Hermes Workshop

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NACCESS project

NAnosCale smart Communication componEnts and SystemS

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energie atomique • energies alternatives

Outline

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

Scenario & applications :

µ-monitoring and smart control

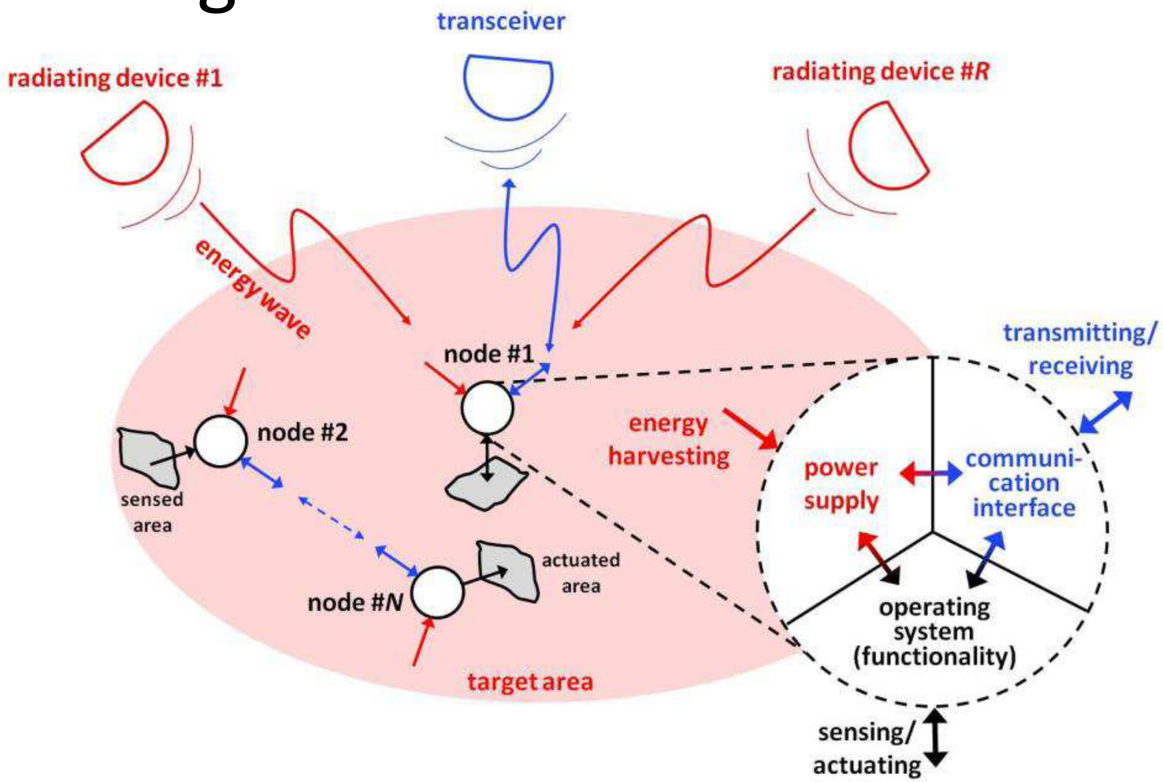
- Biomedicine (physiological data, medical exploration…)
- Robotic (« nano »bots)
- Embedded sensors in structures and objects (car tires, bridges, plane wings…)
- Environmental and agriculture monitoring (plants, animals, water quality…)

- 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

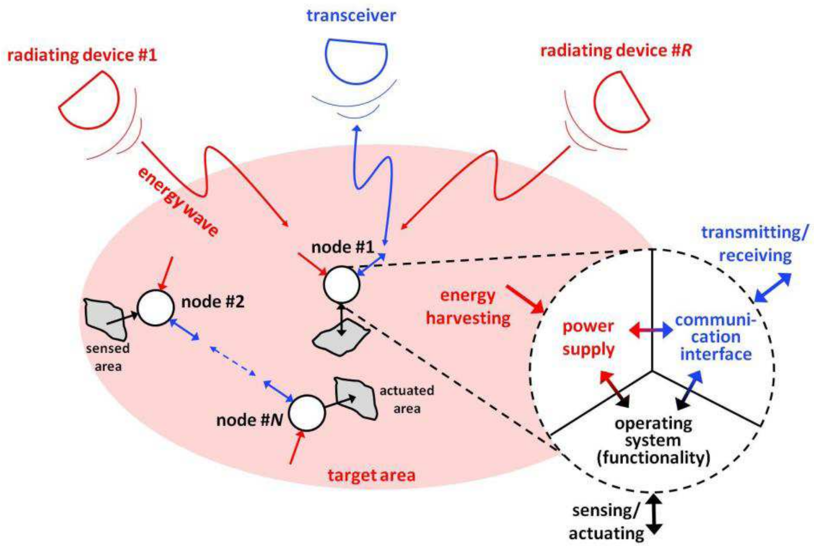


Scenario & applications

- 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

- 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

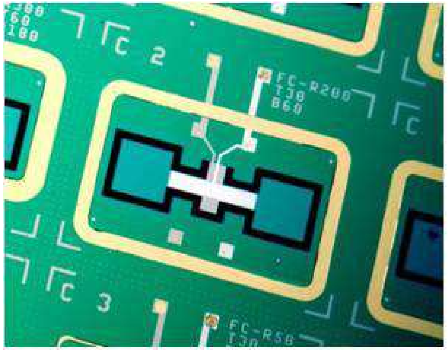
Machine vibration

- Working vibration driven harvester covers a wide range of size and power levels (<1mm^3 (~µW) to >100cm^3 (~mW)
- Ratio of actual power output to theoretical maximum is less than 10%

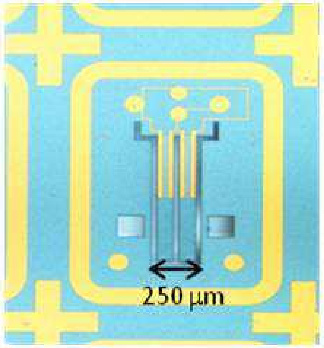
Piezoelectric Mems technology

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

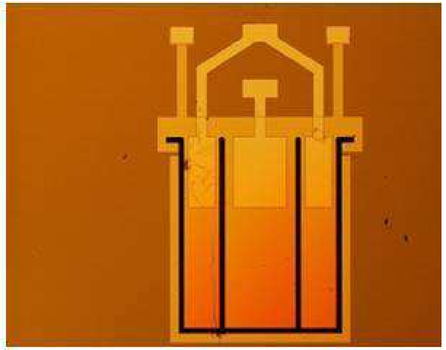
O1 – Vibration and acoustic energy harvesting



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 ambiant source (motion) then we provide the ultrasonic source.
- Demonstrate a power transfer in human tissue or structural material

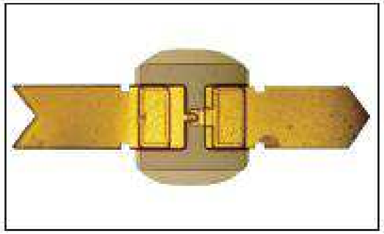
O1 – Vibration and acoustic energy harvesting

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…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

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

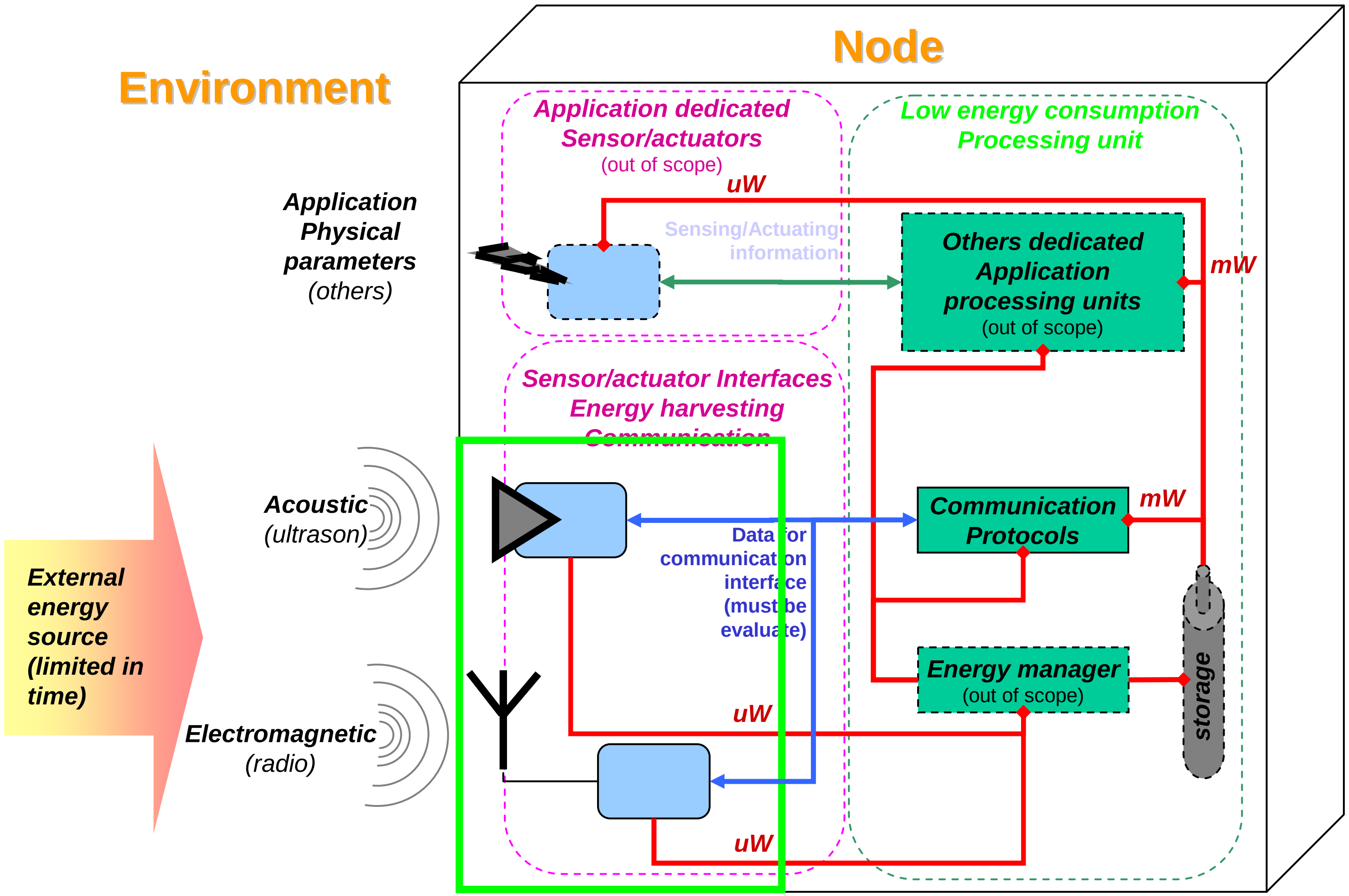
- System architecture and limitations for cooperative multi-node networks communicating wirelessly
- Scalability with respect to multiple parameters (e.g. scalable system, scalable power, scalability of networks and protocols to swarms of multiple nodes, scalability of parameters such as range and data rates)
- Reliability and operation in harsh environments.
- Mote size: 1-2 mm3 (Proof of concept prototype probably ~1cm3)
- Power consumption: ? nJ/bit
- Transmission rate: ? kbps.

O3 - Design

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

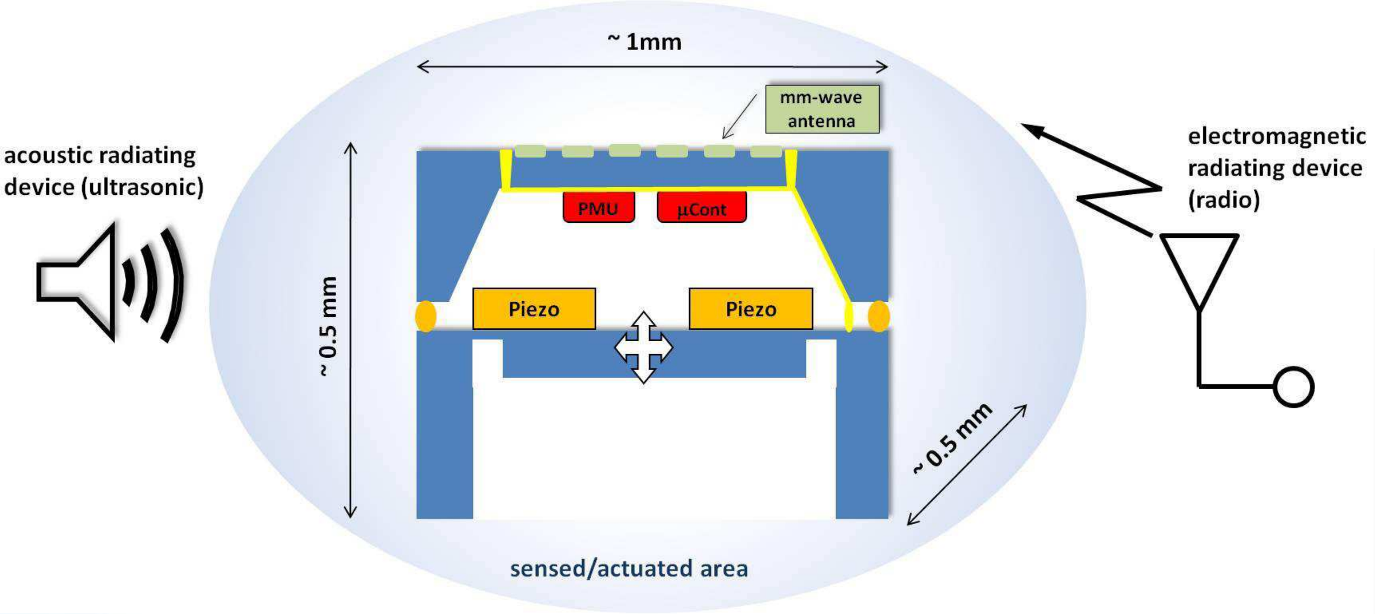
- Initial design approaches for the communication interface and operating system per node
- Joint optimization of the overall node operation (power supply, communication interface and operating system) with respect to form factor, energy consumption and quality of service parameters (service availability/outages, 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.

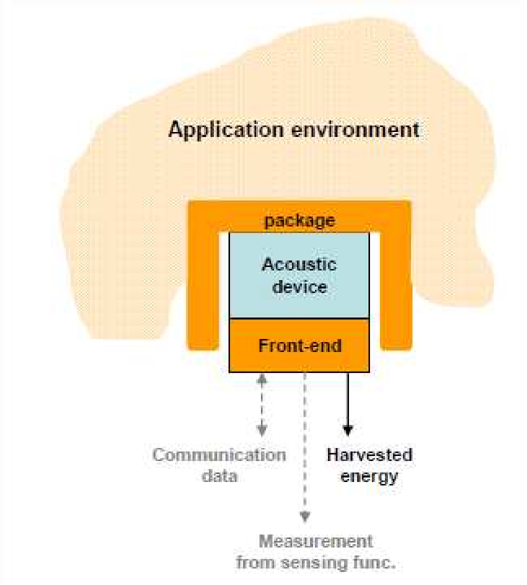
O3 – joint design acoustic/radio device



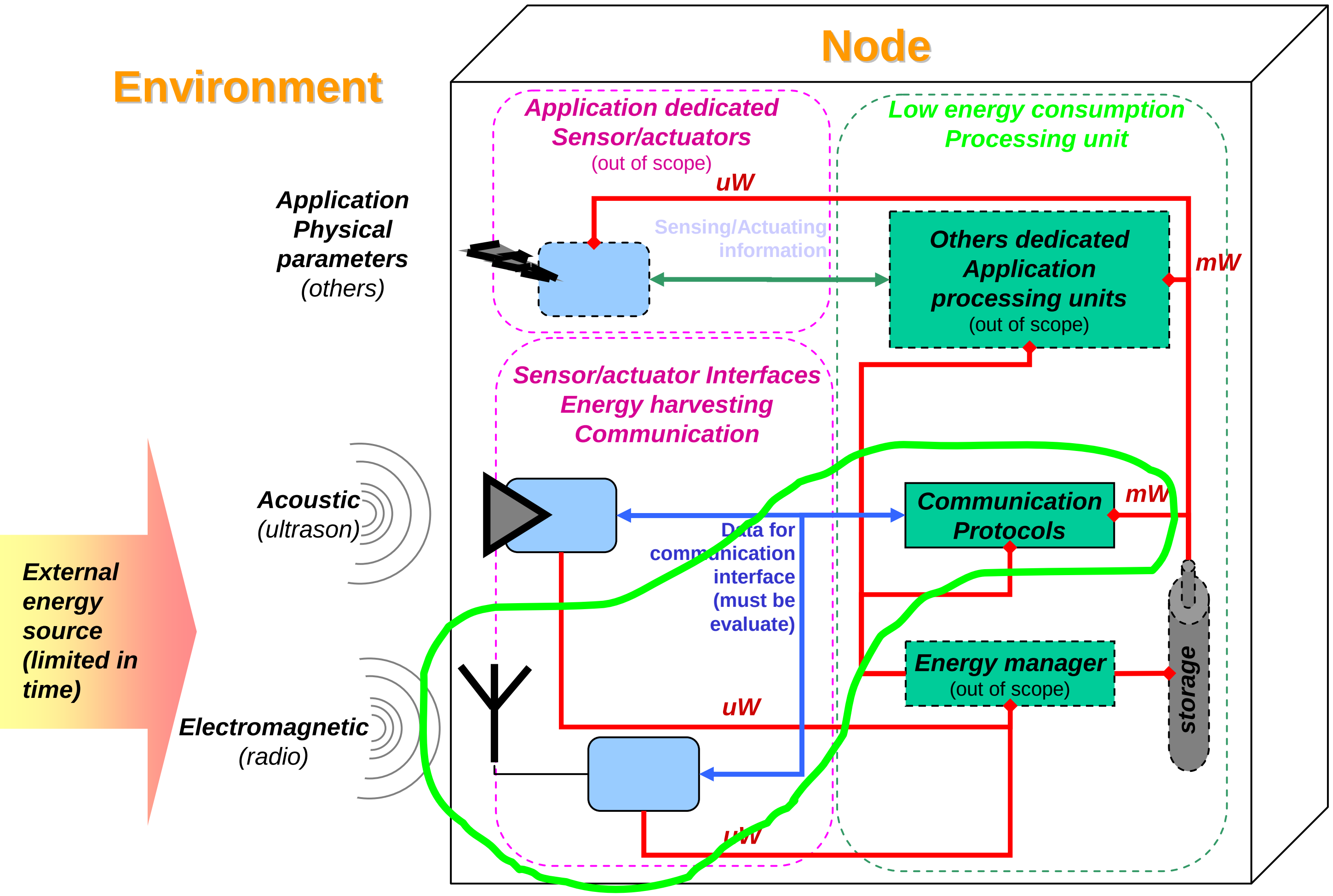
O3 – joint design acoustic/radio device

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

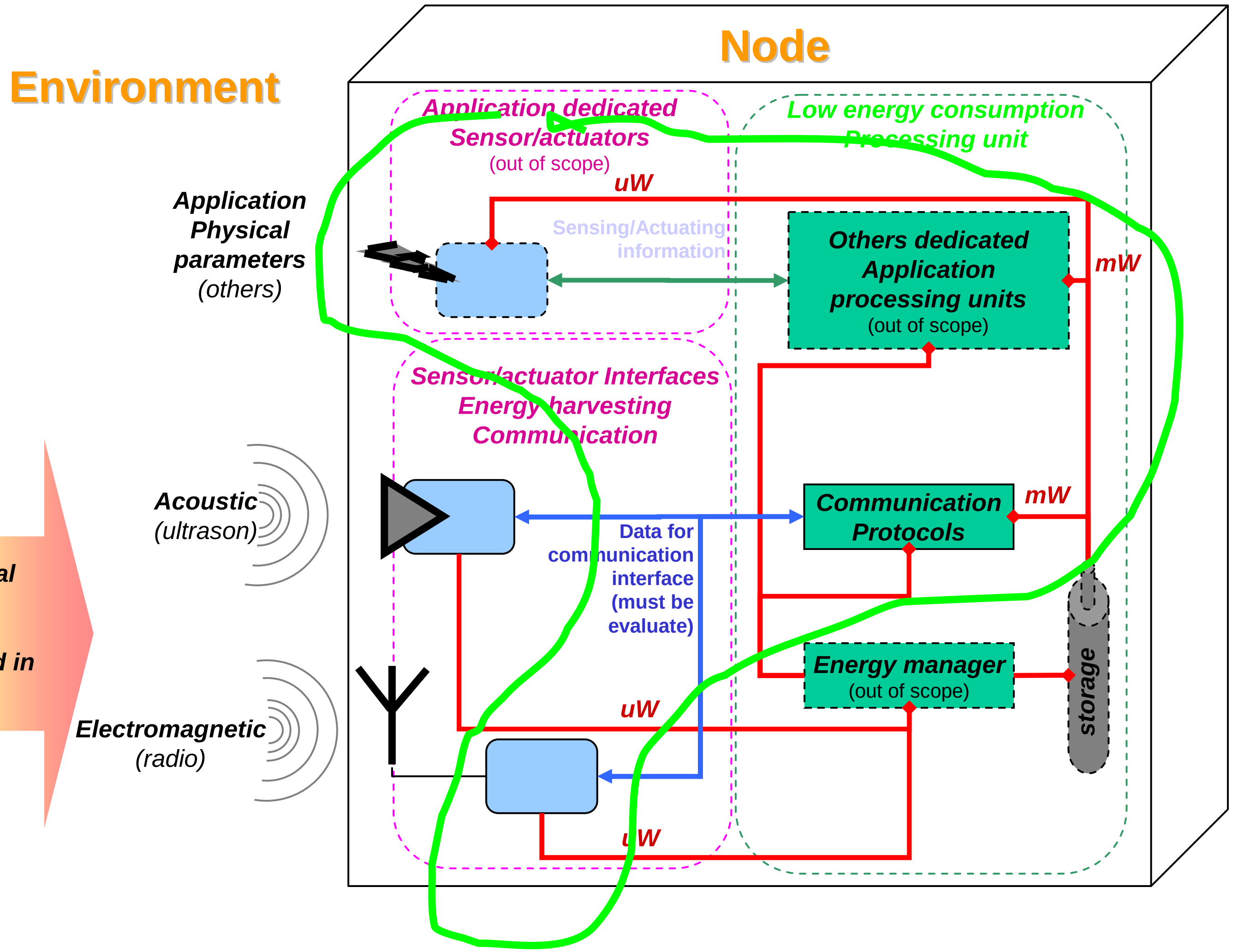




O3 – joint design transceiver/processing unit

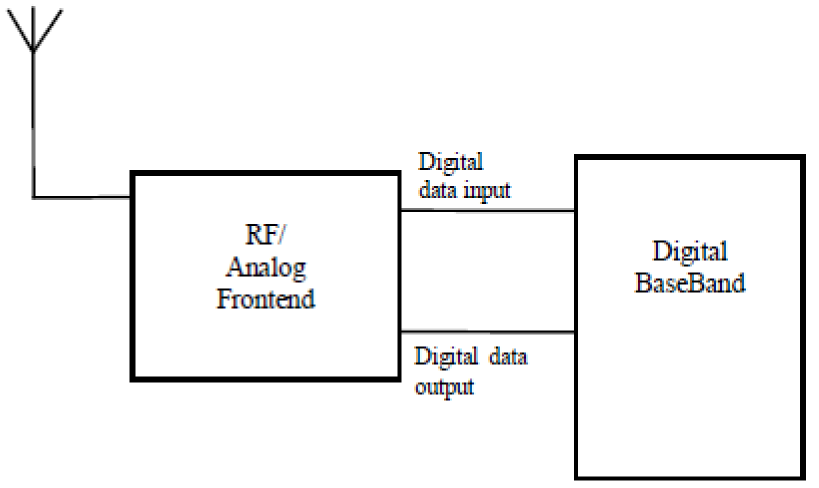


O3 – joint design transceiver/processing unit



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.

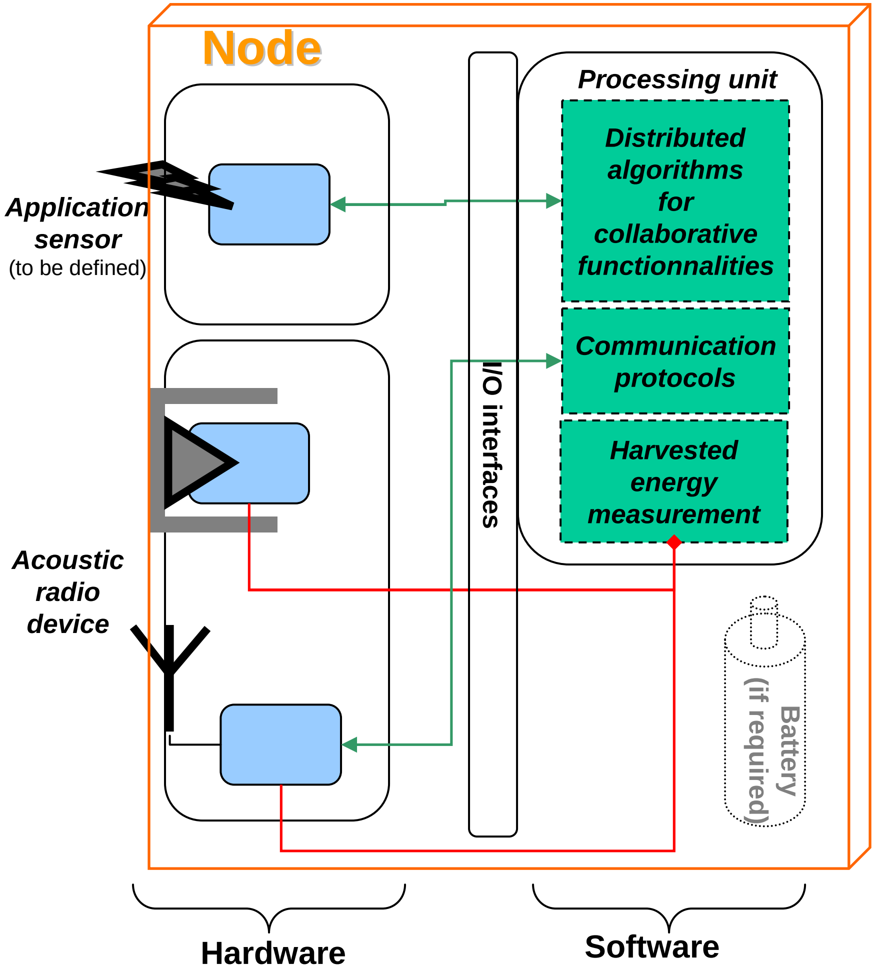


O4 – building a node and a small network

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
- Experimental verification of models for the node design (e.g. RF components based on lumped elements vs. distributed parameters)
- Measurements of required radiation field strengths and their relation to performance metrics (energy harvested by the nodes, interference etc.) of implemented components
- Investigation of key effects for characterizing single and multiple node operation
- Finding most suitable components for a given task with feedback to the design of the underlying architecture

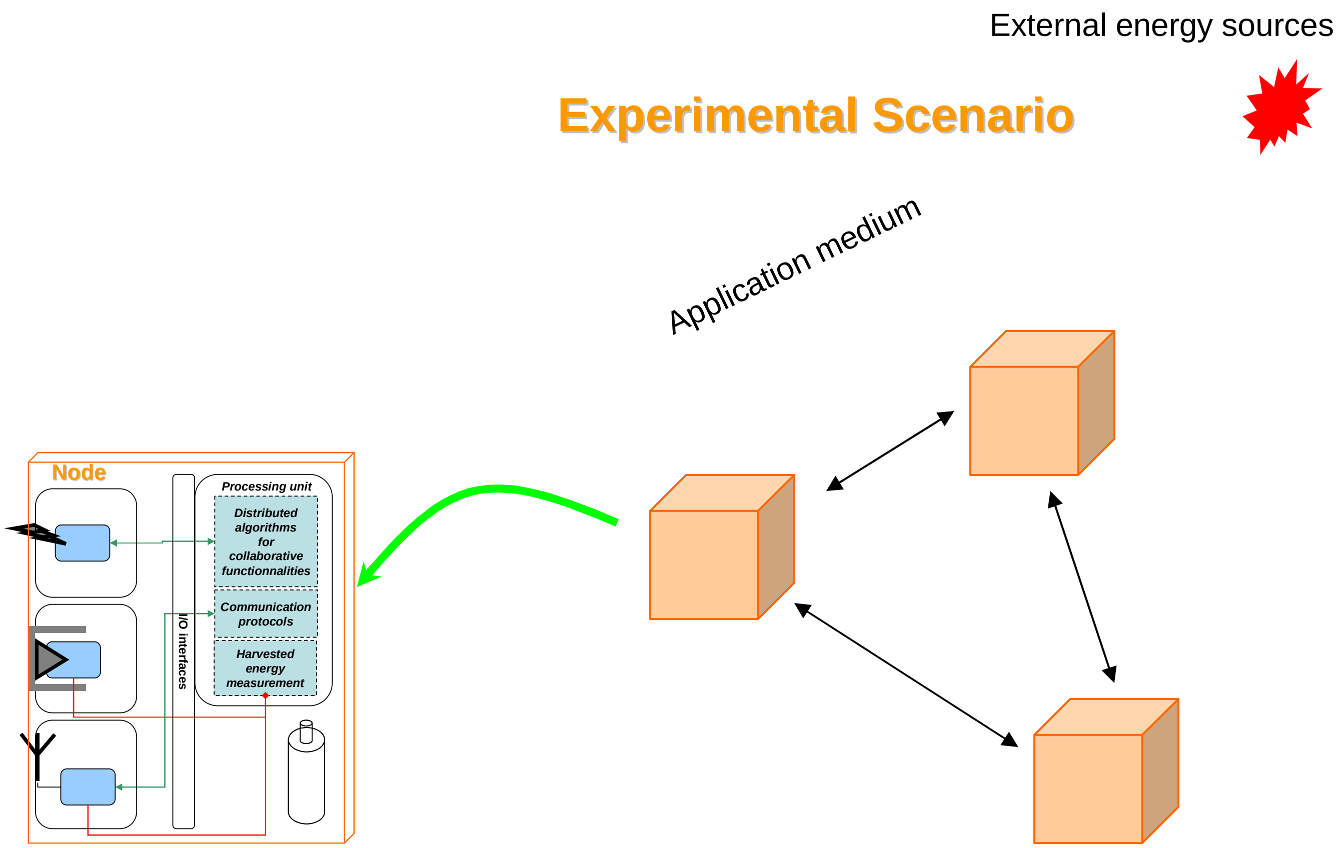
O4 – Node implementation



NACCESS Innovation blocks

04 – Network in a real environment

Performances evaluation



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 WSAN network
  - Several intermediate modules prototypes
  - Integration
  - Packaging