Architecture and Algorithms for the LSE to Manage Thermal Inertial Loads

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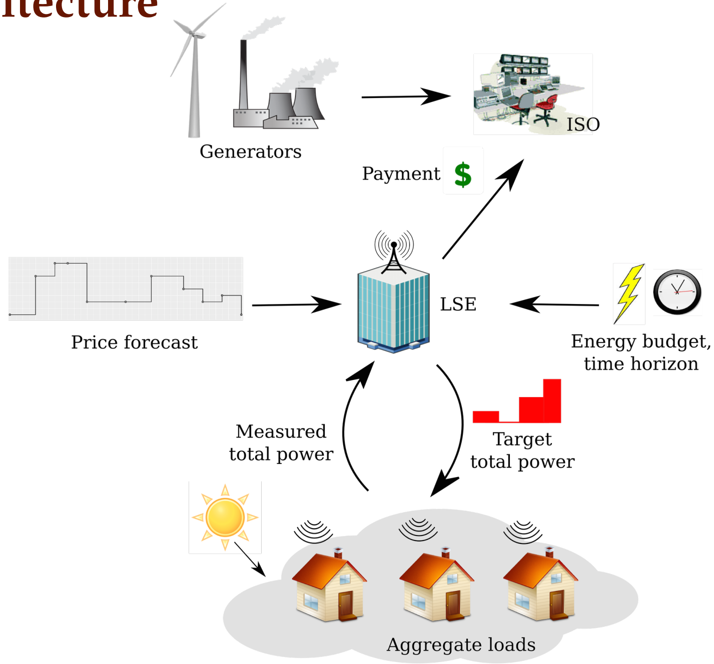
Joint work with X. Geng, F.A.C.C. Fontes, P.R. Kumar, and L. Xie

Controlling Air Conditioners

Direct Control for Demand Response

Architecture



Research Scope

Objective: A theory of operation for the LSE

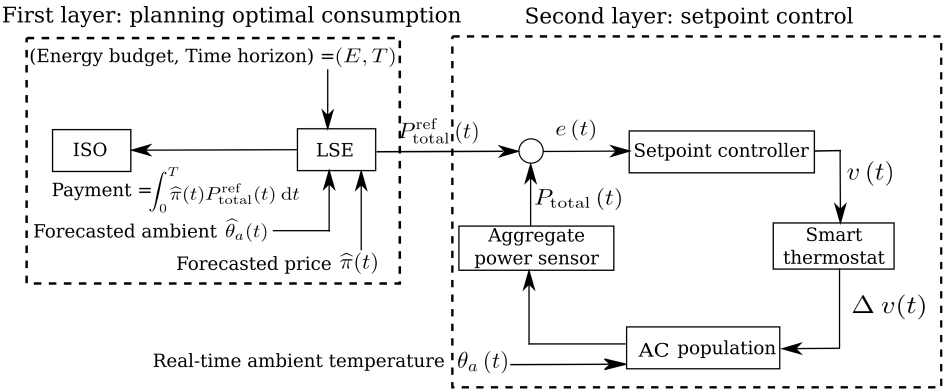
Challenges:

1. How to design the **target consumption as a function of price**?

2. How to control so as to preserve **privacy** of the loads' states?

3. How to respect loads' **contractual obligations** (e.g. comfort range width Δ)?

Two Layer Block Diagram



First Layer: Planning Optimal Consumption

price forecast

$$\underset{\{u_1(t),\ldots,u_N(t)\}\in\{0,1\}^N}{\text{minimize}} \quad \int_0^T \frac{P}{\eta} \; \boxed{\widehat{\pi}(t)} \; \left(u_1(t)+u_2(t)+\ldots+u_N(t)\right)\,\mathrm{d}t$$

subject to

$$(1) \quad \dot{\theta}_i = -\alpha_i\left(\theta_i(t)-\widehat{\theta}_a(t)\right)-\beta_i P u_i(t) \qquad \forall\, i=1,\ldots,N,$$

$$(2) \quad \int_0^T \left(u_1(t)+u_2(t)+\ldots+u_N(t)\right)\,\mathrm{d}t = \tau \doteq \frac{\eta E}{NP}(< T, \text{given})$$

$$(3) \quad L_{i0} \le \theta_i(t) \le U_{i0} \qquad \forall\, i=1,\ldots,N.$$

Optimal consumption: $P^*_{\mathrm{ref}}(t) = \dfrac{P}{\eta}\displaystyle\sum_{i=1}^{N} u_i^*(t)$

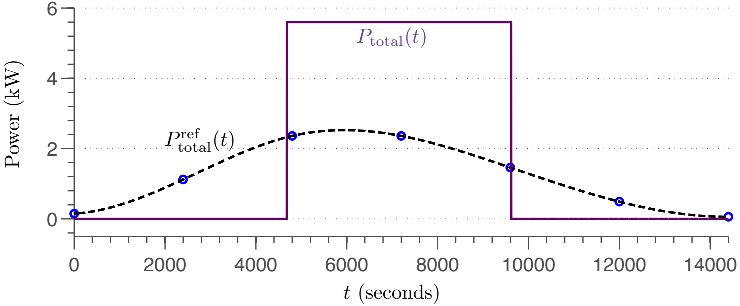
Second Layer: Real-time Setpoint Control

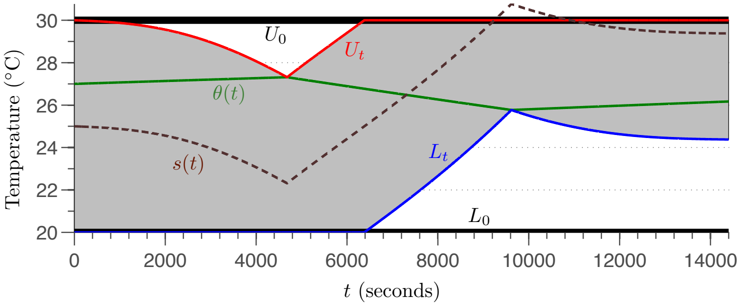
$$\overset{\text{optimal reference}}{\boxed{P^*_{\text{ref}}(t)}} = \frac{P}{\eta}\sum_{i=1}^{N} u_i^*(t), \rightsquigarrow \quad \overset{\text{error}}{\boxed{e(t)}} \quad = P^*_{\text{ref}}(t) - \overset{\text{measured}}{\boxed{P_{\text{total}}(t)}},$$

$$v(t) = \overset{\text{PID velocity control}}{\boxed{k_p e(t) + k_i \int_0^t e(\varsigma)\mathrm{d}\varsigma + k_i \frac{\mathrm{d}}{\mathrm{d}t} e(t)}}, \frac{\mathrm{d}s_i}{\mathrm{d}t} = \quad \overset{\text{gain}}{\boxed{\Delta_i}} \quad \overset{\text{broadcast}}{\boxed{v(t)}} \quad ,$$

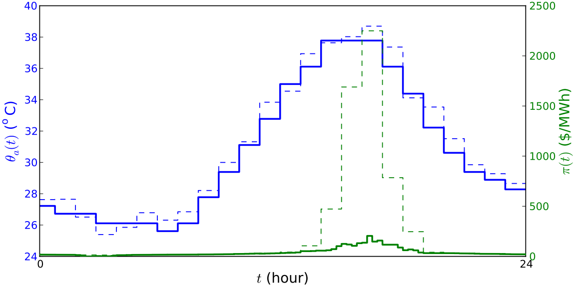
$$L_{it} = U_{i0} \wedge \left[L_{i0} \vee (s_i(t) - \Delta_i)\right], U_{it} = L_{i0} \vee \left[U_{i0} \wedge (s_i(t) + \Delta_i)\right].$$

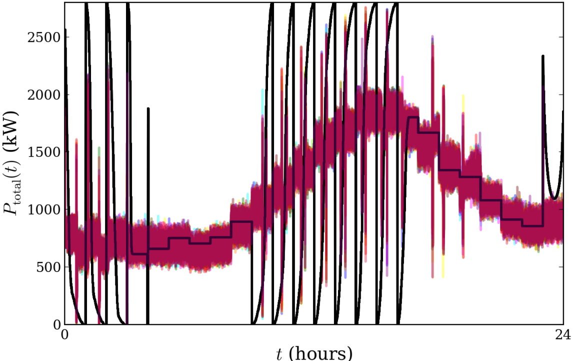
Boundary Control: Deadband → Liveband



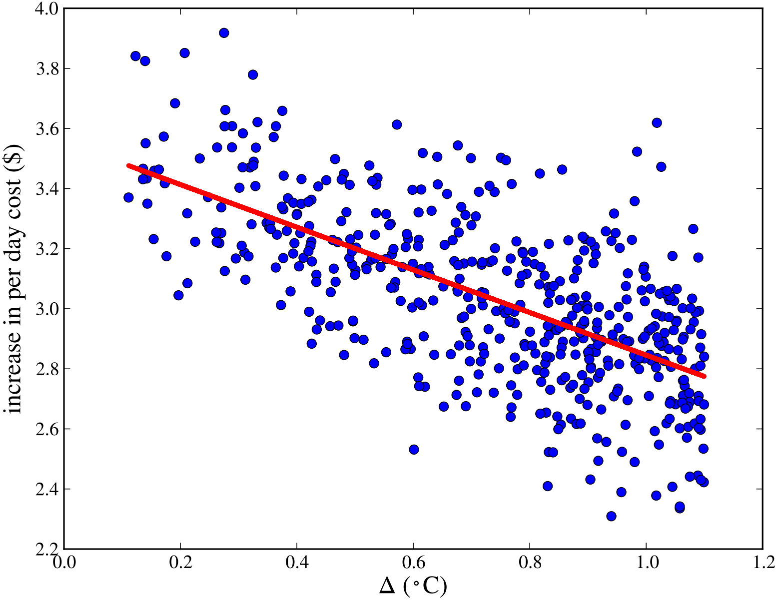


Simulation: 500 homes + ERCOT DA price





How Can the LSE Price A Contract



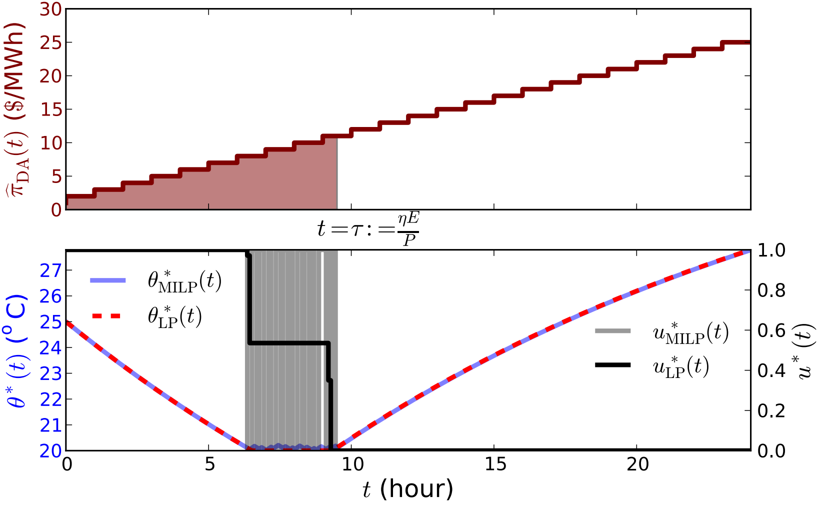
Details in

1. **A. Halder**, X. Geng, G. Sharma, L. Xie, and P.R. Kumar, "A Control System Framework for Privacy Preserving Demand Response of Thermal Inertial Loads", *SmartGridComm*, 2015.
2. **A. Halder**, X. Geng, P.R. Kumar, and L. Xie, "Architecture and Algorithms for Privacy Preserving Thermal Inertial Load Management by A Load Serving Entity", *in revision, IEEE Trans. Power Systems*, 2016.
3. **A. Halder**, X. Geng, F.A.C.C. Fontes, P.R. Kumar, and L. Xie, "Optimal Power Consumption for Demand Response of Thermostatically Controlled Loads", *under review, ACC*, 2017.
4. **A. Halder**, X. Geng, F.A.C.C. Fontes, P.R. Kumar, and L. Xie, "Deterministic and Stochastic Optimal Control of Thermal Inertial Loads", *working manuscript, available upon request*.

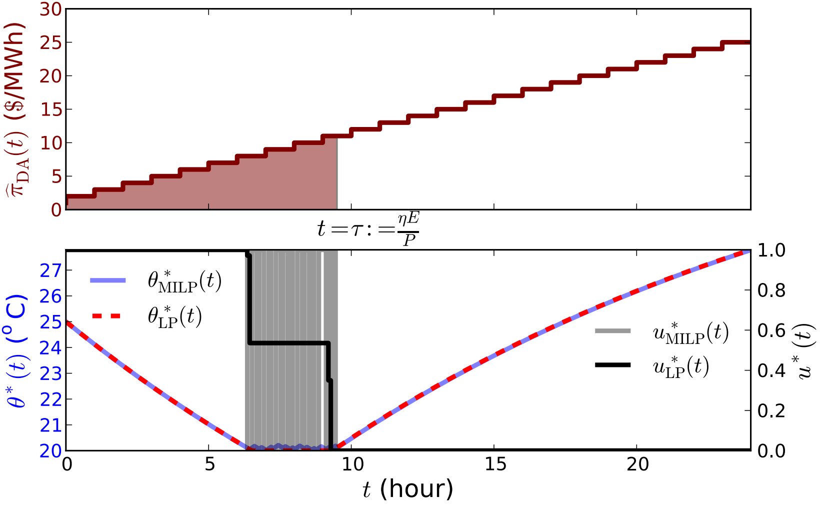
Thank You

Backup Slides

First Layer: "discretize-then-optimize"



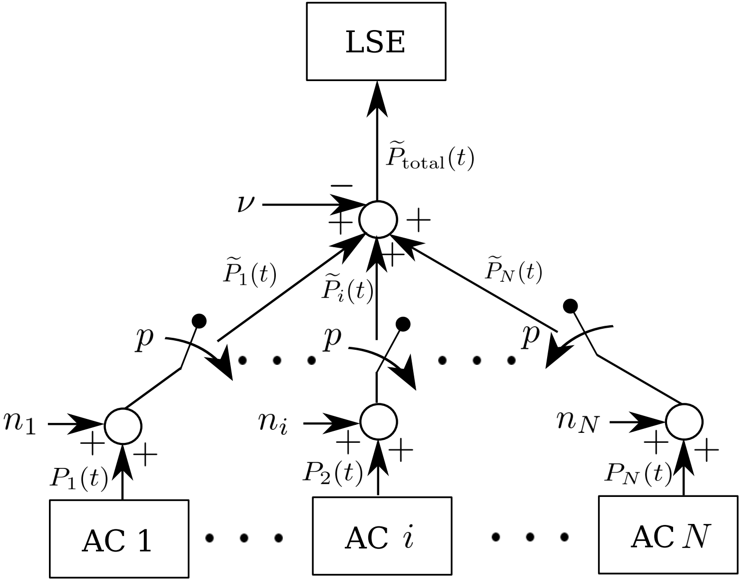
First Layer: "discretize-then-optimize"



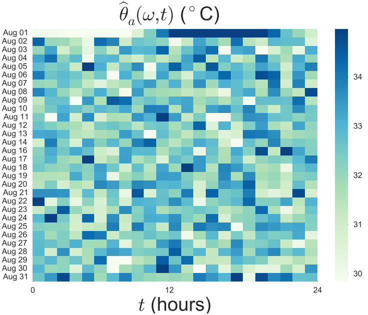
Numerical challenges for MILP and LP

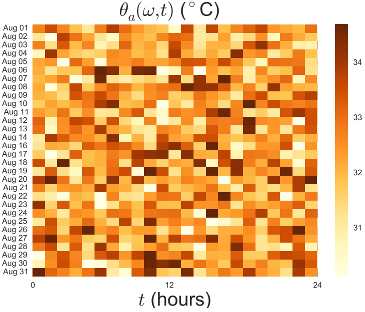
Solution: continuous time $\rightsquigarrow$ PMP w. state inequality constraints

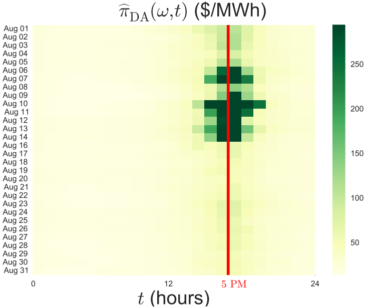
Differential Privacy Preserving Sensing

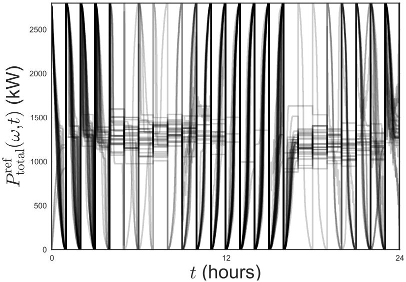


Houston Data for August 2015









Limits of Control Performance