

micro and nanoelectronics  
microsystems  
ambient intelligence  
image chain  
biology and health



Hermes Workshop

30/03/2011

# NACCESS project

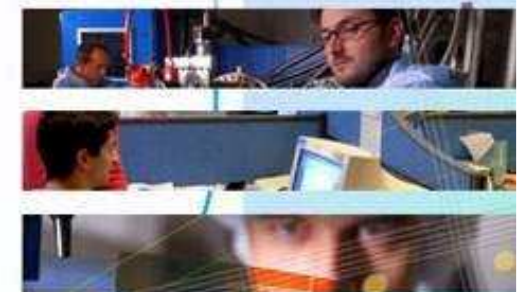
NAnoscale smart Communication components and Systems

Jean-Benoît PIERROT



energie atomique • énergies alternatives

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# Outline

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- Scenarios and applications
- Project overview & objectives
- Partners consortium
- A detailed view of NACCESS project objectives
- Conclusion



# Scenario & applications :

## μ-monitoring and smart control

- Biomedicine (physiological data, medical exploration...)
- Robotic (« nano »bots)
- Embedded sensors in structures and objects (car tires, bridges, plane wings...)
- Environmental and agriculture monitoring (plants, animals, water quality...)
- Main constraints
  - Small size -> must work with the physical limits
    - ◆ Energy scavenging and storage systems
    - ◆ Communication transceivers
    - ◆ Actuated and sensed areas (actuators & sensors sizes)
    - ◆ Node packaging (biologically neutral)
    - ◆ ...
  - Sense a volume with several nodes -> social interaction
  - Act on environment -> increase the energy requirements for the actuators
  - Autonomous system in term of energy

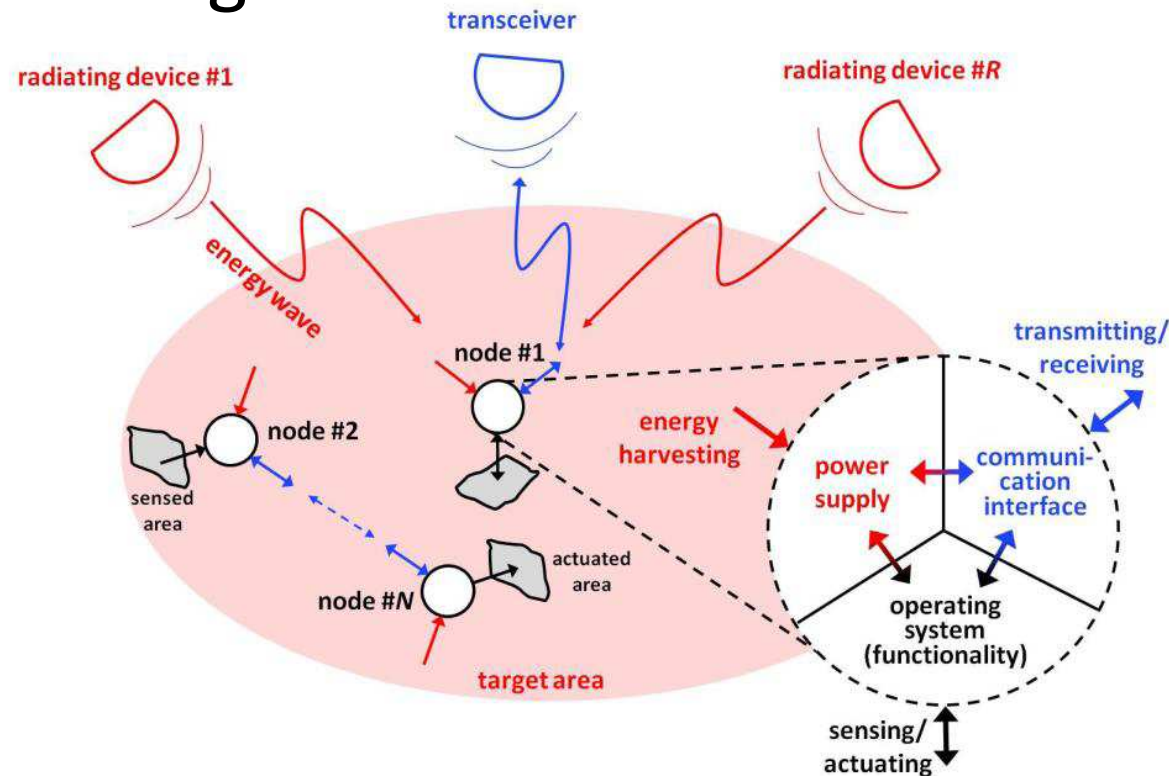




# Scenario & applications

Our proposal :

- A wireless sensor & actuator network (WSAN)
- Ambient intelligence. Collaboration in swarm to catch an higher information level



LUND UNIVERSITY

NACCESS - Jean-Benoî

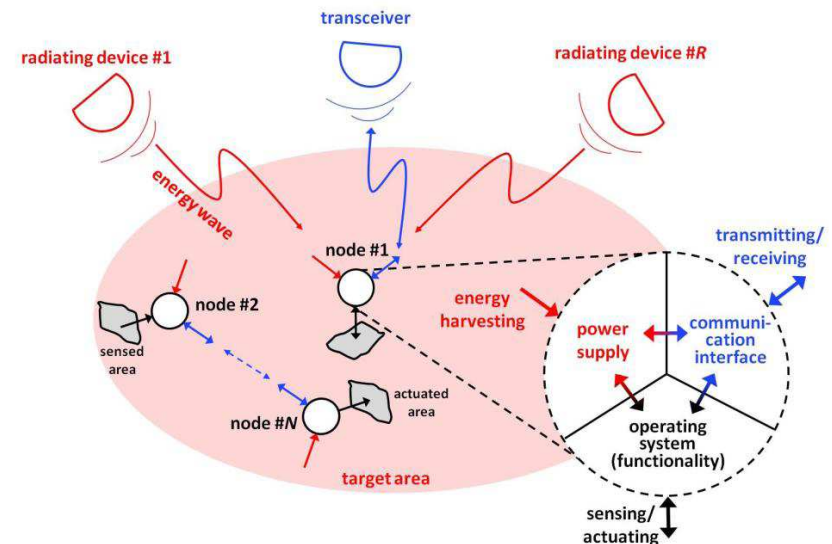
# Scenario & applications

■ New technology : Multimodal interface adapted to the application medium variation

- Acoustic
- Electromagnetic

■ Use existing and radiating energy from two kind of energy sources. Remove batteries if possible.

■ Use the same interface for energy harvesting and communication (and sensing/acting ...?)



# Objectives

1. Autonomous operation of miniaturized smart systems (in particular, permanent provision of energy for wireless powering the components using **acoustic and electromagnetic** THz waves, consideration of different channel environments, energy harvesting and efficient ways of energy storage and supply)
2. Efficient design of **wireless communication** protocols among nodes and/or between nodes and external access networks
3. **Joint design** approach of a node for a given set of specifications (energy supply and usage, communication capabilities, sensing/actuating functionality)
4. Efficient **node implementation** with power supply, communication interface and operating system including the node's functionality (sensing or actuating)



## Who participate ? – 7 partners

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- University of Kassel – *Germany (leader)*
- Commissariat à l'énergie atomique et aux énergies alternatives – *France*
- Imperial college of Science Technology and medecine – *United Kingdom*
- Centre Suisse d'Electronique et de Microtechnique - *Switzerland*
- Delft University – *Netherlands*
- Technical University of Lodz - *Poland*
- Lund University - *Sweeden*

# How ? - Project steps

- Scenarios & system requirements
- Joint design of smart small size systems
- Experimental prototype(s)
  - micromechanical harvesters optimized for extracting power from acoustic waves. Evaluate new architecture.
  - antennas and rectification sub-circuits for collection and down-conversion to DC of power delivered by electromagnetic radiation at millimeter-wavelengths
  - Joint systems prototype and environment integration
- Communication protocols and node/network management
- Validation platform (as small as possible) and overall performances evaluation



# O1 - Energy

## Autonomous operation of miniaturized smart systems

- Efficient ways of wireless powering of autonomous nodes by acoustic and/or THz radio waves
- Characterization of the energy transmission channel and adaptation of system parameters to maximize efficiency
- Front-end/baseband technologies for energy harvesting of acoustic and/or THz waves for single and multiple nodes being in close vicinity to each other
- On-board power conversion (and efficient storage)



# O1 – Vibration and acoustic energy harvesting

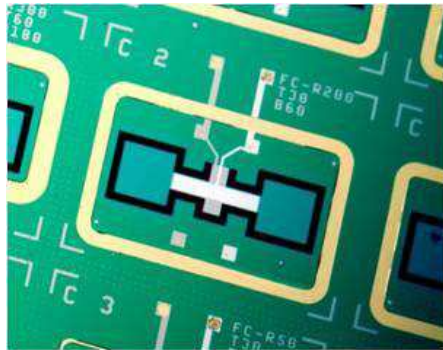
## ■ Machine vibration

- Working vibration driven harvester covers a wide range of size and power levels (<math><1\text{mm}^3</math> ( $\sim\mu\text{W}$ ) to  $>100\text{cm}^3$  ( $\sim\text{mW}$ )
- Ratio of actual power output to theoretical maximum is less than 10%

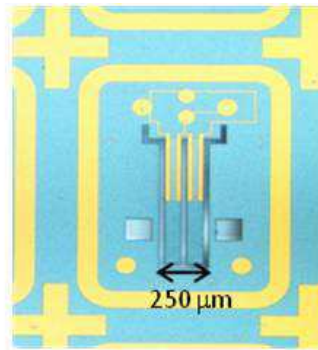
## ■ Piezoelectric Mems technology

- Horowitz paper (2006) suggests  $0.34\mu\text{W}/\text{cm}^2$  with a theoretical potential output of  $250\mu\text{W}/\text{cm}^2$
- IMEC (2009) obtained a  $40\text{mm}^3$  system which can generate  $85\mu\text{W}$  of output power
- CSEM technologies (2009) have been downscaled to  $0.1\text{mm}^3$  size

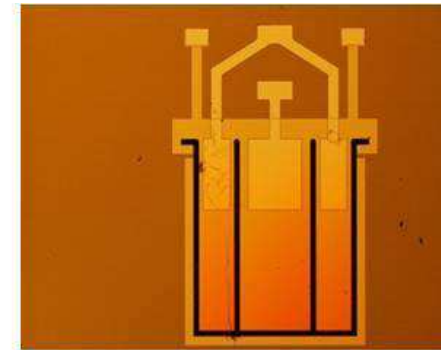
# O1 – Vibration and acoustic energy harvesting



1 MHz



150 kHz



32 kHz

## ■ NACCESS expected outcomes

- establishing the mechanism for power delivery in small systems using acoustic power delivery
- pushing the miniaturization of useful acoustic energy harvesters to new limits (millimeter or less)
- Due to physical limits the resonant frequency tends to be high (>20kHz) for matching ambient source (motion) then we provide the ultrasonic source.
- Demonstrate a power transfer in human tissue or structural material



# O1 – Vibration and acoustic energy harvesting

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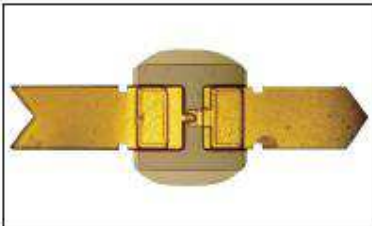
## ■ NACCESS expected outcomes

- extending advanced fabrication, packaging and housing technologies to energy harvesters
- applying proper design optimization to piezoelectric harvesting devices.



# O1 – Electromagnetic power delivery

- Energy harvesting techniques well-known in RFID domain but near-field (<1m)
- Power transfer proof of concept 900MHz, 2.5GHz, 18GHz, 35GHz, 79GHz
  - Required antenna volume is decreasing with frequencies
  - Antenna format have an effect on power transfer quality
- NACCESS expected outcomes
  - Defining a systematic approach for finding the optimum frequency for electromagnetic power delivery at different scales
  - Extending the application of electromagnetic power delivery to smaller devices and higher frequencies, including frequencies in the THz band.



*110GHz, GaAs beam lead  
detector diode of  
approximately 150 microns in  
size*



# O1 – Power conditioning electronic

## ■ Why

- Ensure the transducer operates with maximum power density
- Interface to energy storage (in order to overcome the intermittent nature of the harvested energy)
- Provide power at a suitable voltage to present to the load electronics.





## ■ Recent works with trivial circuits (capacitors) and discrete components.

## ■ NACCESS expected outcomes

- Demonstration for the first time of synchronous pre-biasing (force charge on material) in miniaturized piezoelectric acoustic harvesters
- Demonstration of other enhanced functionality such as dynamic tuning of the harvester to the incoming acoustic energy
- Development of low-power DC-DC converter circuits optimized for very low input voltages
- Increase integration of power electronics with harvester system

## O2 - Communication

Efficient design of wireless communication protocols among nodes and/or between nodes and external access networks

-  Design of a robust (against propagation and radio channel mismatches, component imperfections, etc.) and **energy-efficient** wireless communication interface for transmission between a single node and external transceiver
-  Extension of **single node scenario to energy-efficient cooperative diversity schemes** (communication between nodes and/or external transceiver) with a number of  $N = 2 \dots 5$  nodes including interference mitigation, medium access, decentralized network control, routing and range extension
-  Comparison of schemes for different specifications of available energy (range, field strengths) and information bandwidths
-  Overall system characterization for considered scenarios in terms of quality of service parameters for investigated communication protocols



## O2 –wireless sensor network

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### ■ Concept of WSAN

- Distributed node in an environment
- Communication protocols to share the information transport medium
- Build an information with a high level of interest step-by-step using local node measurement and neighborhood information
- Large to huge number of nodes

### ■ Concept of smart-dust. Add the following constraints

- Small size
- Low energy consumption
- Low cost





## O2 –wireless sensor network

### ■ NACCESS expected outcomes

- System architecture and limitations for cooperative multi-node networks communicating wirelessly
- Scalability with respect to multiple parameters (e.g. scalable system, scalable power, scalability of networks and protocols to swarms of multiple nodes, scalability of parameters such as range and data rates)
- Reliability and operation in harsh environments.
- Mote size: 1-2 mm<sup>3</sup> (Proof of concept prototype probably ~1cm<sup>3</sup>)
- Power consumption: ? nJ/bit
- Transmission rate: ? kbps.

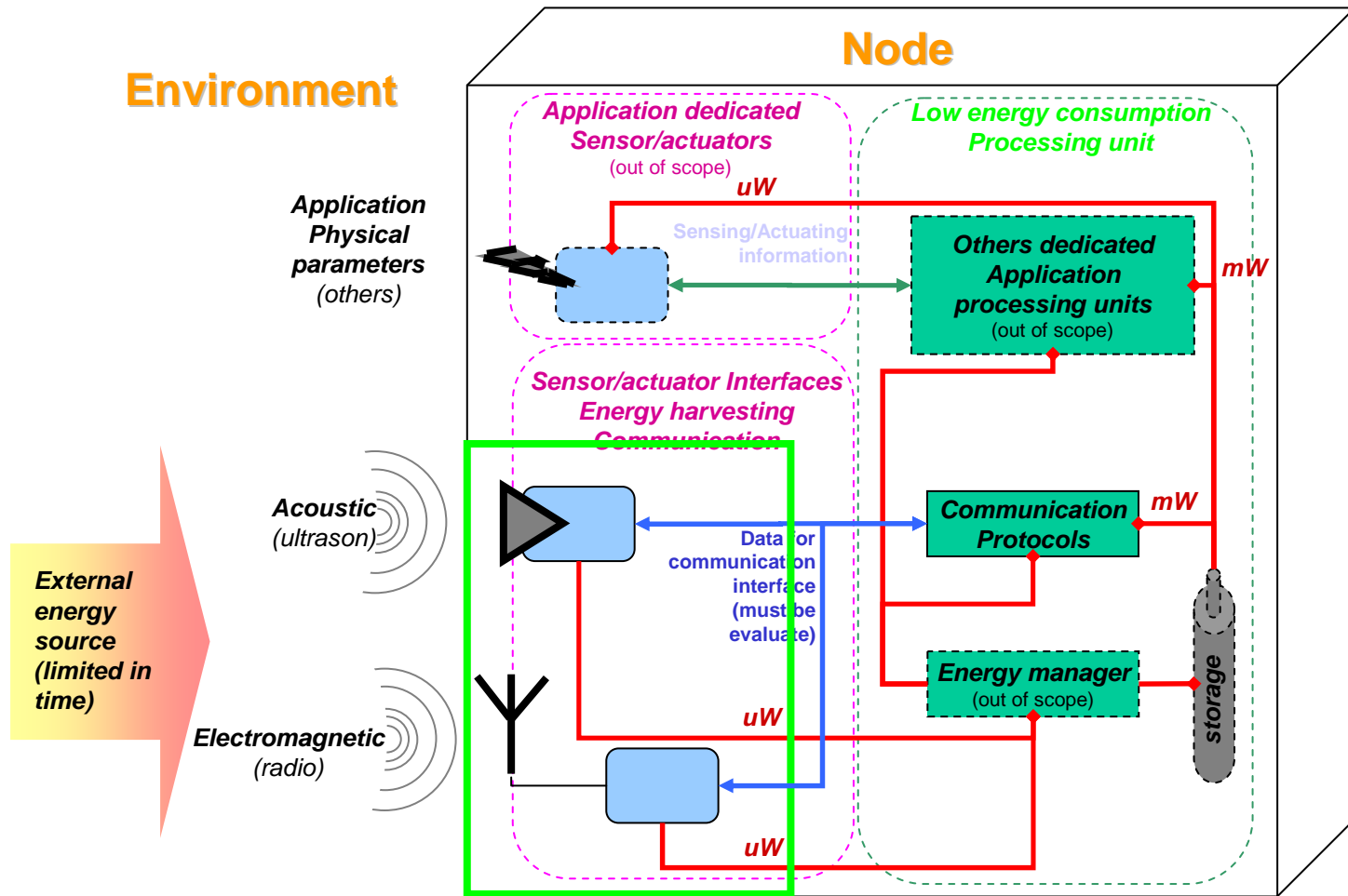
## O3 - Design

Joint design approach of a node for a given set of specifications

- Initial design approaches for the communication interface and operating system per node
- Joint optimization of the overall node operation (power supply, communication interface and operating system) with respect to form factor, energy consumption and quality of service parameters (service availability/outages, error rates, routing, medium access etc.)
- Comparison of suitable components and their embedding in the node architecture
- Characterization of the node operation with respect to power consumption, duty cycles for specific application scenarios etc.

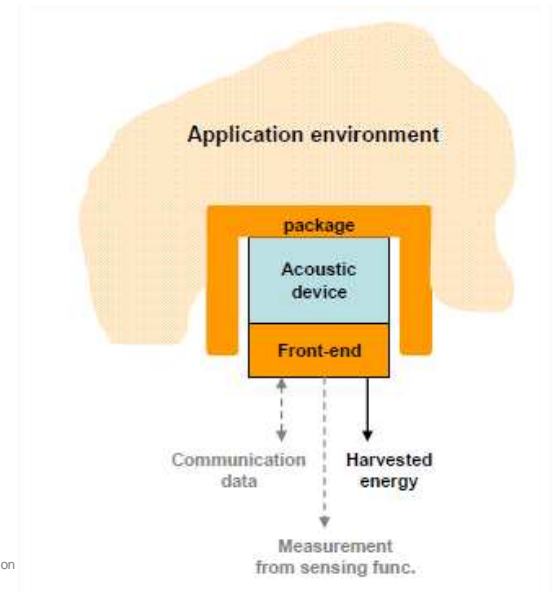
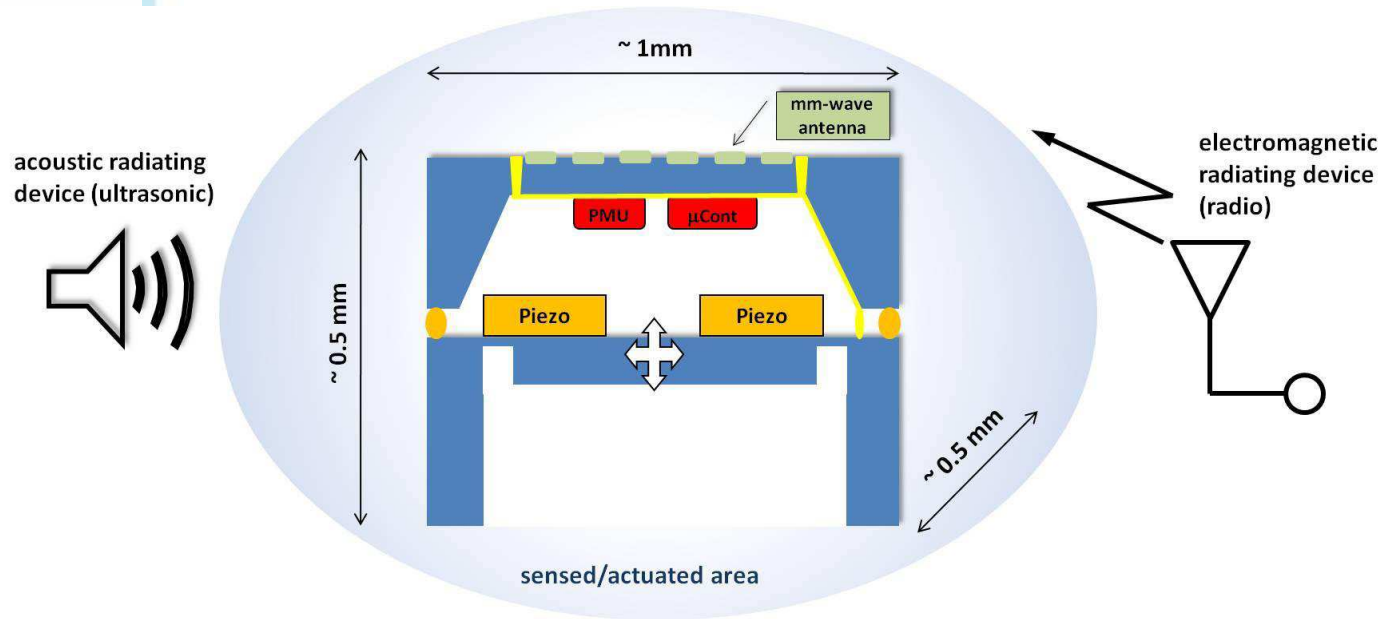


# O3 – joint design acoustic/radio device



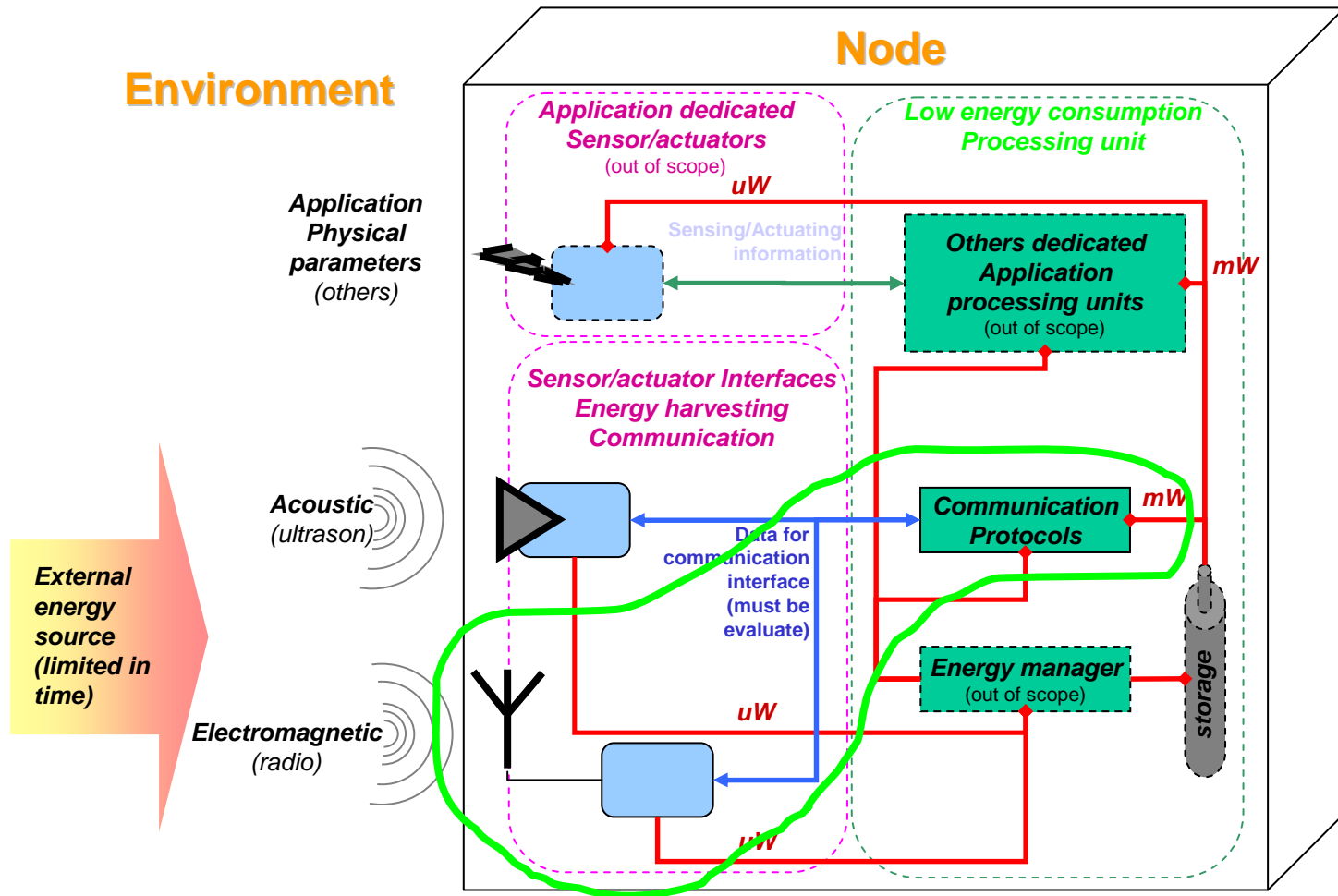
# O3 – joint design acoustic/radio device

- power management unit (PMU)
- piezoelectric circuitry (Piezo)
- Packaging and environment integration



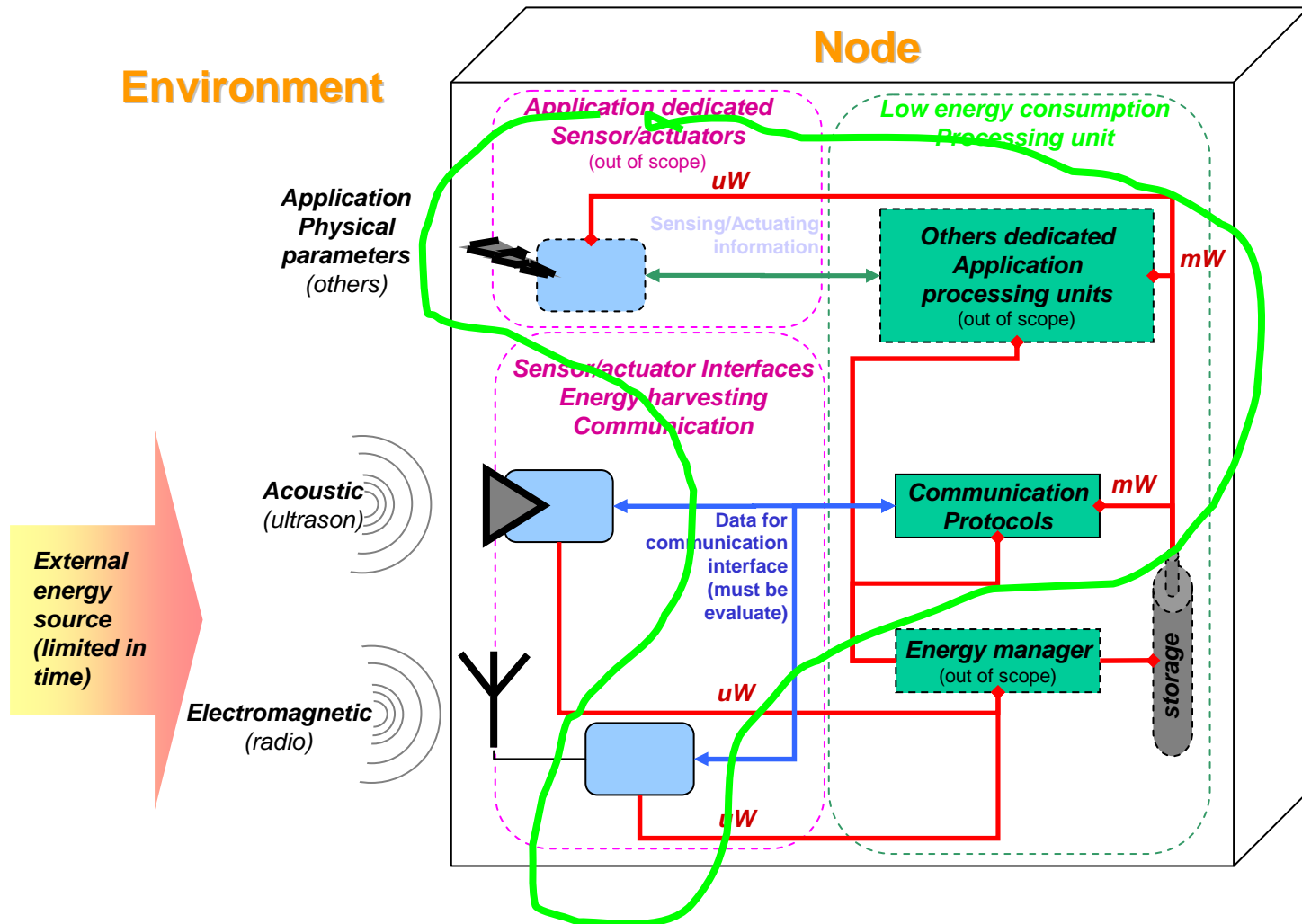


# O3 – joint design transceiver/processing unit



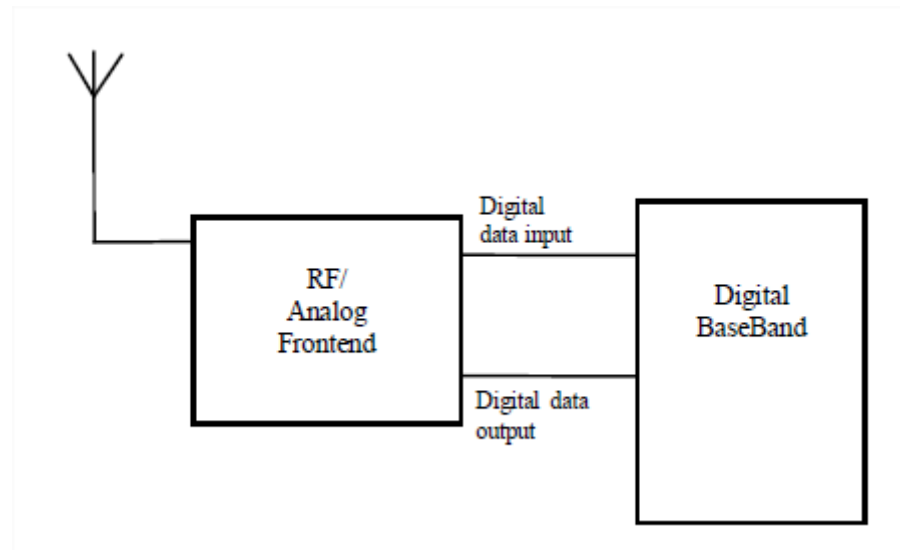


# O3 – joint design transceiver/processing unit










## O3 – joint design transceiver/processing unit

- performance characterization of the proposed communication solutions and protocols
  - Node level (P2P communication and others functionalities which use the transceiver (distancemetrics, synchronization...))
  - Network level. Collaboration and information building.



## O4 – building a node and a small network

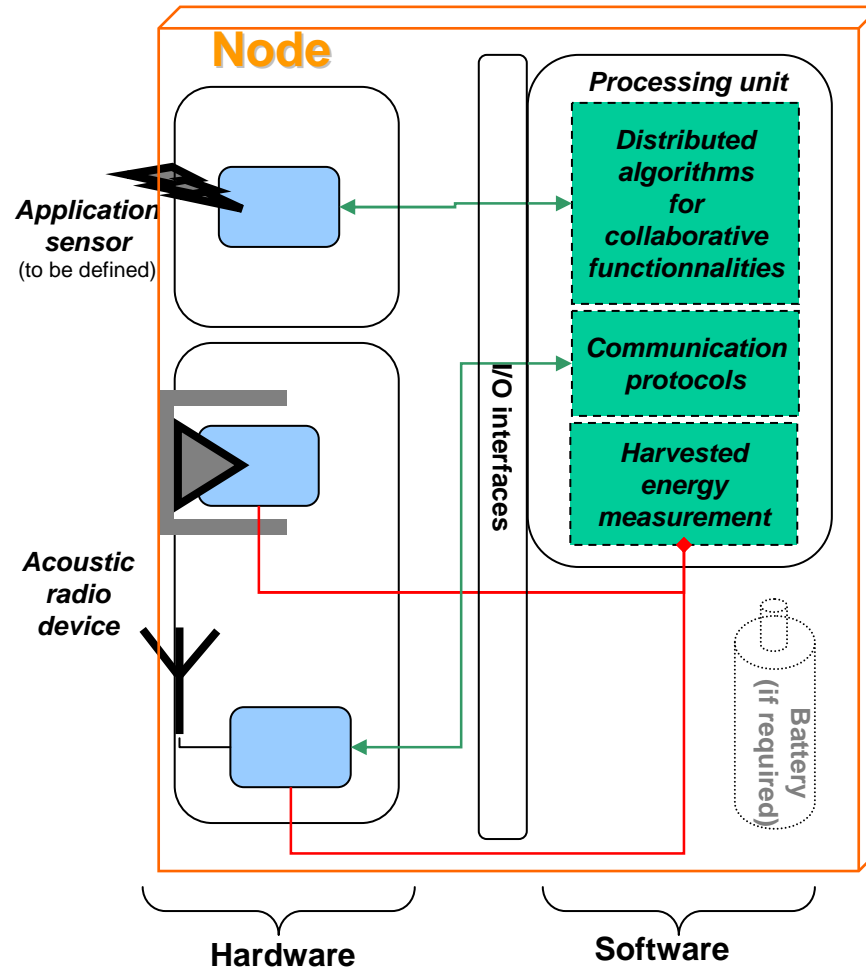
Efficient node implementation with power supply, communication interface and operating system including the node's functionality

- 
 ■ Proof-of-concept and design studies based on implemented subsystems to determine interdependent effects not being taken into account in the design
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 ■ Experimental verification of models for the node design (e.g. RF components based on lumped elements vs. distributed parameters)
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 ■ Measurements of required radiation field strengths and their relation to performance metrics (energy harvested by the nodes, interference etc.) of implemented components
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 ■ Investigation of key effects for characterizing single and multiple node operation
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 ■ Finding most suitable components for a given task with feedback to the design of the underlying architecture
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# O4 – Node implementation



NACCESS Innovation blocks



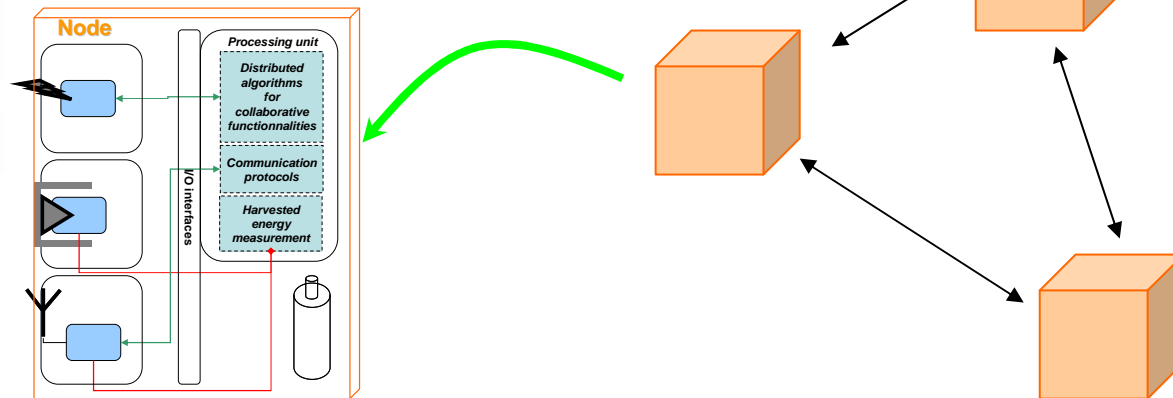


# 04 – Network in a real environment

## ■ Performances evaluation

External energy sources

### Experimental Scenario



# Conclusion

- Joint design of a SoA small size device with joint functionalities
  - Acoustic and radio communication
  - Energy harvesting system
  - And more? (distance metrics...)
- Communication protocols and processing architecture
  - Really low energy consumption constraint
  - Smart and distributed environment monitoring
- Proof of concept for an as small as possible node architecture and WSN network
  - Several intermediate modules prototypes
  - Integration
  - Packaging