SEIDO

Advanced Demand Response Solutions Leveraging Heterogeneous IoT-enabled Loads

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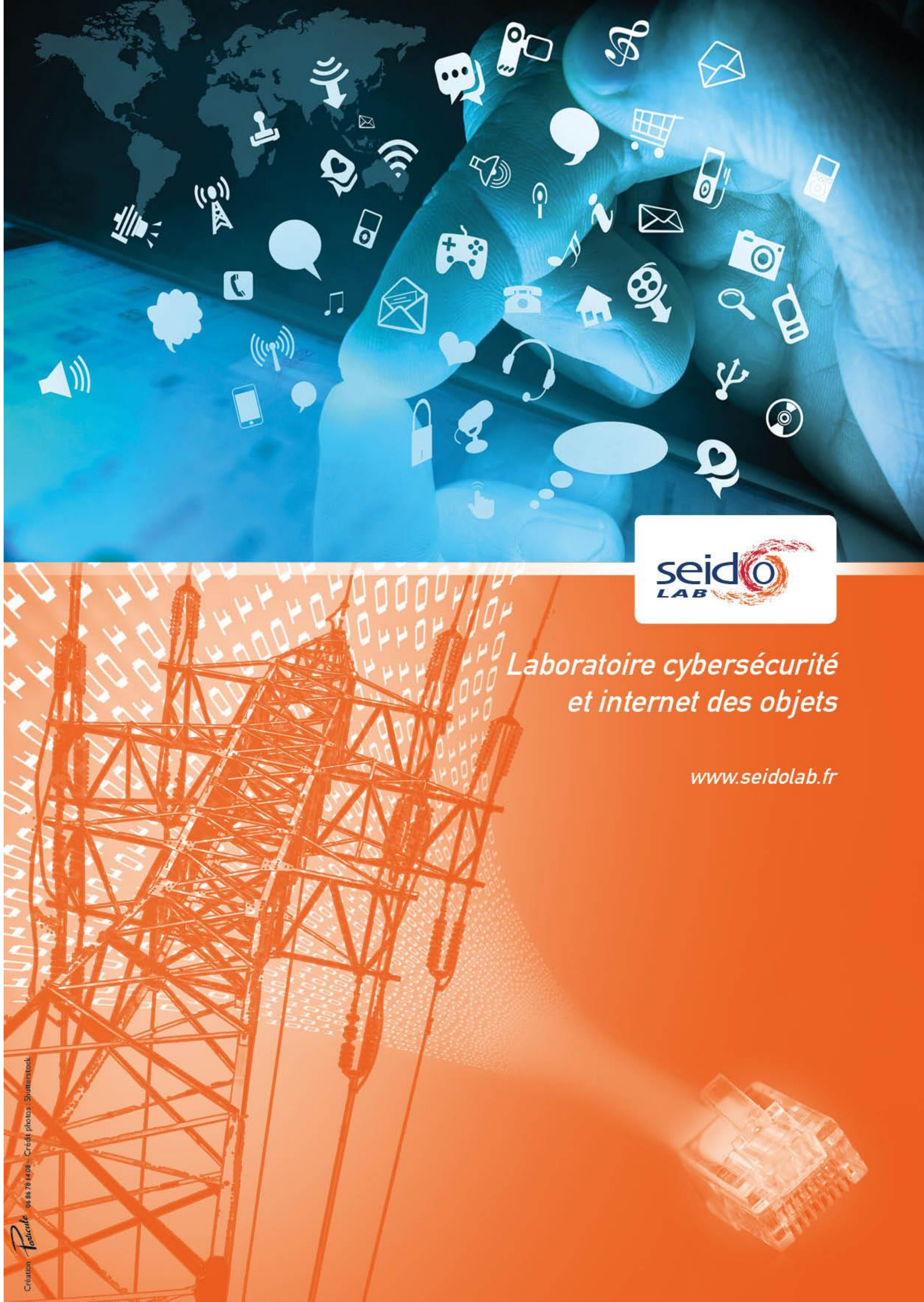


Thesis context

- Demand Response solutions for residential consumers
- Take avantage of IoT capabilities at homes
- Deal with situations of generation scarcity defined on:
  - A known control scope
  - For a known time period

Topics

- Appliances taxonomy
- Direct load control of heterogeneous collections of loads supposing solutions that are:
  - Centralized
  - Hierarchical
  - Distributed
- Time scale of control
  - Ahead of time
  - Real-time

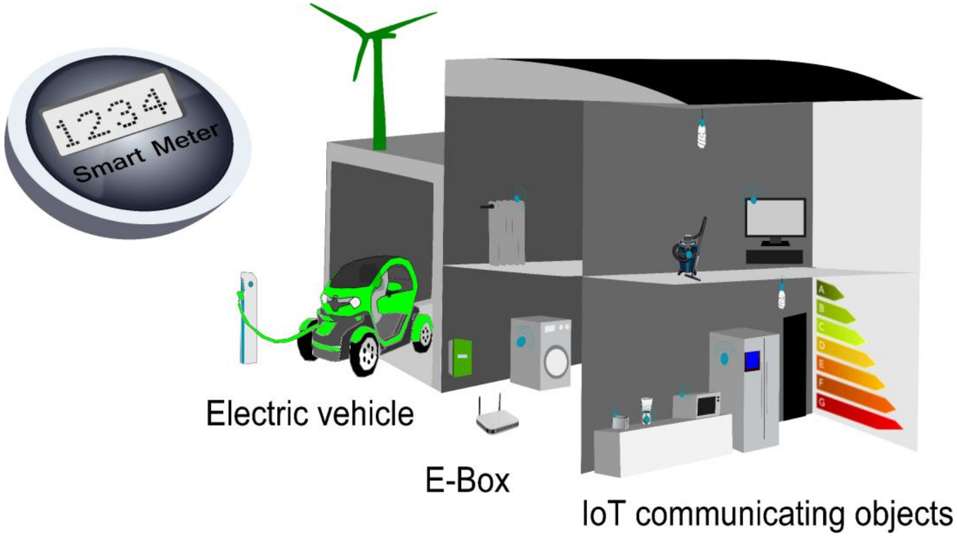
Outline

- Context
- Model
  - Architectural framework
  - Appliances' taxonomy
- Proposed control schemes
  - Fine-grained Centralized solutions
  - Partially distributed solutions
  - Distributed solutions
- Numerical results
- Conclusion

New trends

Less controllable generation

New opportunities on demand side



New services

- Need for new service models
  - **Enhance system reliability** and **reduce system costs**
  - **Control demand** while benefiting consumers

- Demand response (DR)
  - Change end user consumption in response to power grid side signals

Two types of DR

- Pricing-based DR
  - Induce user’s behavior
  - Dynamic energy prices
  - No strict guaranties on the outcome

- Direct load control
  - Control signals (e.g., ON-OFF) and/or Power profiles are sent
  - Tight control
  - Previous efforts mostly focus on homogeneous loads

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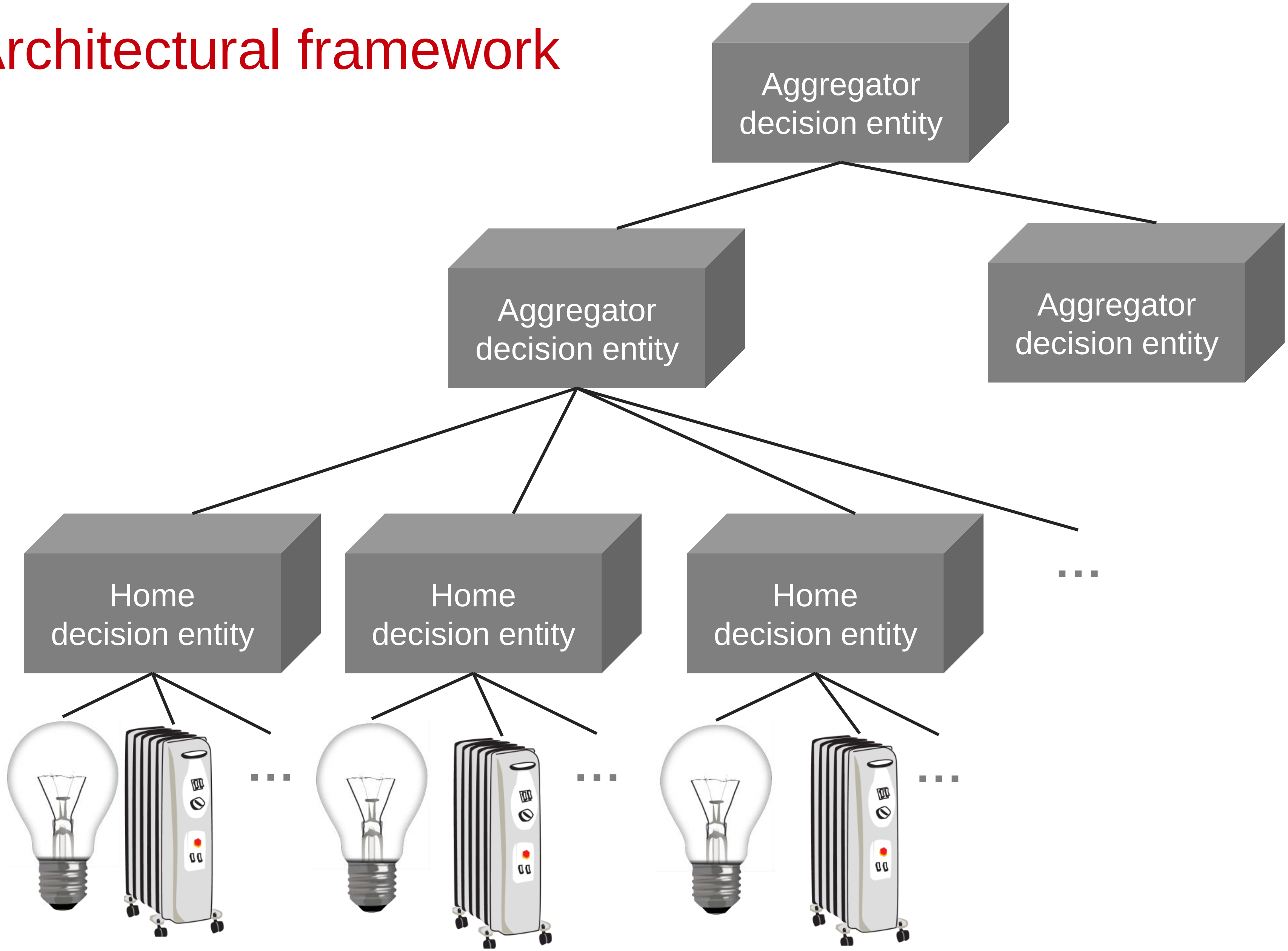
Our goal: Generalize to heterogeneous collections of loads

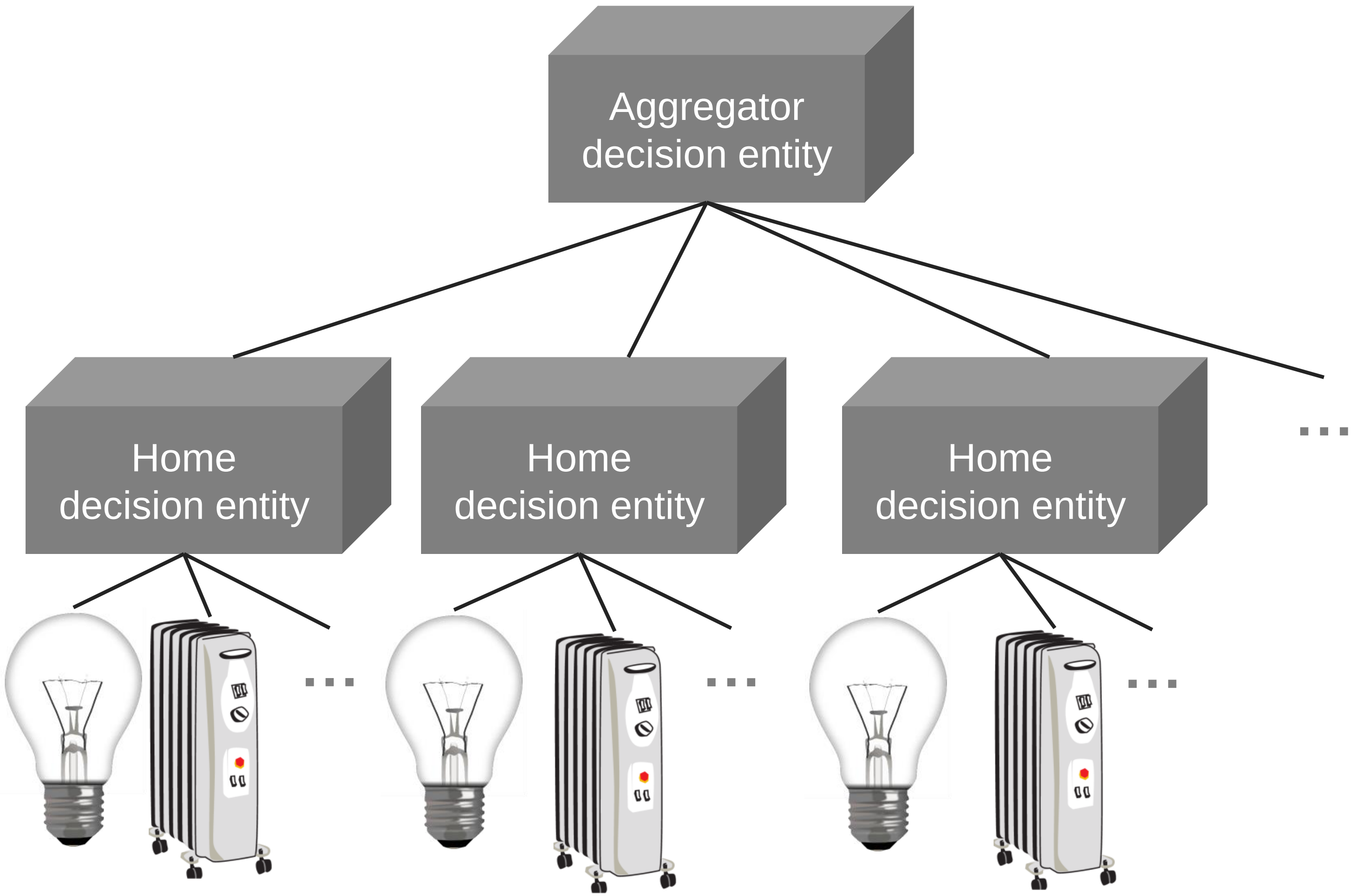
Problem statement

- We are interested in defining architectural frameworks and related **control algorithms** in view of **energy efficiency** and **users' satisfaction** under
  - constraints of scalability
  - users' data dissemination scope (e.g., privacy, anonymity)

Architectural framework



Architectural framework



Control goal

- Lower consumption below a **desired capacity limit** over a **known limited duration of time**.
  - Applications in:
    - Capacity market
    - Crisis management
    - …

Appliances taxonomy

Appliances are characterized by:

- Usage
  - Interactive demands
  - Background loads
  - Program-based loads
- Criticality and preferences
- Electrical characteristics → Operation constraints

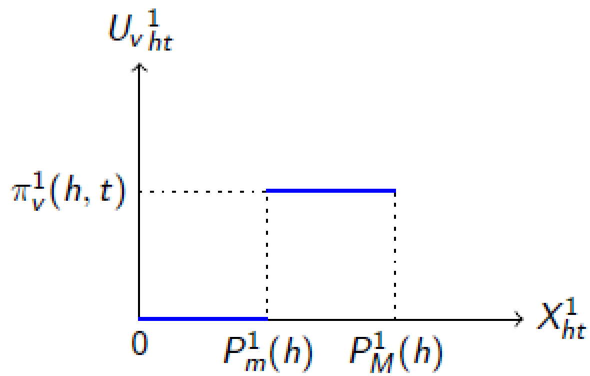
Utility functions

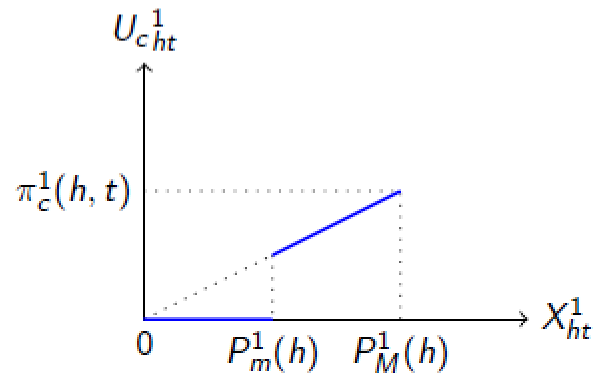
Utility functions based on taxonomy

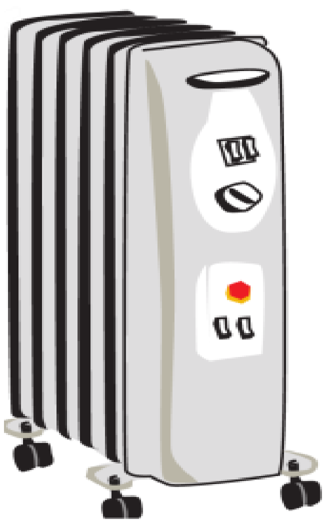
Dealing with fairness:

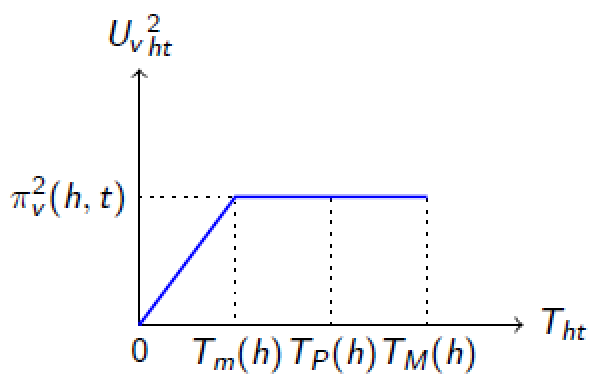
- The utility of an appliance a in home h at time t is represented with a tuple of values $U_{ht}^{a} = (U_{l_1}{}_{ht}^{a}, \ldots, U_{l_n}{}_{ht}^{a})$
  - Two levels:
    - $U_{v}{}_{ht}^{a}$ expresses vital utility
    - $U_{c}{}_{ht}^{a}$ expresses comfort utility
- Policies should enforce fulfillment of all needs at a level before any enhancement of utility at lower levels.

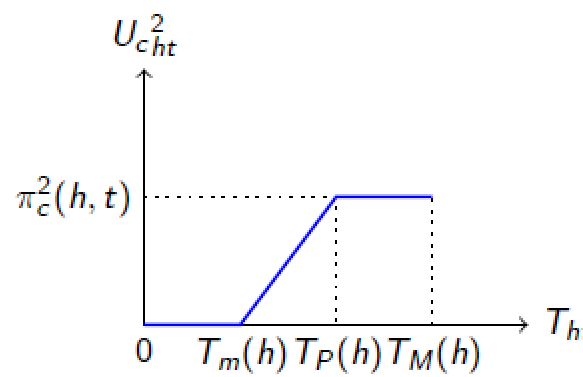
Examples of utility functions



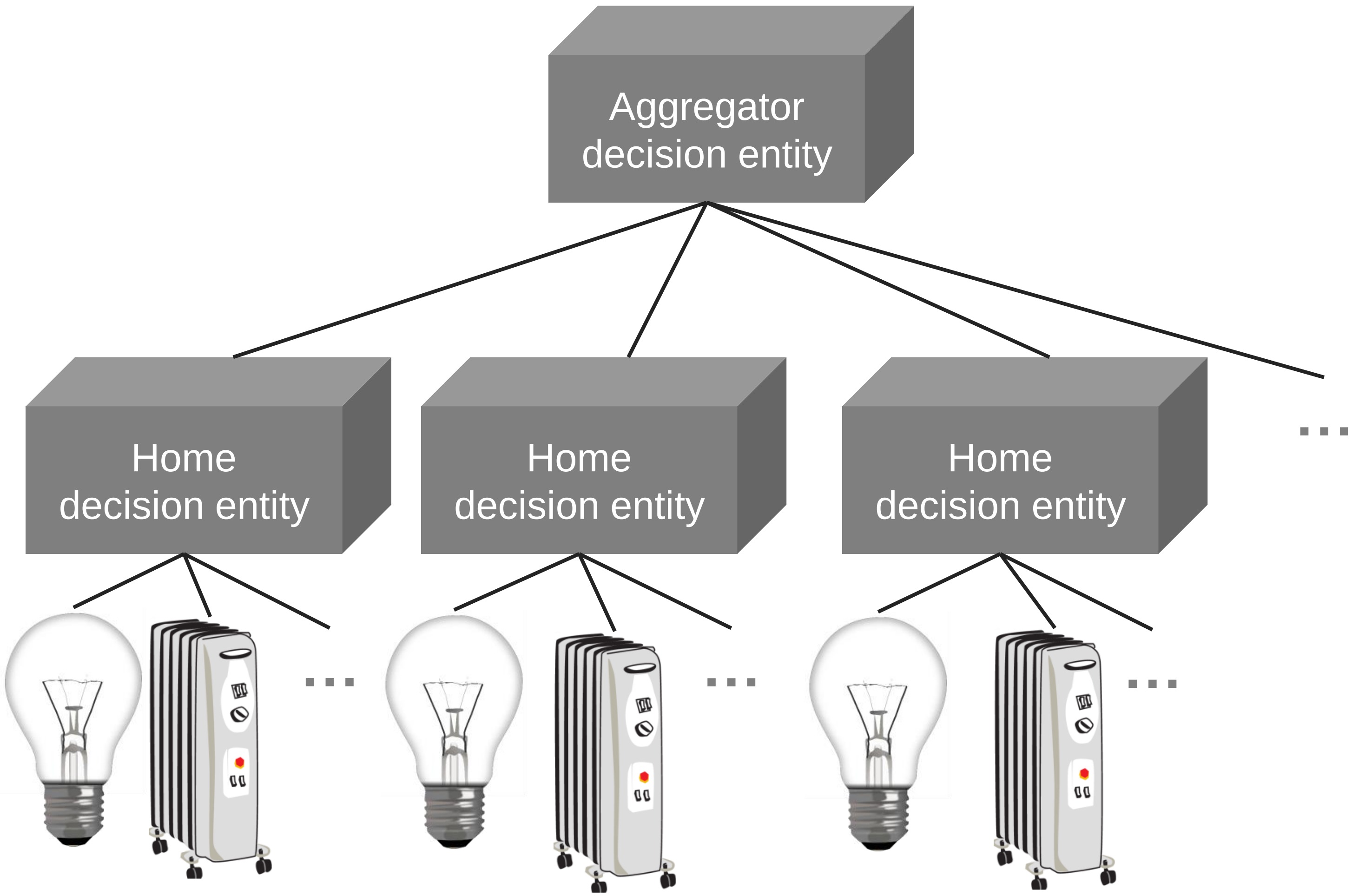




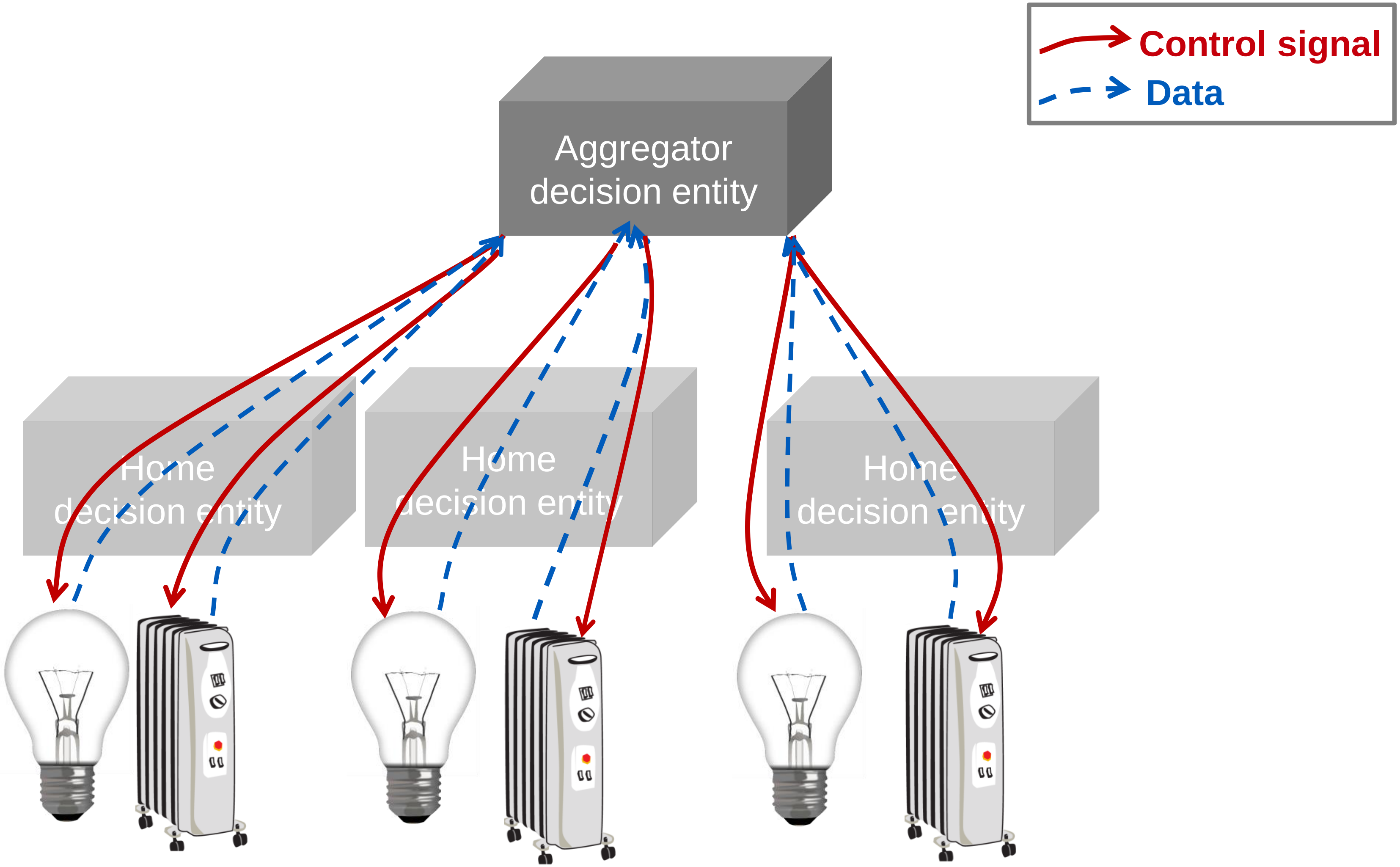




Proposed control schemes - framework



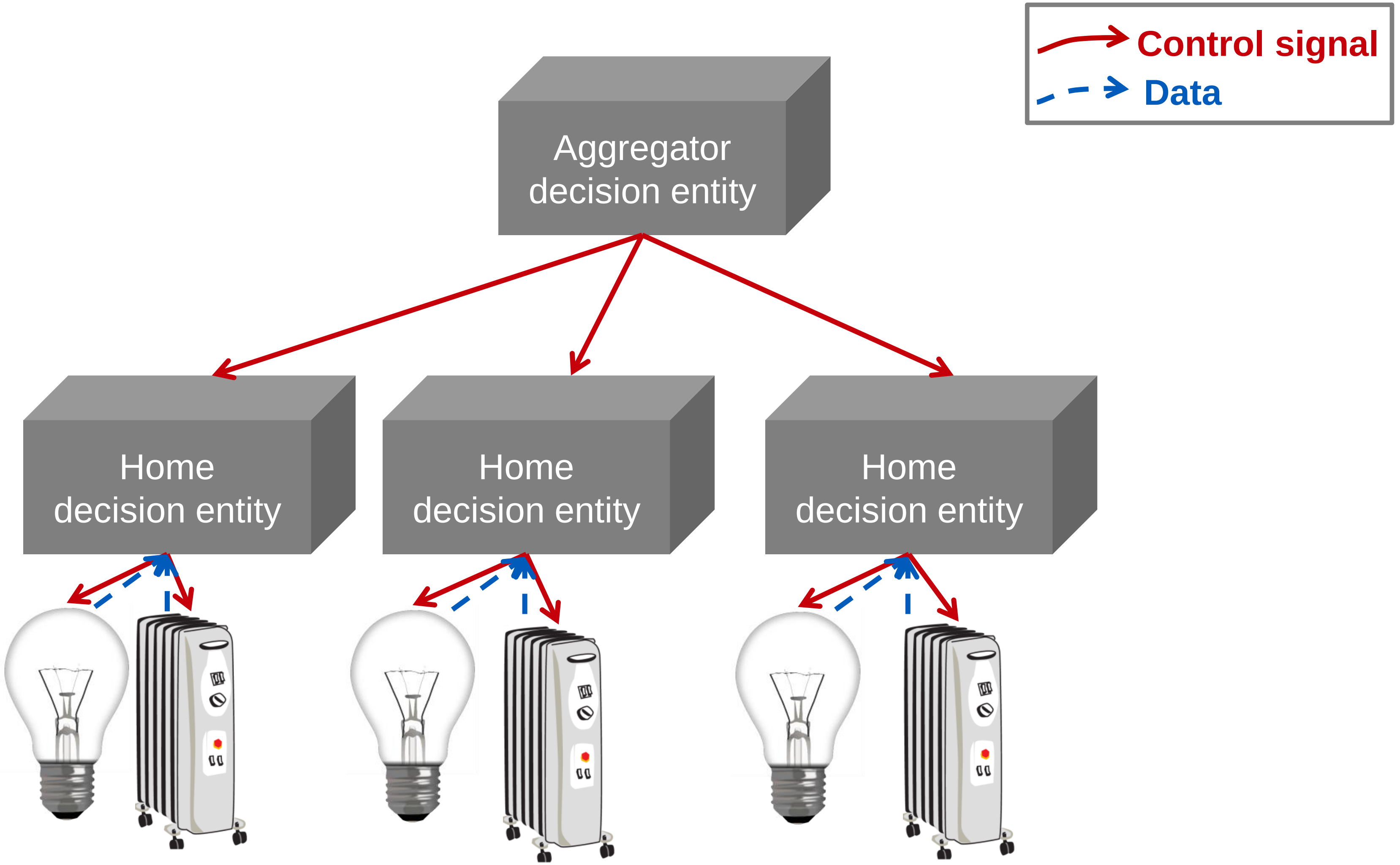
Proposed control schemes – Centralized
Global maximum (GM)



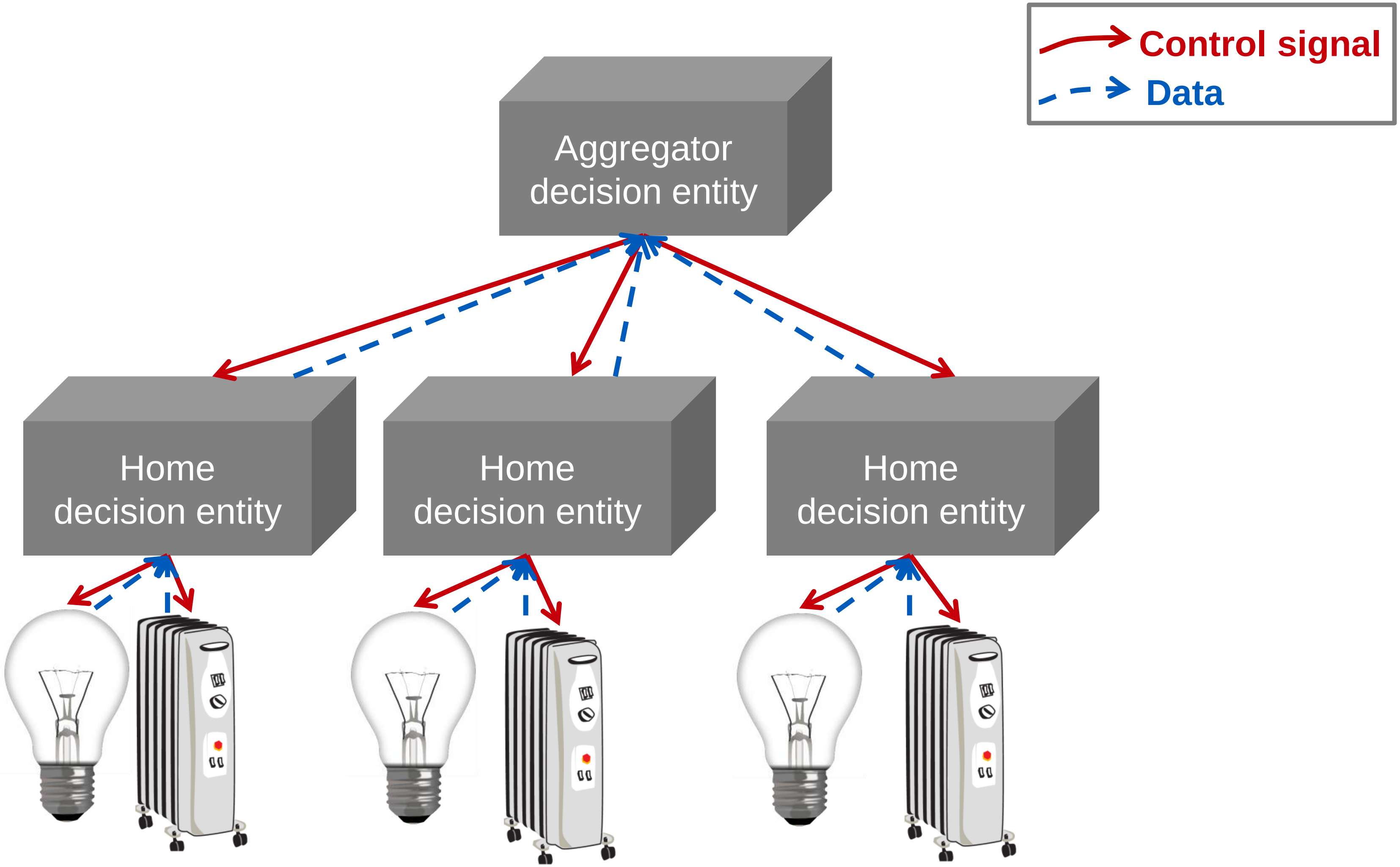
Proposed control schemes – Centralized
Global maximum (GM)

- All needed data from users are sent to Aggregator decision entity.
- Aggregator decision entity directly control each individual appliance by solving:
  - $max_{X_{ht}^{a}, x_{ht}^{a}} \sum_{t=1}^{t\_M} \sum_{h=1}^{H} \sum_{a=1}^{A} U_{ht}^{a}$
  - S.t.
  - $\sum_{h=1}^{H} \sum_{a=1}^{A} X_{ht}^{a} \leq C(t)\ , \quad \forall\, t$
  - $\mathrm{P}_{\mathrm{m}}^{a}(\mathrm{h}) x_{ht}^{a} \leq X_{ht}^{a} \leq \mathrm{P}_{\mathrm{M}}^{a}(\mathrm{h}) x_{ht}^{a}, \quad \forall\, t, \forall\, h, \forall\, a$
  - $x_{ht}^{a} \in \{0,1\}, \quad \forall\, t, \forall\, h, \forall\, a$

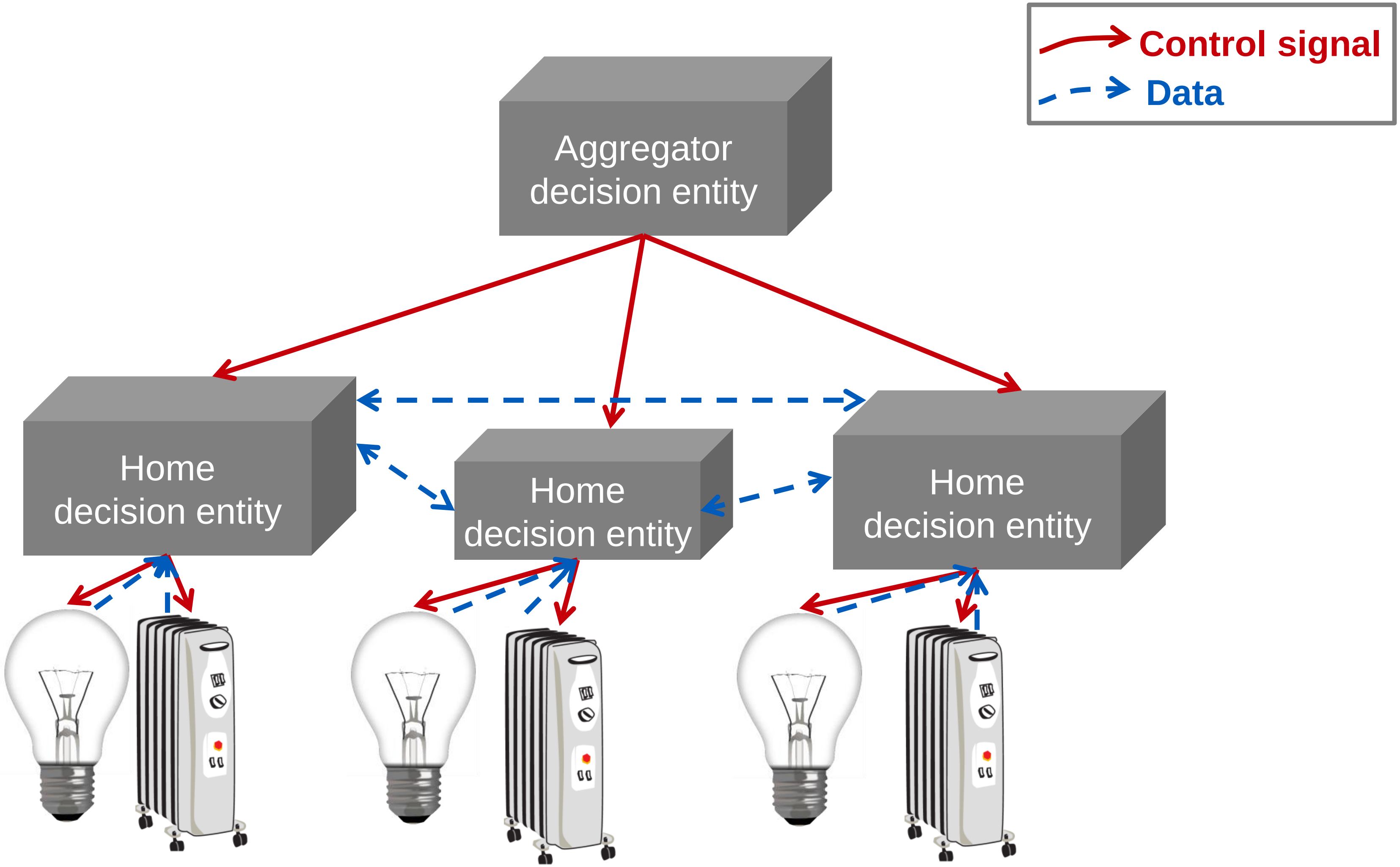
Proposed control schemes – Partially distributed
Local maximum (LM)



Proposed control schemes – Partially distributed
SubGradient (SG)



Proposed control schemes – Distributed

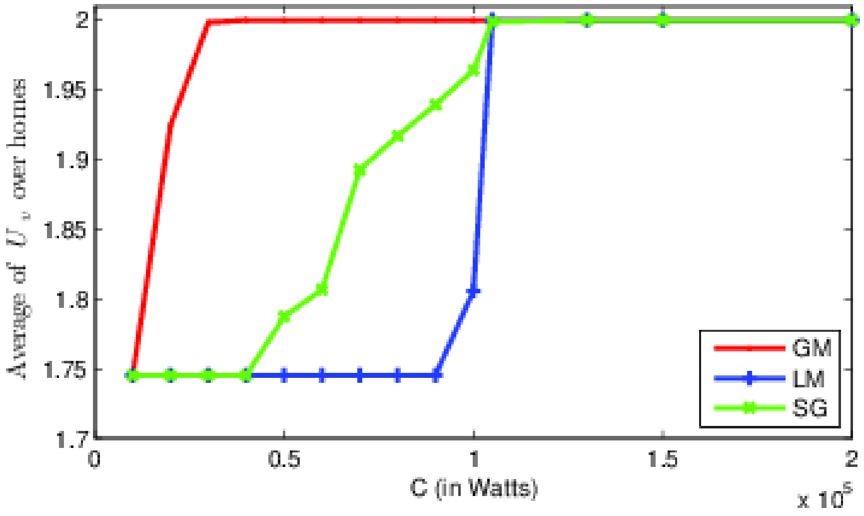


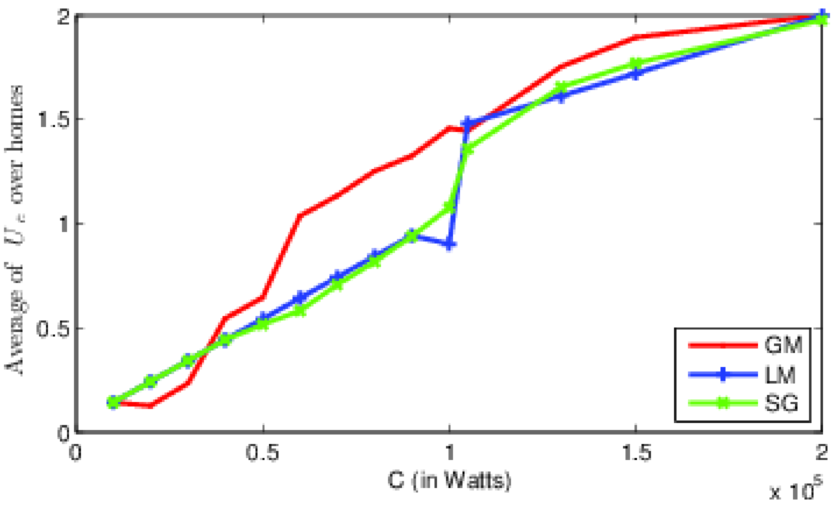
Numerical analysis

- 100 homes
- Time slot duration 5 minutes
- 100 time slots (Time period of 8 hours)
- Constant desired capacity C over the time period
- Home indoor initial and preferred temperature 22° C
- Outdoor temperature for all period is 10° C
- 2 classes of homes (with class 2 better insulated than class 1):

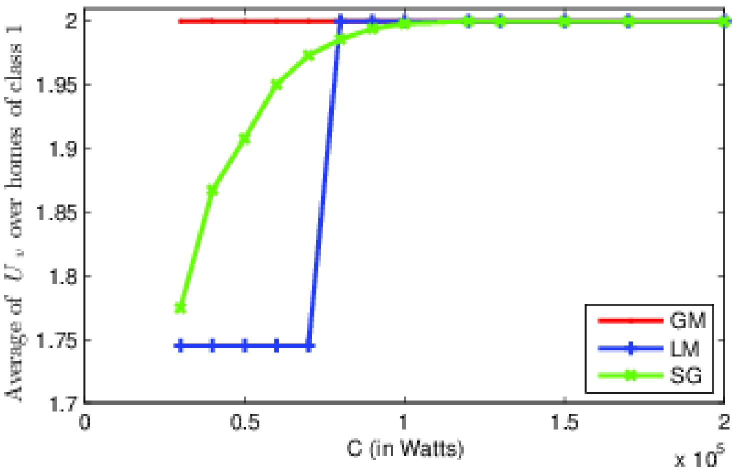
Home class	Lights (W)	Space heater (W)
1	[50,1000]	[1000,4000]
2	[50,500]	[1000,2000]

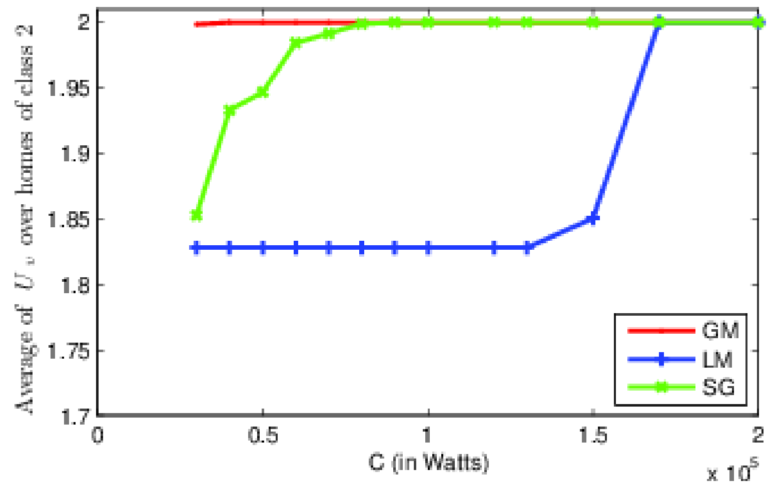
Some numerical results – homogeneous case

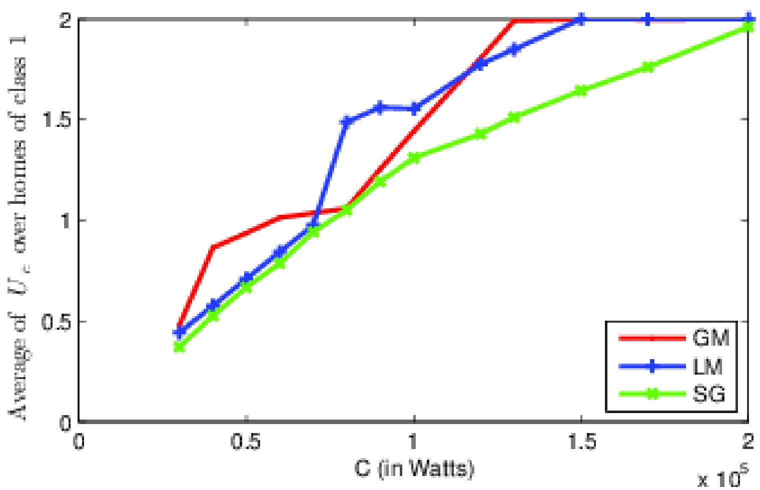


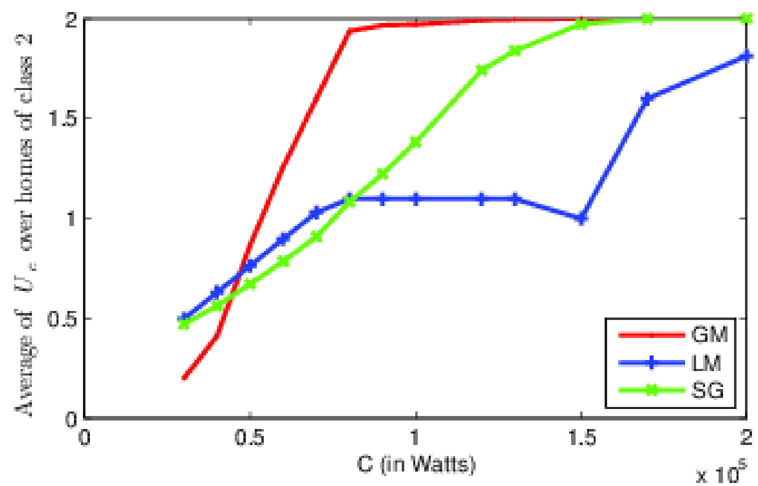


Some numerical results – heterogeneous case









Conclusion

- A generic framework for defining appliances flexibility
- Multi-levels of utility values per appliance → Fairness
- Partially distributed approach:
  - Reasonable performance compared to the optimal centralized solution
  - Mitigates privacy and scalability problems

Question?

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