# Protocols for EH-WSNs

## Sistemi Wireless, a.a. 2013/2014

Un. of Rome "La Sapienza"

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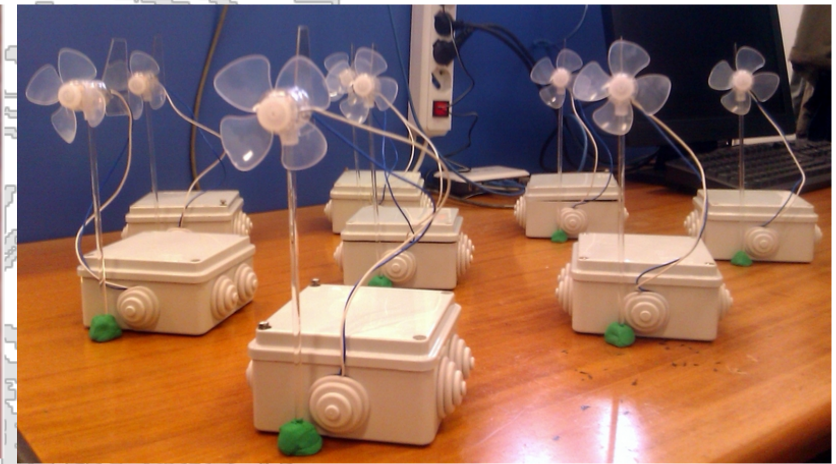
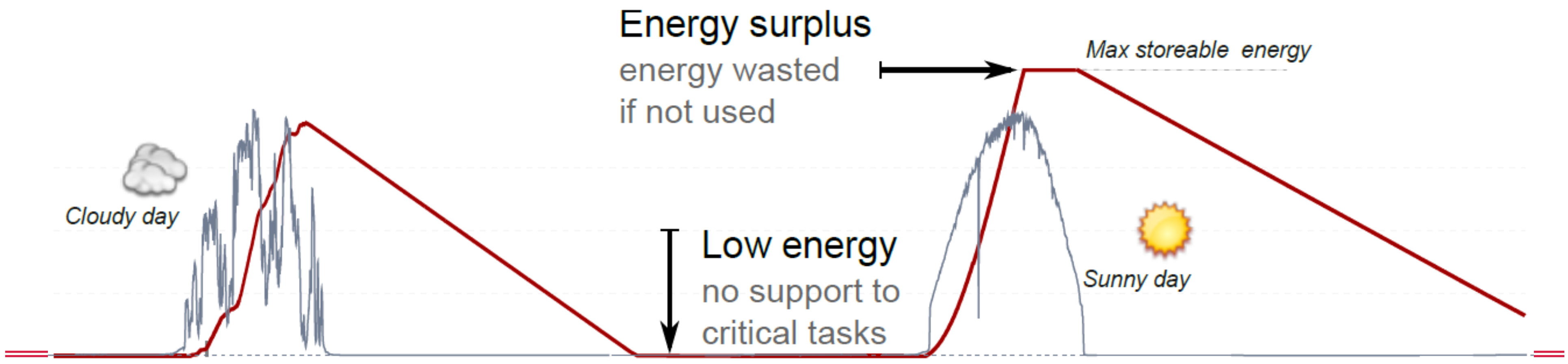



- Pose the basis for very long lasting operation
- Energy Neutral protocols have been proposed for several applications
- Changes also what a WSN can do

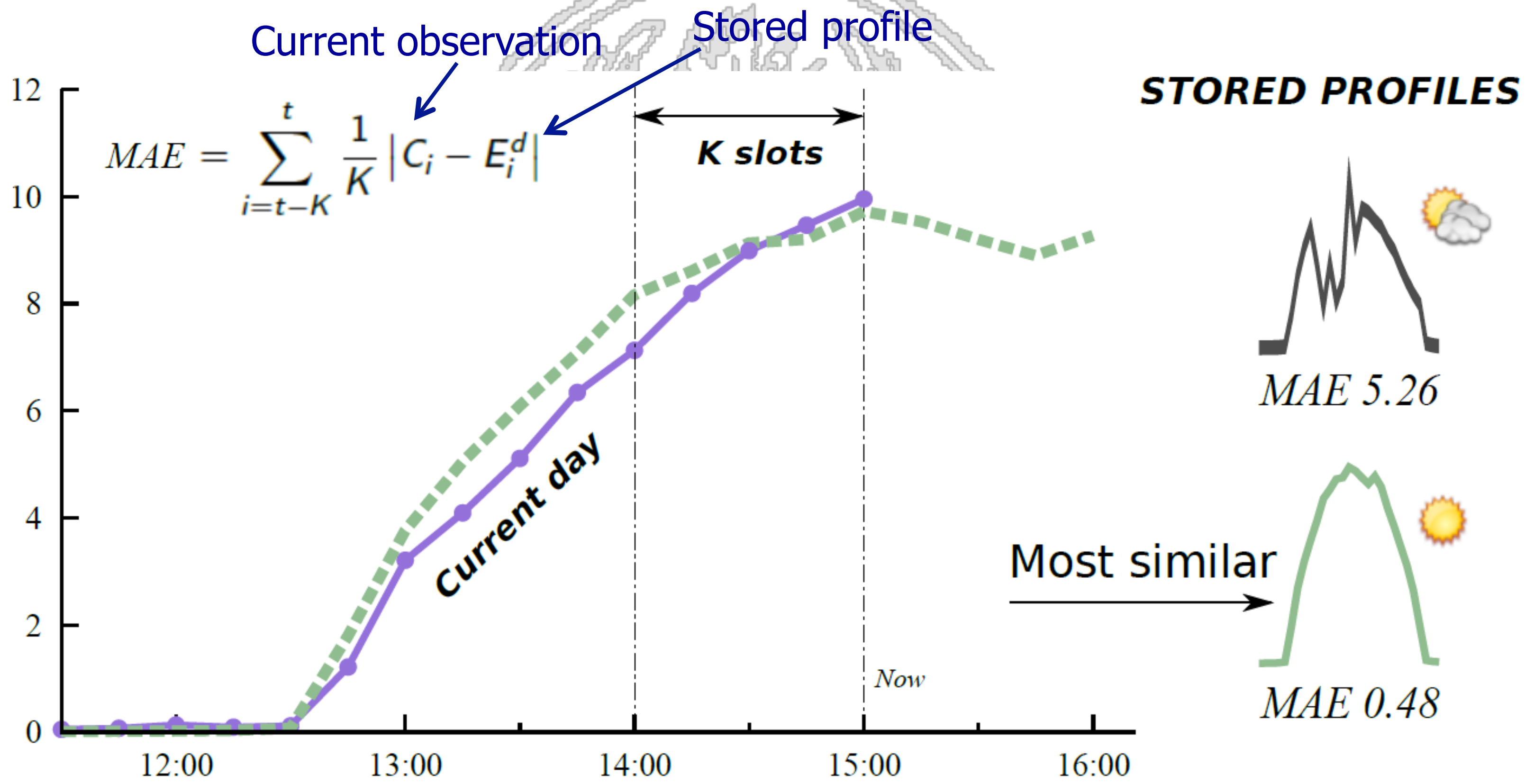
# Why energy predictions?

- Energy predictions to mitigate uncertain energy availability
- Plan energy usage in advance: **proactive** vs reactive energy allocation
- Exploit available energy at best:
  I. Minimizing the likelihood of running out of energy and missing high priority tasks
  II. Minimizing the waste of energy (energy buffers are limited in size and time)
  III. Enable operations which were not considered feasible



# Pro-Energy in a nutshell

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



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# Pro-Energy in a nutshell

$$\hat{E}_{t+1} = \alpha \cdot C_t \ + \ (1 - \alpha) \cdot E^d_{t+1} \qquad (2)$$

where:

- $\hat{E}_{t+1}$ is the predicted energy intake in timeslot $t+1$ of the current day;
- $E^d_{t+1}$ is the energy harvested during timeslot $t+1$ on the stored day $d$;
- $C_t$ is the energy harvested during timeslot $t$ on the current day $C$;
- $\alpha$ is a weighting factor, $0 \leq \alpha \leq 1$.

The weighting parameter, $\alpha$, allows to combine the value reported in the stored profile with the current energy observation, i.e., the energy observed in the last slot, $C_t$.

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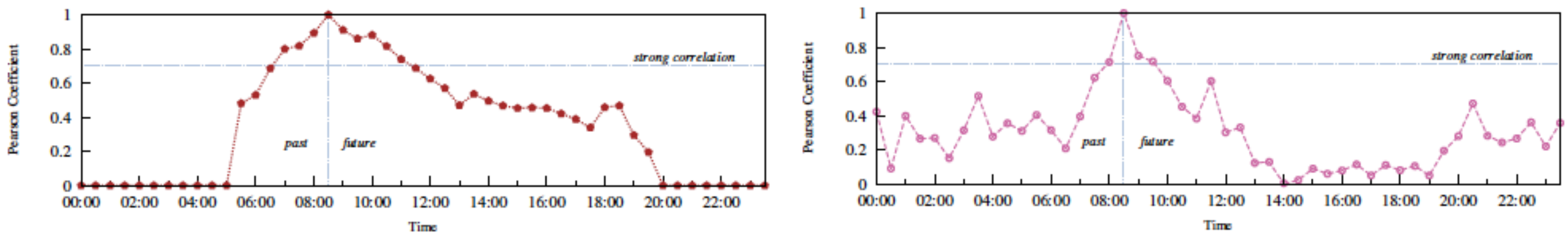
# Medium Term Energy Predictions




(a) (b)

Figure 2. Pearson autocorrelation coefficient for (a) solar ORNL Dataset and (b) wind Bologna Dataset.

$$\gamma_i = \begin{cases} \alpha \cdot \left(1 - \frac{i-1}{G}\right), & \text{if } i \le G \\ 0 & \text{if } i > G \end{cases} \qquad \forall i, 1 \le i \le F$$

where:

- $\alpha$ is the weighting factor defined in Equation (2);
- $i$ is the $i^{th}$ timeslot in the future, with respect to the current slot, $t$;
- $G$ is the number of timeslots in the future which show a correlation above a given threshold with timeslot $t$;
- $F$ is the number of future timeslots for which Pro-Energy is delivering energy predictions.

**Medium term energy prediction estimation**

$$\hat{E}_{t+i} = \gamma_i \cdot C_t + (1 - \gamma_i) \cdot E^d_{t+i}$$

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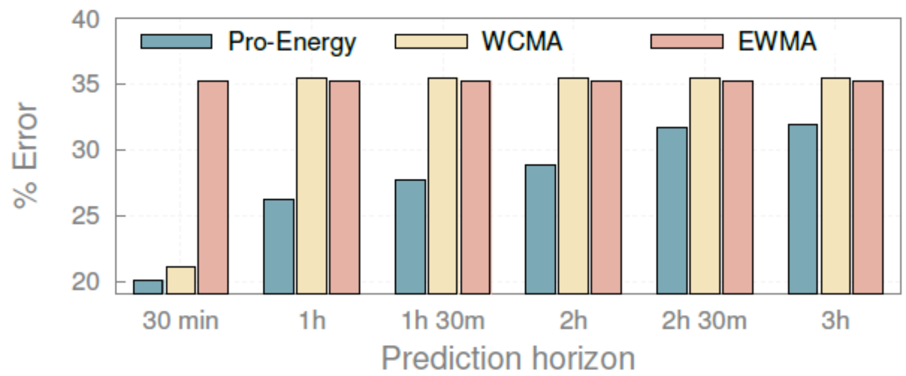
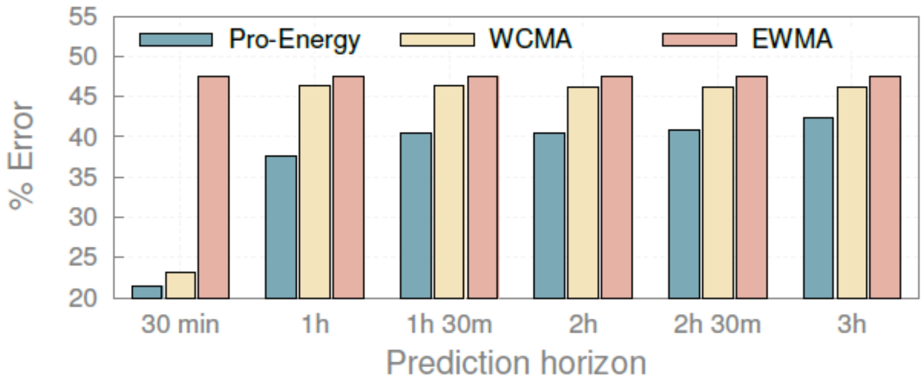
# Pro-Energy accuracy

*Solar*




*Wind*




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

**Wind:** Pro-Energy performs up to **55%** better than EWMA and **10%** better than WCMA

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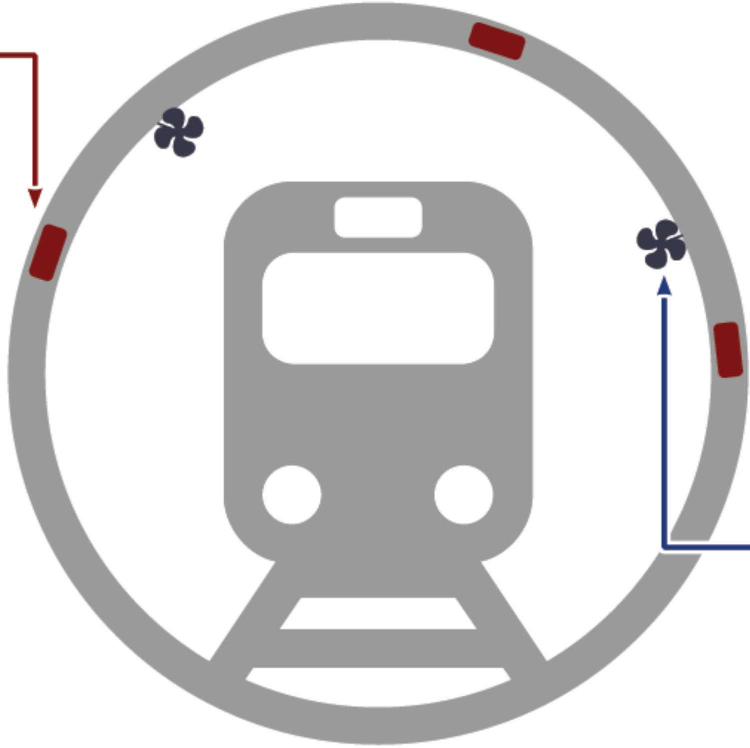
# Rome underground testbed

### Vibrating Wire Strain Gauges

Monitor concrete and steel deformations to evaluate stability of the underground tunnel

SISGEO OVK4200VC00
Dedicated interface board for TelosB mote
Energy consumption: 720 mJ



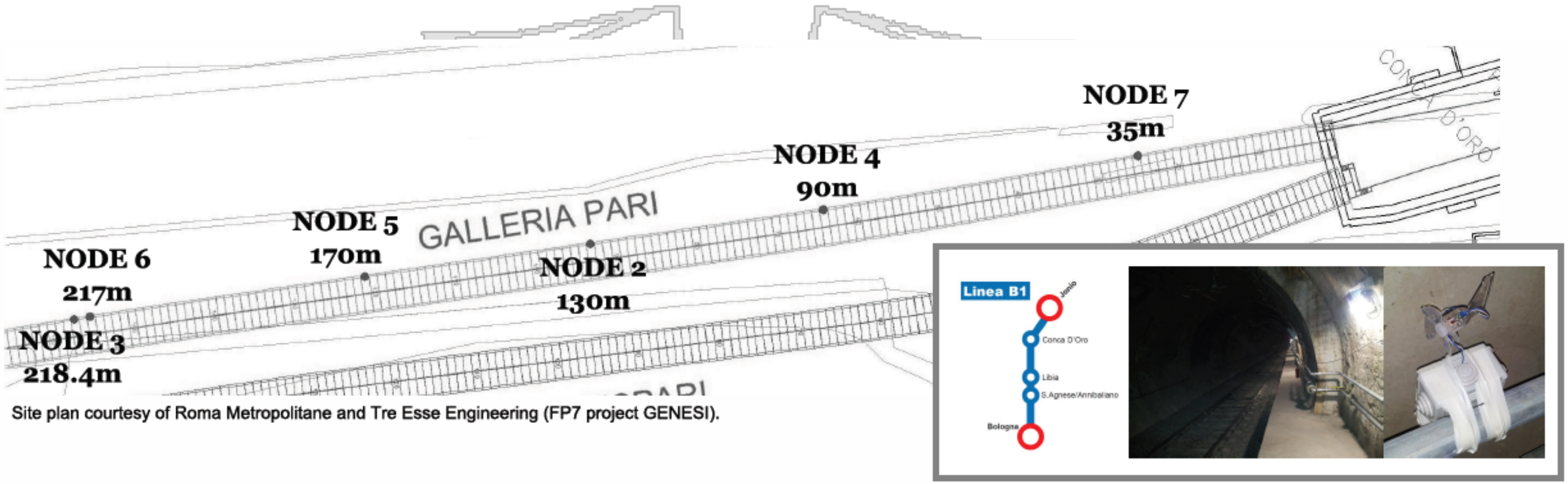
### Micro wind turbines

Energy harvesting from wind generated by trains

**Why air-flow energy harvesting?**

- SHM sensors are power-hungry
- required lifetime of decades or more
- battery-powered WSNs last only a few years

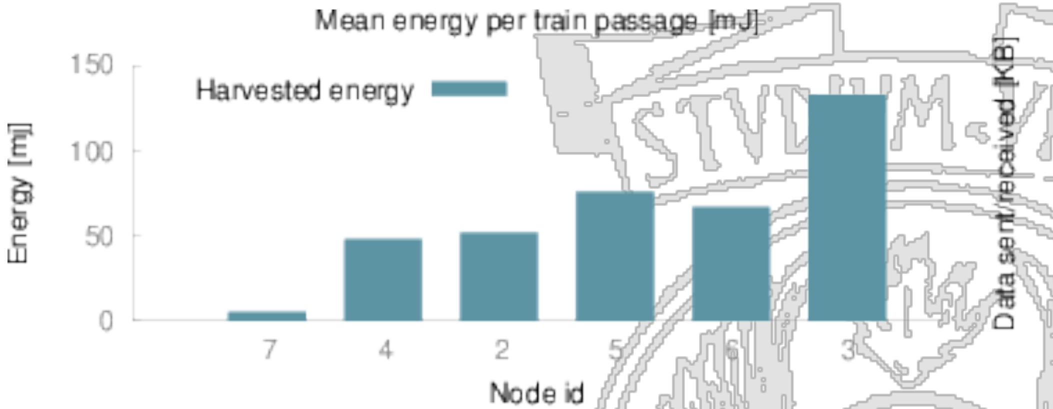
# In-field air-flow data collection



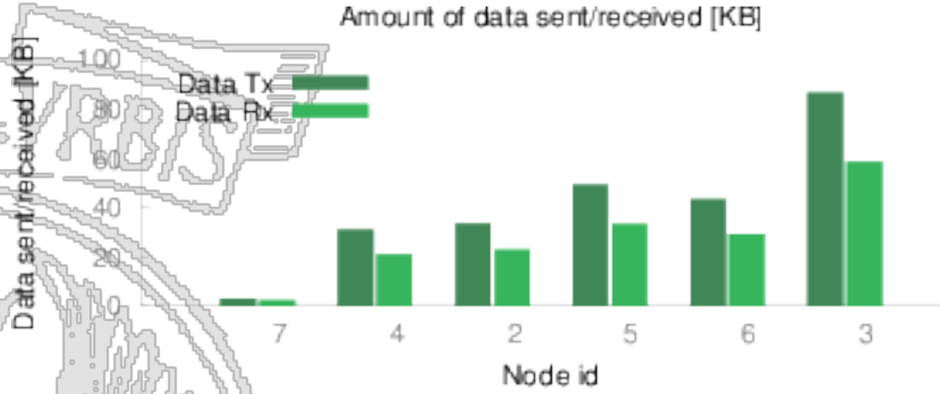

Site plan courtesy of Roma Metropolitane and Tre Esse Engineering (FP7 project GENESI).

**220 meter** of instrumented tunnel
6 energy-harvesting nodes
**33 days** of data collection

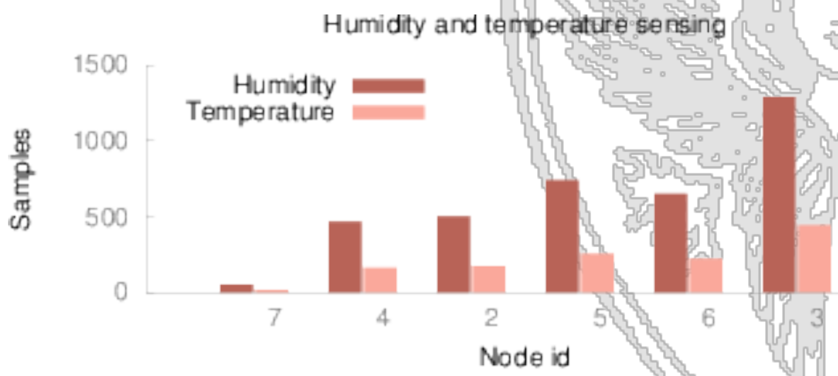
# Feasibility study



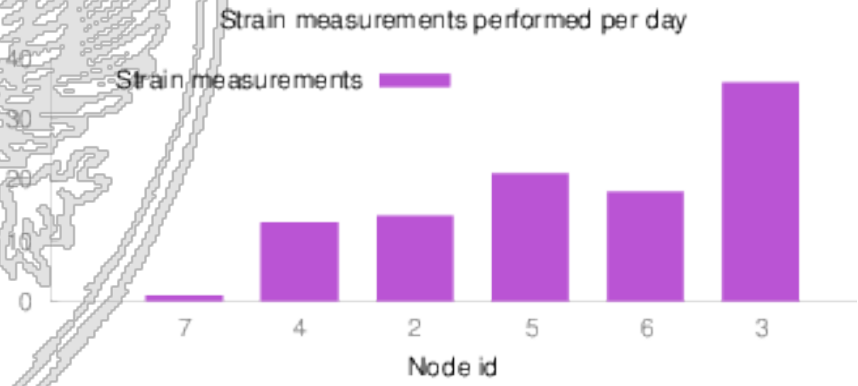

Up to 133 mJ harvested per train passage




Transmit/receive tens of KB

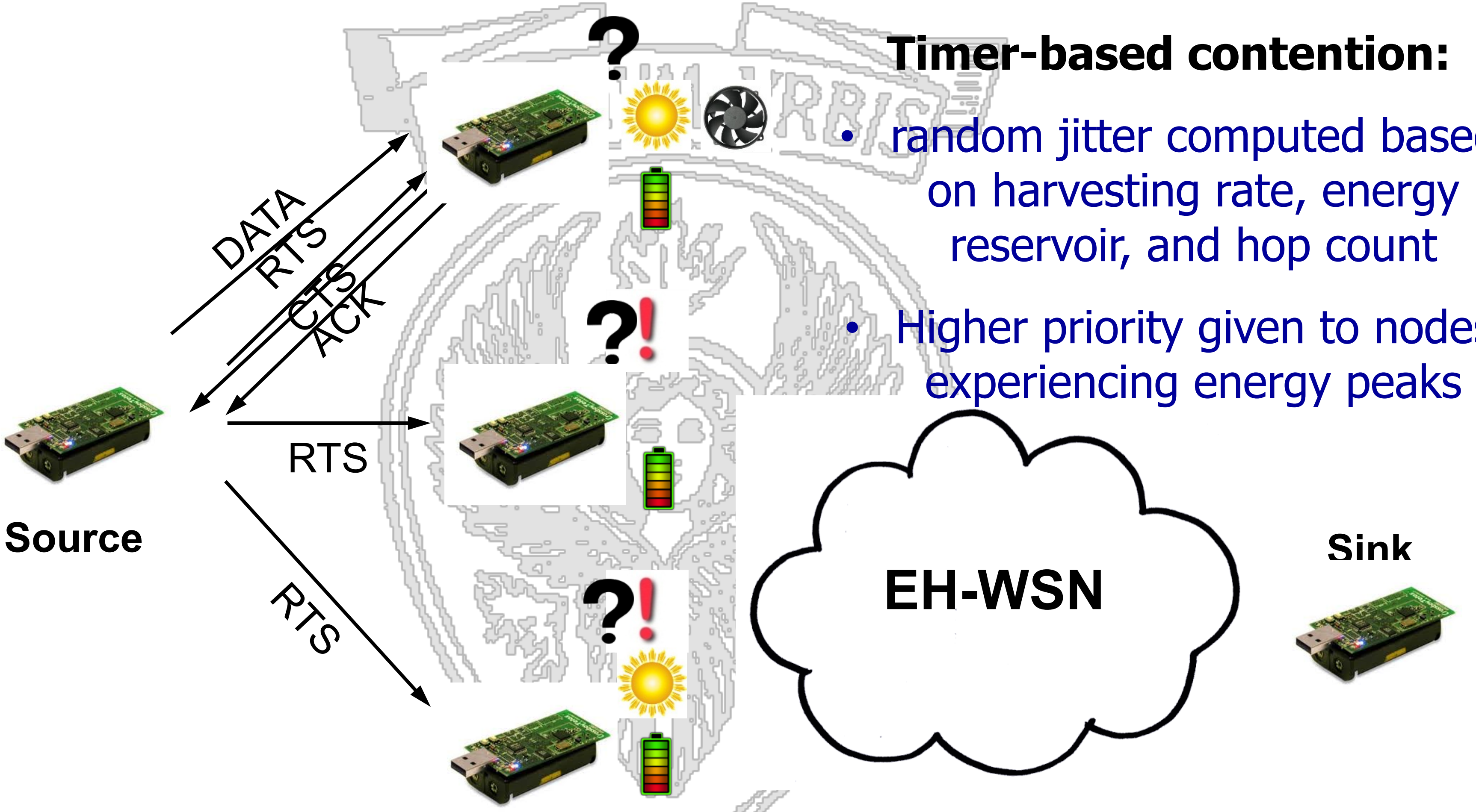



Collect hundreds of humidity and temperature samples




Up to 36 strain measurements per day

# Harvesting-aware routing



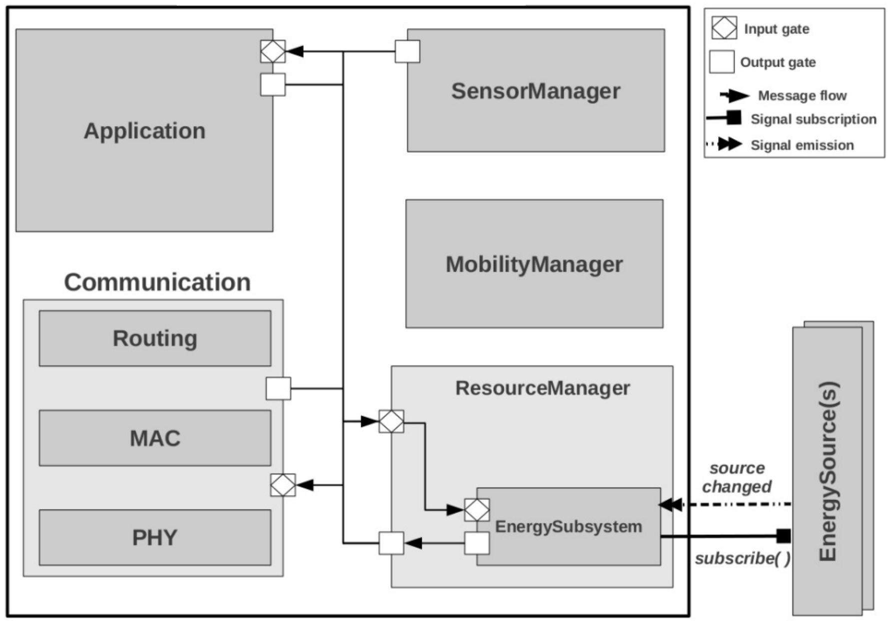

**Timer-based contention:**

- random jitter computed based on harvesting rate, energy reservoir, and hop count
- Higher priority given to nodes experiencing energy peaks

# GreenCastalia: Motivation

- **GreenCastalia features**
  - Support for multi-source harvesting
  - Support for multi-storage devices
  - Support for energy predictions
  - Easily customizable
  - Based on Castalia / OMNET++

Sensor node




TraceEnergySource module: allows to feed the simulator with timestamped power traces collected through real-life deployments, or with energy availability traces obtained by data repositories or meteorological stations

# Harvesting-aware routing: Results

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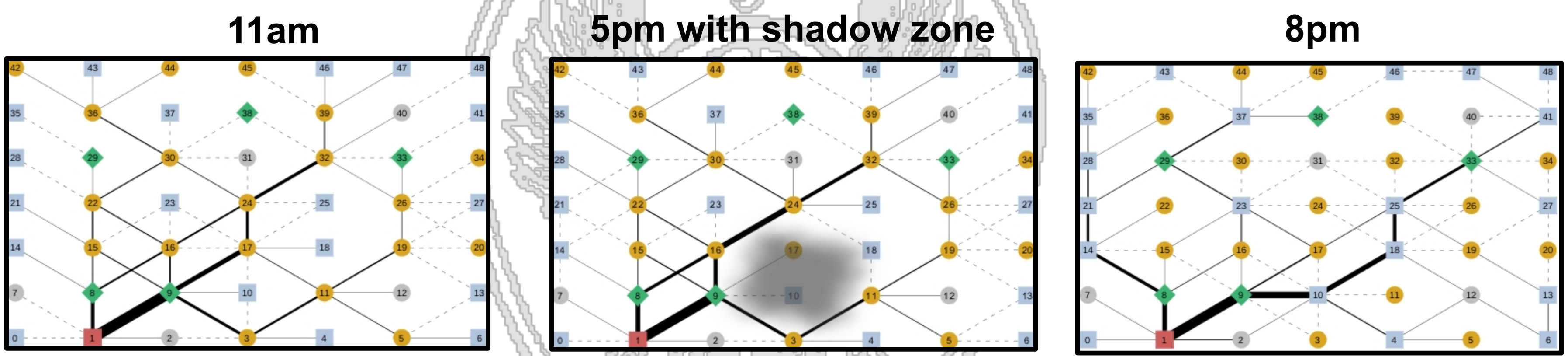
**Simulation settings**

- 120x120 meters field (7x7 grid deployment)
- Nodes with heterogeneous energy harvesting capabilities:
  - solar, wind both, none

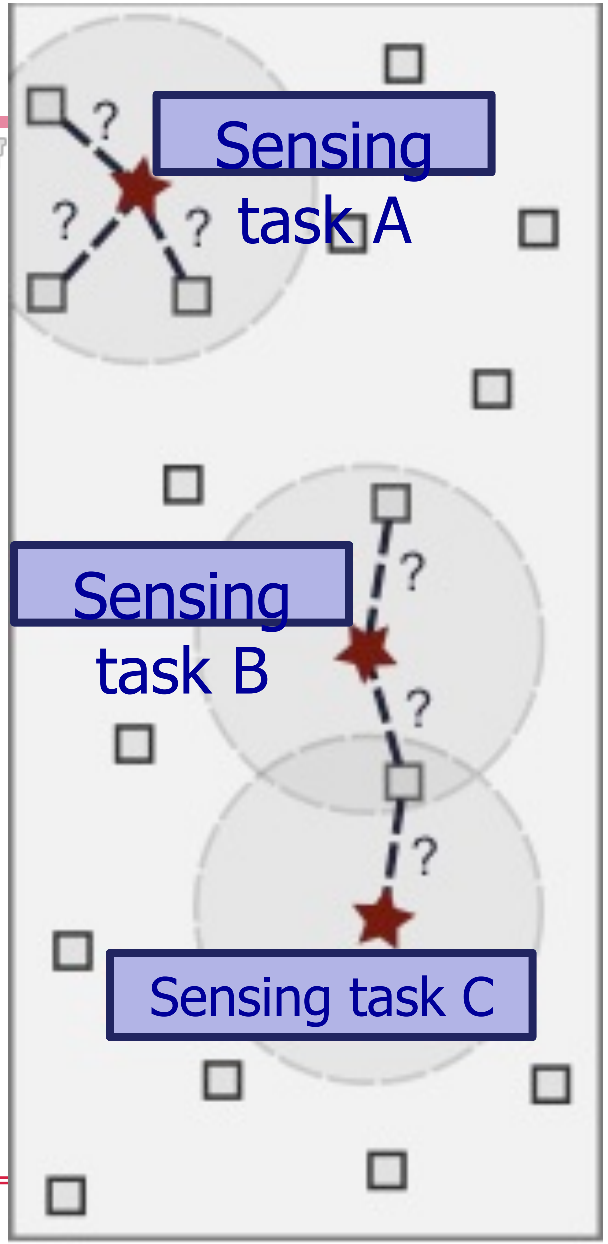



**Self-adaptive behaviour:** nodes experiencing energy peaks are selected with higher priority as next hop relays

# *Task allocation*

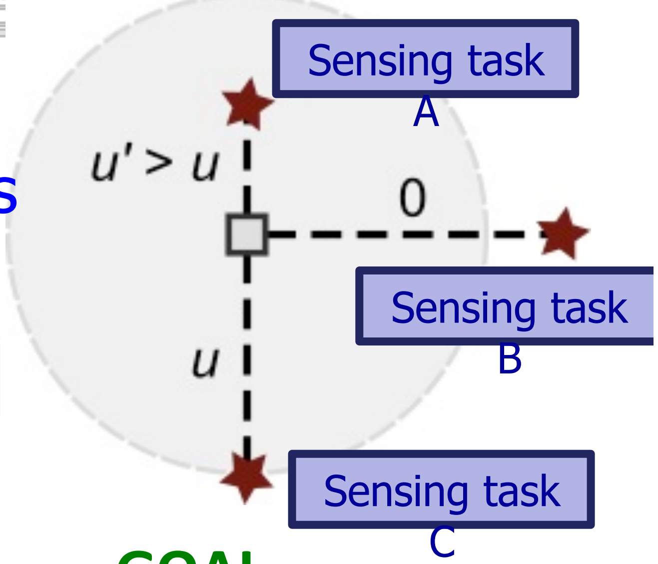
- Sensing tasks (missions) arrive in the network dynamically over time at different locations
- Multiple missions active at the same time, competing for the sensing resources of the network

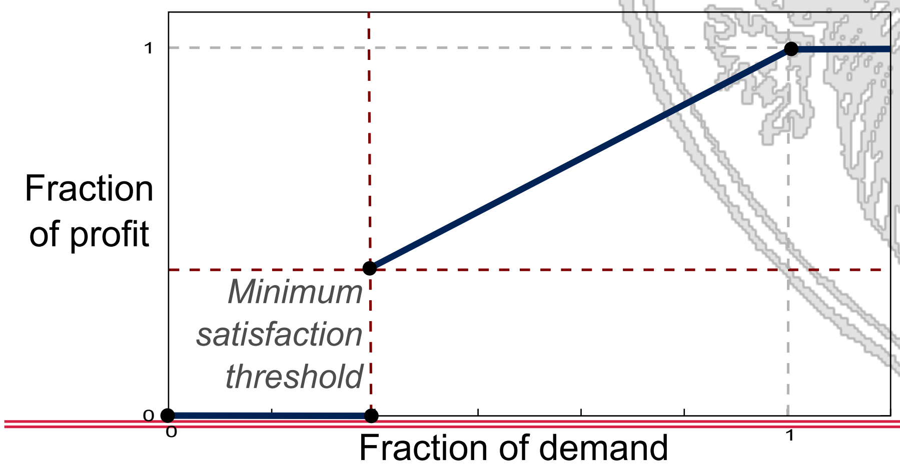
**Decide which sensor(s) should be assigned to each mission**



# QoS-aware operations

- Missions have different priority (profit) and require different amount of resources (demand)
- **Assigments 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**
3. Target network lifetime

**Classify missions**
4. Current energy level of the node (fuel cell + supercap )
5. Energetic cost of the mission
6. Future energy availability

# Mission classification

A new mission arrives → check energy requirements and energy availability

More willing to accept ↓

- **Fuel cell/battery required** not enough energy in the supercapacitor to execute the mission; use energy from the fuel-cell
- **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

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REQUIRE ENERGY PREDICTIONS

# Mission selection rule

## capacitor sustainable and recoverable

Always for free missions

- Expected partial profit of a mission

$$\overline{p} = \frac{E[u]}{E[d]} \times \frac{E[p]}{P},$$

P maximum achievable profit: E[u],E[d],E[p] expecyed utility, demand and profit of a fiven mission

- Partial profit achievable by a node participating to a mission

$$p^* = \frac{e_{ij}}{d_j} \times \frac{p_j}{P} \times w$$

w weight which depends on mission classification. Bid if p*>=expected partial profit

# *Task-Allocation*
# *EN-MASSE-In summary*

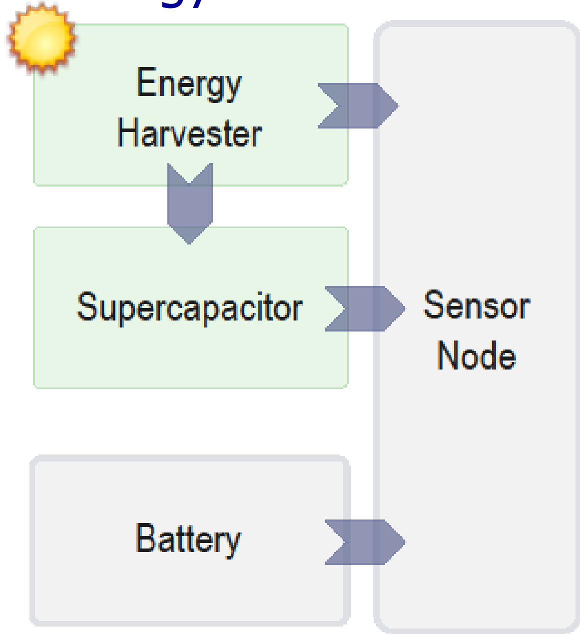
A **decentralized** harvesting-aware heuristic

**Key features:**

- Uses short and long term energy predictions for pro-active energy allocation
- Takes into account missions arrival statistics to make sustainable allocation decisions
- Considers the impact of executing a mission on node energy

**Higher priority to less-impacting missions**

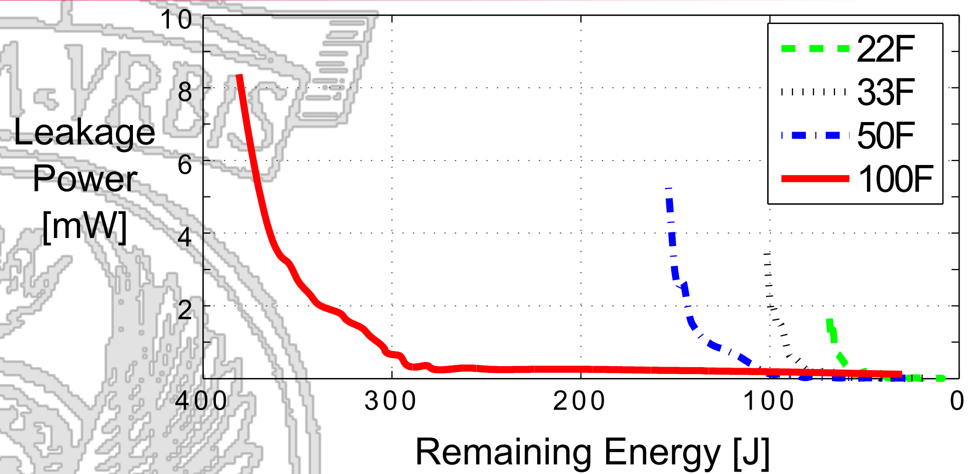
1. **Free:** fully sustained by harvesting
2. **Recoverable:** sustained by supercapacitor and recovered before next mission
3. **Capacitor-sustainable:** sustained by supercapacitor
4. **Battery-required:** sustained by battery



# Modeling real harvesting systems

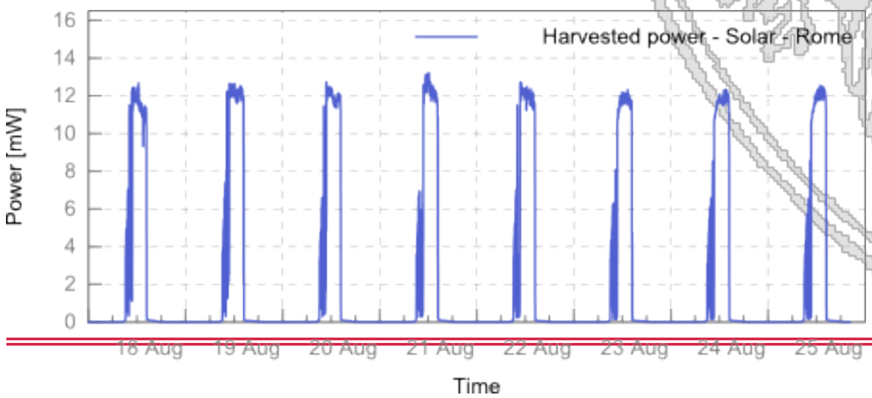
## Non-ideal supercapacitors

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

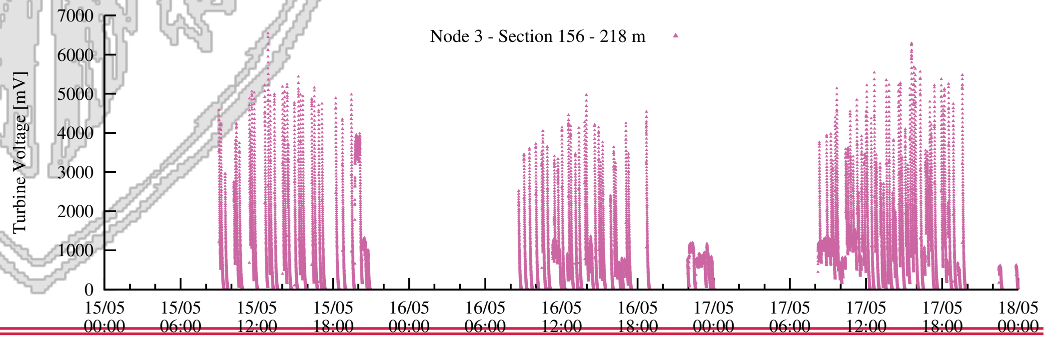



## Real-life energy traces

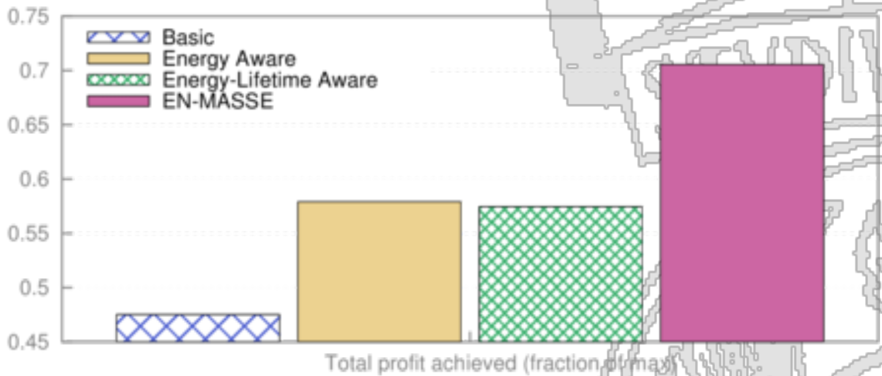
### Photovoltaic cells

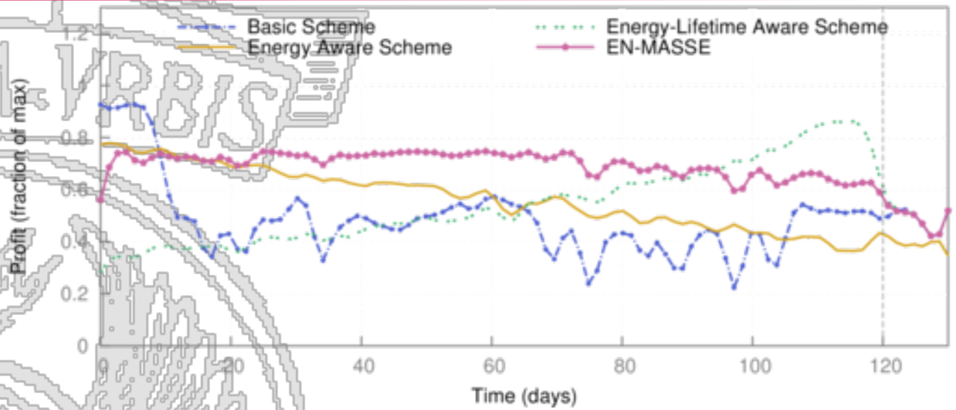



### Wind micro-turbines



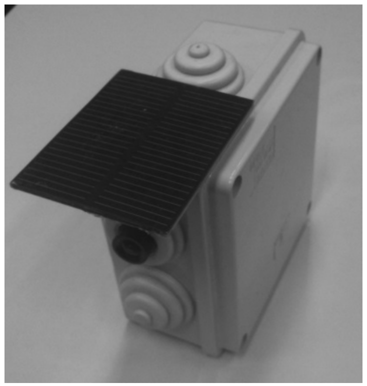
# *Performance evaluation*

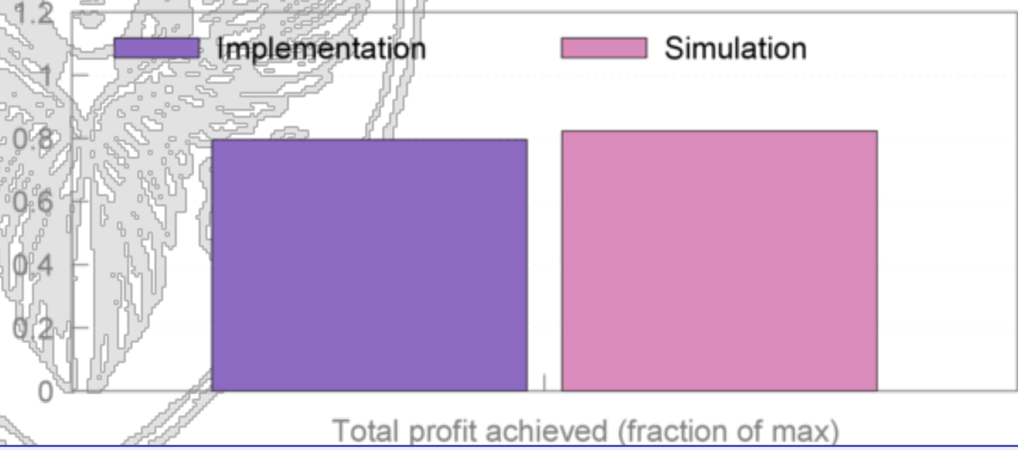



**Profit: up to 60% higher than SoA**

**<u>Stable</u> profit: 70-80% of maximum**






**In-field testbed validation**

Gap between simulations and testbed: **less than 3%** of maximum profit

# Esame-chiarimenti

- Scritto su tutti gli argomenti del corso
- Orale su tutti gli argomenti del corso
- Scritto di "sbarramento"+Progetto (da concordare con il docente; dovreste avere visto delle proposte ma dovete averlo assegnato)
- Scritto/orale su parte del programma+ Tesina (potete sostituire articoli da leggere su un argomento che preferite non approfondire per approfondire leggendo paragonabile numero di articoli un argomento collegato che vi interessa).
  - Esempio di tesine su reti di sensori:
    - ✓ Adaptive Sampling e outlier detection
    - ✓ Low power MAC in reti di sensori
    - ✓ Energy harvesting aware routing
    - ✓ Wireless transfer enabled communication
    - ✓ Protocols under standardization for WSNs (Wireless Heart, ROLL etc)-confronto