Internet of Things

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The instructor

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- Research topics:
  - RFID systems
  - backscattering networks
  - Drones
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- Course web page:
- Office hours:
  - Send me an email to agree on a schedule
  - After the class

Syllabus

- What is Internet of Things (IoT);
- RFID
- Systems based on passive backscattering
- Sensor networks
- Ad hoc networks
- Underwater Internet of Things
- Drones

Teaching material

- Book chapters
- Papers from IEEE, ACM, and Elsevier digital libraries
- Slides
- Notes of the class

Exam

- Written exam at the end of the course (during the exam session)

Required background

- Computer Networking: TCP/IP protocol stack
- Probability Theory
- Wireless systems
- C programming

Questions?

What is Internet of Things?

What kind of things?

Everything that is "Smart"

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- **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

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

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).
- May 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

- 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 and translate them into a stream of information data as well as through the presence of devices able to trigger actions having an impact on the physical realm
- ***Scalability*** (large scale of the resulting system) and ***self-management*** (smart object can move and create ad hoc connections with nearby ones) are the main issues

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)

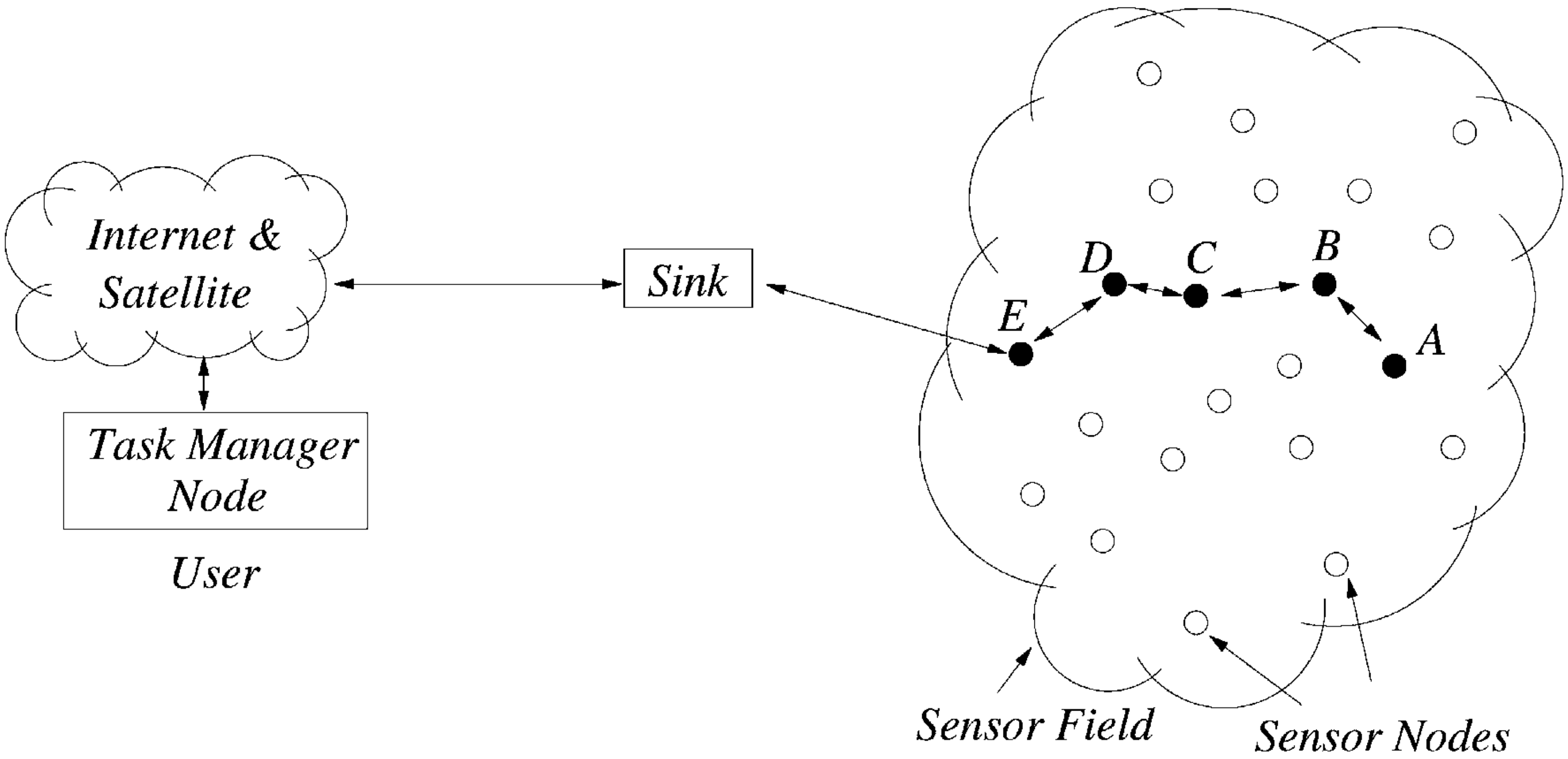
Enabling technologies

- 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)

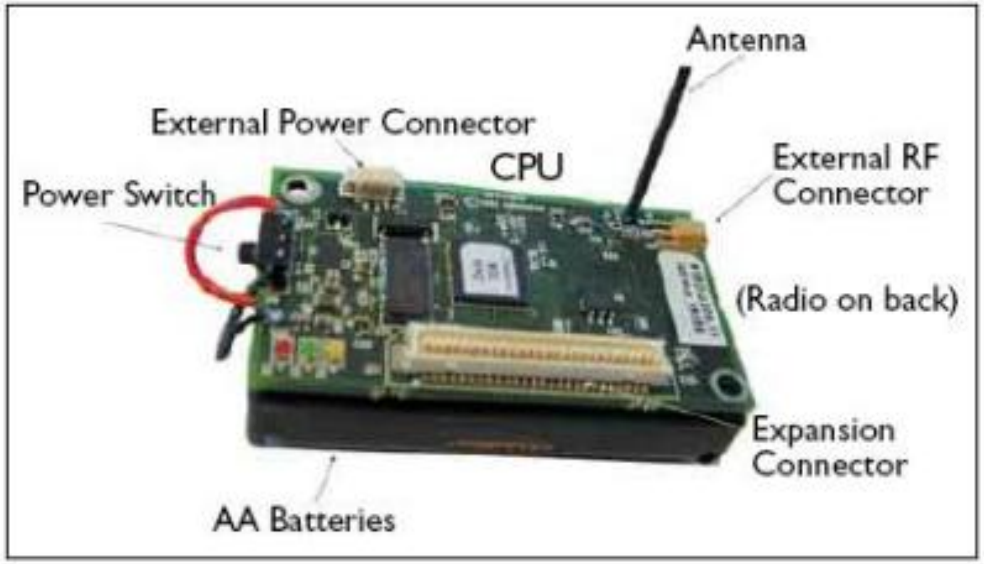
- Sensors passively interface with the physical environment (perform sensing operation)
- Actors actively interface with physical environment (performing actions)
- SANETs are **distributed wireless systems** of **heterogeneous** devices referred to as sensors and actors.
  - Sensors are low-cost, low-power, 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.

Sensor network



Main sensor node components

- an antenna and a radio frequency (RF) transceiver to allow communication with other nodes,
- a memory unit
- a CPU
- the sensor unit (i.e. thermostat)
- the power source which is usually provided by batteries.



- The operating system running on sensor nodes is called TinyOS and was initially developed at the University of California, Berkeley. TinyOS is designed to run on platforms with limited computational power and memory space.The programming language of TinyOS is stylized C and uses a custom compiler called NesC.

Energy efficiency

- Wireless sensor networks use battery-operated computing and sensing devices. A network of these devices will collaborate for a common application such as environmental monitoring.
- Sensor nodes are likely to be battery powered
- **Batteries** have **finite power**
- Battery replacement is a costly process to be avoided as much as possible, especially for large-scale deployments and it is often very difficult to change or recharge batteries for these nodes.
- Low power communication is required
- Sensor networks are typically deployed in an ad hoc fashion, with individual nodes *remaining largely inactive for long periods of time*, but then becoming suddenly active when something is detected.
- **Prolonging network lifetime** is a critical issue.

Low power communication

- Battery power conservation has been a key objective of research on wireless networks over the past decade.
- Main research directions with the goal of prolonging network lifetime:

1. Protocol optimization
2. Energy harvesting
3. Wake-up radio

Sensor networks in IoT

- The ability of sensing the environment and to self-organize into ad hoc networks represent important features from a IoT perspective

- Three main limiting factors need to be overcome in order to foster their widespread adoption
  1. Support of heterogeneous devices
  2. The need of equipping sensor nodes with a battery
  3. The dimension of electronics needed to be embedded in objects (nanotechnologies)

Radio Frequency Identification (RFID)

- Key role as enabling technology in IoT

What is an RFID system?

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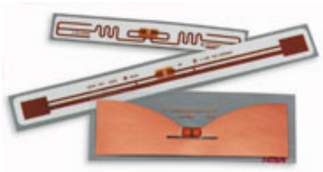


RF Tags

Radio frequency labels store a unique identifier (ex. 96 bits) and consist of an antenna integrated on a microchip.
They are attached to object to be identified

Interrogators
and Antennas

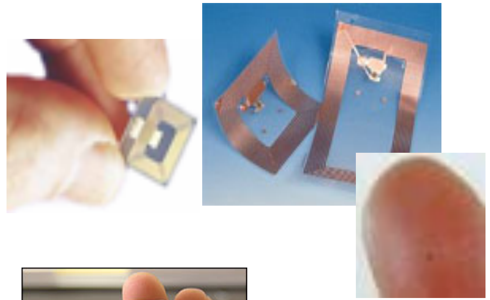
The reader queries tags to get their IDs

Server
& Data repositories

A server handles the data received by the reader and process it based on the application requeirements.

Passive tags

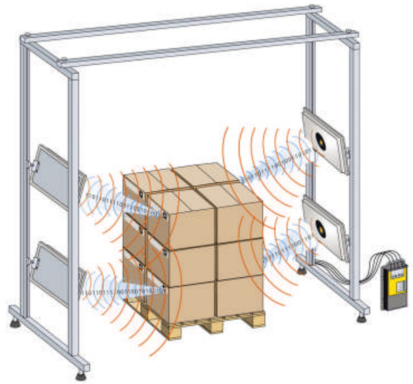
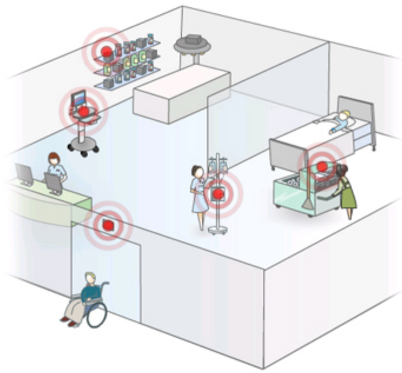
- Small, cheap, long lasting
- No power source (battery)
- Transmission through back-scattering:

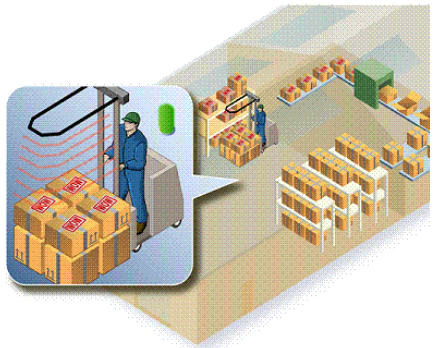


- Active tags: powered by batteries,
- Much more expensive!

Applications

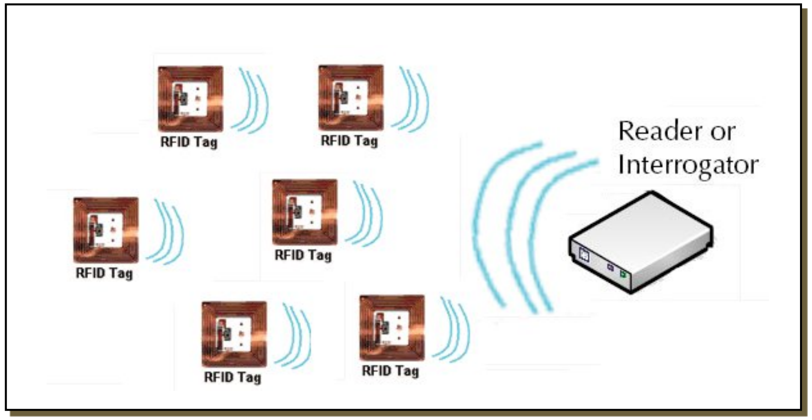
- Inventory and logistics
- Acces controll object tracking
  - Libraries
  - Airport luggages
- Domotics e Assisted Living
  - Intelligent appliances
  - Daily assistance to people with disabilities

RFID system

- RFID is the traditional and most widely used technology that harvests power from RF signals.
- In RFID, the tags — battery free devices — reflect the high-power constant signal generated by the reader — a powered device — to send it their unique ID.



- A variety of applications whose common required functionality is **object identification** — to get the unique ID associated to each tag.
- Tag **identification** and **counting** are the main functionalities so far implemented by RFID systems

Tag identification

- An identification protocol has to
  - Identify tags so as to optimize single tag responses (identifications)
  - Minimize concurrent responses (or collisions that prevents identifications)

- Identification protocol $\Rightarrow$ anti-collision or medium access protocol (MAC)

Application fields

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What is the impact of IoT technologies?

What applications can benefit of their adoption?

The scope of IoT is extremely wide!

Smart homes/Smart buildings

- Instrumenting buildings with IoT technologies may help in both **reducing the consumption of resources** associated to buildings (electricity, water) as well as in **improving the satisfaction level of humans** populating it
- A key role is played by **sensors**, which are used to both **monitor resource consumptions** as well as to **proactively detect current users' needs**
- Energy monitoring
- Home automation
- Home media services
- Home security
- Home confort

Example: smart fridge

- Items stored in a refrigerator are identified by means of RFID
- The fridge has embedded computing and networking capability
- Service offered:
- understand the quantity and type of items stored and decide whether there is a need to buy new items
- By accounting for what is currently in the fridge, the user's dietary constraints and tastes, the user's agenda (i.e., dinner with friends) negotiate for the best food at the best rate
- Suggest best meals based on user's preferences and healthy status

Smart city

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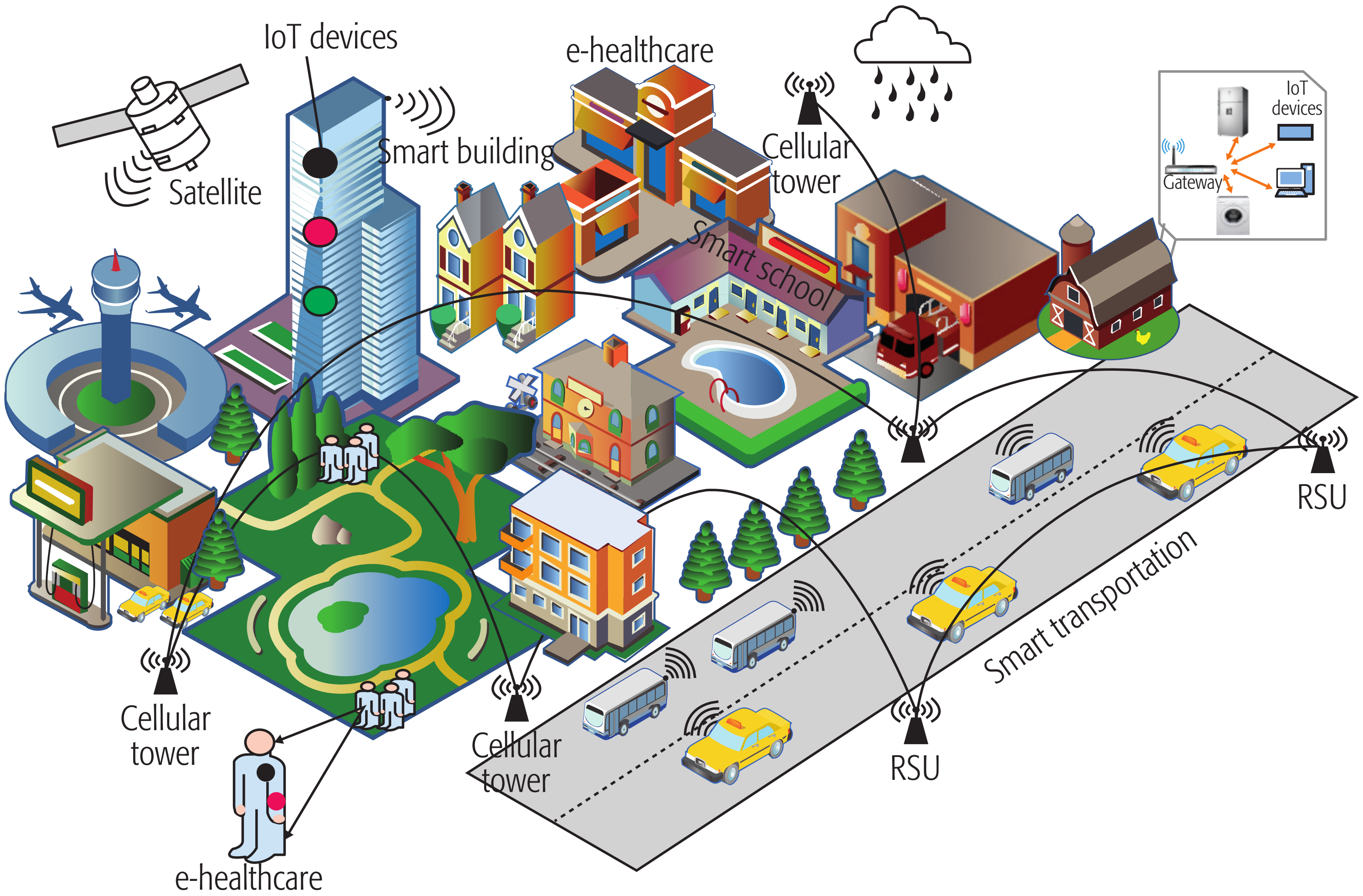

Example: advanced traffic control system

- Car traffic monitoring in big cities or highways
- Traffic routing advice to avoid congestion
- Smart parking device system to provide drivers with automated parking advice
- Detecting violations
- Store information useful in case of accident