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Categorizing Energy using Products for partially decentralised Energy Management

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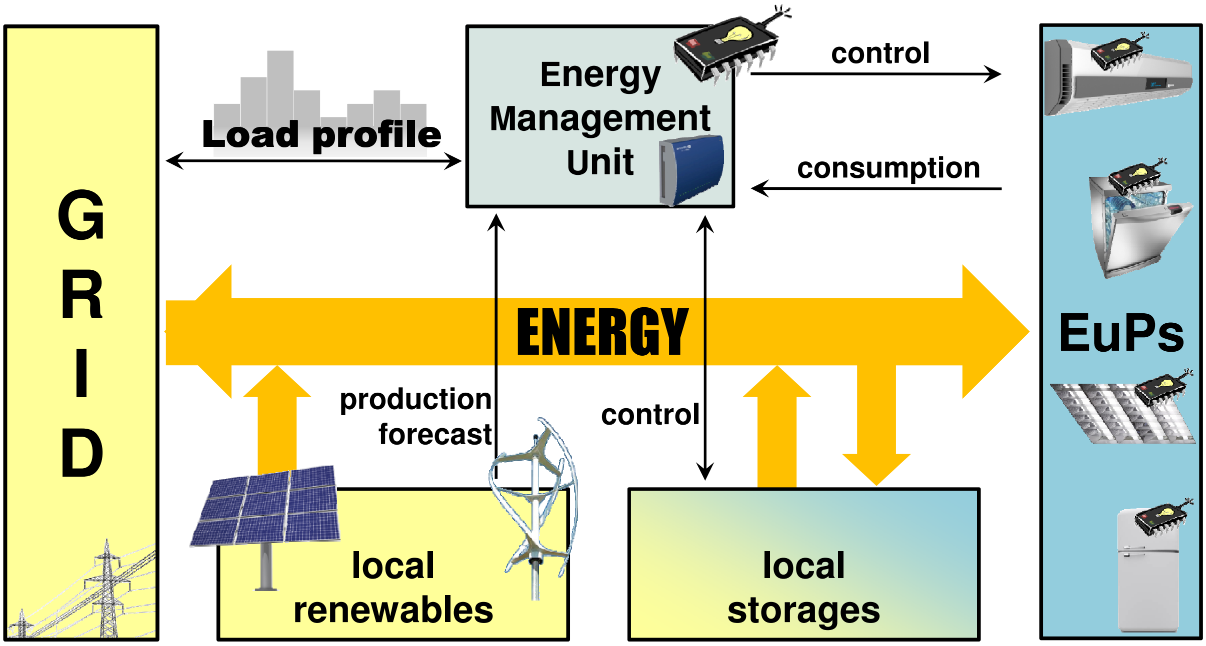
Outline

- SmartCoDe Energy Management problem
- A semi-decentralised approach
- Cost function-based Energy Management
- Classification of Energy using Products (EuPs)
- EuP-class specific Energy Management
- Conclusion

SmartCoDe Energy Resource Cluster

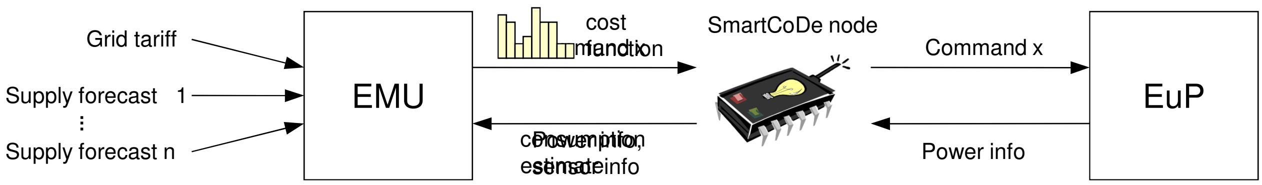


Goal: Harmonise energy consumption with local energy production

Target Area and Requirements

- **Target Area:**
  - Average EU neighbourhoods & small commercial buildings
  - Connected to the public grid
  - Utilise local renewable energy (solar-panel, wind-turbine)
- **Requirements for Energy Management (EM)**
  - The EM-approach should allow to **maximize the usage of** locally produced **renewable energy**.
  - The EM-interference **should be acceptable by the user.**

Centralised and Semi-Decentralised Control



Centralised: Node passes on commands, provides sensor info

Semi-decentralised:

- Cost functions concerning future time periods issued by EMU
- Node controls EuP autonomously while obeying to costs

Centralised vs. Semi-Decentralised Energy Management Approach

	Centralised	Semi-decentralised
Communication overhead	• Sensor data has to be transmitted • Control commands with high frequency	• No sensor data has to be transmitted • Directives can have lower frequency
EuP Management	• Micromanagement • *Every* important aspect of the EuP has to be known by EMU	EuP only needs to know • EuP class • Power consumption forecasts
EMU crash / absence / communication problems	• SmartCoDe nodes "headless“ • What happens to control loops?	• SmartCoDe nodes can operate autonomously
SmartCoDe Node design / software	Simple	Complex
Load balancing between nodes	**Easier** to achieve since EMU has complete control and knowledge	**Harder** to achieve due to autonomy of SmartCoDe nodes
Micro-managing	Is the principle here	**Still possible** for selected EuPs / EuP classes

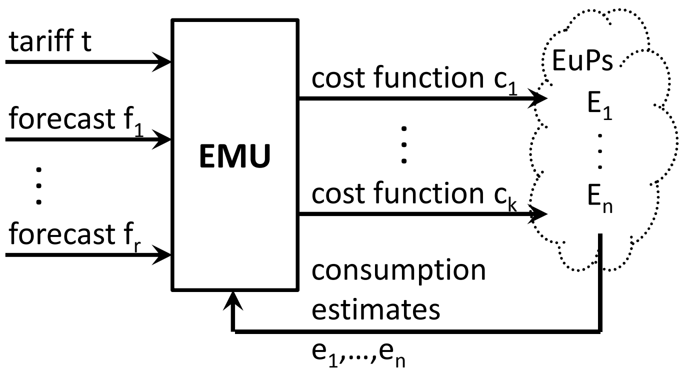
SmartCoDe Semi-Decentralised Energy Management approach

Energy Management Unit:

- Receives tariffs, consumption and production forecasts
- Issues **cost functions** to EuPs w.r.t. a certain optimisation goal

SmartCoDe Node:

- Receives cost function
- Controls EuP while minimising cost w.r.t. cost function
- Produces power **consumption estimates**



Existing demand control message: The ZigBee® Smart Energy Load Control Event

Octets	4	2	1	4	2	1	1
Data Type	Unsigned 32-bit integer	16-bit BitMap	Unsigned 8-bit integer	UTC Time	Unsigned 16-bit integer	Unsigned 8-bit integer	Unsigned 8-bit integer
Field Name	Issuer Event ID (M)	Device Class (M)	Utility Enrolment Group (M)	Start Time (M)	Duration In Minutes (M)	Criticality Level (M)	Cooling Temperature Offset (O)

Octets	1	2	2	1	1	1
Data Type	Unsigned 8-bit integer	Signed 16-bit integer	Signed 16-bit integer	Signed 8-bit integer	Unsigned 8-bit integer	8-bit BitMap
Field Name	Heating Temperature Offset (O)	Cooling Temperature Set Point (O)	Heating Temperature Set Point (O)	Average Load Adjustment Percentage (O)	Duty Cycle (O)	Event Control (M)

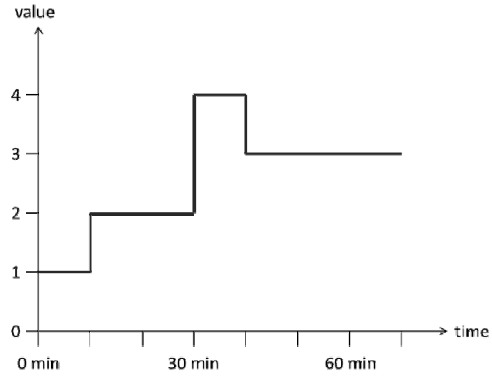
Criticality Level	Description	Participation
0	Reserved	Voluntary
1	Green	Voluntary
2	1	Voluntary
3	2	Voluntary
4	3	Voluntary
5	4	Voluntary
6	5	Voluntary
7	Emergency	Mandatory
8	Planned Outage	Mandatory
9	Service Disconnect	Mandatory
0x0A-0x0F	Utility Defined	Utility Defined
0x10-0xFF	Reserved	

Problems:

- Too much information for our purposes
- Small granularity leads to a lot of messages
- …and we need small granularity (~10 minutes)

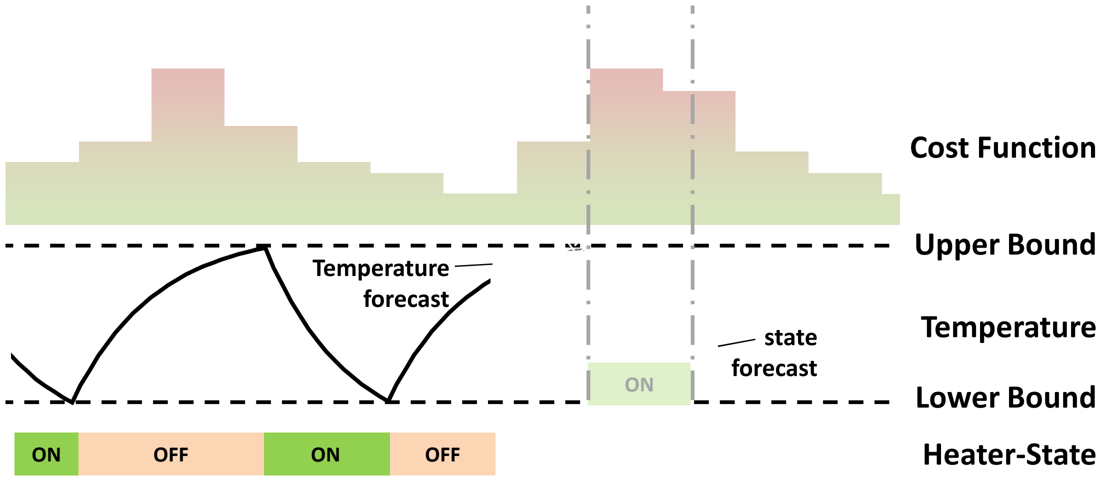
SmartCoDe Cost Function Format

- Values are **abstract** costs
- **Step-function** approach
- Example: (10 min , 1) , (20 min , 2) , (10 min , 4) , (30 min , 3)
- Time resolution can be set (1s – 1h)
- Basically bundles a series of ZigBee SE load control events



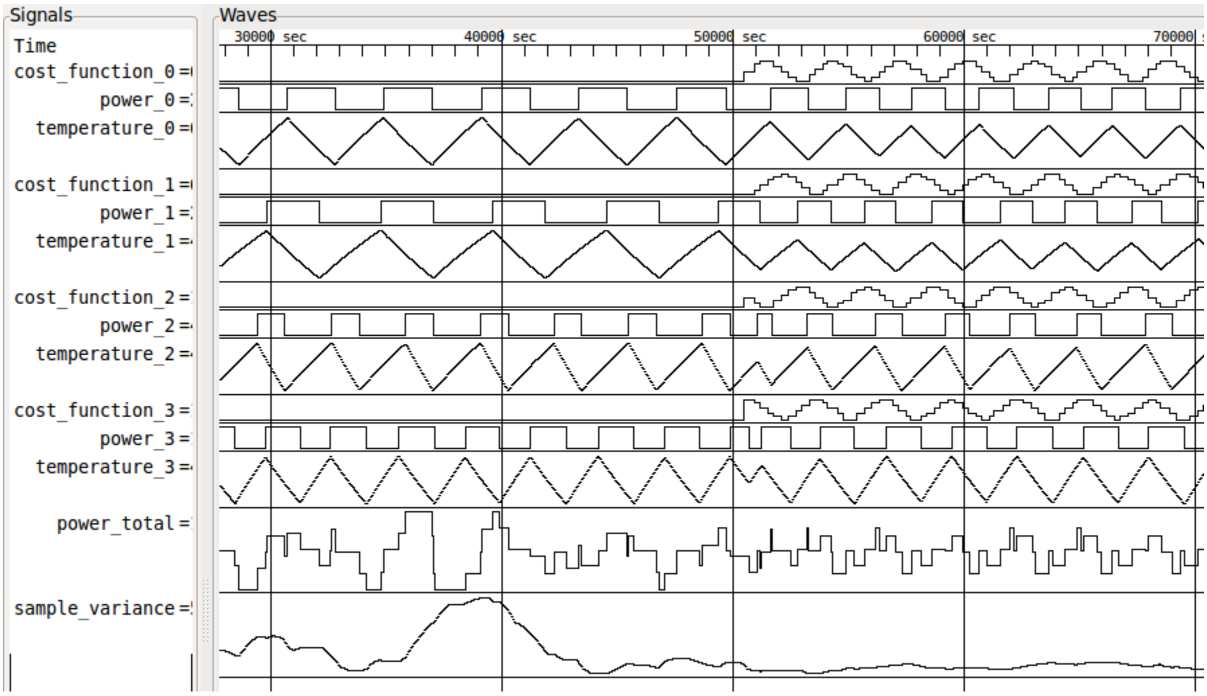
Data Type	8-Bit Flag register	UTC Time	Unsigned 8-bit integer	Unsigned 8-bit integer	Unsigned 8-bit integer	(repeat) …	Unsigned 8-bit integer	Unsigned 8-bit integer
Field Name	Time Resolution	Start Time	cost function length n	Criticality Level 1	Duration 1 (in time resolution units)	…	Criticality Level n	Duration n (in time resolution units)

Local Control Example: Cost Function Based Bang-Bang Control of a Fridge

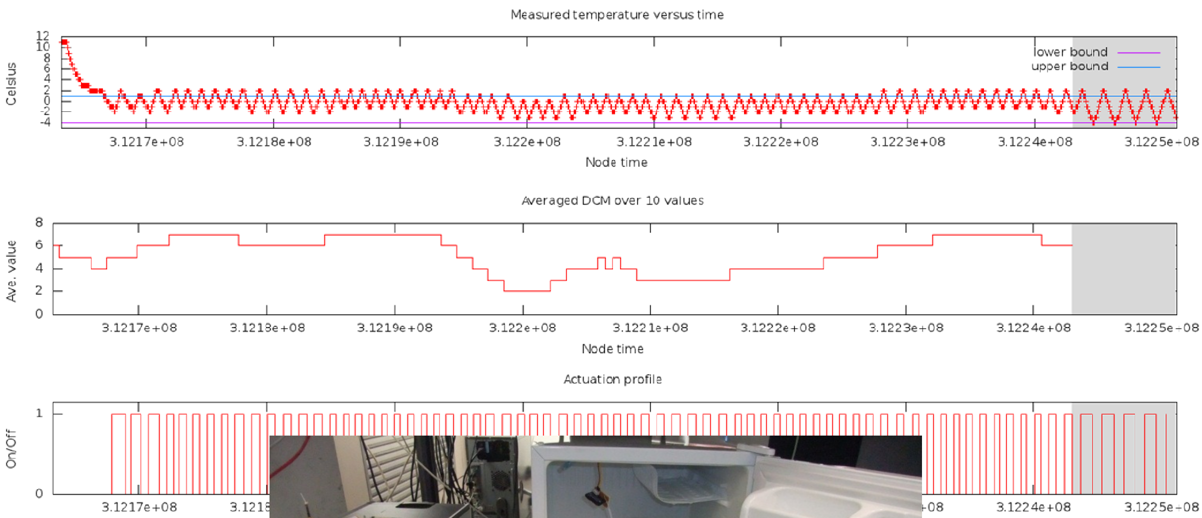


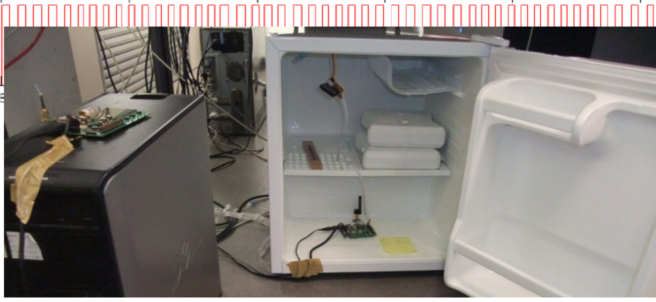
- SmartCoDe node plans ahead to minimise costs
- Generates control plan → effectively a consumption forecast
- Temperature forecast needed

Global Control Example: Load Balancing of Four Fridges with Cost Functions



Working Cost-Function Based Bang-Bang Control on the Functional Node Prototype





EuP Classification - Motivation

- Each class collects EuPs with similar...
  - Service
  - Interfaces
  - Energy Management leverage
- One SmartCoDe node variation for each class
  - Mostly software, in principal also hardware
  - Especially: cost function-based energy management

SmartCoDe EuP Classification

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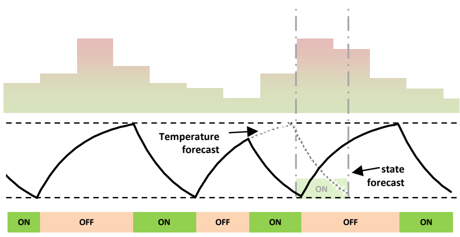
SmartCoDe EuP Classification

Class	Description	Parameters			Energy Management		Examples
		Configuration	Sensor input	Online input	Strategy	cost	
VARSVC	**Variable Service:** The appliance provides a user-variable service, possibly balanced with sensor input.	tolerance bounds	current state of the service, e.g. illuminance	user demand, e.g. setpoint for illuminance	Minimise consumption while balancing the service with user demand, tolerance bounds and sensor measurement.	No	dimmable lighting, blinds, fans
VSTSVC	**Virtual Storage service:** The appliance provides a inert, user-variable service which can serve as a virtual storage.	tolerance bounds	current state of the service, e.g. temperature	user demand, e.g. setpoint for temperature	Balance service with user demand and sensor measurement while exploiting the virtual storage property.	Yes	Fridge, Freezer, HVAC, Water-boiler
SKDSVC	**Schedulable Service:** The appliance provides a service which can be scheduled within a certain time-frame.	runtimes and power profiles of the different programs	none	time-frame	Start program within the given timeframe such that the program's load profile produces minimal costs.	Yes	washing machine, dryer, dishwasher, baking machine
ETOSVC	**Event-Timeout Service:** The appliance is control-led by sensor events and time-outs.	time span	sensor event, e.g. presence detection	none (indirectly through sensor input)	Control appliance according to sensor events and time-outs.	No	lighting controlled by presence detector (e.g. on corridor)
CHACON	**Charge Control:** The appliance charges a possibly removable device.	charging policy	current charge status, device presence	device removal re-insertion	Charge device such that costs are minimised, while obeying charging policy.	Yes	battery chargers, hand-held vacuum, emergency backup storages
COMCON	**Complete Control:** Like CHACON, but the usage of the charged power can also be con-trolled.	charging policy, duty cycles, time slots	current charge status	none	Like CHACON, but also control the usage of the appliance cost-effectively while obeying to the given time-slots and duty cycles.	Yes	robot vacuum, robot lawn-mower
CUSCON	**Custom Control:** device does not fit into other classes.	none	none	user demand	Automatic Energy Management probably not tolerable by user; custom schemes can be defined which are implemented by the EMU.	No	HiFi, PC, Oven

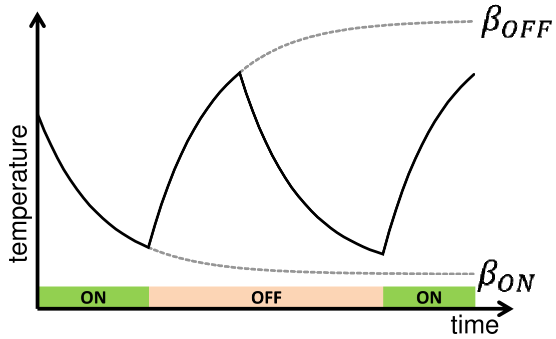
VSTSVC – Virtual Storages



- Inert service (mostly thermal) which can store energy
- Energy Management:
  - Store energy (e.g. cool down) when cost is low, switch off when cost is high
  - Keep temperature in between bounds
- Issues
  - Parameters of thermal process (e.g. thermal capacitance) needed for planning
  - These parameters need to be learned by the SmartCoDe node

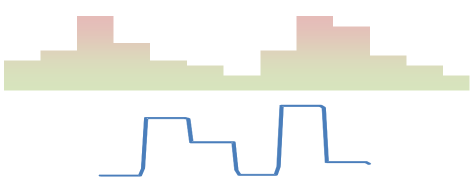
VSTSVC: Modelling and Learning the Thermal Process

- Discrete time lowpass model:
  $t_{i+1} = \alpha \cdot \beta + (1-\alpha) \cdot t_i$
  - t_i : temperature in step i
  - $\boldsymbol{\alpha}$: Smoothing factor
  - $\boldsymbol{\beta}$: boundary temperature (one β for each power level)
- Useful for
  - Temperature forecast
  - Power forecast
  - Smart cost-function based control algorithm



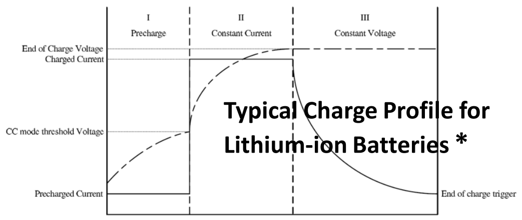
- Need to learn α and the β's
- Microcontroller algorithm
  - Least square method
  - Error term computed from temperature measurements
  - random search

SKDSVC – Schedulable Services



- User chooses a program and a deadline
- Energy Management:
  - Run program such that deadline is met
  - Find start time such that program load profile produces minimal cost
- Issues
  - Program load profile might not be fixed, e.g. can depend on load
  - In principle, a program can be interrupted, but the process might suffer

CHACON & COMCON – Charging EuPs



Typical Charge Profile for Lithium-ion Batteries *

- In between VSTSVC and SKDSVC
  - Provided service: charge status – is inert
  - Charging process can be scheduled
- Energy Management:
  - Schedule charging at minimal cost
  - Obey to charging policy
- COMCON: robotic services
  - Discharging (i.e. using the device) can also be controlled
  - Still exotic, yet interesting EM opportunities

* Taken from Dung, L.-R., & Yen, J.-H *ILP-based algorithm for Lithium-ion battery charging profile*. Proceedings of the 2010 IEEE International Symposium on Industrial Electronics (ISIE), (S. 2286 - 2291). Bari, Italy

VARSVC & ETOSVC

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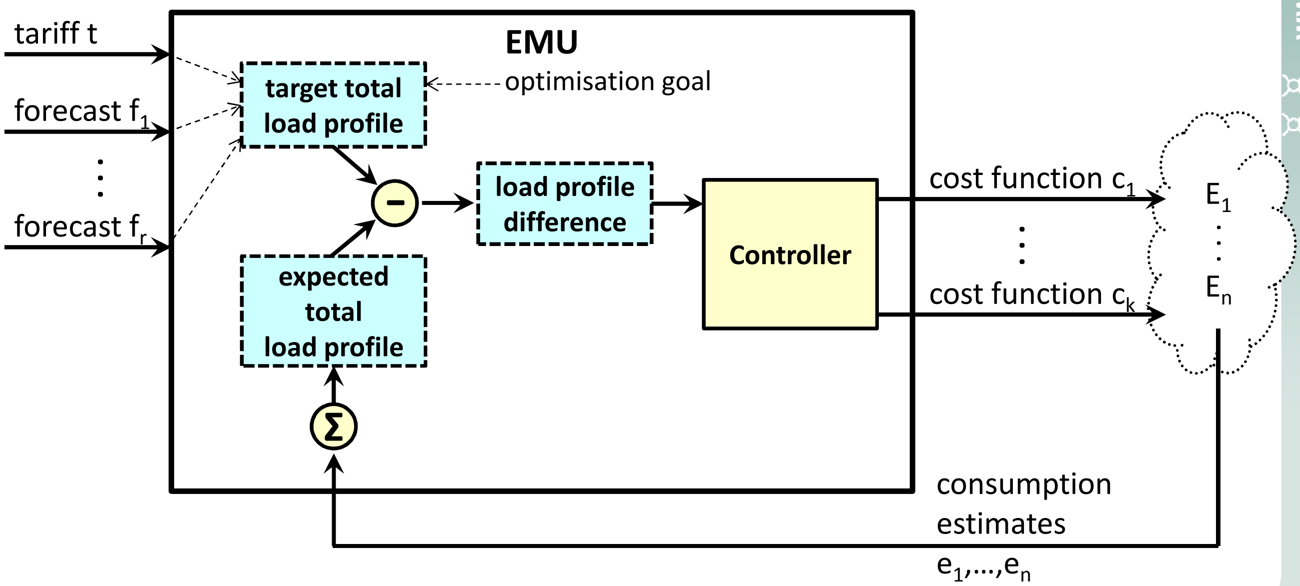
- Covers mostly lighting applications
  - VARSVC: Dimmable lighting, possibly controlled by luminance
  - ETOSVC: Presence detection
- No cost-dependent Energy Management
  - Possible user acceptance issues
  - Worth considering in Island scenarios
- Interesting aspects apart from EM:
  - Networking, Commisioning
  - Consumption forecast

CUSCON – Custom Control

- No Energy Management possible
  - User interaction too high
  - Or process too critical
- SmartCoDe infrastructure usable for custom control
  - Remote control, e.g. via a home gateway
  - User defined schedules
  - Ambient assisted living

A Global Energy Management Control Loop



Conclusion

- Semi-decentralised Energy Management provides abstraction…
  - …between EMU and EuP
  - …between global and local energy management
  - …to keep competence of EuP control with the manufacturer
- Approach can be extended to cover several hierarchy levels
- EuP classification
  - Collects EuPs which can be handled similar
  - Interfaces and EM-opportunities
  - EM algorithms

Thank you for your attention!

Your:

- Questions
- Remarks
- Ideas
- Objections

COOPERATION