A Multiagent System Approach to Scheduling Devices in Smart Homes

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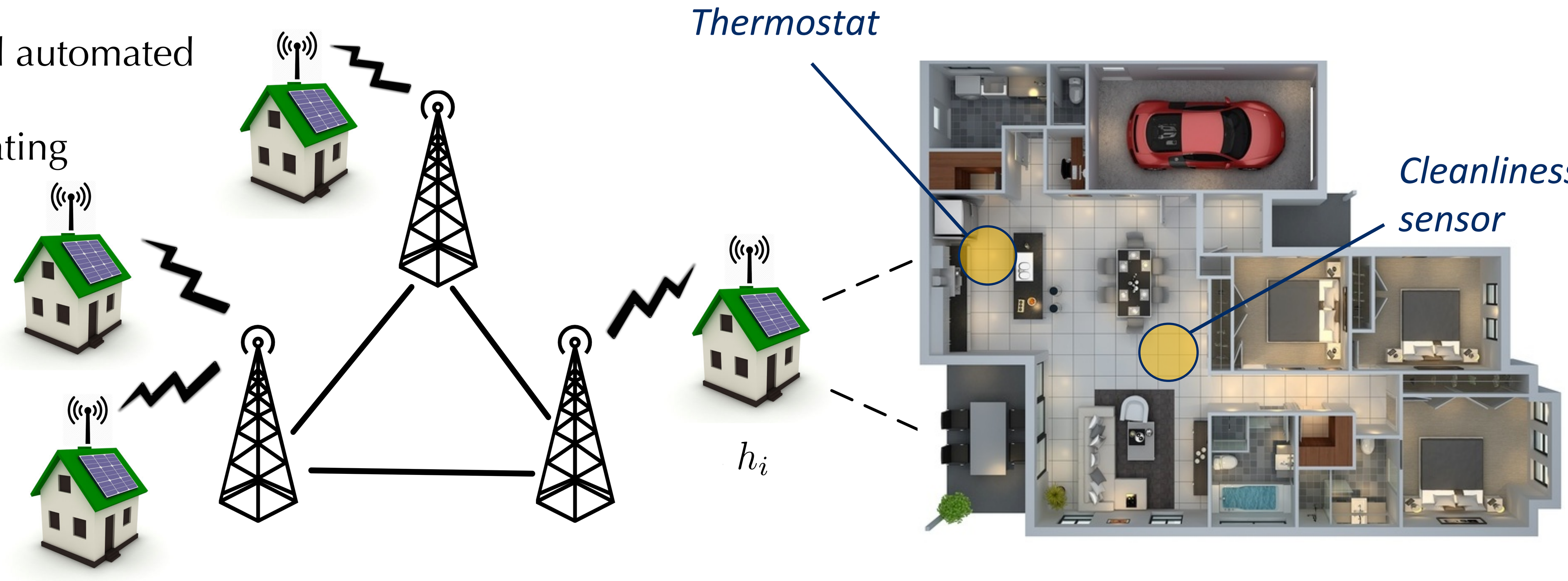
Home Automation in the Smart Grid (why?)

- Smart grid goals: Energy peak reduction and automated energy production and consumption
- Due to availability of smart devices, automating smart homes can play a key role in reducing energy peak reduction

Challenges:

- User autonomy: decisions are made in a distributed environment
- Uncoordinated scheduling may be detrimental to the grid stability
- Data privacy concerns



Smart Homes

- A set of smart devices Z_i it can control (e.g., HVAC, robotic vacuum cleaner)
- A set of locations L_i (e.g., living room, kitchen)
- A set of state properties $\mathbf{P_H}$ (e.g., cleanliness, temperature)

Actuators

- Location: where the device acts
- Actions: what it can perform
- Power Consumption: associated to each action
- The state properties it affects

Sensors

- Sense the effects of the actuators' actions in the environment
- Predictive model: associated to each sensor
- It describes the transition of a state property during time

Action	State property	Power (kW/h)
run	cleanliness	0.0
charge	battery charge	0.26
stop		0.0

	Cleanliness		Battery charge	
Vacuum cleaner	Current State	Next State	Current State	Next State
run	30 %	45 %	55 %	30 %
charge	30 %	30 %	55 %	75 %
stop	30 %	30 %	55 %	55 %

Scheduling Rules

$\langle location\rangle \langle state\ property\rangle \langle relation\rangle \langle state\rangle \langle time\rangle$

- Active Rules: user defined objectives on a desired state of the home

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living_room cleanliness ≥ 75 before 1800
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- Passive Rules: implicit constraints on devices

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z battery_charge ≥ 0 always
z battery_charge ≤ 0 always
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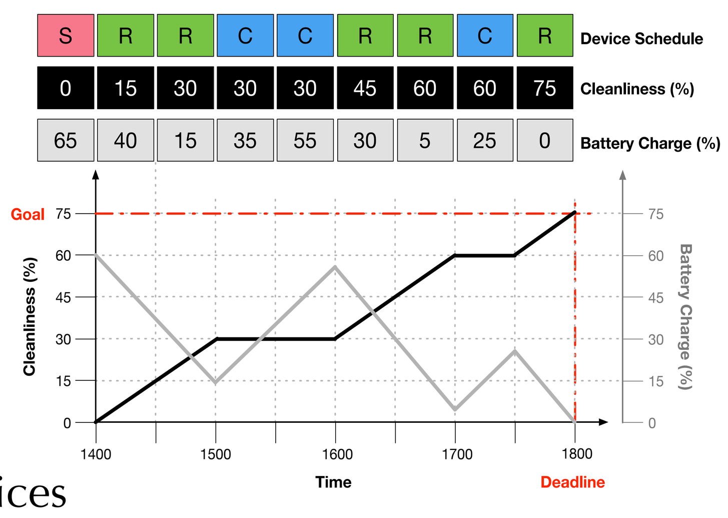


Schedule: sequence of actions for the home devices

SHDS Problem

Objective: Find the homes device schedules which minimize:

- Aggregated monetary cost of the homes schedules
- Energy consumption peaks across all homes

$$\min_{\xi_{\mathbf{Z}_i}^{[1\to H]}} \alpha_c \cdot C^{\text{sum}} + \alpha_e \cdot E^{\text{peak}}$$

Homes' device schedules

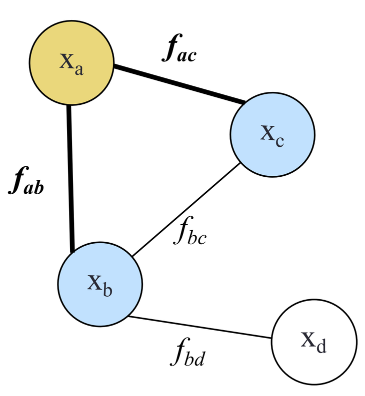
$$C^{\text{sum}} = \sum_{h_i \in \mathbf{H}} c_i(\xi_{\mathbf{Z}_i}^{[1\to H]}) \qquad E^{\text{peak}} = \sum_{t\in \mathbf{T}} \sum_{\mathbf{H}_j \in \mathcal{H}} \sum_{h_i \in \mathbf{H}_j} (E_i^t(\xi_{\mathbf{Z}_i}^{[1\to H]}))^2$$

Subject to:

- All scheduling rules are satisfied: $\forall h_i \in \mathbf{H}, R_p^{[t_a \to t_b]} \in \mathbf{R}_i : \quad \xi_{\Phi_p}^{[t_a \to t_b]} \models R_p^{[t_a \to t_b]}$

Distributed Constraint Optimization

- ***X:*** Set of variables
- ***D:*** Set of finite domains for each variable
- ***F:*** Set of weighted constraints between variables
- ***A:*** Set of agents, controlling the variables in ***X***



- GOAL: Find a cost minimal assignment

$$\mathbf{x}^* = \arg\min_{\mathbf{x}} \sum_{f\in\mathbf{F}} f(\mathbf{x}|_{\text{scope}(f)})$$

DCOP mapping

SHDS	DCOP
Home $h_i \in \mathbf{H}$	Agent $a_i \in \mathbf{A}$
Device z_j (in building h_i)	Variable $x_i \in \mathbf{X}$ (controlled by a_i)
Action k for device z_j	k-th value in domain D_i of variable x_i
Schedule cost for a device z_j	Local soft constraint
Device scheduling feasibility	Local hard constraint
Energy peak consumption	Global soft constraint

Solution Approach

SH-MGM At each iteration agents:

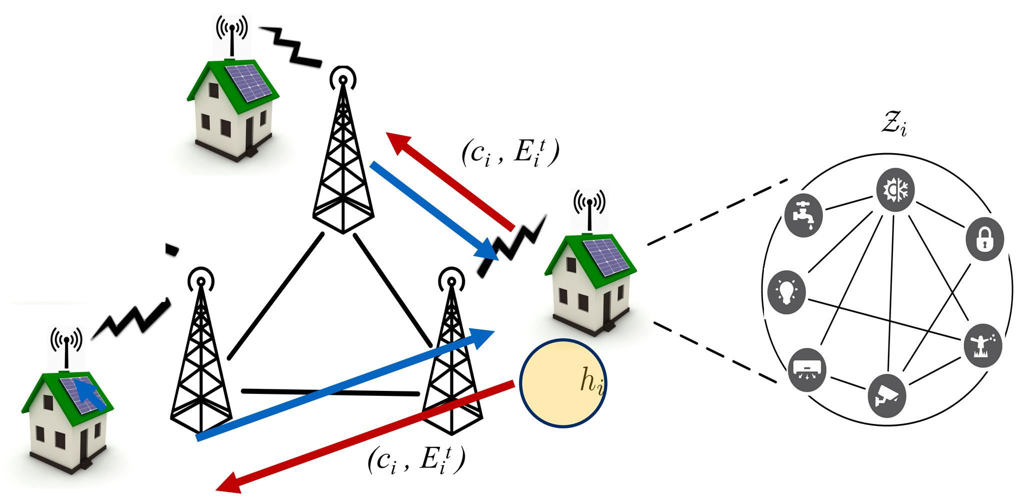
1. Independently search for a feasible schedule for their local devices
2. Exchange their schedules cost (c_i) and energy consumption (E_i^t) with neighbors
3. Within a time limit, generate new schedules taking into account neighbors' energy consumption and satisfying:

$$\alpha_c \cdot c_i(\hat{\xi}_{\mathbf{Z}_i}^{[1\to H]}) + \alpha_e \cdot \hat{E}_i^{\text{peak}} \le \alpha_c \cdot c_i(\xi_{\mathbf{Z}_i}^{[1\to H]}) + \alpha_e \cdot E_i^{\text{peak}}$$

4. Exchange gains:

$$G_i = \left(\alpha_c \cdot c_i(\xi_{\mathbf{Z}_i}^{[1\to H]}) + \alpha_e \cdot E^{\text{peak}}\right) - \left(\alpha_c \cdot c_i(\hat{\xi}_{\mathbf{Z}_i}^{[1\to H]}) + \alpha_e \cdot \hat{E}^{\text{peak}}\right)$$

5. Updates their schedule if they have the largest gain among all neighbors.



Experiments

Settings:

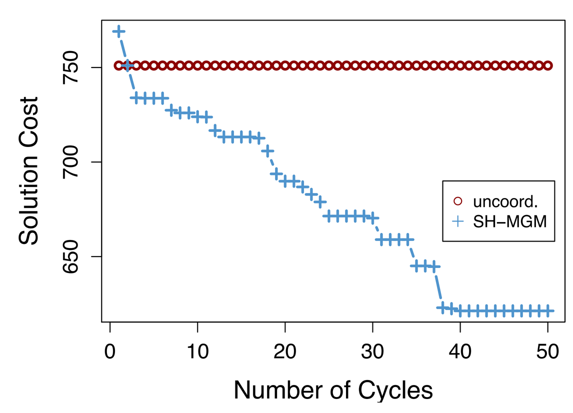
- 7 Raspberry Pis connected via LAN
- Each controlling 9 smart actuators
- JADE: communication and coordination of the MAS
- JaCoP: CP solver internal to each agent (scheduling)
- H = 12 (step – 30 min); CP timeout = 10 sec

A Raspberry PI with a dangle

Smart Devices

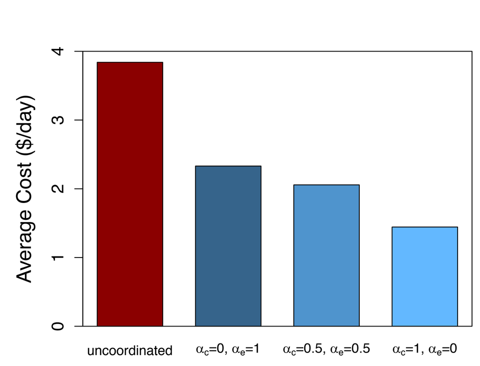
Main Results:

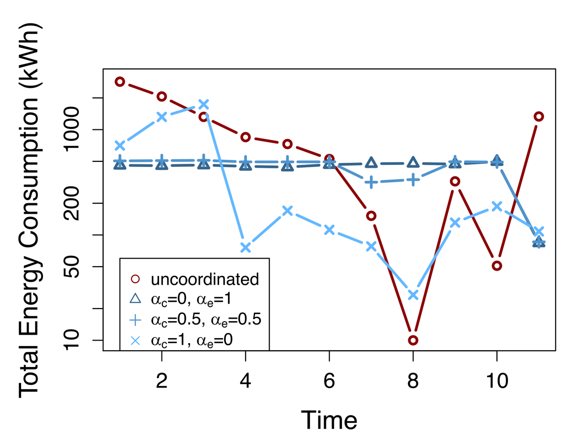
- SH-MGM finds better solution than simple uncoordinated approach
- Solution quality increases with no. iterations
- Energy peak reduction and reduced average spending



Synthetic Benchmarks

- 3 US Cities with density (no. houses per km^2): 718 (DM), 1357 (Bo), and 3766 (SF).
- k = number of coalitions





City	k	convergence time (sec)	avg. l.s. time (sec)	network load	avg. cost ($/day)	max peak (kWh)
Des Moines	-	7.8	0.72	0	3.84	2852
	1	1044	9.62	9.8e+5	2.18	508
	5	304	9.44	4.8e+4	1.89	579
	10	218	9.37	1.2e+4	1.71	607
Boston	-	13.9	1.59	0	3.79	6034
	1	2821	9.91	1.2e+7	2.22	985
	5	866	9.91	6.7e+5	2.05	1058
	10	527	9.89	1.8e+5	1.88	1111
San Francisco	-	26.6	4.51	0	3.81	11944
	1	4238	10.4	1.7e+8	2.36	1870
	5	940	10.4	1.6e+6	2.06	2120
	10	679	10.7	1.1e+6	2.01	2310

The extended SHDS dataset is available for download!