A Multiagent System Approach to Schedule Devices in Smart Homes

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Home Automation

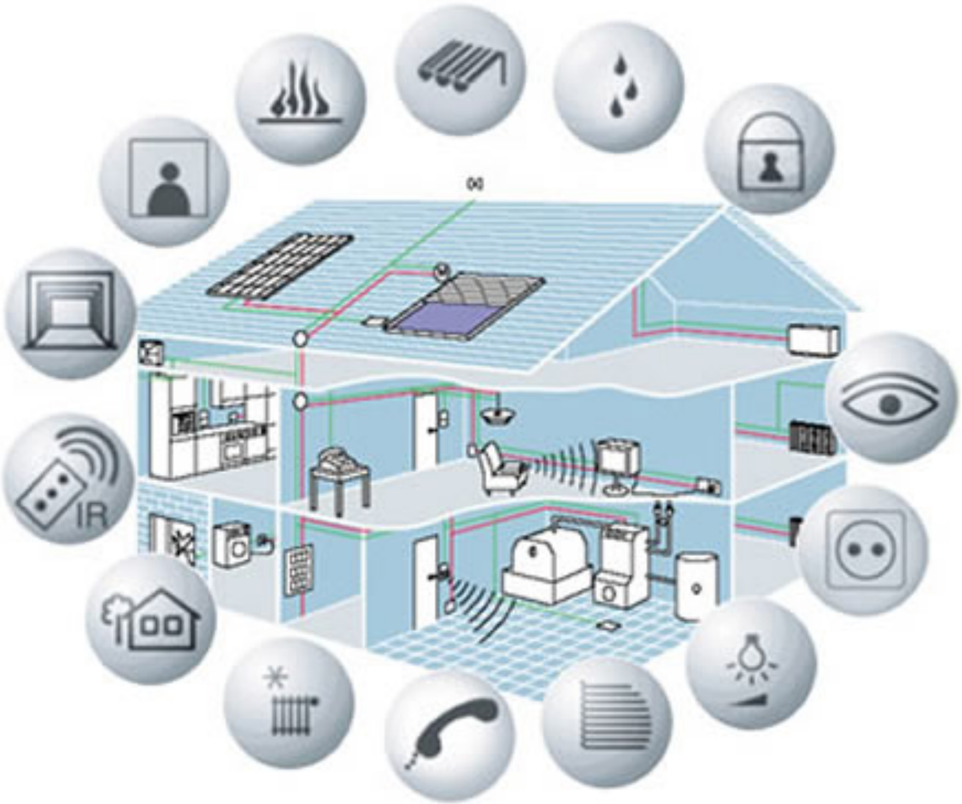


Fig.1

Fig.2

Network of smart homes

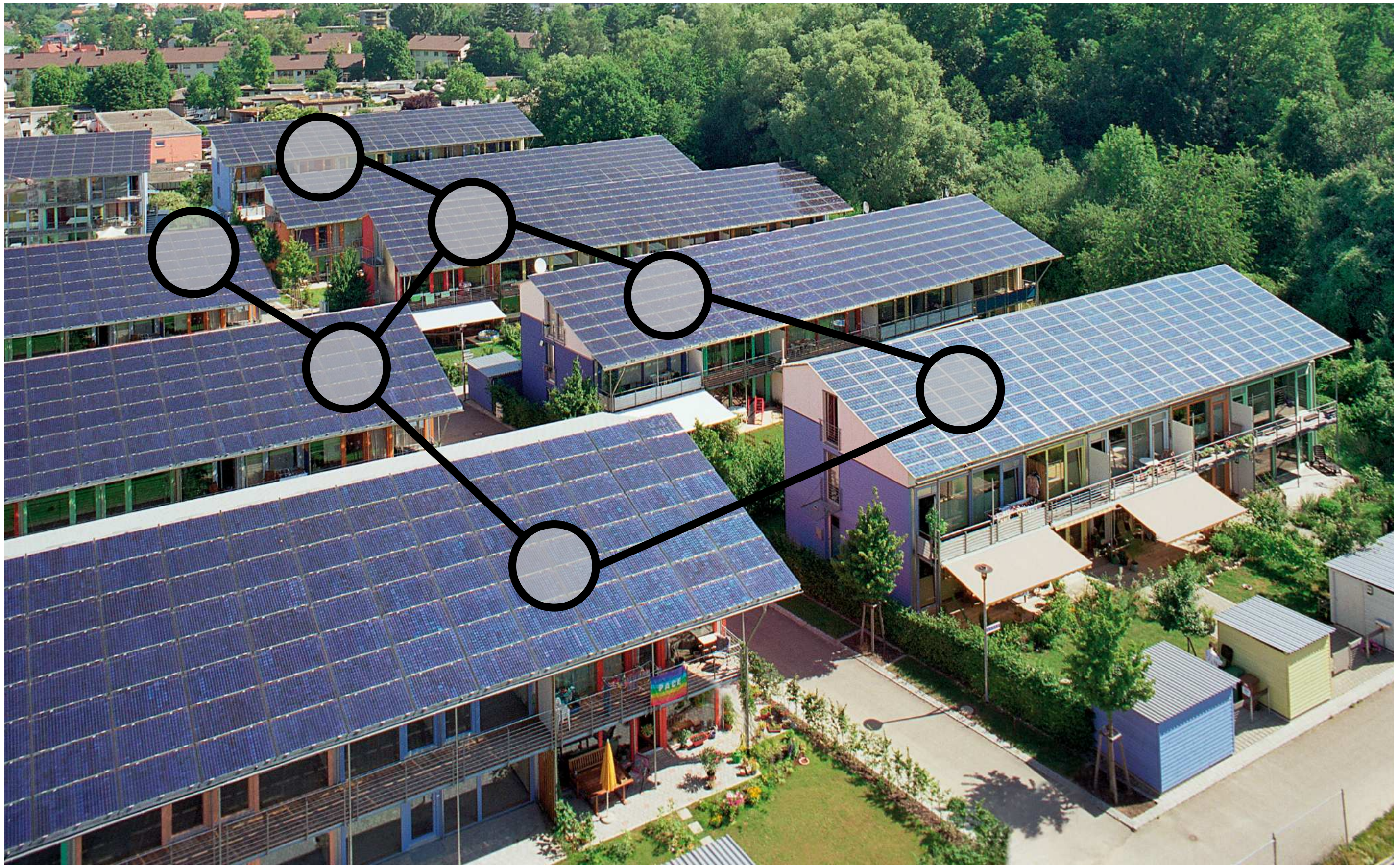


Fig.3

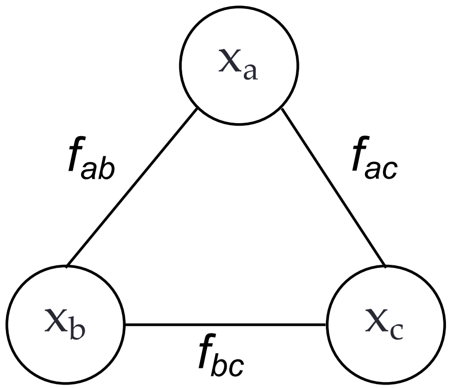
Outline

- Background (DCOPs)
- Smart Homes Device Scheduling (SHDS)
- Results
- Conclusions and Future work

Distributed Constraint Optimization

$<\mathcal{X}, \mathcal{D}, \mathcal{F}, \mathcal{A}, \alpha>$:

- $\mathcal{X}$: Set of variables.
- $\mathcal{D}$: Set of finite domains for each variable.
- $\mathcal{F}$: Set of constraints between variables.
- $\mathcal{A}$: Set of agents, controlling the variables in $\mathcal{X}$.
- α: Mapping of variables to agents.



Constraint graph

x_a	x_b	cost
0	0	3
0	1	∞
1	0	2
1	1	5

Constraint (cost table)

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- GOAL: Find a cost minimal assignment.

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

DCOP: Assumptions

- Agents coordinate an assignment for their variables.
- Agents operate distributedly.

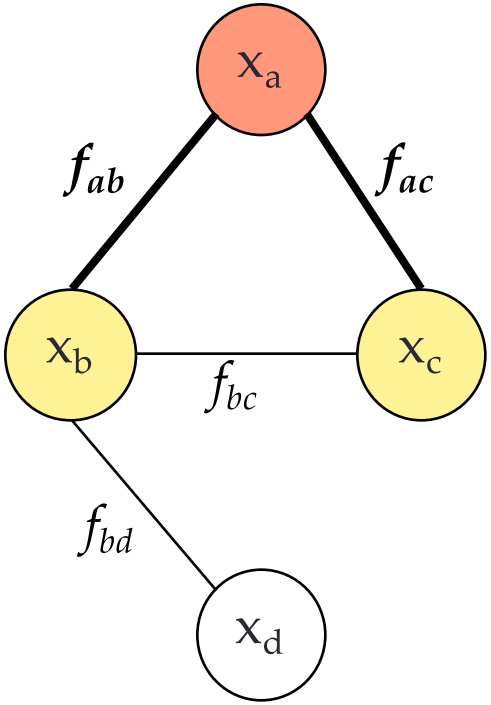
Communication:

- By exchanging messages.
- Restricted to agent's local neighbors.

Knowledge:

- Restricted to agent's sub-problem.

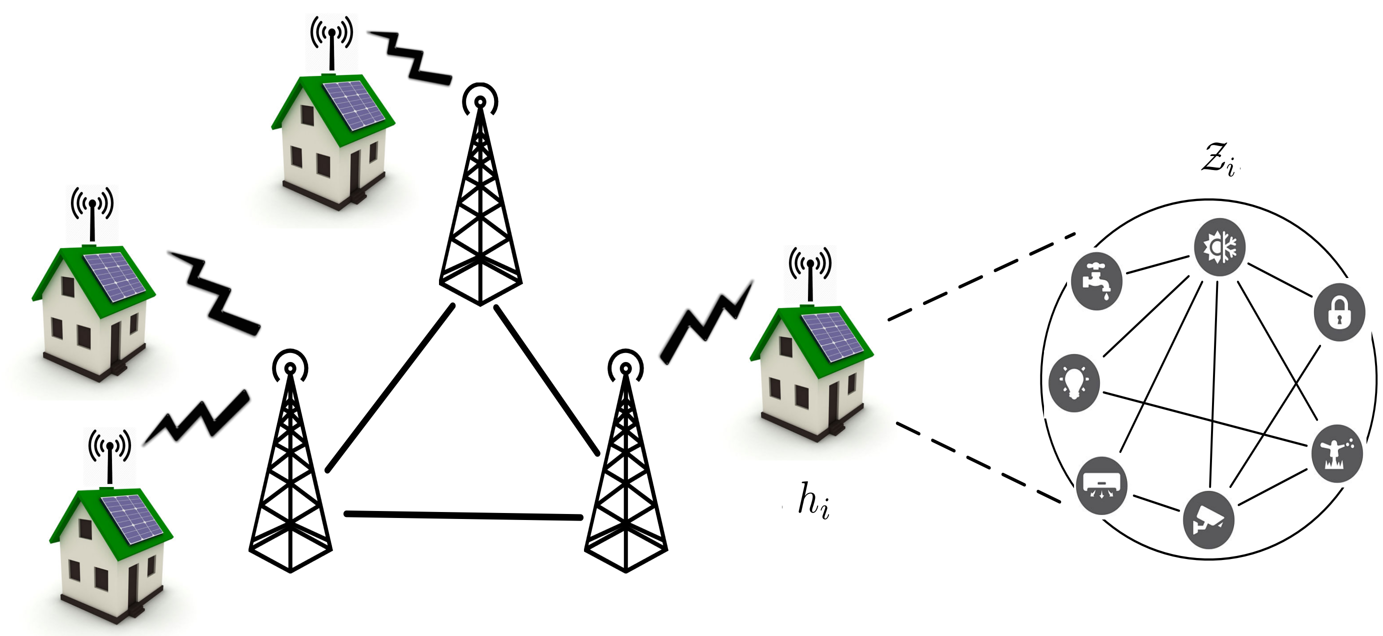
- Privacy preserving.



Smart Home Device Scheduling (SHDS)

A **SHDS** problem is composed of:

- $\mathcal{H}$: A neighborhood of smart homes.
- $\mathcal{Z}_i$: A set of smart electric devices within each home h_i.
- H: A time horizon for the device scheduling.



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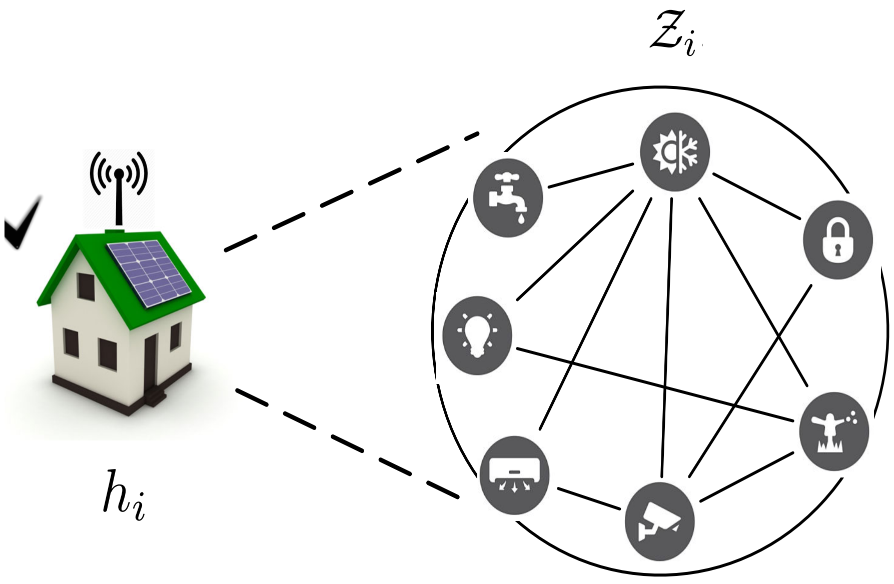
- H: A time horizon for the device scheduling.
- θ : A pricing function expressing cost per kWh of energy consumed.

Time (min.)	[0-60]	[60-120]	[120-180]	[180-240]	[240-300]	[300-360]
RTP ($/kWh)	0.172	0.161	0.191	0.145	0.149	0.174

Smart Home

A smart home h_i has:

- A set of smart devices Z_i it can control.



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- L_i A set of locations (e.g., living room, kitchen)
- $\mathbf{P_H}$ A set of state properties (e.g., cleanliness, temperature)

Smart Devices (Actuators)

A smart device is defined with a

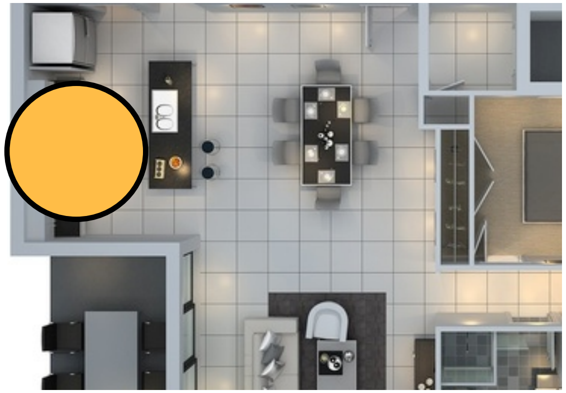
- Location, defining the place where the device can act (e.g., living room)
- The possible actions it can perform (clean, charge, stop) and the power consumption associated to them
- The set of state properties it affects (e.g., cleanliness, battery_charge)

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

Smart Devices (Sensors)

- We associate a *predictive model* to each home sensor.
- It describes the transition of a state property from a state s and time t to time t+1, when affected by a set of actuators.

Thermostat



Heater	Oven	Current State	Next State
off	off	12 C	11 C
off	bake	12 C	13.8 C
on	off	12 C	17.5 C
on	bake	12 C	19.3 C

Effect of the environment

Smart Device Schedules

Scheduling Rules

- Simple syntax to express scheduling rules:

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

- **Active rules**: specify user-defined objectives on a desired state of the home. E.g.,

$$\texttt{living\_room cleanliness} \geq \texttt{75 before 1800}$$

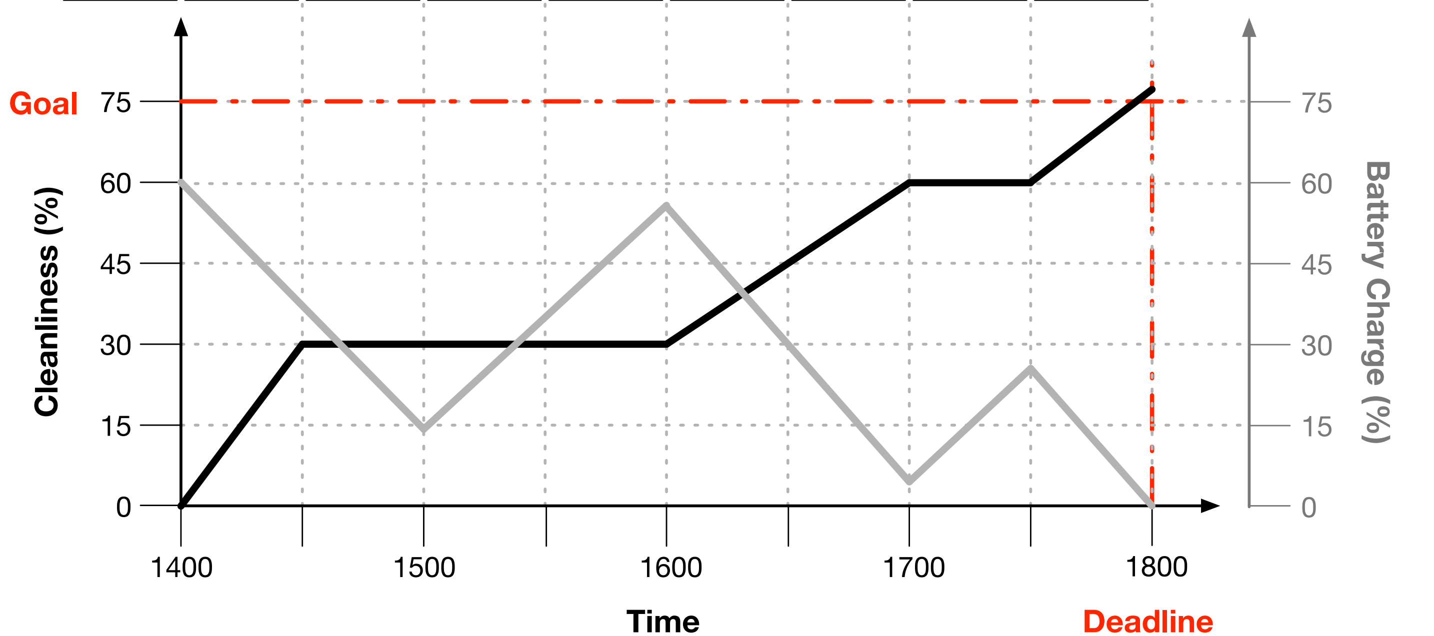
- **Passive rules**: define implicit constraints on devices. E.g.,

$$z_v \; \texttt{battery\_charge} \geq \texttt{0 always}$$
$$z_v \; \texttt{battery\_charge} \leq \texttt{100 always}$$

Smart Device Schedules

Schedule: A sequence of actions for the home devices.

S	R	R	C	C	R	R	C	R	**Device Schedule**
0	15	30	30	30	45	60	60	75	**Cleanliness (%)**
65	40	15	35	55	30	5	25	0	**Battery Charge (%)**



Smart Home Device Scheduling (SBDS)

- SHDS objective:

$$\min_{\xi_{\mathbf{z}_i}^{[0\to H]}} \quad \alpha_c \cdot \overbrace{C^{\text{sum}}}^{\text{Aggregated monetary cost of the homes schedules}} + \alpha_e \cdot \underbrace{E^{\text{diff}}}_{\text{Energy consumption peaks across all homes}}$$

Homes' devices schedules

subject to:

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

All scheduling rules must be satisfied

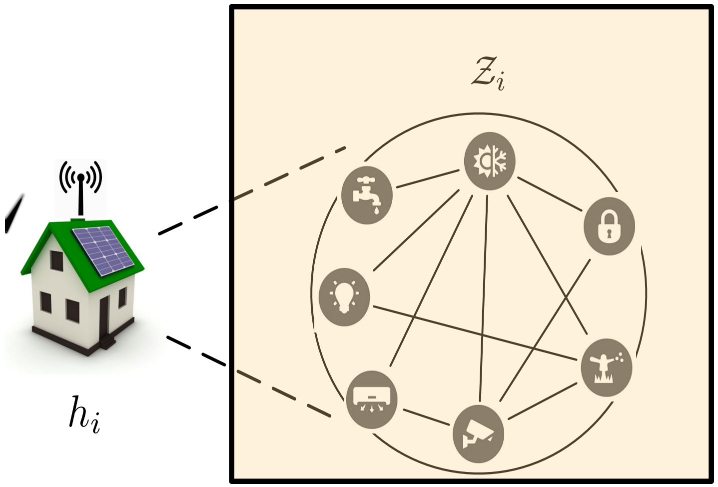
DCOP mapping

SBDS	DCOP
A home $h_i \in \mathcal{H}$.	Agent $a_i \in \mathcal{A}$
A device z_j (in building h_i)	Variable $x_i \in \mathcal{X}$ (controlled by a_i)
Action j for device z_j.	j-th value in domain D_i of variable x_i
Schedule costs for a device z_j	Local soft constraint
Device scheduling feasibility	Local hard constraint
Energy peak consumption	Global soft constraint

Solution Approach

SH-MGM: Adaptation of a local search DCOP algorithm (MGM).

1. Agents independently search for a feasible schedule for their local devices.

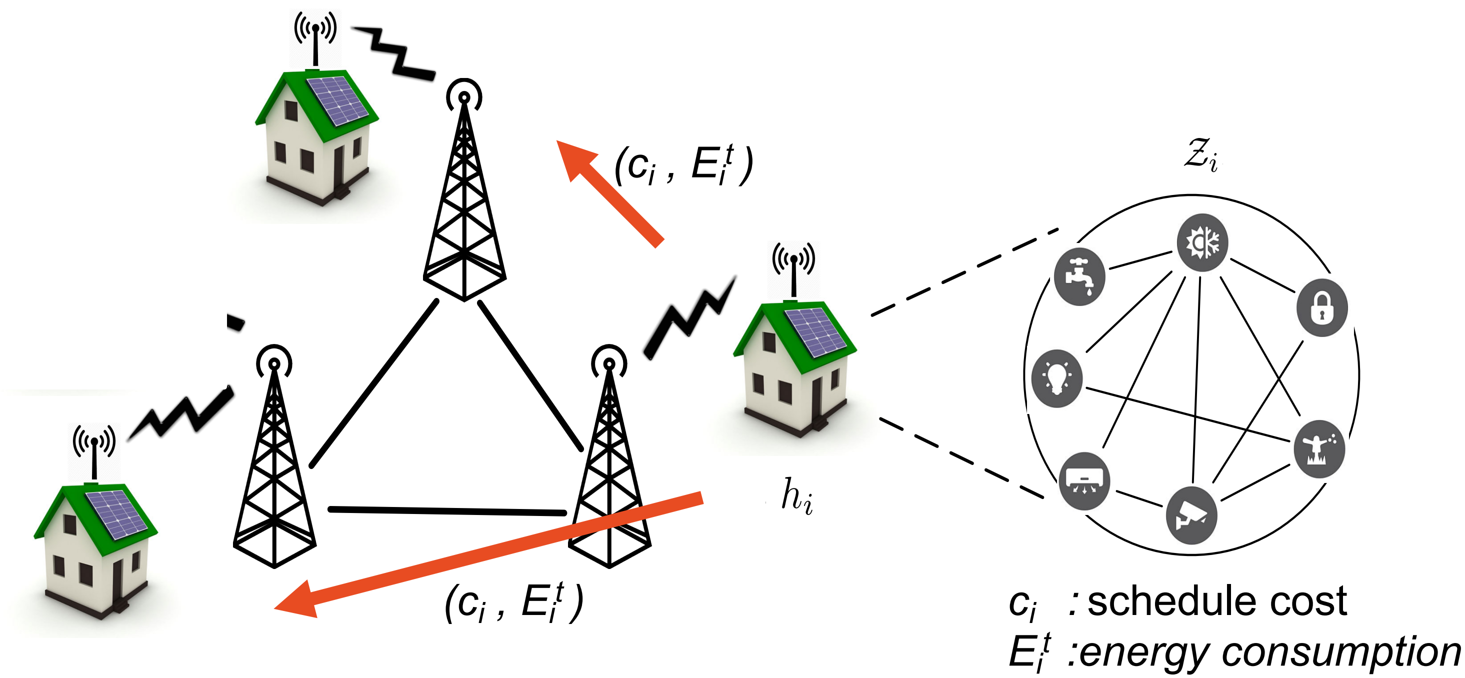


c_i : schedule cost
E_i^t :energy consumption

Solution Approach

SH-MGM: Adaptation of a local search DCOP algorithm (MGM).

1. Agents independently search for a feasible schedule for their local devices.
2. Schedule costs and energy consumption are broadcasted to all other agents.



Solution Approach

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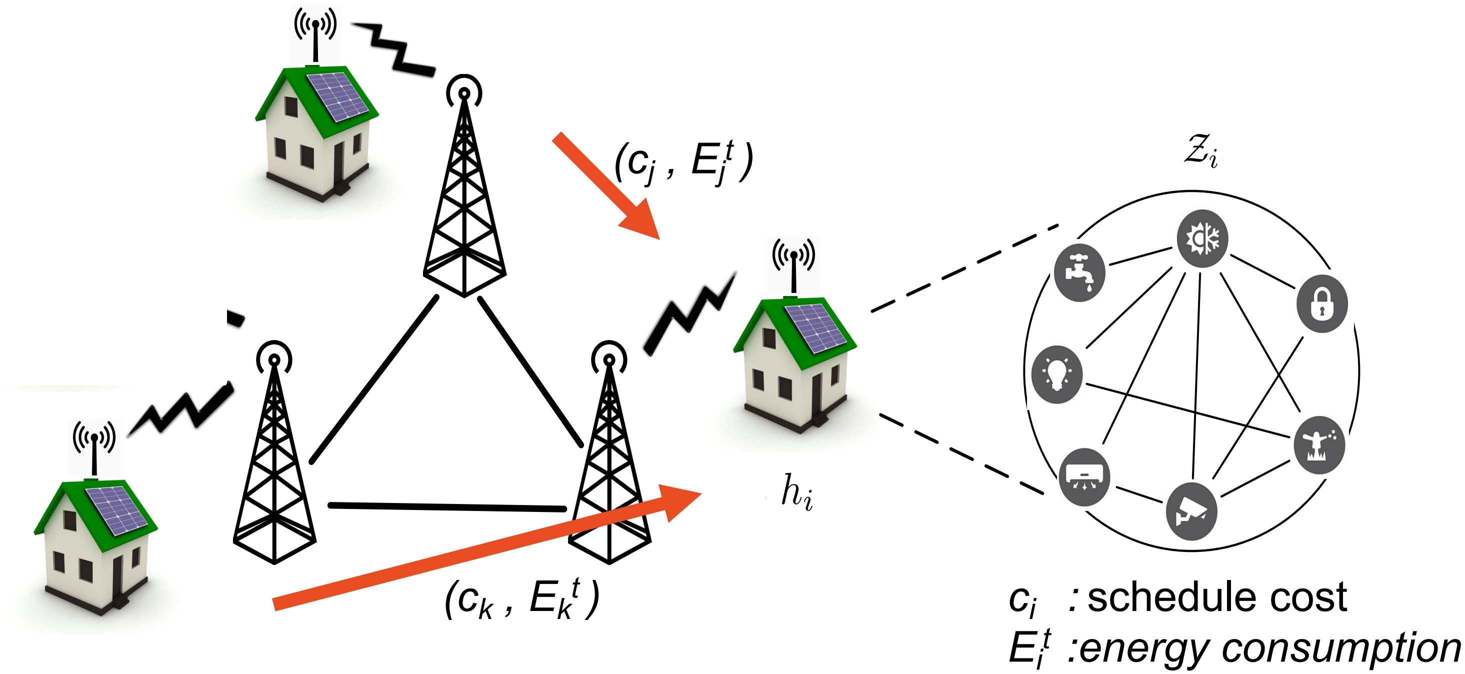
3. Upon receiving all other agents costs and energy consumptions:

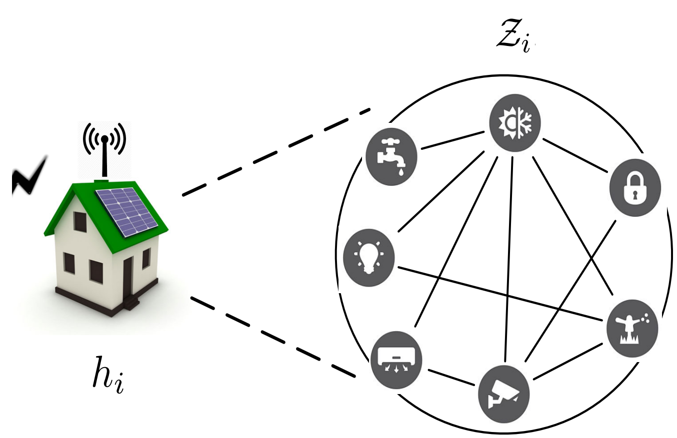


Solution Approach

SH-MGM: Adaptation of a local search DCOP algorithm (MGM).

3. Upon receiving all other agents costs and energy consumptions:
   - Computes the objective cost with its current schedule.

$$\alpha_c \cdot c_i(\underbrace{\xi_{\mathbf{Z}_i}^{[0\to H]}}_{\boxed{\text{current schedule}}}) + \alpha_e \cdot E^{\text{diff}}$$



c_i : schedule cost
E_i^t :*energy consumption*

Solution Approach

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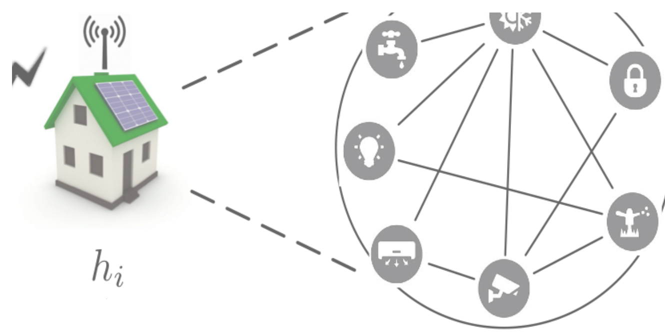
3. Upon receiving all other agents costs and energy consumptions:
   - Computes the objective cost with its current schedule.
   - Within a time limit, it finds a new solution to its local subproblem that is no worse than the current solution.

$$\alpha_c \cdot c_i(\underbrace{\hat{\xi}_{\mathbf{Z}_i}^{[0\to H]}}_{\text{current schedule}}) + \alpha_e \cdot \hat{E}^{\text{diff}} \leq \alpha_c \cdot c_i(\overbrace{\xi_{\mathbf{Z}_i}^{[0\to H]}}^{\text{new schedule}}) + \alpha_e \cdot E^{\text{diff}}$$



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Solution Approach

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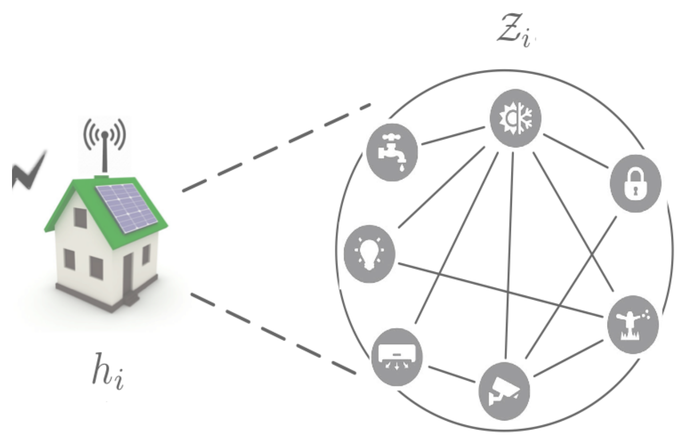
3. Upon receiving all other agents costs and energy consumptions:
   - Computes the objective cost with its current schedule.
   - Within a time limit, it finds a new solution to its local subproblem that is no worse than the current solution.
   - It computes the gain G_i between its current and new solutions, and broadcast it to all other agents.

$$G_i = \left(\alpha_c \cdot c_i(\xi_{\mathbf{Z}_i}^{[0\rightarrow H]}) + \alpha_e \cdot E^{\text{diff}}\right) - \left(\alpha_c \cdot c_i(\hat{\xi}_{\mathbf{Z}_i}^{[0\rightarrow H]}) + \alpha_e \cdot \hat{E}^{\text{diff}}\right)$$



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Solution Approach

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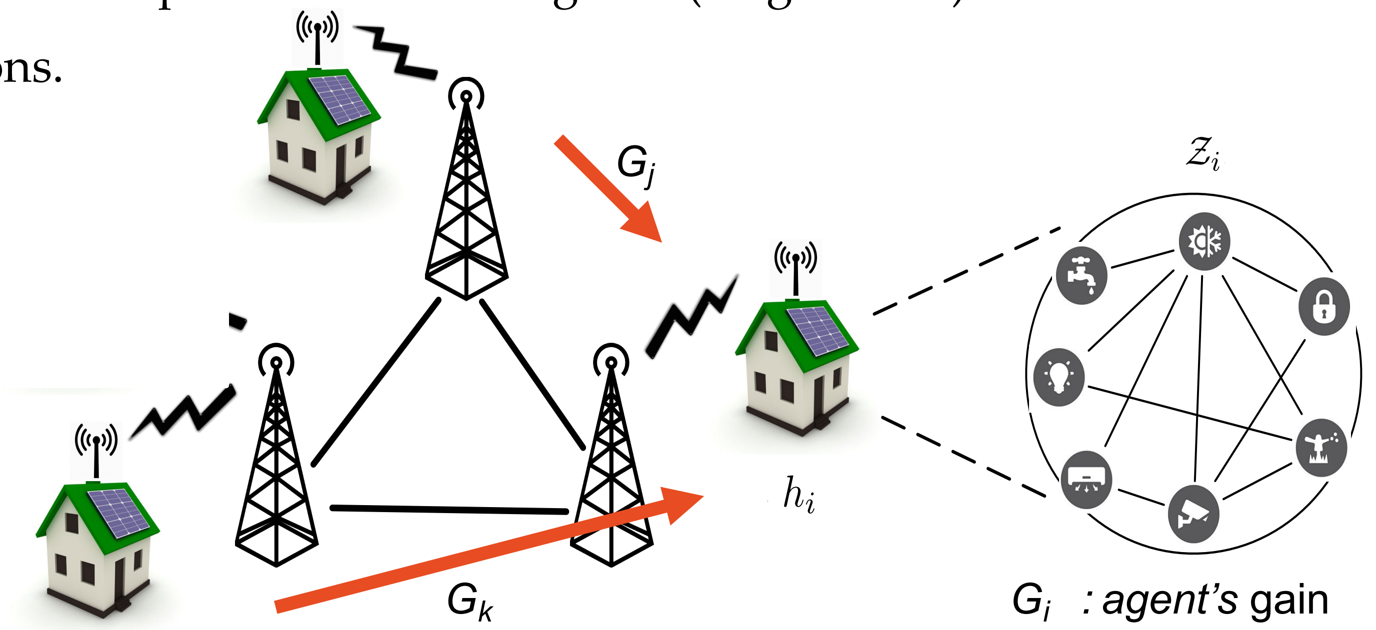
4. Upon receiving all other agents' gains G_k, it checks if the agent has the largest gain among all those received. If so, it updates its schedule to the new schedule, otherwise it retains its old schedule.
5. The process repeats untill convergence (all gains = 0) or a fixed number of iterations.



Evaluation: Settings

- 7 Raspberry Pis connected via a LAN.
- Each controlling 9 smart actuators.
- Communication and coordination of the MAS is implemented via the JADE framework.
- Each agent uses an internal CP solver (JaCoP) to solve its local scheduling problem.

Smart devices

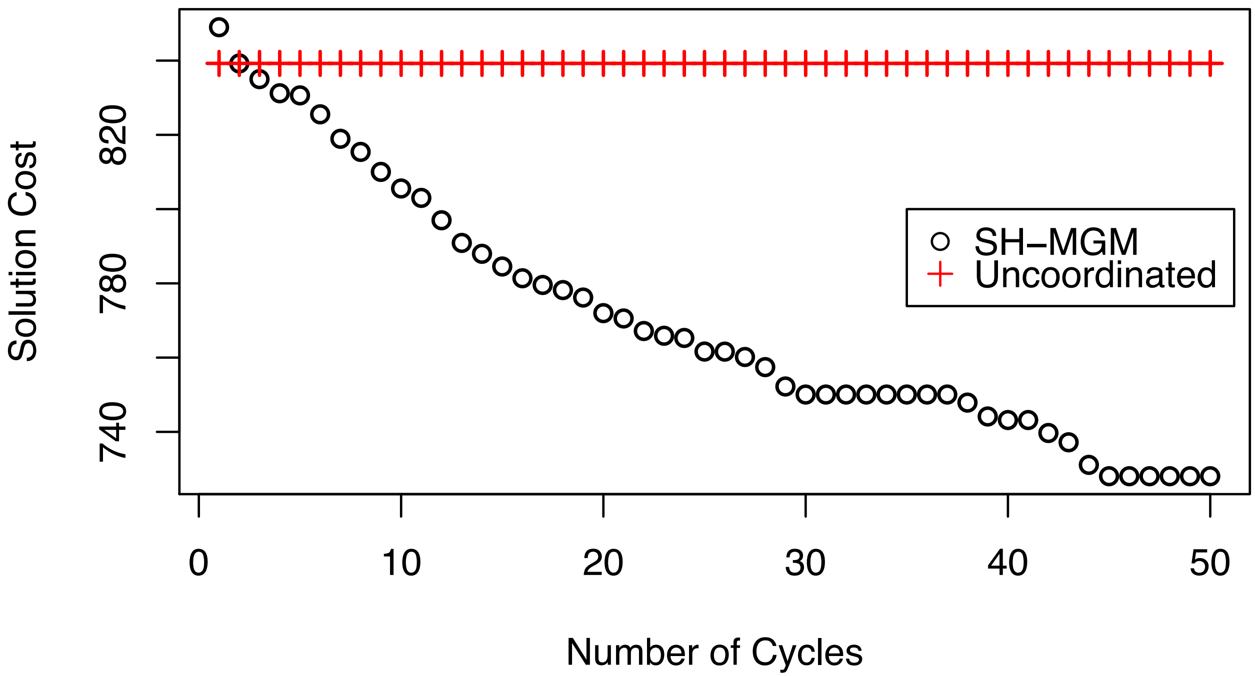
A Raspberry PI with a dangle

Evaluation

Settings:

- H = 12 (step = 30 min)
- Realistic device consumptions and environment settings
- CP timeout = 10 sec

SH-MGM vs. Uncoordinated approach.



Main Results:

- SH-MGM finds better solutions than a simple uncoordinated approach.

- Solution quality increases with the number of cycles.

Conclusions and Future Work

- We formalized the Smart Home Device Scheduling Problem and cast it as a DCOP.
- We propose SH-MGM, a local search-based algorithm to solve SHDS problems.
- Some results:
  - SH-MGM finds better solutions than a simple uncoordinated method.
  - Feasibility established for using a local search-based approach implemented on hardware with limited storage and processing power.
- Future work:
  - More realistic setting for the SHDS agents and devices.
  - Taking account user preferences for the scheduling rules.

Thank You!

References:

Fig. 1: http://goo.gl/5znqip
Fig. 2: goo.gl/dqwUz2
Fig. 3: goo.gl/WFzMhv