Energy management of a Wireless Sensor Network at application level

Olesia MOKRENKO – CEA LETI
olesia.mokrenko@cea.fr

Suzanne Lesecq – CEA LETI

Diego Puschini – CEA LETI

Carolina Albea – LAAS
Smart environment

- **Ensure a given service** for a system over a Wireless Sensor Network (WSN)
- **Maximize** the availability of the application (WSN lifespan)
Maximize WSN lifespan

- Node level
- Network level
- Application level
Context 2/2

Application level

Dense deployment

Gateway(s)

Supervisor

User(s)
**Dummy scheme**

- **All nodes** are active to ensure a given service for an application

**Basic scheme**

- **A given number of nodes** are active to ensure a given service for an application

No control of WSN at application level

“Basic control” of WSN at application level
Objectives

- **Exploit trade-offs:** find a balance between different **contradictory objectives** that occur at the same time

Example:
- Maximize the performance (Ensure a given service)
- Maximize the WSN lifespan
Outline

Context

Model Predictive Control Approach

Hybrid Dynamic System Approach

Implementation on a Test-Bench and Results

Comparisons of Both Control Strategies

Conclusions
Outline

Context

Model Predictive Control (MPC) Approach

- Problem statement
- WSN: system modeling
- MPC design
  - Control design
  - Benchmark description
  - Simulation results
- Conclusion on the MPC approach
Problem statement, control objectives

- **Wireless sensor network**
  - **Nodes** deployed in a geographical area
  - To ensure a given service
  - **Same functionality** → Redundant information

- **Service** = mission
  - Minimum number of *active* nodes during a given time period

- **Energy consumption**
  - Average energy consumption for node *i* in mode *j* for a given time period

<table>
<thead>
<tr>
<th>Node</th>
<th>Mode $M_1$</th>
<th>Mode $M_2$</th>
<th>⋯</th>
<th>Mode $M_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$b_{11}$</td>
<td>$b_{12}$</td>
<td>⋯</td>
<td>$b_{1m}$</td>
</tr>
<tr>
<td>2</td>
<td>$b_{21}$</td>
<td>$b_{22}$</td>
<td>⋯</td>
<td>$b_{2m}$</td>
</tr>
<tr>
<td>⋮</td>
<td>⋮</td>
<td>⋮</td>
<td>⋯</td>
<td>⋮</td>
</tr>
<tr>
<td><em>n</em></td>
<td>$b_{n1}$</td>
<td>$b_{n2}$</td>
<td>⋯</td>
<td>$b_{nm}$</td>
</tr>
</tbody>
</table>

- **Control objectives**
  - Fulfill the mission
  - Maximize the network lifespan
**System modeling**

- **Node \( i \): energy consumption model**

\[
x_i(k+1) = x_i(k) - B_i \cdot u_i(k) + E_i \cdot w_i(k)
\]

\[
y_i(k) = x_i(k) \quad \text{(measurement)}
\]

Maximize lifespan \( \rightarrow \max \sum_{\text{all nodes}} x_i(k+1) \)

- **Whole system model**

\[
x(k) \quad \text{time}
\]

\[
x(k+1) = B \cdot u(k)
\]

Compute \( u(k) \) s.t. \( \min \sum_{\text{all nodes}} B_i \cdot u_i(k) \)

- **Under constraints**

**1. Binary control** (at time \( k \))

| Mode \( M_1 \) | ON | 1 |
| Mode \( M_2 \) | OFF | 0 |
| \vdots | \vdots | \vdots |
| Mode \( M_m \) | OFF | 0 |

\[
\begin{bmatrix}
1 \\
0 \\
\vdots \\
0
\end{bmatrix}
= u_i(k)
\]
Node $i$: energy consumption model

\[ x_i(k + 1) = x_i(k) - B_i \cdot u_i(k) + E_i \cdot w_i(k) \]

\[ y_i(k) = x_i(k) \] (measurement)

Maximize lifespan $\rightarrow \max \sum_{all \ nodes} x_i(k + 1)$

Under constraints

1. Binary control (at time $k$)

Mode $M_1$: ON
Mode $M_2$: OFF
\[ \vdots \]
Mode $M_m$: OFF

2. Node works in a unique mode at time $k$

\[ \sum_{h=1}^{m} u_{ih} = 1 \]

Whole system model

Compute $u(k)$ s.t.

\[ \min \sum_{all \ nodes} B_i \cdot u_i(k) \]
Node $i$: energy consumption model

\[
x_i(k+1) = x_i(k) - B_i \cdot u_i(k) + E_i \cdot w_i(k)
\]

\[y_i(k) = x_i(k) \text{ (measurement)}\]

Maximize lifespan $\rightarrow$ \[
\max \sum_{\text{all nodes}} x_i(k+1)
\]

Whole system model

\[
x(k+1) = x(k) - B \cdot u(k)
\]

Under constraints

1. Binary control (at time $k$)

Mode $M_1$ 
Mode $M_2$ 
\vdots
Mode $M_m$

2. Node works in a unique mode

\[
\sum_{h=1}^{m} u_{ih} = 1
\]

3. Mission definition

For mode $M_h$: \[
\sum_{i=1}^{n} u_{ih} = d_h
\]
Node $i$: energy consumption model

\[
x_i(k + 1) = x_i(k) - B_i \cdot u_i(k) + E_i \cdot w_i(k)
\]

$y_i(k) = x_i(k)$ (measurement)

Maximize lifespan $\rightarrow \max \sum_{all\ nodes} x_i(k + 1)$

Whole system model

Compute $u(k)$ s.t. $\min \sum_{all\ nodes} B_i \cdot u_i(k)$

Under constraints

1. Binary control (at time $k$)
   - Mode $M_1$: ON
   - Mode $M_2$: OFF
   - Mode $M_m$: OFF

2. Node works in a unique mode
   \[
   \sum_{h=1}^{m} u_{ih} = 1
   \]

3. Mission definition

4. Bounded capacity of the battery
   \[
   X_i^{\min} \leq x_i \leq X_i^{\max}
   \]
Model Predictive Control

\[ u^* = \arg \min_u \left( \sum_{j=0}^{N_p} (X^{max} - x_{k+j|k})^T Q (X^{max} - x_{k+j|k}) + \sum_{j=0}^{N_u-1} u_{k+j|k}^T R u_{k+j|k} \right) \]

Subject to:
\[
\begin{align*}
\mathbf{x}_{k+1+j|k} &= A\mathbf{x}_{k+j|k} + B\mathbf{u}_{k+j|k} + E\mathbf{w}_{k+j|k}, & j = 0,1, \ldots, N_p \\
X^{min} &\leq \mathbf{x}_{k+j|k} \leq X^{max}, & j = 0,1, \ldots, N_p \\
\sum_{i=1}^{n} u_{ih} &= d_h \text{ for each } (k + j|k) \\
\sum_{h=1}^{m} u_{ih} &= 1 \text{ for each } (k + j|k) \\
u_{k+j|k} &\in \{0,1\}^{mn}, j = 0,1, \ldots, N_u - 1
\end{align*}
\]

Weighting matrices chosen depending on the application:
\[
\begin{align*}
Q &\in \mathbb{R}_{\geq 0}^{n \times n} \\
R &\in \mathbb{R}_{> 0}^{mn \times mn}
\end{align*}
\]

→ Mixed Integer Quadratic Programming (MIQP)
**Benchmark**

- **6 sensor nodes**
- **3 states:**
  - 2 functioning modes
  - Unreachable condition

**Mission**: 3 active nodes (mode $M_1$)
- $\alpha = \beta = 3$

**Weighting matrices**
- $Q = \left( \text{diag}\left(\frac{1}{X_1^{\text{max}}}, \ldots, \frac{1}{X_6^{\text{max}}}\right) \right)^2$
- $R = B_{\text{cons}}' \times B_{\text{cons}}$, where $B_{\text{cons}} = \text{diag}(b_{11}, b_{12}, \ldots, b_{62})$

**Nodes characteristics** (including harvesting availability) (values from datasheets)

<table>
<thead>
<tr>
<th>Node</th>
<th>Consum. in mode $M_1$, [mWh]</th>
<th>Consum. in mode $M_2$, [mWh]</th>
<th>Nom. bat. capacity, $X_i^{\text{max}}$, [mWh]</th>
<th>Harvesting availability $E_i$, [mWh]</th>
<th>Energy coef. [1]</th>
<th>Harvesting period, per 24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36,593</td>
<td>5,846</td>
<td>3885 (type 1)</td>
<td>missing</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>36,482</td>
<td>6,031</td>
<td>3885 (type 1)</td>
<td>missing</td>
<td>0,8</td>
<td>--</td>
</tr>
<tr>
<td>3</td>
<td>34,854</td>
<td>6,105</td>
<td>3885 (type 1)</td>
<td>77,7</td>
<td>0,9</td>
<td>7h-12h</td>
</tr>
<tr>
<td>4</td>
<td>36,482</td>
<td>6,301</td>
<td>3515 (type 2)</td>
<td>missing</td>
<td>0,7</td>
<td>--</td>
</tr>
<tr>
<td>5</td>
<td>36,556</td>
<td>6,105</td>
<td>3515 (type 2)</td>
<td>99,9</td>
<td>1</td>
<td>13h-18h</td>
</tr>
<tr>
<td>6</td>
<td>33,041</td>
<td>5,735</td>
<td>8510 (type 3)</td>
<td>missing</td>
<td>1</td>
<td>--</td>
</tr>
</tbody>
</table>
Simulation results without harvesting

Large number of switches

WSN lifespan = 175 hours

> WSN lifespan with basic scheme = 128 hours

Constraint is fulfilled

\[ 0 < X_i^{\min} \leq x_i \leq X_i^{\max} \]
Simulation results with harvesting

**WSN lifespan** = 287 hours

**Constraint is fulfilled**

\[ 0 < X_{i}^{\min} \leq x_i \leq X_{i}^{\max} \]
Conclusion on the MPC Approach

😊 Lifespan increase up to 27% (without harvesting) and 33% (with harvesting) when compared to basic scheme
😊 Constraints respected
😊 Large number of switches
   => Properly take into account the cost of the switches
😊 Problem solved with MIQP
   => Complexity (extra energy consumption)

😊 MILP problem formulation

Hybrid Dynamic System (HDS) approach
   => Naturally introduces jumps between systems of different structures
   => Cost of switches naturally taken into account
Outline

Context

Model Predictive Control Approach

Hybrid Dynamic System Approach

Implementation on a Test-Bench and Results

Comparisons of Both Control Strategies

Conclusions
Outline

Context

Model Predictive Control Approach

Hybrid Dynamic System Approach

- Control objectives
- WSN: system modeling
- Hybrid Dynamic System (HDS)
  - Control design, scheduling law
  - Benchmark description
  - Simulation results
- Conclusions on the HDS approach
Same as for the MPC strategy

- Fulfill the mission
- Maximize the WSN lifespan
MPC (discrete time model)

- $B_i$ and $E_i$ are the energy (J, Wh)

\[
x_i(k + 1) = x_i(k) - B_i \cdot u_i(k) + E_i \cdot w_i(k)
\]

\[
y_i(k) = x_i(k) \text{ (measure)}
\]
Node $i$: energy consumption model

- **HDS** (hybrid model)
  - *Flow* (continuous time) dynamics
  - $B_i$ and $E_i$: power (W)
    \[
    \begin{aligned}
    \dot{x}_i(t) &= -B_i \cdot u_i(t) + E_i \cdot w_i(t) \\
    y_i &= \alpha_i(t) \cdot x_i(t) \\
    \dot{u}_i(t) &= 0^m
    \end{aligned}
    \]
  - *Jump dynamics* (2 nodes swap their role)
    Pairwise jump rule for two nodes $i$ and $l$
    \[
    \begin{bmatrix}
    x_i^+ \\
    x_l^+
    \end{bmatrix} =
    \begin{bmatrix}
    x_i - (u_i^+)^T \Delta_i u_i \\
    x_l - (u_l^+)^T \Delta_l u_l
    \end{bmatrix} = g_{x}^{il}(x, u)
    \]
    \[
    \begin{bmatrix}
    u_i^+ \\
    u_l^+
    \end{bmatrix} =
    \begin{bmatrix}
    u_l \\
    u_i
    \end{bmatrix} = g_{u}^{il}(x, u)
    \]
  
  With the **switching consumption matrix** $\Delta_i$
  \[
  \Delta_i =
  \begin{bmatrix}
  0 & \ldots & \delta_{i \rightarrow 1}^m \\
  \vdots & \ddots & \vdots \\
  \delta_{1 \rightarrow m} & \ldots & 0
  \end{bmatrix}
  \]
System modeling (2/2)

- **HDS**
  - *Flow dynamics*
  
  \[
  \begin{align*}
  \dot{x}_i(t) &= -B_i \cdot u_i(t) + E_i \cdot w_i(t) \\
  y_i &= \alpha_i(t) \cdot x_i(t) \\
  \dot{u}_i(t) &= 0^m
  \end{align*}
  \]
  - measure

- **Jump dynamics**

  \[
  \begin{align*}
  x_i^+ &= x_i - (u_i^+)^T \Delta_i u_i \\
  x_i^+ &= x_i - (u_i^+)^T \Delta_i u_i \\
  u_i^+ &= [u^+_l, u^+_i] g_{u}^l(x, u)
  \end{align*}
  \]

- **Constraints**

  1. **Binary control** (at time \( t \)) \( u_i \in \{0,1\}^m \)
  2. **Node work in a unique mode** at time \( t \)
  3. **Mission definition** for mode \( M_h \) \( \sum_{i=1}^{n} u_i^T e_h = d_h \)
  4. **Bounded capacity** of the battery \( 0 < X_i^{\text{min}} \leq x_i \leq X_i^{\text{max}} \)

Compute \( u_i(t) \) such that lifespan maximized

**Lifespan:**

\[
\max_{\text{all nodes}} \sum_i \frac{x_i + (E_i w_i) X_i^{\text{min}}}{B_i u_i}
\]
HDS

- **Flow dynamics**

\[
\begin{aligned}
    \dot{x}_i(t) &= -B_i \cdot u_i(t) + E_i \cdot w_i(t) \\
    y_i &= \alpha_i(t) \cdot x_i(t) \\
    \dot{u}_i(t) &= 0^m
\end{aligned}
\] - measure

- **Jump dynamics**

\[
\begin{aligned}
    [x_i^+] &= [x_i - (u_i^+)^T \Delta_i u_i] = g^x_i(x,u) \\
    u_i^+ &= u_i 
\end{aligned}
\]

**Constraints**

1. **Binary control** (at time \( t \)) \( u_i \in \{0,1\}^m \)
2. **Node** work in a **unique mode** at time \( t \)
3. **Mission** definition for mode \( M_h \) \( \sum_{i=1}^{n} u_i^T e_h = d_h \)
4. **Bounded capacity** of the battery \( 0 < X_i^{\text{min}} \leq x_i \leq X_i^{\text{max}} \)

Compute \( u_i(t) \) such that lifespan maximized

**Lifespan:**

\[
\max_{\text{all nodes}} \sum_{i} \frac{y_i - X_i^{\text{min}}}{B_i u_i}
\]
Compute $u_i(k)$ => when do nodes $i$ and $l$ need to swap their role?

- Lifespan of the solution (WSN lifespan) expressed by a cost function

$$J_{il}(x, u) := \min_{k=i,l;k:u_k \neq 0^m} \frac{y_k - X_k^{\min}}{B_k u_k}$$

- First condition to jump (or swap role)
  - Lifespan of the solution is larger after the swap
Design of the scheduling law

- Compute $u_i(k)$ => when do nodes $i$ and $l$ need to swap their role?
- Lifespan of the solution (WSN lifespan) expressed by a cost function

$$J_{il}(x, u) := \min_{k=i,l; k \neq m} \frac{y_k - X_k^{\min}}{B_k u_k}$$

- First condition to jump (or swap role)
  - Lifespan of the solution is larger after the swap

- Second condition to jump
  - Time of the switch
Compute $u_i(k) \Rightarrow$ when do nodes $i$ and $l$ need to swap their role?

- Lifespan of the solution (WSN lifespan) expressed by a cost function

$$J_{il}(x,u) := \min_{k=i,l; k \neq 0^m} \frac{y_k - X_k^\text{min}}{B_k u_k}$$

First condition to jump (or swap role)
- Lifespan of the solution is larger after the swap

Second condition to jump
- Time of the switch
**Benchmark description**

- **Same benchmark as for MPC**
  - 6 sensor nodes
  - 3 states:
    - 2 functioning modes
    - Unreachable condition

---

- **Mission**: 3 *active* nodes (in mode $M_1$)
  - $\alpha = \beta = 3$

---

- **Nodes characteristics (including harvesting availability)**

<table>
<thead>
<tr>
<th>Node</th>
<th>Consum. in mode $M_1$, [mW]</th>
<th>Consum. in mode $M_2$, [mW]</th>
<th>Nom. bat. capacity, $X_i^{\max}$, [mWh]</th>
<th>Harvesting availability $E_i$, [mW]</th>
<th>Energy coef. [1]</th>
<th>Harvesting period, per 24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36,593</td>
<td>5,846</td>
<td>3885 (type 1)</td>
<td>missing</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>36,482</td>
<td>6,031</td>
<td>3885 (type 1)</td>
<td>missing</td>
<td>0,8</td>
<td>--</td>
</tr>
<tr>
<td>3</td>
<td>34,854</td>
<td>6,105</td>
<td>3885 (type 1)</td>
<td>77,7</td>
<td>0,9</td>
<td>7h-12h</td>
</tr>
<tr>
<td>4</td>
<td>36,482</td>
<td>6,301</td>
<td>3515 (type 2)</td>
<td>missing</td>
<td>0,7</td>
<td>--</td>
</tr>
<tr>
<td>5</td>
<td>36,556</td>
<td>6,105</td>
<td>3515 (type 2)</td>
<td>99,9</td>
<td>1</td>
<td>13h-18h</td>
</tr>
<tr>
<td>6</td>
<td>33,041</td>
<td>5,735</td>
<td>8510 (type 3)</td>
<td>missing</td>
<td>1</td>
<td>--</td>
</tr>
</tbody>
</table>
Simulation results without harvesting

- **Number of switches is very small**
- **WSN lifespan = 164 hours**
- **WSN lifespan with basic scheme = 128 hours**

### Simulation results without harvesting

#### Node 1
- Mode 1 - Active
- Mode 2 - Standby
- Unreachable state

<table>
<thead>
<tr>
<th>Node</th>
<th>Consum. in mode $M_1$, [mW]</th>
<th>Consum. in mode $M_2$, [mW]</th>
<th>Nom. bat. capacity, $X_{i_{max}}$, [mW]</th>
<th>Energy coef. [1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36,593</td>
<td>5,846</td>
<td>3885 (type 1)</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>36,482</td>
<td>6,031</td>
<td>3885 (type 1)</td>
<td>0,8</td>
</tr>
<tr>
<td>3</td>
<td>34,854</td>
<td>6,105</td>
<td>3885 (type 1)</td>
<td>0,9</td>
</tr>
<tr>
<td>4</td>
<td>36,482</td>
<td>6,301</td>
<td>3515 (type 2)</td>
<td>0,7</td>
</tr>
<tr>
<td>5</td>
<td>36,556</td>
<td>6,105</td>
<td>3515 (type 2)</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>33,041</td>
<td>5,735</td>
<td>8510 (type 3)</td>
<td>1</td>
</tr>
</tbody>
</table>

Constraint is respected

$0 < X_{i_{min}} \leq x_i \leq X_{i_{max}}$
Simulation results with harvesting

Number of switches is very small

WSN lifespan = 266 hours

> WSN lifespan with basic scheme = 192 hours

Constraint is respected

\[ 0 < X_i^{\text{min}} \leq x_i \leq X_i^{\text{max}} \]
Conclusion on the HDS approach

- **Lifespan increase** up to 22% (without harvesting) and 28% (with harvesting) when compared to basic scheme
- **Constraints** respected
- Very small number of switches
- Take into account the **cost of the switches** => Promising solution

- Lifespan decrease up to 7% when compared to MPC strategy => Switching cost
Outline

Context

Model Predictive Control Approach

Hybrid Dynamic System Approach

Implementation on a Test-Bench and Results

Comparisons of Both Control Strategies

Conclusions
Outline

Context

Model Predictive Control Approach

Hybrid Dynamic System Approach

Implementation on a Test-Bench and Results
  - Test-bench description
  - Experimental results for the MPC strategy
  - Experimental results for the HDS strategy
  - Conclusion of the section
Test-bench description (1/3)

Benchmark

- Platform **OpenPicus** (FLYPORT Wi-Fi 802.11G with 16 Bit Processor PIC24FJ256) [1]
- Temperature & humidity sensors (Aosong DHT11) [2]
- Li-polymer rechargeable batteries [3]
- Router Wi-Fi
- Without harvesting systems

Deployed in an “open-space” office

- More information than required at the application level of the WSN

Deployed in the open-space office

Control algorithm written in Python

Middleware LINC:
- Node synchronization
- Data management

Measurement of the remaining energy $y_i$?
Estimation!
Test-bench description (3/3)

- Characteristics of nodes (from datasheet and lab. measurements)

<table>
<thead>
<tr>
<th>Node</th>
<th>Consum. in mode $M_1$, [mWh]</th>
<th>Consum. in mode $M_2$, [mWh]</th>
<th>Nom. bat. capacity, $X_{i_{\text{max}}}$, [mWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36,593</td>
<td>5,846</td>
<td>3885 (type 1)</td>
</tr>
<tr>
<td>2</td>
<td>36,482</td>
<td>6,031</td>
<td>3885 (type 1)</td>
</tr>
<tr>
<td>3</td>
<td>34,854</td>
<td>6,105</td>
<td>3885 (type 1)</td>
</tr>
<tr>
<td>4</td>
<td>36,482</td>
<td>6,301</td>
<td>3515 (type 2)</td>
</tr>
<tr>
<td>5</td>
<td>36,556</td>
<td>6,105</td>
<td>3515 (type 2)</td>
</tr>
<tr>
<td>6</td>
<td>33,041</td>
<td>5,735</td>
<td>3515 (type 2)</td>
</tr>
</tbody>
</table>

- **Dynamic Mission**: 3 (or 1) active nodes (in mode $M_1$)

  - Experiments start 5 p.m.
  - Radio environment not under control
Experimental results for the MPC strategy

- WSN lifespan = 53 hours
- Number of switches ≈ 100

Initial energy of whole WSN = $14.521 \times 10^3 [mWh]$
Experimental results for the HDS strategy

- WSN lifespan = 46 hours
- Number of switches ≈ 60

Initial energy of whole WSN = \(13.242 \times 10^3\) mWh
Conclusion of the section

😊 Control strategies are validated on a real-life test-bench
 => Mission is fulfilled

😊 Number of switches is similar

😊 Different radio environment for both experiments
Comparisons of Both Control Strategies

<table>
<thead>
<tr>
<th>Strategy</th>
<th>WSN lifespan, [hours]</th>
<th>Initial energy in the whole WSN, [mWh]</th>
<th>Final energy in the whole WSN, [mWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPC</td>
<td>53 (100%)</td>
<td>14.521 \times 10^3 (100%)</td>
<td>3.032 \times 10^3</td>
</tr>
<tr>
<td>HDS</td>
<td>46 (86.8%)</td>
<td>13.242 \times 10^3 (91.2%)</td>
<td>3.039 \times 10^3</td>
</tr>
</tbody>
</table>

![Graph showing remaining energy over time for MPC and HDS strategies]
Remaining energy evolution

**MPC strategy**

- **S1**
- **S2**
- **S3**
- **S4**
- **S5**
- **S6**

**HDS strategy**

- **S1**
- **S2**
- **S3**
- **S4**
- **S5**
- **S6**

Minimum energy level for the battery of type 1

Minimum energy level for the battery of type 2
Outline

Context

Model Predictive Control Approach

Hybrid Dynamic System Approach

Implementation on a Test-Bench and Results

Comparisons of Both Control Strategies

Conclusions
Conclusions

- Control strategies for WSN energy management are proposed (via MPC and HDS)
  - WSN lifespan extended by >20% when compared to basic scheme

- Implementation on a real test-bench is performed
  - Validation of the control strategies
  - More experiments to be done
Thank you