Sensor networks and applications

IoT, outlook

IoT

Internet (of People)

- The traditional Internet consists of „things” as well
  - PCs, servers, routers
- But the end users generate the content, data
  - emails, documents, web pages, photos, etc.
- People have limited time, attention and accuracy
  - They are not good at monitoring and record all the happenings in the real world

Internet of Things (IoT)

- **Kevin Ashton** (1999)
  - MIT Auto-ID, Procter & Gamble

- Data gathering without human intervention
  - Intelligent devices with unique ID
    - Sensors, smart phones, vehicles, etc.
  - Monitoring and communicating
    - Collected data are sent to the cloud (network)
    - Analytics, filtering, aggregation, data mining
    - Generating value-added services
- It is not the pure data that are valuable, rather its analytics

What is IoT?

Network of ”smart things”

- Why a thing is „smart”?
  - It has a CPU and memory, it can sense its environment using sensors
  - It is able to communicate

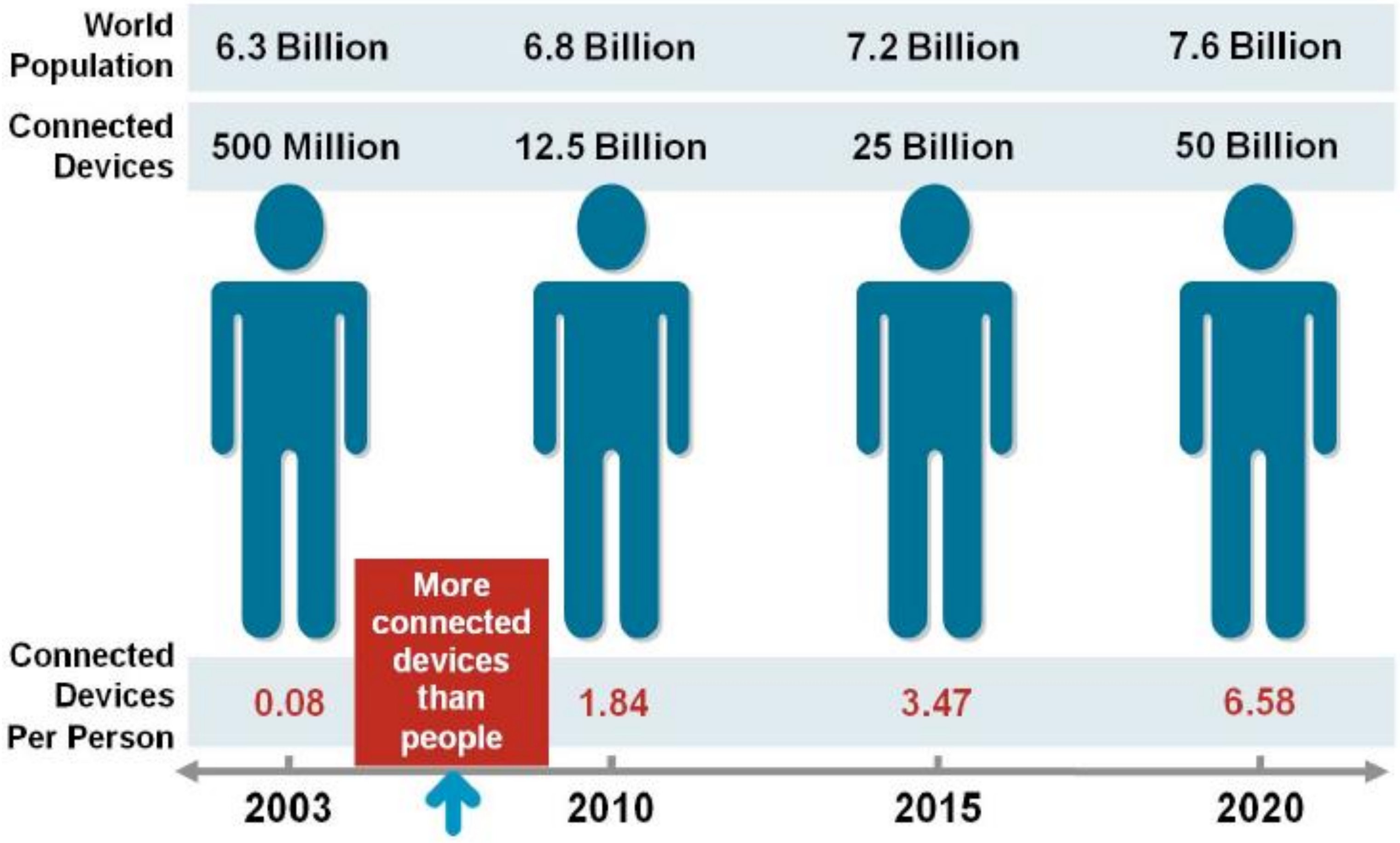
OKOS VÁROS @ BME TMIT

The first IoT device?

- A Coca-Cola vending machine at Carnegie Mellon University (**1982 !!**)
  - It was cheaper by 10 cents than the other machines
  - Everyone went there, but it was annoying if the machine was out of coke, or it was just reloaded and the coke was warm.
  - Four students - Mike Kazar, David Nichols, John Zsarnay, and Ivor Durham
    - Let's connect the machine to the Internet!
  - **It's state could be queried**
    - Are all „empty" lamps turned on?
    - When was it reloaded? (Are the drinks cold enough?)
  - The machine became the most popular vending machine in whole Pennsylvania

How many things?

- Cisco, Ericsson forecasts – 50 billion devices by 2020
-



Source: Cisco IBSG, April 2011

IoT vs. Cloud

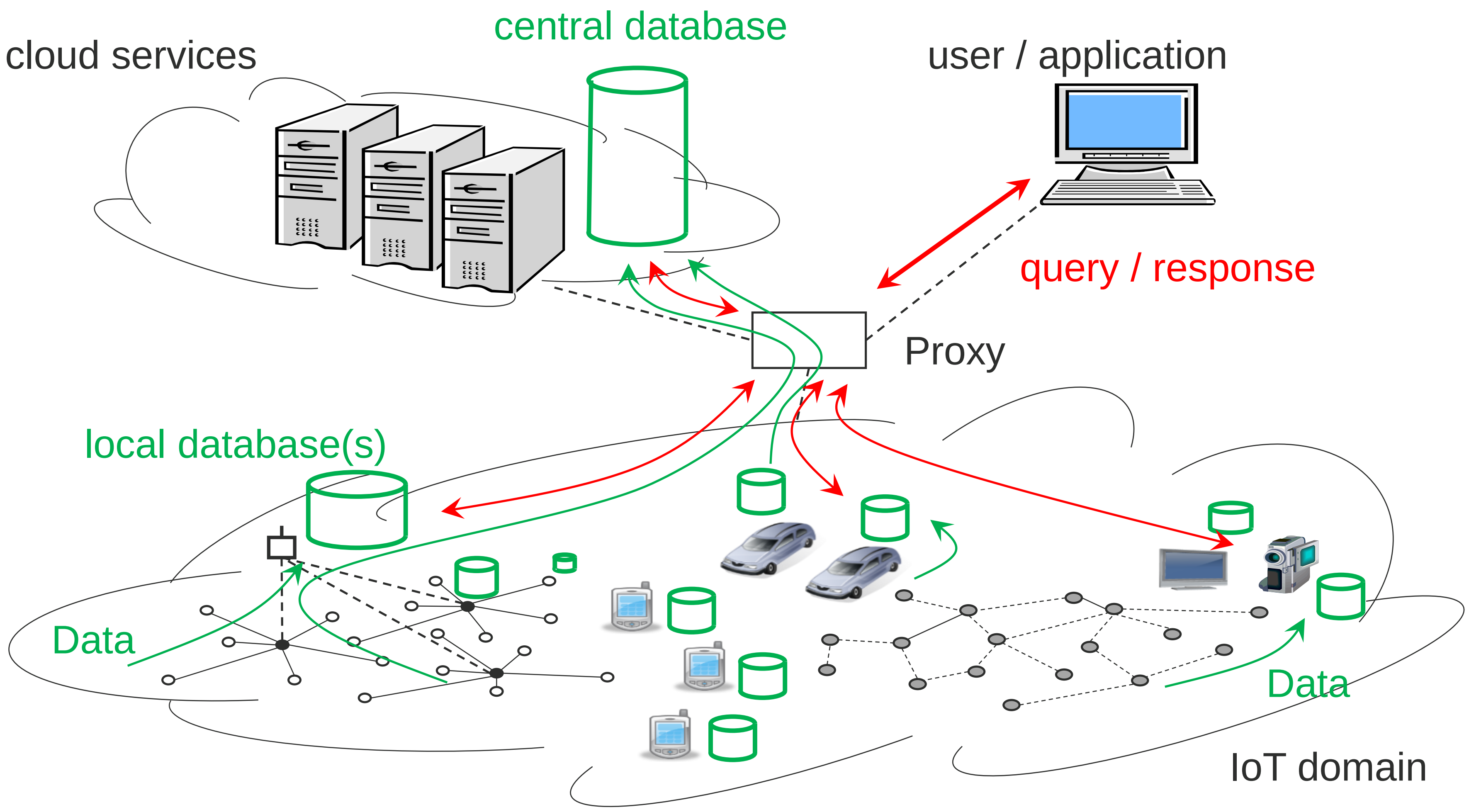
- **Can collect data, and can communicate. What else?**
  - **Where can the collected data be stored?**
  - **How can it be processed?**
    - Filtering, aggregation, correlation analytics, etc.. – Big Data
  - **How are the information be given back to the IoT application?**
- The sensor (IoT) devices cannot store and process the data in the long run
  - Limited memory (RAM, Flash), CPU, energy

IoT vs. Cloud

- **Is it really necessary to send all data to the cloud?**
  - Radio communication is energy hungry
  - It is advisable to do some preprocessing and aggregation locally
  - The measurement and data transmission are two separate tasks
    - Measurements must be done according to the application’s need
    - Data transmission must be done energy efficiently

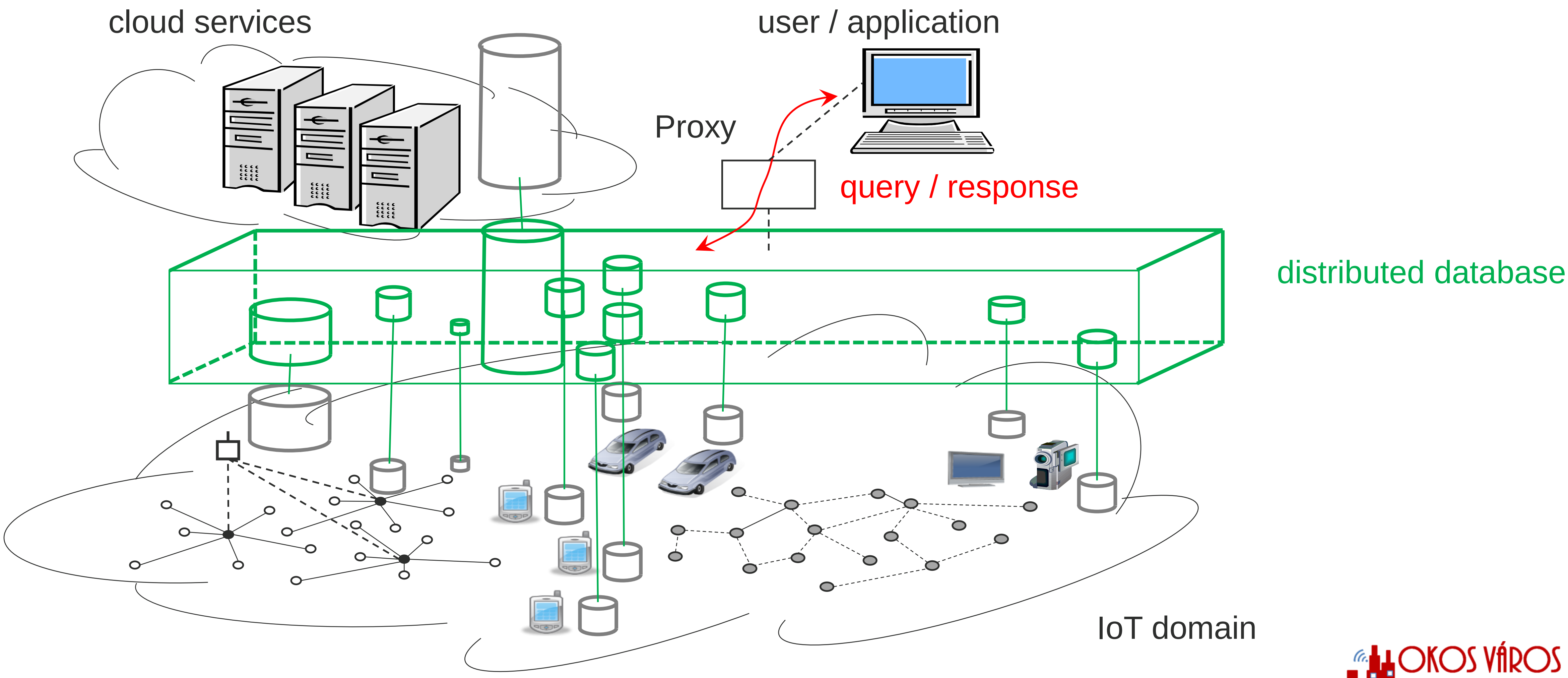
IoT vs. Cloud

- Data in the cloud, but also in the IoT domain



IoT vs. Cloud

- Distributed database between the cloud and the IoT domain



Caching in IoT

- Popular videos on youtube
  - (Slowly) changing popularity, static content
  - (relatively) easy to cache
- Popular web pages
  - Static pages are easy to cache
  - It's harder if the pages are dynamic, it is served directly from the server
- Popular sensor (IoT) data
  - „What are the traffic haracteristics on the Chain Bridge?"
  - **Hard to cache, but it is worth it!**
    - Not just because of energy efficiency, but because of scarce radio resources

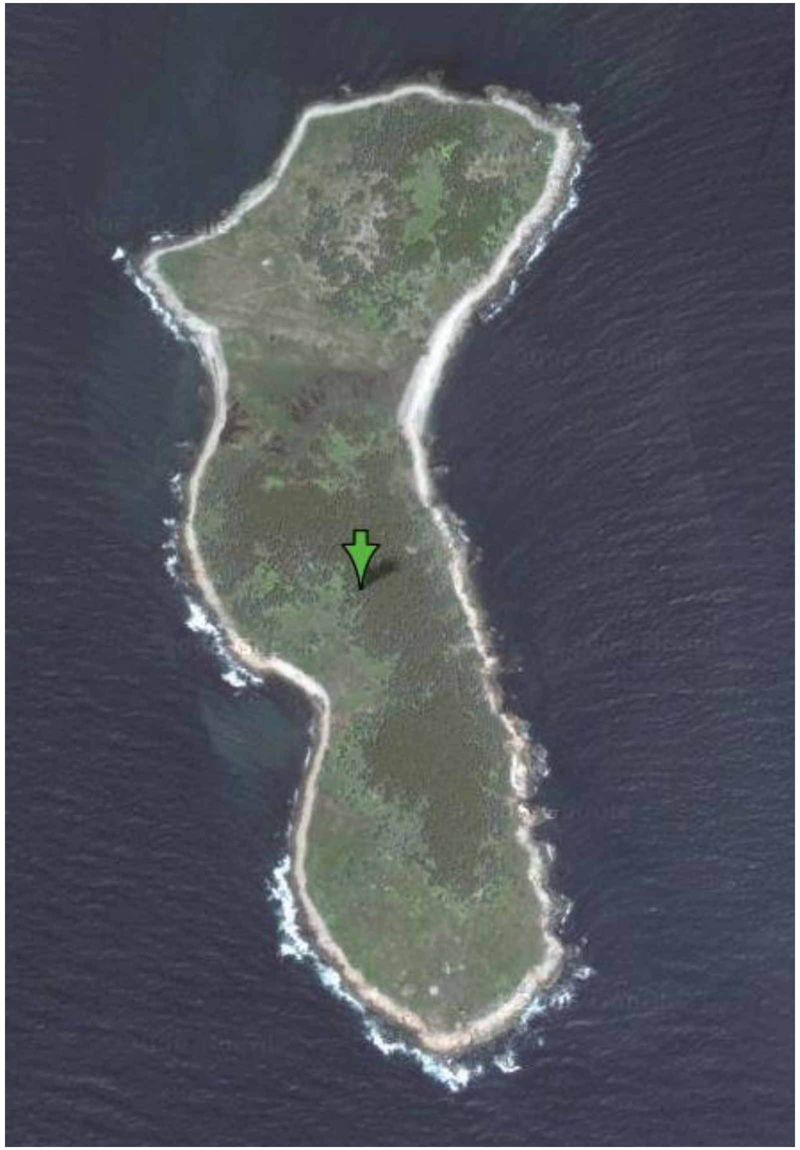
Related notions

- Ubiquituous networking / computing
  - Mark Weiser, Xerox Palo Alto Research Center, 1998
- Pervasive networks
- Everyware
- Disappearing computing
- Ambient networks and services
- Internet of Everything (Cisco)

Great Duck Island

Environmental monitoring

„Great Duck Island” project



Great Duck Island, Maine, USA (2002)

- 2,4 km x 0,8 km
- **Intel** and **Berkeley** joint project

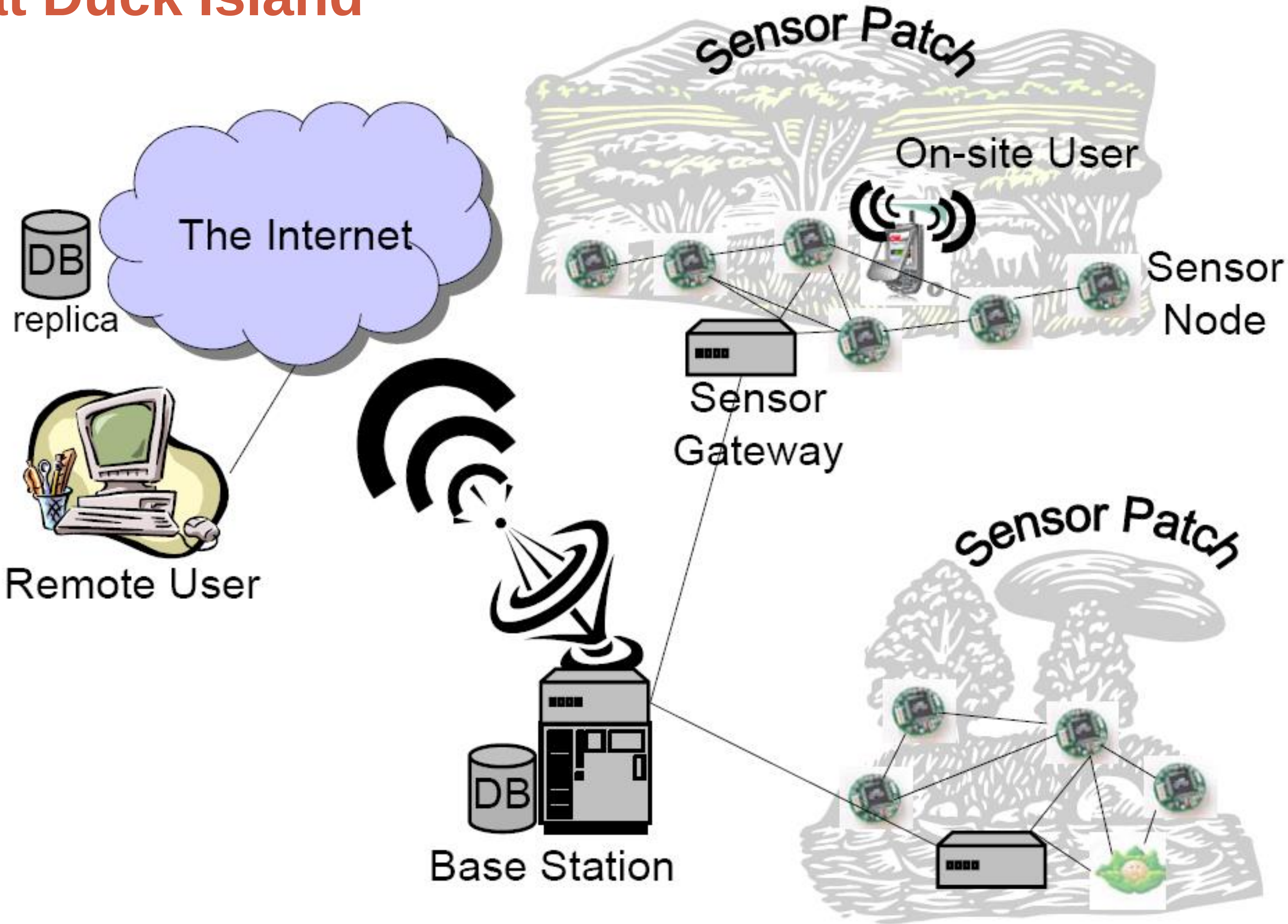
Great Duck Island

- Goal: Monitoring the colony of Leech's Storm Petrel
- Monitoring:
  - nets holes during summer while hatching
  - microclimate of used/abandoned nests
  - all environmental parameters during the 7 months

Great Duck Island

- Requirements of the application:
  - Internet access
  - Hierarchic network (wireless „backbone" is necessary)
  - 9-12 month continuous monitoring
  - No access to mains (solar panels if applicable)
  - Remote network management
    - Through the Internet, local presence is only available for 2-3 months each year, when deploying and collecting equipments
  - Seamless operation
    - Birds must not be disturbed
  - Interaction on site
    - Researcher arriving to the island can comminace with the sensor nodes with a handheld PDA
  - Monitored data (light, temperature, humidity, air pressure) periodically, storage as well

Great Duck Island



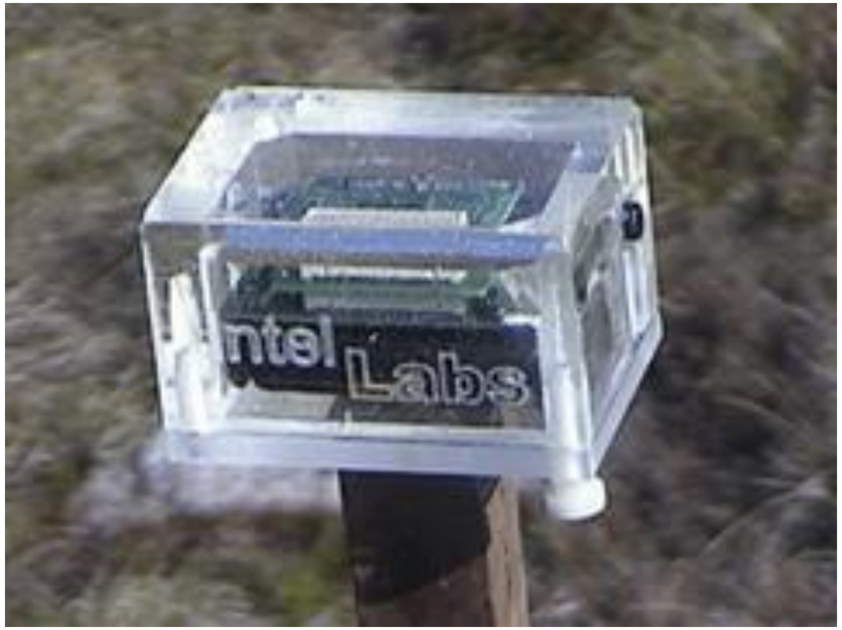
Great Duck Island

- Senzor motes
  - Berkeley (most Crossbow) Mica mote
    - Single channel 916MHz RF Monolithics, duplex communication at 40 kbps
    - Atmel Atmega 103 microcontroller (4kHz, 512 kB)
    - 2db AA batteries

- Sensors have to be protected mechanically

Great Duck Island

- Sensor card: Mica Weather Board
  - own design, the sensors can be turned on and off remotely;
  - temperature, light, IR (Melexis),
    humidity (General Eastern, +-3% rel.),
    air pressure (Intersema, 300-1100 mbar/0.1 mbar)



Great Duck Island

- Energy limitation: The requirement is 9 months and 2.5 Ah from the two batteries, that is 8.15 mAh/day.
- The application decides how the energy is allocated between the different tasks.

Operation	nAh
Transmitting a packet	20.000
Receiving a packet	8.000
Operating sensor for 1 sample (analog)	1.080
Operating sensor for 1 sample (digital)	0.347
Reading a sample from the ADC	0.011
EEPROM Read Data	1.111
EEPROM Program/Erase Data	83.333

Great Duck Island

- Sensor gateways
  - CerfCube embedded system
  - CompactFlash based 802.11b adapter
  - Embedded Linux op. system
  - 1GB(!) IBM MicroDrive
- Gateway power consumption 2.5 W(!)
  - Solar panels with 60-120W power when full sunshine + 50-100Wh chemical batteries

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Great Duck Island

- Base station
  - Connecting to the Internet via full-duplex satellite connection
  - Laptop + relational database
  - Unattended operation and maintenance (with unexpected restarts)

Great Duck Island

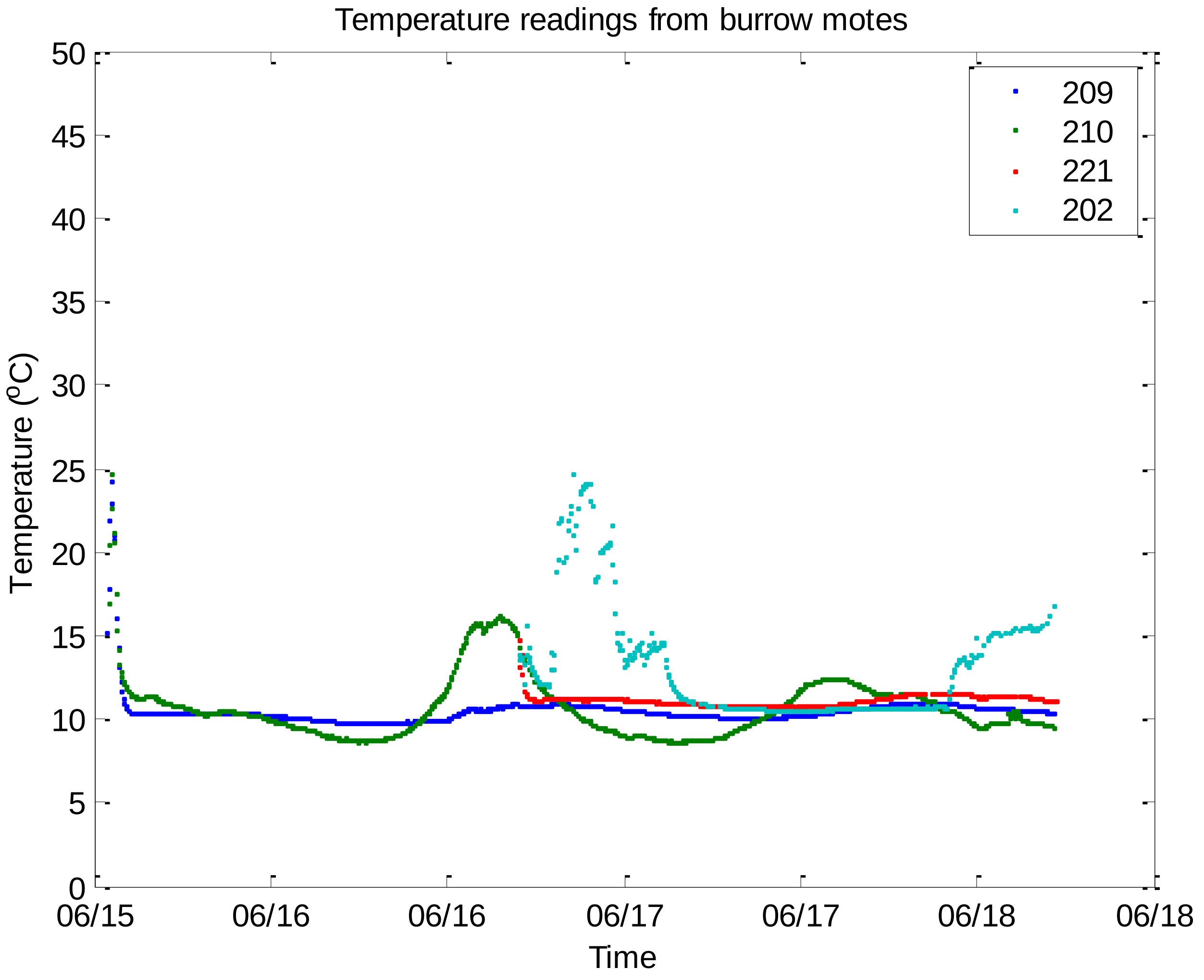
- Relational database
  - SQL database
  - Time stamped sensor data,
  - Information on sensor states (e.g., battery level)
  - Information on network state (connectivity and routing information)
  - Meta-data (e.g., sensor locations, type)
- „Gismo” – handheld PDA
  - iPaq PDA, Linux
- Sensor networks
  - Multi-hop communication
  - In network preprocessing

Great Duck Island

- Problems during the first trials:
  - Sensors are too big, don't always fit into the holes.
  - Sensors are not protected enough (corrosion)
  - Not robust enough, high losses among nodes -> missing measurement data, the quality is inadequate scientifically
- Improvements:
  - Mica2dot platform
  - Calibrated, digital sensors
  - Miniature Weather Station sensors

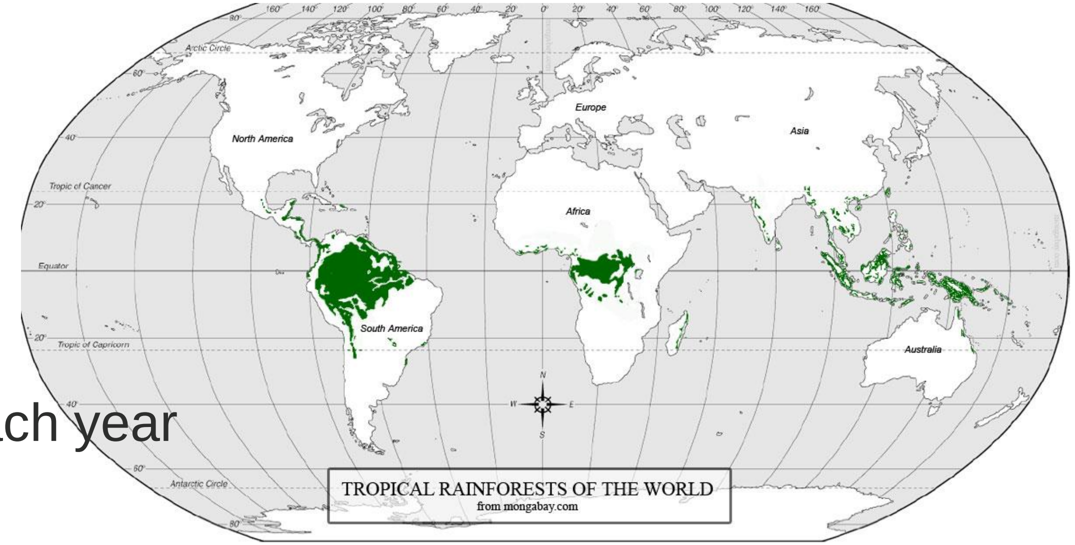
Great Duck Island

- Application status (July 2003):
  - 26 nests monitored
  - 26 Weather Station sensors
  - 2 base stations, 2 full database (robustness)
  - Webcams for surveillance of the area



Rainforest monitoring

Rainforest monitoring



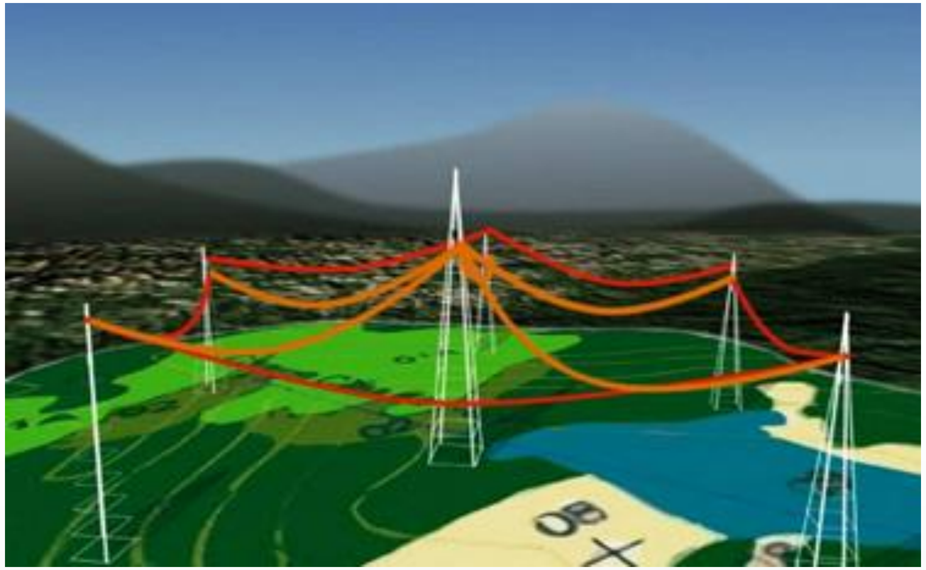
- One third of all the forest areas on Earth are rainforests
  - …still, but 200.000 square kilometers are cleared each year
    - (Area of Hungary: 93.000 km2)
- Yearly amount of rain is between 2000 and 4000 mm on the average
  - (5-600 mm in Hungary)
- About 60-70% of all species on Earth are from here
  - Millions of unexplored plants, insects and microorganisms
- The 28% of oxigene in air are produced here via photosyntheses.

Layers of rainforest

- **Canopy**
  - trees 35-40 meters high, shrouds are continuous
  - ~50% of species of plants on Earth live here
    - parasites on branches
  - ~25% of insect species
  - Hardly known by scientists, much to explore!
- **below canopy**
  - Only 5% of light comes down
  - Rich on animal species (birds, snakes, insects)
- **Ground level**
  - Only 2% of light
  - Rivers, swamps rich in plant varieties


Atlantic Rainforest Sensor Net Research

- Project partners (2009):
  - Microsoft Research
  - Johns Hopkins University (Life Under Your Feet)
  - Sao Paulo Research Foundation – FAPESP
  - Brazlian National Institute for Space Research – INPE
- Monitoring system
  - Towers above canopy level
    - 1 central tower (60m high); 5 smaller towers around
  - Cables between towers
    - 2 meters above canopy; 1 meter above ground level; in between in the middle as well
  - 600 sensors ounted on the cables
    - 18 million measurements each month (40 measurements / sensor / hour)



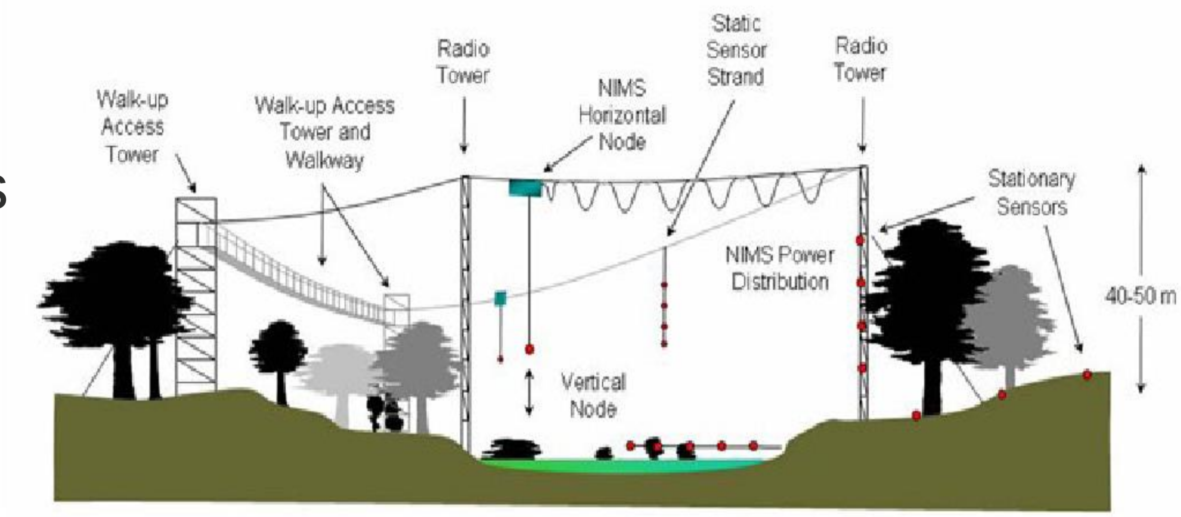
Atlantic Rainforest Sensor Net Research

- Sensors
  - Humidity
  - Temperature
  - Light

- Data gathering
  - Researchers visit the site with laptop and gather the data
    - Motes store the data in their flash memory
    - Send the data to the central tower via radio
    - No need to climb trees or cables
      - Single-hop communication

Atlantic Rainforest Sensor Net Research

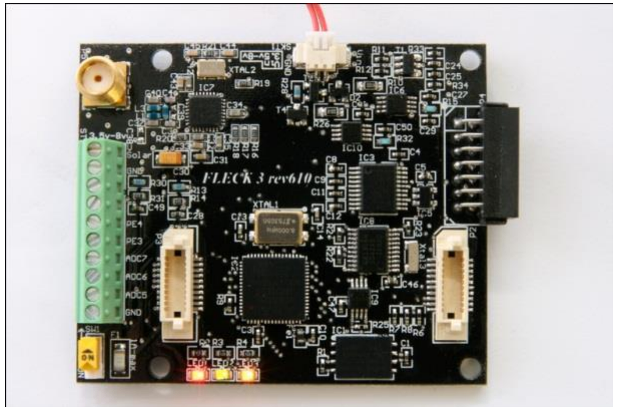
Costa Rica



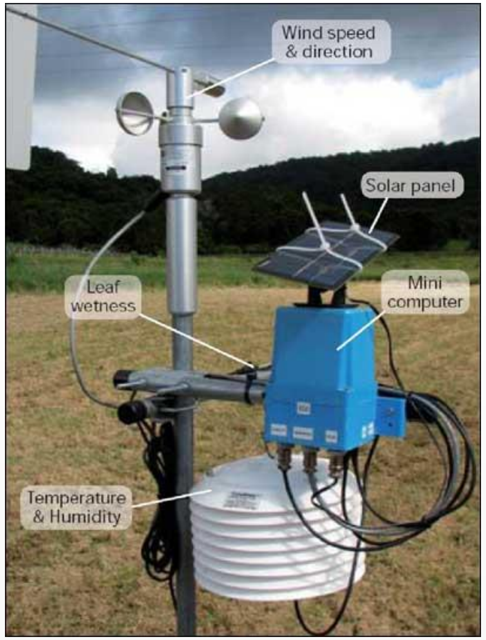
- UCLA (University of California Los Angeles
  - Center for Embedded Networked Sensing
  - 4-6 million USD yarly support from NSF
    - National Science Foundation
- La Salva Biological Station, Costa Rica
  - Mobile sensors on cables
    - Stops after each 1 meter for 30 secs, measure, then proceeds
  - Temperature, CO_2, humidity, precise 3D air movement, convection, sunlight, photosynthetic active radiation (PAR, 400-700 nm)

Costa Rica

Springbrook National Park
South East Queensland, Ausztrália



- Monitoring the expansion of the rainforest
  - Comparing environmental parameters
    - Open spaces (grass)
    - Young forest areas
    - Old, dense forests



- Hardware- Fleck^{TM}-3 sensor platform
  - Atmega128 microcontroller
  - Nordic NRF905 radio, 915 MHz
  - 3 pcs.1.2V 2700mAh rechargeable batteries
  - Solar panels

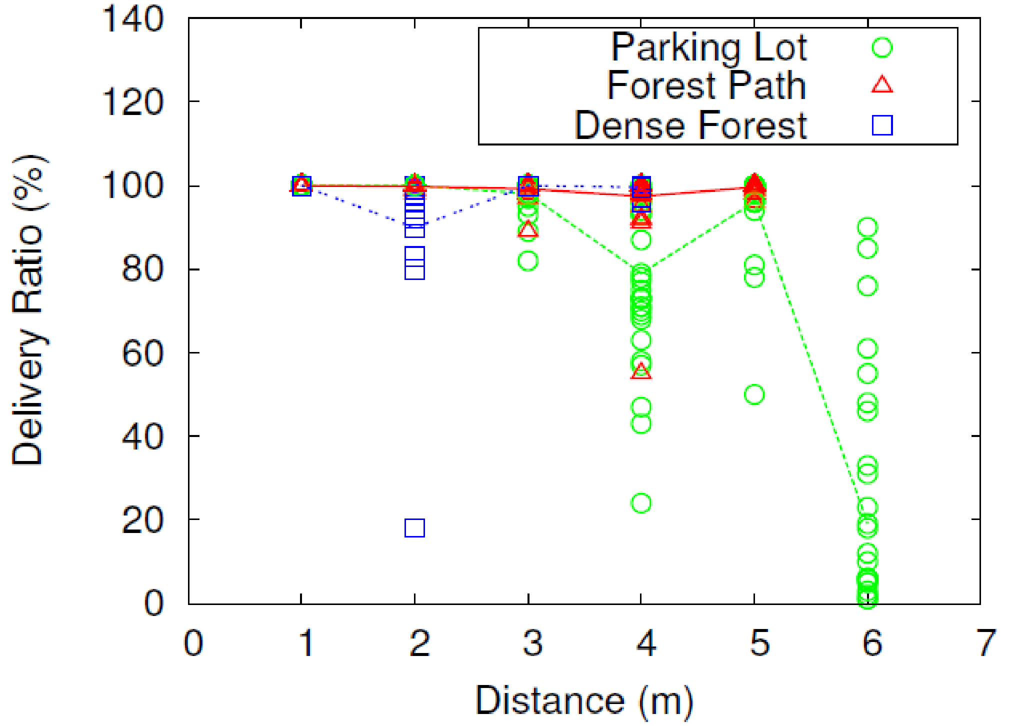
Radio communication in rainforest

- Three different environments:
  - **Parking lot** (for reference)
    - 20 x 200 m, no obstacles
  - **Forest path**
  - **Dense rainforest**

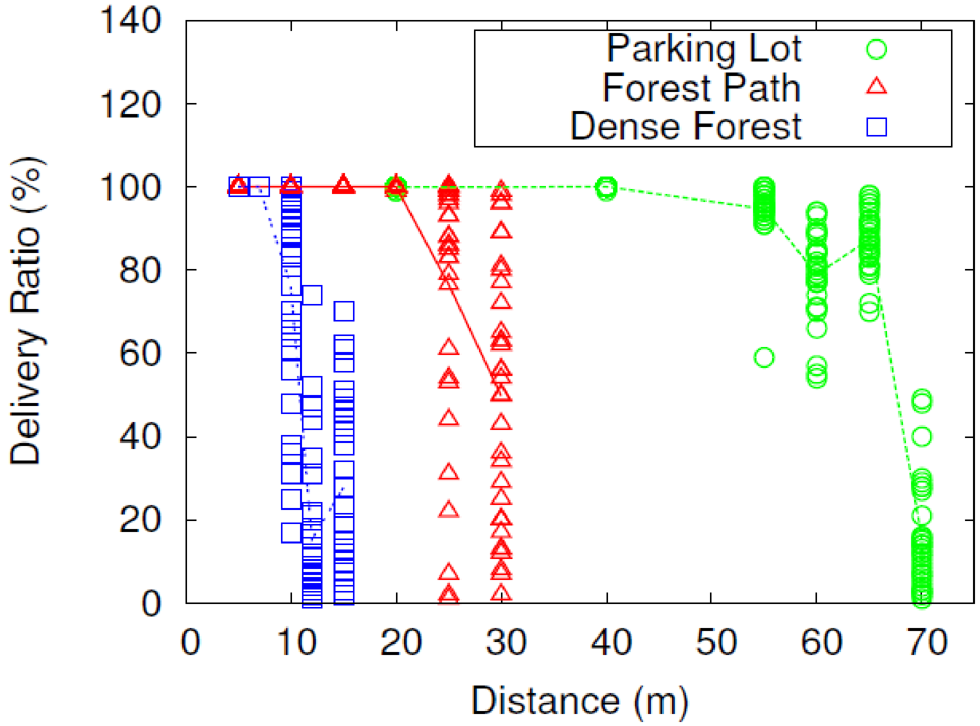
- Figueiredo, C. M. S.; Nakamura, E. F.; Ribas, A. D.; Souza, T. R. B.; Barreto, R. S., **„Assessing the Communication Performance of Wireless Sensor Networks in Rainforests”**, in Proceedings of the 2nd IFIP Wireless Days, 2009.

Radio communication in rainforest

- Sensors on ground level, and at 1,25 m height
  - Crossbow MicaZ



(a) Nodes on the ground.



(b) Nodes at 1.25m from the ground.

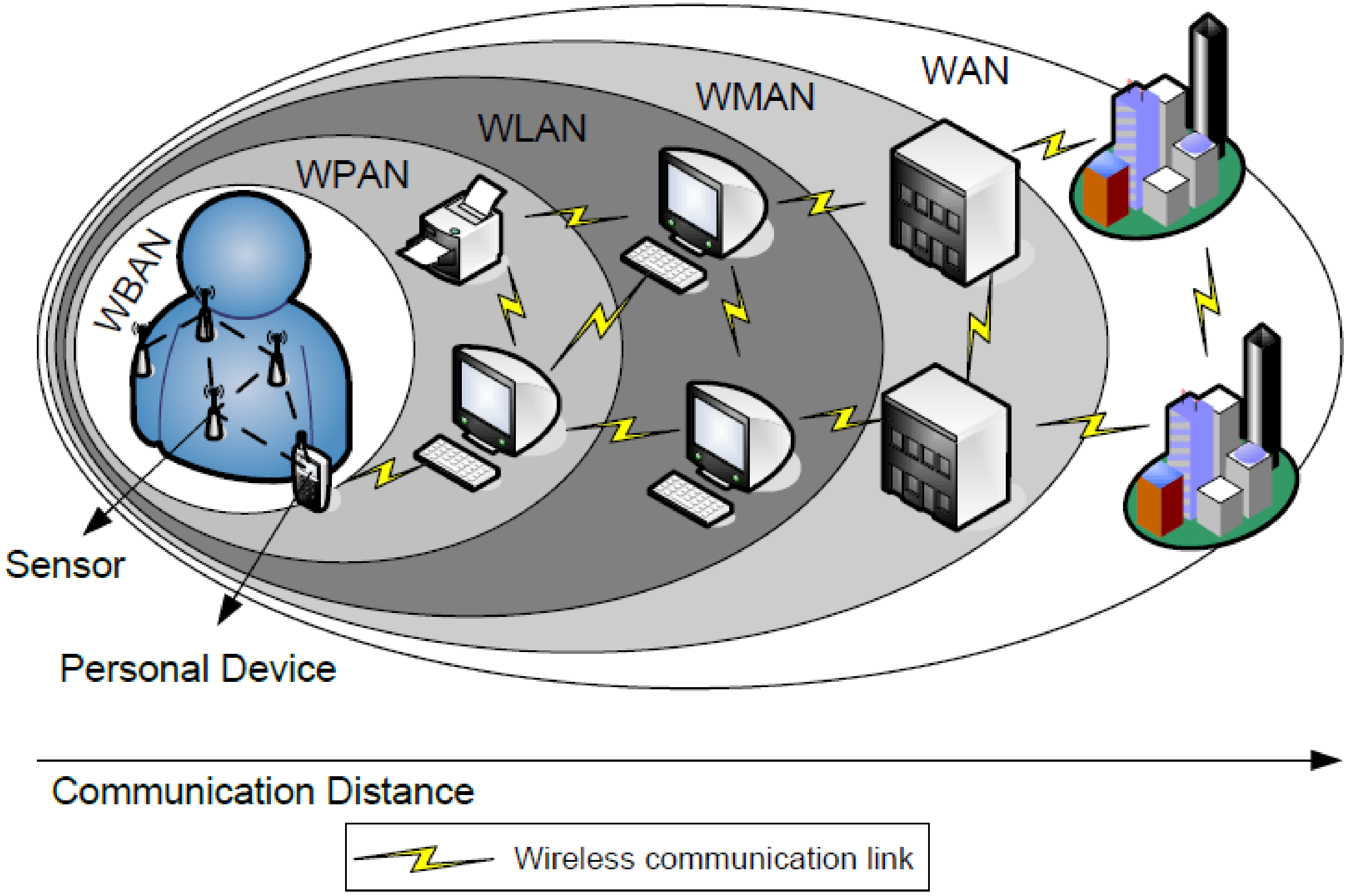
Healthcare sensor networks

Motivation

- Aging societies in developed countries
  - The medical care systems are VERY expensive
  - E.g., 1800 Billion USD in the US (in 2004), 20% of GDP
- eHealth
  - Healthcare with electronic devices
  - Cheaper (on the long run)
    - No need for personnel, hospital bed
  - More freedom for the patients
- mHealth
  - Mobile communications
- Wireless Body Area Network (WBAN)
  - K. Van Dam, S. Pitchers, and M. Barnard, **„Body area networks: Towards a wearable future"** in Proceedings of WWRF kick of meeting, Munich, Germany, 6-7 March 2001.

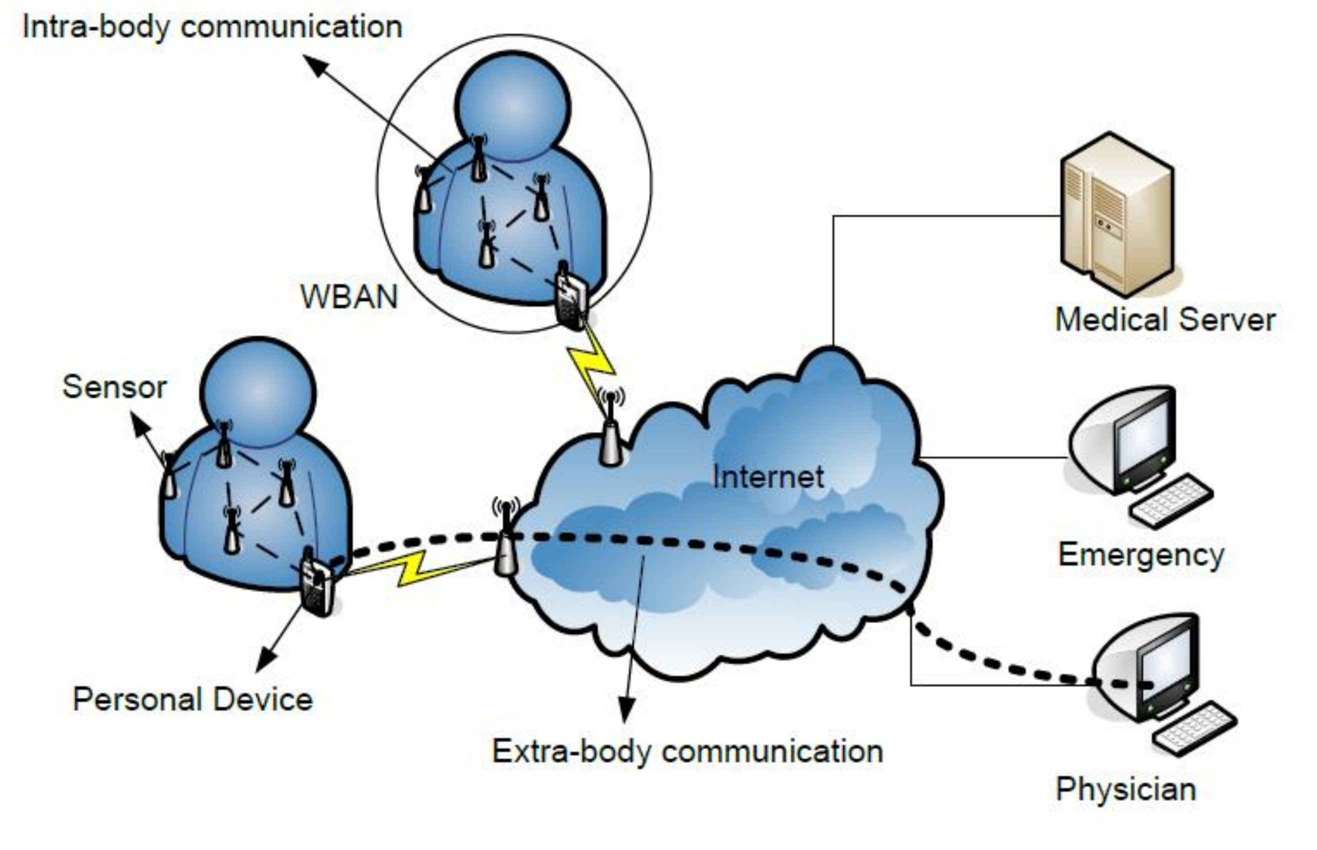
Wireless Body Area Network (WBAN)

- Body area:
  - Sensors in body
  - Sensors on body
  - Sensors inclothing
  - Personal devices



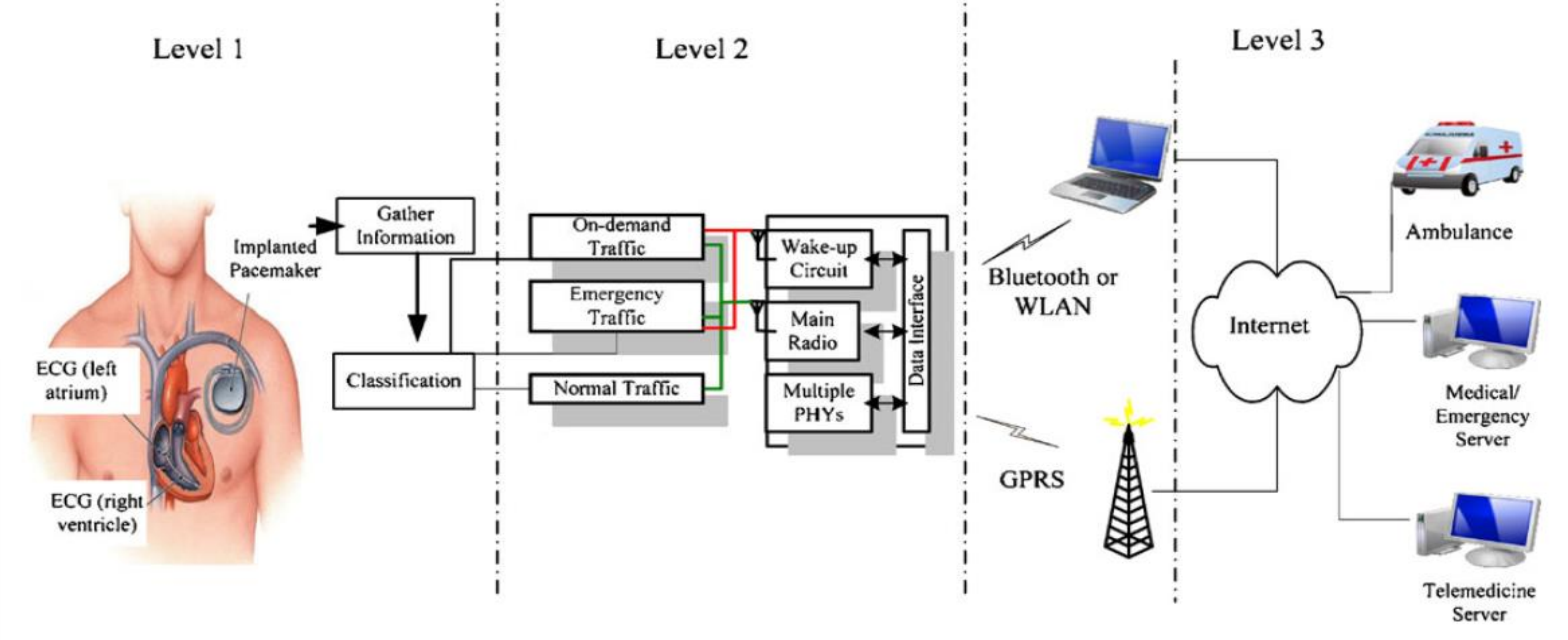
Wireless Body Area Network (WBAN)

- Sensors monitor different vital signs real time
  - Data are sent to the medical center
  - Long term monitoring – much more useful than occasional measurements
- Communication in/on body
  - PDA or smartphone as sink or gateway



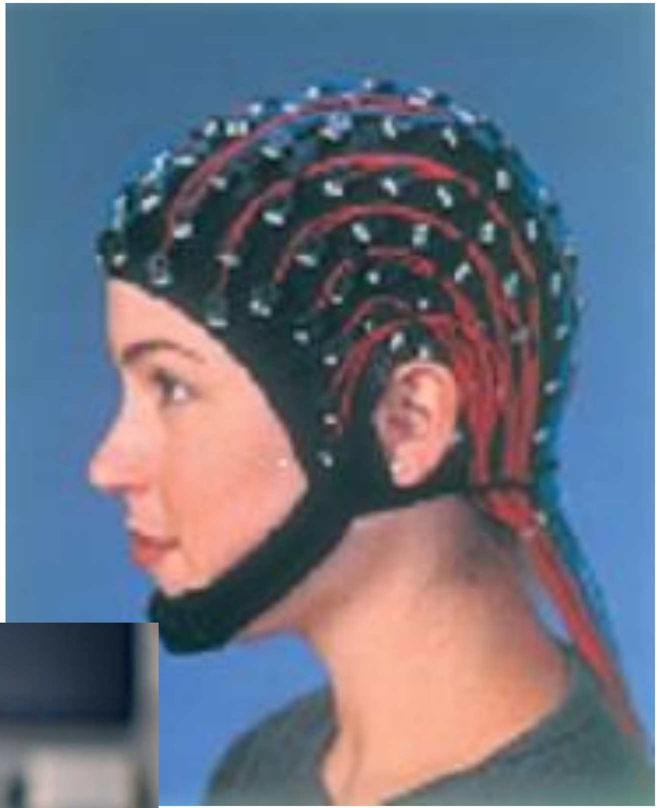
Wireless Body Area Network (WBAN)

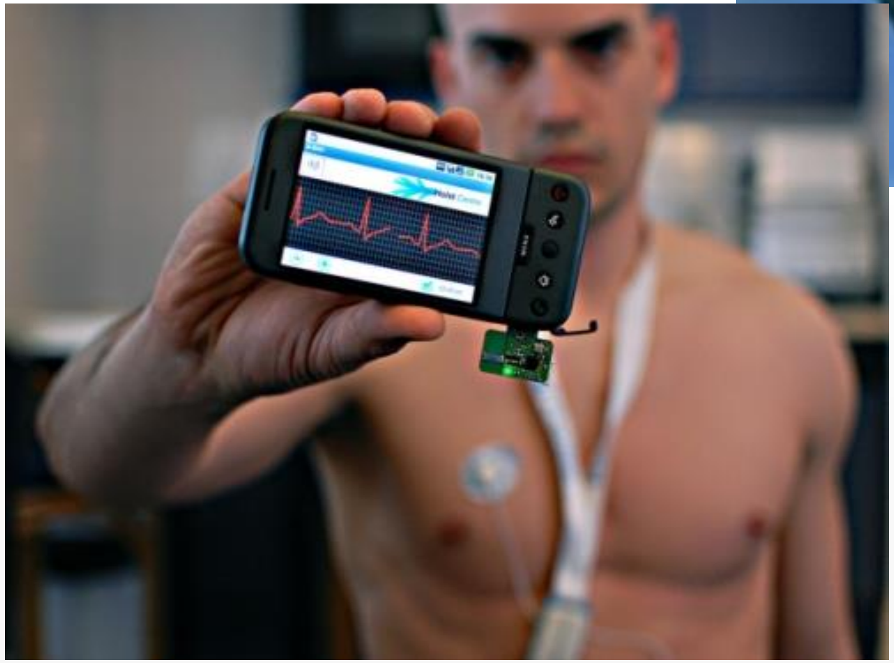
- Three traffic types:
  - **On-demand**: queries by doctor; **Emergency traffic**: unexpected; **Normal traffic**: continuous monitoring and sending



WBAN sensors

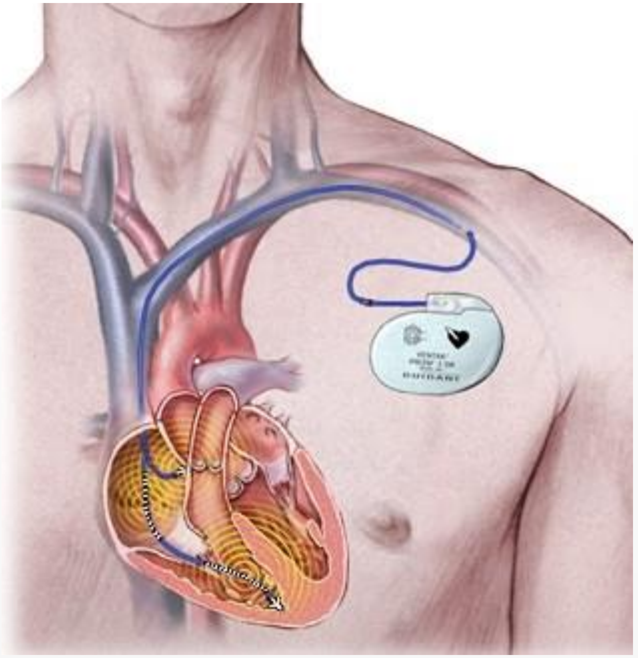
- Continuous monitoring
  - Body temperature
  - Blood pressure, pulse, respiration
  - EKG – elektrocardiogram
    - heart monitoring
  - EEG – electroencephalography
    - brain functions monitoring

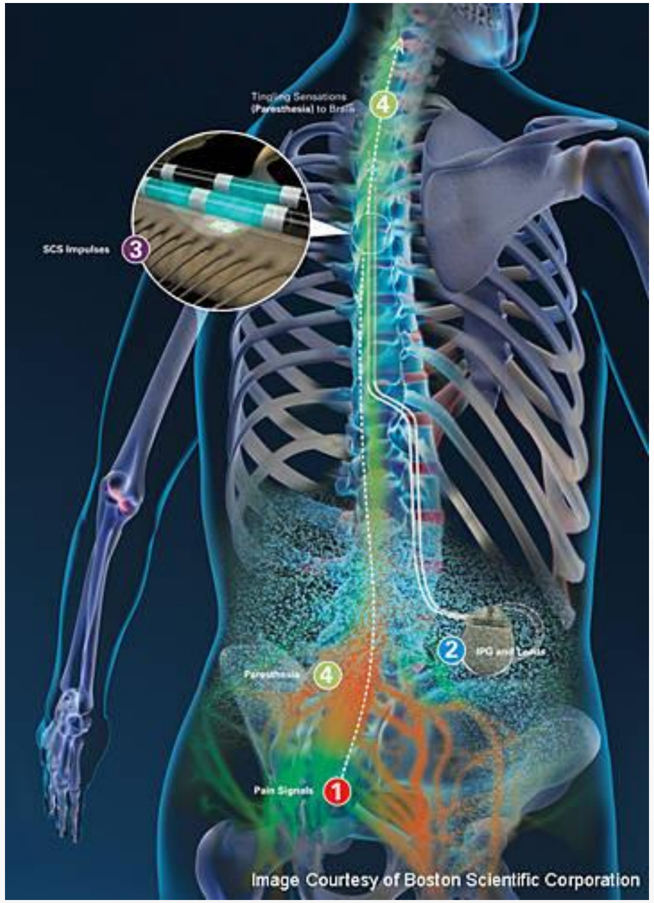




WBAN actuators

- Insulin pump
  - blood-sugar monitoring
- Backbone stimulator, muscle stimulator
- Artificial retine
- Pacemaker





RFID identifier

- Implanted
  - Identification, personal data, medical data...

WBAN vs. WSN

- Very limited energy (WBAN)
  - Small sizes (< 1 cm^3)
  - Non-rechargeable, but expected long lifetime (years or even decades for implants)
    - Energy can be harvested from body heat or movements
  - Limited computational capacity, memory
- There is no redundance, only those devices are implanted that are absolutely needed
- Very low radio transmission power levels
- Radio waves are damped by body tissiues -> highy packet losses
- Topology is changing because of body movement
- For medical data, the reliability (and low delay) is very important
- Privacy issues

Ambient Assisted Living (AAL)

- High priority in the EU
- Smart homes
  - Sensors in house, monitoring the activity of elderly