Algorithms for Multi-Agent Microgrids & Wider Power Systems

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AC Optimal Power Flow

$$\min_{S_{ij}, V_i, I_{ij}, s_j} \quad C(s_j)$$

Generation Cost

s.t.

$$I_{ij} = y_{ij}(V_i - V_j), \quad \forall i \to j \in \mathcal{E}$$

$$S_{ij} = V_i I_{ij}^H, \quad \forall i \to j \in \mathcal{E}$$

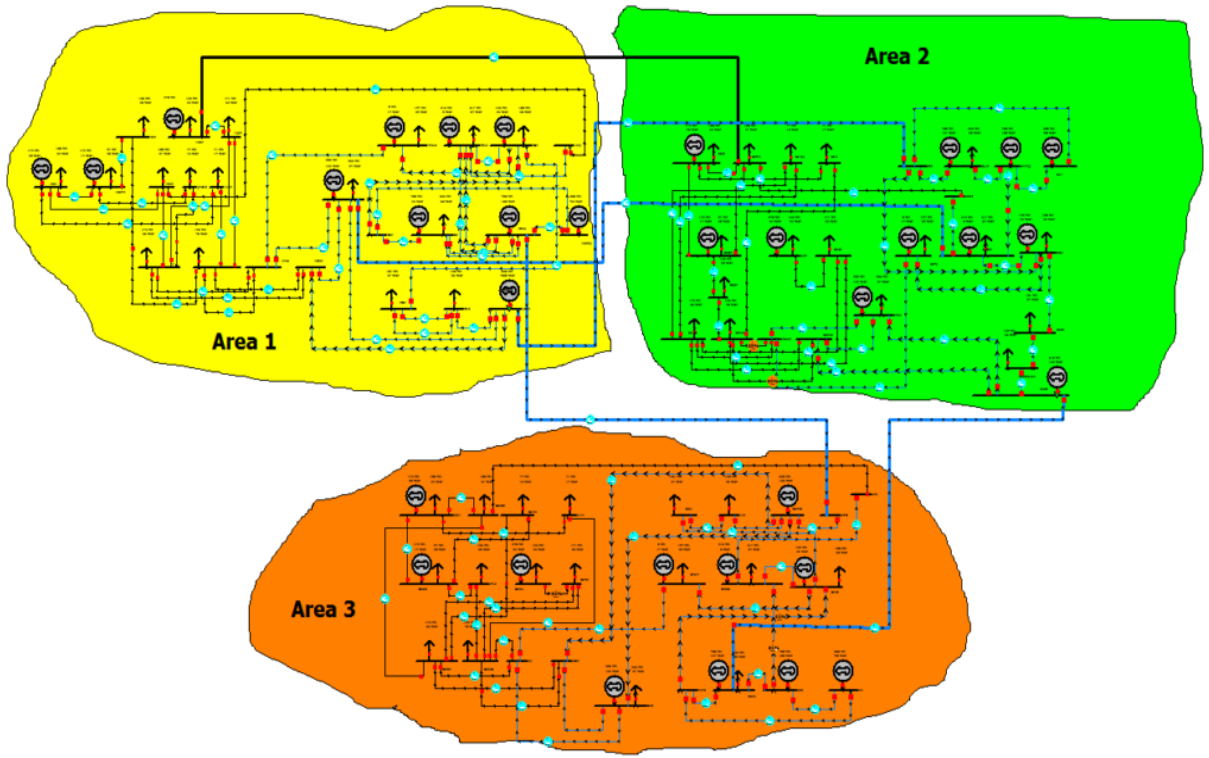
$$s_j = \sum_{k:j\to k} S_{jk} - \sum_{i:i\to j} (S_{ij} - z_{ij}|I_{ij}|^2), \quad \forall j \in \mathcal{N}$$

Power Flow Equations

$$\underline{s}_j \leqslant s_j \leqslant \bar{s}_j, \quad \forall j \in \mathcal{N}$$

$$\underline{v}_j \leqslant |V_j|^2 \leqslant \bar{v}_j, \quad \forall j \in \mathcal{N}$$

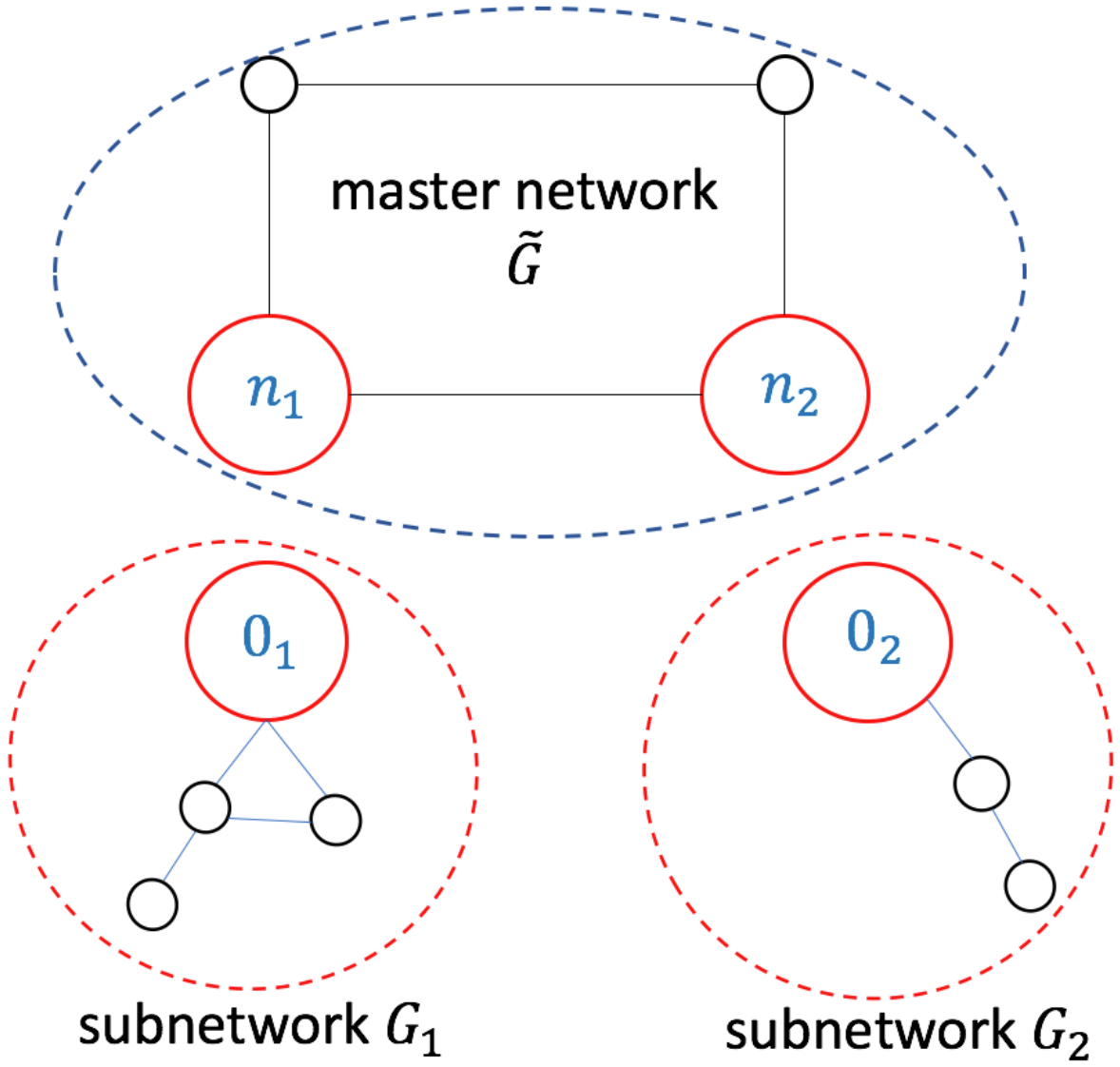
Engineering Constraints



IEEE 96 Reliability Test System

Challenges

- AC optimal power flow
- Nonconvex constraints
- Potentially large scale



Decomposition Based Optimal Power Flow

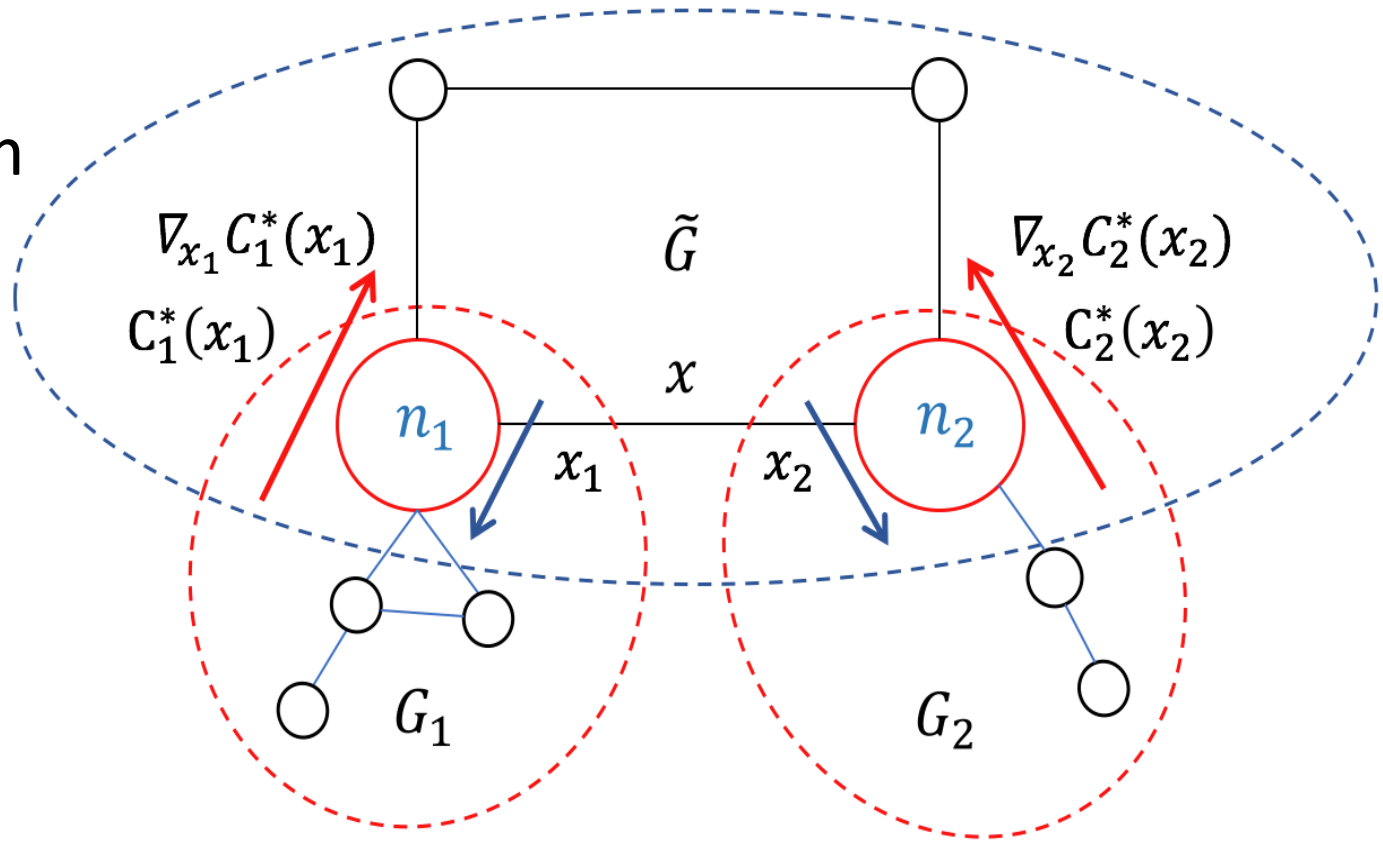
- Reformulate as bilevel problem

Master Problem:

$$\min_{x} \quad C(x) + \sum_{t \in T} C_t^*(x)$$
$$s.t. \quad h(x) \leqslant 0$$

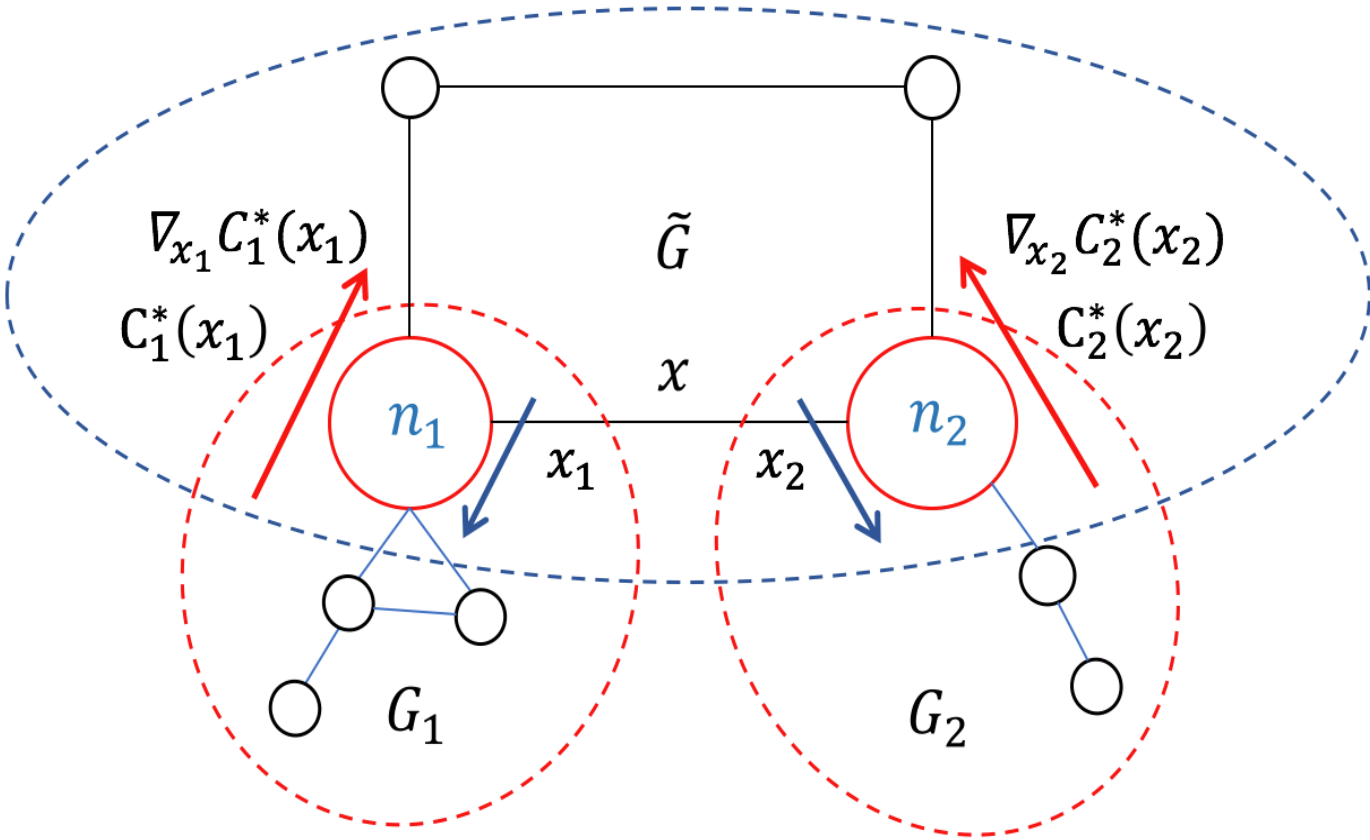
Subproblems:

$$C_t^*(x) = \min_{y_t} \quad C_t(y_t; x)$$
$$s.t. \quad h_t(y_t; x) \leqslant 0$$



Decomposition Based Optimal Power Flow

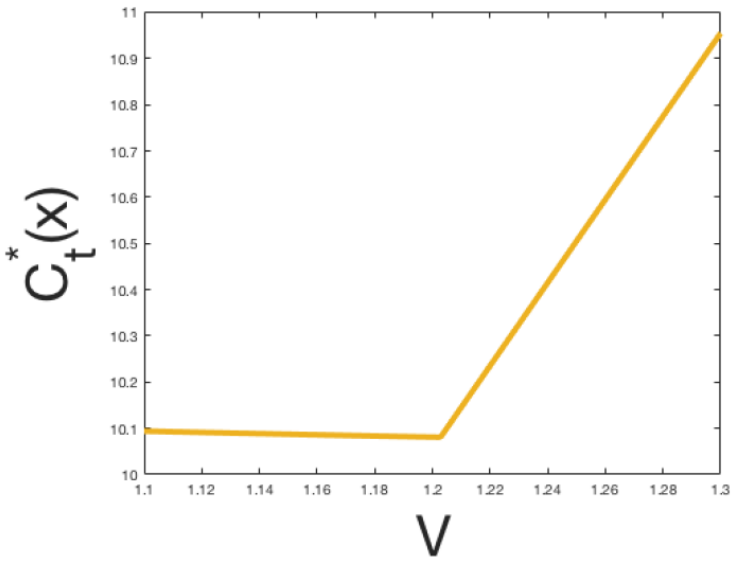
- Allows parallelization
- Subproblems: solved using second order cone (SOCP) or other relaxation techniques
- Master problem: general nonlinear programming solver
- Caveat: $C_t^*(x)$ may be non-smooth



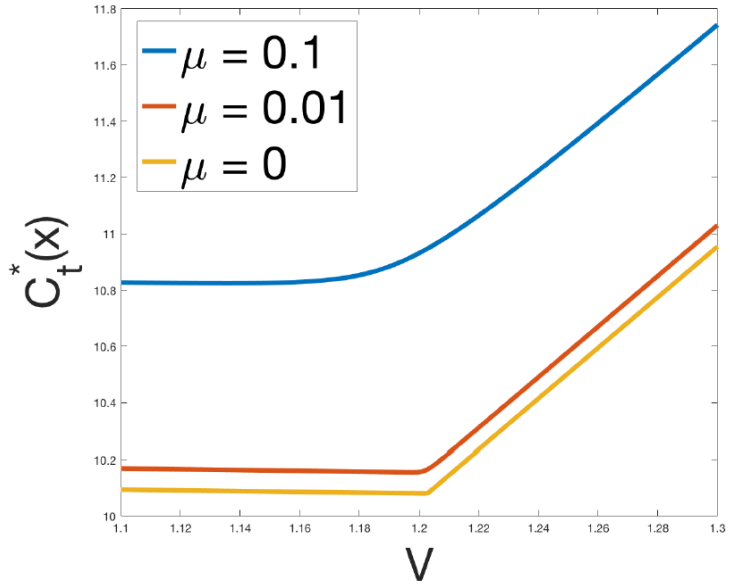
Non-smoothness

$$C_t^*(x) = \min_{y_t} \quad C_t(y_t; x)$$
$$s.t. \quad h_t(y_t; x) \leqslant 0$$

- Change of x may cause $C_t^*(x)$ to be non-smooth.
- Different inequality constraints being tight.



Smoothen subproblems by logarithmic barrier



- Large μ: smoothed value function, but different from the original function.
- Small μ: value function still has high curvature.

Smoothing

Solve a sequence of problems:

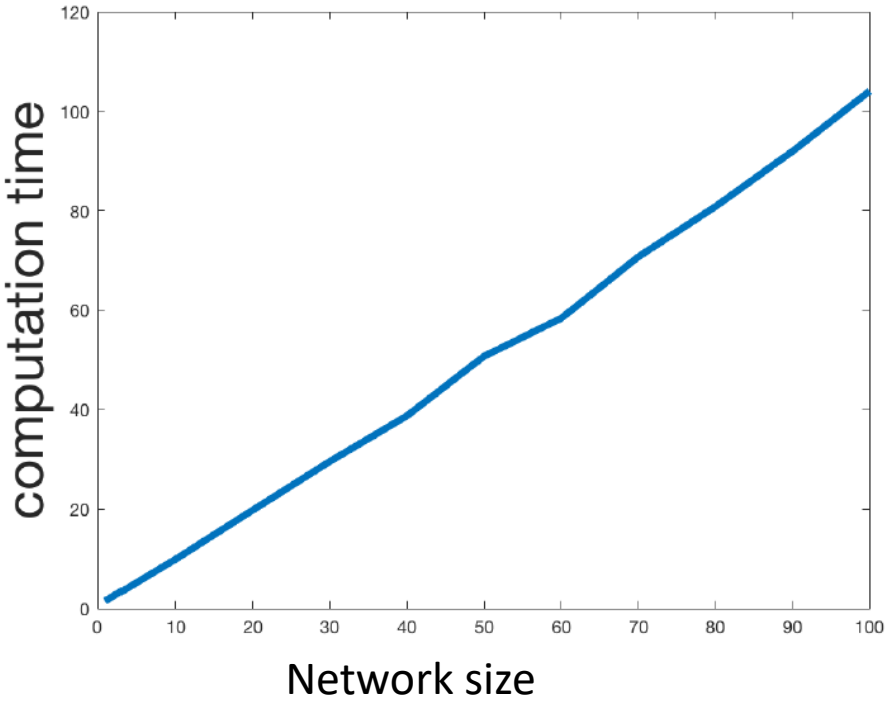
$$\begin{aligned} \min_{x} \quad & C(x) + \sum_{t \in T} C_t^*(x, \mu) \\ s.t. \quad & h(x) \leqslant 0 \end{aligned}$$

1. Start with a large μ to guide towards the solution.
2. Gradually reduce μ, using previous solution as a warm-start.

- $C_t^*(x, \mu)$ is smooth for fixed μ.
- Apply NLP solver to solve the master problem.
- Need to compute $C_t^*(x)$, $\nabla_x C_t^*(x)$, $\nabla_x^2 C_t^*(x)$.

Numerical Performances

- Scales linearly with problem size



Demand Response

Generators

Independent System Operator (ISO)

Consumers/prosumers

Figure from www.gismart.eu

Sample price fluctuations

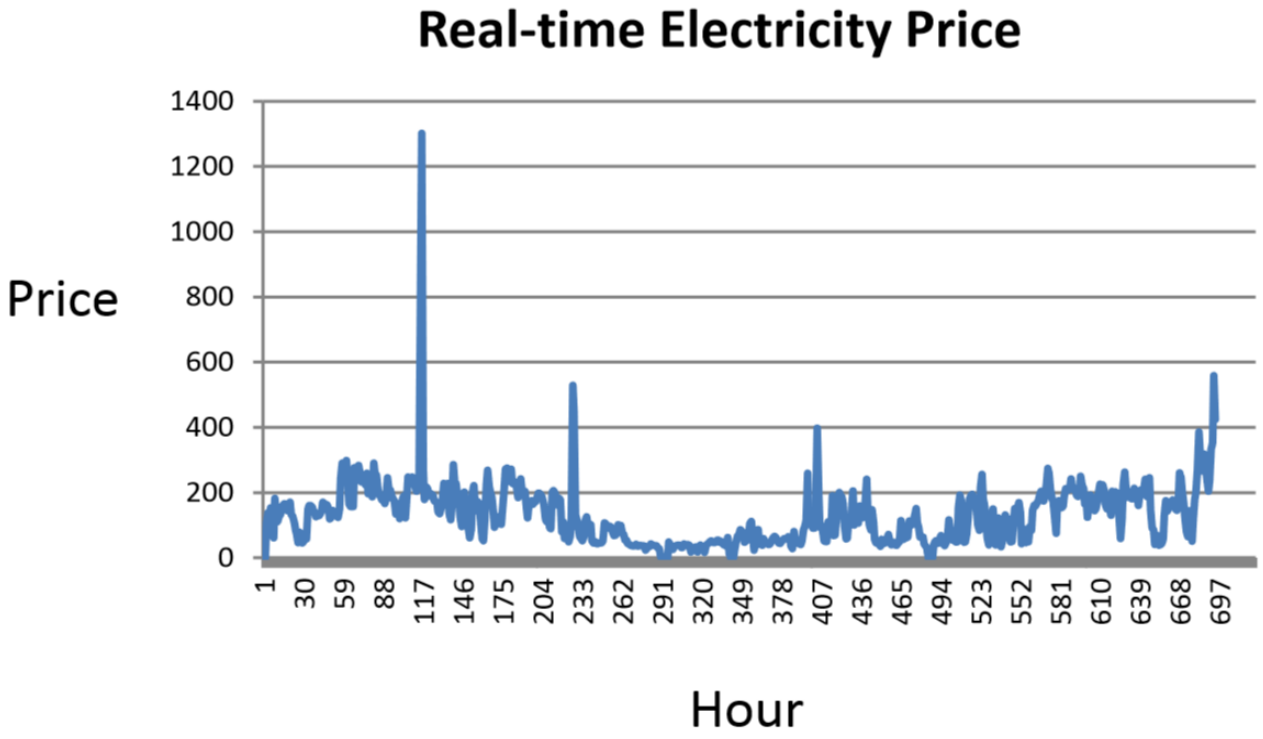
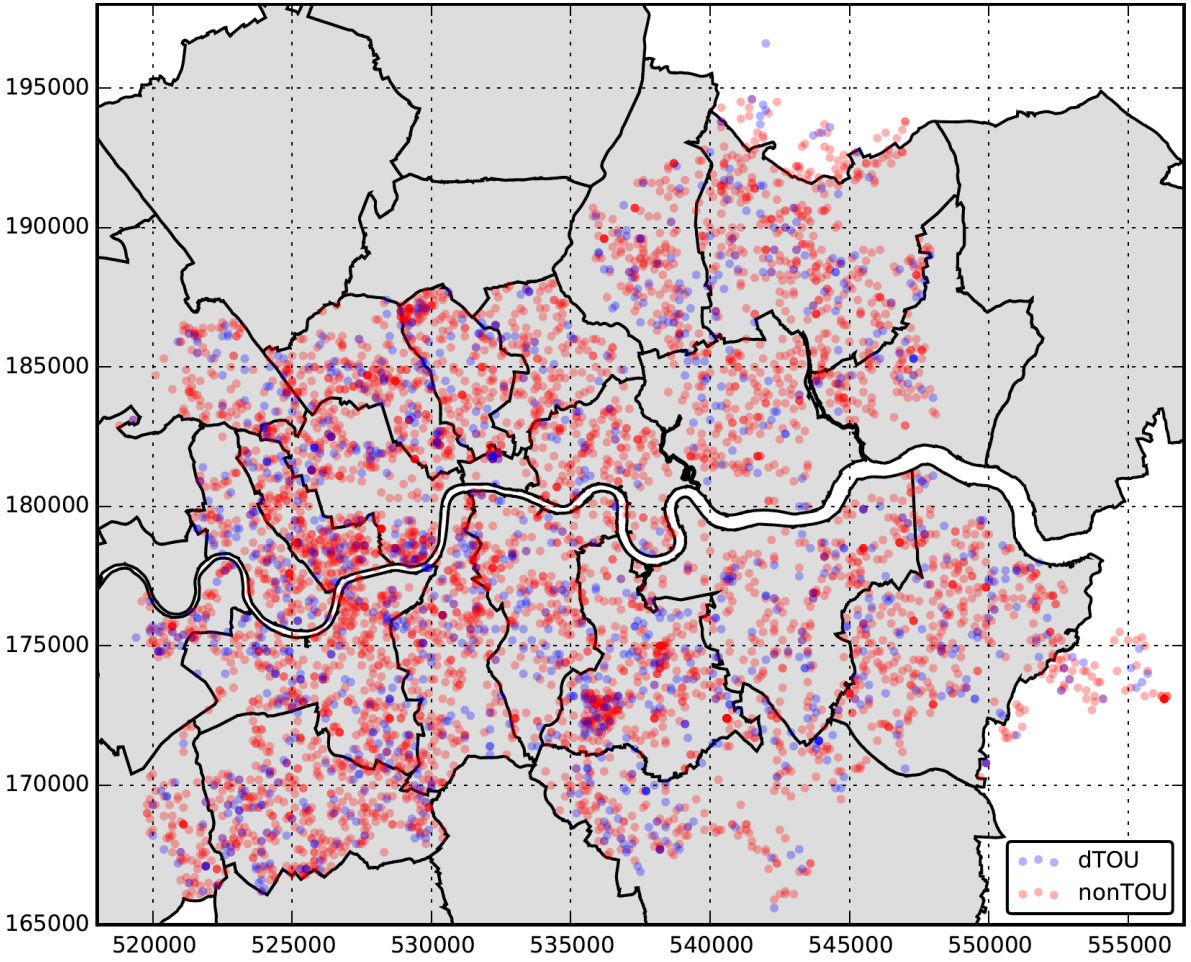


Figure: Hourly real time price per megawatt-hour for Cambridge, MA for Dec 10, 2013 to Jan 7, 2014.

Demand Response

Historical Demand Response Data



Household Samples from UK DR project[1]

5567 Households in London

1126 TOU experiment group

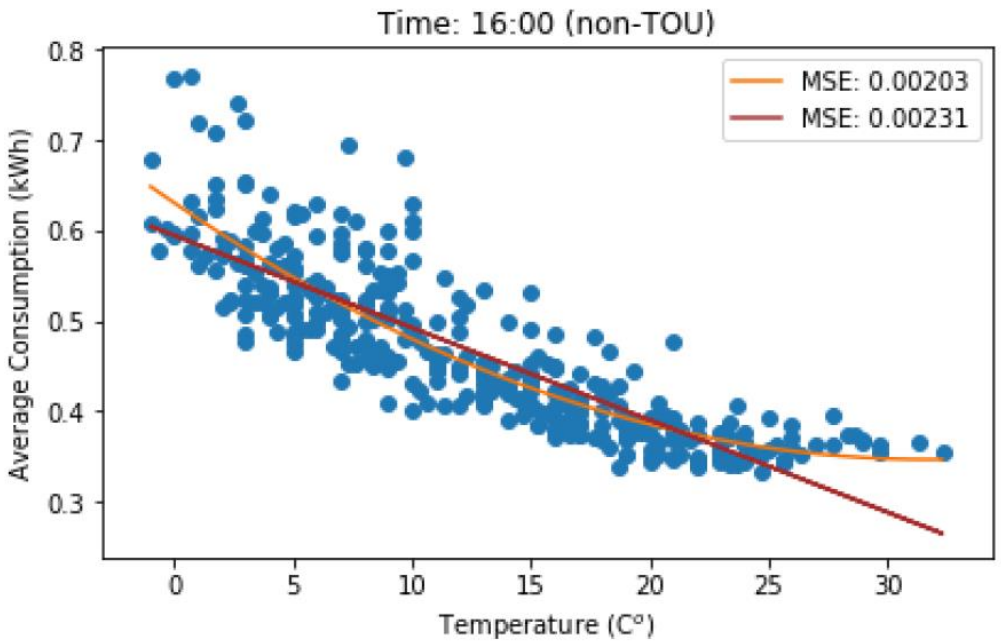
4486 non-TOU control group

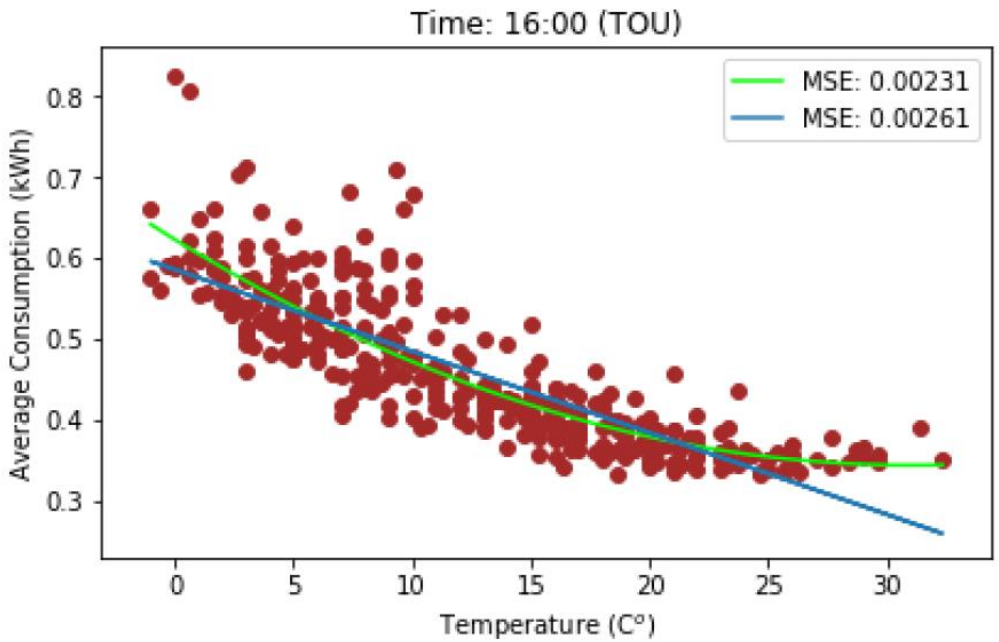
Trial from beginning of 2011 to the end of 2014

Measured 30 min resolution

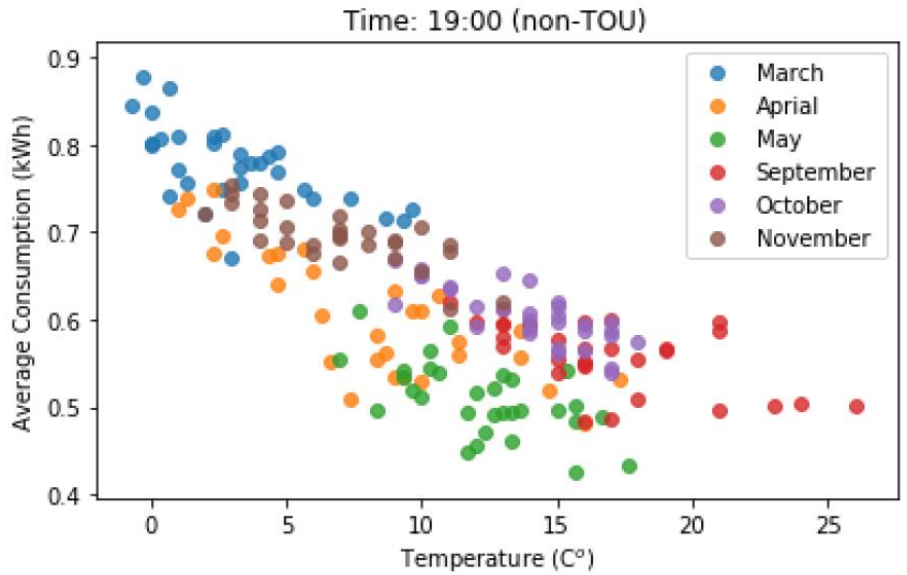
168 million measurements

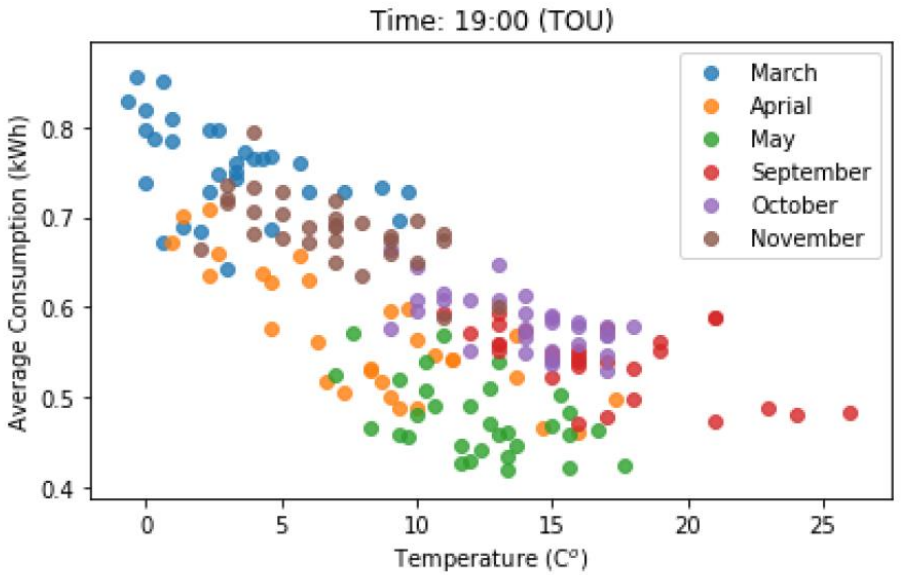
Time-of-Use vs Non-Time-of-Use: Temperature Effects





Time-of-Use vs Non-Time-of-Use: Seasonal Effects





In order to fully explore DR potential, aim to establish models of user behavior