Modeling the Plug-in Electric Vehicles Charging: a Game-Theoretic Perspective

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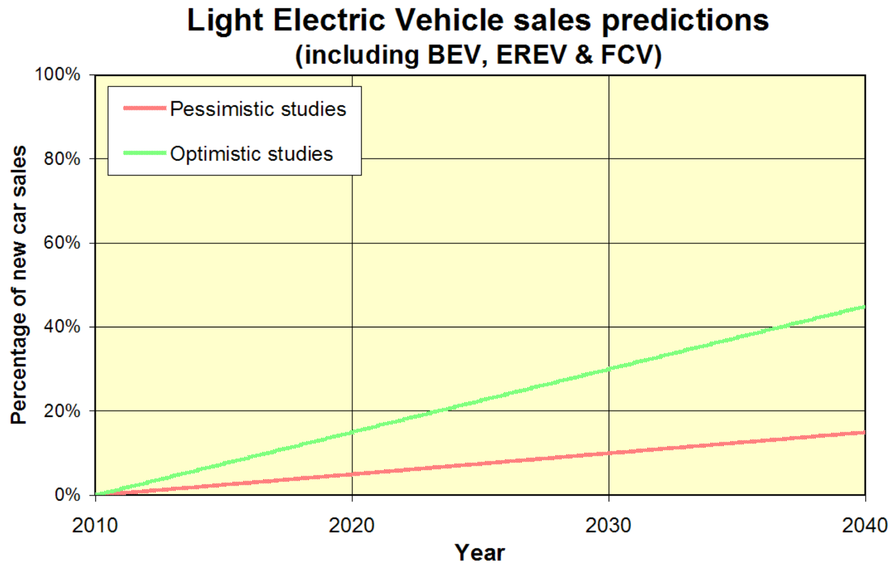
UAB

Outline

- Motivation
- Discussion: batteries charging strategies
- System model
- Market-based solution: the oligopoly game
- Future steps

Motivation: the deployment of Plug-in Electric Vehicles (PEV)

- PEVs prediction: significant growing in next years



Source: www.going-electric.org

- Benefits:
  - Energy efficiency
  - Reduce transportation costs
  - Reduce CO emissions
  - Lower dependence on fossil fuels

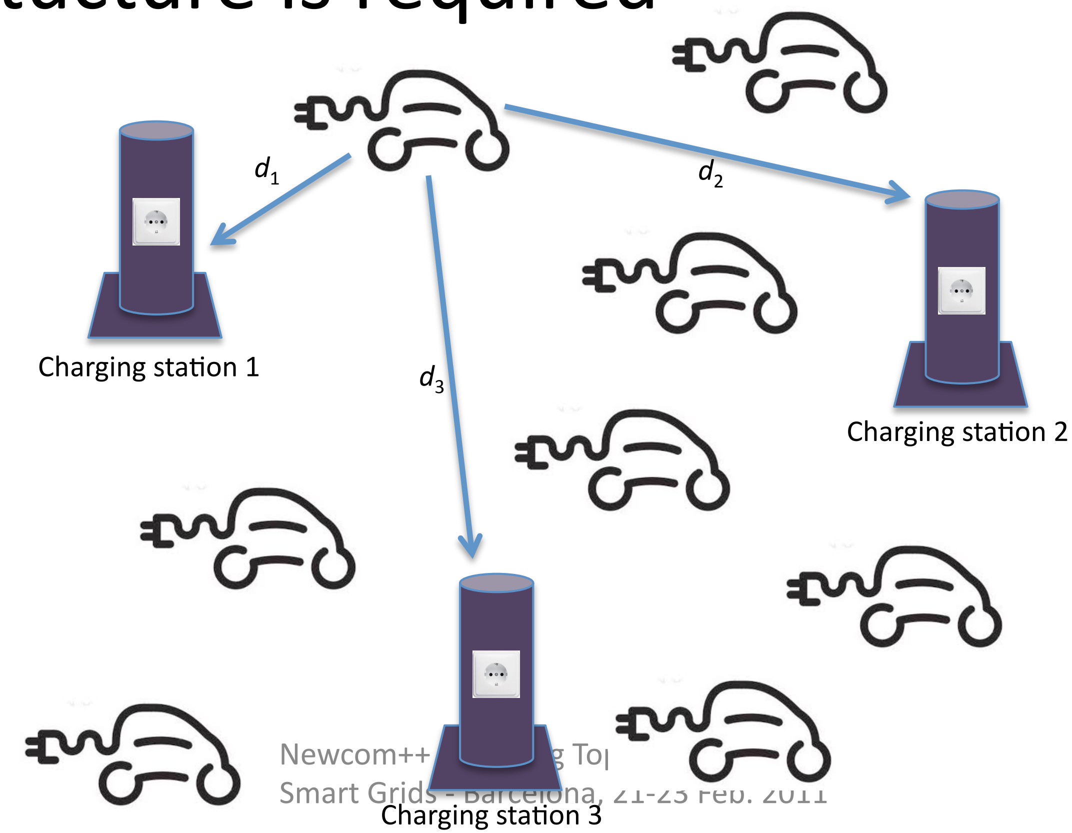
What to do when batteries are exhausting?

- Plug-in at home, garage, office…
  – Grid not prepared to support that: a number of PEVs plugged into, e.g., a garage could cause
    - an overload on the grid, often working close to its operational limit
    - unbalanced conditions may result in degradation of power quality and damage utility equipments and customer appliances[1]
  – Not possible fast charging (Level 3 method)
- We can replace the exhausted battery by a full charged battery
  – Instantaneous ☺
  – Battery manufacturers to agree on a standard ☹
  – Storage ☹
  – Initial costs ☹

[1] A. Ipakchi and F. Albuyeh, "Grid of the future," Power and Energy Magazine, IEEE, vol. 7, no. 2, pp. 52–62, 2009.

What to do when batteries are exhausting? (cont'd)

- Or we can charge the batteries in a charging station (CS) → "only" a dedicated infraestucture is required



And which is the best charging station?

- From the PEV viewpoint: is the best CS the cheapest one?
  - It depends on the distance
- So, a tradeoff among price and distance is required
- Distance PEV-CS: given by positioning application (GPS, Galileo or 3G services, for instance)

The CS's opinion

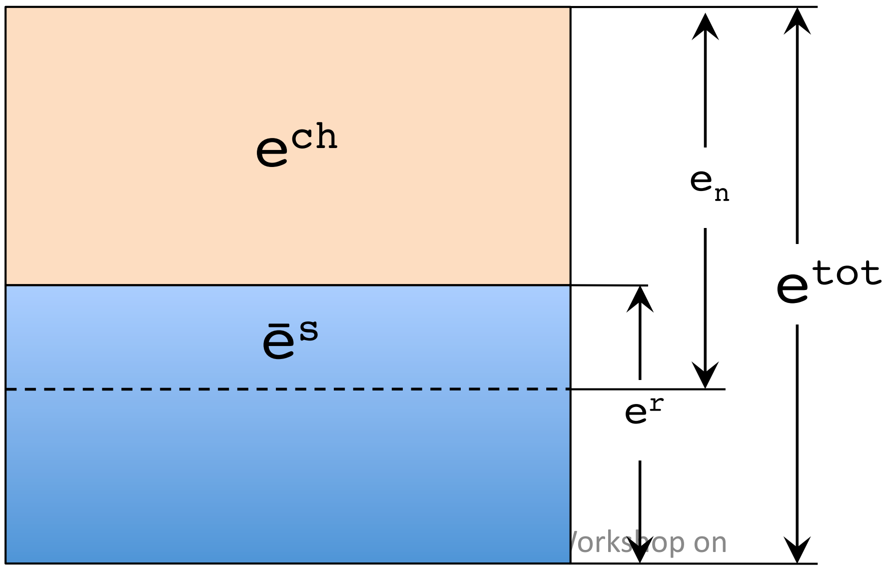
- CSs belong to electric utilities
- Electric utilities want to optimize their benefits: the higher the price, the higher the revenue
- Also CSs compite among them for users

↓

Game theory framework

System model: The PEV's energy model

Parameter	Description
e_n	Total energy demanded by PEV *n*
e^{tot}	Total batteries energy
e^r	Remaining energy when request is made
e^{ch}	Initial demand of energy
$\bar{e}^s$	Estimated consumption (kW/km)



System model: Costs and benefits

- CS benefit: $R_n = \sum_{k=1}^{K_n} p_n e_k^n - C_n$
- PEV cost: $c_k = e_k^n p_n$
- So the problem is:

$$\max_{p_n} R_n = \sum_{k=1}^{K_n} p_n e_k^n - C_n, \text{for all } n \in \mathcal{N}.$$

$$\min_{n} c_k = e_k^n p_n = (\bar{e}_k^s d_{kn} + e_k^{ch}) p_n, \text{for all } n \in \mathcal{N}, \text{ for all } k = 1, \ldots, K$$

- How can we maximize the benefit and minimize the cost?

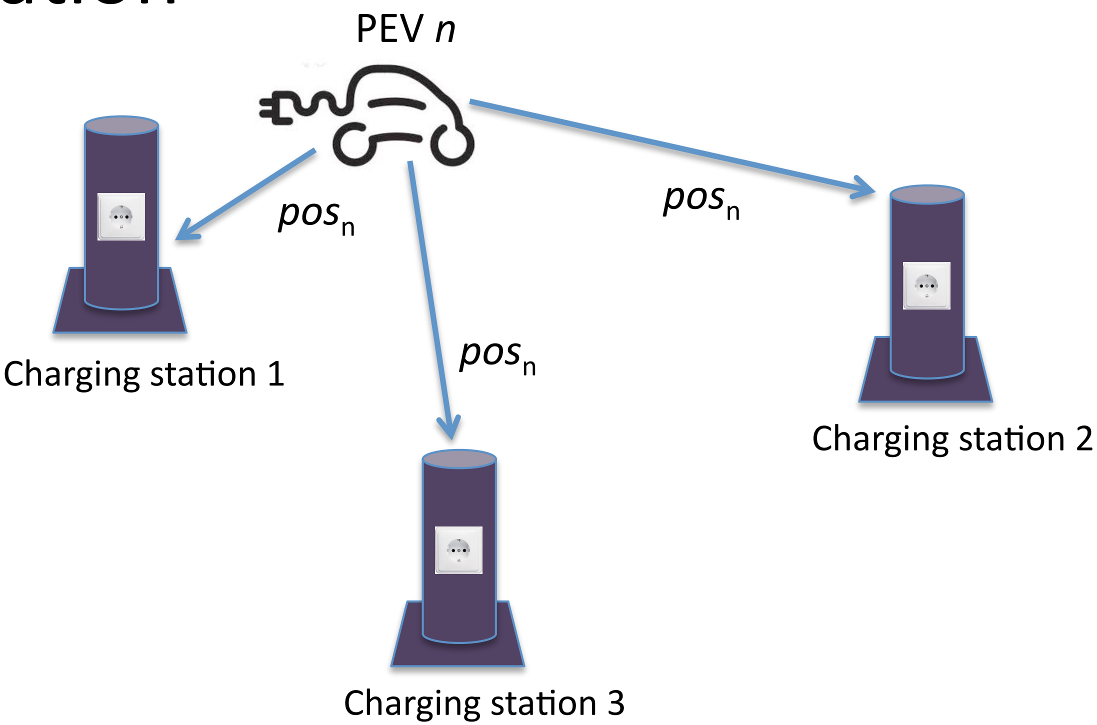
Market-based model: the oligopoly game

- We realize that PEV = customers and CS = providers
- We have, for a given area:
  - Many (N) PEVs with small demand
  - A few (K) CSs provide the energy

  ⇒ **Oligopoly**
- Then, we can model our problem as an oligopoly game

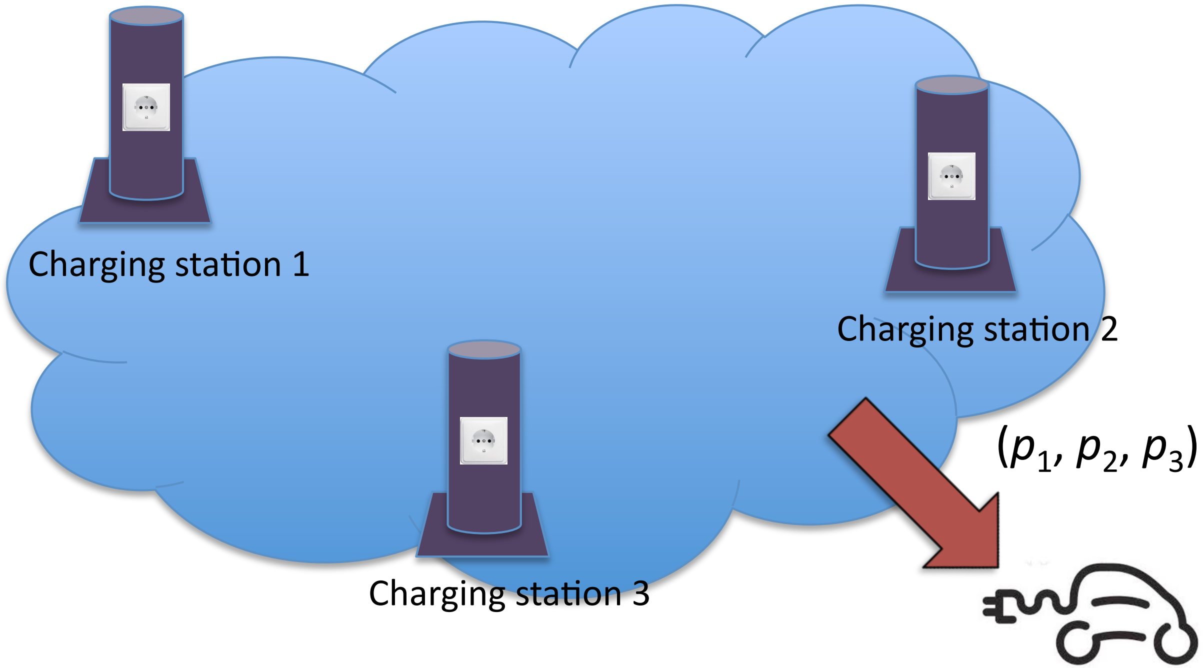
Proposed algorithm

1. The PEVs communicate their willingness to charge by communicating their positioning information



Proposed algorithm (cont'd)

2. The CSs plays the oligopoly game
   – Prices equilibrium
   – Communicate their prices to PEVs



Proposed algorithm (cont'd)

3. The PEVs selects the best CS *n** in order to minimize the cost, considering the distance to cover → solve the problem

$$\min_{n} \quad c_k, \text{for all } n = 1, \ldots, N, \text{ for all } k = 1, \ldots, K$$
$$\text{s.t.} \quad d_{kn} < d_{th} = \frac{e_k^r}{\bar{e}_k^s}.$$

Future steps

- Determine adequate pricing function *p* and cost function *C*
- Oligopoly game algorithm: equilibrium and convergence issues

Thank you for your kind attention!

Any question?