Smart TSO-DSO interaction schemes, market architectures and ICT Solutions for the integration of ancillary services from demand side management and distributed generation

# ICT Architecture Design Specification

## D3.2


## Authors:

S. Horsmanheimo, H. Kokkoniemi-Tarkkanen, P. Kuusela, L. Tuomimäki (VTT), C. A. Andersen, J. Dall (EURISCO), F. Pröstl Andrén, M. Stephan, F. Kupzog, J.L. Baut (AIT), K. N. Gregertsen, I.C.R. Tardy, G. Mathisen (SINTEF ICT), D. Ectors (VITO), R. Rodríguez, (TECNALIA), C. Arrigoni, F. Zanellini, F. Corti (SIEMENS), D. Moneta (RSE), M. Esser, G. Samen Curtis (VODAFONE), M. Pardo (ENDESA)


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|---|---|
| **Distribution Level** | Public |
| **Responsible Partner** | VTT |
| **Checked by WP leader** | Date: 18/04/2017<br>Seppo Horsmanheimo (VTT) |
| **Verified by the appointed Reviewers** | Date: 10/04/2017<br>Sture Holmstrøm (SINTEF-ICT), Jawad Haider Kazmi, Mario Faschang, Friederich Kupzog (AIT) |
| **Approved by Project Coordinator** | Date:<br>Gianluigi Migliavacca (RSE) |


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691405

# Issue Record

| | |
|---|---|
| **Planned delivery date** | 31/12/2016 |
| **Actual date of delivery** | 23/04/2017 |
| **Status and version** | Final version 1.0 |

| Version | Date | Author(s) | Notes |
|---|---|---|---|
| 0.1 | 24/01/2017 | VTT | The first Word version converted from Google Docs version |
| 0.2 | 31/01/2017 | EURISCO, RSE, AIT | Pilot profiles added |
| 0.3 | 12/02/2017 | VTT, VODAFONE | NFV and SDN chapter added |
| 0.4 | 17/02/2017 | All partners | Internal reviewing |
| 0.5 | 18/02/2017 | VTT | Send for the external review |
| 0.6 | 15/04/2017 | VTT | Modifications based on review comments |
| 1.0 | 23/04/2017 | VTT | Final version submitted |

# About SmartNet

The project SmartNet (http://smartnet-project.eu) aims at providing architectures for optimised interaction between TSOs and DSOs in managing the exchange of information for monitoring, acquiring and operating ancillary services (frequency control and restoration, congestion management, and voltage regulation) both at the local and national level, taking into account the European context. Local needs for ancillary services in distribution systems should be able to co-exist with system needs for balancing and congestion management. Resources located in distribution systems, like demand-side management and distributed generation, are supposed to participate in the provision of ancillary services both locally and for the entire power system in the context of competitive ancillary services markets.

Within SmartNet, answers are sought for the following questions:

- Which ancillary services could be provided from distribution grid level to the whole power system?
- How should the coordination between TSOs and DSOs be organised to optimise the processes of procurement and activation of flexibility by system operators?
- How should the architectures of the real-time markets (in particular the markets for frequency restoration and congestion management) be consequently revised?
- What information has to be exchanged between system operators and how should the communication (ICT) be organised to guarantee observability and control of distributed generation, flexible demand and storage systems?

The objective is to develop an ad hoc simulation platform able to model physical network, market, and ICT in order to analyse three national cases (Italy, Denmark, Spain). Different TSO-DSO coordination schemes are compared with reference to three selected national cases Italian, Danish, Spanish.

The simulation platform is then scaled up to a full replica lab, where the performance of real control devices is tested.

In addition, three physical pilots are developed for the same national cases to test specific technological solutions regarding:

- monitoring of generators in distribution networks while enabling them to participate in frequency and voltage regulation,
- capability of flexible demand to provide ancillary services for the system (e.g. thermal inertia of indoor swimming pools, distributed storage of base stations for telecommunication).

## Partners

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# List of abbreviations and acronyms

| Acronym | Meaning |
|---|---|
| 2G, 3G, 4G, 5G | 2nd, 3rd, 4th, 5th Generation mobile technologies |
| 3GPP | 3rd Generation Partnership Project |
| aFRR | Automatic Frequency Restoration Reserve |
| AMS | Advanced Metering System |
| API | Application Programme Interface |
| AS | Ancillary Service |
| ASIC | Application Specific Integrated Circuit |
| BPSK | Binary Phase-Shift Keying |
| BRP | Balance Responsible Party |
| C plane | Control plane |
| CAPEX | Capital Expenditure |
| CBA | Cost Benefit Analysis |
| CDMA | Code Division Multiple Access |
| CEI | Competitive Enterprise Institute |
| CEPT | European Conference of Postal and Telecommunications Administrations |
| CIM | Common Information Model |
| cIoT | Cellular IoT |
| CMP | Commercial Market Player |
| CN | Core Network |
| CoAP | Constrained Application Protocol |
| CS | Coordination Scheme |
| CSV | Comma-Separated Values |
| DER | Distributed Energy Resource |
| DL | Downlink |
| DLT | Distributed Ledger Technology |
| DMS | Distribution Management System |
| DRX | Discontinuous Reception |
| DSO | Distribution System Operator |
| DSSS | Direct-Sequence Spread Spectrum |
| E2E | End-to-End |
| EA | Enterprise Architect (software) |
| ebIX | European forum for energy Business Information eXchange |
| EC-GSM | Extended Coverage GSM |
| ECP | Energy Communication Protocol |
| eDRX | Extended Discontinuous Reception |
| EFET | European Federation of Energy Traders |

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|---|---|
| EGPRS | Enhanced General Packet Radio Service |
| ELECTRA | Integrated Research Programme on Smart Grids |
| EMS | Energy Management System |
| eMTC | Enhanced Machine Type Communication, often referred to as LTE-M |
| eNodeB | Evolved Node B (evolved base stations) |
| ENTSO-E | European Network of TSOs for Electricity |
| EPC | Evolved Packet Core |
| ESB | Enterprise Service Bus |
| ESO | European Standardization Organizations |
| ETSI | European Telecommunications Standards Institute |
| E-UTRA | Evolved Universal Terrestrial Radio Access |
| FAN | Field Area Network |
| FC | Fog Computing |
| FCR | Frequency Containment Reserve |
| FRR | Frequency Restoration Reserve |
| FRRa | Frequency Restoration Reserve (automatic) |
| FRRm | Frequency Restoration Reserve (manual) |
| FTP | File Transfer Protocol |
| FTPS | File Transfer Protocol Secure |
| GERAN | GSM EDGE Radio Access Network |
| GOOSE | Generic Object Oriented Substation Events |
| GPRS | General Packet Radio Service |
| GPS | Global Positioning System |
| GSM | Groupe Spécial Mobile, Global System for Mobile Communications |
| HAN | Home Area Network |
| HetNet | Heterogeneous Network |
| HSPA | High Speed Packet Access |
| HSS | Home Subscriber Server |
| HS | High Voltage Substation |
| HTTP | Hypertext Transfer Protocol |
| HTTPS | HTTP Secure |
| HV | High Voltage |
| HVRS | High Voltage Regulation System |
| ICT | Information and Communications Technology |
| IEC | International Electrotechnical Commission |
| IMO | Independent Market Operator |
| IoT | Internet of Things |
| IP | Internet Protocol |
| IPv4 | Internet Protocol version 4 |

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|---|---|
| IPv6 | Internet Protocol version 6 |
| IT | Information Technology |
| JMS | Java Message Service |
| JSON | JavaScript Object Notation |
| KPI | Key Performance Indicator |
| LMO | Local Market Operator |
| LoRa | Long Range, low power wireless technology |
| LP | Low-Power |
| LPWA | Low-Power Wide-Area |
| LPWAN | Low-Power Wide-Area Network |
| LTE | Long Term Evolution |
| LTE-M | see eMTC |
| LV | Low Voltage |
| M2M | Machine to Machine |
| MAC | Media Access Control |
| MADES | MArket Data Exchange Standard |
| MCL | Maximum Coupling Loss |
| MEC | Mobile Edge Computing |
| mFRR | Frequency Restoration Reserve (manual) |
| MIMO | Multiple-Input and Multiple-Output |
| MME | Mobility Management Entity |
| MMS | Manufacturing Message Specification |
| MMS | Market Management System |
| mMTC | Massive Machine Type Connectivity |
| MO | Market Operator |
| MQ | Message Queue |
| MQTT | MQ Telemetry Transport, ISO standard (ISO/IEC PRF 20922) publish-subscribe-based lightweight messaging protocol |
| MTC | Machine-Type Communication |
| MV | Medium Voltage |
| MVRS | Medium Voltage Regulation System |
| NB | Narrowband |
| NB-IoT | Narrowband IoT |
| NCAS | Network Calculation Algorithms System |
| NFV | Network Function Virtualisation |
| NFVI | Network Function Virtualisation Infrastructure |
| NIST | National Institute of Standards and Technology |
| NMS | Network Management System |
| NoSQL | No Structured Query Language |

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|---|---|
| NVE | Norwegian Water Resources and Energy Directorate |
| OLTC | On Load Tap Changers |
| OPEX | Operating Expenditure |
| OPF | Optimal Power Flow |
| PGW | Packet Gateway |
| PSM | Power Save Mode |
| PS | Primary Substation |
| PV | Photovoltaics |
| QoE | Quality of Experience |
| QoS | Quality of Service |
| RAN | Radio Access Network |
| RAT | Radio Access Technology |
| RES | Renewable Energy Source |
| REST | Representational State Transfer, communication protocol |
| RFC | Request For Comments |
| RNC | Radio Network Controller |
| RR | Replacement Reserve |
| RTU | Remote Terminal Unit |
| SCADA | Supervisory Control and Data Acquisition |
| SDN | Software-Defined Networking |
| SGAM | Smart Grid Architecture Model |
| SOA | Service Oriented Architecture |
| SOAP | Simple Object Access Protocol |
| SON | Self-Organising Network |
| SPOF | Single Point of Failure |
| SS | Secondary Substation |
| SSL | Secure Sockets Layer |
| SWOT | Strengths, Weaknesses, Opportunities, and Threats, analysis model |
| TETRA | Terrestrial Trunked Radio |
| TLS | Transport Layer Security |
| TR | Technical Report (3GPP) |
| TS | Trading System |
| TSO | Transmission System Operator |
| UC | Use Case |
| UDN | Ultra-Dense Network |
| U plane | User plane |
| UE | User Equipment |
| UL | Uplink |
| UML | Unified Modelling Language |

| | |
|---|---|
| uMTC | Ultra-reliable Machine Type Communication |
| UMTS | Universal Mobile Telecommunications System |
| URLLC | Ultra-Reliable Low Latency Communications |
| UTRA | Universal Terrestrial Radio Access |
| WAN | Wide Area Network |
| VC | Voltage Control |
| VNF | Virtual Network Function |
| WLAN | Wireless Local Area Network |
| VoLTE | Voice over Long-Term Evolution |
| WSN | Wireless Sensor Network |
| XML | eXtensible Markup Language |

# 1 Executive summary

Energy markets and energy systems are evolving. The question is what the modern ICT can offer for the energy systems to make them smarter and more flexible for future ancillary services, i.e., functions needed to guarantee quality and security of electrical grids? The specified five TSO-DSO coordination schemes [1] revealed new challenges and opportunities for ICT with respect to communication cost, quality, resiliency, response time, and security. In the future, communications can either be one of the key enablers or a hindrance in the transition towards flexible energy systems. In order to fully exploit the potential offered by ICT, we analysed the TSO-DSO coordination schemes carefully and took advantage of existing and future ICT technologies to elaborate a flexible ICT architecture to fulfil the identified communications and security requirements.

In this report, we present the analysis procedure that was created to identify and classify ICT requirements of today's and tomorrow's energy systems. We broke the relationships among interacting stakeholders (business actors) down to system components and interfaces. Each data exchange between system components was described with ICT and security requirements. The core TSO-DSO coordination schemes were presented with four processes: prequalification, procurement, activation, and settlement.

The architecture design was done both top-down and bottom-up, so that we can differentiate common system components suited for all TSO-DSO coordination schemes and those that are highly TSO-DSO coordination scheme specific. The analysis also involved the study of new technologies including e.g. the next generation wireless networks (5G), Internet-of-Things (IoT), the data hub, and the blockchain. They are potential tools to improve reliability, cost-effectiveness, and security in interactions between different systems in the SmartNet ecosystem.

We also created an ICT architecture design model with the Enterprise Architect tool. The architecture was created according to the Smart Grid Architecture Model (SGAM), which describes the structure of the architecture and interactions between entities from the business layer down to the component layer. As a part of SGAM, we also created detailed SGAM models for pilots and simulation platform. These derived models focus on real ICT system implementations covering mainly one TSO-DSO coordination scheme. They are used to map the common ICT architecture and communication requirements of specific coordination schemes to the pilot realizations.

After the completion of the architecture design, the specifications and SGAM models are handed over to other work packages to support the implementation or deployment of ICT solutions for the pilots and simulation platform.

# 2 Introduction

Energy systems are moving from static and centralised architectures towards more flexible, automated, and distributed structures due to the growing share of ICT and distributed energy resources (DER) [2]. ICT is gradually expanded throughout geographically distributed networks allowing an increased number of remotely controllable subsystems and components. Moreover, large-scale deployment of distributed generation and storage are boosting the evolution from passive systems towards more proactive ones that can react on various dynamics of the energy systems with improved efficiency and agility. As the energy flow becomes more and more bidirectional, the amount of required information increases and demands for ICT become more versatile depending on e.g. offered ancillary services, end-users' preferences, and market regulations This poses new challenges for communication systems, because the communication cost, quality, availability, response time, and security, as experienced/available today, do not always meet the expectations. Improved communication and security solutions are needed to increase controllability, to manage loads, and to ensure high quality and flexibility of distributed energy systems.

In this document, we use the illustration depicted in Figure 1 as a reference model for the ICT architecture, actors, system components, and services.

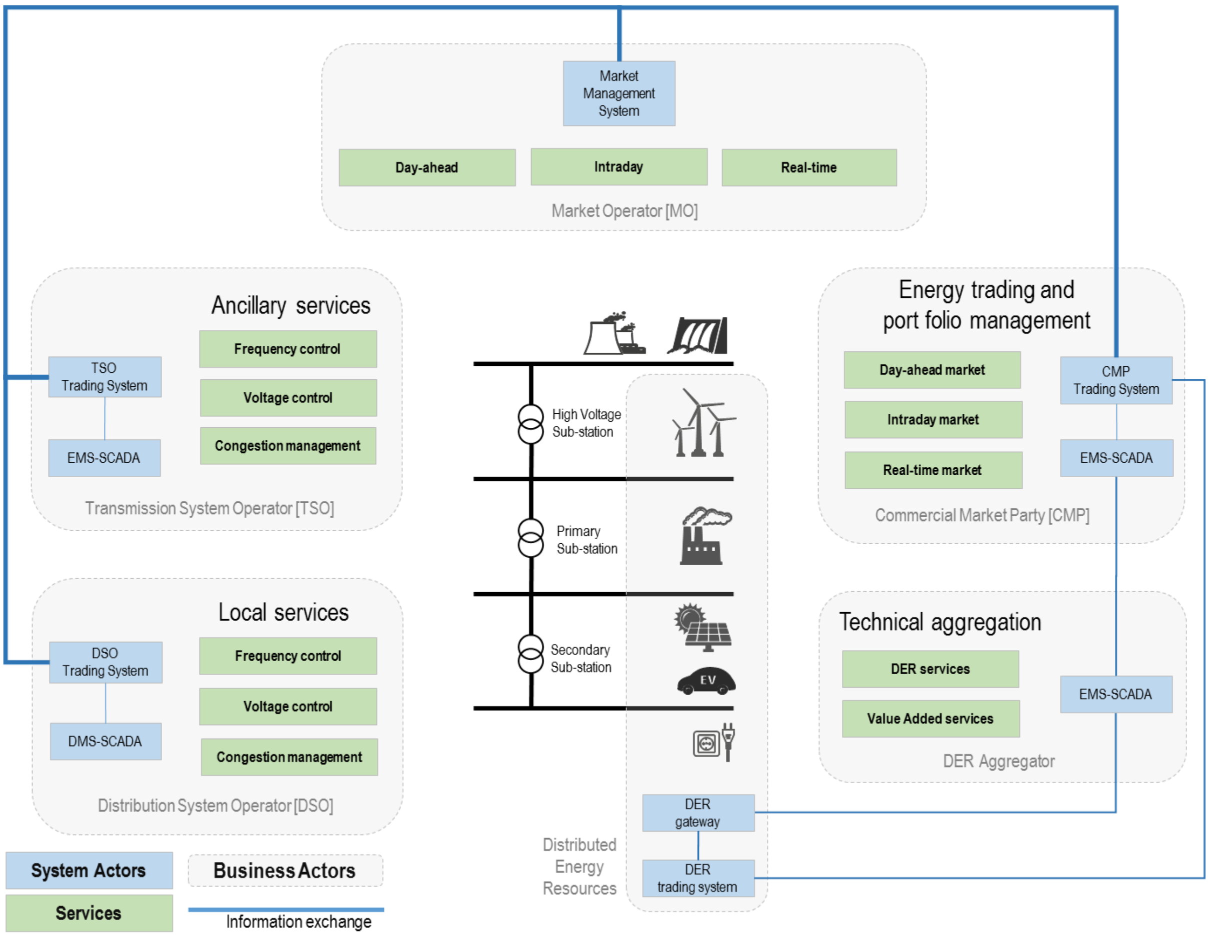



*Figure 1. SmartNet reference model illustrating the ICT architecture, actors, system components, and services.*

The gray boxes present core business actors/roles in five coordination schemes. The stakeholders can play multiple business actor roles. For example, an aggregator can do both technical aggregation and energy trading, and, in this reference model, the Market Operator (MO) is a role that could be played by various actors depending on the market scenario: central market (TSO), local (DSO), shared (TSO-DSO), and independent (IMO).

Blue boxes represent the main system components used by business actors:

- Trading system (TS) is the system devoted to exchanging information with the market management system, e.g. schedules for planning or activation of ancillary services.
- DMS/EMS-SCADA is considered here as the system used for network operation.
- Market management system (MMS) is the system used to run the market processes (by the TSO, DSO or IMO) and to connect market operator and stakeholders.

Connecting blue lines in the figure represent communication links between system components. Most of the connections are related to services exchanged in the market framework and, therefore, they are not time critical. They do not require an immediate response. Only DMS/EMS-SCADA related communications

are considered real time, involving mainly measurement exchange in SmartNet use cases. Some of the interfaces are internal and they are depicted with thinner lines.

Green boxes are ancillary services identified in deliverable D1.3 including frequency restoration/balancing (aFRR, mFRR and RR) and congestion management, frequency containment reserve (FCR), and voltage control (VC) [1]. DER services in technical aggregation block include different types of technical aggregation services, which can be used to help the grid operations related to e.g. frequency and voltage control. The figures in the middle represent the grid infrastructure and distributed energy resources, from high-voltage down to low-voltage.

This drawing is used as a reference illustration throughout this document to help the reader to understand the relationship between the SmartNet architecture and the ICT requirements described.

This report is a continuation to the deliverable D3.1, which defined the foundation for ICT requirements and the process to capture the ICT requirements at business and operation levels from the WP1 TSO-DSO coordination schemes [3]. This deliverable presents the SGAM models for the overall ICT architecture and for pilot systems. In this context, the SGAM models for pilots are called profiles and they are created for WP4 (Simulation Platform) and WP5 (Pilots) as ICT recommendations.

## 2.1 Scope

Today's communication architectures are designed for generic communication needs. They do not address all of the energy system requirements [4]. Our architecture design scope was the five coordination schemes and associated ancillary service use cases presented in the deliverable D1.3 [1]. We focused on a common ICT architecture design as well as on the creation of derived models for each pilot and simulation platform. The coordination schemes specified in D1.3 contain the following market models:

- **Centralised AS market model:** There is one common market for ancillary services, operated by the TSO for resources at both transmission and distribution levels. The TSO is responsible for the operation of its own ancillary service market. The DSO is not involved in the procurement and activation process. The TSO does not take DSO constraints actively into account. The DSO may buy some flexibility resources in the longer term to solve e.g. structural grid congestion or to postpone certain grid reinforcements.
- **Local AS market model:** There is a separate local market managed by the DSO. DSO level resources are offered to the TSO via the DSO/local market after the DSO has allocated resources needed for solving local congestions. The DSO aggregates and transfers bids to the AS market, operated by the TSO. The DSO assures that only bids respecting the DSO grid constraints can take part in the AS market. The TSO is responsible for the operation of its own market for ancillary services, where both resources from the transmission grid and DSO aggregated resources from

the distribution grid can take part. The DSO has priority to use the flexible resources from the local grid.

- **Shared balancing responsibility model:** There is an ancillary market for resources connected to the TSO's grid and a separate local market for resources connected to the DSO's grid. The TSO and DSO are sharing balancing responsibilities according to a predefined schedule. Resources from the DSO's grid cannot be offered to the TSO's grid. DSO constraints are integrated into the market clearing process of the local market. The TSO is limited to resources connected at the transmission level. The TSO is responsible for the balancing of the transmission grid. The DSO is the operator of a local market. The DSO contracts local flexibility for both local congestion management and balancing of the DSO-grid. The DSO is responsible for the balancing of the DSO grid according to the predefined schedule.
- **Common TSO-DSO AS market model:** There is a common market for flexibilities for both TSO and DSO with resources connected at both transmission and distribution levels. TSO and DSO are both responsible for the management and operation of the market. DSO constraints are integrated into the market clearing process. Two alternatives are considered:
  (1) All constraints are integrated into one optimization process that encompasses both TSO and DSO grid constraints (centralised),
  (2) A separate local DSO market for local grid constraints runs first (without a commitment to the market participants) and communicates with an AS market operated by a TSO with transmission grid-connected resources. The outcome of the second market communicates back to the first market to find the optimal solution to be communicated to the market participants (decentralised variant).

  The TSO and DSOs are jointly responsible for the market operation of the common TSO-DSO market in the centralised case or jointly responsible for the final outcome of the two separate market runs in decentralised case. The TSO is contracting AS from both transmission and distribution. In practice, in the centralised variant, the joint responsibility could be organised by allocating the responsibility to a third party, under the guidance of both TSOs and DSOs.

- **Integrated flexibility market model:** The common market is operated by an independent/neutral market operator. There is no priority for TSO, DSO or CMP. Resources are allocated to the party with the highest willingness to pay. There is no separate local market. DSO constraints are integrated into the market clearing process. TSOs and DSOs are contracting AS in a common market. TSOs and DSOs can sell previously contracted DER to the other market participants. Market forces dictate how flexibility will be allocated.

This report continues the work that was started in D3.1 (ICT requirements specifications) to convert the ICT requirements into architecture design and functional specifications. The architecture design with SGAM modelling was extended from business and operation layers down to information, communication,

and component layers. The work included also the study of existing energy and communication system architectures and forthcoming technological enablers to assist us to design a flexible ICT architecture.

The report is divided into five main chapters. Chapter 3 gives an overview of existing architectures in energy sectors providing the foundation for the architecture design. Chapter 4 focuses on methodology and describes the main stages and iterations required for discovering the ICT requirements and creating the ICT architecture for the ancillary services. Chapter 5 gives an overview of SGAM modelling and describes the ICT architecture model. Chapter 6 describes the pilot systems and the method how the developed ICT requirement capturing process was applied to the pilots. Chapter 7 introduces enabling technologies in ICT offering potential solutions to improve flexibility, reliability, security, and cost-efficiency. The selected technologies cover 5G and IoT to collect information from all parts of the network. Technologies such as Network Function Virtualisation (NFV), Software Defined Networking (SDN) and network slicing are offering dedicated services for stakeholders over the same physical communication network. Data hub is providing easy access to up-to-date data storage, and the blockchain is offering improved security and privacy in market actions. These technologies come with a cost that needs to be assessed before introducing them to the architecture.

The annexes present profile tables, which were utilised in SGAM modelling and pilot profiling. The SGAM models created with Enterprise Architect are presented in a separate model file.

## 2.2 Motivation

Energy systems and markets are changing. They will become smarter, more flexible, and more adaptive. For this, more detailed information is needed from all parts of the grid and that requires an increased amount of communication. However, there are challenges with respect to communication availability, quality, and security. Forthcoming technologies are tackling these challenges and offering potential solutions. Despite this fast evolution in ICT, there is a need to evaluate and elaborate communication architecture for energy systems to fully exploit the potentials offered by ICT technologies. This includes the operations from the business layer down to the component layer. The architecture needs to be able to:

- fulfil monitoring aspects,
- guarantee observability,
- control distributed generation, flexible demand and storage systems, and
- permit the participation of DER in energy markets.

Our motivation for carefully analysing different TSO-DSO coordination schemes and associated use case descriptions was to better understand the interactions between different stakeholders and their systems. Each interaction has been identified with communication and security requirements. In order to

fulfil those requirements, we were also enforced to gather more information about existing energy and ICT architecture designs and forthcoming communication solutions with their pros and cons.

Figure 2 depicts the role of ICT as an enabler for services and applications in energy systems. Effective coupling of communication and energy networks is essential for the creation of an agile energy system with two-way electricity and information flow from the power plants down to appliances. Open energy markets and ICT technologies allow small DER owners and aggregators to participate in energy markets and to create new renewable power generation options and ancillary services.

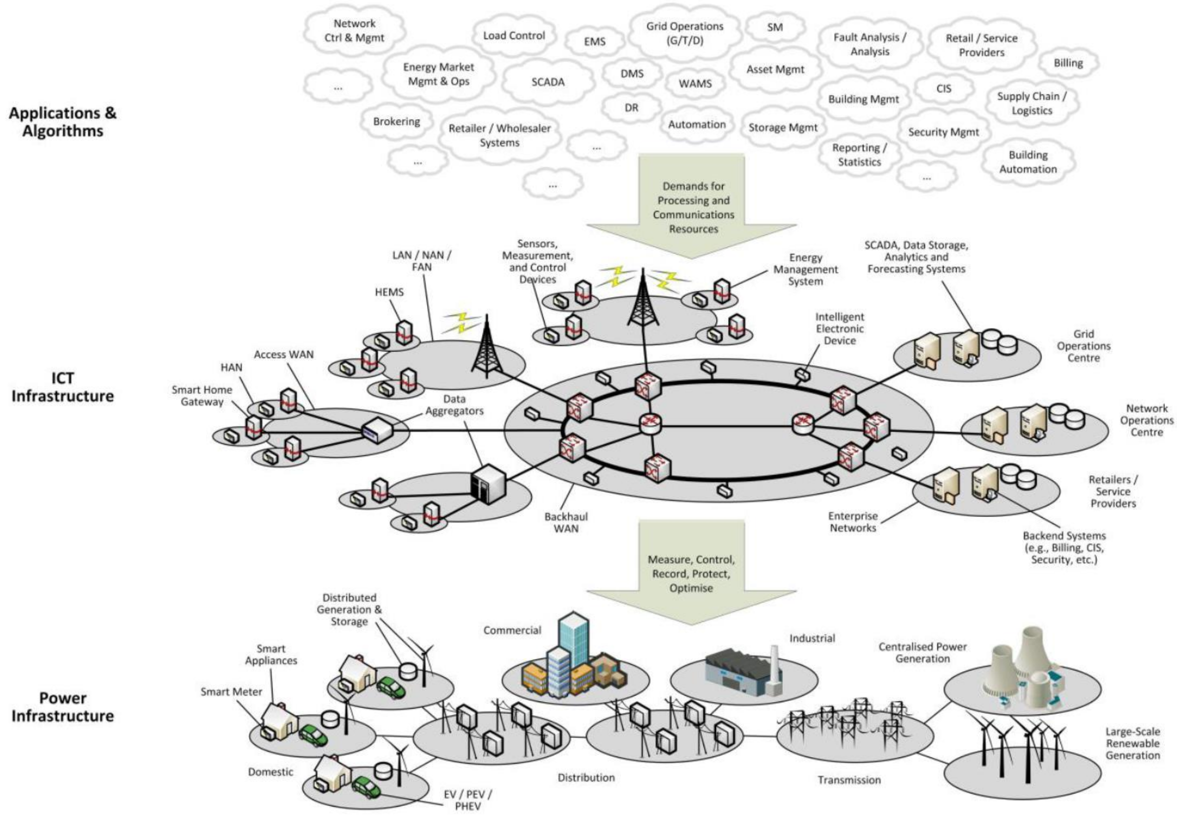



*Figure 2. Smart grid as a system-of-systems [5].*

## 2.3 Key objectives

The goal of this report is to present the outcome of the design and analysis procedure to capture ICT requirements for future energy systems in different coordination schemes and to design a common ICT architecture model to support selected ancillary services. The other goal is to test the architecture design with the information obtained from Danish, Spanish, and Italian pilots and simulation platform presented in chapter 6 and to evaluate its feasibility for practical implementations.

There was a technical gap between energy and ICT experts, so a co-operative process was needed to enforce both energy and ICT experts to interact closely. We used an iterative and incremental design process to find the suitable design level. The procedure included the following tasks:

- Analysis of the need for information exchange and communication among different stakeholders in centralised and distributed coordination schemes.
- Discovery of ICT technologies available now and in the future, and understanding possibilities and challenges associated with them.
- Elaboration of ICT architecture design and the creation of profile specifications to the SmartNet pilots and simulation platform.

Our first goal was to utilise and enhance the results of deliverables D1.3 and D3.1, and take them closer to ICT system realisations in WP4 (simulation platforms) and WP5 (pilots). We selected Enterprise Architect software with SGAM extension as the main tool for the design and management of the ICT architecture model. The model specifications in the electrical form significantly eased our design work during iteration cycles and later, the delivery of specifications to WP4 and WP5.

Our second goal was to use well-defined terms and definitions in order to support the exploitation of the ICT architecture design model during and after the SmartNet project. For this, common terms, definitions, and use case template skeleton were taken from the ELECTRA project [6]. They were modified during the design and analysis process to support both TSO-DSO level market and ICT aspects.

Our ICT architecture design does not completely fulfil the detailed specifications needed for ICT system realisations. It is not possible to come up with a detailed design that fits in all market, business, and ICT environments. Therefore, we see this report and the associated SGAM model as a starting point or guidelines for practical system realisations. These guidelines are prepared together with energy and ICT experts focusing on specific ancillary service use cases. To ease the understanding of the guidelines, we also created design examples for Danish, Spanish, and Italian pilots as well as for simulation platform.

Our last goal was to create pilot specific SGAM models for each of the pilots based on the realisation plans and identified requirements. Such models should include the main steps of functionalities and a graphical presentation of the architecture covering system actors, services and the relations between them.

# 3 Energy architecture overview

This chapter presents the system implementation of selected ancillary services today and in the future in the context of SmartNet. The studied ancillary services include frequency restoration/balancing (aFRR, mFRR and RR) and congestion management, frequency containment reserve (FCR), and voltage control (VC) [1].

## 3.1 Illustrations of present and future energy architectures for ancillary services

Ancillary services refer to a range of functions, which TSOs need for guaranteeing the adequacy and security of electrical grids. These services include frequency regulation, provision of reactive power and other services. Access to a broad range of services offered by a wider range of providers (including RES, aggregators, consumers, etc.) will allow TSOs to make more efficient decisions in order to improve the adequacy and security.

Today, resources connected to a medium voltage (MV) grid cannot provide ancillary services; however, implementing smart grid functionalities, DSOs will be allowed to manage new devices and information from the network and, consequently, improve the real-time operations. New smart grid functionalities will provide new opportunities and facilitate the involvement of new actors. The following subchapters illustrate the frequency containment control, frequency restoration reserve, and voltage control in today's and tomorrow's ancillary services. The future implementation of the ancillary service is illustrated by applying a specific coordination scheme to the architecture.

### 3.1.1 Frequency containment reserve

The purpose of the frequency containment reserve (FCR) is to control and balance any frequency fluctuations from the nominal value in order to maintain the power balance in the interconnected system.

As can be seen in Figure 3, this service is limited to high voltage (HV) units, which can adjust swiftly their active power in order to balance any frequency fluctuations. Today this service is mandatory for the adequate power plant (P > 10 MVA) and generally, it is not remunerated.

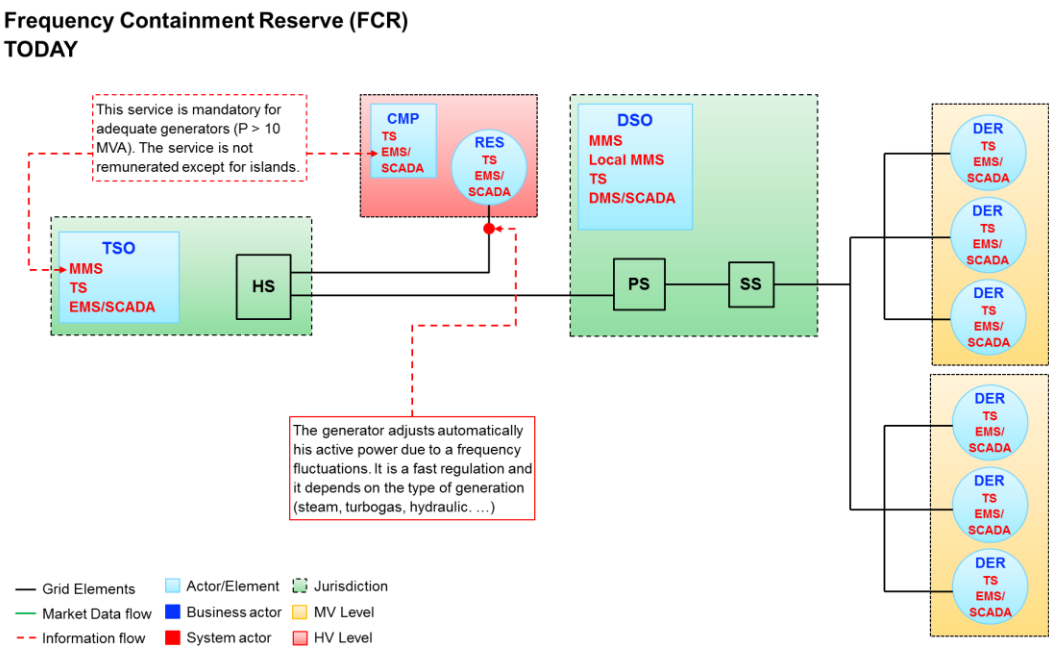



*Figure 3. Frequency Containment Reserve (FCR) today.*

According to Figure 4, the TSO operates a centralised common AS market, in which it contracts FCR services from units connected to HV or MV. TSO and DSO have a common object of minimizing their (operational) costs. Currently, the activation of FCR is totally autonomous. Therefore, the communication during activation is not necessary.

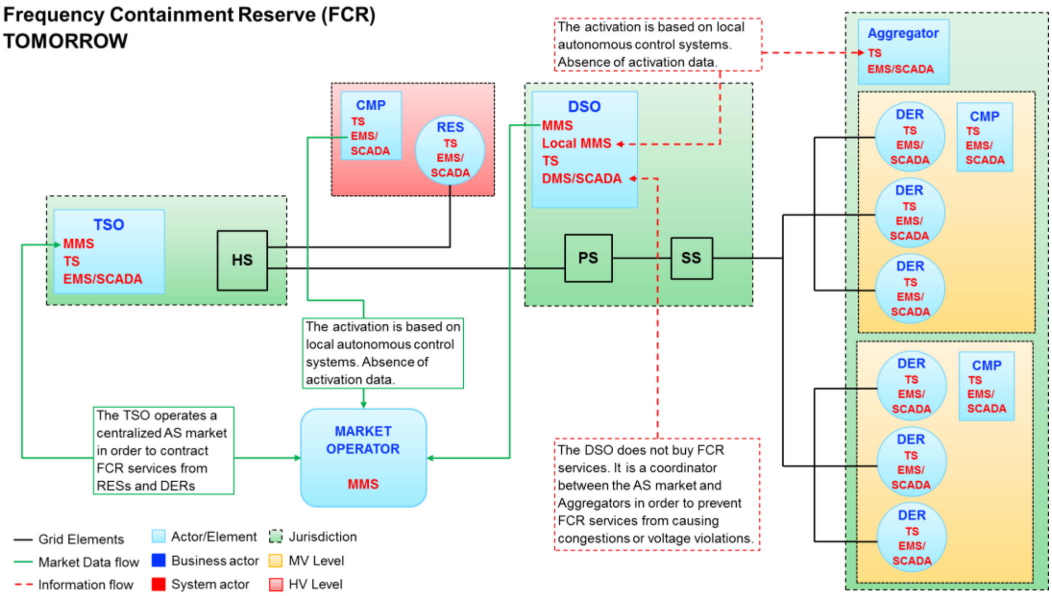



*Figure 4. Frequency Containment Reserve (FCR) tomorrow.*

Prequalification, procurement, activation, and settlement procedures are the most important AS procedures with respect to TSO-DSO coordination schemes. In FCR, those stages include:

1. Prequalification: Aggregated resources have to match some FCR requirements in terms of response speed, network constraints, and reliability.
2. Procurement: In this phase, FCR resources are purchased from the market through bilateral contracts or obligations.
3. Activation: The FCR activation is based on the local frequency measurement and it does not need any communication.
4. Settlement: This phase regards the financial settlement of agreed responses base on the results of the procurement and verification stage

### 3.1.2 Frequency restoration reserve

The purpose of the frequency restoration reserve (FRR – FRRa and FRRm) is to restore the frequency to its nominal value after sudden occurrences of system imbalances and to release activated frequency containment reserves back to normal use after the restoration. As can be seen in Figure 5, the current FRR service is open only to HV resources connected to transmission grids. The bid submissions session takes place in the ex-ante Ancillary Services Market. This market is managed by TSOs.

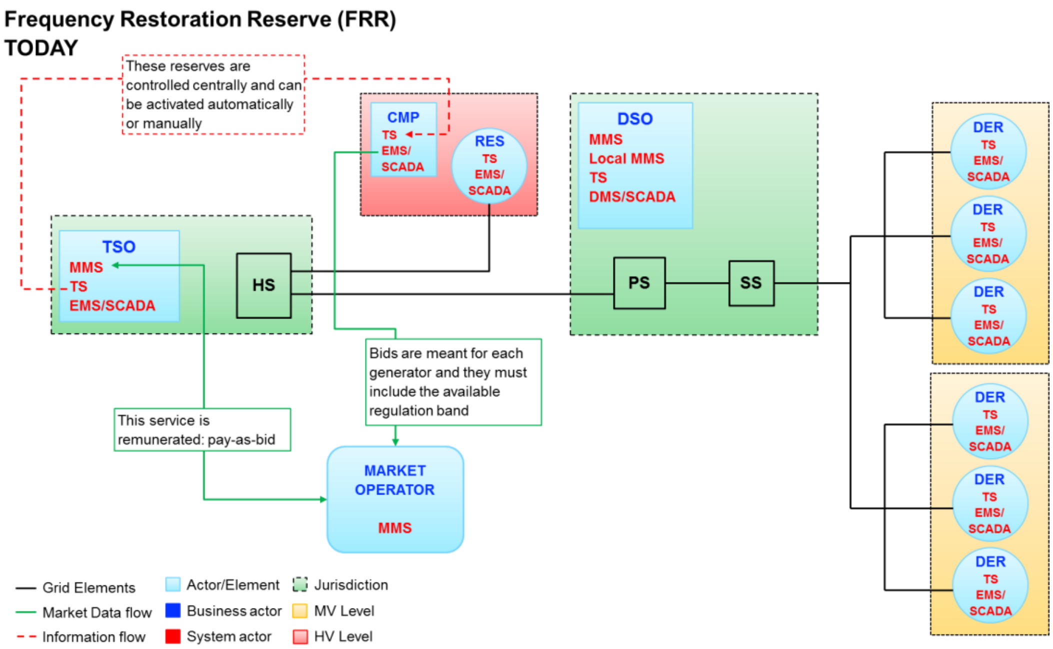



*Figure 5. Frequency Restoration Reserve (FRR) today.*

Figure 6 shows a possible scenario according to Shared balancing responsibility market. It uses new Smart Grid functionalities, in which DSOs are responsible for the balancing management of MV grids. This responsibility is specified by the definition of an energy exchange profile at the interconnection between the TSO and DSO. In order to manage its own grid, the DSO runs a local market where CMP and Aggregators can sell local ancillary services.

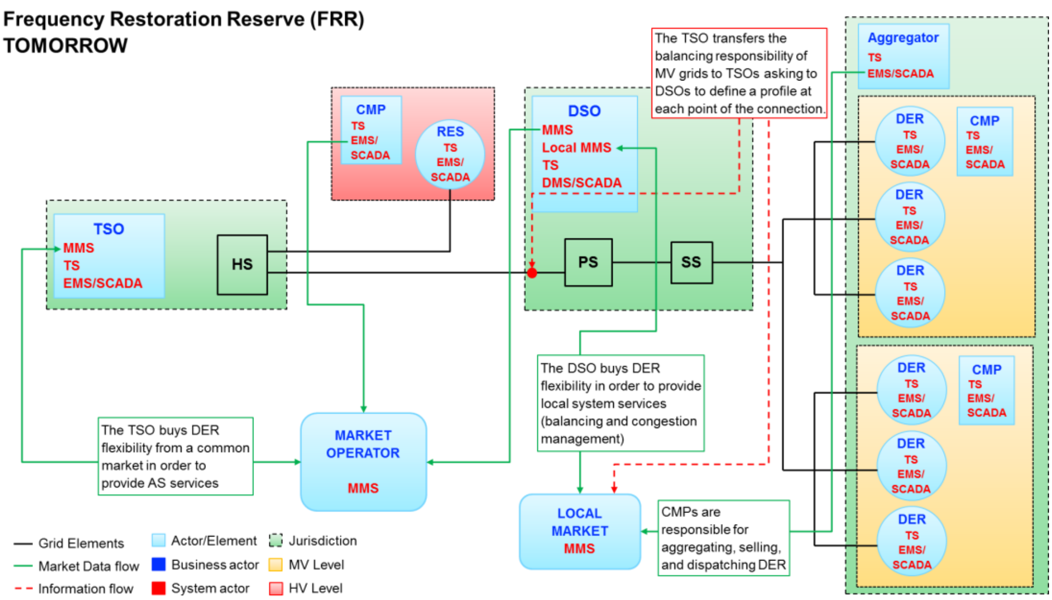



*Figure 6. Frequency Restoration Reserve (FRR) tomorrow.*

In FRR, the main stages are the same than in the frequency containment reserve including the following stages:

1. Prequalification: This stage is characterised by two parts: technical and system prequalification. The first is carried out once in order to verify if the asset complies with the technical requirements. The latter checks regularly if the asset complies the real-time grid constraints.
2. Procurement: The DSO runs a market where bids for DER, by commercial market players or aggregators, are collected. The bid contains information regarding the energy, the asset location, and its constraints. Procurement at TSO level remains “business as usual”.
3. Activation: In this phase, DSO procures any flexibility for the balancing management of its MV grid. Activation at TSO level remains “business as usual”.
4. Settlement: DSO and TSO collect metering data for assets in their respective networks.

## 3.1.3 Voltage control

The purpose of the voltage control (VC) is to maintain voltages within acceptable limits and enable the system to respond to both contingencies and shifts in generation and demand. The present version of voltage control is illustrated in Figure 7. This service is mandatory for each adequate generator, and it is not remunerated.

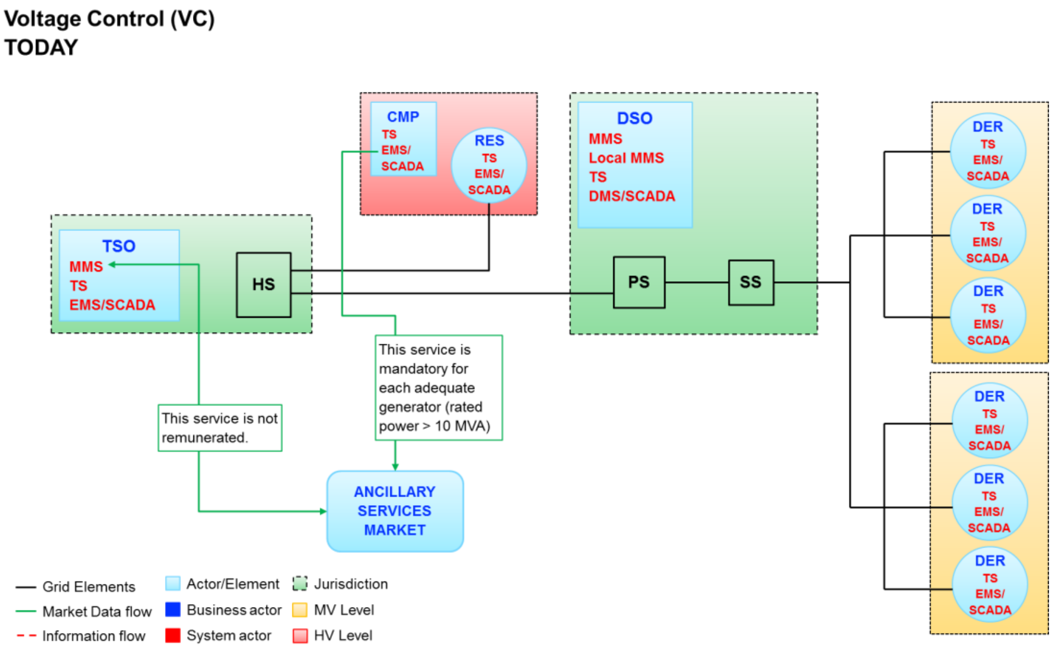



*Figure 7. Voltage Control today.*

The diagram of the future version of Voltage Control service in the Shared balancing responsibility market case is presented in Figure 8. The TSO runs a market to attain resources connected to the HV grid to manage a balance in transmission and, at the same time, the TSO dispatches voltage setpoints to DSOs. DSOs run their own local market in order to use the flexibility of local DER to fulfil their balancing responsibility.

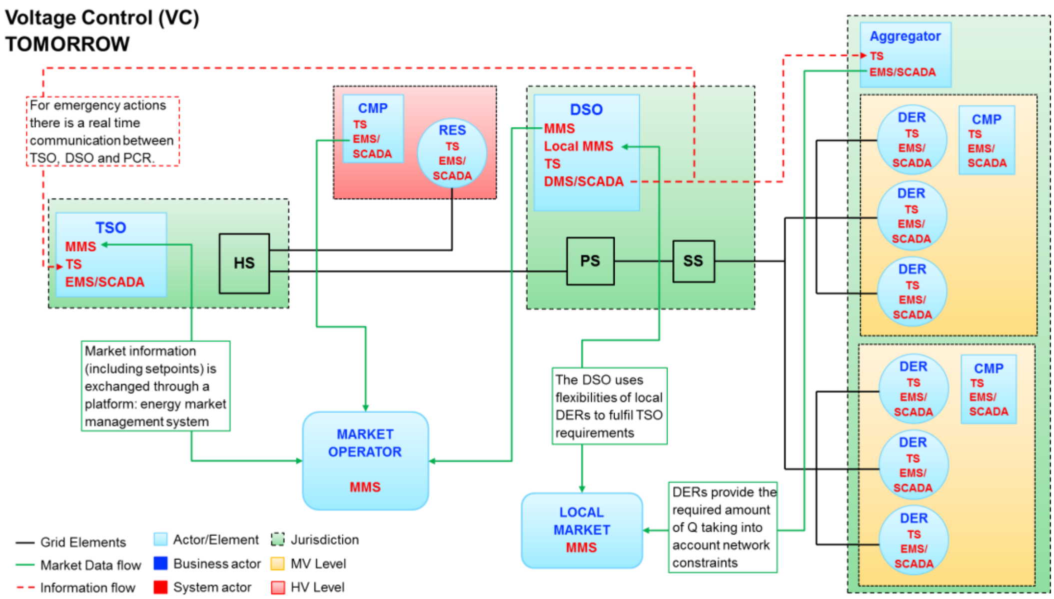



*Figure 8. Voltage Control tomorrow.*

The main stages in the voltage control case are.

1. Prequalification: This stage is performed e.g. annually in order to define the overall reactive power band. Moreover, it is possible to perform more precise day-ahead prequalification as refinements to the annual band.
2. Procurement: In this stage, the TSO runs an Optimal Power Flow (OPF) based on the results from the day-ahead market in order to achieve each setpoint.
3. Activation: The TSO sends to all service providers their setpoints for each market period of the day after; DSOs receive a voltage setpoint meanwhile consumers and DERs receive a power factor setting. Moreover, the TSO is able to modify, in the operation day, the previsions of the day-ahead taking into account the real-time conditions of the network.
4. Settlement: During the operation day, the TSO sends, for each market period, voltage measurements or estimates related to the previous market period to each market participants.

## 3.2 Energy components

### 3.2.1 The Traditional DSO SCADA system architecture

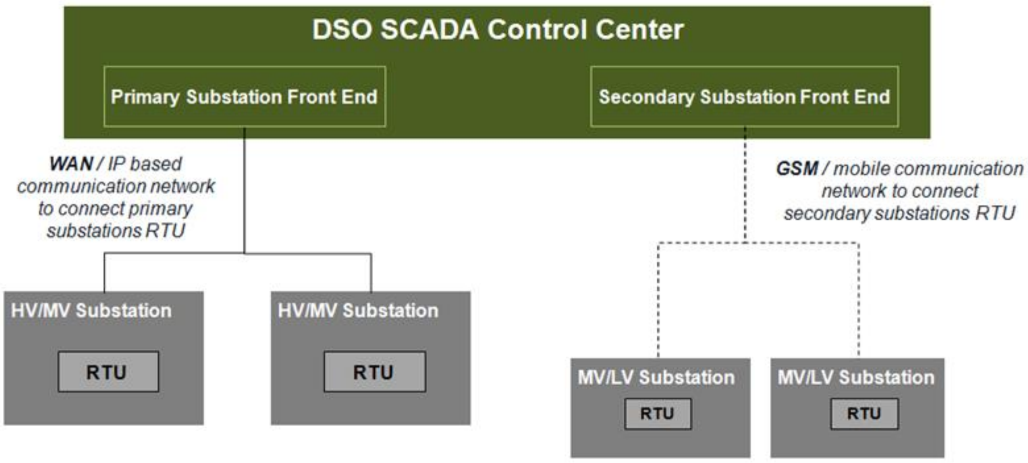



*Figure 9. Conventional DSO SCADA control center.*

The Supervisory Control and Data Acquisition system (SCADA) is responsible for the supervision and control of the MV network 24 hours/7 days. A traditional DSO SCADA system supervises the distribution network by acquiring (only) the most significant information from the devices installed in the HV/MV substations and in the MV/LV substations.

The SCADA operators carry out two main activities:

- Planned Work Management - coordinate and support planned field activities on the network;
- Outage Management - react on unplanned outage on the network in order to minimise the outage time and the number of customers without power supply

The field devices in a traditional Network Management System (NMS) installed in the Primary Substations have an interface to the SCADA central system exchanging information about the HV/MV Transformers (primary/secondary switches state; P, Q, I measures flows from HV to MV), HV feeder switches state, HV busbar measures (V), MV busbar measures (V), MV feeder measures (I), and MV feeder switches state. All the Primary Substations are controlled by the SCADA with an IP-based (always-on) connection.

The field devices installed in the Secondary Substations exchange information with the SCADA about MV/LV Transformer (primary switches state), Secondary Substation switches state, MV busbar measures (V, not always), MV feeder measures (I, not always), and LV feeder switches state (not always). Not all Secondary Substations are controlled by the SCADA; the controlled Substations are typically connected via a GSM/GPRS connection (IEC 60870-5-104 protocol).

The communication between TSO and DSO in a traditional SCADA system architecture is performed using the IEC 60870-5-104 protocol. The DSO sends to the TSO information related to all the HV components of the Primary Substation: alarms (i.e. RTU faults, etc.), measurements (i.e. voltage on the HV busbars, current on the HV feeders, real and reactive power on the HV/MV transformers), and switch states (open/close). There is no communication in the opposite way from the TSO to the DSO.

### 3.2.2 The Smart DSO SCADA system architecture

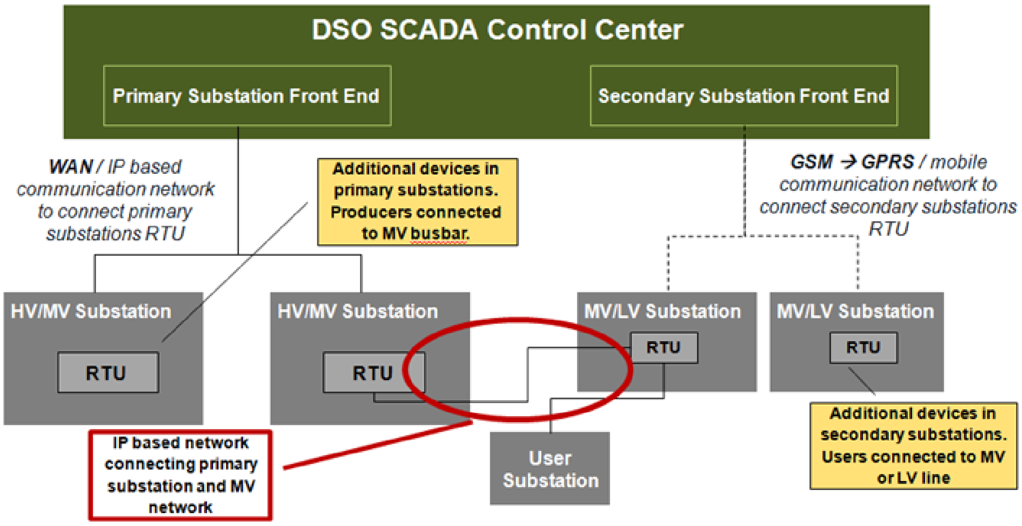



*Figure 10. Smart SCADA control center in DSO including IP connection between a primary substation and MV network.*

The new Smart Grid challenges (significant expansion of Distributed Generation plants connected to the MV&LV networks) brought the following impacts on the DSO SCADA system:

- SCADA enhancements for managing new devices and
- information coming from the network and new applications to support the DSO in the real-time operation.

To implement Smart Grid functionalities, the first requirement is to have an IP-based communication network among the Primary Substation and MV network (IEC 61850 protocol). The Primary Substation device is an IEC 61850 client. The Primary Substation devices were replaced due to more complex functional requirements. IEC 61850 Interfaces were added to the transformer protection (tap changer) and to MV network smart devices. The secondary substation devices were enhanced by introducing more secondary substation measures (P, Q, V, I) and advanced automation procedures for fault detection and local regulation. Some new devices were provided on the customer side secondary substations to collect substation state and measurements and to control user profiles according to setpoints calculated by the Network Calculation Algorithms System (NCAS).

All new devices installed on secondary substations communicate with the Primary Substation via IEC 61850 protocols. The devices are identified as IEC 61850 Service instances, which can subscribe GOOSE messages and manage MMS messages. The communication between TSO and DSO in smart SCADA system architecture is performed using the IEC 60870-5-104 protocol extended considering also the "multicast" mode (one sender and multiple receivers).

The new systems and functions developed on the TSO side include:

- MV load emergency management: For every HV/MV transformer, the TSO receives the real and reactive power measurements, and MV switch states along with their availability to be opened, from the DSO. In the case of an emergency, (considering the electrical network frequency measurements) the TSO sends a request/command to the DSO (for some specific Primary Substations) for the disconnection of the HV/MV transformer from the whole MV busbar. The MV load emergency management includes both "manual" commands sent directly by the TSO operators and "automatic" commands triggered by specific "sentinel" devices monitoring the grid (real-time frequency, critical events, etc.); in any case, to enable the HV/MV transformer disconnection, a specific procedure has to be performed beforehand to "arm/disarm" the devices located in the Primary Substations.
- MV generation emergency management: The TSO receives from the DSO a forecast for the real power of the Distributed Generation and the availability of those generators to be disconnected from the MV grid; in case of emergency (considering the electrical network frequency measurements) the TSO sends to the DSO (for some specific Primary Substations) a command to disconnect all the MV generators from the grid (i.e. every single MV generator receives a

disconnection command). When the emergency situation is solved, the TSO sends to the DSO a restoration command to reconnect to the grid all the MV generators.

An application designed for the DSO SCADA includes both the traditional interface and the Web interface. From this interface, it is possible to perform the entire activation process involving the devices needed to control each single MV generator, to define which group of MV generators will be included in the "MV generation emergency management" function and obtain detailed reports about it.

New information from the DSO to the TSO is added related to network management and control. The TSO receives from the DSO (for each MV busbar)

a) the forecast for the real power of the Distributed Generation split in solar/non-solar energy resource,
b) the forecast for the real power of the Distributed Generation that was disconnected,
c) the forecast for the real power of the load.

The forecast data is calculated considering the difference between the real power measurements on the HV/MV transformer and the forecast contribution on the Distributed Generation plants. This data flow considers the whole generation contribution involving both MV and LV generators. A more detailed division about the categories of Distributed Generation (not only solar/non-solar) is under investigation with the TSO and DSOs. This study is also a part of the SmartNet project activities. Recently, the measurements and states of the MV components of the Primary Substation (MV feeders and busbars) were added in the data flow between DSO and TSO in the system design.

# 4 Methodology

The ancillary service use case specifications for coordination schemes were created in the work package focusing on TSO-DSO coordination for accommodating ancillary services. The identification of ICT requirements was challenging, because those five TSO-DSO coordination schemes were in the research phase. We used an iterative and incremental process to capture ICT requirements and to elaborate ICT architecture design (see Figure 11). The work required several analysis cycles and a close collaboration with partners involved in the energy market activity.

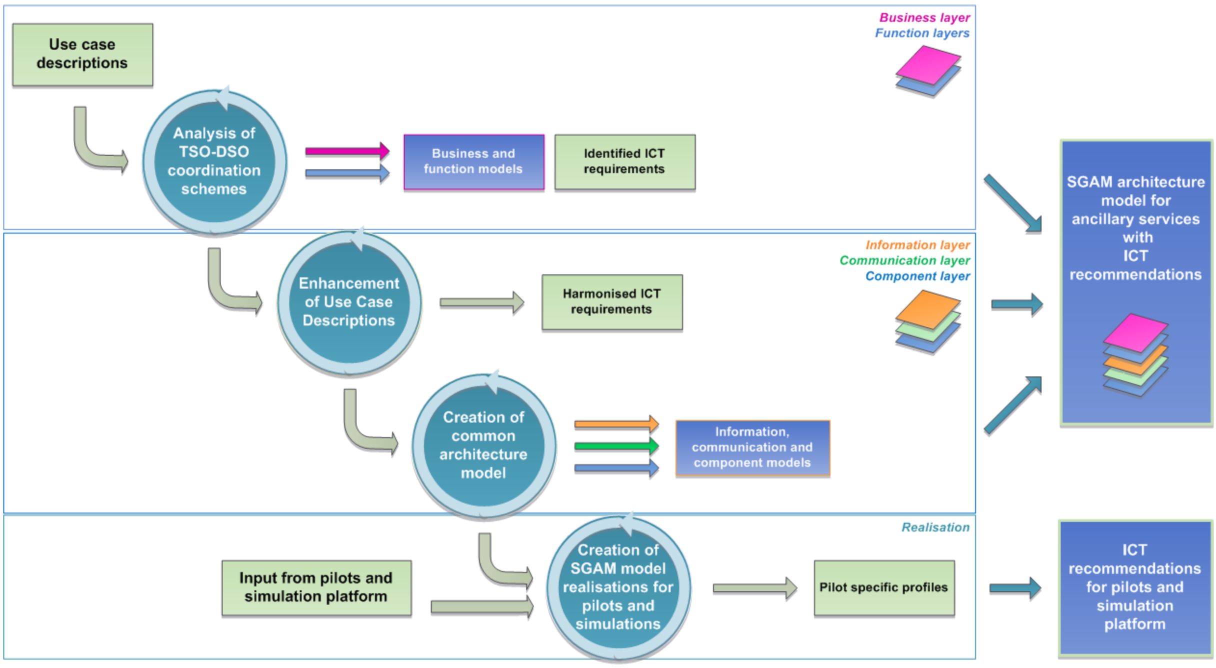



*Figure 11. Analysis procedure used for capturing ICT requirements and specifying the architecture design.*

The first analysis cycle was done together with partners specifying the TSO-DSO coordination schemes, since we needed a more profound understanding of involved business/system actors, interactions between systems, and exchanged data in order to be able to identify ICT requirements. During this cycle, the use case descriptions were updated together to fill discovered ICT related gaps. The use case descriptions were refined and extended with ICT requirements for each data exchange event. The requirements were collected in a table format that was added at the end of each use case description document. We utilised the use case template, common definitions, and terms specified in the ELECTRA project [6]. This helped us to align the specifications in both energy markets' and ICT's viewpoints.

During the second iteration cycle, we compiled the use case specific ICT requirement tables into an all-in-one ICT requirement table. It was a compressed presentation including all ICT interactions between system components, identified exchanged data objects, and ICT requirements covering networking, security, latency, data protocol, and communication technology properties. After the compilation, the number of ICT requirements exchanged data objects and even system components were too high to be

used for the SGAM modelling. An additional iteration cycle was needed to harmonise the use case descriptions and associated ICT requirements. To make the number of ICT requirements manageable, we grouped the ICT requirements into classes, and only the classes were used with information exchanged events. We focused on the four core processes of the ancillary service operations (Figure 12): prequalification, procurement, activation, and settlement. Since prequalification, activation, and settlement are rather similar in all coordination schemes, it helped us to reduce significantly the number of exchanged data objects and their requirements. After the compilation of the all-in-one ICT requirement table, we still validated the harmonised use case specifications and the ICT requirement table against the original energy market use case specifications in order to ensure that all interactions, system components, and requirements in the selected ancillary services were correctly taken into account.

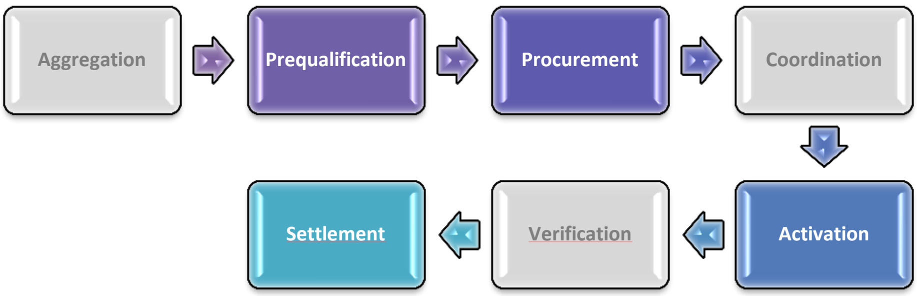
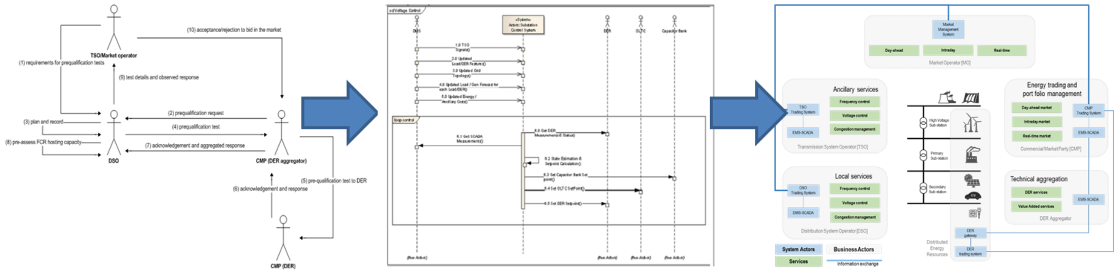



*Figure 12. Four core procedures in ancillary services.*

The third analysis cycle included the creation of a common architecture model. The architecture model was created with the Enterprise Architect tool and the SGAM Toolbox extension. As a background for modelling, we used the modified use case specifications, all-in-one ICT requirement table, and to some extend the results from the study focusing on existing energy and communication architectures and enabling ICT technologies. Our goal was not to create an entirely new architecture, but to elaborate the existing one in order to fulfil the requirements set by the five TSO-DSO coordination schemes. The existing business and function layer SGAM models created in the first analysis phase were updated and complemented with information, communication, and component model layers. Figure 13 depicts the transition from business actors and relationships to communication and component layers with associated ICT requirements.



Business and function layers | Information layer | Communication and component layers

*Figure 13. The transition from business layer presentation down to the component model.*

The final ICT SGAM model included use case diagrams, system/component and interface charts, and sequence diagrams associated with ICT requirements. This model is well-suited for studying the common architecture design and for modifying it further for a system realisation, but it requires the direct use of the Enterprise Architect tool. To overcome the presentation complexity problem, we created a reference model illustration presented in chapter 2. This simplified presentation helps the reader of this document to understand the relations between the SmartNet architecture, SGAM modelling, and ICT requirements.

The last analysis cycle involved the creation of SGAM model realisations for pilots and simulation platform. The derived model focuses on the design of a specific ICT system implementation. The derived model is called profile, and it maps the common ICT architecture design and communication requirements of a specific coordination scheme to a SmartNet pilot system. We started with the Danish pilot in order to generate compact guidelines for partners involved in other pilots and simulation platforms to provide required input for the creation of the profiles.

The analysis and design procedure followed the same steps that we used for capturing ICT requirements for the common architecture design including [3]:

- Creation of a layered overview of the system components
- Creation of information exchanged sequence diagrams
- Creation of communication interface profiles using the all-in-one ICT requirement table

We used the creation of profiles as a feedback loop to verify the common architecture design and its flexibility to cover four different system realisations. Interactions between system components, the content of exchanged data objects, and ICT requirements were assessed and refined. During the analysis, latency, reliability, security, and cost were taken as the most critical requirements. We analysed those properties from trading and resource management viewpoints. The reliability aspects were assessed by studying the most actively utilised communication links requiring a higher level of reliability and resiliency. In general, latency and security requirements dictate whether a wireless or wired connection could be used. The data amounts in trading and resource control are not restrictive. The cost is multi-facial property including investment and operation costs. In our analysis, we used the cost property as a

metric to indicate the system actors' willingness to invest in communication technology and security. A more detailed Cost-Benefit Analysis (CBA) will be carried out later in the project.

# 5 Architecture model

The created common ICT architecture model for ancillary services is based on the analysis of different coordination schemes, use case descriptions, and study of the energy system architectures. We used the SGAM architecture model [7] as the base for the design. The main goal was to derive SGAM components, information and communication layers containing also the requirements for communication cost, availability, response time, and security. This allows examining either the common ICT architecture or a particular coordination scheme from business information exchange, communication protocol, communication technology, or communication cost viewpoints. The presented treatment of ICT and security requirements goes beyond the state of the art. It extends the analysis compared to related work on SGAM reference architecture [8], that is based on NIST guidelines and generic security requirements [9].

## 5.1 Coordination schemes from ICT perspective

The coordination schemes are described in deliverable D1.3 [1] from a business and function layer perspectives. Based on this input certain high-level insights from the ICT point of view can be made. The focus is on the procurement phase, which is most impacted by changes in the market design, roles adopted, and type of information exchanged.

Main information and communication technology perspectives of the coordination schemes are:

- **Centralised AS market model:** There is one central platform operated by the TSO and there is no real-time (procurement) communication between the DSO and the TSO.
- **Local AS market model:** This implies several local market platforms, one per DSO, that have to communicate with the TSO market platform. The markets are decoupled and have to be synchronised, but not necessarily in real-time. For instance, the local DSO market could have a clearing every hour and the TSO market every 5 minutes. Several smaller DSO markets could be integrated into one platform.
- **Shared balancing responsibility model:** The TSO and DSO markets are completely decoupled. Only the constraints schedule agreed in advance between TSO and DSOs has to be exchanged. The market platforms do not have to communicate with each other.
- **Common TSO-DSO AS market model:** TSO and DSO have a common objective and are both responsible for the management and operation of the market.
    - **The centralised variant:** The common objective is realised by the joint operation of the TSO and DSO of a common market. All TSO and DSO constraints are included and taken into account in one huge optimization process. There is physically one market platform,

operated by TSO and DSO. TSO and DSO provide the input for the optimization and clearing process. There are two options related to the input data:

1. All input data and orders are visible to the TSO and DSO.
2. Only the data necessary to have a functional market is shared.

Obviously, the latter option will be preferred by some of the actors, since less data has to be exchanged and is visible to the others. Obviously, clear rules on security and privacy of the shared data are necessary. However, in the case of having numerous DSOs, this variant is less suitable, because of the huge optimization process.

- **The decentralised variant:** The common objective is realised by the dynamic integration of a local market operated by the DSO, and a central market operated by the TSO. Compared to the centralised versions, the operation cost of this variant will likely be higher due to a multitude of platforms that have to be operated. An intermediate solution could be to have the markets running on one platform in a two-step process. The DSOs perform a local optimization compliant with the local constraints and provide a set of potential options to the DSO. The DSO performs thus a decentralised optimization without making a choice by selecting a particular option. The TSO will run its optimization process taking into account all options provided by the DSO and the TSO will perform the final selection. Compared to the centralised variant, the amount of shared and exchanged data between the TSO and DSOs is a lot less. The markets, however, have to be synchronised, almost simultaneously. This is far more crucial in this solution compared to the Local AS market model and will impose higher constraints on communications.

- **Integrated flexibility market model:** Contrary to the other models where the TSO, DSO or TSO-DSO cooperation is operating the market platform and incorporates the constraints in the market clearing process, in this model an independent operator is running the market platform. To incorporate the grid constraints in the market clearing process there are two options:
  - The constraints have to be calculated upfront by the TSO/DSO and have to be sent to the market on a regular basis, for instance, every hour.
  - No constraints are sent upfront, but the market clearing results are checked by the TSO and DSOs, and potentially blocked when they do not match with the constraints. As a result, several iterations may be needed to come to a solution at closure, and consequently, the solution at closure time might not be the most optimised, the best solution. The TSO/DSO has to solve the remaining problem in that case with other means.

If local problems almost never occur, the blocking variant is the best option; otherwise, the version with the constraints sent upfront is the preferred option. As regards communication the

blocking version might induce more intensive communication traffic due to the iteration process. Nevertheless, the TSO and DSOs have to share information with an independent market operator.

Although the mentioned five models are distinct, this doesn't mean that they are static permanent models. Over time there can be a transition from one model to another model. For instance, the Centralised AS market model could transform into a Common TSO-DSO AS market model using the centralised variant, and also this model could transform further on into an integrated flexibility market model. Similarly, the Local AS market model, for instance, could transform over time into the decentralised Common TSO-DSO AS market model. The trigger for such a transition should be based on regulatory and/or organizational reasons. The ICT/communication infrastructure should never be an obstruction to such a transition. This means that when the communication infrastructure is designed, a transition over time to another model or multiple (hybrid) models should be taken into account in the design process and in the definitions of requirements for the infrastructure.

An additional provision that needs to be taken into account when we are defining ICT requirements is that the clearing intervals may get shorter in the future, and regarding the market platforms, these could run in the cloud as a service, technically managed by an ICT organization, but operated market wise by a TSO, DSO or IMO.

Regarding the activation process, in the case of frequency control and voltage control, the activation signals are always triggered by the buyer. However, these signals could run relayed via the market platform to decouple the buyers and sellers, and thus limit the number of communication links between all involved parties. In frequency restoration/balancing and congestion management, the activation is implicitly incorporated in the market orders.

## 5.2 SGAM model

The SGAM approach was created as a result of the "European Commission M/490 Standardization Mandate to European Standardization Organizations (ESO)" [7]. It provides a structured approach for modelling smart grid use cases. The basis for the SGAM is a three-dimensional framework consisting of domains, zones, and layers. In the domains, the traditional layout of the electrical energy infrastructure can be found: generation, transmission, distribution, Distributed Energy Resources (DER), and customer premises. The zones depict a typical hierarchical power system management: market, enterprise, operation, station, field, and process. These two axes (domains and zones) form the component layer. On top of the component layer, four interoperability layers are placed: communication, information, function, and business layers [10].

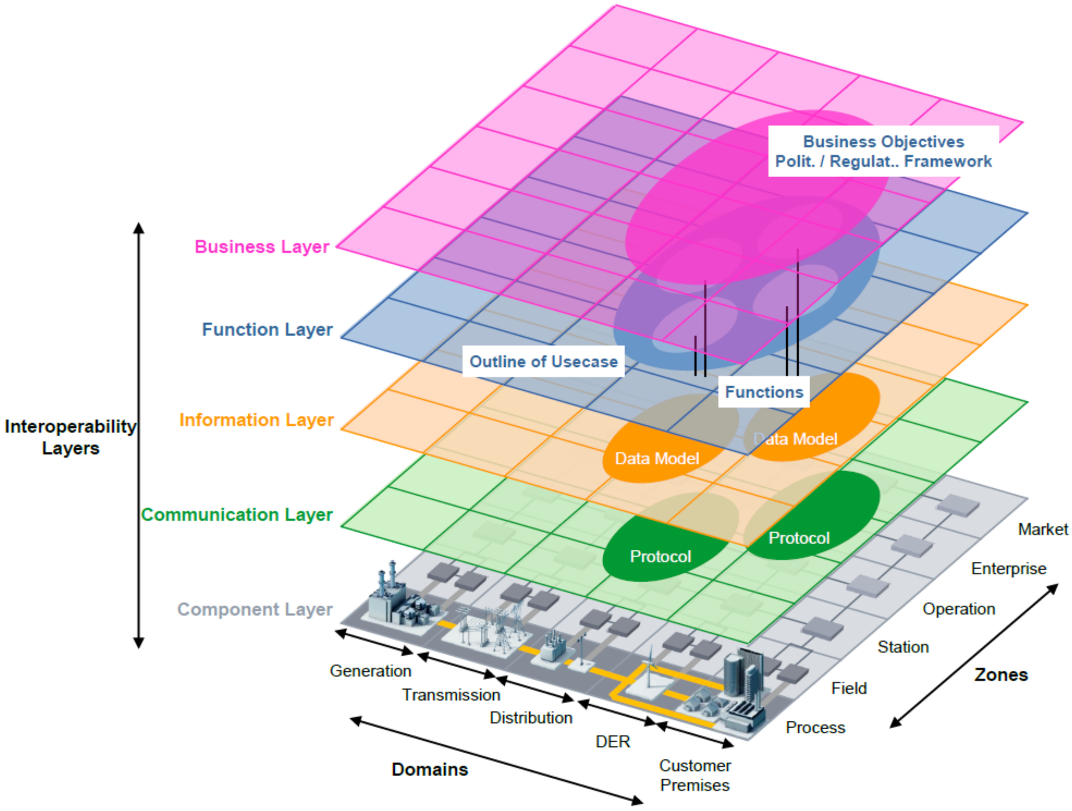



*Figure 14. Smart Grid Architecture Model (SGAM) [10].*

Accompanying the framework, a use case design methodology is also provided. The methodology is based on the IEC 62559 use case template, which is used as a basis for a use case description and then mapped into the different layers of the SGAM framework. In order to do this in a structured way, the following design steps are defined:

- **Use Case Analysis:** The first step is an analysis of a use case. It is suggested to use the IEC 62559 template to create an initial use case description.
- **Business Layer Design**: In the business layer, business processes, services, and organizations which are linked to the use case are mapped. These business entities are located at the appropriate domain and zone.
- **Function Layer Design:** In the function layer, functions and their interrelations should be represented. The functions are derived from the initial use case description. The use case can be hierarchically divided into sub use cases and functions.
- **Component Layer Design:** After the business layer and the function layer have been modelled, they have to be matched with a certain system. Thus, the next step is to model the component layer. Based on the actors involved in the use case, and any existing system components, the needed components for the use case can be derived and assigned to a domain and a zone.

Subsequently, the derived functions from the function layer can be assigned to a corresponding hardware.

- **Information Layer Design:** In the information layer, the information exchanged between functions, services, and components is represented. Information objects can be identified by analysing the data exchanged between actors involved in the use case (e.g., using sequence and activity diagrams). Another important aspect of this layer is to represent which data models are used for the information exchange.
- **Communication Layer Design:** Taking the exchanged information and data models identified in the information layer into account, suitable communication protocols and ICT techniques have to be identified. These should be represented in the communication layer.

In order to support the user with the methodology described above, the so-called "SGAM Toolbox" has been developed. It is based on the Unified Modelling Language (UML) and available as an extension to the Enterprise Architect software [11].

## 5.3 Modelling with Enterprise Architect

Enterprise Architect is a commercial multi-purpose system and architecture design software by Sparx Systems [12]. It is designed for large enterprises to visualise, analyse, model, test, and maintain their systems, processes, and architectures. The tool has a configurable graphical user interface and it supports large globally distributed teams that need to work with the same models. The tool supports very complex and large models with built-in visualisation, reporting, and documentation capabilities.

The SGAM Toolbox is a free extension to the Enterprise Architect developed by Salzburg University of Applied Sciences [13]. The toolbox adds an SGAM plug-in into the Enterprise Architect to support architecture design of Smart Grid systems in reference to the Smart Grid Architecture Model.

For our work, we selected these tools for the following reasons:

- Several partners were familiar with the Enterprise Architect and SGAM Toolbox, and it was already used in D3.1 ICT requirements specification,
- Standardisation groups are using Enterprise Architect tool in their work,
- The tool enabled sharing the models between partners located in different parts of Europe,
- The tool provided the framework for the energy and ICT system modelling with standard layer and component definitions,
- The tool uses UML, which is widely used in energy and ICT domains for architecture designs,
- The electrical architecture design model could be handed over to the pilot and simulation platform tasks after the architecture design work was completed.

The preliminary business and function layer were created during the ICT requirements specification work (presented in D3.1 [3]). During it, interactions between business actors were modelled covering all

of the selected ancillary services, and four main ancillary service procedures were defined. Figure 15 shows an example of function layer presentation created during the ICT requirement specification phase.

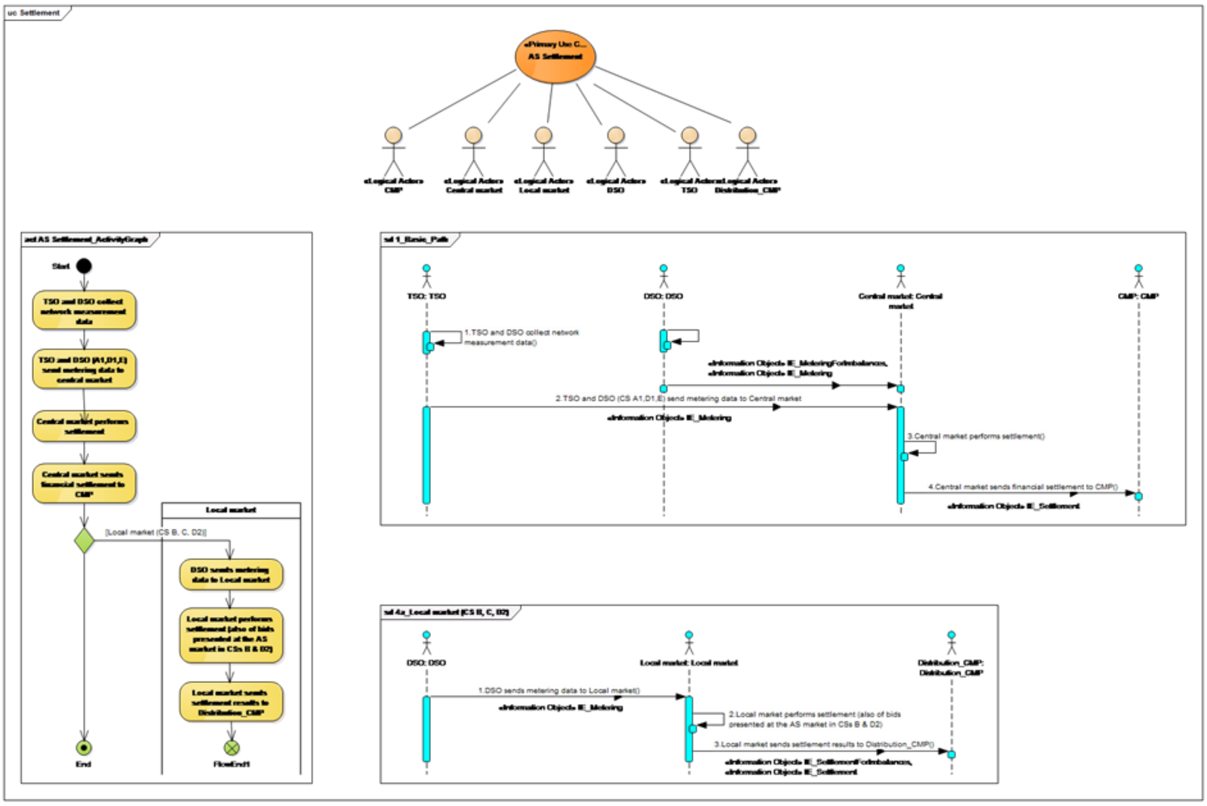


*Figure 15. Part of the function layer showing the activity and sequence diagrams for the settlement phase.*

As mentioned in chapter 4, before we could use the Enterprise Architect tool for the modelling of information, communication, and component layers, we compiled all ancillary service specific ICT requirements to an all-in-one ICT requirements table that was maintained in a shared Excel file. The number of specific requirements was so high that it was necessary to use generalised requirement classes for the architecture design. This ICT requirements table with requirement classes was imported to the Enterprise Architect tool, which helped us to keep the compact ICT requirements table and graphical presentation of the model in the Enterprise Architect software aligned during multiple iteration cycles. The following subchapters describe how the modelling was done in different layers.

## 5.4 Component layer

After the ICT requirements specification phase, we had the business and function layers modelled with identified business actors. Next, we needed to map them to physical components. For it, we used the harmonised ICT requirements table that was created during the second cycle of the analysis procedure. This table included a complete list of system actors derived from business actors that were extracted from the WP1 use case descriptions and subsequently harmonised with respect to the four main phases:

prequalification, procurement, activation, and settlement. The table with the harmonised system actors is found in Appendix 10.1. Moreover, for the component layer model, we created mappings between system actors and logical actors. To show this relationship in the model, the system actor name always starts with the name of the logical actor. Each system actor represents one system component in the component layer, and each system component is assigned to a specific SGAM domain and zone. Subsequently, the derived functions from the function layer were translated into corresponding hardware components in different SGAM zones and domains. The resulting component layer is presented in Figure 16.

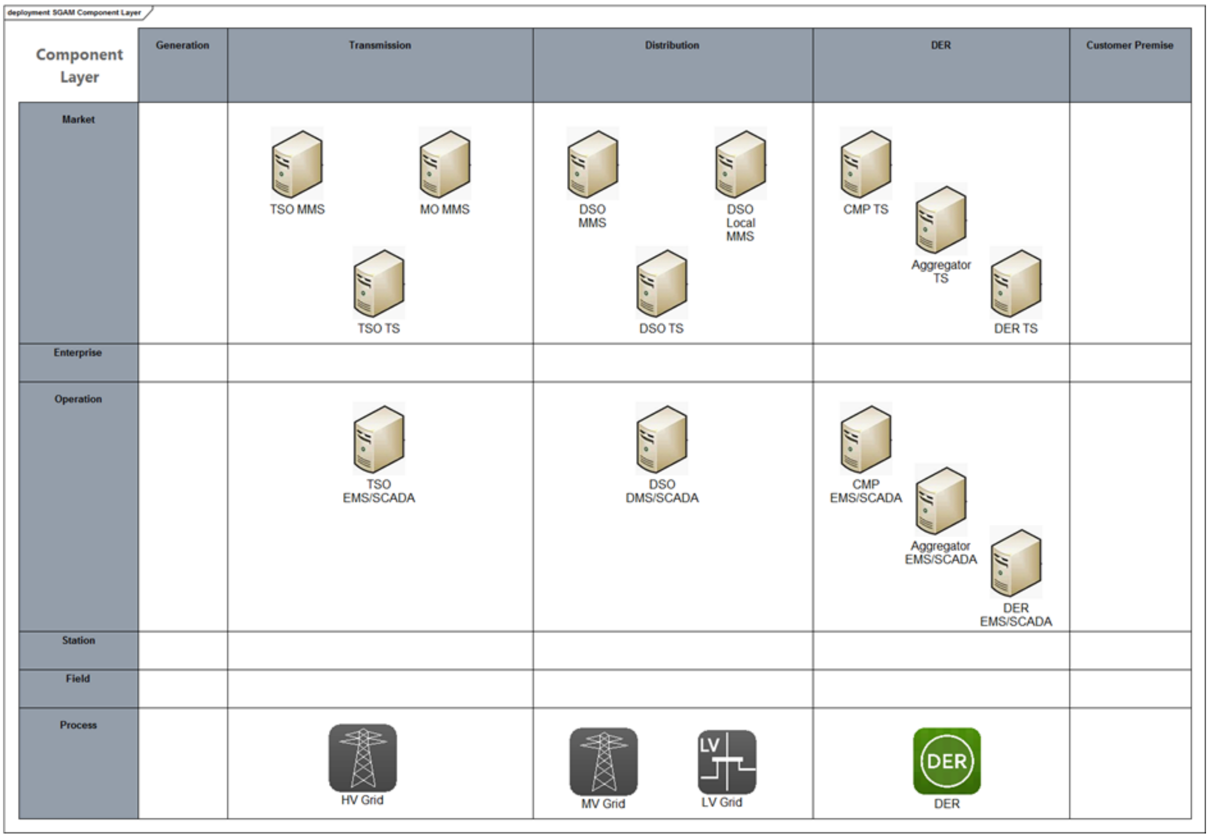



*Figure 16. Component layer without any connections between the components.*

We placed all components with market interactions in the Market zone. These components are *TSO MMS, TSO TS, MO MMS, DSO MMS, DSO TS, DSO Local MMS, CMP TS, Aggregator TS, and DER TS*. The system components are described in Appendix 10.1. According to their affiliations, these components were divided into different domains. Consequently, we placed all components affiliated to the *TSO* (and the *MO MMS*) in the Transmission domain, all *DSO* components in the Distribution domain, and all components affiliated to the *CMP*, Aggregator, and *DER* in the DER domain. The remaining components: *TSO EMS/SCADA, DSO DMS/SCADA, CMP EMS/SCADA, Aggregator EMS/SCADA, and DER EMS/SCADA* were placed in the Operation zone. All these components are presented in the reference architecture model in Figure 1 on page 12, where they are grouped by business actors.

The component layer model includes also the mappings between components and logical actors, which were used in the business and function layer models. This is important, because it shows how the logical actors are related to the physical components. When we modelled business and function layers, as a part of the analysis process to capture ICT requirements in different coordination schemes, we had to abstract the business actors in order to cover all aspects of all coordination schemes. Thus, the actual system that was used was not always specified. This resulted in a one-to-many mapping between the function layer actors and the components in the components layer, which is illustrated in Figure 17.

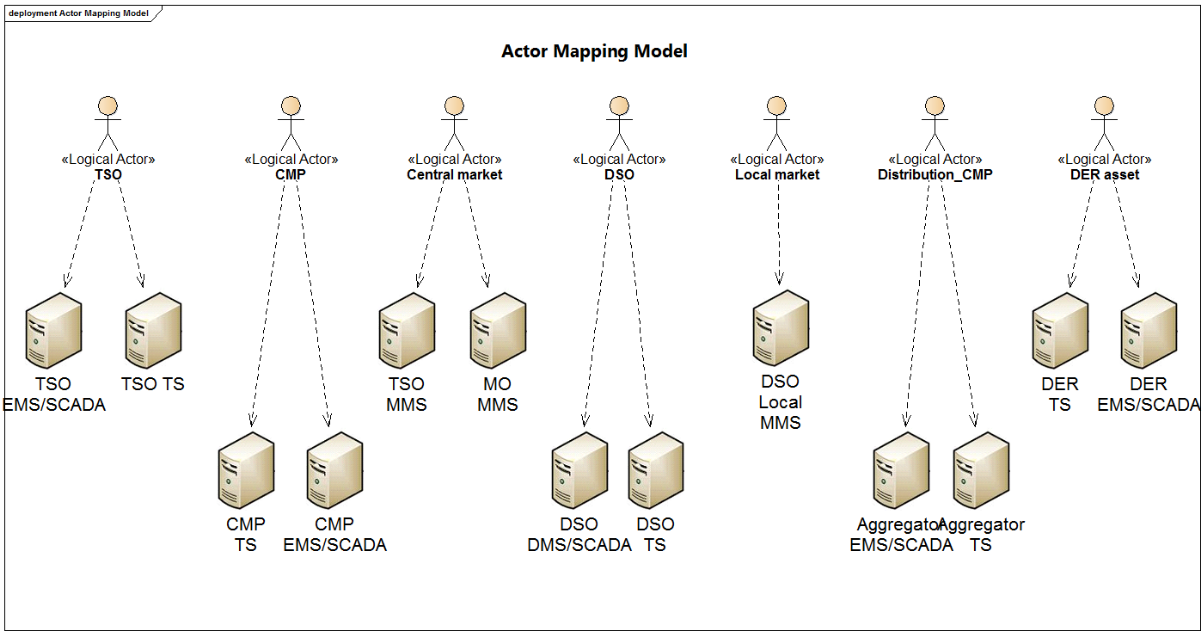



*Figure 17. Actor mapping model between the logical actors of the function layer (top) and the components in the component layer (below).*

Figure 17 illustrates that each logical actor is linked to market and control components e.g., the *CMP* actor is mapped to the *CMP TS* and the *CMP EMS/SCADA*. The same logical actors can be found in the function layer model. For example, Figure 15 shows the activity and sequence diagrams for the settlement procedure in the function layer, which contains these logical actors.

## 5.5 Information layer

The information layer presents the information exchanged between functions, services, and components. Information objects can be identified by analysing the data exchanged between actors involved in the use case (e.g., using sequence and activity diagrams). Another important aspect of this layer is to represent which data models are used for the information exchange.

After the second analysis iteration, the harmonised (and reduced) ICT requirements table included 170 different information exchanged events. One of the main challenges in the third iteration cycle was to

model each of these events in Enterprise Architect. The following sections address this as well as different possibilities to visualise the information layer data.

### 5.5.1 Representing information exchanged events

Each of the information exchange events included information about what was transmitted and between which components. Furthermore, each event was mapped to one Requirement Class (see Appendix 10.5) and one Protocol Class (see Appendix 10.6), both presented in Figure 18. In order to model this in Enterprise Architect, each event was represented as one Information Exchanged object identified with the exchanged data, the sending actor and the receiving actor. The figure below shows the market clearing event between *TSO MMS* and *TSO TS*. The exchanged information with ICT requirement and protocol classes is called *IE_MarketClearingResult*.

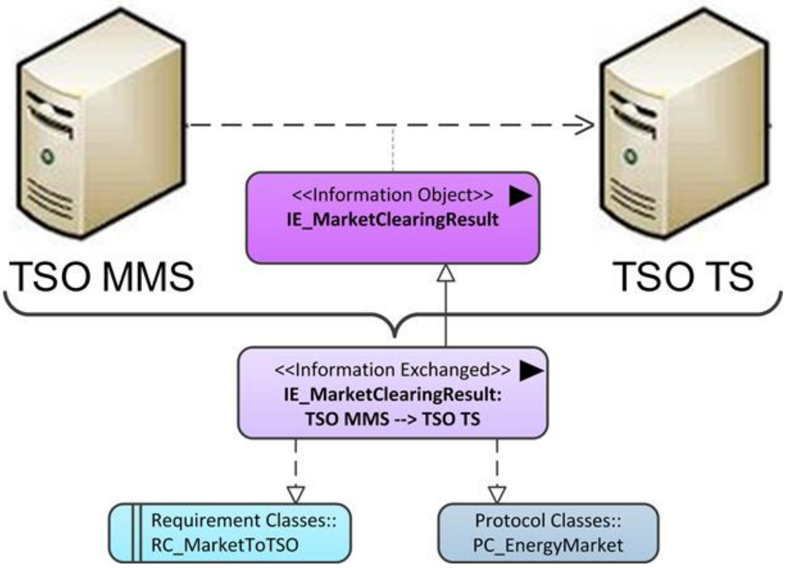



*Figure 18. Representation of an information exchanged event between the actors as an Information Exchanged object.*

Each Information Exchanged object realises one Requirement Class and one Protocol Class. This is also seen in Figure 18, where the Information Exchanged object realises the Requirement Class *RC_MarketToTSO* and the Protocol Class *PC_EnergyMarket*. Using the scripting functionality of Enterprise Architect, it was possible to automatically import all information exchanged events from the ICT requirements table. During the import, a new Information Exchanged object was created for each defined Information Exchanged event, and the new object had automatically assigned relations to Requirement and Protocol Classes as illustrated in Figure 18.

### 5.5.2 Business context views

Once the Information Exchanged object is represented in Enterprise Architect, different possibilities exist how to visualise the modelled information. One possibility mentioned in the SGAM methodology is

to show a business context view of the exchanged information. In such a view, the information exchanged is represented by information flows between components. Each information flow conveys one or more Information Exchanged objects between two components. Figure 19 shows the business context view with all information flows. The thickness of a connection (line) gives an illustration of the activity level of information exchange between components. The more information events are exchanged, the thicker the connection is. The blue line indicates business actors' internal connections. The model helped us to ensure that all components are taken into account and the links between components are consistent among all ancillary service use cases in all coordination schemes.

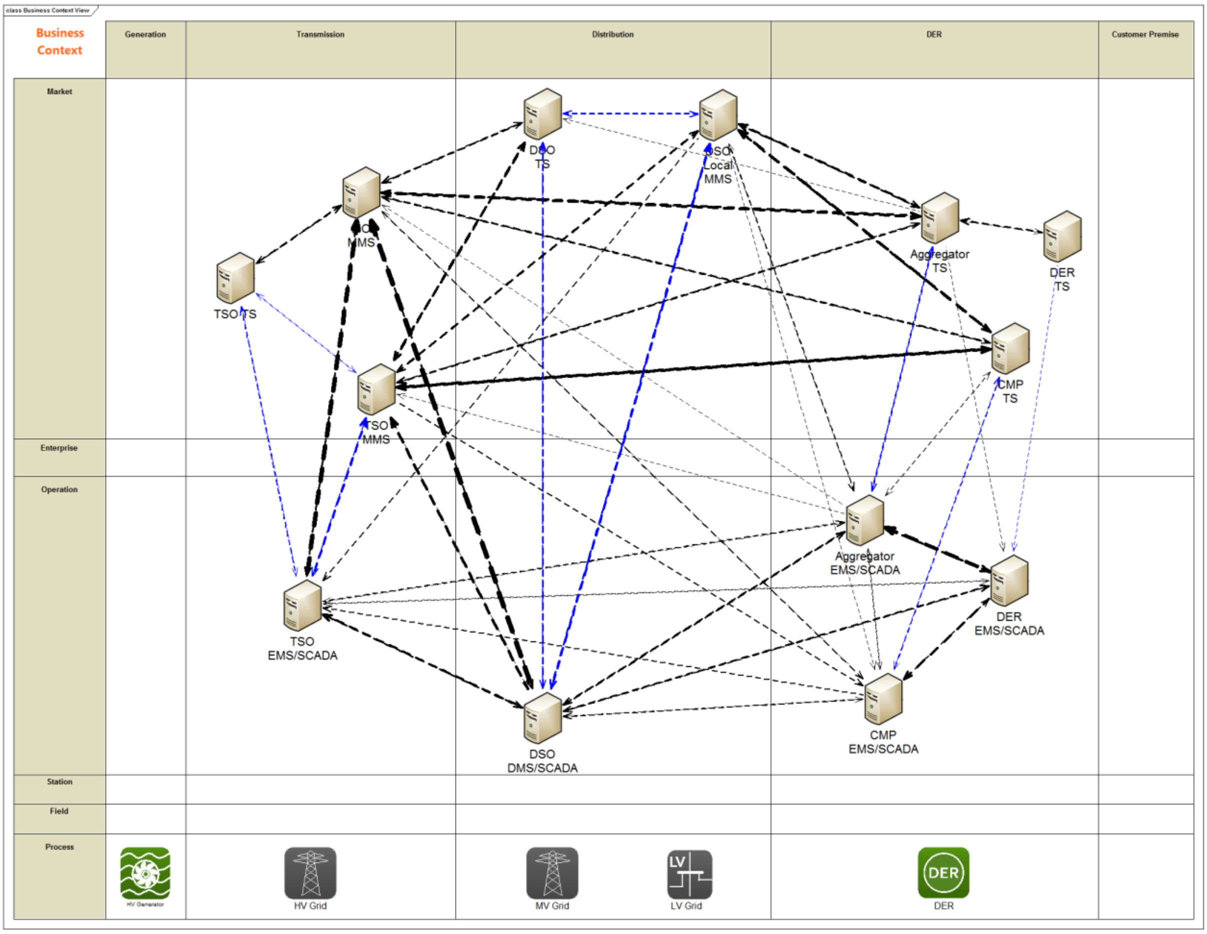



*Figure 19. Overview of the business context view, where the information flows between the components are shown. The thickness of the lines indicates how many Information Exchanged objects are transmitted, and blue colour indicates business actor's internal links.*

The thickness of the connections is one parameter to filter information in the business context view diagram. However, this is not always enough for a detailed analysis. Another possibility is to use filters depending on the requirements of each Information Exchanged object conveyed by a connection. Such a filter can be created manually or automatically using the scripting functionality of Enterprise Architect.

### 5.5.3 Analysis of different ancillary services and coordination schemes

Next, we show as an example how Enterprise Architect filters are utilised to present only connections that are associated with a certain use case or coordination scheme. This was used to examine differences between different market schemes and to discover possible anomalies created during use case specification or harmonisation phases. Since all the coordination schemes are not feasible or relevant for all the ancillary service use cases, we created filters only for those relevant ancillary service and coordination scheme pairs identified in WP1. They are illustrated with green colour in the AS matrix in Figure 20. We also generated filters for coordination schemes containing selected ancillary services (green plus signs in the same row in Figure 20). It is likely that hybrid TSO-DSO coordination schemes will be used. Thus, the following examples concentrate on differences in ancillary services.

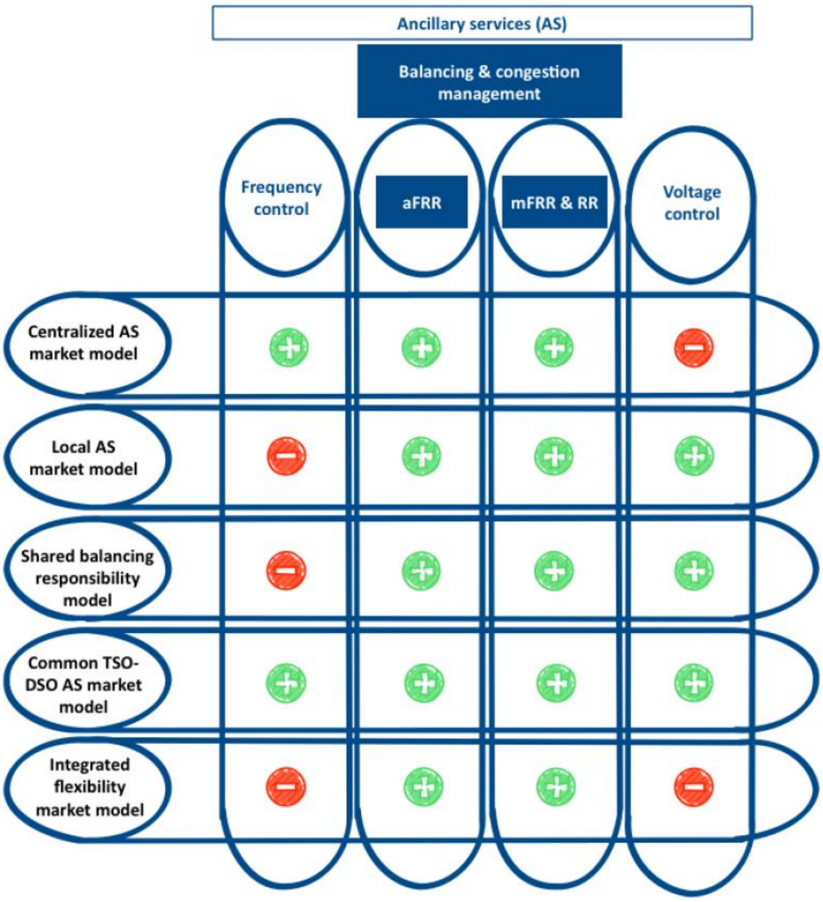



*Figure 20. Mapping of ancillary services and coordination schemes [1].*

In order to create a filter, we wrote a script that searches all the connections in the diagram. For each connection, the conveyed objects (i.e., the Information Exchanged objects) are investigated. If this Information Exchanged object is used in, for example, *Coordination Scheme B* the connection remains visible. If none of the conveyed objects are used in the coordination scheme, then the connection is made hidden.

An example result of using the filter is shown in Figure 21. For the visible connections at least one of the conveyed objects is used in *Coordination Scheme B*. The thickness of the connections indicates how many of the conveyed objects are used in *Coordination Scheme B*. Blue colour indicates business actor's internal links. The DSO Local MMS has active information exchange with multiple business actors.

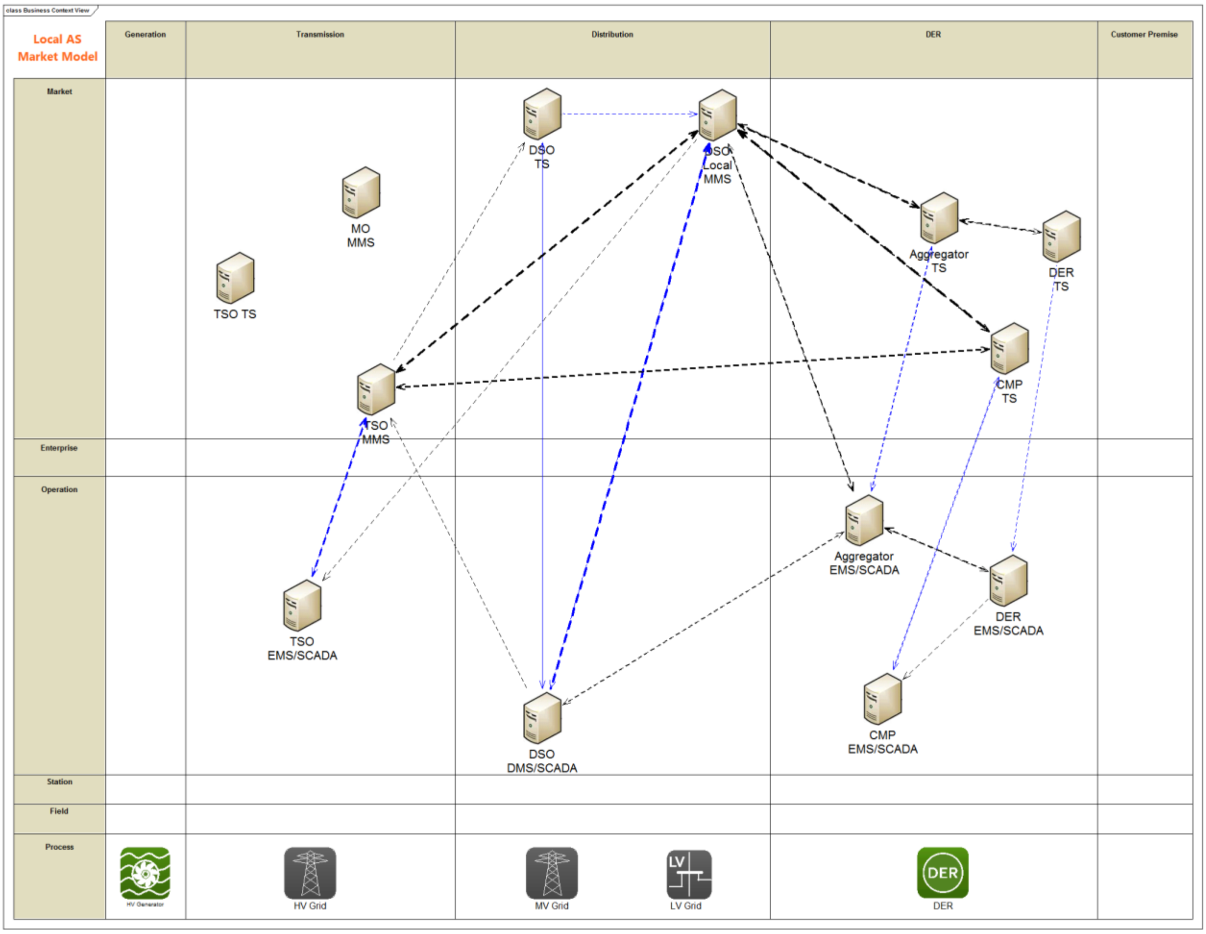



*Figure 21. Business information context view for Coordination Scheme B. Blue colour indicates business actor's internal links.*

Another example is shown in Figure 22, where the business context view for *Coordination Scheme D (centralised variant)* is presented. In this case, the MO MMS has an active role in market related interactions.

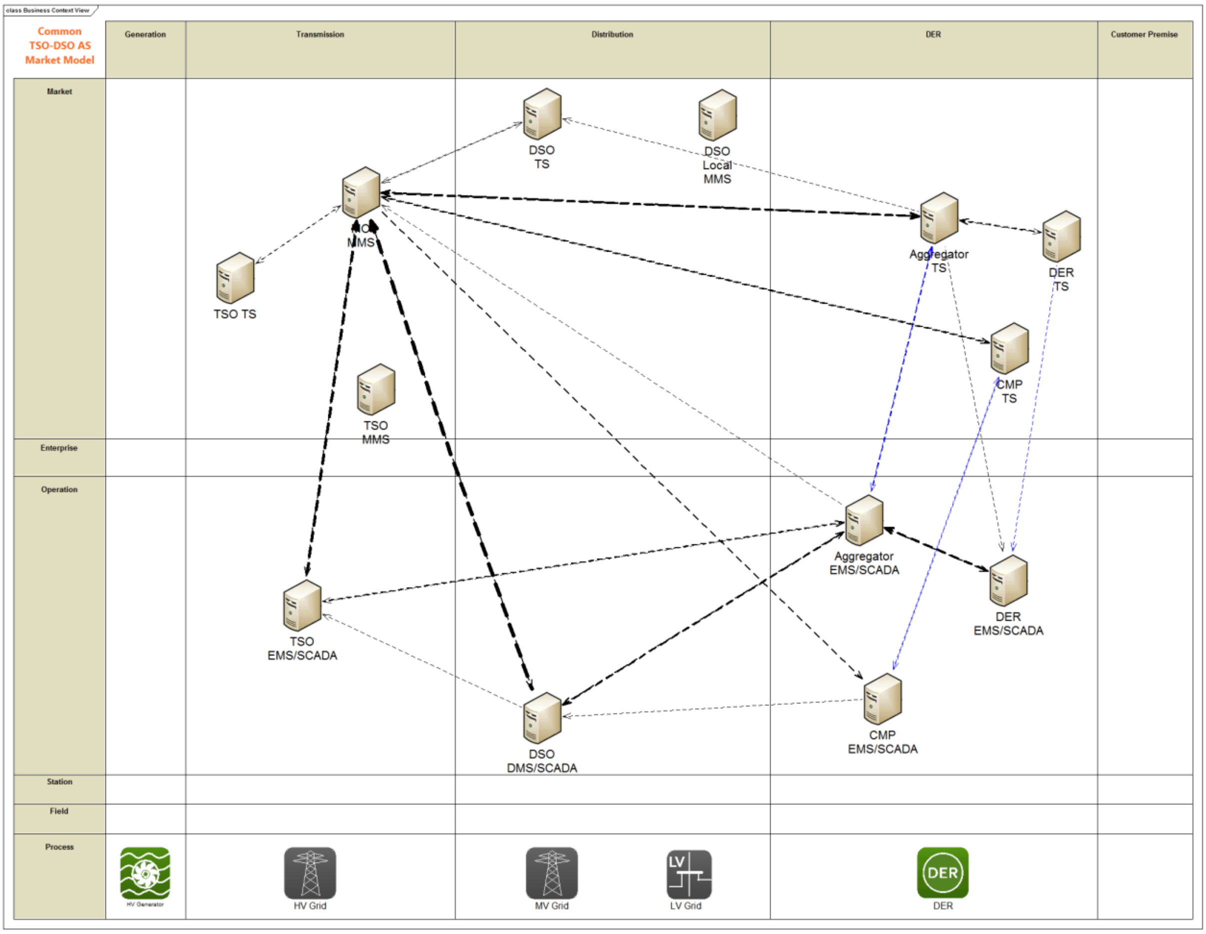



*Figure 22. Business information context view for Coordination Scheme D (centralised variant). Blue colour indicates business actor's internal links.*

## 5.5.4 Analysis of different protocols

We also used filters to illustrate how different protocol classes were used in the interactions between components. For this, we wrote a script that filters connections depending on if any of the conveyed objects is associated with a certain Protocol Class.

Figure 23 shows this filter for the protocol class *PC_DER*. The thickness shows how many of the conveyed objects are using *PC_DER* protocol class. As expected communication to and from the *DER EMS/SCADA* component is active, but there is also communication between the *TSO* and the *DSO* that is using *PC_DER*. The assessment of the diagram reveals how frequently a specific protocol class is used, how relaxed the requirements for protocols are, and are there any clear errors in requirements for protocols. In real system realisations, the protocol classes can easily be replaced with specific protocols depending on how much information is available about system components and supported protocols.

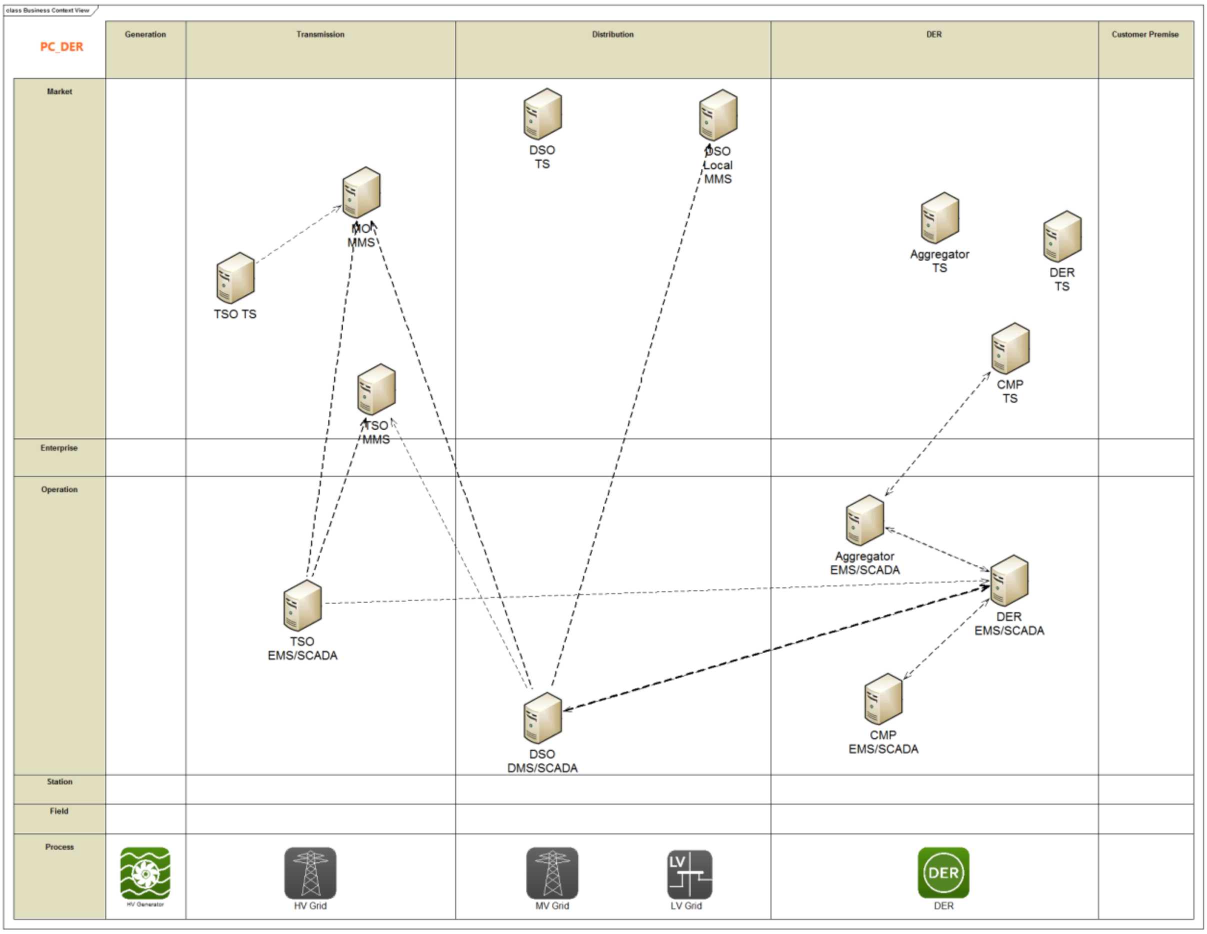



*Figure 23. Information flows where the protocol class PC_DER is used.*

In comparison, Figure 24 shows the same diagram with a filter using the protocol class *PC_EnergyMarket*. In this case, almost all of the connections are visible (compare with Figure 19). This is due to fact that most specified coordination schemes and use cases are mainly focusing on market interactions.

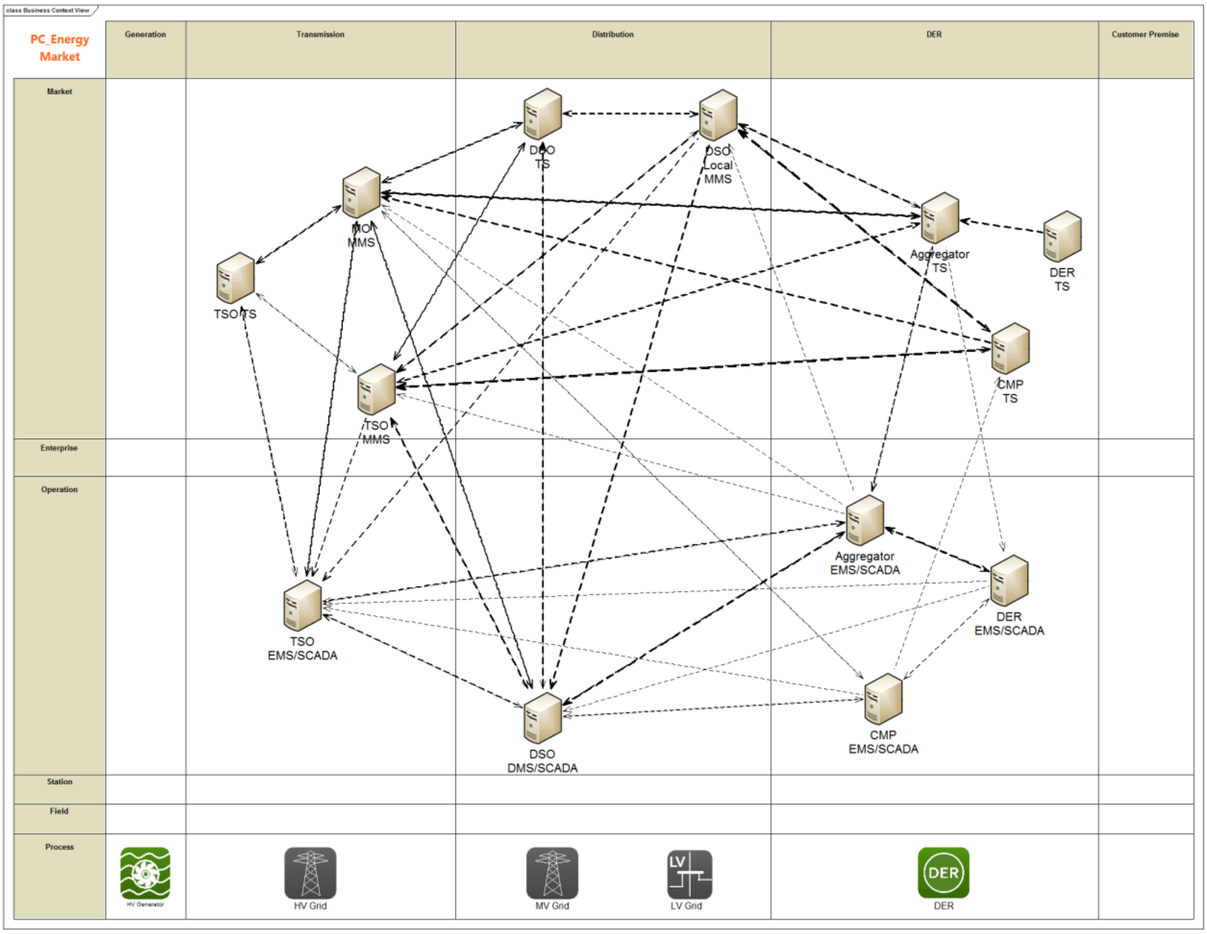



*Figure 24. Information flows where the protocol class PC_EnergyMarket is used.*

## 5.6 Communication layer

After analysing the exchanged information, data models and protocol classes in the information layer, we moved to the communication layer to identify suitable communication protocols and ICT technologies for each information exchange link. The creation of the communication layer requires more detailed information about e.g. used services, communication infrastructure, and even about a geographical area.

The use case specifications studied during the ICT requirements specification phase did not give enough information to identify exact communication protocols or dedicated ICT technologies for each link. The analysis process revealed mainly information about requirements concerning data models e.g., IEC 61850 was identified as one possibility but it was not specified if the implementation should be using Manufacturing Message Specification (MMS) or Web Services. As a result, we were forced to present the

communication layer in a more generalised way. However, by using requirements defined in different Requirement Classes, we were able to assess on a high level where different wired or wireless technologies would make sense to apply.

### 5.6.1 Wired or wireless?

By studying each conveyed object and associated latency and security requirements (more particularly, requirement classes), it was possible to create a diagram, where types of communication links are presented. In our analysis, we limited our assessment only to wireless or wired technologies. The criterion for a wired technology is that at least one of the conveyed objects must have one of the following requirements:

- Latency ≤ 100 ms or Security Level ≥ 4

If none of the conveyed objects has stricter criteria, then the link can be implemented using a wireless technology. Figure 25 shows an example, where wired connections are presented in black (a stringent requirement for latency or security) and wireless connections with more relaxed requirements in green.

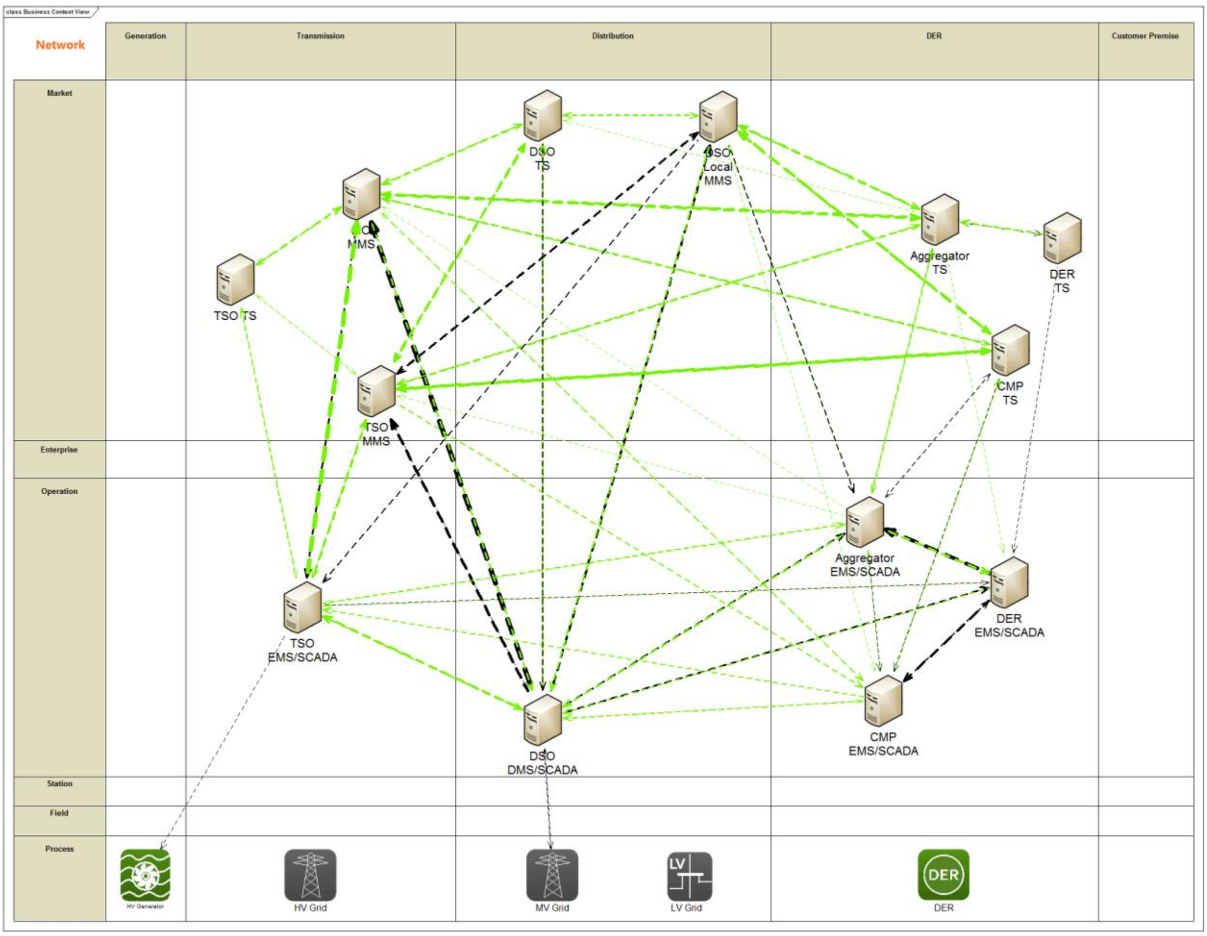



*Figure 25. Communication Layer with different network types: Wireless connections are shown in green, and wired connections are shown in black.*

The ICT requirements and thresholds e.g. for latency and security level can be changed, so the outcome depends on how we parametrised the model during the system design.

### 5.6.2 Cost estimation

Another possibility to assess the architecture in the communication layer is to evaluate how much stakeholders would be willing to pay for the required QoS (Quality of Service). In other words, how much a network operator could charge for offering information exchange that fulfils the defined Requirement Class.

For this, we created a filter that calculates the average cost of each connection. For all conveyed objects, the cost was summed and divided by the number of conveyed objects. The cost of each connection was presented in the business context view. Figure 26 shows the result of this filter by using different colours for different costs: high (red), medium (orange), and low (green). The diagram was used to analyse the overall cost level in different coordination schemes and to validate that there were no anomalies in the input data. The parameters for defining and calculating the cost can be changed, because the cost function is coded in the script.

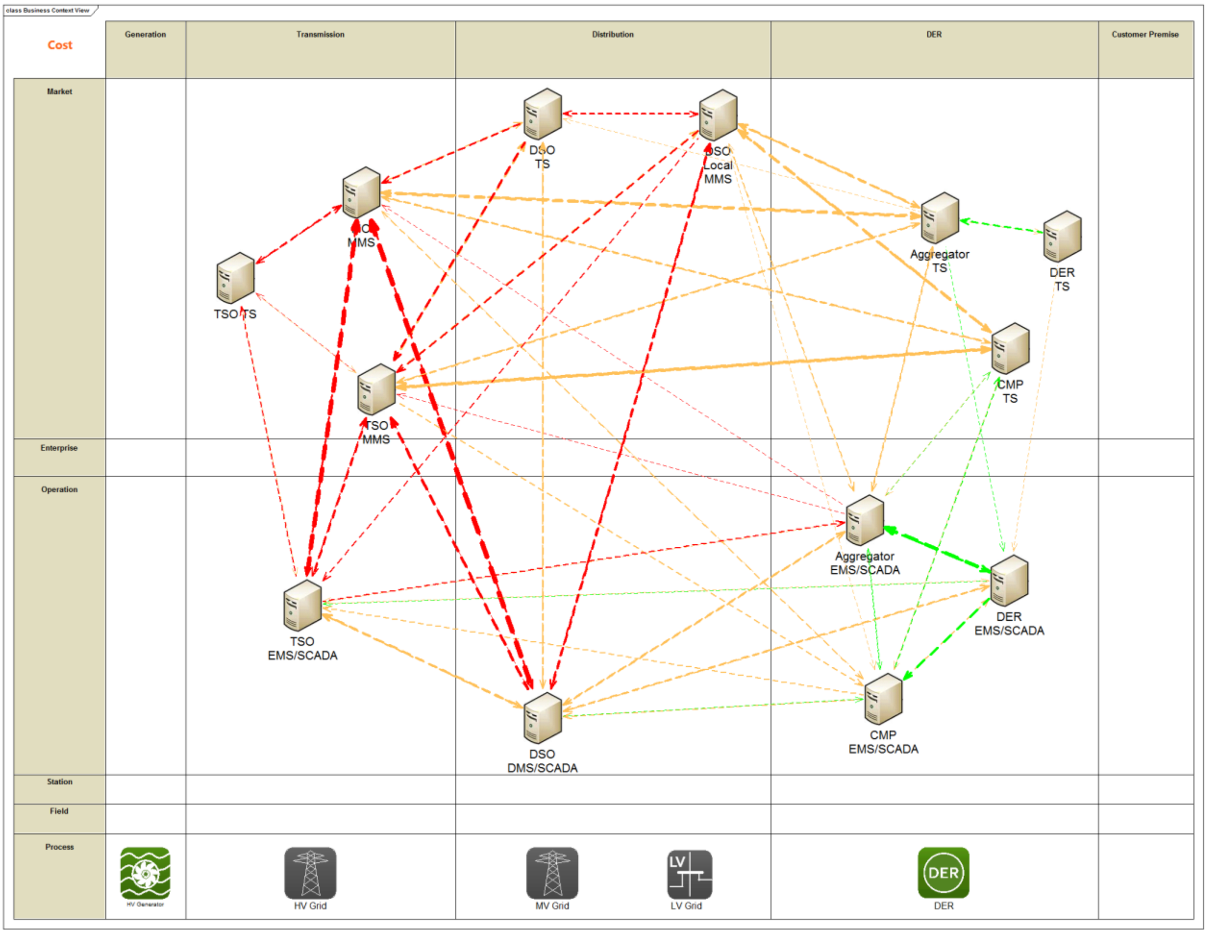


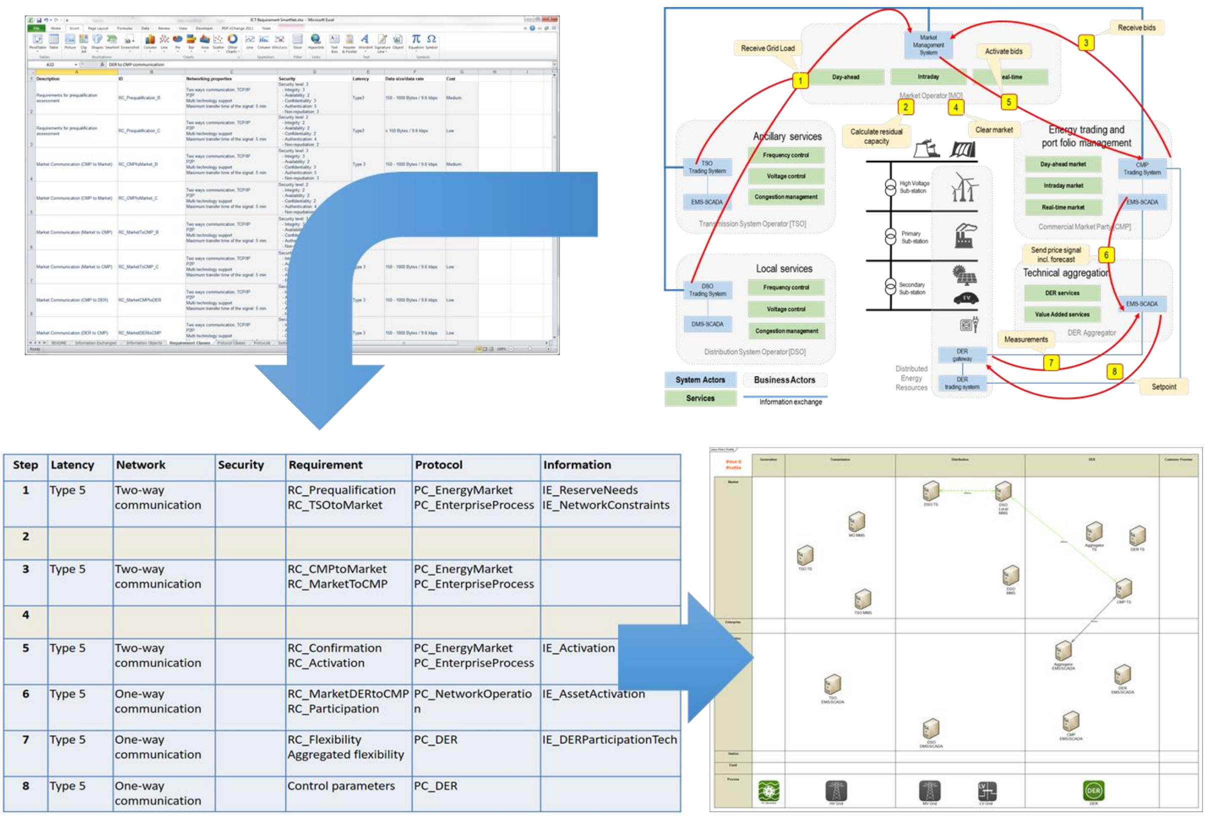

*Figure 26. Communication links with different costs: High cost (red), medium cost (orange), and low cost (green).*

Comparison of Figure 26 to Figure 22 indicates that most of the highly active connections belong to the high-cost class e.g., connections *MMO MMS*, *DSO DMS/SCADA*, *DSO MMS*, *TSO EMS/SCADA* etc. However, connections at the edge of the network can have highly active connections e.g. between *DER EMS/SCADA* and *Aggregator EMS/SCADA,* but those connections belong to the low-cost class indicating lower willingness to pay for reliable communication or security. Most of the medium cost connections can be implemented by wireless technologies.

# 6 Profile models

The applicability of our analysis process and common architecture model was tested using specifications from pilots and simulation platform. The purpose of including them in our work was to benefit from the early alignment of design and implementation work and to support coherent results in the end of the project.

Figure 27 shows a graphical illustration of the analysis steps taken as well as outcomes created for each pilot and the simulation platform. The work started with defining the core interactions between system components. Then, information exchange events and associated ICT requirements were compiled using the available planning material and aligned with the common architecture design. Finally, ICT requirements were re-parametrised according to pilot and simulation platform specific ICT requirements. The generated ICT requirement tables and SGAM models are basically the results of the profile modelling and validation work.



| Step | Latency | Network | Security | Requirement | Protocol | Information |
|---|---|---|---|---|---|---|
| 1 | Type 5 | Two-way communication | | RC_Prequalification RC_TSOtoMarket | PC_EnergyMarket PC_EnterpriseProcess | IE_ReserveNeeds IE_NetworkConstraints |
| 2 | | | | | | |
| 3 | Type 5 | Two-way communication | | RC_CMPtoMarket RC_MarketToCMP | PC_EnergyMarket PC_EnterpriseProcess | |
| 4 | | | | | | |
| 5 | Type 5 | Two-way communication | | RC_Confirmation RC_Activation | PC_EnergyMarket PC_EnterpriseProcess | IE_Activation |
| 6 | Type 5 | One-way communication | | RC_MarketDERtoCMP RC_Participation | PC_NetworkOperation | IE_AssetActivation |
| 7 | Type 5 | One-way communication | | RC_Flexibility Aggregated flexibility | PC_DER | IE_DERParticipationTech |
| 8 | Type 5 | One-way communication | | Control parameters | PC_DER | |

*Figure 27. A graphical representation of analysis steps for the Danish pilot.*

## 6.1 Pilot A (Italy)

The Pilot A aims at testing the provision of flexibility from aggregated RES plants connected to the MV networks (mainly hydro). In particular, at the primary substation, the actual and forecasted load and

production will be provided in order to get information for balancing purposes and to provide the voltage support at the transmission network.

Physically the pilot project is located in the North of Italy in the Ahrntal Valley with the availability of several and different generators connected on all voltage levels. The part of the distribution network used in the pilot includes substations and generation units in order to have a complete system to test several functionalities with different devices: the substation of Molini di Tures with 2 TR 40 MVA 132/20 kV; 2 HV hydraulic generators (20 MW each) connected to the substation; the generation is composed by 33 MV generators with a total 43.5 MW installed power (41.7 MW hydro, 1.5 MW thermal, 0.2 MW PV), and 0.85 MW of generation on the LV (0.73 MW PV). Also, there are 9.6 MW of generation waiting to be connected to the grid.

### 6.1.1 Description of Pilot A

The Italian pilot will implement new features for an innovative experimentation in the field. The main goals are:

- **Aggregation** of information in real time at the interconnection point between TSO-DSO (HV/MV transformer). The data exchanged are installed total power differentiated by source (PV, rotating machine, etc.), real-time load data (total load, gross amount of load compensated by distributed generation) presented in terms of P and Q (for all the sources), and forecast data (active power profiles for each type of source, photovoltaic or other sources that will be updated every 3 hours taking into consideration the network topology of the distribution network and all the variations of the topology in the short period).
- **Voltage control** is seen as the development of an architecture and implementation in the field of a system for the voltage control by generators connected to HV and MV levels (virtual capability) in order to get a desired voltage level at the HV busbar.
- **Frequency restoration control** intended as the development of an architecture and implementation in the field of a system for the power-frequency regulation by generators connected to MV levels. The service performs a variation of the active power value according to a signal level (0÷100) sent by TSO to the customer's control system.

The Pilot A is basically divided into two ICT systems with different scopes:

- **Medium Voltage Regulation System (MVRS):** this system implements the functions of information aggregation and control of the distributed generation.
- **High Voltage Regulation System (HVRS):** this system implements the algorithms to perform the functions of the information aggregation and to control the high voltage generation.

All the actors involved in the Pilot A are illustrated in the following figures, the yellow boxes describe the sequence of basic information exchanges for this pilot. They are:

*Aggregation:*

1. The DSO collects real-time data from its network
2. The DSO collects real-time data from DERs
3. The DSO performs the equivalentation (observability, virtual capability) and sends the relevant data to the TSO

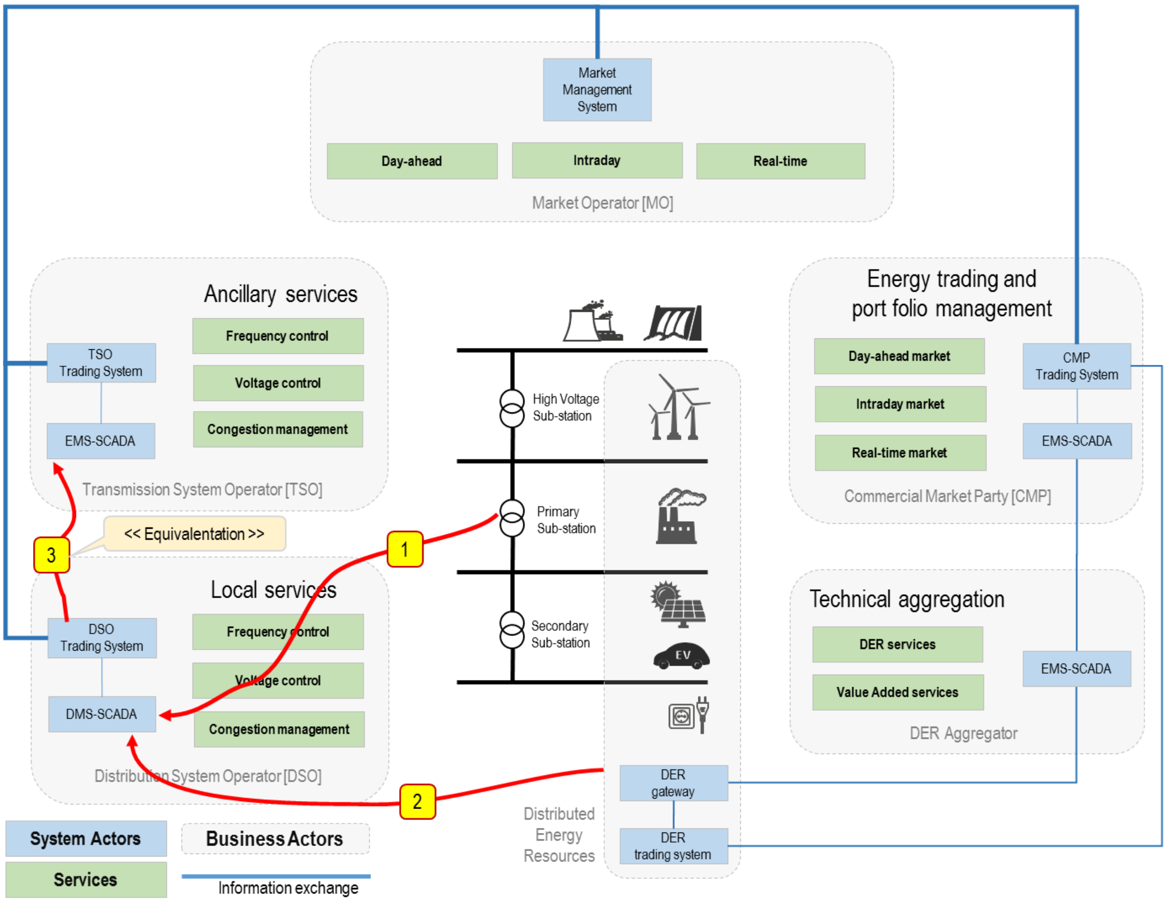



*Figure 28. The Pilot A sequence of steps for the basic data exchange – Aggregation function.*

*Voltage control:*

1. The TSO sends the setpoint for the HV/MV substation (V level for the HV bus bar)
2. The DSO calculates the setpoints and sends them to DERs (Q set point) and to the OLTC (V setpoint)

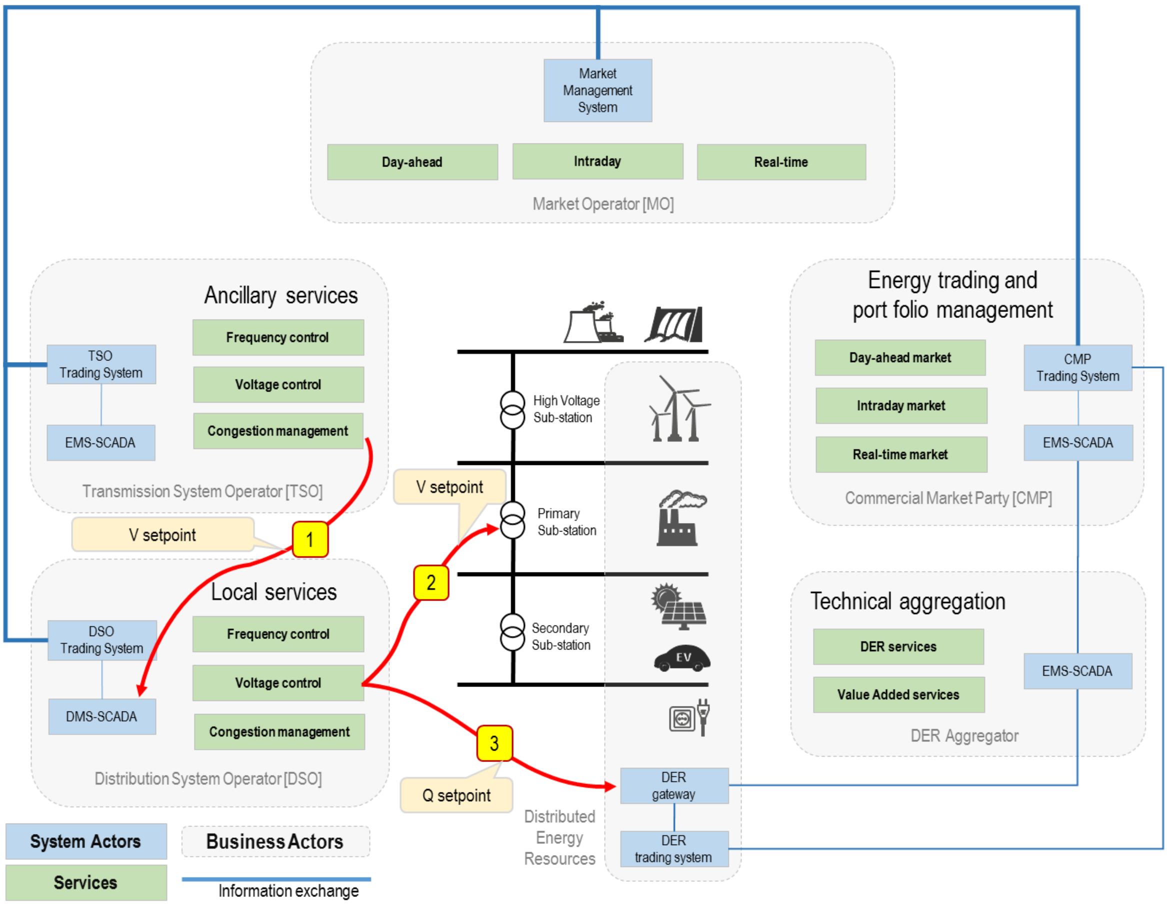



*Figure 29. The Pilot A sequence of steps for the basic data exchange – Voltage regulation.*

*Frequency restoration control:*

1. The TSO calculates the setpoint (level) for the generators and delivers it directly to HV generators ("relevant users") and send it to the DSO
2. The DSO forwards the setpoints (level) to MV DERs ("not relevant users")

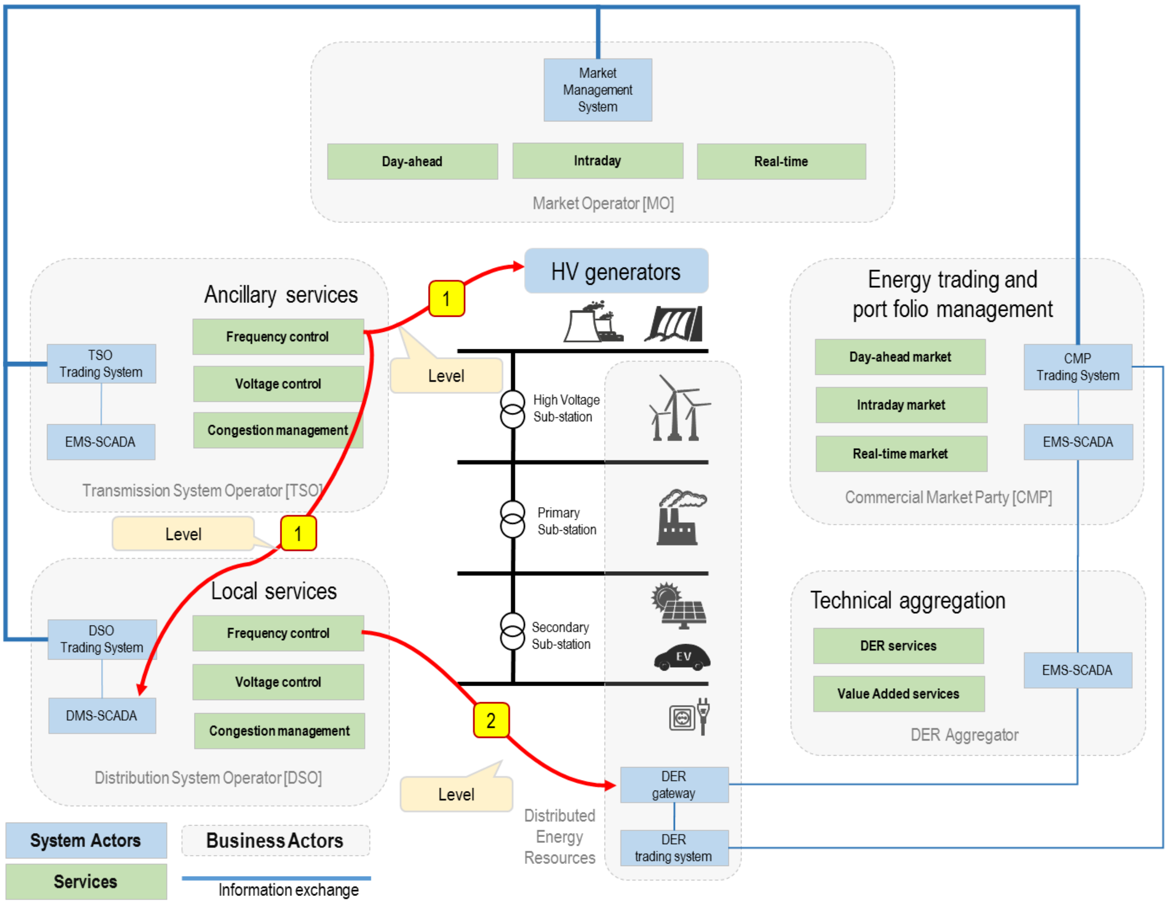



*Figure 30. The Pilot A sequence of steps for the basic data exchange – Frequency restoration control.*

The partners in Pilot A have the following roles:

- **Transmission System Operator** (TERNA) is responsible for the balancing services for the transmission grid incl. ancillary services (132 kV and above).
- **Distribution System Operator** (Edyna) is responsible for managing the distribution grid.
- **Relevant users** (≥10 MVA) participate to the voltage regulation. The interaction with the TSO is direct, without any aggregation.
- **Not relevant users** connected to the medium voltage grid, interact through the DSO (allowing them to provide grid services for the relevant system Operator). The equivalentation of distributed resources at nodal level permits the TSO to transparently access the underlying resources.

### 6.1.2 Summary of the Pilot A profile

Based on the sequence of profile creation steps defined in chapter 6.1.1 (see Figure 28, Figure 29, and Figure 30), the captured preliminary ICT requirements for the Pilot A are presented in the following tables (see Table 1, Table 2, and Table 3).

*Table 1. The Pilot A profile with ICT requirements – Aggregation.*

| Step | Latency[1] | Network[2] | Security[3] | Requirement[4] | Protocol[5] | Information[6] |
|---|---|---|---|---|---|---|
| **1,2** | Type 5 | Two-way communication | Level 4 | RC_Activation | PC_DER | IE_Activation |
| **3** | Type 5 | Two-way communication | Level 4 | RC_Activation | PC_NetworkOperation | IE_Activation |

*Table 2. The Pilot A profile with ICT requirements – Voltage control.*

| Step | Latency | Network | Security | Requirement | Protocol | Information |
|---|---|---|---|---|---|---|
| **1** | Type 5 | Two-way communication | Level 4 | RC_Activation | PC_NetworkOperation | IE_Activation |
| **2** | Type 5 | Two-way communication | Level 4 | RC_Activation | PC_DER | IE_Activation |

*Table 3. The Pilot A profile with ICT requirements – Frequency restoration control.*

| Step | Latency | Network | Security | Requirement | Protocol | Information |
|---|---|---|---|---|---|---|
| **1** | Type 5 | Two-way communication | Level 4 | RC_Activation | PC_NetworkOperation<br>PC_DER | IE_Activation |
| **2** | Type 5 | Two-way communication | Level 4 | RC_Activation | PC_DER | IE_Activation |

The Pilot A profile was also modelled with Enterprise Architect. Figure 31 shows the connections between the involved actors in the pilot. The figure shows also which connections are recommended to

[1] See Latency property list in Appendix 10.2
[2] See Network property list in Appendix 10.3
[3] See Security property list in Appendix 10.4
[4] See Requirement classes in Appendix 10.5
[5] See Protocol classes in Appendix 10.6
[6] See Information objects in Appendix 10.7

be wired (black) or wireless (green) based on the network type filter described in Section 5.6.1. The reason for wired connections is the high-security requirements rather than the latency.

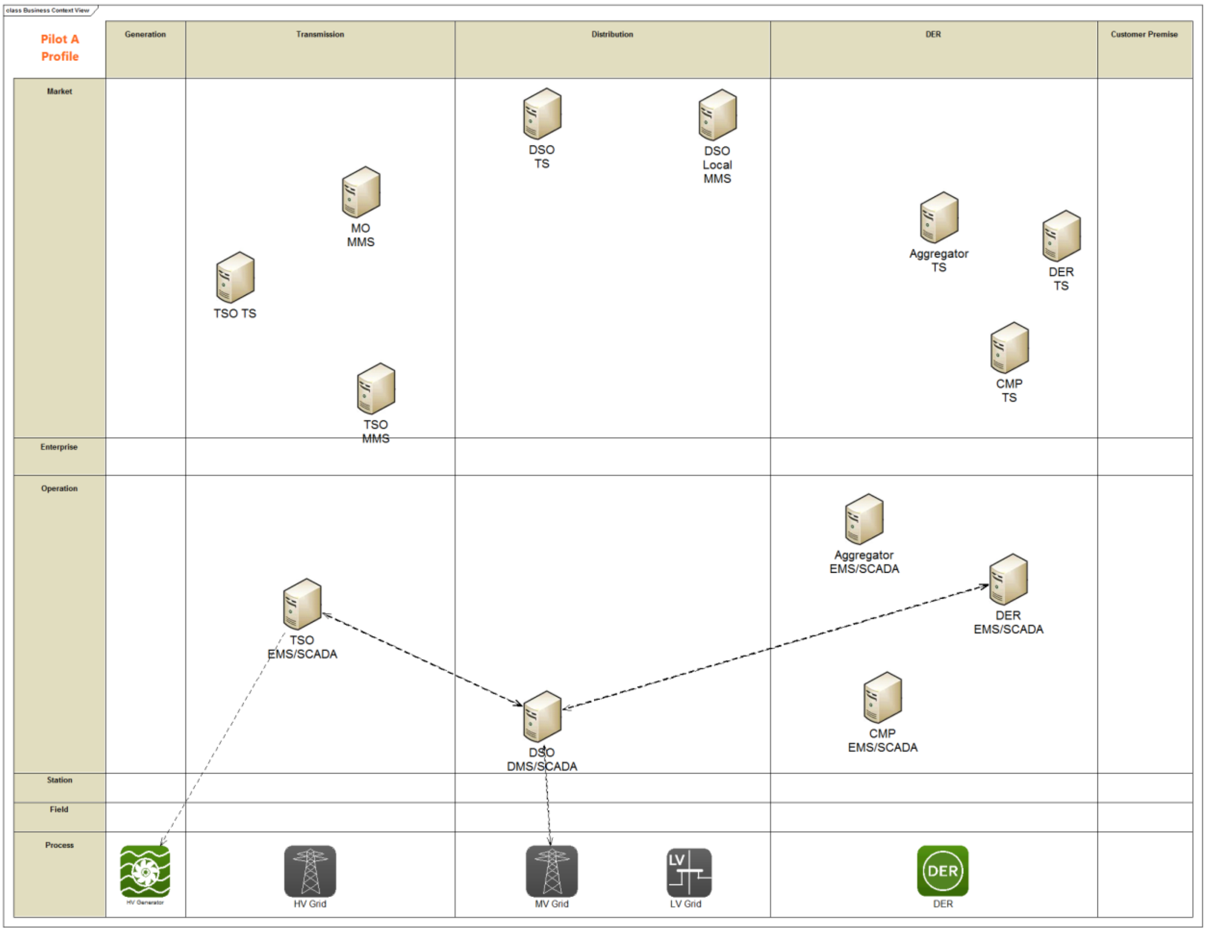



*Figure 31. A profile model in Enterprise Architect for the Pilot A including the network type. Wired connections are used in all links.*

## 6.2 Pilot B (Denmark)

The Pilot B aims at assessing potentials originated from the aggregation of Danish summer houses with swimming pools for the provision of ancillary services. Summer houses have a relatively large and flexible consumption, e.g. the electrical load used to heat water in a swimming pool can be easily shifted in time. This makes summer houses with pools particularly well suited to the provision of ancillary services.

Considering the current situation, the implementation of the pilot requires the following infrastructural additions:

- Remote data acquisition and control system in a properly selected set of summer houses
- Integration with a weather and load forecasting system on a local scale

- Infrastructure for the exchange of data between DSO/TSO and aggregator for the activation of ancillary services.

### 6.2.1 Description of the Pilot B

The main task of the Pilot B is to use the large inertia of heat storage in summer house swimming pools to allow for a shift of electricity consumption by several hours. The summer houses can affect the aggregation by broadcasting an appropriate control signal to the aggregator.

**The main goals of Pilot B are listed below:**

- Aggregation of energy storage consisting of 30 Danish summer houses.
- Implementation of ICT technology in the field to exchange data between TSO, DSO, aggregator, and smart homes.
- Use of online web-based services for price, load, and wind power forecasting.
- Development of architecture and a Proof-of-Concept system for voltage regulation (measurements) by flexible summer houses.
- Development of architecture and a Proof-of-Concept system for the provision of balancing power (smart use of energy).
- Development of architecture and a Proof-of-Concept system for the provision of congestion management services (load curtailment).

**Pilot B is basically divided into two ICT systems with different scopes:**

- **SYSTEM A**: This ICT system has a focus on IoT hardware deployment in summerhouses using a high degree of proprietary technologies and non-standard protocols.
- **SYSTEM B**: This ICT system has a focus on grid measurements for the low-voltage feeder to summerhouses based on standard IEC data protocols with interoperability to DSO SCADA systems.

All the actors involved in the Pilot B are illustrated in Figure 32. The yellow boxes describe the sequence of basic information exchanges for this pilot. They are:

1. Receive grid load information from TSO
2. Calculate residual capacity
3. Receive bids from CMP
4. Clear market
5. Activate bids to CMP
6. Send a price signal to the technical aggregator
7. Measurements from the DER
8. Send setpoint to the DER

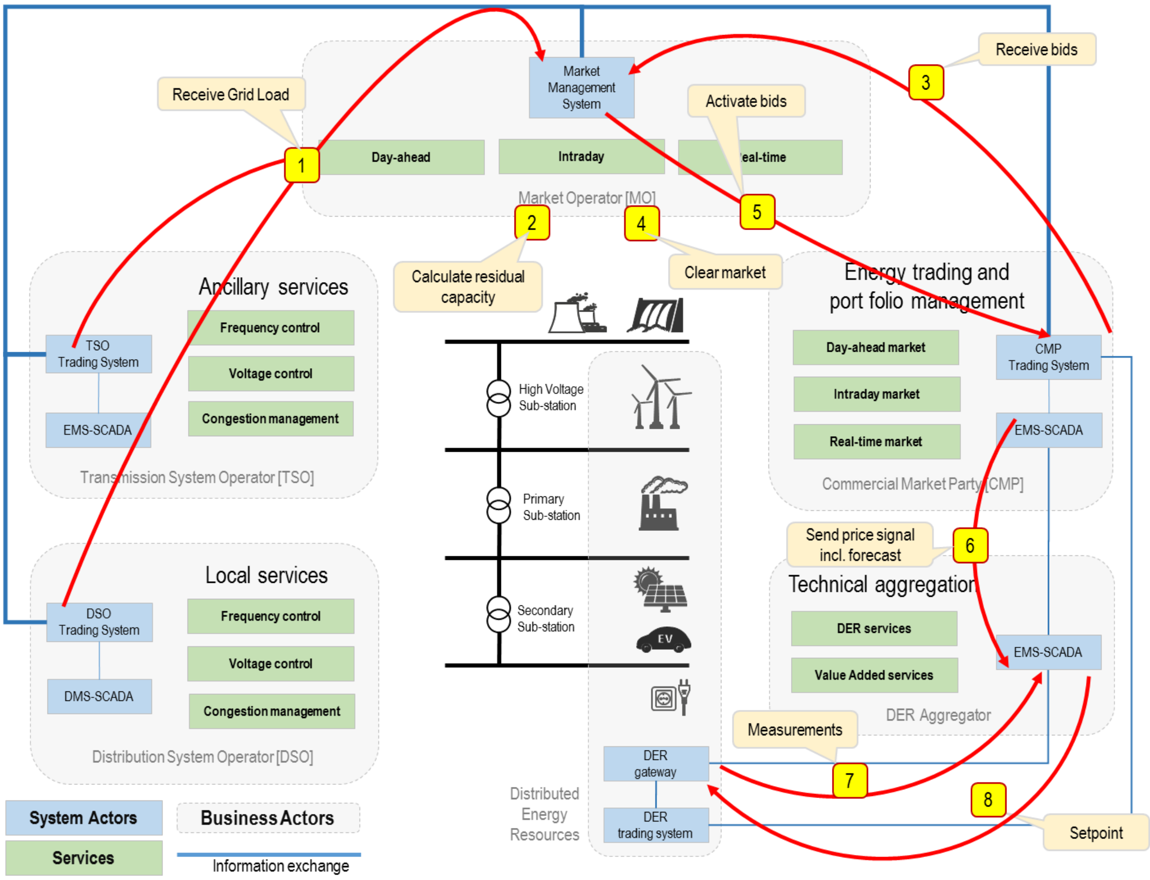



*Figure 32. The Pilot B sequence of steps for the basic data exchange.*

The partners in the Pilot B have the following roles:

- **Transmission System Operator** (Energinet.dk) is responsible for the balancing services for the transmission grid incl. ancillary services (150 kV and above).
- **Distribution System Operator** (Syd Energi) is responsible for using ancillary services from the distributed Energy resources and managing the distribution grid.
- **Commercial Market Players** (ONE and NEAS) are responsible for trading the services from the distributed resources with the Market Operator.
- **Technical Aggregators** (NOVASOL, EURISCO and DTU/ENFOR) are responsible for managing all the distributed resources, which in this case are the summerhouses.

### 6.2.2 Summary of the Pilot B profile

Based on the sequence of profile creation steps illustrated in Figure 32, the preliminary ICT requirements for Pilot B are defined in Table 4.

*Table 4. The Pilot B profile with ICT requirements.*

| Step | Latency[7] | Network[8] | Security[9] | Requirement[10] | Protocol[11] | Information[12] |
|---|---|---|---|---|---|---|
| **1** | Type 5 | Two-way communication | Level 3 | RC_Prequalification<br>RC_TSOtoMarket | PC_EnergyMarket<br>PC_EnterpriseProcess | IE_ReserveNeeds<br>IE_NetworkConstraints |
| **2** | No communication required | | | | | |
| **3** | Type 5 | Two-way communication | Level 3 | RC_CMPtoMarket<br>RC_MarketToCMP | PC_EnergyMarket<br>PC_EnterpriseProcess | IE_MarketBids |
| **4** | No communication required | | | | | |
| **5** | Type 5 | Two-way communication | Level 4 | RC_Confirmation<br>RC_Activation | PC_EnergyMarket<br>PC_EnterpriseProcess | IE_Activation |
| **6** | Type 5 | One-way communication | Level 4 | RC_MarketDERtoCMP<br>RC_Participation | PC_NetworkOperation | IE_AssetActivation |
| **7** | Type 5 | One-way communication | Level 3 | RC_Flexibility<br>RC_AggFlexibility | PC_DER | IE_DERParticipationTech |
| **8** | Type 5 | One-way communication | Level 4<br>Level 3 | RC_Control<br>RC_Control | PC_DER | IE_DERParticipationTech |

Figure 33 shows the Pilot B profile in Enterprise Architect including the connections between the involved actors. The same network type filter is used to generate recommendations for wired and wireless links. Security requirements are more relaxed than in the Pilot A case, so there is more flexibility to use wireless connections.

[7] See Latency property list in Appendix 10.2
[8] See Network property list in Appendix 10.3
[9] See Security property list in Appendix 10.4
[10] See Requirement classes in Appendix 10.5
[11] See Protocol classes in Appendix 10.6
[12] See Information objects in Appendix 10.7

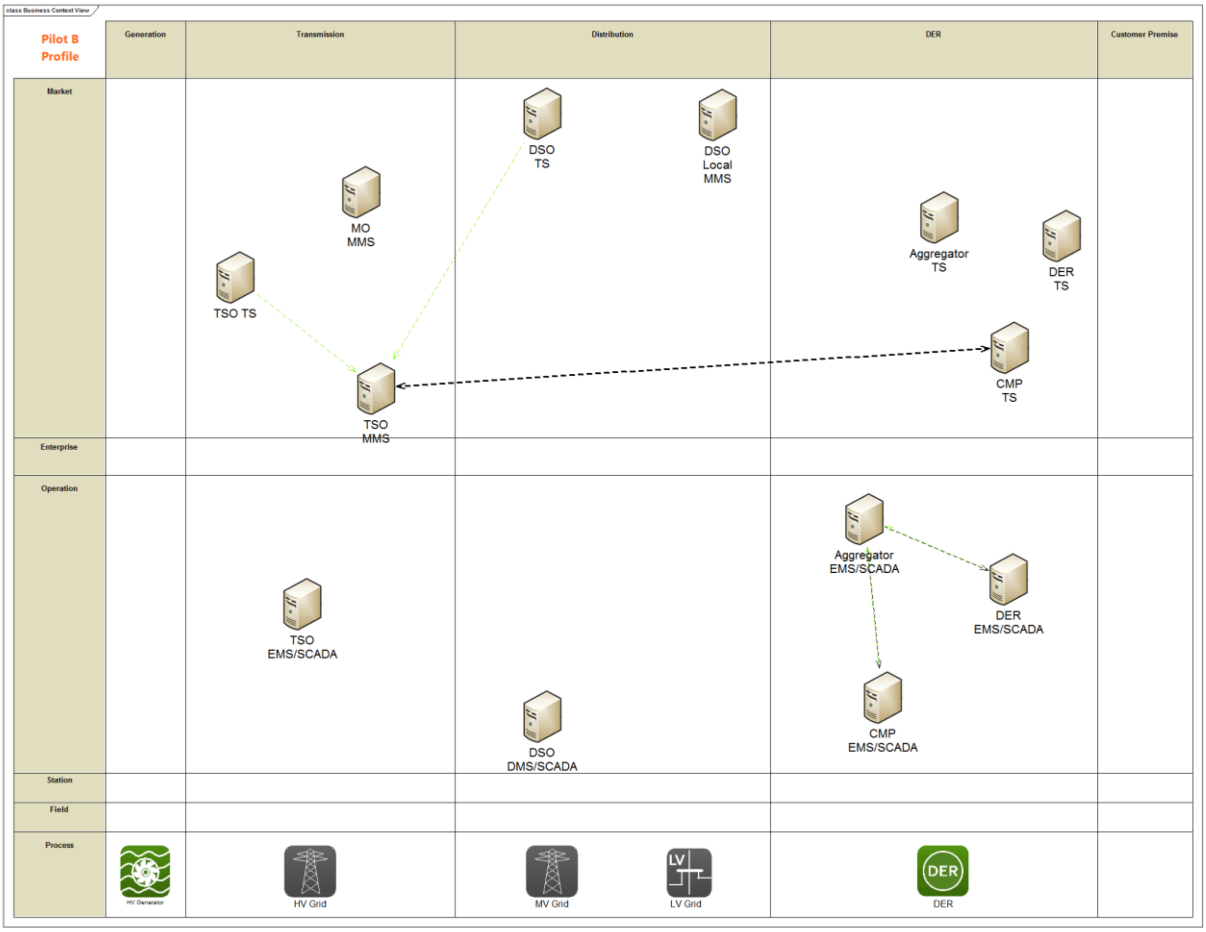



*Figure 33. A profile model in Enterprise Architect for the Pilot B including the network type (wireless connections are shown in green and wired ones in black).*

## 6.3 Pilot C (Spain)

The Pilot C manages a set of radio base stations located in the city of Barcelona for the provision of local services. Each site is equipped with batteries for uninterrupted service of Vodafone's clients. The batteries will supply the amount of energy needed for well-functioning of the sites when load curtailment is activated (demand response). Not only radio base station sites will be provided as flexibility assets, but also to provide a wide portfolio of demand response options. Some of those will be simulated to complement the pilot.

The Spanish pilot requires new implementations in order to solve ICT challenges:

- Installation of demand response devices in Vodafone radio base stations.
- Installation of DER meters in each base station site for the billing between the aggregator and DER owner.
- Other hardware to enable the exchange of data between all parties (LMO, DSO, TSO, Aggregator and DER owner) for the provision of the local services.

## 6.3.1 Description of the Pilot C

Main objectives of the Pilot C are:

- Aggregation of 10-20 radio base stations in Barcelona with a flexible capacity of 50 kW.
- Provision of local ancillary services balancing at the TSO-DSO interconnection point and solving local congestion using flexibility.
- Testing the Shared balancing responsibility model.
- Implementation of ICT solutions for communication between parties to enable the provision of local services.

The aggregator and the DER owners should build ICT communication architecture so that data exchange between the aggregator and each radio base station will exist (presented in orange in Figure 34). Moreover, the installed communication technology solutions should lead to considerable simplifications in the communication protocols between Aggregator and Assets.

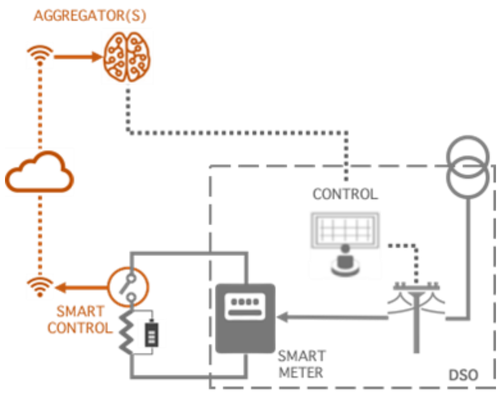



*Figure 34. Data and control flows between different actors in the Pilot C.*

The data exchange includes information from the Assets' Smart Controllers such as current energy consumption [kWh] and the availability of the Asset to be included within any dispatch service request. The Aggregator will then manage the information feeds from the various Assets to determine the total load available for dispatch to meet the needs of any DSO dispatch requests.

Upon receipt of dispatch request from the DSO, the Aggregator can fulfil the requested demand by selecting from a pool of available Assets, based upon current energy consumption and availability. Once the Aggregator has selected the mix of Assets required to fulfil the demand, dispatch signals will be sent to the Smart Controllers of the selected Assets to remove the load from the Grid.

Based on the real-time data exchange updates, the Aggregator can confirm the amount of load that has been dispatched to fulfil the DSO request and reports back accordingly. On the other hand, local market operator, the role played by Endesa, will exchange data with aggregators.

All the involved actors in the Pilot C are illustrated in Figure 35. The yellow boxes describe the sequence of basic information exchanges for this pilot.

DAY-AHEAD:

1. Definition of the schedule profile agreed between TSO and DSO (simulated)
    - From now on, REAL-TIME:
2. Send last market results (from LMO to DSO)
3. Send CMP's information (baselines and flexibility bids for the following market) (FROM CMP TO LMO)
4. Send CMP's baselines for the following market (from LMO to DSO)
5. Calculation of DSO needs
6. Send DSO needs to Local Market Operator
7. Market clearing
8. Send following market results (from LMO to CMPs)
   Each CMP allocates matched volume among DERs
9. Send Activation orders (from each CMP to each DER)
10. Consumptions during activation period (activation check)

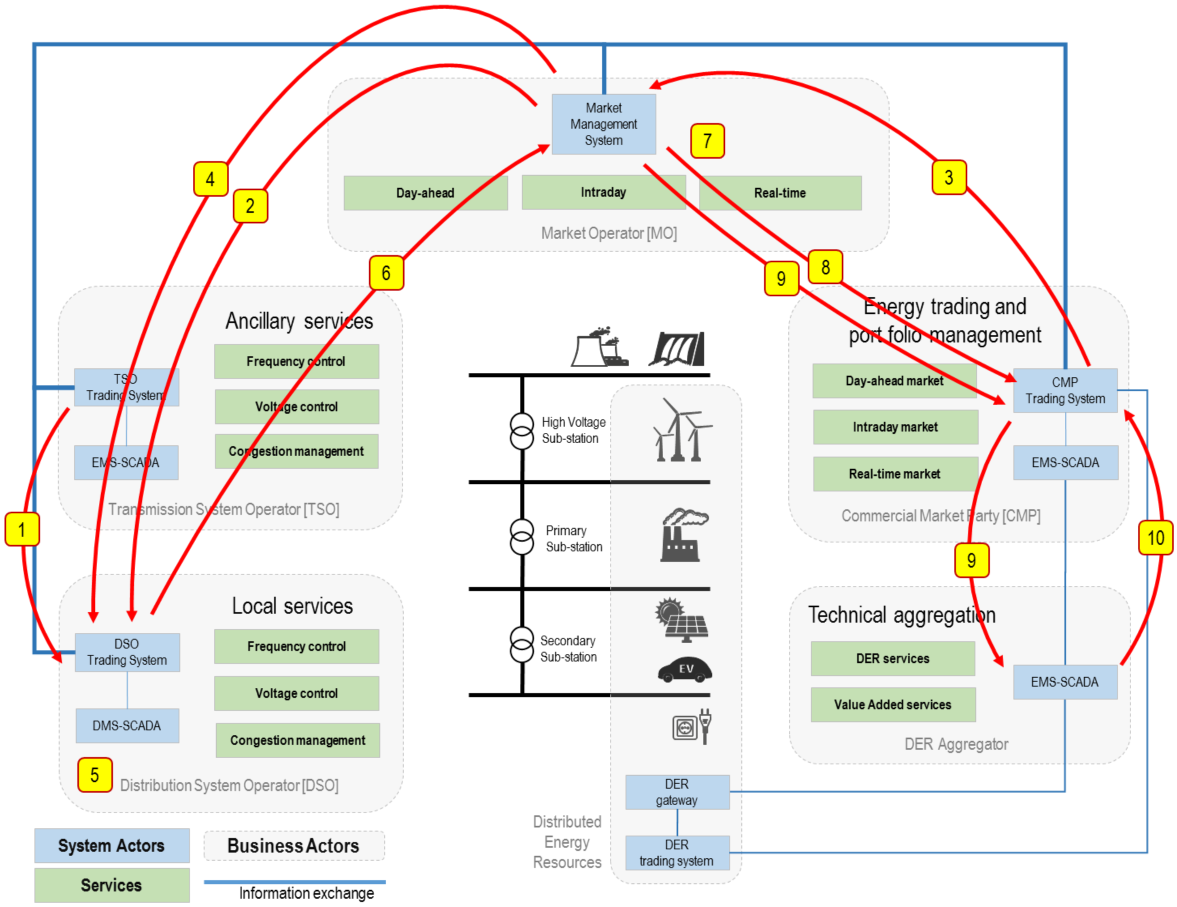



*Figure 35. The Pilot C sequence of steps for the basic data exchange.*

The partners in the Pilot C have the following roles:

- **Transmission System Operator** (Endesa Distribución) is responsible for balancing the Transmission System. The TSO operates the AS market on transmission level.
- **Distribution System Operator** (Endesa Distribución) is responsible for balancing the local network on behalf of the TSO, by means of respecting a defined exchange profile. The DSO operates a local AS market, where it buys flexibility to deal with local grid congestion and to respect the defined exchange profile. It is also responsible for dispatching DERs, which are not aggregated by CMPs.
- **Commercial Market Players** (ONE, Endesa Distribución) aggregate local DER resources. As a consequence, they are responsible for selling the flexibility of the DER in their portfolio on the local markets run by DSOs dispatching (and balancing) the DERs in their portfolios.
- **Market Operator** (Endesa Distribución) is an entity that operates a platform in which bids from CMPs are placed. In this use case, both the TSO and DSO are Market Operators, each for their own market.
- **DER Owner** (Vodafone) is a party that produces electricity via a flexible resource. A flexible resource is a connected unit that provides flexibility for one or more purposes.

### 6.3.2 Summary of the Pilot C profile

Based on the sequence of profile creation steps illustrated in Figure 35, the preliminary ICT requirements for the Pilot C profile are presented in Table 5.

*Table 5. The Pilot C profile with ICT requirements.*

| Step | Latency[13] | Network[14] | Security[15] | Requirement[16] | Protocol[17] | Information[18] |
|---|---|---|---|---|---|---|
| 1 | No communication required.<br>This link will be simulated (protocol class: PC_EnterpriseProcess) | | | | | |
| 2 | Type 5 | Two-way communication | Level 3 | RC_MarketToDSO | PC_EnergyMarket | IE_MarketClearing- |
| 3 | Type 5 | Two-way communication | Level 3 | RC_CMPtoMarket<br>RC_Flexibility | PC_EnergyMarket | IE_MarketBids |

13 See Latency property list in Appendix 10.2
14 See Network property list in Appendix 10.3
15 See Security property list in Appendix 10.4
16 See Requirement classes in Appendix 10.5
17 See Protocol classes in Appendix 10.6
18 See Information objects in Appendix 10.7

| Step | Latency[13] | Network[14] | Security[15] | Requirement[16] | Protocol[17] | Information[18] |
|---|---|---|---|---|---|---|
| **4** | Type 5 | Two-way communication | Level 3 | RC_MarketToDSO | PC_EnergyMarket | IE_Prequalification- |
| **5** | No communication required | | | | | |
| **6** | Type 5 | Two-way communication | Level 3 | RC_DSOtoMarket<br>RC_Reserves | PC_EnergyMarket | IE_ReserveNeeds |
| **7** | No communication required | | | | | |
| **8** | Type 5 | Two-way communication | Level 3 | RC_MarketToCMP | PC_EnergyMarket | IE_MarketClearing- |
| **9** | Type 5 | Two-way communication | Level 4 | RC_MarketToCMP<br>RC_MarketCMPtoDER<br>RC_Activation | PC_DER | IE_AssetActivation |
| **10** | Type 5 | Two-way communication | Level 4 | RC_MarketDERtoCMP<br>RC_Metering<br>RC_Confirmation | PC_DER | IE_AssetConfirmation |

Figure 36 shows the connections between the involved actors in the Pilot C using the same network type filter that was used in the Pilots A and B. The connection between the CMP TS and the Aggregator EMS/SCADA is qualified as wired due to high-security requirements. Other links can be implemented with wireless connections.

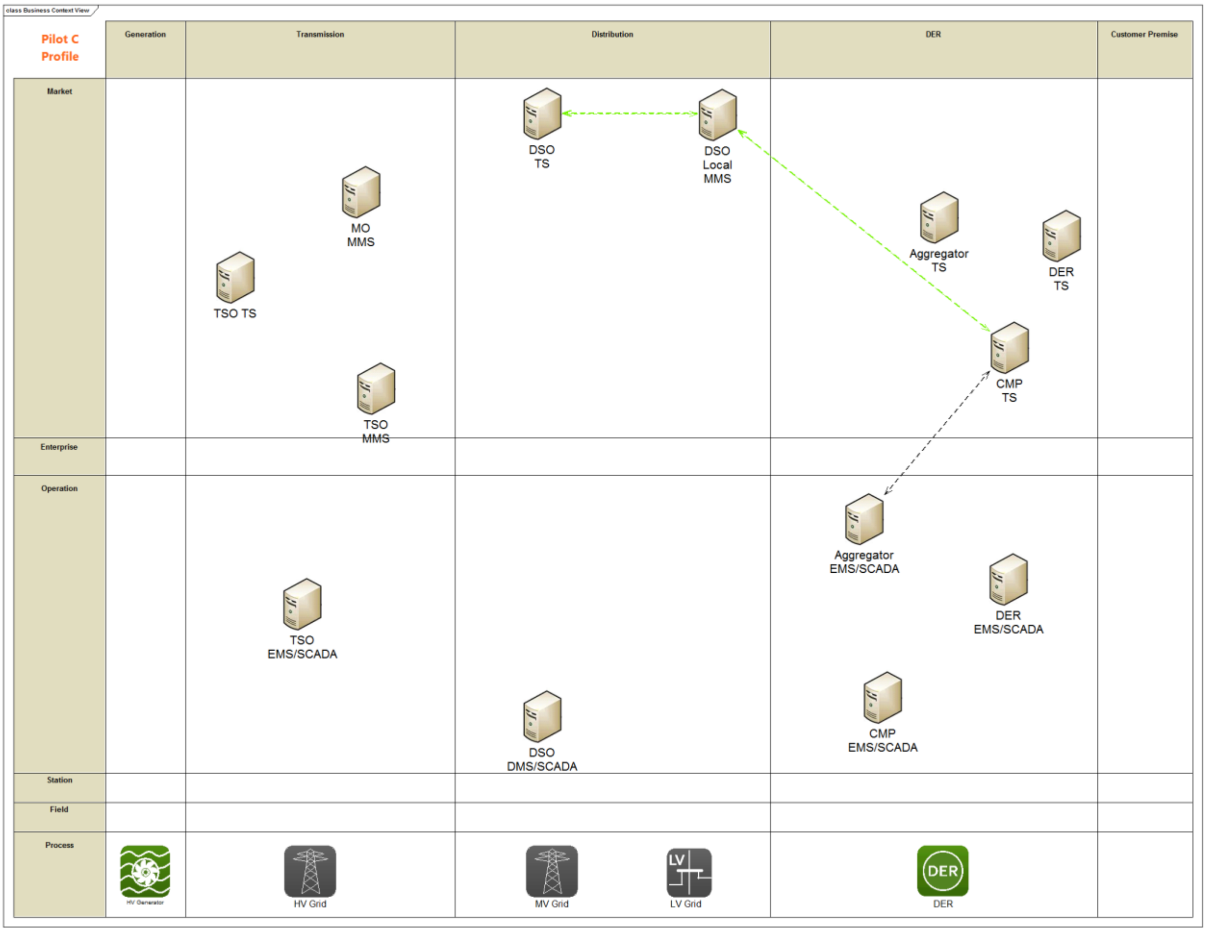



*Figure 36. A profile model in Enterprise Architect for the Pilot C including the network type (wireless connections are shown in green and wired ones in black).*

## 6.4 Simulation Platform

In WP4, the aim is to create a simulation platform for national cases covering the pilots A, B, and C. All of the TSO-DSO coordination schemes cannot be experimented with physical pilots, because this type of market arrangements is not allowed for experimentation in the real world. Those schemes need to be simulated. The simulation platform will contain a full implementation of TSO-DSO interaction schemes, but with simplified representations of the electrical grid, ancillary services market/markets, and the ICT infrastructure. The simulation platform is configured according to national regulations and particularities and for each of them, the scenario data is matched for the target horizon 2030.

In addition to software simulations, an implementation of a testbed in a laboratory environment is intended. The laboratory facility can give further possibilities to implement and test new functions that are not yet supported by the current regulatory framework. Specific technologies that can be taken into account are:

- Data exchange between TSO and DSO for different interaction schemes and also between hardware equipment located in the substations of the TSO and the DSO.
- Setting the reactive power values to be injected/absorbed by DER at a given time, for example for voltage regulation purposes

### 6.4.1 Description of Simulation Platform

The simulation platform is divided into simulation blocks that cover different parts of the system's functionality. These blocks are placed in different layers, as shown in Figure 37. The physical layer simulates the physical components. It consists of transmission and distribution networks, and flexible devices. If these devices are too small to participate in the market on their own, then these devices are aggregated by an aggregator. The aggregator is simulated in the bidding and resource dispatching layer. Also, the flexible devices that participate in the market on their own are active in this layer. The topmost layer is the market layer (at the bottom of the picture) where the different market and coordination schemes are modelled.

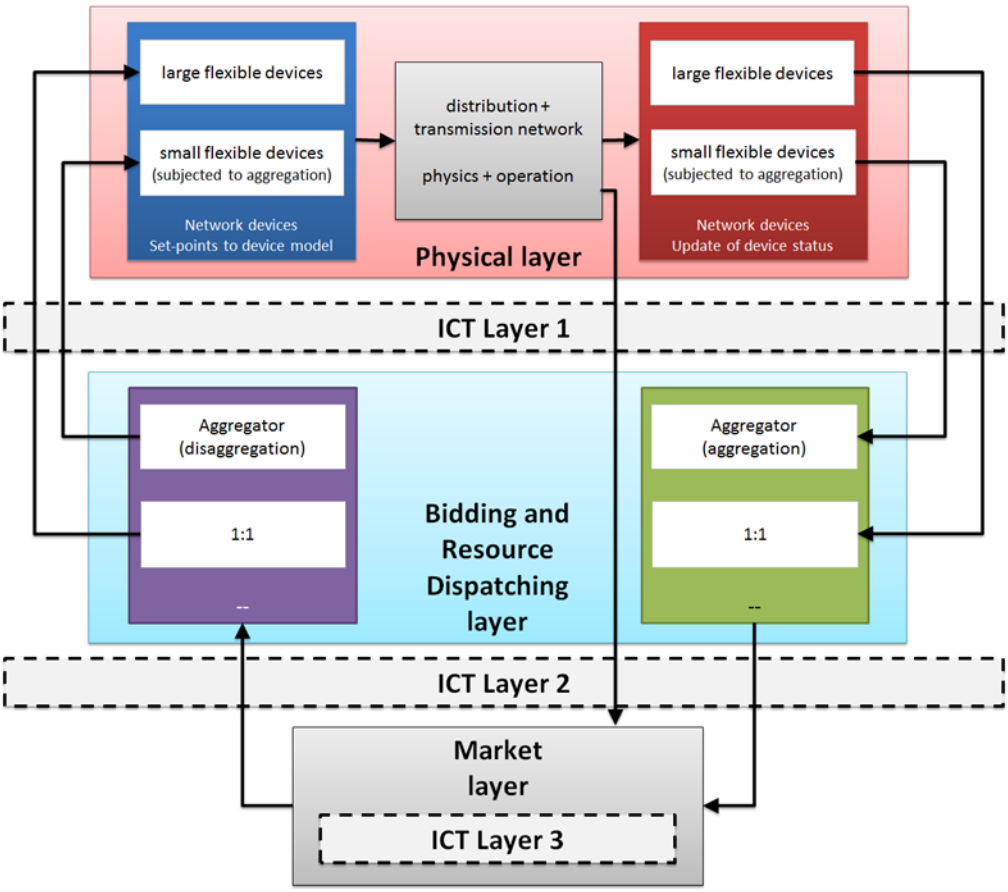



*Figure 37. An overview of the simulation platform.*

In order to simulate the ICT infrastructure as well, ICT layers have been added to the platform as illustrated in Figure 37. First of all, there is a communication between the physical layer and the bidding

and resource dispatching layer that is modelled in ICT Layer 1 (top dashed box). With this layer, all communication between the DER components and the Aggregator components are covered. Secondly, the communication between the Bidding and Resource Dispatching Layer and the Market Layer is modelled with ICT Layer 2 (middle dashed box). This layer covers the communication between the trading systems and the market management systems. To cover intercommunication between market systems, an ICT Layer 3 is added within the Market Layer (bottom dashed box).

### 6.4.2 Summary of Simulation Platform profile

Compared to the pilot profiles, the simulation platform profile is based on the common ICT architecture model defined in Section 4. This means that no additions to the ICT requirements table are needed. Furthermore, the simulation platform profile must be created within the context of a certain simulation test case. Once a test case has been defined, this can be used to filter the ICT architecture model for further studies. There are a number of possibilities where the simulation platform profile can support the ICT simulation in WP4:

- *Identify communication links*: By filtering the business context view of the ICT architecture depending on a certain test case (e.g., coordination scheme or use case), it is possible to show only the communication links that are active in this scenario.
- *Identify network simulation parameters*: After it is known which communication links need to be studied for a test case the requirements associated with each link can be further studied. From these requirements, important network simulation parameters (e.g. latency, data rate/data size, protocol, network type) can be extracted. These parameters can be used for the implemented ICT simulation.
- *Identify model errors*: During the modelling of the overall ICT architecture, minimal requirements were identified for each information exchanged event. If the simulated ICT network is modelled according to these requirements it is also possible to use this simulation model for validation purposes. For example, if the identified requirements are too relaxed this may affect the simulation results in a negative way. On the other hand, if the requirements are too strict this may result in unnecessarily high costs, since it would be possible to achieve similar simulation results with more relaxed ICT requirements.

Figure 38 shows an example of a simulation platform profile that was made for the Frequency Containment Reserve case. Involved systems and communication links are presented in the figure. In this use case, there are only three connections from *DSO DMS/SCADA*, which are critical enough to be implemented as wired. The links are not internal connections, since they connect different system actors.

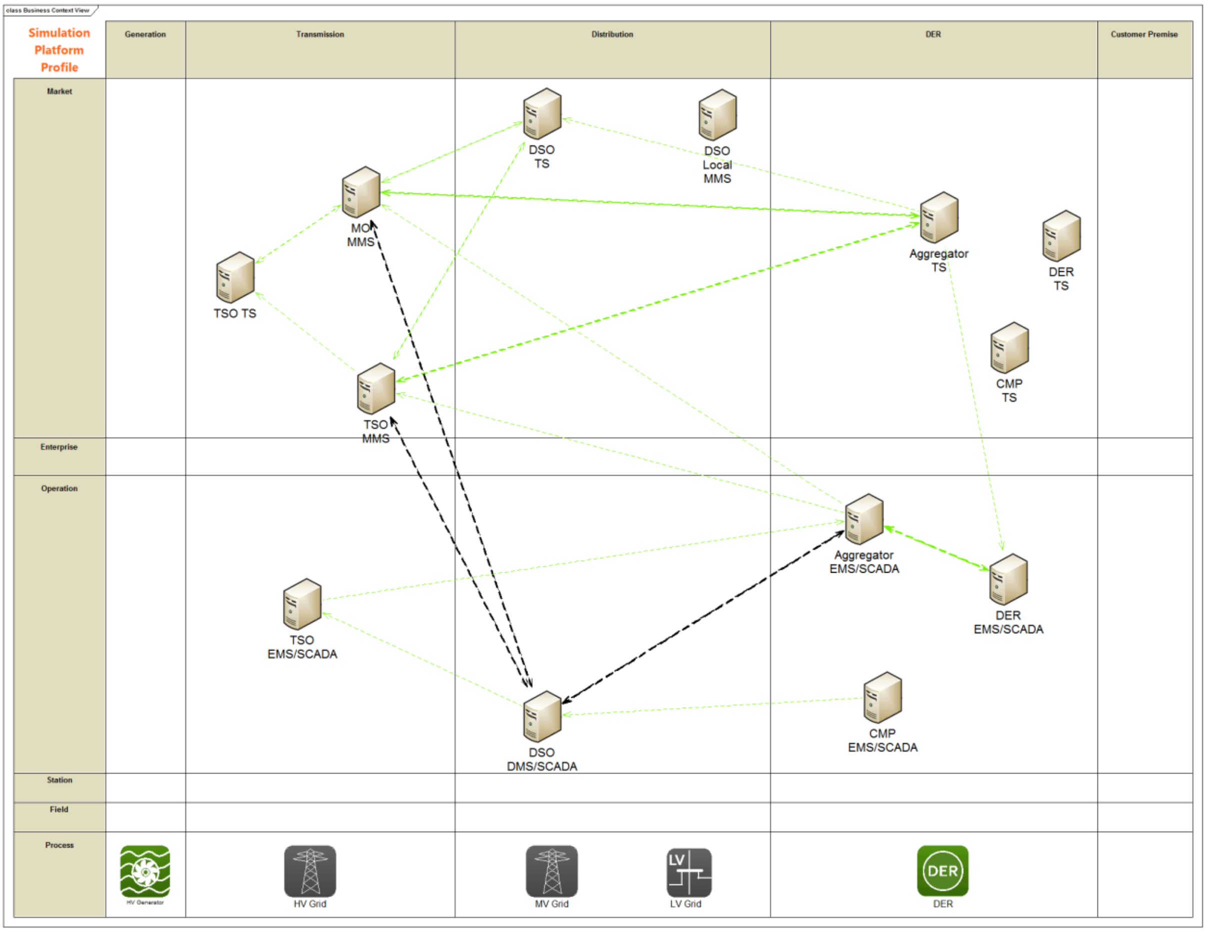



*Figure 38. Simulation platform profile for Frequency Containment Reserve including the network type (wireless connections are shown in green and wired ones in black).*

# 7 Enabling technologies

The study of enabling communication technologies covered both human and machine users. Our focus was on Machine-to-Machine (M2M) and Internet-of-Things (IoT), because M2M/IoT applications for energy systems have very different requirements compared to conventional human-centric applications. Security aspects has been addressed more in details in D3.1 [3] where security requirements were identified, For this, NIST guidelines and generic security requirements has been presented in NISTR 7628 - Guidelines for Smart Grid Cyber Security vol. 1-3 [9] and  Smart Grid Information Security [14] were utilized. The role of new trust model, new service delivery model, and E2E security utilizing network slicing have been addressed in 5G technology concept,

In SmartNet context, some applications have very relaxed latency requirements, such as remote meter reading for billing purposes, whereas others may require ultra-reliable real-time communication than cannot be offered by today's wireless networks. These applications are mainly used for control and protection of critical parts in electrical grids. There are also surveillance applications that are transmitting high volumes of information in contrary to low power remote metering devices using very small data payloads. To exploit communication capabilities offered today and tomorrow, we shortly present the potential technologies for grid communications including their pros and cons, and evolution plans.

## 7.1 Existing telecommunication networks

In traditional telecommunication networks, two key performance indicators are capacity and coverage. In 2G and 3G telecommunication networks, capacity and coverage were almost fixed. Networks were designed to meet particular capacity and coverage targets. Once the network was designed, it stayed as it was for a long time. Whenever the coverage or capacity demand increased, mobile operators were forced to deploy more base stations to offer additional radio resources. There were no means to dynamically adjust network capacity or coverage to cope with fluctuating traffic loads and moving subscribers.

Long term evolution (LTE / 4G) is the most recently deployed technology after GSM (2G) and UMTS (3G) with some level of flexibility. The main technology goal of LTE was to speed up broadband mobile services (e.g. video) and deliver better service quality to end-users. The architecture does not have any circuit-switched components, so all traffic is transmitted through IP packets, even voice (Voice over LTE, VoLTE). In LTE, intelligence is distributed among base stations (eNodeB) whereas in GSM and UMTS networks use centralised controllers (radio network controllers, RNCs). Therefore, in LTE, a base station can make decisions without consulting with the controller. This flattens the architecture, shortens the connection setup time and also the time required for handovers.

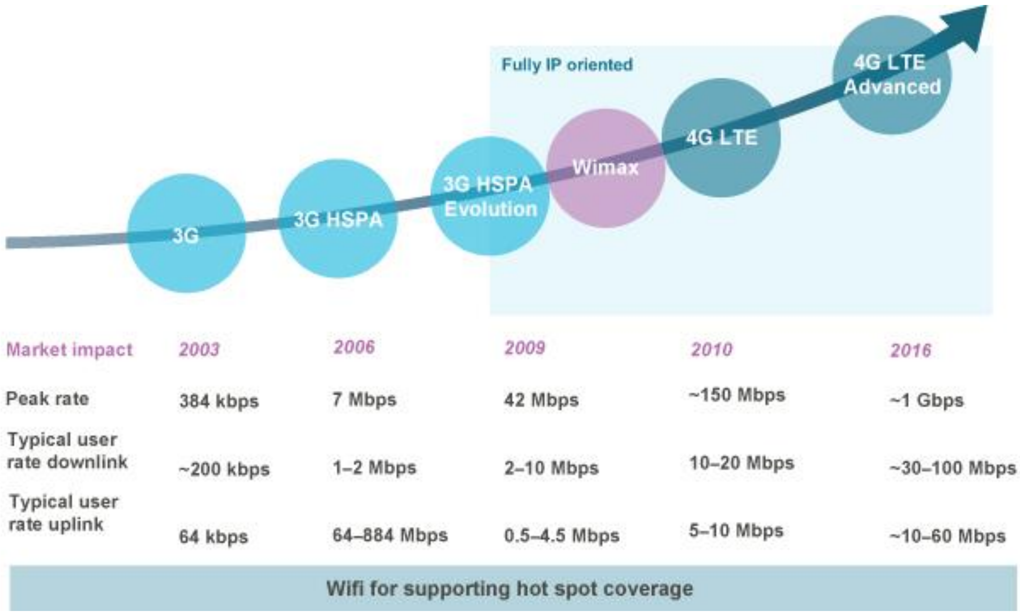



*Figure 39. Evolution of cellular technologies and data rates [15].*

In 4G networks, a new concept was introduced called self-organising networks (SON). This means that base stations are more intelligent and can steer their coverage and capacity based on the changing needs/demand in the network. If demand increases, the base station increases its capacity. For example, if more capacity is needed at a particular location, the base station shrinks its coverage to serve better those users in the smaller region with higher capacity and the excluded areas are serviced by other base stations. In addition to that, 4G technology exploits advanced antenna techniques such as Multiple Input Multiple Output (MIMO) and beamforming to increase data rates and reliability. A MIMO equipped base station or terminal uses more than one antenna to transmit and receive information over the air. Various antenna beamforming techniques are used to increase the coverage and capacity on hotspots and to reduce the interference in the network.

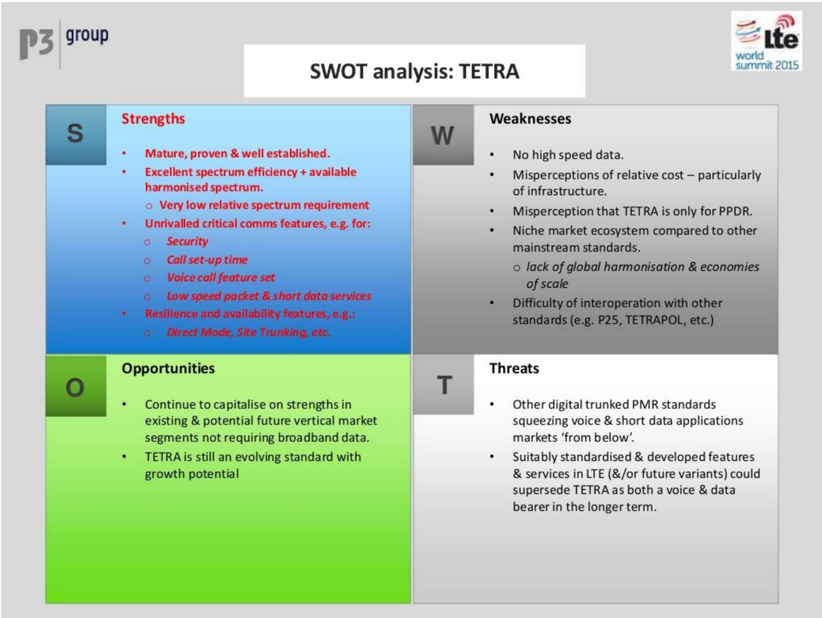
4G networks are designed to cover large geographical areas. Large mobile operators have thousands of base stations in order to cover their service area. To improve the performance of the overall network, base stations are collaborating directly (through X2 interface), which enables to exchange information about current load levels, predicted capacity, and coverage levels, etc. Each base station will adjust its configuration to meet the users' demand while minimizing the negative impact on the overall network performance. Thus, network optimises itself to changing traffic conditions.

There have been a lot of discussions around LTE for critical communications [16]. Does LTE hardware meet the needs of the critical communications sector and, can LTE really offer the security, reliability, and resilience required for critical communications?

The conventional communication technology for critical applications has been TETRA (Terrestrial Trunked Radio). This covers applications that require a secure, reliable, and robust communication

system. This technology has also been exploited by many DSOs and TSOs for critical operations. The advantage of TETRA is that it was designed for mission-critical services, and it is suitable for use cases to deliver mission critical data on demand within a secure pipe. The drawback of TETRA technology is that it is a narrowband technology with limited data transmission capabilities. LTE and its future releases are offering mobile broadband and high data rate services more cost-effectively. However, it requires several LTE releases to get to the point where LTE can offer TETRA's key features such as group working, pre-emptive services, network resilience, call set-up times, and direct mode. Apparently today, we have two technologies, one offering what end-users want, and the other offering what end-users need.

The figure below (Figure 40) shows the strength and weaknesses of both technologies as a SWOT analysis.



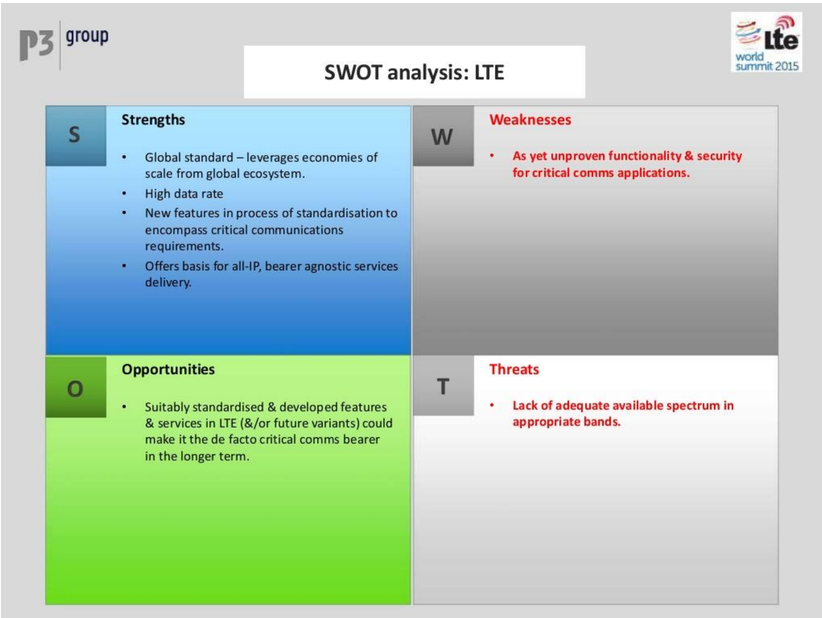




*Figure 40. SWOT analysis TETRA vs. LTE capabilities [17].*

There are three evolution paths to consider: one looking at LTE (and its future releases or 5G) as a replacement, one seeing LTE as a complementary technology to be used together with TETRA to give the best of both technologies, and one adopting a range of different standards for both narrow and broadband according to their operational and business requirements, spectrum availability, and legislation.

## 7.2 Wireless sensor networks

Wireless sensor networks (WSN) are infrastructures containing sensing, computing, and communication elements that give the ability to measure, collect, and react to events in a restricted area or space. Wireless sensor networks were designed for flexible and scalable communication. Typical applications in the smart grid domain are metering of energy; environmental monitoring such as indoor temperature and humidity, and weather conditions from distributed sensors; and different smart building solutions for measurement and control of energy usage.

The IoT devices typically require very little energy to operate, and thus they can function over a long time without charge of battery. This greatly simplifies the deployment of sensors, compared to having to connect to a power adapter. The use of a wireless Wide Area Network (WAN) instead of a Home or Field Area Network (HAN/FAN) with a gateway for connecting also greatly simplifies deployment and reduces cost. However, the connecting technology must also require a modest use of power in order to ensure long battery lifetimes. In order to operate with very low power consumption, the devices may not continuously be in an active state and ready for receiving and sensing messages.

The sensor network can be homogeneous or heterogeneous. In homogeneous WSN, all the nodes have same capabilities. In a heterogeneous network, devices that are more capable can be harnessed to carry more of the burden on the network. WSN applications can be divided into time-driven, event-driven, and query-driven. The classification is based on the network activity. In a time-driven implementation, sensors will transmit their readings periodically. Sampling and communication occur periodically meaning that the communication times are known beforehand. In an event-driven sensor network, the sensors monitor the area and transmit information only when something meaningful happens. The attempt is to minimise the data traffic and transmission of redundant information. The last application category is query-driven systems where gathered information is stored locally in the sensor network and specific information is retrieved with queries. Scheduled communication protocols are typically used in time-driven and on-demand protocols in event-driven implementations.

The most flexible sensor network topology for energy systems is cluster-star. It is a hybrid topology formed from star and mesh network topologies. In this topology, sensor nodes are divided into normal nodes and cluster heads. Normal nodes are only communicating with their cluster head whereas cluster heads can also communicate with each other. This structure allows the most of the sensors in the network to be simple, and only a few nodes need to be more intelligent with additional memory and processing capabilities. The communication link between the sensor network and global network is through gateways using licensed or unlicensed radio access technologies.

## 7.3 Low-power wide area networks

Low-power wide area networks (LPWAN) are designed for M2M applications that communicate over a long communication link (even a few hundred km), have low data rates and long battery lives, and that operate unattended for long periods of time. LPWA products have low channel bandwidth and transmit power according to local regulation, which makes them appropriate for energy efficient and modest data rate transmissions. The focus has been on frequencies below 1 GHz, because it offers longer range and better penetration e.g. indoors.

The key requirements for LPWA networks to support massive M2M deployment are:

- **Long battery life**: IoT device must operate for a very long time. The goal is to have a minimum of 10 years of battery duration for simple daily connectivity with small packets.
- **Low device cost**: The target is to reduce the module cost below 5 dollars.
- **Low deployment cost**: The target is to avoid any new hardware installations and site visits in order to minimise CAPEX and OPEX costs.
- **Full coverage**: The target is to improve the communication link budget by 15-20 dB. The coverage enhancements will improve the indoor coverage by offering better wall or floor penetration with deeper indoor coverage.

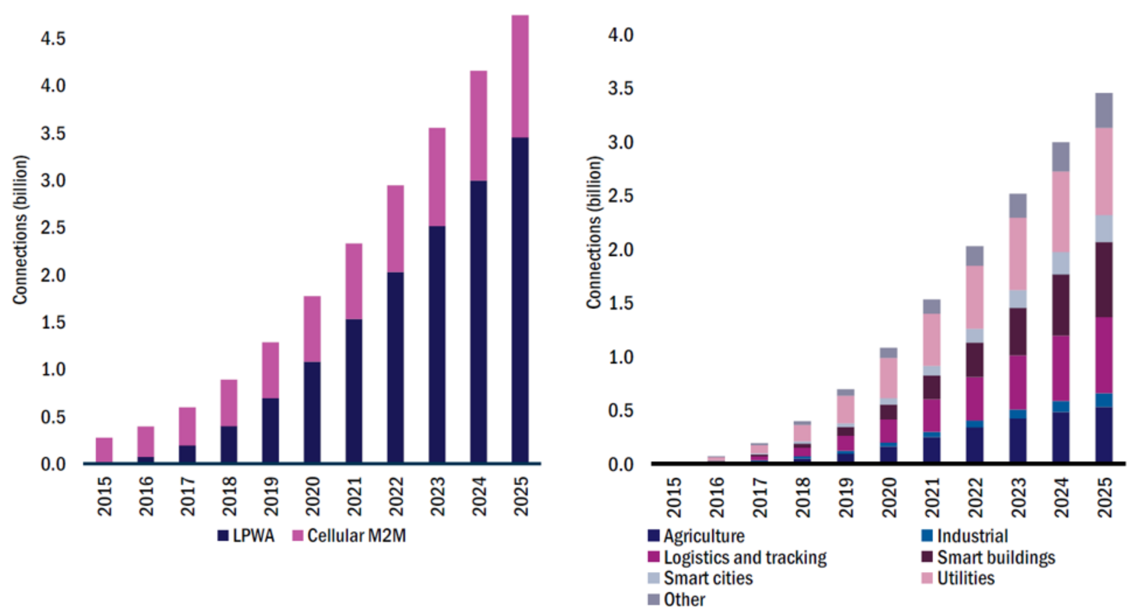



*Figure 41. Analysys Mason's forecasts for LPWA and cellular M2M connections (left) and potential LPWA connections (right), 2015–2025 [18] .*

LPWA networks are an emerging area of the IoT and they represent a huge market opportunity as the IoT matures. This technology is anticipated to create new M2M use cases where connectivity costs are expressed in dollars per year rather than dollars per month. It is estimated that there will be 3.5 billion LPWA network connections and 1.3 billion cellular network connections by the year 2025 [18]. That is equivalent to the current number of global cellular subscriptions, but the density of connected devices is

likely to be less uniform. The deployment of IoT for energy systems will gradually extend towards utility and transport networks by 2020. The final goal after 2025 is to have plug-and-play smart objects, which can be installed in any environment with an interoperable backbone allowing them to communicate with other smart objects in the vicinity.

There are several factors affecting the energy consumption of the communicating devices e.g. modulation technique, media access protocol, acknowledgements with the gateway, possible adaptive techniques, mobility/tracking, and length of the duty cycle. Low duty cycles allow a device to be in sleep mode for a long period and awake only for transmitting data during the duty cycle. The higher the duty cycle, the more data will be transmitted. The drawback is that it prevents other devices in the vicinity to transmit data. Mitigation of interference is often done with a listen before talk technique. Therefore, it is beneficial for everyone that the shared radio spectrum is managed so that it allows to all users a fair share of the available bandwidth. LPWA products focus much on low duty cycles in order to reduce power consumption. The European Conference of Postal and Telecommunications Administrations (CEPT) have defined the bands with different transmit powers and duty cycles [19]. The specifications are different in the USA and Europe. For instance, in the USA much focus is only on transmit power in order to lower power consumption. To further mitigate the possibility of interference, a listen before talk scheme can be used to complement low duty cycles,

LPWA technologies are split into two separate sub-categories (see Table 6). The current proprietary LPWA technologies, such as SigFox, LoRa, M-bush or Dash-7 operate on unlicensed spectrum, while Clean Slate or forthcoming 3GPP standardised cellular IoT technologies e.g. NB-IoT and NB-LTE-M operate in licensed spectrum. LTE-M and NB-LTE-M would be supplementary solutions addressing different use cases, with higher capacity on LTE-M and slightly lower cost and better coverage on NB-LTE-M.

*Table 6. LPWA IoT connectivity overview [20].*

| | SigFox | LoRa | clean slate | NB LTE-M Rel. 13 | LTE-M Rel. 12/13 | EC-GSM Rel. 13 | 5G (targets) |
|---|---|---|---|---|---|---|---|
| | sigfox | LoRa | cIoT | lte | lte | GSM | 5G |
| **Range (outdoors)** | < 13 km | < 11 km | < 15 km | < 15 km | < 11 km | < 15 km | < 15 km |
| **MCL** | 160 dB | 157 dB | 164 dB | 164 dB | 156 dB | 164 dB | 164 dB |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Spectrum Bandwidth** | Unlicensed 900 MHz 100 Hz | Unlicensed 900 MHz < 500 kHz | Licensed 7-900 MHz 200 kHz or dedicated | Licensed 7-900 MHz 200 kHz or shared | Licensed 7-900 MHz 1.4 MHz or shared | Licensed 8-900 MHz 2.4 MHz or shared | Licensed 7-900 MHz shared |
| **Data rate** | < 100 bps | < 10 kbps | < 50 kbps | < 150 kbps | < 1 Mbps | < 10 kbps | < 1 Mbps |
| **Battery life** | > 10 years | > 10 years | > 10 years | > 10 years | > 10 years | > 10 years | > 10 years |
| **Availability** | Today | Today | 2016 | 2016 | 2016 | 2016 | beyond 2020 |

### 7.3.1 Unlicensed LPWA technologies

SigFox, LoRa, and Wireless M-bus are the most known unlicensed band LPWA technologies. SigFox and Lora have the same goal to make mobile network operators to adopt their technology for IoT deployments over both city and nationwide LPWANs, but their business models and technologies are quite different.

SigFox is a narrowband (or ultra-narrowband) technology. It uses a standard radio transmission method called binary phase-shift keying (BPSK), and it takes very narrow chunks of spectrum and changes the phase of the carrier radio wave to encode the data. This allows the receiver to only listen in a tiny slice of spectrum, which mitigates the effect of noise. It requires an inexpensive endpoint radio, but a more sophisticated base station to manage the network. It offers bidirectional communication, but its capacity to downlink direction (i.e. from the base station to the end point) is more limited. SigFox owns all of its technology from the backend data and cloud server to the endpoints software. SigFox has opened its endpoint technology to silicon manufacturers or vendors as long as certain business terms are agreed. The business idea is to allow the applications to be very inexpensive and offer already-installed nation-wide networks. The drawback is that only one SigFox network can be deployed in an area due to exclusive arrangements with the selected network operator. Moreover, the technology is not applicable for continuous communication due to the relatively high latency with low predictability.

LoRa is a wideband CDMA technology with the inherently higher noise level. In practice, communication link budget figures are about the same due to the efficient coding. LoRa uses the same radio for a receiver on the base station and at the endpoints. The cost of a LoRa terminal is more expensive than a SigFox terminal but the lower cost of the LoRa base stations makes the overall technology less expensive. LoRa ecosystem is open (LoRa Alliance), so anyone can basically build and manage their own network. Both large network operators and also private companies and startups can exploit LoRa networks. However, there are open issues related to the roaming from public network to public network and private network to private network. This type of roaming requires simultaneous

connection to several networks. The LoRa specifications can be downloaded, and any hardware or gateway manufacturer can build a module or gateway that conforms to the LoRa specifications. Even if the ecosystem itself is open, it contains a closed element. Semtech is the only company that makes the radio for LoRa.

Wireless M-bus has specifically been standardised for the smart grid market where the interface is M-bus, and the wireless part merely an extension. Although Wireless M-bus has been deployed for Advanced Metering System (AMS), the limitation to IPv4 may restrict its deployments in Asia [21].

*Table 7. Properties of unlicensed LP-WAN technologies [22].*

| | SigFox | LoRa | M-Bus | Dash-7 |
|---|---|---|---|---|
| **Frequency (MHz)** | 865-868/ 902-928 | EU:433/868 USA:780/915 | 868, 169 | EU: 433/868 USA: 780/915 |
| **Channel width (Hz)** | 100 Hz | ≥125 kHz | 10 kHz to 100 kHz | 25 or 200 kHz |
| **Transmitted power (dBm)** | Up to 20 | EU: 14 dBm, US: 27 dBm | 10 dBm | 433 MHz: 10dBm 868/915 MHz: 27dBm |
| **Topology** | Star | Star | Star | Star, tree, mesh |
| **Uplink data rate** | 4x8b/day | EU: 30 b/s-50 kb/s US: 100-900 kb/s | 4.8-100 kb/s | 9.6-167 kb/s |
| **Downlink data rate** | 100 b/s | EU: 30 b/s-50 kb/s US: 100-900 kb/s | 4.8-100 kb/s | 9.6-167 kb/s |
| **Battery life** | 10 years | 10 years | Years | 10 years |
| **Support for IPv6** | Unlikely | Likely | No | Likely |
| **Governing body** | SigFox | LoRa alliance | M-Bus | Dash-7 alliance |
| **Deployment status** | Deployed since 2009 | Deployed | Available | Deployed since 2015 |
| **Nodes per gateway** | 1000000 | 250000 | Not specified | N/A (connectionless) |
| **Est. costs ($)** | Node: 2 | Node: 30 | Node: 10 | Node: 2 |

### 7.3.2 Licensed LPWA technologies

The challenge with unlicensed systems is that the communication is not guaranteed and other devices can use the same frequency band and interfere with the communication. 3GPP introduced MTC (machine type communication) in LTE to represent machine-to-machine communications, which covers all form of data communication without human intervention. Several variations have been introduced to the LTE specifications: e.g. LTE-M, NB-LTE-M, and NB-IoT. The last two are using narrow band communication with limited data rates. The narrow band solution offers improved coverage especially indoors, which makes it more compelling for both M2M and IoT applications. Three separate tracks for licensed cellular IoT technologies are being standardised in 3GPP [23] [24].

- **eMTC (or LTE-M)**, an evolution of LTE optimised for IoT in 3GPP RAN. The first version was introduced in release 12 in 2014 and further optimization included in release 13 with specifications completed in 2016 [24].
- **NB-IoT**: the narrowband evolution of LTE for IoT in 3GPP RAN, included in release 13 with specifications completed in 2016 [24].
- **EC-GSM-IoT**, an evolution of GSM optimised for IoT in 3GPP GERAN, included in release 13 with specifications completed 2016 [24].

The table shows the comparison of the properties of GSM and LTE systems.

*Table 8. LPWA IoT and legacy LTE connectivity overview [25].*

| | GSM (Rel. 8) | EC-GSM-IoT (Rel. 13) | LTE (Rel. 8) | eMTC (Rel. 13) | NB-IoT (Rel. 13) |
|---|---|---|---|---|---|
| **LTE user equipment category** | N/A | N/A | Cat. 1 | Cat. M1 | Cat. NB1 |
| **Range**<br>**Max. coupling loss** | < 35 km<br>144 dB | < 35 km<br>164 dB | < 100 km<br>144 dB | < 100 km<br>156 dB | < 35 km<br>164 dB |
| **Spectrum** | Licensed GSM bands | Licensed GSM bands | Licensed LTE bands in-band | Licensed LTE bands in-band | Licensed LTE in-band guardian band stand-alone |
| **Bandwidth** | 200 kHz | 200 kHz | LTE carrier bandwidth (1.4-20 MHz) | 1.08 MHz (1.4 MHz carrier bandwidth) | 180 kHz (200 kHz carrier bandwidth) |
| **Max. data rate**[19] | < 500 kbps (DL/UL) | < 140 kbps (DL/UL) | < 10 Mbps (DL)<br>< 5 Mbps (UL) | < 1 Mbps (DL/UL) | < 170 kbps (DL)<br>< 250 kbps (UL) |

**Technical details:**

- **LTE Release 8 Cat-1**: With a Cat-1 UE, it is possible to achieve 10 Mbps downlink and 5 Mbps uplink channel data rates. However, it was not a relevant UE category for LTE-based mobile broadband services, since its performance was below the best 3G performance. Recently, it has become attractive to IoT applications over standard LTE. The technology fulfils a wider

[19] Max. data rates provided are instantaneous peak rates.

range of MTC application requirements, so it can also be used as a complementary solution for eMTC and NB-IoT.

- **LTE Release 12 Cat-0**: It is one of the newest standardised technologies. The UEs are intended for IoT use cases and provide 1 Mbps data rates for both uplink and downlink directions. The UE is simpler including only one receiver antenna and support for the half-duplex operation.
- **eMTC / LTE Release 13 Cat-M1**: This refers to the current work in Release 13, where UE complexity is reduced even further. Up to 75-80% complexity reductions compared to Cat-1 have been anticipated. The most important additional feature is the possibility to implement the UE transmitter and receiver parts with reduced bandwidth (1.4 MHz) compared to normal LTE UEs (20 MHz) bandwidth. Cat-M1 UEs are able to operate anywhere within an LTE carrier. Another improvement is coverage enhancements of more than 15 dB, which enables deeper indoor coverage.
- **NB-IoT / LTE Release 13 Cat-NB1**: It stands for Narrowband IoT and is a new radio technology being standardised in 3GPP. NB-IoT is not based on conventional LTE. It uses a DSSS modulation, which reduces the hardware complexity. The reduction compared to Cat-1 is anticipated to be up to 90%. The bandwidth is 180 kHz bandwidth and uplink and downlink data rates around 200 kbps with the half-duplex operation. 200 kHz carrier channels can be arranged between conventional LTE channels, which mean that the NB-IoT deployment will not interfere with the conventional LTE. The problem with NB-IoT is that it is not a part of LTE and it requires a dedicated band, which may be costly for the mobile operators. NB-IoT offers similar data rates than LPWA technologies, but more guarantee to achieve them in a stable way as the frequency band is licensed. Although in a band that allows for up to 23 dBm transmission, NB-IoT is likely to be deployed at a maximum 14 dBm in order to limit power consumption. The downside of the highest frequency bands is that at the lower range is expected. Therefore, NB-IoT seems well adapted to uMTC at short distances.

Both eMTC and NB-IoT have been designed to be competitive with cheap GSM or LPWA M2M modules. The initial NB-IoT module cost is expected to be less than 5 dollars.

The EC-GSM-IoT, earlier referred to as EC-EGPRS, stands for Extended Coverage GSM for IoT. It includes the latest enhancements to the GSM and EGPRS standards to support better coverage and other IoT enhancements. EC-GSM-IoT may be deployed in-band within a GSM carrier. EC-GSM-IoT supports 20 dB coverage improvements and can be deployed in the existing GSM networks. The solutions for narrow band LTE-M and EC-GSM-IoT will equally operate in a spectrum shared with existing LTE or GSM networks.

*Table 9. Complexity/cost reductions for LTE-M and NB-IoT evolution [25] [26] .*

| | Rel-8 Cat 4 | Rel-8 Cat-1 | Rel-12 Cat-0 | Rel-13 Cat-M1 | Rel-13 NB1 | Rel-13 EC-GSM-IoT |
|---|---|---|---|---|---|---|
| **Downlink peak rate** | 150 Mbps | 10 Mbps | 1 Mbps | 1 Mbps | 170 kbps | ~500 kbps |
| **Uplink peak rate** | 50 Mbps | 5 Mbps | 1 Mbps | 1 Mbps | 250 kbps | ~500 kbps |
| **Number of antennas** | 2 | 2 | 1 | 1 | 1 | 1 |
| **Duplex mode** | Full duplex | Full duplex | Full / half duplex | Full/ half duplex | Half duplex | Half duplex |
| **UE receive bandwidth** | 20 MHz | 20 MHz | 20 MHz | 1.4 MHz | 0.18 MHz | 0.2 MHz |
| **UE transmit power** | 23 dBm | 23 dBm | 23 dBm | 20/23 dBm | 20/23 dBm | 23 / 33 dBm |
| **Multiplexed within LTE** | Yes | Yes | Yes | Yes | Yes/No | Yes/No |
| **Modem complexity** | 100 % | 80 % | 30 % | 20 % | 15 % | Not evaluated |

## Narrowband IoT (NB-IoT)

NB-IoT bridges the gap between current network infrastructure and connected devices. It distinguishes itself through lower costs and energy efficiency, making it an appealing solution also for the energy industry. NB-IoT, as the underlying network technology for the low-power wide area (LPWA) market, has several useful characteristics for IoT solutions. As low power consumption is vital for most LPWA use cases, NB-IoT proves more than capable of fulfilling such a requirement, as it enables a battery life of approximately 10 years. eDRX (extended discontinuous reception) and PSM (power save mode) are two innovative features that extend NB-IoT battery life to beyond 15 years.

The smart metering application will benefit of PSM, which allows the device to have increased sleep periods and report data to the backend system once a day. DRX is better suited for event-based applications, because there is not always need to know the exact state of the device continuously but to retrieve the data in a few seconds after triggering the event via the application on the server.

Moreover, it can offer improved indoor coverage, as NB-IoT link budget and coverage benefits from a higher device output of 23 dB, which increases the throughput at cell-edge and even locations at the Maximum Coupling Loss of 164 dB (equivalent to 179 dB if antenna gain included). The improved indoor coverage enables extending the wireless remote monitoring of grid components in basements that used to be problematic with the wideband LTE technology. Additionally, NB-IoT enables a vast array of connections per cell (50 k) to send small amounts of data in parallel, thus providing an extensive ecosystem for network operators.

In order to create a technology that is affordable while also sustainable for the future, the specification of NB-IoT builds on synergies of existing mobile network infrastructure. It thus provides a natural evolution and extension of LTE, with flexible deployment options. As a finite resource, spectrum needs to be used as efficiently as possible. And so technologies that use spectrum tend to be designed to minimise usage. The recently agreed technology for LPWA by the 3GPP, allows NB-IoT to offer three deployment options: stand-alone, guard-band, and in-band.

In terms of security, NB-IoT uses the same encryption algorithms as the existing LTE category technologies with proven standards in the market, NB-IoT will rely on 128 Bit keys with frequent key management updates to maintain security and integrity. Secure tunnelling between the device and the MME will be also supported.

## 7.4 The future 5G technology

In 2008, Europe, Asia, and the United States started the design of a new generation of worldwide wireless communication systems (5G) that should fulfil latency and reliability requirements of new mobile network users (Figure 42). 3G/4G networks were not designed for carrying mission-critical or massive machine type of traffic, or connecting efficiently other types of devices than mobile terminals.


*Figure 42. 5G verticals and potential applications [27].*

5G is planned to be launched around the year 2020, and the majority of its development will be done in the next few years, reflected in yearly updates of the 5G standard called releases in 3GPP. Release 14 is being defined now (see Figure 43). Therefore, it is important to study the communication needs of evolving energy systems in different TSO-DSO coordination schemes in order to exploit the full potential of 5G technology and even to propose enhancements to forthcoming specifications.

There are six challenges addressed in 5G:

- need for higher capacity,
- lower end-to-end latency,
- massive device connectivity (IoT),
- reduced OPEX and CAPEX costs, and
- consistent QoE (Quality of Experience) provisioning.

Despite the fact that the standardisation of 5G is still an ongoing process (no full consensus on its architecture yet), its key requirements and capabilities have been agreed. The 5G communication technology is no longer intended exclusively for human communications. The volume of data and information communicated with and between things and machines is increasing. The potential applications span from traditional voice and video to industrial automation, virtual reality, automated driving, and robotic systems like illustrated in Figure 42. This new communication technology is also designed as an enabler for network automation needed in future energy systems offering services everywhere and anytime.

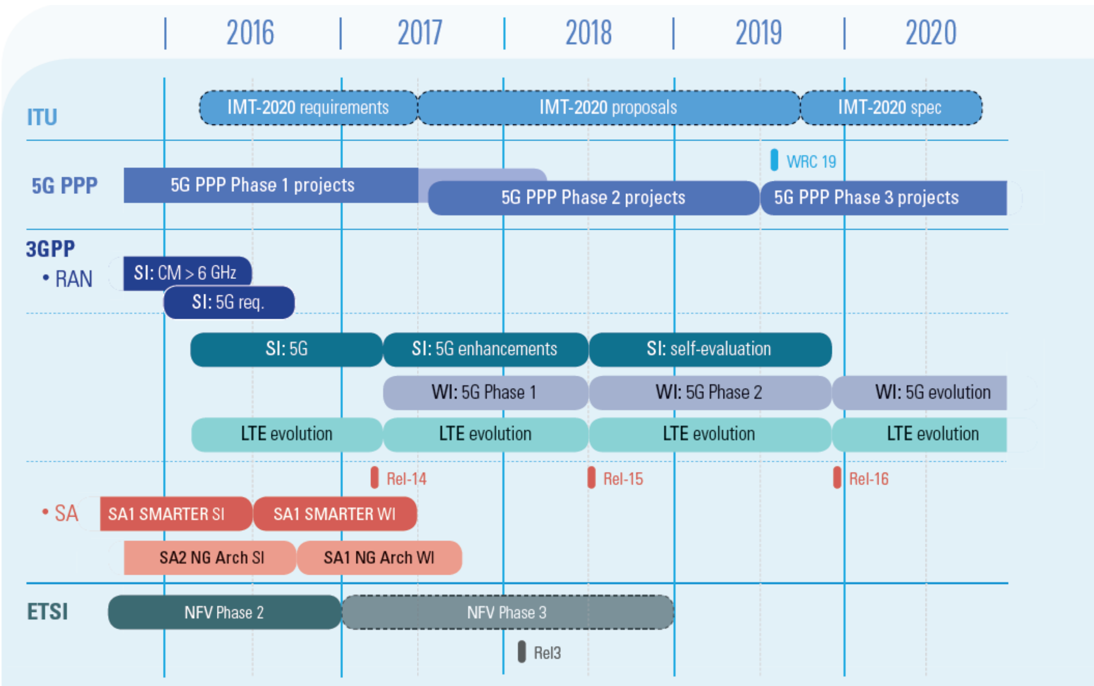



*Figure 43. Standardisation timeline [28].*

There is a consensus that 5G will be a single radio access network (Single RAN) technology that is built upon new radio access technologies and evolved existing ones such as LTE, HSPA (High-Speed Packet Access), GSM, and WLAN. This Single RAN technology will enable operators to simplify their network architecture by operating different radio technologies on a single multi-purpose hardware platform. This platform will exploit both licensed and unlicensed bands. The unlicensed bands are used to provide additional capacity in the best effort manner.

Another goal is a unified and programmable infrastructure that should offer a scalable service experience everywhere and anytime. Although significant improvements have been made in 4G architecture design and implementation, the future requirements cannot be fulfilled with the evolutionary 4G architecture design. As a result, the 5G architecture is designed to be highly software oriented with programmable flexibility. The changes in logical network architecture can be done simply by software updates. This flexibility can be achieved by upcoming architectural trends like aforementioned network clouds, software-defined networking (SDN), network function virtualisation (NFV), mobile edge computing (MEC), and fog computing (FC). Network clouds allow resource pooling that reduces overprovisioning and underutilisation of network resources. SDN decouples control (C) and user (U) data planes of network devices and provides a logically centralised network view and control. In a complementary way, NFV decouples network functionality from dedicated hardware and promotes the software driven implementation of system functionality. Together SDN and NFV offer new tools for load optimisation and improved resilience by enabling functions re-positioning according to network load, service quality, or operational reasons. For energy stakeholders, this opens possibilities to obtain enterprise specific network configurations from telecommunication operators. Mobile edge computing offers a solution to move cloud-computing capabilities and an IT services at the edge of the mobile network, which enables higher reliability and lower latency for real-time access to radio network information. For example, some base stations dedicated for low-latency services could be connected directly to a small nearby data centre, whereas in the case of no latency critical services, the connection could be to a large data centre further away. Such flexibility would allow network operators or energy stakeholders to deploy data centres of different sizes to meet specific service needs. The more general fog computing concept offers an architecture that exploits end-user clients or near-user edge devices to carry out storage, communication, computation, and control in a network. For energy stakeholders, this offers more flexible and more localised low latency data exchange between system components.

As stated before, the 5G is designed to extend the mobile communication to different business verticals by offering performance enhancements (presented in Figure 44).

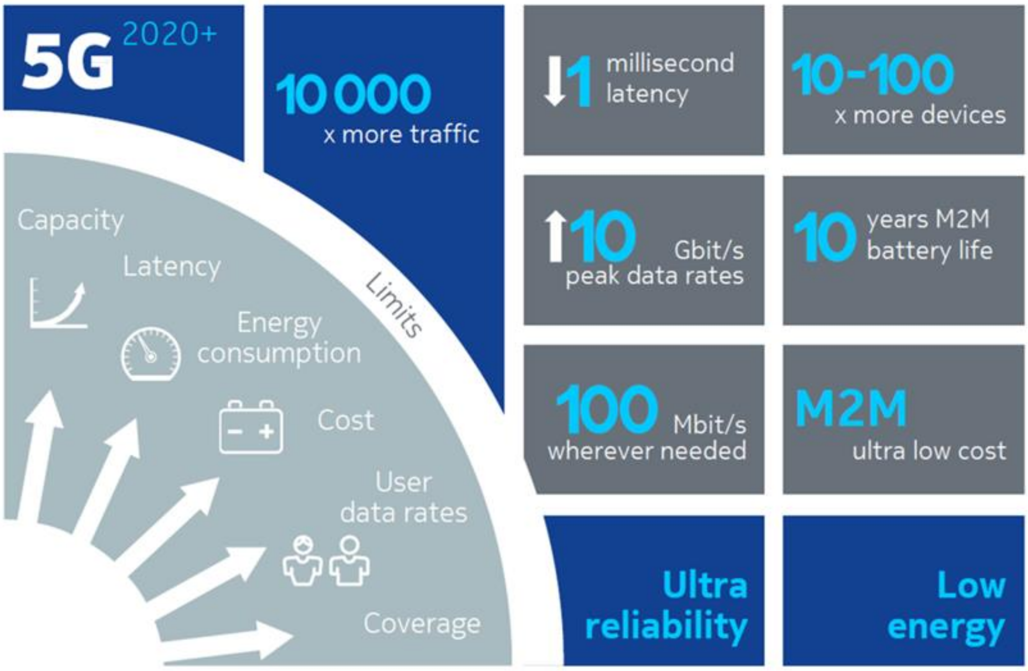



*Figure 44. Performance enhancements designed for 5G [29].*

The summary of 5G related trends is presented in Table 10, and they focus on offering reliable, high quality, and flexible data services using different radio access technologies.

*Table 10. A summary of major trends in 5G.*

| Trends | Description |
|---|---|
| **Low latency and high reliability** | Several scenarios require very low latency and very high reliability. For instance, in the case of industrial control, where the 5G system is deployed to enable wireless remote control of industrial devices to accomplish complicated and precise time-sensitive actions, the expected latency should be no longer than 1 ms while the expected reliability being 99.999%. |
| **Network slicing** | Network slicing allows the operator to provide deeply customised networks. Different requirements on functionality (e.g. charging, policy control, security) and performance (e.g. latency, mobility, and throughput) can, therefore, be realised with the same physical networks by offering dedicated network slices for different end-users. |

| Trends | Description |
|---|---|
| **Diverse mobility management** | 5G will support devices with a range of mobility management, e.g. devices embedded in smart grid infrastructure, which are stationary during their entire usable life, or devices designed to provide fixed access therefore being stationary during active period but can be nomadic between activations, or mobile devices restricted in a well-defined area (e.g. factory), or devices with full mobility (e.g. sensors embedded in vehicles). |
| **Multiple access technologies** | 5G will support 3GPP access technologies, including one or more 5G RATs and E-UTRA as well as non-3GPP access technologies, to ensure interoperability. For optimisation and resource efficiency, the 5G system will select the most appropriate 3GPP or non-3GPP access technology for a service, potentially allowing multiple access technologies to be used simultaneously (e.g. LTE-Wi-Fi aggregation) for one or more services active on a device. |
| **Resource efficiency** | 5G enables the opportunity to optimise the system to support diverse devices and services through efficient resource utilisation. In addition to smartphones, 5G is designed to support a variety of sensors that send data packages ranging in size from small a few bits status updates to streaming videos. Specifically, to support short data bursts, the network should be able to operate in a mode where there is no need for a lengthy and high overhead signalling procedure before and after small amounts of data are sent. The system will, as a result, avoid both a negative impact on battery life for the device and wasting signalling resources. |
| **Efficient user plane** | As 5G will provide a much-enhanced performance (e.g. low latency, high throughput, massive connections) with different data traffic models, the user plane should be more efficient to support such differentiated requirements, through Hosted Services inside of operator's network as well as flexible user plane paths. |
| **Efficient content delivery** | With the massive growth of video-based services and personal data storage applications in mobile broadband traffic, 5G will enable in-network content caching including both operator and 3rd party provided, which can improve user experience, reduce backhaul resource usage, and utilise limited radio resource efficiently. |
| **Priority, QoS, and policy control** | As 5G network will support many commercial services, and some of them require priority treatment, the network will offer a means to provide the required QoS e.g. guaranteed bandwidth, low latency, high reliability and to prioritise resources. While existing QoS and policy frameworks handle latency and improve reliability by traffic engineering, it is necessary for the 5G network to offer QoS and policy control for reliable communication with latency required for a service and enable the resource adaptations as necessary. Additionally, unlike for existing EPC that QoS only covers RAN and the core network, 5G network QoS aims for an E2E achievement, covering not only RAN and core network but also backhaul and network-to-network interconnections. |

| Trends | Description |
|---|---|
| **Connectivity models** | In a 5G network, the UE can connect to the network directly or connect with the network using another UE as a relay UE, or they may be capable of using both types of connections in multi-hop mode. |
| **Network capability exposure** | Future UEs are equipped with various types of sensors (e.g. accelerometer, gyroscope, magnetometer, barometer, proximity sensor, GPS) and have access to various radio access networks. 5G network will exploit this information with data from supported access technologies, application context, and traffic characteristics to optimise radio resource utilisation. |
| **Self-backhaul** | The 5G network will support the increasingly high densification of access nodes with wireless backhaul, which enables simpler deployment and incremental rollout. Network planning and installation efforts can be reduced by leveraging plug-and-play type features including self-configuration, self-organising, and self-optimisation. |
| **Flexible subscription** | For IoT scenarios, the 5G network will support IoT devices being subscribed in a flexible way. The subscription can be provided when IoT device is deployed, being added to existing subscriptions, or ownership has changed during the life cycle of the devices. Therefore, 5G network will implement dynamic subscription generation and management, together with flexible connectivity models. |
| **Energy efficiency** | Being a critical issue for the 5G network, energy efficiency will be improved by various means, including enabling energy saving mode, restricted services, battery life improving mechanism, etc. |
| **Extreme long range coverage in** low-density **areas** | As a fully connected society is expected in the near future, 5G network will enable access everywhere over long distances (e.g. in extremely rural areas or at sea) including both human and machine users. To realise the above explained capability, one huge difference in 5G design principles is a layered architecture with separated control and user planes. In this way, the control plane enables micro services architecture through single and modular RAN-CN interface, supports network slicing and controls APIs for mobile edge computing, while the user plane focuses on providing connectivity function with rigorous requirements on latency, throughput, etc. Furthermore, the separated control and user planes can also be easily scaled up or down respectively, to meet specific user needs. |

The performance requirements for 5G are strict, especially for data rates, latency, flexibility, and reliability. As such, the development encompasses the following focus areas:

- enhanced mobile broadband (more capacity)
- the massive machine type communication
- the critical machine type communication

The needs associated with the three types of communications can be described in terms of qualitative KPIs such as in Figure 45.

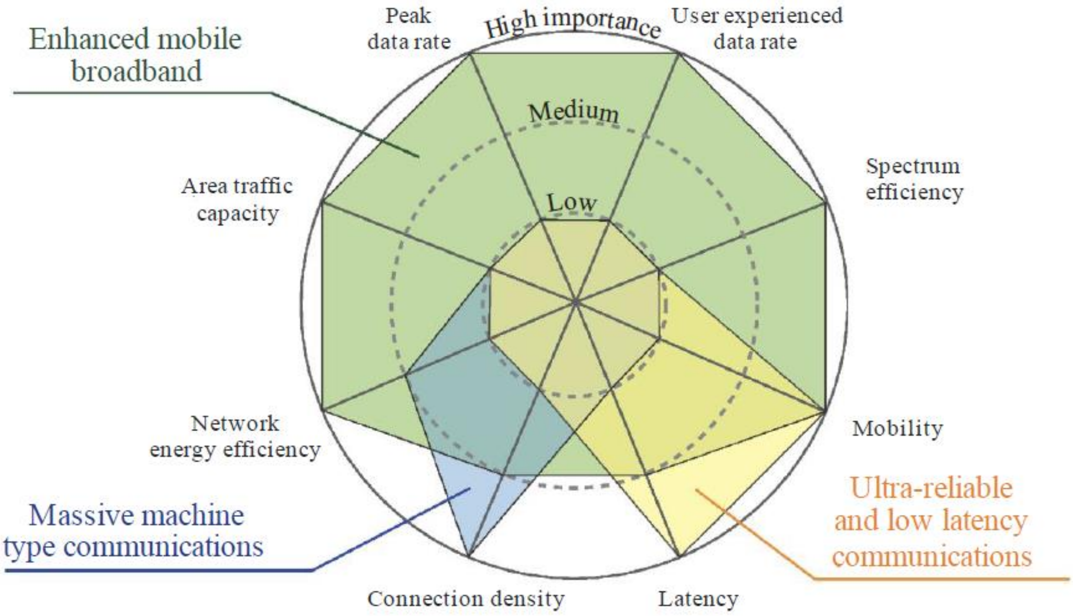



*Figure 45. 5G KPIs according to service type [30].*

The revolution of 5G involves the introduction of new technologies such as ultra-dense networks (UDN), massive-MIMO (m-MIMO), SDN, NFV, ultra-reliable low latency connectivity (URLLC or uMTC), massive machine type connectivity (mMTC) with new computing and cloud-based storage solutions. mMTC is designed to connect millions of inexpensive sensors and machines and uMTC to connect more expensive devices having stricter requirements on reliability and availability. While data transmissions from mMTC devices are infrequent and not delay-dependent, uMTC addresses services with high reliability, and short latencies. uMTC services are often safety or mission critical, where failure will have a serious consequence on the system. According to [31] [32], the main Key Performance Indicators (KPI) characterising the two types of device communications are:

- mMTC: 106 devices/km$^2$, 99.9 % availability, 125 b/s
- uMTC: high reliability (1-10$^{-5}$) success for 32 bytes under 1 ms, latency < 0.5 ms

Contention-based and connectionless access procedures are needed for mMTC applications that only require intermittent connectivity to transmit small packages. Energy-efficiency of baseband processing can be improved by utilising centralised-RAN (C-RAN), which pools and shares the baseband processing of multiple sites, allowing more flexible radio resource utilization. Moreover, the future network can also be taught also to be energy-aware through activation and deactivation of parts of the network in response to changing traffic loads. The savings are significant in those parts of networks where the average utilization of the network is low.

uMTC are services requiring to transfer information before the latency exceeds the threshold time with very high probability [33]. In radio systems, it is difficult to guarantee uMTC services at all times, but it is common to define a goal for service availability where delay, data rates or coverage requirements can be met. An uMTC wireless system will be reliable for a portion of the time.

Advanced radio technologies and use of wider spectrum will help to increase the capacity of existing macro-cells. The future mobile networks will be heterogeneous networks (HetNets) consisting 10…100x more cells than today's networks. UDNs with small cells are offering high capacity and hyper-connectivity indoors, and tera and macro cells provide wide area coverage and capacity. Applications such as media caching, mobile edge computing (MEC) and time-critical cloud services will force data processing and storage to be moved closer to users. The processing and storage pooling is designed to be integrated with the base station sites. These new features are compelling for a wide variety of grid business, monitoring, control, and protection applications in energy grids.

The connectivity is evaluated in terms of how well the applications work regardless of device type, time, or location. A new air interface with shorter transmission interval has been proposed in 5G to reduce the over-the-air latency to few hundred microseconds. End-to-End (E2E) latency can be reduced even more by the enhancements in higher-layer protocols using context and network-aware admission/congestion control algorithms. The split of control (C) and user (U) data among different cells is also proposed to offer better flexibility for coverage and capacity resources independently at different regions. For example, future macro-cells can be used to provide both coverage and sufficient capacity (C+U) whereas small cells focus only on localised capacity (U). In these scenarios, one device could be used as a smart gateway or relay to aggregate traffic from multiple devices in order to reduce signalling load and power consumption on the network. The aggregated traffic can be from both unlicensed and licensed radio access networks, which enables energy stakeholders to adjust their own local network to service better their own needs.

## 7.5 Communication architecture

The forthcoming energy systems must respond faster to end-users' demands, react ad-hoc on market needs, manage more and more versatile data and on top of these, with reduced CAPEX and OPEX costs. This cannot be achieved with the classical deployment model of using dedicated and specific hardware per required function. The ICT industry has started to migrate from hardware-centric towards software-centric deployments as the availability of high-performance processing and storage capabilities of commodity hardware have increased. Network functions that were tied in the past to specific hardware are increasingly run in software requiring network virtualization.

### 7.5.1 Network functions virtualization (NFV)

To manage flexible ICT architecture, the NFV framework is defined as the result of an industry initiative started by operators and vendors within European Telecommunications Standards Institute (ETSI). Network functions virtualization (NFV), also known as virtual network function (VNF), offers a flexible way to design, deploy, and manage software-centric networking services. NFV decouples the network functions from proprietary hardware appliances, so that they can run in software. It is designed to consolidate and deliver the networking components needed to support a fully virtualised infrastructure including e.g. virtual servers and storage. The virtualization can be applied for both wired and wireless network infrastructures, which makes it more flexible for the energy systems [34].

Use cases defined by ETSI cover Network Slicing and Virtualization of Internet of Things (IoT) use cases [35]. Ideally, virtualised functions should be located where they are the most effective and least expensive. That means a service provider should be free to locate NFV in all possible locations, from the data centre to the network node to the customer premises. This approach, known as distributed NFV, has been emphasised from the beginning when NFV was being developed and standardised and is prominent in the recently released NFV specifications [36].

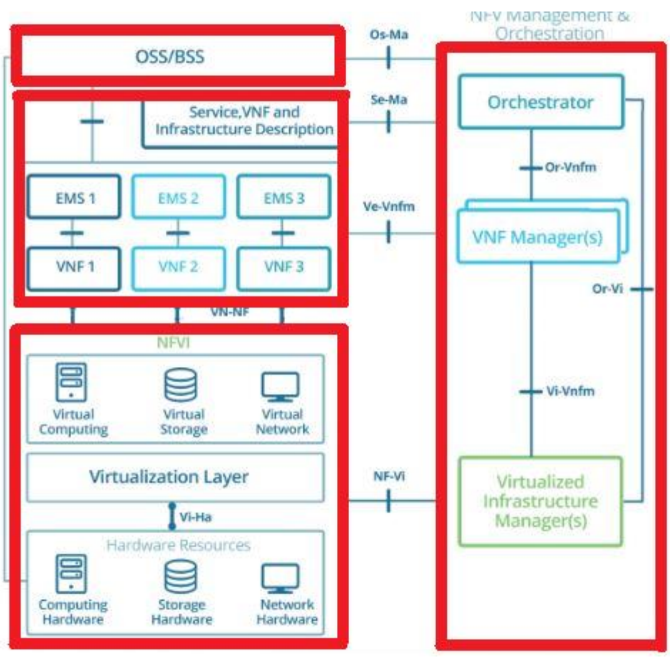



*Figure 46 ETSI NFV Reference Architectural Framework [37].*

The NFV framework consists of four components [37]:

1. **The NFVI layer** is responsible for providing the NFV application layer with the needed computing, networking and storage resources by virtualising and abstracting the corresponding physical resources. The NVFI layer has three components:

I. Hardware resource layer provides computing resources (servers and RAM), storage resources (disks and network attached storages (NAS)), and network resources (switches, routers, and firewalls).

II. The virtualization layer abstracts the hardware resources and decouples the software from the hardware. Common for virtualization layer are ESXI (used in VMWare), KVM and QEMU (mostly used in OpenStack), and Hyper-V (Microsoft).

III. Virtualised resources include virtual computing, virtual storage, and virtual network.

2. **Virtualised network functions layer** contains the software-based network functions.
3. **The management network and orchestration layer** contains three blocks:

I. The virtualised infrastructure manager controls the interaction of NFVs with NFVI.

II. The NFV manager controls the lifecycle of virtualised elements.

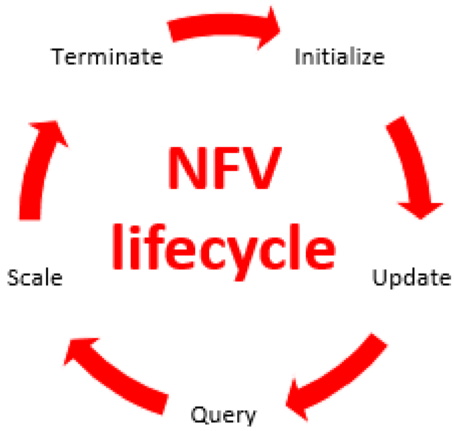



*Figure 47. NFV lifecycle.*

III. The orchestrator manages the lifecycle of network services including initiation, policy management, aggregation of performance and reporting measurements. Its responsibility is to provide service control, automation, flexibility, and reliability.

2. **Inside the OSS/BSS layer**

I. OSS provides network, fault, configuration, service and element management.

II. BSS provides operations, customer, order and revenue management plus billing.

Communication industry including operators and network suppliers agreed to deploy virtualised network functions according to this architecture. On outside interfaces, the new virtual networks functions shall act in the same manner as in traditional built-in hardware components. This allows an easy integration of NFV into existing networks and the service consistency when built-in hardware functions and NFVs coexist. End-users have many benefits of deploying NFV framework presented in Table 11. Grid communication systems can be virtualised in the same manner as virtualisation proceeds in commercial communication systems.

*Table 11. Benefits of using the NFV framework.*

| Benefits | Description |
|---|---|
| **Costs benefits** | • In general, it is more cost-efficient to run software on own hardware, compared to being forced to buy a bundle of software and dedicated hardware. Deployment of new services just requires association of commodity resources and not the deployment of new dedicated hardware. On the other hand, the total cost of ownership of the virtualised solutions can be comparable due to licenses and support costs.<br>• Costs benefits can also be achieved for existing services as resources can be flexibly adapted according to service needs and not linked to hardware steps. In addition, NFV allows the assignment of network resources over time. For example, service A has its peak load in the morning and has appropriated virtual network resources assigned for this timeframe. After peak load, the number of assigned resources for service A can be reduced and made available for an increasing demand of service B. In the final case, the commoditised network resources can be reused when a service reaches its end-of-life.<br>• One option to achieve OPEX savings is by turning off not required NFV infrastructure during phases with lower load (nights and weekends), to reduce power consumption and required cooling. To achieve such savings, capabilities must move VNFs across the network without impacting the E2E service, which is required and supported by NFV. |
| **Operational benefits** | • Operational teams have to maintain less hardware due to higher utilization of existing hardware. Also, the number of redundant/standby hardware is reduced, because the NFV management & orchestration functions will ensure VNFs are assigned spare capacity. This spare capacity can be pooled due to that fact it is not a service-specific hardware.<br>• Also, the number of maintenance windows is reduced by an optimised service upgrade process. A new service version could be tested in a sandbox under same conditions as in production. After a passed test session, new versions could be transferred into production without a maintenance window or to take the nodes out-of-service.<br>• An additional benefit is the reduced training effort due to reduced hardware types. |

| Benefits | Description |
|---|---|
| **E2E Service benefits** | • New E2E services can benefit from a shorter time-to-market with reduced risk of losing investments. This is archived by the flexibility introduced by virtualization and which will allow the re-use of IT industry concepts like micro-services and agile methodology when developing and introducing new E2E services.<br>• Higher E2E service availabilities will be achieved by the usage of automated NFV fail-over mechanisms. NFV allows, for example, an easier establishment of geographical redundancy, and faster reaction to different fault scenarios.<br>• Also, service degradations due to unexpected load increase can be avoided when using NFV architecture. In the past, services could be impacted as long as additionally required dedicated hardware has to be ordered, delivered, deployed and taken into service. With NFV architecture, by detecting a performance issue additional resources could be assigned ad-hoc to the service. Depending on the configured rule base, the action can be triggered manually or in best case automatically. In such a case, the end customer will recognise no service impact.<br>• Worth a mention is the fact that additional functions can be offered faster due to better in-service upgrade capabilities (see above).<br>• Overall, the network services can be adopted with more flexibility to service demands. It is possible to move VNF inside the network to the location where it is best for the service demand. Centralised deployments are in most cases cost optimised, whereby decentralised deployments are by trend latency optimised. NFV allows the communication industry to mix from NFV options the best matching combination. |

## 7.5.2 Software-defined networking (SDN)

NFV architecture is impacting network functions in general. On the other hand, software-defined networking (SDN) is an approach to separate control plane from forwarding plane and focuses on transport. Both SDN and NFV are seen as complementary technologies.

Traditional transport equipment includes control and data (= forwarding) plane on each transport node. To realise a connection, as in from PC A to PC B, a number of independent devices have to be configured in the right manner.

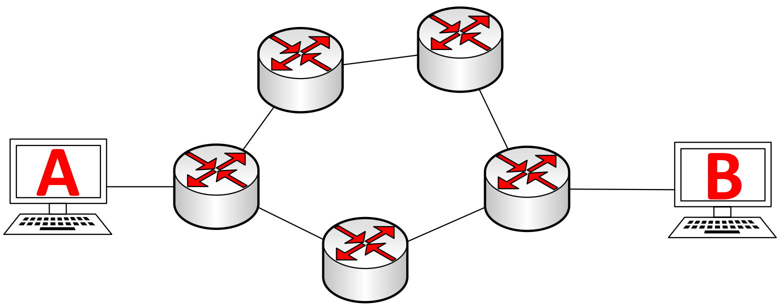



*Figure 48. A conventional transport model from PC A to PC B via network components.*

In larger networks such a configuration is complex and misconfigurations cannot be avoided even if they occur very rarely. To reduce such complexity and make configuration and management of connections in larger networks more efficient, SDN follows the approach of functional separation into control and data (= forwarding).

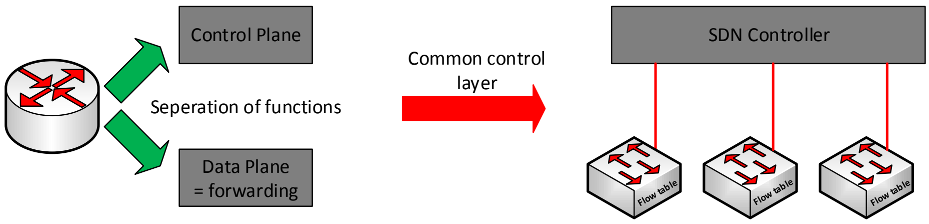



*Figure 49. A SDN model separating control and data plane.*

This allows the control of a number of forwarding devices via the same SDN controller. Via this approach, the configuration for a connection between PC A and PC B requires actions just on one device, which is called SDN controller.

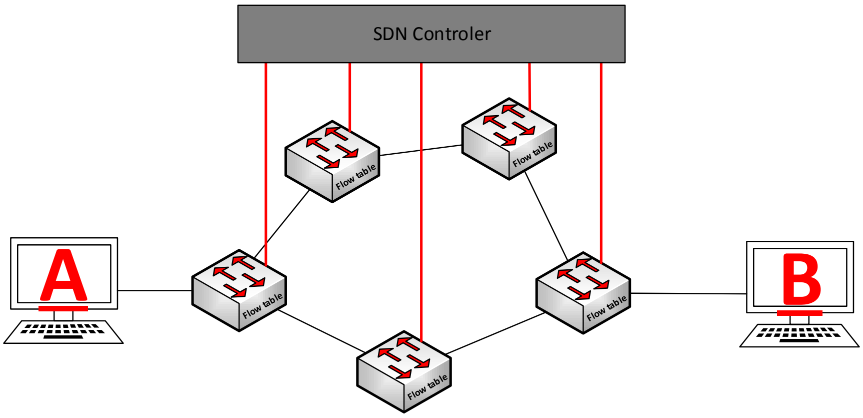



*Figure 50. SDN Controller managing network elements between PC A and PC B.*

From an architecture point of view, SDN is a three-layer model.

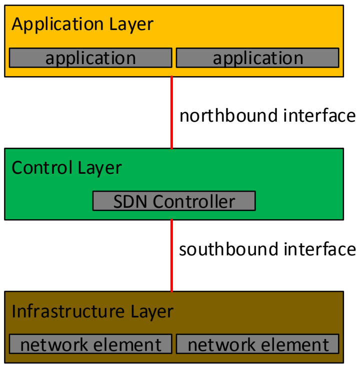



*Figure 51. Three layers of SDN architecture.*

The control layer contains the SDN controller, which is the brain inside SDN architecture. In most cases, this layer will be built in NFV architecture. In a larger network, there could be one or more of such controllers split into regional responsibilities under a central controller.

The infrastructure layer includes network elements like switches or firewalls. This layer could be built in NFV architecture, but also deployments in Application Specific Integrated Circuit (ASIC) or hybrid deployments are possible. The SDN controller is able to manage infrastructure elements via the southbound interface. Common protocols on this interface are Openflow, NETCONF and SNMP. The goal is to use open interfaces to manage the multi-vendor infrastructure layer via a joint controller.

The Northbound of the control layer is the application layer. The northbound interface (typically JAVA and REST APIs) allows applications to trigger actions on the control layer. This could be used for an API triggered automated configuration inside infrastructure layer to meet applications needs.

By implementing the aforementioned aspects, the transport network will get similar benefits as achieved with NFV, as described below.

- **Cost savings:** Distributed elements in infrastructure layer have reduced functionality and even when built-in ASIC shall be cheaper than a node with control and user planes. In addition, the network will be used more efficient with a centralised controller.
- **Time to market:** Product & Service introduction and lifecycle management timescales become agile.
- **Resource administration:** Optimised resource orchestration via central SDN controller.
- **Transport agility:** Possibility to offer connections/Quality of Service on demand. Applications could request matching transport resources when required and transport service could be adopted in an automated way near real time.

### 7.5.3 Outlook: 5G and network slicing

NFV and SDN architectures are defined and functionality is already available. Nevertheless, the networks are still in concept or migration phase. For the next years, the operational focus is on the deployment of these technologies. In parallel, the specification work for next generation 5G communication networks has started. The specifications are at the early stage, but some trends are already visible.

- More elements in networks will split into control and data plane similar to SDN. This would allow nodes with heavy throughput like Packet Gateways (PGWs) to deploy the data plane where it is best for the service, but keep the control plane manageable on a few centralised controllers.
- Some proposals have been placed to store also configuration and topology information in Home Subscriber Server (HSS).
- The biggest change could be the introduction of the concept of slices. Based on NFV and SDN architecture it shall be possible to define a number of virtual networks (slices).

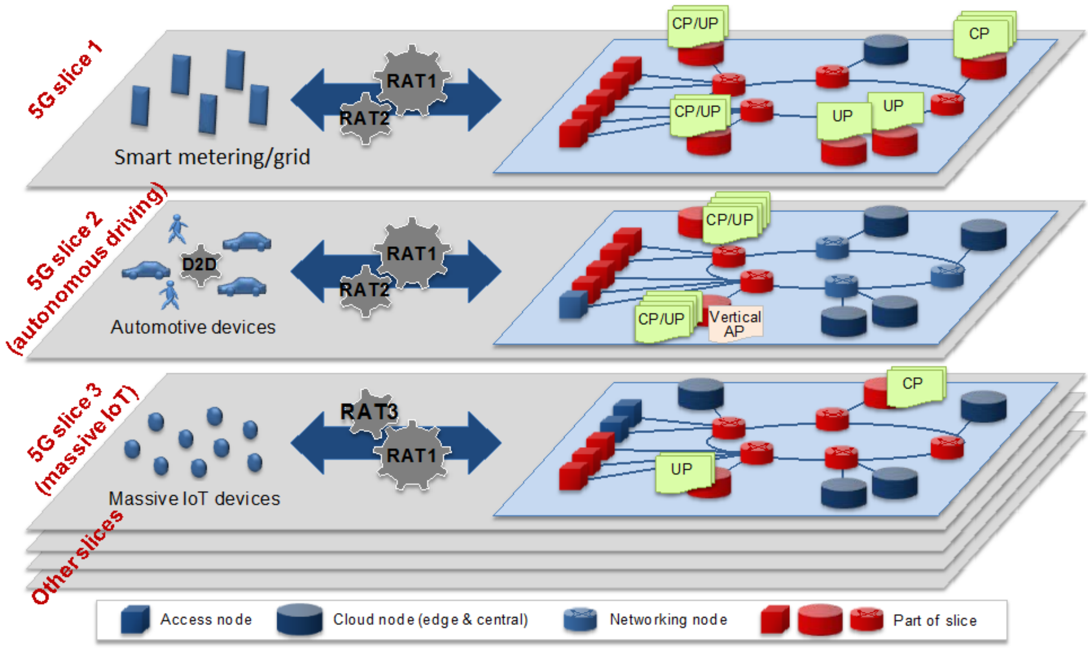



*Figure 52. Use of network slicing in 5G for smart metering and grid communications [38].*

The customer/service demands in today's communication industry are diverse and diversity will increase in the future. With network slicing, operators would be able to adapt to customer/service needs via a dedicated virtual network (=slice).

- The slice for consumers could be optimised for best-effort with the option to grant better on-demand QoS e.g. for video.
- A massive slice of IoT devices could be cost optimised and get most resources assigned in an overall low load timeframe (nights and weekends).
- The slice for autonomous driving is optimised for latency and reliability. This may be reached with computing close to the edge.
- The slice for smart metering/grid could support transport SLAs for example, via regional deployment options. High availability even in critical events (e.g. black start) can be guaranteed due to the configuration of this slice.

Each of the slices should get guaranteed resources to offer their service independent of issues present in other slices. Based on existing or future technologies, the slices should be agile to offer extra resources on demand and based on configured policies.

## 7.6 Applicability of telecommunication networks to Smart Grid needs

Smart grid is an important vertical stakeholder sector for the communication industry. As a result, existing communication solutions will also be enhanced to meet future smart grid requirements.

Network slicing will be used to create logical end-to-end networks (slices) for the smart grid. This is due to the criticality of the smart grid. The architecture of smart grid slices ensures that enough resources are available for required service characteristics (e.g. low latency; high bandwidth) on a calendar scheduled, periodic or ad-hoc basis. Also, the dependency to other services can be realised in an easier way.

Other very important ICT enhancement is the possibility to transport information with very low latency. 5G example use cases – as an alternative/back-up to fibre services or where fibre performance is required but difficult to deliver could be

- Transmission – Phasor Measurement Units
- Transmission – SCADA/Telemetry
- Transmission – Renewables integration
- T&D – Demand Side Response
- Distribution – Distributed Energy Resources
- Distribution - Large scale renewables – the wind, PV and hydro
- Distribution - Primary Substation services – including grid interconnect
- Distribution - Medium scale generation (wind)

The following table covers expected data and communication requirements by 2020 for distribution level services [39]. All of those requirements are considered as targets for 5G.

*Table 12. Expected data requirements by 2020 for distribution level services [39].*

| Data Class | Data | Description | Criticality | Latency | Avail-ability | Resili-ence | Power Auto-nomy | Typical Volume | Min Bandwidth |
|---|---|---|---|---|---|---|---|---|---|
| **A** | High priority | Delivers critical traffic that enables management of network service and demand | High | 0.1 - 1 s | 99.98 % | Yes | 72 h | 1 kB every 6 s | 10 kbps |

| Data Class | Data | Description | Criticality | Latency | Avail-ability | Resili-ence | Power Auto-nomy | Typical Volume | Min Bandwidth |
|---|---|---|---|---|---|---|---|---|---|
| **B** | Medium priority | Delivers important traffic that enables management of network service and demand | High | 1 - 10 s | 99.94 % | No | 24 h | 100 B every min | 1 kbps |
| **C** | Medium priority (to third party devices) | Delivers important traffic that enables management of demand | Medium | 1 min | 99.90 % | No | 12 h | 100 B ever hour | 1 kbps |
| **D** | Low priority | Delivers traffic that enables monitoring of data that may impact network service | Low | 1 min | 99 % | No | None | 100 B every hour, 1 MB every day | 10 kbps - 200 kbps |

## 7.6.1 Low-cost communication at the edge of the network

In the case of reduced ICT requirements, LPWAN technologies could be the best option. LPWA products have low channel bandwidth and transmit power according to local regulation, which makes them appropriate for modest data rates of a few hundreds of kb/s, needed to be transmitted a few hundred m/km away. Most products are cheap, well established and widely deployed. Their evolution may be towards increased downlink data rates (e.g., SigFox) but simplicity is the key for keeping costs low. The products made for the unlicensed bands, with different requirements in the USA or Europe, cannot guarantee mitigation against interference when many devices are deployed in an uncoordinated manner. Unlicensed LPWA is then well suited to mMTC.

LPWAN allows IoT to be available to a massive amount of devices at lower costs, and in turn, an array of use cases. LPWAN reduces device complexity and it will be ideal for addressing ultra-low-end applications in markets. It can be employed in the electricity sector, which has a lot of devices which need to be connected, while usually being situated in locations which do not have the best network reception. At present, it is common to note the utility metering device status and replace the meter's battery manually, which is an expensive venture. In the long term, NB-IoT would enable the management of smart meters, whereby it would not only become easily accessible in terms of reachability of the devices,

but it would also reduce the cost of registering each device's status. The possibility to connect a massive amount of sensors gives utilities the capability to get a detailed picture of the situation in distribution and transport network. By knowing the in detailed the decentralised consumption and generation of electric energy the smart grid can be planned and prepared accordingly.

### 7.6.2 Reliability of critical operations

Critical functionality for the safe and stable operations in the grid requires high reliability and predictable latency in communication. Notice that real-time communication in this context means predictable worst-case latency, and not necessarily very low latency. For such control applications, the number of nodes is assumed significantly lower than for mMTC. Examples of smart grid functionality with stringent real-time requirements are circuit breakers and the control of big loads for balancing the grid. Failing to send control signals to such equipment within the deadline could result in instability in the grid and outages. Also, there are measurements of the state of the grid that need to be received by the control algorithm within a relatively short deadline to be relevant. The safe operation of the grid requires a reliable and predictable closed control loop.

The service reliability is the probability that the information is transmitted before a deadline (latency smaller than deadline). The end-to-end latency is the sum of delays at the MAC processing, channel access, transmission and possible re-transmission. Some applications define also acceptable variations of delay, also known as jitter. In radio systems, it is difficult to guarantee uMTC services at all times, but it is common to define a goal for service availability where delay, data rates or coverage requirements can be met. An uMTC wireless system will be reliable for a portion of the time. If the system can lower availability expectations by allowing non-guaranteed or outage more often (say from 0.01% of the time to 1% of the time), it will increase reliability. Licensed spectrum is needed to ensure a stable reliability and very limited outage. LPWA technologies, in general, are not applicable due to the relatively high latency with low predictability due to the low-power and scalability design goals of such systems. Licensed LPWA technologies such as NB-IoT seem better candidates. NB-IoT has similar data rates, but more guarantee to achieve them in a stable way as the frequency band is licensed and distinct from the LTE spectrum. Although in a band that allows for up to 23 dBm transmission, NB-IoT is likely to be deployed at a maximum 14 dBm in order to limit power consumption. The downside of higher, licensed frequency bands is that at the lower range is expected. Therefore, NB-IoT seems well adapted to uMTC at short distances.

## 7.7 Service architectures

The challenge in future grids is not only to coordinate the operation of millions of different devices and subsystems, but also to manage and orchestrate an increasing number of services. The downfall of the system responsible for performance or flexibility may be result from the unsuitable service architecture.

For managing especially web services, a Service-Oriented Architectures (SOAs) was designed for IT enterprises struggling with constantly changing application versions and upgrades, integration, and security issues etc. The Enterprise Service Bus (ESB) is one of the core SOA realisations, which defined a set of rules and principles for integrating numerous applications together over a bus-like infrastructure. This service-based abstraction layer between applications and loose coupling enabled the needed flexibility for application lifecycle management. However, applications and services have evolved since ESB was introduced. Nowadays, services are more distributed and agile with significantly shorter lifecycle especially in a case of mobile and IoT applications. The conventional all-or-nothing SOA/ESB implementation was found too expensive and restrictive for smaller enterprises, so new complementary architecture concepts were introduced to support better IoT and mobile applications. Based on our study, conventional ESBs are applicable for TSO-DSO level market interactions offering already proofed reliability and security. The SOA gateway offers additional security and is applicable for dividing the centralised core system parts from the distributed and less reliable system parts including e.g. aggregator and DER service levels. Microservices architecture offers the highest flexibility and support for IoT and mobile services with lowest OPEX and CAPEX costs. Thus, it would be most applicable for DER owners and small aggregators. Naturally, boundaries between systems are not this straightforward to define. The boundary depends on existing legacy systems, regulations, used market model, and offered ancillary services. Therefore, short descriptions of different service architecture designs and their key properties are given in the following subchapters.

### 7.7.1 Enterprise Service Bus

The core concept of the Enterprise Service Bus (ESB) architecture is that different applications are integrated by putting a communication bus between them and then enable each application to talk to the bus. This decouples applications and services from each other allowing them to communicate without dependency or knowledge of other applications on the bus. ESB provides basic adoption, translation, and routing services as well as so-called commodity services including e.g. event handling, data transformation and mapping, correlation, business activity monitoring, message and event queuing and sequencing, security and exception handling, protocol conversions and enforcing proper quality of communication service. Big data service providers like IBM, Google, Oracle, Cisco, and Microsoft offer their own ESB solutions, which often are vendor-specific product suites and application platforms. There exists also open source ESB solutions, but their capabilities are not as rich and reliable as in commercial

products. The implementations of ESB use event-driven and standards-based message-oriented middleware in combination with message queues.

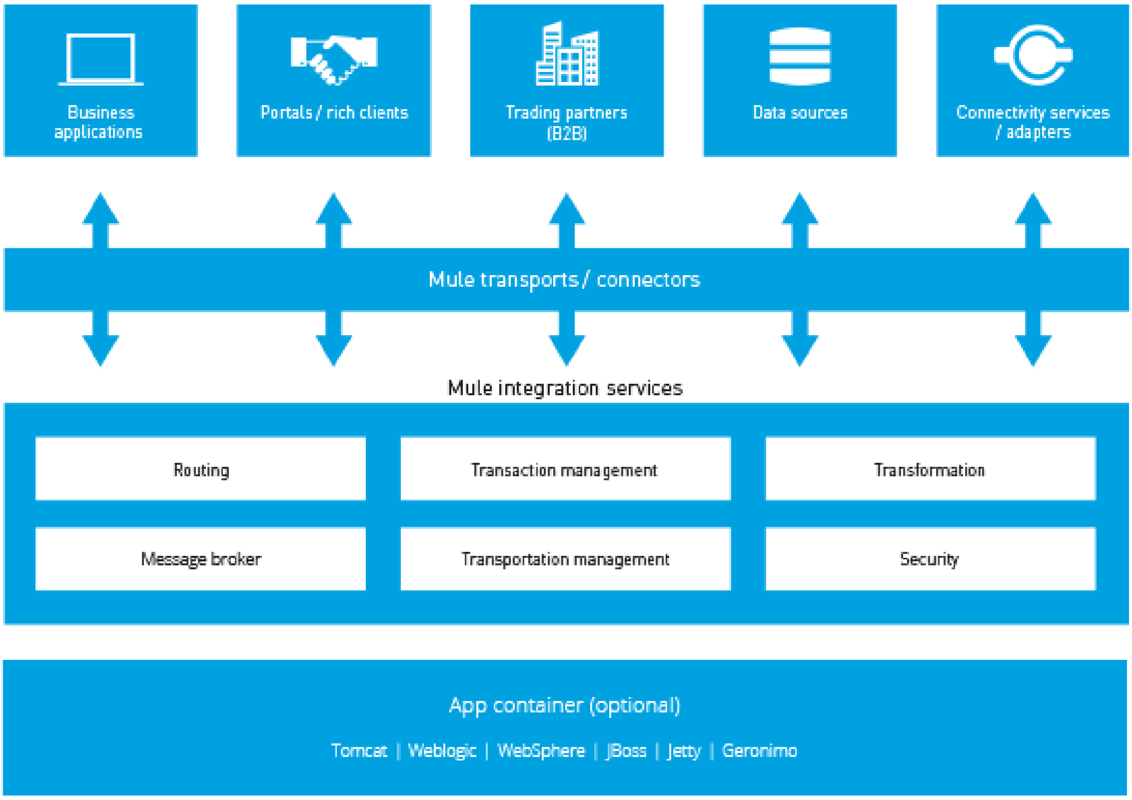



*Figure 53. An example of Mule ESB implementation [40].*

The main operations of ESB include:

- **Orchestration**: Composition of multiple fine-grained components into a single higher order aggregated service. This helps to achieve appropriate "granularity" of services and promote reuse and manageability of the service components.
- **Transformation**: Data transformation between canonical data formats and specific data formats required in each ESB connector e.g. transformation from ordinary Excel CSV to SOAP/XML format.
- **Transportation**: Transport protocol negotiation between multiple formats (such as HTTP).
- **Mediation**: Providing multiple interfaces for supporting multiple versions of a service or to allow multiple interfaces to the same underlying service component.
- **Non-functional consistency**: Enforcing consistency of security and monitoring policies to be implemented. Scalability and availability can be achieved by using multiple instances of an ESB to provide increased capacity and eliminate single-points-of-failure (SPOFs).

ESB architecture is suitable for large monolithic systems with in-built security and service orchestration. Therefore, it is applicable for applications and services in TSO-DSO level and could be

bought as a turnkey solution from big service providers. However, those ESB solutions are too expensive and too inflexible at the aggregator and DER levels where heterogeneity of applications and small mobile or embedded devices is higher. Integration of those two types of services is a challenging task requiring a lot of specialised knowledge. To lower the complexity of integration, complementary technologies such as SOA Gateways (see section 7.7.2) and microservices (see section 7.7.3) have been introduced. They are simpler, and they enable a lightweight deployment and services with higher agility at lower cost.

### 7.7.2 SOA Gateway

SOA Gateway was initially created to protect internal applications when interfaces protected only by IP firewalls are being exposed to external parties over HTTP and HTTPS transport protocols. The SOA Gateway enables integrating services securely. The gateway is typically deployed as a hardware component that seamlessly controls access to services, protects information through data-level encryption, ensures the integrity of a message through signatures, and controls corporate information flow. Hardware-based gateways are mainly used for the following reasons [41]:

- **Ease of Deployment**: SOA Gateways are easy to install in a network as a plug-in appliance. Appliance-based SOA Gateways eliminate the need to install software packages and operating system patches and enable technologist to focus on configuring business policies.
- **Centralised Policy Management**: SOA Gateways provide centralised policy management removing the burden of security policies from service developers, which enables more consistent policy management and security.
- **Better Performance**: Hardware-based SOA Gateways process SOAP/XML messages faster than software based solutions. Resource-intensive processing is needed for message encryption-decryption, signature-verification, filtering, transformation, and access control.

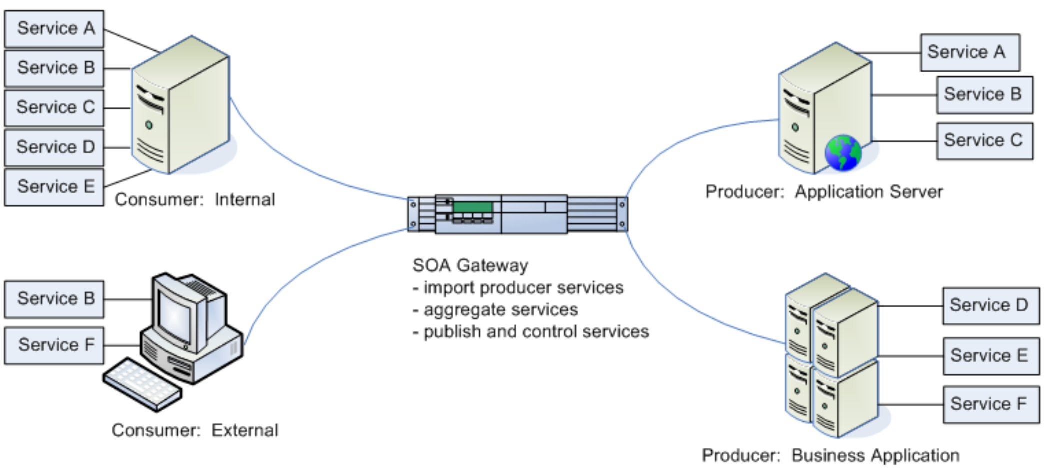



*Figure 54. Enabling Service Virtualization through a SOA Gateway [41].*

Key benefits of SOA Gateway are:

- Scales from point-solutions to enterprise-wide deployment
- More configuration rather than integration
- No central rules or brokers
- Easy to plug-in and plug-out and loosely coupling system
- Incremental upgrades and patches without service interruptions

On the other hand, key disadvantages are

- Slower communication speed compared to compatible services
- Single point of failure can bring down all communications in the enterprise
- High configuration and maintenance complexity

The strengths of SOA gateway are related to security, high-performance transformation, and edge-based protocol mediation. SOA gateway can act as a bridge between different technologies, which is important to build integrated enterprise and IoT/mobile services. It also offers secure extensions to applications deployed in public or private cloud environments.

### 7.7.3 Microservice architecture

The microservice architecture encourages implementing IT solutions as microservices without using any intermediate integration products such as ESB. These microservices can be best illustrated by comparing a traditional creation of a three-tier web service application to the microservice based one. In the traditional three-tier design, the server-side application takes the role of the middle layer, processing business logic and serving data from database tier to clients (web browsers, mobile apps, internet of things, etc.). In the traditional approach, scaling of service is typically done by replicating the same monolithic application on multiple servers.

In microservice architecture, the application or service is decomposed into multiple small, granular, independently deployable services. These services can be developed and enhanced by different teams using different technologies. Since the parts are independently deployed, they can also be independently scaled to fulfil different end-user needs.

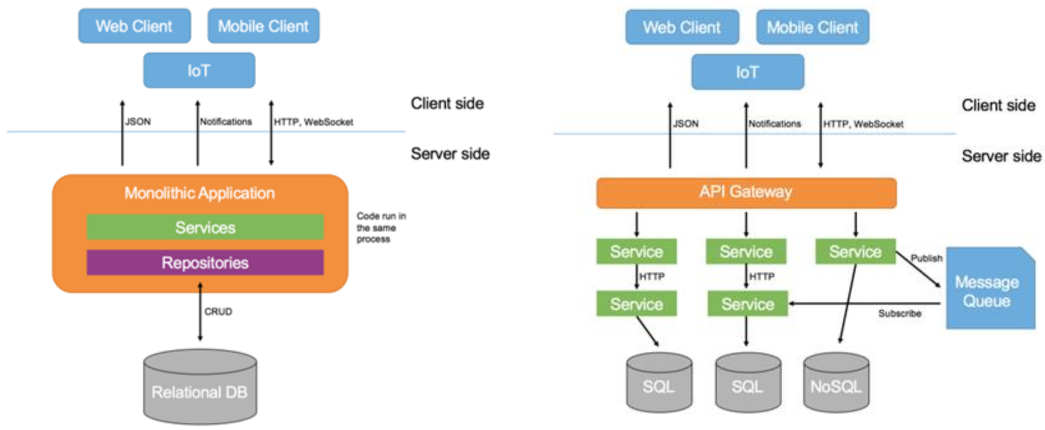



*Figure 55. Differences between conventional 3-tier and microservices-based applications, traditional architecture on the left and microservices on the right [42].*

Microservices are designed with agility in mind and they include following properties [42]. Services are very simple and they focus on doing only one functionality well. They are easier to test and validate, which ensures higher service quality.

- Each service can be built with the best-suited technologies and tools, allowing high flexibility for implementation.
- Multiple developers and teams can deliver services independently enabling continuous delivery and frequent releases while keeping the rest of the system stable.
- In case a service goes down, it will only affect the parts that directly depend on the service. The other parts will continue to function well.

In practice, microservices cannot be used alone in energy systems, since enterprises tend to have internal proprietary or legacy systems, which cannot be converted into microservices. Instead of focusing on one service architecture, the most suitable and flexible solution for the SmartNet system is to apply ESB, SOA Gateway, and microservices in a mixed way. Microservices can be used to address specific service cases executed at the edges of the grid. ESB can take care of service orchestration in grid level and cater all integration needs requiring high security and reliability. SOA Gateway can offer interactions between microservices and a bridge between mobile and IoT-driven flexible microservice environment and the conventional secure and more inflexible ESB environment.

### 7.7.4 Transition from enterprise SOAP/XML to mobile REST/JSON

The conventional enterprise ESBs uses mainly XML (eXtensible Markup Language) that has been a dominant standard for encoding documents. XML is a great technical specification, but for today's needs, it has a too complex structure for most users. Moreover, the overhead of XML encoding is significant due to tagging. The encoded data can bloat up to sevenfold. XML is ideal for structured enterprise information but not for the IoT or mobile semi-structured information. Moreover, XML is better suited for reliable

wired connections than to less reliable wireless connections used with IoT and mobile applications. Consequently, the industry is gradually moving to a much more compact standard called JavaScript Object Notification (JSON). It is a lightweight and flexible data format. It can handle both structured and unstructured data. When IoT and mobile services grow, the format is likely to overtake XML also in large SOA implementations.

Software-oriented architectures promote the “everything as a service” paradigm, but the conventional ESB felt short due to the lack of agility and lightweight standards. The agility can be achieved with SOA Gateway and microservice implementations. The ESBs are based on Simple Object Access Protocol (SOAP), which was once regarded as the protocol of the choice for inter-application and business-to-business communications. Today, Application Programming Interfaces (APIs) have become the de facto mode of publicly exposing content and internal business processes. The border between enterprise and web content are rapidly blurring. Mobile and enterprise APIs are primarily exposed over the REpresentational State Transfer (REST) protocol with the data encoded via JSON [43]. From the service integration viewpoint, REST/ JSON are more compelling solutions for future services than the conventional SOAP/XML. There are also other web transfer protocols to consider such as CoAP (RFC 7252 Constrained Application Protocol), Tiny Web Services and MQTT that are optimised for constrained devices. CoAP is a subset of HTTP offering specialised functionalities such as multicast support, very low overhead, and simplicity for constrained environments. MQTT stands for MQ Telemetry Transport. It is a publish/subscribe, extremely simple and lightweight messaging protocol, designed for constrained devices and low bandwidth, high-latency or unreliable networks. The aforementioned protocols are designed to minimise network bandwidth and device resource requirements while attempting to ensure sufficient reliability and some degree of assurance of delivery. They are designed for emerging mobile M2M and IoT worlds of connected devices, and thus suitable also for the future energy systems.

## 7.8 Data hub

A data hub is a central service platform that facilitates the transparent and neutral exchange of market information and execution of business processes between all market parties [44].

- DSOs (distribution system operators), or in some countries Metering Operators, are responsible for collecting metered values directly from smart meters. The metered values are sent to the data hub through standardised processes, timeframes and communication formats.
- In the Nordic context, a data hub contains the data necessary for consumption settlement and execution of market processes, such as master data related to consumers and metering points, metered values with a relevant time resolution, and historical data for analysis purposes. Additionally, the data hub provides other functionalities such as calculations of settlement and imbalance data, as well as providing data for reconciliations and aggregation processes by the market parties. Similar schemes are adopted in other EU countries (e.g. in Italy, the Integrated Information System) [45].
- Information about how consumers and market players are related is managed through standardised market processes like supplier switch, move-in/out, etc.
- In a data hub, the transactions and actual metered values are interlinked with the identified metering point and can be traced upwards or downwards in the executed processes.

The figure below (Figure 56) illustrates how a data hub becomes the central and neutral facilitator of data (after) instead of peer-to-peer communication between market players (before).

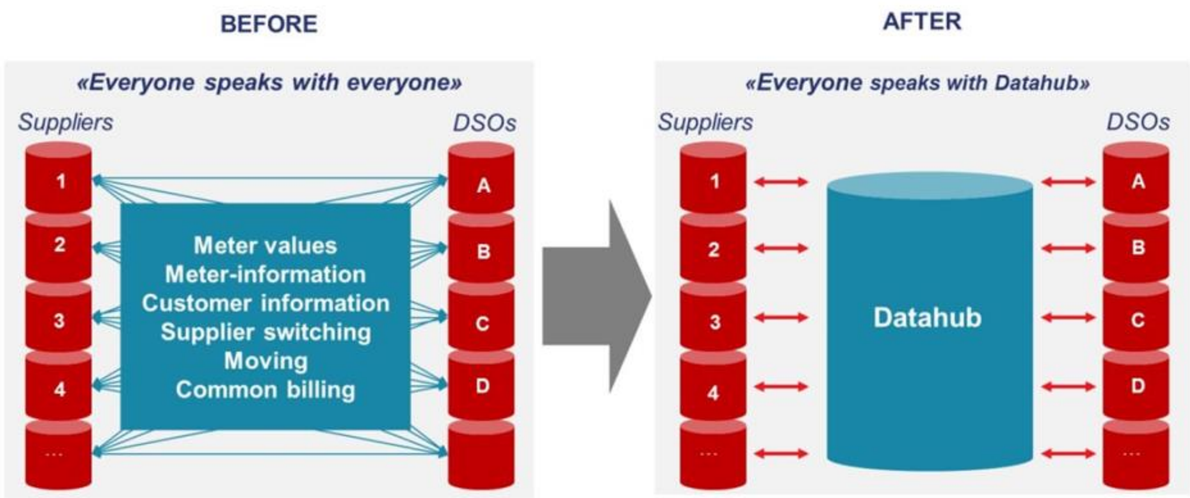



*Figure 56. Benefits of going from peer-to-peer communication to a data hub [44].*

## 7.8.1 Norwegian data hub

Norway has about 3.000.000 electric metering points, 130 DSOs, and 110 electricity suppliers. In addition, the customer can choose from a number of suppliers for service [46]. All these actors exchange information about:

- termination of agreements or end of supply,
- a customer moving in or out of a building,
- change of suppliers,
- new supply agreement,
- imbalance settlement,
- distribution of metering values,
- changes or update of metering point master data,
- disconnected metering point or removed metering point,
- collecting metering values, and
- 3rd party access for metering values.

As an example, if a customer wants to change supplier, the following information exchange takes place:

1. customer contacts the new supplier,
2. new supplier informs DSO,
3. DSO informs old supplier,
4. old supplier terminates the agreement and inform DSO about this, and
5. DSO informs the new supplier about the termination and current meter value.

In Norway, 400 000 supply changes take place each year, of which 360.000 for private end users, 40 000 for commercial and industry end-users. The processes are complex and resource demanding, and the interpretation of the rules may vary.

In 2013, the Norwegian Water Resources and Energy Directorate (NVE) decided that a data hub for electric metering should be established in Norway to provide an economically efficient IT-infrastructure for the retail market for electricity in Norway. The solution is called Elhub, and is developed and deployed within the organization of Statnett, the Norwegian TSO. Elhub is intended to be a centralised information exchange system for the electricity retail market. It is to be online from the beginning of 2017.

The main motivation for the Elhub is as shown in Figure 57, to simplify the interaction between the customers and the marked players by having a single data hub that everyone communicates with instead of the current many-to-many communication.

Elhub will help to achieve:

- Standardised and verified dataset of customers, metering endpoints etc.
- Efficient and secure distribution of metered values from AMS with high quality.
- Cost savings by removing duplication of effort for grid owners.
- Simplify business procedures such as change of energy supplier.
- Exploit potential of AMS for new solutions and services for grid owners, suppliers, and end-users.
- Nordic harmonization of retail markets.
- Neutral platform for all market parties.
- Improved security compared to having many smaller databases.

Elhub does not support any energy trading. Due to up to 1 ½ day delay for the meter values, Elhub is not suitable as a metering basis for energy trading in near future.

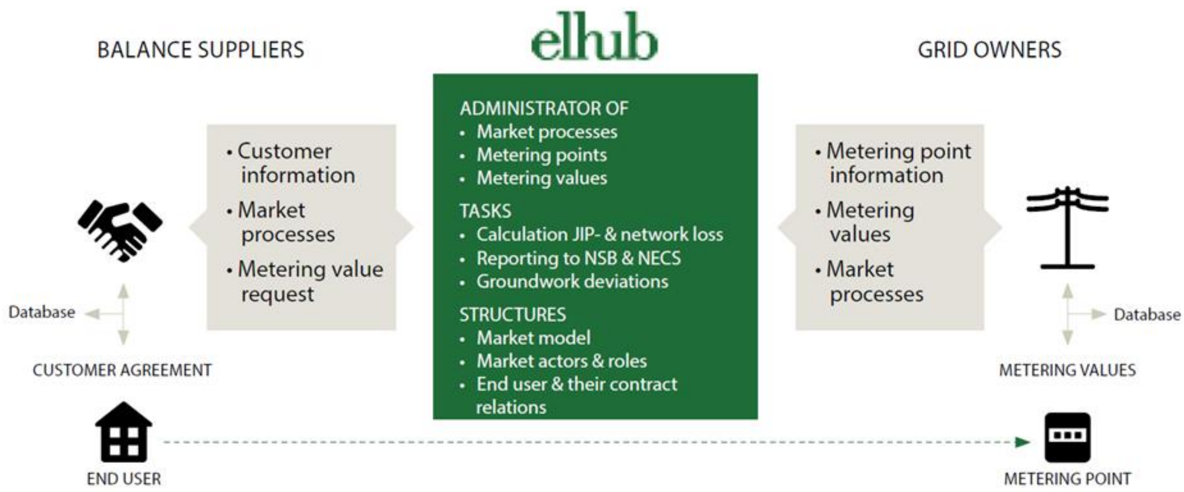



*Figure 57. Elhub overview [46].*

The basic functionality of the Elhub services is shown in Figure 2. Interfaces for the balance suppliers and the grid owners are web-based, the data hub works in 24-hour cycles:

- The metering data for the previous day from the metering points are due at 07:00.
- The received metering data is subject to validation, estimation, and changes if necessary.
- The validated data is stored and checked.
- Inquiries are made for missing metering data.
- The metering data is processed, and settlements and profiling are prepared.
- The metering data is made available for customers and authorised partners (e.g. balance providers, power suppliers, thirds parties) by 09:00.

The Elhub role and domain model uses a subset of the harmonised electricity market role models provided by ENTSO-E, EFET and ebIX with some adaptations to the Norwegian market and regulations. The adaptation includes new roles for handling the meters and settlement of metering inaccuracies.

### 7.8.2 Danish data hub

The Danish DataHub was established in 2013 based on a Danish law (no. 622) from 2010. It defined that Energinet.dk (the national TSO of Denmark) should develop and operate this instrument for further liberalization the electricity market in Denmark. The DataHub is the core ICT platform for the new electricity market model called Engrosmodel established in Denmark on the 1st of April 2016. [47]

The DataHub is a central and independent repository for all the measurements made by the approximately 3.3 million electricity meters in Denmark. Today 500 million yearly measurements are processed on the DataHub, which will increase to 42 billion in the year 2020 when all electricity customers in Denmark has remotely controlled meters.

It is the common ICT platform for information exchange between 120 actors on the electricity market, from Meter Operator (DSO responsibility) and Balance Responsible Party (BRP) to electricity trader and supplier, all the way down to the single customer, who can login and see the measurements from the main meter in his or her house.

The main purpose of the DataHub is to ensure a uniform and harmonised information exchange between the actors in the Danish electricity market, which includes:

- Supporting an open and liberalised market
- Standard procedures for e.g. switching electricity supplier
- Simplified billing with one bill including all tariffs, trading, taxes and supply fees
- A future hourly metering to support flexible demand

All specifications about terms and conditions for the Danish DataHub are available from Energinet.dk's web-site, which also includes an introduction to the Danish electricity retail market and DataHub.

### 7.8.3 Nordic data hub cooperation

The Nordic countries (Denmark, Norway, Finland and Sweden) have a long history of close regional cooperation – both on a political/regulatory level through NordREG and on TSO level. The operation and development of the energy system and energy markets are sought optimised from a regional perspective to the benefit of the region as a whole. The common establishment of the Nord Pool Spot marketplace is an example on this.

The Nordic countries continue to seek for regional solutions. Within a few years four Nordic countries will have separate data hubs, but through close coordination, the solutions are based on the same frameworks and standards, to enable smooth and cross-border operations and development of an integrated Nordic retail market. Integration and interoperability between the national data hubs is a natural next step.

Dedicated political visions of a harmonised regional retail market have led to close co-operation on multiple levels between the Nordic countries ensuring also regional interests when making vital national decisions such as implementing data hubs.

Further, the Nordic regulators (NordREG) have a strong vision of a regional retail market to the benefit of the consumers. Over the past 5-10 years, NordREG has initiated the development of a number of recommendations on how to achieve a common Nordic market. The TSOs together with regulators and the industry are now implementing some of those recommendations. An example is the efficient information exchange through data hubs with specific recommendations on central market processes such as supplier switching and customers moving in and out.

Harmonisation of crucial market processes and market design, in general, are prioritised between the Nordic TSOs through the vision of empowered consumers across the Nordic region. By facilitating an integrated and harmonised market, new business models and service offerings will be easier to emerge in all countries, when market players can achieve access to all 15 million consumers in the Nordic region. It will provide an easy and cost efficient marketplace where consumers are no longer limited in choosing their preferred ancillary services nationally.

### 7.8.4 ENTSO-E transparency platform

Transparency is essential for the implementation of the Internal Electricity Market and for the creation of efficient wholesale markets [48]. As of 2013, EU regulation has mandated European Member State data providers and owners to submit fundamental information related to electricity generation, load, transmission, and balancing to be shared through the ENTSO-E Transparency Platform. In accordance with regulation, the ENTSO-E Transparency Platform was launched at the beginning of 2015.

The information published through the Transparency Platform is collected from data providers such as TSO's, power exchanges and other qualified third parties. The data includes [49]:

- Information on total load from the TSO control areas per market time unit published at the latest H+1 after the end of the operating period.
- Day-ahead forecast per market time unit for the total load in TSO control areas, published at latest two hours before the gate closure of the day-ahead market. It should also be updated if significant changes occur.
- Week-ahead forecast per day for the total load in TSO control areas published each Friday no later than two hours before gate closure of the day-ahead market and updated on significant changes.
- Month-ahead forecast per week for the total load in TSO control areas published no later than one week before the delivery month and updated on significant changes.

- Year-ahead forecast per week for the total load in TSO control areas published no later than the 15th of the month before the year to which the data relates.
- Year-ahead forecast margin for the TSO control areas with the same deadlines as a total load.
- Forecasts for cross-zonal capabilities on the yearly, monthly and weekly basis.
- Forecasts for offered cross-zonal capabilities on the yearly, monthly, weekly and daily basis.
- Day-ahead prices per market time unit for a bidding zone, made available no later than one hour after gate closure.
- The physical flow between bidding zones that is to be published as close to real-time as possible, and not later than one hour after the operational period.
- Congestion management information on market time unit basis, made available no later than one hour after the operational period.
- Day-ahead forecast for aggregated generation and solar/wind generation per market time unit.
- Planned unavailability of generation and consumption, imbalance forecasts and more.

The system is based on XML formatted data being submitted over Energy Communication Protocol (ECP), secure File Transfer Protocol (FTPS) or web services, either by machine users or human users.

ECP is an implementation of MArket Data Exchange Standard (MADES) following the CIM IEC 62325-503 Technical Specification, and provides [50]:

- Security by encryption so that only the recipient of a message can read it, and signature to verify the message sender unambiguously.
- Reliability by guaranteeing message delivery.
- Integration and portability between a wide variety of technologies and operation systems.
- Transparency in that any message can be tracked with regards to delivery, etc.

ECP is developed for ENTSO-E and is free to use for participants in the electricity market following ENTSO-E's terms of use. However, there does not appear to be any free open source software for further tool development or for using it from existing systems.

### 7.8.5 Applicability of data hubs for Smart Grid needs

As mentioned in 7.8.1, the Norwegian Elhub is not meant to support energy trading, and thus is not usable for continuous (5-minute intervals) updating from measurement points. As the Nordic data hubs are based on the same frameworks and standards, it is likely that none of the Nordic data hubs is directly suitable for energy trading. However, the Nordic data hubs may be used for monitoring trends, and forecasts of electric energy consumption, which can be used as inputs for energy trading.

The trend (at least in Norway) is that the use of electricity decreases, while effects of load peaks are increasing. This means that there is a need for monitoring the momentary loads in the grid, i.e. measurements with higher update rate. The idea with a centralised database seems attractive, putting all

the management handling in one professional organization, guaranteeing security, efficiency, robustness and 24/7/365 uptime. Such a momentary measurement database may be the basis for intraday trading, to fulfil or balance committed supply.

The ENTSO-E Transparency Platform and its technical solution Energy Communication Platform (ECP) handles near to real-time data and could in this way serve as inspiration for the SmartNet solution. In particular, the ECP seems to have good solutions with regards to message security with SSL/TLS encryption, verification of sender and message integrity using X.509 certificates, portability, reliability, and transparency. This solution should be further studied when implementing the SmartNet solution.

One issue with the usage of data hubs is the introduction of a single point of failure in the system. However, one must bear in mind that a data hub is seldom hosted on a single server, but rather distributed in a professionally maintained server farm, possibly also geographically distributed. This means that the overall reliability and availability of the system is well under control, and it should not be anticipated to have a great negative impact on these metrics compared to having peer-to-peer networks of servers at different companies' premises.

The benefits of having data hubs is a single set of services that all the systems actors can connect to and trust rather than having many peer-to-peer connections, and also to have a coherent and verified data set in a well-specified format.

## 7.9 Blockchain

The blockchain is the technology which was invented to create the peer-to-peer digital cash Bitcoin in 2008, based upon the paper of Nakamoto [51]. The underlying concepts for this technology, however, date already from 1979 [52]. Blockchain can be regarded as an electronically distributed ledger. A distributed ledger is essentially an asset transaction database that can be shared across a network of multiple sites, geographies or institutions. All participants within a network can have their own identical copy of the ledger. Any changes to the ledger are reflected in all copies in minutes, or in some cases, seconds. The assets can be financial, legal, physical or electronic. The security and accuracy of the assets stored in the ledger are maintained cryptographically through the use of 'keys' and signatures to control who can do what within the shared ledger. Entries can also be updated by one, some or all of the participants, according to rules agreed by the network. [53]

The uniqueness of this technology lies in the fact that blockchains are maintained by a shared or 'distributed' network of participants (so-called 'nodes') and not by a centralised entity, meaning that there is no central validation system. Transactions can be created collaboratively by multiple writers, without either party exposing themselves to security threats. This is what allows delivery versus payment settlement to be performed safely over a blockchain, without requiring a trusted intermediary. Another important feature of distributed ledger technologies (DLT) is the extensive use of cryptography, i.e.

computer-based encryption techniques such as public/private keys and hash functions, to store, secure and validate asset transactions.

The blockchain is, in essence, an open system where all participants can contribute to the validation process ('permissionless' system). However, the use of blockchains or distributed ledger technologies in energy trading markets could be a permission-based system with authorised participants only.

In [54] the blockchain mentioned above is regarded as blockchain 1.0, the technology to enable digital cryptocurrencies like Bitcoin. In the meantime, however, blockchain technology has evolved. Blockchain 2.0 provides smart contracts: distributed, autonomous applications that are more extensive than simple cash transactions. Blockchain 3.0 is about blockchain applications beyond currency, finance, and markets covering application domains like health, government, science, literacy, culture, art, and energy.

To develop blockchain applications, several commercial and open source blockchain platforms are available now. Some of these platforms provide software components for building or participating in a blockchain, others provide blockchain-as-a-service on top of their cloud platforms.

Potential uses of blockchain technology in the energy domain are quite diverse; from the microenergy market, even behind the meter trading, providing energy contracts ledgers (consumer can change energy supplier in just a few clicks online, without the administrative complexity and costs of today's operations), to energy and flexibility trading.

The blockchain technology has the potential to make trading processes far more efficient, lower the cost of trading, improve regulatory control and eliminate unnecessary intermediaries. Security, privacy, non-repudiation, traceability, immutability, availability are fundamental characteristics inherent to blockchain technology. Its decentralised approach and peer-to-peer architecture makes it very robust. A failure of a single node or even multiple nodes will not break down the entire system. Also, real-time processing, the capability to process mass data and payment/settlement as a by-product in the trading process [55] are characteristics of this technology.

This technology has the potential to provide the fundamentals for a multi-market coordination scheme, even to have an impact on the selection or the design of a coordination scheme. For instance, some roles might not be addressed by a business actor, but by smart contracts on top of the blockchain.

Not only can blockchain technology be used in energy trading domain, it can also be applied in the CMP–RES domain. Blockchains could open the markets for the RES owner, eliminating even the aggregator role. Besides the impact on the business processes blockchain use enforces a common data format and communication protocol, which supports also cross-border operations.

### 7.9.1 Applicability in the different coordination schemes

Before looking at the applicability of blockchain technology in the five coordination schemes, it is important to investigate whether blockchain is, in general, an appropriate technology for the SmartNet system. Article [56] sets out several conditions:

1. **The blockchain is a technology for shared databases:** if you just need a structured repository of information, there are other technologies much more mature like relational, NoSQL or other types of databases that will be better suited.
2. **The blockchain is a technology for databases with multiple writers:** There needs to be more than one entity that modifies the database directly. In the case of blockchains, the writers may run "nodes" which hold a copy of the database, but transactions can also be created by users who are not running a node themselves.
3. **The blockchain is a technology for databases with multiple non-trusting writers:** There needs to be some degree of mistrust between the writers. Mistrust can be interpreted as one user not willing to let another user modify database entries which it "owns".
4. **Is disintermediation needed or wanted?** There is a solution to solve the mistrust problem: a trusted intermediary that controls the database. Blockchains remove the need for trusted intermediaries by enabling databases to be modified by multiple non-trusting writers directly, thus no gatekeeper controlling the database transactions. The question, in this case, is: "is there anything wrong with having a central party who maintains an authoritative database and acts as the transaction gatekeeper?". Good reasons to prefer a blockchain-based database over a trusted intermediary might include lower costs, faster transactions, automatic reconciliation, new regulation or a simple inability to find a suitable intermediary.
5. **Dependency between the transactions:** Because of this dependency, the transactions naturally belong together in a single shared database. Otherwise, extra mechanisms or intermediators to validate and to guard the conditions of the interaction between the transactions are needed.

The next paragraph regards the use of blockchain technology at the level of TSO-DSO market models. It has to be noted that even if blockchain technology at the level of the model is not suited to implement a particular coordination scheme, this doesn't exclude a market operator from using this technology internally to realise a market platform implementation e.g. to guarantee a higher availability at a lower cost than by means of a traditional implementation.

In the *Centralised AS market model*, there is only one central platform and it is inherent to the model that this platform is operated by the TSO. This means there is no shared database and there are no multiple non-trusting writers. The TSO is the only one writing to the central platforms' database. The blockchain technology is thus not suited for this model.

In the *Local AS market model*, there are several local market platforms, one per DSO, that communicate with the TSO market platform. Similar to the previous model it is inherent to the model that the central market platform is operated by the TSO and the local market platforms by the DSOs. The conclusions are therefore the same as for the Centralised AS market model. However, in situations with multiple DSOs, several smaller DSO markets could be integrated into one platform. In this case, it must be operated by an independent operator, or it could be implemented by means of blockchain technology, eliminating the Independent Market Operator.

In the *Shared balancing responsibility model*, the TSO and DSO markets are completely decoupled. Only the constraints schedule agreed ahead between TSO and DSOs has to be exchanged. From a technology point of view, this is similar to the previous model: several market platforms operated by either the TSO or the DSO.

In the *centralised variant of the Common, TSO-DSO AS market model*, the TSO and DSO have a common objective. This objective is realised by the joint operation of the TSO and DSO of a common market. From the ICT point of view, this is again a central platform, but the clearing function is defined by the common objective of TSO and DSOs. The applicability of blockchain technology for this variant is similar to the Centralised AS market model.

In the *decentralised variant of the Common, TSO-DSO AS market model*, the common objective is realised by the dynamic integration of a local market operated by the DSO, and a central market operated by the TSO. In this variant, the local market runs an optimization process that returns several options. The clearing at the local level cannot be finished before the TSO market has made a selection. This decentralised variant is more suitable for the blockchain technology than the centralised one.

In the *Integrated flexibility market model*, there is one central market platform operated by an Independent Market Operator. There is no prioritization based upon the submitters' nature (DSO, TSO, CMP) or identity. Considering all five coordination schemes, this scheme is the most likely candidate to be implemented by means of blockchain technology. Contrary to the other models, in the integrated flexibility market model, there is an independent operator running the market platform. In this market model, the use of blockchain could eliminate the independent market operator without changing the nature of the coordination scheme.

Because of the tight association of blockchain (1.0) and Bitcoin, it is important to know that the distributed ledger technology applied to AS trading services would differ from the blockchain designed for Bitcoins in a number of ways. In particular, while the Bitcoin blockchain 1.0 is an open system where anyone can contribute to the validation process ('permissionless' system), the blockchain technology that is likely to be used in AS markets would be a permission-based system with authorised participants only.

Blockchains could speed the clearing and settlement of certain financial transactions, by reducing the number of intermediaries involved and by making the reconciliation process more efficient. It could also

ease performing cross-border transactions, thereby reducing the need for multiple intermediaries. Because of the shared nature of the ledgers, all the participants to the blockchain network would hold own copies of the ledger without conflicting information. This technology could also make the reconciliation process faster and more efficient due to use of algorithms to agree on a consensus. Certain proponents of the technology believe that the clearing and settlement of transactions could be effectively and (almost) instantaneously combined into a single step [57].

The blockchain technology has also shortcomings such as computational work consumes a lot of energy; how to deal with dead data versus active data. Blockchains will always be less performant than centralised databases; lack of privacy, transaction data should not be accessible to all participants, but to authorised users only. On the other hand, blockchain technology is not yet a mature technology. The technology is evolving rapidly and a rich ecosystem of players experimenting with different blockchain variants is emerging. These players focus on particular application domains and offer blockchain technology variants with fewer flaws and better fitted to this particular application domain. Except for the bitcoin case, proof of the technology promises in other domains, have still to be delivered. It may take years before a blockchain technology is suitable for ancillary services and it may have an impact on coordination schemes. And although blockchain technology has a lot of potential in energy or flexibility trading, it will be economic, legal and regulatory issues that determine whether blockchains will be used [55].

# 8 Summary and conclusions

This report presents the analysis and design process used for converting the ICT requirements identified in D3.1 (ICT requirements specification) into a common ICT architecture design. The design process has been experimented with Italian, Danish, and Spanish pilots, as well as with the simulation platform to fine-tune the analysis process steps and to find the practical balance between a common architecture and system realisation designs.

For our work, we had a close collaboration between energy and ICT experts in order to make an ICT architecture design for energy systems, and partly because the five TSO-DSO coordination schemes were under research and plans for the pilots were in progress. Therefore, very detailed or consistent information about ICT requirements was not possible to obtain. To manage this challenge, we carried out consecutive iterations in order to gradually fill the gaps and to find a suitable presentation level for the ICT architecture. This incremental analysis of AS use cases and close collaboration with WP1 gave us sufficient understanding about business actors and their interactions in different market models.

In high level, we were able to capture the most relevant information exchange events and associated ICT and security requirements for our generic ICT architecture design. The architecture model was flexible enough to present centralised, local, shared, common TSO-DSO, and integrated market models. The main conclusions that can be drawn from the work done are:

- From ICT's viewpoint, the most relevant ancillary service procedures are prequalification, procurement, activation, and settlement. Since they are similar in all coordination schemes, the ICT requirements for them are also consistent.
- The analysis revealed that the most critical requirements, and also most difficult ones, are related to response time (latency), security, and cost. The challenge is that at the edge of the network, the security threat is the highest due to the lowest interest in investing for communication quality and security. It can be argued that this is not a severe problem, since the impact of one component at the edge is negligible and used service and communication technologies should inherently take care of all possible security threats. The challenge is that the number of infected edge components can explode multi-fold in several security threat scenarios making the overall impact significant. However, this is the subject of risk assessment, which is beyond the scope of this report. Nevertheless, we should not rely blindly on service or communication technologies to resolve all security issues especially when the evolution of technologies keeps getting faster.
- The deployed service architecture has an impact on energy system interoperability, flexibility, and security. Conventional ESB solutions are applicable in core parts of the systems in the TSO-DSO level. SOA Gateways are offering additional security by enabling to split the secure and insecure parts of the networks. Moreover, Microservices may be a cost-effective way of building services for DER level trading offer services also for mobile and IoT devices.

- NFV and SDN are new enablers in communications to offer high flexibility. It allows mobile operators to reconfigure their networks to offer dedicated network slices for ancillary service providers with different properties with respect to cost, quality and quantity.
- The assessment of communication technologies can be categorised into three classes: wired communication with stringent security and latency requirements, licensed wireless communication with mobile operator specific frequency bands, and unlicensed wireless communication with publically shared frequency bands. The selection of suitable communication options, however, depends on e.g. business models, existing communication infrastructure, ICT requirements, and investment and operation costs, which are system realisation specific.
- When the SGAM model is used for ICT architecture design, we must pay attention to terms and definitions in all layers of SGAM. The design in each layer can easily lead to an over detailed description, which makes it very difficult to comprehend. Therefore, a generalization of architecture in specifications and use of architecture design tools are essential.
- Enterprise Architect with SGAM extension was an excellent tool for visualising the design. The generated all-in-one ICT requirement table was very practical for iterative and incremental design and to keep the specifications aligned. Moreover, it created the base for parametrised architecture design where ICT requirements could be adjusted according to end-user needs.
- We found generalised requirement classes appropriate for a common architecture design where we wanted to keep the mappings to the ancillary service use case specifications (provided by WP1). Especially security requirements are so diverse that classification was required. The studied security aspects and review of security standards has been presented in ICT requirements specifications deliverable D3.1 [3] Appendix C.
- During the analysis process, we moved to use configurable SGAM models where parametrisation was implemented with scripts and importing changed all-in-one ICT requirement table. The model analysis revealed that requirements e.g. for latency and security will significantly affect the cost and communication technology to be used. Therefore, we see that re-configurable scripts in EA tool are very useful for analysing different architecture designs with different ICT requirements in both regional and European levels.

The final goal of this document and associated electrical SGAM models are expected to deliver general guidelines for designing ICT systems for pilots and simulation platform. The models are in electrical form, so designs and associated requirements can further be tailored and parametrised. Moreover, chapters presenting enabling technologies indicate that there exists a wide range of technological possibilities as long as the requirements are clear. The challenge is to differentiate those ICT functionalities that we actually need and those that would be nice to have. The presented analysis process and parametrised architecture model will support this kind of performance assessment.

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# 10 Appendix

## 10.1 System Actors

*Table 13. Identified system and business actors of the ancillary service use cases.*

| System Actor | Business Actor | System |
|---|---|---|
| **MO MMS** | Market Operator | Market Management System |
| **TSO MMS** | Transmission System Operator | Market Management System |
| **TSO TS** | Transmission System Operator | Trading System |
| **TSO EMS/SCADA** | Transmission System Operator | Energy Management System/ Supervisory Control and Data Acquisition |
| **DSO MMS** | Distribution System Operator | Market Management System |
| **DSO Local MMS** | Distribution System Operator | Local Market Management System |
| **DSO TS** | Distribution System Operator | Trading System |
| **DSO DMS/SCADA** | Distribution System Operator | Distribution Management System/ Supervisory Control and Data Acquisition |
| **Aggregator TS** | DER Aggregator | Trading System |
| **Aggregator EMS/SCADA** | DER Aggregator | Energy Management System/Supervisory Control and Data Acquisition |
| **CMP TS** | Commercial Market Player | Trading System |
| **CMP EMS/SCADA** | Commercial Market Player | Energy Management System/Supervisory Control and Data Acquisition |
| **DER TS** | Distributed Energy Resources | Trading System |
| **DER EMS/SCADA** | Distributed Energy Resources | Energy Management System/Supervisory Control and Data Acquisition |

## 10.2 Latency Properties

*Table 14. Latency requirements for electricity network operations [58].*

| Property | Latency requirements[20] | Network technology |
|---|---|---|
| **Type 1A**<br>**Trip (fault isolation & protection)** | 3-10ms (P1/P2) | Fiber optic communication, Metro-Ethernet, High performance microwave |
| **Type 1B**<br>**Other IED automation** | 20 ms (P3) | Fiber optic, Metro-Ethernet, High performance microwave, LTE-advanced |
| **Type 2**<br>**Medium speed control** | 100ms (P4) | LTE, WiMAX and above |
| **Type 3**<br>Low speed **control** | 500 - 1000 ms (P5/P6) | PLC, RF-mesh, 3G, LTE, WiMAX and above |
| **Type 4**<br>**Continuous Raw IED data messages** | 3-10ms (P7/P8) | Fiber optic, Metro-Ethernet, High performance microwave, future LTE-advanced |
| **Type 5**<br>**File transfer functions** | ≥ 1000ms (P9) | PLC, RF-mesh, 3G, LTE, WiMAX and above |

[20] The P numbers refers to performance classes according to the IEC 61850-5 standard. Also described in deliverable D3.1_20161118_V2.3 page 23.

## 10.3 Network Properties

*Table 15. Network characteristics.*

| Property | Description |
| --- | --- |
| **Availability** | Focuses on identifying and assuring data and services that need to be available for a specific purpose at a very precise time. |
| **Cost and ownership** | Depends on the number of connections, capacity, type of equipment, installation complexity, the scale of deployment (geographic area), and the operation & maintenance needed thereafter. In this study, how much user is willing to pay for communications. |
| **Coverage** | The geographic area where the service is available. |
| **Data rates** | The speed at which the data is sent over a communication link or channel; generally expressed in bytes per second. |
| **Density of terminals** | Defines how many terminals are required to fulfil. |
| **Latency** | The time between initiating a request and receiving the answer. More in details, the time difference between a packet being sent and received. |
| **Multi-technology support** | The ability to use more than one technology at the same time. |
| **Networking properties** | Contains properties such as coverage, two ways communication, P2P, data rates, availability, latency, and multi-technology support. |
| **One-way communication** | A form of transmission in which information is always transferred in only one preassigned direction. |
| **Open-standards support** | The ability to use technical standards, which are developed in a vendor-neutral manner. |
| **P2P** | Point-to-point connection refers to a bidirectional communications link between two nodes or endpoints. |
| **Reliability and security** | Reliability is the ability of a system or component to perform its required functions under stated conditions for a specified period of time. Security refers to the ability of a system to protect information and system resources with respect to confidentiality and integrity. |
| **Two-way communication** | A form of transmission in which both parties involved transmit information. |

## 10.4 Security Properties

*Table 16. Security levels [14].*

| Security level | Name | Expected power loss | Geographic impact |
|---|---|---|---|
| **5** | Highly critical | Above 10 GW | Pan European |
| **4** | Critical | 1 - 10 GW | European/country |
| **3** | High | 100 MW - 1 GW | Country/regional |
| **2** | Medium | 1 MW - 100 MW | Regional/Town |
| **1** | Low | Under 1 MW | Town/Neighbourhood |

## 10.5 Requirement Classes

*Table 17. Identified requirement classes of the ancillary service use cases.*

| Class | Description |
|---|---|
| **RC_Prequalification** | Requirements for prequalification assessment |
| **RC_CMPtoMarket** | Market Communication (CMP to Market) |
| **RC_MarketToCMP** | Market Communication (Market to CMP) |
| **RC_MarketCMPtoDER** | Market Communication (CMP to DER) |
| **RC_MarketDERtoCMP** | Market Communication (DER to CMP) |
| **RC_DSOtoMarket** | Market Communication (DSO to Market) |
| **RC_MarketToDSO** | Market Communication (Market to DSO) |
| **RC_TSOtoMarket** | Market Communication (TSO to Market) |
| **RC_MarketToTSO** | Market Communication (Market to TSO) |
| **RC_Metering** | Metering of activated flexibility |
| **RC_Blocking** | Blocking |
| **RC_Activation** | Flexibility Activation |
| **RC_Confirmation** | Acknowledgement of activation |
| **RC_Data** | Profile data based on historical data |
| **RC_CongestionSolving** | Congestion solving |
| **RC_Participation** | DER to CMP communication |
| **RC_Settlement** | Financial settlement |
| **RC_Response** | Delayed responses |
| **RC_Acknowledgement** | Acknowledgement |
| **RC_Flexibility** | DER flexibility |
| **RC_AggFlexibility** | Aggregated flexibility |
| **RC_Reserves** | Reserve needs |
| **RC_Control** | Control parameters |

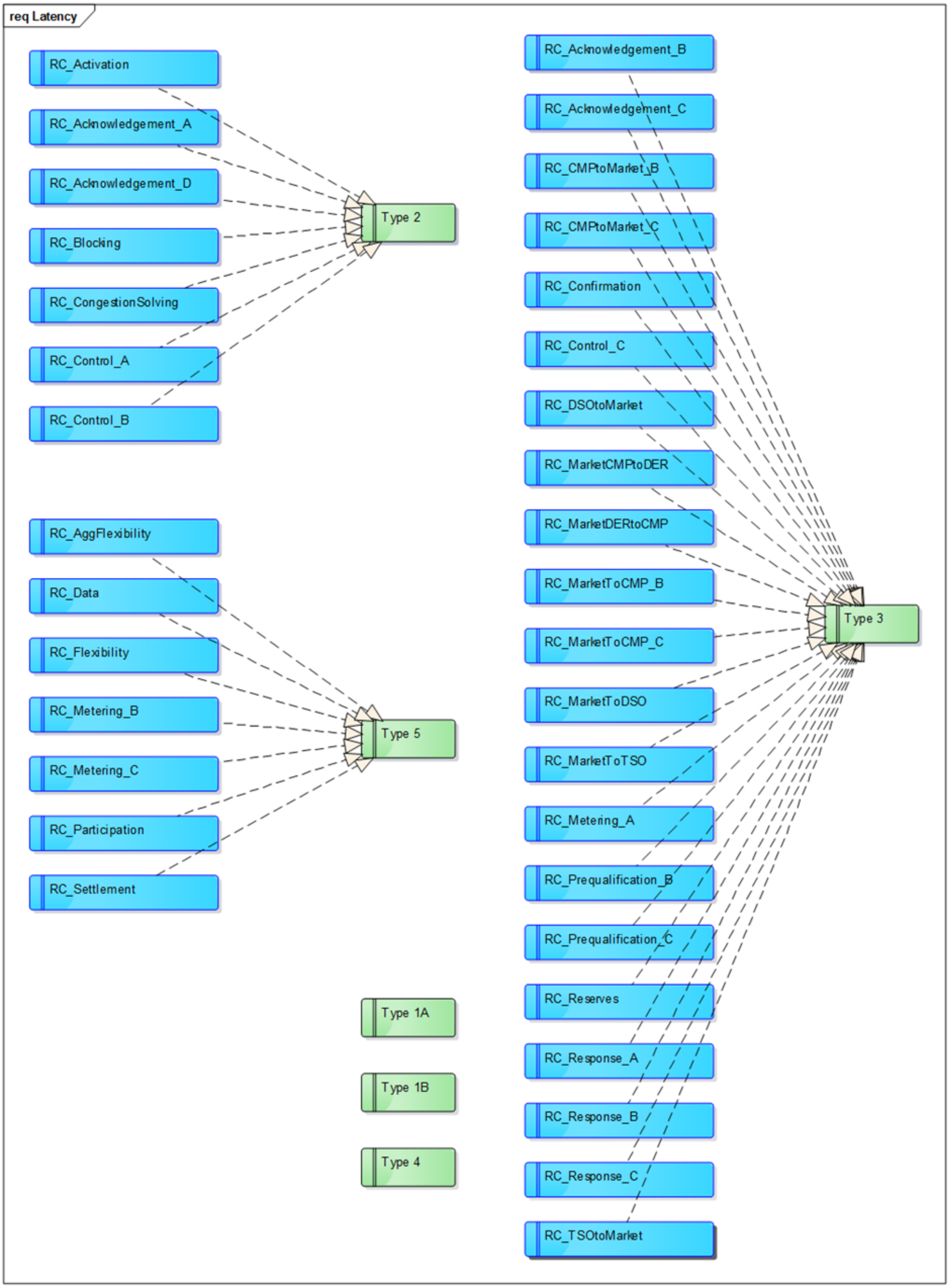


*Figure 58. The mapping between Requirement Classes and Latency properties.*

## 10.6 Protocol Classes

*Table 18. Identified protocol classes of the ancillary service use cases and related protocols.*

| Class | Description | Protocols |
|---|---|---|
| **PC_EnergyMarket** | Energy Markets Standards | IEC 62325 (CIM for energy markets),<br>ENTSOE-EDI |
| **PC_EnterpriseProcess** | Enterprise Process Standards | CIM (IEC 61968, IEC 61970) |
| **PC_NetworkOperation** | Network Operation Standards | SEP 2.0<br>IEC 61850<br>IEC 60870-5-101/104, IEC 60870-6 (ICCP)<br>Open ADR/IEC 62746<br>IEC 62056 (DLMS/COSEM)<br>REST |
| **PC_DER** | DER Standards | Open ADR/IEC 62746<br>IEC 62056 (DLMS/COSEM)<br>EI<br>IEC 60870-6<br>IEC 61850<br>SEP 2.0 |
| **PC_AMI** | AMI Standards | IEC 62056 (DLMS/COSEM)<br>SEP 2.0 |
| **PC_Settlement** | Settlement standards | EDI<br>IEC 62325 |
| **PC_Registration** | Registration/enrolment for services | OpenADR/IEC 62746-10, EI, SEP2.0 |
| **PC_InternetOfThings** | Internet Of Things protocols | CoAP |

## 10.7 Information Objects

*Table 19. Identified information objects of the ancillary service use cases.*

| Object | Description |
|---|---|
| **IE_PrequalificationRequirements** | Requirements for prequalification tests. Includes technical prequalification parameters. |
| **IE_TechnicalPrequalificationResults** | The results of the technical prequalification. Definition of required response. Incl. response time, location, volume, and duration |
| **IE_PrequalificationRequest** | Request prequalification assessment. E.g. information about flexible asset characteristics (type, location, response time, duration, …) |
| **IE_TestResult** | Acknowledgement and response or aggregated response. May be used also for delivering test details and observed response. |
| **IE_PrequalificationConfirmation** | Send prequalification results. Acceptance/Rejection of participation for the unit in the market. E.g. information whether DER can provide flexibility (no restrictions), flexibility (with restrictions), or no flexibility at all. |
| **IE_MarketBids** | Bids info or aggregated bids info are sent to the market. Response prices, volumes in MW, durations and periods (time ranges) when available. This aggregated offer must also comply with the format of the SmartNet Reserve product [volume, price, time]. Aggregated offer may be a smart order. |
| **IE_AcknowledgementOrFailureInfo** | The signal that acknowledges the required action or reports if there are failures that can prevent the source/sources from delivering the service as agreed. For example, a signal that acknowledges the required action or acknowledgment if a bid message is accepted or not. |
| **IE_ServiceAllocation** | Amount (MWh) of SmartNet Reserve (and associated remuneration - Euros/MWh) that is to be provided within the DSO control area for a specific period (according to market characteristics and settlement). The price could vary between DSO-TSO, DSO-CMP, CMP-DER owner. |
| **IE_Activation** | Activation signal is communicated (schedule or setting resulting from market economic and technical optimization) |
| **IE_Blocking** | Blocking of a selected bid |
| **IE_AssetActivation** | Activation signal of bids and/or DER assets.<br>Communication of volumes (MW), duration, time and price for DER resource. |
| **IE_AssetConfirmation** | Confirmation signal from asset (DER) to CMP that the required resources |

| | |
|---|---|
| | were activated |
| **IE_CMPConfirmation** | Confirmation signal from CMP that the required resources were activated |
| **IE_MeteringForImbalances** | Realised metering of bids accepted in local and AS market (MW, location, BRP responsible, timing) are communicated to the TSO |
| **IE_Metering** | Collected metering data is communicated |
| **IE_ReserveNeeds** | System and grid operators inform about their reserve needs to the market operator |
| **IE_NetworkConstraints** | Distribution network constraints to be considered in the central market |
| **IE_Settlement** | Financial settlement |
| **IE_SettlementForImbalances** | Correction of collateral affectation of CMPs' balancing perimeters |
| **IE_ScheduledProfile** | Scheduled load profile between DSO and TSO. This must be respected by the DSO. |
| **IE_BRPNominations** | The amount of produced and consumed energy (MWh) for each DSO area is communicated to the system operators |
| **IE_FCRNominations** | The amount of FCR per transmission grid node. |
| **IE_AreaDroopControlParameters** | Droop control parameters for each distribution grid area. |
| **IE_DroopControlParameters** | Droop control parameters for the DER. |
| **IE_DSOGridConstraints** | DSO constraints to be considered during market clearing. Communicating capacity allocation to each node. This could be organised on a node level or on an aggregated level (aggregation of several nodes) |
| **IE_DERflexibility** | DER sends to the aggregator its flexibility for the next hours or market periods |
| **IE_DERParticipationEcon** | Informing CMP on technical characteristics [onetime event] |
| **IE_DERParticipationTech** | Technical characteristics of DER unit. |
| **IE_BRPParameterCorrection** | The DSO informs the TSO about the local bids accepted for solving local congestion |
| **IE_MarketClearingResult** | Market results or aggregated market results from clearing. Accepted bids or not accepted bids (MW, location, BRP responsible bid, timing). Price is only communicated when a final solution is reached. The activation orders may be included. |
| **IE_CapacitiesUpdate** | DER owner, DSO or consumer available Q (MVAr) range about the mandatory band |

| | |
|---|---|
| **IE_ResponseData** | The observed responses and/or aggregator responses |
| **IE_FCRVerification** | Informing on what extent the observed responses were accepted as procured |
| **IE_MessageData** | Message sent without a corresponding request (e.g. message sent triggered by event) |

*This paper reflects only the author's view and the Innovation and Networks Executive Agency (INEA) is not responsible for any use that may be made of the information it contains.*