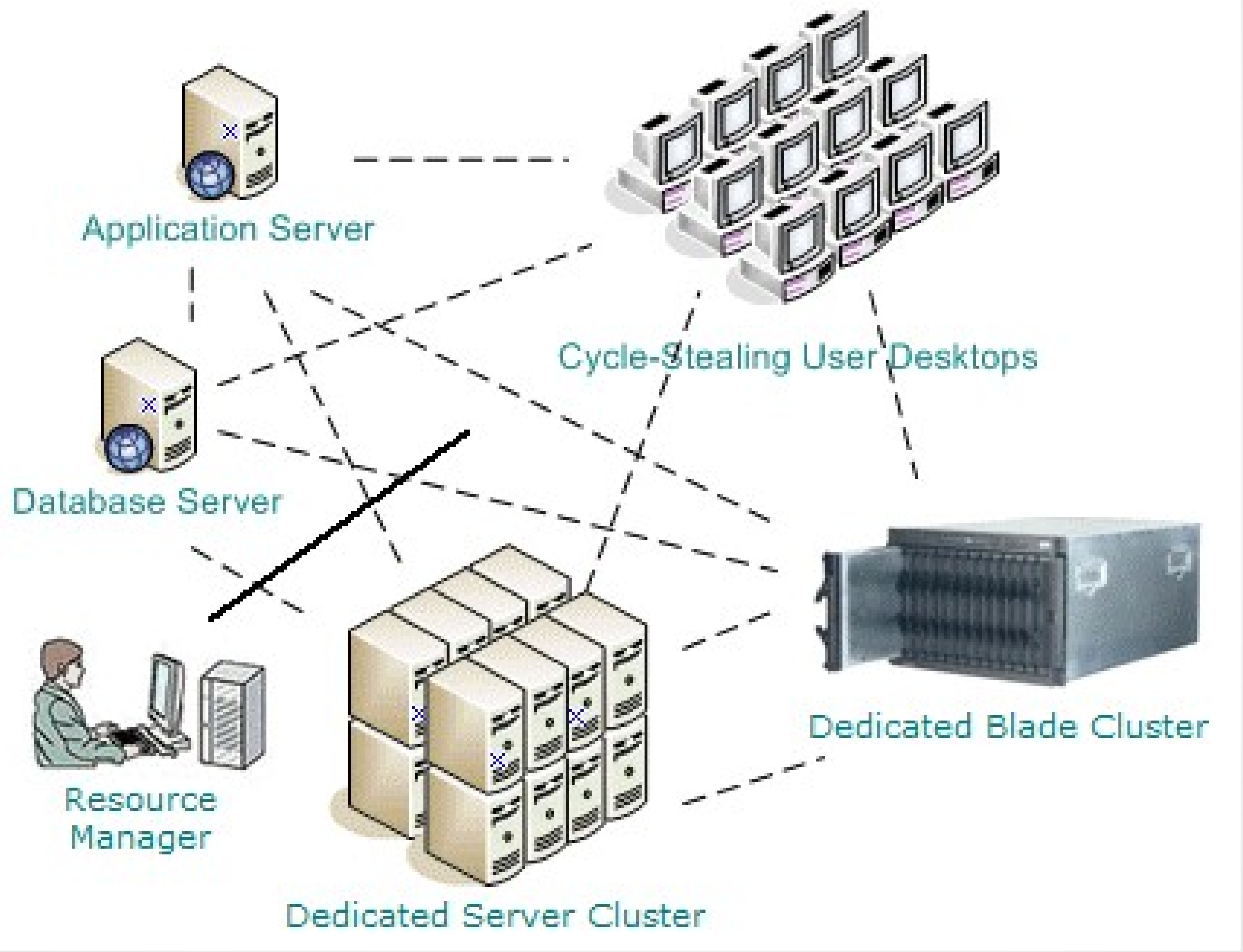
Mobile Cloud Computing (MCC) in the e-Health Scenario

José L. Ayala
Complutense University of Madrid
jayala@ucm.es

From distributed computing



To the Internet of Things

And the Smart City

ICT for Smart Cities

Innovative Products or Applications	ICT	Impacts
Transportation and mobility		
• Autonomous smart vehicles • Vehicle-to-vehicle and vehicle-to-infrastructure communication	• Drive by wire vehicles/systems • Plugins and smart cars • Interactive traffic control systems • Next-generation air transport control • Electric vehicle	• Accident prevention and congestion reduction (zero-fatality highways) • Greater safety and convenience of travel • Optimized energy consumption

ICT for Smart Cities

Innovative Products or Applications	ICT	Impacts
Buildings and Structures		
• High performance residential and commercial buildings • Net-zero energy buildings • Appliances	• Whole building controls • Smart HVAC equipment • Building automation systems • Networked appliance systems	• Increased building efficiency, comfort and convenience • Improved occupant health and safety • Control of indoor air quality

ICT for Smart Cities

Innovative Products or Applications	ICT	Impacts
Healthcare		
• Medical devices • Personal care equipment • Disease diagnosis and prevention	• Wireless body area networks • Assistive healthcare systems • Wearable sensors and implantable devices	• Improved outcomes and quality of life • Cost-effective healthcare • Timely disease diagnosis and prevention

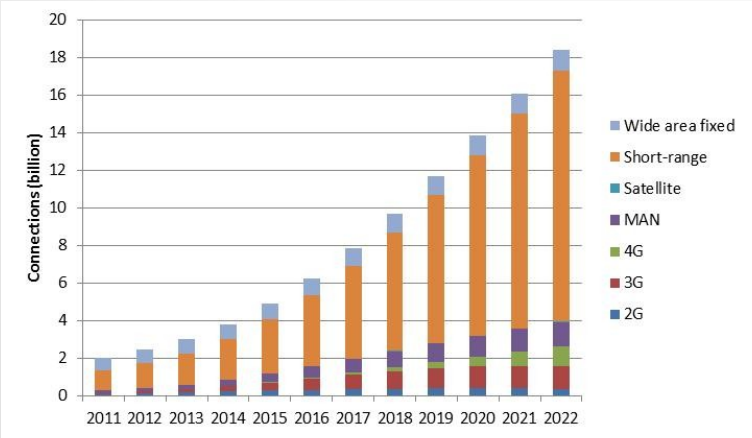
Growing Market

The march towards the Internet of Everything

e-Health, Smart-everything (cars, cities, buildings...)

Huge increase of computational needs

Global M2M Communication Growth



Global Data Center traffic growth (Cisco)

Identified Challenges

- Integrating **complex, heterogeneous large-scale** systems
  - This includes aggregating and sharing data within systems as well as across systems and components
- Interaction between **humans** and systems
  - Modeling and measuring situational awareness
- Dealing with uncertainty
  - Complex ICT systems need to be able to evolve and operate reliably in new and uncertain environments
- Measuring and verifying system performance
  - Test beds and datasets
- Trust, security and privacy
  - Design evolutionary and resilient architectures to handle rapidly evolving cyber and physical threats

Identified Challenges

- Dealing with emerging mobile communication technologies
  - Unreliable and noisy channels
- Scalability
- Dealing with heterogeneity
  - Support of different sensors, actuators and computing platforms
- Guaranteeing real-time exchange of data
  - Low overhead control mechanisms
- Tight interaction of network, **data center** and urban spaces
- Energy efficiency at a macroscopic level

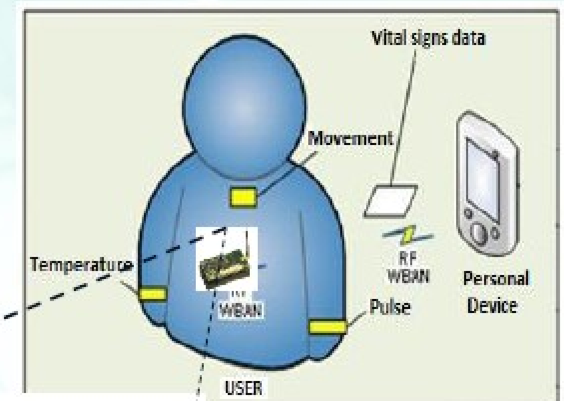
Our context

MCC in the eHealth scenario

User devices and channel

User devices

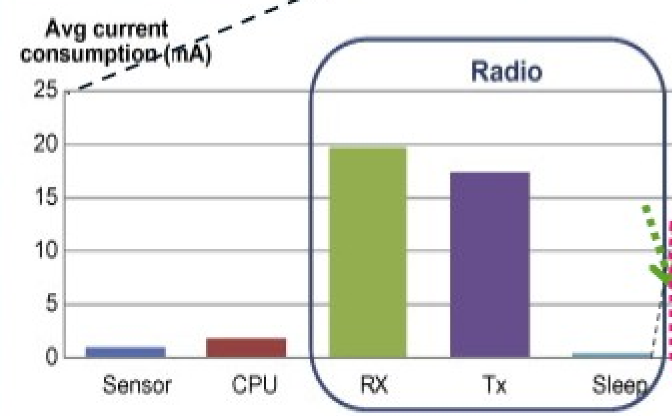
Power consumption in WBSNs is divided in: sensing, communication and data processing [4].



Wireless Body Sensor Networks (WBSNs)

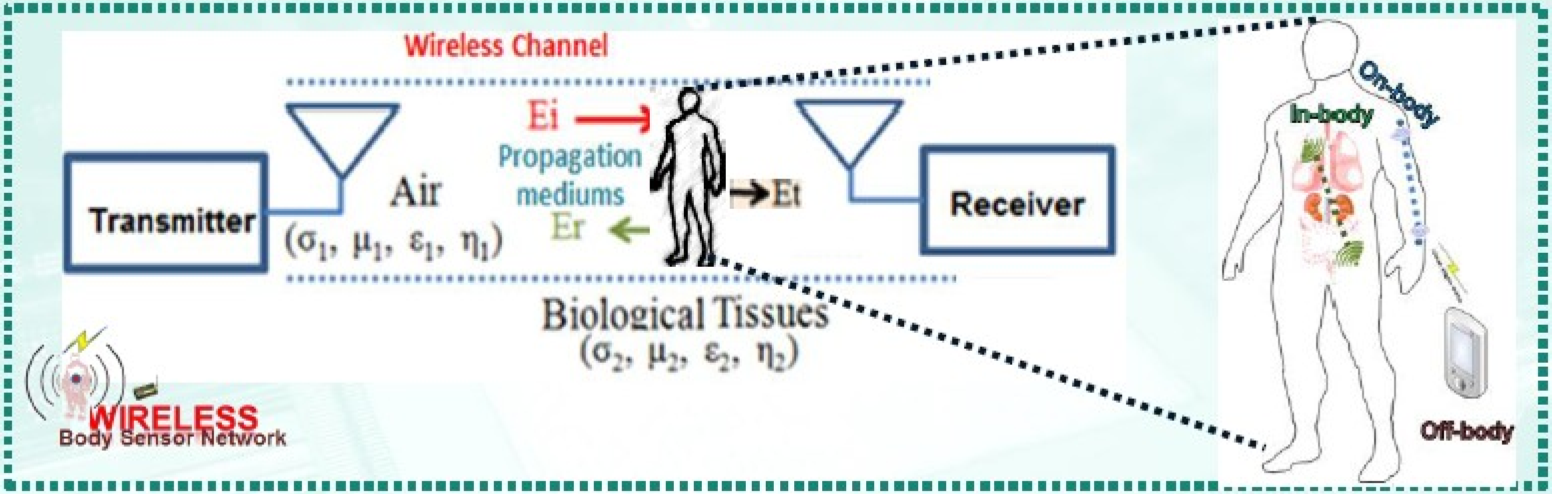
WBSN is composed of [1]:

- wireless sensor node
- wireless actuator node
- personal device



The wireless communication is the most power consuming task.

Biological channel



Human body is hostile environment for a wireless signal:

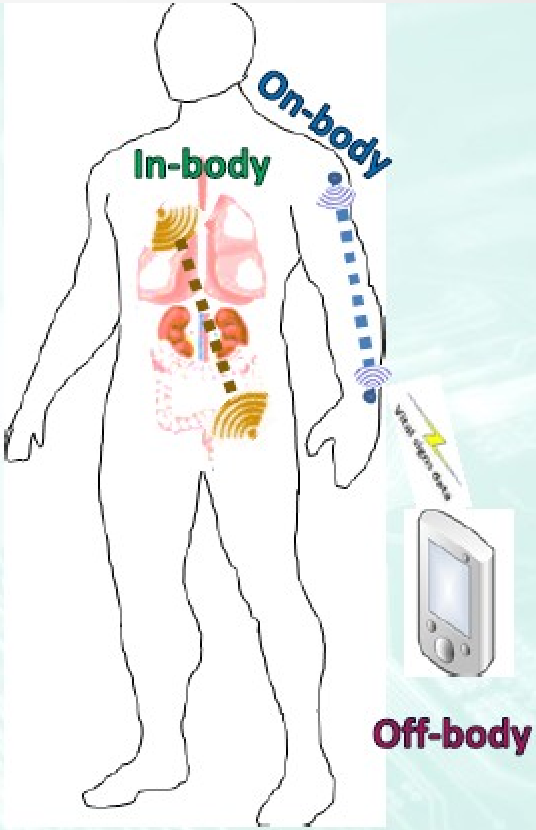
- Higher attenuation in tissue composed mainly of water
- Higher penetration depth in tissues with low water content
- Penetration depth decreases as the frequency increases
- Permittivity and conductivity is different for each kind of tissue and person

Communication standards

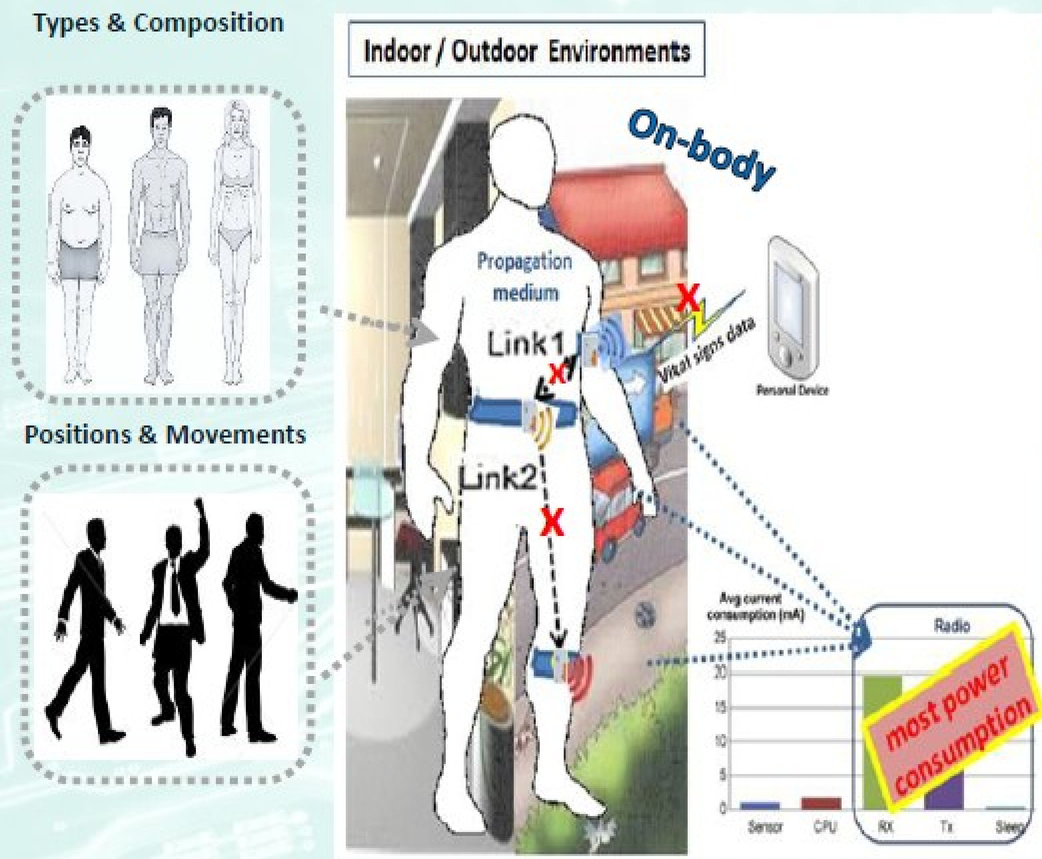
Body Communications Channels

	MICS	IEEE 802.15.4 (Zigbee)	UWB IEEE (802.15.6)	IEEE 15.1 (Bluetooth)	WLANs (802.11b/g)
Frequency bands	402-405 MHz	2.4 GHz, (868/915MHz Eur./US)	3-10 GHz	2.4 GHz	2.4GHz
Bandwidth	3 MHz	5 MHz	>500MHz	1 MHz	20 MHz
Data rate	16 kbps (AMIS)*	250 kbps(2.4 GHz)	850 kbps	1 Mbps	>11 Mbps
Multiple Access	CSMA/CA, Polling	CSMA/CA	ALOHA	FHSS	OFDMA, CSMA/CA
Tx Power	- 16 dBm (25µW)	0 dBm	-41dBm	4 dBm , 20 dBm	250 mW
Range **	0-10 m	0-10m	2 m	10, 100m	0-100 m

* MICS bands can use a data rate more than 250 kbps.
**Transmission range for a medical sensor network has commonly been 10 m



Modeling goals and TPC

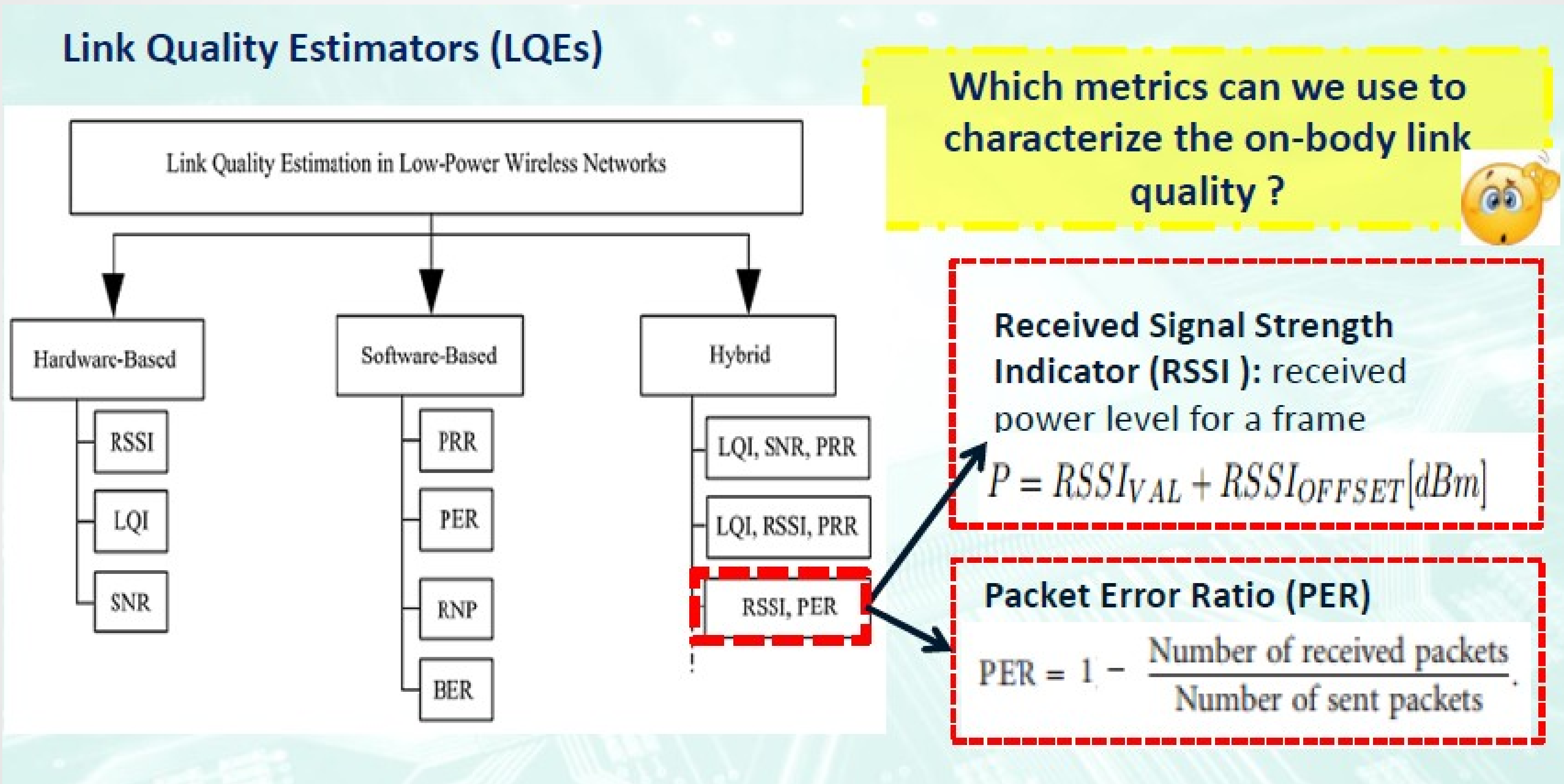


What do factor affect mainly the on-body channels communication?

1) Simple and complex body movements
2) Dielectric properties of biological tissues
3) Human body physical characteristics

Goal → Transmission Power Control Policies for energy optimization according to the changing conditions of on-body links guaranteeing the reliability of network

Modeling metrics

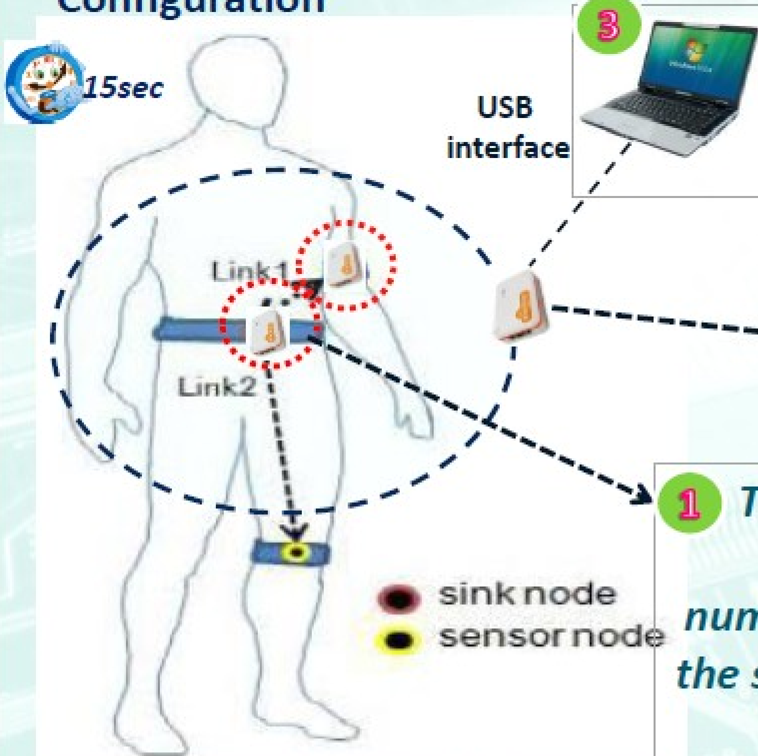


Experimental work

Test 1A — **On-Body communication channels in an indoor environment**

- Analyze the effect of simple and complex body movements

Configuration



3. *A Java application draws in real time the RSSI of each packet and the noise floor measured during the test*

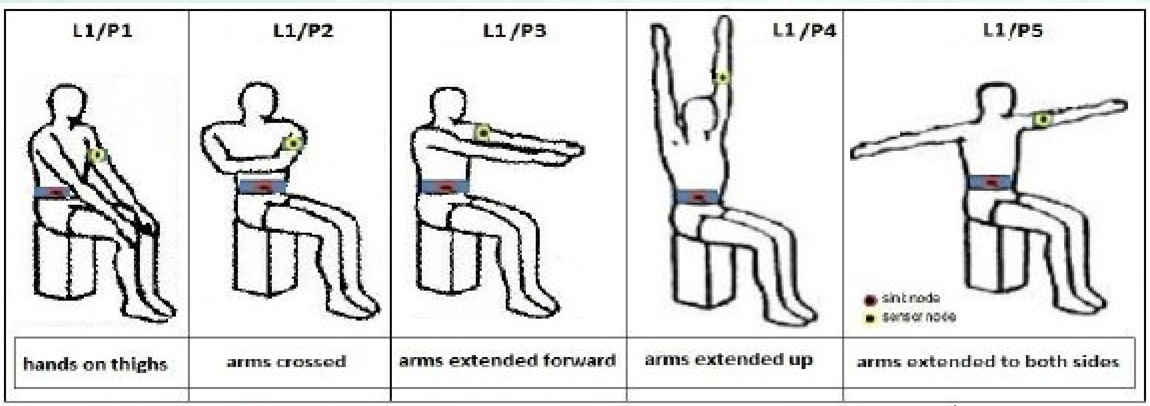
2. *External node passively listens the beacon packets and takes periodic noise floor measurements*

1. *The coordinator is programmed to provide RSSI reading, CRC bit reading, and the sequence number for each data packet received. Then, from the second beacon, the coordinator integrates and sends this information on payload.*

Experimental work

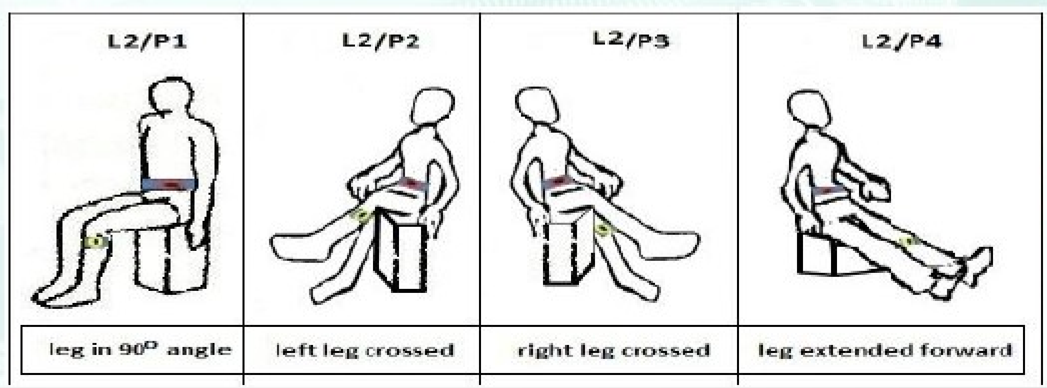
Test 1A **On-Body communication channels in an indoor environment**

- Analyze the effect of simple and complex body movements



Experimental Scenarios

Scenario 1:* *subject sitting on a chair, performs five arm movements



Scenario 2:* *subject sitting on a chair, performed four leg movements

Experimental work

Test 1B **Communications near biological tissue**

- Analyze the effects of the dielectric properties of biological tissues

Place

a) Anechoic chamber

b) Outdoor environment

Scenarios

a) LOS

b) NLOS by tissues

Tissues types

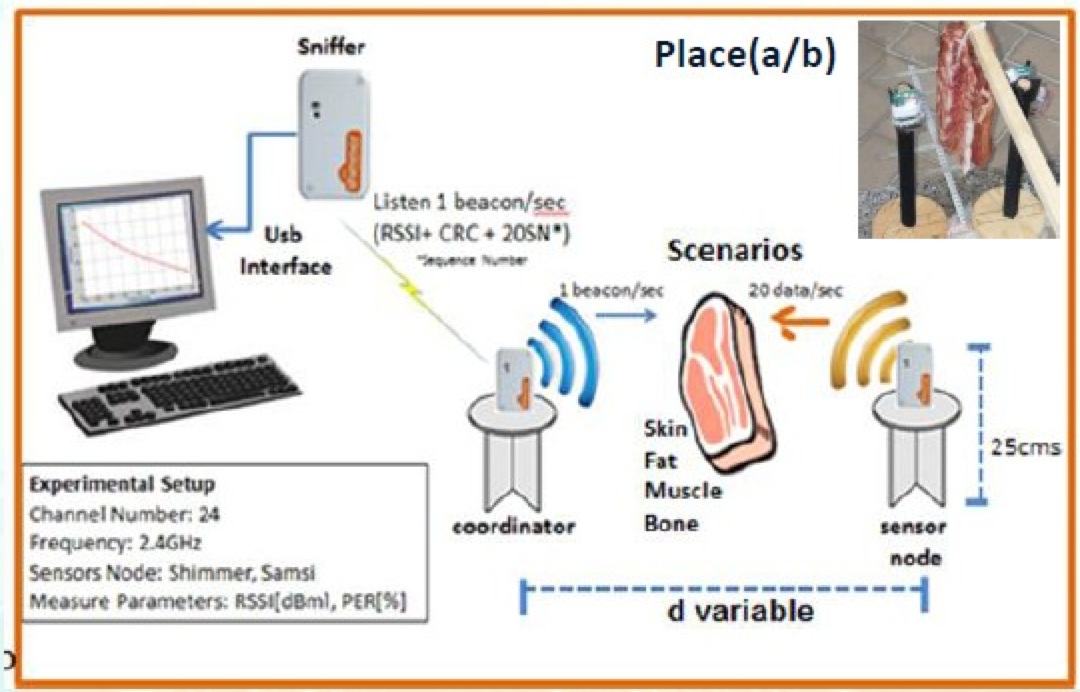
Skin, fat, muscle, bone

Tissues Organization

a) homogeneous

b) layered tissues /homo

c) layered tissues/ hetero

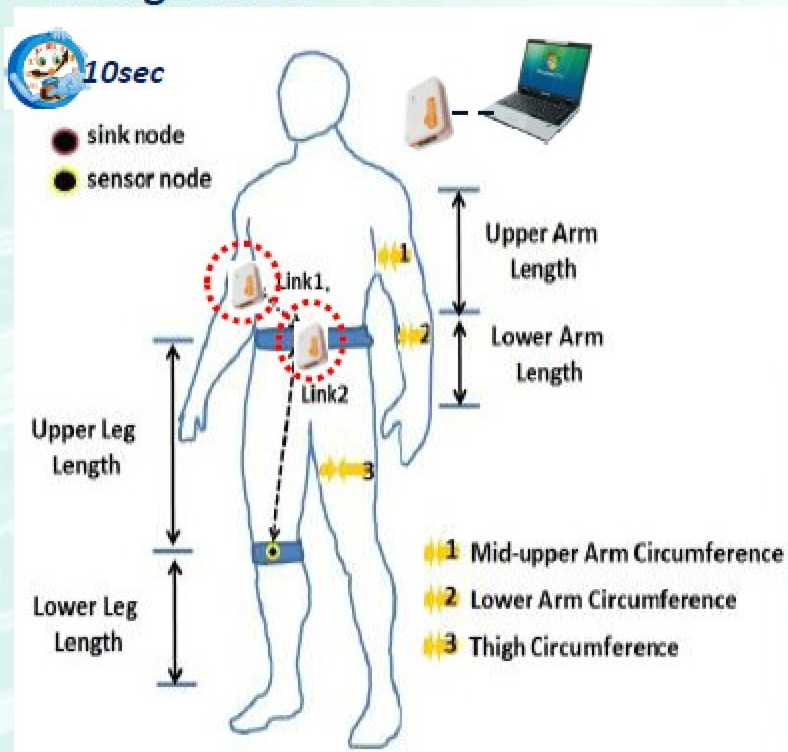


Experimental work

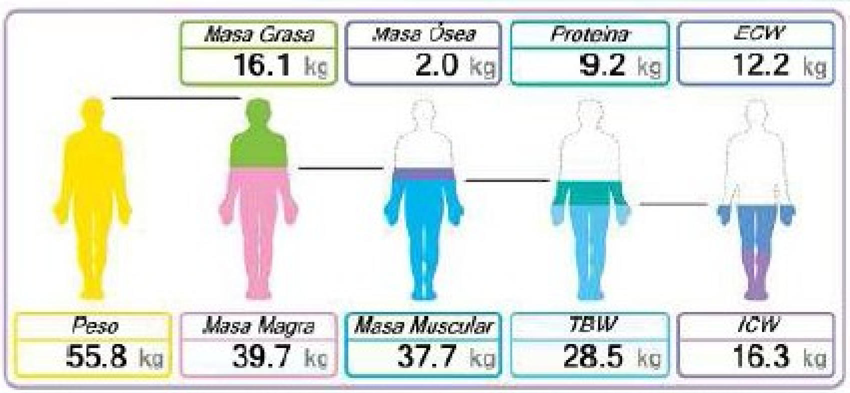
Test 1C **On-Body communication channels in an indoor environment**

- Analyze the effect of human body physical characteristics

Configuration



We took anthropometric measurements and body composition parameters

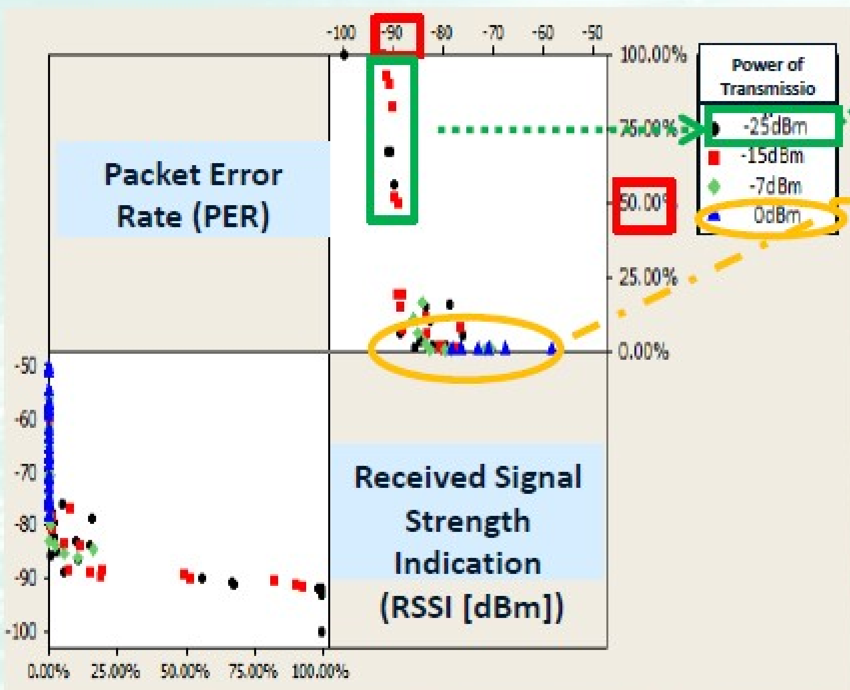


Measures done at different transmission power levels in a sample of 40 human subjects Including female and male gender

Experimental work

Results 1A — **On-Body communication channels in an indoor environment**

- Analyze the effect of simple and complex body movements



RSSI<-85dBm and PER>50%

RSSI>-80dBm and PER=0 (regardless, link and position)

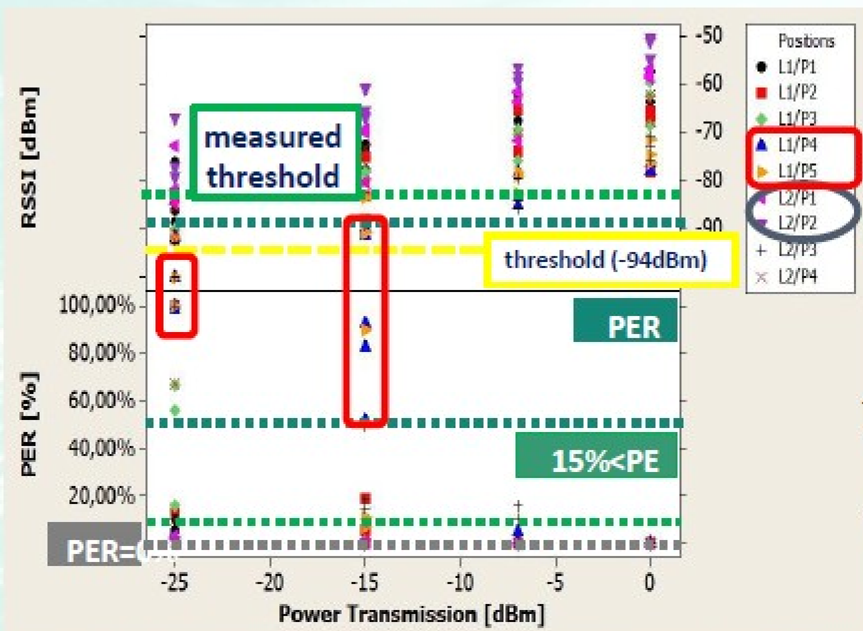
Observations

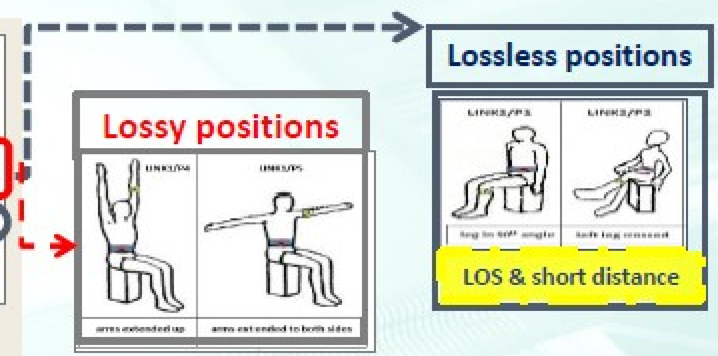
- For RSSI ≤ -85dBm the link quality varies radically.
- The packet loss > 50% for some links and positions at power transmission levels -15dBm and -25dBm.

Experimental work

Results 1A **On-Body communication channels in an indoor environment**

- Analyze the effect of simple and complex body movements





This study allows identify which positions and links require higher or lower power transmission level to meet the sensitivity threshold while reduce the energy consumption.

TPC

Approach 1 Reactive algorithm for transmission power control

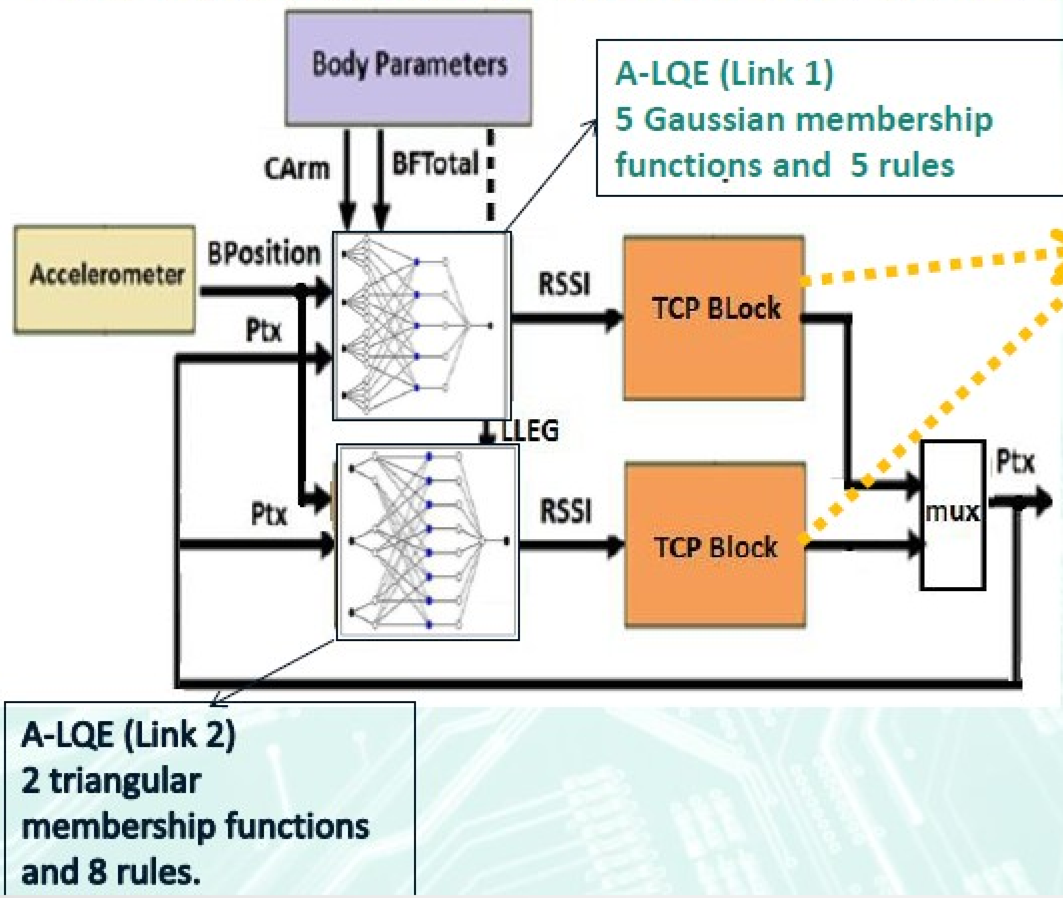
Algorithm 1 Optimization policy for a characterized radio link.

```
procedure ENERGY-AWARE SEND DATA PACKET(data)
    accXYZ ← measureAcceleration()
    if module(accXYZ) >> 9.8 then
        radioPower ← MAXIMUM
    else
        radioPower ← getOptimumLevel(accXYZ)
    end if
    status ← sendData(data, radioPower)
    while status <> ACK do
        radioPower ← getMinimumLooselessLevel(accXYZ)
        status ← sendData(data, MAXIMUM)
    end while
end procedure
```

- The communication link is correctly characterized for each subject and scenario at different transmitted power.
- The adjust of the transmission power is done using the movement detection based on accelerometry with low-complexity and low overhead.
- we will choose dynamically the lowest energy transmission level that requires the overall lowest energy budget.

TPC

Approach 2 Predictive algorithm for transmission power control (A-LQE)



Algorithm 1 Transmission Power Control policy

```
Tmaxupper ← −68
Tmaxlower ← −80
Tmin ← −85
if RSSI ≥ Tmaxupper then
    PTxnew ← −15
else if RSSI ≤ Tmaxupper AND RSSI > Tmaxlower then
    PTxnew ← −10
else if RSSI ≤ Tmaxlower AND RSSI > Tmin then
    PTxnew ← −5
else RSSI ≤ Tmin
    PTxnew ← −3
end if
```

The TPC block adjusts the transmission power to the minimum value to assure that the RSSI value does not drop below a threshold

Results

Results of Approach 1 — Reactive algorithm
Approach 2 — Predictive algorithm A-LQE + TCP Block

Sequence of movements that simultaneously combine positions of the scenario 1 ,2:
L1/P1+L2/P4, L1/P2+L2/P3, L1/P3+L2/P1, L1/P4+L2/P2 and L1/P5+L2/P1.

Subjects	Energy Consumption [Joules]			Energy Saving [%]	
	Max Power	Reactive	A-LQE+TCP	Reactive	A-LQE+TCP
Subject 1	57.50	34.22	39.4	40.48	31.3
Subject 2	58.86	36.89	42.8	[illegible]	[illegible]
Subject 3	57.50	36.95	43.3	[illegible].73	[illegible].6
Subject 3	57.44	34.44	44.02	40.03	23.3

Reduction of 38.3%

Reduction of 26.5%

At maximum power the transmission is lossless but consumes 57.8 J

At optimum power the total energy is 35.6 J

At optimum power the total energy is 42.3 J

Results

Reduction of 38%

- In run-time, it only requires the accelerometer as input
- Off-line, the policy requires that each subject is fully characterized in all positions and power levels

REACTIVE

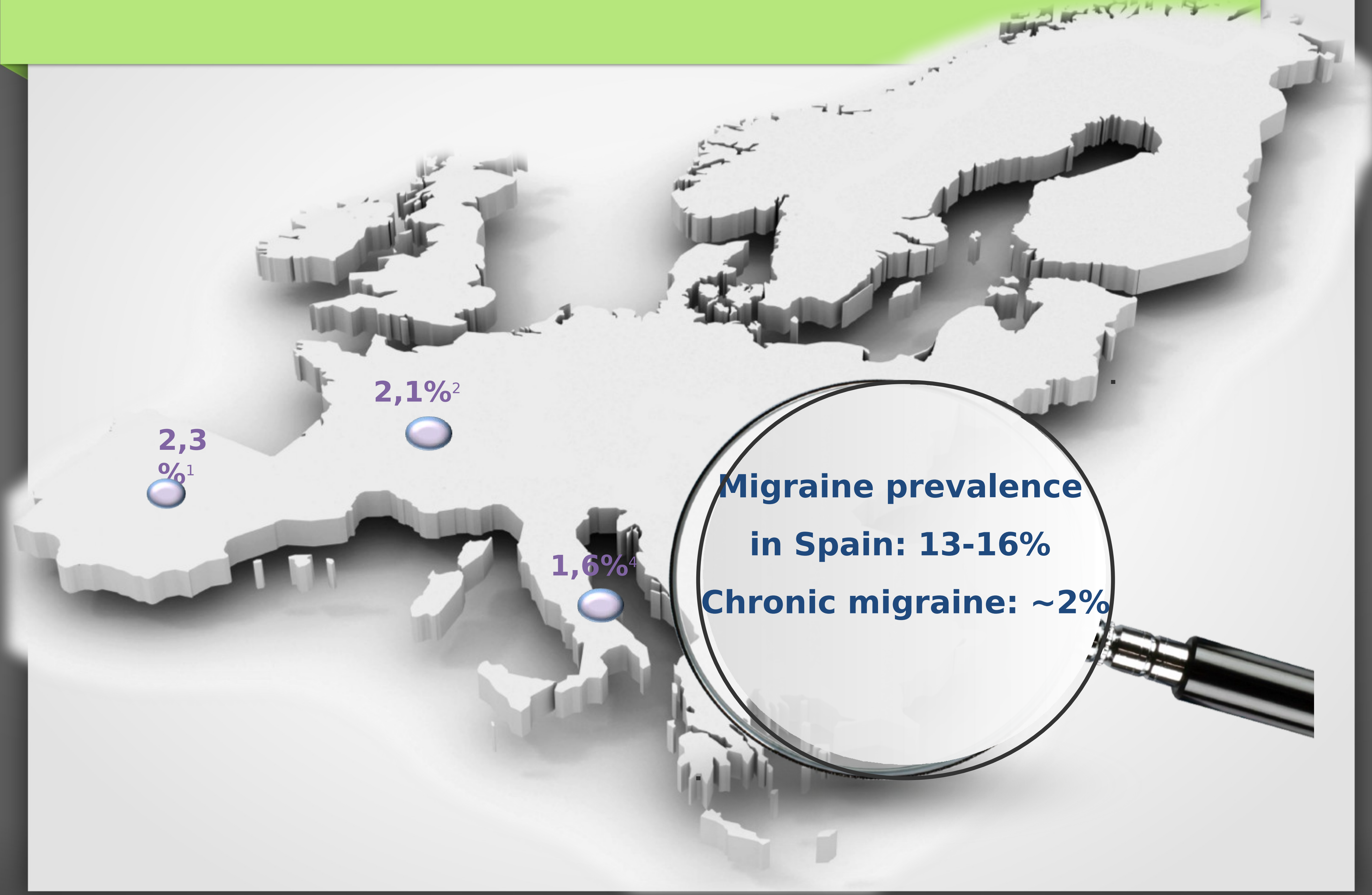
Reduction of 26.5%

- In run-time, it requires some constants, the transmission power level and the accelerometer as inputs
- Off-line, the policy requires to be trained with a large data set just once, and then can be applied to any user
- It incorporates for the first time the effect of body characteristics

PROACTIVE

The application

Pervasive Wireless Monitorization for Migraine Crisis Prediction



2,1%[2]
2,3 %[1]
1,6%[4]
Migraine prevalence
in Spain: 13-16%
Chronic migraine: ~2%

Migraine impact

- On the patient
  - Short term
    - Diminished quality of life
  - Long term
    - Low school performance
    - Low job performance
    - Impact on well-being
    - Damaged family relations
    - Damaged social relation
- On the society
    - High economical impact for direct and indirect costs

What if we could predict a migraine crisis?

Benefits of prediction

- We could detect the beginning of the crisis before any pain is suffered.
- Pharmacologycal treatment would have the highest effectiveness preventing the symptoms.

What do we need?

- Quantifiable bio-metric variables
- Monitoring system
  - Portable
  - Non intrusive
  - Processing capability
  - Multi-variable acquisition

- A mathematical relation that models patient's pain as a function of the acquired variables
  - Predictive
  - Robust

Deployed WBSN

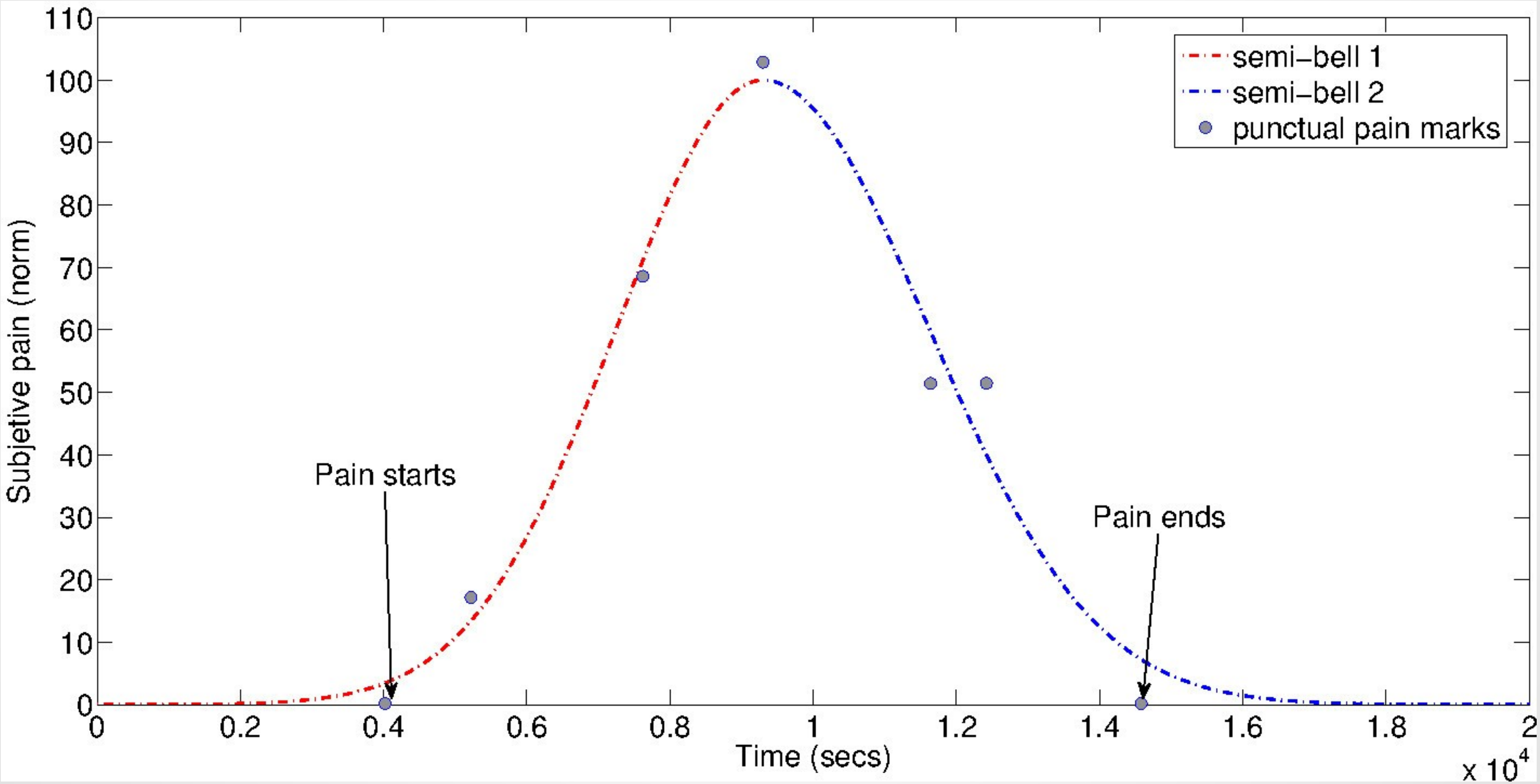
- Two sensing motes that communicate with an Android smartphone via Bluetooth
- EDA, skin temperature, EEG and ECG signals are acquired by one of the motes, while SpO_2 is acquired by the other
- Signal processing is performed in the smartphone (HR, blood pressure estimation, EEG energy bands)
- All data have 12 bit accuracy, and a decimation of 1 minute has been established per data
- Data are stored and transmitted through Internet to the data center

Deployed WBSN

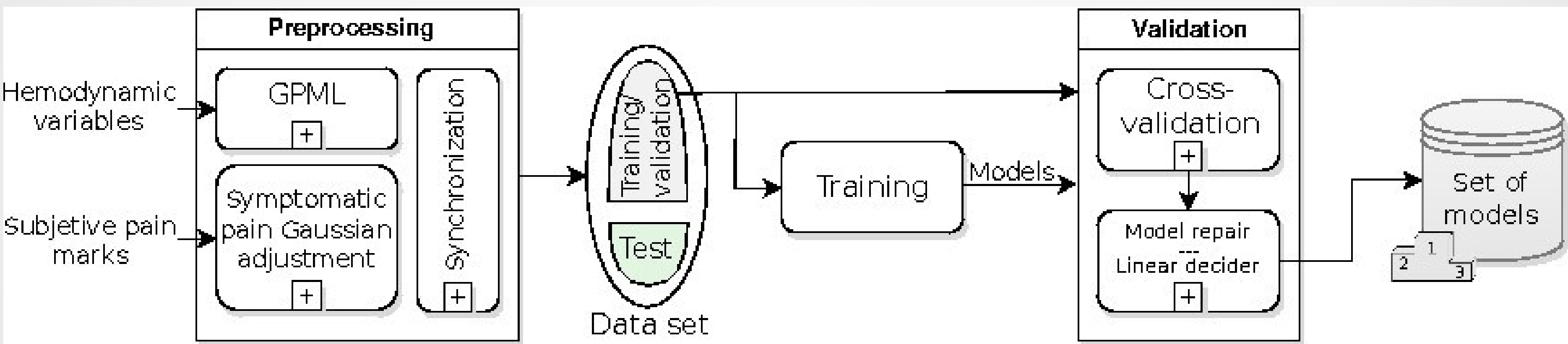
The symptomatic pain curve

- Each patient evaluates its pain in two ways: a global index of pain for the total migraine period, and punctual pain levels continuosly marked in the smartphone during the migraine attack
- The curve of pain evolution is normalized in amplitude
- The symptomatic curve has been modeled as a two semi-Gaussian curves as it fits the patient's subjective response

The symptomatic pain curve

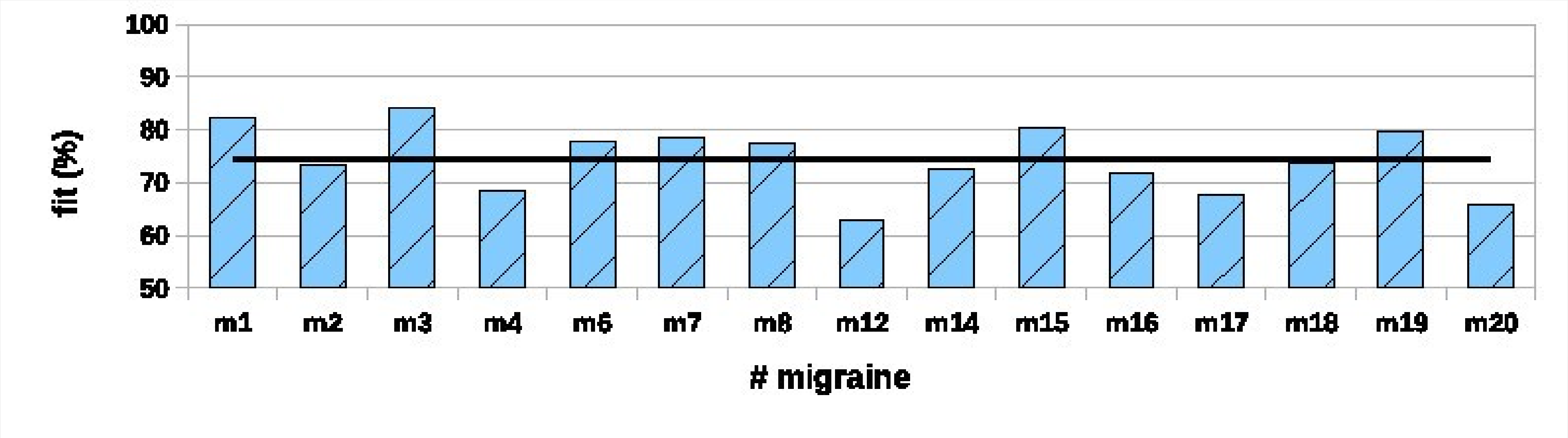


Modeling technique



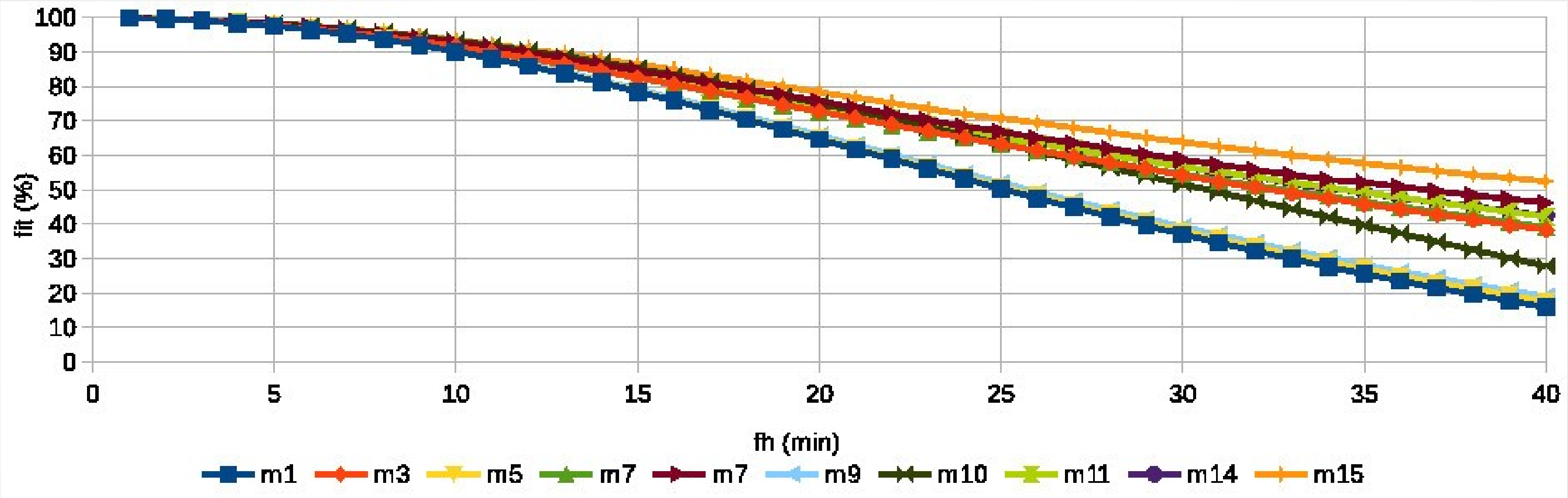
Some results

- Fit for 15 randomly selected migraines and 30 minutes of future horizon



Some results

- An averaged model is created by averaging the 5 best models in terms of fit value.
- The averaged model is applied to the remaining migraines

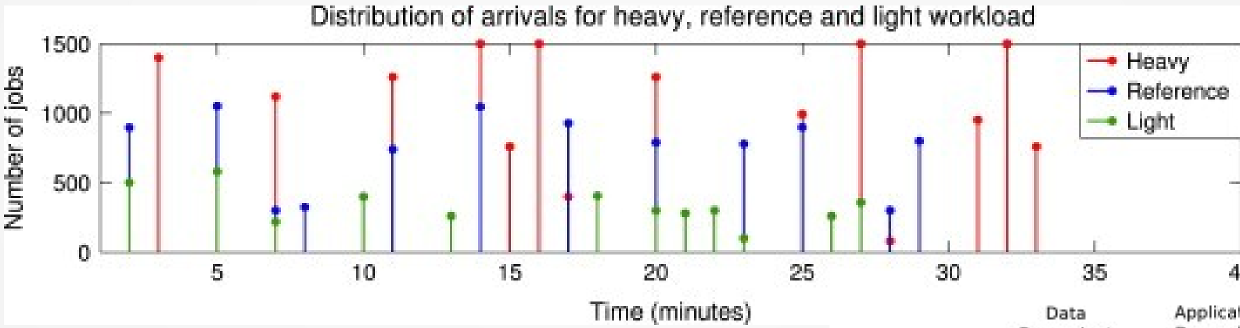


Case study in MCC

- User node coordinator
  - android-based smartphone, CPU 1 GHz, 1 GB of RAM, 16 GB of Flash Memory
- Cloud Computing facility
  - Rack servers (SunFire v20z 2x AMD Opteron @2 GHz)
  - Rack servers (RX-300 S6 Intel Xeon @2.4 GHz)
- Deployment
  - 300 user nodes, 300 coordinators
  - Air cooled data center with a total amount of 160 cores, belonging to 40 Intel or AMD

Case study in MCC

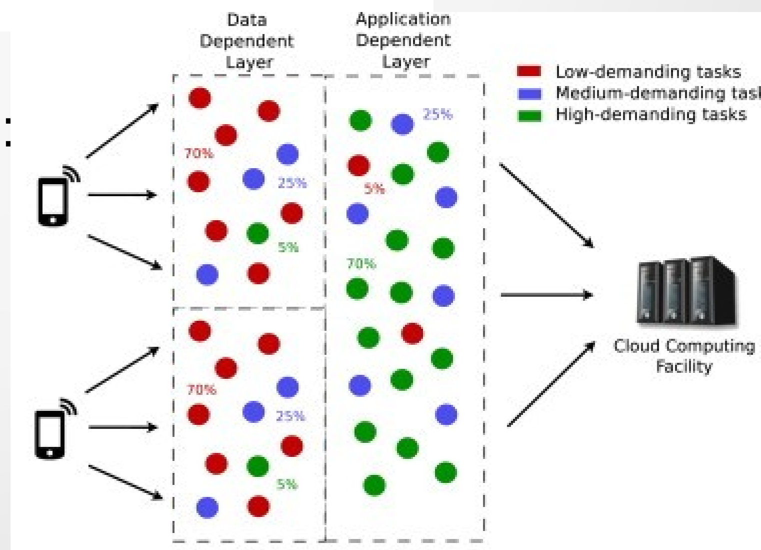
- Workload
  - Profiles: (i) heavy, (ii) reference and (iii) light workload
  - Organized in 10 different job sets that arrive following a Poisson distribution



  - each job set is split in two different levels:

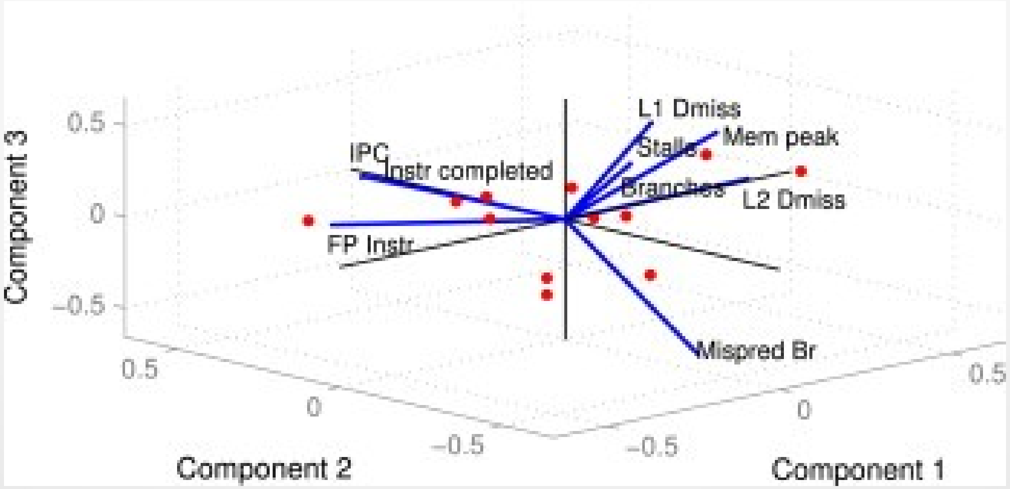
    (i) a data-dependent layer (60%),

    (ii) an application-dependent layer (40%)



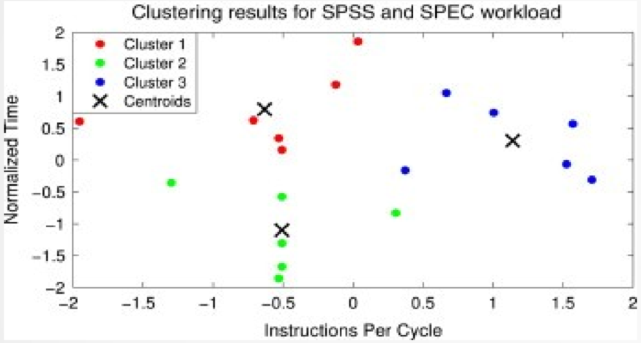
Case study in MCC

- Run-time application profiling
  - information of the performance counters by means of PAPI
  - principal component analysis (PCA): first 3 components together explain an 87% of the variance



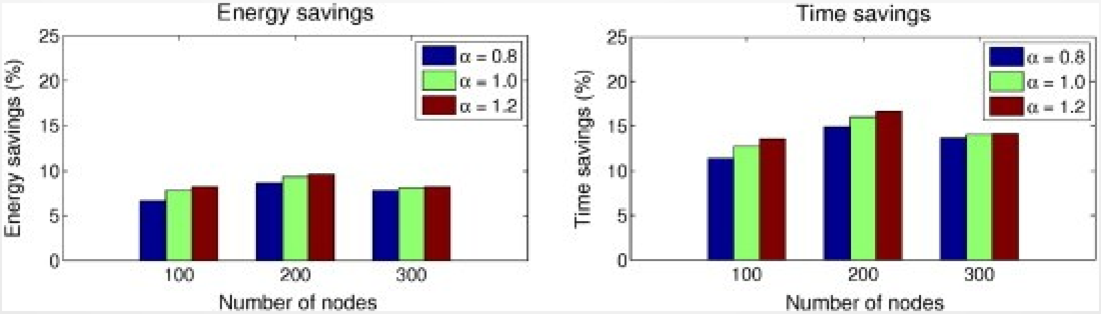
Case study in MCC

- Global resource allocation techniques
  - Task classification



Cluster	Tasks
Low demanding	Correlation, regression, Bayes bankloan, omnetpp, xalancbmk
Medium demanding	Bootstrapping, conjoint, gcc mcf, astar, gobmk
High demanding	Perlbench, bzip2, hmmer sjeng, libquantum, h264ref

  - Run-time allocation algorithm: based on Satisfiability Modulo Theory (SMT) formulas



Case study in MCC

- Data center resource management
  - Server selection: Mixed Integer Linear Programming (MILP) problem

Workload profile	Coordinators	Server selection
Heavy	100	35 Intel + 5 AMD
	200	36 Intel + 4 AMD
	300	37 Intel + 3 AMD
Reference	100	36 Intel + 4 AMD
	200	35 Intel + 5 AMD
	300	36 Intel + 4 AMD
Light	100	31 Intel + 9 AMD
	200	31 Intel + 9 AMD
	300	35 Intel + 5 AMD

Case study in MCC

- Data center resource management
  - Run-time workload assignment: MILP vs SLURM

Workload profile	Number of tasks	Energy consumption (kWh)			Execution time (h)		
		AMD	Intel	Intel + AMD	AMD	Intel	Intel + AMD
100 nodes, Heavy	8559	127.1	67.46	63.21	16.3	9.23	8.7
200 nodes, Reference	3765	61.7	34.12	31.89	7.8	4.7	4.5
300 nodes, Light	1961	37.31	28.02	27.6	4.8	4.3	4.3

New challenges

- **Heterogeneity** (in processing architectures, communication channels, user devices, data sources, etc.) provides further further opportunities for energy-optimization but it also encourages the seeking of global-optimization techniques that consider the heterogeneity of the system since the application conception.
- **High dynamism** of the scenario, where variable workloads and tasks arrive to the computing platform and a varying number of processing nodes can be available for processing or ready to feed new data.
- The constraints imposed by the Ubiquitous Computing model are determinant on the architecture of the computing paradigm. An all-over access to the computing services provided by the **Cloud** is required.
- Only with an **application-driven design style**, the energy footprint of the whole computing scheme can be reduced, while the reliability and performance requirements are still satisfied.

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Who are we?

http://greendisc.dacya.ucm.es