C-DAX
Support & Validation for EV Charging Services

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SEVENTH FRAMEWORK PROGRAMME

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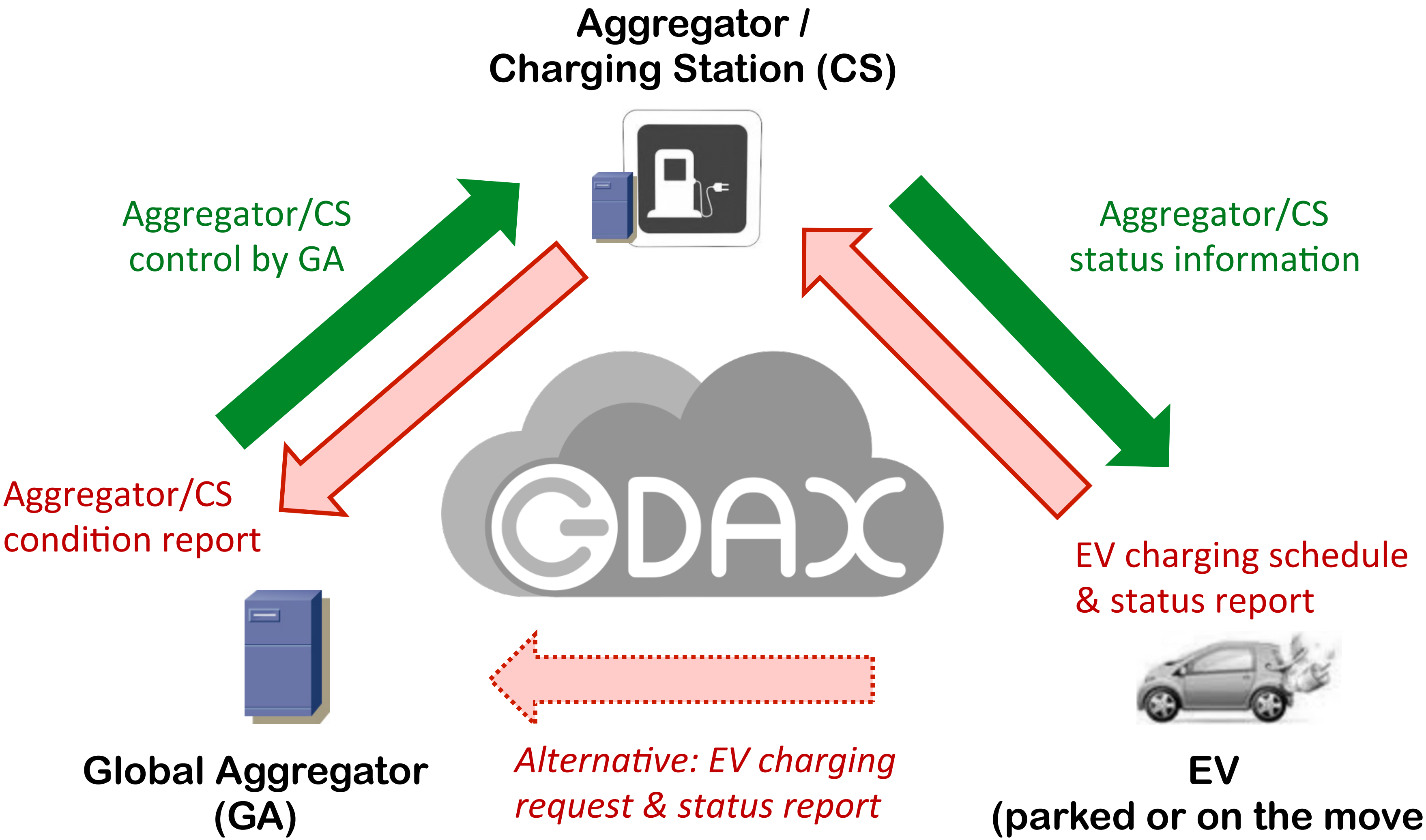
Smart EV charging overview

- Use case objectives
  - Design an efficient C-DAX platform for EV charging services
  - **For the grid**: Efficient demand response control, Energy load balancing
  - **For the EVs**: Optimised service performance (e.g., reduced charging waiting time)

- Charging scenarios with EV – grid communication:
  - **Parked**: Smarter charging for optimal grid operations and user experience
  - **On-the-move**: Ensure optimal selection of a charging station

- Main actors
  - Aggregator: global aggregator (GA) and/or at charging station level
  - EVs – either in parking mode or on the move

Smart EV charging overview



Why is C-DAX suitable?

- Flexible support of **different communication modes**

Mode	Scenario Example
1-to-1	GA controls aggregators/CSs for information publication
M-to-1	Aggregator/CS condition update to GA
M-to-1 / 1-to-M	Aggregator/CS information publication to EVs

- **Security** functionality
  - C-DAX key management to defend against malicious parties
  - Where necessary, encryption techniques should be used (e.g., shared privacy sensitive information such as EV charging preferences)
- **Scalable and flexible** platform
  - To add and remove clients: Simply join/leave the relevant topics

Part I:
Parked EV charging

Demand Response for parked EVs
Outline

- Introduction to demand response and smart charging
- Example use case for smart charging
- Smart charging
  - System overview
  - Information flows
  - Deployment on C-DAX
  - Performance analysis
- Conclusions

Introduction: Demand Response (1)

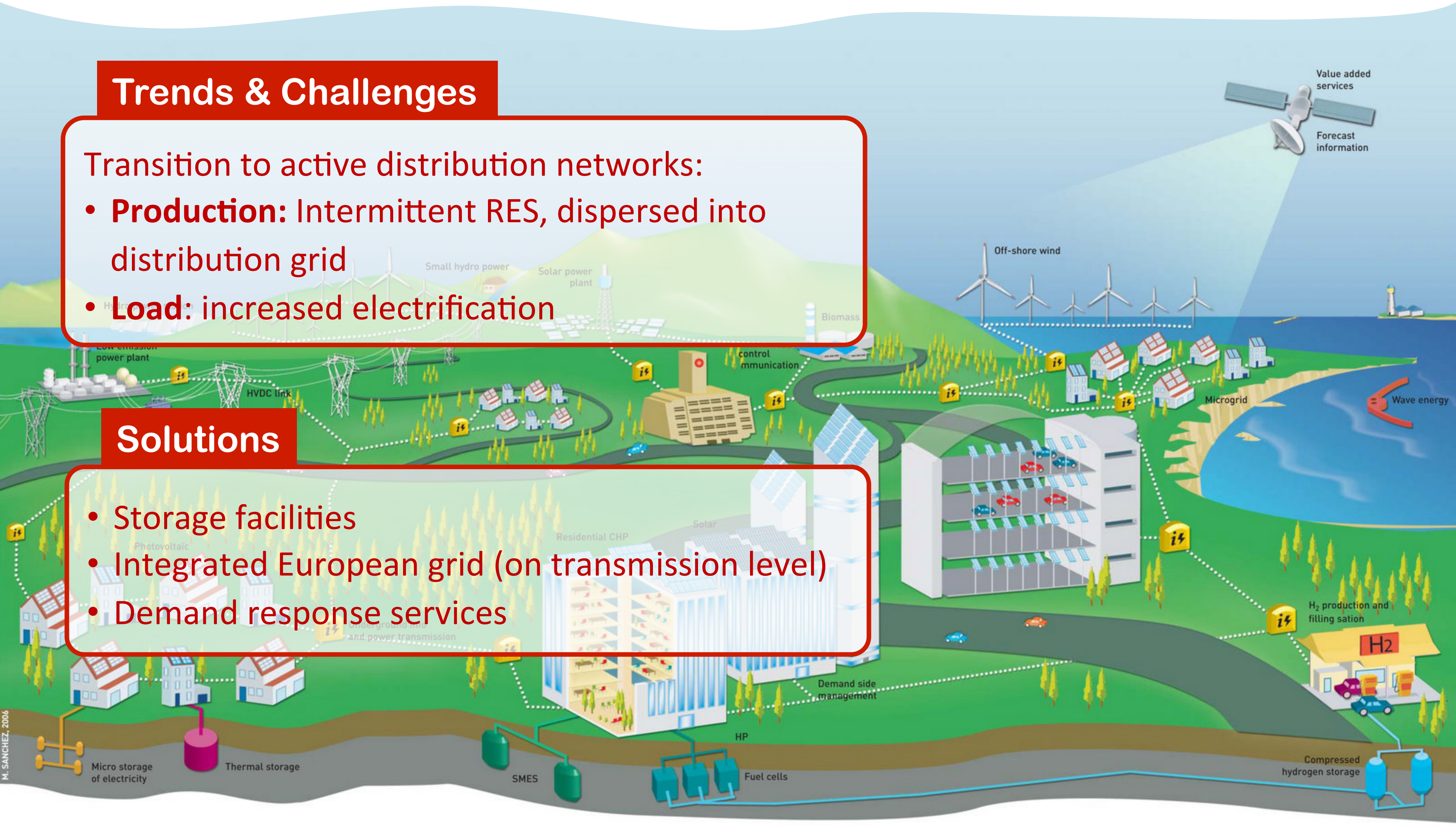
Trends & Challenges

Transition to active distribution networks:

- **Production:** Intermittent RES, dispersed into distribution grid
- **Load**: increased electrification

Solutions

- Storage facilities
- Integrated European grid (on transmission level)
- Demand response services



Introduction: Demand Response (2)

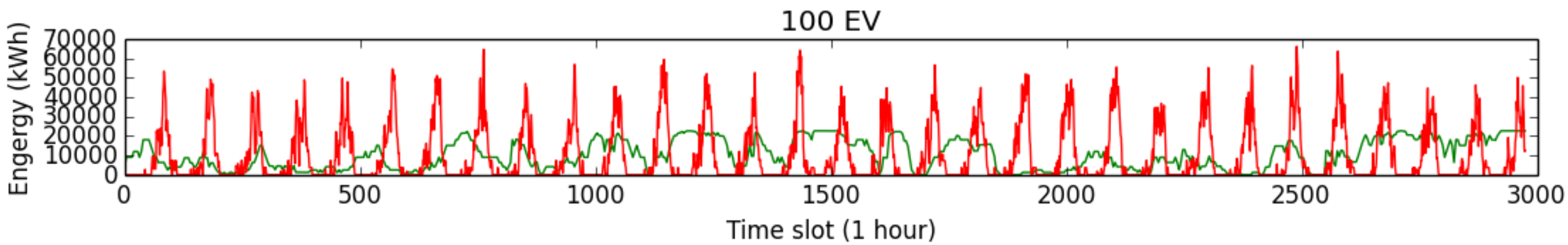
Algorithms focus on distributed and hybrid approaches

- **Scalability**: computational, memory, and communication benefits
  - *Computational*: Computational complexity is spread over users (i.e., many small and simple models versus one large and complex model)
  - *Memory*: Reduced model complexity (e.g., constraints, decision variables)
  - *Communication*: Localize communication intensive parts
- **Reliability**: avoid single point-of-failure, limited to one way communication, …
- **Privacy**: users no longer need to share privacy sensitive information and hand over control to a third party

Example scenario: Wind balancing

- Aim: **demand-supply balancing** by exploiting flexibility of EVs
  … instead of grid storage, additional generating power, etc.
  - *Supply*: Power generated by wind turbine
  - *Demand*: EV charging

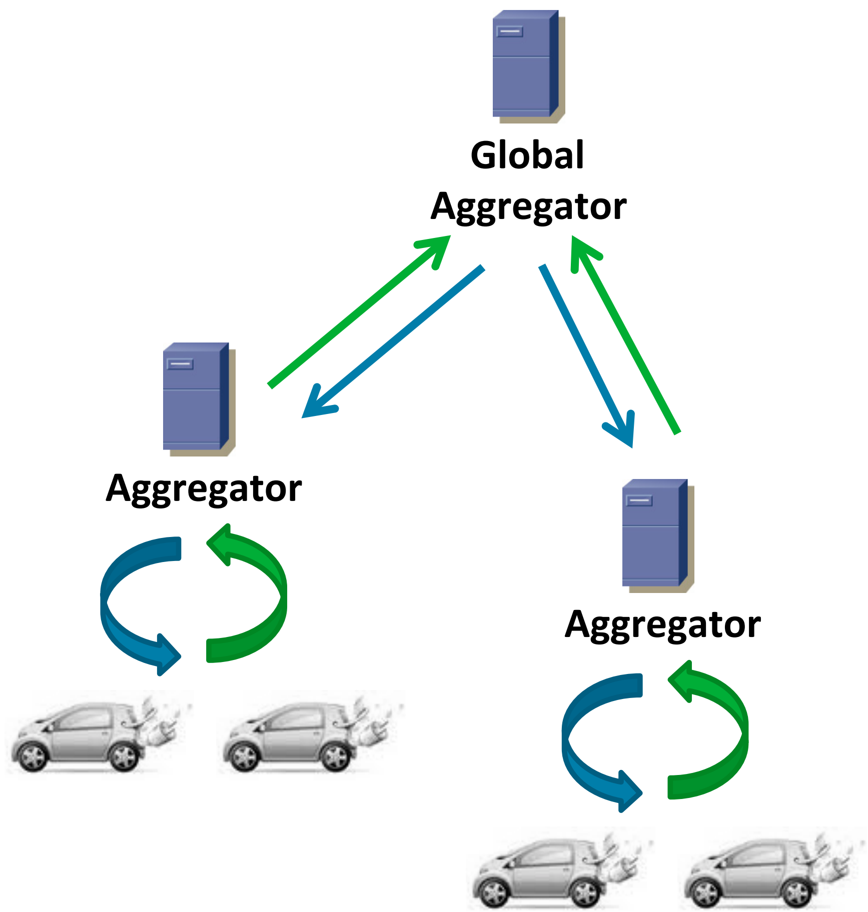
- Exploiting flexibility
  - Always respect user constraints (e.g., fully charged when departing)
  - Time shifting**:** Control action = turning charger on/off
  - Demand shaping**:** Adapt charging power (in [0, P_{max}])



System Overview

Information sharing

Incentive (control) signal



Global Aggregator

- Manage system objective (e.g., balancing)
- Process flexibility info
- Create target profiles

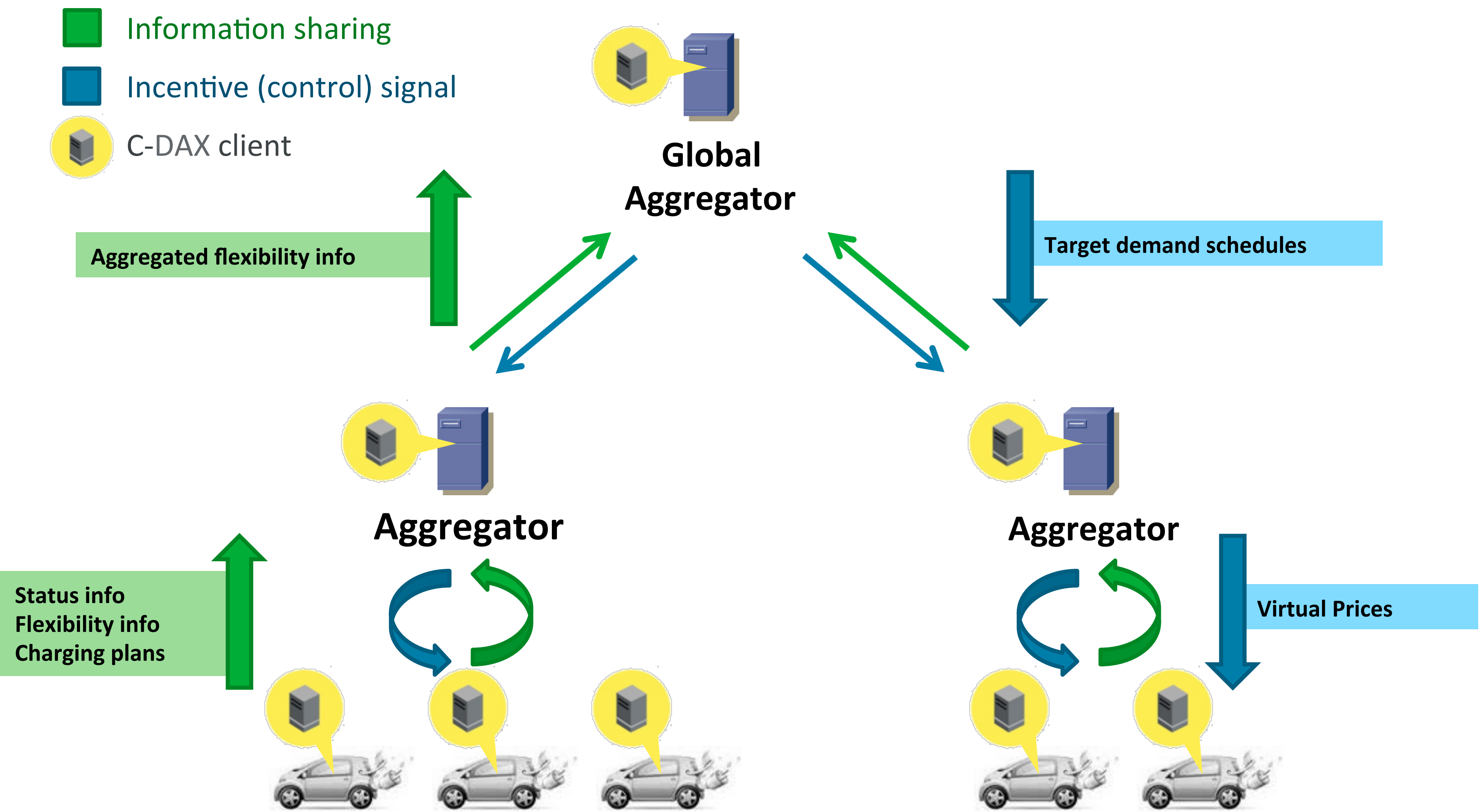
Aggregator

- Manage user & system objectives
- Collect, aggregate, and forward flexibility info.
- Negotiate charging plans
- Manage sessions.
- Localize communication and information sharing

Electric vehicles

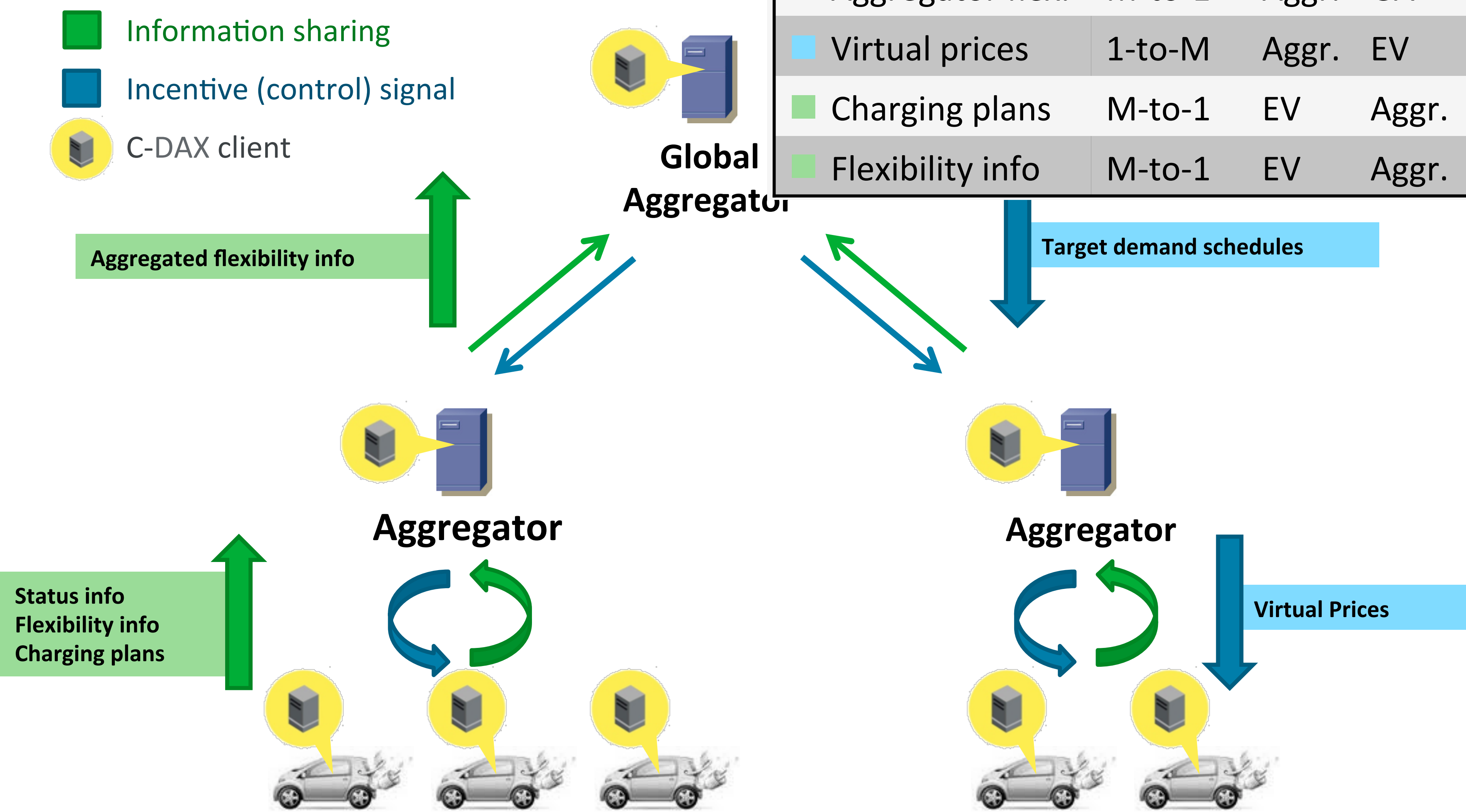
- Provide flexibility info
- Negotiate and execute charging plans

Information Flows

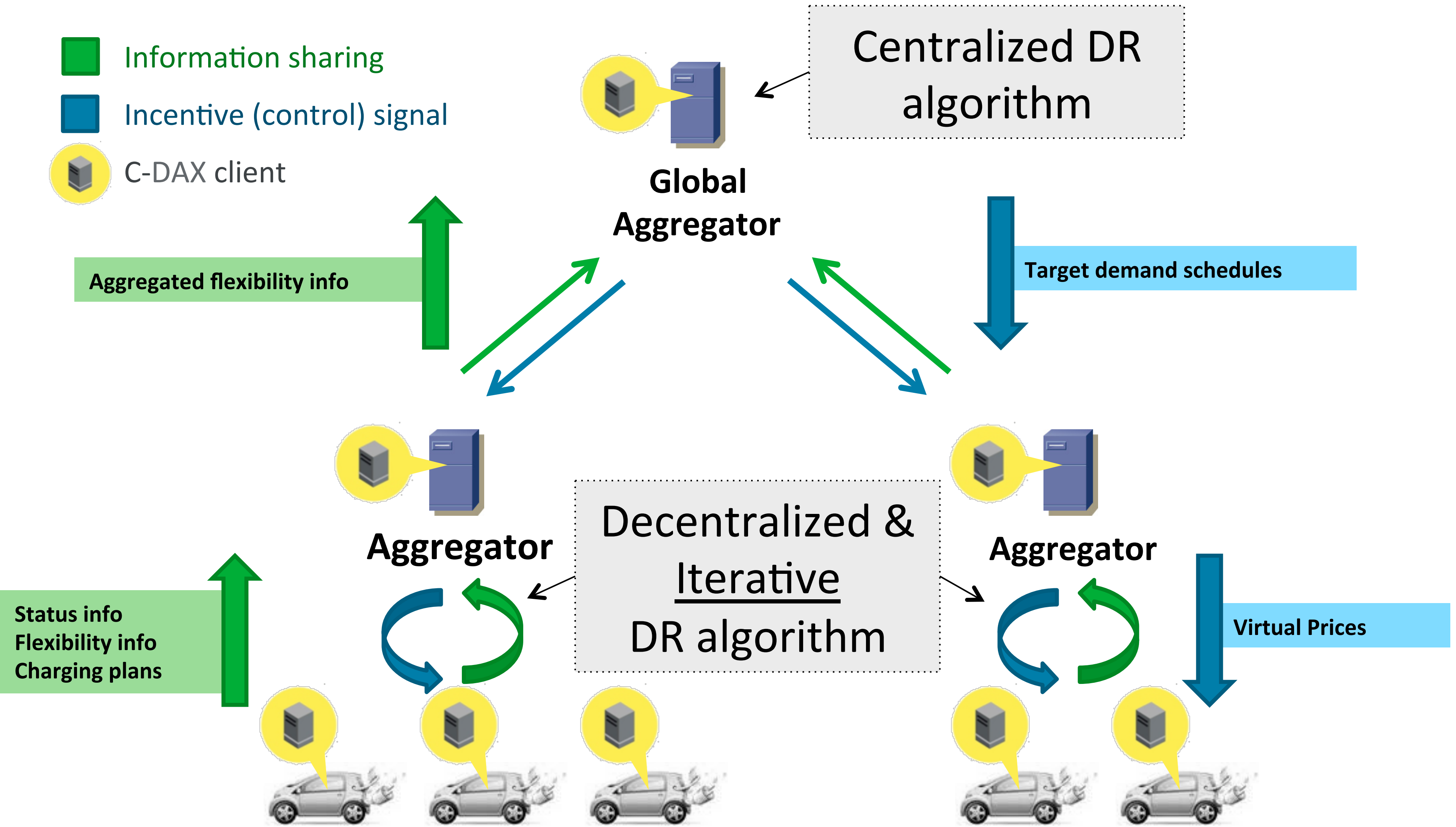


Information Flows

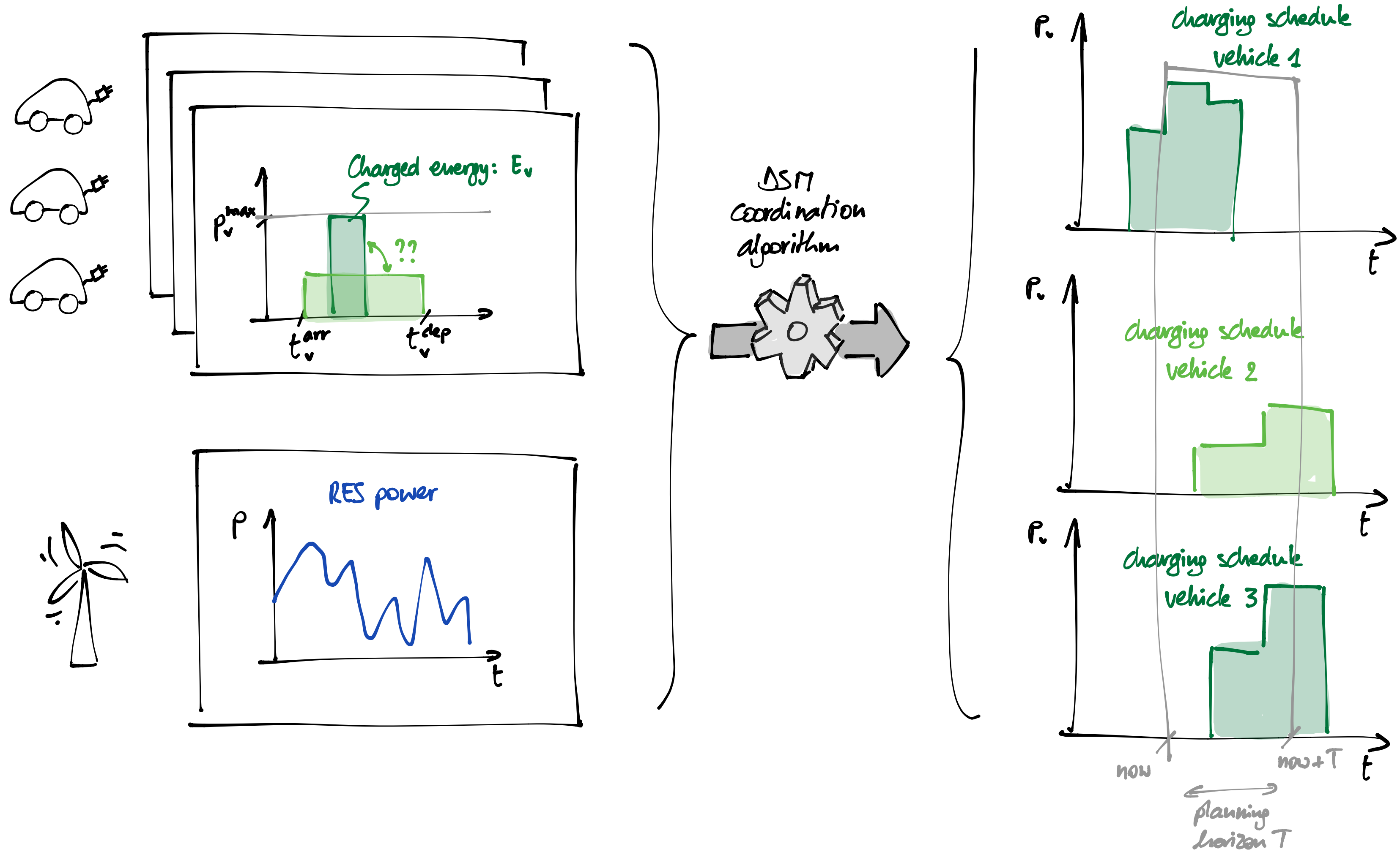
Topic	Mode	Pub	Sub
Target sched.	1-to-1	GA	Aggr.
Aggregator flex.	M-to-1	Aggr.	GA
Virtual prices	1-to-M	Aggr.	EV
Charging plans	M-to-1	EV	Aggr.
Flexibility info	M-to-1	EV	Aggr.



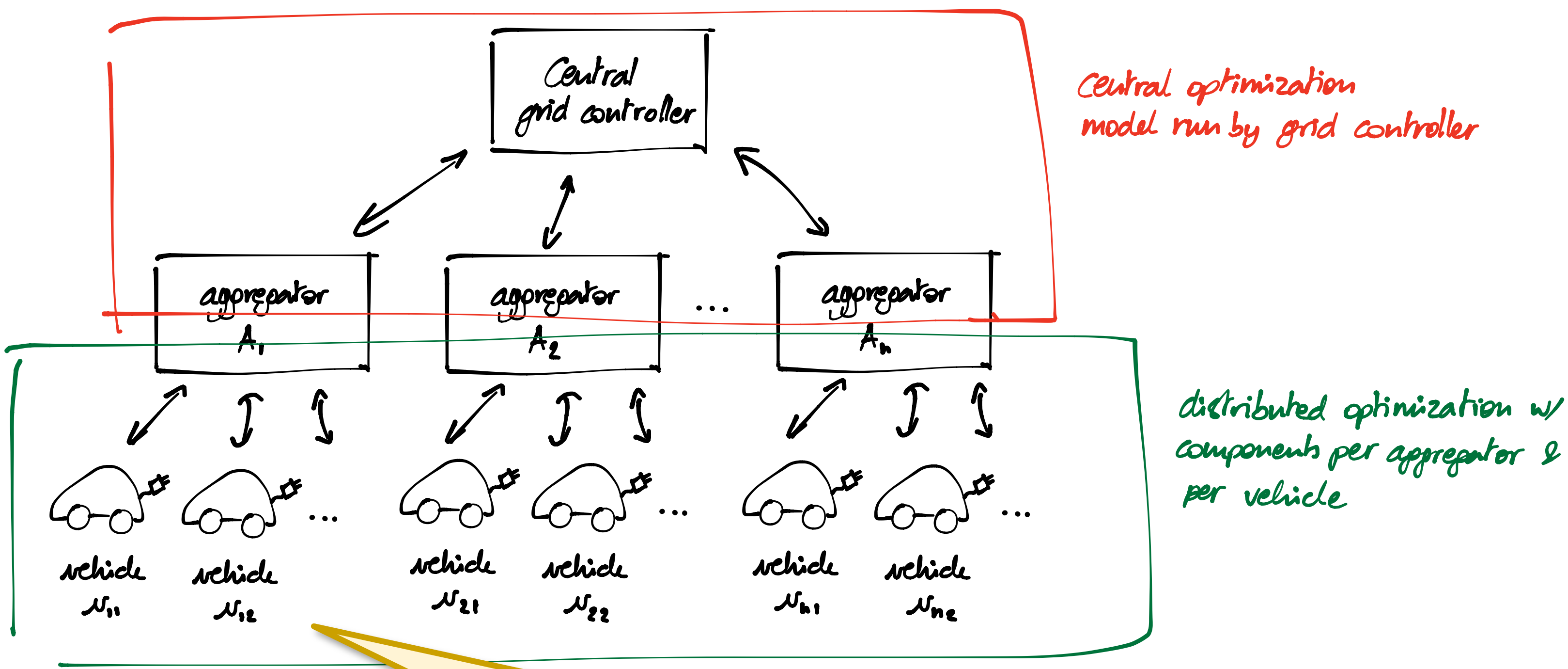
Information Flows



RES balancing: Problem Statement



System overview



Multiple **types of users**, e.g.:
- *Fast*: wants to be charged as quickly as possible
- *Flex*: doesn't care, as long as charging happens

Global Aggregator optimization model

Minimize "black" supply (i.e., non-RES)

Avoid "discarding" supply from RES

Aim for "smooth" power transitions

$$\min_{\{\mathbf{x_a},\mathbf{b},\mathbf{d}\}} \sum_{t\in\{1,\dots,T\}} (\beta_t\, b_t + \delta_t\, d_t) + \sum_{t\in\{1,\dots,T-1\}} \sum_{a\in A} \sigma_a\, |x_{a,t+1} - x_{a,t}| \quad (2)$$

subject to:

$$\sum_{a\in A} x_{a,t} + d_t = g_t + b_t \qquad t\in\{1,\dots,T\} \quad (3)$$

$$\sum_{t'=1}^{t} x_{a,t'} \geq e_{a,t} \qquad t\in\{1,\dots,T-1\}, a\in A \quad (4)$$

$$\sum_{t=1}^{T} x_{a,t} = e_{a,T} \qquad a\in A \quad (5)$$

$$p_{a,t}^{\min} \leq x_{a,t} \leq p_{a,t}^{\max} \qquad t\in\{1,\dots,T\} \quad (6)$$

$$b_t \geq 0, \quad d_t \geq 0 \qquad t\in\{1,\dots,T\} \quad (7)$$

Aggregator optimization model – central version

Minimize “black” supply (i.e., non-RES)

Avoid “discarding” supply from RES

Exploit “flex” but try to respect user prefs.

$$\min_{\{\mathbf{x_v},\mathbf{b_a},\mathbf{d_a}\}} \beta \cdot \mathbf{b_a} + \delta \cdot \mathbf{d_a} + \qquad (8)$$

$$\sum_{v \in V_a} \varphi_{\mathbf{v}} \cdot (\mathbf{p_v^{max}} - \mathbf{x_v}) \qquad (9)$$

subject to:

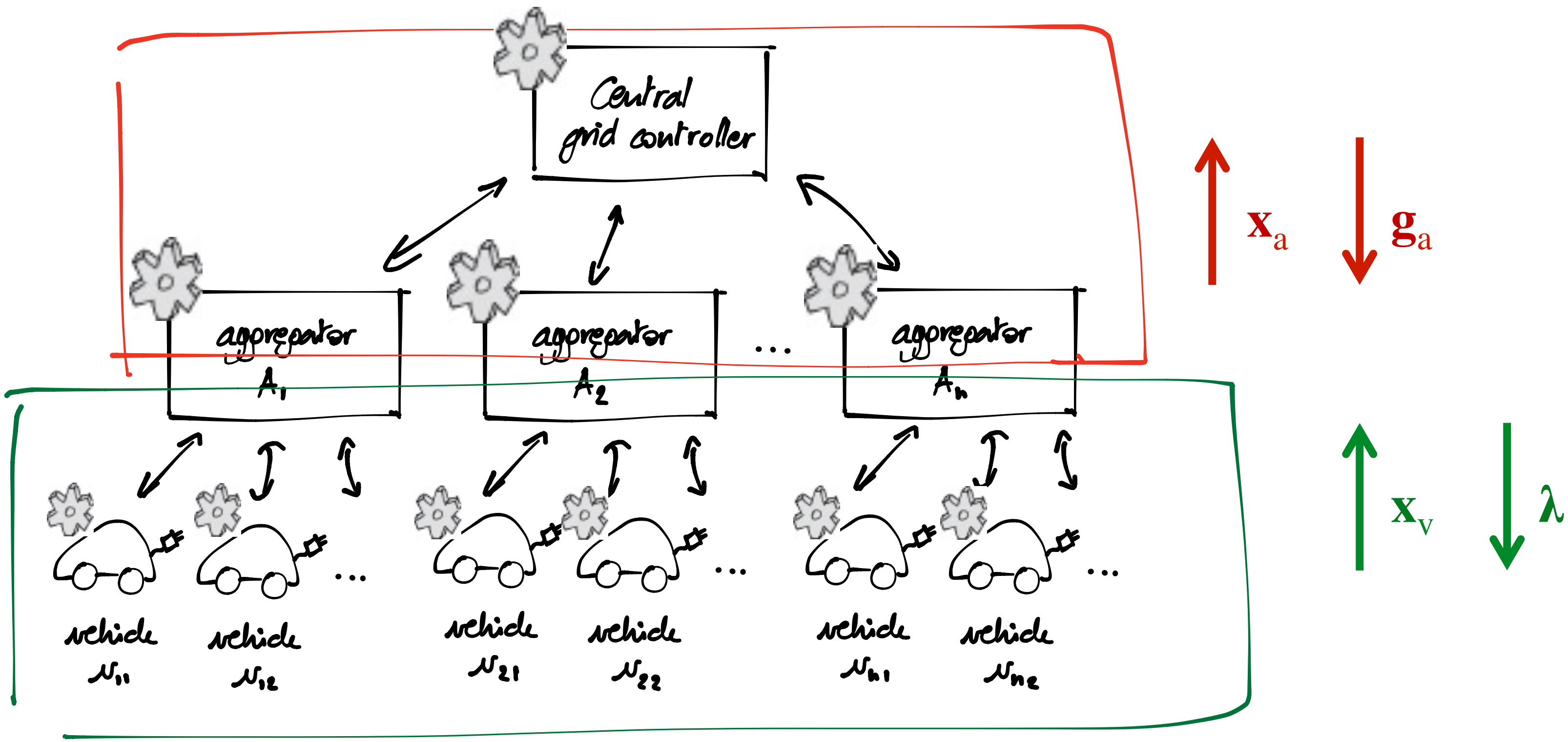
$$\sum_{v \in V_a} \mathbf{x_v} + \mathbf{d_a} = \mathbf{g_a} + \mathbf{b_a} \qquad (10)$$

$$\mathbf{1} \cdot \mathbf{x_v} = e_v \qquad v \in V_a \qquad (11)$$

$$\mathbf{p_v^{min}} \leq \mathbf{x_v} \leq \mathbf{p_v^{max}} \qquad v \in V_a \qquad (12)$$

$$\mathbf{b_a} \geq \mathbf{0}, \quad \mathbf{d_a} \geq \mathbf{0} \qquad (13)$$

Communication over C-DAX platform



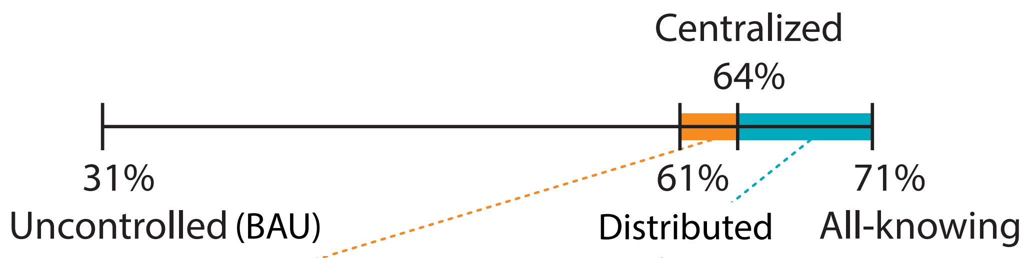
Sample scenario

- T = 31 days divided in 15 minute time slots
- 1 Global Aggregator, 2 Aggregators
- 100 EVs at home charging sessions
  - 3.68 kW maximum charging power
  - 10 kWh batteries
  - Time shifting and/or demand shaping
  - Different flexibility profiles tailored to user preferences
  - Sessions randomly assigned to aggregator
- Power from wind turbine: Scaled to match total demand over T

2 types of users:
- *Fast*: charge as quickly as possible
- *Flex*: only deadline to meet

Sample results: RES contribution to EV charging

User mix	% of load supplied by RES			
Fast–Flex	Distributed	Centralized	BAU	Upper bound
100% – 0%	48.85%	62.65%	39.49%	71.17%
75% – 25%	56.57%	63.51%		
50% – 50%	61.73%	64.13%		
25% – 75%	63.76%	64.87%		
0% – 100%	63.97%	[illegible]5.28%		



How to close the gap?

Improve algorithm:
- Consider alternate solutions
- Hyper-parameter tuning

Add/extend forecasting of:
- Future charging sessions
- Future wind energy supply

Thanks. Any questions?

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