Towards longevous wireless sensor networks operation

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Multi-source energy harvesting changes the way we design communication protocol stacks for WSNs

- Traditionally WSNs follow a duty cycle
- Their operation aims at maximizing lifetime by reducing the rate at which nodes consume energy
  - Through low power algorithms and protocols
  - Low power HW design

Assumptions:
- Monotonically decreasing limited battery energy
- Sensing cost is negligible
Communications in GENESI

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In SHM sensing and communication costs can be comparable
➢ Selective activation
➢ Adaptive sampling
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Non monothonic, variable, only partially predictable energy availability
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Non monothonic, variable, only partially predictable energy availability
  ➢ there maybe times where there is an excess of energy
  ➢ and when energy demanding tasks which are considered unsuitable for WSNs can be performed
EH-WSN non monotonic behaviour

Max supercapacitor energy level

Supercapacitor discharging

Supercapacitor charging

Excess energy
would be wasted
if not used

Energy [J]

Power [mW]
GENESI WP4

Energy prediction models

Selective activation

Task allocation
(how to bid for missions)

Task allocation at
the node level

Low power comm.
protocols

Energy harvesting aware
comm. protocols

Comm protocols
exploiting radio
triggering and harvesting

Automatic code generation

Wireless reprogrammability

Coexistence with other technologies
operating on the same bandwidth
• Power Management (TelosB)
  • Current drain CPU: 1.2mA (active), 5.1uA (sleep)
  • Current drain Radio: 17-20mA (tx/rx), 426uA (idle)
• Expected Lifetime:
  • Node (Cpu sleep + Radio rx) - 2xAA battery 2000 mAh: ≈ 4-5 days
• Application requirements:
  • Nodes running unattended for 1-5 years
DISSense

- Different strategies, but the same goal: minimize radio activity
- Tradeoff: strict schedule vs. protocol overhead
- DISSense approach: in many applications only one sample/node each 5-60 minutes is required
  - Save most of the energy between sampling periods
  - Perform all the required tasks in the shortest time as possible without energy saving techniques
DISSense

- Adaptive cross layer communication protocol
- Designed for environmental monitoring applications

Issues:
- Length of GT, RI, DCI?
- How often resync is needed?
- Synchronization algorithm?
- Collection protocol?
- Dissemination of the schedule?
DISSense

- GT
- RI
- DCI

sleep

- GT
- DCI

sleep

- GT
- RI
- DCI

Issues:
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For how many sampling period resync is NOT required

Sampling Period

Time To Resync

Time To Collect Data

Adaptive Engine

GT

RI

DCI

Skip
DISSense
### DISSense

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<tr>
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</table>
Task allocation

- WSN deployed for structural monitoring
- Sensing tasks *(missions)* arrive in the network dynamically over time at different locations
- Multiple missions active at the same time, competing for the sensing resources of the network

**Decide which sensor(s) should be assigned to each mission**
QoS-aware operations

- Missions have different priority (profit) and require different amount of resources (demand)
- **Assignments are not all equal.**
  - Nodes contribute to different missions with different utility (quality of information)
  - Achieved profit depends on allocated demand

**GOAL**
Maximize the profit obtained by the network for missions execution within a given target lifetime
EN-MASSE

- Distributed heuristic for task allocation in WSN with **energy harvesting**
- Nodes make **independent** decisions about task execution
- Decision based on:
  - **Partial profit**
    1. Profit of the mission
    2. Potential contribution to the mission
  - **Tune eagerness**
    1. Target network lifetime
  - **Classify missions**
    1. Current energy level of the node
    2. Energetic cost of the mission
    3. Future energy availability
Mission classification

A new mission arrives → check energy requirements and energy availability

**Battery required** not enough energy in the supercapacitor to execute the mission; use energy from the battery

**Capacitor sustainable** mission energy cost sustained by supercapacitor

**Recoverable** mission energy cost sustained by supercapacitor AND energy cost recovered through harvesting before the next mission arrives

**Free** mission energy cost expected to be fully sustained by energy harvesting

More willing to accept

REQUIRE ENERGY PREDICTIONS
Modeling real harvesting systems

Non-ideal supercapacitors
1. Finite size
2. Charging\discharging efficiency < 1
3. Leakage\self-discharge

Real-life energy traces

Photovoltaic cells

Wind micro-turbines
EN-MASSE performance

Highest profit

Stable profit over time
Pro-Energy

- Keep track of the solar energy profile observed during D **typical** days
- Maintain traces representative of different weather conditions (sunny, cloudy, ...)
- Predict the future energy intake by looking at the **most similar** stored profile

**Most Similar Profile**

\[
E^d = \min_{E^d \in E} \sum_{i=t-K}^{t} \frac{1}{K} |C_i - E_i^d|
\]

**Current day: energy harvested**

- **Aging mechanism**: discard stored profiles obsolete due to seasonal patterns.
Pro-Energy short-term predictions

Predict the energy intake in the next timeslot, given the energy harvested during the current timeslot and the stored profile that is the most similar to the current day.

Energy harvested during the previous timeslot of the current day

\[ \hat{E}_{t+1} = \alpha \cdot C_t + (1 - \alpha) \cdot E_{t+1}^d \]

Energy predicted for the next timeslot of the current day

Energy harvested during the next timeslot of the stored day d

Among the D stored profiles, find the one that is the most similar to the current day (up to timeslot t).
Pro-Energy performances

**Solar energy predictions:** Pro-Energy performs up to 75% better than EWMA and 60% better than WCMA

**Wind energy predictions:** Pro-Energy performs up to 54% better than EWMA and 10% better than WCMA
Questions?

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