

Smart Objects

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UNIVERSITÀ DI PISA



Smart Object



Real-world object + instrumenting device



Instrumenting devices



- Sensors
 - Passive Sensors
 - Semi-passive Sensors
- Sensor Nodes
 - Sensor Platforms
- Sensor/Actuator Nodes



Sensors

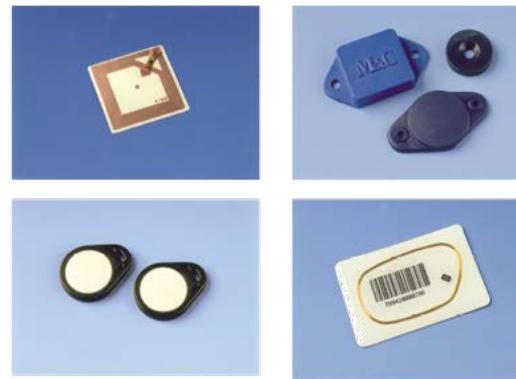
Sensors: Classification



■ Passive Sensors

■ RFID

NON TIENI BATTERIA, sono ATTIVATI
USANDO IL RIFLETTORE



non sono veloci
Acce iBeacons
Anche se le
funzioni sono
esiste solo

■ Semi-passive Sensors

■ Data loggers

Sono e interfaccia con dei sensori e

QUANDO SONO INCONTRATI FORNISCONO INFORMATI CON INFORMATI COLLEGATI



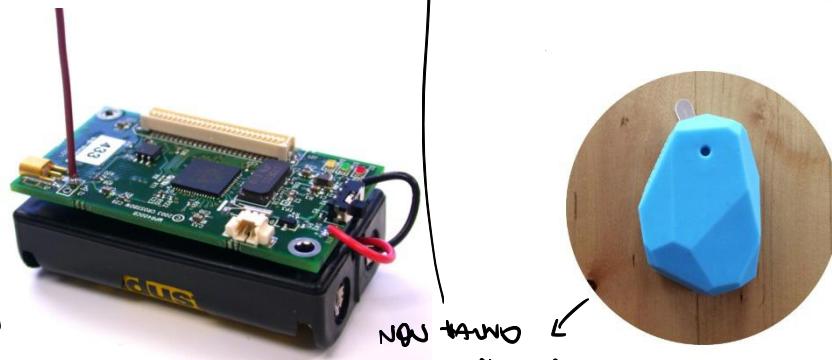
■ Active Sensors

■ Sensor nodes

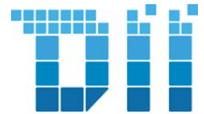
■ iBeacons

NON HANNO BATTERIA MA CI È NELLA

LE INFORMAZIONI POSSONO ESSERE PROCESSATE LOCALMENTE
GARANTENDO UN RAGGIO DI 100 METRI



Sensors: Classification



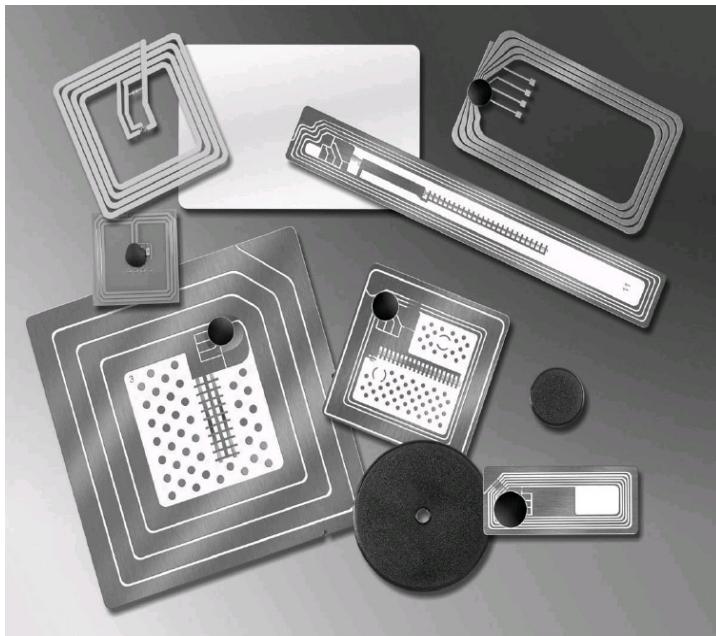
CLASSIFICATION FOR FUNCTIONS (FISCHER):

- Temperature
- Humidity
- Light intensity
- Infrared (Presence)
- Sound (Noise)
- Accelerometer
- Compass (direction)
- Speed
- Pressure
- Seismic
- Chemical Sensors
- Optical Sensors
- Pollution
 - CO, CO₂, NO₂, O₃, Benzene
 - PM10, PM2.5, PM1
- Smart Meters
 - Power Consumption
 - Energy Consumption
 - Gas Consumption
 - Water Consumption
- ...



Passive Tags

RFID, QR-codes

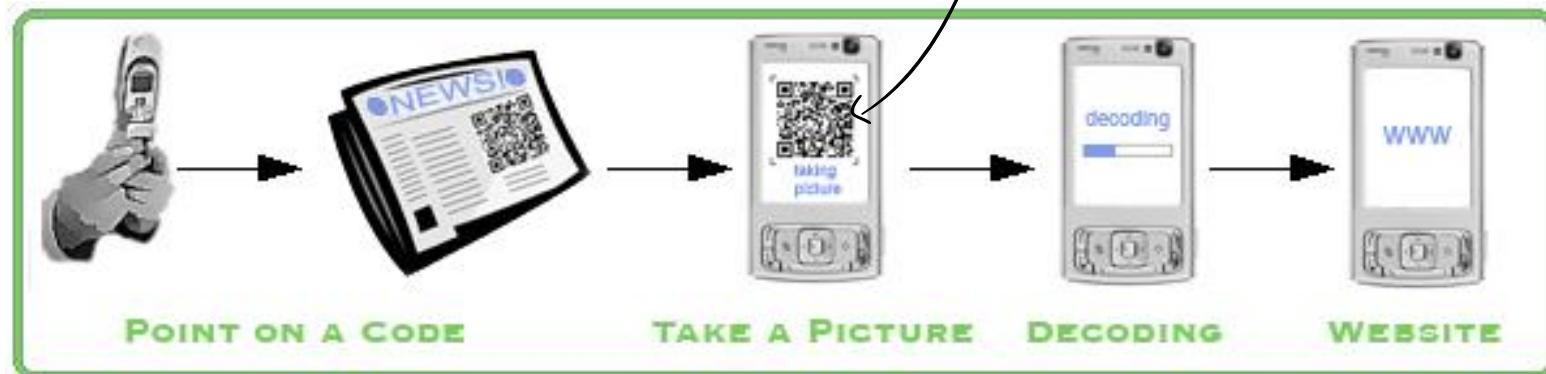


Quick Response (QR) Code

Two dimensional barcode that stores information in black and white dots (data pixels or “QR code modules”)



Process of reading a QR code:



QR code generation



Many online generators available

e.g., <http://goqr.me/>

- ⇒ URL (Website)
- ⇒ Text
- ⇒ Vcard
- ⇒ Sms
- ⇒ Phone Call
- ⇒ Geolocation
- ⇒ Event
- ⇒ E-mail
- ⇒ WiFi

INFORMATI^N
WE POSSONO
ESSERE CONNESSE
WWW.QR CODE

<https://www.dii.unipi.it/>



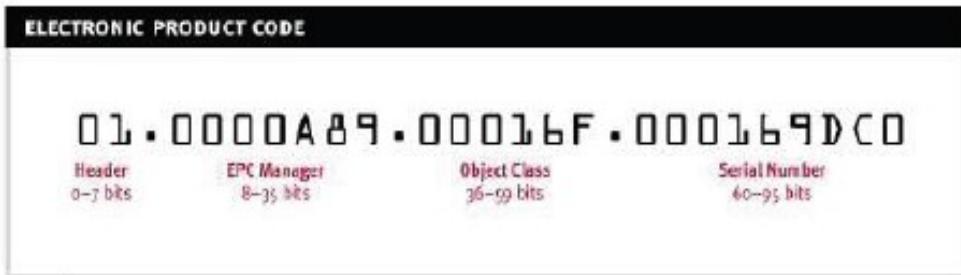
NOV POSSONO ESSERE CONNESSE
UN IOT DEVICE ALL'ALTRO
PER SONO SUE CINQUE DEVICES



Using RFID



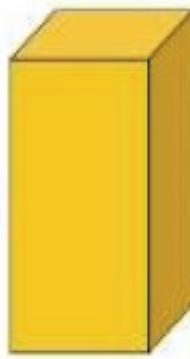
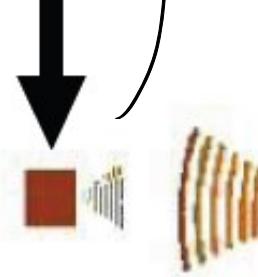
EFFICIENTMENT IN ELECTRONIC DEVICE



**EPC
Network**



Reads sleek
4D UN QR CODES



Tag

Reader

Middleware



**Enterprise
Systems**

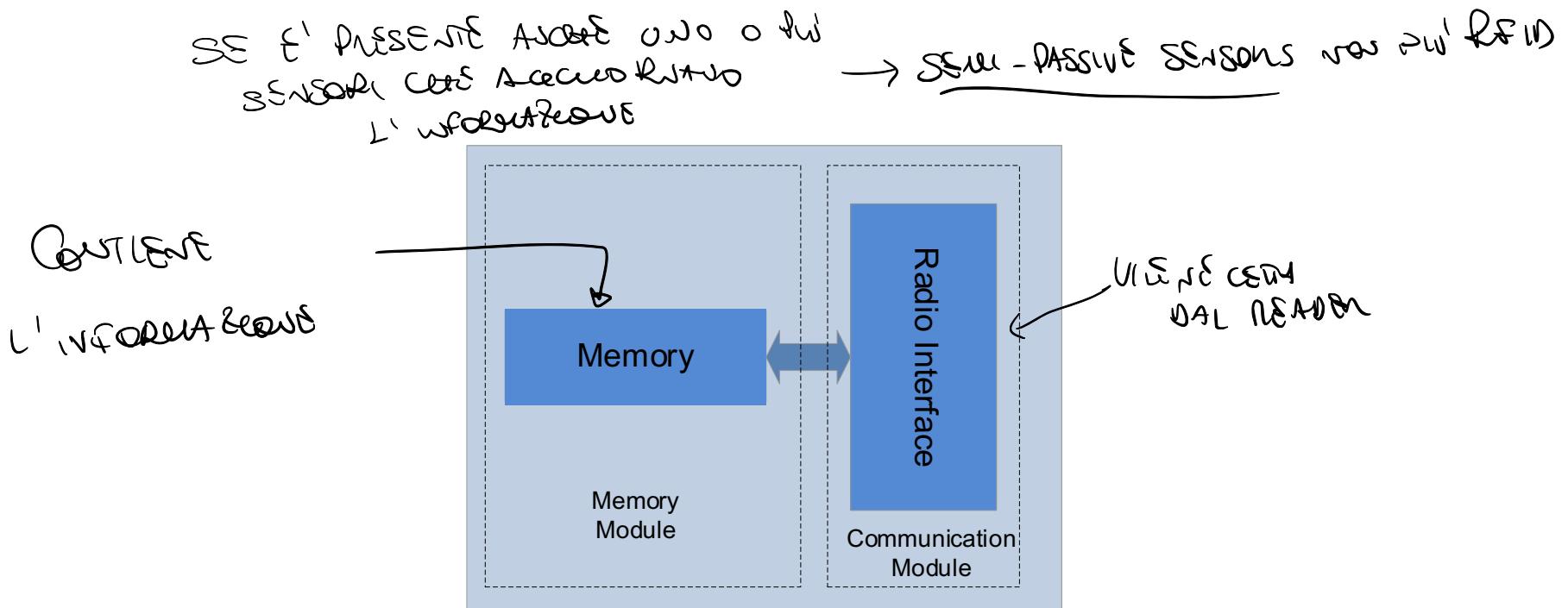


RFID Architecture



RFID Tags: only connectivity

RFID Reader required for communication



Application Areas



- Supply chain management
- Baggage/Animal tagging
- Library information systems
- Parcel tracking (postal services)
- Smart cities
 - Access control
 - Ticketing (public transport, parking, etc.)
 - Parking area management
 - Augmented reality
 - ...



Electronic Product Code



ELECTRONIC PRODUCT CODE

01.0000A89.00016F.000169DC0

Header
0-7 bits

EPC Manager
8-35 bits

Object Class
36-59 bits

Serial Number
60-95 bits



Illustrative Example (EAN-13): 99 00508 07686 8



Remove
Check Digit

9 9 0 0 5 0 8 0 7 6 8 6 8

EPC: **3** **9900508** **07686** **0000000123456**

Header

EPC Manager Number

Object Class Number

Serial Number

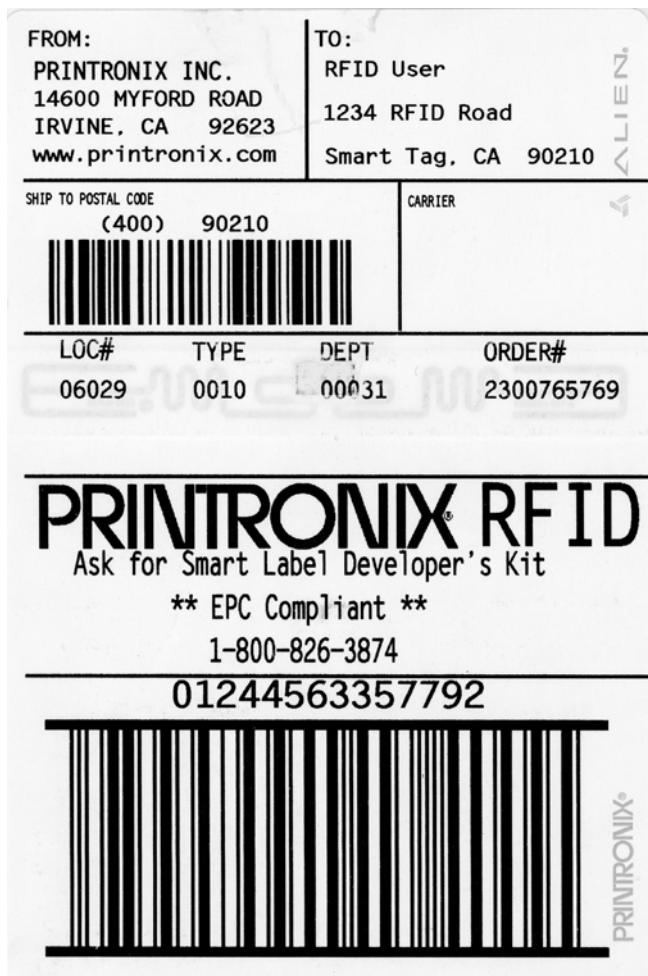
GTIN



Supply Chain Management



Baggage Tagging



Animal Tagging



TX1400 B 12mm x 2.0mm



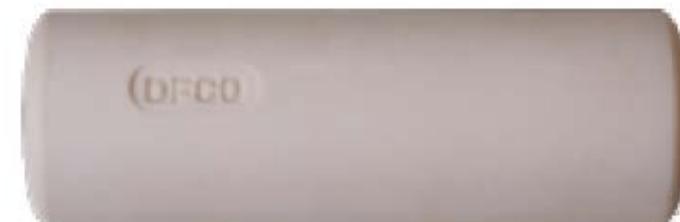
TX1410 B 18mm x 3.0mm



TX1415 B 23 mm x 3.83mm



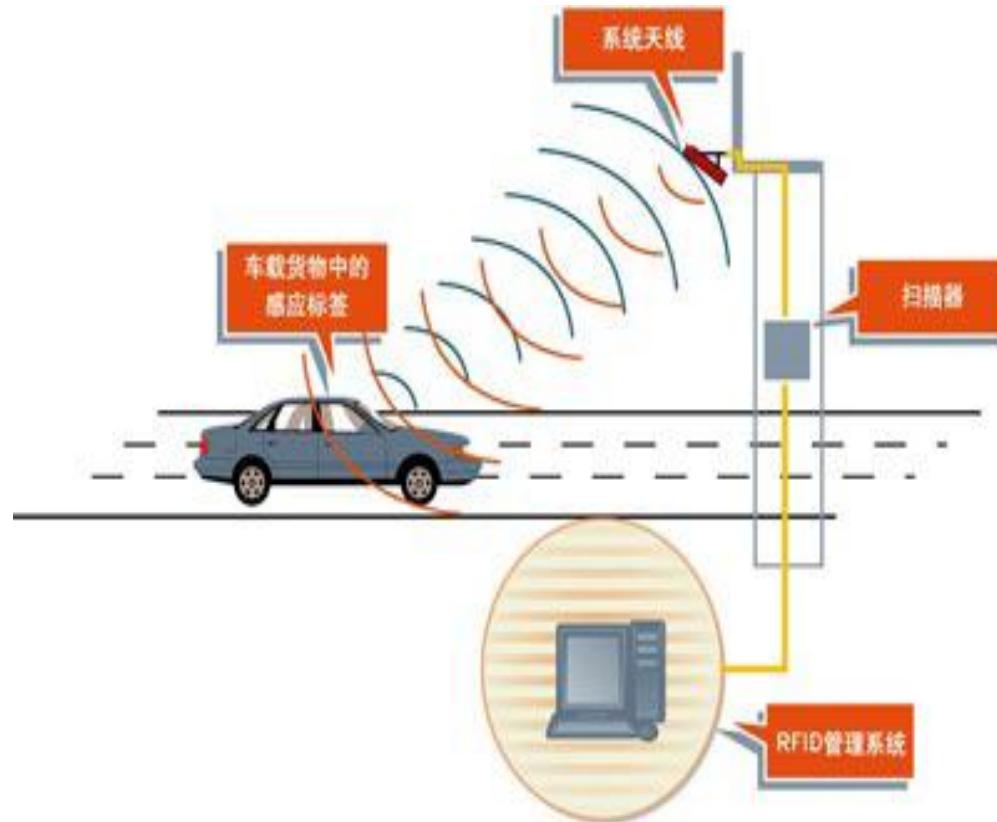
190-0003-00B Rumen Bolus 65mm x 21.1mm



189-0000-00 Umbilical Implant 65mm x 9.8mm



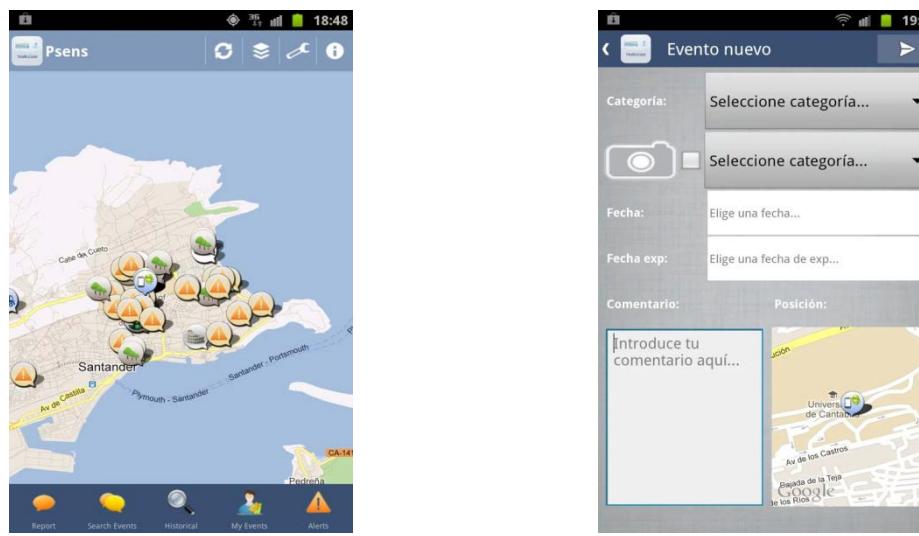
Automatic Access/Tolling



Augmented Reality

Points of interest in the city (touristic point of interest, shops and public places) can be tagged through RFIDs or QR codes

Information about the tagged point are made available to the user (tourist, citizen, ...)



Parking Area Management

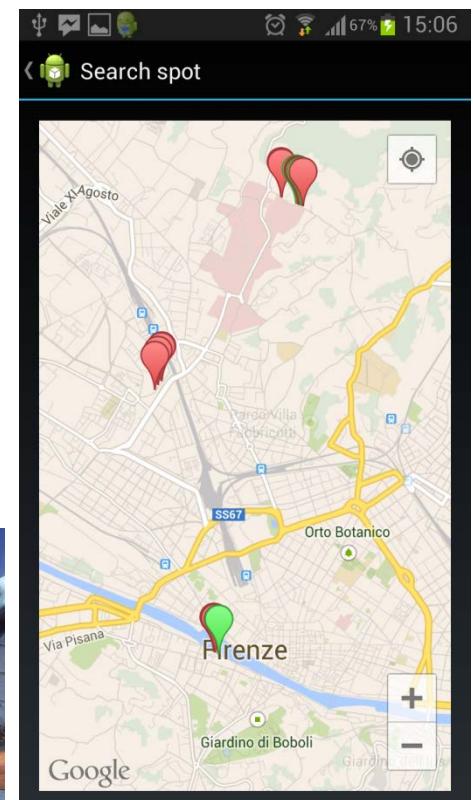


Price
Euro: 2.10
Thanks



After more or less two hours.....

Lot: 12987
Time: 15:25
User: 34678



Active Tags

Beacons



Introduction

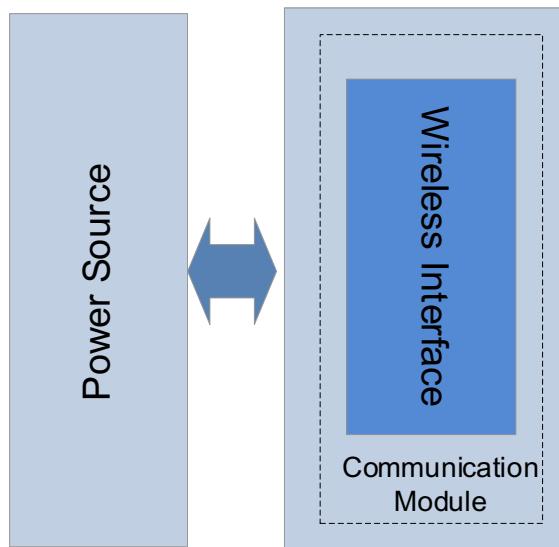


- iBeacon is a technology originally developed by **Apple**
 - iBeacon-compatible hardware transmitters - typically called Beacons - available also for non-Apple devices
- Enables devices to perform actions when in close proximity to a Beacon
 - Beacons emit periodic signals
 - Mobile devices **understand their location**
 - ⇒ based on the received signal
 - and perform a specific action

Beacon Architecture



now sans passiv
→ ELEKTRO IN SCHAFFEN A POTENTIALEDWERTA



Basic Idea



Beacon uses **Bluetooth Low Energy (BLE)** to transmit **Advertisement (ADV) messages**



↳ Tasse für den Cow
Docorssions
Ensecut
DA BLE4

The ADV message is received by a smartphone and forwarded to a server (e.g., on the cloud)

The server localizes the device (user) and sends appropriate information to the smartphone



Bluetooth Low Energy (BLE)



- Wireless **PAN technology** for novel applications
 - healthcare, fitness, security, home entertainment, ...
 - Also known as Bluetooth smart
- **Main goal**
 - providing considerably reduced power consumption and cost
 - while maintaining a similar communication range
- Requirements
 - Android 4.3 and above
 - iOs 7 and above



BLE vs. Traditional Bluetooth



■ Power Consumption

- BLE has lower power consumption than traditional Bluetooth
- Lifetime up to 3 years with a single coin cell battery

■ Cost

- BLE is 60-80% cheaper than traditional Bluetooth

■ Applications

- BLE is ideal for simple applications requiring periodic transfers of small data
- Traditional Bluetooth is better for more complex applications
 - ⇒ requiring consistent communication and higher throughput

How BLE works



- BLE communication mainly consists in
Advertisement (ADV) messages
 - small data packets broadcast at a regular interval by enabled devices via radio waves
 - **one-way** communication
- Typical parameter values for Beacons
 - Broadcast interval of 100 ms
 - Broadcast range of up to 100 meters

Beacon Advertisement Messages



Advertisement messages consist of four main pieces of information

- UUID (Universal Unique IDentifier)
- Major
- Minor
- Tx Power

WFOENZCOWI usero SSeelueC

Beacon Advertisement Message



- **UUID (Universal Unique Identifier)**
 - 16 byte string used to differentiate a large group of related Beacons
 - In its canonical form, a UUID is represented by 32 lowercase hexadecimal digits, displayed in five groups separated by hyphens, in the form 8-4-4-4-12 for a total of 36 characters
 - E.g., ebefd083-70a2-47c8-9837-e7b5634df524
- **Major**
 - 2-byte string distinguishing a subset of Beacons within the larger group
- **Minor**
 - 2-byte string used to identify individual Beacons
- **Tx Power**
 - Used to determine proximity (distance) from the beacon
 - ⇒ TX power is defined as the strength of the signal at exactly 1 meter from the device.
 - ⇒ This has to be calibrated and hardcoded in advance. Devices can then use this as a baseline to give a rough distance estimate.



Example



Application for locating people within the University of Pisa

- **UUID (Universal Unique IDentifier)**
 - ⇒ Allows to recognize that ADV messages are emitted from Beacons belonging to the University of Pisa
- **Major**
 - ⇒ Identifies ADV messages emitted from Beacons inside a specific building belonging to the University of Pisa (e.g., Building A)
- **Minor**
 - ⇒ Identifies a specific room in that Building (e.g., Room A28)



Example

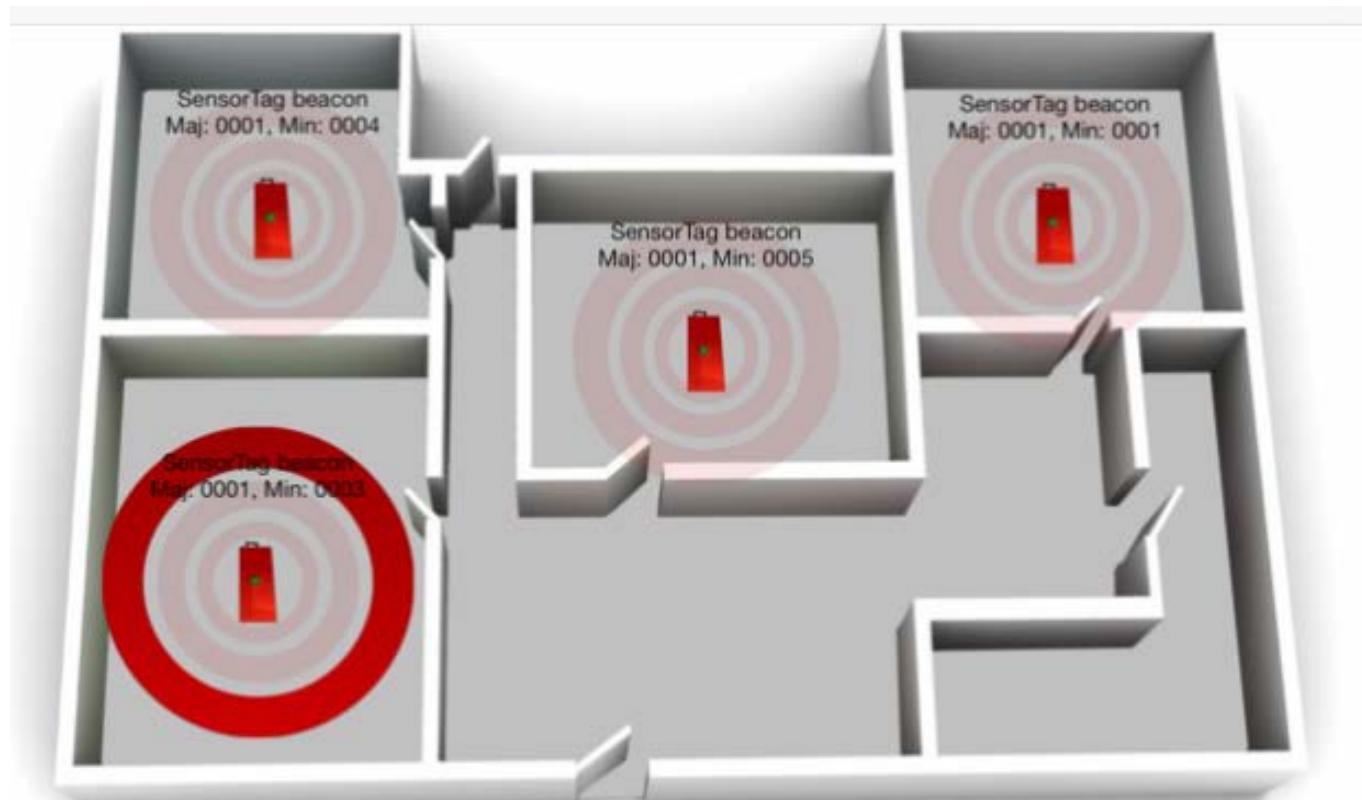


A beacon broadcasts the following ADV message

- UUID: ebefd083-70a2-47c8-9837-e7b5634df524
- Major: 21
- Minor: 17

The system realizes that it was emitted by a Beacon located at the **University of Pisa** (UUID), in **Building A** (Major), inside the **Room A28**(Minor)

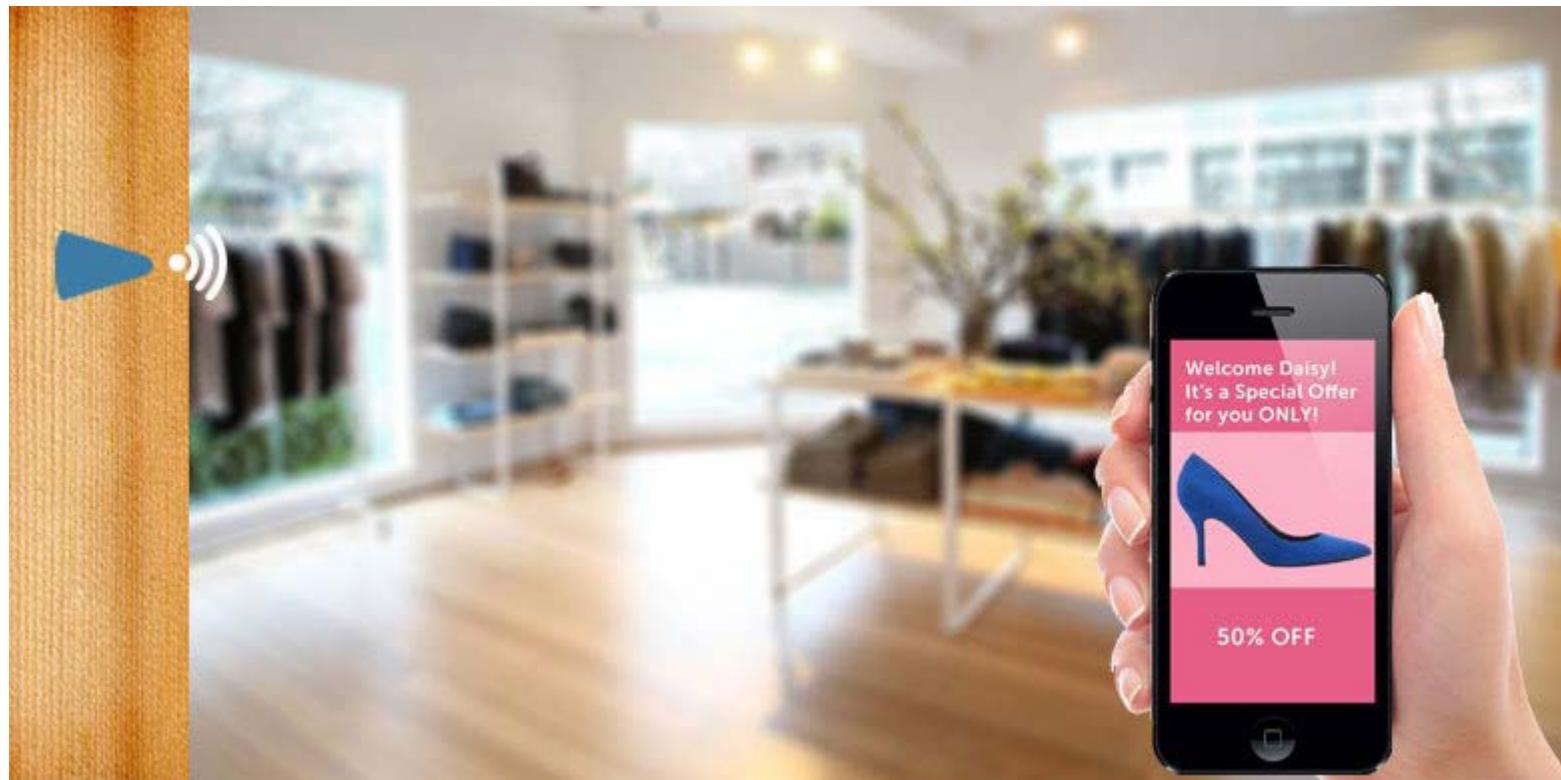
Localization in Buildings



Application Areas



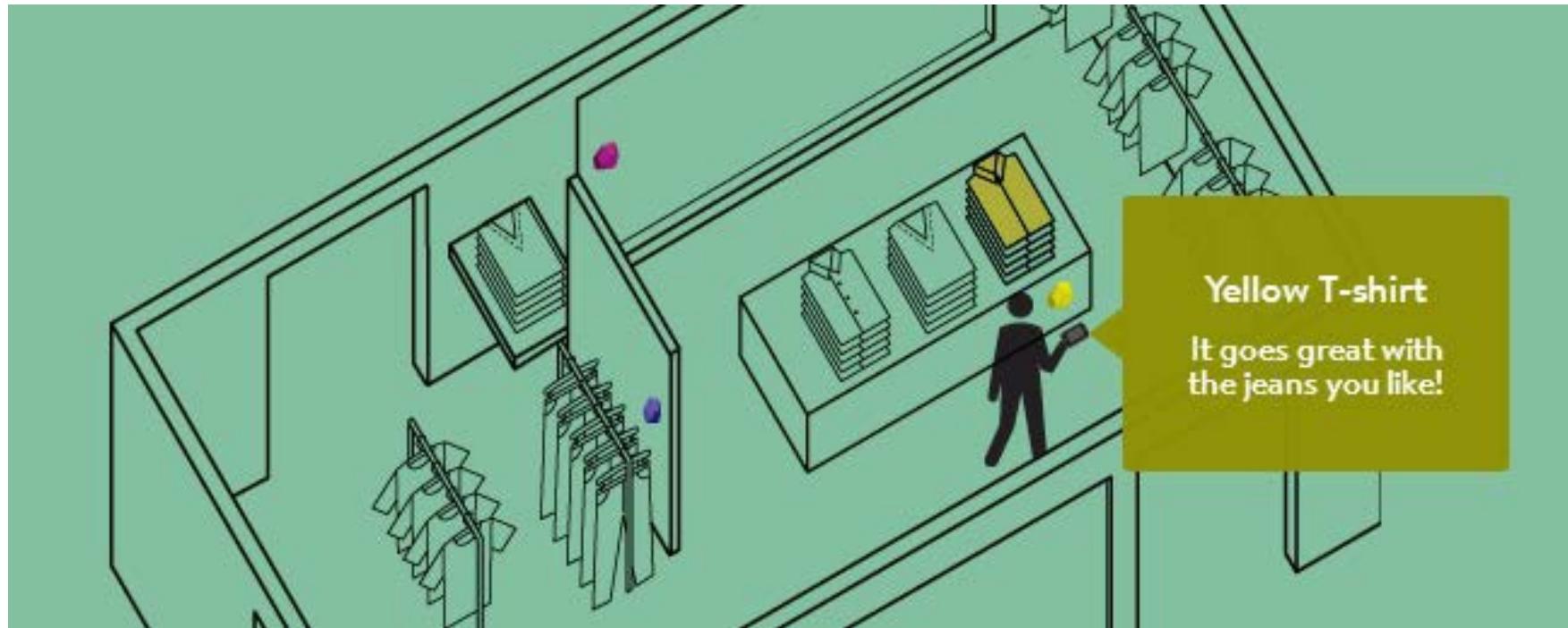
Retails: coupons delivered via Beacons to customer phone (e.g., special offers)



Application Areas



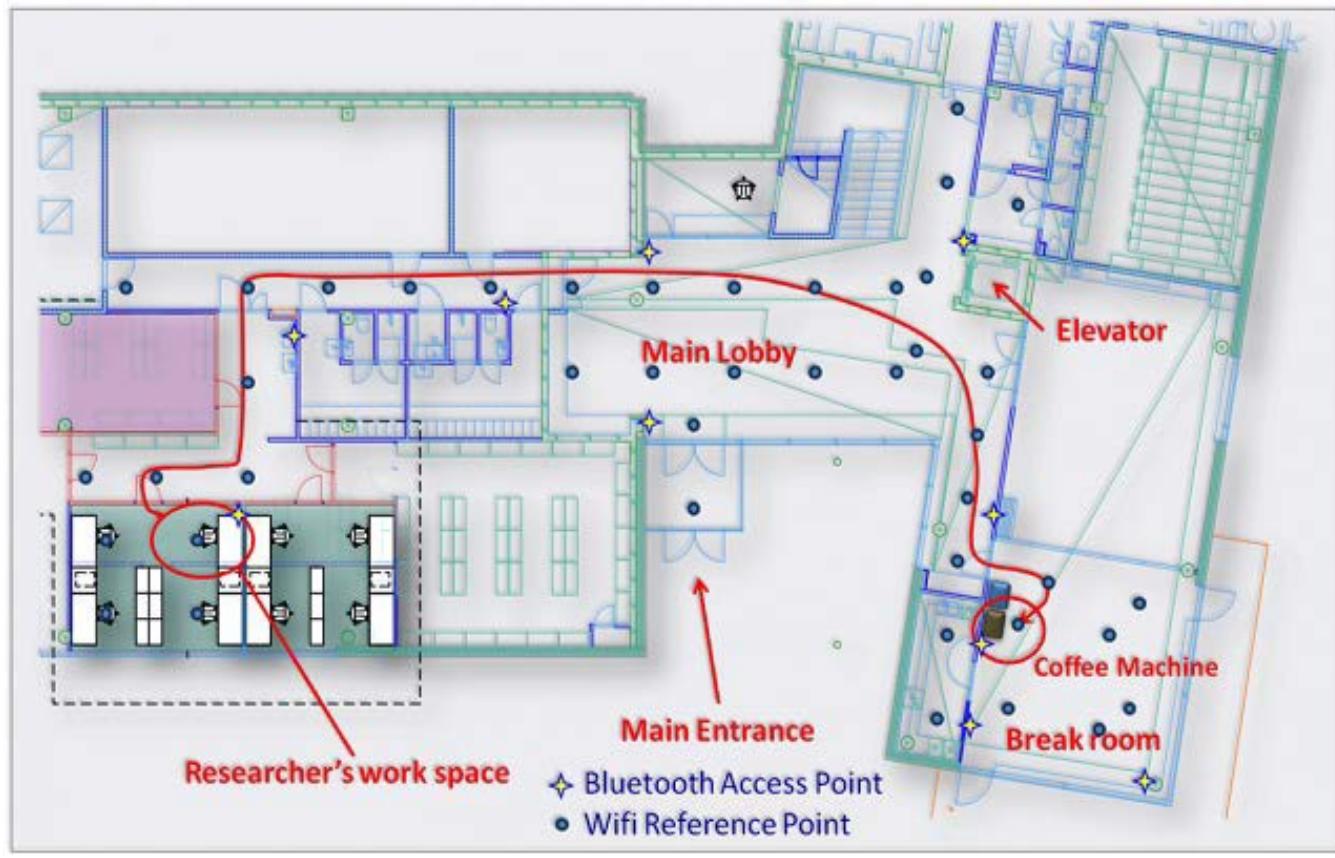
Tracking: locate museum artworks, shop products, or cargo containers



Applications Areas



Indoor Navigation: path discover inside a building and user localization



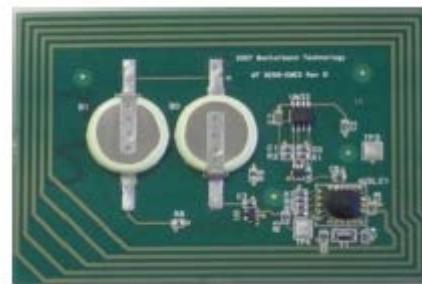
Application Areas



Smart Tagging: allows to give more information about artworks (also in many languages)



Semi-Passive Sensors



Semi Passive Sensors



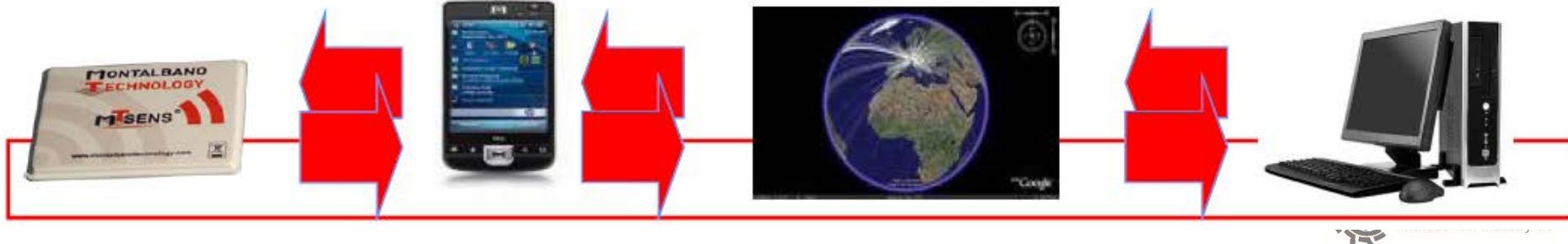
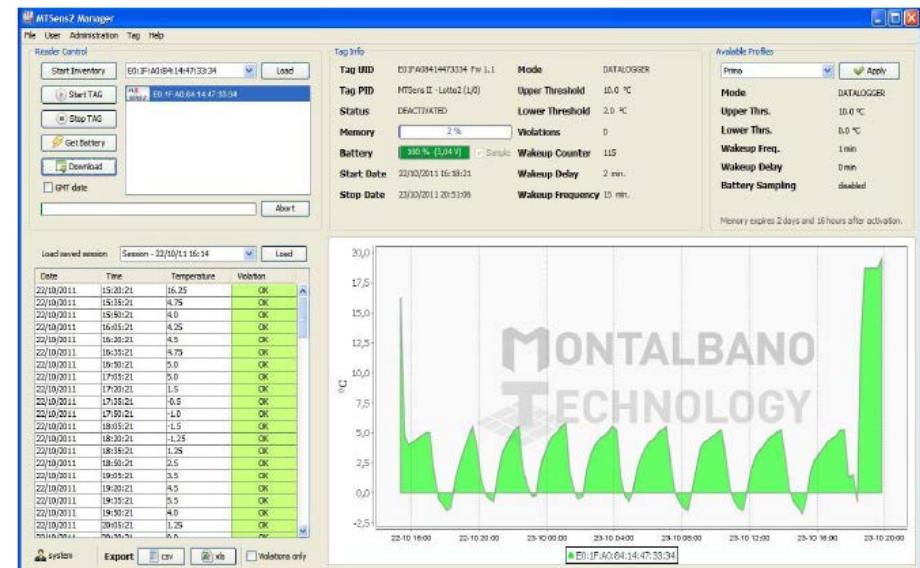
- Also called data loggers
- Powered by a battery
- Measures and stores physical quantities
 - Temperature
 - Humidity
 - Shock
 - ...
- Can be attached to goods to track their history
 - Low-cost solution



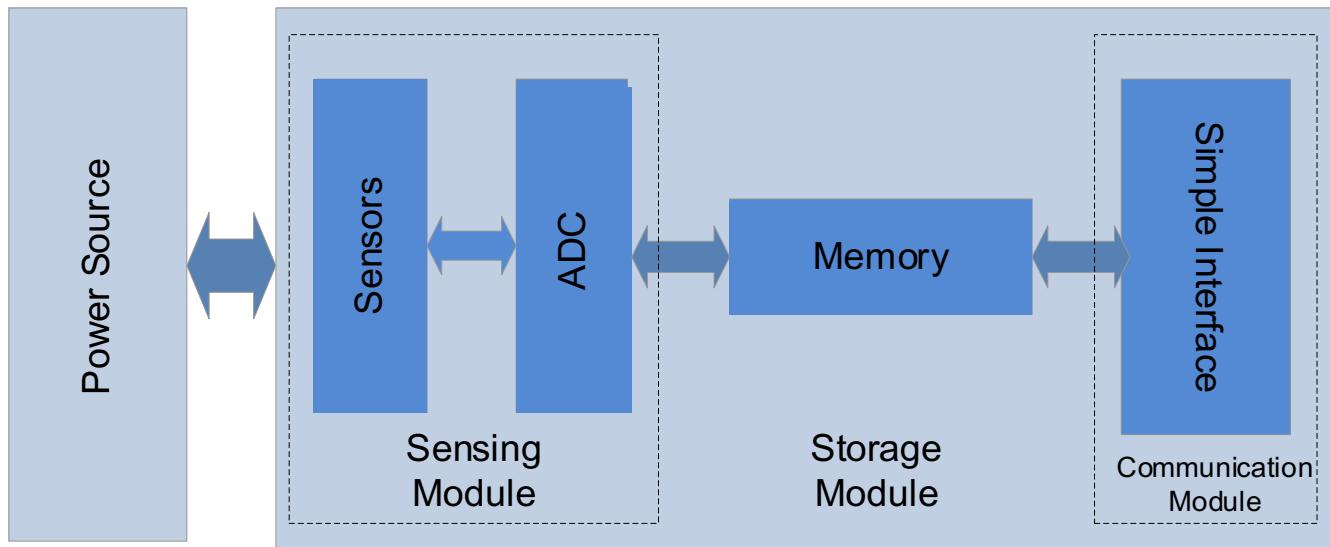
System Architecture



- Semi-passive Tag
- Reader
- Server
- Data manager
 - Tag management
 - Data retrieval and archival
 - Data visualization
⇒ Table, plots



Device Architecture



MTSensell Data Logger



RFID	ISO15693 (13,56 MHz)
Modalità di Acquisizione	1.Modalità senza soglie (datalogger): il tag acquisisce la temperatura ad intervalli regolari (impostabili dall'utente) 2.Solo violazioni di temperatura: vengono memorizzate solamente le temperature che si trovano al di fuori delle soglie di temperatura impostate 3.Registrazione continua con indicazione del numero di violazioni: il funzionamento è identico a quello senza soglie con la differenza che viene comunque tenuta traccia del numero delle temperature fuori soglia (violazioni).
Temperatura Operativa	-30°C; +60°C
Risoluzione	0,25°C
Accuratezza	±1°C
Capacità di memoria (2)	3840 nella prima e terza modalità di acquisizione 1920 nella seconda modalità (solo violazioni di temperatura)
Tempo di campionamento temperatura	L'intervallo dei valori per il tempo di campionamento è compreso tra 1 minuto e 1440 minuti (24 ore).
Programmazione Delay	Valore intero espresso in minuti che indica dopo quanto tempo il tag dovrà partire rispetto all'attivazione del tag.
Area dati utente	26 byte x 32 (832 Byte) a disposizione per la memorizzazione di dati personali.
Dimensioni	89mm x 69mm x 4.5mm
Durata Batterie (funzionamento continuo a +25°C)	10 mesi (2)
Lettura diretta del valore della batteria	(3)

.0

Application Areas



- Ice cream, Frozen Products Distribution
 - Temperature monitoring
- Wine Transport
 - Temperature monitoring
 - Shock tracking
- Blood Bags Transport
 - Bag Identification
 - Temperature tracking
- ...



Home work



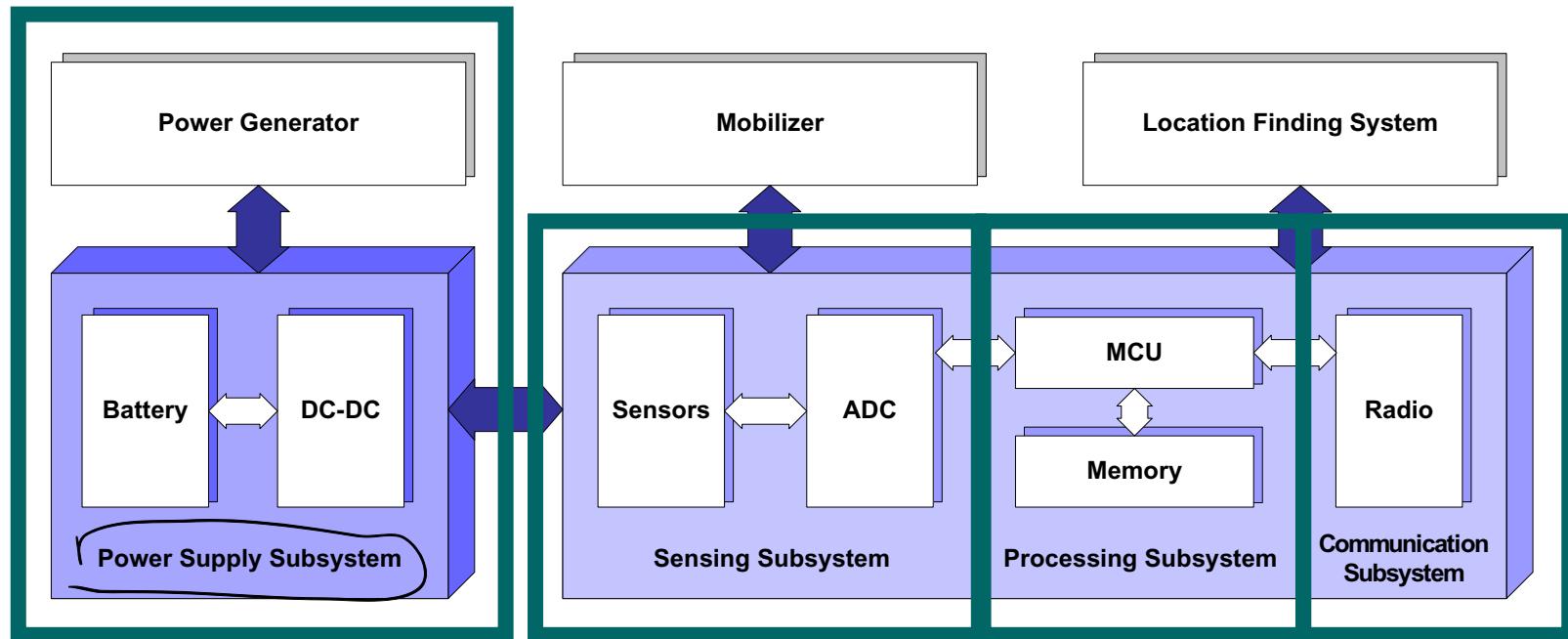
- Form small groups
- Think about possible simple application based on Passive/active tags
 - ⇒ Objectives
 - ⇒ Requirements
 - ⇒ Main components
 - ⇒ Links between components



Sensor Nodes



Sensor Node Architecture



Battery powered devices

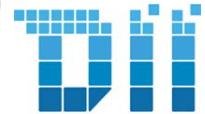
Batteries cannot be charged over long distances

Usually negligible power consumption

Radio is the most power hungry component

CHANGED OR
RECHARGED

Available Sensor Platforms



Sensor Node	Microcontroller	Transceiver	Program+Data Memory	External Memory	Programming	Remarks
<u>BT node</u>	Atmel ATmega 128L (8 MHz @ 8 MIPS)	Chipcon CC1000 (433-915 MHz) and Bluetooth (2.4 GHz)	64+180 K RAM	128 KB FLASH ROM, 4 KB EEPROM	C and nesC Programming	BTnut and TinyOS support
<u>IMote</u>	ARM core 12 MHz	Bluetooth with the range of 30 m	64 KB SRAM	512 KB flash		TinyOS Support
<u>IMote 1.0</u>	ARM 7TDMI 12-48 MHz	Bluetooth with the range of 30 m	64 KB SRAM	512 KB flash		TinyOS Support
<u>IMote 2.0</u>	Marvell PXA271 ARM 11-400 MHz	TI CC2420 802.15.4/ZigBee compliant radio	32 MB SRAM	32 MB flash		Microsoft .NET Micro, Linux, TinyOS Support
<u>Mica</u>	<u>ATmega 103</u> 4 MHz 8-bit CPU	RFM TR1000 radio 50 kbit/s	128+4 KB RAM	512 KB flash	nesC Programming	TinyOS Support
<u>Mica2</u>	ATMEGA 128L	Chipcon 868/916 MHz	4 KB RAM	128 KB flash		TinyOS, SOS and MantisOS Support
<u>Mica2Dot</u>	ATMEGA 128		4 KB RAM	128 KB flash		
<u>MicaZ</u>	ATMEGA 128	TI CC2420 802.15.4/ZigBee compliant radio	4 KB RAM	128 KB flash	nesC	TinyOS, SOS, MantisOS and Nano-RK Support
<u>TelosB</u>	Texas Instruments MSP430 microcontroller	250 kbit/s 2.4 GHz IEEE 802.15.4 Chipcon Wireless Transceiver	10 KB RAM	48 KB flash		Contiki, TinyOS, SOS and MantisOS Support
<u>T-Mote Sky</u>	Texas Instruments MSP430 microcontroller	250 kbit/s 2.4 GHz IEEE 802.15.4 Chipcon Wireless Transceiver	10 KB RAM	48 KB flash		Contiki, TinyOS, SOS and MantisOS Support

http://en.wikipedia.org/wiki/List_of_wireless_sensor_nodes

Available Sensor Platforms



Sensor Node	Microcontroller	Transceiver	Program+Data Memory	External Memory	Programming	Remarks
Wasp mote	Atmel ATmega 1281	ZigBee/802.15.4/Dig iMesh/RF, 2.4 GHz/868/900 MHz	8 KB SRAM	128 KB FLASH ROM, 4 KB EEPROM, 2 GB SD card	C/Processing	GPRS, Bluetooth, GPS modules, sensor boards..
Zolertia Z1	Texas Instruments MSP430F2617	Chipcon CC2420 2.4 GHz IEEE 802.15.4 Wireless Transceiver	8 KB RAM	92 KB flash	C, nesC	Contiki and TinyOS Support. 16 Mbit external flash + 2 digital on-board sensors
WiSense	TI MSP430G2955	TI CC2520 (2.4 GHz), TI CC1101 (865-867 MHz)	4 KB RAM	56 KB FLASH, 256 bytes EEPROM	C	Modular (pluggable), No OS (Loop with event flags), Basic node includes temperature sensor, light sensor and coin cell retainer
Shimmer	MSP430F1611	802.15.4 Shimmer SR7 (TI CC2420)	48 KB flash 10 KB RAM	2 GB microSD Card	nes C and C Programming	TinyOS Support. Built in 3 Axis Accel, Tilt/Vib Sensor. Full range of expansion modules.
SunSPOT	ARM 920T	802.15.4	512 KB RAM	4 MB flash	Java	Squawk Java ME Virtual Machine
....						

http://en.wikipedia.org/wiki/List_of_wireless_sensor_nodes

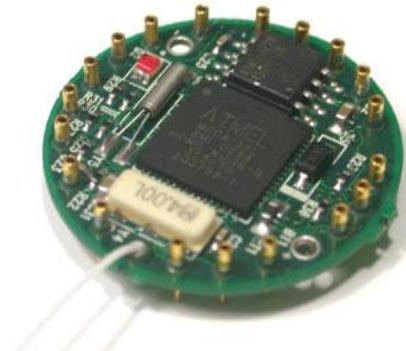
Mica Motes



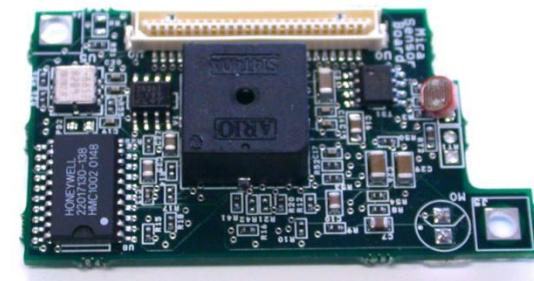
Mica2



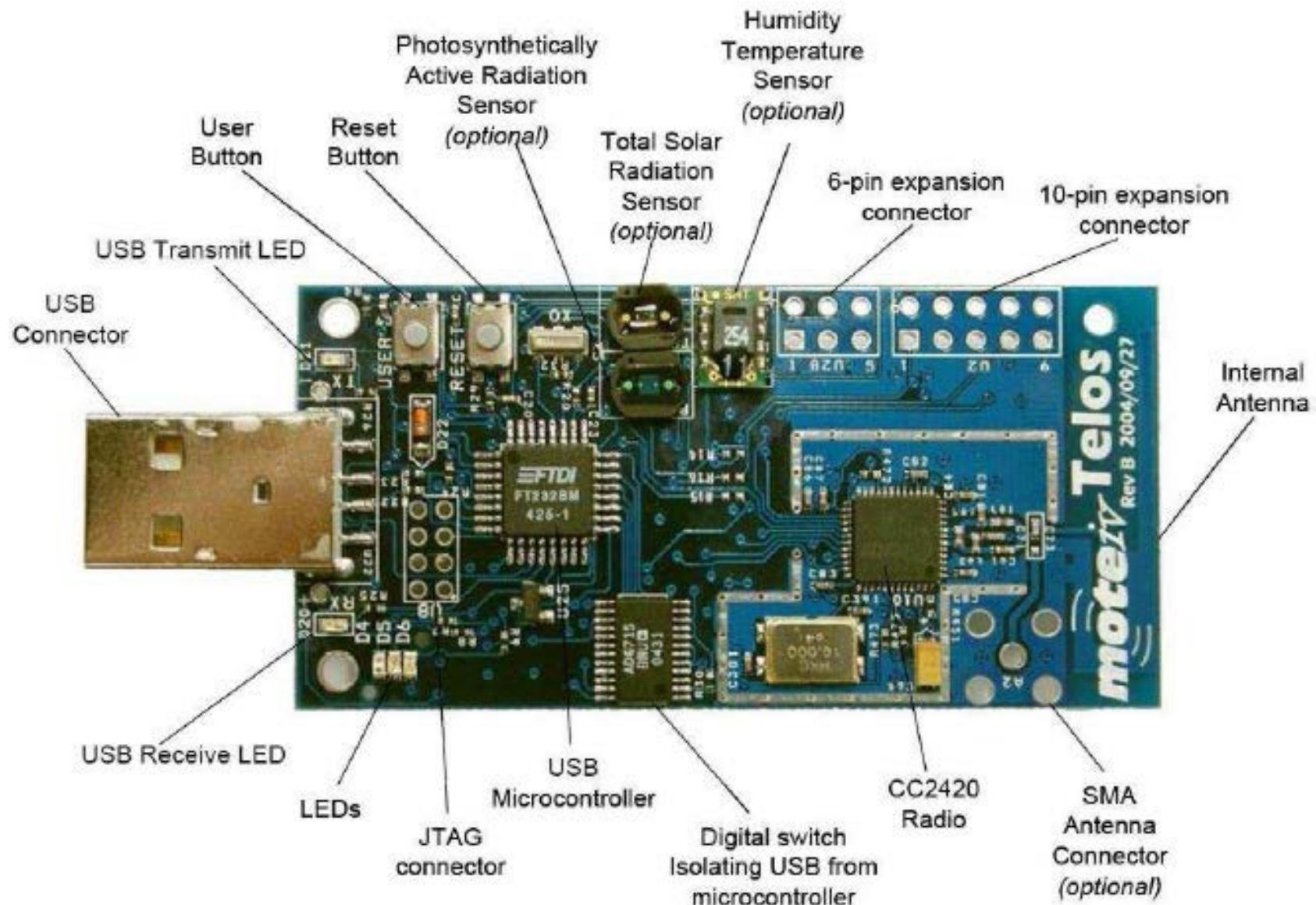
Mica2dot



Sensor Board for Mica
light, temperature, accelerometer,
magnetometer, microphone, tone
detector, 4.5 KHz sounder



Telos/Tmote Sky Mote



Challenges to be addressed



- Driven by interaction with environment
 - Message arrival, sensor acquisition
 - Concurrency Management
 - ⇒ Event arrival and data processing are concurrent activities
 - ⇒ Potential bugs must be managed (e.g., race conditions)
- Limited Resource
 - Due to small size, low cost and low power consumption
- Reliability
 - Although single node may fail, we need long-lived applications
 - No recovery mechanism in field, except automatic reboot
- Soft real-time requirements

The TinyOS Operating System



- Specifically targeted to WSNs

- Component-based architecture → Consist w/ un centralizd
di componenti che possono
essere aggiornati o no
- Event-based concurrency
- Split-phase operation

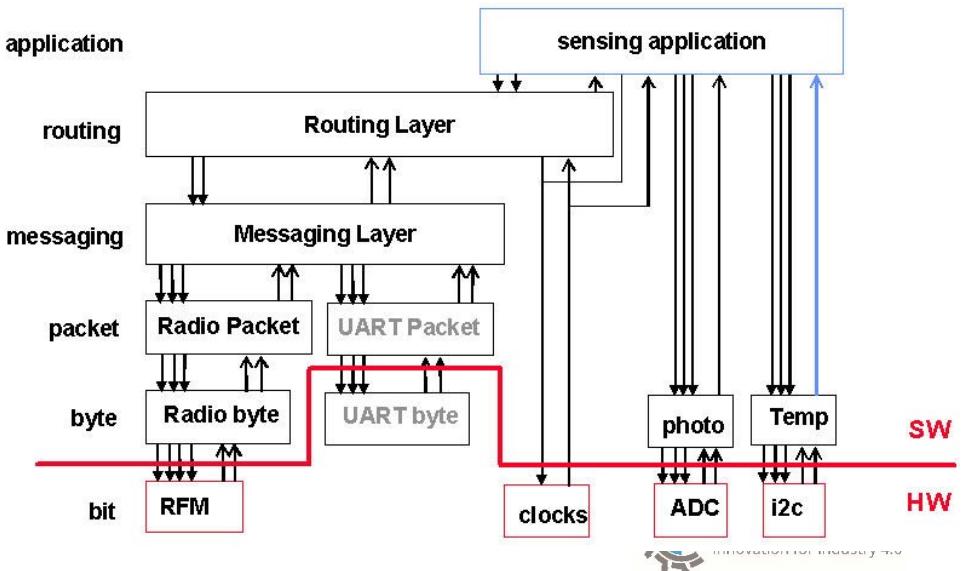
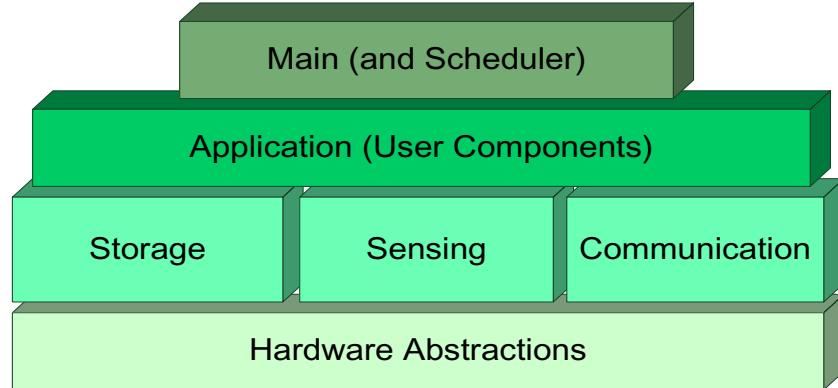
<http://www.tinyos.net/>



TinyOS Architecture



- Component-based architecture
- Components
 - Software modules
 - Hardware modules
 - The distinction is invisible to developers
- Unused Services
 - Excluded from the application



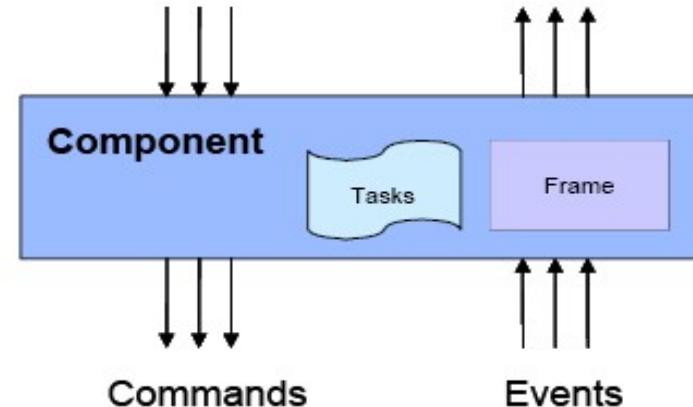
Component-based computation model



■ Component

- computing entity
 - ⇒ interface
(commands and events)
 - ⇒ frame (private variables)

A FUNCTION => WALKS IN A COMPONENT



■ Computing abstractions

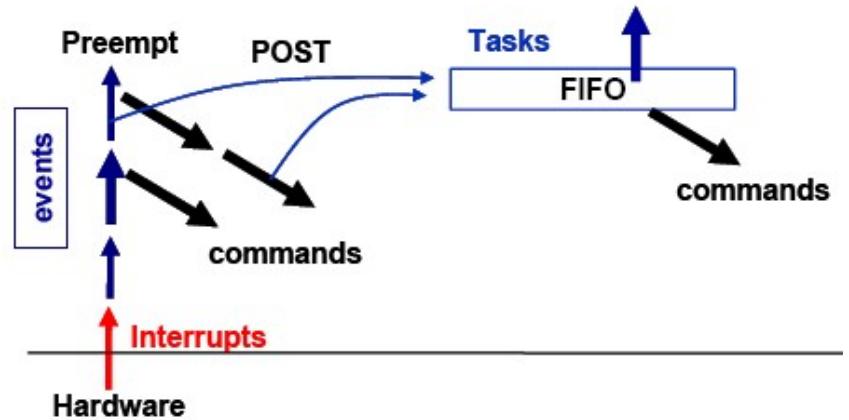
- command
 - ⇒ service request to a component
 - ⇒ non-blocking
- event
 - ⇒ command completion, message or interrupt
- task
 - ⇒ context of execution (~function)
 - ⇒ run to completion, preemption by event



Concurrency Management



- Two sources of concurrency
 - Tasks and Events (interrupts)
 - Components can post a task
 - The post operation returns immediately
- Task scheduling
 - FIFO (non pre-emptive)
- Tasks run to completion
 - Can be pre-empted only by events
- Events run to completion
 - Signify either an external event (message) or completion of a split-phase operation
 - May pre-empt tasks



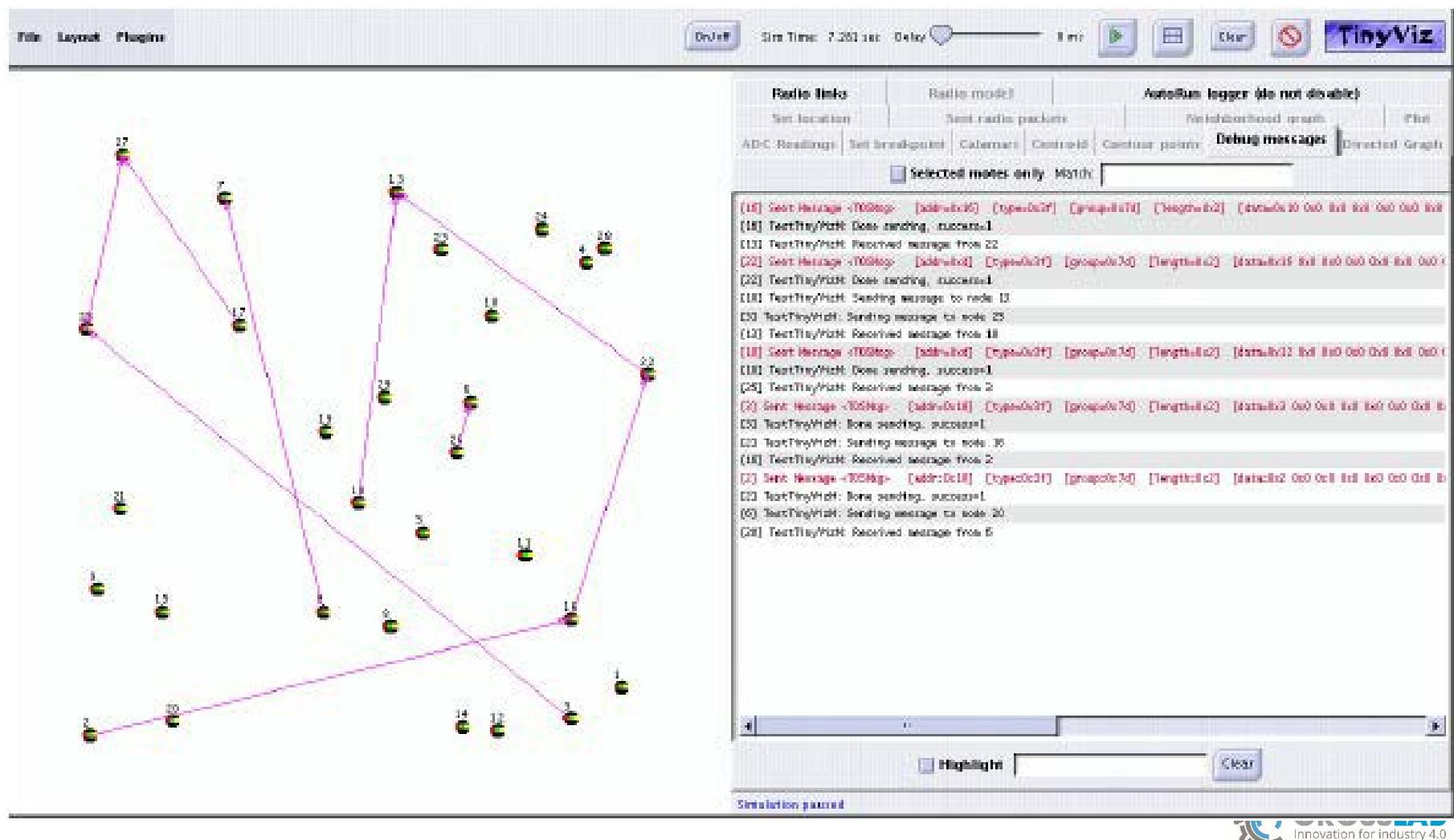
TinyOS development environment



NETWORKED FEDDED SYSTEMS

- nesC language
 - extension to the C language
 - definition of interfaces
 - abstraction between definition and composition of components
- nesC compiler and OS source
 - composition of the component graph (at compilation time)
 - TinyOS computational model (additional checks)
- TOSSIM simulator
 - same code runs in actual nodes and simulator
 - flexible models for radio and sensors
 - scripting (Python), graphical interface (TinyViz)





Tutorials on TinyOS Programming Environment



- TinyOS/TOSSIM Tutorial,
[http://docs.tinyos.net/index.php/TinyOS Tutorials](http://docs.tinyos.net/index.php/TinyOS_Tutorials)
- TinyOS Reference Manual, <http://www.tinyos.net/tinyos-2.x/doc/pdf/tinyos-programming.pdf>
- D. Gay et al., "The nesC Language: A Holistic Approach to Networked Embedded Systems", 2002.
- nesC Reference Manual, <http://www.tinyos.net/dist-2.0.0/tinyos-2.0.0beta1/doc/nesc/ref.pdf>

Contiki Operating System



PENSATO SPECIFICAMENTE PER IOT

- Limited Memory Footprint
- Event-driven Kernel
- Portability
 - Many different platform supported
 - ⇒ Tmote Sky, Zolertia, RedBee, etc
- C Programming per ora variante
- Academic and Industrial support
 - Cisco and Atmel are part of the *Contiki project*



Contiki Operating System



- Protothread (optional multi-threading)
- Dynamic Memory Allocation
- TCP/IP stack (**uIP**)
 - Both IPv4 and **IPv6**
- Power profiling → *exact AncoPA J1850bus*
- Dynamic loading and over-the-air programming
Post different RAC scenarios
- IPsec
- On-node database Antelope
- Coffee file system
- ...

Contiki Operating System



- Prototread example
 - Stop-and-wait sender

```
PROCESS_THREAD(reliable_sender, ...) {
    PROCESS_THREAD_BEGIN();

    do {
        PROCESS_WAIT_UNTIL(data_to_send());
        send(pkt);
        timer_start();
        PROCESS_WAIT_UNTIL((ack_received() || timer_expired()));
    } while (!ack_received());

    PROCESS_THREAD_END();
}
```

References



- A. Dunkels, B. Gronvall, T. Voigt, “**Contiki - a lightweight and flexible operating system for tiny networked sensors**”, IEEE International Conference on Local Computer Networks, 16-18 November 2004
- Contiki: The Open Source OS for the Internet of Things, <http://www.contiki-os.org/>
<http://en.wikipedia.org/wiki/Contiki>
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Mote's Application Areas



Ανάδο ή ΝΟΔ σενσόρι σαν κέντρο πλεού

- Environmental Monitoring
 - Temperature, Humidity, Light Intensity, ...
- Presence Detection
 - Home security systems
 - Energy efficiency in buildings
- Location Detection
 - Anti-theft systems
- Activity Detection
 - Fall detection
 - Athlete monitoring
- ...



A very special sensor node



Very Special Sensor Node



Mobile Phone Sensing Applications



- Personal Sensing
 - E.g., personal tracking
 - SoundSense
- E-health
 - Fall detection, Activity detection
 - Well-being support
- CenceMe
 - Captures what the user is doing and the information on their surrounding context (collectively called sensing presence)
 - Pushes collected information to facebook, myspace and twitter
- EyePhone
 - Allows to activates your mobile phone using only your eyes

You can find a lot of interesting apps at <http://sensorlab.cs.dartmouth.edu/index.html>



Participatory Sensing

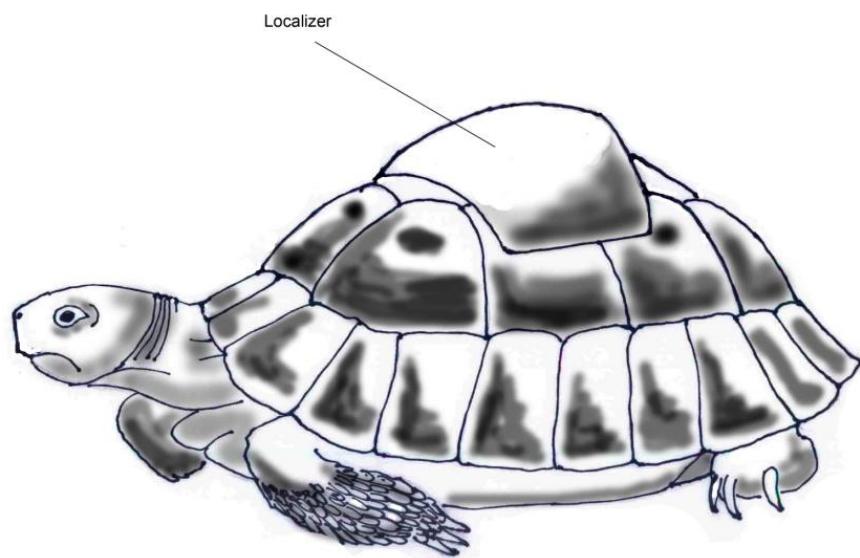


Citizens utilize their mobile phones to send physical sensing information to a data collection center

Sensing information can be used for various applications



An example of smart object (animal)



- Project of the University of Pisa

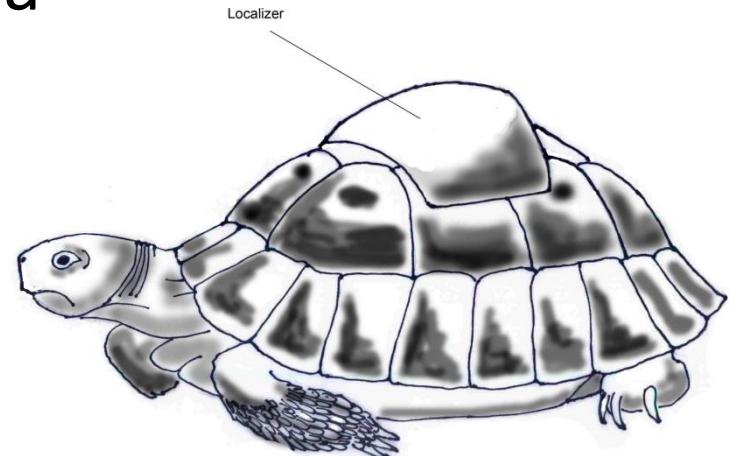
- Dept. of Computer Science
- Dept. of Information Engineering
- Patent Pending

- Goal

- protection of wild tortoise populations
- early localization of the nesting sites

- Solution

- sensor-based system installed on top of the carapace
- localizes the tortoise during its deposition phase
- transmits its geographic coordinates to a remote control center in real time



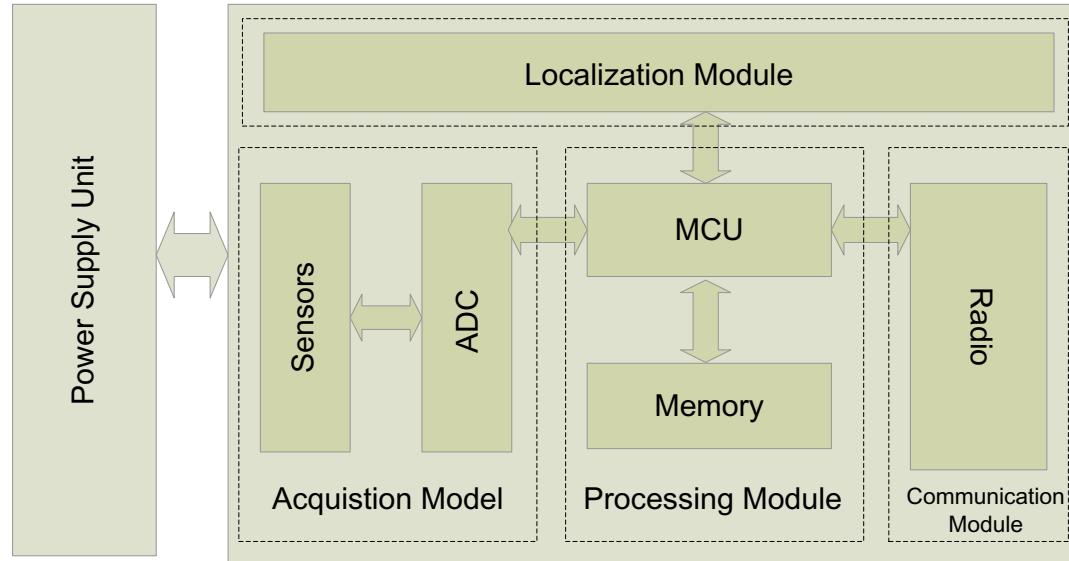
Tortoise@: challenges



- Weight limitations
- Form factor
- Energy limitations
 - Power management strategies
- Deposition pattern recognition
 - Deposition occurs only under some environmental conditions
 - Typical movements
 - ⇒ Due to nest excavation phase



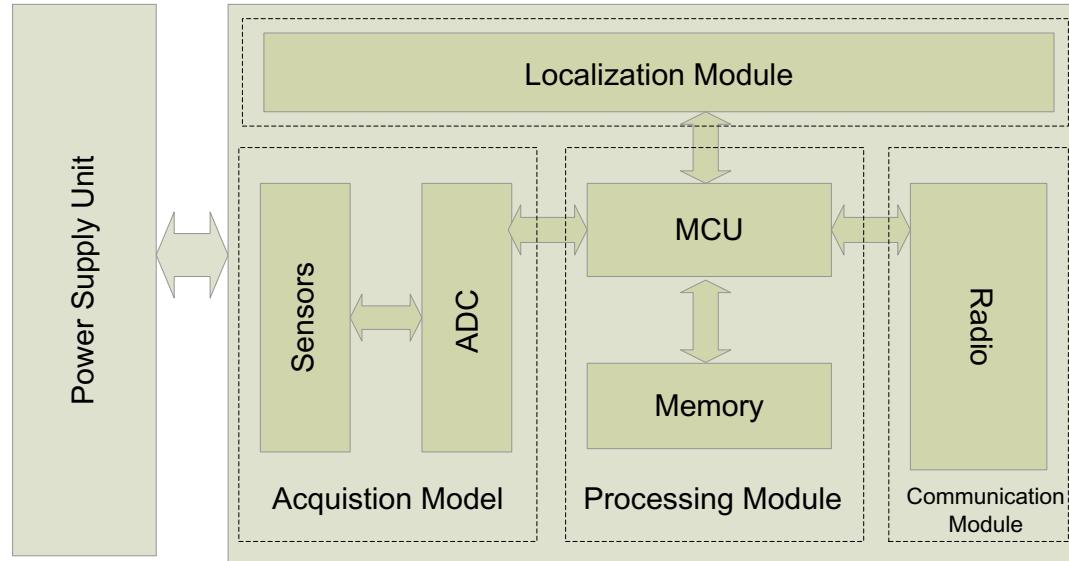
Tortoise@: system architecture



■ Acquisition Module

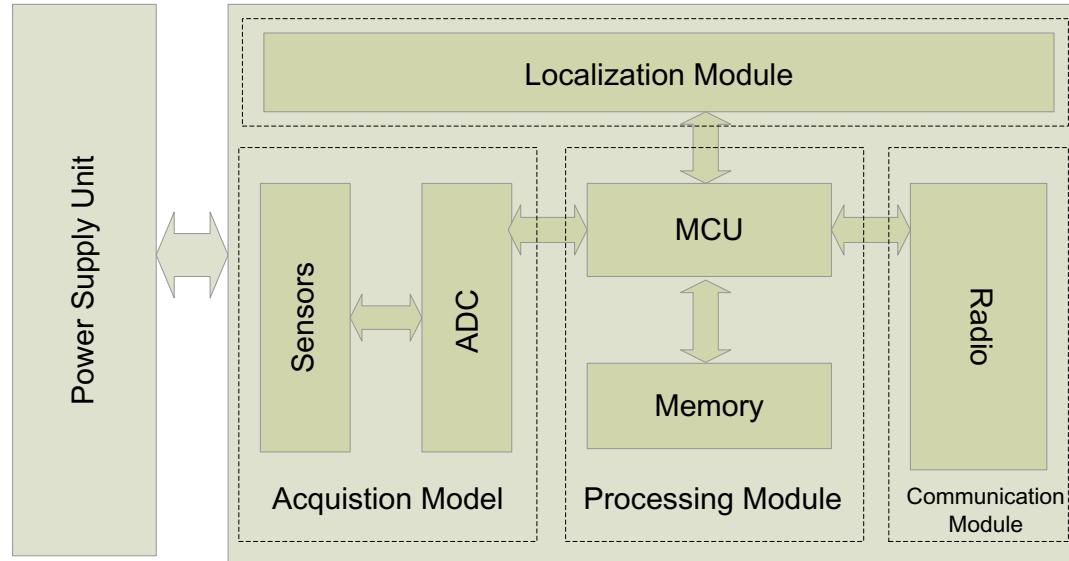
- monitors external conditions and tortoise's movements
- Environmental sensors
 - ⇒ temperature, light intensity, humidity
- 3-axis accelerometer, compass

Tortoise@: system architecture



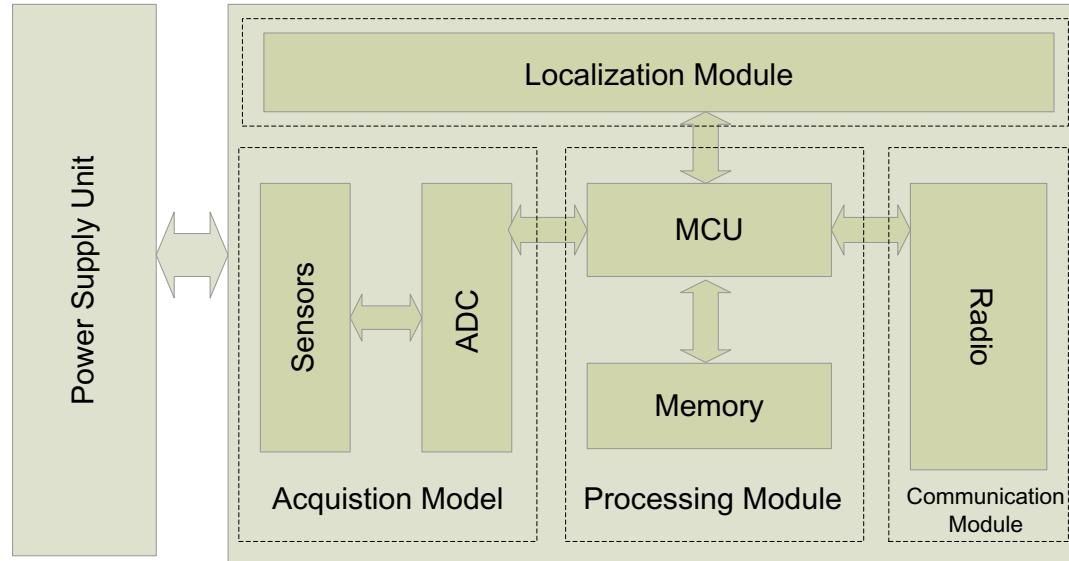
- Localization Module
 - Geographic localization system (e.g. GPS receiver)
 - Allows to localize the monitored tortoise

Tortoise@: system architecture



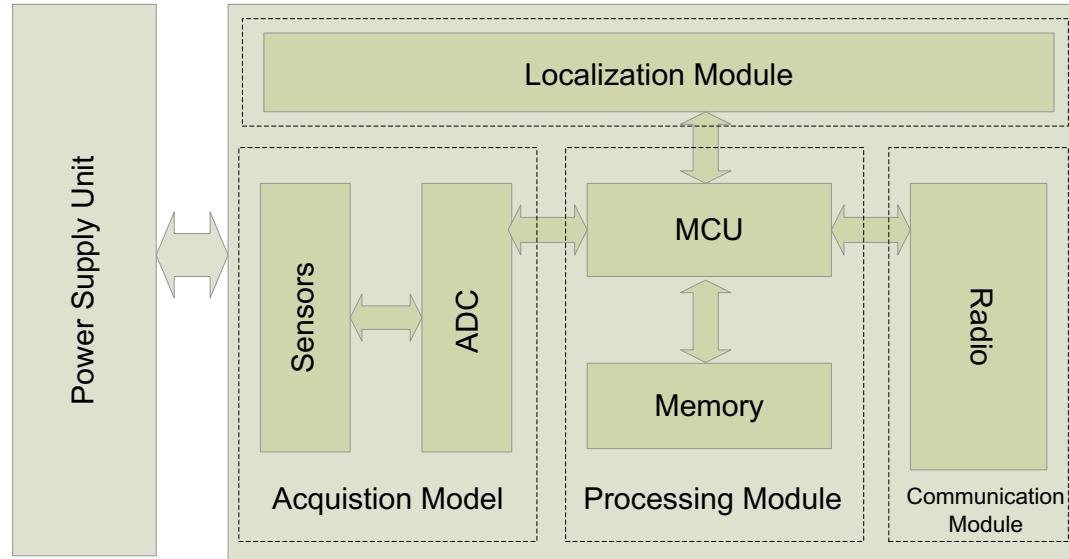
- Processing Module
 - micro-controller and (RAM + Flash) memory
 - stores and processes data received from the sensors and/or the localization module.

Tortoise@: system architecture



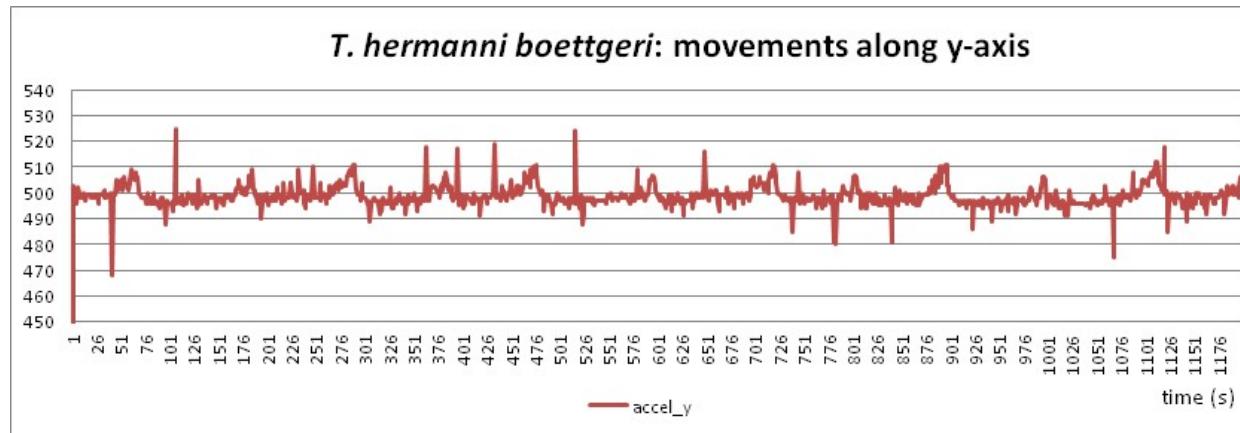
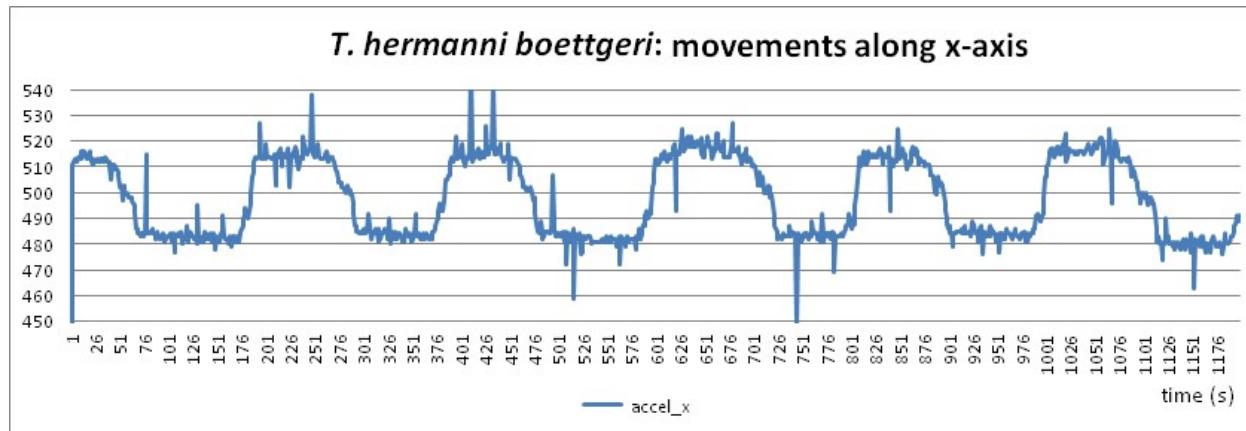
- **Communication Module**
 - long-range radio to communicate in real time
 - ⇒ the tortoise's location and motion direction (reported by the localization module and compass, respectively)

Tortoise@: system architecture



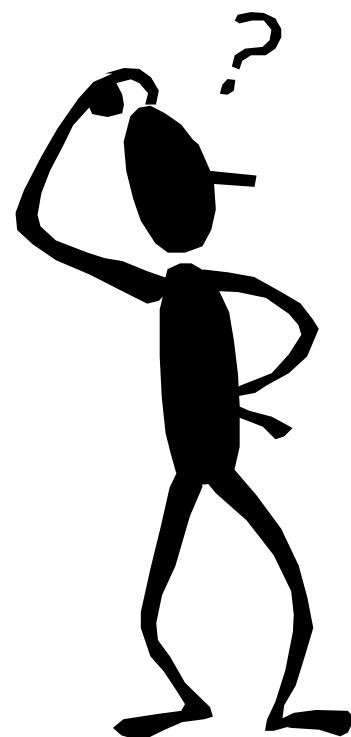
- Power Supply Unit
 - consists of one or more batteries
 - feeds all the system components
 - must have a lifetime of some months
 - ⇒ Power management required

Tortoise@: experimental data

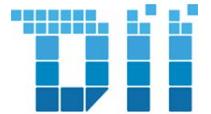


Typical movements of a *T. hermanni boettgeri* tortoise during the nest excavation phase, along the x-axis (top side) and y-axis (bottom side)

Questions



Practical Activity



- Think of a realistic application based on
 - Passive tags (QR codes, RFIDs)
 - Active Tags (Beacons)
 - Data Loggers
 - Sensors/Sensor Nodes
- Application Requirements
 - Application Domain, Potential Users
 - Goals, User Desires
 - Requirements
- Define the overall system
 - Services
 - Overall architecture
 - Components
 - Functionalities provided by each component
 - ...