SMARTC²NET

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Smart control of energy distribution grids over heterogeneous communication networks

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Technologies for Resilience

SEVENTH FRAMEWORK PROGRAMME

Agenda overview

- Background of the project
- Objectives and overall approach for the project
- System scope, use cases and architecture
- Fault management architecture
- Fault management approach

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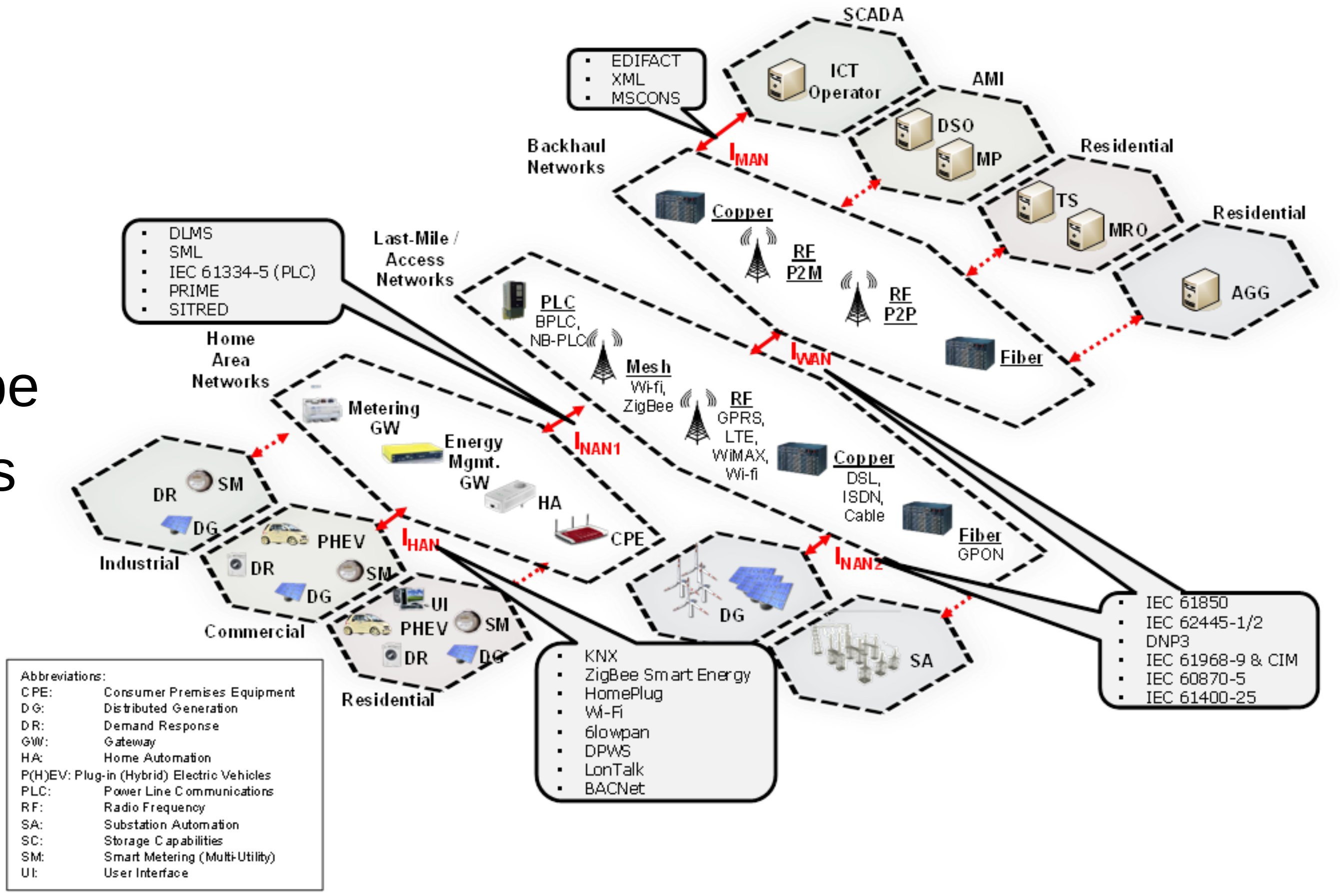
Background

- Use Cases in Future Smart Grid
  - distribution grid scope
  - many different actors
  - renewable energy resources
  - use of existing communication networks



Abbreviations:

CPE:	Consumer Premises Equipment
DG:	Distributed Generation
DR:	Demand Response
GW:	Gateway
HA:	Home Automation
P(H)EV:	Plug-in (Hybrid) Electric Vehicles
PLC:	Power Line Communications
RF:	Radio Frequency
SA:	Substation Automation
SC:	Storage Capabilities
SM:	Smart Metering (Multi-Utility)
UI:	User Interface

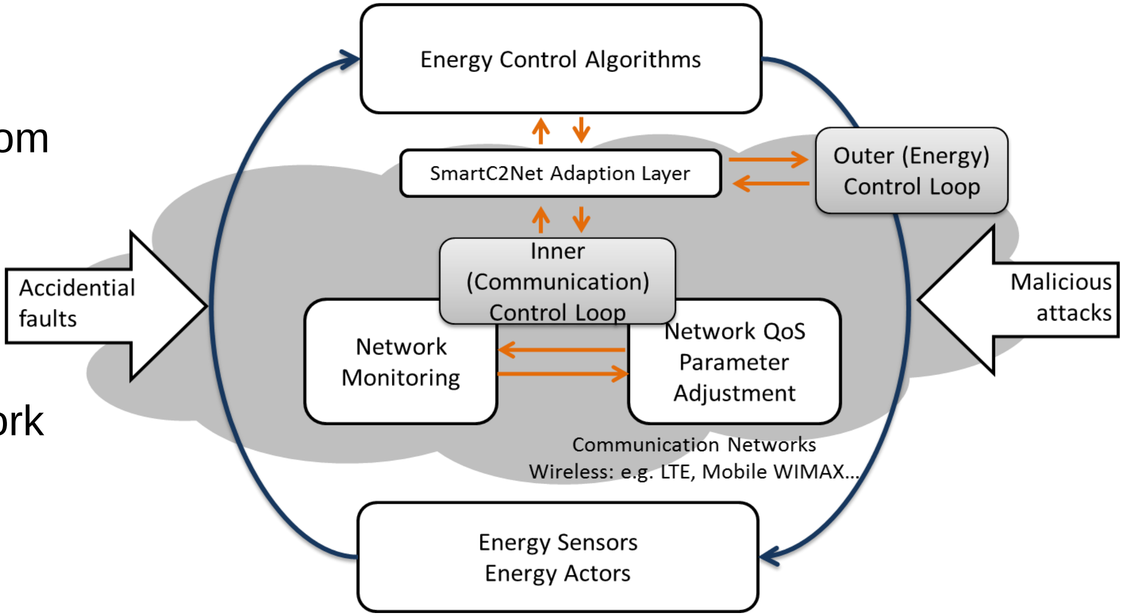
- Complex Network Architectures with many protocols
  - Complex information flow management
  - Hard to ensure reliable data transport
  - Exposed to cyber attacks

SmartC2Net approach and objective

Enable **robust smart grid control** utilizing **heterogeneous third-party communication infrastructures**.

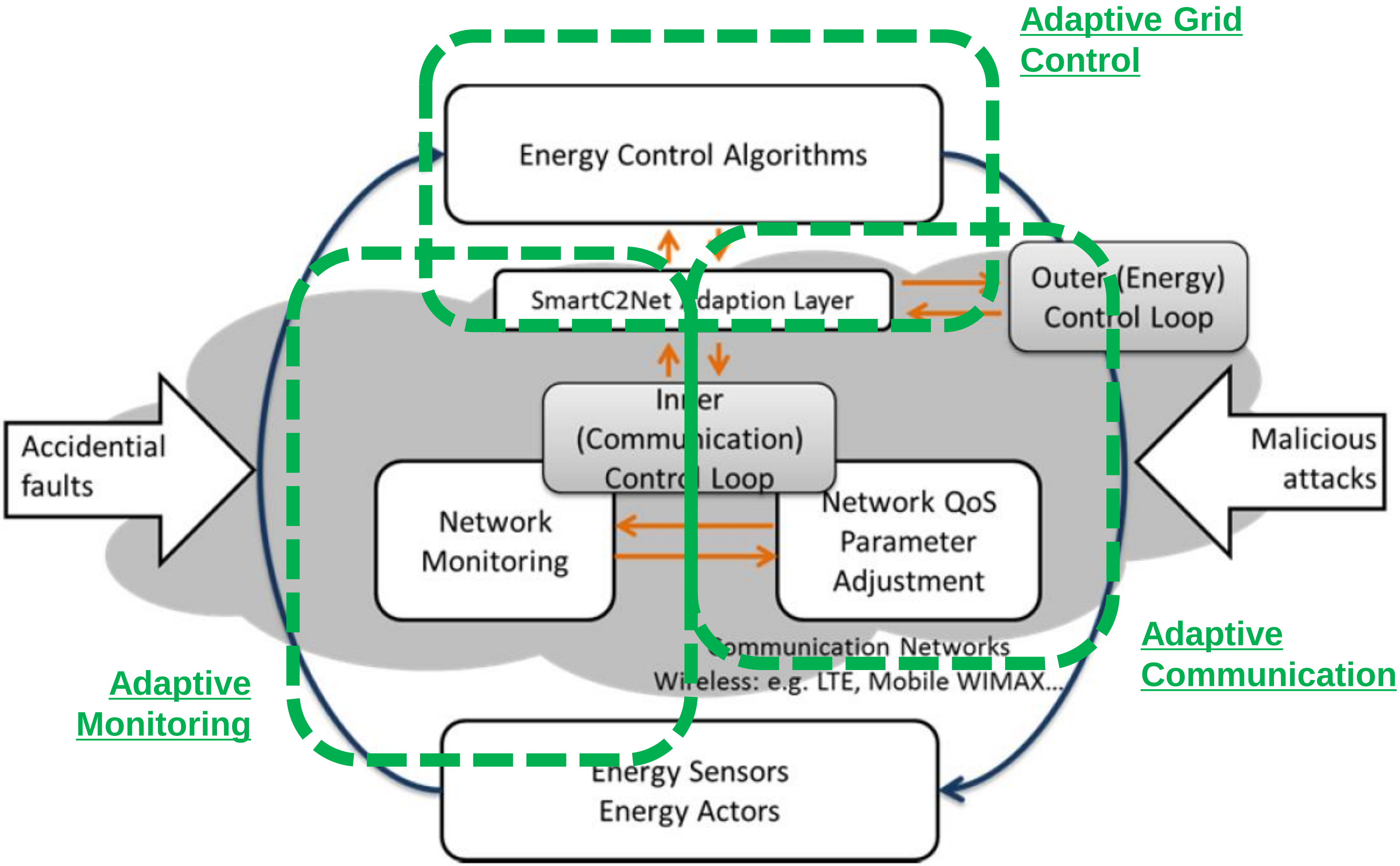
Robustness and interoperability target:

- Variability of network performance impacting
  - (a) quality of the input data obtained from energy related information sources
  - (b) timeliness/reactivity of the performed control actions (downstream communication).
- Security threats due to additional network interfaces and the use of off-the-shelf communication technology.
- Seamless information exchange for heterogeneous infrastructures using IP based middleware functions for adaptive management and control.



→ Optimize interplay between two control loops

SmartC2Net context



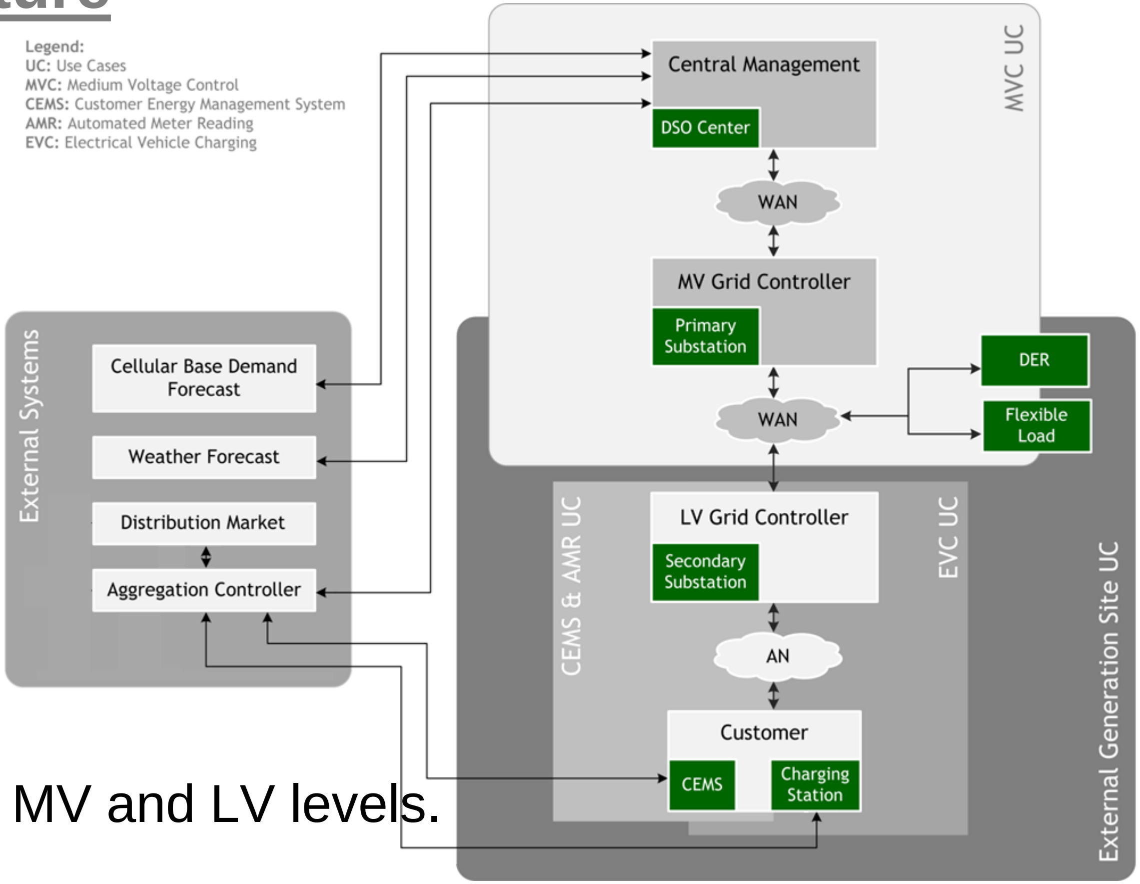
Challenge

- Exploit heterogeneous telecommunication means
  - Exploit wireless communication means
    - Reduce cost of installation
    - Tackle performance issues
  - Deploy countermeasure against cyber-security attack

- Provide grid control functionalities at LV level
  - As for now no control at LV is deployed, especially for faults management

System scope and architecture

- Architecture
  - Hierarchical control layers
  - Logical/physical components/interfaces
  - Communication networks and protocols



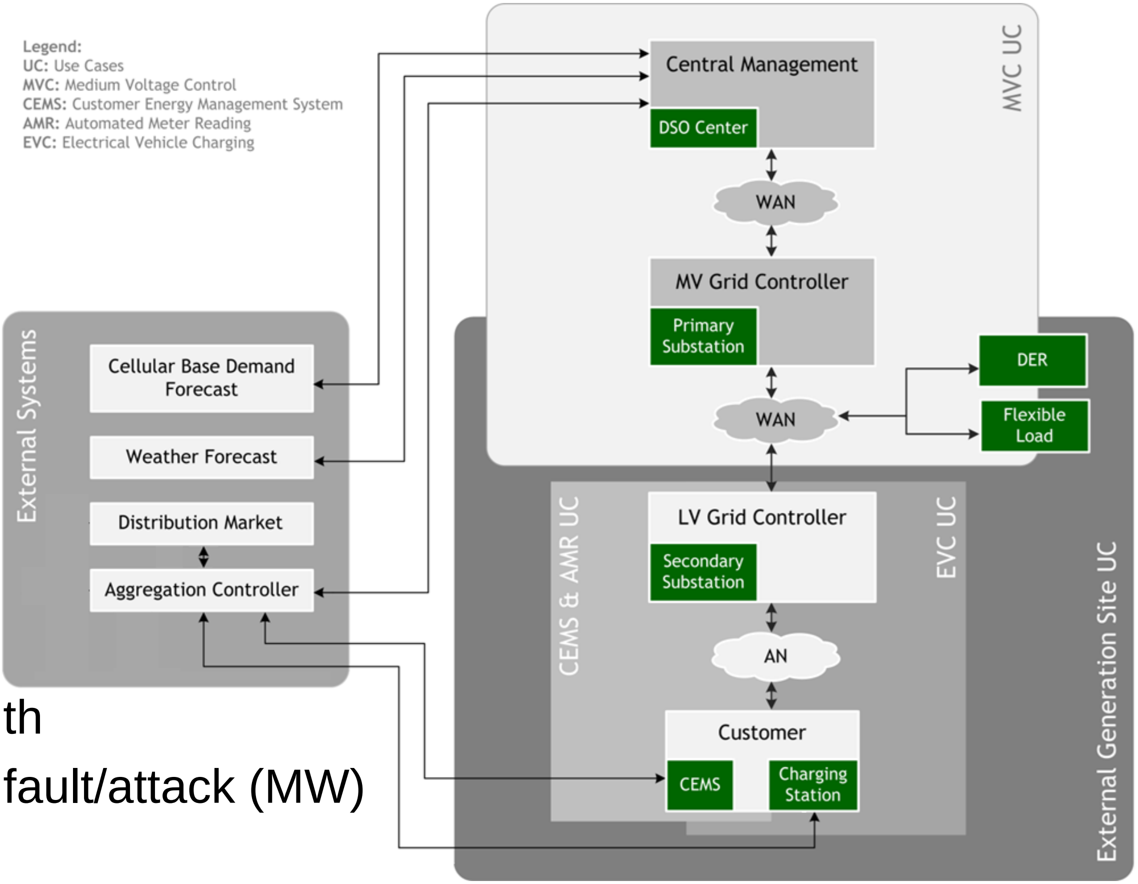
- Global aim:
  - Manage energy flexibility on MV and LV levels.

-> Aim at MV level:
- Power quality
- Loss minimization

-> Aim at LV level:
- Power quality
- Energy flexibility

Use cases and architecture

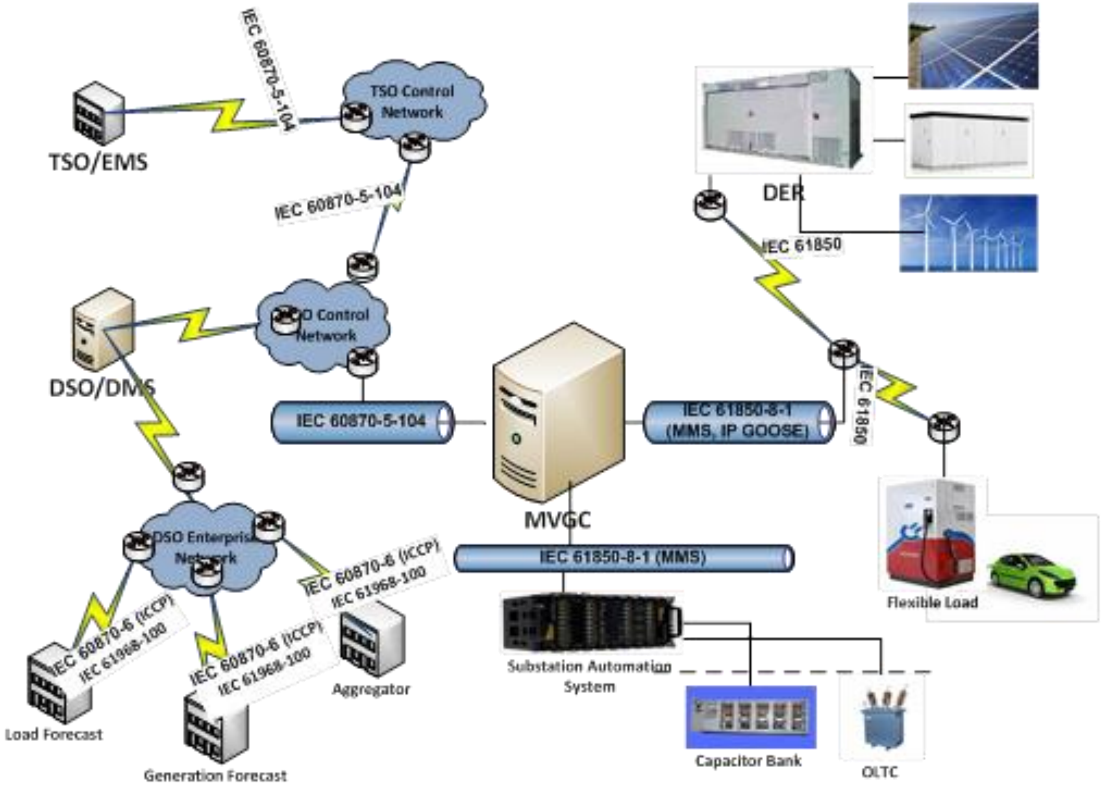
- 4 Use Cases
  - Synthetic views
    - Actors
  - Detailed IEC templates
    - Information flows
    - Control steps
  - Requirements
  - KPIs
    - E.g. Energy saved per month
    - Size of the grid affected by fault/attack (MW)
    - Power Loss
    - Voltage limit excess



Legend:
UC: Use Cases
MVC: Medium Voltage Control
CEMS: Customer Energy Management System
AMR: Automated Meter Reading
EVC: Electrical Vehicle Charging

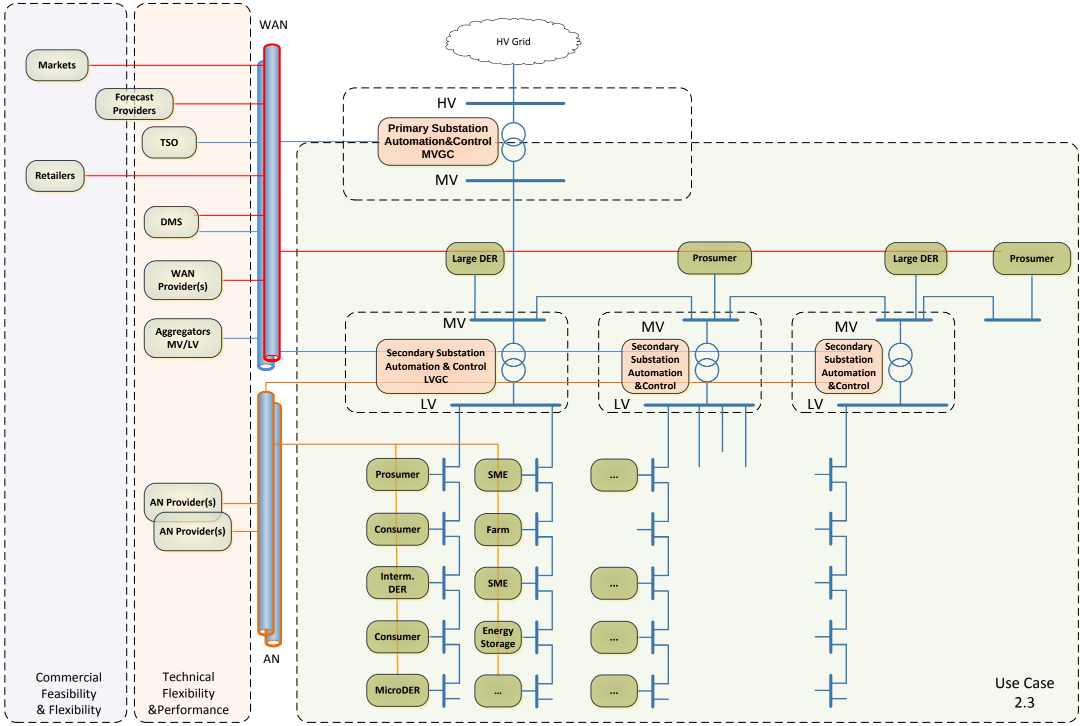
Use Case: Medium Voltage Control

- Address the communication needs of a Medium Voltage Control (MVC)
  - Connection with Distributed Energy Resources (DERs).
- Definition of an ICT architecture suitable for security analysis.



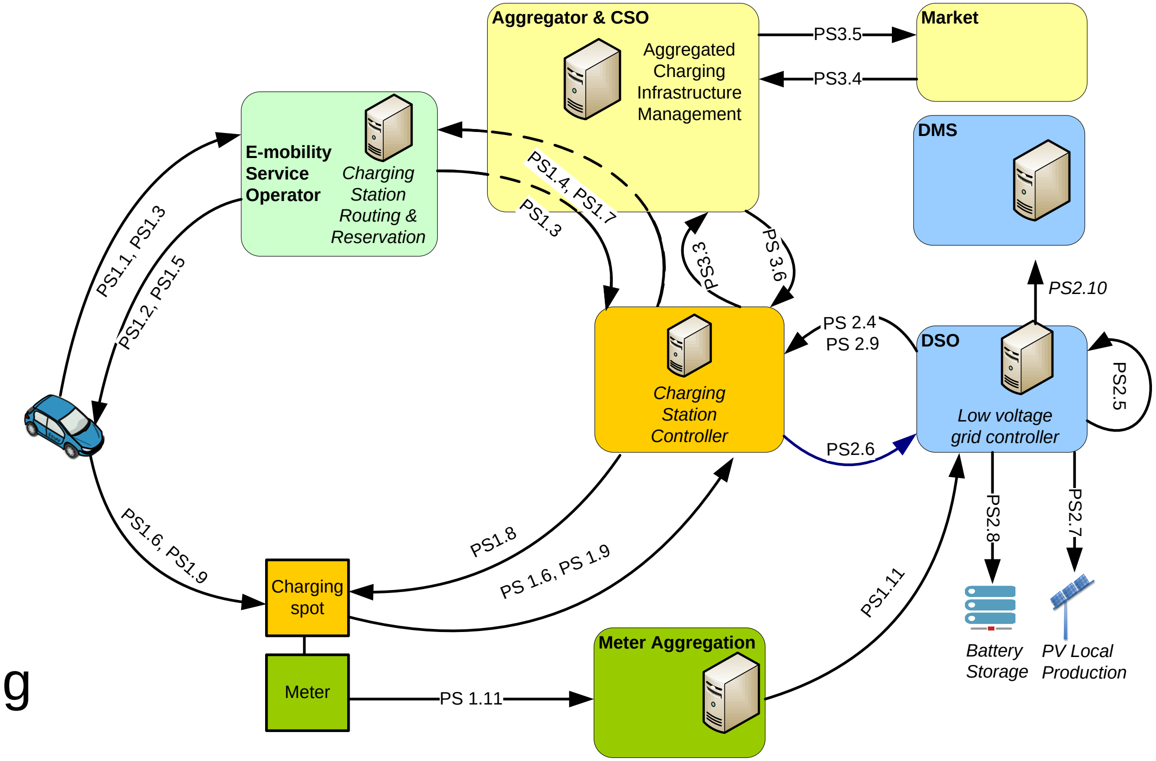
Use Case: External Generation Site

- Improve LV grid operation
  - Low voltage (LV) grids are exposed to new load scenarios due to DER.
  - New high consumer demands from Electrical Vehicle (EV) mobility.
- Automation and control techniques for future LV grids
  - Enables the DSO to utilize the flexibility of the LV grid assets
- The objective is to demonstrate the feasibility of distribution grid operation over an imperfect communication network



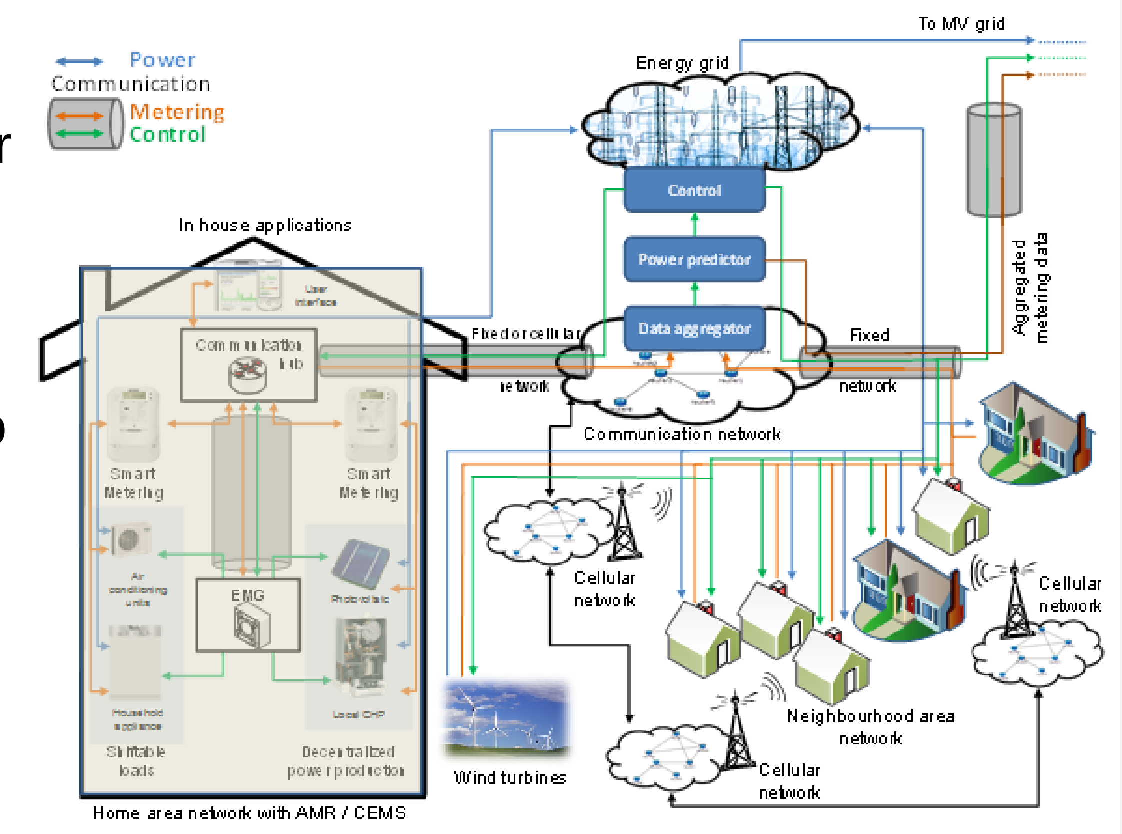
Use Case: Electric Vehicle Charge

- Satisfy charging demands of arriving EVs
  - Generated and stored energy is efficiently used
  - The grid is not overloaded.
- Enable electrical vehicle charging to become a flexible consumption resource
  - To balance energy and power resources in the LV grid
- Enable interoperation between new actors (e.g. CSO) and existing one (e.g. DSOs).
- Enable DSOs to monitor state of low voltage grid under EV load conditions.



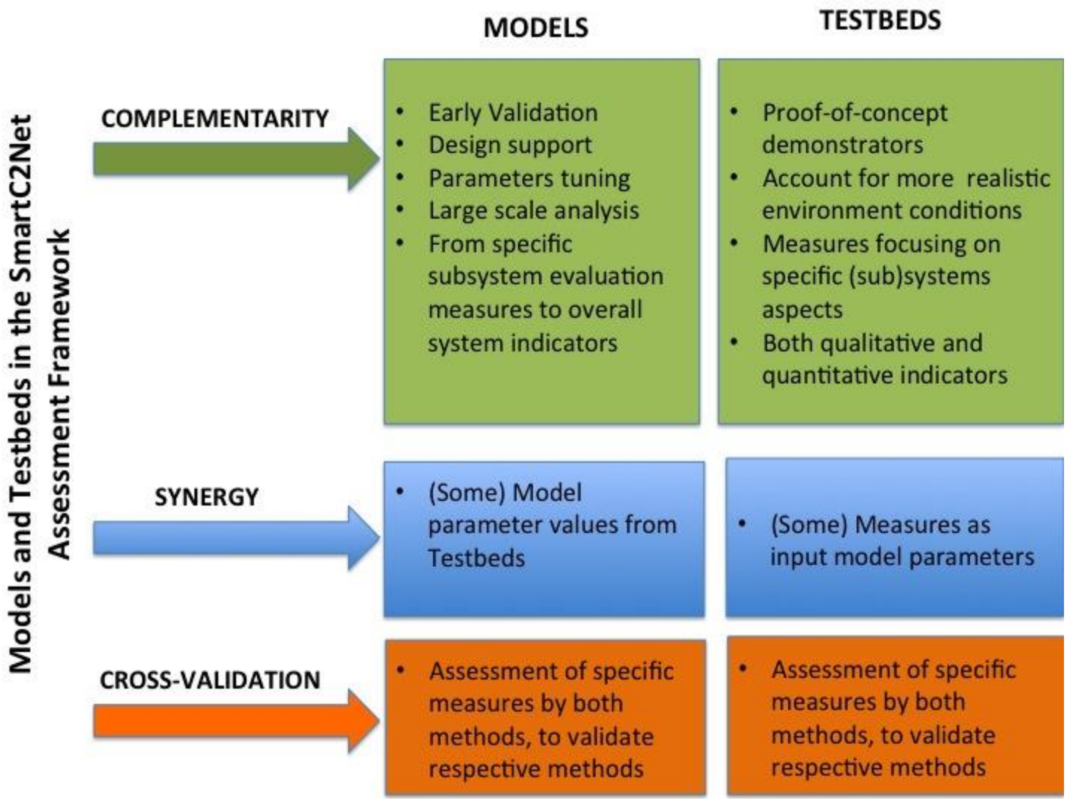
Use Case: CEMS & AMR

- Collection and transmission of aggregated data from the households to the energy utilities/meter reading operators for billing and accounting
- Improve distribution grid stability
  - Aggregate information of energy consumption in order to balance the distribution grid by enabling direct demand side management
  - Reduce energy costs for consumers by shifting flexible loads to less expensive time slots or improve utilization of local energy resources



Evaluation of project outcome

- **Model-based analysis**, to address early stage assessment of QoS and resilience indicators, ***considering faults and interdependencies effects***, and to conduct ***large-scale analysis*** of QoS parameters of different technologies approaches adopted/developed in the project
- **Testbeds-based analysis**, exploited as ***proof-of-concepts demonstrators*** for the project technologies in a wide range of relevant scenarios



Models and Testbeds in the SmartC2Net Assessment Framework

	MODELS	TESTBEDS
COMPLEMENTARITY	• Early Validation • Design support • Parameters tuning • Large scale analysis • From specific subsystem evaluation measures to overall system indicators	• Proof-of-concept demonstrators • Account for more realistic environment conditions • Measures focusing on specific (sub)systems aspects • Both qualitative and quantitative indicators
SYNERGY	• (Some) Model parameter values from Testbeds	• (Some) Measures as input model parameters
CROSS-VALIDATION	• Assessment of specific measures by both methods, to validate respective methods	• Assessment of specific measures by both methods, to validate respective methods

Coordinated assessment plan:

Complementarities exploited both inter- and intra-approaches; e.g:

- **complementarities among the 3 testbeds**
- **between state-space modelling and simulation**

Identification of measurements assessable through testbeds and relevant as input to models

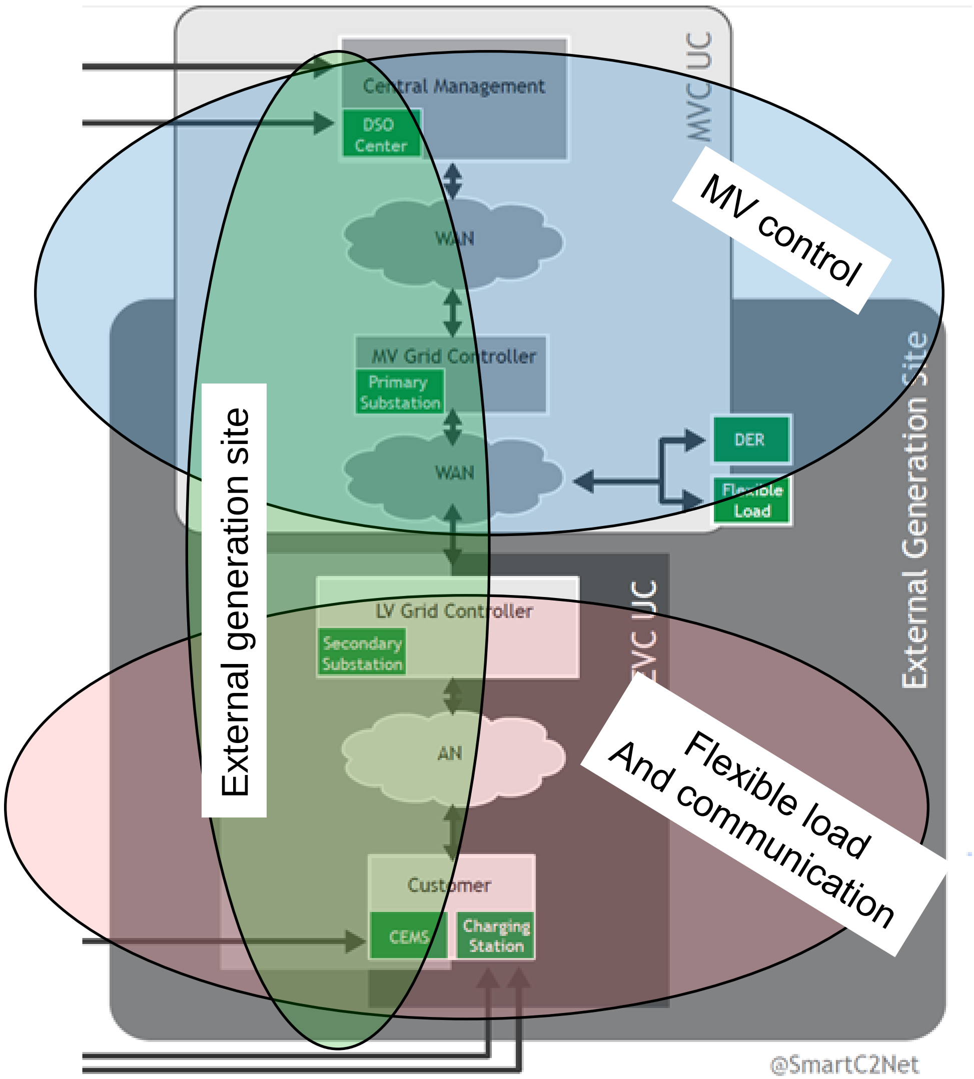
Identification of Metrics for cross-validation

Overview of the three test beds

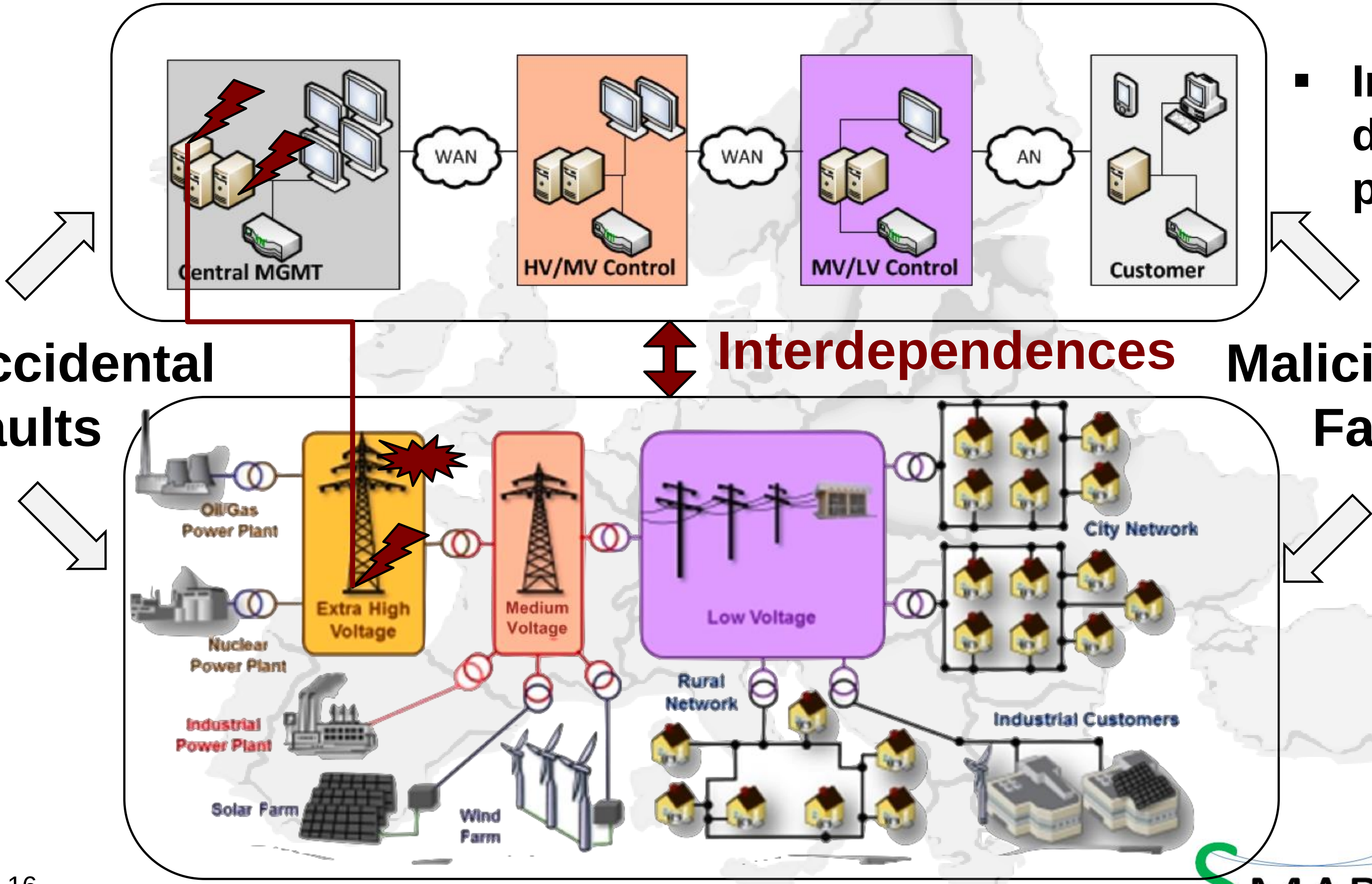
- MV control
  - MV control
  - Cyber attacks
  - Fully simulated

- External generation site
  - LV/MV grid control
  - Network performance adaptation
  - Both simulated and emulated

- Flexibility load and communication
  - LV Flexible load control
  - Network failure and adaptation
  - Fully simulated



ICT and Grid Cascading Failure



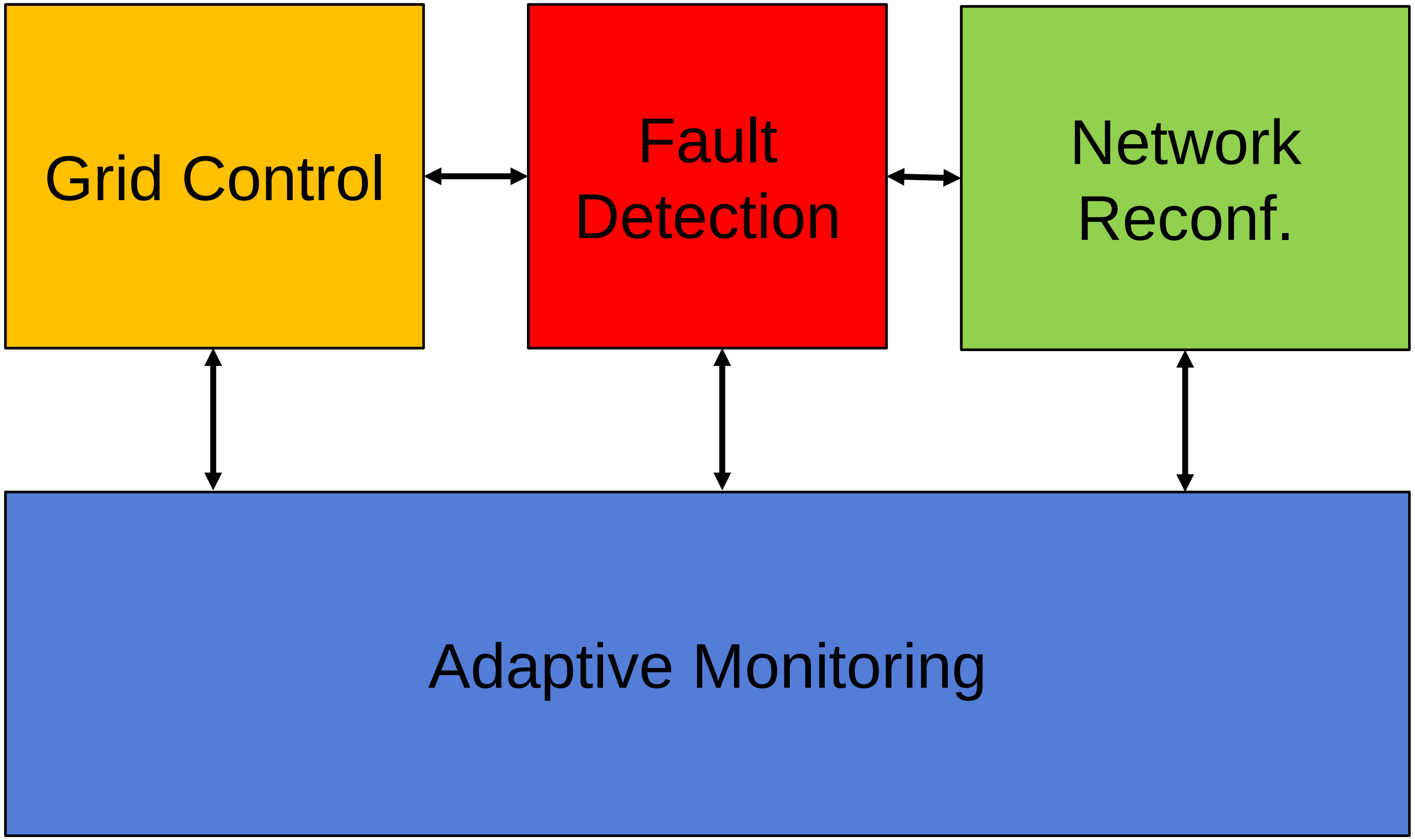
Interdependences

Accidental Faults

Malicious Faults

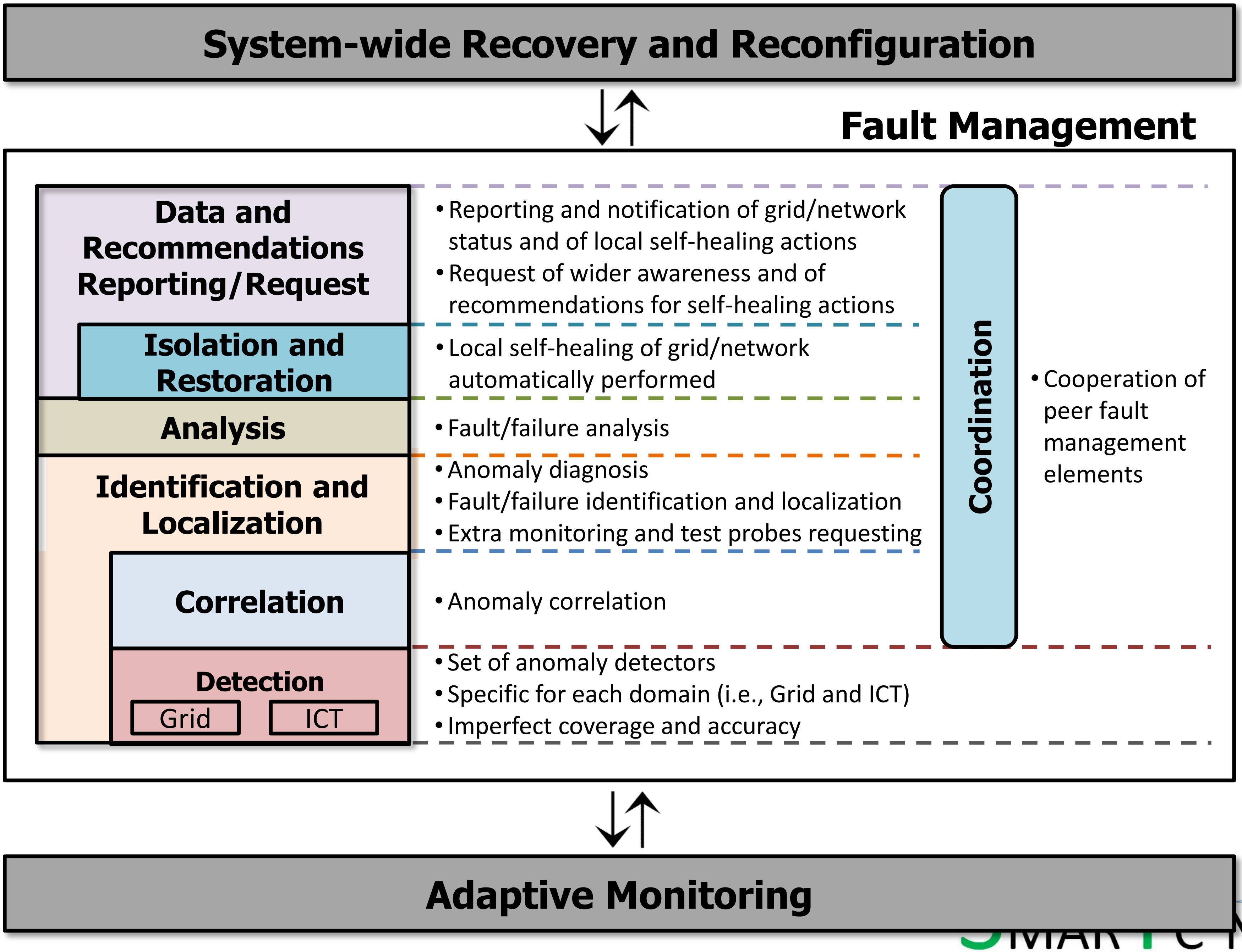
- **Multiple faults**
  - grid and control
- **Intra & Inter domain propagation**
  - e.g., ’03 Blackout

Fault Management Architecture



Fault Detection & Diagnosis aims

- The focus is on:
  - Identifying which faults have occurred when QoS levels dramatically decrease.
  - Localize these faults.
  - Recovery actions can be initiated.
  - Prediction to foresee network fault scenarios before they occur and lead to disruption of the grid control



System-wide Recovery and Reconfiguration

Fault Management

Data and Recommendations Reporting/Request
- Reporting and notification of grid/network status and of local self-healing actions
- Request of wider awareness and of recommendations for self-healing actions

Isolation and Restoration
- Local self-healing of grid/network automatically performed

Analysis
- Fault/failure analysis

Identification and Localization
- Anomaly diagnosis
- Fault/failure identification and localization
- Extra monitoring and test probes requesting

Correlation
- Anomaly correlation

Detection

Grid ICT
- Set of anomaly detectors
- Specific for each domain (i.e., Grid and ICT)
- Imperfect coverage and accuracy

Coordination
- Cooperation of peer fault management elements

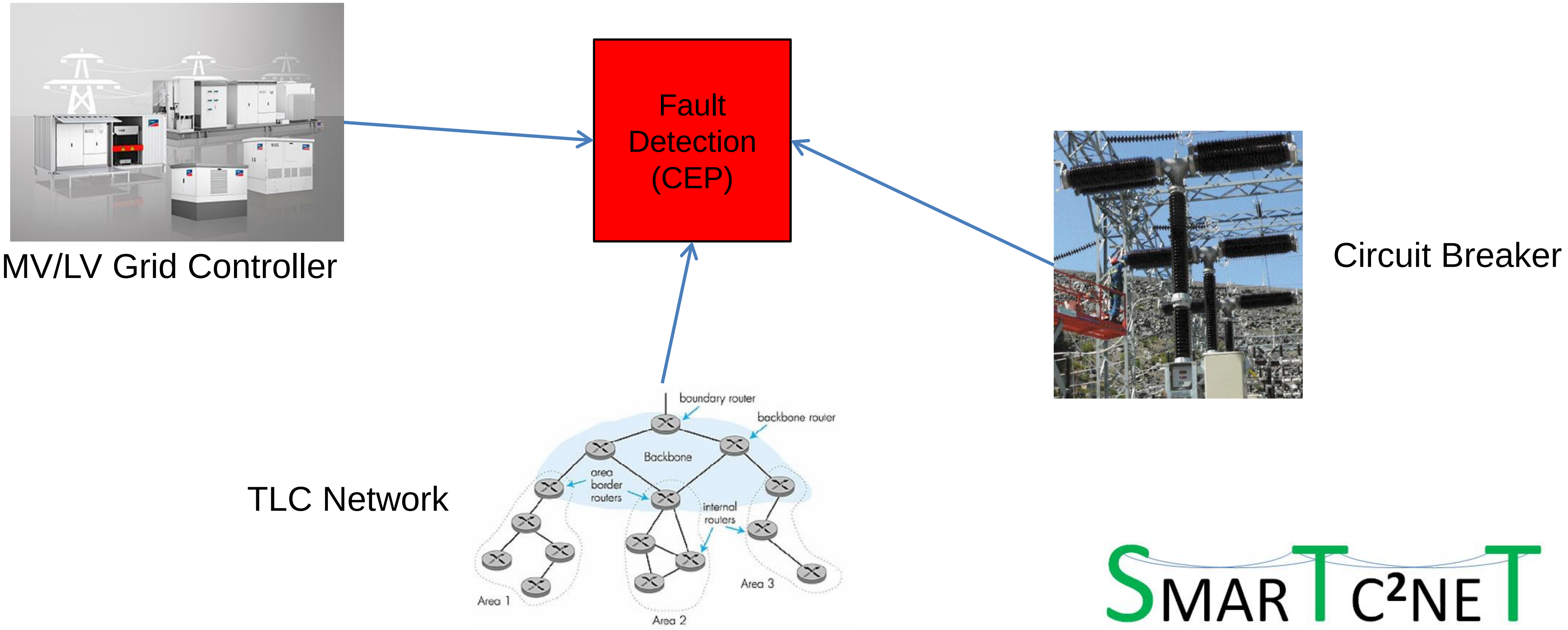
Adaptive Monitoring

Fault Detection

- Complex Event Processing (CEP) technology
  - It allows an efficient management of the pattern detection process in the huge and dynamic data streams.
  - It is very suitable for recognizing complex events and situations online.
  - It allows **fusion of information** generated by heterogeneous sensors supporting the goal of this work (i.e. Network sensors and Grid sensors)

Fault Detection

- CEP consists of the processing of events generated by the combination of data from multiple sources and aggregated in *complex-events* representing situations or part of them
  - Processing data coming from both grid and ICT domain can help to improve the fault diagnosis, because of their interdependencies.



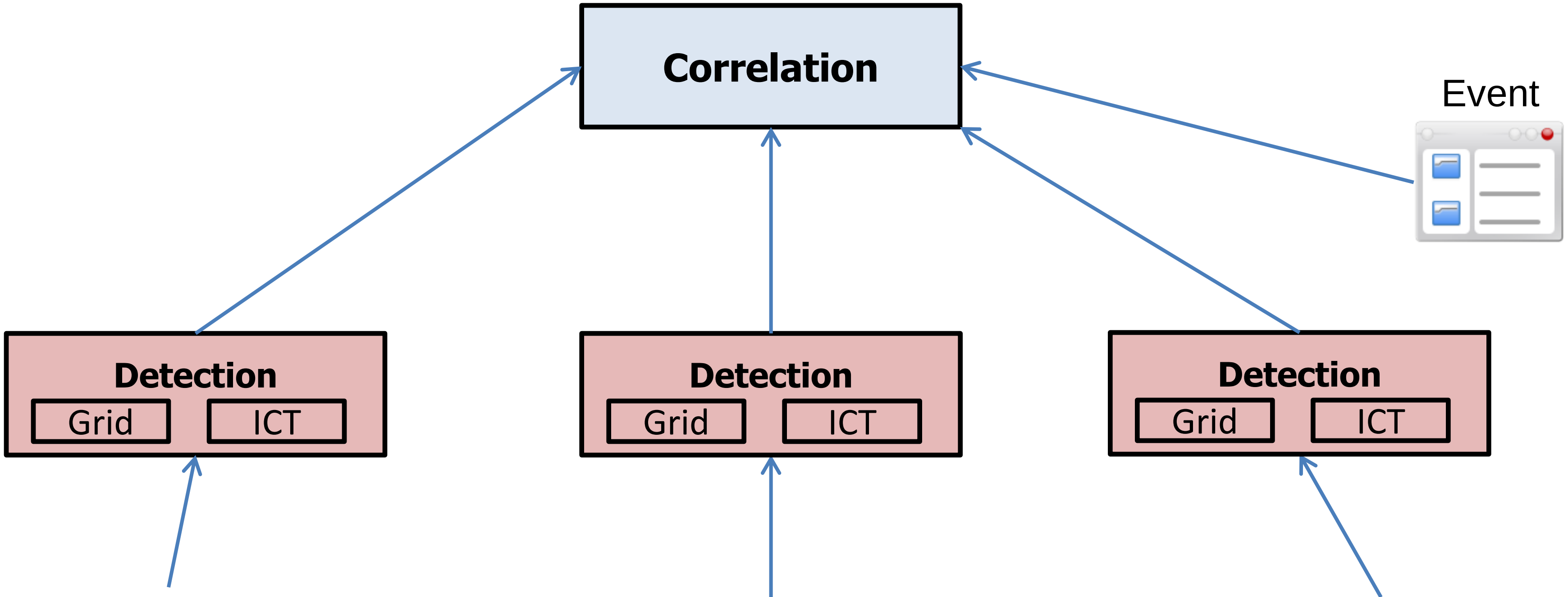
Fault Detection (CEP)

MV/LV Grid Controller

Circuit Breaker

TLC Network

Fault Detection



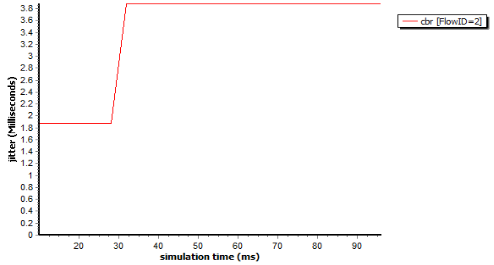
Correlation

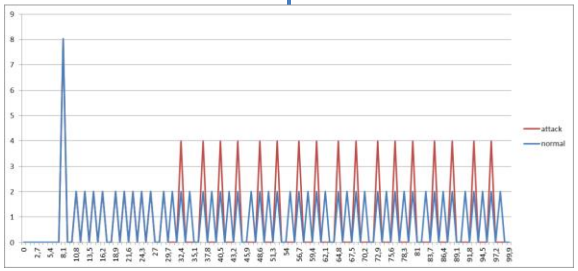
Event

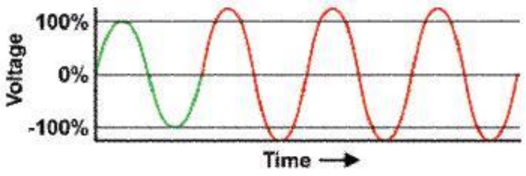
Detection
Grid
ICT

Detection
Grid
ICT

Detection
Grid
ICT





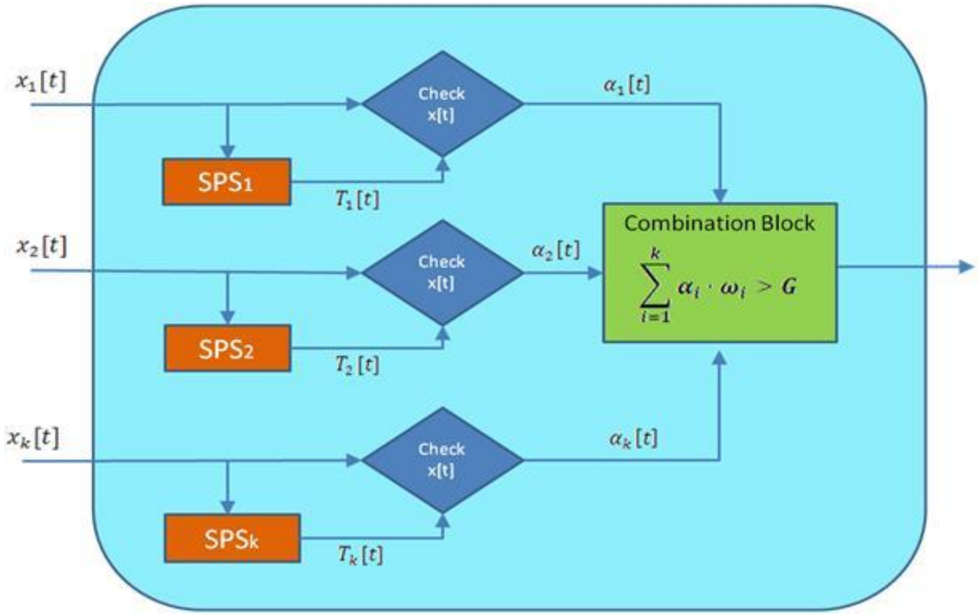


Detection [1] [2]

- Data samples are checked against their prediction Statistical Predictor and Safety Margin (SPS)

- If exceed the threshold then a flag is raised

- Combination block combines flags coming from several indexes α_i, each one weighted with weight ω_i



$$T_i^l[t+k] = x_i[t] - P[t+k] + SM[t]$$

$$T_i^u[t+k] = x_i[t] + P[t+k] + SM[t]$$

Correlation

- Correlate anomaly events which are detected in order to make fault diagnosis easier.

- Which anomaly/ies should be correlated?
  - Interested failure models are needed and should be developed!

- First of all failure scenarios that are relevant should be identified

Challenging failure scenarios

- Main/MV Circuit Breaker:
  - CB failure
  - CB controller failure
    - Possiblity to have cascading failure
  - Remote commands not executed
- Grid fault detector:
  - Unexpected Fault notification (False Positive)
  - Missed fault notification (False Negative)
  - Babbling failure
- Assets Communication Means:
  - Connection lost
  - Latency not satisfying requirements
  - Packet error rate exceeding the allowed one.
  - Etc..

Acknowledgement

- This work has been supported by the European Project SmartC2Net (grant agreement no 318023). Further information are available at www.smartc2net.eu

References

- [1] Antonio Bovenzi, Francesco Brancati, Stefano Russo, Andrea Bondavalli: An OS-level Framework for Anomaly Detection in Complex Software System. IEEE Transaction fo Dependable and Secure Computing
- [2] Andrea Bondavalli, Francesco Brancati, Andrea Ceccarelli: Safe Estimation of Time Uncertainty of Local Clocks. In Proc. of Int. IEEE Symp. On Precision Clock Synch. for Measur. Contr. and Comm., ISPCS 2009 pp 47-52

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Thank you!

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SEVENTH FRAMEWORK
PROGRAMME

Backups

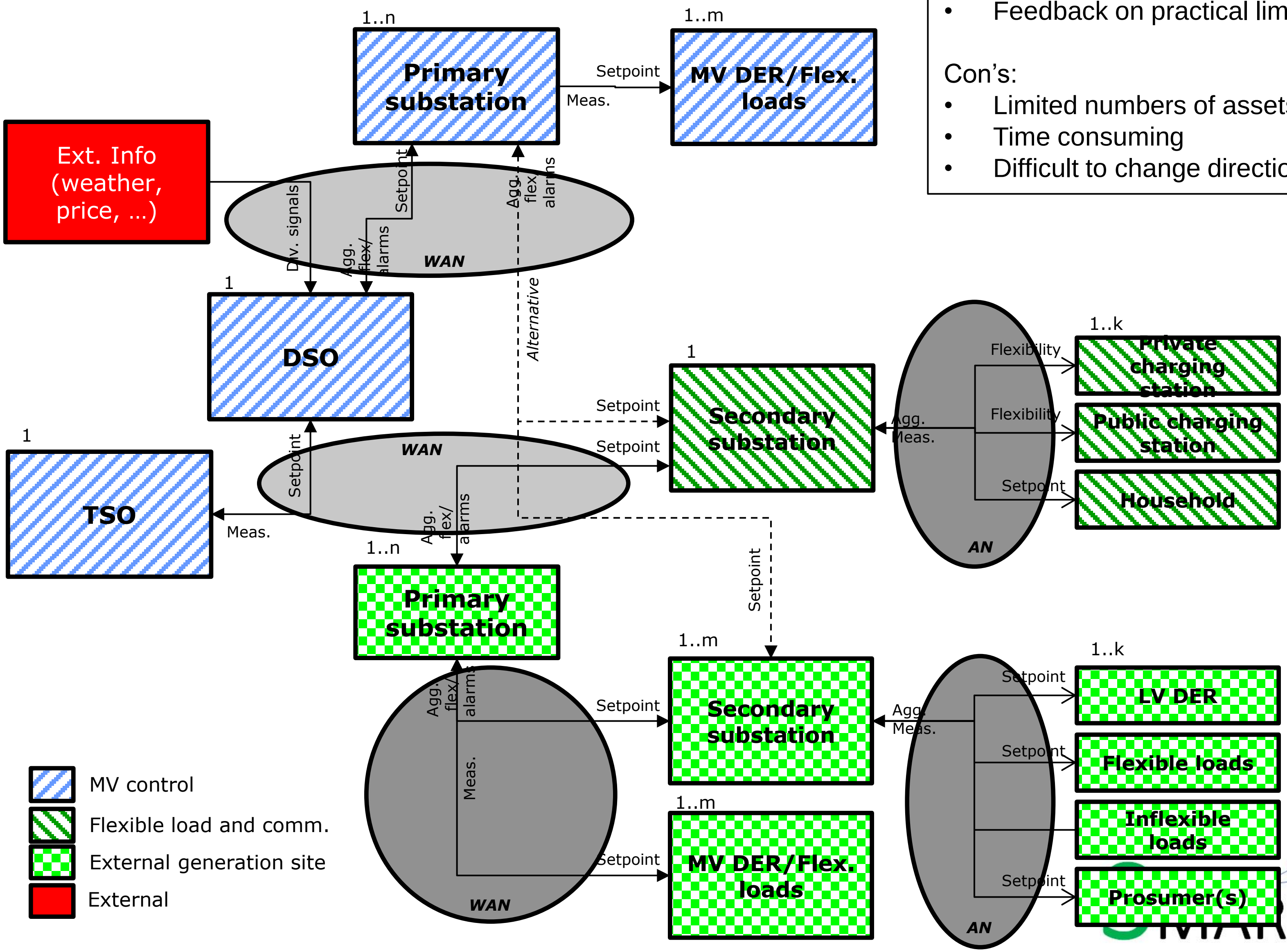
Overview of test bed components

Pro's:

- Realistic test environments for validation
- Expertices at each test site fully utilized
- Safe; no customers gets hurt
- Feedback on practical limitations

Con's:

- Limited numbers of assets per test bed
- Time consuming
- Difficult to change directions if needed



Ext. Info (weather, price, …)

1..n Primary substation

1..m MV DER/Flex. loads

Setpoint

Meas.

WAN

Div. signals

Setpoint

Agg. flex/ alarms

Agg. flex alarms

1 DSO

Alternative

1 TSO

Meas.

Setpoint

WAN

Setpoint

Agg. flex/ alarms

1..n Primary substation

1 Secondary substation

Setpoint

Setpoint

Agg. Meas.

AN

Flexibility

Flexibility

Setpoint

1..k Private charging station

Public charging station

Household

Setpoint

1..m Secondary substation

1..m MV DER/Flex. loads

WAN

Agg. flex/ alarms

Meas.

Setpoint

Setpoint

Agg. Meas.

AN

Setpoint

Setpoint

Setpoint

1..k LV DER

Flexible loads

Inflexible loads

Prosumer(s)

▨ MV control

▨ Flexible load and comm.

▦ External generation site

🟥 External