Scheduling energy consumption with local renewable micro-generation and dynamic electricity prices

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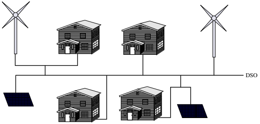
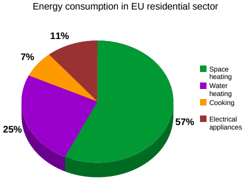
Outline

Introduction

- Smart grid
  - Transformation of electricity generation: distributed generation
  - Transformation of electricity trading: real-time pricing, short-term contracting



- Smart home
  - Transformation of electricity consumption: peak demand response, balancing power, load adjustment

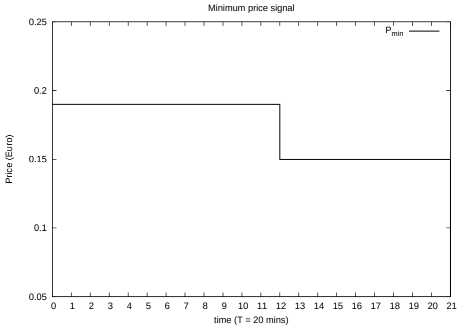


System model

Price signals

- a set P of *price signals*
- assumed to be predicted or provided for some time

$$p_{min}(t) = min\{p_i(t)\}$$

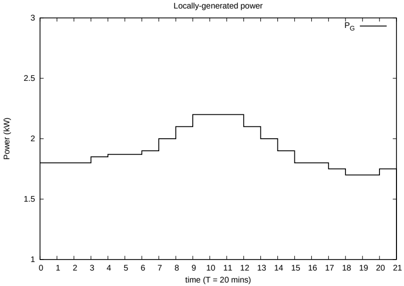


System model

Locally-generated power

- a set G of local power micro-generators such as photovoltaics and wind mills
- $P_{G_i}(t)$ depends on weather, location
- assumed to be predicted
- assumed to be costless

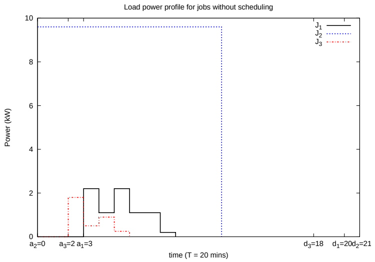
$$P_G(t) = \sum P_{G_i}(t)$$



System model

Flexible tasks

- a set J of flexible tasks
- $J_i = (a_i, d_i, pr_i, L_i)$
  - a_i: earliest start time
  - d_i: deadline
  - pr_i: preemptability
  - L_i: load power profile



Problem statement

The scheduling problem

Given a task set J, a price signal set P, a locally-generated power P_G, and maximum allowed consumable power at any instant as P_{max}; determine a schedule of the tasks such that the total cost for their execution is minimized.

Discretization of the problem

We assume piecewise constant functions with interval T

- $p_{min}(t), P_G(t)$ in interval $[min(a_i), max(d_i)]$

becomes

- $p_{min}[n], P_G[n]$ of length

$$N = \frac{(max(d_i) - min(a_i))}{T}$$

$L_i(t)$ becomes $L_i[n]$ with length

$$N_{L_i} = \frac{length(L_i)}{T}$$

Cost function

- Schedule for task J_i, $s_i[n]$: sequence of 0s and 1s
- Power consumed by J_i

$$P_i[j] = \begin{cases} L_i[\sum_{k=1}^{j} s_i[k]] & \text{if } s_i[j] = 1 \\ 0 & \text{otherwise} \end{cases}$$

- Total power consumed by all tasks

$$P_{tot} = \sum_i P_i$$

- Power to be billed (negative values are zeroed in P_{billed})

$$P_{billed} = P_{tot} - P_G$$

- Cost of the energy

$$C = P_{billed} \cdot p_{min} \cdot T$$

Constraints

- Tasks are scheduled to start after their earliest starting time:

$$\forall J_i : \qquad a_i \leq T \cdot min\{k : s_i[k] = 1\}$$

- Tasks are scheduled to finish before their deadlines:

$$\forall J_i : \qquad d_i - T \geq T \cdot max\{k : s_i[k] = 1\}$$

- Task J_i is scheduled as many times as the length of its load power profile:

$$\sum_{k=1}^{N} s_i[k] = N_{L_i}$$

- If task J_i is not preemptable, then it should be scheduled to run all at once:

$$pr_i = 0 \Rightarrow s_i(l) = 1$$
$$\text{for } l \in [min\{k : s_i(k) = 1\}, max\{k : s_i(k) = 1\}]$$

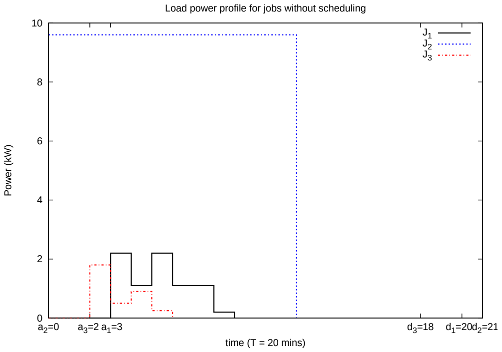
- At no time, the total power withdrawn by all tasks exceeds the allowed maximum, P_{max}.

$$P_{tot}[k] \leq P_{max} \qquad \text{for all } k$$

Case study

Task (J_i)	earliest start	deadline	total duration	preemptable
Clothes washing	1:00	6:40	2h	no
Car recharge	0:00	7:00	4h	yes
Dish washing	0:40	6:00	1h20'	no

$P_{max} = 15kW$

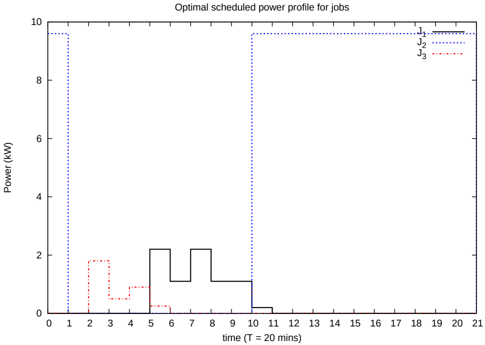


Case study

- huge search space

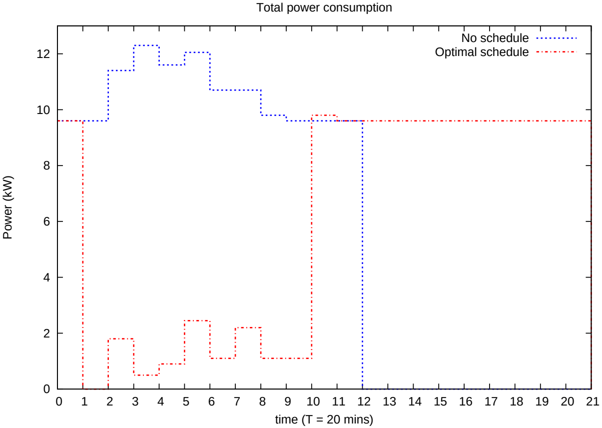
$$\binom{21}{12} \cdot 12 \cdot 11 = 38,798,760 \textit{ valid schedules}$$

- took 35 minutes on a 1.8 GHz Intel Pentium Dual Core computer with 2GB of RAM
- 23% cost reduction from €6.5 to €5.0



Case study

- better use of P_G



Discussion

Scheduling algorithm

- worst case complexity is $\mathrm{O}(2^{MN})$
  M: number of tasks, N: number of time slots
- the scheduler should run in a reasonable time when new tasks arrive or predictions change
- need for fast admittance tests

$$P_{max} \cdot N \geq \sum_i \sum_j L_i[j]$$

ICT requirements

- A controller device
  - reads price signals,
  - makes contracts for short-terms with different DSOs.
  - communicates with home appliances (start, pause, resume and task information)
  - runs the scheduling algorithm
  - can be integrated with a smart metering device
  - may communicate with other controllers nearby
- need for standards for interoperable devices and seamless integration

Discussion

Use cases

- Home level
- Community level
  - better trading power;
  - less communication/computation requirements on the infrastructure;
  - less cost of the ICT infrastructure per home due to sharing;
  - more predictable consumption at the community level;
  - ability to impose peak demand response and balancing power policies at the community level.
  - privacy concerns due to making household tasks transparent to a shared controller;
  - a community-level scheduling might provide less optimal results than home-level scheduling from the stand point of single users.

Management of locally-generated energy

- store, sell or waste

Conclusion

- A scheduling problem has been proposed to save money for household tasks based on the current trends in electricity markets, smart grids and smart homes.
- Finding the optimal schedule through exhaustive search is not feasible.
- We need efficient heuristics that would work for large number of tasks and time slots; and run on embedded systems.

Future work

- develop heuristics, assess their performance
- evalute optimization performance in presence of prediction errors in p_{min} and P_G
- investigate negotiation in buying and selling of the energy
- investigate scheduling policies for demand side management

Thank you!

Questions?