Smart Systems for Healthcare and Wellness

Wireless Communication Challenges and Solutions

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CATRENE
Cluster for Application and Technology Research in Europe on NanoElectronics

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Introduction

Healthcare: medical devices

- Implants (cardiac, cochlear, insulin pumps)
- On-body devices: hearing aids, activity monitoring, rehabilitation

Cardiac implant

Insulin pump

Cochlear implant

Hearing aids

Motion capture

Introduction

Healthcare: medical devices

- Implants (cardiac, cochlear, insulin pumps)
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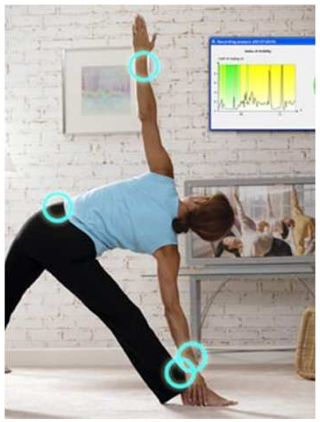
Wellness: wireless sensing and communicating devices

- Sport: monitoring, training
- Gaming: motion capture and sensing
- Leisure: smart glasses (assisted, augmented vision)

Sport



Gaming

Leisure

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Wellness: wireless sensing and communicating devices

- Sport: monitoring, training
- Gaming: motion capture and sensing
- Leisure: smart glasses (assisted, augmented vision)

Application drivers:

- Ageing population, healthcare costs, prevention
- Smart sensor technologies, ubiquitous wireless networks, IoT

Key challenges:

- Cost, Power consumption, Miniaturization, Security

Introduction

Application Layer
- Communication
- Navigation
- Monitoring
- Motion capture

Communication
Localization
Sensing

Network Layer
- Architecture
- Routing
- Localization

Self-organization, flexibility
Localization

Data Link Layer
- MAC Protocol
- Modulation
- Relaying

Power efficiency
QoS (rate, reliability, latency)
Security

Physical Layer
- Digital Processing
- RF transceiver
- Antenna
- Propagation channel

Power efficiency
Miniaturization / Integration
Low cost

Agenda

Introduction

Wireless solutions

Standards, MAC protocols, Security, Localization

Hardware solutions

Low-power radios, Miniature antennas, Reconfigurability, Integration

EM environment

Propagation, EM exposure and dosimetry

Conclusion

Wireless solutions

Standards needed for interoperability of Smart Systems

ISO/IEEE 11073 Health informatics
- Medical / health device communication standards

Continua Health Alliance

TC Smart BAN

IEEE 802.15.4j Medical BAN
IEEE 802.15.6 Wireless BAN

Low-power wireless sensor network technology

ZigBee Health Care

Security

Medical devices shall not be vulnerable to security attacks

(highly sensitive personal informations)

- **Availability:** the communication service should be robust against service denial.
- **Confidentiality:** information should not be disclosed to illegitimate entities.
- **Integrity:** the integrity of the delivered message should be guaranteed.
- **Authentication:** nodes should be able to identify each other.
- **Non-repudiation:** a message origin may not be disclaimed.

Wireless solutions

Adaptive and low-power communication protocols for Body Area Networks

Flexible and **transparent** for several application profiles

- Autonomously and dynamically adaptive (network size, topology)
- Trade off between QoS and energy consumption
- Adapted to heterogeneous traffics

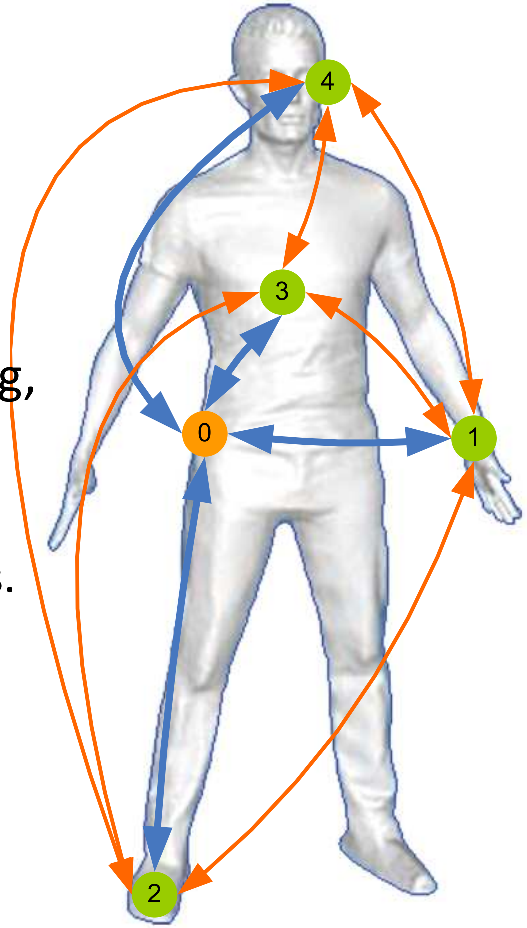
Providing **network functionalities** (association, self-organizing, data collection…)

Quality of Service (QoS) guaranteed (reliability, latency,…)

- Several Medium Access Controls supporting different traffics.
- Dynamic and Automatic relaying mechanisms mitigating the shadowing impact on PER

Adapted to **Body Area Networks**

Low power consumption optimization for a long autonomy



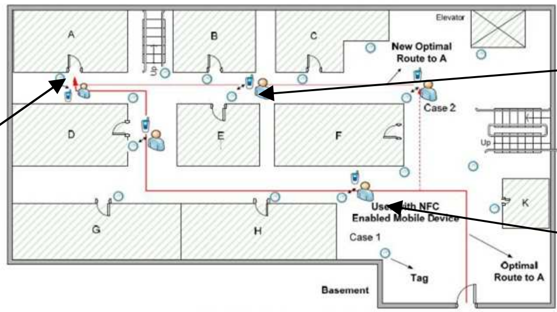
Wireless Localization – Applicat° (1)

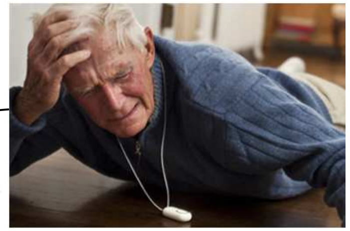
Health management systems: Needs for precise/reliable localization and long-term tracking in daily-life environments

Ergonomic, less intrusive and reactive monitoring, prevention and rescue systems

- **Physical rehab** at home through **motion/posture capture** or non-invasive and geographically unrestricted monitoring of the patient's activity;
- **Assisted mobility** for physically or mentally disabled people;
- **Finding people** (e.g., trace elderly that are roaming in the hospital).

Christine has travelled 10.6kms this week by foot





Grand-Pa's felt down in the kitchen

Doctors control progresses in your physical rehab remotely

Wireless Localization – Applicat° (2)

Wellness, Fitness and Personal sports: Monitor and capture in real-time and/or analyse offline the user's mobility and gesture

- Optimize and secure the **user's performance** (e.g. offline jogging statistics, peak and average speeds) → Possibly correlated with other physiological informations from other sensors (link with Healthcare systems);
- Enable **self-learning of the good practice/gesture** with quantified feedback (e.g. martial arts, skating);

Training with location-enabled smartphones as "personal coaches"

http://spoonphone.com/en/

Assessing (individual and collective) performance vs. physical risk

Wireless Localization – Challenges (1)

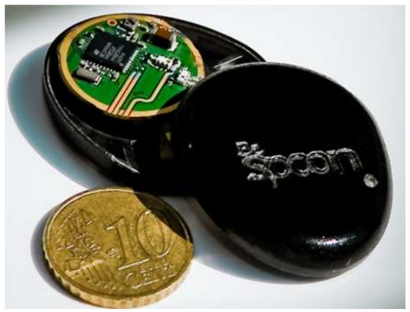
New required features and functionalities

- Augment **indoor navigation capabilities** through motion/posture capture with limited usage of extra and costly equipments at home;
- Ensure **remote patient monitoring** (e.g. from a distant hospital or medical centre).
- Retrieve the **real-time** (time-stamped) **trajectory** of a mobile patient/user, possibly while collecting geo-referenced physiological measurements (i.e. as a function of the occupied position);
- Authorize **self-learning of mobility patterns and personal habits** out of the retrieved trajectories;
- Authorize **detection of anomalies** or unexpected events based on adequate decision tools;

Wireless Localization – Challenges (2)

Current research axes for robust, scalable and privacy-aware localization services

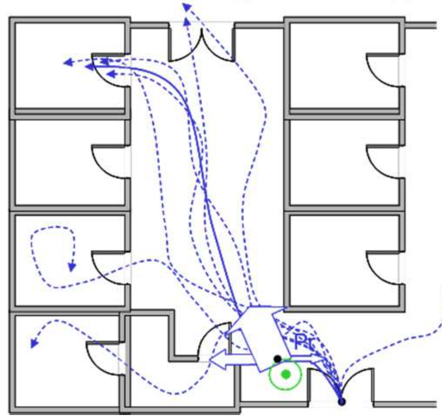
- **Integrated radio technologies** with scalable levels of precision and ranges (down to cm accuracy at low data rates);
- Opportunistic **cooperation between mobile units**, as well as decentralized and/or multi-hop localization approaches;
- **Cross-layer protocol** design to ensure synergies btw communication and localization;
- **Secure location protocols** limiting the location-specific infos over public channels;
- **Models and algorithms** robust to propagation and usage conditions
- **Hybrid data fusion** (heterogeneous radios and inertial units)
- **Mobility learning** to assist tracking



Low-power low data rate ranging-enabled tags (IR-UWB)

Cooperative localization

Mobility learning



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Wireless solutions

Standards, MAC protocols, Security, Localization

Hardware solutions

Low-power radios, Miniature antennas, Reconfigurability, Integration

EM environment

Propagation, EM exposure and dosimetry

Conclusion

Low-power radios

Technology

- Technology shrink
- Benefit from **F_T ↗**

…. but leakages ….

Protocol

- Cooperative & standards
- Interoperability

…. but **overhead** ….

Design

- Technology pulled
- Easy **Digital-Analog mix**

…. but tuneability ….

RF Architecture

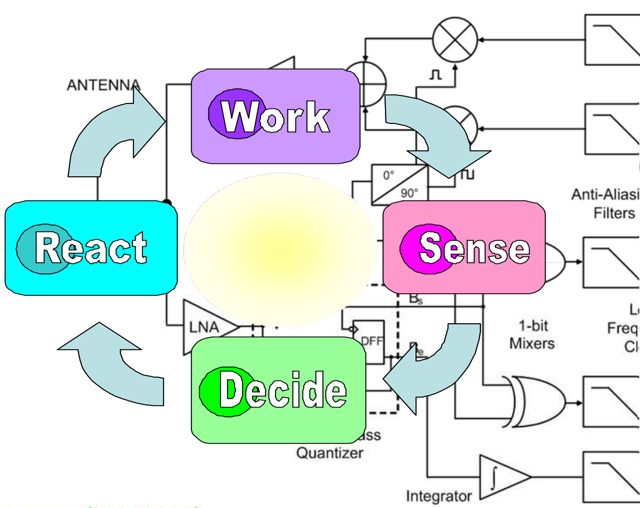
- Always at the **best fit**
- Efficiency & Performance

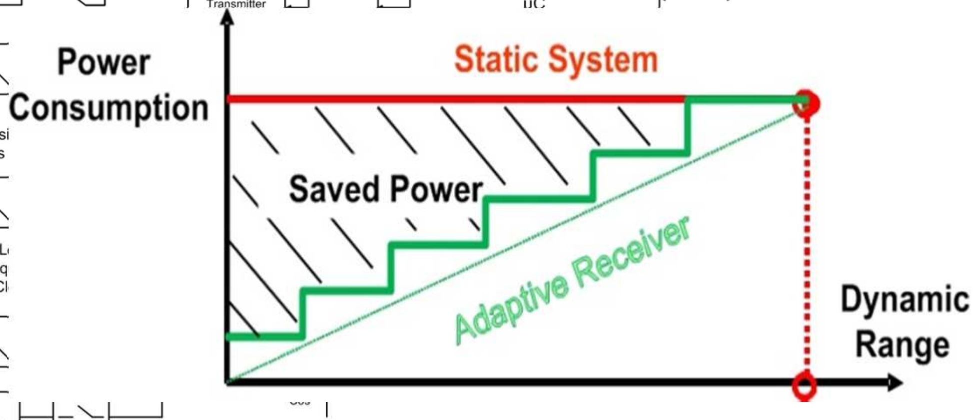
…. but dynamically ….

Low-power radios

Low-power RFIC design and architectures

- Objective : **Sub-1 mW** RF transceivers
- **Advanced silicon technologies** (e.g. FD-SOI), low voltage operation
- **Digital-oriented** front-ends for a real-time flexibility of RFIC functions to optimize sensitivity/ linearity/ output power and power efficiency
- **Protocol-level** features to take advantage of RFIC flexibility for efficiency optimization.
- New **design methodologies**: meta-modeling at system/circuit/device levels.

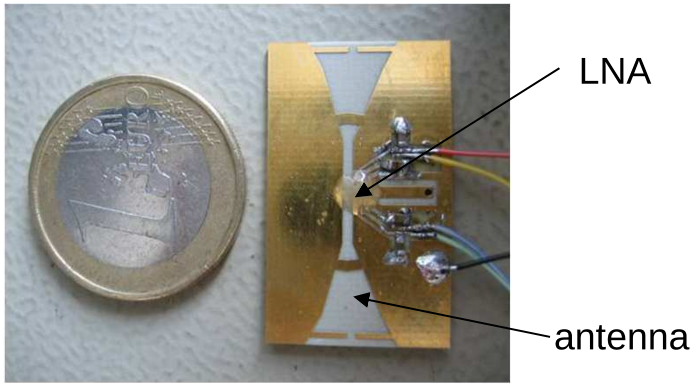


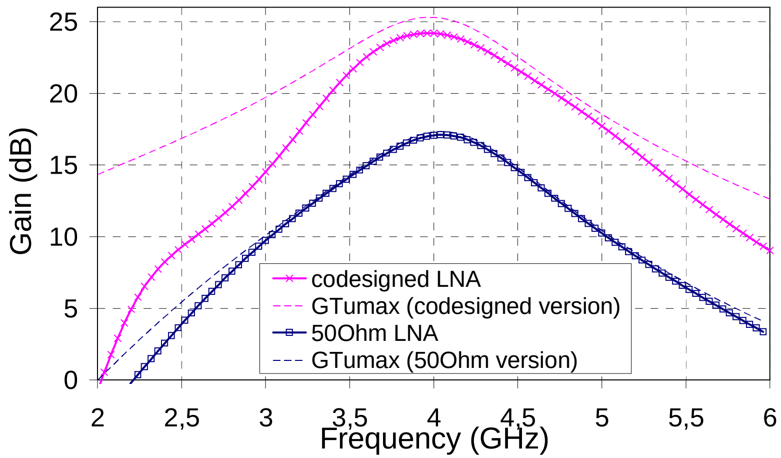


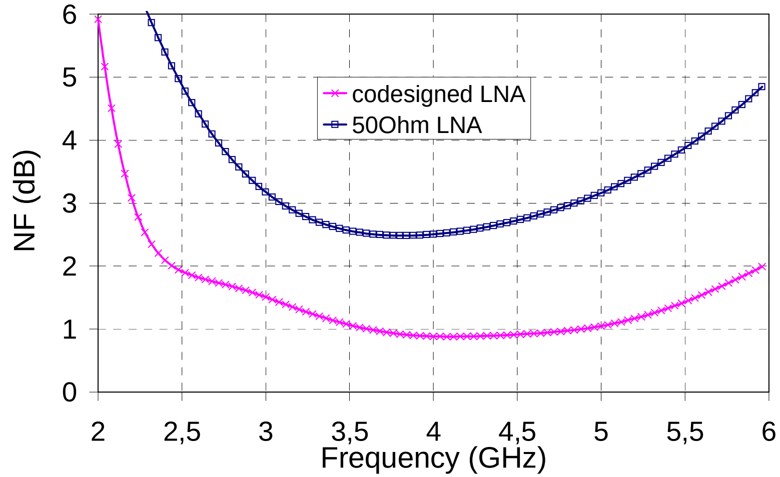
Radio-Antenna codesign

Joint optimization of RF performances and miniaturization

- **PA-Antenna** : Output power and power efficiency improvement
- **LNA-Antenna**: Gain and Noise Figure improvement







Miniature antennas

Key requirements:

small size, efficiency, robustness to environment changes.

Small antennas: $$Efficiency \times Bandwidth \propto Volume$$

Typical figures for a 1 cm^3 antenna

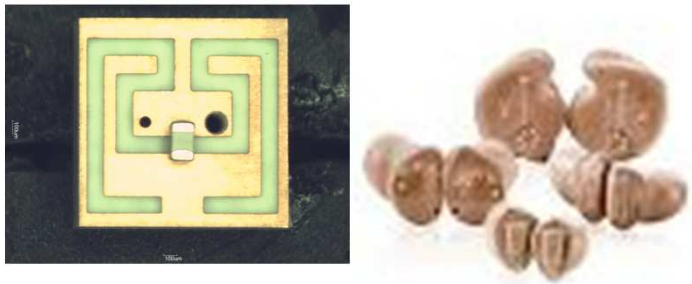
Freq./Wavelength	Max. Efficiency* Bandwidth
433 MHz / 692 cm	6.6×10^{-5}
868 MHz / 346 cm	5.3×10^{-4}
2.4 GHz / 12.5 cm	1.1×10^{-2}

Needs / solutions:
- **Low-loss materials**
- **Accurate EM models**
- **Electronic tuning (frequency, impedance)**

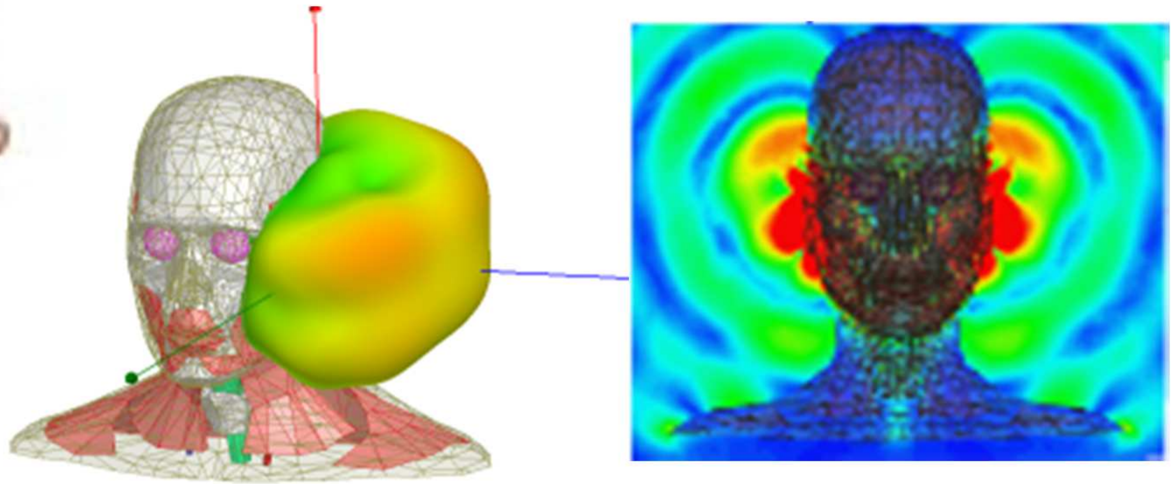
Miniature antennas

Human body environment: accurate EM models for simulation and characterization

On-body devices



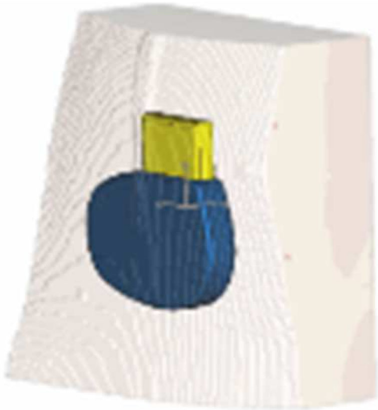
Ultra miniature antenna
for hearing aids
(5x5x2 mm^3)
Source: FP7-Wiserban project



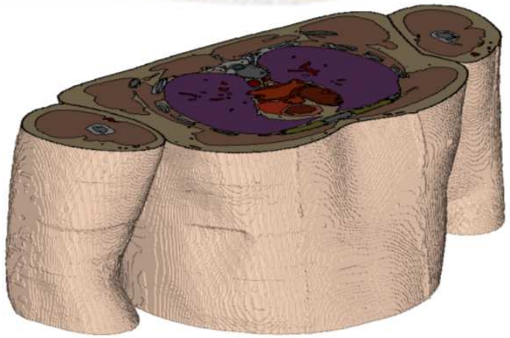
Miniature antennas

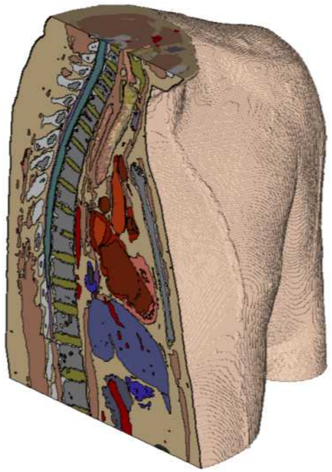
Human body environment: accurate EM models for simulation and characterization

In-body devices (implants)



Pacemaker antennas





UHF brain computer interface antenna

Source: CEA-LETI.

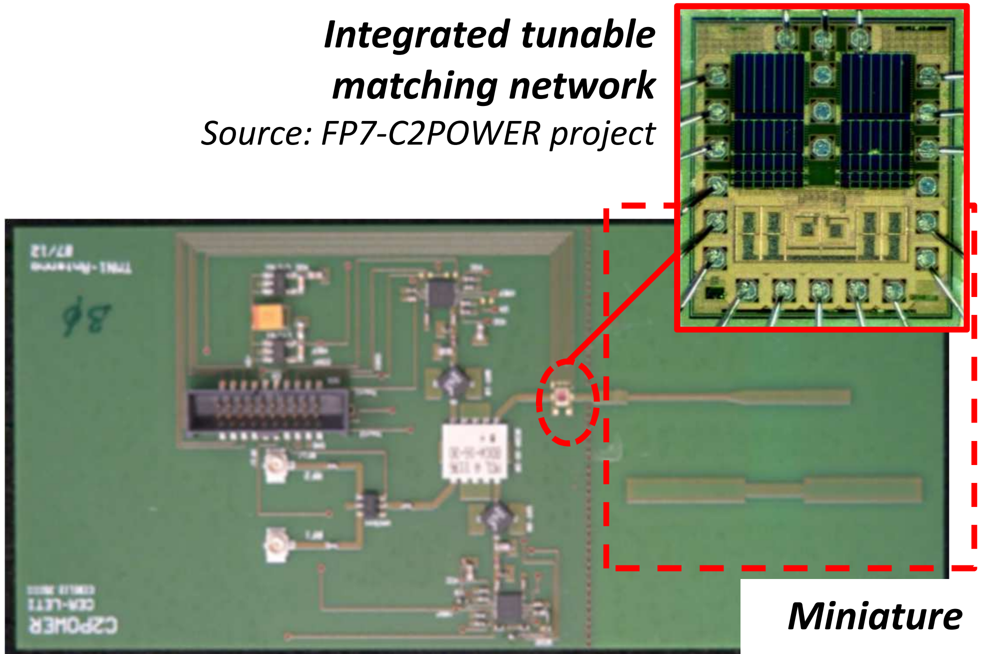
Reconfigurable antennas

On-body miniature antennas are highly sensitive to environment changes:

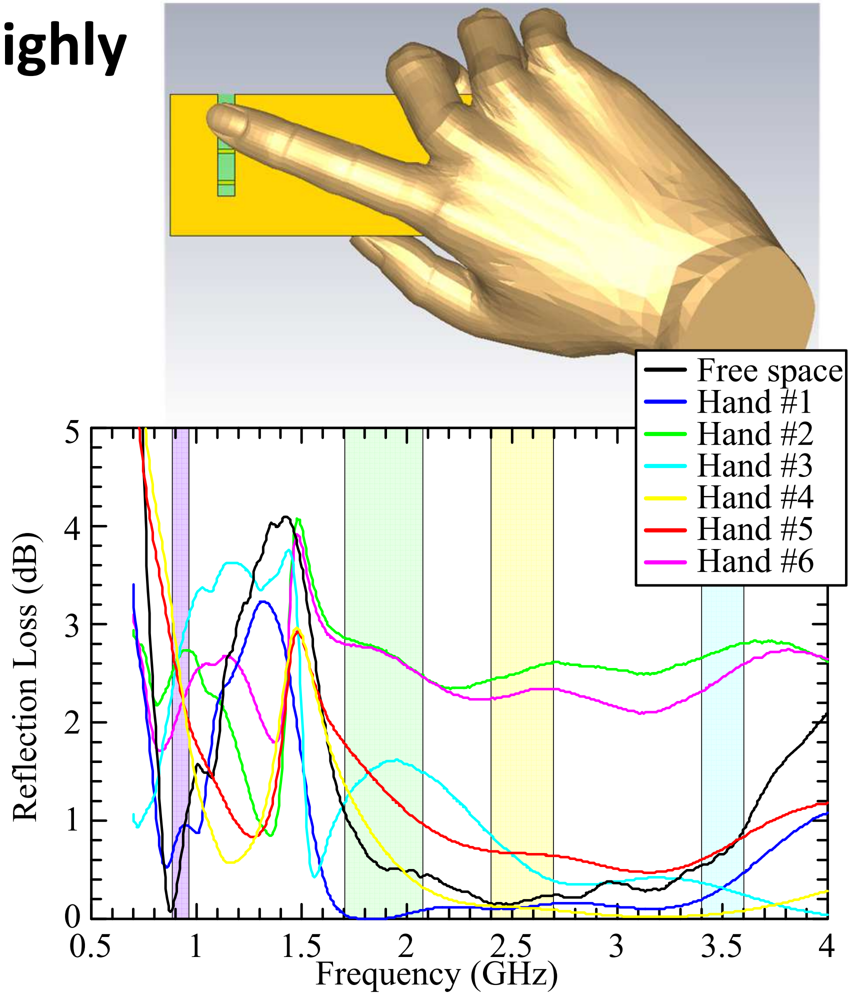
Self-adjusting impedance tuning

Integrated tunable matching network

Source: FP7-C2POWER project



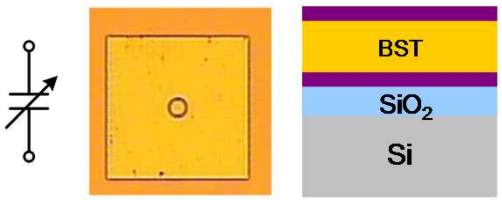
Miniature antenna

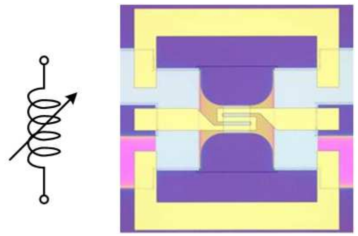


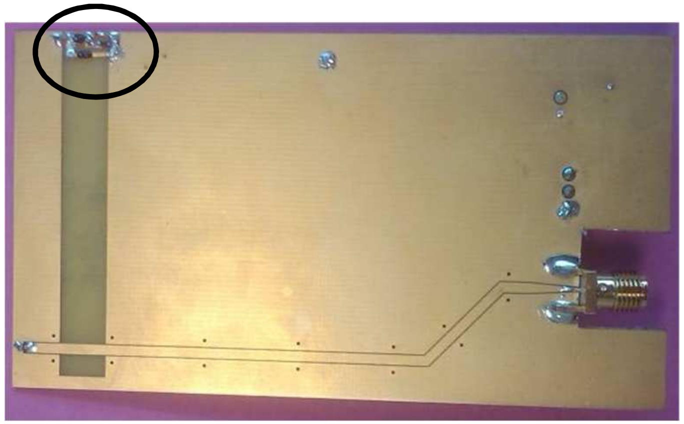
Reconfigurable antennas

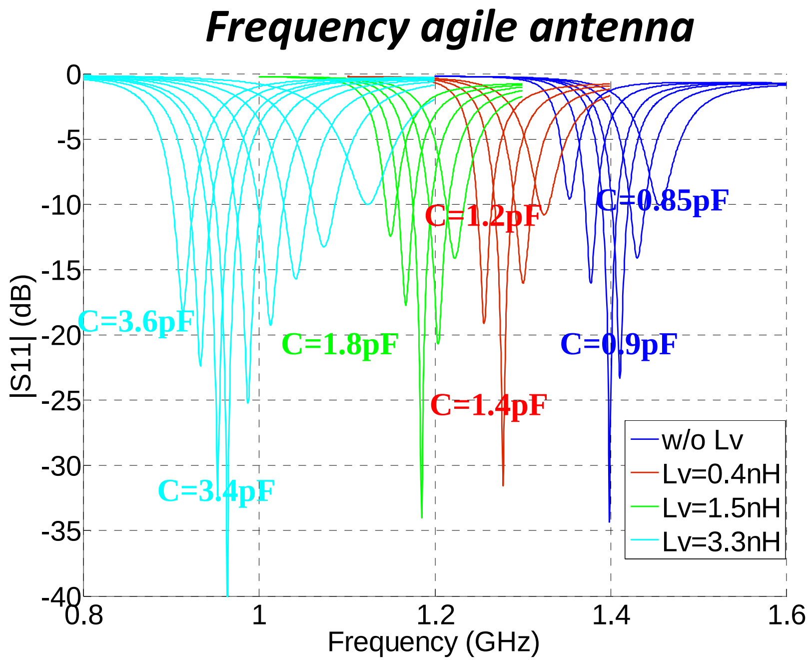
Switchable/tunable RF components on antenna structure

- Tunable capacitors (MEMS, BST, CMOS)
- Tunable inductors (MEMS)







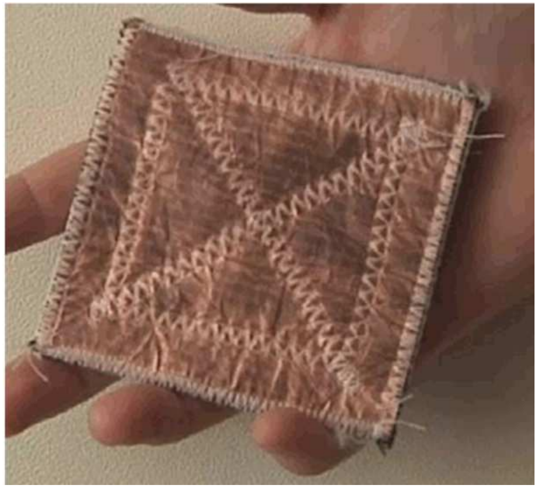


Antennas integration

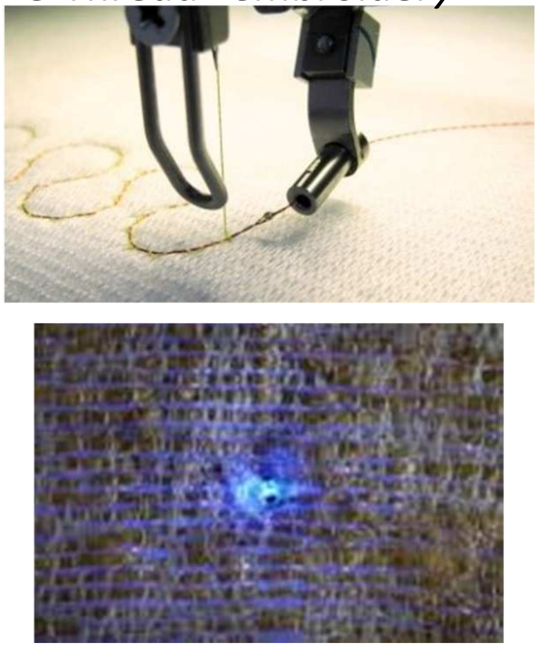
Embedding antennas and circuits in textiles and fabrics for comfortable wearable devices.

- Conductors in textiles
- Polymer electronics

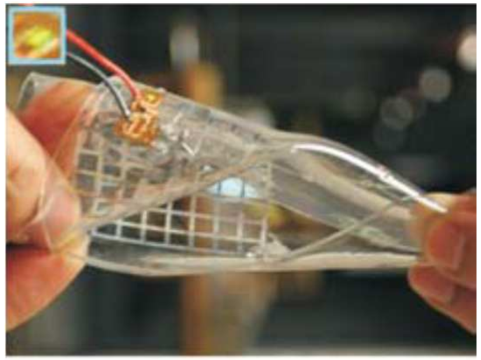
Metal on textile



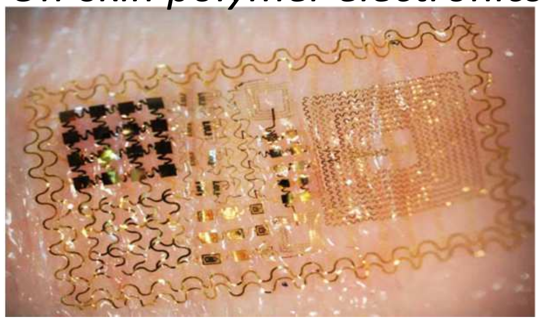
"e-Thread" embroidery



Flexible liquid metal



On-skin polymer electronics



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Wireless solutions

Standards, MAC protocols, Security, Localization

Hardware solutions

Low-power radios, Miniature antennas, Reconfigurability, Integration

EM environment

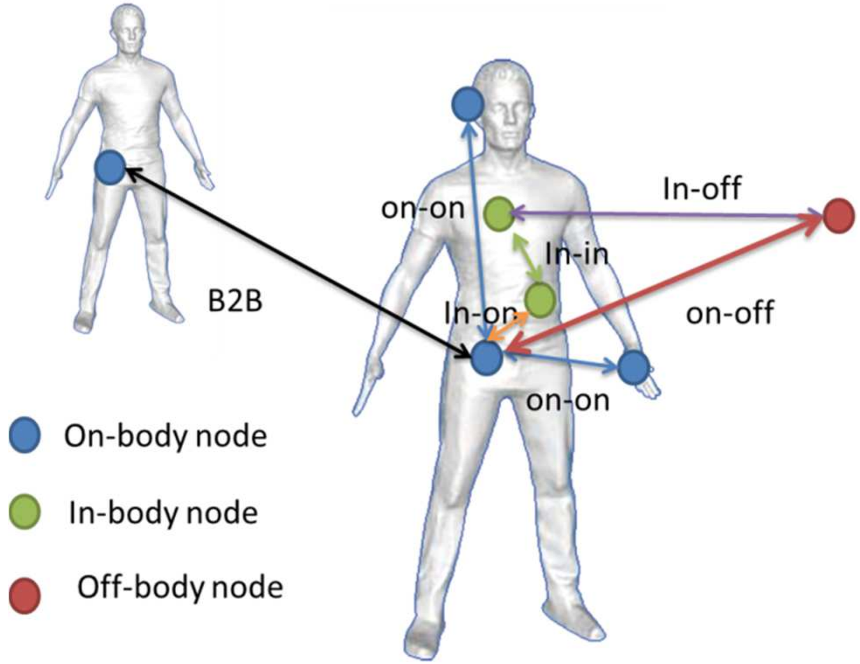
Propagation, EM exposure and dosimetry

Conclusion

Propagation

Knowledge of the propagation channel specific to the body environment

- Different devices and **different propagation models** : In-Body, On-body, Off-body
- **Human tissues – wave interaction** and propagation models over wide frequency range (from 10 MHz to 80 GHz)
- **Time-variant** channel models
- **Antenna-channel** joint **models** (New criteria for antenna designs)



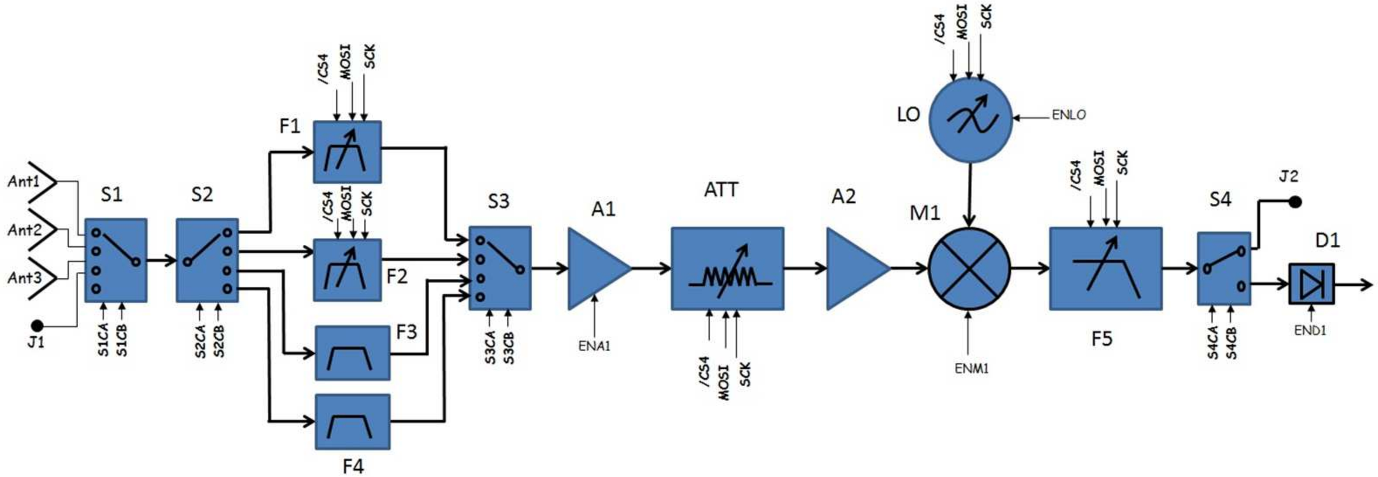
EM exposure and dosimetry

Growing concern about the actual EM exposure of citizens and professionals

- Accurate modeling and characterization tools
- Dosimeter embedded in smart systems: miniature, low-power, multi-standards

Measurement setup with phantom and dosimeter probe (Source: Project FP7-Lexnet).

Multiband dosimeter architecture (source: Project FP7-Lexnet).



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Wireless communications and localization are key enablers for many smart systems applications in the field of Healthcare and Wellness

Systems interoperability based on **standards**

Key challenges: Cost, Power consumption, Miniaturization, Security

… leading to **S&T challenges** in all system layers:

- **Network** Layer: self-organized architectures
  - **Data Link** Layer: flexible protocols
    - **Physical** layer: radio, antenna, propagation, integration

Smart Systems
for Healthcare and Wellness

Wireless Communication Challenges and Solutions

Thank you for your attention

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