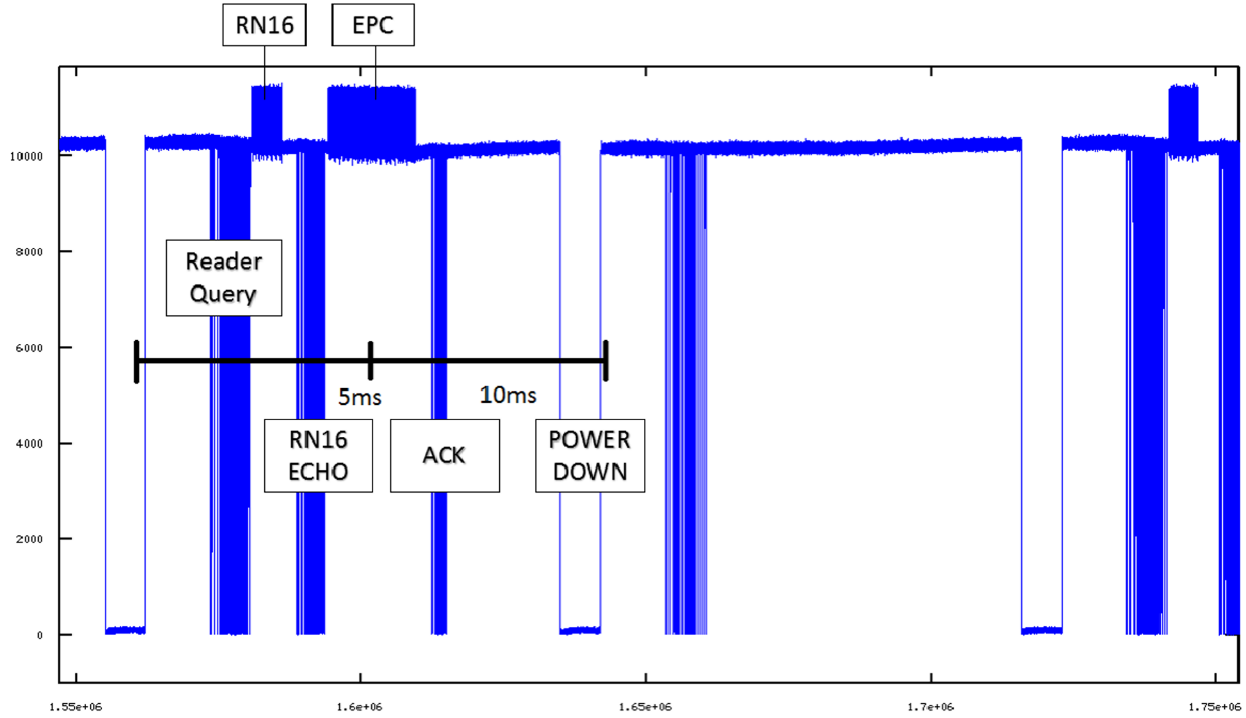
FIGURE 3. Button pressure on the battery-free mouse and corresponding action on the screen.

Performance: experiments

- To interact with our prototypes, we use a USRP RFID reader equipped with two RFID antennas, and a server that interconnects the RFID reader with smart home applications
- The Moo tag receives the reader signal and uses it to harvest operating power using the RFID circuit
- The harvested power runs onboard sensing, encoding of measurement data, cyclic redundancy check (CRC) error coding, and backscatter communication to wirelessly send data back to the reader
- The communication protocol between the reader and the tags is based on the EPC Gen 2 Class 1 standard, which has been modified to acquire data from sensors and store them in the buffer that is traditionally used to maintain the tag ID.

Communication

- What is the communication protocol?
- Sensor-augmented RFID tags run EPC Global Standard



Performance results

Device	Reaction time (ms)	CI
SapyJoy	92.92	[82.31–102.92]
Commercial controller	104.58	[96.31–112.85]
Commercial mouse	110.41	[103.09–117.74]

TABLE 1. Reaction time for different controllers.

Device	Reaction time (ms)	CI
Light switch	62.91	[67.41–73.41]
Mouse	92.92	[82.91–102.92]

TABLE 2. Reaction time for battery-free light switch and mouse.

Good result but …

Devices have been tested standalone

There is only one device answering to the reader queries

No possibilities for collisions

What if multiple devices coexist?

Interoperability

- Although results clearly show the feasibility of battery-free RFID- based smart objects, whose performance is comparable to that of the battery-powered counterparts, their coexistence cannot be taken for granted.
- When multiple devices operate **simultaneously**, the reaction time increases significantly with respect to the case of a device working alone.

Results with multiple devices

- We run experiments with three devices working at the same time: two environmental sensors — temperature and presence — and a video game controller (our SapyJoy)
- The devices are queried (and hence transmit sensed data) following a time-division multiple access approach, which provides different time slots to different devices in a cyclically repetitive frame structure
- If a device is queried at each slot, the reaction time is clearly shorter with respect to the case in which it is queried once every multiple slots. The outcome of our experimentation is that the **reaction time increases significantly** (i.e., 200 ms) with respect to when it works alone (i.e., 92.92 ms).
- This delay would certainly increase if the number of transmitting devices increases, making interoperability a challenge as the joystick may experience delays that are too long.

Open problem

- Would an equal assignment of channel resources satisfy devices' needs?
- Multi-kind multiple battery-free devices, operating simultaneously, have widely varying communication requirements in terms of data transmission, ON/OFF activity, and deadlines.
- Example, a joystick may sense no changes for hours (while it is OFF), and then start sensing new data (while used for playing) at very different rates (from a few milliseconds to one or more seconds), depending on the game type and player activity.
- How to rule channel access?

Readings

Paper available on Elsevier digital library	Paper available on ieeexplore library
• D. Miorandi, S. Sicari, F. De Pellegrini, I Chlamtac,"**Internet of things: Vision, applications and research challenges**", *Ad Hoc Networks*, volume 10, issue 7, sept. 2012, pp 1497-1516	• G. Maselli, M. Pietrogiacomi, M. Piva and J. A. Stankovic, "**Battery-Free Smart Objects Based on RFID Backscattering**," in *IEEE Internet of Things Magazine*, vol. 2, no. 3, pp. 32-36, September 2019

Exam

1. **Lab homework (during the course)**
   a) Homework 1 + discussion : max grade 20
   b) Homework 1 + homework 2 + discussion : max grade 25
   c) Optional integration only for case b) : max grade 30
      - project or
      - paper discussion or
      - partial written exam

2. **Written exam**
   1. First part (multiple choice) : max grade 22
   2. If grade first part > 18 then second part (open questions) : max grade 30