

RF-power harvesting
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Charger positioning problem
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The problem of cost
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Future work
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The cost and charger placement problems in RF-power harvesting IoT networks

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Outline

- 1 RF-power harvesting
- 2 Charger positioning problem
- 3 The problem of cost
- 4 Future work

1 RF-power harvesting

- Introduction to energy harvesting
- Modeling RF-power harvesting

2 Charger positioning problem

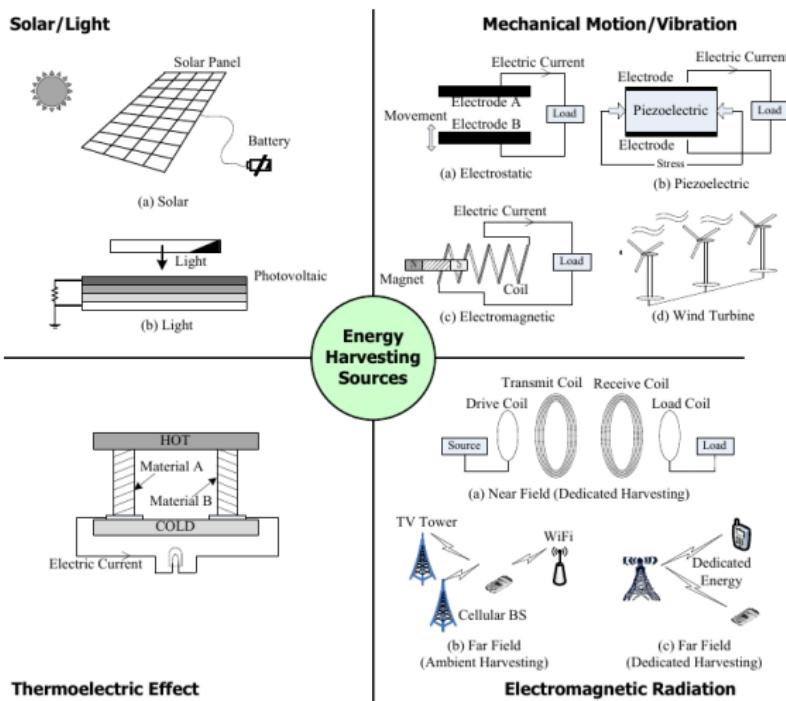
- Introduction
- Problem description
- Our solutions
- Evaluation

3 The problem of cost

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- Evaluation

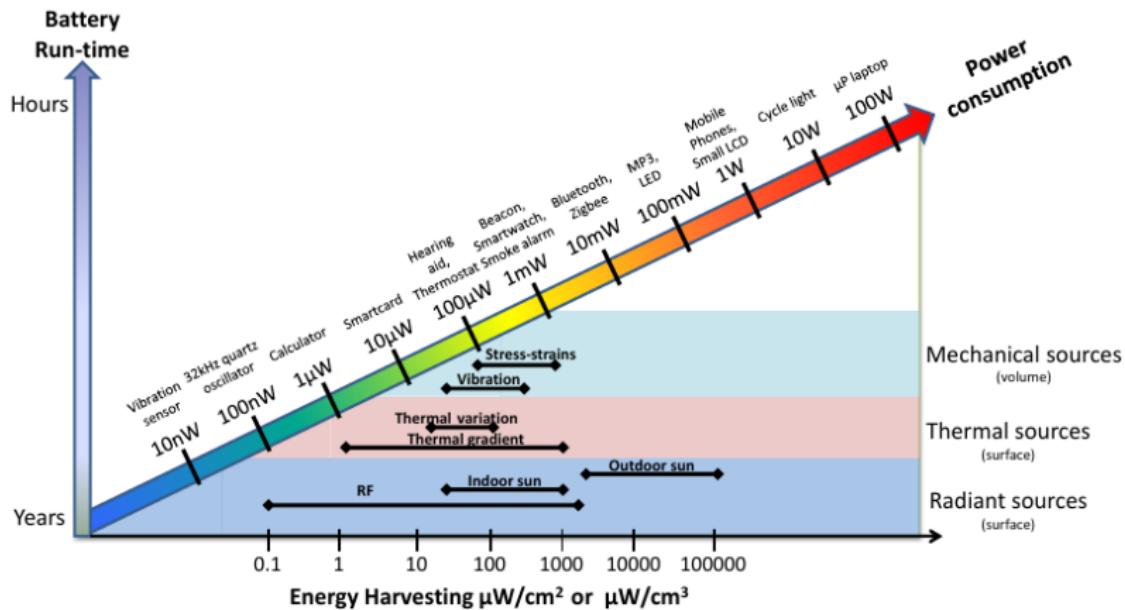
4 Future work

Types of energy harvesting

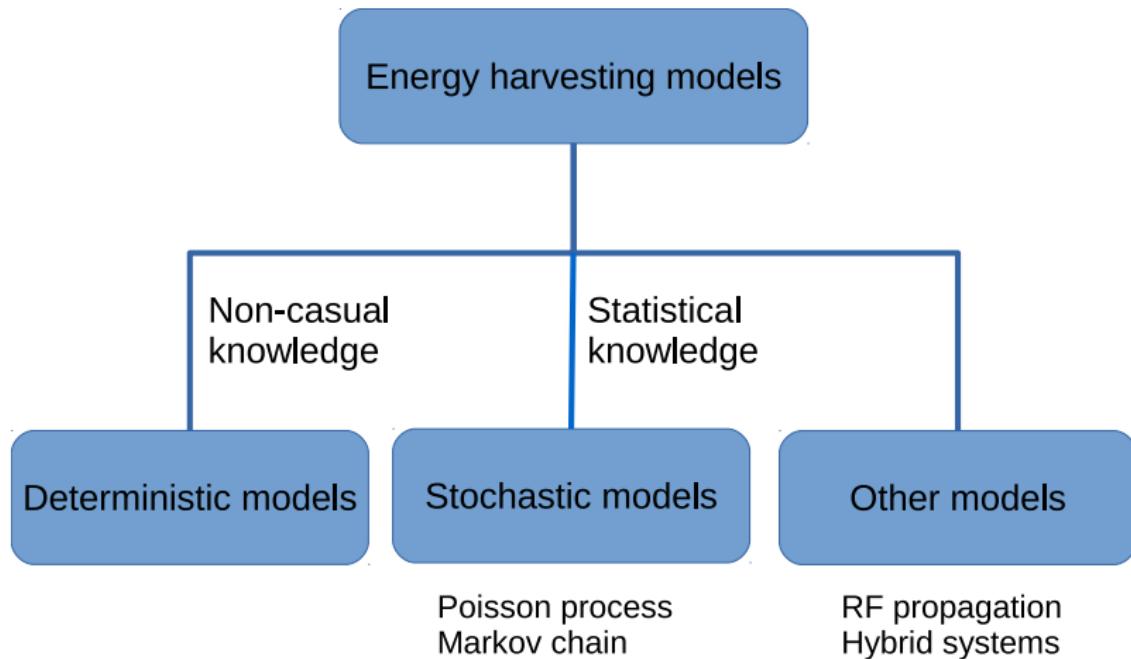


M. L. Ku, W. Li, Y. Chen and K. J. Ray Liu, "Advances in Energy Harvesting Communications: Past, Present, and Future Challenges," in *IEEE Communications Surveys & Tutorials*, vol. 18, no. 2, pp. 1384-1412, 2016.

Energy harvesting quantification



Harvesting models



RF-power harvesting

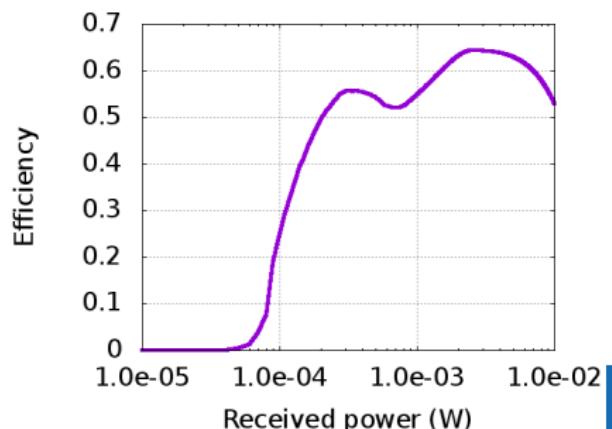
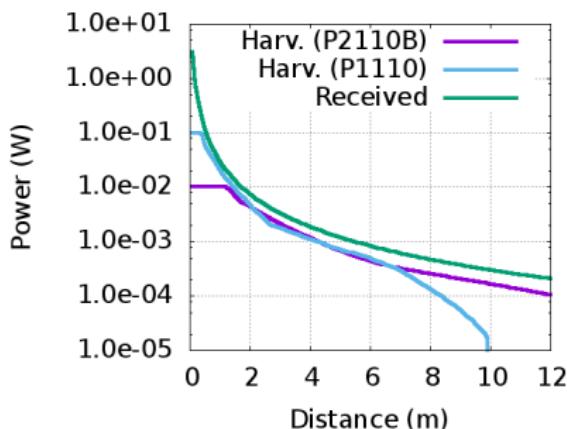
- The nodes can *harvest* energy from RF signals
- The amount of harvesting energy depends on:
 - transmitted power,
 - duration of the transmission,
 - distance between source-destination,
 - efficiency of the RF-power harvesting antenna,
 - power losses.
- The nodes can *consume* energy by:
 - taking measurements,
 - communicating with the sink,
 - carrying out other operations.
- $E_i = E_{cons_i} - E_{harv_i}$

Harvesting model

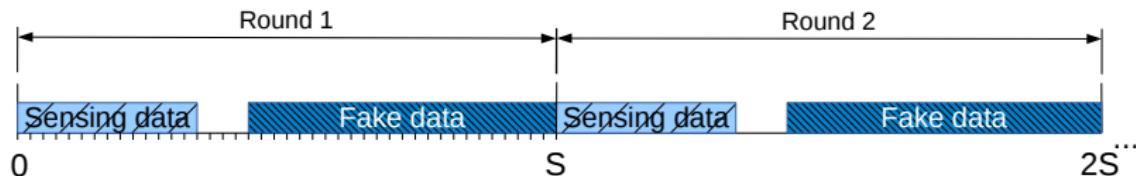
$$E_{h_i} = \int_0^{\infty} \sum_{j=1}^T P_{rx}^{d_{ij}} f^{d_{ij}} \frac{ps \cdot k'}{dr} dt,$$

$$P_{rx}^d = P_0 \frac{e^{2\sigma G}}{d^{2b}},$$

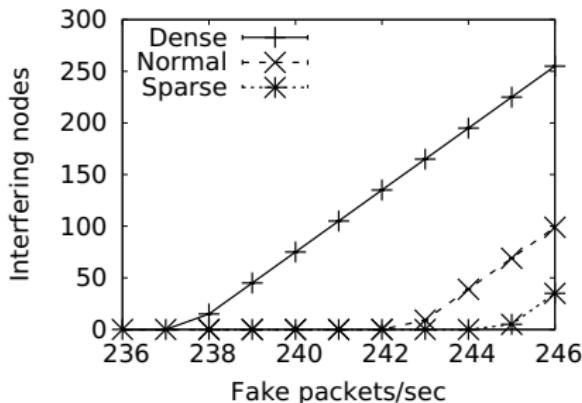
$$P_0 = P'_{tx} G_T G_R \left(\frac{\lambda}{4\pi} \right)^{2b}.$$



Communication model



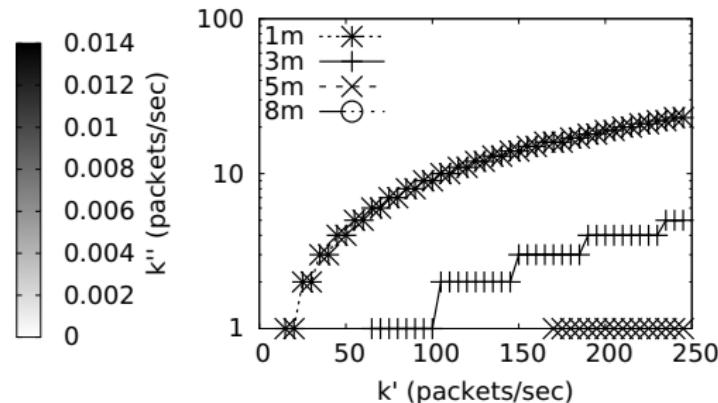
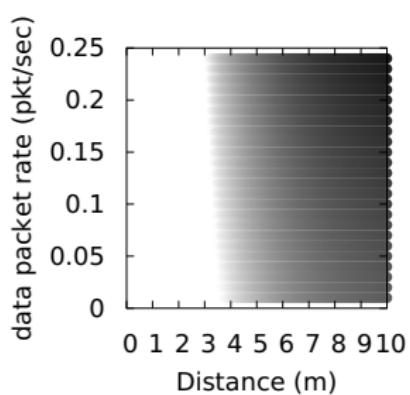
$$\frac{ps}{dr}(k(N_{max} + 1) + k') \leq \tau.$$



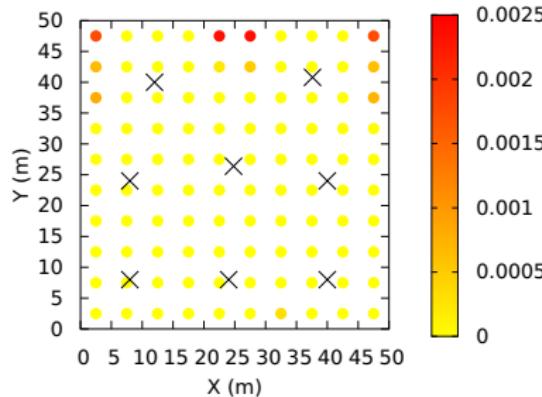
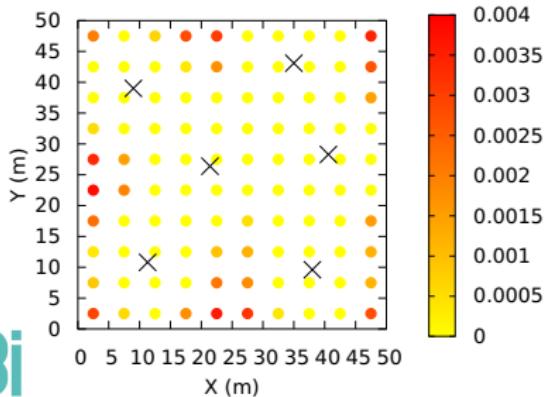
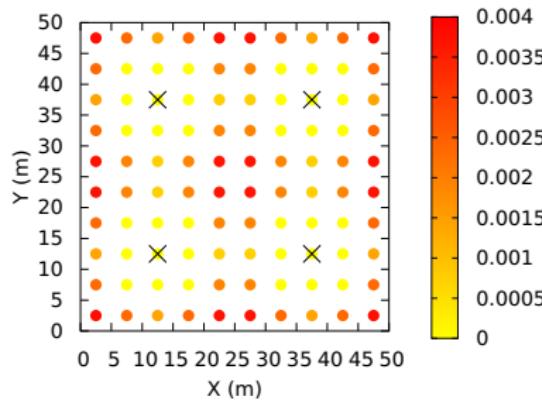
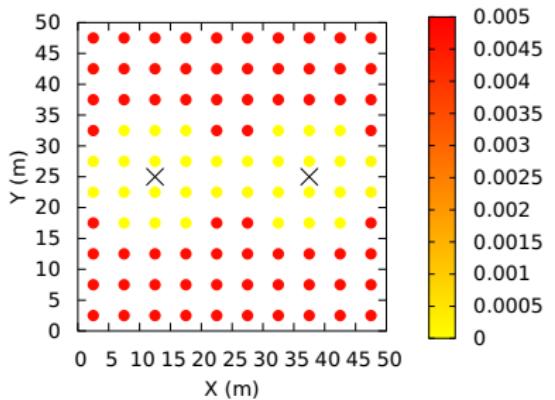
Multi-hop energy transfer

$$E_{extra_i} l(\tau) \geq P'_{tx} \frac{ps}{dr},$$

$$E_{extra_i} = \int_0^\tau dt \left(\sum_{j=1}^T P_{rx}^{d_{ij}} f^{d_{ij}} \frac{ps \cdot k'}{dr} - P_{tx} \frac{ps \cdot k}{dr} \right) - E_{rest}^\tau.$$



Example with 100 nodes and 2, 4, 6 and 8 chargers



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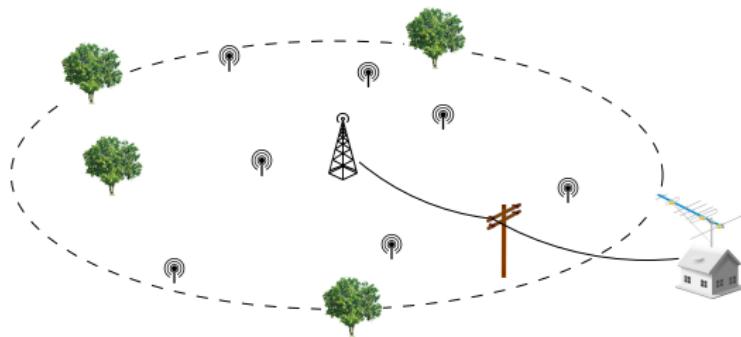
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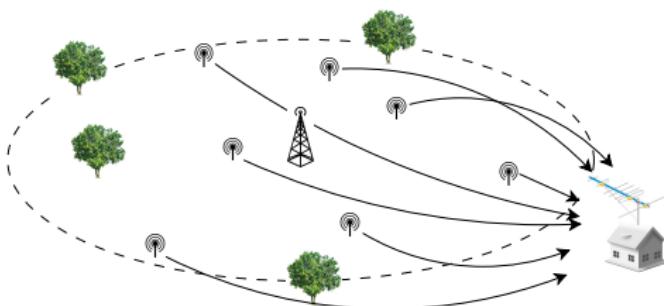
RF-power harvesting network

- A network with power constrained nodes
- Chargers with unlimited power resources
- RF-power harvesting is used to recharge the nodes



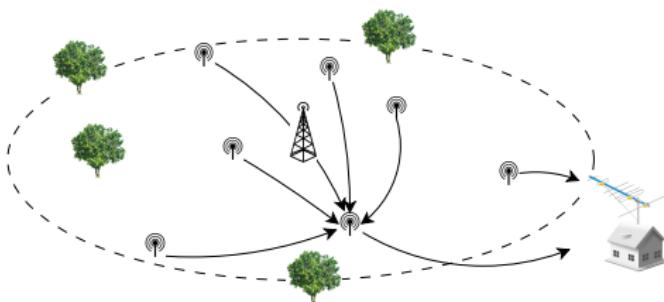
Objective: prolong the network lifetime as much as possible

Motivation



- Two major issues:
 - Long communication links → fast battery depletion
 - Low received power/efficiency → low harvesting energy
- Idea:
 - Group the nodes in clusters
 - Place a charger close to the cluster head

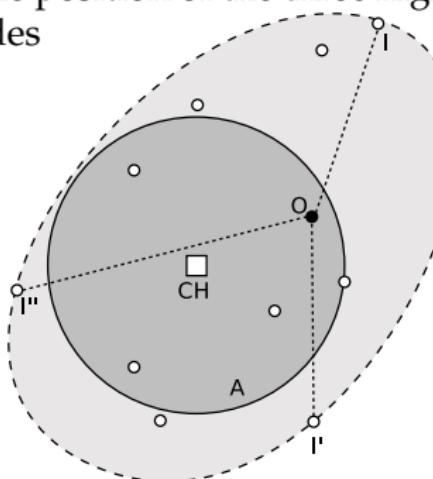
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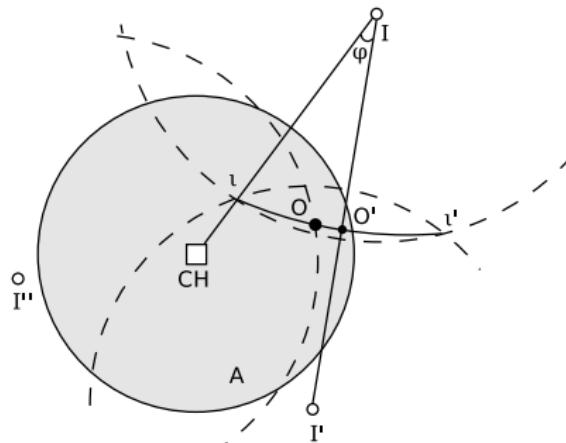
The Optimal Charger Positioning problem

- Formulation
 - Compute a position O : $\min(\max(E_i))$, $i \in [1, n]$
 - Facility Location Problem (NP-Hard)
- Preliminaries
 - the number of cluster members, the distance to the sink and harvesting parameters define the maximum charger distance to the CH (i.e. \mathcal{A}).
 - O is defined by the position of the three highest consumption nodes
 - $E_I^O = E_{I'}^O = E_{I''}^O$



Local Search (LS)

- a localized algorithm with low complexity
- a mobile charger is moving with a step ϵ
- the start point is the selected CH
- the destination point is the node with the highest consumption
- at each step LS checks the energy consumptions of the nodes

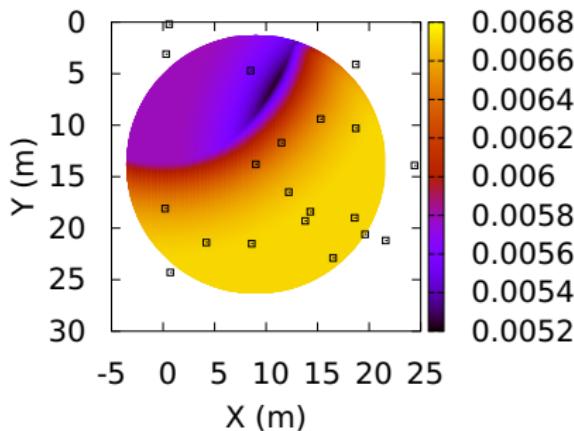
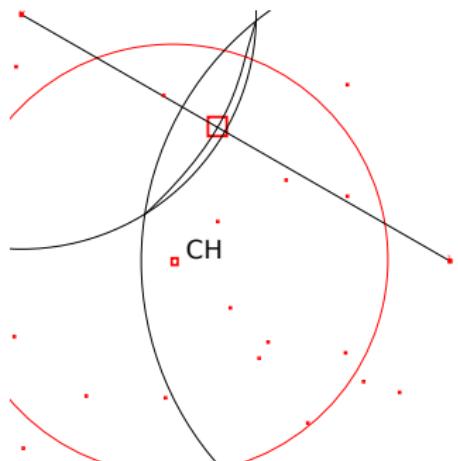


Brute Force (BF)

- all the position in \mathcal{A} with a step of ϵ' are evaluated
- centralized solution
- high complexity ($\mathbb{O}(\frac{\pi d_{CH}^2}{\epsilon'^2} n) = \Omega(\frac{\pi d_{CH}^2}{\epsilon'^2} n)$)

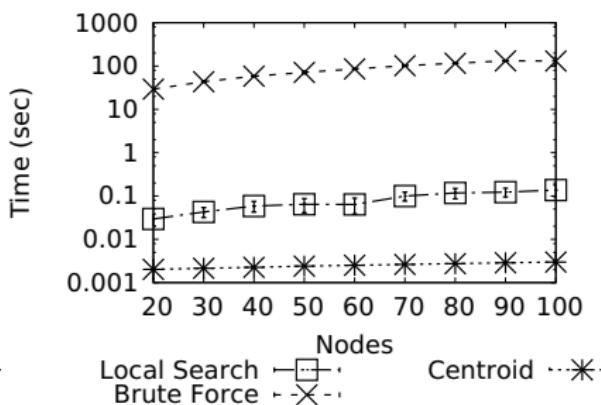
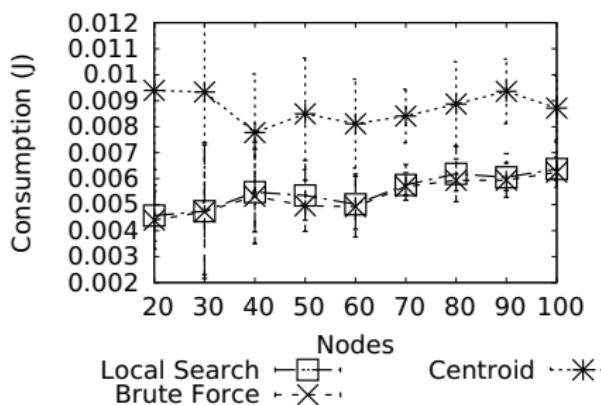
Solutions provided by the two algorithms

- Scenario with 20 random placed nodes



Energy consumption & Execution time

- Scenario with different node populations



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The minimum reimbursement time problem

- Capital expenditures (CAPEX) = the cost of harvesting module, chargers, batteries etc.
- Operating expenditures (OPEX) = the cost of maintenance, electricity etc.
- *Can a reduced OPEX cover extra CAPEX?*

Reimbursement Ratio (RR)

$$RR(D) = \min \left(\frac{CAPEX_D^{wh} - CAPEX_D^{woh}}{OPEX_D^{woh} - OPEX_D^{wh}} \right),$$

s.t.

$$CAPEX_D^{woh} = n(C_{nd} + C_b), \quad (1)$$

$$CAPEX_D^{wh} = n(C_{nd} + C_{rb} + C_{hu}) + T \cdot C_{st}, \quad (2)$$

$$OPEX_D^{woh} = n(C_{mnt} + C_b), \quad (3)$$

$$OPEX_D^{wh} = p(C_{mnt} + C_{rb}) + C_{el}, \quad p \leq n, \quad (4)$$

$$C_{mnt} = t_{mnt} C_{mh}, \quad (5)$$

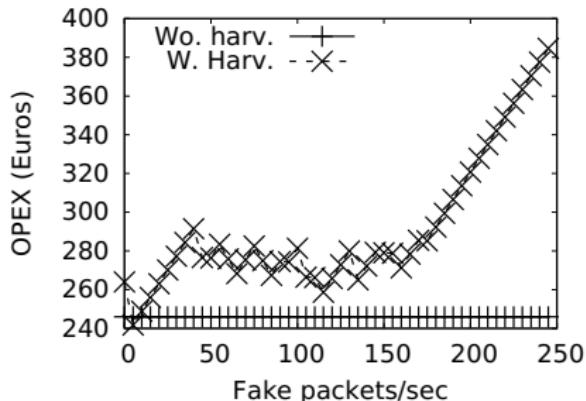
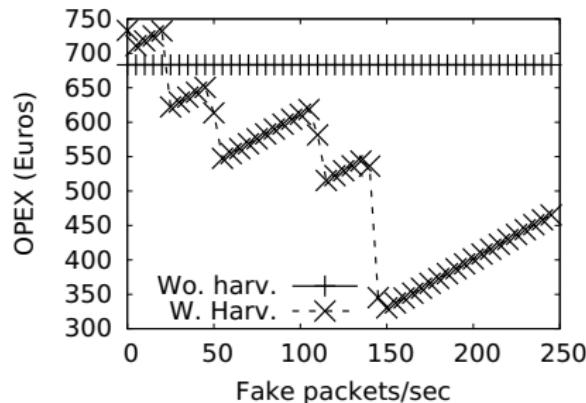
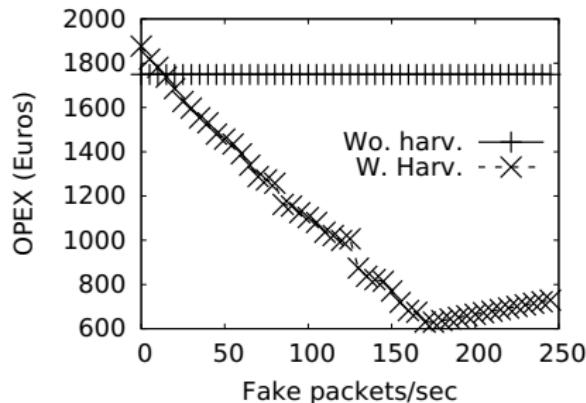
$$C_{el} = T(C_{el_b} t_{el_b} + C_{el_r} t_{el_r}) \frac{P'_{tx} ps k'}{dr}, \quad (6)$$

$$OPEX_D^{woh} > OPEX_D^{wh}, \quad (7)$$

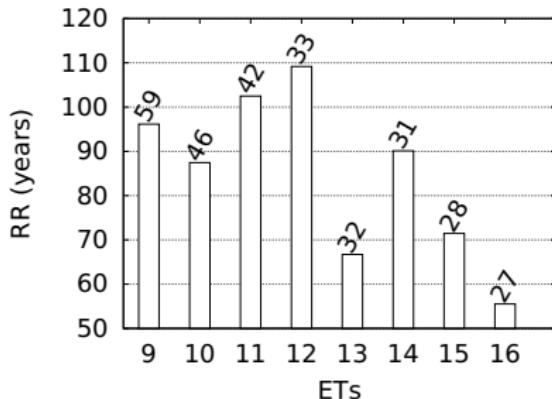
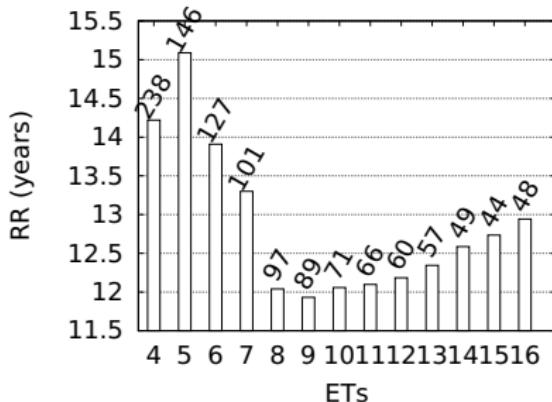
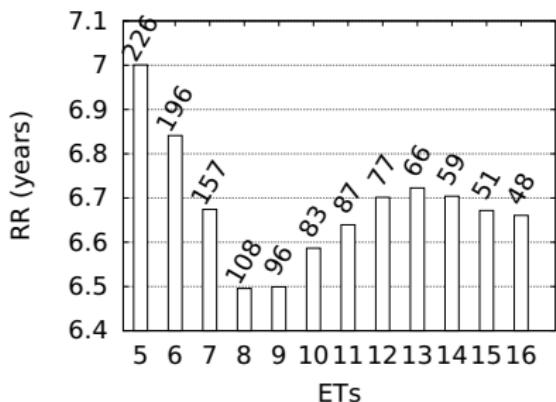
Evaluation methodology

- We vary k' , T , and network density
- Stock battery lifetime is 1 year
- Maintenance every six month (after the 1st year)
- All the batteries are replaced within a time slot of 4 years
- We measure the RR per visit and the average RR

OPEX of the first maintenance



Average RR



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Future work

- Consider different network lifetime definitions
- Consider node characteristics that change over time
- Investigate the feasibility of powering up chargers with solar panels

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Charger positioning problem
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The problem of cost
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Future work
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Thank you!