CEN-CENELEC-ETSI Smart Grid Coordination Group

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CEN-CENELEC-ETSI Smart Grid Coordination Group

Smart Grid Reference Architecture

Contents

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History of document

Number	Date	Content
v0.5	24/01/2012	First TR external version for SG-CG "Sanity Check"
v1.0	02/03/2012	First Interim TR draft for official comments
v2.0	31/07/2012	Second interim TR draft for official comments
v3.0	**08/11/2012**	**Final TR for adoption by M/490**

Main changes in this version

The adoption of the SG-CG report template has induced a reordering and renumbering of most of the sections and annexes.

The changes between version 2.0 and 3.0 have been kept minimal, considering that this version was not to be reviewed.

However, Annex C has been largely changed. A lot of new work has been done within SG-CG/RA between TR2.0 and TR3.0 on the Conceptual Model. Considering that is was useful to the readers, even if it could not be introduced in the main section of the report because of the many uncommented changes, it has been decided to present it as an informative reference.

In addition, Annex F (Communication Architecture) has been largely changed and is provided as a separate document, as in the previous versions of this report.

Foreword

Based on the content of the M/490 EU Mandate, the general scope of work on Standardization of the Smart Grid might be considered as follows:

> CEN, CENELEC, and ETSI are requested to develop a framework to enable European Standardization Organizations to perform continuous standard enhancement and development in the field of Smart Grids, while maintaining transverse consistency and promote continuous innovation.

The expected framework will consist of a set of deliverables. The deliverable addressed in this document is:

> "A technical reference architecture, which will represent the functional information data flows between the main domains and integrate several systems and subsystems architectures."

The development of this technical Reference Architecture, under the form of a Technical Report (TR), is the main responsibility of the Reference Architecture Working Group (SG-CG/RA), working under the Smart Grid Coordination Group (SG-CG) established by CEN, CENELEC and ETSI in order to fulfill the tasks laid down the Mandate M/490 of the European Commission.

The members of the Reference Architecture WG have been nominated, following an official call for experts. They have met since June 2011 in order to produce the various versions of the Technical Report. A Work Programme has been set-up that involves the production of several versions of the TR until final completion.

A first version v0.5 has been circulated in January 2012 for "Sanity check" within the SG-CG, to get guidance on the main aspects of the report.

The version v1.0 was the first Interim Report. It was a first solid step towards the Reference Architecture and has initiated a discussion about the architectural model proposed as well as its different viewpoints and dimensions.

The version v2.0 was the second Interim Report. It has been developed on the basis of the feedback (over 340 comments) received on v1.0 and on new contributions from the SG-CG/RA team.

The version v3.0 (this document) is the final version of the report within the current iteration of the M/490 mandate. It will be handed over to the European Commission in November 2012 and sent for approval by CEN, CENELEC and ETSI.

Further work on this report is expected in a subsequent iteration of the M/490 mandate, still to be decided.

1 Scope

This document is prepared by the Smart Grid Coordination Group (SG-CG) Reference Architecture Working Group (SG-CG/RA) and addresses the M/490 mandate's deliverable regarding the technical reference architecture.

This report is the final report due at the end of 2012.

1.1 How to use the document

The overall content of this document is as follows.

Chapter 1 (this chapter) introduces the approach chosen by the SG-CG/RA to address a complex problem space and the corresponding choices to define the scope of work. It outlines the main outcome expected at the end of the work and clarifies what is the main (but by far not the only) audience for the report. It also briefly outlines what is not in the scope of the SG-CG/RA work.

Chapters 2, 3 and 4 provide background information to the report (References, etc.) whenever they are not common to all SG-CG Reports.

Chapter 5 is an Executive Summary which is reproduced as such in the overall M/490 Framework Document.

Chapter 6 provides the European view of the Smart Grids Conceptual Model and an overview of the general elements of a Reference Architecture. It introduces the viewpoints chosen as target of the SG-CG/RA work.

Chapter 7 introduces the Smart Grids Architecture Model (SGAM) framework. The SGAM introduces interoperability aspects and how they are taken into account via a domain, zone and layer based approach. It finally introduces the methodology associated with the SGAM. Taking into account the interoperability dimension, the SGAM is a method to fully assign and categorize processes, products and utility operations and align standards to them.

Chapter 8 outlines the main elements of the different architectural viewpoints chosen for development by the SG-CG/RA, i.e. the Business, Functional, Information and Communication Architectures. Additional material or more detailed presentations of these architectures are provided in Annexes (that can be separate documents if their size requires it).

Chapter 1 lists the work items that SG-CG/RA may address in view of the next iteration of the M/490 mandate.

Annex A is grouping all the background work that serves as a foundation to the SG-CG/RA Report but was deemed not essential to the understanding of the Reference Architecture principles.

Annex B provides an overview how the SG-CG Sustainable Processes Work Group's Use Cases can be applied alongside the SGAM model, providing a holistic architectural view comprising the most important aspects for Smart Grid operations. In particular, it contains a detailed example regarding the application of the SGAM Methodology to a generic Smart Grid use case.

Annexes C to F provide details of the Reference Architecture viewpoints.

1.2 Approach to the problem domain

Considering that the overall scope of an architectural description can be quite large, the SG-CG/RA has chosen to focus on the following aspects of the reference architecture:

- Means to communicate on a common view and language about a system context, not only in the SG-CG but also with industry, customers and regulators;
- Integration of various existing state-of-the-art approaches into one model with additional European aspects;
- Methods to serve as a basis to analyze and evaluate alternative implementations of an architecture;
- Support for planning for transition from an existing legacy architecture to a new smart grid-driven architecture;
- Criteria for properly assessing conformance with identified standards and given interoperability requirements.

This has led the SG-CG/RA to address three major objectives:

- Ensuring that the main elements of the architectural model be able to represent the Smart Grid domain in an abstract manner with all the major stakeholders. Such a model should be coherent with already existing comparable models worldwide.
- Define an architectural framework that would support a variety of different approaches corresponding to different stakeholders' requirements and make it in a timeframe that would force to choose a limited set of such approaches.
- Providing a methodology that would allow the users of the architectural model to apply it to a large variety of use cases so that, in particular, it would provide a guide to analyze potential implementation scenarios, identify areas of possible lack of interoperability (e.g. missing Standards), etc.

Regarding the first objective, the NIST Conceptual Model [NIST 2009] was considered as a first essential input, though it required adaptation to the European context and some of its specific requirements (identified by prior work of the European Smart Grid Task Force).

Completion of the second objective required a careful selection of the architecture viewpoints to be developed. In general, reference architectures aim at providing a thorough view of many aspects of a system viewed by the different participating stakeholders throughout the overall system lifecycle. This means that, on a complex system like the Smart Grid, it is not always possible to cover all viewpoints and choices had to be made.

In particular, the viewpoints had to be chosen in order to allow for a meaningful description of relevant and essential aspects of the system (e.g. intended use and environment, principles, assumptions and constraints to guide future change, points of flexibility or limitations), documenting architectural decisions with their rationales, limitations and implications.

The third objective was reached through the provision of a model that would make the link between the different architecture viewpoints and that could be used in a systematic manner, thus leading to the provision of a methodology.

1.3 Outcome: an architecture framework and a mapping methodology

This report addresses the technical reference architecture part of mandate M/490 and provides the main results below:

- <u>European Conceptual Model</u>. It is an evolution of the NIST model in order to take into account some specific requirements of the EU context that the NIST model did not address. The major one is the integration of "Distributed Energy Resources" (DER).

- <u>Architecture Viewpoints</u>. They represent a limited set of ways to represent abstractions of different stakeholders' views of a Smart Grid system. The viewpoints selected are the Business, Functional, Information, Communication viewpoints.

- <u>Smart Grids Architecture Model (SGAM) Framework</u>. The architecture framework takes into account already identified relevant aspects [JWG-SG 2010] like interoperability (e.g. the

GridWise Architecture Council (GWAC) Stack), multi-viewpoints (SGAM Layers). Additionally, a functional classification, overview on needed and existing data models, interfaces and communication layers and requirements is provided to the First Set of Standards Work Group (FSSWG).

This framework can be applied, as a mapping methodology, to document smart grid use cases (developed by the Sustainable Processes Work Group - SG-CG/SP) from a technical, business, standardization and security point-of-view (as developed with the Smart Grids Information Security Work Group - SG-CG/SGIS) and identify standards gap.

1.4 Main target audience: Standardization Technical Committees

The target audience of the reference architecture is mainly standardization bodies and technical groups which can use the architectural framework, the methodological guidelines as well as the mappings of existing architectures (developed in the report annexes) to guide their work.

The SGAM provides a holistic view on the most important existing standards and architectures from different SDOs, making this deliverable a valuable document for members of standardization dealing with Smart Grid standards.

1.5 What is not in the scope of this document

For a variety of reasons, the work of SG-CG/RA shall not address notably the following domains:

- Standards development; Certification
- Market Models
- Regulation issues
- Home Automation, Building, …
- Gas

2 References

Smart Grids Coordination Group Documents

[SG-CG/A]	SG-CG/M490/A Framework for Smart Grid Standardization
[SG-CG/B]	SG-CG/M490/B_ Smart Grid First set of standards
[SG-CG/C]	SG-CG/M490/C_ Smart Grid Reference Architecture (this document)
[SG-CG/D]	SG-CG/M490/D_Smart Grid Information Security
[SG-CG/E]	SG-CG/M490/E_Smart Grid Use Case Management Process

References made in the main part of this document

[ENTSO-E 2011]	The Harmonized Electricity Market Role Model (December 2011), ENTSO-E, online: https://www.entsoe.eu/fileadmin/user_upload/edi/library/role/role-model-v2011-01.pdf.
[ENTSO-E 2012]	'Modular Development Plan of the Pan-European Transmission System 2050' of the e-HIGHWAY2050 Project Consortium: https://www.entsoe.eu/system-development/2050-electricity-highways/
[GWAC2008]	GridWise Interoperability Context-Setting Framework (March 2008), GridWise Architecture Council, online: www.gridwiseac.org/pdfs/.
[IEEE2030-2011]	IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation, with the Electric Power System (EPS), End-Use Applications, and Loads, IEEE Std. 2030 (2011).
[IEC61850-2010]	IEC 61850, Communication networks and systems for power utility automation, 2010.
[IEC62357-2011]	IEC 62357-1, TR Ed.1: Reference architecture for power system information exchange, 2011.
[IEC62559-2008]	IEC 62559, PAS Ed.1: Intelligrid Methodology for developing requirements for Energy Systems
[IEC 62264-2003]	IEC 62262, Enterprise-control system integration
[ISO/IEC42010]	ISO/IEC 42010: Systems Engineering – Architecture description, 2011
[JWG-SG 2011]	JWG Smart grids: Final report: JWG report on standards for smart grids – V1.1
[NIST2009]	NIST Framework and Roadmap for Smart Grid Interoperability, Interoperability Standards Release 1.0 (2009), Office of the National Coordinator for Smart Grid Interoperability, National Institute of Standards and Technology, U.S. Department of Commerce. Online: www.nist.gov/public_affairs/releases/smartgrid_interoperability.pdf
[NIST 2012]	Framework and Roadmap for Smart Grid Interoperability, Interoperability Standards Release 1.0 (2009), Office of the National Coordinator for Smart Grid Interoperability, National Institute of Standards and Technology, U.S. Department of Commerce. Online: www.nist.gov/public_affairs/releases/smartgrid_interoperability.pdf

References made in the Annexes of this document

It should be noted that the SG-CG First Set of Standards Work Group report [SG-CG/B] provides a list of references that may include most of the references below. In case of doubt on the applicable referenced documents, the [SG-CG/B] list prevails.

The following references are made in Annex E:

- Mapping of IEC 61850 Common Data Classes on IEC 60870-5-104 (IEC 61850-80-1 TS)
- OASIS EMIX
- UN/CEFACT CCTS
- EN 60870-6-802:2002 + A1:2005, *Telecontrol equipment and systems – Part 6-802: Telecontrol protocols compatible with ISO standards and ITU-T recommendations – TASE.2 Object models*
- EN 60870-5-1:1993, *Telecontrol equipment and systems – Part 5: Transmission protocols – Section 1: Transmission frame formats*
- EN 60870-5-3:1992, *Telecontrol equipment and systems – Part 5: Transmission protocols – Section 3: General structure of application data*
- IEC 61850-7-410 Ed. 1.0, *Communication networks and systems for power utility automation – Part 7-410: Hydroelectric power plants – Communication for monitoring and control*
- IEC 61850-7-420, *Communication networks and systems for power utility automation – Part 7-420: Basic communication structure – Distributed energy resources logical nodes*
- IEC 61400-25-2, *Communications for monitoring and control of wind power plants – Part 25-2: Information models*
- IEC 61400-25-3, *Communications for monitoring and control of wind power plants – Part 25-3: Information exchange models*
- IEC 61400-25-6, *Communications for monitoring and control of wind power plants – Part 25-6 Communications for monitoring and control of wind power plants: Logical node classes and data classes for condition monitoring*
- IEC 62056 series, *Electricity metering – Data exchange for meter reading, tariff and load control*, Parts 21, 31, 41, 42, 46, 47, 51, 52, 53, 61, 62
- IEC 61334, *Distribution automation using distribution line carrier systems* – Part 4 Sections 32, 511, 512, Part 5 Section 1
- EN 61970-301:2004, *Energy management system application program interface (EMS-API) – Part 301: Common information model (CIM) base*
- EN 61970-402:2008 Ed. 1.0, *Energy management system application program interface (EMS- API) – Part 402: Component interface specification (CIS) – Common services*
- EN 61970-403:2007, *Energy management system application interface (EMS- API) – Part 403: Component Interface Specification (CIS) – Generic Data Access*
- EN 61970-404:2007, *Energy management system application program interface (EMS-API) – Part 404: High Speed Data Access (HSDA))*
- EN 61970-405:2007, *Energy management system application program interface (EMS-API) – Part 405: Generic eventing and subscription (GES)*
- EN 61970-407:2007, *Energy management system application program interface (EMS-API) – Part 407: Time series data access (TSDA)*
- EN 61970-453:2008, *Energy management system application interface (EMS- API) – Part 453: CIM based graphics exchange*
- EN 61970-501:2006, *Energy management system application interface (EMS- API) – Part 501: Common information model resource description framework (CIM RDF) Schema*
- EN 61968-:2004, Application integration at electric utilities – System interfaces for distribution management – Part 3: Interface for network operations
- EN 61968-4:2007, Application integration at electric utilities – System interfaces for distribution management – Part 4: Interfaces for records and asset management
- EN 61968-9:2009, System Interfaces For Distribution Management – Part 9: Interface Standard for Meter Reading and Control
- FprEN 61968-11:2010, System Interfaces for Distribution Management – Part 11: Distribution Information Exchange Model
- EN 61968-13:2008, System Interfaces for distribution management – CIM RDF Model Exchange Format for Distribution

- IEC 61850-5 Ed. 1.0, *Communication networks and systems in substations – Part 5: Communication requirements for functions and device models*
- IEC 61850-6 Ed. 1.0, *Communication networks and systems in substations – Part 6: Configuration description language for communication in electrical substations related to IEDs*
- IEC 61850-7-1 Ed. 1.0, *Communication networks and systems in substations – Part 7-1: Basic communication structure for substation and feeder equipment – Principles and models*
- IEC 61850-7-2 Ed. 1.0, *Communication networks and systems in substations – Part 7-2: Basic communication structure for substation and feeder equipment – Abstract communication service interface (ACSI)*
- IEC 61850-7-3 Ed. 1.0, *Communication networks and systems in substations – Part 7-3: Basic communication structure for substation and feeder equipment – Common data classes*
- IEC 61850-7-4 Ed. 1.0, *Communication networks and systems in substations – Part 7-4: Basic communication structure for substation and feeder equipment – Compatible logical node classes and data classes*
- IEC 62325-301 Ed.1.0 : Common Information Model Market Extensions
- IEC 62325-501 Framework for energy market communications - Part 501: General guidelines for use of ebXML
- IEC 62325-351 Framework for energy market communications - Part 351: CIM European Market Model Exchange Profile
- IEC 62325-502 Framework for energy market communications - Part 502: Profile of ebXML

Other references pertaining to Communication Architecture are made in Annex F.

3 Terms and definitions

Architecture
Fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution [ISO/IEC42010].

Architecture Framework
Conventions, principles and practices for the description of architectures established within a specific domain of application and/or community of stakeholders [ISO/IEC42010].

Conceptual Model
The Smart Grid is a complex system of systems for which a common understanding of its major building blocks and how they interrelate must be broadly shared. NIST has developed a *conceptual architectural reference model* to facilitate this shared view. This model provides a means to analyze use cases, identify interfaces for which interoperability standards are needed, and to facilitate development of a cyber security strategy. [NIST2009]

Interoperability
Interoperability refers to the ability of two or more devices from the same vendor, or different vendors, to exchange information and use that information for correct co-operation [IEC61850-2010].

Reference Architecture
A Reference Architecture describes the *structure* of a system with its element types and their structures, as well as their *interaction* types, among each other and with their environment. Describing this, a Reference Architecture defines restrictions for an instantiation (concrete architecture). Through abstraction from individual details, a Reference Architecture is universally valid within a specific domain. Further architectures with the same functional requirements can be

constructed based on the reference architecture. Along with *reference* architectures comes a *recommendation*, based on experiences from existing developments as well as from a wide acceptance and recognition by its users or per definition. [ISO/IEC42010]

SGAM Interoperability Layer
In order to allow a clear presentation and simple handling of the architecture model, the interoperability categories described in the GridWise Architecture model are aggregated in SGAM into five abstract interoperability layers: Business, Function, Information, Communication and Component.

SGAM Smart Grid Plane
The Smart Grid Plane is defined from the application to the Smart Grid Conceptual Model of the principle of separating the Electrical Process viewpoint (partitioning into the physical domains of the electrical energy conversion chain) and the Information Management viewpoint (partitioning into the hierarchical zones (or levels) for the management of the electrical process. [IEC62357-2011, IEC 62264-2003]

SGAM Domain
One dimension of the *Smart Grid Plane* covers the complete electrical energy conversion chain, partitioned into 5 domains: Bulk Generation, Transmission, Distribution, DER and Customers Premises.

SGAM Zone
One dimension of the *Smart Grid Plane* represents the hierarchical levels of power system management, partitioned into 6 zones: Process, Field, Station, Operation, Enterprise and Market [IEC62357-2011].

4 Symbols and abbreviations

Acronyms

3GPP	3rd Generation Partnership Project
6LoWPAN	IPv6 over Low power Wireless Personal Area Networks
ADSL	Asymmetric digital subscriber line
AN	Access Network
ANSI	American National Standard Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning
BCM	Business Capability Model
CEN	Comité Européen de Normalisation.
CENELEC	Comité Européen de Normalisation Electrotechnique
CIM	Common Information Model
DER	Distributed Energy Resources
DSO	Distribution System Operator
eBIX	(European forum for) energy Business Information Exchange
EGx	EU Smart Grid Task Force Expert Group x (1 to 3)
ENTSO-E	European Network of Transmission System Operators for Electricity
ESCO	Energy Service Company
eTOM	extended Telecom Operations Map
ETSI	European Telecommunications Standard Institute
EV	Electrical Vehicle
EVO	Electrical Vehicle Operator
FACTS	Flexible Alternating Current Transmission Systems
FLISR	Fault Location Isolation and Service Recovery
GSM	Global System for Mobile
GWAC	GridWise Architecture Council
HAN	Home Area Network

HDSL	High-bit-rate digital subscriber line
HSPA	High Speed Packet Access
ICT	Information & Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPv6	Internet Protocol Version 6
ISO	International Organization for Standardization
ITU-T:	International Telecommunications Union for the Telecommunication Standardization Sector
JWG	Joint Working Report for Standards for the Smart Grids
KNX	EN 50090 (was Konnex)
L2TP	Layer 2 Tunneling Protocol
LR WPAN	Low Rate Wireless Personal Area Network
LTE	Long Term Evolution
MAC	Media Access Control
MPLS	Multiprotocol Label Switching
MPLS-TP	MPLS Transport Profile
NAN	Neighborhood Area Network
NAT	Network Address Translator
OSI:	Open System Interconnection
OTN	Optical Transport Network
PLC	Power Line Carrier
PLC	Power Line Communication
PON	Passive Optical Network
QoS	Quality of Service
RPL	Routing Protocol for Low power and lossy networks (LLN)
SDH	Synchronous Optical Networking
SDO	Standards Developing Organization
SG-CG	Smart Grids Coordination Group
SG-CG/FSS	SG-CG First Set of Standards Work Group
SG-CG/RA	SG-CG Reference Architecture Work Group
SG-CG/SP	SG-CG Sustainable Processes Work Group
SLA	Service Level Agreement
TDM	Time Division Multiplexing
TMF	TeleManagement Forum
TOGAF	The Open Group Architecture Framework
TSO	Transmission System Operator
UMTS	Universal Mobile Telecommunications System
WAN	Wide Area Network
WAMS	Wide Area Management Systems
WAN	Wide Area Network
WASA	Wide Area Situation Awareness
WPAN	Wireless Personal Area Network
xDSL	Digital Subscriber Line
XG-PON	10G PON

5 Executive Summary

The “SG-CG/M490/C_ Smart Grid Reference Architecture” report prepared by the Reference Architecture Working Group (SG-CG/RA) addresses the M/490 mandate deliverable regarding the development of a Technical Reference Architecture.

The Reference Architecture challenge

The CEN/CENELEC/ETSI Joint Working Group report on standards for smart grids has defined the context for the development of the Smart Grids Reference Architecture (RA):

> “It is reasonable to view [the Smart Grid] as an evolution of the current grid to take into account new requirements, to develop new applications and to integrate new state-of-the-art technologies, in particular Information and Communication Technologies (ICT). Integration of ICT into smart grids will provide extended applications management capabilities over an integrated secure, reliable and high-performance network.
>
> This will result in a new architecture with multiple stakeholders, multiple applications, multiple networks that need to interoperate: this can only be achieved if those who will develop the smart grid (and in particular its standards) can rely on an agreed set of models allowing description and prescription: these models are referred to in this paragraph as Reference Architecture.”

To develop a coherent and useful Reference Architecture, two main issues have been addressed:

- Clarification of the requirements for the reference architecture and description of its major elements. Reuse of existing results has been considered essential to a fast progress. In particular, the Reference Architecture elements are positioned with respect to existing models (e.g. NIST) and architectural frameworks (GWAC, TOGAF, etc.). Extensions have been limited and, in general, focused on addressing the European specificities.

- Coherence of the RA with respect to the overall Smart Grids standardization process. Notably, the work of SG-CG/RA has been aligned with the other SG-CG Work Groups.
  - Using upstream results of SG-CG/SP on (generic) use cases and the flexibility concept;
  - Providing results to SG-CG/FSS regarding the identification of useful standards and a method to support standards gap analysis;
  - Clarifying the alignment with SG-CG/SGIS regarding the representation of the Security viewpoint in the RA and providing a method to analyze Information Security use cases.

  In addition, alignment with existing initiatives from other organizations (e.g. NIST, ENTSO-E, EU Task Force Experts Groups …) has been a constant objective.

Main elements of the Reference Architecture

The main components of the Reference Architecture are now in place. The most important are described below.

<u>European Conceptual Model</u>
The National Institute of Standards and Technology (NIST) has introduced the Smart Grid Conceptual Model which provides a high-level framework for the Smart Grid that defines seven high-level domains and shows all the communications and energy/electricity flows connecting each domain and how they are interrelated.

Though the NIST model is a sound and recognized basis, it has been necessary to adapt it in order to take into account some specific requirements of the EU context that the NIST model did not address. Two main elements are introduced to create the EU Conceptual Model. The first one is the Distributed Energy Resource (DER) domain that allows addressing the very important role that

DER plays in the European objectives. The second one is the Flexibility concept (developed in SG-CG/SP) that group consumption, production and storage together in a flexibility entity.

The EU Conceptual Model is a top layer model (or master model) and will also act as a bridge between the underlying models in the different viewpoints of the Reference Architecture.

During the course of this first iteration of the M/490 mandate, a constant discussion has taken place with NIST SGIP/SGAC to ensure optimal alignment on the Conceptual Model. The model that is presented in the main part of the SG-CG/RA report is reflecting these discussions.

Smart Grids Architecture Model (SGAM) Framework

The SGAM Framework aims at offering a support for the design of smart grids use cases with an architectural approach allowing for a representation of interoperability viewpoints in a technology neutral manner, both for current implementation of the electrical grid and future implementations of the smart grid.

It is a three dimensional model that is merging the dimension of five *interoperability layers* (Business, Function, Information, Communication and Component) with the two dimensions of the Smart Grid Plane, i.e. *zones* (representing the hierarchical levels of power system management: Process, Field, Station, Operation, Enterprise and Market) and *domains* (covering the complete electrical energy conversion chain: Bulk Generation, Transmission, Distribution, DER and Customers Premises).

SGAM Methodology

This SGAM Framework can be used by the SGAM *Methodology* for assessing smart grid use cases and how they are supported by standards, thus allowing standards *gap analysis*. The model has largely evolved in v2.0, with clearer basic definitions, more detailed presentation of the elements (zones, domains, etc.), a clarification of the methodology and a complete detailed example.

Architecture Viewpoints

They represent a limited set of ways to represent abstractions of different stakeholders' views of a Smart Grid system. Four viewpoints have been selected by the SG-CG/RA: Business, Functional, Information and Communication, with associated architectures:

- The Business Architecture is addressed from a methodology point of view, in order to ensure that whatever market or business models are selected, the correct business services and underlying architectures are developed in a consistent and coherent way;
- The Functional Architecture provides a meta-model to describe functional architectures and gives an architectural overview of typical *functional groups* of Smart Grids (intended to support the high-level services that were addressed in the Smart Grids Task Force EG1);
- The Information Architecture addresses the notions of data modeling and interfaces and how they are applicable in the SGAM model. Furthermore, it introduces the concept of "*logical interfaces*" which is aimed at simplifying the development of interface specifications especially in case of multiple actors with relationships across domains;
- The Communication Architecture deals with communication aspects of the Smart Grid, considering generic Smart Grid use cases to derive requirements and to consider their adequacy to existing communications standards in order to identify communication standards gaps. It provides a set of recommendations for standardization work as well as a view of how profiling and interoperability specifications could be done.

How to use the Reference Architecture

Given the large span of the Reference Architecture components described above, the Reference Architecture can be used in a variety of ways, amongst which:

- Adaption of common models and meta-models to allow easier information sharing between different stakeholders in pre-standardization (e.g. research projects) and standardization;

* Analysis of Smart Grids use cases via the SGAM methodology. This is a way to support, via an easier analysis of different architectural alternatives, the work of those who are going to implement those use cases;
* Gap analysis: analysis of generic use cases in order to identify areas where appropriate standards are missing and should be developed in standardization;
* …

Outlook

The current version of the Reference Architecture document is the result of the work done by the SG-CG/RA Working Group during the first iteration of the M/490 Mandate.

The final version (v3.0) of this report addresses the comments made on v2.0 and clarifies some of the remaining issues, such as the handling of Security aspects in the Architecture and in SGAM, an (SG-CG) agreed functional meta-model, or the respective role of markets and business viewpoints.

However, there are still areas where the document can be completed such as a role-based definition of the European Conceptual Model (developed but still to be validated), expansion of the Functional Architecture, more in-depth exploration of the communication profiles, etc. This work could be addressed if the extension of the M/490 Mandate for a second iteration is decided.

6 Conceptual Model and Reference Architecture Principles

6.1 Motivation for Conceptual Model and Reference Architecture

Smart Grids standardization is not a green field. It is largely relying on previous work done at national, regional (in particular European) and international level, both on standardization (largely focused on the identification of the existing set of standards that are applicable to the Smart Grid) and on pilot and research project (that validate early ideas that may be brought to standardization).

The work of the Reference Architecture WG will, in particular, use significant existing material such as the NIST Conceptual Model [NIST 2009], the GridWise Architecture Council Stack interoperability categories [GWAC 2008], architecture standards like TOGAF and Archimate [Jonkers 2010].

The development of the SG-CG framework (as already noted above in section 5) addresses 'continuous standard enhancement and development in the field of Smart Grids, while maintaining transverse consistency and promote continuous innovation'.

To achieve consistency and gradual integration of innovation in an incremental manner, two elements are deemed essential, that are both addressed by the SG-CG/RA:

- An overall high-level model that describes the main actors of the Smart Grid and their main interactions. This is captured by the <u>Conceptual Model</u>. The approach taken by the SG-CG/RA, considering the need to reuse existing models whenever possible, has been to take into account the NIST Conceptual Model, analyze which differences a European approach would need to bring to it and further reduce these differences as much as possible;
- A set of universal presentation schema that allow for the presentation of the Smart Grid according to a variety of viewpoints that can cope with
    - The variety of Smart Grid stakeholders,
    - The need to combine power system management requirements with expanded interoperability requirements, and
    - The possibility to allow for various levels of description from the top-level down to more detailed views.

  This is captured in the <u>Reference Architecture</u> that should be seen as the aggregation of several architectures (e.g. functional, communication, etc.) into a common framework.

The motivation for the creation and utilization of reference architectures can be to have a blueprint for the development of future systems and components, providing the possibility to identify gaps in a product portfolio. It can also be used to structure a certain Smart Grid domain and provide a foundation for communication about it to other domains which need to interoperate. Furthermore, it can be used to document decisions which have been taken during the development process of an infrastructure.

An additional – and important - motivation for the SG-CG/RA was to ensure that the Reference architecture could help, by providing an appropriate <u>methodology</u> to identify where standardization gaps may exist.

It is also important to finally point out a very essential motivation for the Reference Architecture work: reuse as much of the existing work as possible and not re-invent the wheel. This has guided both the Conceptual Model (as noted above) as well as the Reference Architecture.

6.2 Requirements for the M/490 Reference Architecture

The reference architecture has to be very much in consistency with the following aspects and requirements already outlined in this report.

It must support the work of Smart Grids standardization over a long period of time:

- Be able to **represent the current situation** (snapshot of already installed basis and reference architectures)
- Be able to **map future concepts** (migration and gap analysis)
- Achieve a **common understanding of stakeholders**
- **Fulfill the demand for systematic coordination of Smart Grid standardization** from an **architectural perspective**
- **Provide a top-level perspective encompassing entire smart grid but enabling enlargements to details**
- Be able to be represented using established and state-of-the art System Engineering technology and methodologies (e.g. lifecycle model, architecture standards and methods)
- Take into account Standardization activities (regional, Europe, international)
- Be able to reflect European Pilot and research projects (regional, Europe, international)

More specifically, the Reference Architecture must be able to address the complexity of the Smart Grid in a coherent manner:

- Be **consistent with the M/490 conceptual model**;
- **Fulfill the need for an universal presentation schema – a model**, allowing to map stakeholder specific prospective in a common view
- Being able to **represent the views of different stakeholders (not only SDOs)** in an universal way , e.g. provide <u>some of</u> the following viewpoints in an abstract way:
    - **Enterprise** viewpoint,
    - **Information** viewpoint,
    - **Computational** viewpoint,
    - **Engineering** viewpoint,
    - **Technology** Viewpoint (RM-ODP, ISO/IEC 10746)
    - **Business Architecture** viewpoint,
    - **Application Architecture** viewpoint,
    - **Data Architecture** viewpoint,
    - **Technology Architecture** viewpoint
- Be **consistent with established interoperability categories and experiences**
- Provide an **abstract view on SG specific structures** (domains, zones, layers)
- **Fulfill the need for an universal presentation schema – a model**, allowing to map stakeholder specific prospective in a common view

6.3 Conceptual Model

This section will present the Conceptual Model practically unchanged since the draft version 2.0 of the Reference Architecture report.

Nevertheless, a lot of new work has been done within SG-CG/RA between TR2.0 and TR3.0 on the Conceptual Model, in order to better support the flexibility concept and to take into account the comments made on version 2.0. A new version of this section has been produced but it could not be introduced in the main section of the report because of the many uncommented changes. Consequently, it has been decided to present it as an informative reference in Annex C, section C.1. It is expected that this new section will be introduced in the subsequent versions of this report, should the new M/490 iteration be decided.

6.3.1 Introduction

The electrical energy system is currently undergoing a paradigm change, that has been affected by a change from the classical centralistic and top down energy production chain "Generation", "Transmission", "Distribution" and "Consumption" to a more decentralized system, in which the participants change their roles dynamically and interact cooperative. The development of the concepts and architectures for a European Smart Grid is not a simple task, because there are various concepts and architectures, representing individual stakeholders' viewpoints.

The National Institute of Standards and Technology (NIST) has introduced the Smart Grid Conceptual Model which provides a high-level framework for the Smart Grid that defines seven high-level domains (Bulk Generation, Transmission, Distribution, Customers, Operations, Markets and Service Providers) and shows all the communications and energy/electricity flows connecting each domain and how they are interrelated. Each individual domain is itself comprised of important smart grid elements (actors and applications) that are connected to each other through two-way communications and energy/electricity paths. The NIST Conceptual Model helps stakeholders to understand the building blocks of an end-to-end smart grid system, from Generation to (and from) Customers, and explores the interrelation between these smart grid segments.

In order to develop the different viewpoints in an aligned and consistent manner, the EU Conceptual Model is introduced. It is based on the NIST Model which is used with some customizations and extensions regarding the general European requirements. This EU Conceptual Model forms the top layer model or master model and it is therefore the bridge between models from different viewpoints. Its task is to form a bracket over all sub models.

6.3.2 Approach and Requirements

The electrical power grid in the European Union is based on a big number of heterogeneous participants; that are hierarchically and next to each other connected. Every participant of the electrical power grid builds and operates its part of the network in its own manner; and at the same time they have to work together. So the EU Conceptual Model has to deal with different levels of decentralization (see Figure 1). The figure shows still another effect. Regarding to the history of electrical power supply systems, the electrical power supply started more than a century ago with decentralized isolated networks and developed to an European centralized mixed network. With the beginning of the 21st century, more and more decentralized energy systems are coming into the network again, so future architectures will have to support both centralized and decentralized concepts. Consequently requirements for distributed and centralized concepts and applications need to be considered. . From this follows the requirement to the EU conceptual model to allow to model different levels of decentralization between the two extremes: “Fully Centralized Energy System” and “Fully Decentralized Energy System”.

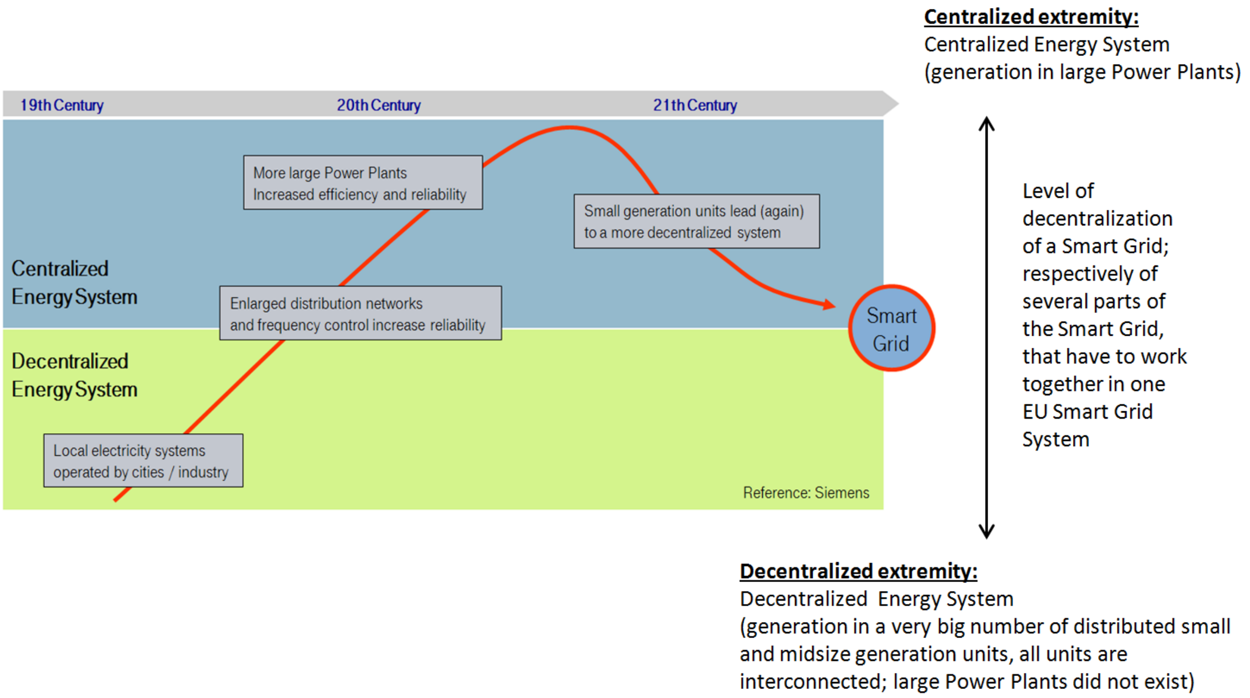

Figure 1: Different levels of decentralization

6.3.3 An EU extension of the NIST Model

To integrate the “Distributed Energy Resources” (DER) into the NIST Model, it will be extended by a new “Distributed Energy Resources” Domain, which is (in terms of electricity and communications) connected with the other NIST Domains shown in Figure 2.

The extension of the NIST Model with a new DER Domain is necessary for the following reasons:

- Distributed Energy Resources require a new class of use cases
- In order to comply to future anticipated regulation and legislation explicit distinction of Distributed Energy Resources will be required
- Distributed Energy Resources represent the current situation
- A consistent model requires clear criteria to separate the new DER Domain from the existing Domains, especially from Bulk Generation and the Customer Domain. Initial criteria are given in Table 1: Separation criteria for the DER-Domain.
    - “Control” The generation units in the Customer Domain can not be remote controlled by an operator. The generation units in the DER and Bulk Generation Domain are under control of an operator, (approximately comparably with the controllability of bulk generation units today).
    - “Connection point”. The generation units in the bulk generation domain are predominantly connected to the high voltage level. The generation units in the DER Domain are predominantly connected to the medium voltage level (in some cases also to the low voltage level) and the generation units in the customer domain to the low voltage level.

Table 1: Separation criteria for the DER-Domain

Criteria / Domain	Bulk Generation	Distributed Energy Resources	Consumer
Control	Direct	direct	indirect
Connection Point	high voltage	medium voltage / low voltage	low voltage

One can uniquely model the two extremes as shown in Figure 1 (“Centralized Energy System” and “Decentralized Energy System”) and the space between them as follows:

- “Fully Centralized Energy System”
  At the extreme point of “Centralized Energy System”, no distributed energy resources exist and “Distributed Energy Resources” Domain is not needed.

- “Fully Decentralized Energy System”
  At the extreme point of “Decentralized Energy System”, no bulk generation systems exist and the “Bulk Generation” Domain is not needed. The power generation is realized by a large number of distributed and interconnected power generation units. The generation power of the distributed generation units are aggregated by the distribution network to the transmission network. Areas with power reserve can supply areas with power demand. Due to the constantly changing weather situation over Europe the mix of the regions will permanently change.

- A level of decentralization between both turning points.
  This case will correspond to reality, which shows that the trend here is towards an increasing degree of decentralization. Furthermore, it is assumed that both extreme positions will not be reached, they are only theoretical. The mixture of ‘bulk generation’ and ‘distributed energy generation’ (which includes a significant proportion of volatile energy generating units) will effect an increase of volatility in the operation of classical generating units. This is primarily the case in countries, where legislations determine the feed-in of energy from renewable sources.

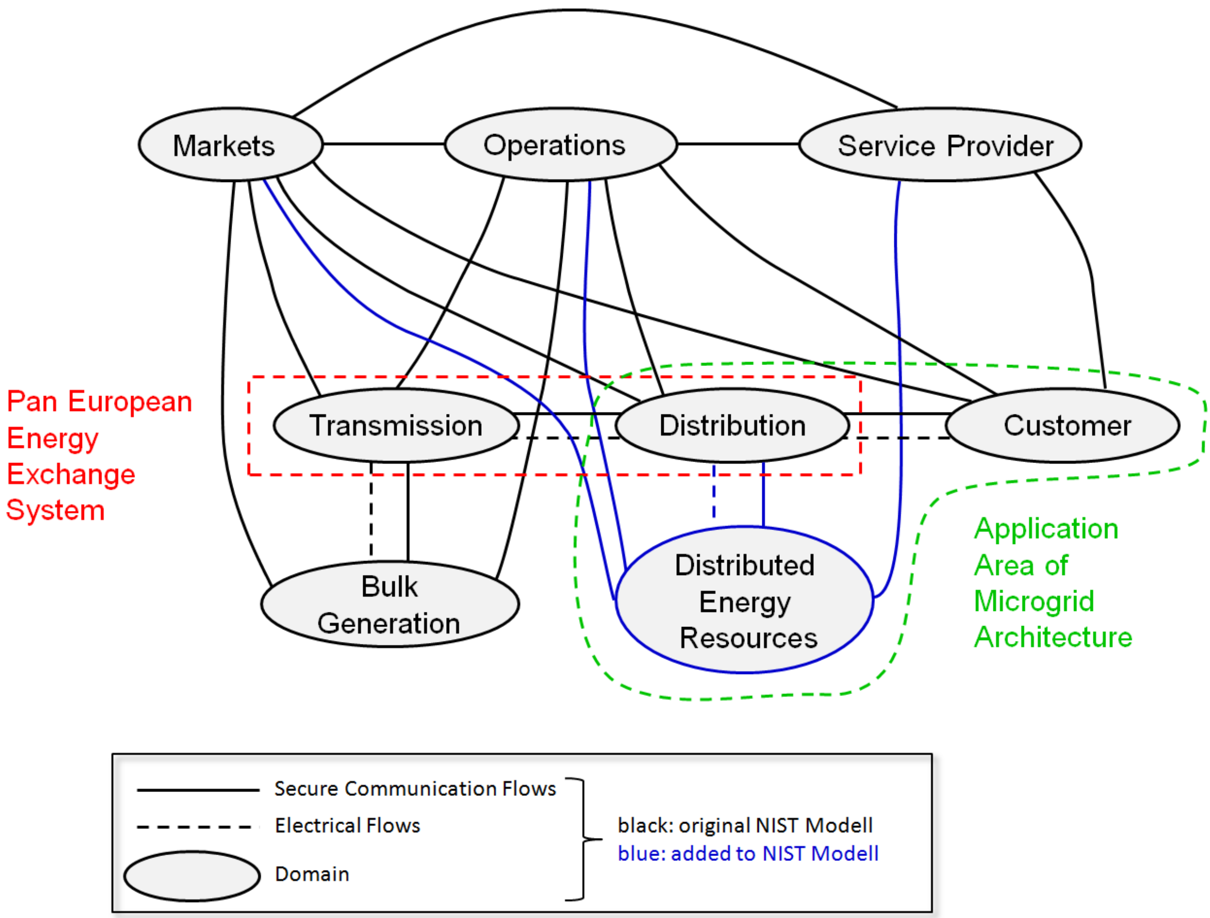

Figure 2: EU extension of the NIST Model

Figure 2 also defines the scope of PAN European Energy Exchange System and application area of a microgrid architecture:

- The application area of the hierarchical mesh cell architectures (microgrids) includes the Customer, Distribution, and Distributed Energy Resources domains. One objective is to find a balance between production and consumption as locally as possible in order to avoid transmission losses and increase transmission reliability through ancillary services such as reserves volt/var support, and frequency support .For other objectives for microgrids see also use case WGSP-0400 The Pan European Energy Exchange System (PEEES), which includes technologies in the transport network for low-loss wide-area power transmission systems (e. g. high-voltage direct current transmission, HVDC), better realizing the large-scale energy balance between the regions, which is essential due to the constantly changing weather situation, which has a significant influence on the power generation capacity of different regions.
  In version 3.0 examples of microgrids and a PAN European Energy Exchange System will be given.

One should not forget that the customer domain in a Smart Grid has the ability to control their energy consumption within certain limits. In the future, the smart grid will have two adjustment possibilities: generation and power consumption (load)) and a large number of new degrees of freedom to control the power balance (frequency stability).

6.3.4 The Flexibility Concept

As a result of ongoing work in the M490 Working Groups (SG-CG/RA and SG-CG/SP), the flexibility concept has been introduced and is discussed. In this model, consumption, production and storage are grouped together in a flexibility entity (next to the entities Grid, and Markets). It is believed that this concept creates much more the required flexibility to support future demand response use cases then the more rigid classification given in table 1. In version 3.0 of this document the existing conceptual model will be re-represented in a way that it supports the flexibility concept and also that it enables maximum re-use of results and standards derived from the existing conceptual model.

Initial ideas on this are given in table 2 below.

Table 2 (for further study)

CM Domains/Flexibility entities	Market	Grids	Flexibility
Markets	+		
Bulk Generation			+
DER			+
Customer			+
Transmission		+	
Distribution		+	
Operations	+	+	+
Service Provider	+	+	+

6.3.5 Conclusion

The EU Conceptual Model corresponds for the most part with the NIST Model and extends it with a new DER Domain to fulfill the specific European requirements. It is a future-oriented model, because it allows the description of a totally centralized grid, a totally decentralized grid and a mixture between both extreme points on a defined level. The application area of the hierarchical mesh cell architectures will allow in future the description of microgrid architecture and local energy management systems, that are integrated in the future European Smart Grid system.

6.4 Reference Architecture Viewpoints

The report of the Joint Working Group (JWG) for Standards for the Smart Grids [JWG-SG 2011] had outlined some of the potential viewpoints that the work of M/490 might have to deal with:

- Conceptual Architecture. A high-level presentation of the major stakeholders or the major (business) domains in the system and their interactions.
- Functional Architecture. An arrangement of functions and their sub-functions and interfaces (internal and external) that defines the execution sequencing, the conditions for control or data flow, and the performance requirements to satisfy the requirements baseline. (IEEE 1220)
- Communication Architecture. A specialization of the former focusing on connectivity.
- Information Security Architecture. A detailed description of all aspects of the system that relate to information security, along with a set of principles to guide the design. A security architecture describes how the system is put together to satisfy the security requirements.
- Information Architecture. An abstract but formal representation of entities including their properties, relationships and the operations that can be performed on them.

As such, these viewpoints could be very much targeting the Information and Communication Technology (ICT) aspects of the Smart Grid. However, this aspect – though an essential element of the Smart Grid – cannot be seen in isolation of the other essential aspect of the Smart Grid: the Power Technology. The choice of the appropriate viewpoints and their level of granularity are therefore very important. This is addressed by the section below.

Considering the JWG recommendations and the requirements defined in section 6.2, the following viewpoints have been selected as the most appropriate to represent the different aspects of Smart Grids systems:

- Business Architecture
- Functional Architecture
- Information Architecture
- Communication Architecture

The ‘Information Security Architecture’ listed in the JWG list above has been handled separately from the SG-CG/RA work by the SG-CG/SGIS. However, alignment of work of both WGs is deemed essential. At this stage, first elements of this alignment can be found in 7.2.7.

7 The Smart Grid Architecture Model (SGAM) Framework

7.1 Interoperability in the context of the Smart Grid

7.1.1 General

Interoperability is seen as the key enabler of smart grid. Consequently the proposed SGAM framework needs to inherently address interoperability. For the understanding on interoperability in the context of smart grid and architectural models, a definition and requirements for achieving interoperability are given.

7.1.2 Definition

A prominent definition describes interoperability as the ability of two or more devices from the same vendor, or different vendors, to exchange information and use that information for correct co-operation [IEC61850-2010].
In other words, two or more systems (devices or components) are interoperable, if the two or more systems are able to perform cooperatively a specific function by using information which is exchanged. This concept is illustrated in Figure 3.

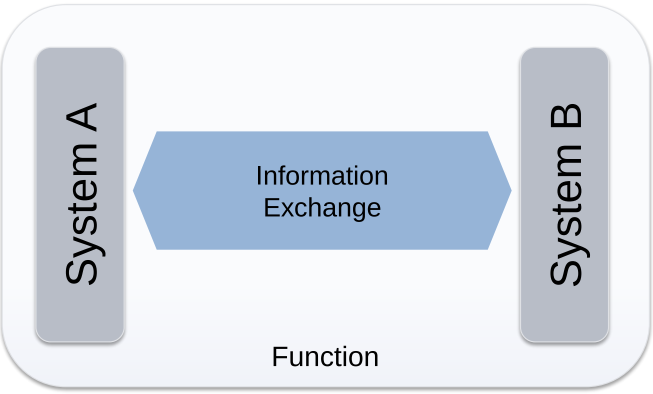

Figure 3: Definition of interoperability – interoperable systems performing a function

Being formulated in a general way, the definition is valid to the entire smart grid.

7.1.3 Interoperability Categories

The interoperability categories introduced by the GridWise Architecture Council [GWAC2008] represent a widely accepted methodology to describe requirements to achieve interoperability between systems or components (Figure 4).

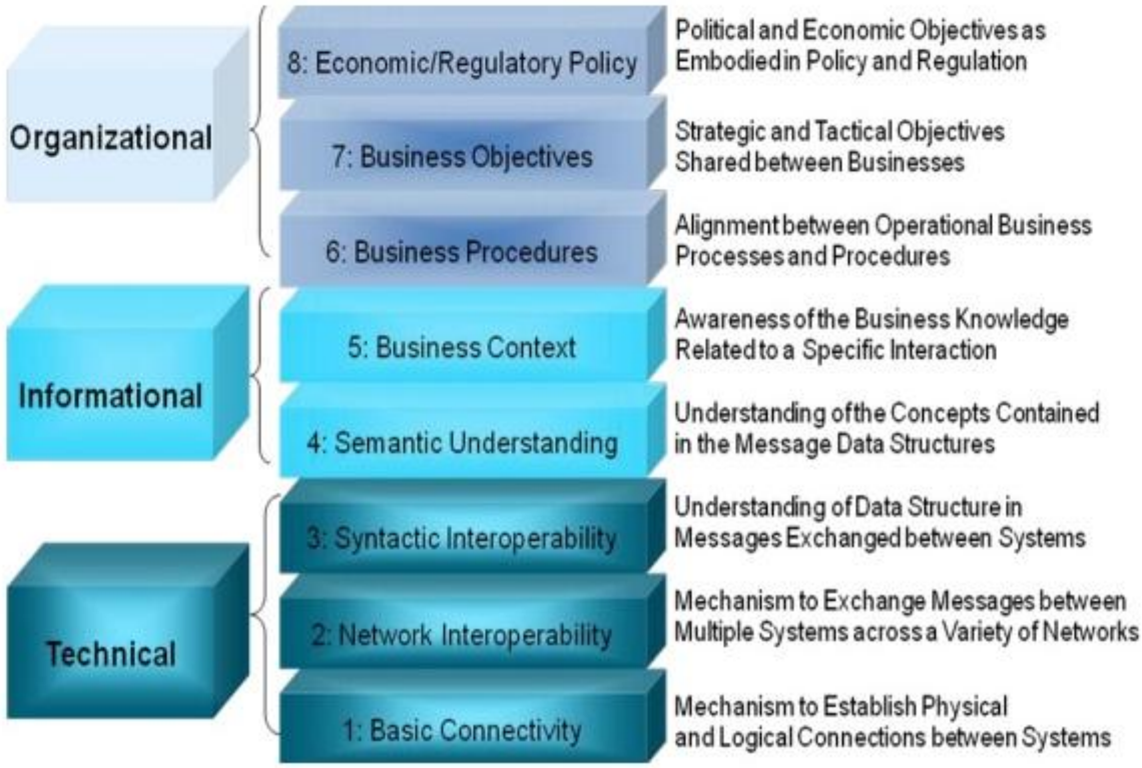

Figure 4: Interoperability Categories defined by GWAC [GWAC2008]

The individual categories are divided among the three drivers “Technical”, “Informational” and “Organizational”. These interoperability categories underline the definition of interoperability in the previous section 7.1.2. Hence for the realization of an interoperable function, all categories have to be covered, by means of standards or specifications.

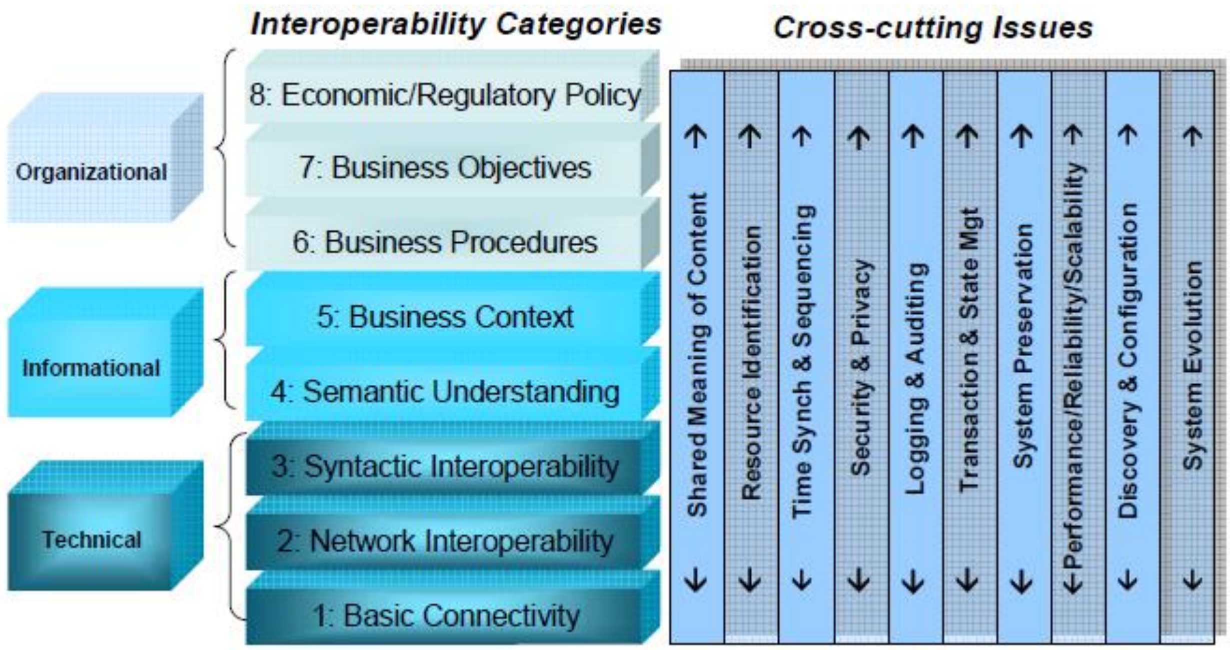

Figure 5: Interoperability Categories and Cross-Cutting Issues [GWAC2008]

Cross-cutting issues are topics which need to be considered and agreed on when achieving interoperability [GWAC 2008]. These topics may affect several or all categories to some extent. Typical cross-cutting issues are cyber security, engineering, configuration, energy efficiency, performance and others.

7.2 SGAM Framework Elements

7.2.1 General

The SGAM framework and its methodology are intended to present the design of smart grid use cases in an architectural viewpoint allowing it both- specific but also neutral regarding solution and technology. In accordance to the present scope of the M/490 program, the SGAM framework allows the validation of smart grid use cases and their support by standards.

The SGAM framework consists of five layers representing business objectives and processes, functions, information exchange and models, communication protocols and components. These five layers represent an abstract and condensed version of the interoperability categories introduced in section 7.1.3. Each layer covers the smart grid plane, which is spanned by electrical domains and information management zones (section 7.2.3). The intention of this model is to represent on which zones of information management interactions between domains take place. It allows the presentation of the current state of implementations in the electrical grid, but furthermore to depict the evolution to future smart grid scenarios by supporting the principles universality, localization, consistency, flexibility and interoperability.

7.2.2 SGAM Interoperability Layers

In order to allow a clear presentation and simple handling of the architecture model, the interoperability categories described in section 7.1.3 are aggregated into five abstract interoperability layers (refer to Figure 6). However in case of a detailed analysis of interoperability aspects, the abstraction can be unfolded.

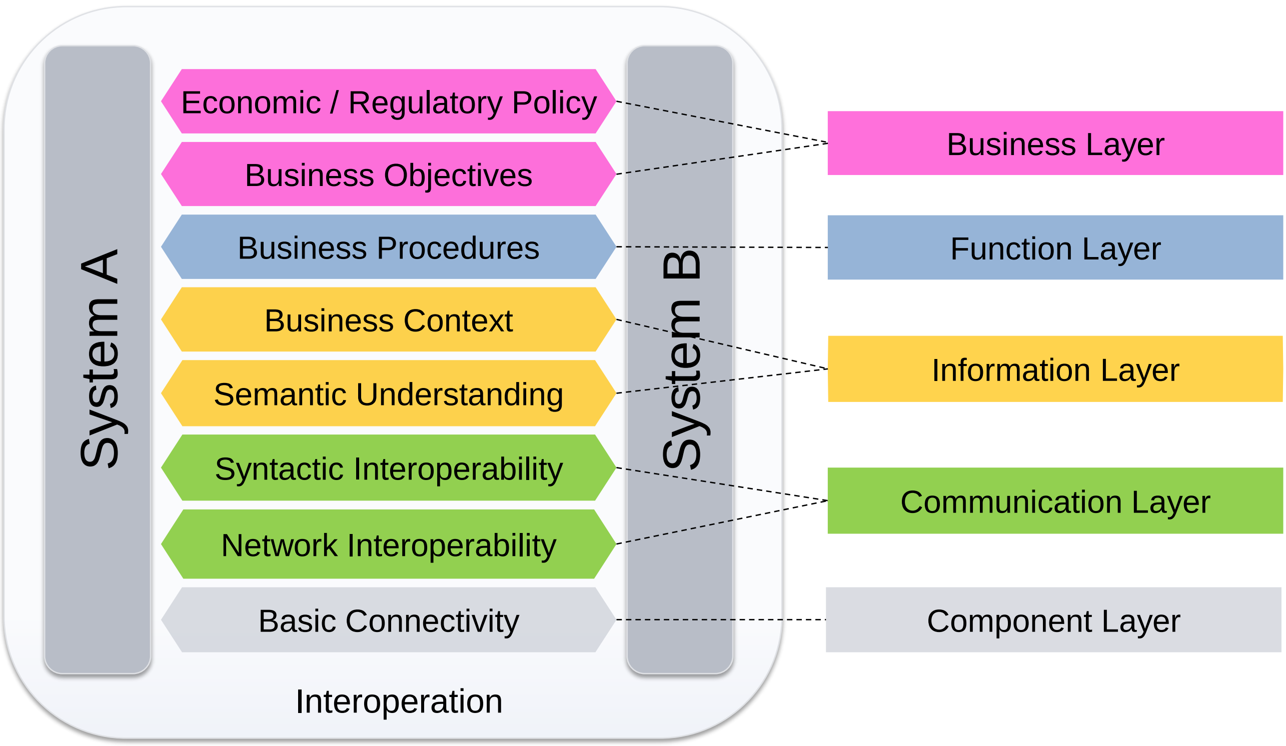

Figure 6: Grouping into interoperability layers

7.2.2.1 Business Layer

The business layer represents the business view on the information exchange related to smart grids. SGAM can be used to map regulatory and economic (market) structures and policies, business models, business portfolios (products & services) of market parties involved. Also business capabilities and business processes can be represented in this layer. In this way it supports business executives in decision making related to (new) business models and specific business projects (business case) as well as regulators in defining new market models. The Business layer is addressed in more detail in paragraph 8.1.

7.2.2.2 Function Layer

The function layer describes functions and services including their relationships from an architectural viewpoint. The functions are represented independent from actors and physical implementations in applications, systems and components. The functions are derived by extracting the use case functionality which is independent from actors.

7.2.2.3 Information Layer

The information layer describes the information that is being used and exchanged between functions, services and components. It contains information objects and the underlying canonical data models. These information objects and canonical data models represent the common semantics for functions and services in order to allow an interoperable information exchange via communication means.

7.2.2.4 Communication Layer

The emphasis of the communication layer is to describe protocols and mechanisms for the interoperable exchange of information between components in the context of the underlying use case, function or service and related information objects or data models.

7.2.2.5 Component Layer

The emphasis of the component layer is the physical distribution of all participating components in the smart grid context. This includes system actors, applications, power system equipment (typically located at process and field level), protection and tele-control devices, network infrastructure (wired / wireless communication connections, routers, switches, servers) and any kind of computers.

7.2.3 SGAM - Smart Grid Plane

In general power system management distinguishes between electrical process and information management viewpoints. These viewpoints can be partitioned into the physical domains of the electrical energy conversion chain and the hierarchical zones (or levels) for the management of the electrical process (refer to [IEC62357-2011, IEC 62264-2003]). Applying this concept to the smart grid conceptual model introduced in section 6.3 allows the foundation of the *Smart Grid Plane* (see Figure 7.). This smart grid plane enables the representation on which levels (hierarchical zones) of power system management interactions between domains take place.

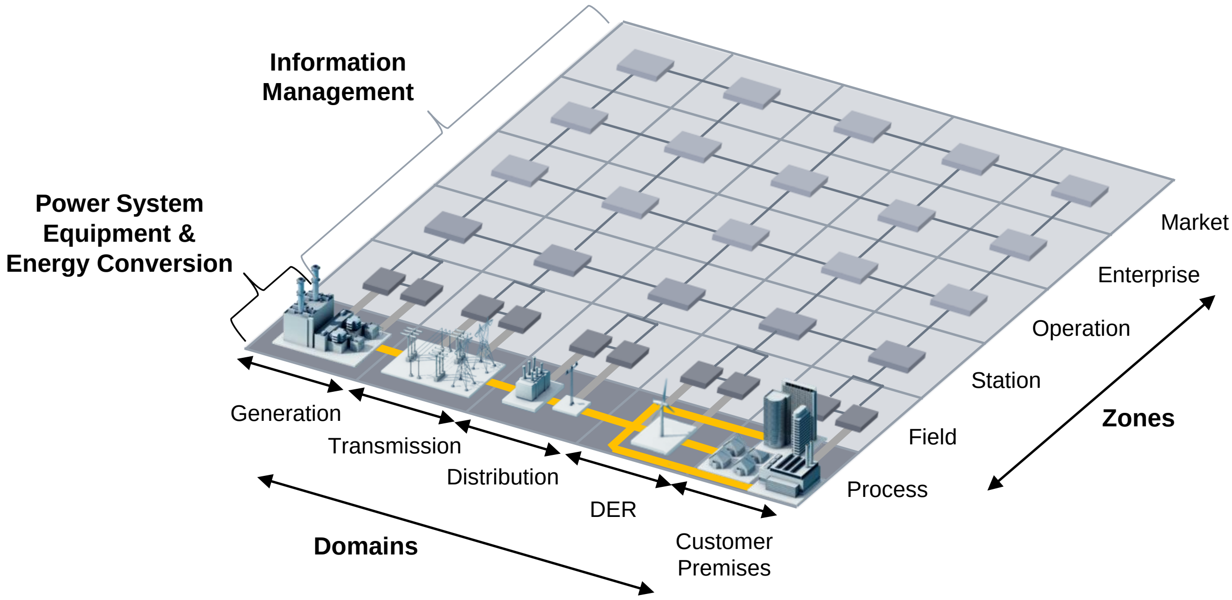

Figure 7: Smart Grid plane - domains and hierarchical zones

According to this concept those domains, which are physically related to the electrical grid (Bulk Generation, Transmission, Distribution, DER, Customer Premises) are arranged according to the electrical energy conversion chain. The conceptual domains Operations and Market are part of the information management and represent specific hierarchical zones. The conceptual domain Service Provider represents a group of actors which has universal role in the context of smart grid. This means that a Service Provider can be located at any segment of the smart grid plane according to the role he has in a specific case.

7.2.4 SGAM Domains

The *Smart Grid Plane* covers the complete electrical energy conversion chain. This includes the domains listed in Table 2:

Table 2: SGAM Domains

Domain	Description
Bulk Generation	Representing generation of electrical energy in bulk quantities, such as by fossil, nuclear and hydro power plants, off-shore wind farms, large scale solar power plant (i.e. PV, CSP)– typically connected to the transmission system
Transmission	Representing the infrastructure and organization which transports electricity over long distances
Distribution	Representing the infrastructure and organization which distributes electricity to customers
DER	Representing distributed electrical resources directly connected to the public distribution grid, applying small-scale power generation technologies (typically in the range of 3 kW to 10.000 kW). These distributed electrical resources may be directly controlled by DSO
Customer Premises	Hosting both - end users of electricity, also producers of electricity. The premises include industrial, commercial and home facilities (e.g. chemical plants, airports, harbors, shopping centers, homes). Also generation in form of e.g. photovoltaic generation, electric vehicles storage, batteries, micro turbines… are hosted

7.2.5 SGAM Zones

The SGAM zones represent the hierarchical levels of power system management [IEC62357-2011]. These zones reflect a hierarchical model which considers the concept of aggregation and functional separation in power system management. The basic idea of this hierarchical model is laid down in the Purdue Reference Model for computer-integrated manufacturing which was adopted by IEC 62264-1 standard for "enterprise-control system integration" [IEC 62264-2003]. This model was also applied to power system management. This is described in IEC 62357 "Reference architecture for object models services" [IEC 62357-2003, IEC 62357-1-2012].

The concept of aggregation considers multiple aspects in power system management:

- Data aggregation – data from the field zone is usually aggregated or concentrated in the station zone in order to reduce the amount of data to be communicated and processed in the operation zone
- Spatial aggregation – from distinct location to wider area (e.g. HV/MV power system equipment is usually arranged in bays, several bays form a substation; multiple DER form a plant station, DER meters in customer premises are aggregated by concentrators for a neighborhood)

In addition to aggregation the partitioning in zones follows the concept of functional separation. Different functions are assigned to specific zones. The reason for this assignment is typically the specific nature of functions, but also considering user philosophies. Real-time functions are typically in the field and station zone (metering, protection, phasor-measurement, automation…). Functions which cover an area, multiple substations or plants, city districts are usually located in operation zone (e.g. wide area monitoring, generation scheduling, load management, balancing, area power system supervision and control, meter data management…).
The SGAM zones are described in Table 3.

Table 3: SGAM Zones

Zone	Description
Process	Including the physical, chemical or spatial transformations of energy (electricity, solar, heat, water, wind …) and the physical equipment directly involved. (e.g. generators, transformers, circuit breakers, overhead lines, cables, electrical loads any kind of sensors and actuators which are part or directly connected to the process,…).
Field	Including equipment to protect, control and monitor the process of the power system, e.g. protection relays, bay controller, any kind of intelligent electronic devices which acquire and use process data from the power system.
Station	Representing the areal aggregation level for field level, e.g. for data concentration, functional aggregation, substation automation, local SCADA systems, plant supervision…
Operation	Hosting power system control operation in the respective domain, e.g. distribution management systems (DMS), energy management systems (EMS) in generation and transmission systems, microgrid management systems, virtual power plant management systems (aggregating several DER), electric vehicle (EV) fleet charging management systems.
Enterprise	Includes commercial and organizational processes, services and infrastructures for enterprises (utilities, service providers, energy traders …), e.g. asset management, logistics, work force management, staff training, customer relation management, billing and procurement…
Market	Reflecting the market operations possible along the energy conversion chain, e.g. energy trading, mass market, retail market..

In general organizations can have actors in several domains and zones. In the smart grid plane the areas of the activity of these actors can be shown. E.g. according to the business area of a transmission utility it is likely that the utility covers all segments of the transmission domain, from process to market.

A service provider offering weather forecast information for distribution system operators and DER operators could be located to the market zone interacting with the operation zone in the distribution and DER domain.

7.2.6 SGAM Framework

The SGAM framework is established by merging the concept of the interoperability layers defined in section 7.2.2 with the previous introduced smart grid plane. This merge results in a model (see Figure 8) which spans three dimensions:

- Domain
- Interoperability (Layer)
- Zone

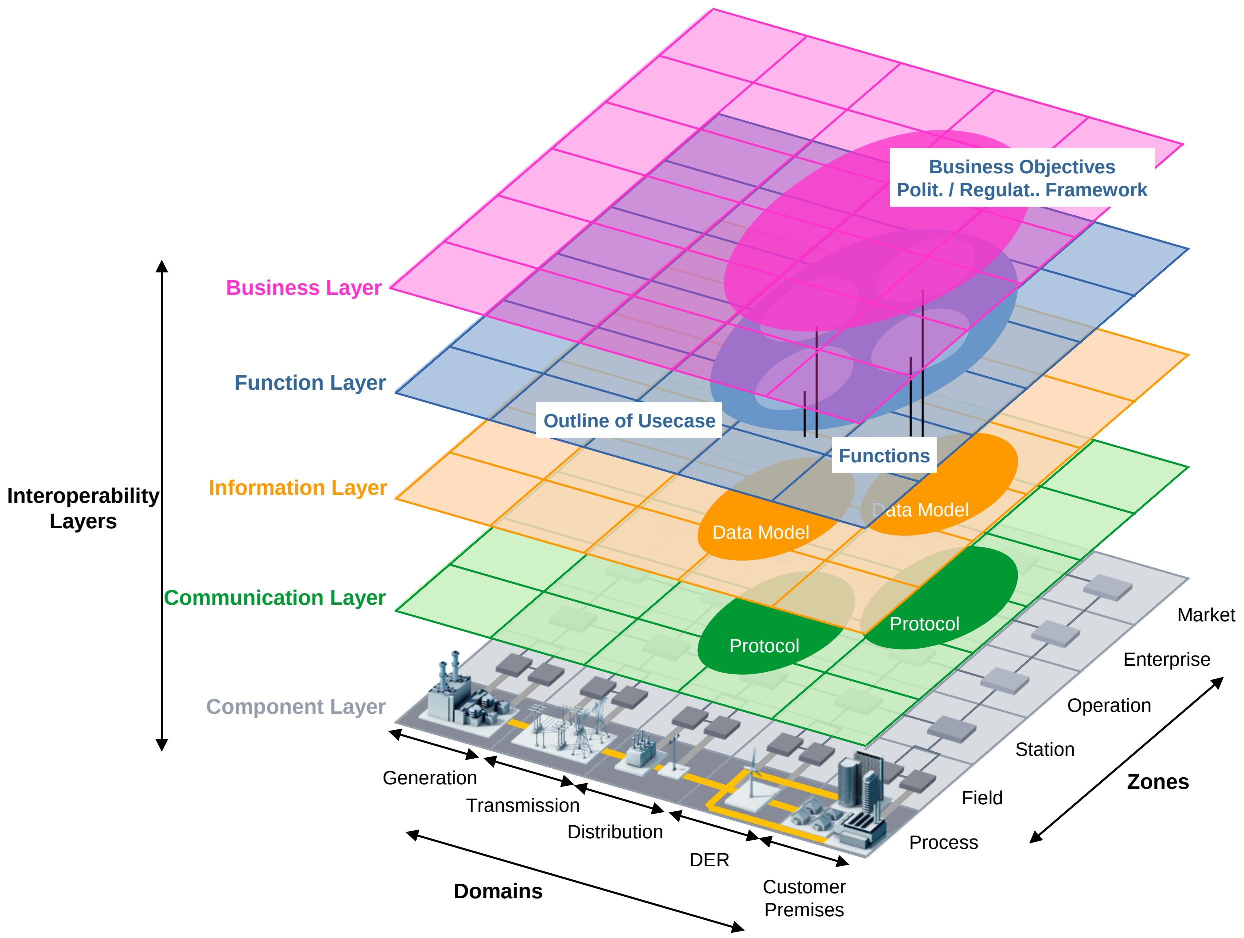

Figure 8: SGAM framework

Consisting of the five interoperability layers the SGAM framework allows the representation of entities and their relationships in the context of smart grid domains, information management hierarchies and in consideration of interoperability aspects.

7.2.7 Cross-cutting Issues and SGAM

7.2.7.1 Application to SGAM interoperability layers

According to the adopting of the concept of interoperability categories, which was introduced in section 7.1.3, cross-cutting issues apply in the same manner to the abstract interoperability layers. Figure 9 shows the relation of cross-cutting issues to the five abstracted interoperability layers.

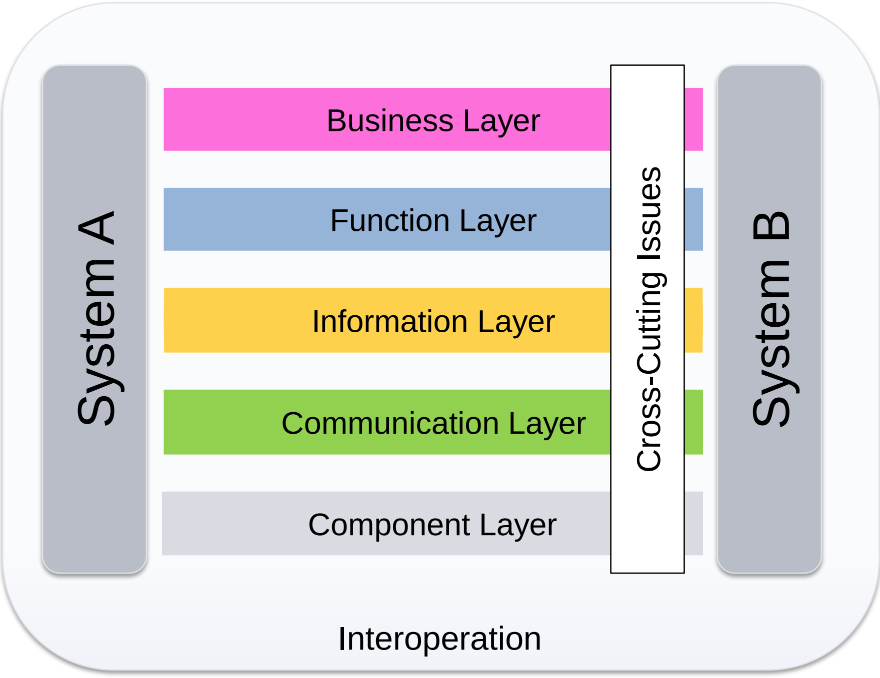

Figure 9: Interoperability layers and cross-cutting issues

Figure 10 depicts the impact of crosscutting issues to the individual interoperability layers from the overall SGAM framework prospective.

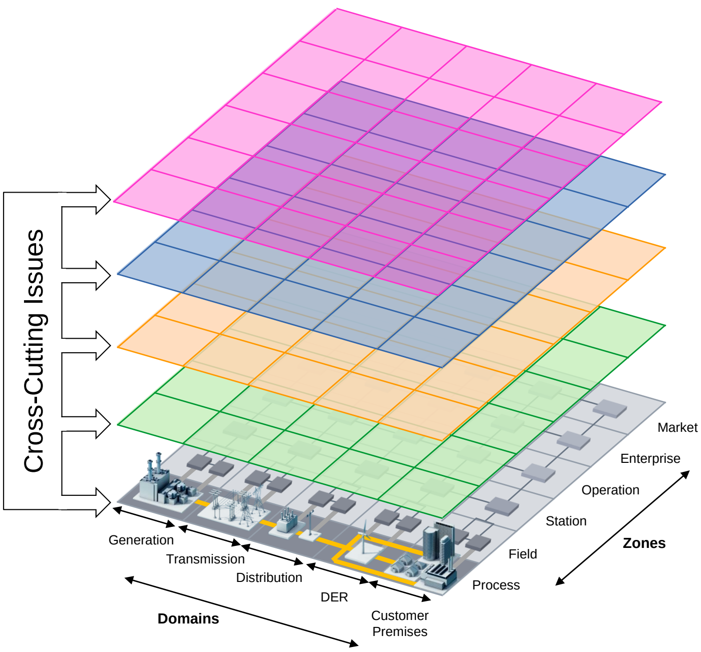

Figure 10: Impact of cross-cutting issues on SGAM interoperability layers

7.2.7.2 Example cyber security

Information Security in Smart Grid is an integral part of the Reference Architecture. The incorporation of the security aspects is the task of the Smart Grid Information Security Work Group (SG-CG/SGIS) investigating into existing security standards and their feasibility in a smart grid environment. A commonly agreed view of SG-CG/RA and SG-CG/SGIS is that security is a consistent process and has to be addressed upfront, both from a functional and non functional perspective.

The question has been addressed in two angles:

- How to benefit from the SGAM Methodology to address Security Use Cases
- How to represent the Information Security viewpoint within SGAM.

Regarding the first question, the SGAM Methodology based on a Use Case analysis as depicted in Figure 12 can be directly used for dedicated security functions. Security specific interactions can be shown on different SGAM layers showing the involved entities, their functional interface in terms of protocols and information models and also the relating business case. This has been shown on the example of Role-based Access Control, where SGAM allowed depicting the security specifics on each layer.

Regarding the representation of security within SGAM, it has been discussed (between SG-CG/RA and SG-CG/SGIS) to provide a “security view per layer” emphasizing that security is a cross functional topic, which has to be obeyed in each of the SGAM layers and has been depicted in that way by the SG-CG/SGIS. This can even more underlined as security is actually to be obeyed per layer, per domain, and per zone and thus basically per SGAM cell. To allow for the consideration of security aspects in that detail the SG-CG/SGIS has provided a toolbox, supporting the analysis and determination of security risks on a per use case base, following the SGAM methodology.

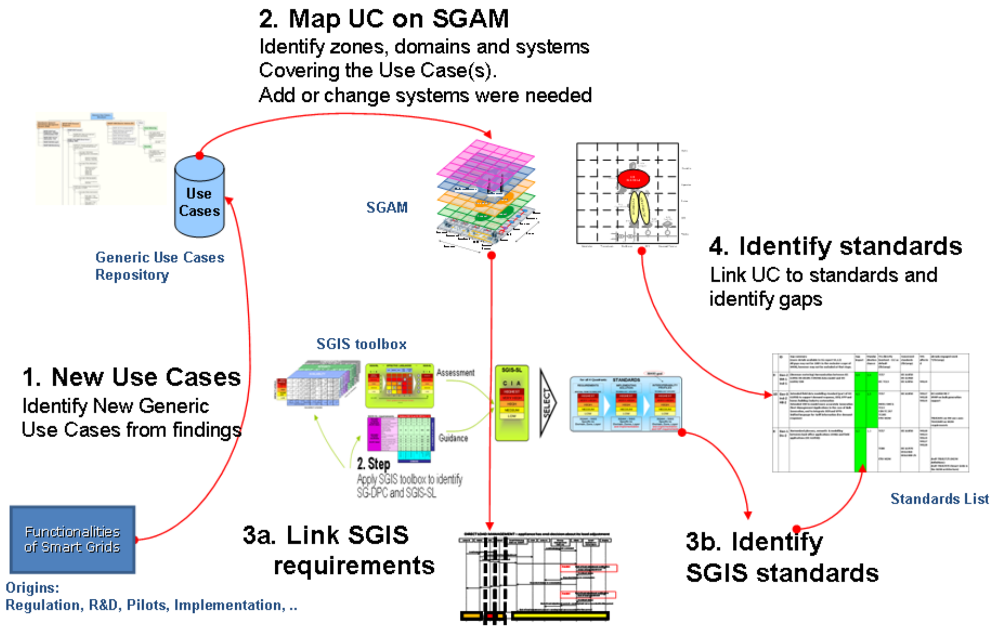

Figure 11: Using the SGIS Toolbox

Moreover, using the toolbox allows identifying available standards, applicable in dedicated use cases and also to identify gaps, for which further work is has to be done. This approach completes the SGAM methodology with inherent security considerations.

7.3 The SGAM methodology

7.3.1 General

This section introduces the methodology of the SGAM framework. It is intended to provide users an understanding on its principles and a guideline how to use the SGAM framework.

7.3.2 Principles

The definition of the principles of the SGAM is essential in order to leverage its capabilities for the universal representation of smart grid architectures. In the following the SGAM principles universality, localization, consistency, flexibility, scalability, extensibility and interoperability are described.

7.3.2.1 Universality

The SGAM is intended as a model to represent smart grid architectures in a common and neutral view. For the M/490 objectives it is essential to provide a solution and technology agnostic model, which also gives no preferences to existing architectures.

7.3.2.2 Localization

The fundamental idea of the SGAM is to place entities to the appropriate location in the smart grid plane and layer respectively. With this principle an entity and its relation to other entities can be clearly represented in a comprehensive and systematic view. E.g. a given smart grid use case can be described from an architectural viewpoint. This includes its entities (business processes, functions, information exchange, data objects, protocols, components) in affected and appropriate domains, zones and layers.

7.3.2.3 Consistency

A consistent mapping of a given use case or function means that all SGAM layers are covered with an appropriate entity. If a layer remains open, this implies that there is no specification (data model, protocol) or component available to support the use case or function. This inconsistency shows that there is the need for specification or standard in order to realize the given use case or function. When all five layers are consistently covered, the use case or function can be implemented with the given specifications / standards and components.

7.3.2.4 Flexibility

In order to allow alternative designs and implementations of use cases, functions or services, the principle of flexibility can be applied to any layer of SGAM. This principle is essential to enable future mappings as smart grid use cases, functions and services evolve. Furthermore the principle of flexibility allows to map extensibility, scalability and upgradability of a given smart grid architecture.

Flexibility includes the following methods:

- Use cases, functions or services are in general independent of the zone. E.g. a centralized Distribution Management System (DMS) function can be placed in operation zone; a distributed DMS function can be placed in field zone.
- Functions or services can be nested in different components case by case.
- A given use case, function or service can be mapped to information and communication layer in many different ways in order to address specific functional and non-functional requirements. E.g. the information exchange between control centers and substations can be realized with IEC 61850 over IP networks or with IEC 60870-5-101 over SDH (Synchronous Digital Hierarchy) communication networks.

7.3.2.5 Scalability

The SGAM encompasses the entire smart grid from a top level view. An enlargement to specific domains and zones is possible in order to detail given use cases, functions and services. E.g. the SGAM could be scaled and detailed focusing on microgrid scenarios only.

7.3.2.6 Extensibility

The SGAM reflects domains and zones of organizations which are seen from the current state. In the evolution of the smart grid there might be a need to extend the SGAM by adding new domains and zones.

7.3.2.7 Interoperability

Picking up the GWAC Stack methodology [GWAC2008], the SGAM represents a kind of a three-dimensional, abstract aggregation of the GWAC Stack interoperability categories to the smart grid plane. By doing this, the interaction between actors, applications, systems and components (component layer) is indicated by their connections or associations via information exchange and data models (information layer), protocols (communication layer) ,function or service (function layer) and business constraints (business layer). Generally the connection between entities (components, protocols, data models) is established by interfaces. In other words the consistency of an interoperable interaction can be represented by a consistent chain of entities, interfaces and connections in the *SGAM* layers.

The principles of *Consistency* and *Interoperability* constitute the coherency of the SGAM. Consistency ensures that the five layers are unambiguously linked; interoperability ensures that the conditions for interaction (interfaces, specifications, standards) are met within each layer. Both principles need to be fulfilled for a given use case, function or service to be realized.

7.3.3 Mapping of use cases to SGAM framework

This section describes the basic process to map use cases to the SGAM framework. A detailed example can be found in annex B.2.4.

The mapping process can be applied to the following tasks, which are considered relevant for the present mandate M/490:

- Mapping of use cases in order to validate the support by standards
- Identifying gaps in respect to standards
- Mapping of existing architectures into a general view
- Developing smart grid architectures.

On overview of the process and its steps is depicted in Figure 12.

Depending on the task the process can be carried out iteratively.

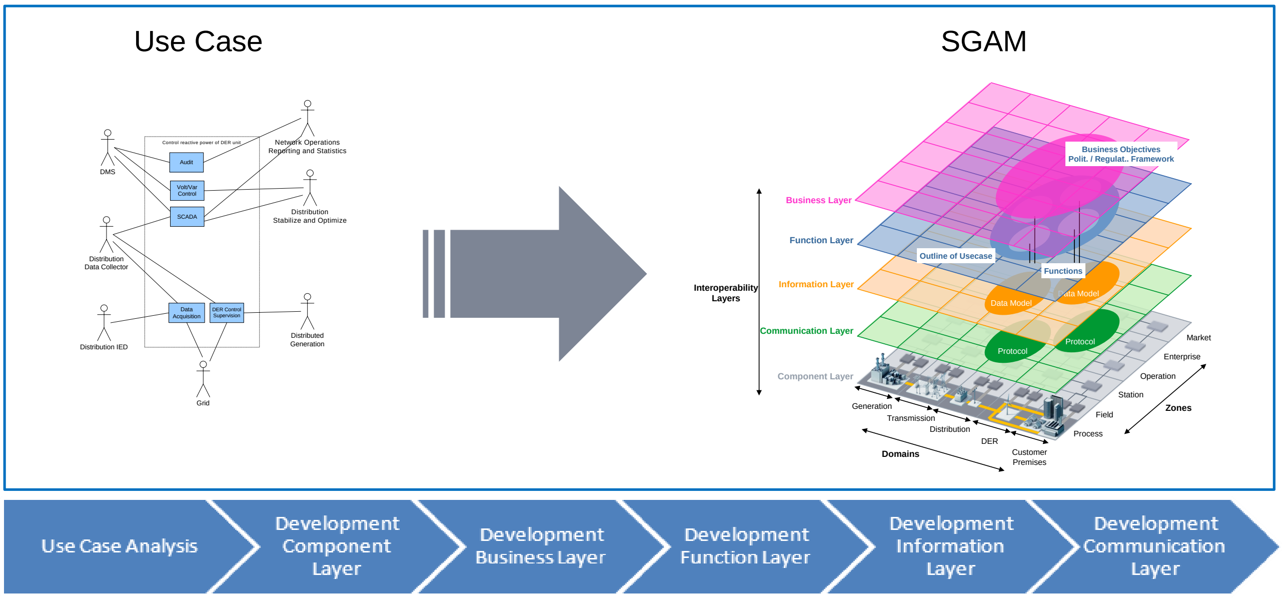

Figure 12: Use case mapping process to SGAM

7.3.3.1 Use Case Analysis

The starting point is an analysis of the use case to be mapped. It needs to be verified that a use case description provides the sufficient information which is necessary for the mapping. This information includes:

- Name, scope and objective
- Use case diagram
- Actor names, types
- Preconditions, assumptions, post conditions
- Use case steps
- Information which is exchanged among actors
- Functional and non-functional requirements.

The use case template considered by M/490 Sustainable Process WG provides the required information.
It is crucial that hard constraints are identified from a use case description. These constraints may have impact on the sequence of steps carried out for the mapping process.

7.3.3.2 Development of the Component Layer

The content of the component layer is derived from the use case information on actors. As actors can be of type devices, applications, persons and organizations, these can be associated to domains relevant for the underlying use case. In the same manner the hierarchical zones can be identified indicating where individual actors reside.

7.3.3.3 Development of the Business Layer

The business layer is intended to host the business processes, services and organizations which are linked to the use case to be mapped. This includes also the business objectives, economic and regulatory constraints underlying to the use case. These business entities are located to the appropriate domain and zone.

7.3.3.4 Development of the Function Layer

The function layer is intended to represent functions and their interrelations in respect to domains and zones. Functions are derived from the use case by extracting its functionality. Typically a use case consists of several sub use cases with specific relationships. These sub use case can be transformed to functions when formulating them in an abstract and actor independent way.

7.3.3.5 Development of the Information Layer

The information layer describes the information that is being used and exchanged between functions, services and components. The information objects which are exchanged between actors are derived from the use case description in form of use case steps and sequence diagrams. Underlying canonical data models are identified by analysis of available standards if these provide support for the exchanged information objects. Information objects and canonical data models are located to the appropriate domain and zone being used.

7.3.3.6 Development of the Communication Layer

The emphasis of the communication layer is to describe protocols and mechanisms for the interoperable exchange of information between the use case actors. Appropriate protocols and mechanisms are identified on the basis of the information objects and canonical data models and by consideration of non-functional requirements of the use case. Protocols and mechanisms are located to the appropriate domain and zone being used.

7.3.4 Mapping the business layer with the lower SGAM layers

This is a crucial phase of the methodology. Some guidelines below can be applied.

7.3.4.1 European market structure alignment

Guideline
Define architectural elements on the business layer in accordance to business roles that are identifiable within the European electricity market.

Rationale
In order to have business architectures derived from this reference architecture match the situation in all European countries, the roles used in the business interactions must be defined and agreed upon, or otherwise the responsibilities carried out by those roles are inconsistent and the interactions (and consequently the interfaces) between roles are unclear. This results in a system that is not interoperable.

Currently, the Harmonized Electricity Market Role Model by ENTSO-E, EFET and ebIX [ENTSO-E] is the best candidate, since it is harmonized and fits on all European electricity markets. Note that this model only represents the current EU situation, based on the current regulations, and that this might not fit future developments. Any deviation from this model should be documented and preferably discussed and agreed upon with the creators of the model and/or regulators (e.g. through Expert Group 3 of the European Commission's Task Force on Smart Grids).

Approach
Use the HEM-RM of ENTSO-E, EFET and ebIX (freely downloadable from the ebIX website at http://www.ebix.org/content.aspx?ContentId=1117&SelectedMenu=8) as a guidance to select and define your business roles and their interactions.

7.3.4.2 Consistency with the business layer

Guideline
Ensure consistent association between roles identified on the business layer and architectural elements identified on other layers, such as functions, applications, databases, or power system elements. Make sure there is a 1-to-n mapping from a single role to one or more architectural elements in the other layers, mitigating ambiguity of responsibilities for architectural elements.

Rationale
when a clear mapping is made between the roles in the business layer and the architectural elements in the other layers of SGAM (functions, interfaces, information, communication infrastructure, components …), one automatically knows which role is responsible for an architectural element and which business interfaces exist between these roles.

For example: the functional layer provides a list of functions required for the execution of a business process in the business layer. Due to the role mapping it is clear which roles are responsible for a specific function. Consequently none of the functions (and in lower layers information, interfaces and components) is omitted when realizing the business process and ownership/responsibility is clear.

Approach

once the architectural elements of the layer under work are defined, one needs to check how these map to the business roles from the roles defined on the business layer. If one cannot map an element onto a single role from the role model, the responsibility on that element is unclear and needs further investigation before continuing.

8 Reference Architecture Elements

The Conceptual Model (as defined in 6.3) consists of several domains, each of which contain applications and actors that are connected by associations through interfaces.

The Conceptual Model can be regarded as the basis from which regulation, business models, ICT architectures, standards etc. can be derived. Since it forms the common starting point for all these activities, it has the potential to ensure consistency between all these mentioned perspectives / viewpoints.

8.1 Business Architecture

It is commonly understood that ICT solutions are meant to support business processes, and that business processes of an organization produce products or services (in the service industry). Products and/or services are offered by that organization to its customers (residential of business) on a market. These markets may be subject to regulation in order to ensure a level playing field. Some markets/ products /services may even be fully regulated (e.g. unbundling).

Therefore it is essential that in creating ICT standards for inter-operability, the relation to markets, products and processes as described here, is well understood and aligned. Only then ICT solutions really support the business. This logic is well presented in the SGAM, showing the business layer as the top layer of the SGAM frame work.

Although standardization of market models and business models itself is out of scope of M/490, good interoperability is essential in order to create well-functioning markets. This requires standardized business services and interfaces, and this is in scope of M/490.

In this paragraph the business architecture is addressed from a methodology point of view, with the objective to ensure that whatever market or business models are selected, the correct business services and underlying architectures are developed in a consistent and coherent way. The business architectures are modeled in the business layer of the SGAM, and comprise the markets and enterprise zone of the SGAM layer, thereby also coping with regulatory aspects of markets and business objectives ate enterprise level.

The basis for alignment between organizations, roles & responsibilities, and application & information architectures, is created by the use of the meta-model, as shown in Figure 13 (source TOGAF 9.1).

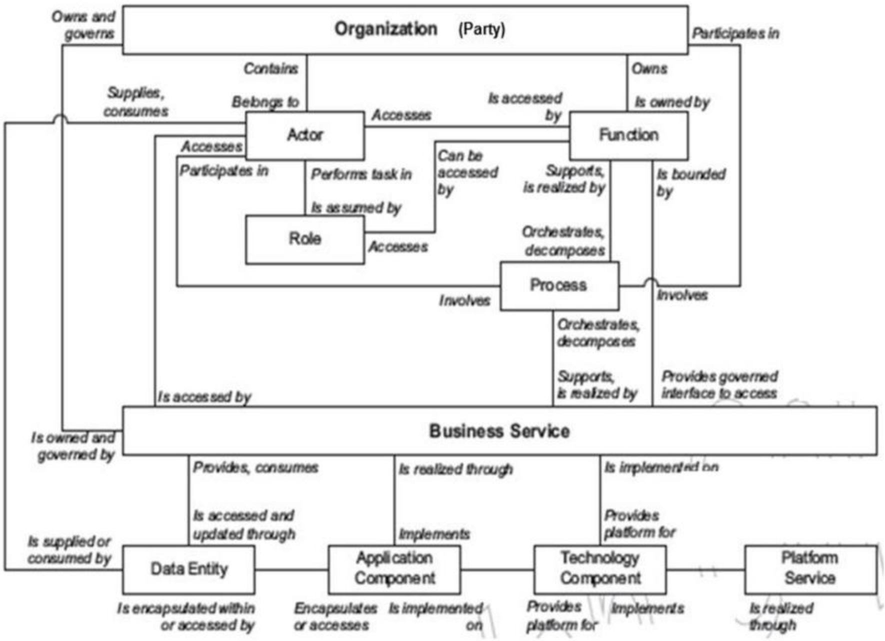

Figure 13: Meta model (TOGAF 9.1)

The use of this model also ensures alignment between the work of the M/490 working groups SG-CG/SP (Sustainable Processes WG), SG-CG/RA (Reference Architecture WG), and the development of a generic market model by the EU taskforce smart grids (EG3).

Figure 14 defines the relation between the metamodel and the SGAM framework, and it specifies more in detail what artifacts/deliverables should come out of the business architecture layer. The data entity corresponds with the information layer, the application component with the functional layer, and the technology component and platform services with the communication and component layer.

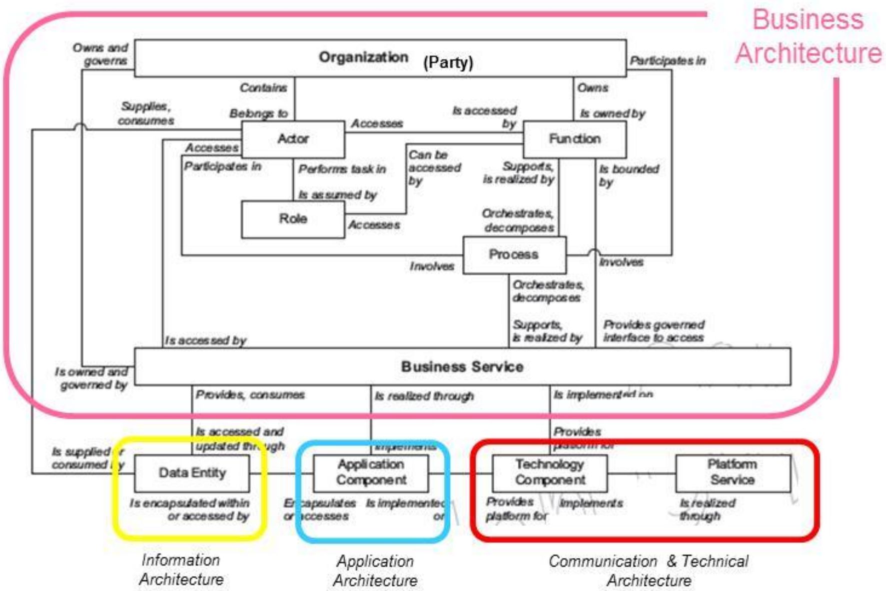

Figure 14: Relation Meta-model to SGAM

In the business architecture layer, the definition and overview (listing) of the following deliverables are foreseen:

- Roles & actors
- Business functions (or business function model)
- Business services
- Business processes (or business process model)

8.1.1 Roles & actors

In a market model in the business layer, roles are defined. These roles are mainly defined in terms of responsibility (ref. ENTSO-E/eBIX, see also Annex H). Then these roles are allocated to market parties. A party hereby is defined as a legal entity performing one or more roles (ref.[NIST 2009]).

This role-allocation to parties may be subject to regulation / legislation.

A role represents the external intended behavior of a party. A party cannot share a role. Businesses carry out their activities by performing roles (e.g. System Operator, Trader). Roles describe external business transaction with other parties in relation to the goal of a given business transaction.

The concept of an “Actor” is very general and can cover People (their roles or jobs), systems, databases, organizations, and devices.

Roughly actors, as identified by SG-CG/SP, might be divided into system actors and business actors (Ref. IEC TC8).

- System actors are covering functions or devices which for example are defined in the Interface Reference Model (IEC 61968-1). A system actor will perform a task under a specific role.
- A business actor specifies in fact a « Role » and will correspond 1:1 with roles defined in the eBIX harmonized role model (possibly some new roles will be required and added to the eBIX model).

An actor represents a party that participates in a business transaction. Within a given business transaction an actor assumes a specific role or a set of roles.

For example with respect to unbundling in Europe, the market models define what activities are regulated and what activities are allowed in the commercial market;
In that respect smart grid parties (DSO, TSO) and smart market parties (suppliers, Energy Service Companies (ESCOs), traders, customers, etc.) are defined.

The energy transition will require an update of existing market models, which differ today, even in different EU member states. It is the ambition of the EU to harmonize existing market models and to develop a generic EU market model.

With respect to mandate M/490, work on the definition of a EU generic market models is out of scope but work on components which are to be used for defining a market model (roles & business services) is in scope. Therefore, strong alignment between M/490 (especially SG-CG/SP) and EG3 of the EU Smart Grid Task Force is necessary, to guarantee use of the same definition and overview (listing) of roles & business services.

Only then EU work on market model development and the M/490 work on standards are in sync.

8.1.2 Business Functions

A business function delivers business capabilities closely aligned to an organization, but not necessarily governed by the organization (ref. TOGAF 9.1)

8.1.3 Business Services

A business service supports a business function through an explicitly defined interface and is explicitly governed by an organization (ref. TOGAF 9.1).

Actors in the conceptual model are connected by associations. Where these actors are represented by applications, information is exchanged via application interfaces. Where these interfaces cross boundaries between market parties, we define the information exchanged as business services. Through these business services market parties will interact.

The definition of business services via which regulated and unregulated market parties will interact, will be subject or part of regulation/legislation in order to create a level playing field in the smart market.

The 'physical" energy product, being an energy "end user proposition" from a commercial market party or an energy transport product (underlying) from a regulated market party, is defined as a business product. Associations between business products and business services are foreseen (e.g. a business transaction service related to EV charging). In order to fully facilitate "smart markets" by "smart grids", it is expected that business services (interfaces) between regulated and unregulated environments will be prioritized.

A Smart Market hereby is defined as an unregulated environment where energy products and energy related services are freely produced, traded, sold and consumed between many market actors.

A Smart Grid is defined a regulated environment where energy is transported and distributed via energy networks, and which provides relevant data & functionality to facilitate envisioned market functioning (e.g. switching customers, providing metering data).

8.1.4 Business Processes

In order to realize business services between markets parties, it is important to have a good insight in the underlying business processes. Furthermore the business processes drive the requirements for the functional and information architectures.

Creating a Utility common Business process model, (to be derived via a business function model) contributes to EU economy of scale with respect to application development and can lead to an "eco -system" of interconnected applications; It contributes to M490 interoperability objectives that go beyond 2 systems interfacing, leading to the realization of defined and specified use cases.

Today, a generic process model for utilities does not exist (for example, in contrast to the telecom sector where the eTOM reference model of TMF is internationally widely accepted and used).

Related work, leading a smart grid/ smart market high level process model is considered to be in scope of M490. Input for this work could come from:

- ENTSO-E/eBIX where processes/interactions between actors are described.
- Cooperation between ENTSO-E/eBIX and IEC related to the HMM and CIM model
- IEC standards (e.g. 61850) in which also processes/functions entities are described
- Work from relevant EU research programs
- The SG-CG/SP on sustainable processes is working on use case and generic use cases.

All these results will be input, next to other contributions and existing material for drafting an initial business capability and process model. This is for further study, input is welcome.

8.1.5 Methodology/ Process

In order to reach and maintain alignment between market model developments and ICT architecture & services development, the process that needs to be followed is:

1. The definition of a market model which includes defining and allocating clear roles and responsibilities to market parties. EG3 defines the roles, building on the existing ENTSO-E/eBIX Harmonized Role Model. EG3 and maps these roles to all market parties and DSO's. An initial mapping of existing roles is given in annex H. New roles may come out of analysis of uses cases (SG-CG/SP) as well as market model discussions (EG3)
2. M/490 (SG-CG/SP) derives from the use cases, the actors, and maps these actors onto the roles used by EG3.
3. M/490 (SG-CG/SP) is identifying the information exchange between actors from the use cases, and since actors are allocated to roles, this also defines the information exchange between roles. As roles are also allocated to market parties it consequently also defines the information exchange between market parties, thereby defining the basis for the standard business services.
4. From the business services defined, the process model, the information, application, communication & technical architecture should be derived.

This process is shown in Figure 15.

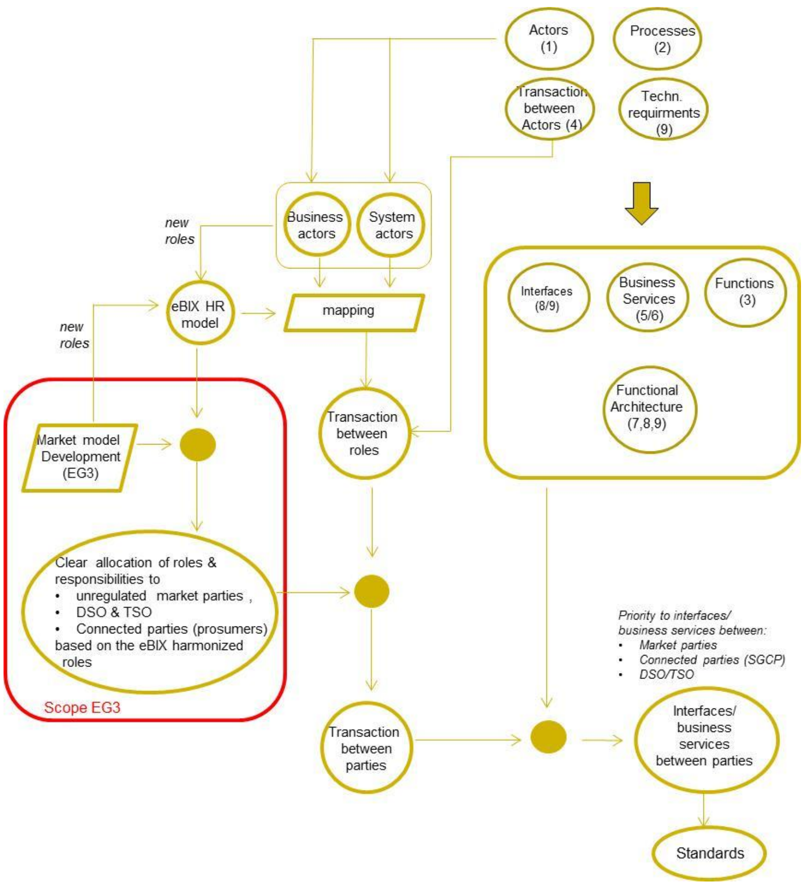

Figure 15: Alignment process between market model developments and ICT architecture & services development

It is envisaged that, at the end of 2012, the EU commission in its revision of mandate M490 will prioritize business services that will be necessary between connected parties (SGCP), market parties and DSO's. So, these business services should be addressed with priority, leading to a first set of standardized interfaces and business services, also required for implementation of the flexibility concept.

8.2 Functional Architecture

8.2.1 General

A functional architecture is intended to describe the functional elements of a system and their relationship independent from physical implementation, applied technology or assigned actor. In the context of Smart Grid a functional architecture consists of functions that enable Smart Grid use cases. The functional layer of the SGAM model hosts functional architectures of Smart Grids.

This section provides the concept of a meta-model to describe functional architectures and gives an architectural overview of typical functional groups of Smart Grids.

8.2.2 Functional Architecture Meta-model

8.2.2.1 Concept

The objective of this section is to introduce a meta-model, which describes Smart Grid functions and their relationship from an architectural viewpoint. The basic concept for the description of functional architectures for Smart Grid is adopted from the M/441 Smart Metering Reference Architecture [CEN CLC ETSI TR 50572:2011].

Figure 1Figure 16 shows the meta-model concept for the description of functional architectures for Smart Grid.

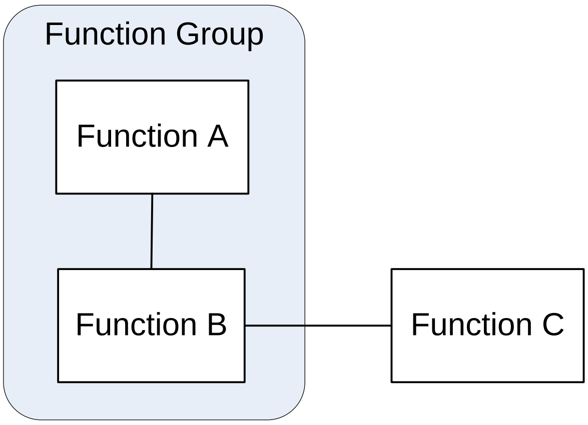

Figure 16: Functional architecture meta-model

Table 4: Terms of functional architecture meta-model

Term	Description
Function	Represents a logical entity which performs a dedicated function. Being a logical entity, a function can be physically implemented in various ways.
Function Group	Is a logical aggregation of one or more functions. A function group may also contain one or more function groups.
interaction	An “interaction” of two or more functions is indicated by a connecting line between these functions. Interaction is realized by information exchange via the interfaces of functions and communication means..
Functional architecture	Identifies the functional elements of a system and relates them to each other.

Figure 16 shows a function group containing the functions A and B that mutually interact. Function C interacting with function B, is not contained by any function group.

An example for a functional architecture is given for the use case “control of reactive power in section B.2.4.

8.2.2.2 Flexibility

Being able to describe functional elements of a system and their relationship independent from physical implementation, applied technology or assigned actor, allows an abstract and flexible development and use of functional architectures. In terms of SGAM this means, that functions or function groups can be assigned and shifted over the segments of the SGAM smart grid plane.

The example in Figure 17 illustrates the flexible assignment of functions to SGAM segments.

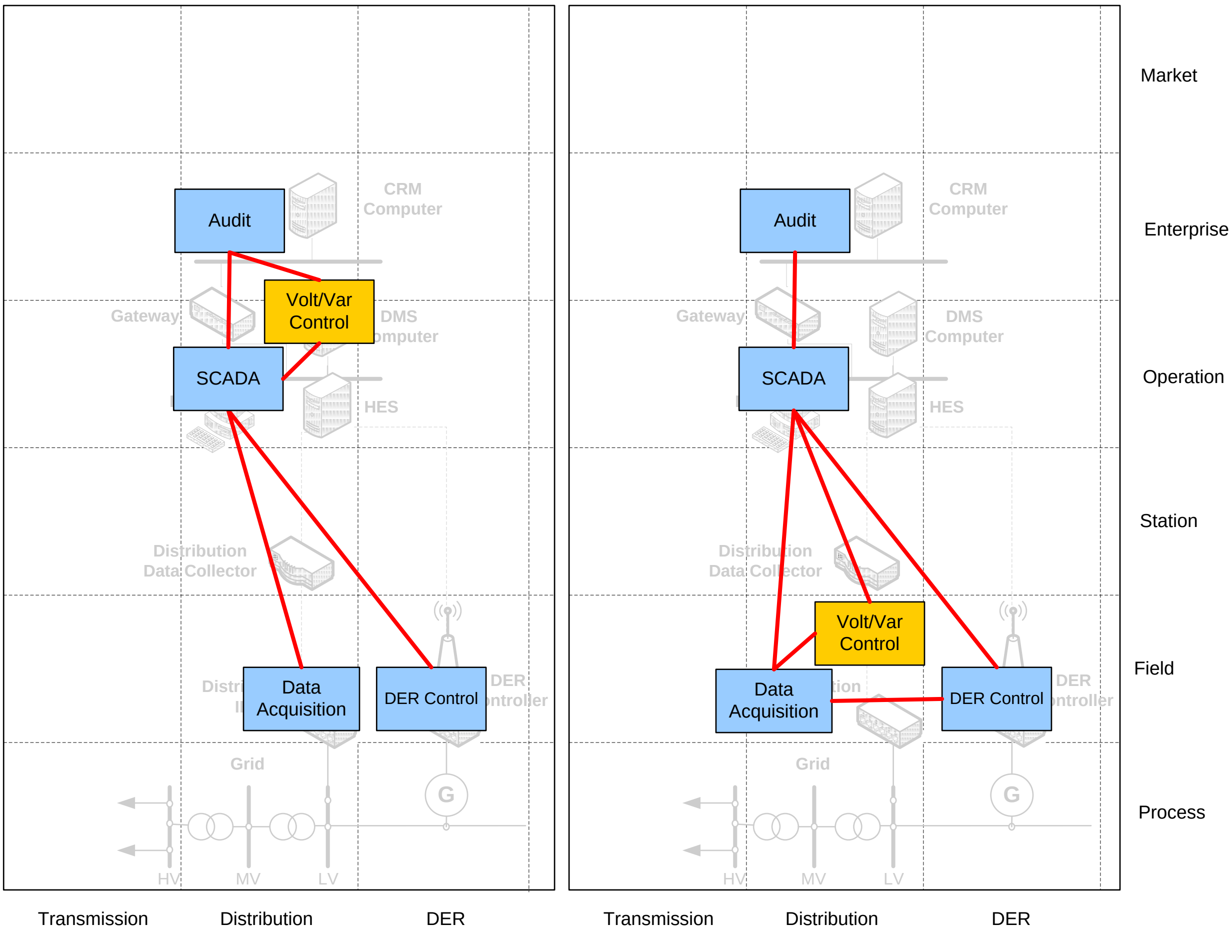

Figure 17: Flexibility for assignment of function “Volt/Var Control” to SGAM segments, case A - in operation zone, case B - in field zone

In case A, the function “Volt/Var Control” is assigned in the operation zone. This is a typical functional architecture in centralized DMS systems. In case B, the function is located in the field zone representing a local or decentralized concept. Both scenarios have specific impact on the other SGAM layers in terms of information exchange, canonical data models, communication protocols and component capabilities (see example in section B.2.4).

8.2.3 Smart Grid Functional Architecture

8.2.3.1 General

This section provides an overview on function groups that are derived from the Smart Grid systems introduced by SGCG/FSS [SG-CG/B]. Moreover these function groups are intended to support the high-level services, which were addressed in the Smart Grids Task Force EG1 report:

- Enabling the network to integrate users with new requirements
- Enhancing efficiency in day-to-day grid operation
- Ensuring network security, system control and quality of supply
- Enabling better planning of future network investment
- Improving market functioning and customer service
- Enabling and encouraging stronger and more direct involvement of consumers in their energy usage and management

8.2.3.2 Smart Grid Function Groups

The smart grid systems cover all five SGAM interoperability layers. Consequently the systems have specific content in the functional architecture viewpoint. Figure 18 shows the functional groups of the Smart Grid systems mapped to the Smart Grid domains and zones.

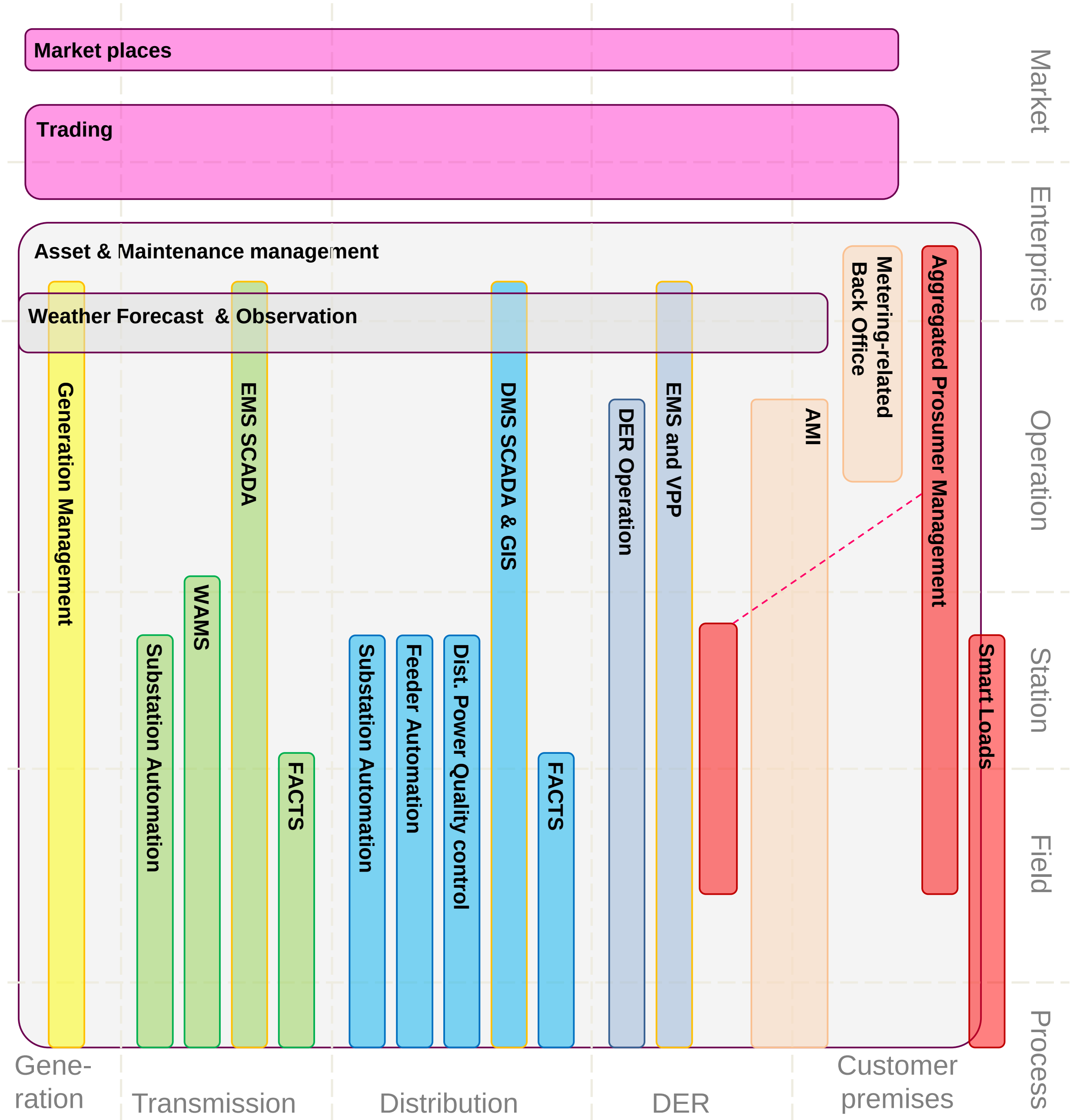

Figure 18: Overview on Smart Grid function groups derived from Smart Grid Systems

A description and further details on the smart grid systems is given in [SG-CG/B].

From a functional prospective the function groups of the individual systems contain further function groups or function of smaller granularity. E.g. the function group "Substation Automation" can be decomposed into the function groups "protection", "control", "monitoring", "data acquisition"… which themselves can be break down in further functions or function groups. The key idea is to identify basic functions which can be seen as reusable building blocks for complex functions. By the help of these basic functions different functional layouts can be studied and compared (see section 8.2.2.2).

8.3 Information Architecture

8.3.1 General

This section of the report focuses of the overview of the most important concepts for the representation and management of the needed information for the Smart grid elements. An Information Architecture is an abstract but formal representation of entities including their properties, relationships and the operations that can be performed on them. Important aspects which are addressed are data management, integration concepts and the interfaces needed. For those main aspects, the Smart Grid JWG report has already provided a thorough overview what has be considered state-of-the-art from the viewpoints of standardization bodies. In order to distinguish between those three aspects in the SGAM, the integration aspects must be seen as a link between either two or more layers and between one or more fields at plane level. Data models are typically focusing on the information layer and can be mapped easily onto the SGAM planes.

The following paragraphs focus on the three very aspects of the information architecture in more detail. Furthermore the concept of "logical interfaces" is introduced which is dedicated to simplify the development of interface specifications especially in case of multiple actors with relationships across domains.

8.3.2 Integration technology

While systems and applications in the past were often operated separately, today business requires interactions between multiple systems and applications to operate effectively. To do so, a coupling of former separated and heterogeneous systems is necessary. This requires solutions to integrate those systems in a way their functionality is still available and can be adapted to changing need. The establishment of a common information model that is to be used throughout many applications and systems requires solutions to cope with different data sources from the various actors.

To allow the recombination of different data sources and the establishment of new interfaces between those systems, syntactic and semantic interoperability is required. Different than in data or function integration, the implementation of the original systems is not affected by this enterprise application integration approach.

Usually, the integration will be realized through integration platforms that allow the implementation of required interfaces – Middleware is often the layer where this integration effort takes place. Often times the middleware is message-based, meaning components exchange data defined in messages which are sent from one component to another. XML is then used for various purposes, like message description and interchange. By shifting the intelligence to interfaces in conjunction with intelligent routing, publish/subscribe and event mechanisms, it is possible to define efficient systems spanning across multiple organizations and actors. In general this approach is labeled as EAI.

SOA goes one step further with the integration approach as well as with the organizational embedding, but also share the technological concepts of EAI. A SOA requires specific features according to the service paradigm from the applications to be coupled in order to allow for successful process integration. The smallest units in SOAs are services that provide a defined set of functionality, being so fine-grained that they provide units for reuse.

However, what exactly a service is and its level of granularity is in many cases defined different. The term service is often considered from a certain perspective from a particular stakeholder group, for instance, regarding the structuring of the business or the IT, as being stated by TOGAF. Different approaches to describe SOAs and to classify their services are further mentioned in [Uslar et al 2012].

Services, both business and technical, are self-contained, have a contract assigned that specifies their functionality and how to access it, and produce predictable results. In contrast to the sizing of applications and their functionality, services are designed to be used with other services in terms of composition and orchestration. This level of granularity adds more flexibility to business processes, as they may defined and executed using the services. Services are characterized by loose coupling and will usually be provided in specific directories where they can be found by third parties or process engines. Technical services are mostly realized as Web Services using the WS* technology stack from W3C. The service localization is then realized with Universal Description, Discovery and Integration (UDDI) that provides standardized way to locate those services. Besides the possibility of direct coupling, the usage of a platform providing the required functionality to orchestrate and compose services is highly important and can be realized in SOA middleware.

The features that middleware for this application area usually offers can for example be data transformation, connection to data sources, automation technology, logging, reporting as well as filtering and transformation. Such complex middleware is often named ESB. A platform like this can serve as a focal point for data, but it can also become a bottleneck for the decentralized arranged services. Therefore, it is beneficial to have a redundant middleware infrastructure that is scalable. In case a part of the IT infrastructure is not operated by a company itself but by another provider, the provided infrastructure becomes more and more abstract and blurred, meaning it appears as to be surrounded by a cloud.

By turning from a central IT to more decentralized systems in the energy sector, more efforts on system integration have to be spent. The mentioned integration paradigms are very valuable for Smart Grids, as they can be applied for the integration of decentralized systems, comprising producers, storage, consumers and other data sources. Here, the integration paradigms of EAI and SOA may be used for communication, automation as well as for secondary and primary IT. Internationally standardized solutions already exist to simplify this, like for instance the IEC 62357 SIA, which can be realized using a SOA, or the IEC 62541 OPC Unified Architecture as a SOA-based approach for data exchange. Nevertheless, there are still gaps that require harmonization between semantic and syntactic interfaces.

8.3.3 Data Models

According to literature, a data model in software engineering is an abstract model that documents and organizes the business data for communication between team members and is used as a plan for developing applications, specifically how data is stored and accessed. If the abstract level is higher, usually, business functions implemented and exchanged in processes are represented in a data model, focusing on the data in terms of payloads between stakeholders being exchanged.

Data modeling and description languages are typical “system enablers” transversal to use cases and should be seen in priority from a top-down approach. It may conflict with the traditional bottom-up approaches. However, there are many benefits of proceeding top-down starting with the data models:

- Avoiding useless translators, which increase the complexity of the deployment of smart grids, increase its costs, reduce its overall reliability, reduce flexibility in the future and finally speed down the over all market acceptance.
- Avoid misunderstanding between stakeholders from different domains involved in the system development, and increase the global reliability and interoperability of the system.

- Increase the flexibility of the system.
- Increase the speed of spreading the smart grid, by reducing the amount of engineering time per additional point of connection of IEDs.
- Providing harmonized data model and description language leads to think ”transverse” to be efficient, with the constraint not only to define an “ultimate” target but also the migration path from the existing situation.
- Harmonization between various data models takes place before the actual system development and might lead to a better seamless integration.

In the utility domain, several data models in context with the different aspects for the corresponding SGAM plane “Information layer” exist and have been thoroughly documented.

Annex 6.2 of the JWG-SG Report on Smart Grid Standardization provides a thorough overview on the most important data models which have to be seen in context with the smart grid standardization. As most reports point out, the CIM (IEC 61968, 61970 and 62325) and the IEC 61850 data model are the most prominent data models [Uslar et al 2012]. Fortunately, there are strong initiatives started by the SG-CG FSSWG group to harmonize the most important data models for smart grids. Therefore, we assume for a future version of the SGAM, seamless integration of data model at the information plane between the domains and zones can be reached.
This report does not recommend (apart from the obvious standards form the JWG reports) any data model standards but leaves this for the final report of the first set of standards group which will cover, based on the SGAM methodology described in this report, individual standards to be included in the M/490 First list of Standards focusing on meaningful data model standards for the Smart Grid. Additionally, the identified gaps between those data models are identified and will be addressed by the final report of the first set of standards group, e.g. IEC 61850 and CIM harmonization. Additionally, the SGAM method and EA techniques applied like TOGAF and Archimate provide for a meaningful integration and identification of needed date models in a context.

8.3.4 Interfaces

Most of the interfaces are normally seen between the domains and zones on the information plane. However, also interfaces between the planes must exist. Data like measurements and control signals are to be exchanged between those layers. The SGAM principles were created to make sure that both data models and interfaces for technical standardization could be mapped and properly addressed for standards.

As most utility standards were developed with the focus on the separation of concerns, interfaces are usually specified technology independent (ETSI M2M, IEC 61850 ACSI, CIM profiles (in RDF, OPC UA) and CIS/IRM) and can therefore be assumed somehow fix for a reference architecture as the semantics and syntax usually stays stable over the system’s lifecycle.

The generic basic interfaces can be supplied by literally unlimited numbers of technology mappings) most of the time, a vast number already exists because of the different use cases the standards have), however standardization most of the time recommends some of them only. Choosing the appropriate technology mapping for an interface depends on the functional and non-functional requirements of a use case and on the given context. This aspect is similar for the communications architecture plane. The non-functional aspects of an interface and data model are addressed by the IEC PAS 62559 IntelliGrid template and its extensions by the WG SP of the mandate. In a Use case, the interfaces and data models which will be mapped onto the SGAM for structuring can be identified from a pre-filled template and easily be annotated for the later system development.

The SGAM focuses on the possibility to model different types of uses for interfaces on plane and layer level, making it easier to distinguish between the interfaces which cover different domains of the conceptual models, different roles (e.g. at market or unbundling level) and of course technical systems.

8.3.5 Logical interfaces

The concept of logical interfaces is intended to provide a methodology for a systematic development of interface specifications. The resulting interface specification includes the information to be exchanged via the interface. This method offers advantages especially when multiple actors interoperate among different domains. Focusing on logical relationships, this method is independent from physical implementations of interfaces making it well applicable in concept studies e.g. in standardization.

Figure 19 illustrates the concept of logical interfaces in the context of SGAM domains and zones.

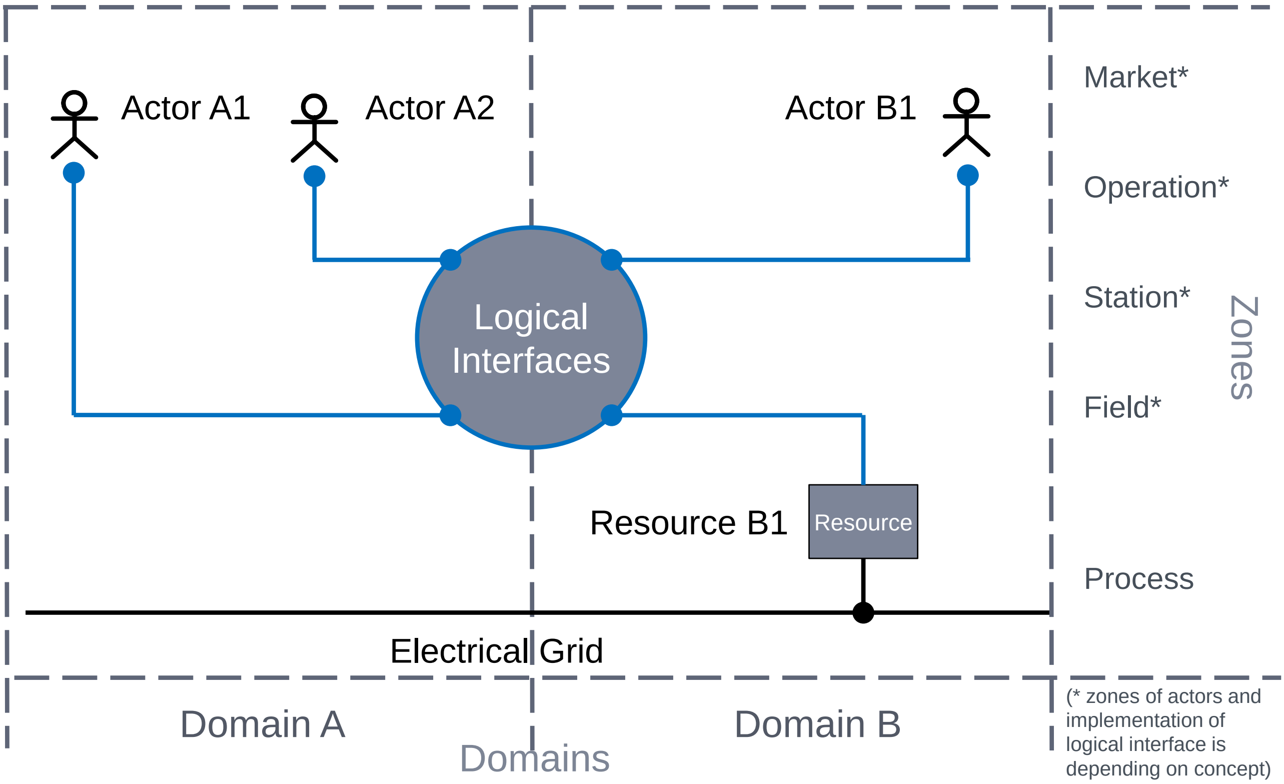

Figure 19: Concept of logical interfaces in the context of domains and zones

The generic example consists of business actors (A1, A2, B1) and a system actor (resource B1) assigned to domains A and B. In this example resource B is connected to the electrical grid and might be assigned to process zone. The business actors can be assigned to any zone, depending on the type of actor and the specific use case.

All actors may interact with other actors across the domain boundary but also within domains, e.g. actor A1 interacts with resource B1, actor A2 interacts with actor B2, actor B1 interacts with resource B1. The logical interfaces, indicated by the dots on the circle line at the domain boundary, manage the information exchange among all connected actors. For doing this, all actors have to provide the information in quality and quantity which is expected by the other actors. This idea of logical information exchange is independent from physical implementation, which can be realized with computers, dedicated gateways, and interface components (e.g. integrated in resource B1). This makes this concept flexible providing the necessary interface specifications required for implementation.

For the systematic development of interface specifications the information which is available in use case descriptions can be used. The necessary steps can be summarized as follows:

- Sorting use cases to logical interfaces
    - The use case actors are mapped to the appropriate domains and zones
    - The logical interfaces result from crossing through the circle of the connection between interacting actors
- Identification of exchanged information per logical interface
    - The exchanged information is assigned to the respective logical interfaces (dot on circle line)
    - This is done for all use cases
- Merging of interfaces specifications
    - The result is a list of information for each logical interface
    - Duplicates can be identified and removed

In conclusion this concept can be used for the development of information specifications

- For the analysis if standards are available which provide necessary support by data models
- For the extension of data model standards for new use cases
- Used in R&D and customer projects.

8.4 Communication Architecture

The Communication Architecture document (see Annex F) deals with communication aspects of the Smart Grid. The main objective of the study on Smart Grid communications is to identify gaps that need to be addressed in standardization organizations. This work considered generic Smart Grid use cases to derive the requirements and to consider the adequacy of those requirements to the existing communications standards in order to identify communication standards gaps. It was found that there are no specific standardization gaps for Layer 1 to Layer 4 standards (according to OSI model) mandating the immediate need for evolution of existing standards.

However, there is an immediate need to develop profiling and interoperability specifications based on the existing communications standards. The profiling work is the task of the SDOs. However, for the purpose of explaining our vision of such a profiling, a draft profile is proposed as an example of Smart Grid sub-network architecture.

The first section of the document provides a set of recommendations for standardization work as well as a mapping of the communication technologies to Smart Grid communication sub-networks that are listed in the section below.

The remaining part of the document provides:

- An overview of the Communication standards applicable to Smart Grid communications.
- A description of generic Smart Grid use cases, their communication requirements, along with recommendations on how to setup the communication networks to address these requirements.
- An example of profile and some interoperability considerations.

8.4.1 Recommendations

8.4.1.1 Recommendation 1

Examining the communication needs of different Smart Grid use cases, it appears that there are cases that have very stringent communications requirements (PMU, Tele-protection, etc.). However, all these requirements can be addressed using existing communications standards with sufficient engineering guidelines (see Recommendation 2). There is already a large set of communication standards for each network segment identified and no gaps mandating the need for new communication standards have been identified.

8.4.1.2 Recommendation 2

Communication network performance including QoS, reliability, and security must be managed so as to achieve the smart grid communications requirements. This mandates the need to develop communication profiles on “how to use” the current communication standards for Smart Grids. IEC in collaboration with bodies such as IETF, IEEE, ETSI, CEN and CENELEC is the right place to develop such profiles. A profile is defined as a description of how to use the different options and capabilities within a set of standards for a particular use.

8.4.1.3 Recommendation 3

There is a need to develop a standardized Service Level Specification (i.e. the technical part of a Service Level Agreement: availability, resiliency, DoS, etc.) that allows a utility network or application to rely on predictable network performance when communication is provided by a shared communication infrastructure.

8.4.1.4 Recommendation 4

Deployment constraints mandate the need for both wireline and wireless communications. Utility access to wireless network resources is necessary. Where spectrum is allocated for use by utility networks, this will help progress the Smart Grid deployments ensuring the standard work and products take into account the allocated spectrum for utilities.

8.4.1.5 Recommendation 5

Given the plethora of L1 and L2 technologies (according to OSI) used in the different communication standards (as well as the upcoming ones), IP shall be the recommended L3 technology to ensure communications are future proof and avoid the unnecessary need for interworking gateways in different parts of the Smart Grid communication networks.

8.4.1.6 Recommendation 6

This Communication Architecture document recommends a list of applicable communication technologies as well as their applicability statement to different sub-networks of the communications architecture. The choice of a technology for a sub-network is left to implementations, which need to take into account a variety of deployment constraints.

8.4.1.7 Recommendation 7

Profiles (see Recommendation 2) should be used as a basis for building interoperability test specifications. When interoperability test specifications / suites exist, those should be leveraged for building test specifications for the communication profiles.

8.4.1.8 Recommendation 8

ESOs should consider the approval of their specifications applicable to Smart Grid as ENs.

Recognizing the role of consortia in providing & developing specifications for communications and considering the fact that these consortia adopt an open standards approach (i.e. IEEE, IETF, W3C) the European Commission should endorse the importance of their specifications in building communications network, including for Smart Grid. There are globally recognized technologies & deployments for communications that use a selection of open specifications from ESOs, global SDOs and these consortia. The endorsement of the specifications into ENs, may not be reasonable in defined timeframe or achievable.

8.4.2 Smart Grid sub-networks

We are identifying the different networks that play a role in the overall communication architecture and we are representing their scope using the SGAM model (see Figure 8).

The following networks could be defined, see figure 3-2 below where these terms are used:

- **(A) Subscriber Access Network**

Network that is not part of the utility infrastructure but involve devices and systems that interact significantly with the utility such as responsive loads in residences and commercial/industrial facilities, etc.

- **(B) Neighborhood network**

Network at the distribution level between distribution substations and end users. It is composed of any number of purpose-built networks that operate at what is often viewed as the "last mile" or Neighborhood Network level. These networks may service metering, distribution automation, and public infrastructure for electric vehicle charging, for example.

- **(C) Field Area Network**

Network at the distribution level upper tier, which is a multi-services tier that integrates the various sub layer networks and provides backhaul connectivity in two ways: directly back to control centers via the WAN (defined below) or directly to primary substations to facilitate substation level distributed intelligence. It also provides peer-to-peer connectivity or hub and spoke connectivity for distributed intelligence in the distribution level.

- **(D) Low-end intra-substation network**

Network inside secondary substations or MV/LV transformer station. It usually connects RTUs, circuit breakers and different power quality sensors.

- **(E) Intra-substation network**

Network inside a primary distribution substation or inside a transmission substation. It is involved in low latency critical functions such as tele-protection. Internally to the substation, the networks may comprise from one to three buses (system bus, process bus, and multi-services bus).

- **(F) Inter substation network –**

Network that interconnects substations with each other and with control centers. These networks are wide area networks and the high end performance requirements for them can be stringent in terms of latency and burst response. In addition, these networks require very flexible scalability and due to geographic challenges they can require mixed physical media and multiple aggregation topologies. System control tier networks provide networking for SCADA, SIPS, event messaging, and remote asset monitoring telemetry traffic, as well as peer-to-peer connectivity for tele-protection and substation-level distributed intelligence.

- **(G) Intra-Control Centre / Intra-Data Centre network**

Networks inside two different types of facilities in the utility: utility data centers and utility control centers. They are at the same logical tier level, but they are **not** the same networks, as control centers have very different requirements for connection to real time systems and for security, as compared to enterprise data centers, which do not connect to real time systems. Each type provides connectivity for systems inside the facility and connections to external networks, such as system control and utility tier networks.

- **(H) Enterprise Network**

Enterprise or campus network, as well as inter-control center network. Since utilities typically have multiple control centers and multiple campuses that are widely separated geographically.

- **(I) Balancing Network**

Network that interconnects generation operators and independent power producers with balancing authorities, and network which interconnects balancing authorities with each other. In some emerging cases, balancing authorities may also dispatch retail level distributed energy resources or responsive load.

- **(J) Interchange network**

Network that interconnects regional reliability coordinators with operators such as transmission operators and power producers, as well as network that connects wholesale electricity markets to market operators, providers, retailers, and traders. In some cases, the bulk markets are being opened up to small consumers, so that they have a retail-like aspect that impacts networking for the involved entities.

- **(K) Trans-Regional / Trans-National network**

Network that interconnects synchronous grids for power interchange, as well as emerging national or even continental scale networks for grid monitoring, inter-tie power flow management, and national or continental scale renewable energy markets. Such networks are just beginning to be developed.

- **(L) Wide and Metropolitan Area Network**[1]

Network that can use public or private infrastructures. They inter-connect network devices over a wide area (region or country) and are defined through SLAs (Service Level Agreement).

- **(M) Industrial Fieldbus Area Network**

Networks that interconnect process control equipment mainly in power generation (bulk or distributed) in the scope of smart grids.

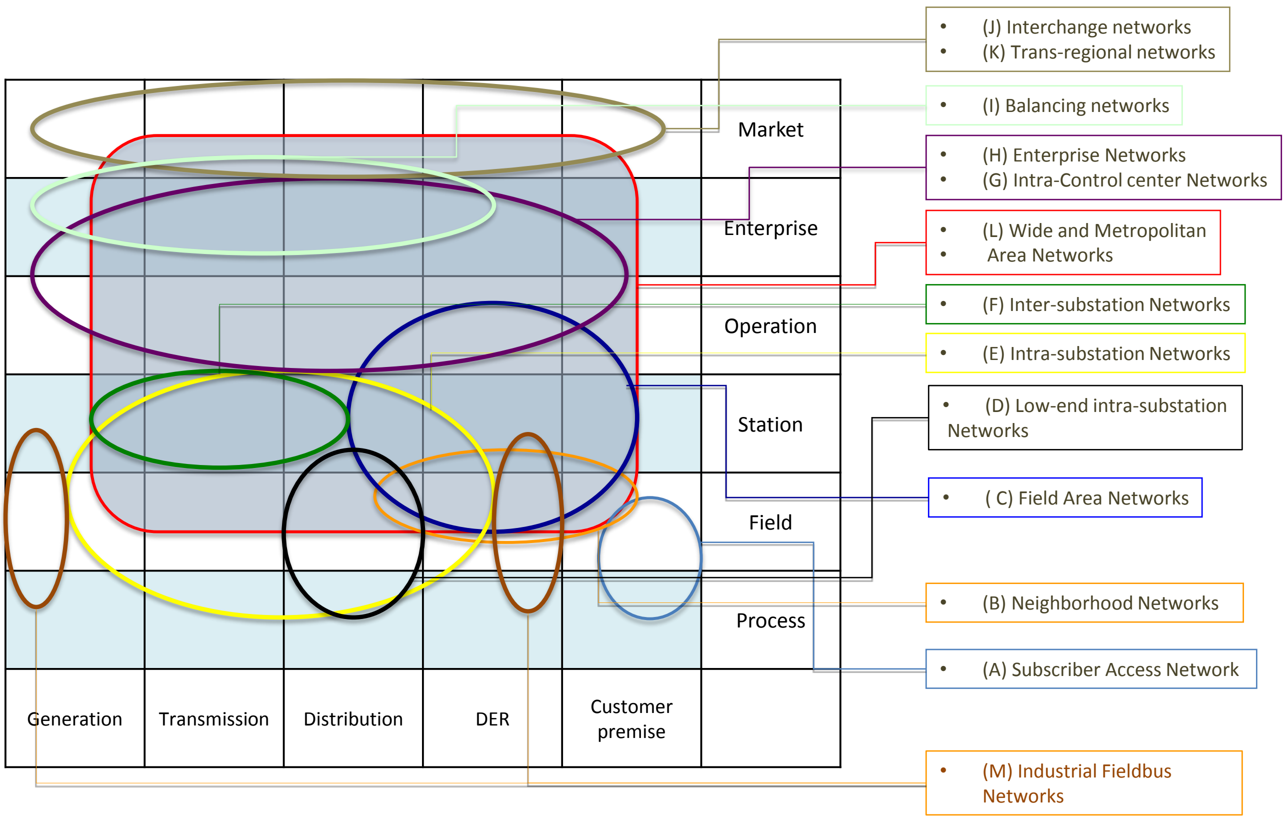

Figure 20: Mapping of communication networks on SGAM Communication Layer

Note 1 These areas of responsibility are an example mapping and cannot be normative to all business models.

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1 Several of the shown networks could be based on WAN technologies. However since those networks
A. can be run / managed by different stakeholders,
B. could provide different level of security or different SLAs
they are depicted separately. It should be noted however that this is a logical view and that in practice multiple logical networks can be implemented using a single WAN technology. Implementation design choices are beyond the scope of this report

Note 2 It is assumed that that sub-networks depicted in the above figure are interconnected (where needed) to provide end-to-end connectivity to applications they support. VPNs, Gateways and firewalls could provide means to ensure network security or virtualization.

8.4.3 Applicability statement of the Communication Technologies to the Smart Grid Sub-networks

The following table provides an applicability statement indicating the standardized communication technologies to the Smart Grid sub-networks depicted in the previous sub-clause. As per Recommendation 6, the choice of a technology for a sub-network is left to implementations, which need to take into account a variety of deployment constraints.

Note This report addresses communication technologies related to smart grid deployment. It includes communication architecture and protocols that could be used in smart metering deployments as well as other use cases (like feeder automation, FLISR etc.). For AMI only specific standards, please refer to CEN/CLC/ETSI TR 50572 and other future deliverables as listed in SMCG_Sec0025_DC_V0.3 Work Program Document.

Table 5: Applicability statement of the communication technologies to the smart grid sub-networks

	Subscriber access network	Neighbourhood Network	Field area	Low-end intra substation	Intra-substation	Inter-substation	Intra control centre	intra data centre	Enterprise	Balancing	Interchange	Trans regional	Trans national	WAN	Industrial Fieldbus
	A	B	C	D	E	F	G		H	I	J	K		L	M
Narrow band PLC (Medium and Low voltage)	x	x	x												
Narrow band PLC (High and very High voltage)					x	x									
Broadband PLC	x	x													
IEEE 802.15.4	x	x	x												
IEEE 802.11	x	x		x	x										
IEEE 802.3/1				x	x		x	x	x						x
IEEE 802.16	x	x	x												
ETSI TS 102 887		x	x												
IPv4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
IPv6	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
RPL / 6LowPan	x	x	x												
IEC 61850		x	x	x	x	x								x	
IEC 60870-5				x	x	x								x	
GSM / GPRS / EDGE	x	x												x	
3G / WCDMA / UMTS / HSPA	x	x					x	x	x	x	x	x	x	x	
LTE/LTE-A	x	x	x	x		x	x	x	x	x	x	x	x	x	
SDH/OTN	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
IP MPLS / MPLS TP	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
EN 13757		x													
DSL/PON [2]	x	x				x								x	

[2] IEEE GEPON and EPON are considered to be part of DSL/PON line

Annex A
Background Architecture Work

A.1 Objectives of this annex

This annex is dealing with the main principles for architecture management which have been applied developing both the SGAM and the Reference Architecture.

A.1.1 Aspects of a Common View: evolvability, simplicity and reuse of building blocks

For the understanding of the term Reference Architecture in the context of this document, various definitions have to be taken into account. Different relevant terms and definitions exist for architectures. The paragraphs provides and overview on how the term is used in context of this document and the ISO 42010.

One relevant ISO/IEC definition can be found in the ISO/IEC FDIS 42010 (2011): “Systems and software engineering — Architecture description”

Architecture

Fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution.

Architecting

Process of conceiving, defining, expressing, documenting, communicating, certifying proper implementation of, maintaining and improving an architecture throughout a system’s life cycle.

Architecture Framework

Conventions, principles and practices for the description of architectures established within a specific domain of application and/or community of stakeholders.

Reference Architecture

A Reference *Architecture* describes the *structure* of a system with its element types and their structures, as well as their *interaction* types, among each other and with their environment. Describing this, a Reference Architecture defines restrictions for an instantiation (concrete architecture). Through abstraction from individual details, a Reference Architecture is universally valid within a specific domain. Further architectures with the same functional requirements can be constructed based on the reference architecture. Along with *reference* architectures comes a *recommendation*, based on experiences from existing developments as well as from a wide acceptance and recognition by its users or per definition.

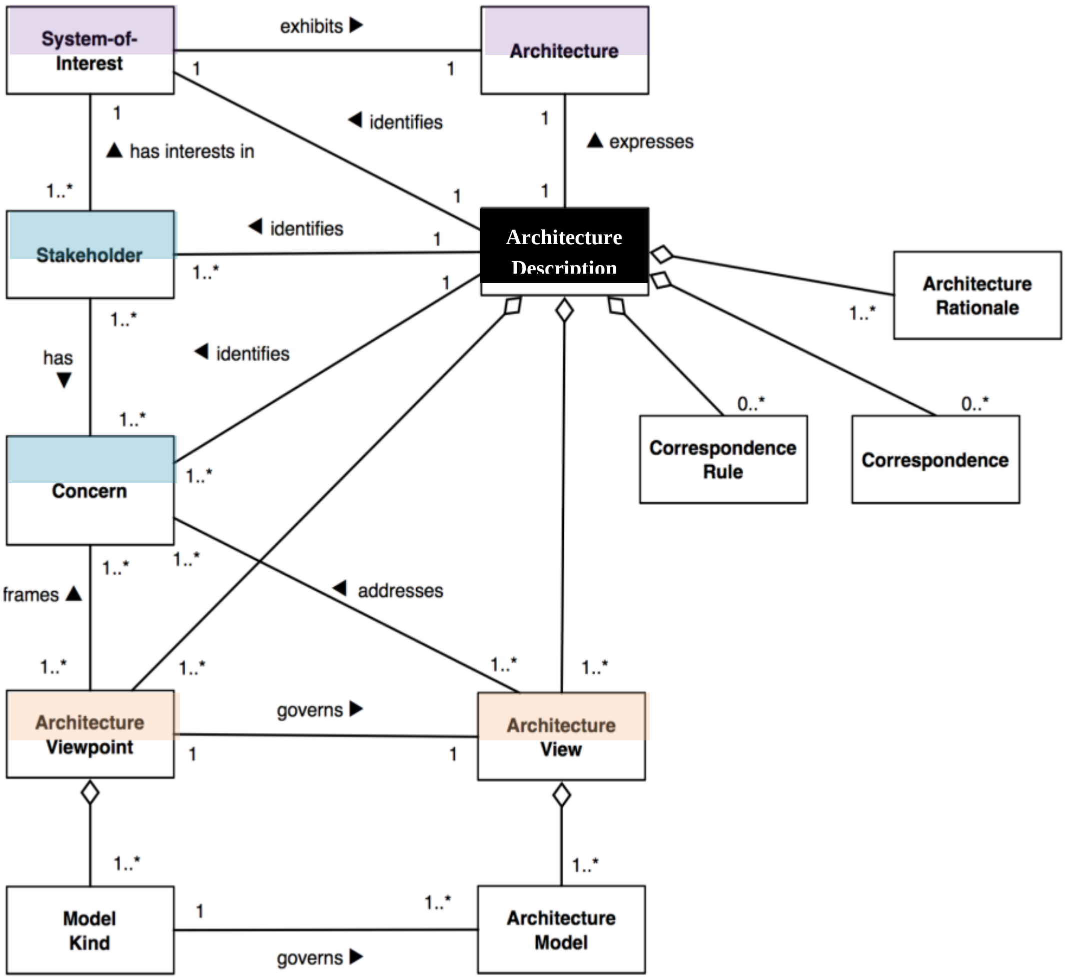


Figure 21: Metamodel of ISO/IEC 42010

What characterizes a Reference Architecture can be seen in the following list and overview of typical attributes which are covered by it:

- Recommendation character
- Declared by author
- Acceptance and recognition by users
- Generality
- Abstracts from specific characteristics
- Universal validity just possible within a specific domain or in relation to a set of use cases

In general, an architecture description is a work product used to express an architecture (of a system). Its content varies depending on the architecture. Stakeholders and their concerns and the Architecture Description usually depict the relevant stakeholders concerns.

Different Architecture Views are used to express architecture and to cover the stakeholder's concerns. Architecture Viewpoints are used to describe (relevant) architecture views; those Viewpoints describe stakeholders, concerns, notations, etc.

A.1.2 Clarification of views: power vs. communication; applications vs. services

When developing a Reference Architecture, it is important to know which aspects and view-points should be addressed in order to keep the model as simple as possible and not to introduce to much un-needed complexity. Often, those viewpoints differ in granularity, depending on the covered concerns. Typical possible viewpoints are:

- **Enterprise** viewpoint,
- **Information** viewpoint,
- **Computational** viewpoint,
- **Engineering** viewpoint,
- **Technology** Viewpoint (RM-ODP, ISO/IEC 10746)
- **Business Architecture** viewpoint,
- **Application Architecture** viewpoint,
- **Data Architecture** viewpoint,
- **Technology Architecture** viewpoint

With regard to methodologies like The Open Group Architecture Framework (TOGAF) or Zachman some of those viewpoints should always be addressed in context because they are inseparable. As for the SGAM, section 7 of this document will show the addressed viewpoints at zones, planes and layers.

A.2 Relationship to existing Architectures

As this is not the first architecture to be developed, most SDOs and their TCs already have created certain reference models and different viewpoints which are already used all around the world. As the overall project time to create the RA for the M490 process was limited, existing work was taken into account. The following (non-exhaustive) list contains already existing work whose principles and ideas were used by the RWAG:

- IEC SIA (TC 57 and SMB SG 3)
- GridWise
- Intelligrid Framework
- NIST Conceptual Model
- eTom/SID/Frameworx
- Electrinet
- OASIS, ebIX, ENTSO-E
- SG-CG First Set of Standards and Security Work Groups key issues

As for the SGAM, section 7 of this document outlines which aspects of those models were incorporated into the SGAM and which were not. Annex B of this document provides conceptual mappings to the SGAM layers for several of the aforementioned frameworks, making an alignment of SGAM use cases with those models possible.

A.3 Overview of one possible RA lifecycle-model

The possible lifecycle for the creation and maintenance of a reference architecture depicted in Figure 22 can be easily adopted by M/490 processes.

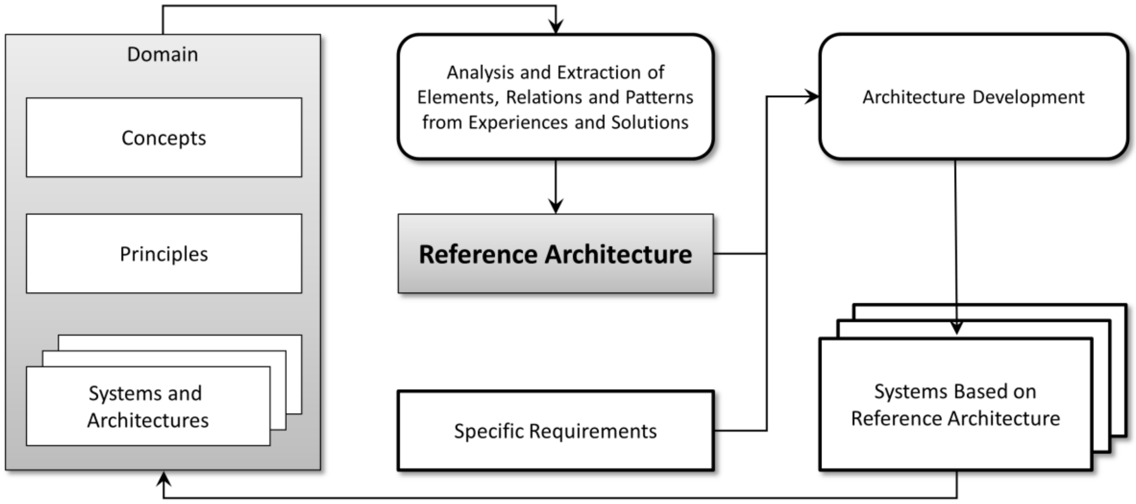


Figure 22: General Lifecycle for a reference architecture model

Firstly, the existing systems and architecture, principles and concepts of a domain, some relevant elements, relations and patterns are extracted, This step was performed by the SG-CG/RA members, taking into account exiting work and EGx and JWG reports. A first version of the reference architecture, the SGAM has been developed. However, as it is applied in practice, special requirements which are not covered by the general model can occur and must be instantiated. They must be incorporated in the architecture development and will be fulfilled by the systems which are instance-based on the reference architecture form the domain. Again, the knowledge gathered about the domain and application of the reference architecture is brought back in the process to build a new version of the reference architecture. It is strongly suggested to use this model when first experiences with the SGAM in practice are gained to create a new version 2.0 of the SGAM.

Annex B
Model mappings

B.1 Conceptual Model

This section will be completed in a subsequent version.

B.2 SGAM Framework

B.2.1 Quality of interoperability

The quality of interoperability can be measured by integration effort. When systems are to be integrated to fulfill a function cooperatively, all interoperability categories need to be covered. Here standards help to increase the quality of interoperability by reducing the integration effort.

Figure 23 shows the relationship between integration efforts and system complexity in respect to the use of standards. A standard is designated

- "rich", when the standard covers several interoperability categories (e.g. IEC 61850, covering the categories from basic connectivity up to semantic understanding, even including aspects of business context)
- "simple", when the standard covers a single or few interoperability categories (e.g. Ethernet, covering aspects of basic connectivity, syntactic and network interoperability)

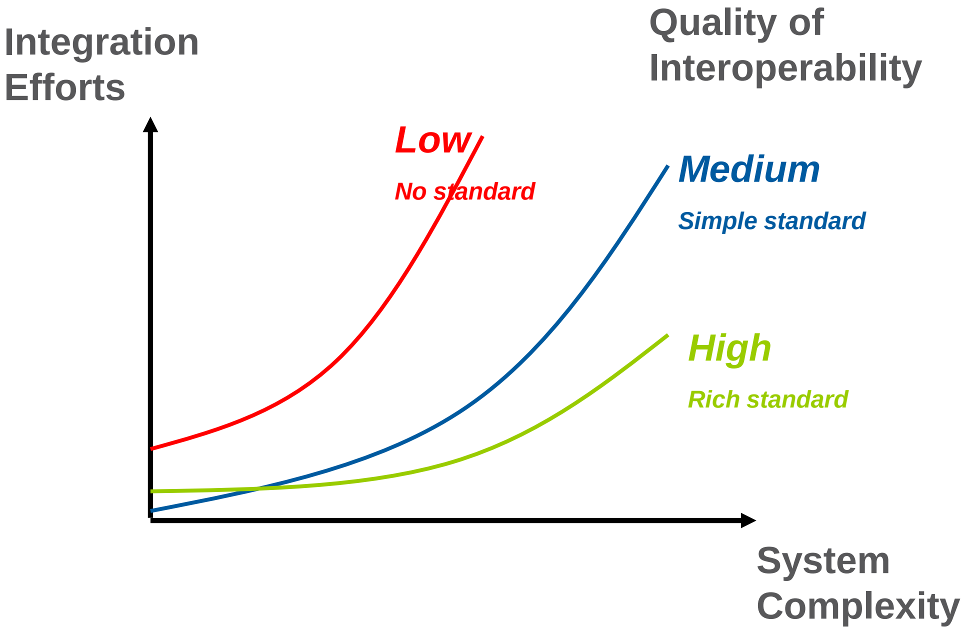


Figure 23: Quality of interoperability

Generally the integration effort to achieve full interoperability increases by system complexity. Having rich standards available (for a given integration task), which provide specifications for the required interoperability categories (e.g. standardized connectors, communication protocols, semantic data models, standardized functions), will ease the integration work. Having simple or even no standards applicable for the integration task may result in higher efforts due to project specific adaptions.

Consequently “rich” standards bridging as many interoperability categories as possible are to be preferred for smart grid interoperability.

B.2.2 Specific qualities of interoperability: “Plug-and-play” and “Interchangeability”

In the discussion about the meaning of interoperability, the terms “plug-and-play” and “exchangeability” are quite common. Rather than synonyms for interoperability, these terms represent a specific quality of interoperability.

Plug-and-play

Plug-and-play can be described as the ability to add a new component to a system and have it work automatically without having to do any technical analysis or manual configuration. In other words this includes the automatic configuration of specific settings necessary for the integration for systems. In respect to the interoperability categories, the concept of automatic configuration complements standards and specifications with mechanisms and procedures to simplify system integration. At best these mechanisms and procedures are standardized.

Interchangeability

Interchangeability is defined as “*the ability to replace a device supplied by one manufacturer with a device supplied by another manufacturer, without making changes to the other elements in the system”* [IEC61850-2010]. This means that interchangeability represents “hot plug” capability of a system or component. For this purpose the system requires a well-defined behavior in respect of function and information exchange, in other words the full specification of all interoperability categories. This full specification can be achieved by using standard profiles (see 2.2.6).

For a given system or component, the *Plug-and-play* (auto configuration) capability is not necessary for the support of interchangeability, since pre-configuration is sufficient.

B.2.3 Standard profiles – a measure to increase the quality of interoperability

Generally a profile defines a subset of an entity (e.g. standard or specification). Profiles can be used to reduce the complexity of a given integration task by selecting or restricting standards to the essentially required content. A standard profile may contain a selection of data models, communication services applicable for a specific use case. Furthermore a profile may define instances (e.g. specific device types) and procedures (e.g. programmable logics, message sequences) in order to support interchangeability.

B.2.4 SGAM Mapping Example

The following example illustrates how a use case can is mapped to the SGAM framework. For this example the process which is described in section 7.3.3 is applied. The sample use case “*Control reactive power of DER unit”* is a typical use case, which falls under the area of the distribution management.

This example also illustrates that a use case can be represented with existing devices, infrastructures, functions, communication and information standards and business objective and constraints. Consistency of the layers in respect to the use case is provided by standards, which are applicable for the implementation of the use case.

B.2.4.1 Use Case Analysis

Starting point is an analysis of the use case to be mapped. It needs to be verified that a use case description provides the sufficient information which is necessary for the mapping.

For this mapping example the required information is taken from

- Name, scope and objective (Table 6)
- Use case diagram (Figure 24)
- Actor names, types (Table 7)
- Preconditions, assumptions, post conditions (Table 8)
- Use case steps (Table 9)
- Information which is exchanged among actors (Table 10)

The underlying business objective of the use case is the operation of the distribution system in order to deliver electrical energy to customers under consideration of specific constraints. These constraints are typically economic and regulatory oriented, such as e.g. grid codes (incl. technical and non-technical requirements), security of supply, system stability, quality standards, company processes, etc.

Table 6: Scope and Objective

Scope and Objectives of Use Case	
Related business case	Operation of distribution grid
Scope	Monitor voltage level in distribution grid, control reactive power of DER unit, volt/var control of distribution grid,
Objective	Monitor and control voltage level of distribution grid in tolerated limits

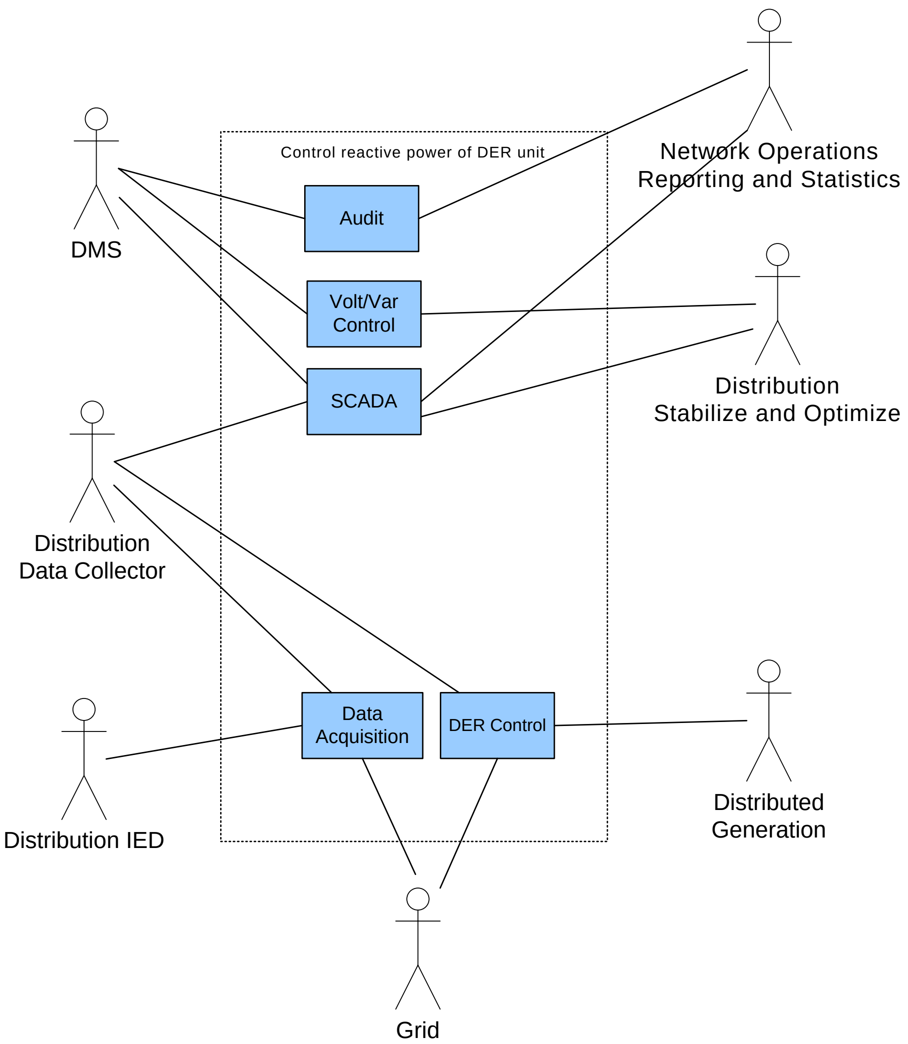


Figure 24: Use Case Diagram for "*Control reactive power of DER unit*"

214 **Table 7: Actor List "*Control reactive power of DER unit*"**

Actors			
Grouping (Community)		***Group Description***	
Actor Name see Actor List	***Actor Type*** see Actor List	***Actor Description*** see Actor List	***Further information specific to this Use Case***
Grid	System	Power Distribution system	
Distribution-IED	Device	Intelligent Electric Device (IED) is a communications-enabled controller to monitor and control automated devices in distribution which communicates with Distribution SCADA or other monitoring/control applications, as well as distributed capabilities for automatic operations in a localized area based on local information and on data exchange between members of the group. Operations such as such as tripping circuit breakers if they sense voltage, current, or frequency anomalies.	
Distributed Generation	Device	Distributed Generation, also called Distributed Energy Resources (DER), includes small-scale generation or storage of whatever form. This is in contrast to centralized or bulk generation and/or storage of electricity. These generation facilities are part of Demand/Reponse programs and may be dispatchable resources. The primary distictions between Distributed Generation (DG) and Bulk Generation is: Bulk Generation is attached via Transmission facilities, output is sold in wholesale markets, provides base load; DG is sited on a Customer permises attached to the Distribution grid, output is Retail (unless sold via an aggregator), can provide ancillary services. These generation facilities include but are not limited to Photvoltaic panel (PV), micro-hydro, mindmill, Plug-in Hybrid/Electric Cars (PHEV), and potentially Fuel cells. These facilites are usually not scheduled but can be dispatched.	
Distribution Data Collector	Device	A data concentrator bringing data from multiple sources and putting it into different form factors.	
Distribution Stabilize and Optimize	Application	Performed by actors to ensure the network is operating within appropriate tolerances across the system. They gather information for control decisions that ensure reliable, proper operations (stability) and more efficient operations (optimization). Measurement and control form a feedback loop that allows grid operators to stabilize the flow of energy across the electric network or safely increase the load on a transmission path.	
Distribution Management	Application	A suite of application software that	

System		monitors and controls the distribution system equipment based on computer-aided applications, market information, and operator control decisions.	
Network Operations Reporting and Statistics	Application	Operational Statistics and Reporting actors archive on-line data and to perform feedback analysis about system efficiency and reliability.	

Table 8: Preconditions, Assumptions, Post condition "*Control reactive power of DER unit*"

Use Case Conditions			
Actor/System/Information/Contract	***Triggering Event***	***Pre-conditions***	***Assumption***
Distribution Management System		• The Grid is continuously monitored • The Grid topology is known and reflects the real topology • The Grid energy path is known and reflects the real path (effective status of remote monitored and controllable switches)	
Distribution-IED		The device is up and running	
Distributed Generation		The DER is connected to the grid and injects active and reactive power	
Distribution Data Collector		The device is up and running	
Distribution Stabilize and Optimize		The application is up and running	
Distribution Management System		The application is up and running	
Network Operations Reporting and Statistics		The application is up and running	

Table 9: Step by Step Analysis of Use Case "*Control reactive power of DER unit*"

Scenario Conditions					
No.	**Scenario Name**	**Primary Actor**	**Triggering Event**	**Pre-Condition**	**Post-Condition**
4.1	Data Acquisition	Distribution IED	Periodically		
4.2	SCADA	DMS	Periodically		
4.3	Voltage/Var Control	Distribution Stabilize and Optimize	Voltage Measurement exceeded threshold		
4.4	DER Control	DMS	Control value, equipment id, received		
4.5	Audit	DMS	Control action		

Table 10: Use Case Steps "*Control reactive power of DER unit*"

Step #	***Triggering Event***	***Actor*** *What actor, either primary or secondary is responsible for the activity in this step?*	***Description of the activity*** *Describe the actions that take place in this step including the information to be exchanged. The step should be described in active, present tense*	***Information producer***	***Information Receiver***	***Information exchanged***	***Additional Notes*** *Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column*
Data Acquisition"							
1a	Periodically	Distribution IED	Distribution IED acquires analogue voltage measurement	Grid	Distribution IED	Analogue Voltage Measurement	
2	Periodically	Distribution IED	Distribution IED transmits voltage measurement	Distribution IED	Distribution Data Collector	Voltage Measurement	
3	Periodically	Distribution Data Collector	Distribution Data Collector transmits voltage measurement to DMS system.	Distribution Data Collector	DMS	Voltage Measurement	
Scada							
4	Periodically	DMS	The DMS System collects data from the grid, reformates the data and complements it with additional relevant information , distributes the data to DMS applications	DMS	Network Operations Reporting & Statistics, Distribution Stabilize and Optimize	Voltage Measurement, location, topology information	
Voltage/Var Control							
5	Voltage Measurement exceeded threshold	Distribution Stabilize and Optimize	Distribution Stabilize and Optimize application detects a threshold violation of voltage	Distribution Stabilize and Optimize	Distribution Stabilize and Optimize	Violation information	
6	Threshold Violation	Distribution Stabilize and Optimize	Distribution Stabilize and Optimize application starts Voltage/Var calculation	Distribution Stabilize and Optimize	Distribution Stabilize and Optimize	Start of voltage/Var calculation	
7	Start voltage Var calculation	Distribution Stabilize and Optimize	Distribution Stabilize and Optimize application calculates control value and identifies equipment to be controlled and transmits value to DMS	Distribution Stabilize and Optimize	DMS	Control value, equipment id	

Step #	Triggering Event	Actor What actor, either primary or secondary is responsible for the activity in this step?	Description of the activity Describe the actions that take place in this step including the information to be exchanged. The step should be described in active, present tense	Information producer	Information Receiver	Information exchanged	Additional Notes Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column
DER Control							
8	Control value, equipment id, received	DMS	DMS reformats control value and equipment id and transmits controllable setpoint to Distribution Data Collector	DMS	Distribution Data Collector	Controllable setpoint	
9	Controllable setpoint received	Distribution Data Collector	Distribution Data Collector device forwards information to Distributed Generation device	Distribution Data Collector	Distributed Generation	Controllable setpoint	
10	Controllable setpoint received	Distributed Generation	Distributed Generation device updates its operation parameters according to setpoint	Distributed Generation	Distributed Generation	Operation parameter	
11	Operation parameter update	Distributed Generation	Distributed Generation device verifies updated operation mode and acknowledges parameter change	Distributed Generation	Distribution Data Collector	Acknowledge information	
12	Acknowledge information received	Distribution Data Collector	Distribution Data Collector device forwards information to DMS	Distribution Data Collector	DMS	Acknowledge information	
Audit							
13	Control action	DMS	DMS application posts control action to Network Operations Reporting & Statistics application	DMS	Network Operations Reporting & Statistics	Control action	
14	Control action	Network Operations Reporting & Statistics	Network Operations Reporting & Statistics application documents control action	Network Operations Reporting & Statistics	Network Operations Reporting & Statistics	Control action	

222

B.2.4.2 Development of the Component Layer

The content of the component layer is derived from the use case information on actors. In this example the actors are of type devices, applications and system. These actors are located to the appropriate domain and zone (Figure 25).

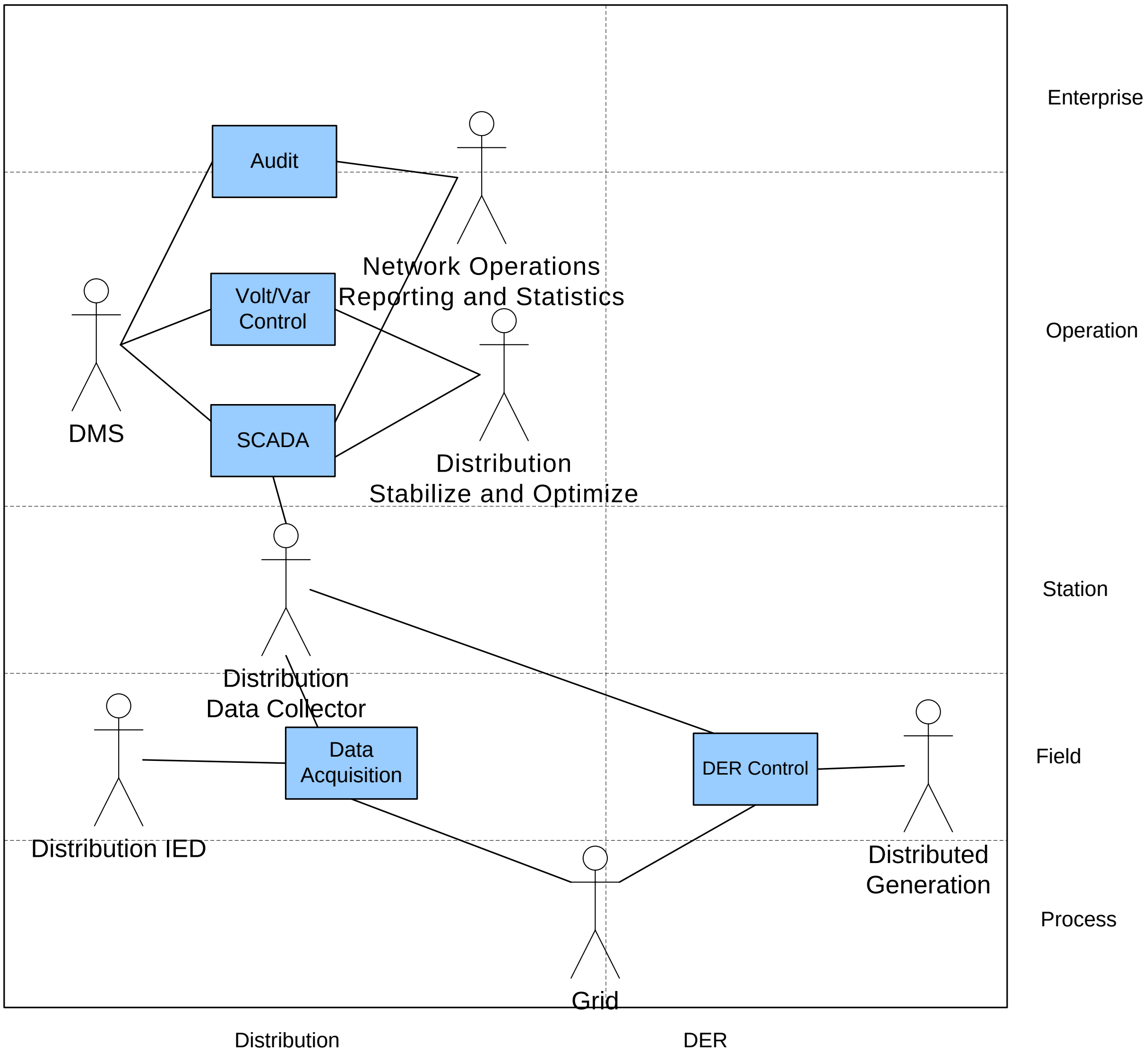


Figure 25: Actors and sub use cases mapped to domains and zones, "*Control reactive power of DER unit"*

The actors "DMS", "Network Operations, Reporting and Statistics" and "Distribution Stabilize and Optimize" typically reside in the distribution domain. DMS and Distribution Stabilize and Optimize" are on operation zone, whereas "Network Operations, Reporting and Statistics" can be in enterprise zone. "Distribution Data Collector" is depicted in distribution domain and station zone, "Distribution IED" in distribution domain and field zone. "Distributed Generation" is consequently located at DER domain and Field zone. The actor "Grid" is valid in both distribution and DER domain in the process zone.

In the next step, the mapped use case diagram is transformed to a technical configuration representation by using typical technical symbols (Figure 26)

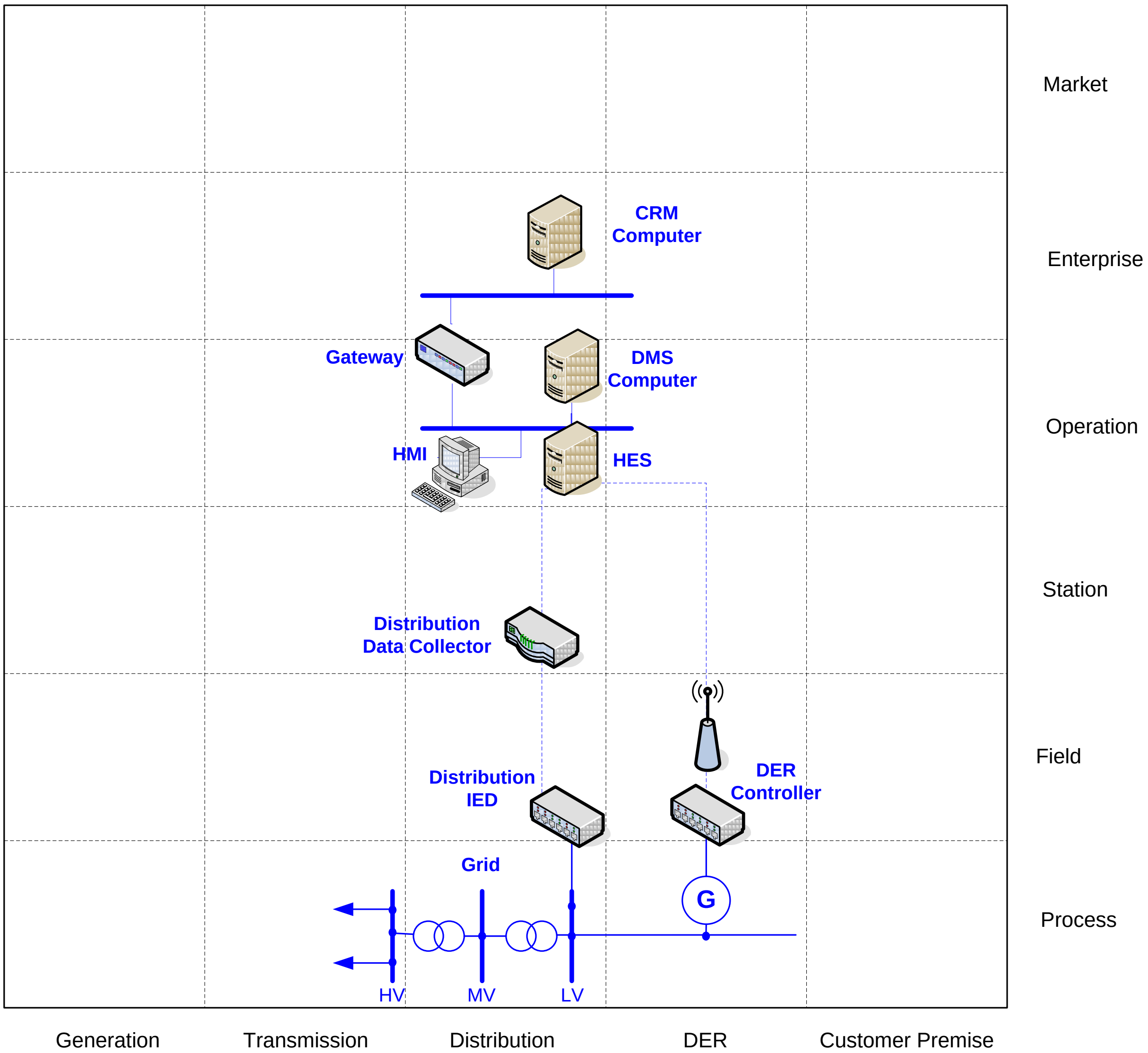


Figure 26: Component Layer "*Control reactive power of DER unit*"

The component layer (Figure 26) depicts the use case actors in form of hardware which is used to provide the intended use case functionality. In this example these are computers in the enterprise and operation zones which host the application type actors, dedicated automation devices in field and station zones, and nevertheless the grid is depicted with power system equipment (lines, bus bars, transformers, generators …). To complete this view the typical communication infrastructure is added. This configuration is a sample application, thus various scenarios are possible

B.2.4.3 Development of the Business Layer

The business layer is intended to host the business processes, services and organizations which are linked to the use case to be mapped. This includes also the business objectives, economic and regulatory constraints underlying to the use case. These business entities are located to the appropriate domain and zone.

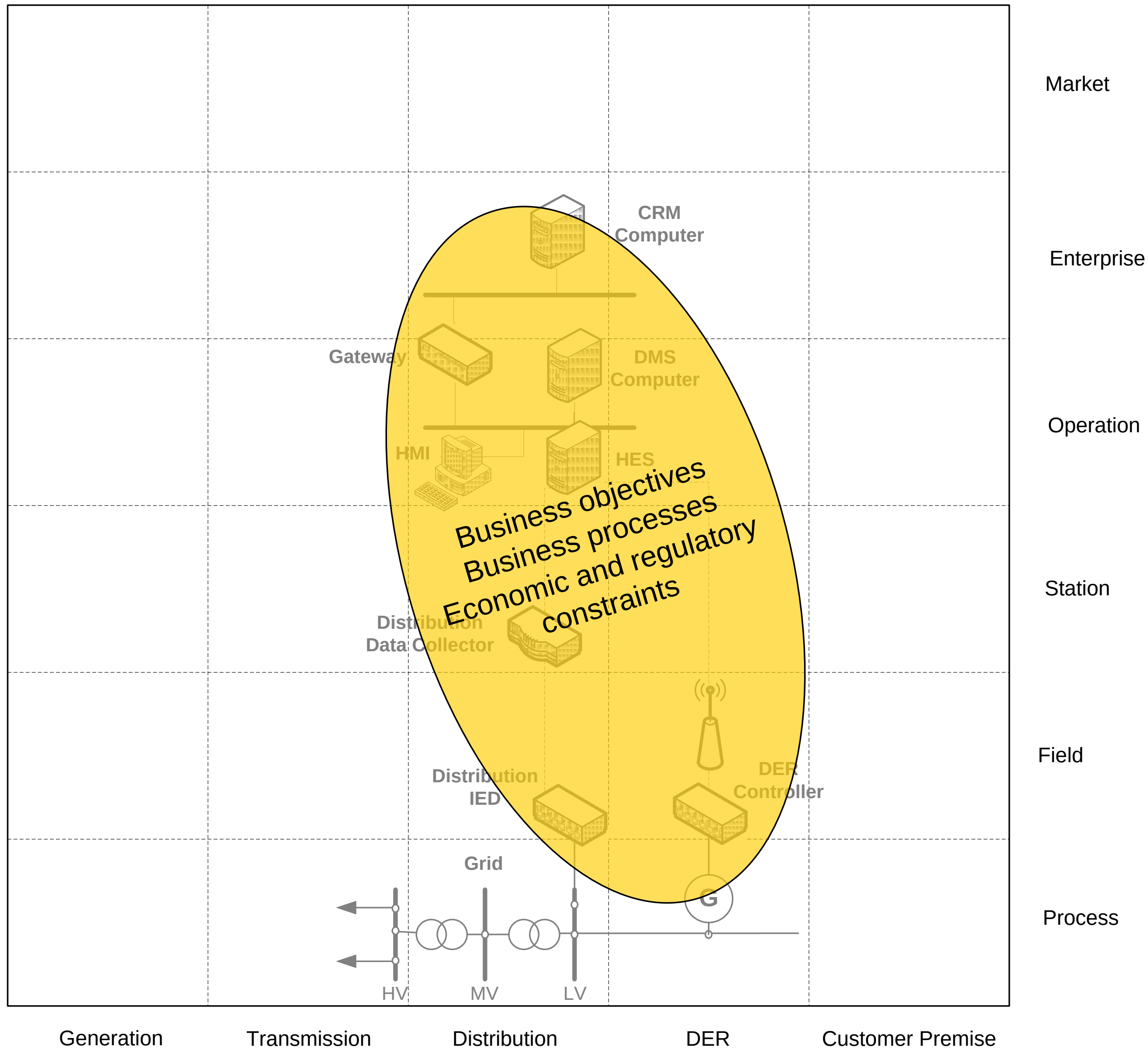


Figure 27: Business Layer "*Control reactive power of DER unit*"

The business layer (Figure 27) shows the area which is affected by the use case and consequently influenced by underlying business objectives and economic and regulatory constraints. This means that this objectives and constraints need to be taken into account as non-functional requirements for implementations.

B.2.4.4 Development of the Function Layer

The function layer is intended to represent functions and their interrelations in respect to domains and zones. Functions are derived from the use case by extracting its functionality. In this example the step-by-step analysis provides the functions of the uses case (Figure 28). The interrelation between functions is implicitly derived from the exchanged information documented in the use case steps (Table 10).

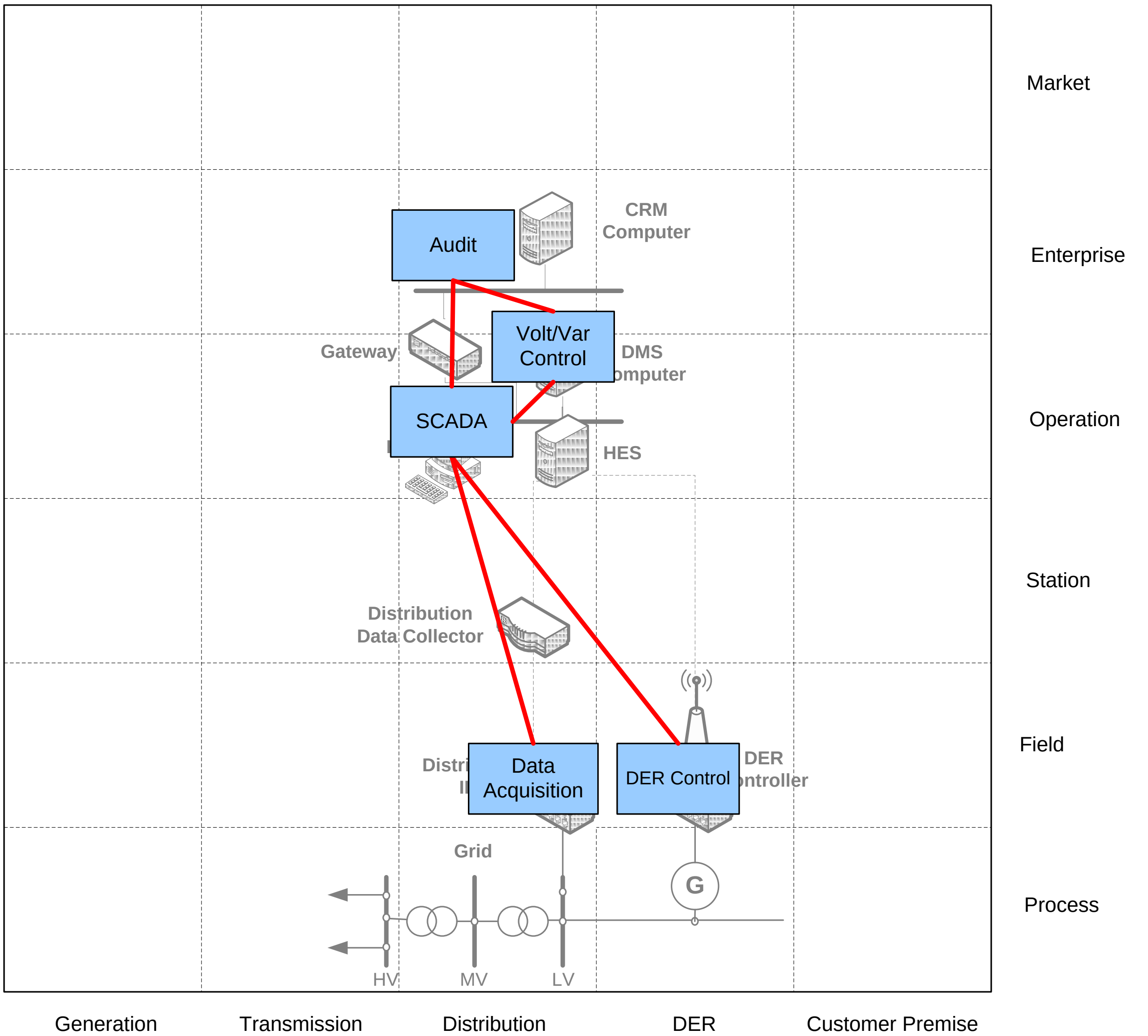


Figure 28: Function Layer "*Control reactive power of DER unit*"

The functions "Volt/Var Control" and "SCADA" typically reside in Distribution/Operation. The function "Audit" is located in Distribution/Enterprise. The functions "Data Acquisition" and "DER Control" are located to Distribution/Field and DER/Field, respectively.

B.2.4.5 Development of the Information Layer

The information layer describes the information that is being used and exchanged between functions, services and components. The information objects which are exchanged between actors are derived from the use case step description (Table 10). Figure 29 shows the result of the mapping of the exchanged information to the components that represent the use case actors.

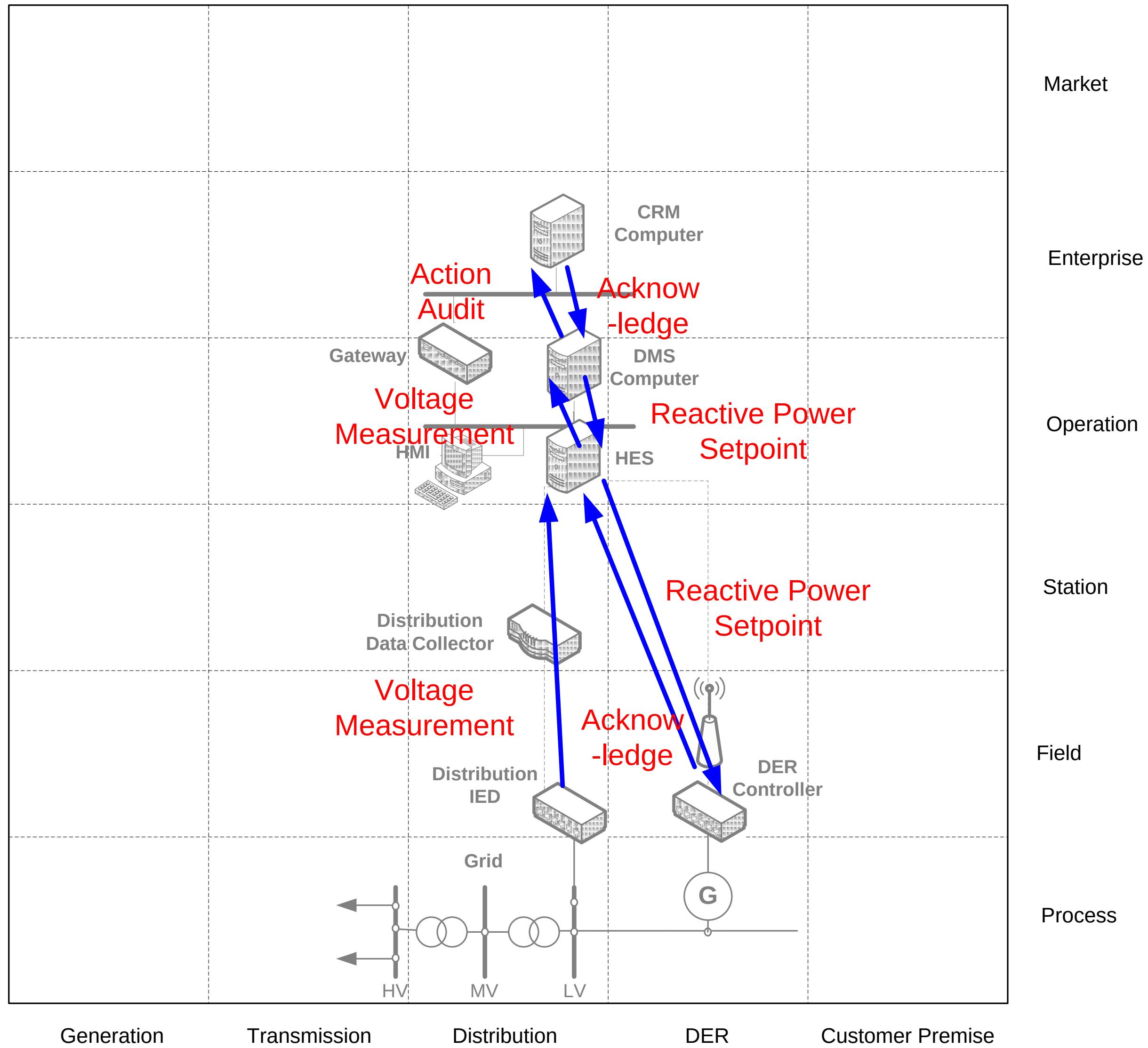
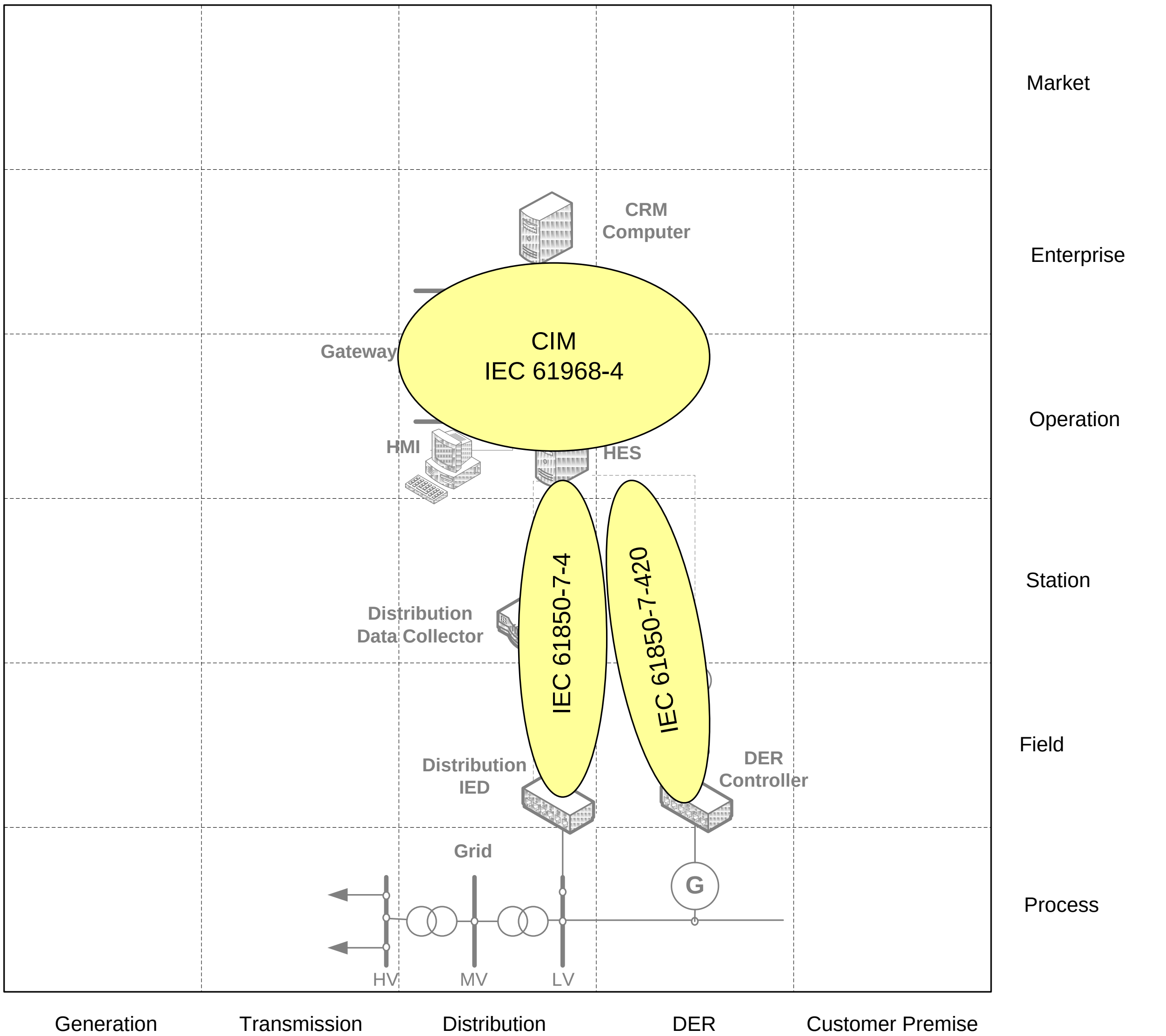


Figure 29: Information Layer / Business Context view, "*Control reactive power of DER unit*"

The Canonical Data Model view (Figure 30) of the information layer is intended to show underlying canonical data model standards which are able to provide information objects. In other words for the implementation of the present use case, instances of data objects according to the standards are required. In the present example CIM standard (IEC 61968-4) is an appropriate basis for exchanging information objects in the enterprise and operation zones. From field to operation zone, data objects according IEC 61850-7-4 (Compatible logical node classes and data object classes) and IEC 61850-7-420 (Distributed energy resources logical nodes) are applied.



291

292 **Figure 30: Information Layer / Canonical Data Model view, "*Control reactive power of DER*
293 ***unit*"**

294 ### B.2.4.6 Development of the Communication Layer

295 The emphasis of the communication layer is to describe protocols and mechanisms for the
296 interoperable exchange of information between the use case actors. Appropriate protocols and
297 mechanisms are identified on the basis of the information objects and canonical data models and
298 by consideration of non-functional requirements of the use case. The communication layer (Figure
299 31) presents the communication protocols for the data exchange of the necessary information
300 between the components
301

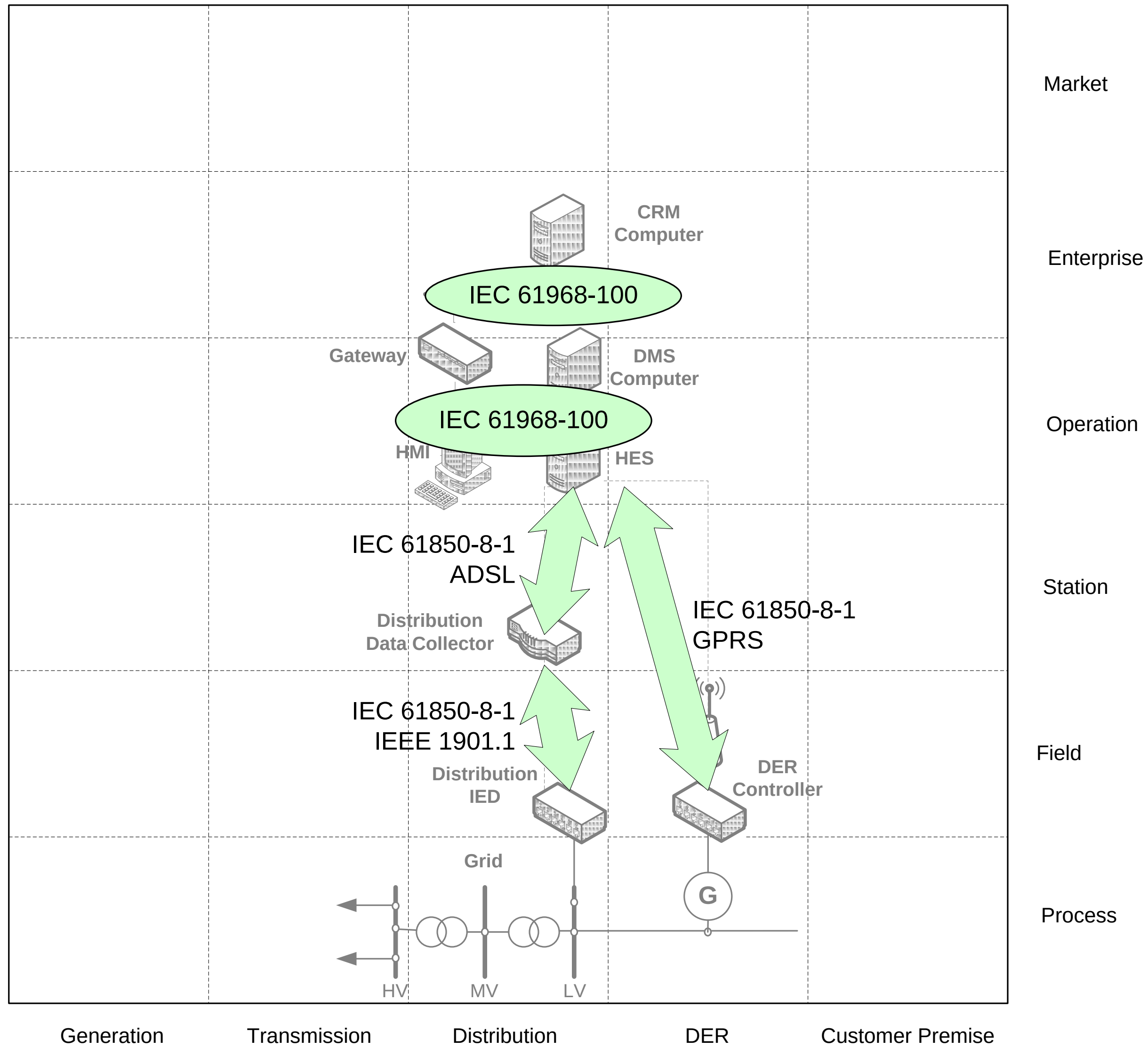


Figure 31: Communication Layer "*Control reactive power of DER unit*"

In the enterprise and operation zone IEC 61980-100 is an option for the exchange of CIM data objects. In the field to operation zones there are options of communication standards. IEC 61850 is the state-of-the-art communication protocol in power system automation. This standard can be mapped to different lower layers, such as Ethernet, PLC or wireless communications.

B.2.5 Relation of SGAM framework to Architecture Standards

The SGAM framework has been developed with the focus on supporting the very needs of standardization experts and architects in the utility domain. The focus grew originally out of the need of the conceptual model described in section 6 of this document to be put in context with the very existing smart grid architectures from the view of standardization.

Section B.2.6 "Examples and Mappings of existing solutions" provides the most relevant examples of how the existing meta-models on reference frameworks to been seen in context with smart grid standardization can be mapped onto the SGAM model itself. However, this section focuses on the need form the domain perspective developed in Utilities by engineers for primary technology, communication technology and standardization engineers. Another possible view towards the smart grid architecture can be given from the point of a non-domain oriented software engineer.

In the very context of documenting software architectures, different standards or methodologies have evolved. One of the most prominent standards is the ISO/IEC 42010: Systems Engineering – Architecture description. It focuses on the tool-independent way of conceptualizing architectures for systems, which may be hybrid (e.g. hardware, communications and software). The scope is further detailed as followed [ISO/IEC 42010].

The complexity of systems has grown to an unprecedented level. This has led to new opportunities, but also to increased challenges for the organizations that create and utilize systems. Concepts, principles and procedures of architecting are increasingly applied to help manage the complexity faced by stakeholders of systems.

Conceptualization of a system's architecture, as expressed in an architecture description, assists the understanding of the system's essence and key properties pertaining to its behavior, composition and evolution, which in turn affect concerns such as the feasibility, utility and maintainability of the system.

Architecture descriptions are used by the parties that create, utilize and manage modern systems to improve communication and co-operation; enabling them to work in an integrated, coherent fashion. Architecture frameworks and architecture description languages are being created as assets that codify the conventions and common practices of architecting and the description of architectures within different communities and domains of application.

The ISO/IEC 42010 addresses the creation, analysis and sustainment of architectures of systems through the use of architecture descriptions. It provides a core ontology for the description of architectures. The provisions of this International Standard serve to enforce desired properties of architecture descriptions, also specifying provisions that enforce desired properties of architecture frameworks and architecture description languages (ADLs), in order to usefully support the development and use of architecture descriptions. ISO/IEC 42010 provides a basis on which to compare and integrate architecture frameworks and ADLs by providing a common ontology for specifying their contents and can be used to establish a coherent practice for developing architecture descriptions, architecture frameworks and architecture description languages within the context of a life cycle and its processes (which have to be defined outside the standard). This International Standard can further be used to assess conformance of an architecture description, of an architecture framework, of an architecture description language, or of an architecture viewpoint to its provisions.

One particular way of implementing the ISO/IEC 42010 based ideas proven in industry, addressing the aspect of operationalizing the ideas from the meta-model [Jonkers 2010] are the standards from the Open Group TOGAF and Archimate.

A major strength of the TOGAF method is its ability to stress the importance of stakeholder concerns for each enterprise architecture development phase: creation, change, and governance. This ability may suggest that TOGAF also describes how an architect should address these concerns. This, however, is not the case. What TOGAF actually offers is a sort of "open interface" for the declaration of a "concern". The actual specification of the concern is left to any suitable modeling language which is capable of capturing such concerns and is compliant with the ISO/IEC 42010:2007 standard like ArchiMate.

ArchiMate is a modeling standard following the definitions and relationships of the concepts of concern, viewpoint, and view proposed by the ISO/IEC 42010:2007 standard for architecture descriptions. The ArchiMate framework is capable of defining stakeholder concerns in viewpoints, while the ArchiMate language is capable of addressing these with corresponding views showing the right aspects of the architecture conforming to defined viewpoints.

The core of TOGAF is basically a process, the so-called Architecture Development Method (ADM) describing viewpoints, techniques, and reference models, but not a complete formal language. ArchiMate describes viewpoints and provides a formal modeling language, including a (graphical) notation.

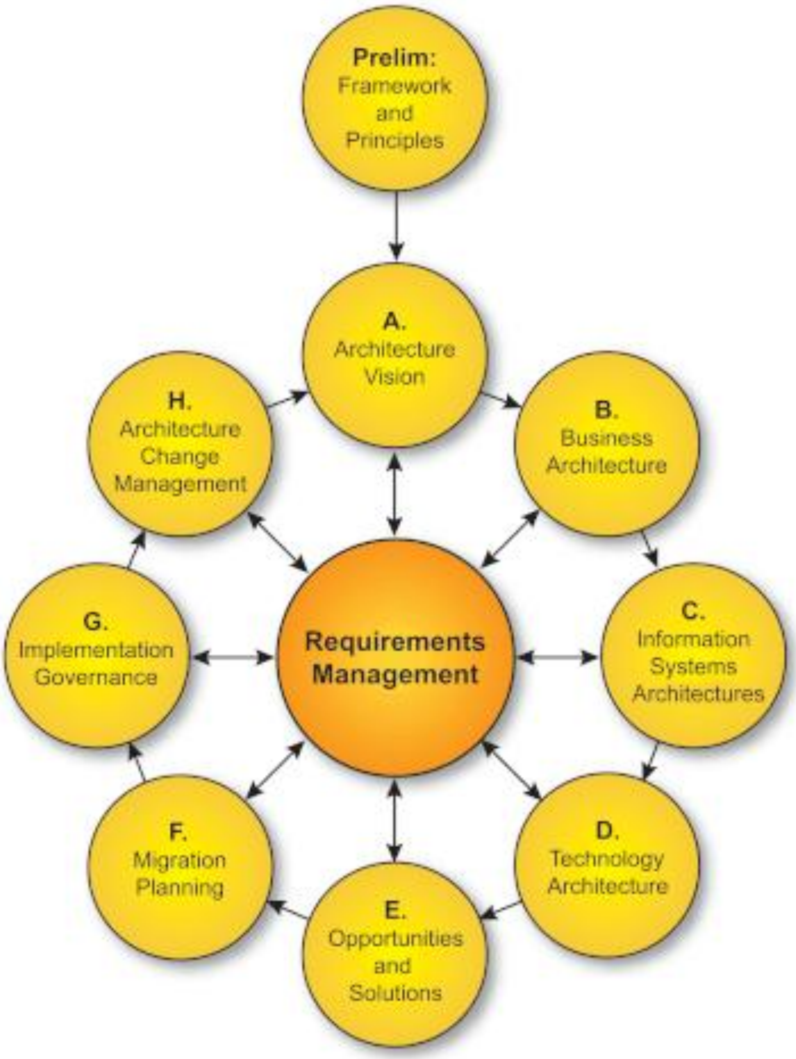


Figure 32: TOGAF ADM model

TOGAF and ArchiMate overlap in their use of viewpoints, and the concept of an underlying common repository of architectural artifacts and models; i.e., they have a firm common foundation. Both complement each other with respect to the definition of an architecture development process and the definition of an enterprise architecture modeling language.

ArchiMate 1.0 chiefly supports modeling of the architectures in Phases B, C, and D of the TOGAF Architecture Development Method (ADM). The resulting models are used as input for the subsequent ADM phases. However, modeling concepts specifically aimed at the other phases are still missing in the language.

Those three main standards (ISO/IEC 42010, TOGAF and Archimate) which are domain independent can also be used to express the SG-CG/RA work's group for the M/490 mandate. However, this method has a major drawback of using Software and system engineering specific vocabulary and a new specification language most standardization members are not familiar with. Therefore, we suggest the use of the architecture related, non-domain specific standards is possible but suggest fort his document to adhere to the known principles and provide and example in the how to use the three standards for a Smart grid Use Case in the annex.

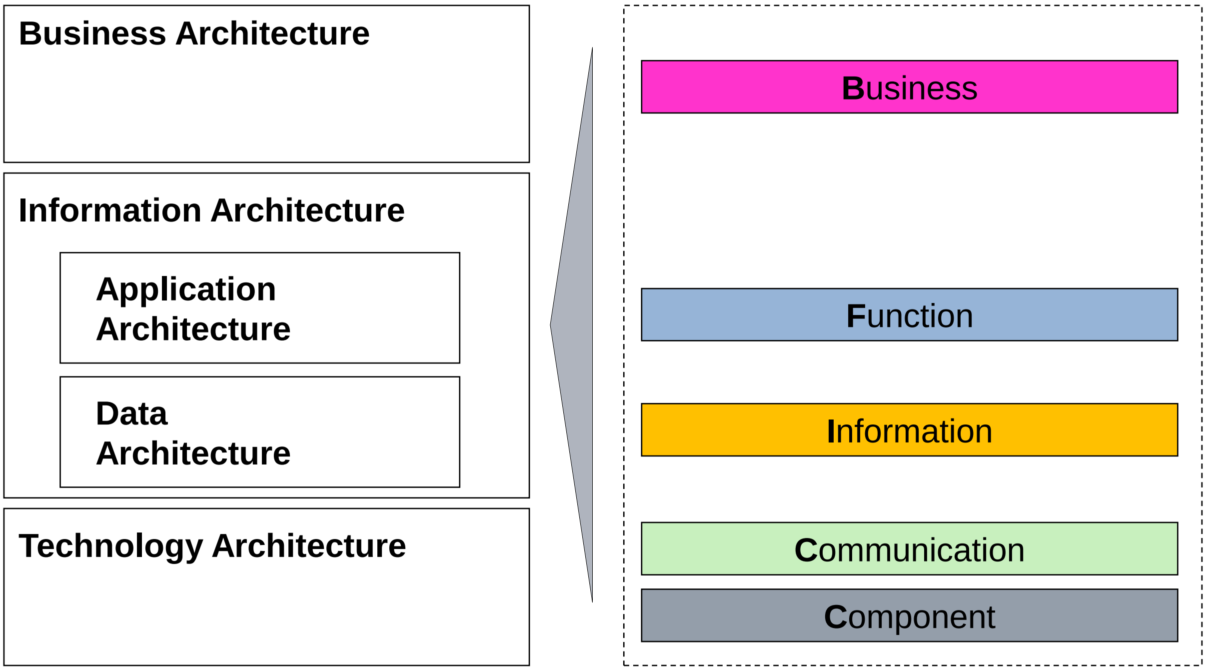
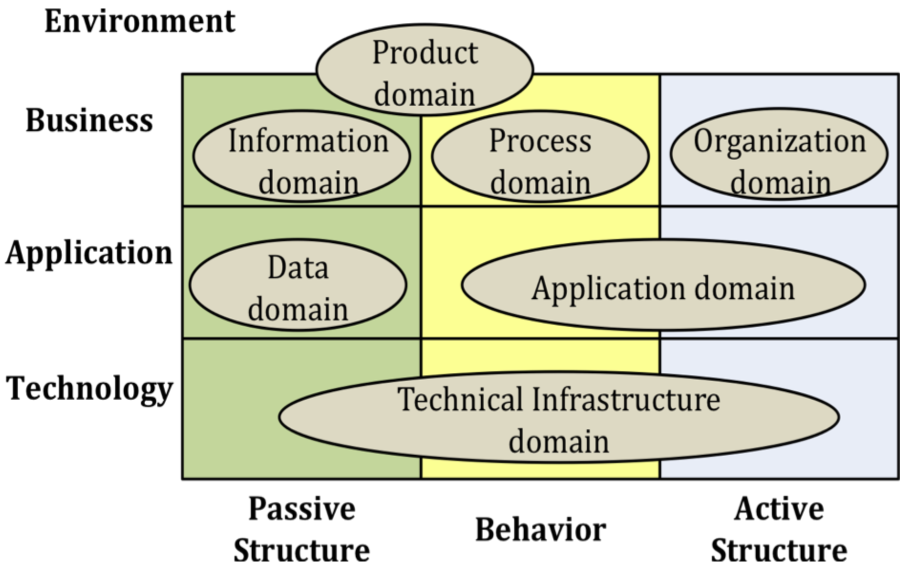


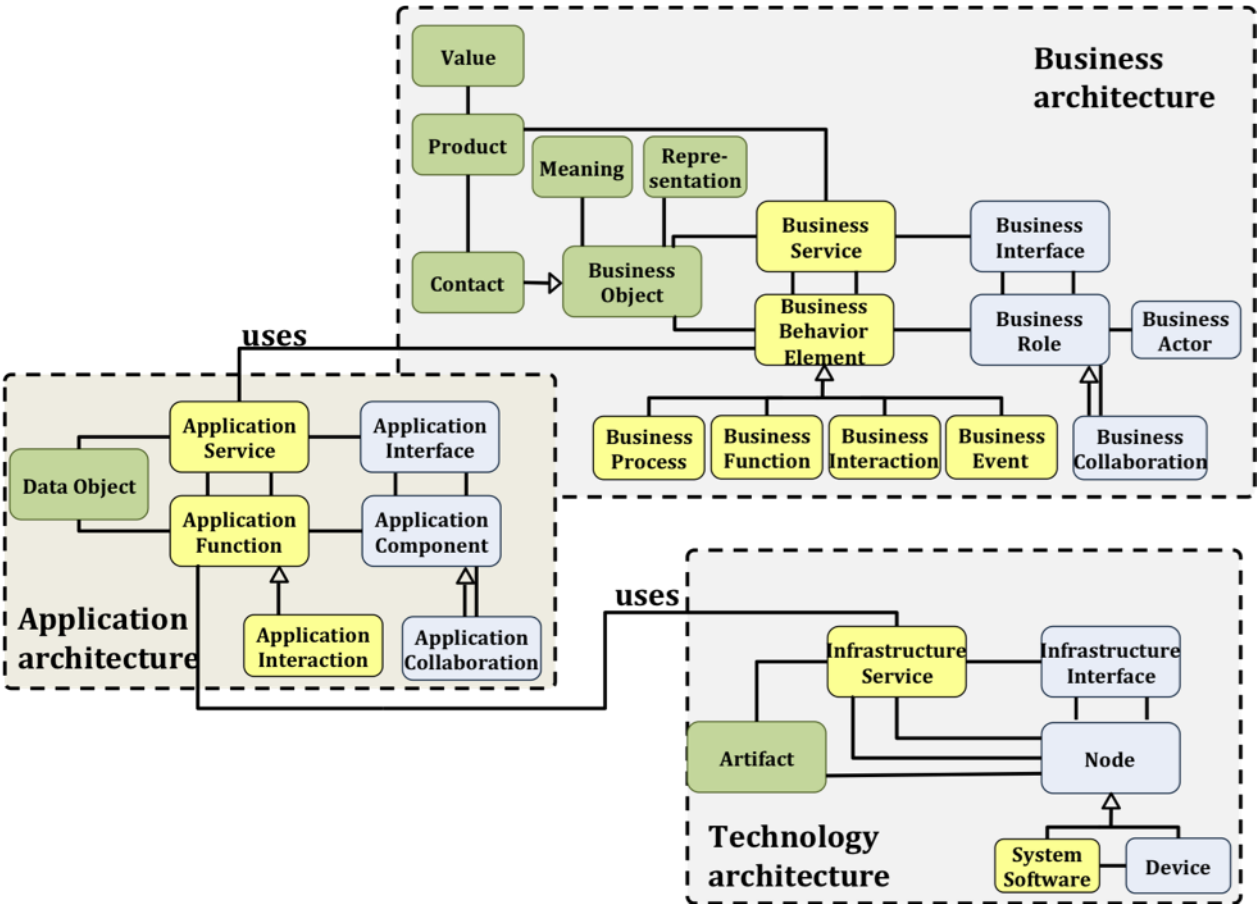
Figure 33: Mapping of GWAC dimensions onto Archimate

Figure 33 provides a representation of the different aspects form the GWAC stack and dimension onto the Archimate view for a reference architecture model. Figure 34 shows that additionally to the three main dimensions, finer viewpoints addressing more precise objects exist. Figure 35 shows how the model can be applied in a multi-dimensional view if e.g. an unbundled European utility must be modeled. This approach shows that existing, non-domain related views and methodologies can be applied in conjunction with the SGAM and its views.



413
414 **Figure 34: Archimate representation of the architectural viewpoints**

415



416
417 **Figure 35: interdependencies between the three most important dimensions with Archimate**

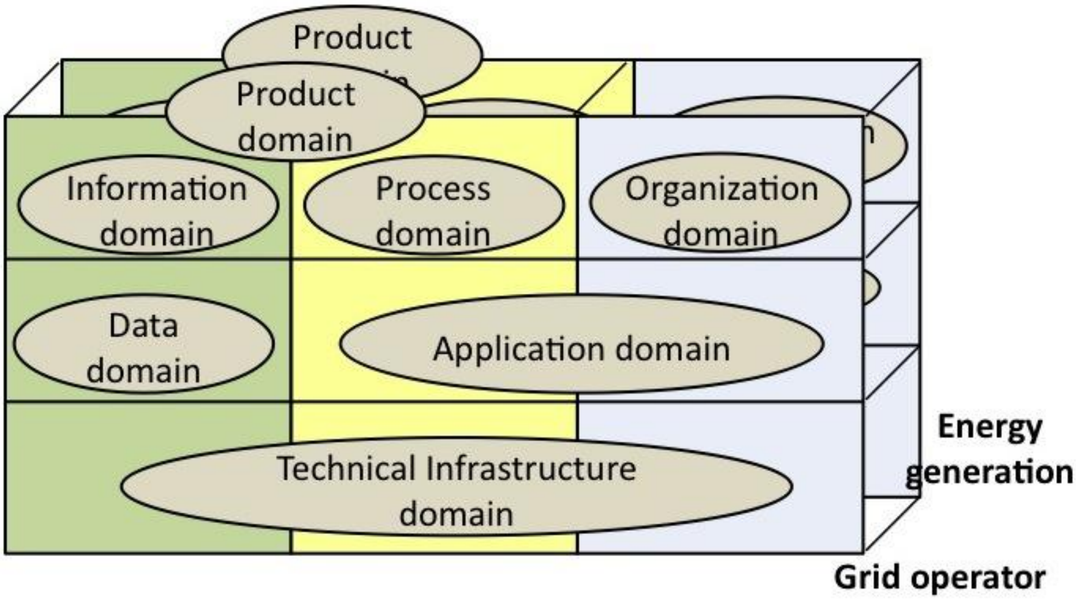


Figure 36: Multi-dimensional view for unbundled utility

B.2.6 Examples and Mappings of existing solutions

Possible examples on how the *SGAM* model can be applied to existing solutions and meta-models from ETSI or IEC can be seen in the following graphics. A mapping was made with respect to the existing models; in case of gaps - these need to be fixed or addressed in general.

B.2.6.1 Example: ETSI “M2M Architecture”

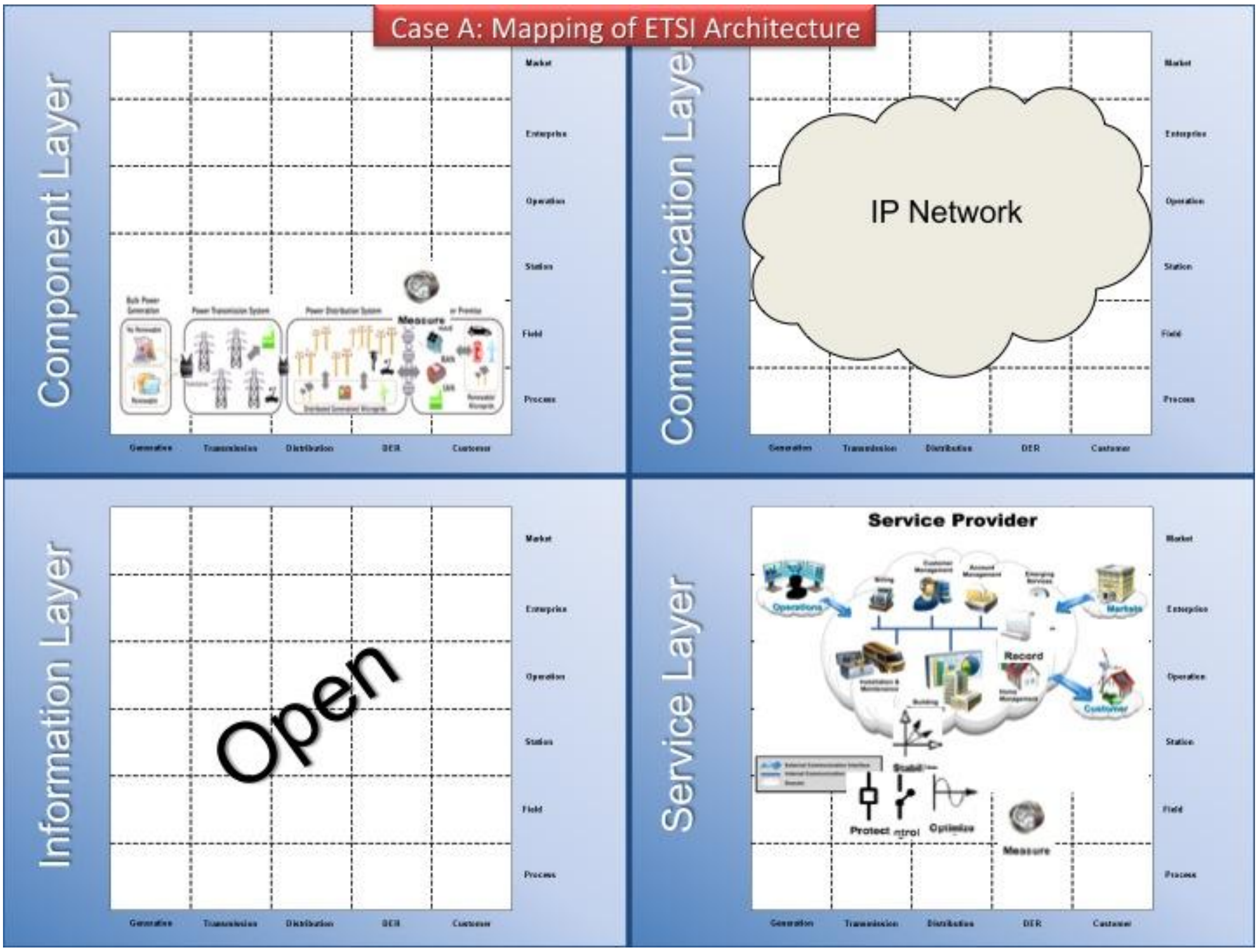


Figure 37: SGAM Mapping of ETSI M2M Architecture

Most of the issues could be directly addressed; a direct mapping for the information model was not possible.

B.2.6.2 Example: IEC SG3 “Mapping Chart”

Case B from the IEC SG 3 addresses the existing model from the IEC SG group which is also covered in the IEC roadmap and the standards mapping tool for smart grid solutions.

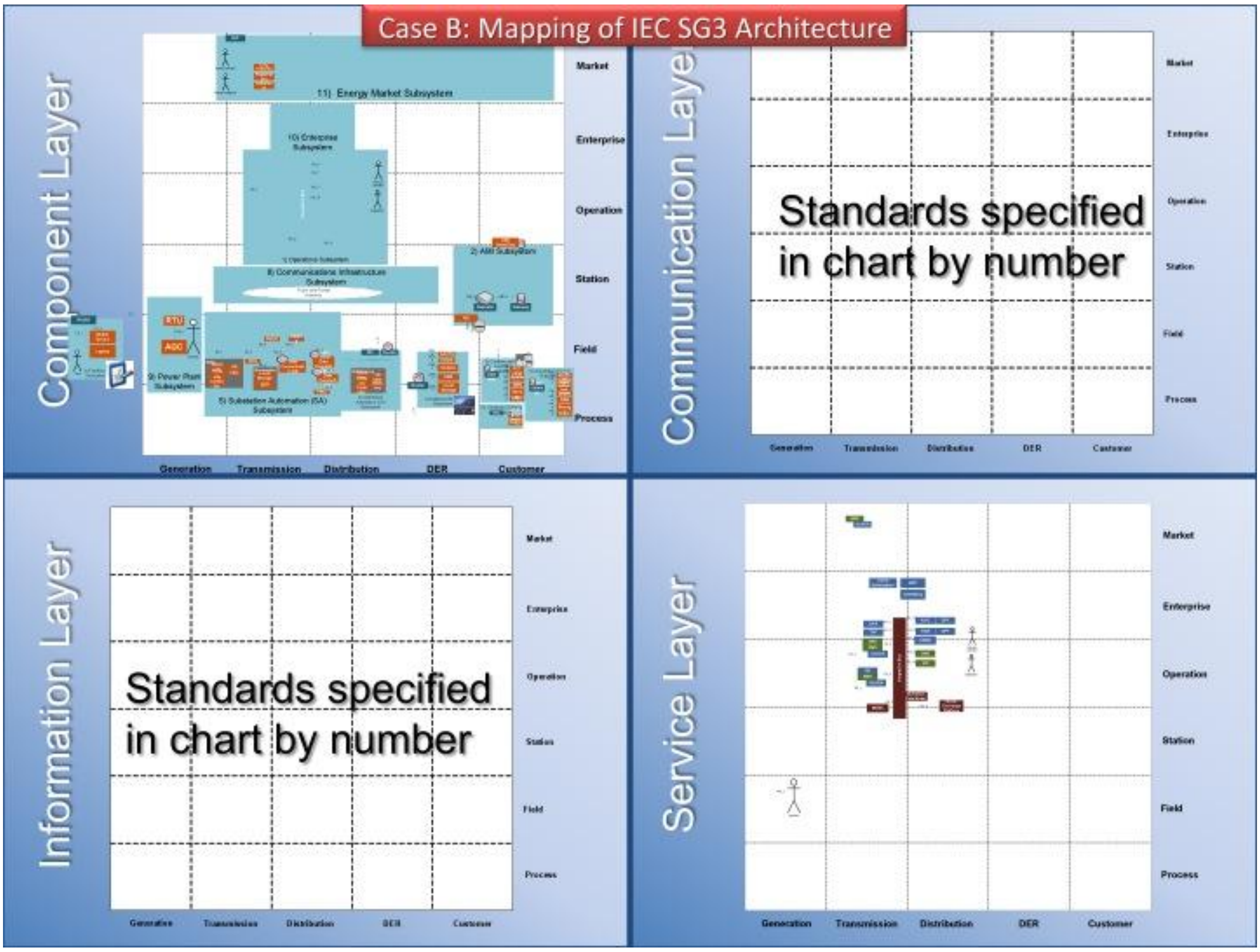


Figure 38: SGAM Mapping of IEC SG3 Mapping Chart

This example also shows that even information layers and their corresponding standards can be mapped if the original meta-model addresses the *SGAM* relevant viewpoint. The model is sliced just as the ETSI model; therefore, needed viewpoint for the different stakeholders (e.g. communications parts of existing models) can be easier identified.

B.2.6.3 Example: IEC TC57 "RA for Power System Information Exchange"

Last example is the existing seamless integration architecture (SIA) from the IEC TC 57 which covers all the relevant smart grid standards form TC 57 in a layered architecture and links to other relevant standards from TCs outside 57.

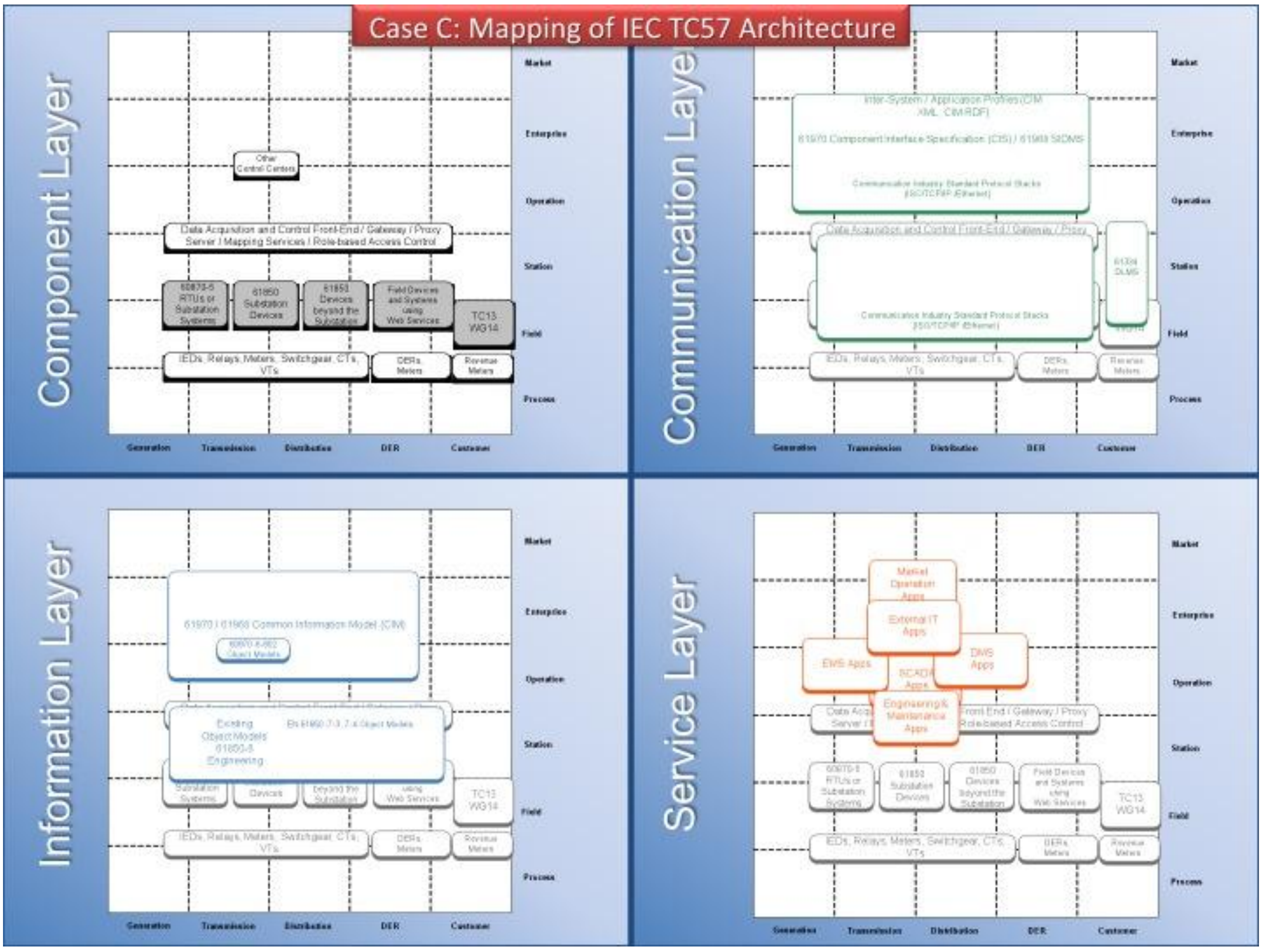


Figure 39: SGAM Mapping of IEC TC57 Reference Architecture for Power System Information Exchange

The SIA has taken most of the SGAM architectural viewpoints into account and provides for easy mapping onto SGAM.

B.2.7 Findings

As those, from an European perspective main relevant examples clearly show, is that the *SGAM* meta model with its viewpoints provides a proper way to represent existing solutions which have been developed by the various standardization bodies and stakeholder groups. One important additional conceptual model which should be taken into account fort his *SGAM* document is the NIST Conceptual model as international alignment of initiatives is of high interest. A future version will address this model.

The *SGAM* model provides, additionally, a good way of both categorizing existing models and identifying gaps. Categorizing in terms of finding out what the specific scope of an existing model is and, using this, finding out about is proper application and on the other hand, finding out what is missing and might need to be addressed.

B.2.8 Mapping of business transactions

Architectures in general provide services and functionality which is addressed by the corresponding technical or business processes. For the reference architecture, use cases with systems within this architecture are of highest importance. Starting at the function layer, the processes are mapped onto the *SGAM*, sub-functions are then distributed and things are drilled down to components, information and communication model. Using this, not only existing processes and use cases can be mapped onto the *SGAM* but also onto the existing reference architectures from IEC or ETSI and the *SGAM* can be used as alignment ontology for the processes and use cases between those models like common semantic mediator.

Annex C
Business Architecture and Conceptual Model

This Annex is introducing informative reference on the following elements:

- The new version of the European Smart Grids Conceptual Model that has been developed by the SG-CG/RA Work Group to take into account the comments on the previous version (v2.0) of this report as well as the need to address the Flexibility Concept. This version has not been introduced in the main section of this report for reasons explained in 6.3.5
- The European Harmonized Electricity Market Role Model and the list of Actors involved.
- A clarification of the relationship between the domains of the European Smart Grids Conceptual Model and the European Harmonized Electricity Market Role Model.

C.1 Conceptual Model

C.1.1 Introduction

The electrical energy system is currently undergoing a paradigm change, that has been affected by a change from the classical centralistic and top down energy production chain "Generation", "Transmission", "Distribution" and "Consumption" to a more decentralized system, in which the participants change their roles dynamically and interact cooperative. In the future decentralized energy system, distributed energy resources and consumers produces will become key elements. The development of the concepts and architectures for an European Smart Grid is not a simple task, because there are various concepts and architectures, representing individual stakeholders viewpoints. To imagine the paradigm change from the current situation to future situation, both situations are described below:

The current situation can best be described as:

- Supply follows demand
- One-way energy flow in the grid:
  bulk generation => transmission => distribution => consumption.
- Capacity in distribution networks is dimensioned on peak (copper plate), resulting in (almost) no network congestion
- Capacity required in the lower voltage range is predictable, since it is only based on energy usage.

The future situation can best be described as:

- Demand follows supply, due to the insertion of renewables, which are by nature of intermittent character
- Electrification of society in order to meet 202020 objectives, which will lead to a further growth of electricity demand
- Two way energy flow in the grid: consumers will also produce (e.g. by means of a photovoltaic cells, micro combined heat and power installations, etc.) and supply their surplus to the grid
- A future grid will need to support:
  - Multiple producing consumers, that will aggregate their electrical surplus to an Virtual Power Plant.
  - Electrical cars, in such a way that the grid won't fail when they want to charge simultaneously or use their batteries for energy storage to use in situations with high consumption or high production.
  - The integration of all kinds of distributed energy resources (wind, solar, …)

- A grid which will have to fulfill these requirements, not only by expanding grid capacity (which might become very costly due to the expected increase of peaks), but also by implementing smartness via ICT solutions, in a way that it will fully support current and future market processes.
- Furthermore a future grid will need the Smart Grid functions, described in the EG1 report of the CEN/CENELEC/ETSI Joint Working Group.

In the future situation it will have more and very different dynamics in the grid, as in the current situation, because the dynamics results from the distributed (renewable) energy resources, that behavior are difficult to predict. These increased dynamics will require a much more flexible (and intelligent) approach towards the management of electricity supply and demand. Furthermore, the future situation should also allow for new market models and let all kinds of customers participate in the trade of electricity energy.

Flexibility, thus, will be key. Where until today in the current “supply follows demand” model, flexibility was offered in bulk generation, in the future in the “demand follows supply” model the flexibility must be equivalent offered on both sides (generation (centralized and decentralized) and consumption (e.g. demand side management)).

Therefore the ICT infrastructure and ICT solutions, which enables the required flexibility on demand and supply side in a fully interchangeable way, becomes a key component of the smart grid and therefore it will be become part of the smart grid eco system.

This paragraph defines the conceptual model of the European smart grid. This conceptual model should be regarded as the initial “umbrella” model from which all future frameworks, architectures and standards could be derived from, and from which also existing standards could be (re) positioned. This conceptual model should also be able to act as a basis for future market models and related regulation, in order to guarantee that market models are supported by the right architectures and standards.

The Reference Architecture for the Smart Grid must support several stakeholders in building the European smart grid, and each stakeholder today has a different view on this smart grid. The more and more decentralized energy production requires new methods to guarantee the stable operation of the electrical part of the smart grid.

The development of the future smart grid requires the collaboration of different stakeholders. The future smart gird technology is the equivalent integration of power system management technology and information and communication technology (IT/OT convergence).

The conceptual model attempts to be the common framework, thereby enabling this convergence and facilitating the dialog between all these stakeholders, resulting in an aligned and consistent smart grid.

It is the basis of a common dictionary, necessary to talk the same language. The Conceptual Model will be this common dictionary and describe the key concepts in the European smart grid.

C.1.2 Historical context

A starting point for the development of a European conceptual model was the reuse of existing know-how to avoid redundant work and to build up on it. This led in the previous version of this report initially to the full adoption of the US conceptual model, defined by NIST. This model provides a high-level framework for the Smart Grid that defines seven high-level domains (Bulk Generation, Transmission, Distribution, Customers, Operations, Markets and Service Providers).

The NIST model shows all the communications and energy/electricity flows connecting each domain and how they are interrelated. Each individual domain is itself comprised of important smart grid elements (actors and applications) that are connected to each other through two-way communications and energy/electricity paths.

Due to strong European focus on decentralized energy generation, the original NIST model was extended by a new “Distributed Energy Resources” Domain (see 0), for the following reasons:

- Distributed Energy Resources require a new class of use cases
- In order to comply to future anticipated regulation and legislation explicit distinction of Distributed Energy Resources will be required
- Distributed Energy Resources represent the current situation

Consistent and clear criteria to separate the new DER Domain from the existing Domains, especially from Bulk Generation and the Customer Domain were identified.

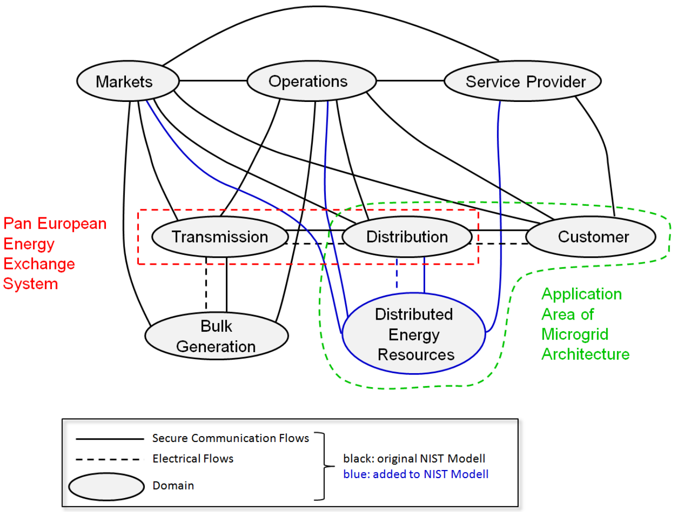


Figure 40: EU extension of the NIST Model

Review comments and discussion on the M490 report version 2.0 led to the insight that a rigid separation of the DER domain from the customers domain, would actually create complexity and would rule out required flexibility that emerges in the energy transition from customers both consuming and producing energy.

As a result of these discussions it was decided that the European conceptual model should incorporate/ enable the flexibility concept that was defined by SG-CG/SP.

<u>The European Flexibility Concept</u>

The objective of the flexibility concept, shown in Figure 41, is to describe the flexibility (demand and generation) methods for technical and commercial operations.

Figure 41: Flexibility concept (result of WGSP)

In the flexibility concept the management (control) of flexible demand and supply is fully interchangeable at the Smart Grid Connection Point (SGCP); in principle any connected party (Smart Customer) with flexible generation, consumption and/or storage.

In the elaboration of the flexibility model commercial and technical flexibilities are identified, leading to commercial flexibilities for interaction with the market (e.g. contracts, pricing) and technical flexibilities (control signals, technical information exchange) for interaction with grid operations. This is shown in Figure 42.

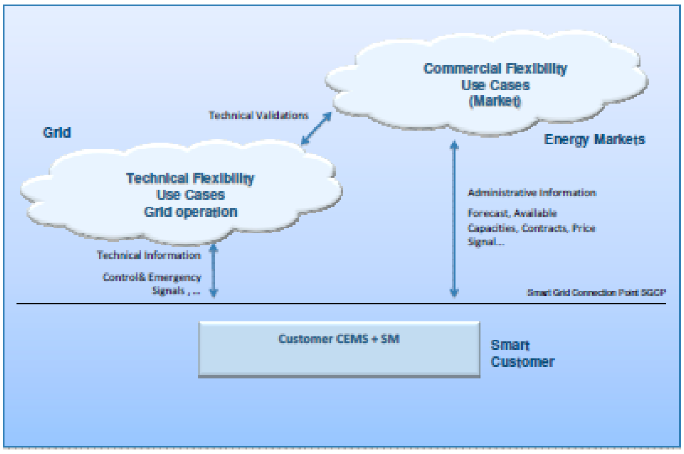


Figure 42: Technical & commercial flexibilities

With the historical background in mind, as described above, this led to the formulation of starting principles and to a clear definition of an (evolved) European Conceptual Model, addressing all stakeholders' interests.

C.1.3 Starting Principles

Defining a European conceptual model, from which architectures and standards can be derived, requires explicit starting principles, to be used as acceptance criteria for the Conceptual Model. These starting principles are described in this paragraph.

The evolution of the European Conceptual Model in a way that it is aligned with the rather technical aspects of the extended NIST Model and with the rather future energy markets aspects of the SG-

CG/SP Flexibility Concept is guaranteed by the following approach and procedure, which is based on the 5 principles below.

Approach
Domains are a grouping of roles and actors. So roles and actors in the domains of both models can be used as a fix point for the alignment of the models. To identify the same roles and actors in the domains of both models, the European harmonized electricity market role model will be used. The alignment is based in detail on the following 5 principles, which form the basis for the development of the EU Conceptual Model (described in C.1.4).

Principle 1: Extract business roles and system actors from the EU extended NIST conceptual model

The EU extension of the NIST conceptual model is organized in domains. These domains group business roles and thereby system actors which perform tasks in these roles as shown in Figure 43. This figure illustrates the meta-model used for the European conceptual model for Smart Grids.

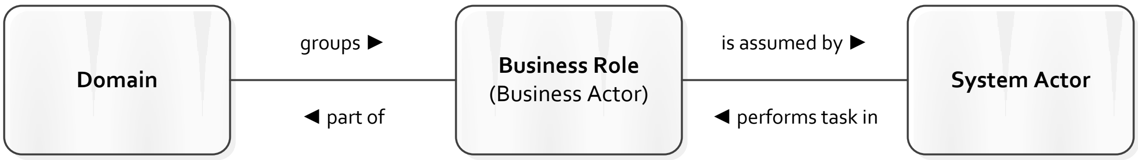


Figure 43: Meta-model for the European conceptual model for Smart Grids

The approach to model the conceptual model based on business roles and related system actors ensures ‘compatibility’ between market and technologies/standards. Section 6.1 provides a more detailed description of this approach.

Principle 2: Alignment with the European electricity market

In the WGSP flexibility model, the business roles are based on the European harmonized electricity market role model, developed by ENTSO-E, ebIX and EFET and defined in [ENTSO-E 2011]. This ensures alignment of technologies/standards which are developed from this model with the European electricity market. The grouping of roles of the harmonized electricity market role model into the domains of the WGSP flexibility model supports initial understanding of the European electricity market (at a higher level of abstraction than the 36 roles identified in [ENTSO-E 2011]).

Principle 3: Support central and distributed power system deployments

The EU conceptual model (described in the next part) must support fully centralized, fully distributed and hybrid deployments of the power system. Energy resources connected to all levels of the grid are relevant in Smart Grids, ranging from bulk generation and industrial loads down to distributed energy resources and domestic loads. Also support for grids outside the traditional public infrastructure should be supported, as e.g. analyzed in the use cases of the workgroup on sustainable processes from the SG-CG. Examples include (non-public) grids used in local energy cooperatives, ranging from industrial areas (sea- and airports) to agricultural areas (e.g. in the greenhouse sector).

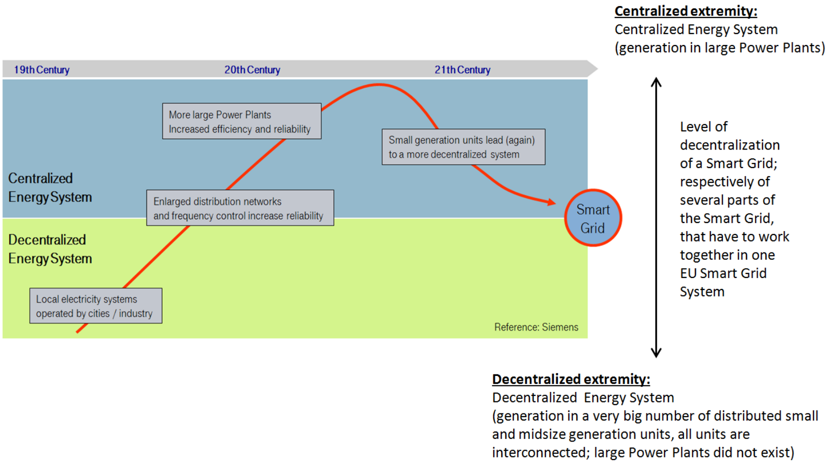


Figure 44: Evolution of centralized/ decentralized power systems deployments

Principle 4: Support micro grids and a Pan European Energy Exchange System (PEEES)

The objective of micro grids is to start the optimization of the grid as locally as possible, e.g. to find a balance between production and consumption, in order to avoid transmission losses and increase transmission reliability through ancillary services such as reserves volt/var support, and frequency support. For other objectives to be met for micro grids see also use case WGSP-0400.

PEEES are essential to realizing the large-scale energy balance between regions with a low-loss wide-area power transmission.

The Pan European Energy Exchange System (PEEES), includes technologies in the transport network for low-loss wide-area power transmission systems (e. g. high-voltage direct current transmission, HVDC), better realizing the large-scale energy balance between the regions, which is essential due to the constantly changing weather situation, which has a significant influence on the power generation capacity of different regions.

The PEEES is here to be understood as a abstract model for further discussions to cover the concepts for low-loss wide-area power transmission systems. As an example of this, the "Modular Development Plan of the Pan-European Transmission System 2050" of the e-HIGHWAY2050 Project Consortium can be mentioned here. [ENTSO-E 2012]

Principle 5: Support providing flexibility in electricity supply and demand

Providing flexibility in electricity supply and demand – on all levels in the power system – is paramount for integration of renewable energy sources in the Smart Grid. The EU conceptual model must support the use cases identified by the workgroup on sustainable processes on providing and using flexibility.

C.1.4 European Conceptual Model of Smart Grids

The definition of the European conceptual model of Smart Grids is defined through grouping of (European harmonized) roles and system actors, in line with the European electricity market. Figure 45 depicts the European conceptual model for the Smart Grid. The model consists of four main domains, *Operations*, *Grid Users, Markets, and Energy Services*.

Each of these domains contains one or more subdomains which group roles which can be identified in the European electricity market. For this the European harmonized electricity market role model developed by ENTSO-E, ebIX and EFET is used as defined in [ENTSO-E 2011] and introduced in C.2. Detailed definitions of the domains of the European conceptual model for the Smart Grid and the relationship to the role model used is provided annex C.2

Operations and *Grid Users* are domains which are directly involved in the physical processes of the power system: electricity generation, transport/distribution and electricity usage. Also, these domains include (embedded) ICT enabled system actors. The *Markets* and *Energy Services* domains are defined by roles and (system) actors and their activities in trade of electricity products and services (markets), and the participation in the processes of trade and system operations representing grid users (energy services).

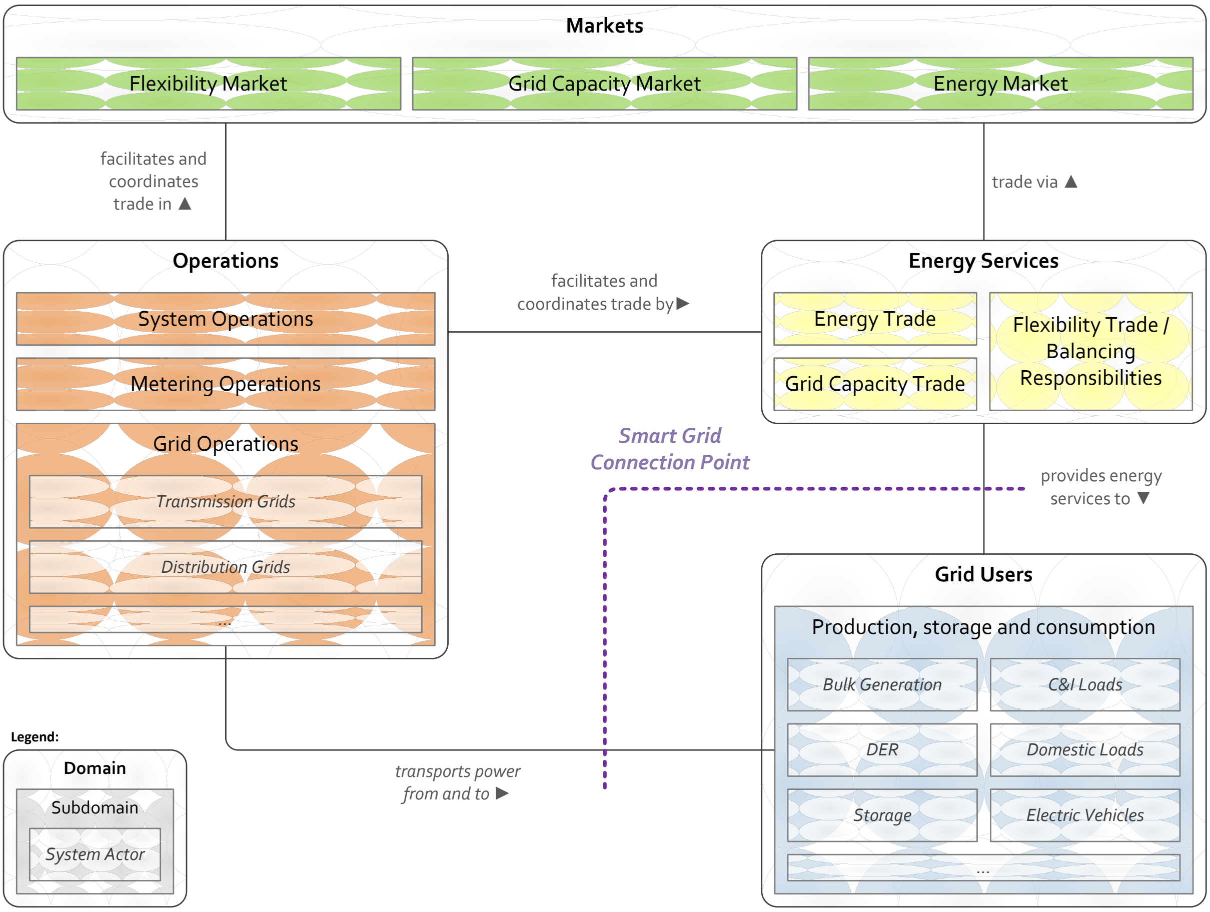


Figure 45: European Conceptual Model for the Smart Grid

Operations

The *Operations* domain is defined by roles and actors related to the stable and safe operations of the power system; the domain ensures the usage of the grid is within its constraints and facilitates the activities in the market. *Grid Operations*, *System Operations* and *Metering Operations* are identified as sub-domains in the *Operations* domain. System actors in this domain include grid assets such as transformers, switchgear, etc. in *Transmission* and *Distribution Grids*, metering systems and control centre systems.

Grid Users

The *Grid Users* domain is defined by roles and actors involved in the generation, usage and possibly storage of electricity; from bulk generation and commercial and industrial loads down to distributed energy resources, domestic loads, etc. The roles and actors in this domain use the grid to transmit and distribute power from generation to the loads. Apart from roles related to the generation, load and storage assets, the *Grid Users* domain includes system actors such as (customer) energy management and process control systems.

Energy Services

The *Energy Services* domain is defined by roles and actors involved in providing energy services to the *Grid Users* domain. These services include trading in the electricity generated, used or stored by the *Grid Users* domain, and ensuring that the activities in the Grid Users domain are coordinated in e.g. the system balancing mechanisms and CIS systems.

Through the *Energy Services* domain the *Grid Users* domain is connected to activities such as trade and system balancing. From the *Grid Users* domain, flexibility in power supply and demand is provided. This flexibility is used for system balancing (through e.g. ancillary services, demand response, etc.) and trading on the market. Also roles are included which are related to trade in grid capacity (as currently is traded on the transmission level).

Example (system) actors in this domain include systems for customer relationship management, and billing, trading systems, etc.

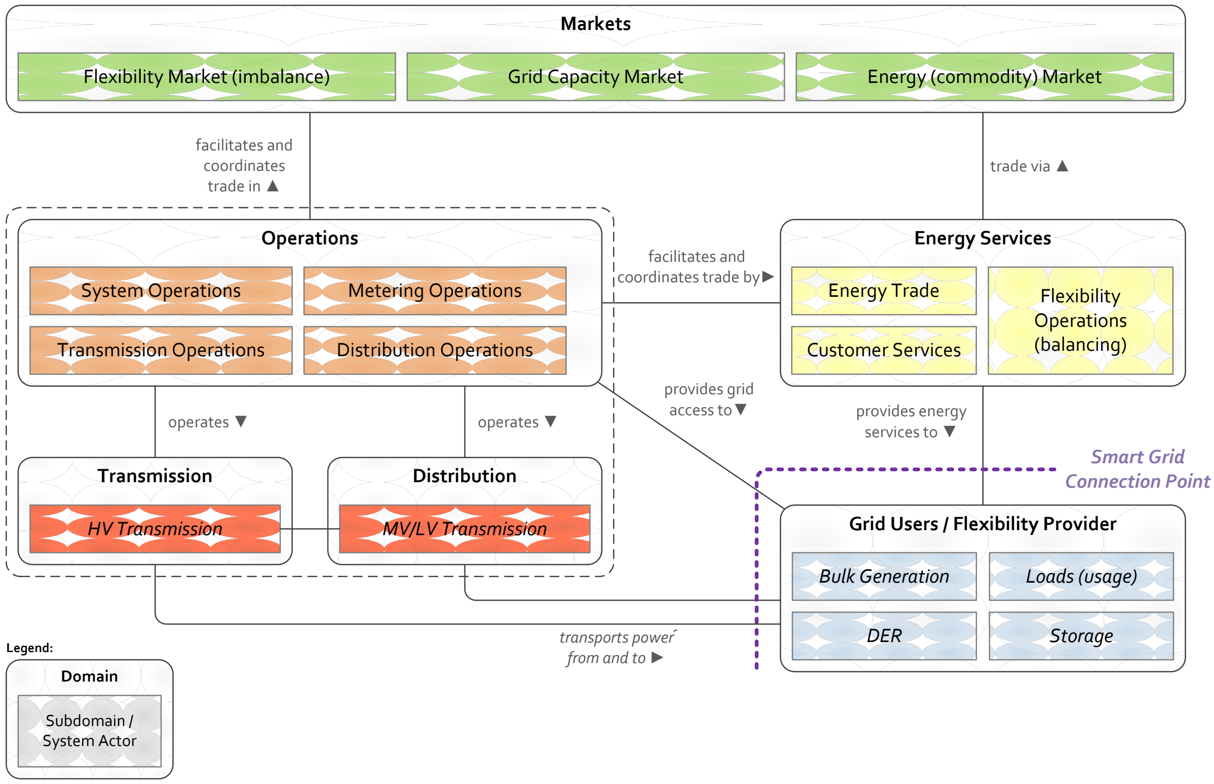
I.e. the roles and actors from the *Energy Services* domain facilitate participation in the electricity system, by representing the *Grid Users* domain in operations (e.g. balance responsibility) and markets (trading).

Markets

The *Market* domain is defined by roles and actors which support the trade in electricity (e.g. on day ahead power exchanges) and other electricity products (e.g. grid capacity, ancillary services). Sub domains which are identified in this domain are: *Energy Market, Grid Capacity Market*, and *Flexibility Market*. Activities in the *Market* domain are coordinated by the *Operations* domain to ensure the stable and safe operation of the power system. Example (system) actors in this domain are trading platforms.

C.1.4.1 Alternative Figure: European Conceptual Model for the Smart Grid

The figure below is provided as a possible alternative for Figure 45*. The main difference is in presentation: 1) in the grouping of grid assets (by introducing the transmission and distribution domains which only contains system actors) and 2) in different naming of the domains* Grid Users *and* Energy Services*. This is to be discussed in the next meeting of the architecture workgroup in Bilbao. The essence is the same as the figure above, however for commitment a graphical representation is chosen to accommodate more were we are coming from.*



Alternative Figure: European Conceptual Model for the Smart Grid

The table below shows which domains contain business actors and which contain system actors in this alternative figure.

Table C-1: Mapping of domains to roles and actors

Domain	*ENTSO-E role*	*Business Actor*	*System Actor*
Market	+	+	+
Operations	+	+	+
Service Provider	+	+	+
Flexibility Provider	+	+	+
Transmission	*n/a*		+
Distribution	*n/a*		+

C.1.5 Alignment

This paragraph identifies and describes the required alignment with other relevant initiatives/ activities that are required for building a smart grid based on standards and common reference architectures.

C.1.5.1 Alignment with the EU flexibility concept

In the energy transition, Europe is focusing on managing flexibility of demand and supply. This concept of flexibility is elaborated in the M490 WGSP, resulting in several related use cases. These use cases on ‘providing flexibility’ concern control/management of flexible demand & supply.

Flexibility in demand and supply is provided by ‘smart customers. In the conceptual model as described in paragraph C.1.4 this is reflected by the *Grid Users* domain, which provides flexibility. This flexibility is used by parties related to grid/power system management and electricity markets.

Operating this flexibility is performed by an actor 'Flexibility Operator'. In annex xx this use case is analyzed in the context of the European Harmonized Electricity Market Role Model (HEM-RM) which underpins the European conceptual model for Smart Grids. The Flexibility Operator relates to one of various roles in the *Energy Services* domain. Depending on the type of interaction with the 'smart customers' in the use cases of WGSP, the Flexibility Operator acts in the *Resource Provider*, *Balance Responsible Party, Balance Supplier* or *Grid Access Provider* role from [ENTSO 2011].

In the flexibility market flexibility in demand and supply (interchangeable) will be traded, by services providers with balance responsibilities that have access to this (wholesale) market.

C.1.5.2 Alignment with SG-CG/SP on Sustainable Processes

The SG-CG/SP Work Group on Sustainable Processes, in collecting use cases, has defined generic use cases. The deliverables coming from WG SP from these uses cases are:

- Actors (business actors and system actors)
- Identification and interaction between actors
- Processes
- Technical requirements

Based on these deliverables, SG-CG/RA is able to identify existing standards via the SGAM framework (see 7.2), to be possible modified and used in the smart grid standards. In future work a more refined functional architecture with well-defined interfaces and services definitions between market parties will be defined. Since actors and transaction between actors will form the basis for this reference architecture, alignment is guaranteed.

In the future smart grid eco system a well-defined interaction between the capacity market and the energy market will be crucial. The traffic light concept as defined by WGSP will form the basis for this. This interaction will be modeled between roles (and subsequently parties) as identified in the EU Harmonized Electricity Market Role Model, leading to required information exchange on the Smart Grid Connection Point (SGCP), being the information interface between the grid users' domain and the other domains.

C.1.5.3 Alignment with NIST, SGIP, SGAC

Since market models in US and EU differ, it is important to derive standards which are, as much as possible, market model independent. Also the Harmonized Electricity Market Role Model as defined by ENTSO-E/ebIX/EFET is currently not used in the US. Alignment therefore is created and maintained on the basis of common actor list and interactions between actors, driven from use case analysis. From this common International standards can be derived and interoperability is achieved. There for even if the market models and the conceptual model differ (grouping of roles and actors), the same standards may be applicable (although priorities may differ). (The alignment of actor lists and interactions between actors is currently on going work extended into 2013).

C.1.5.4 Alignment with Harmonized Electricity Market Role Model

The Harmonized Electricity Market role model has been picked up for use, both by WGSP as WGRA, leading to a consistent and solid approach for all future modeling exercises. From discussion within the M490 groups, as well in market model discussions (EG3) new roles in this model may become necessary. It therefore will be required to come to working arrangements with ENTSO-E on this, in order to establish adequate version control of the Harmonized Electricity Market Role Model.

C.1.5.5 Alignment with EU market model developments (EG3)

In the EU standardization activities, the Harmonized Electricity Market Role Model (HEM-RM) is promoted to be used to map responsibilities of market parties to the harmonized roles. This means that the interaction between actors, as defined by WGSP and translated to interaction between roles, can define the interaction between market parties.

The task force smart grid (EG3) recommended the EU commission that in the market model discussions, whatever the outcome will be, the roles & responsibilities of market parties, related to the market models, will be mapped onto the HEM-RM roles. In this way interaction between actors and roles can be translated tot interaction between market parties.

In this way it becomes clear which standards on interfaces and business services are required, and is alignment between market model development and M490 standards.

C.1.6 Conclusions

As a conclusion from the above:

- The conceptual model is solid and well defined, based on roles and actors
- It accommodates the flexibility concept
- It bridges the 2 approaches/cultures coming from power system management and IT technology; it forms a common ground for cooperation.
- It accommodates alignment between M/490 Standardization activities and market model discussions
- It identifies the way alignment should be reached with US (NIST, SGIP, SGAC)

C.2 The European Harmonized Electricity Market Role Model

The text in this section is an excerpt taken from the [ENTSO-E 2011] Harmonized Electricity Market Role Model, and included for informational purpose. Please refer to the original document for more detailed information on this role model.

A “Role Model” provides a common definition of the roles and domains employed in the electricity market which enables people to use a common language in the development of information interchange.

A party on the market may play several roles, for example a TSO frequently plays both the role of System Operator and the role of Imbalance Settlement Responsible. However two different roles have been defined since these roles are not always played by the same party. Even in a large organisation the roles may not be played by the same business unit. Consequently it is necessary to clearly define the roles in order to be in a position to correctly use them as required. It is important to differentiate between the roles that can be found on a given marketplace and the parties that can play such roles. ENTSO-E and the associated organisations have identified a given role whenever it has been found necessary to distinguish it in an information interchange process.

The model consequently identifies all the roles that intervene in the exchange of information in the electricity market. These roles define the external interfaces managed by a party for given processes. It also identifies the different domains that are necessary in the electricity market for information interchange. A domain represents a grouping of entities with common characteristics.

The objective of decomposing the electricity market into a set of autonomous roles and domains is to enable the construction of business processes where the relevant role *participates to satisfy a specific transaction. Business processes should be designed to satisfy the requirements of the roles and not of the parties.*

C.2.1 Role model – role definitions

The table below quotes the definitions from [ENTSO-E 2011] of all the roles in the European harmonized electricity market role model.

Role	**Description**
Balance Responsible Party	A party that has a contract proving financial security and identifying balance responsibility with the Imbalance Settlement Responsible of the Market Balance Area entitling the party to operate in the market. This is the only role allowing a party to nominate energy on a wholesale level. *Additional information*: The meaning of the word “balance” in this context signifies that that the quantity contracted to provide or to consume must be equal to the quantity really provided or consumed. Equivalent to “Program responsible party” in the Netherlands. Equivalent to “Balance group manager” in Germany. Equivalent to “market agent” in Spain.
Balance Supplier	A party that markets the difference between actual metered energy consumption and the energy bought with firm energy contracts by the Party Connected to the Grid. In addition the Balance Supplier markets any difference with the firm energy contract (of the Party Connected to the Grid) and the metered production. *Additional information*: There is only one Balance Supplier for each Accounting Point.
Billing Agent	The party responsible for invoicing a concerned party.
Block Energy Trader	A party that is selling or buying energy on a firm basis (a fixed volume per market time period).
Capacity Coordinator	A party, acting on behalf of the System Operators involved, responsible for establishing a coordinated Offered Capacity and/or NTC and/or ATC between several Market Balance Areas.
Capacity Trader	A party that has a contract to participate in the Capacity Market to acquire capacity through a Transmission Capacity Allocator. *Note*: The capacity may be acquired on behalf of an Interconnection Trade Responsible or for sale on secondary capacity markets.
Consumer	A party that consumes electricity. *Additional information*: This is a Type of Party Connected to the Grid.

Role	**Description**
Consumption Responsible Party	A party who can be brought to rights, legally and financially, for any imbalance between energy nominated and consumed for all associated Accounting Points. *Additional information*: This is a type of Balance Responsible Party.
Control Area Operator	Responsible for : 1. The coordination of exchange programs between its related Market Balance Areas and for the exchanges between its associated Control Areas. 2. The load frequency control for its own area. 3. The coordination of the correction of time deviations.
Control Block Operator	Responsible for : 1. The coordination of exchanges between its associated Control Blocks and the organisation of the coordination of exchange programs between its related Control Areas. 2. The load frequency control within its own block and ensuring that its Control Areas respect their obligations in respect to load frequency control and time deviation. 3. The organisation of the settlement and/or compensation between its Control Areas.
Coordination Center Operator	Responsible for : 1. The coordination of exchange programs between its related Control Blocks and for the exchanges between its associated Coordination Center Zones. 2. Ensuring that its Control Blocks respect their obligations in respect to load frequency control. 3. Calculating the time deviation in cooperation with the associated coordination centers. 4. Carrying out the settlement and/or compensation between its Control Blocks and against the other Coordination Center Zones.
Grid Access Provider	A party responsible for providing access to the grid through an Accounting Point and its use for energy consumption or production to the Party Connected to the Grid.
Grid Operator	A party that operates one or more grids.
Imbalance Settlement Responsible	A party that is responsible for settlement of the difference between the contracted quantities and the realised quantities of energy products for the Balance Responsible Parties in a Market Balance Area. *Note*: The Imbalance Settlement Responsible has not the responsibility to invoice. The Imbalance Settlement Responsible may delegate the invoicing responsibility to a more generic role such as a Billing Agent.

Role	Description
Interconnection Trade Responsible	Is a Balance Responsible Party or depends on one. He is recognised by the Nomination Validator for the nomination of already allocated capacity. *Additional information*: This is a type of Balance Responsible Party.
Market Information Aggregator	A party that provides market related information that has been compiled from the figures supplied by different actors in the market. This information may also be published or distributed for general use. *Note*: The Market Information Aggregator may receive information from any market participant that is relevant for publication or distribution.
Market Operator	The unique power exchange of trades for the actual delivery of energy that receives the bids from the Balance Responsible Parties that have a contract to bid. The Market Operator determines the market energy price for the Market Balance Area after applying technical constraints from the System Operator. It may also establish the price for the reconciliation within a Metering Grid Area.
Meter Administrator	A party responsible for keeping a database of meters.
Meter Operator	A party responsible for installing, maintaining, testing, certifying and decommissioning physical meters.
Metered Data Aggregator	A party responsible for meter reading and quality control of the reading.
Metered Data Collector	A party responsible for the establishment and validation of metered data based on the collected data received from the Metered Data Collector. The party is responsible for the history of metered data for a Metering Point.
Metered Data Responsible	A party responsible for the establishment and qualification of metered data from the Metered Data Responsible. This data is aggregated according to a defined set of market rules.
Metering Point Administrator	A party responsible for registering the parties linked to the metering points in a Metering Grid Area. He is also responsible for maintaining the Metering Point technical specifications. He is responsible for creating and terminating metering points.
Merit Order List (MOL) Responsible	Responsible for the management of the available tenders for all Acquiring System Operators to establish the order of the reserve capacity that can be activated.

Role	**Description**
Nomination Validator	Has the responsibility of ensuring that all capacity nominated is within the allowed limits and confirming all valid nominations to all involved parties. He informs the Interconnection Trade Responsible of the maximum nominated capacity allowed. Depending on market rules for a given interconnection the corresponding System Operators may appoint one Nomination Validator.
Party Connected to the Grid	A party that contracts for the right to consume or produce electricity at an Accounting Point.
Producer	A party that produces electricity. *Additional information*: This is a type of Party Connected to the Grid.
Production Responsible Party	A party who can be brought to rights, legally and financially, for any imbalance between energy nominated and produced for all associated Accounting Points. *Additional information*: This is a type of Balance Responsible Party.
Reconciliation Accountable	A party that is financially accountable for the reconciled volume of energy products for a profiled Accounting Point.
Reconciliation Responsible	A party that is responsible for reconciling, within a Metering Grid Area, the volumes used in the imbalance settlement process for profiled Accounting Points and the actual metered quantities. *Note*: The Reconciliation Responsible may delegate the invoicing responsibility to a more generic role such as a Billing Agent.
Reserve Allocator	Informs the market of reserve requirements, receives tenders against the requirements and in compliance with the prequalification criteria, determines what tenders meet requirements and assigns tenders.
Resource Provider	A role that manages a resource object and provides the schedules for it.
Scheduling Coordinator	A party that is responsible for the schedule information and its exchange on behalf of a Balance Responsible Party. For example in the Polish market a Scheduling Coordinator is responsible for information interchange for scheduling and settlement.

Role	Description
System Operator	A party that is responsible for a stable power system operation (including the organization of physical balance) through a transmission grid in a geographical area. The System Operator will also determine and be responsible for cross border capacity and exchanges. If necessary he may reduce allocated capacity to ensure operational stability. Transmission as mentioned above means “the transport of electricity on the extra high or high voltage network with a view to its delivery to final customers or to distributors. Operation of transmission includes as well the tasks of system operation concerning its management of energy flows, reliability of the system and availability of all necessary system services”. (Definition taken from the ENTSO-E RGCE Operation handbook Glossary). *Note*: additional obligations may be imposed through local market rules.
Trade Responsible Party	A party who can be brought to rights, legally and financially, for any imbalance between energy nominated and consumed for all associated Accounting Points. *Note*: A power exchange without any privileged responsibilities acts as a Trade Responsible Party. *Additional information*: This is a type of Balance Responsible Party.
Transmission Capacity Allocator	Manages the allocation of transmission capacity for an Allocated Capacity Area. For explicit auctions: The Transmission Capacity Allocator manages, on behalf of the System Operators, the allocation of available transmission capacity for an Allocated capacity Area. He offers the available transmission capacity to the market, allocates the available transmission capacity to individual Capacity Traders and calculates the billing amount of already allocated capacities to the Capacity Traders.

C.3 Relationship between the domains of the conceptual model and the European harmonized electricity market role model

Figure 46 below shows the relationship between the domains of the conceptual model and the European harmonized electricity market role model.

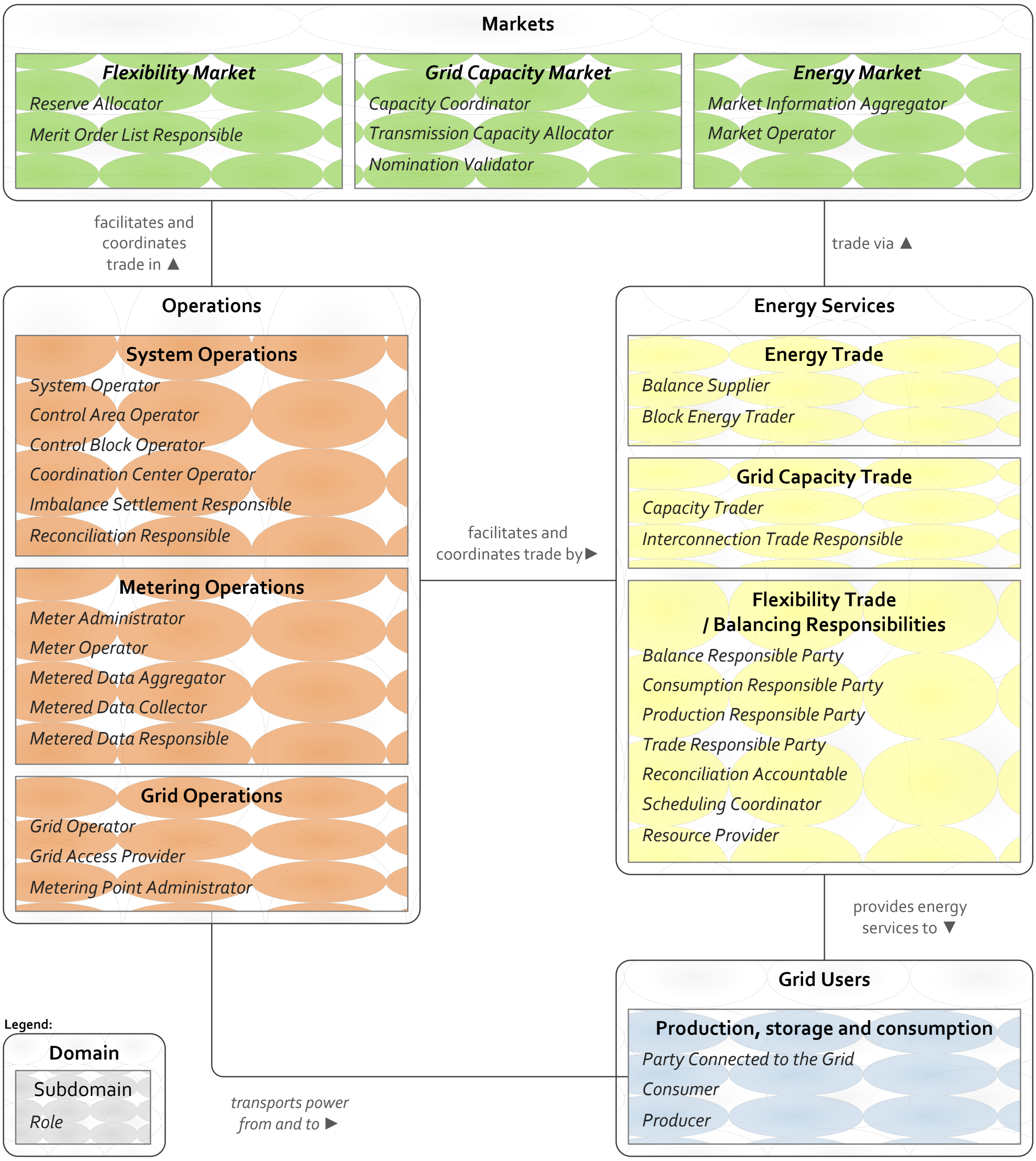


Figure 46: Relationship between the domains of the conceptual model and the European harmonized electricity market role model

Note that in the figure above, the Billing Agent role is not included in the relationship between domains of the conceptual model and the harmonized electricity market roles due to its generic nature. In [ENTSO-E 2011] the Billing Agent role is not associated to any other role.

C.4 Relation between the flexibility operator actor and the European harmonized electricity market role model

The use cases identified by the SG-CG/SP Sustainable Processes Work Group on 'providing flexibility' concerns control/management of flexible demand & supply. In these use case, flexibility in demand and supply is provided by 'smart customers', for usage in use cases related to e.g. system balancing, network constraint management, voltage / var optimization, network restoration and black start, power flow stabilization, market balancing.

I.e. the flexibility is used by parties related to grid / power system management and/or electricity markets. Pooling of this flexibility is performed by a so called 'Flexibility Operator'. The flexibility use cases cover several means of interacting with 'smart customers', including:

- Communication of price signals, tariffs and other economic incentives
- Explicit trade in flexibility in demand and/or supply
- Direct control of demand and/or supply

Although analyzed in combination in the flexibility use case, distinguishing between these approaches allows for better analysis in relation to the European electricity market. Below, each of these approaches is analyzed further in relationship to the organizational structure of the European electricity market.

The figures used throughout the analysis below show roles and their associations from the European harmonized electricity market role model and how they relate to actors and their associations from the use case. This is graphically represented according to the legend as shown in Figure 47.

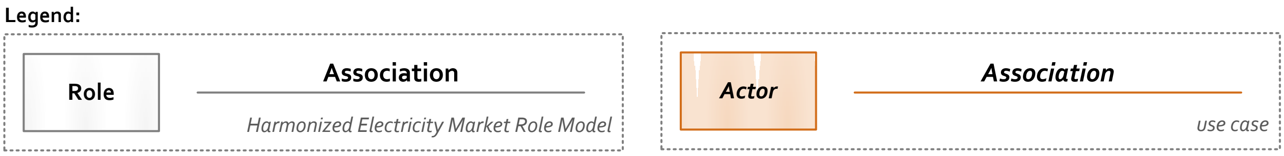


Figure 47: Legend used in analysis of relation between the flexibility operator actor and the European harmonized electricity market role model

C.4.1 Communication of price signals, tariffs and other economic incentives

Economic incentives can be given to parties connected to the grid, primarily based on state of the grid or market. Within [ENTSO-E 2011], parties connected to the grid are 'associated' to the market through the Balance Supplier role and connect to grid operations through the Grid Access Provider role. Figure 48 provides a visualization of this mapping.

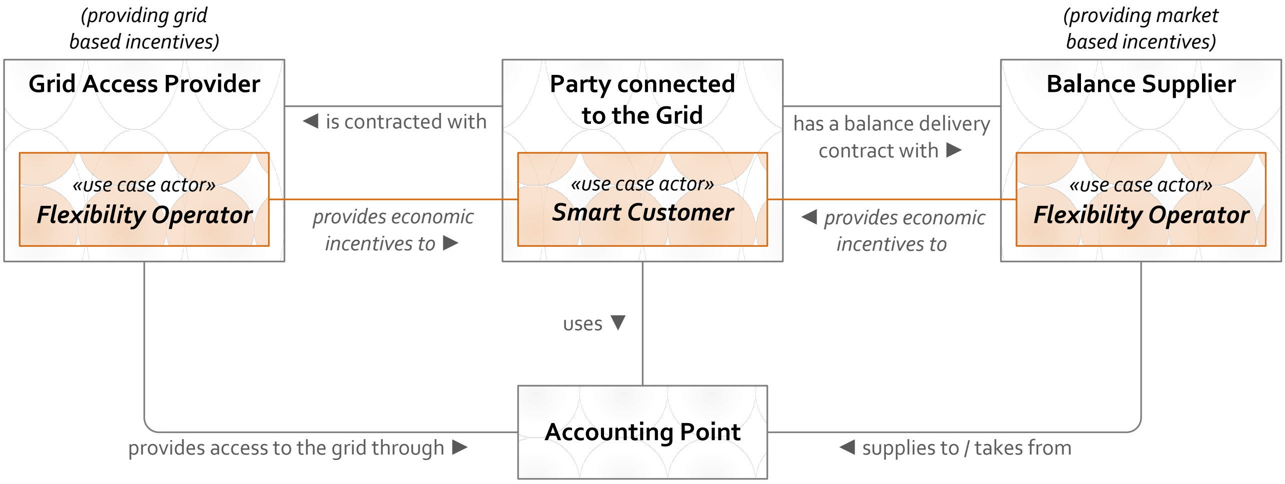


Figure 48: Economic incentives in the flexibility use cases in relation to European electricity market

C.4.2 Explicit trade in flexibility in demand and/or supply

The explicit trade in flexibility is closely related to the mapping of the use case wherein the Flexibility Operator performs direct control; with the major differences that the ‘smart customer’ moves in the value chain in the sense that it now takes the Resource Provider role itself instead of the Flexibility Operator. This mapping is visualized in Figure 49.

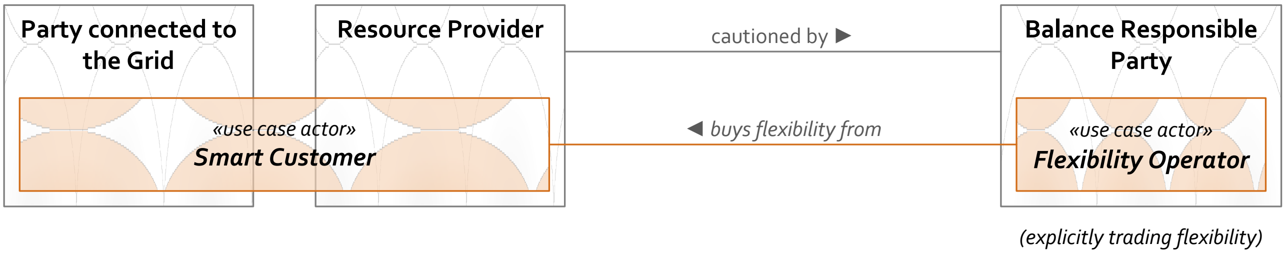


Figure 49: Explicit trade in flexibility in relation to European electricity market

C.4.3 Direct control of demand and/or supply

Within [ENTSO-E 2011] the role of Resource Provider is identified, actors with this role take part in system operations by providing reserve (balancing) services, by up/down regulation of ‘resource (or reserve) objects’ under its control. In case of direct control, the Flexibility Operator can be considered performing the Resource Provider role. The mapping of this use case to the roles of [ENTSO-E 2011] is visualized in Figure 50.

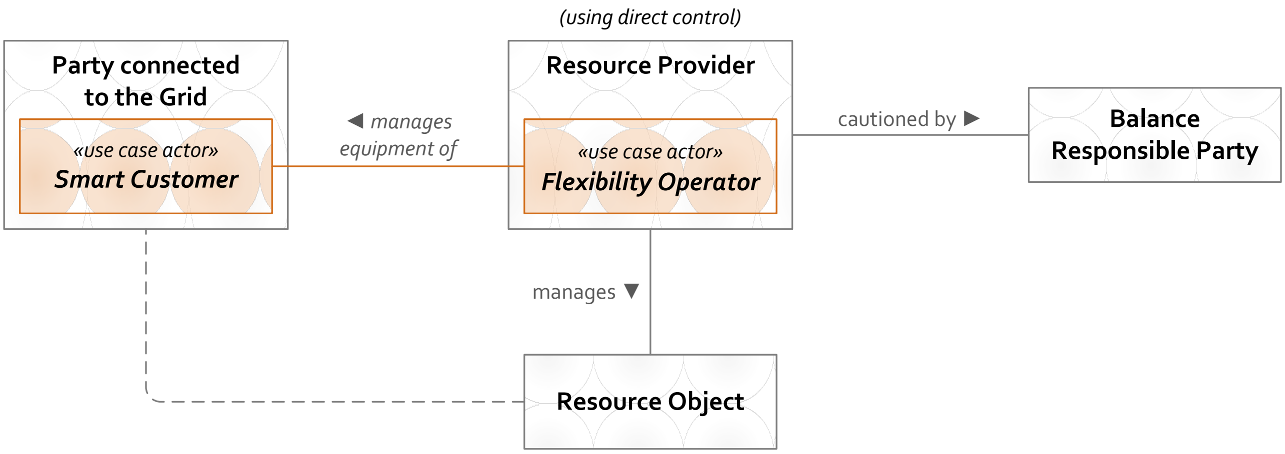


Figure 50: Direct control of demand and/or supply use case in relation to European electricity market

Note: the relationship between Party connected to the Grid and Resource Provider is not defined in [ENTSO-E 2011]. The relationship between Resource Object (a domain from [ENTSO 2012], not to be mistaken with the organizational domains of the European conceptual model) and the Party connected to the Grid is assumed.

Note: the Flexibility Operator in its role of Resource Provider connects to power system management and the market via another party (or by itself) performing the Balance Responsible Party role.

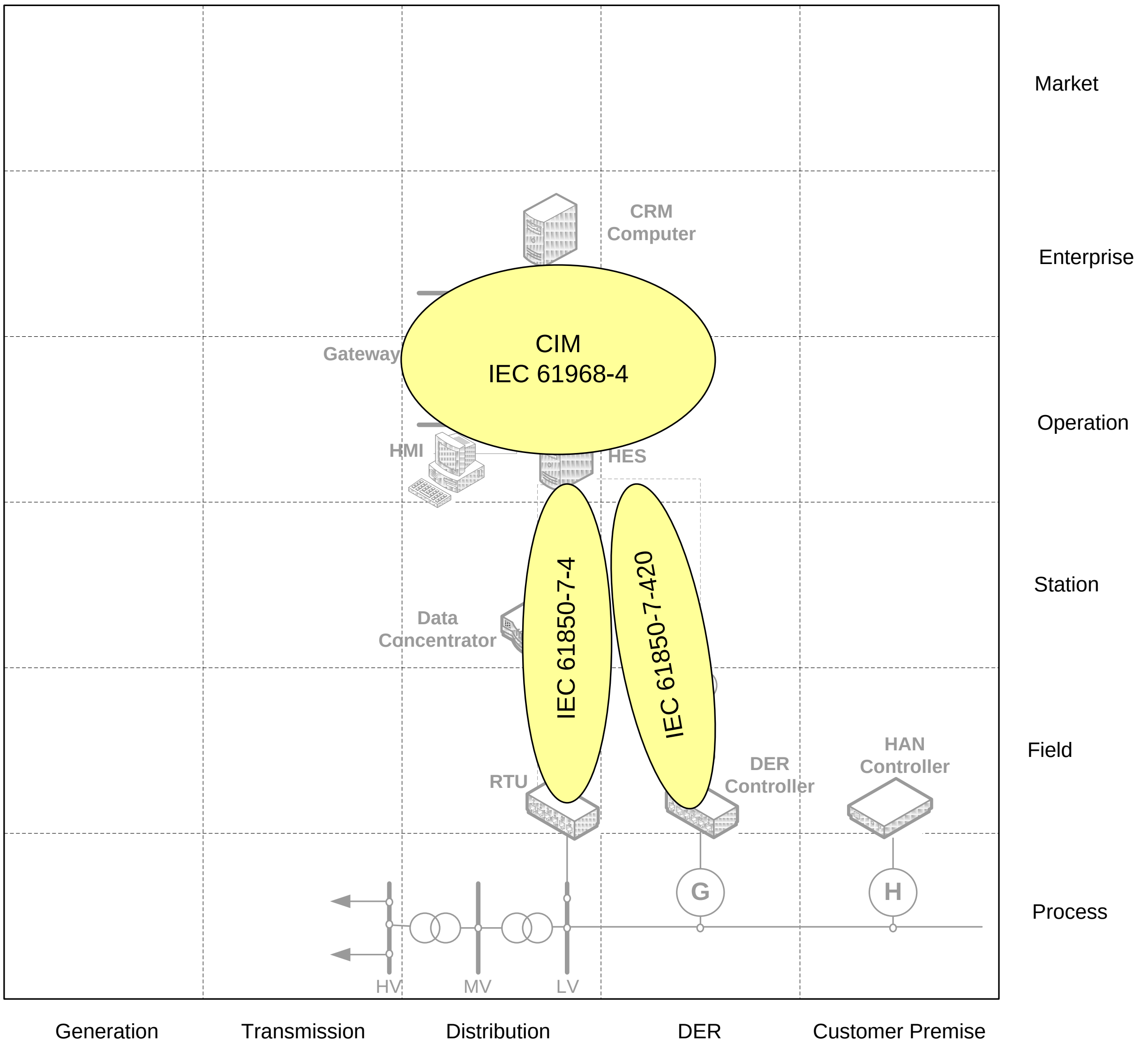
Annex D
Functional Architecture

969 This section will be filled if applicable or necessary.

Annex E
Information Architecture

Within the SGAM, one particular aspects of the layer is the level of data exchanged between the various layers. The particular focus of the layer within the SGAM is the meaningful representation and localization of the data models, abstract communication system interfaces towards the communication layer and the functional (system) layers implementing the logics and the smart grid component using standards and data models.

The Information layer is intended to show data models that are used by the sub-functions in order to fulfill the use case. Within section 5 of this document, the SGAM use case has already outlined the application of the mapping as depicted in the next graphic.



In addition to the standards already used and depicted, the JWG report form CEN/CENELEC and ETSI [3] and its annex 6 have already outlined the needed data model standards which will also be

[3] JWG report on standards for smart grids, version 1.0

evaluated from the view of the first set of standards group. Harmonization on the view of data integration technology vs. system/sub-system taxonomy of FSS 2.0 report is envisioned for version 3 of this SG-CG/RA report.

For this version of the report, relevant data models already identified are the following ones which will be mapped onto the SGAM domain/zones plane (note: subject to further extension):

- Mapping of IEC 61850 Common Data Classes on IEC 60870-5-104 (IEC 61850-80-1 TS)
- OASIS EMIX
- UN/CEFACT CCTS
- EN 60870-6-802:2002 + A1:2005, *Telecontrol equipment and systems – Part 6-802: Telecontrol protocols compatible with ISO standards and ITU-T recommendations – TASE.2 Object models*
- EN 60870-5-1:1993, *Telecontrol equipment and systems – Part 5: Transmission protocols – Section 1: Transmission frame formats*
- EN 60870-5-3:1992, *Telecontrol equipment and systems – Part 5: Transmission protocols – Section 3: General structure of application data*
- IEC 61850-7-410 Ed. 1.0, *Communication networks and systems for power utility automation – Part 7-410: Hydroelectric power plants – Communication for monitoring and control*
- IEC 61850-7-420, *Communication networks and systems for power utility automation – Part 7-420: Basic communication structure – Distributed energy resources logical nodes*
- IEC 61400-25-2, *Communications for monitoring and control of wind power plants – Part 25-2: Information models*
- IEC 61400-25-3, *Communications for monitoring and control of wind power plants – Part 25-3: Information exchange models*
- IEC 61400-25-6, *Communications for monitoring and control of wind power plants – Part 25-6 Communications for monitoring and control of wind power plants: Logical node classes and data classes for condition monitoring*
- IEC 62056 series, *Electricity metering – Data exchange for meter reading, tariff and load control*, Parts 21, 31, 41, 42, 46, 47, 51, 52, 53, 61, 62
- IEC 61334, *Distribution automation using distribution line carrier systems* – Part 4 Sections 32, 511, 512, Part 5 Section 1
- EN 61970-301:2004, *Energy management system application program interface (EMS-API) – Part 301: Common information model (CIM) base*
- EN 61970-402:2008 Ed. 1.0, *Energy management system application program interface (EMS- API) – Part 402: Component interface specification (CIS) – Common services*
- EN 61970-403:2007, *Energy management system application interface (EMS- API) – Part 403: Component Interface Specification (CIS) – Generic Data Access*
- EN 61970-404:2007, *Energy management system application program interface (EMS-API) – Part 404: High Speed Data Access (HSDA))*
- EN 61970-405:2007, *Energy management system application program interface (EMS-API) – Part 405: Generic eventing and subscription (GES)*
- EN 61970-407:2007, *Energy management system application program interface (EMS-API) – Part 407: Time series data access (TSDA)*
- EN 61970-453:2008, *Energy management system application interface (EMS- API) – Part 453: CIM based graphics exchange*
- EN 61970-501:2006, *Energy management system application interface (EMS- API) – Part 501: Common information model resource description framework (CIM RDF) Schema*
- EN 61968-:2004, Application integration at electric utilities – System interfaces for distribution management – Part 3: Interface for network operations
- EN 61968-4:2007, Application integration at electric utilities – System interfaces for distribution management – Part 4: Interfaces for records and asset management

- EN 61968-9:2009, System Interfaces For Distribution Management – Part 9: Interface Standard for Meter Reading and Control
- FprEN 61968-11:2010, System Interfaces for Distribution Management – Part 11: Distribution Information Exchange Model
- EN 61968-13:2008, System Interfaces for distribution management – CIM RDF Model Exchange Format for Distribution
- IEC 61850-5 Ed. 1.0, *Communication networks and systems in substations – Part 5: Communication requirements for functions and device models*
- IEC 61850-6 Ed. 1.0, *Communication networks and systems in substations – Part 6: Configuration description language for communication in electrical substations related to IEDs*
- IEC 61850-7-1 Ed. 1.0, *Communication networks and systems in substations – Part 7-1: Basic communication structure for substation and feeder equipment – Principles and models*
- IEC 61850-7-2 Ed. 1.0, *Communication networks and systems in substations – Part 7-2: Basic communication structure for substation and feeder equipment – Abstract communication service interface (ACSI)*
- IEC 61850-7-3 Ed. 1.0, *Communication networks and systems in substations – Part 7-3: Basic communication structure for substation and feeder equipment – Common data classes*
- IEC 61850-7-4 Ed. 1.0, *Communication networks and systems in substations – Part 7-4: Basic communication structure for substation and feeder equipment – Compatible logical node classes and data classes*
- IEC 62325-301 Ed.1.0 : Common Information Model Market Extensions
- IEC 62325-501 Framework for energy market communications - Part 501: General guidelines for use of ebXML
- IEC 62325-351 Framework for energy market communications - Part 351: CIM European Market Model Exchange Profile
- IEC 62325-502 Framework for energy market communications - Part 502: Profile of ebXML

Annex F
Communication Architecture

This section is provided as a separate document.

Annex G
Bibliography

The following references are made in the main body of the Report:

[Dänekas 2011] Christian Dänekas, Sebastian Rohjans, Carsten Wissing, Hans-Jürgen Appelrath: Future Energy Grid" - Migration Paths into the Internet of Energy, In: Proceedings of the eChallenges Conference (e-2011),

[Jonkers 2010] TOGAF 9 and ArchiMate 1.0 White paper, The Open Group 2010

[Uslar et al 2012] Mathias Uslar, Michael Specht, Sebastian Rohjans, Jörn Trefke, Jose M Gonzalez: The Common Information Model CIM: IEC 61970, 61968 and 62325, Springer Heidelberg, 2012

The following references are made in Annex F:

OPEN meter. Energy Project No 226369. Funded by EC

Cenelec TC205 new working group WG18 Kick of Presentation 24.11.2011

CEN-CENELEC-ETSI Smart Grid Coordination Group

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SG-CG/M490/C_Smart Grid Reference Architecture

Annex F
Communication Architecture

(Version 3.0)

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v0.5	24/01/2012	First TR external version for SG-CG “Sanity Check”
v1.0	02/03/2012	First Interim TR draft for official comments
v2.0	31/07/2012	Second interim TR draft for official comments
v3.0	**15/11/2012**	**Final TR Annex E for adoption by M/490**

Main changes in this version

The document has been deeply changed, in particular with an entirely new structure.

It has also a new Annex number, due to the changes to the main part of the Reference Architecture 3.0 Report.

1 References

It should be noted that the SG-CG First Set of Standards Work Group report [SG-CG/B] provides a list of references that may include most of the references below. In case of doubt on the applicable referenced documents, the [SG-CG/B] list prevails.

References

[1] OPEN meter. Energy Project No 226369. Funded by EC

[7] CENELEC TC205 new working group WG18 Kick of Presentation 24.11.2011

[57] IEEE ISPLC2007 - Standards & Regulations Framework for LV-MV-HV Powerline Communication Systems – Pisa, 2007 ITALY.

[60] IEC TC57 – Working Group 20 works.

[61] CLC SC205A – Working Groups 9 and 10 works.

[62] CIRED – Communication Requirements for Smart Grids – Frankfurt, June 2011, GERMANY

[63] ADDRESS EC FP7 Project – http://portal.addressfp7.org/

[66] A Standardized and Flexible IPv6 Architecture for Field Area Networks

[67] Cisco Gridblocks architecture for Smart Grid

List of standards

[1] ISO/IEC 7498-1:1994; Information Technology – Open Systems Interconnect – Basic Reference Model: The Basic Model

[2] ITU-T I.322 (02/99); Generic protocol reference model for telecommunication networks

[3] IETF RFC5654 Requirements of an MPLS Transport Profile

[4] IETF RFC5921 A Framework for PLS in Transport Networks

[5] CEN/CENELEC/ETSI JWG report on standards for smart grids – V1.0

[6] CEN/CENELEC/ETSI First set of standards – V1.0

[8] IETF RFC 6272: Internet Protocols for the Smart Grid. http://www.rfc-editor.org/rfc/rfc6272.txt

[9] IETF RFC 5086: Structure-Aware Time Division Multiplexed (TDM) Circuit Emulation Service over Packet Switched Network (CESoPSN)

[10] IETF RFC4553: Structure-Agnostic Time Division Multiplexing (TDM) over Packet (SAToP)

[11] IEEE P1901.2 Standard for Low Frequency (less than 500 kHz) Narrow Band Power Line Communications for Smart Grid Applications

[12] IEEE 802.11: a list of standards is available under this link http://standards.ieee.org/about/get/802/802.11.html

[13] IEEE 802.3: a list of standards is available under this link http://standards.ieee.org/about/get/802/802.3.html

[14] IEEE 802.16: a list of standards is available under this link http://standards.ieee.org/about/get/802/802.16.html

[15] IEEE 802.15.4: a list of standards is available under this link http://web.archive.org/web/20080224053532/http://shop.ieee.org/ieeestore/Product.aspx?product_no=SS95552

[16] ETSI 102 887
- Electrocompatibility and radio spectrum Matters (ERM); Short Range Devices; Smart Metering Wireless Access Protocol (SMEP). Part 1; PHY Layer
- Electrocompatibility and radio spectrum Matters (ERM); Short Range Devices; Smart Metering Wireless Access Protocol (SMEP). Part 2; MAC Layer

[17] RFC 4919: IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals

[18] IETF roll: a list of Internet RFC is available under: http://tools.ietf.org/wg/roll/

- IETF RFC 6550: RPL IPv6 Routing Protocol for Low-Power and Lossy Network
- IETF RFC 6551: ROLL routing metrics
- IETF RFC 6552: ROLL objective Function Zero
- IETF RFC 6206: ROLL Trickle
- draft-ietf-roll-minrank-hysteresis-of -11 2012-06-30 RFC Ed Queue
- draft-ietf-roll-security-framework
- draft-ietf-roll-p2p-measurement
- draft-ietf-roll-p2p-rpl
- draft-ietf-roll-trickle-mcast

[19] EN 50090:

- EN 50090-2-1:1994 : System overview-Architecture
- EN 50090-3-1:1994 : Aspects of application-Introduction to the application structure
- EN 50090-3-2:1995 : Aspects of application-User process
- EN 50090-3-2:2004 : Aspects of application-User process for HBES Class 1
- EN 50090-4-1:2004 : Media independent layers-Application layer for HBES Class 1
- EN 50090-4-2:2004 : Media independent layers–Transport layer, network layer and general parts of datalink layer for HBES Class 1
- EN 50090-5-1:2005 : Media and media dependent layers-Power line for HBES Class 1
- EN 50090-5-2:2004 : Media and media dependent layers-Network based on HBES Class1, TwistedPair
- EN 50090-7-1:2004 : System management-Management procedures

[20] LTE3GPP TS 36.300 Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 http://www.3gpp.org/ftp/Specs/html-info/36300.htm

- TS 36.201 Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description.
- TS 36.211 Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation.
- TS 36.212 Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding.
- TS 36.213 Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures.
- TS 36.214 Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; Measurements.
- TS 36.216 Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer for relaying operation
- 3GPP TS 23.401 General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access
- 3GPP TS 22.368 Service requirements for Machine-Type Communications (MTC); Stage 1
- TR 23.888 System improvements for Machine-Type Communications (MTC)Service requirements for Machine-Type Communications (MTC);
- 3GPP TS 23.682 Architecture Enhancements to facilitate communications with Packet Data Networks and Applications
- 3GPP TS 24.312. Access Network Discovery and Selection Function (ANDSF) Management Object (MO)
- 3GPP TS 23.402 Architecture Enhancements for Non-3GPP Accesses (Release 10)

[21] G.991.1 High bit rate digital subscriber line (HDSL) transceivers
[22] G.991.2 Single-pair high-speed digital subscriber line (SHDSL) transceivers
[23] G.992.1 Asymmetric digital subscriber line (ADSL) transceivers

[24] G.992.2 Splitterless asymmetric digital subscriber line (ADSL) transceivers
[25] G.992.3
[26] G.992.4 Splitterless asymmetric digital subscriber line transceivers 2 (splitterless ADSL2)
[27] G.993.1 Very high speed digital subscriber line transceivers (VDSL)
[28] G.993.2 Very high speed digital subscriber line transceivers 2 (VDSL2)
[29] G.993.5 Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers
[30] G.994.1 Handshake procedures for digital subscriber line (DSL) transceivers
[31] G.995.1 Overview of digital subscriber line (DSL) Recommendations
[32] G.996.1 Test procedures for digital subscriber line (DSL) transceivers
[33] G.996.2 Single-ended line testing for digital subscriber lines (DSL)
[34] G.997.1 Physical layer management for digital subscriber line (DSL) transceivers
[35] G.998.1 ATM-based multi-pair bonding
[36] G.998.2 Ethernet-based multi-pair bonding
[37] G.998.3 Multi-pair bonding using time-division inverse multiplexing
[38] G.999.1 Interface between the link layer and the physical layer for digital subscriber line (DSL) transceivers
[39] G.998.4 Improved Impulse Noise Protection (INP) for DSL Transceivers
[40] G.983.1: Broadband optical access systems based on Passive Optical Networks (PON)
[41] G.983.2: ONT management and control interface specification for B-PON
[42] G.983.3: A broadband optical access system with increased service capability by wavelength allocation
[43] G.983.4: A broadband optical access system with increased service capability using dynamic bandwidth assignment
[44] G.983.5: A broadband optical access system with enhanced survivability
[45] G.984.1: Gigabit-capable passive optical networks (GPON): General characteristics
[46] G.984.2: Gigabit-capable Passive Optical Networks (G-PON): Physical Media Dependent (PMD) layer specification
[47] G.984.3: Gigabit-capable Passive Optical Networks (G-PON): Transmission convergence layer specification
[48] G.984.4: Gigabit-capable passive optical networks (G-PON): ONT management and control interface specification
[49] G.984.5: Gigabit-capable Passive Optical Networks (G-PON): Enhancement band
[50] G.984.6: Gigabit-capable passive optical networks (GPON): Reach extension
[51] G.984.7: Gigabit-capable passive optical networks (GPON): Long reach
[52] G.987.1: 10-Gigabit-capable passive optical networks (XG-PON): General requirements
[53] G.987.2: 10-Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification
[54] G.987.3: 10-Gigabit-capable passive optical networks (XG-PON): Transmission convergence (TC) layer specification
[55] G.709: Interfaces for the Optical Transport Network (OTN)

[56] IETF RFC 4090: Fast Reroute Extensions to RSVP-TE for LSP Tunnels, http://www.ietf.org/rfc/rfc4090.txt

[58] IEC 62488-1 (Formerly EN60663) - Part 1: Planning of analogue and digital power line carrier systems operating over EHV/HV/MV electricity grids.

[59] IEC 61334-4-1 - Distribution automation using distribution line carrier systems - Part 4: Mains. Data communication protocols - Section 1: Reference model of the communication system.
[68] G.707 : Network node interface for the synchronous digital hierarchy (SDH)
[69] G.7042: Link capacity adjustment scheme for virtual concatenated signals.

[70] G.7041: Generic Framing Procedure (GFP)

[71] G.803: Architecture of transport networks based on the synchronous digital hierarchy (SDH)

[72] G.783: Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks

[73] ISO/IEC 14908:
- ISO/IEC 14908-1: Control network protocol stack
- ISO/IEC 14908-2: Twisted-pair channel for networked control systems
- ISO/IEC 14908-3: Power Line channel in the EN 50065-1 CENELEC C-Band
- ISO/IEC 14908-4: Transporting over Internet Protocol (IP) networks
- ETSI TS 103 908: Power Line channel in the EN 50065-1 CENELEC A-Band

[74] ITU- T G 9955 / 56 Narrow-band OFDM power line communication transceivers

[75] W3C REC-xml-20001006, Extensible Markup Language (XML) 1.0

[76] W3C WD-ws-arch-20021114, Web Services Architecture

[77] W3C REC-xml-names, Name spaces in XML

[78] IETF RFC 2616Hypertext Transfer Protocol -- HTTP/1.1

[79] W3C RECsoap12-part1-20070427, SOAP Version 1.2 Part 1: Messaging Framework

[80] W3C REC-soap12-part2-20070427, SOAP Version 1.2 Part 2: Adjuncts, Section 7: SOAP HTTP Binding,

[81] OASIS, wsdd-soapoverudp-1.1-spec-pr-01, OASIS Standard, SOAP-over-UDP

[82] IETF RFC 5246The Transport Layer Security (TLS) Protocol, Version 1.2

[83] W3C REC-ws-addrcore-20060509, Web Services Addressing 1.0

[84] W3C RECws-addr-soap-20060509, Web Services Addressing 1.0 - SOAP Binding

[85] OASIS, wsdd-discovery-1.1-spec-os, Web Services Dynamic Discovery (WS-Discovery)

[86] W3C, SUBM-WSEventing-20060315, Web Services Eventing (WS-Eventing)

[87] W3C, NOTEwsdl-20010315, Web Services Description Language (WSDL) 1.1,

[88] W3C, SUBM-wsdl11soap12-20060405, WSDL 1.1 Binding Extension for SOAP 1.2

[89] ETSI, TS 102690 Machine-to-Machine communications (M2M); Functional architecture

[90] ETSI, TS 102921 Machine-to-Machine communications (M2M); mIa, dIa and mId interfaces

[91] IETF RFC 6120Extensible Messaging and Presence Protocol (XMPP): Core

[92] IETF RFC 6121Extensible Messaging and Presence Protocol : Instant Messaging and Presence

[93] IETF RFC 6122Extensible Messaging and Presence Protocol : Address Format

[94] IETF RFC 3031Multiprotocol Label Switching Architecture

[95] IETF RFC 3032MPLS Label Stack Encoding

[96] IETF RFC 791 Internet Protocol

[97] IETF RFC 2460Internet Protocol, Version 6 (IPv6) Specification

[98] ITU-T G.991.1 High bit rate digital subscriber line (HDSL) transceivers

[99] ITU-T G.798 Characteristics of optical transport network hierarchy equipment functional blocks

[100] ITU-T G.781 Synchronization layer functions

[101] ITU-T G.872 Architecture of optical transport networks

[102] IETF RFC 6178Label Edge Router Forwarding of IPv4 Option Packets

[103] ITU-T G.783 Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks

[104] ITU-T G.798 Characteristics of optical transport network hierarchy equipment functional blocks

[105] ITU-T G.803 Architecture of transport networks based on the synchronous digital hierarchy (SDH)

[106] IEEE 802.1: a list of standards is available under this link http://standards.ieee.org/about/get/802/802.1.html

2 Symbols and abbreviations

Acronyms

3GPP	3rd Generation Partnership Project
6LoWPAN	IPv6 over Low power Wireless Personal Area Networks
ADSL	Asymmetric digital subscriber line
AES	Advanced Encryption Standard
ANSI	American National Standard Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning
ASK	Amplitude Shift Keying
ATM	Asynchronous Transfer Mode,
B-PON	Broadband PON
BPL	Broadband Power Line
BPSK	Binary Phase Shift Keying
CCM	Cloud Controls Matrix
CEMS	Customer Energy Management Systems
CEN	Comité Européen de Normalisation.
CENELEC	Comité Européen de Normalisation Electrotechnique
CO	Central Office
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance
DA	Distribution Automation
DLMS/COSEM	Device Language Message Specification / Companion Specification for Energy Metering
DNP	Distributed Network Protocol
DODAG	Destination Oriented Directed Acyclic Graph
DRMS	Demand Response Management System
DSL	Digital Subscriber Line
DSSS	Direct Sequence Spread Spectrum
DWDM	Dense Wavelength-division multiplexing
E-UTRAN	Evolved UTRAN
EIRP	Equivalent Isotropically Radiated Power
ENC-MAC	Encrypted Message Authentication Code
ENODEB	Evolved Node B
ETSI	European Telecommunications Standard Institute
ETX	Expected Transmission
FAN	Field Area Network
FCC	Federal Communication Commission
FDD	Frequency-Division Duplexing
FLISR	Fault Location and Service Recovery
FR	Frame Relay
FTTB	Fiber To The Building (Business)
FTTC	Fiber To The Cabinet
FTTH	Fiber-to-the-Home
G-PON	Gigabit capable Passive Optical Networks.
GMPLS	Generalized Multi-Protocol Label Switching
GOOSE	Generic Object Oriented Substation Events
GPRS	General Packet Radio Service
GSM	Global System for Mobile
H2H	Human to Human
HAN	Home Area Network
HBES	Home and Building Electronic Systems

HDSL	High-bit-rate digital subscriber line
HeNB	Home eNodeB
HIPERMAN	HIgh PErformance Radio Metropolitan Area Network
HSPA	High Speed Packet Access
HV	High Voltage
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPTV	Internet Protocol Television
IPV4	Internet Protocol Version 4
IPv6	Internet Protocol Version 6
ISM	Industrial Scientific and Medical (frequency band)
ISO	International Organization for Standardization
ITU-T	International Telecommunications Union for the Telecommunication Standardization Sector
KNX	EN 50090 (was Konnex)
L2TP	Layer 2 Tunnelling Protocol
LF NB	Low Frequency Narrow Band
LLN	Low power and Lossy Networks
LNAP	Local Network Access Point
LON	local operation network
LR WPAN	Low Rate Wireless Personal Area Network
LSP	Label Switched Path
LTE	Long Term Evolution
LV	Low Voltage
MAC	Media Access Control
MIMO	Multiple Input Multiple Output
MPLS	Multiprotocol Label Switching
MPLS-TP	MPLS Transport Profile
MV	Medium Voltage
NAN	Neighborhood Area Network
NNAP	Neighborhood Network Access Point
O-QPSK	Offset Quadrature Phase Shift Keying
O&M	Operation and Maintenance
OAM	Operations, Administration, and Maintenance
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
OLT	Optical Line Termination
ONU	Optical Network Unit
OPEX	Operation Expenditure
OSI	Open System Interconnection
OSS	Operations support system
OTN	Optical Transport Network
P2P	Point To Point
PAN	Personal Area Network
PBR	Performance Based Rates
PDH	Plesiochronous Digital Hierarchy
PEV	Plug in Electric Vehicle
PHP	Penultimate Hop Popping
PLC	Power Line Carrier
PLC	Programmable Logic Controller
PON	Passive Optical Network

PSN	Packet Switched Network
QoS	Quality Of Service
RF	Radio Frequency
RFC	Request for Comments
RPL	Routing Protocol for Low power and lossy networks (LLN)
SAIDI	System Average Interruption Duration Index
SC-FDMA	Single Carrier Frequency Division Multiple Access
SCADA	Supervisory control and data acquisition
SDH	Synchronous Digital Hierarchy
SHDSL	Single-pair high-speed digital subscriber line
SON	Self Organizing Network
SONET	Synchronous Optical Networking
SRD	Short Range Device
TDD	Time-Division Duplexing
TDM	Time-Division Multiplexing
TPR	Tele-Protection Relay
TTI	Transmission Time Interval
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
VDSL	Very-high-bit-rate digital subscriber line
WAN	Wide Area Network
WASA	Wide Area Situation Awareness
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPA	Wi-Fi Protected Access
WPA2	Wi-Fi Protected Access version II
WPAN	Wireless Personal Area Network
XG-PON	10G PON
xDSL	Digital Subscriber Line

3 Executive Summary

This document deals with communication aspects of the Smart Grid. The main objective of the study performed by the RAWG on Smart Grid communications is to identify gaps that need to be addressed in standardization organisations. This work considered generic Smart Grid use cases to derive the requirements and to consider the adequacy of those requirements to the existing communications standards in order to identify communication standards gaps. RAWG found that there are no specific standardisation gaps for Layer 1 to Layer 4 standards (according to OSI model) mandating the immediate need for evolution of existing standards. However, there is an immediate need to develop profiling and interoperability specifications based on the existing communications standards. The profiling work is the task of the SDOs, however for the purpose of explaining our vision of such profiling, a draft profile is proposed in this document for an example[1] Smart Grid sub-network architecture.

The remaining of this document is organised as follows

- Clause 1 continues to provide a set of recommendations for standardisation work as well as a mapping of the communication technologies to Smart Grid communication sub-networks
- Clause 2 provides an overview of the Communication standards that are applicable for Smart Grid communications
- Clause 3 provides a description of generic Smart Grid use cases, their communication requirements, along with recommendations on how to setup the communication networks to address these requirements
- Clause 4 provides an example profile and develops interoperability considerations

3.1 Recommendations

3.1.1 Recommendation 1

RAWG has examined the communication needs of different Smart Grid use cases. There are cases that have very stringent communications requirements (PMU, Tele-protection, etc.), however we believe all these requirements can be addressed using existing communications standards with sufficient engineering guidelines (see R2). There is already a large set of communication standards for each network segment identified. RAWG did not identify any gaps mandating the need for new communication standards.

3.1.2 Recommendation 2

Communication network performance including QoS, reliability, and security must be managed so to achieve the smart grid communications requirements. This mandates the need to develop communication profiles on “how to use” the current communication standards for Smart Grids. IEC in collaboration with bodies such as IETF, IEEE, ETSI, CEN and CENELEC is the right place to develop such profiles. A profile is defined to be a description of how to use the different options and capabilities within a set of standards for a particular use.

3.1.3 Recommendation 3

There is a need to develop a standardised Service Level Specification (i.e. the technical part of a Service Level Agreement: availability, resiliency, DoS, etc.) that allows a utility network or application to rely on predictable network performance when communication is provided by a shared communication infrastructure.

[1] RAWG may develop more than one profile

3.1.4 Recommendation 4

Deployment constraints mandate the need for both wireline and wireless communications. Utility access to wireless network resources is necessary. Where spectrum is allocated for use by utility networks, this will help progress the Smart Grid deployments ensuring the standard work and products take into account the allocated spectrum for utilities.

3.1.5 Recommendation 5

Given the plethora of L1 and L2 technologies (according to OSI) used in the different communication standards (as well as the upcoming ones), IP shall be the recommended L3 technology to ensure communications are future proof and avoid the unnecessary need for interworking gateways in different parts of the Smart Grid communication networks.

3.1.6 Recommendation 6

This document provides a list of applicable communication technologies as well as their applicability statement to different sub-networks of the communications architecture. The choice of a technology for a sub-network is left to implementations, which need to take into account a variety of deployment constraints.

3.1.7 Recommendation 7

Profiles (see Recommendation 2) should be used as a basis for building interoperability test specifications. When interoperability test specifications / suites exist, those should be leveraged for building test specifications for the communication profiles.

3.1.8 Recommendation 8

ESOs should consider the approval of their specifications applicable to Smart Grid as ENs.

Recognizing the role of consortia in providing & developing specifications for communications and considering the fact that these consortia adopt an open standards approach (i.e. IEEE, IETF, W3C) the European Commission should endorse the importance of their specifications in building communications network, including for Smart Grid. There are globally recognized technologies & deployments for communications that use a selection of open specifications from ESOs, global SDOs and these consortia. The endorsement of the specifications into ENs, may not be reasonable in defined timeframe or achievable.

3.2 Smart Grid sub-networks

We are identifying the different networks that play a role in the overall communication architecture and we are representing their scope using the SGAM model (figure 1, below).

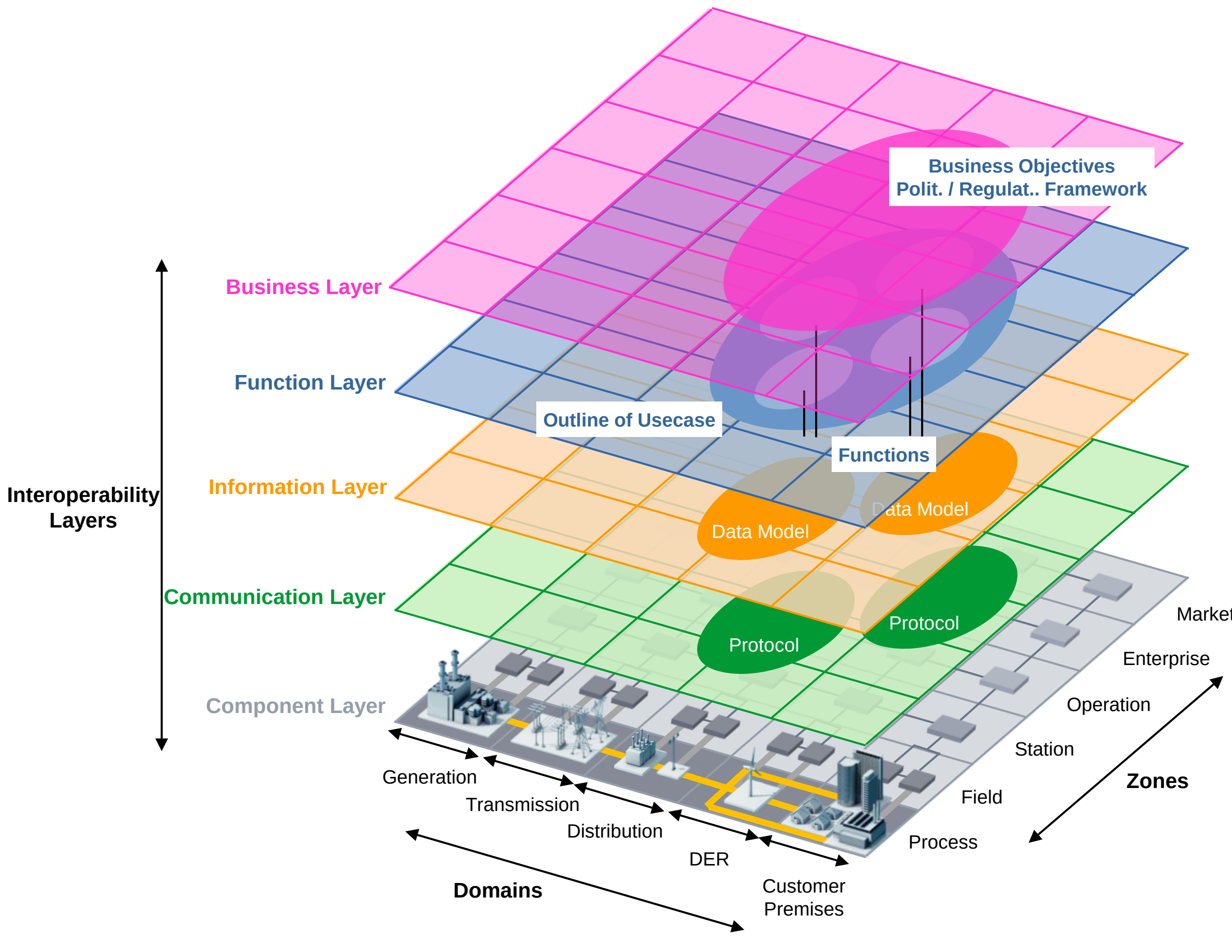

Figure 1: SGAM Framework Architecture

The following networks could be defined, see figure 3-2 below where these terms are used:

- **(A) Subscriber Access Network**
  Networks that provide general broadband access (including but not limited to the internet) for the customer premises (homes, building, facilities). They are usually not part of the utility infrastructure and provided by communication service providers, but can be used to provide communication service for Smart Grid systems covering the customer premises like Smart Metering and Aggregated prosumers management.

- **(B) Neighborhood network**
  Networks at the distribution level between distribution substations and end users. It is composed of any number of purpose-built networks that operate at what is often viewed as the “last mile” or Neighborhood Network level. These networks may service metering, distribution automation, and public infrastructure for electric vehicle charging, for example.

- **(C) Field Area Network**
  Networks at the distribution level upper tier, which is a multi-services tier that integrates the various sub layer networks and provides backhaul connectivity in two ways: directly back to control centres via the WAN (defined below) or directly to primary substations to facilitate substation level distributed intelligence. It also provides peer-to-peer connectivity or hub and spoke connectivity for distributed intelligence in the distribution level.

- **(D) Low-end intra-substation network**

Networks inside secondary substations or MV/LV transformer station. It usually connects RTUs, circuit breakers and different power quality sensors.

- **(E) Intra-substation network**
  Network inside a primary distribution substation or inside a transmission substation. It is involved in low latency critical functions such as tele-protection. Internally to the substation, the networks may comprise from one to three buses (system bus, process bus, and multi-services bus).

- **(F) Inter substation network**
  Networks that interconnect substations with each other and with control centres. These networks are wide area networks and the high end performance requirements for them can be stringent in terms of latency and burst response. In addition, these networks require very flexible scalability and due to geographic challenges they can require mixed physical media and multiple aggregation topologies. System control tier networks provide networking for SCADA, SIPS, event messaging, and remote asset monitoring telemetry traffic, as well as peer-to-peer connectivity for tele-protection and substation-level distributed intelligence.

- **(G) Intra-Control Centre / Intra-Data Centre network**
  Networks inside two different types of facilities in the utility: utility data centres and utility control centres. They are at the same logical tier level, but they are **not** the same networks, as control centres have very different requirements for connection to real time systems and for security, as compared to enterprise data centres, which do not connect to real time systems. Each type provides connectivity for systems inside the facility and connections to external networks, such as system control and utility tier networks.

- (H) **Enterprise Network**
  Enterprise or campus networks, as well as inter-control centre networks. Since utilities typically have multiple control centres and multiple campuses that are widely separated geographically.

- **(I) Balancing Network**
  Networks that interconnect generation operators and independent power producers with balancing authorities, and networks those interconnect balancing authorities with each other. In some emerging cases, balancing authorities may also dispatch retail level distributed energy resources or responsive load.

- **(J) Interchange network**
  Networks that interconnect regional reliability coordinators with operators such as transmission operators and power producers, as well as networks that connect wholesale electricity markets to market operators, providers, retailers, and traders. In some cases, the bulk markets are being opened up to small consumers, so that they have a retail-like aspect that impacts networking for the involved entities.

- **(K) Trans-Regional / Trans-National network**
  Networks that interconnect synchronous grids for power interchange, as well as emerging national or even continental scale networks for grid monitoring, inter-tie power flow management, and national or continental scale renewable energy markets. Such networks are just beginning to be developed.

- **(L) Wide and Metropolitan Area Network**[2]

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[2] Several of the shown networks could be based on WAN technologies. However since those networks –

Networks that can use public or private infrastructures. They inter-connect network devices over a wide area (region or country) and are defined through SLAs (Service Level Agreement).

- **(M) Industrial Fieldbus Area Network**

  Networks that interconnect process control equipment mainly in power generation (bulk or distributed) in the scope of smart grids.

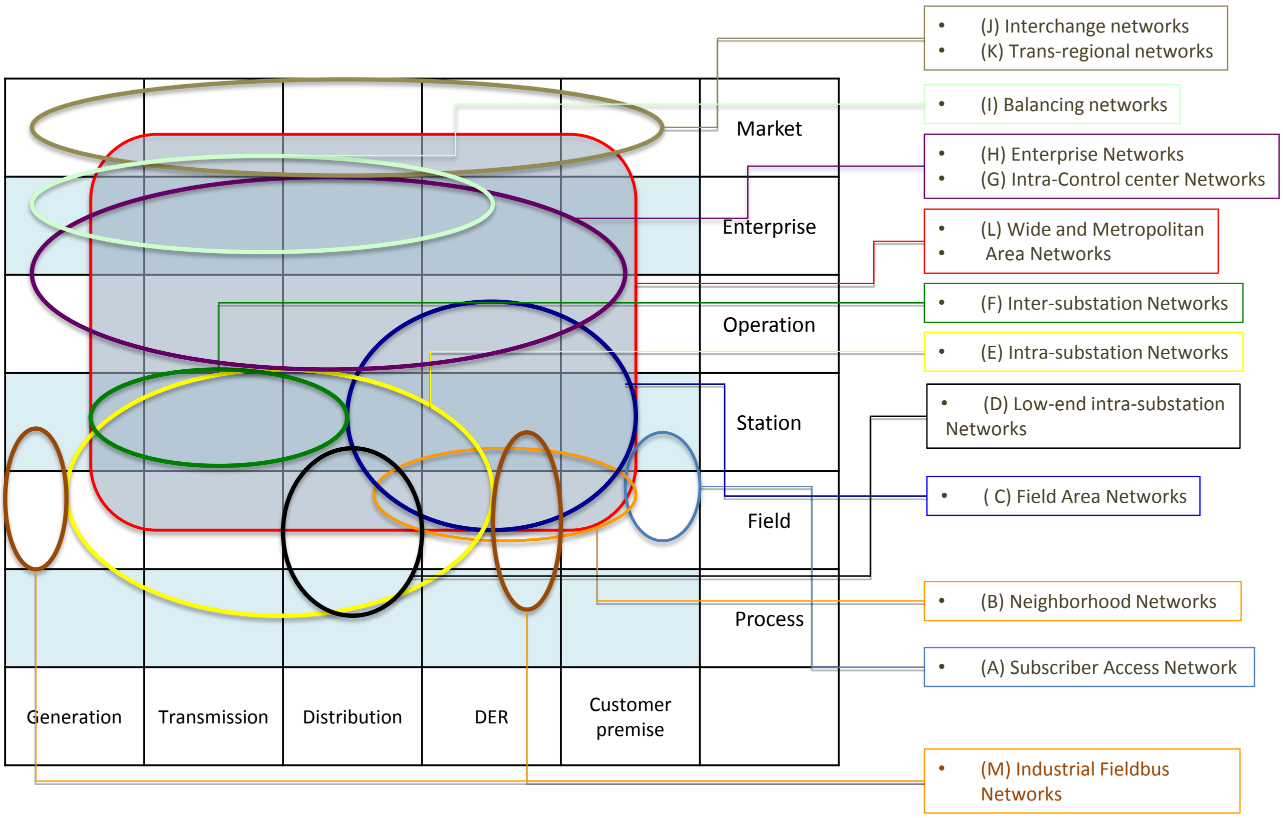


Figure 2: Mapping of communication networks on SGAM Communication Layer

Note 1: These areas of responsibility are an example mapping and cannot be normative to all business models.

Note 2: It is assumed that that sub-networks depicted in the above figure are interconnected (where needed) to provide end-to-end connectivity to applications they support. VPNs, Gateways and firewalls could provide means to ensure network security or virtualization.

A. can be run / managed by different stakeholders,
B. could provide different level of security or different SLAs
- they are depicted separately. It should be noted however that this is a logical view and that in practice multiple logical networks can be implemented using a single WAN technology. Implementation design choices are beyond the scope of this report

3.3 Applicability statement of the Communication Technologies to the Smart Grid Sub-networks

The following table provides an applicability statement indicating the standardized communication technologies to the Smart Grid sub-networks depicted in the previous sub-clause. As per Recommendation 6, the choice of a technology for a sub-network is left to implementations, which need to take into account a variety of deployment constraints.

Note: This report addresses communication technologies related to smart grid deployment. It includes communication architecture and protocols that could be used in smart metering deployments as well as other use cases (like feeder automation, FLISR etc.). For AMI only specific standards, refer to CEN/CLC/ETSI TR 50572 and other future deliverables as listed in SMCG_Sec0025_DC_V0.3 Work Program Document.

Table 1: Applicability statement of the communication technologies to the smart grid sub-networks

	Subscriber access network	Neighbourhood Network	Field area	Low-end intra substation	Intra-substation	Inter-substation	Intra control centre	intra data centre	Enterprise	Balancing	Interchange	Trans regional	Trans national	WAN	Industrial Fieldbus
	A	B	C	D	E	F	G		H	I	J	K		L	M
Narrow band PLC (Medium and Low voltage)	x	x	x												
Narrow band PLC (High and very High voltage)					x	x									
Broadband PLC	x	x													
IEEE 802.15.4	x	x	x												
IEEE 802.11	x	x		x	x										
IEEE 802.3/1				x	x		x	x	x						x
IEEE 802.16	x	x	x												
ETSI TS 102 887		x	x												
IPv4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
IPv6	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
RPL / 6LowPan	x	x	x												
IEC 61850		x	x	x	x	x								x	
IEC 60870-5				x	x	x								x	
GSM / GPRS / EDGE	x	x												x	
3G / WCDMA / UMTS / HSPA	x	x					x	x	x	x	x	x	x	x	
LTE/LTE-A	x	x	x	x		x	x	x	x	x	x	x	x	x	
SDH/OTN	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
IP MPLS / MPLS TP	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
EN 13757		x													
DSL/PON	x	x				x								x	
Higher layer comm protocol	x	x	x			x	x	x	x	x	x	x	x	x	

[3]

[3] IEEE GEPON and EPON are considered to be part of DSL/PON line

4 Communication Standards for the Smart Grid

4.1 Internet Protocol Technology

4.1.1 The Key Advantages of Internet Protocol

An end-to-end IP Smart-Grid architecture can leverage 30 years of Internet Protocol technology development [RFC 6272] guaranteeing open standards and interoperability as largely demonstrated through the daily use of the Internet and its two billion end-users [Stats].

Note: Using the Internet protocol suite does not mean that an infrastructure running IP has to be an open or publicly accessible network–indeed, many existing mission-critical but private and highly secure networks leverage the IP architecture, such as inter- banking networks, military and defense networks, and public-safety and emergency-response networks, to name a few.

One of the differences between Information and Communications Technology (ICT) and the more traditional power industry is the lifetime of technologies. Selecting the IP layered stack for Smart Grid infrastructure brings future proofing through smooth evolutionary steps that do not modify the entire industrial workflow. Key benefits of IP are:

- **Open and Standards-based:** Core components of the network, transport and applications layers standardized by the Internet Engineering Task Force (IETF) while key physical, data link, and applications protocols come from usual industrial organizations, such as, IEC, ANSI, SAE, IEEE, ITU, etc.
- **Lightweight:** Devices installed in the last mile such as smart meters, sensors, and actuators are not like PC and servers. They have limited resources in terms of power, CPU, memory, and storage. Therefore, an embedded networking stack must work on few kilobits of RAM and a few dozen kilobits of Flash memory. It has been demonstrated over the past years that production IP stacks perform well in such constrained environments.
- **Versatile**: Last mile infrastructure in Smart Grid has to deal with two key challenges. First, one given technology (wireless or wired) may not fit all field deployment's criteria. Second, communication technologies evolve at a pace faster than the expected 15 to 20 years lifetime of a smart meter. The layered IP architecture is well equipped to cope with any type of physical and data link layers, making it future proof as various media can be used in a deployment and, over time, without changing the whole solution architecture and data flow.
- **Ubiquitous:** All recent operating systems releases from general-purpose computers and servers to lightweight embedded systems (TinyOS, Contiki, etc.) have an integrated dual (IPv4 and IPv6) IP stack that gets enhanced over time. This makes a new networking feature set easier to adapt over time.
- **Scalable:** As the common protocol of the Internet, IP has been massively deployed and tested for robust scalability. Millions of private or public IP infrastructure nodes, managed under a single entity have been operational for years, offering strong foundations for newcomers not familiar with IP network management.
- **Manageable and Secure:** Communication infrastructure requires appropriate management and security capabilities for proper operations. One of the benefits of 30 years of operational IP networks is its set of well-understood network management and security protocols, mechanisms, and toolsets that are widely available. Adopting IP network management also helps utility operational business application by leveraging network-

management tools to improve their services, for example when identifying power outage coverage through the help of the Network Management System (NMS).

- **Stable and resilient:** With more than 30 years of existence, it is no longer a question that IP is a workable solution considering its large and well-established knowledge base. More important is how we can leverage the years of experience accumulated by critical infrastructures, such as financial and defense networks as well as critical services such as Voice and Video that have already transitioned from closed environments to open IP standards. It also benefits from a large ecosystem of IT professionals that can help designing, deploying and operating the system solution.
- **End-to-end:** The adoption of IP provides end-to-end and bi-directional communication capabilities between any devices in the network. Centralized or distributed architecture for data manipulations are implemented according to business requirements. The removal of intermediate protocol translation gateways facilitates the introduction of new services.

4.1.2 IP layered architecture

The IP architecture offers an open standard layered architecture that perfectly fit in the smart grid new requirements. It offers also a migration path for some non-IP protocols and implementations like DNP, Modbus and KNX.

The following diagram is representing such architecture:

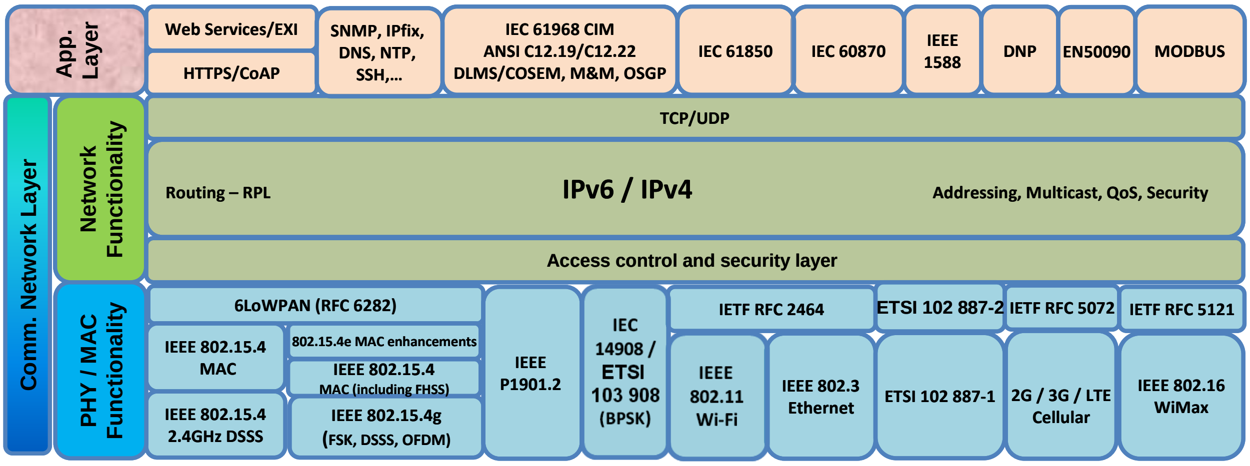


Figure 3: IP standard protocol layers

Note: this Protocol Architecture is promoting the use of IP in the protocol layers; innovative data transport solutions may be developed in the future.

4.1.3 The Technical Components of IPv6 Smart Grid Infrastructure

Today, the Internet runs mostly over IP version 4 (IPv4), with exceptions in academic and research networks, leading Internet Service Providers or Enterprises, and government networks (where IPv6 is increasingly being deployed). However, the Internet faces a major transition [OECD] due to the exhaustion of address pool managed by IANA since February 2011. With little existing IPv4 networking legacy in the areas of AMI and Distribution Automation, there is an opportunity to start deploying IPv6 as the de facto IP version from Day One. The industry has been working on IPv6 for nearly 15 years, and the adoption of IPv6 —which provides the same IP services as IPv4 would be fully aligned with numerous recommendations (U.S. OMB and FAR, European Commission IPv6 recommendations, Regional Internet Registry recommendations, and IPv4 address depletion countdown) and latest 3G cellular evolution known as LTE (Long Term Evolution).

Moreover, all new developments in relation to IP for Smart Objects and LLNs as discussed above, make use of or are built on IPv6 technology. Therefore, the use of IPv6 for Smart Grid deployment benefits from several features, some being extensively reviewed in the next sections:

- A huge address space accommodating any expected multi-millions meter's deployment (AMI), thousands of sensors (DA) over the hundred thousands of secondary substations and additionally all standalone meters. It includes additional flexibility of address configuration that helps adapting with the size of deployments as well as the need to lower field workers tasks when installing small devices. The structure of the IPv6 address is also flexible enough to manage a large number of sub-networks that may be created by futures services such as e-vehicle charging stations or distributed renewable energy
- IPv6 is used IP version for meter communication over RF Mesh wireless (IEEE 802.15.4g, DECT Ultra Low Energy) and Power Line Communications infrastructures (IEEE P1901.2) using the 6LoWPAN adaptation layer that only defines IPv6 as its protocol version.
- IPv6 is the de facto IP version for the standardized IETF Routing Protocol for Low Power and Lossy Networks (RPL)—IETF RoLL WG—RPL is an IPv6-only protocol.

4.1.4 IPv6 Addressing

The adoption of IPv6 requires an Energy Provider to consider all steps required by an IP network design and particularly an understanding of IPv6 addressing and how internal policies may help the operations.

Global, public, and private address space have been defined for IPv6, therefore a decision must be made regarding which type of IPv6 addressing scheme should be used in utility networks. Global addressing means the utility must follow the Regional Internet Registries (RIR) policies (such as ARIN https://www.arin.net/policy/nrpm.html) to register an IPv6 prefix that is large enough for the expected deployment and its expansion over the coming years. This does not mean the address space allocated to the infrastructure must be advertised over the Internet allowing any Internet users to reach a given device. The public prefix can be advertised if representing the entire utility corporation–or not–and proper filtering mechanisms are in place to block all access to the Field Area Networks and devices. On the other end, using a private address space means the prefix not be advertised over the Internet, but, in case there is a need for B2B services and connectivity, a private address would lead to the deployment of additional networking devices known as IPv6-IPv6 NPT (Network Prefix Translation, RFC 6296) gateways.

Once the IPv6 addressing structure (see RFC 4291, 4193) and policies are well understood and a prefix is allocated to the infrastructure, it is necessary to structure the addresses according to the number of sites and end- points that would connect to it. This is no different to what an ISP or a large Enterprise has to perform. (See 6NET)

Internal policies may be defined by the way an IPv6 address is assigned to an end-device, by using a global or private prefix.

Three methods to set an IPv6 address on an end-point are available:

- **Manual configuration–This** is appropriate for Head-End and NMS servers that never change their address, but is inappropriate to millions of end-points, such as meters, in regards to the associated operational cost and complexity
- **Stateless auto-configuration–A** mechanism similar to Appletalk, IPX and OSI, meaning an IPv6 prefix gets configured on a router interface (interface of any routing device such as a meter in a mesh or PLC AMI network), which is then advertised to nodes attached to the

interface. When receiving the prefix at boot time, the node can automatically set-up its IPv6 address

- **Stateful auto-configuration–Through** the use of DHCPv6 Individual Address Assignment, this method requires DHCPv6 Server and Relay to be configured in the network but benefits of a strong security as the DHCPv6 process can be coupled with AAA authentication, population of Naming Services (DNS) available for Head-End and NMS applications. The list above is the minimum set of tasks to be performed, but as already indicated; you must also establish internal policies and operational design rules. This is particularly true when considering security and management tasks such as registering IPv6 addresses and names in DNS (Domain Name System) and in NMS (network management station(s) or setting-up filtering and firewalling across the infrastructure.

4.2 Field, Neighborhood, home / building area networks overview

4.2.1 Introduction

These networks are different from the access network and Wide area network in the sense that they mainly interconnect the end devices each together as an autonomous network or to the access network. Some examples of these networks are:

- HAN (Home area networks which interconnects home devices)
- PAN (Personal area networks which interconnects body sensors, personal display, personal phones or smart phones etc…
- FAN (Field Area networks which in the case of smart grid interconnects smart meters, power sensors, EVs, etc…).
- NAN (Neighbor area networks: other name for the FAN)

This section will list the main specifications of technologies that are based on open standards.

4.2.2 Power Line Technology

4.2.2.1 Introduction

Under the term of **Power Line Communication (PLC)** a wide class of technologies is identified which allow the exploitation of almost all type of power line cables. PLC can be applied to multiple Smart Grid sub-networks such as inter substation networks and neighbor area networks.

The figure below, provided for the sole purpose of illustration, gives some examples of PLC communications.

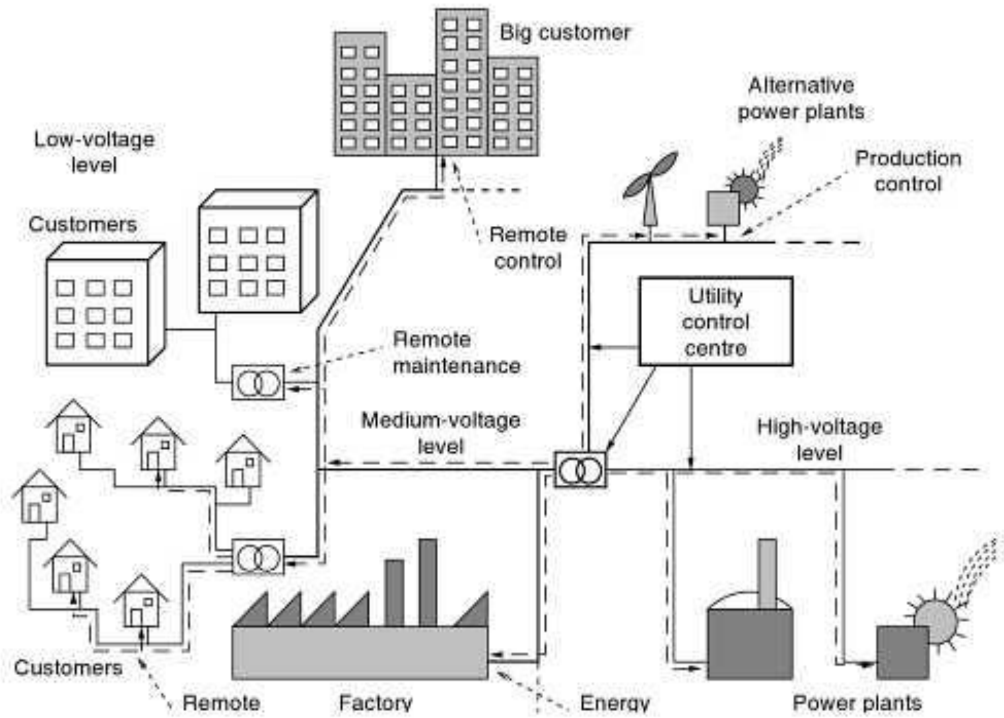


Figure 4: Example of PLC usage

PLC has been used since long time providing for both specific solutions for power utility applications as well as communications access solutions and more recently due to increasingly interest and market needs has been extended to cover in-home systems needs.

Furthermore power lines provide a communication path that puts the utility in control of the communication capabilities.

4.2.2.2 PLC Technologies Classification

For our initial considerations, PLC technology can be classified taking into account three key features:

- The level of voltage where they are operated (Low, Medium, High, Extra High Voltage LV/MV/HV/EHV)
- The allocated ranges of frequencies
- Data rates (throughput)

A) Narrowband PLC technologies, also known as **Distribution Line Carrier (DLC), is** capable of data rates of few kilobits per second operate in Europe in the so called ***CENELEC bands***:

- CENELEC A band: 3–95 kHz reserved exclusively to power utilities;
- CENELEC B band: 95–125 kHz any application;
- CENELEC C band: 125–140 kHz in-home networking;
- CENELEC D band: 140–148.5 kHz alarm and security systems.

In countries out of Europe Narrowband PLC could be allocated within 3–500 kHz bands.

Recently advanced multicarrier modulation technologies, using the same allocated CENELEC bands, made it possible to reach data rates in the order of hundreds of kilobits per second.

B) **Broadband PLC (BPL)** technologies supporting both high data rate bidirectional transmission as well as last mile internet-access providing for data rates ranging between tens of kilobits per second up to ten of megabits per second. They can be operated over Medium and Low Voltage electricity Power Lines.

4.2.2.3 PLC Standards

There are several existing and ongoing standards that deal with PLC communications. These standards have been ratified by Standards Developing Organizations (SDOs) like IEC, ISO, CENELEC, ETSI, ITU-T, and IEEE or based on industry fora or alliances.

Table 2: Relevant Narrowband PLC Standards

Note: fora/consortia specifications are depicted in Appendix A.

SDOs - Alliance - Industry	Standard Name	Frequency Bands	Power Line Segment
IEC	IEC62488-X	40-492kHz (1MHz)	High and Extra High Voltage
IEC	IEC 61334-X	3-500kHz	Medium and Low Voltage
IEC	IEC61334-3-1 IEC61334-5-1 IEC61334-5-2 IEC61334-4-32	CENELEC A 20kHz-95kHz	Low Voltage
ISO/IEC	14908-3	125 kHz to 140 kHz	Low Voltage
ISO/IEC	ISO/IEC 14908-3	A (86kHz & 75.543kHz 125kHz-140kHz F_c=131.579kHz) CENELEC A/B/C	Low Voltage
ISO/IEC BS	ISO/IEC 14543-3-5 EN 50090	PL110 (95kHz-125kHz F-c=110kHz) PL132 (125kHz-140kHz F-c=132.5kHz)	Low Voltage
ITU-T	G.9955 (PHY) G.9956 (DLL)	CENELEC A (G.hnem) CENELEC B (G.hnem) CENELEC CD (G.hnem)	Medium and Low Voltage
ETSI	TS 103 908	9 kHz to 95 kHz	Low Voltage
IEEE P1901.2	P1901.2 (Draft)	CENELEC A	Medium and Low Voltage

Table 3: Relevant Broadband PLC Standards

Note: fora/consortia specifications are depicted in Appendix A

SDOs - Alliance - Industry	Standard Name	Frequency Bands	Power Line Segment
CLC	prEN 50412-4 - LRWBS	2-4MHz	Low Voltage
ISO/IEC	ISO/IEC 12139-1	2-30MHZ	Low Voltage
ITU	ITU G.h : - G.9960 (PHY) - G.9961 (DLL) - G.9962 (MIMO) - G.9964 (PSD)	2-100MHz	Low Voltage
IEEE	IEEE 1901	2-50MHz	Low Voltage

4.2.3 Mesh Network technologies

4.2.3.1 RF mesh network

4.2.3.1.1 Introduction

A RF mesh network (or wireless mesh network) is a communications network made up of radio nodes organized in a peer-to-peer or mesh topology. In this topology, mains-powered radio nodes route and forward data traffic on behalf of other adjacent, mains-powered radio nodes; routing and forwarding of traffic can occur at L2 or L3. In the Smart Grid, a RF mesh network is most often used for “last mile” communications, often referred to as a Field Area Network (FAN) or Neighborhood Area Network (NAN). RF meshes support 2-way communication involving the following Domains: Markets, Operations, Distribution and Customer (as described in the Conceptual Model). The RF mesh network typically consists of mains-powered RF nodes, including but not limited to:

- Access Points: a dedicated infrastructure device that provides ingress and egress to the FAN via a WAN. The WAN interface is typically an IP-based backhaul that uses cellular connectivity (e.g., 3G), xDSL, or other commodity backhaul connectivity collocated at DSO substations. These devices may also be referred to as concentrators, take-out points, or ingress/egress devices. These devices might perform simply as a router or have more complex application state and persistent storage.
- Relays: a dedicated infrastructure device that is designed to extend coverage and range to the FAN. These devices are often referred to as repeaters.
- RF nodes such as RTUs connected to devices such as EVSEs, transformer/substation monitors, faulted circuit indicators, switch reclosers, load tap changers, capacitor bank controllers, streetlights, etc.

- RF nodes deployed in Smart Meters (either tightly integrated or as “standalone” telecommunications hubs or multi-utility controllers) may also be leveraged to route and forward certain distribution automation traffic within the mesh in accordance to DSO policy.

Some typical Smart Grid applications that may be supported by a RF mesh network are:

- Conservation voltage reduction
- Voltage monitoring
- Transformer monitoring
- FLISR
- Grid reliability applications such as with teamed switch reclosers
- EVSE monitoring and round-robin charging schemes
- DER management including integrated micro-inverters
- Load control applications such as DR or DSM

Smart Grid applications may utilize a mesh network exclusively within an orthogonal, overlay network, but in many cases, the same RF mesh FAN may be configured to interface with the Smart Metering infrastructure. In the latter case, the communications architecture should not preclude the exchange of smart metering and smart grid traffic, but appropriate policy mechanisms (e.g., authentication, authorization, network admission control) need to intrinsic to the implementation. An often-cited advantage of RF mesh networks is that it allows for the distribution of compute power and intelligence deep into the network, which in turn allows for local, low latency, cost-effective communications.

One advantage of mesh networks is reliability and redundancy by way of rich path diversity; mesh nodes may typically count many adjacencies or “neighbors”. A radio integrated into a Smart Grid device may also associate with one or more concentrators (for ingress/egress diversity) and with other RF mesh nodes, which act as stepping-stones for extending the coverage. All together this forms a mesh network with multiple alternative communication paths for a node to reach multiple concentrators. When one node can no longer operate, the rest of the nodes can still communicate with one another, directly or through one or more intermediate nodes. The concentrators may contain intelligence ensuring that communication is always updated and optimized.

4.2.3.1.2 Radio frequency

A wide range of radio frequency bands may be exploited by RF mesh technologies that could be operated under “licensed”, “light-licensed” or “unlicensed” regulatory regimes.
For Field Area Network RF meshes, spectrum bands below 1 GHz are often preferred. Standards have been defined that exploit spectrum in the bands 169 MHz, 433 MHz, 444 MHz, 868 MHz used for short range devices (SRD), and 870 – 876 MHz. Some RF mesh implementations are also available in the band 2.45 GHz. The standards that cover these particular bands are EN 13757-4, EN 13757-5, IEEE 802.15.4g, IEEE 802.15.4-2006, and ETSI TS 102 887-1.

4.2.3.2 Mesh networking technologies using power line

When you are using power line as the carrier media for information transport, you are using a shared media (the copper) sensitive to radio interferences and signal attenuation.
The issues that you are getting are quite similar to the ones you will get using Air Radio Frequency.

The use of repeaters along the line has been very challenging to deploy, as there is no way to formally predict where to position these repeaters. Signal level is fluctuating and the antenna that the power line is forming is very sensitive to external radio interferences.

One solution to this issue is to use routing mesh technologies equivalent to RF mesh. Each of the equipment along the line is acting as a router in the same way we do for RF mesh.

The routing protocol and routing algorithms are able to compute the best path between these equipments while the conditions are changing.

RPL routing protocol (IETF RFC 6550) is designed to satisfy these requirements.

4.2.4 Physical and MAC layers

The following Technologies are a set of those most well known & collected in the meetings there is no aim to be exhaustive.

4.2.4.1 P1901.2 - Standard for Low Frequency (less than 500 kHz) Narrow Band Power Line Communications for Smart Grid Applications

http://grouper.ieee.org/groups/1901/2/

This standard specifies communications for low frequency (less than 500 kHz) narrowband power line devices via alternating current and direct current electric power lines. This standard supports indoor and outdoor communications over low voltage line (line between transformer and meter, less than 1000 V), through transformer low-voltage to medium-voltage (1000 V up to 72 kV) and through transformer medium-voltage to low-voltage power lines in both urban and in long distance (multi- kilometre) rural communications. The standard uses transmission frequencies less than 500 kHz. Data rates will be scalable to 500 kbps depending on the application requirements. This standard addresses grid to utility meter, electric vehicle to charging station, and within home area networking communications scenarios. Lighting and solar panel power line communications are also potential uses of this communications standard. This standard focuses on the balanced and efficient use of the power line communications channel by all classes of low frequency narrow band (LF NB) devices, defining detailed mechanisms for coexistence between different LF NB standards developing organizations (SDO) technologies, assuring that desired bandwidth may be delivered. This standard assures coexistence with broadband power line (BPL) devices by minimizing out-of-band emissions in frequencies greater than 500 kHz. The standard addresses the necessary security requirements that assure communication privacy and allow use for security sensitive services. This standard defines the physical layer and the medium access sub-layer of the data link layer, as defined by the International Organization for Standardization (ISO) Open Systems Interconnection (OSI) Basic Reference Model.

4.2.4.2 IEEE 802.3 Ethernet

Ethernet is a widely used networking technology spanning the physical layer and the Media Access Control (MAC) layer. Ethernet is standardized in IEEE 802.3-2008 and ISO/IEC 8802-3:2000. Ethernet is specified for the exchange of data between devices (e.g., PC, printer, switch) connected in a wired network. Ethernet was originally specified for Local Area Networks (LAN), of which the Home Area Network (HAN) is an application specific subset. Ethernet is also applied to, e.g., Metro networks or Wide Area Networks. Ethernet is deployed within sub-stations and power generation plants.

Ethernet is based on Carrier Sense Multiple Access with Collision Detection (CSMA/CD) as a shared media access method. Today, point-to-point full duplex communication is also used. The standard defines the frame format for the data communication, the data rates, the line codes, the cable types, and interfaces.

The specified data rates are 10 Mbit/s, 100 Mbit/s (Fast Ethernet), 1000 Mbit/s (Gigabit Ethernet) and 10 GBit/s. 40-Gbit/s and 100-Gbit/s.

Table 4 contains a sample of specified interface types with the corresponding technical data. Several media types as coax cable, twisted-pair cable and fiber cable are possible. The interface types have different line codes.

Table 4: Sample of specified interface types

Interface type	Data rate	Cable type	Maximum segment length	Line code
10Base2	10 Mbit/s (half duplex)	Thin coax	185 m	Manchester code
10BaseT	10 Mbit/s (half duplex) 20 Mbit/s (full duplex)	2-pairs CAT3 or CAT5 cable	100 m	Manchester code
100BaseTX	100 Mbit/s (half duplex) 200 Mbit/s (full duplex)	2-pairs CAT5 unshielded cable	100 m	4B/5B
1000BaseT	1000 Mbit/s (half duplex) 2000 Mbit/s (full duplex)	4-pairs CAT5 cable	100 m	PAM5
1000BaseSX	1000 Mbit/s (half duplex) 2000 Mbit/s (full duplex)	2 multi-mode fiber cables	550 m	8B/10B

Ethernet is compatible with some other protocols. IEEE 802.11 supports the Ethernet data format. The Media Redundancy Protocol is a solution to compensate for failures in a ring topology like the Rapid Spanning Tree Protocol in IEEE 802.1 (LAN bridging and architecture). The Media Redundancy Protocol is specified in IEC 62439 and can be applied to Ethernet networks. IEC 62439 is used in industrial automation. Recently this standard has been referenced by IEC TC57 in IEC TR 61850-90-4 to be applied to substations.

Ethernet is extended to be applicable in telecommunications networks with the operator's requirements. These extensions are called Carrier Ethernet. Metro Ethernet Forum (MEF) defined Carrier Ethernet Services to be certified, which the operator can provide their customers:

- E-line (point-to-point Ethernet service over a WAN),
- E-LAN (multipoint-to-multipoint Ethernet service),
- E-tree (point-to-multipoint Ethernet service).

The Carrier Ethernet services are carried over the WAN using different technologies:

- Ethernet over SDH or OTN (ITU-T),
- Ethernet over MPLS / MPLS-TP (IETF),
- Provider Backbone Bridge – Traffic Engineering PBB-TE (IEEE),

PBB-TE supports connection oriented packet transport, traffic engineering and OAM.

Synchronous Ethernet (G.8262), Precision Time Protocol (IEEE 1588), and Audio Video Bridges (AVB, IEEE 802.1) can be used for time sensitive applications.

4.2.4.3 IEEE 802.11 (WIFI) [5]

Technology Overview

There is a set of standards comprised under the IEEE 802.11 family [7], aiming at low cost wireless LAN functionality, with the goal of providing a service equivalent to Ethernet layer 2 wired connectivity. These standards use Direct Sequence Spread Spectrum (DSSS) and Multi Carrier Orthogonal Frequency Division Multiplexing (OFDM) radio technologies. Unlike other wireless communication technologies, IEEE 802.11 makes use of unlicensed frequency bands in the range of 2.4 and 5GHz. This fact has the following key attributes:

- Plenty of equipment and vendors available.
- Guaranteed interoperability via an independent product certification entity (WiFi Alliance).
- Worldwide availability of (at least some channels) on the same frequency bands.
- Transmission data rates of the order of tens of megabits can be achieved (802.11a/g technology has a limit of 54Mbps).
- Low cost of the devices and no exploitation costs for the service. On the other hand, there are some drawbacks that must be taken into account:
- The maximum allowed radiated power (EIRP) is very low, typically 100mW in many countries, including Europe. The link distance is therefore limited by both transmitted power and antenna directivity.
- These frequency bands are very sensible to attenuation from water molecule absorption. In this way fog, rain and snow can degrade seriously the link power budget.
- The frequency bands are free for anyone to use them, and thus there may be some interference problems arising from congestion, both by 802.11 devices and other appliances using the same unlicensed band. This is particularly important in the 2.4GHz ISM band.
- Last, but not least, security aspects are mandatory, as IEEE 802.11 systems can be easily sniffed. Strong encryption mechanisms, such as WPA and preferably WPA2, have proved secure enough to let this technology be used in different environments such as meter reading.
- These standards were not designed with lowest power consumption in mind, so these technologies have slightly higher standby power consumptions than other WLAN/WPAN solutions, usually in the order of 1W. The IEEE 802.11 family currently includes multiple over-the-air modulation techniques that all use the same basic protocol. The segment of the radio frequency spectrum varies between countries and includes 2.4 GHz and 5GHz.

IEEE 802.11b and 802.11a were the first widely accepted wireless networking standard, followed by 802.11g and then 802.11n. Other standards in the family (c–f, h, and j) are service amendments and extensions or corrections to previous specifications.

IEEE 802.11n is based on a new multi-streaming modulation technique and at the time of preparation of the present document, is still under draft development, although proprietary products based on pre-draft versions of the standard are available on the market.

Frequency Bands IEEE 802.11 technology operates in unlicensed frequency bands. Some of these bands are not available worldwide, even though frequency spectrum harmonization tasks have been carried out since these technologies hit the market. The frequency bands in use are:

- 2.4GHz ISM band for IEEE 802.11b, g, n.
- 5GHz band (5.15-5.825GHz) for IEEE 802.11a, n.

Key Applications The relative low cost and use of unlicensed frequency bands makes possible the usage of IEE802.11 technologies in many application scenarios, such as the following: • Provide wireless bridging between fixed Ethernet networks. In this case a fixed Ethernet network can be reached by means of two wireless bridges, which create a wireless link between them, and create a layer 2 bridge. This is very useful when the deployment of a fixed Ethernet connection is not feasible due to physical constraints or high costs. Link distances in the order of kilometres may be reached using standard equipment.

4.2.4.4 IEEE 802.16 (WIMAX)[5]

Technology Overview

IEEE802.16 is working group within IEEE focused in Wireless Metropolitan Area (WMAN) access technology [8]. Since its initial conception, two main standards have been developed:

- 802.16d - fixed IEEE 802.16d (“802.16-2004”) is aimed at fixed applications and providing a wireless equivalent of DSL broadband data.

  802.16d is able to provide data rates of up to 75 Mbps and as a result it is ideal for fixed, DSL replacement applications. It may also be used for backhaul where the final data may be distributed further to individual users. Cell radii are typically up to 75 km.
- 802.16e - Nomadic / Mobile
  This standard is also known as “802.16-2005”. It currently provides the ability for users to connect to a cell from a variety of locations, and there are future enhancements to provide cell handover.

  802.16e is able to provide data rates up to 15 Mbps with cell radius distances typically 2÷4 km.

Frequency Bands

The IEEE 802.16 standard allows data transmission using multiple broadband frequency ranges.

The original 802.16a standard specified transmissions in the range 10÷66 GHz, but 802.16d allowed lower frequencies in the range 2 to 11 GHz. The lower frequencies used in the later specifications provide improved range and better coverage within buildings; this means that external antennas are not required.

Different bands are available for IEEE802.16 applications in different parts of the world.

The frequencies commonly used are 3.5 and 5.8 GHz for 802.16d and 2.3, 2.5 and 3.5 GHz for 802.16e but the use depends upon the countries.

The 5.8GHz band is not available in most European countries.

IEEE802.16 uses OFDM (Orthogonal Frequency Division Multiplex) as its modulation scheme. For 802.16d, 256 carriers are used, but for 802.16e the system is scalable according to the conditions and requirements.

More advanced versions including 802.16e utilize MIMO (Multiple Input Multiple Output) and support for multiple antennas. The use of these techniques provides potential benefits in terms of coverage, self-installation, power consumption, frequency re-use and bandwidth efficiency.

The IEEE 802.16a (256 OFDM PHY) and ETSI HIPERMAN (High Performance Radio Metropolitan Area Network) standards share the same PHY and MAC. The purpose of 802.16e is to add limited mobility to the current standard which is designed for fixed operation.

Key Applications

IEEE802.16 technologies are further along in terms of deployments with several operators throughout the world using it to provide *fixed* wireless broadband services. But so far, the technology has had a slow start as a *mobile* technology.

Most of new 802.16-based operators come from the fixed network space, and they are looking to use these technologies as an enhanced DSL service.

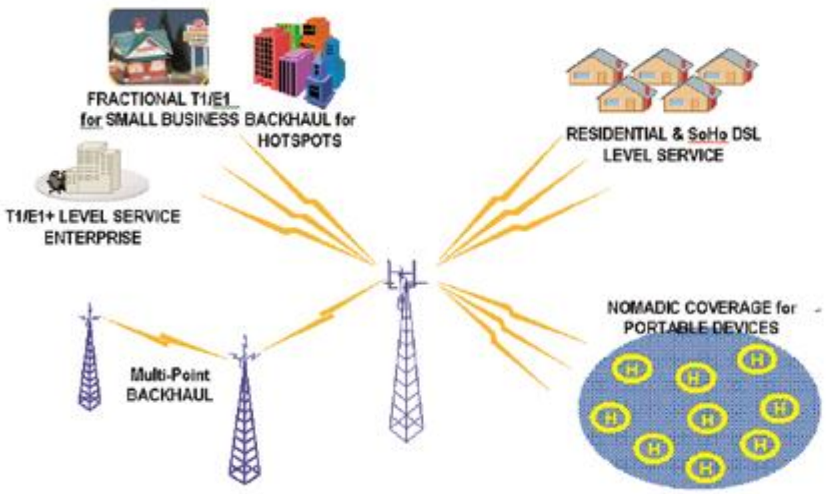


Figure 5: WiMAX usage model

4.2.4.5 IEEE 802.15.4

http://www.ieee802.org/15/pub/TG4.html

The IEEE 802.15.4 standard ([IEEE-802-15-4]) describes a LR WPAN (Low Rate Wireless Personal Area Network). In addition to low rate the standard also attempts to achieve several goals simultaneously: extremely low cost, short-range operation with a reasonable battery life. Finally, the networks should be simple to install and offer reliable data transfer.

The two major parts of the standard are the PHY and the MAC. These two layers are the common foundation layers of the OSI model and are found in almost all other communication protocols.

The PHY layer describes the modulation, operating frequency, over the air data rates, channels and other important aspects of radio operation such as receiver sensitivity and transmission power.

Frequency range

There are four frequency ranges that the standard defines (IEEE 802.15.4 C defines the Chinese band). The ranges are:

- China: 779 to 787 MHz
- Europe: 863 to 870 MHz
- North America: 902 to 928 MHz
- Worldwide: 2400 to 2483.5 MHz

Channels

The Chinese band allows for 4 channels with channel spacing of 2 MHz and center frequencies at 780, 782, 784 and 786 MHz. One channel is available for the European band at 868.3 MHz. Ten channels are available in the North American ISM band with 2 MHz channel spacing and center frequencies at 906, 908, 910, 912, 914, 916, 918, 920, 922 and 924 MHz. Finally, 16 channels are available in the worldwide band with 5 MHz channel spacing and center frequencies at 2405, 2410, 2415, 2420, 2425, 2430, 2435, 2440, 2445, 2450, 2455, 2460, 2465, 2470, 2475 and 2480 MHz.

Modulation

In IEEE 802.15.4 standard for the RF transmission there are two modulation modes described, BPSK (Binary Phase Shift Keying) and O-QPSK (Offset Quadrature Phase Shift Keying.

Bit rates

There are various bit rates within the channels and modulation modes. These are summarized as follows:

Table 5: 802.15.4 main characteristics

PHY Frequency Band	Channel(s)	Modulation	Bit Rate (kb/s)
868 MHz	0	BPSK	20
902 - 928 MHz	1 - 10	BPSK	40
868 MHz (optional mode)	0	ASK	250
902 - 928 MHz (optional mode)	1 - 10	ASK	250
868 MHz (optional mode)	0	O-QPSK	100
902 - 928 MHz (optional mode)	1 - 10	O-QPSK	250
2400 - 2480 MHz	11 - 26	O-QPSK	250

Transmission power

Maximum transmission power is regulated by government agencies such as the FCC in the United States and ETSI in Europe. Generally, in 802.15.4 systems, a node must be capable of transmitting at least -3 dBm.
Clear channel assessment

The PHY needs to be able to detect whether or not another radio is transmitting and employ a method to avoid interference. The mechanism used is CSMA-CA (Carrier Sense Multiple Access with Collision Avoidance). In this algorithm the radio first listens for energy or modulated data on the air. If any is sensed the algorithm provides for random wait times (backoffs) to retry the transmissions.

The Media Access Control (MAC) layer provides the network and higher layers an interface to the radio (PHY) layer. Its primary function is to limit when each node transmits on the shared media (the wireless channel) so that transmissions occur one at a time. Like most links, IEEE 802.15.4 supports a Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) mechanism.

4.2.4.6 ETSI 102 887

The requirement to wirelessly interconnect Smart Meters is one of the responses to the EC mandate 441 [include reference to CEN, CENELEC and ETSI arch development] for an open architecture for utility meters. The EC Short Range Device (SRD) Decision and associated spectrum rules (CEPT REC 70-03) have been identified as suitable regulations to govern interconnection of meters to the Local Network (LNAP) and Neighborhood Network Access Points (NNAP), and potential MESH networks built from these APs, identified in the M/441 Technical Report on Communications.

To that end, reference document ETSI TS 102 887-1 provides the necessary modifications for use in Europe of the IEEE 15.4 Amendment g, Physical Layer Specification for Low Data Rate Wireless Smart Meter Utility Networks standard, and specifies the necessary RF performance parameters to meet the provisional requirements identified in TR 102 886. The PHY specification in TS 102 887-1 is supported by a MAC specification in TS 102 887-2."

4.2.5 IPv6 adaptation layer

4.2.5.1 6LowPan

http://tools.ietf.org/html/rfc4919

The 6LoWPAN format defines how IPv6 communication is carried in 802.15.4 frames and specifies the adaptation layer’s key elements. 6LoWPAN has three primary elements:

- Header compression. IPv6 header fields are compressed by assuming usage of common values. Header fields are elided from a packet when the adaptation layer can derive them from link-level information carried in the 802.15.4 frame or based on simple assumptions of shared context.
- Fragmentation. IPv6 packets are fragmented into multiple link-level frames to accommodate the IPv6 minimum MTU requirement.
- Layer-two forwarding. To support layer-two forwarding of IPv6 datagrams, the adaptation layer can carry link-level addresses for the ends of an IP hop.

Alternatively, the IP stack might accomplish intra-PAN routing via layer-three forwarding, in which each 802.15.4 radio hop is an IP hop.

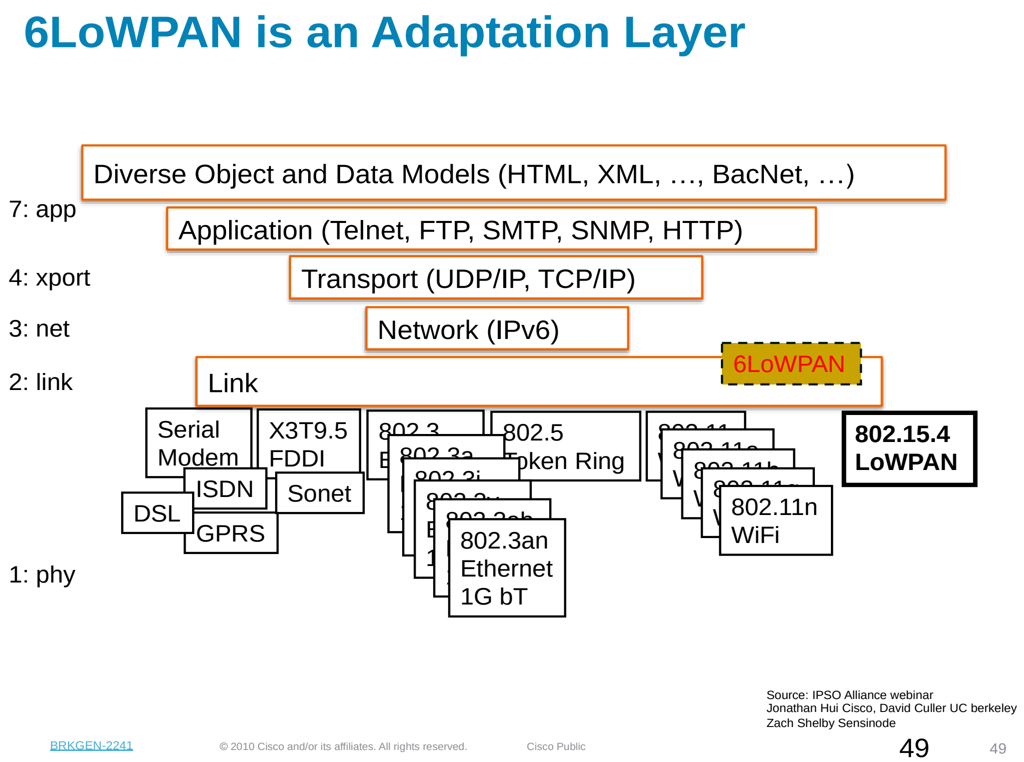


Figure 6: 6LoWPAN within IP protocol stack

4.2.6 IP protocols layer 3 and above

There is a broad consensus that Internet Protocol (IP), especially its most advanced iteration (IPv6), will serve as an important element in Smart Grid Information networks. This, as there are several significant attributes that address many smart grid communication requirements, including: wide range of available standards, proven at scale, large development community, an inherent benefit of adaptation between applications and the underlying communication medium (affording application independence of the underlying communication data-link infrastructure), and bindings with emergent utility app layer protocols such as DLMS/COSEM.

It is expected that the Smart Grid will be formed from a number of interoperable systems. Of particular note here is the inherent benefit of access to a wide range of available standards. To that end, the use of IP facilitates the use of a number of existing and future innovations pertaining privacy/confidentiality and a variety of gateway routing protocols. Specific examples of such standards are referenced here.

4.2.6.1 IPv6 routing protocol RPL (RFC 6550)

http://tools.ietf.org/html/draft-ietf-roll-rpl

The ROLL Working Group conducted a detailed analysis of the routing requirements focusing on several applications: urban networks including smart grid, industrial automation, home and building automation. This set of applications has been recognized to be sufficiently wide to cover most of the applications of the Internet of Things. The objective of the WG was to design a routing protocol for LLNs, supporting a variety of link layers, sharing the common characteristics of being low bandwidth, lossy and low power. Thus the routing protocol should make no specific assessment on the link layer, which could either be wireless such as IEEE 802.15.4, IEEE 802.15.4g, (low power) Wi-Fi or Powerline Communication (PLC) using IEEE 802.15.4 such as IEEE P1901.2.

Note that RPL operates at the IP layer according to the IP architecture, and thus allows for routing across multiple types of link layers, in contrast with other form of “routing” operating at lower layer (e.g. link layers).

RPL is a Distance Vector IPv6 routing protocol for LLNs that specifies how to build a Destination Oriented Directed Acyclic Graph (DODAG sometimes referred to as a graph in the rest of this document) using an objective function and a set of metrics/constraints. The objective function operates on a combination of metrics and constraints to compute the ‘best’ path. There could be several objective functions in operation on the same node and mesh network because deployments vary greatly with different objectives and a single mesh network may need to carry traffic with very different requirements of path quality. For example, several DODAGs may be used with the objective to (1) ‘Find paths with best ETX [Expected Transmissions] values (metric) and avoid non-encrypted links (constraint)’ or (2) ‘Find the best path in terms of latency (metric) while avoiding battery-operated nodes (constraint)’. The objective function does not necessarily specify the metric/constraints but does dictate some rules to form the DODAG (for example, the number of parents, back-up parents, use of load-balancing,...).

The graph built by RPL is a logical routing topology built over a physical network to meet a specific criteria and the network administrator may decide to have multiple routing topologies (graphs) active at the same time used to carry traffic with different set of requirements. A node in the network can participate and join one or more graphs (in this case we call them “RPL instances”) and mark the traffic according to the graph characteristic to support QoS aware and constraint based routing. The marked traffic flows up and down along the edges of the specific graph.

RPL and Security

Security is critical in smart object networks but implementation complexity and size is a core concern for LLNs such that it may be economically or physically impossible to include sophisticated security provisions in a RPL implementation. Furthermore, many deployments can utilize link-layer or other security mechanisms to meet their security requirements without requiring the use of security in RPL. Therefore, the security features in RPL are available as optional extensions.

When made available, RPL nodes can operate in three security modes. In the first mode, called "unsecured," RPL control messages are sent without any additional security mechanisms. Unsecured mode implies that the RPL network could be using other security primitives (e.g. link-layer security) to meet application security requirements. In the second mode, called "pre-installed," nodes joining a RPL instance have pre-installed keys that enable them to process and generate secured RPL messages. In the third mode, called "authenticated", nodes can join as leaf nodes using pre-installed keys as in pre-installed mode, or join as a forwarding node by obtaining a key from an authentication authority.

Each RPL message has a secure variant. The level of security (32-bit and 64-bit MAC and ENC-MAC modes are supported) and the algorithms (CCM and AES-128 are supported) in use are indicated in the protocol messages. The secure variants provide integrity and replay protection and confidentiality and delay protection as an added option.

4.2.7 EN 50090 family (KNX)

The CLC EN 50090 describes Home and Building Electronic Systems (HBES).
KNX, the system behind CLC EN 50090, it is the mature HBES system with more than 20 years experience in the market.

KNX is a worldwide open standard, the associated standards are:

- International Standard ISO/IEC 14543-3
- European Standards CLC EN 50090 and CEN EN 13321-1
- Chinese Standard GB/Z 20965
- US Standard ANSI ASHRAE 135).

Home and Building Electronic Systems (HBES) according EN 50090 are able to handle whole commercial and residential buildings, *independent of it being HVAC or a BMS application*.

EN 50090-5 which describes different PHY layers secures that all different needs from existing and new Buildings will be fulfilled

KNX standardizes the layers 1 to 7 of the OSI reference model. It additionally standardizes a rich set of application specifications to allow for a single and common information exchange.

4.2.7.1 Communication security

The KNX communication security provides for

- Authentication
- Confidentiality

For this, AES-128 encryption is again used and the data integrity is controlled over an HMAC-MD5 signature.

The communication security is situated in the Application Interface Layer, making it available to all services for runtime and for configuration, yet not requiring explicit support on Retransmitters or Couplers, which would be a security risk.

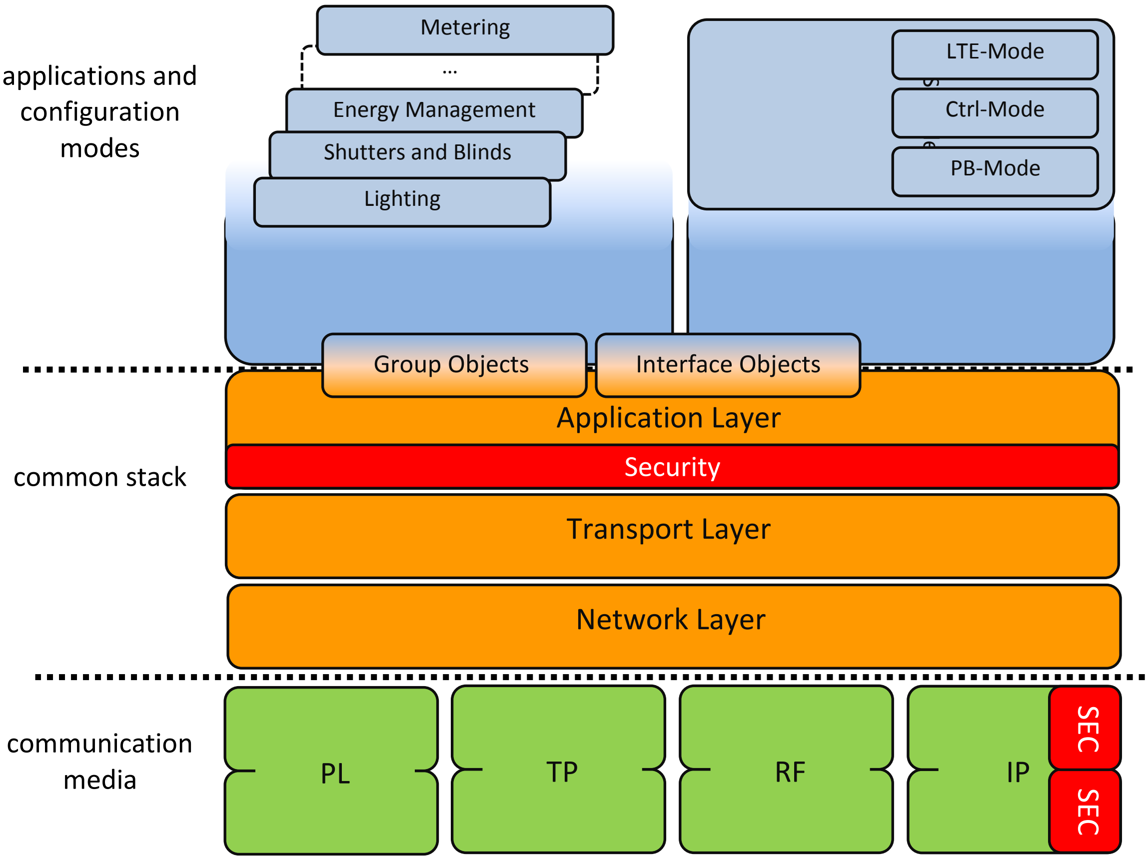
The configuration uses Diffie-Hellman key exchange supported in the multiple Configuration Modes. This keeps the security transparent to the application and maintains the Interworking.

4.2.7.2 Proposed EN 50090 developments

Create a neutral interface between Smart Grid and HBES (Smart Grid demand side) within CLC TC205 WG18

1353 ### 4.2.7.3 Stack architecture

1354



1355

1356 **Figure 7: EN 50090 protocol stack**

1357 ### 4.2.7.4 The EN 50090 Standard Landscape

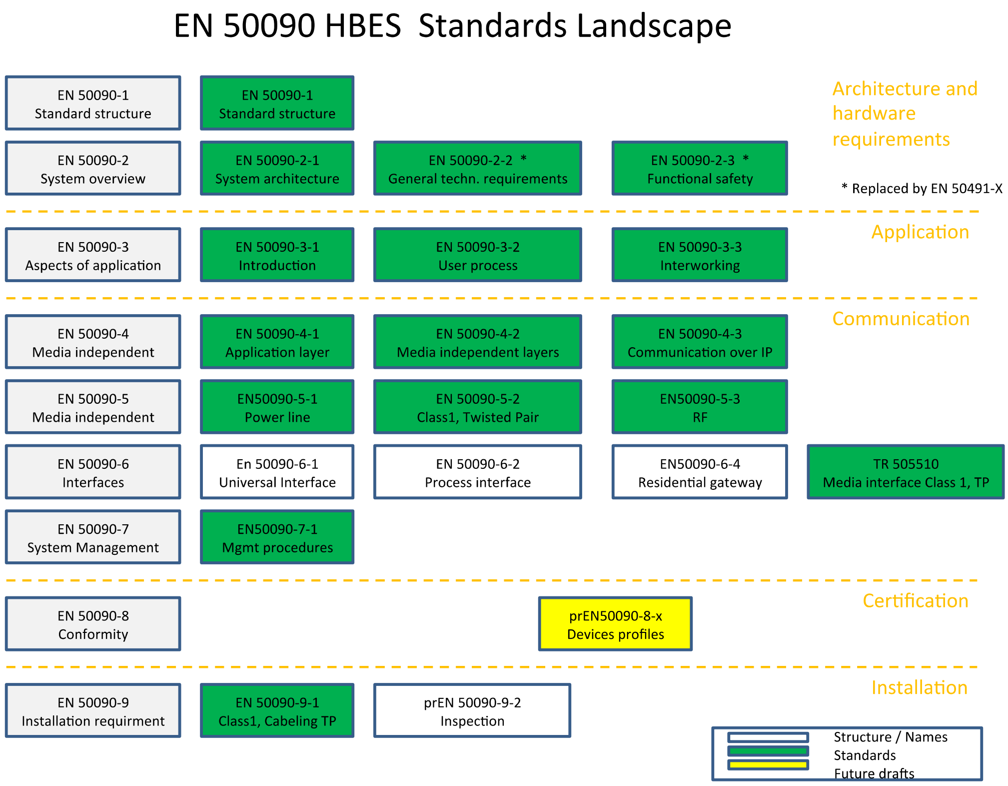


Figure 8: EN 50090 HBES Standards Landscape

4.2.8 EN 14908 family

EN 14908 is a family of standards for control networking that is widely used in smart grid, smart building, and smart grid applications.

The full suite of worldwide, open standards includes the following associated standards:

- ISO/IEC 14908-1, which specifies a multi-purpose control network protocol stack optimized for smart grid, smart building, and smart city applications
- ISO/IEC 14908-2, which specifies a free-topology twisted-pair channel for networked control systems in local area control networks and is used in conjunction with ISO 14908-1
- ISO/IEC 14908-3, which specifies a control network Power Line (PL) channel that operates in the EN 50065-1 CENELEC C-Band and serves as a companion document to ISO 14908-1
- ISO/IEC 14908-4 specifies the transporting of the control network protocol packets for commercial local area control networks over Internet Protocol (IP) networks and is used in conjunction with ISO 14908-1
- ETSI TS 103 908, which specifies a high-performance narrow band power line channel for control networking in the smart grid that operates in the EN 50065-1 CENELEC for use with ISO 14908-1
- US standards ANSI 709.1, .2, .3. and .4
- EU standards EN 14908-1, -2, -3, -4, -5 and -6
- China standards GB/Z 20177.1

- US standard IEEE 1473-L
- US standard SEMI E54

EN 14908 family standardizes layers 1 to 7 of the OSI reference model as shown in the figure below. It includes standard definitions for a number of physical layer channels optimized for specific control networking applications such as smart grid and smart buildings, and includes a rich set of data models to promote interoperable devices in smart building, smart city and smart grid applications.

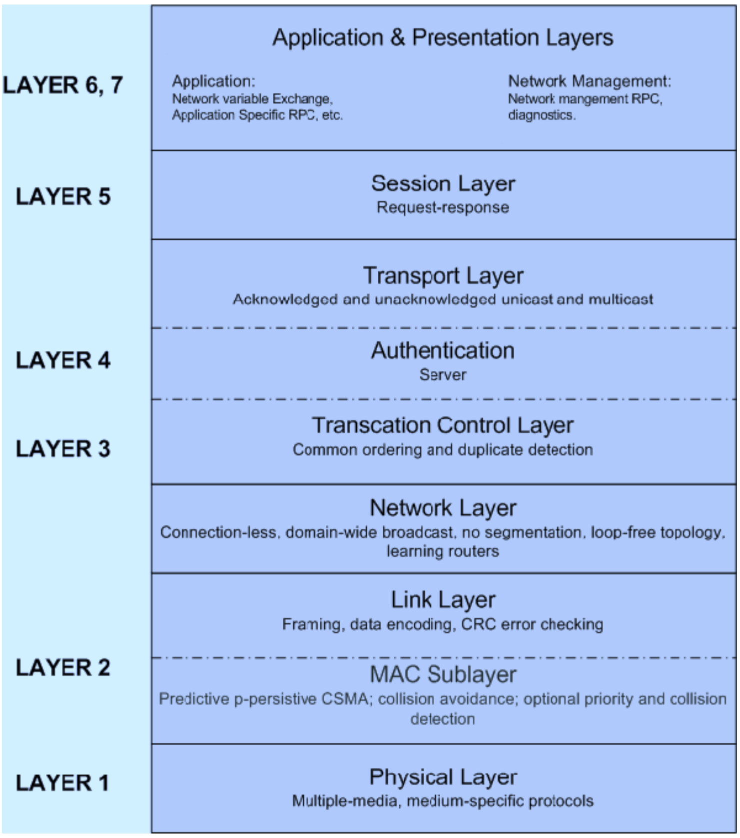


Figure 9: EN 14908 protocol stack

4.3 SCADA substation protocols

4.3.1 IEC 60870

IEC 60870-5 refers to a collection of standards produced by the International Electrotechnical Commission (IEC) which provides an open standard for the transmission of SCADA telemetry control and information. The standard provides a detailed functional description for remote control equipment and systems for controlling geographically widespread processes, in other words for SCADA systems.

When the IEC 60870-5 set of standards was initially completed in 1995 with the publication of the IEC 870-5-101 profile, it covered only transmission over relatively low bandwidth bit-serial communication circuits. With the increasingly widespread use of network communications technology, IEC 60870-5 now also provides for communications over networks using the TCP/IP protocol suite.

The IEC 60870 standard is structured in a hierarchical manner, comprising parts, sessions and companion standards. The companion standards extend the definition provided by the main parts of the standard by adding specific information objects for the field of application.

The parts of IEC 60870 are as follows:

a. Main Part
IEC 60870-1, General Considerations
IEC 60870-2, Operating Conditions
IEC 60870-3, Interfaces (electrical characteristics)
IEC 60870-4, Performance Requirements
IEC 60870-5, Transmission Protocols
IEC 60870-6, Telecontrol Protocols Compatible With ISO and ITU-T Recommendations

b. Sections of IEC 60870-5
IEC 60870-5-1, Transmission Frame Formats
IEC 60870-5-2, Link Transmission Procedures
IEC 60870-5-3, General Structure of Application Data
IEC 60870-5-4, Definition and Coding of Application Information Elements
IEC 60870-5-5, Basic Application Functions

c. Companion Standards of IEC 60870-5
IEC 60870-5-101, Companion Standard for Basic Telecontrol Tasks
IEC 60870-5-102, Companion Standard for Transmission of Integrated Totals
IEC 60870-5-103, Companion Standard for Protection Communication
IEC 60870-5-104, Network Access using Standard Transport Profiles

The IEC 60870-5-104 defines the transport of IEC 60870-5 application messages over networks.

4.3.2 IEC 60870-5-101 System topology

IEC 60870-5-101, or T101, supports point-to-point and multidrop communication links carrying bit-serial low-bandwidth data communications. It provides the choice of using balanced or unbalanced communication at the link level.
With unbalanced communication, only the master can initiate a communication by transmitting primary frames. All communications are initiated by master station requests, which poll for user data if available.
Balanced communication is available, but it is limited to point-to-point links only.
Therefore whilst T101 can support unsolicited messages from a slave, it cannot do so for a multidrop topology and must employ a cyclic polling scheme to interrogate the secondary stations.
A ‘monitor direction’ and a ‘control direction’ are also defined: monitored data such as analog values from the field are sent in the monitoring direction, and commands are sent in the control direction. If a station both sends monitored data and sends commands, it is acting both as a controlled and a controlling station: this last is defined as dual-mode operation. It is accommodated by the protocol, but requires the use of originator addresses in the ASDU[4].

4.3.3 IEC 60870-5-101 Message structure

The message structure under IEC 60870-5-101 is composed by a data link layer frame carrying link address and control information, a flag to indicate if Class 1 data (highest priority information) is available, and optional application data. Each frame can carry a maximum of one application service data unit, or ASDU. The following figure shows the data link frame structure, and the structure of the application layer ASDU carried by it.

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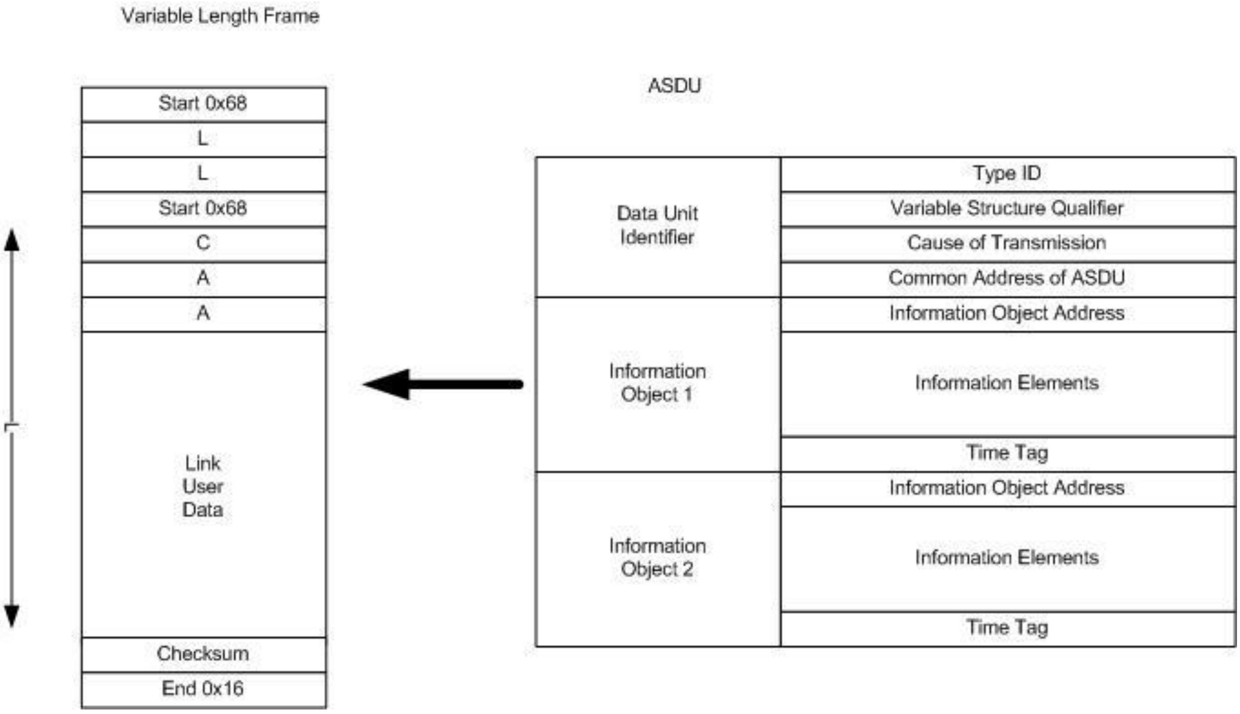

Figure 10: Message Structure of IEC 60870-5-101[5]

4.3.4 IEC 60870-5-101 Addressing

Under IEC 60870-5-101 addressing is provided the link at the application level. The link address field may be 1 or 2 octets for unbalanced and 0, 1 or 2 octets for balanced communications. As balanced communications are point-to-point the link address is redundant, but may be included for security. The link address FF or FFFF is defined as a broadcast address, and may be used to address all stations at the link level.

At the application level, the ASDU contains a 1 or 2 octet common address. This is defined as the address of the controlling station in the 'control direction', and the address of the controlled station in the 'monitoring direction'. The common address of the ASDU combined with the information object address contained within the data itself combine to make the unique address for each data element.

There may be more than one logical or common address per device. As for the link level, the address FF or FFFF is defined as a broadcast address. Therefore to send a broadcast message it is necessary to include this address in both the data link and application address fields.

4.3.5 IEC 60870-5-104 Networked version

Under IEC 60870-5 there are two different methods of transporting messages. The first is IEC 60870-5-101, or T101, which provides for bit-serial communications over low-bandwidth communications channels.

The second method was defined with the release of the IEC 60870-5-104, or T104 profile. In this protocol the lower levels of the protocol have been completely replaced by the TCP and IP

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transport and network protocols. These protocols provide the transport of the application service data units (ASDUs) over corporate local area networks and wide area networks.
The structure of the protocol or ‘protocol stack’ is shown in Table 4.

Table 4: Protocol Stack IEC 60870-5-104[6]

Layer	Source	Selections
User Process	IEC 60870-5-101	Application functions
Application	IEC 60870-5-101	ASDU and application information Elements
Transport	TCP / IP Protocols Suite	
Network		
Link		
Physical		

Whereas T101 provides full definition of the protocol stack right down to the physical level, this is not provided under T104 as existing and varied physical and link layer operations are employed.

4.3.6 IEC 60870-4-101 Application data objects

IEC 60870-5 includes a set of information objects that are suited to both general SCADA applications and electrical system applications in particular. Each different type of data has a unique type identification number. Only one type of data is included in any one ASDU, and the type identification is the first field in the ASDU.

The information object types are grouped by direction and by type of information, as follows:

Table 5: Information Object Type Groups

Group	Example in Monitoring Direction	Example in Control Direction
Process Information	A measured value, E.g. bit or analog	A command E.g. to set a bit or a set point value
System Information	End of initiation flag	Interrogation command, reset process command
Parameter		Set a filter time
File Transfer	Read data file, write a configuration file	

4.4 Wireless Access & Wide Area Technologies

4.4.1 Overview of GSM Family of Cellular Communication Systems

4.4.1.1 GSM family of cellular communication systems – overview

GSM technology has been in development since 1987. The evolution of GSM standard-based mobile communication systems will be consistent globally, and will follow a clear path from the second and third generation of mobile networks that is widely available today to LTE technology [Figure 10].

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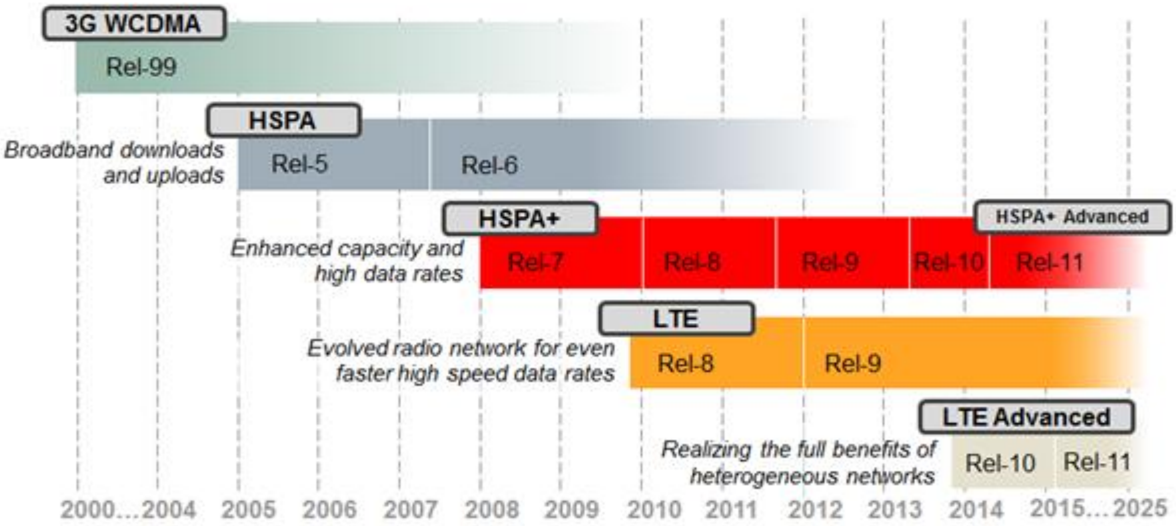


Figure 10: Evolution of 3GPP Family of Mobile Broadband Technologies

Note: HSPA+ peak theoretical data rate reaches up to 42 Mbps when using single carrier with QAM 64 and 2x2MIMO

Table 6: Technical Characteristics of Different Generations of Mobile Technology

		Peak Data rate* (downlink)	Latency/Round-trip time
2G	GSM	9.6kbps	150-200ms
	GPRS	40kbps	>500ms
	EDGE	236.8kbps EDGE Evolution has downlink speeds of up to 1.3Mbps in the downlink and 653Kbps in the uplink	100-200ms
3G	UMTS	384kbps	200-250ms
	HSPA	14.4Mbps	50-100ms
	HSPA+	28Mbps in Rel-7 42Mbps in Rel-8 84Mbps in Rel-9 168Mbps in 20MHz in Rel-10 336+Mbps in 40 MHz in Rel-11	28+ms
4G	LTE	170Mbps in Rel-8 and Rel-9	5-10ms
	LTE-Advanced	>300 Mbps by aggregating multiple 20 MHz carriers in Rel-10 >1Gbps in 80 MHz and 4x4 MIMO in Rel-11	5-10ms

Note: Theoretical maximum data rates are quoted in this table – achievable throughput tends to 1/5th to 1/7th of this theoretical maximum
Source: GSMA

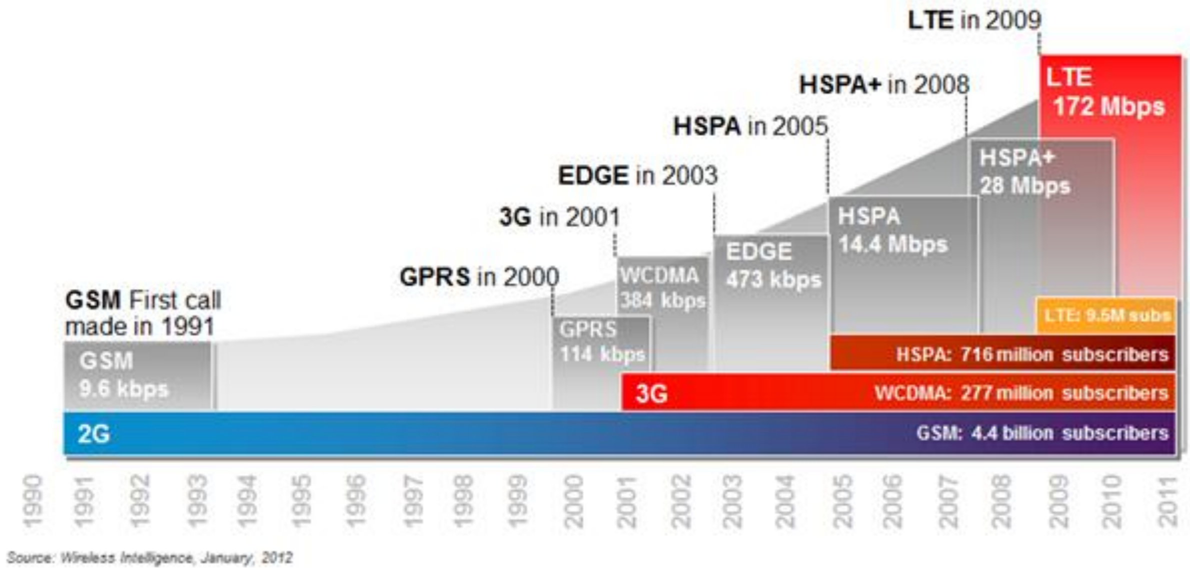


Figure 11: GSMA family of technologies development to date

4.4.2 GPRS / EDGE (General packet radio service / Enhanced Data rates for Global Evolution

Technology Overview

GPRS (General packet radio service) is a second generation (2G) wireless broadband technology, originally standardized by the European Telecommunications Standards Institute (ETSI), and currently maintained by the Third Generation Partnership Project (3GPP) industry trade group. GPRS (Release 97) and EDGE (Release 98) are largely specified in the GSM EDGE Radio Access Network (GERAN) group of 3GPP.

Based on specifications in Release 97, GPRS typically reaches speeds of 40Kbps in the downlink and 14Kbps in the uplink by aggregating GSM time slots into one bearer. Enhancements in Releases R'98 and R'99 meant that GPRS could theoretically reach downlink speeds of up to 171Kbps.

In practice, GPRS is a best-effort service, which means that throughput and latency can be variable depending on the number of other users sharing the service concurrently.

EDGE (Enhanced Data rates for Global Evolution) or Enhanced GRPS is the next advance in GSM radio access technology. EDGE re-uses the existing GSM spectrum, with a new modulation technique yielding a three-fold increase in bit rate (8PSK replacing GMSK) and new channel coding for spectral efficiency.

On-going standards work in 3GPP has delivered EDGE Evolution as part of Release 7, designed to complement high-speed packet access (HSPA).

EDGE Evolution, resulting from the HUGE and RED HOT work items, has:

- Improved spectral efficiency with reduced latencies down to 100ms
- Increased throughput speeds to 1.3Mbps in the downlink and 653Kbps in the uplink

4.4.3 UMTS (Universal Mobile Telecommunications System)

Technology Overview

UMTS is an umbrella term for the third generation (3G) radio technologies developed within 3GPP. The 3G radio technologies include:

- W-CDMA (Wideband Code Division Multiple Access), the radio technology, which is a part of the ITU IMT-2000 family of 3G Standards, and
- HSPA (High-Speed Packet Access), the radio technology largely covered by the Radio Access Network (RAN) group of 3GPP.
- HSPA+ (Evolved High-Speed Packet Access), the radio technology first defined in 3GPP's Release 7.

W-CDMA was specified in Release 99 and Release 4 of the specifications. High Speed Packet Access (HSPA) was introduced in Releases 5 (Downlink) and 6 (Uplink) giving substantially greater bit rates and improving packet-switched applications.

HSPA improvements in UMTS spectrum efficiency are achieved through:

- New modulation (16QAM) techniques
- Reduced radio frame lengths
- New functionalities within radio networks (including re-transmissions between NodeB and the Radio Network Controller)
- Consequently, throughput is increased and latency is reduced (down to 100ms and 50ms for HSDPA and HSUPA respectively).

HSPA+ a natural evolution of 3G networks, much like HSPA was an evolution of UMTS and EDGE was an evolution of GSM. HSPA+ generally only requires a software upgrade to the infrastructure as well as increased backhaul and transport capabilities in order to support the significantly higher data rates offered by the technology. For certain legacy systems new hardware may be required to make the transition, although this requirement has not stopped some operators from moving forward with HSPA+. In other situations operators may upgrade their infrastructure as part of the natural hardware refreshment process or to take advantage of more power efficient and smaller form factor solutions, at which point only new software would be required for HSPA+.

HSPA+ introduces the following new functionalities for HSPA:

- Release 7 added multiple input/ multiple output (MIMO) antenna capability and 16QAM (Uplink)/ 64QAM (Downlink) modulation. 64QAM (Quadrature Modulation Scheme) enables theoretical peak data rates in the downlink direction of up to 21Mbps. This compares with a peak data rate of 14.4Mbps with HSPA.

  The data capacity of HSPA+ in Rel-7 is double of HSPA Rel-6, which is an important improvement for Smart Grid applications.

  MIMO (Multiple Input, Multiple Output) enables theoretical peak data rates of up to 28Mbps in a single 2x5MHz radio channel. MIMO uses two antennas at the cell site (transmitter) and two antennas at the mobile terminal (receiver) to send data bits in parallel streams down two separate transmission paths. MIMO is a key feature in all next-generation wireless technologies, including LTE and LTE Advanced.

HSPA+ is backwards compatible with HSPA, meaning that MIMO-enabled HSPA+ devices work in an HSPA network and that legacy UMTS/HSPA devices work in a MIMO-enabled HSPA+ network.

- Enhanced CELL_FACH significantly increases signalling load and improves the capacity for bursty traffic.
- Coupled with improvements in the radio access network for continuous packet connectivity, HSPA+ allows Uplink speeds of 11Mbps and Downlink speeds of 42Mbps within the Release 8 time frame.

Further improvements were introduced in Dual-cell or Dual-carrier HSPA (DC-HSPA). Dual cell or Dual carrier HSPA was defined in 3GPP Release 8, specifying carrier aggregation for increased spectrum efficiency and load balancing across the carriers.

- DC-HSPA+ (Rel-8) can double the capacity for bursty applications, which includes most Smart Grid applications.
- Release 7, MIMO deployments can benefit from the DC-HSDPA functionality as defined in Release 8.
- Release 8, DC-HSPDA operates on adjacent carriers
- Release 9, paired cells can operate on two different frequency bands, possible to use DC-HSDPA in combination with MIMO. In Release 9, it will also be possible to implement DC-HSPA in the uplink, thus doubling the peak data rate to 11Mbps or 23Mbps with the addition of 16QAM.

  Release 9 also supports an innovative feature called Supplemental Downlink, which combines unpaired spectrum (e.g. TDD) with the downlink of paired spectrum, and significantly increases the downlink capacity.

- HSPA+ Rel-10, which is already standardized, supports aggregation of up to 4 carriers enabling 20 MHz deployments. HSPA+ through its many features allows operators leverage all of their spectrum resources.

HSPA+ Advanced consists of enhancements being defined in Release 11 and beyond, introducing a range of new performance improvements. These enhancements can be divided into five broad areas:

1. Evolving Multicarrier to utilize all available spectrum assets;
2. Introducing features such as MultiFlow to exploit uneven network loading;
3. Optimizing HetNets to get even higher performance from small cells;
4. Further leveraging advanced antenna techniques;
5. Efficiently connecting the next explosion of interconnected, low-traffic and bursty machine-to-machine devices, which are forecast to reach billions in the next 5-10 years, and supporting the continued growth of smartphones.

Users of HSPA+ networks would benefit from the backwards compatibility of HSPA+ with UMTS/HSPA as well as the large ecosystem of device and chipset suppliers that are available. LTE and HSPA+ are considered to be complementary technologies and an operator's initial support of one technology will not come at the expense of their support for the other technology. Many of the operators who have already deployed HSPA+ are also in the process of deploying LTE. Still other operators may opt to deploy LTE first and then upgrade their HSPA networks to HSPA+ to augment the capabilities and coverage of their LTE network. LTE is best suited for new and wider bandwidth (10 MHz or more) as well as TDD spectrum. HSPA+, on the other hand, is well suited for the existing spectrum or new spectrum with 5MHz bandwidths.

The HSPA/HSPA+ system development have benefitted from large-scale adoption worldwide. Following an explosive rise in demand for smartphones, connected tablets and Mobile Broadband dongles across the globe, there are now more than 590 million HSPA Mobile Broadband connections worldwide, making it the fastest growing wireless technology ever. Mobile Broadband adoption in its first six years was ten times faster than the take up of 2G mobile phones when they were first introduced in the early 1990s. The global mobile industry is now connecting 19 million new HSPA devices each month and is on course to reach one billion HSPA connections by the end of 2012. HSPA Mobile Broadband networks have now been deployed in 135 countries.

Over the next five years, Rethink Technology Research forecasts that mobile operators will invest almost US$100 billion in HSPA, HSPA+ and next-generation LTE networks, which offer peak download speeds of up to 100Mbps – ten times faster than the average wired broadband connection today.

4.4.3.1 Mobile Network Resilience

Mobile networks are built to deliver ‘’five nines’ availability: the networks are up for 99.999% of the time, which translates into 38 minutes/year downtime.

Equipment is deployed with ‘N+1’ or ‘1+1’ redundancy and has stand-by powering available in case of power outage. For every piece of equipment in the network there is always a ‘spare’ that is in ‘warm stand-by’, so that if a fault occurs, the stand by equipment takes over. In reality, both pieces of equipment are active and load balancing is taking place between the two. This means that there is always spare capacity in the network elements since both have to run at low efficiency so they can handle the calls/sessions the other is managing if there is a failure.

Links between network equipment are usually installed with:-

- Sufficient capacity to handle busy hour traffic peaks and unexpected surges in demand
- Redundancy (often including geo-redundancy) to offset the risk of link breakage disrupting service.

Critical network elements are installed in geo-redundant locations. If one site is attacked, another site has all information stored and can take up service.

All mobile networks have a Network Operations Centre (NOC) where all faults and outages are reported and necessary repairs are coordinated from.

4.4.3.2 Embedded SIM

The UICC (Universal Integrated Circuit Card) is the smart card used in mobile devices in GSM and UMTS networks. In a GSM network, the UICC contains a Subscriber Identity Module (SIM) application and in a UMTS network it is the Universal Subscriber Identity Module USIM application.

The Embedded SIM is a separately identifiable hardware component (tamper-resistant microprocessor with secure memory), which is installed in a device at manufacture, replacing the need for a traditional SIM. It is not intended to be removed or replaced, and it has functionality allowing its secure remote management including loading/reloading of mobile operator credentials and applications. It is supported by a set of secure interfaces and standards that allow operator credentials to be transported securely from the Operator to the Embedded SIM, thus providing the integrity and trust necessary to protect users and operators during the transport and provisioning of sensitive data. This is a fundamental change to current models of hard coded SIM applications.

Embedded SIM allows selection of a mobile operator and country to happen independently of distribution channel, which is a significant benefit to manufacturers through the reduction of stock items needed. It enables subscribers to switch operator during product life cycle, which for many smart grid products is in excess of 10-15 years. The Embedded SIM also permits removal of MNO credentials from SIM card (termination) with re-use of device/eUICC on the same or another network.

Embedded SIM will have the potential to support the following major business use cases relevant to the smart grid:

a. Provisioning of multiple Machine subscriptions, where an Service Provider sets-up subscriptions for a number of connected data devices to start telecommunication services with a Network Operator;
b. Subscription change, where a subscriber changes the subscription for a device to stop services with the current Mobile Network Operator and start services with a new Mobile Network Operator;
c. Stop subscription remotely, where a subscriber stops services with the current MNO
d. Transfer subscription, where a subscription is transferred between devices

The standardization of the Embedded SIM is taking place at ETSI SCP (Smart Card Platform) technical committee (http://portal.etsi.org/scp), which is currently defining the requirements.

It is worth noting that the Embedded SIM preserves the traditional advantages of the SIM/UICC card platform, some of which may be of particular interest in the smart grid context and especially in smart metering:

1. A programmable tamper-resistant microprocessor able to support multiple applications, which could be used as the security module in the gateway of a smart metering systems to comply with the requirements of the BSI Protection Profile for Smart Meter Gateway issued in Germany.
2. An standardized programming environment (JavaCard virtual machine) and Application Programming Interface (Card Application Toolkit) enabling the interoperable downloading and remote management of third-party applications
3. Support of Global Platform specifications, which enable the following features:
    a. Provisioning and management of third party applications in confidentiality from the communication service provider, where desired
    b. Ability for each third party application to run in its own "Security Domain", providing firewall protection for its private information
    c. Ability for each third party application to establish a secure channel with its service provider independently from the other applications.

The combination of these features may assist in resolving the privacy issues associated with smart metering as depicted in the following figure, where raw energy data are processed independently in the applications Security Domains of the embedded SIM to extract only the information of interest to their service providers:

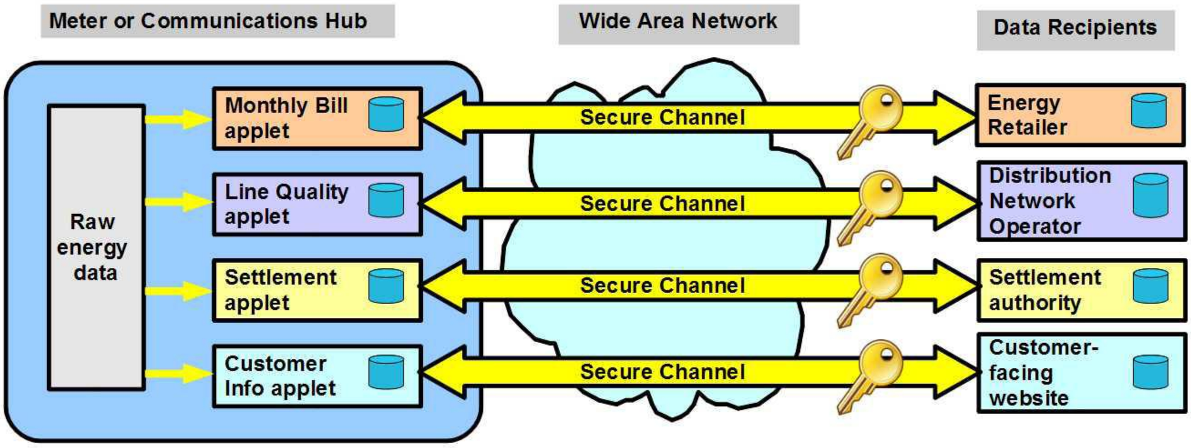


Figure 12: Privacy issues associated with smart metering

4.4.4 Long Term Evolution (LTE) for Smart grid

4.4.4.1 Overview of LTE

LTE (Long Term Evolution) is the next generation wireless broadband technology developed and standardized by the Third Generation Partnership Project (3GPP) industry trade group. LTE is the next step in a progression from GSM (2G), & UMTS (3G), providing increased data rates, reduced latency, and scalable bandwidth capacity. The air interface (originally specified in 3GPP Release 8) combines OFDMA based modulation and multiple access scheme for the downlink, with SC-FDMA for the uplink. The available spectrum is split into a thousand or more of narrowband carriers, each carrying a part of the signal. In LTE, the innate spectral efficiency of OFDM is further enhanced with higher order modulation schemes (64QAM), sophisticated error correction schemes, and radio techniques such as MIMO and Beam Forming with up to four antennas per station enables greater throughput.

The combined effect of these radio interface features is significantly improved radio performance with up to 300 Mbit/s per 20 MHz of spectrum for the downlink and 75 Mbit/s per 20 MHz of spectrum for the uplink.

A key characteristic of LTE technology is that bandwidths are scalable from 1.4 MHz to 20 MHz. 3GPP release 8 defines LTE bandwidths of 1.4, 3, 5,10, 15 and 20 MHz. OFDMA, the chosen transmission scheme for LTE ’s physical layer enables such bandwidth flexibility. Bandwidth scalability inherent in LTE provides a flexible and easy way to increase capacity on the air interface into the future to meet the demands of higher data throughputs, new applications and changes.

Table 7: 3GPP Long Term Evolution Requirements

Metric	Description	Requirement
Bandwidth	Support of scalable bandwidth	1.4,3,5,10,20MHz
Peak data rate	Downlink	100Mbps
	Uplink	50Mbps
Latency	Transfer delay in RAN	5ms (one way)
	Connection setup delay	100ms

Every 3GPP LTE UE is required to support these afore mentioned bandwidths already from Release-8, therefore increasing system capacity in terms of cell throughput is as simple as scaling up the LTE allocated bandwidth. Where spectrum is shared with other systems such as GSM, scalability allows for progressive spectrum allocation, conserving capacity for legacy systems until such time as the extra bandwidth is required for LTE applications.

Existing and Proposed LTE features

- Dual-Stack IPv4/IPv6 support – IPv6 addressing is essential for large “machine communities”, and allows applications to work seamlessly across mobile and fixed broadband connections.
- Very low latency on user plane, control plane and scheduling (Short setup time & Short transfer delay, Short TTI,) essential for Grid applications handling thousands of devices within a cell. Previous generation technologies have slower radio reestablishment procedures and require larger overheads.
- Support of variable and scalable bandwidth (1.4, 3, 5, 10, 15 and 20 MHz) to effectively address capacity issues whilst optimizing spectrum utilization by legacy applications (GSM/UMTS). This is essential in enabling efficient and simple spectrum sharing, and allows a smooth migration, increasing bandwidth as the demands on the network increases (as the number of devices increases, or data requirements increase).
- Simple protocol architecture (Shared channel based, Packet Switched optimized with VoIP capability). Grid applications are data based; LTE is a network made especially to handle data as first priority.
- Simple Architecture (eNodeB as the only E-UTRAN node) – reduces system complexity, reduces latency and enhances scalability.
- Efficient Multicast/Broadcast. This is a desirable feature for future deployment of applications intended to make use of broadcast data.
- Support of Self-Organizing Network (SON) operation – reduces the need for OPEX intensive O&M tasks through automatic neighbour optimization and automatic interference management. This saves costs associated with manually configuring and tuning the network.
- Guard bands are part of the LTE specification, meaning that no extra consideration needs to be taken in calculating spectrum requirements. LTE can be put right next to GSM/HSPA without any extra guard band required.
- Increased spectrum efficiency in DL from 15bps/Hz to 30bps/Hz. This provides capacity expansion into the future to meet the needs of new applications and faster downlink data transfer rates.
- Support for non-contiguous bandwidth scalability, allowing aggregation of non-adjacent bandwidth allocations (increasing capacity). This provides greater flexibility for capacity expansion into the future without the need to secure contiguous spectrum.
- Improved support for heterogeneous deployments and relaying, reducing the cost of network coverage expansion.

In addition to the technological and business reasons for selecting it, LTE also benefits from its foundation as a global standard. With the selection of LTE, the following benefits are guaranteed:

- Backwards compatibility: Future releases maintain compatibility with existing releases, so that old equipment is not made obsolete.
- Robust evolution: LTE is constantly being improved and operators are constantly upgrading their networks. It is envisaged that LTE radio access technology could be evolved for the coming 20 years.

- Large ecosystem: The reliance on standardized solutions ensures that there is healthy competition and a large menu of products available.
- Standardization of not only the radio technology, but of a coherent system as a whole including the core network, services aspects, security aspects, and management aspects.
- High bandwidth, low latency, high reliability, QoS, secure ecosystem,

4.4.4.2 LTE and Wide Area Networks

LTE is primarily a wide area technology. It is developed for data communications (voice is considered just another type of data). It is being considered extensively for machine-to-machine communications. As it is a next generation technology, meaning that 3GPP has a considerable base of previous knowledge to work with in developing wireless networks. Much of this worked focused not only on specifying a system with improved performance, but also on standards to reduce the total cost of ownership. Within 3GPP many of the standardized technologies such as SON or Minimization of Drive Tests are focused on simplifying the deployment and maintenance of the network.

3GPP also allows for various business types of arrangements that may reduce costs such a sharing of the network between multiple operators or virtual network operators.

Since LTE is global standard, this requires a large amount of flexibility. LTE must be able to be deployed within various national frequency band plans. It must be able to coexist with other technologies, and conform to various nation regulations. In Release 10, LTE was defined for 25 FDD bands and 11 TDD bands with new bands being added all the time. In addition to individual bands, 3GPP has the concept of carrier aggregation, which allows different bands to be aggregated to act as a wideband carrier.

LTE is required to exist in many radio environments such as rural areas, urban canyons, subways etc. For this reason, 3GPP allows for a variety of sizes of cells ranging from macro cells that cover 100 square miles to micro cells, pico cells, and recently home eNodeb's that are intended to work in residential or hotspot type of environments. LTE is specified to fullfil the full performance requirements in cells with 5 km radius, with slight performance degradations (reasonable performance) in cells with 30 km radius and should not preclude (acceptable performance) cells with 100 km radius. 100 km radius translates to around 12000 square miles while 30 km radius covers around 1100 square miles.

Even when LTE devices are not mobile, the radio environment can vary wildly over time. LTE is designed to make optimal use of the available micro cells and macro cells to provide throughput and increase reliability.

Although LTE was designed for data communications, it was realized that not all data communications are the same. LTE allows for different QoS characteristics to be associated with different data streams. These characteristics include aspects such as:

- Guaranteed bit rate or not
- Allocation retention priority
- Priority
- Bit rate
- Delay
- Maximum bit loss

LTE Release 8 supported bit rates of 100Mbit/sec, latencies in - the order of 10ms on the radio interface, and maximum bit error rates as low as10^-5. These numbers are constantly improving with each release.

Support for these parameters is integrated into the system and extends from the terminals through the radio network and through the core network. In addition, 3GPP is working on further optimizing the system to cater to machine-to-machine type characteristics such as bursty traffic, infrequent message sending and greater uplink traffic than downlink.

Optimizations will improve the efficiency of the network; whilst maintaining backwards compatibility. This means that whatever changes are made to improve efficiency or improve performance will not affect the ability of existing devices and applications to continue to work. 3GPP Release 10 addressed Overload Control mechanisms to protect mobile networks from data signaling congestion and overload, e.g. the distributed ability to reject connection requests from delay-tolerant services to maintain critical services. Whereas in Release 10 the focus was in the core network overload control, in Release 11 3GPP is working on overload control of the radio network and Random Access Channel in particular.

One specific expectation with machine-to-machine type of devices is that there will be a large number of devices. LTE devices are dual stack (ipv4/ipv6) to ensure that growth is not limited by IP addresses. Other identifiers are not seen as an immediate problem, however 3GPP is also working to ensure that there are no limitations in that area.3GPP Release 11 is currently working on System improvement for Machine Type Communication focusing on reachability aspects e.g. addressing and identifiers, Device triggering and architectural enhancements for machines & meters.

Another area were LTE has a strong heritage is in security. The need for security is a fundamental requirement on LTE systems. 3GPP ensures that the systems are not only secure, but that backup algorithms exist in case the primary algorithms are ever compromised.

4.4.4.3 LTE and Field Area Networks

LTE is designed to work in licensed bands. This will in many cases mean that it is more reliable than networks deployed on the ISM band. The 3GPP standard certainly allows for small cell sites and many such products exist and are currently deployed today.

However, another option is to use a commercial LTE network and thus completely eliminate the need for a field area network. LTE may of course also be deployed in dedicated bands owned by the utilities. 3GPP can consider standardizing additional bands if required. 3GPP will not however extend the technology to the ISM bands.

It should be noted that LTE is ideally suited to scenarios where large populations of devices require concurrent data communication within a sector. This is a key requirement during scenarios such as soft starting a network after a blackout (remotely disconnecting a large volume of residences and then turning them on in smaller groups so as not to overload the systems with high start-up current), suburb-by-suburb off-peak tariff control, street light control, distributed generation and so on.

Typically, the devices on the network are fixed geographically and spend most of their time in an idle mode. When a traffic event occurs (initiated either by the terminal device or a system external to the LTE network), the devices attach to the network using standard 3GPP LTE protocols, and are then able to send or receive data, depending on the application and traffic case.

In general, the devices do not move, and have no need to use the various mobility management functions inherent in the LTE system. However, devices that are situated in marginal coverage areas (towards the edge of a coverage cell) will be able to signal via different sectors as the need arises.

One of the areas currently being investigated by 3GPP is the specification of low cost LTE devices. These are devices or modules, which are suitable for low demand applications and achieve a lower price point than full-fledged LTE modules.

4.4.4.4 LTE and Premises Networks

LTE has two methods of addressing premises networks:

- Home ENodeBs (femtocells) are small base stations that are specified to connect to the cellular network over the customer's broadband connection. These use LTE (or HSPA)
- WLAN integration allows for cellular traffic to be tunneled over the customer's broadband connection. This requires devices that are Wi-Fi capable.

For these two options, there are various possibilities with respect to steering traffic, offloading traffic, and access/visibility of local network resources.

These two methods have been specified within 3GPP. The primary advantage of these methods over traditional Wi-Fi only is that it provides the mobility, security, management, QoS capabilities inherent in 3GPP networks.

A special case within this scenario is the Plug in Electric Vehicle (PEV). PEVs are expected to sometimes be part of the premises network, but also require mobility. LTE is an obvious candidate for such mobility. With a LTE HeNB or integrated Wi-Fi, then the same applications that work in the premises continue to work while on the road.

4.4.5 Wireline access technologies

4.4.5.1 Digital Subscriber Lines, xDSL

For the past twenty years, digital subscriber lines technologies have been adopted worldwide with a high penetration by the operators and users. The main driver of its success is the constant increase of the bit rate over existing copper wires, which opens the doors to numerous new services like high speed internet and IPTV (Internet Protocol Television). This highlighted the importance of guaranteed rate and almost error free transmission. Accompanying this trend to higher and more stable bit rates, the ITU-T has generated a series of Recommendations dedicated to DSL systems and updated them regularly.

Table 8: ITU-T Recommendations on DSL systems

(S)HDSL	HDSL **G.991.1**	SHDSL **G.991.2**			
ADSL	ADSL **G.992.1**	Splitterless ADSL **G.992.2**	ADSL2 **G.992.3**	Splitterless ADSL2 **G.992.4**	ADSL2plus **G.992.5**
VDSL	VDSL **G.993.1**	VDSL2 **G.993.2**	VDSL2 with Vectoring **G.993.5**		
Common aspects	Handshake **G.994.1**	Overview DSL systems **G.995.1/G.sup50**	Test procedures **G.996.1**	Single ended line testing **G.996.2**	
	Physical layer management for DSL **G.997.1**	Multi-pair bonding **G.998.1/2/3**	Interfaces PHY / Link Layer **G.999.1**	Improved impulse noise protection for DSL transceivers **G.998.4**	

The first series of ITU-T Recommendations, G.991.x, on DSL targets business services. They are characterized by single carrier baseband system using the same frequencies in upstream and downstream directions. They provide symmetric services up to 6 Mbit/s with very low latency.

The second series of ITU-T Recommendations, G.992.x, targets residential services from the central office. Using a multi-carrier modulation and frequency division duplexing, they provide asymmetric services up to 16 Mbit/s in the downstream direction and 800 Kbit/s to the central office. The variants ITU-T G.992.1 (ADSL), ITU-T G.992.3 (ADSL2), and ITU-T G.992.5 (ADSL2plus) are the most widely deployed DSL systems in the world.

The third series of ITU-T Recommendations, G.993.x, is intended for residential and business services from the cabinet. The first variant is ITU-T G.993.1 (VDSL). It was quickly followed by the second variant, ITU-T G.993.2 (VDSL2). The latter is now the most deployed one. ITU-T G.993.2 is a multi-carrier system with a frequency division multiplexing similar to ITU-T G.992.3, but using a wider frequency band to provide bit rates up to 100 Mbit/s. VDSL2 has been designed to keep as many common functions with ADSL2. The third variant, ITU-T G.993.5, is an addition to VDSL2 that permits to increase the rate or to extend the reach by using crosstalk cancellation between the pairs.

On top of those three series, a set of Recommendations applicable to multiple ITU-T Recommendations were developed. For examples, ITU-T G.994.1 is a common protocol to negotiate between different xDSL technologies, ITU-T G.997.1 provides a common management interface to DSL technologies, ITU-T G.998.1/2/3 describes common bonding protocol for DSL, and ITU-T G.998.4 specifies a common retransmission technique for VDSL2 and ADSL2.

4.4.5.2 Passive Optical Access Networks (PON)

Optical fibre is capable of delivering bandwidth intensive integrated voice, data and video services at distances beyond 20 km in the access network. Various configurations can be imagined for the deployment of the optical fibre in the local access network. The most well known are Fibre to the Home (FTTH), Fibre to the Building (FTTB) and Fibre to the Curb (FTTC).

Passive Optical Network (PON) is a technology viewed by many network operators as an attractive solution to minimize the amount of optical transceivers, central office terminations and fibre deployment. A PON is a point-to-multipoint optical network with no active element in the signal path from source to destination. The only interior elements used in a PON are passive optical components such as fibre, splices and splitters.

The PON is completely passive and the maximum distance between the OLT and the ONU is typically limited to 20 km at nominal split ratios. However, there are also solutions that include deployment of active elements in the network structure (e.g., optical amplifiers) when it is necessary to achieve a longer reach (e.g., up to 60 km) or to reduce the number of CO sites (CO concentration), or to connect a larger number of users to a single OLT port (e.g., where higher power budget is required due to a higher split ratio). Such solutions are typically referred to as “long-reach PON”.

A PON can be deployed in a FTTH (fiber to the home) architecture, where an ONU / ONT is provided at the subscriber's premises, or in FTTB (fiber to the building), FTTC (fiber to the curb) or FTTCab (fiber to the cabinet) architectures, depending on local demands. In the latter cases, the optical link is terminated at the ONU, and the last stretch to the subscriber's premises is typically deployed as part of the copper network using e.g., existing xDSL lines. Typically, Various types of xDSL technology are used, from the xDSL family of technologies, e.g., VDSL2 (Very high speed Digital Subscriber Line 2).

Several versions of PON are at present specified in ITU-T: B-PON (G.983.x series), G-PON (G.984.x series), 10G-PON (G.987.x series). These three PON architectures have the same infrastructure, design and installation. The main difference among the three solutions is related to downstream and upstream data rates, as shown in Table 9.

Table 9: Downstream and upstream data rates for PON technologies

Type	Downstream (max.)	Upstream (max.)
— **ITU G.983.x series (BPON)**	Standard:1.2 Gbit/s In service: 622 Mbit/s	Standard: 622Mbit/s In service: 155 Mbit/s
ITU G.984.x series (GPON)	2.5 Gbit/s	Standard: 2.5 Gbit/s In service: 1.2 Gbit/s
ITU G.987.x series (XG-PON1)	10 Gbit/s	2.5 Gbit/s
IEEE802.3ah (GEPON)	1 Gbit/s	1 Gbit/s
IEEE802.3av (10G-EPON)	10 Gbit/s	10 Gbit/s

The ITU-T G.983.x series described PON systems based on ATM technology (A-PON / B-PON) and consisted of five Recommendations. The first described the base system, including the requirements, architecture, physical interfaces, and transmission convergence functions. The following four described features that were added subsequently.

The ITU-T G.984.x series described gigabit PON systems (G-PON), and consisted of seven Recommendations and one Supplement. The first four defined the base system, with one document each handling requirements, physical layer specifications, transmission convergence layer specifications, and management functions. The other four documents contained additional features and enhancements that arose later.

The ITU-T G.987.x series described 10 Gigabit capable Passive Optical Networks (XG-PON) systems, and consists of five Recommendations. The first provides defined terms and acronyms, and then the following three defines the base system, using the similar structure as for G-PON, with the exception of ONU management, which is handled by ITU-T G.988. The fifth document describes reach extension for XG-PON.

IEEE has defined Ethernet based PON solution (EPON). 802.3ah provides 1 Gbit/s and 802.3av 10 Gbit/s bit rates. 802.3av supports simultaneous operation with 802.3ah by using separate wavelengths downstream and a shared wavelength upstream.

4.5 Core and metro networks overview

4.5.1 Introduction

4.5.2 IP MPLS

To be completed in a subsequent release

4.5.3 MPLS-TP

The MPLS Transport Profile (MPLS-TP) is an extension of the original MPLS protocol to optimize MPLS operation in transport (Layer 2) networks.

A transport network provides efficient, reliable, qualitative and scalable connectivity over which multiple services can be supported, with a clear separation between the operations and management of the service layer from those of the transport layer. MPLS-TP is designed to satisfy transport network challenges like:

- Providing efficient, reliable, long-standing, aggregated transport paths
- Traffic Engineering for efficient utilization of the network resources
- Efficient support of all kind of services
- Transparent for service creation and modification
- Effective and scalable bandwidth management, resiliency, and QoS
- QoS with guaranteed bandwidth, controlled jitter and delay
- Robust carrier-grade OAM
- Protection and restoration mechanisms to provide high reliable services
- Simple provisioning
- Scalable to support millions of connections and global reach
- Optimal interworking with upper and lower layer network technologies

MPLS-TP is a technology applicable for packet-switched transport networks and a profile of the extended MPLS toolkit defined by IETF. The IETF (bringing IP and MPLS packet expertise) and ITU-T (bringing transport expertise) together define the capabilities and ensure compatibility with the MPLS architecture and Mechanisms.

Much of the original MPLS design, architecture and mechanisms can be used in transport networks. However MPLS-TP is being extended in the following areas to fully support the transport's requirements:

1. Architecture:
   - Both Operation Support System (OSS) based and dynamic control plane based provisioning or/and management
   - Enhancements to work as pure Layer 2 technology without relying on IP functionality.
   - Transmission of OAM messages in-band at all levels, i.e. along with the data traffic, subjecting them to the same treatment.
2. Data-plane
   - Support of bidirectional and co-routed connections
   - MPLS path merging features such as multipoint-to-point and Penultimate Hop Popping (PHP) are disabled to ensure there is a unique label to identify a path end-to-end
3. Resilience
   - MPLS and GMPLS recovery mechanisms can be provisioned by the management plane.
   - Support of linear protection mechanism with bi-directional operation to ensure co-routing of traffic in protection state.
   - Support of hold-of timers to allow protection switching a several MPLS-TP levels.
   - On-going work to optimize the protection operation of MPLS-TP in ring topologies.
4. OAM
   - Support of carrier grade transport network OAM mechanisms:
     Continuity Check, Connectivity Verification, Alarm notifications, Performance monitoring, Diagnostics
   - OAM support at all MPLS-TP levels
5. Management-plane and control-plane

- Management-plane and control-plane can be used in conjunction or independently to provision paths and services
- Mechanisms are provided to provision and manage QoS and performance measurement parameters.

MPLS-TP provides transport services for various kinds of protocols, from IP, IP/MPLS to Ethernet, ATM, SDH, PDH, Frame Relay and others and enables therefore a migration from legacy transport network and protocols (e.g. circuit switched technologies like PDH and SDH). It can run over various transport infrastructures like Ethernet, OTN and SDH.

MPLS-TP supports point-to-point and point-to-multi point connectivity and can be used in access, aggregation and core networks scenarios providing a unified end-to-end solution.
The traffic engineering, carrier-grade OAM and resilience mechanisms make MPLS-TP very suitable for applications, which require high reliability, low packet loss and low and deterministic delay/latency. The capability to differentiate between traffic classes allows to prioritize important traffic and to support different Service Level Agreements as needed.

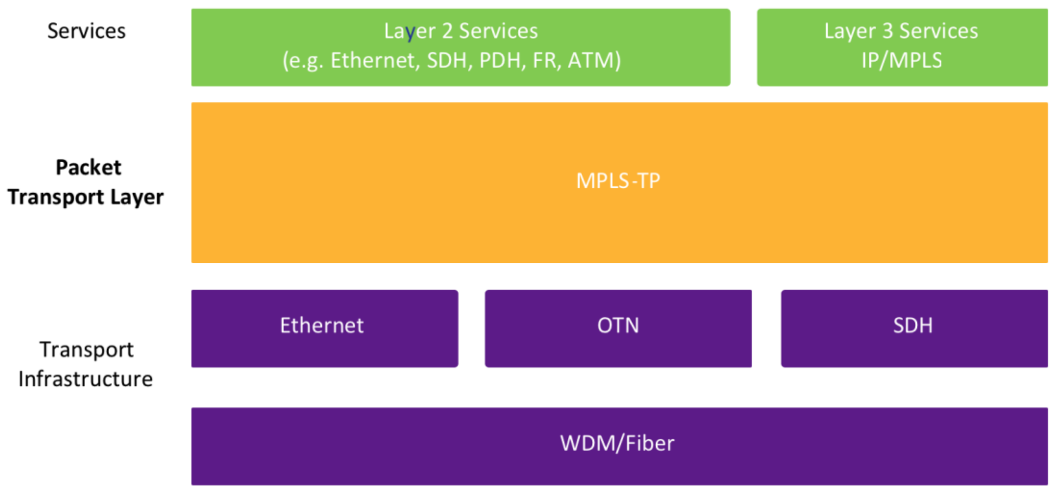


Figure 13: MPLS TP context

General application areas for MPLS-TP are for mobile backhaul for cellular networks from the base stations to the core network, wireline aggregation networks and core router inter-connection and off-loading.

In the Smart Grid context MPLS-TP fits very well for sub-station to sub-station and sub-station to control centre communication including support for low latency applications and Ethernet services (e.g. teleprotection, IEC61850 GOOSE messages). Also high precision timing applications, using for example IEEE1588, benefit from the predictable delay of MPL-TP services.

The first phase of MPLS-TP specifications includes requirements (e.g. RFC5654[3]) and frameworks (e.g. RFC5921[4]) documents; architectural elements; a comprehensive set of transport-based operations, administration, and management tools for fault management and performance measurement; and a mechanism for transport-like linear protection.

4.5.4 OTN

The Optical Transport Network (G.709) technology offers a multi-service capable infrastructure supporting lambda and sub-lambda services with guaranteed quality. OTN is characterized by a feature set and granularity that suits metro and core transport requirements, while mixing photonic and electronic technology in a complimentary way to achieve carrier grade OAM and resilience.

Some key features include:

- Future proof flexibility and scalability for any service mix and traffic distribution, enabling flexible grooming at lambda, port, and sub-port levels.
- Connection-oriented transport of any variable bit-rate, leveraging its flexible-sized container (1.25 Gbps increments), to enable full utilization of network resources
- Optimized support for Gigabit Ethernet services, ranging from 1 Gb/s to 100 Gb/s,
- Gigabit/ Multi-Gigabit -level bandwidth granularity required to scale and manage Multi-Terabit networks.
- Enhanced SLA verification capabilities in support of multi-carrier, multi-service environment.

Initial OTN technology built upon the industry's positive experience with SDH/SONET, providing support for new revenue generating services, and solutions for offering enhanced OAM capabilities, while addressing inherent optical transmission challenges that did not exist for SDH (e.g., DWDM system engineering rules with/without flexible Optical NEs). Current OTN technology like OTUflex extends and enriches the foundation OTN hierarchy as a seamless transition towards enabling optimized service transparent support for an increasingly abundant service mix.

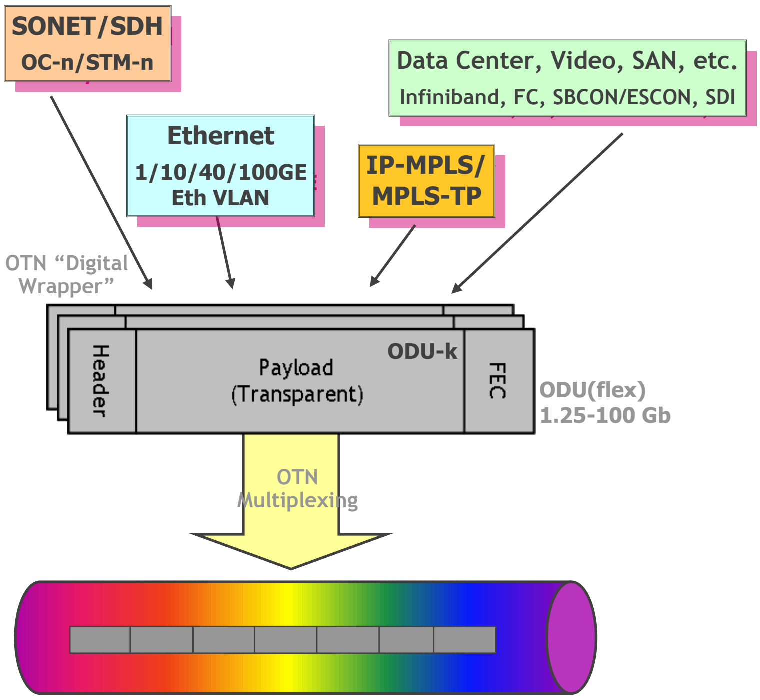


Figure 14: OTN multiplexing

Integration of GMPLS optical control plane technology has enabled dynamically configurable OTN networking, with control plane survivability schemes expanding the data-plane protection solutions toolkit for network reliability and availability.

As a scalable, survivable, and manageable L1/L0 transport infrastructure, OTN complements higher Layer Packet Transport technologies in offering a robust foundation for Smart Grid applications.

4.5.5 Data services over SDH

SDH was first introduced into the world's telecommunications networks in the early 1990s, yet within five years of its launch had all but displaced the deployment of its predecessor, the Plesiochronous Digital Hierarchy (PDH) [3].

That this transition took place so quickly is not so difficult to explain [4]. User interfaces on SDH equipment remained those of the standard PDH rates of 2Mbit/s (E1), 34Mbit/s (E3) and 140Mbit/s (E4), whilst SDH technology delivered a decided improvement in the efficient dropping and inserting of any individual payload directly from the aggregate optical stream, without the need for PDH's more convoluted de-multiplexing and re-multiplexing processes. Coupled with its comprehensive performance, fault management and sub-50ms autonomous payload protection, SDH offered operators greater networking flexibility, faster provisioning and substantial total cost of ownership benefits.

SDH's benefits of adding and dropping traffic, together with its fast protection schemes, was best realized within fibre ring topologies, with their inherent spatial diversity and reduced fibre demands, compared to PDH's previously established hub and mesh topologies. This had an immediate and lasting impact on network build, as fibre rings became the preferred topology, particularly in the access and metro environment.

Given all of SDH's benefits, its almost universal deployment throughout all of today's public telecommunications networks and its established operational practices, the key question now is whether and over what period SDH might, itself, succumb to the pressures from Ethernet, as the next generation transport technology.

4.5.6 Mapping into SDH payloads

The starting point was SDH (or its North America SONET counterpart). Its adoption was not only a major factor in shaping global network technology and operating practice, it was, also, instrumental in the literal shaping of the [ring based] fibre topologies.

Unsurprisingly, the first phase in handling Ethernet was built on SDH's incumbency and proven performance. The addition of a simple process to map Ethernet into the SDH frame became the basis of what has become known as "Next Generation SDH (NG SDH)".

Frequently, this capability was developed as an add-in card or "blade", which could replace existing traffic cards in both existing and installed SDH equipment. This process of TDM to packet migration allowed the installed base to be progressively "upgraded" to support the introduction of Ethernet, in line with demand and without the need to replace existing equipment.

Very quickly, virtually all SDH equipment became NG SDH, consigning any product that did not come up to this level with the pejorative label, "legacy". More specifically, to qualify as NG SDH, the minimum requirement was that traffic presented on a given Ethernet port could be mapped, using the ITU-T Generic Framing Procedure (GFP), into one or more SDH Virtual Containers (VCs).

To counter the large step in VC payload sizes (a VC-12 has an approximate 2Mbit/s payload capacity; VC-3 = 45Mbit/s; VC-4=150Mbit/s), an extension of the mapping procedure enabled the otherwise coarse steps of the individual VC payload granularities to be replaced by the construction of more elastic payloads from multiple smaller individual VCs to form a single, larger virtual concatenated payload (VCAT). In this way, for example, a 10Mbit/s Ethernet could be carried more efficiently in five VC-12s (5x 2Mbit/s) than if it had to be mapped into its nearest equivalent VC-3 (34Mbit/s) payload.

The efficiency enabled by VCAT and GFP could be further extended to handle any fractional rate Ethernet service, down to granularities as small as 64kbit/s, depending on the implementation adopted by the NG SDH equipment vendor.

This ability to size the SDH payload to match the Ethernet rate led to two further opportunities to enhance NG SDH.

The first was the introduction of the ITU-T's Link Capacity Adjustment Scheme (LCAS), which allowed the size of the VCAT to be seamlessly and automatically increased or decreased in service, in line with changes in payload requirements or under fault conditions.

The second was that the policing and shaping required for handling fractional Ethernet, laid the foundations for introducing Layer 2 bridging, aggregation, switching, grooming and for the handling of multiple flows per port, QoS levels etc.

Throughout, the initial deployment was characterized by a continuous process of adding packet functionality to an established SDH product architecture, with the advantages that existing SDH functionality was not compromised and the cost of migration was incurred only incrementally.

It, offered a quick and relatively painless first step on the road to deliver wide area packet networking for best effort, statistical gain services and for business services, such as E-LINE and VLAN services, on the shoulders of SDH's proven carrier class performance.

4.6 Higher level communication protocols

Smart grid applications and standards rely heavily on Web Services for the upper layers protocols. Web Services are defined to be the methods to communicate between applications over communication networks, generally IP based. Two major classes of Web Services can be distinguished (the pros/cons of each class are beyond the scope of this document). These are RESTful Web Services and SOAP/RPC based Web Services. More information on these two classes of Web Services is provided by the W3C under this link: http://www.w3.org/TR/ws-arch/#relwwwrest

The Web Services messaging protocols are designed to be independent of the underlying transport protocols. HTTP, XMPP and CoAP are the most relevant messaging /transport protocols.

The IEC TC57 WG17 is currently working on Web Services profiles for 61850 specifications.

4.6.1 RESTful Web Services

REST (Representational State Transfer) is an architectural style defined by Roy T. Fielding in 2000.

It is a set of principles that enable distributed systems to achieve greater scalability and allow distributed applications to grow and change over time, thanks to loose-coupling of components and stateless interaction.

The main concept of REST is that a distributed application is composed of RESOURCES, which are stateful pieces of information residing onto one or more servers.

Regardless of their content, in REST it is possible to manipulate them through a uniform interface that is composed of 4 basic interactions: CREATE, UPDATE, DELETE and READ.

Each of these operations is composed of a request and a response messages, and, with the exception of CREATE, they are IDEMPOTENT, meaning that the end result of each operation does not change regardless how many times the operation itself is repeated. In other words, these operations do not have side-effects. This makes it distribute resources around and to proxy them, since the lack of side effects allows more efficient caching and scalability.

Most importantly however, since the same set of operations can manipulate the most diverse kind of resources, it is not necessary to develop a dedicated client or infrastructure whenever the application domain changes. Rather, the same underlying architecture can be reused times and times again in face of changes in the application space.

The most common implementation of REST is HTTP, where the above operations are mapped into the methods of this protocol: CREATE is mapped on HTTP POST, READ on HTTP GET, UPDATE on HTTP PUT and DELETE on HTTP DELETE.

However other implementations are possible: CoAP (Constrained Application Protocol), XMPP (Extensible Messaging and Presence Protocol), etc.

4.6.2 SOAP/RPC Web Services

SOAP/RPC based Web Services: applications expose interfaces that are described in machine processable format, the Web Service Description Language (WSDL). It is also possible for applications to interact through SOAP interfaces which provide a means to describe message format. These messages are often transported over HTTP and encoded using XML.

SOAP is method for exchanging XML based message over the Internet for providing and consuming web services. SOAP message are transferred forming the SOAP-Envelope.

RPC (remote procedure call) is another way of providing and consuming web services. It uses XML to encode and decode the remote procedure call along with its parameter.

4.6.3 Architectures, Protocols and languages for Web Services

4.6.3.1 HTTP

According to Wikipedia, “The Hypertext Transfer Protocol (HTTP) is an application protocol for distributed, collaborative, hypermedia information systems. HTTP is the foundation of data communication for the World Wide Web”.

Hypertext is a multi-linear set of objects, building a network by using logical links (the so-called hyperlinks) between the nodes (e.g. text or words). HTTP is the protocol to exchange or transfer hypertext.

The standards development of HTTP was coordinated by the Internet Engineering Task Force (IETF) and the World Wide Web Consortium (W3C), culminating in the publication of a series of Requests for Comments (RFCs), most notably RFC 2616 (June 1999), which defines HTTP/1.1, the version of HTTP in common use.”

HTTPS is the secure version of HTTP based on Transport Layer Security (TLS).

4.6.3.2 CoAP

CoAP is an IETF defined **protocol** that aims at porting the features of a REST-based architecture to a wireless sensor network (although it can be used in other environments), in particular constrained networks supporting 6-LoWPAN.

CoAP is a non-HTTP approach to REST. The reason for specifying CoAP is mainly motivated by the difficulty to implement HTTP in small, constrained devices or networks. Therefore, CoAP defines some primitives that allow REST on top of UDP.

In order to simplify the message format, the HTTP headers have been simplified to fixed-position, fixed-size binary fields inside a CoAP payload, and only a limited set of MIME types are available.

4.6.3.3 XMPP

XMPP is a communications **protocol** that permits bi-directional exchange of messages between entities using globally addressable clients and servers. In order to exchange messages between entities, the entities connect to a server as a client. The clients may connect to the same or different servers. In the case clients connecting to multiple servers, the servers to which the client(s) connect are themselves connected.

In order to exchange messages between XMPP clients, the client establishes an XML stream with a server by:

- Setting up a TCP session
- Negotiating a TLS encrypted XMPP channel
- Authenticating the XMPP channel using SASL credentials
- Binds the resource of full JID of the client

Once the client establishes the XML stream, the client then exchanges messages with other clients using XML Stanzas.

4.6.3.4 ETSI M2M

ETSI M2M **architecture** defines a set of standards that allow M2M communications using a REST architecture style. In ETSI M2M, applications publish resources which can be addressed using URLs. Every resource can be read, created, deleted or updated subject to access rights and related permissions which provide an adequate means to ensure privacy and security.
The high level architecture framework for ETSI M2M is provided in the following figure:

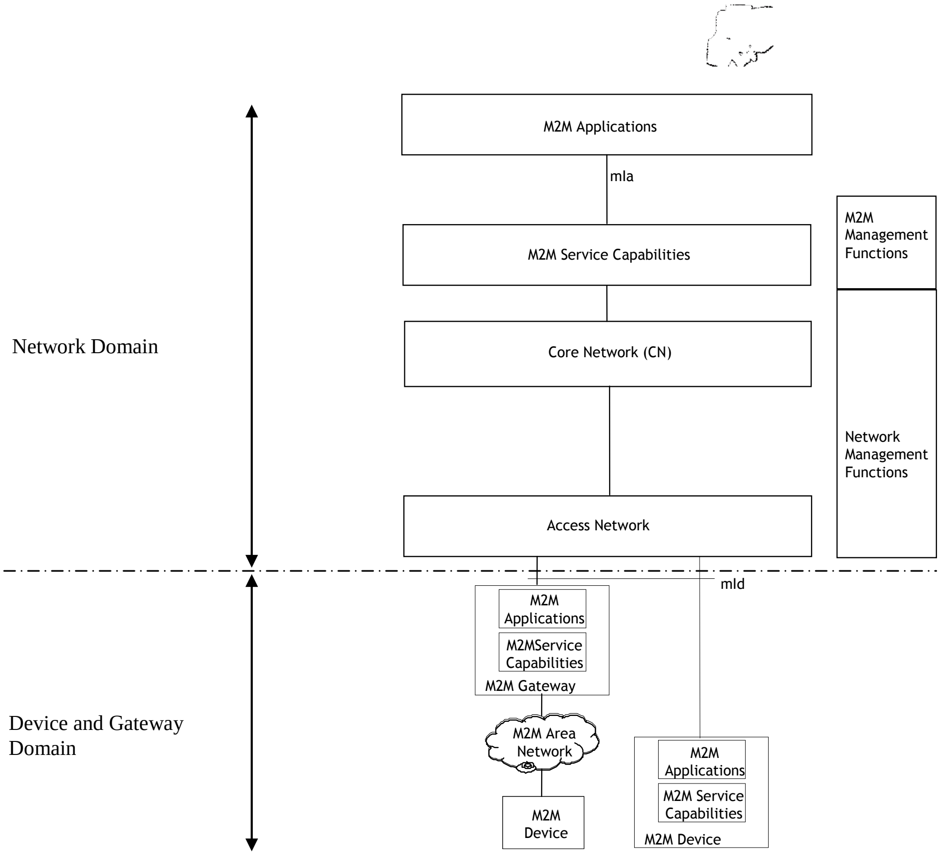


Figure 15: ETSI M2M architecture framework

In this architecture figure resources can be stored in the device M2M Service Capabilities, in the M2M gateway Service Capabilities or the in the M2M Service Capabilities in the Network domain. mId, mIa and dIa denote reference points which are specified according to the REST architecture style where both HTTP and CoAP can be supported (the dIa reference point, not shown in the figure, allows a device application to communicate to the M2M service capabilities in the Device). Mapping to other protocols is possible (e.g. XMPP) but the current ETSI specifications provide a mapping to HTTP and CoAP only. M2M service capabilities can be seen as a set of functions (such as data sharing, security and device management) which are exposed to applications via the RESTful reference points.

4.6.3.5 XML

According to Wikipedia: “Extensible Markup Language (XML) is a markup language that defines a set of rules for encoding documents in a format that is both human-readable and machine-readable. It is defined in the XML 1.0 Specification produced by the W3C, and several other related specifications,[5] all gratis open standards.

The design goals of XML emphasize simplicity, generality, and usability over the Internet. It is a textual data format with strong support via Unicode for the languages of the world. Although the design of XML focuses on documents, it is widely used for the representation of arbitrary data structures, for example in web services.”

4.6.4 Performance considerations

To keep the cost of network at reasonable level and at the same time assuring the right performance under any traffic condition specific rules for sizing and optimize the network design have to be clearly defined. Network dimensioning aspects pertaining to the use of Web Services performance aspects will be handled in future versions of this document.

5 Generic Use Cases and related Communication Architecture examples

The intention of this section is to reference the generic use cases coming from the sustainable process group and to add the communication requirements, which will lead to proposed communication architecture.

In this version of the document only 3 use cases have been developed, more will be added in subsequent version.

Note: While the communication within the home network is out of scope for M490, the below use case provide information flows inside the residential environment for the sake of completeness and to aid the understanding of the use cases.

5.1 Use cases

5.1.1 Demand Response

5.1.1.1 High level overview

Demand response is the key reliability resource to the power system. It helps reduce the electricity consumption or smooth the load in peak demand in response to emergency, peak-load, and high-price conditions. Utilities and policymakers at all levels of government have long recognized the benefits of demand response. Demand response refers to all functions and processes applied to influence the behavior of energy consumption. In order to facilitate DR, feedback and visualization of energy consumption are necessary and as such, fast real-time (moderate latency 30-100 ms) & high availability network communication will be the critical component enabler. The communication aspect can range from simple signaling, e-mail, SMS, or a phone call to a person who manually switches a load on or off, to fully integrated load management, where many consumption devices are dynamically controlled according to profiles based on the availability or price of energy (tariffs).

5.1.1.2 Communications requirements

The table below lists the network communication requirements. Within the smart home which is not controlled by the utility providers, the requirements may vary.

Table 10: Demand Response communication requirements

	Data useCategory	
Parameter	Control/Protection Data	Monitoring/Management Data
Latency	In the range of seconds	5 – 10 Minutes
Data occurrence interval	Minutes	Minutes/Hours
Method of Communication	Multicast/Broadcast /Unicast	Unicast/multicast
Reliabilit	High	Medium
Data security	High	High
Data volume	Bytes/Kilobytes	Kilobytes/Megabytes
Priorit	High	Medium
Level assurance	High	Low

In addition to the above traditional communication requirement, 'Smart Grid demand side' network would have some non-traditional communication requirements. For example,

- Longer Life Time Support - once deployed, the appliance may be used for more than ten years. This is as opposed to consumer electronics products that are normally replaced within 3-5 years
- Plug and Play network- some may want to connect their appliances after purchase which may be 5 years later. Some may want to purchase appliances one by one, not at once.
- Maximum Commonality- different markets/regions (e.g., EU/US/CN) and regulatory domains may require different set of data communication features among networked appliances, however, maximum data communication commonality may achieve broad market potential.
- Lightweight- low processing ability is assumed in many existing home appliances.

5.1.1.3 Controlling energy consumption or generation via CEMS

The home is one of the very important components in the overall Smart Grid System. The home is full with appliances that consume, generate or store energy and the vast majority of appliances have no connectivity other than to the power socket. As today's home becomes smarter (aka the Smart Grid demand side) the majority of the demand side devices is not yet networked and connected to the Smart Grid. In order to fill the gap between today's and tomorrow's 'Smart Grid demand side', data communication technologies & Customer Energy Management systems (CEMS/DRMS) will play a key role.

Demand Response event signals are not sent to appliances directly, but to the customer's Energy Management System (CEMS/DRMS) to trigger a user manually or a program that automatically manages load by interacting with a number of object devices associated with the CEMS/DRMS.

This is based on a Flow of Communication from the Energy Service Provider to the Customer Energy Management system (CEMS/DRMS).

5.1.1.4 Proposed communication architecture setup – CEMS/DRMS

Demand Response (DR)	Mechanisms and incentives for utilities, business, industrial, and residential customers to cut energy use & smooth demand at peak times.

High Level functions

0	A Price change schedule or signal is received from the Energy Service Provider to the CEMS & Displayed on the IHD
1	Customer Reduces Their Usage in Response to variable or real-time Pricing or Voluntary Load Reduction Events
2	Customer Uses an EMS or IHD for real-time feedback on their usage, costs and projected bill.
3	Customer Uses Smart Appliances
4	CEMS/DRMS Manages Demand Through Direct Load Control (Out of Scope)
5	CEMS/DRMS Manages Demand in Response to Pricing Signal
6	External clients use the AMI to interact with devices at customer site (e.g. measurement and verification)
7	Dynamic pricing - ESP Energy and Ancillary Services Aggregation
8	Utility Procedures Energy and Settles Wholesale Transactions Using Data from AMI System
9	Voltage, Var, and Watt Control (VVWC) with DR, DER, PEV, and ES
10	Energy control
11	Energy management service
12	Dynamic pricing related service
13	Dynamic pricing information transfer to BEMS through ESI
14	DR message transfer to BEMS through ESI
15	Demand response signal generation for controlling home appliances (Out of Scope)
16	Verification of a price change signal.

Communication Requirements

- End to end delay shall aim to be less than: 5s.
- Support for communication includes short and long range.
- Resiliency: the impact of failure in the telecommunications networks should not be noticed by applications.
- Standard Data Model that can work seamlessly over any communication media
- Time synchronization
- Secure Communication
- Confidentiality data Integrity
- Mutual Authentication
- Notify transactions for informational & metering services
- Acknowledged transactions for time critical services
- Different regulations will exist for the Interface from ESP to CEMS. DRMS, hence a variety of communication Standards & paths are required.

Proposed Communication Architecture Setup

The figure below depicts an example communication architecture whereby ‘Smart Grid demand side’ devices are connected via network adapter and each adapter represents a communication interface point through which the network controller is connected. The utility network is connected either via AMI networks or neighborhood area network (NAN) or directly using broadband network such as cellular data network.

Note: Dashed circles indicate the likely home networks. Red dashed ellipse is the Utility Smart Meter network. The Green dashed ellipse is the ISP Home entertainment/appliance network. These networks may overlap at the IP layer with communications Gateways to the NAN/LAN. The IP Router & PC are illustrative and do not imply the location of routing, gateway & controller functionality, as the entire Home network may be a tree, bus or mesh it is not clear where the controller functions reside. IP routers may exist in every node & appliance, IP Gateways are required by the Premises(CPN), NAN & LAN owners.

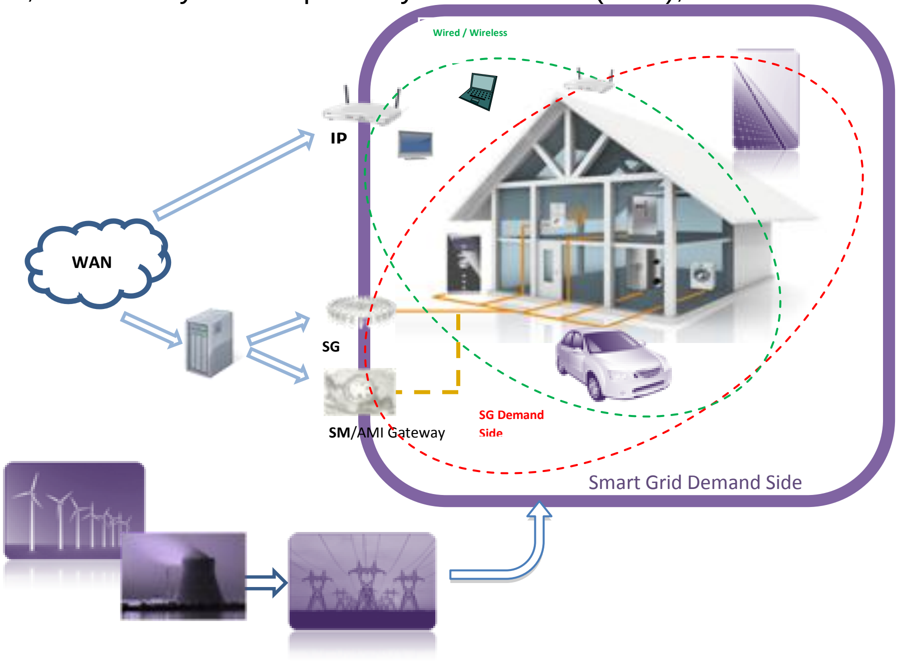


Figure 16: Smart Home Communication Example architecture

5.1.1.5 Flows for Demand response with CEMS

5.1.1.5.1 Functional Architecture for Demand response

This is a generic Demand Response Architecture taken to represent the Functional entities in scenario with communication via a CEMS and scenario with direct communication from Smart appliances (and an optional CEMS).

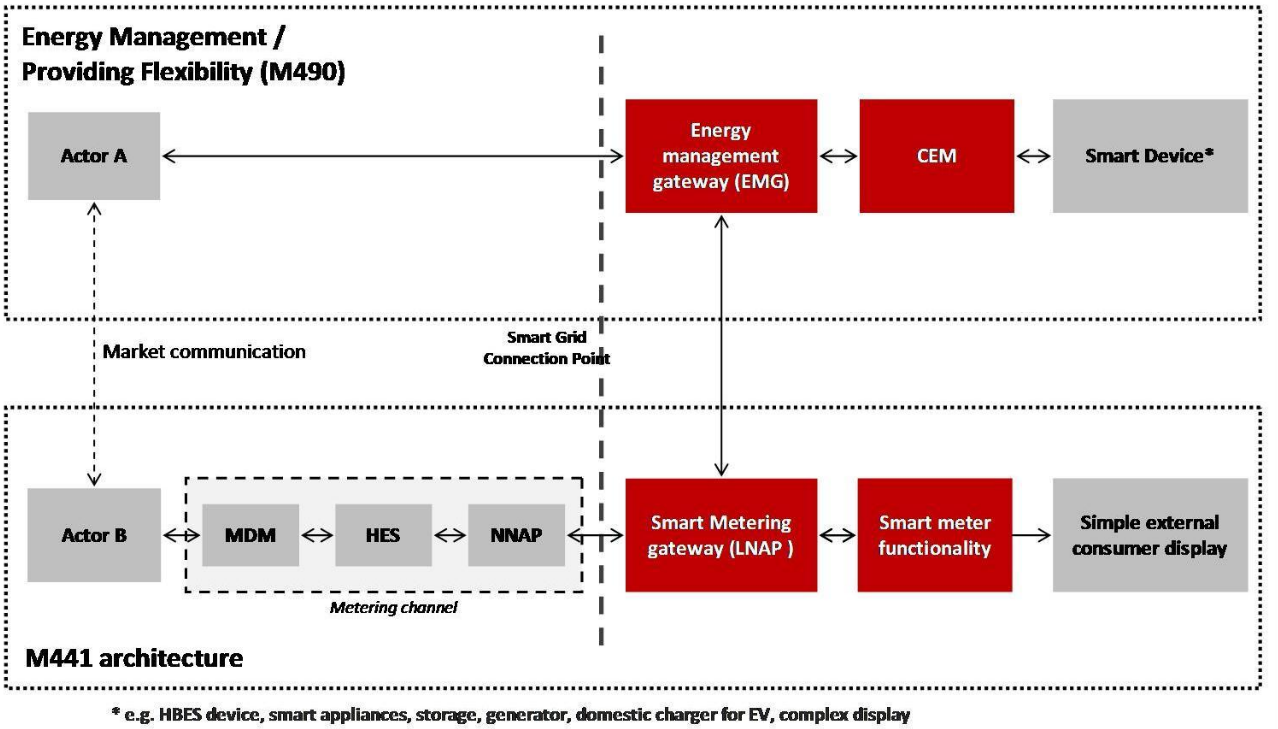
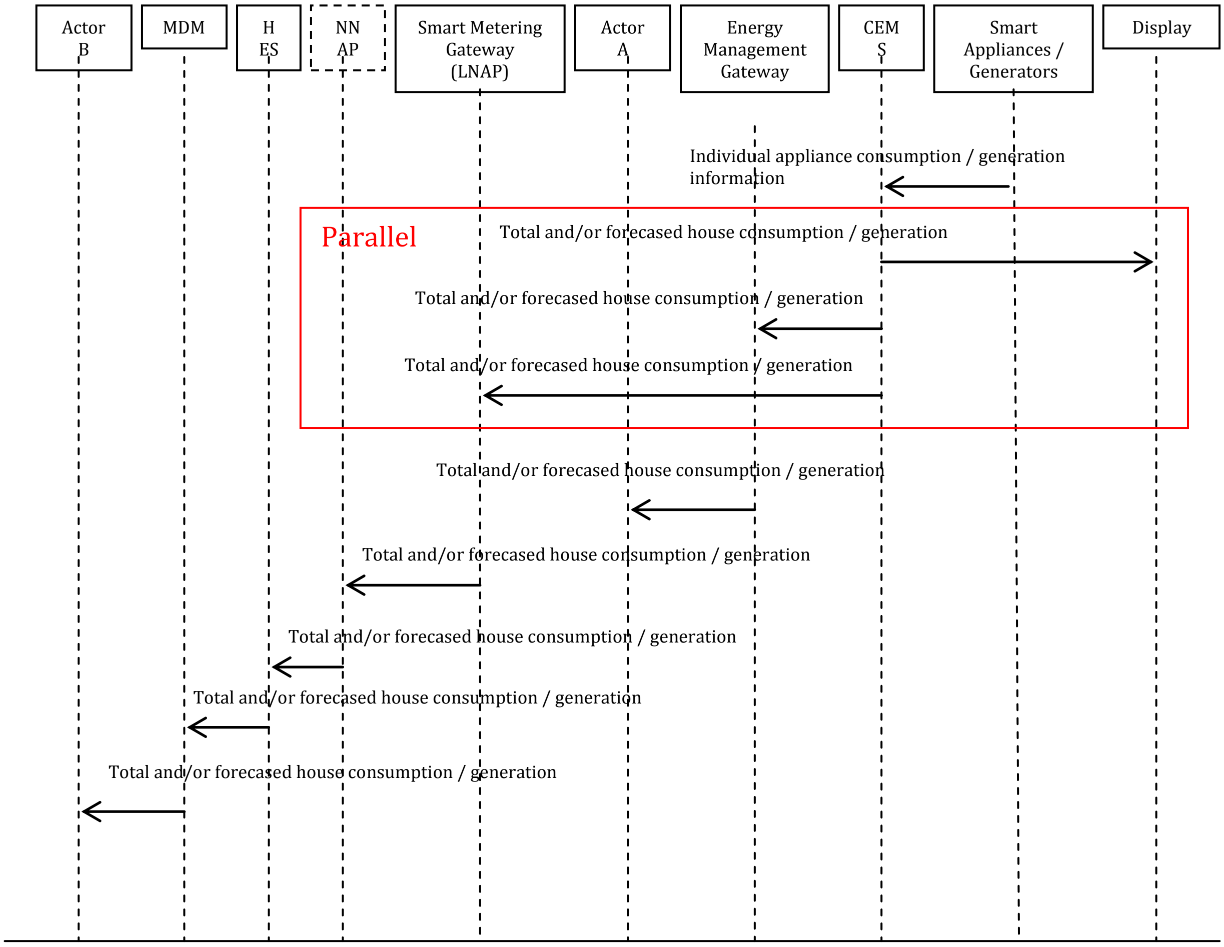


Figure 17: Demand Response functional Architecture

5.1.1.5.2 Use case scenario 1a: Information regarding power consumption or generation of individual appliances/generators

Information regarding power consumption / generation of individual appliances



2464

2465 ## Step by Step Analysis of Use Case

2466

S.No	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
	Smart appliance / Generator	New consumption / generation information is available in the smart appliance / generator	Communication connection between all actors is established	(forecasted) consumption / generation is received by actor A and/or actor B and/or display

2467

Scenario Name :							
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Zones / Domains***	***Ref.***
1	New consumption / generation information is available in the smart appliance/generator	Smart appliance / generator sends information regarding consumption to the CEMS	Smart appliance / generator	CEMS	Individual appliance consumption / generation	Field / Customer premise	FINS-0089 p 2

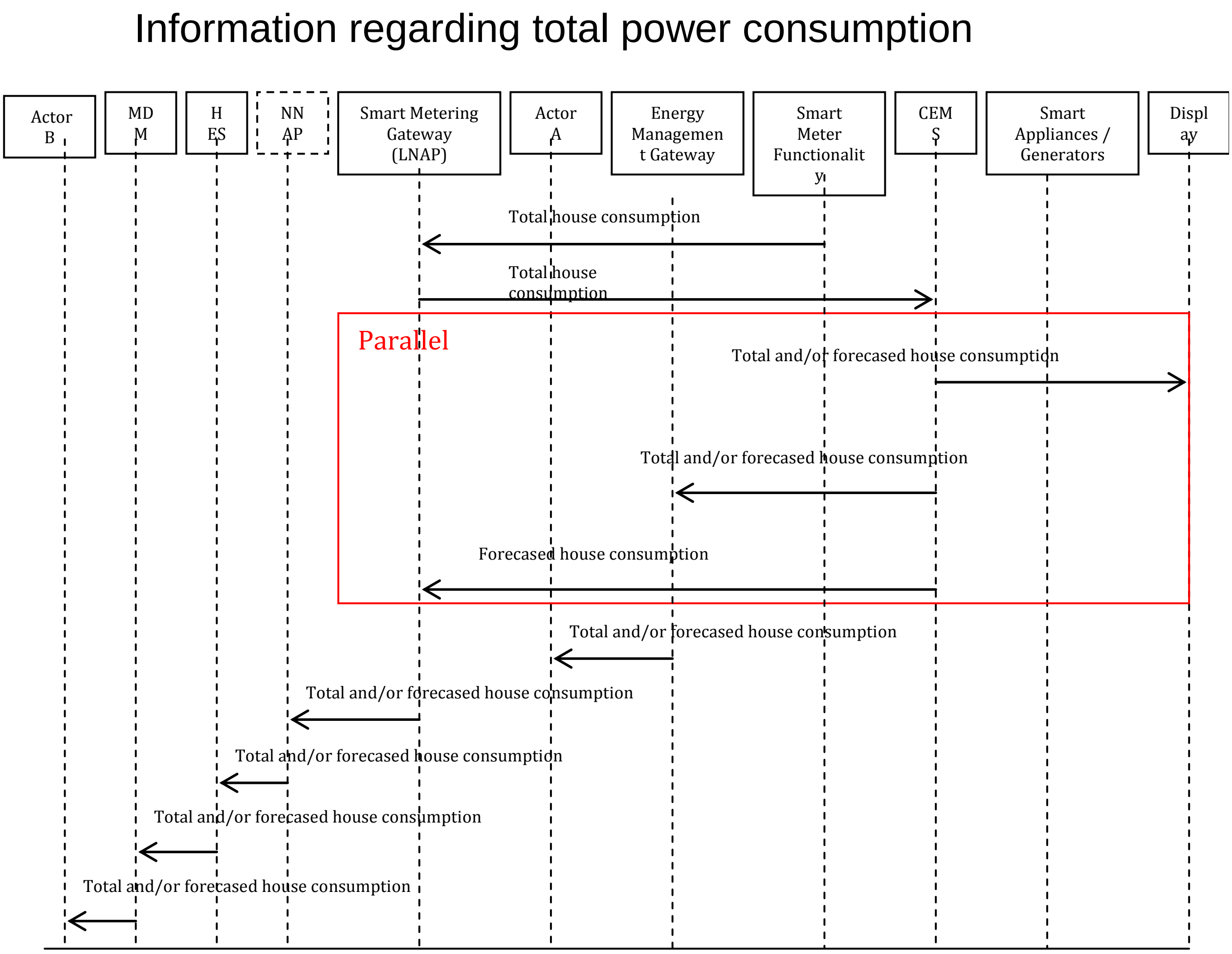
Scenario Name :								
Step No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Zones / Domains	Ref.
2	CEMS received consumption / generation information per individual appliance	The CEMS aggregates and/or forecasts total consumption and sends this information to the display	CEMS	Display	*Total and/or forecasted house consumption / generation*	Field / Customer premise	*FINS-0090 p 2* *FINS-0089 p 2*
3a	CEMS received consumption / generation information per individual appliance	The CEMS aggregates and/or forecasts total consumption and sends this information to the Energy Management Gateway *(alternative)*	CEMS	Energy Management Gateway	*Total and/or forecasted house consumption / generation*	Field / Customer premise	
3b	Energy Management Gateway received (forecasted) consumption / generation	Energy Management Gateway forwards information to Actor A	Energy Management Gateway	Actor A	*Total and/or forecasted house consumption / generation*	Field - Enterprise / Customer premise	
4a	CEMS received consumption / generation information per individual appliance	The CEMS aggregates and/or forecasts total consumption and sends this information to Smart Metering Gateway (LNAP) *(alternative)*	CEMS	Smart Metering Gateway (LNAP)	*Total and/or forecasted house consumption / generation*	Field / Customer premise	
4b	Smart Metering Gateway (LNAP) receives (forecasted) consumption / generation	Smart Metering Gateway (LNAP) forwards information to HES *(optional: signal is sent through NNAP)*	Smart Metering Gateway (LNAP)	HES	*Total and/or forecasted house consumption / generation*	*Field-station-operation/Customer premise*	
4c	HES receives (forecasted) consumption / generation	HES forwards information to MDM	HES	MDM	Total and/or forecasted house consumption / generation	Operation – Enterprise /Customer premise	ESMIG-0001 7.2.1
4d	MDM receives (forecasted) consumption / generation	MDM forwards information to Actor B	MDM	Actor B	Total and/or forecasted house consumption / generation	Enterprise/customer premise	ESMIG-0001 7.2.1

2468

2469 2470 ### 5.1.1.5.3 Use case scenario 1b: Information regarding total power consumption or generation

2471

2472 **Drawing or Diagram of Use Case**



2473

2474 **Step by Step Analysis of Use Case**

S.No	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
	Smart Meter	New consumption/generation information is available in the Smart Meter	Communication connection between all actors is established	(forecasted) consumption/generation information is received by actor A and/or or Actor B and/or display

2475

Scenario Name :							
Step No.	*Event*	*Description of Process/Activity*	*Information Producer*	*Information Receiver*	*Information Exchanged*	*Zones / Domains*	*Ref.*
1	New consumption/ generation information is available in the Smart Meter	The Smart Meter forwards the consumption information to the Smart Metering Gateway (LNAP)	Smart Meter	Smart Metering Gateway (LNAP)	*Consumption information*	Field / Customer premise	
2	Smart Metering Gateway (LNAP) receives the information	Smart Metering Gateway (LNAP) forwards the consumption information to CEMS	Smart Metering Gateway (LNAP)	CEMS	*Consumption information*	Field / Customer premise	

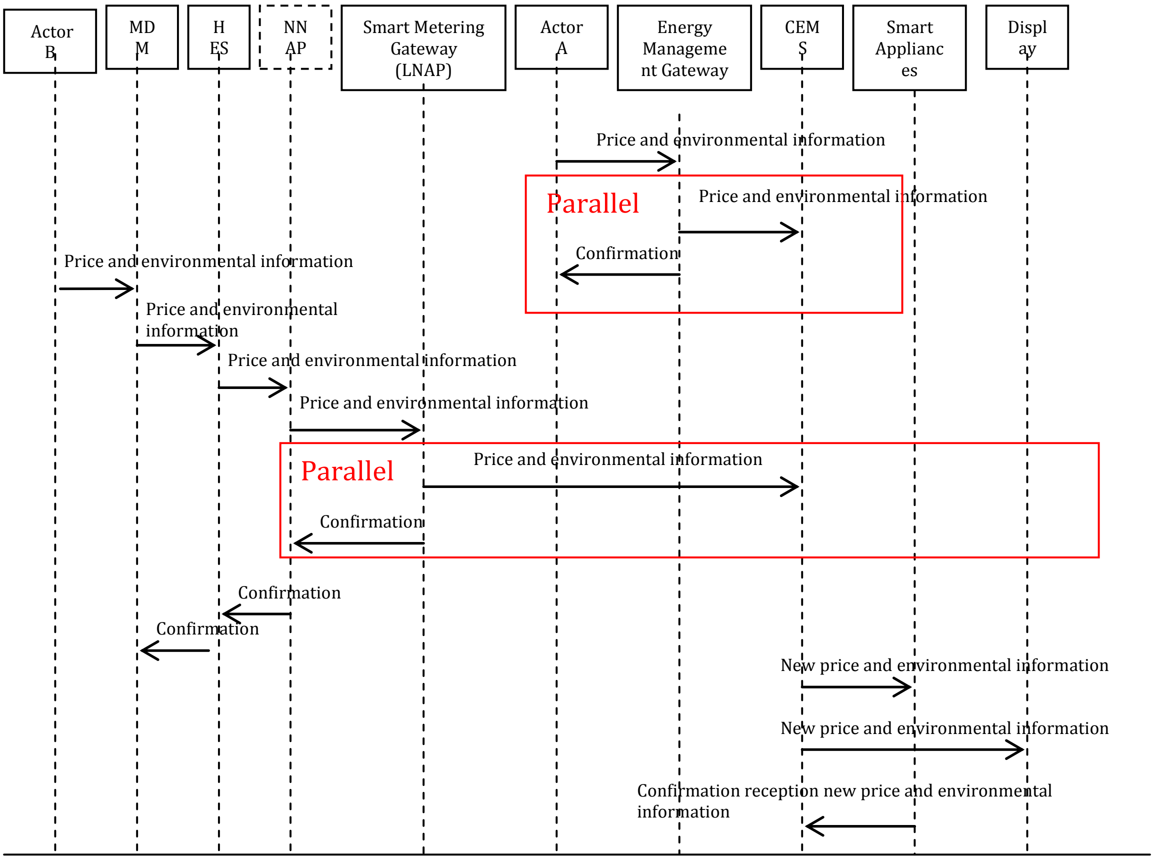
Scenario Name :								
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Zones / Domains**	**Ref.**
3	New consumption information is available in the CEMS	The CEMS may forecast total consumption and sends (forecasted) consumption information to the display	CEMS	Display	*Total and/or forecasted house consumption*	Field / Customer premise	FINS-0089 p 2 FINS-0090 p 2
4a	CEMS received consumption information per individual appliance	The CEMS aggregates and/or forecasts total consumption and sends this information to the Energy Management Gateway *(alternative)*	CEMS	Energy Management Gateway	*Total and/or forecasted house consumption*	Field / Customer premise	DKE0014
4b	Energy Management Gateway received (forecasted) consumption	Energy Management Gateway forwards information to Actor A	Energy Management Gateway	Actor A	*Total and/or forecasted house consumption*	Field - enterprise/ Customer premise	DKE0014
5a	CEMS received consumption information per individual appliance	The CEMS aggregates and/or forecasts total consumption and sends this information to Smart Metering Gateway (LNAP) *(alternative)*	CEMS	Smart Metering Gateway (LNAP)	*Total and/or forecasted house consumption*	Field / Customer premise	DKE0014
5b	Smart Metering Gateway (LNAP) receives (forecasted) consumption	Smart Metering Gateway (LNAP) forwards information to HES *(optional: signal is sent through NNAP)*	Smart Metering Gateway (LNAP)	HES	*Total and/or forecasted house consumption*	*Field-station-operation/Customer premise*	
5c	HES receives (forecasted) consumption	HES forwards information to MDM	HES	MDM	Total and/or forecasted house consumption	Operation - Enterprise/customer premise	*ESMIG-0001 7.2.1*
5d	MDM receives (forecasted) consumption	MDM forwards information to Actor B	MDM	Actor B	Total and/or forecasted house consumption	Enterprise/customer premise	*ESMIG-0001 7.2.1*

2476

2477 ### 5.1.1.5.4 Use case scenario 2: Price and environmental information

2478 ***Drawing or Diagram of Use Case***

Price & environmental information



Step by Step Analysis of Use Case

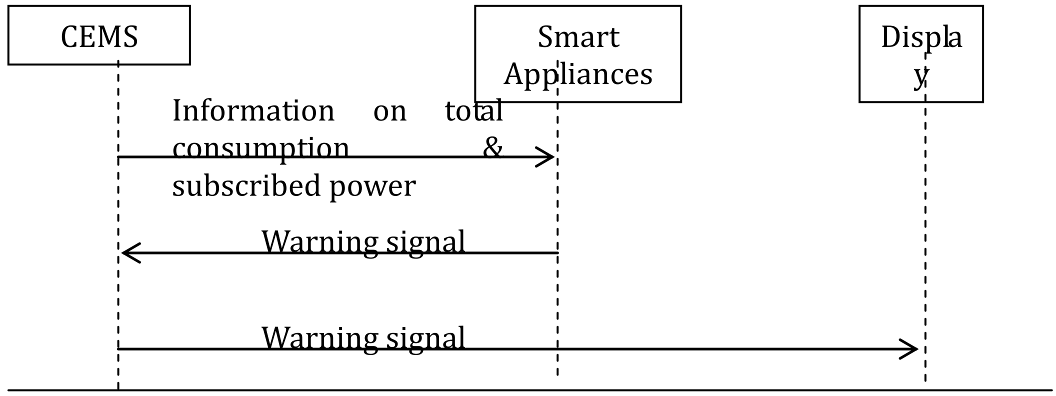
S.No	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
	Actor A or actor B	New price and environmental information is available in Actor A or Actor B	Communication connection between all actors is established	Price and environmental information is received by Smart Appliances

Scenario Name :							
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Zones / Domains***	***Ref.***
1a	New price and/or environmental is available in actor A (alternative)	Actor A sends information to Energy Management Gateway	Actor A	Energy Management Gateway	Price and/or environmental information	Enterprise – field /customer premise	DKE0014p 7
1b	Energy Management Gateway received information	Energy Management Gateway forwards price and/or environmental informatio n to CEMS	Energy Management Gateway	CEMS	Price and/or environmental information	Field/ customer premise	DKE0014p 7
1c	Energy Management Gateway received information	Energy Management Gateway sends confirmation to Actor A (alternative)	Energy Management Gateway	Actor A	Confirmation	Field – Enterprise / Customer premise	DKE0014p 7
2a	New price and/or environmental is	Actor B esends price and/or environmental information to	Actor B	MDM	Price and/or environmental	Enterprise / Customer	ESMIG 0006

Scenario Name :							
Step No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Zones / Domains	Ref.
	available in actor B	MDM			information	premise	
2b	MDM receives price and/or environmental information	MDM determines all consumers involved by the price and/or environmental information and routes the information to the HES	MDM	HES	Price and/or environmental information	Enterprise-Operation / Customer premise	ESMIG 0006
2c	HES receives information by MDM	HES forwards price and/or environmental information to Smart Metering Gateway (LNAP) *(optional: signal is sent through NNAP)*	HES	Smart Metering Gateway (LNAP)	Price and/or environmental information	Operation – station – field / customer premise	
2d	Smart Metering Gateway (LNAP) receives information	Smart Metering Gateway (LNAP) forwards price and/or environmental information to CEMS	Smart Metering Gateway (LNAP)	CEMS	Price and/or environmental information	Field / Customer premise	TC205 p4-40 DKE00 14p 7
3a	Smart metering Gateway (LNAP) received information	Smart metering gateway sends confirmation to HES (alternative) *(optional: signal is sent through NNAP)*	Smart Metering Gateway	HES	Confirmation	Field – Operation / Customer premise	
3b	HES received confirmation	HES forwards confirmation to MDM	HES	MDM	Confirmation	Operation – Enterprise / Customer premise	ESMIG 0006
4	CEMS received new price and/or environmental information	CEMS identifies relevant Smart Appliances and forwards the new price and/or environmental information to the Smart Appliances	CEMS	Smart Appliciances	Price and/or environmental information	Field / Customer premise	DKE00 14p 7
5	CEMS received new price and/or environmental information	CEMS forwards the new price and/or environmental information to the Display	CEMS	Display	Price and/or environmental information	Field / Customer premise	
6	Smart Appliances receive new price and/or environmental information	Smart Appliances confirm reception to CEMS	Smart Appliances	CEMS	Confirmation	Field / Customer premise	DKE00 14p 7

2483 ### 5.1.1.5.5 Use case scenario 3a: Warning signals based individual appliances consumption

2484 *Drawing or Diagram of Use Case*



Step by Step analysis of Use Case

S.No	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
	Smart appliance	The CEMS received information on a new operation to be executed	The subscribed power limits are made known to the smart appliance	Warning signal is received by display and/or smart appliances

Scenario Name :							
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Zones / Domains***	***Ref.***
1	The CEMS received information on a new operation to be executed	The CEMS sends information on total house consumption and subscribed power to the appliance involved	CEMS	Smart appliance	Total house consumption and subscribed power	Field / Customer premise	FINS0088 p2 FINS0048 p27
2	The smart appliance received information on total house consumption and subscribed power to the appliance	The smart appliance estimates the maximum power tobe consumed for the operation and deducts this from the available power. In case there is insufficient power available, it displays a warning message and sends a warning message to the CEMS	Smart Appliance	CEMS	Warning message	Field / Customer premise	FINS0088 p2 FINS0048 p27
3	The CEMS received a warning message	The CEMS sends the warning message to the external display	CEMS	Simple external consumer display	Warning message	Field / Customer premise	FINS0088 p2 FINS0048 p27

5.1.1.6 Proposed communication architecture setup – Smart Home with direct communication with Smart Appliances

The home is one of the very important components in the overall Smart Grid System. The home is full with appliances that consume, generate or store energy the vast majority of appliances will have direct connectivity with the Internet & Smart Grid, as well as connectivity via the power. As today's home becomes smarter (a.k.a. the Smart Grid demand side) the majority of the demand side appliances will be networked and connected to the Internet & Smart Grid. Within tomorrow's 'Smart Grid demand side', data communication technologies will play a key role.

Demand Response event signals are sent to smart appliances directly and to the customer's Energy Management System (CEMS/DRMS). The pre-configured program that automatically manages load by interacting with a number of object devices associated with the CEMS/DRMS becomes less important.

This is based on a Flow of Communication from the Energy Service Provider to the Smart Appliances.

Demand Response (DR)	Mechanisms and incentives for utilities, business, industrial, and residential customers to cut energy use & smooth demand at peak times.

High Level functions

0	A Price change schedule or signal is received from the Energy Service Provider to the CEMS & Smart appliances
2	Customer Uses an EMS or IHD for real-time feedback on their usage, costs and projected bill.
3	Customer may use Smart Appliances
4	CEMS/DRMS Manages Demand Through Direct Load Control (Out of Scope)
6	External clients use the AMI to interact with devices at customer site (e.g. measurement and verification)
7	Dynamic pricing - ESP Energy and Ancillary Services Aggregation
8	Utility Procedures Energy and Settles Wholesale Transactions Using Data from AMI System
9	Voltage, Var, and Watt Control (VVWC) with DR, DER, PEV, and ES
10	Energy control
11	Energy management service
12	Dynamic pricing related service
13	Dynamic pricing information transfer to BEMS through ESI
14	DR message transfer to BEMS through ESI
15	Demand response signal generation for controlling home appliances (Out of Scope)
16	Verification of Price change signal

Communications requirements

- End to end delay shall aim to be less than: 5s for control signals.
- Support for communication includes short and long range.
- Resiliency: the impact of failure in the telecommunications networks should not be noticed by applications.
- Standard Data Model that can work seamlessly over any communication media
- Time synchronization
- Secure Communication
- Confidentiality data Integrity
- Mutual Authentication
- Notify transactions for informational & metering services
- Acknowledged transactions for time critical services
- Non repudiated delivery for critical and billing type transactions.
- Different regulations will exist for the Interface from ESP to Smart Home, hence a variety of communication Standards & paths are required.

Proposed communications architecture setup

The figure below depicts an example communication architecture whereby 'Smart Grid demand side' devices & appliances are directly connected & controlled to the Smart Grid and endpoint is a communication interface point where controller is connected. The utility network is connected either via AMI networks or neighborhood area network (NAN) or directly using broadband network such as cellular data network.

Note: Dashed circles indicate the likely home networks. Red dashed ellipse is the Utility Smart Meter network. The Green dashed ellipse is the ISP Home entertainment/appliance network. These networks may overlap at the IP layer with communcations Gateways to the NAN/LAN. The IP Router & PC are illustrative and do not imply the location of routing, gateway & controller functionality, as the entire Home network may be a tree, bus or mesh it is not clear where the controller functions reside. IP routers may exist in every node & appliance; IP Gateways are required by the Premises (CPN), NAN & LAN owners.

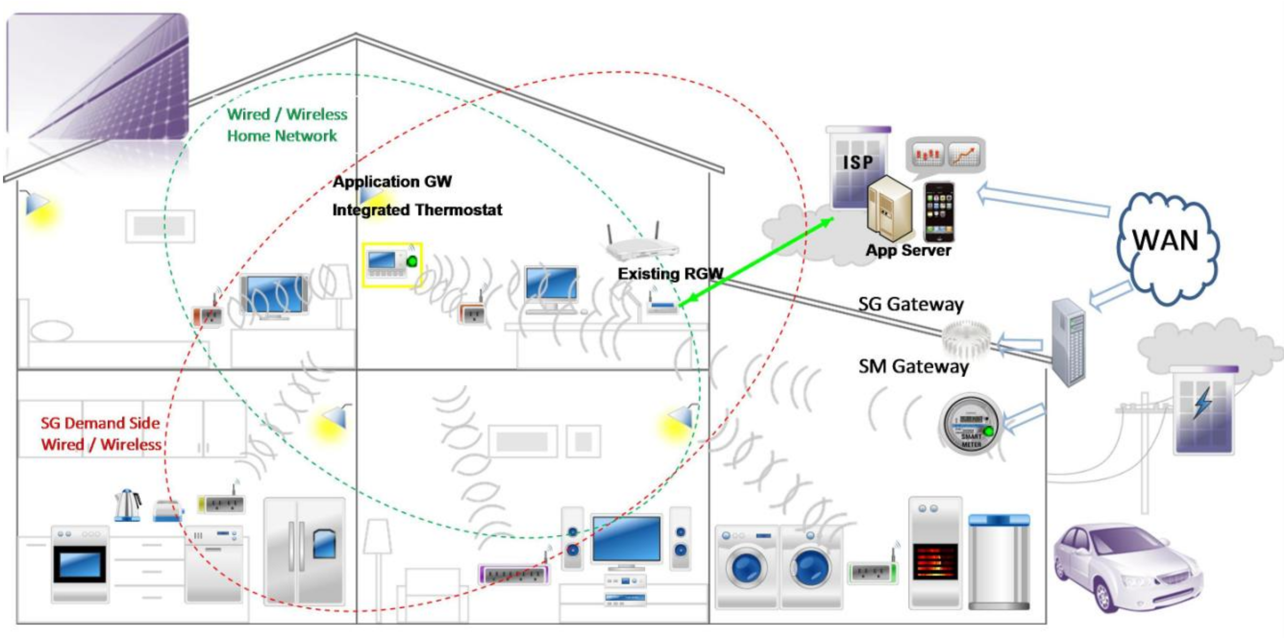


Figure 18: Smart Home Communication Example architecture

5.1.1.7 Flows for Demand response - with Direct control of Smart Appliances

5.1.1.7.1 Functional Architecture for Demand response

This is a generic Demand Response Architecture taken to represent the Functional entities in scenario with communication via a CEMS and scenario with direct communication from Smart appliances (and an optional CEMS).

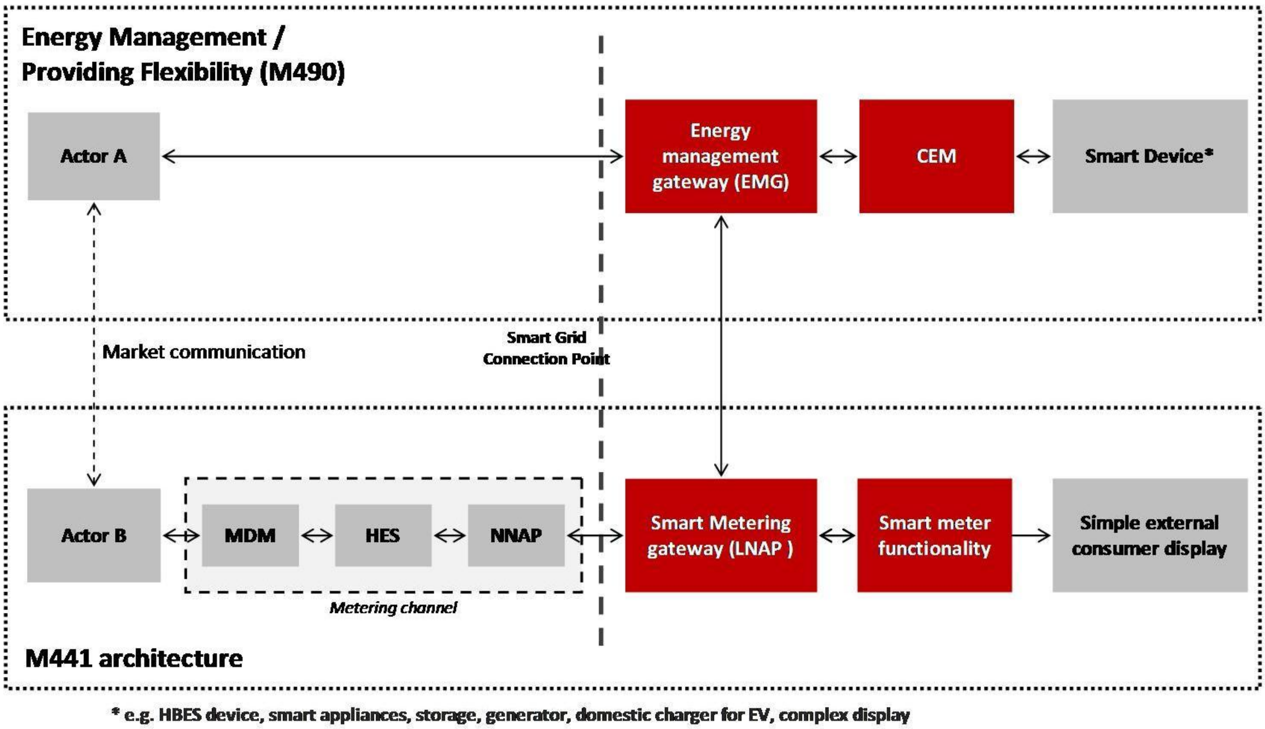


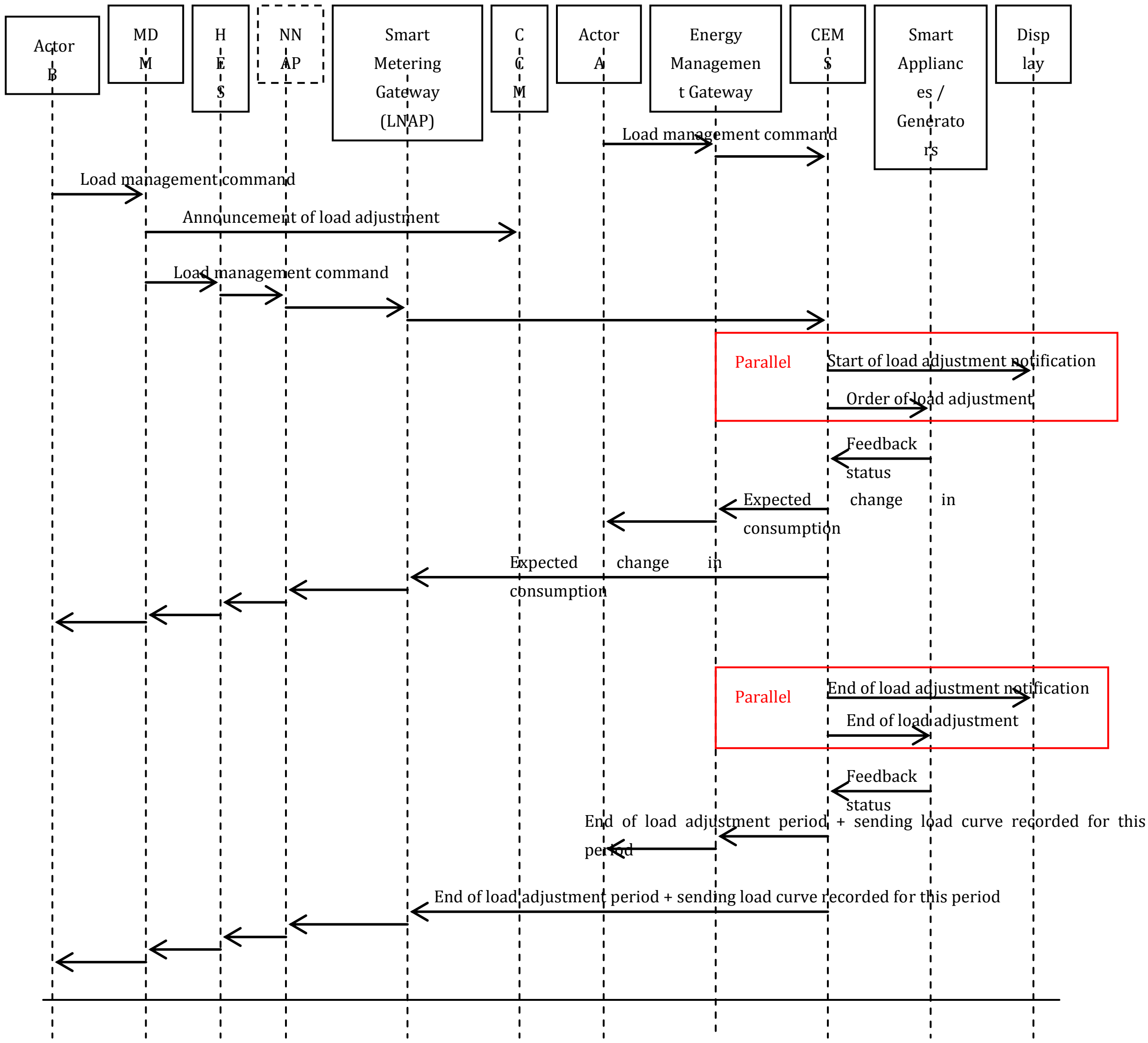
Figure 18: Demand Response functional Architecture

5.1.1.7.2 Use case scenario 1: Direct load management - appliance has end-decision about its load adjustment

Note: in order to keep this use case clear, only "load management" and "changes in consumption" are described. Please note that this use case is also applicable on generation management or storage management.

Drawing or Diagram of Use Case

DIRECT LOAD MANAGEMENT – appliance has end-decision about its load adjustment



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2559 ## Step by Step Analysis of Use Case

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S.No	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
	Actor A or Actor B	Actor A or Actor B wants to send a load management command to the market	Communication connection between all actors is established The consumer configured the CEMS and/or the participating devices (appliances and generators). The consumer configured the device settings and thresholds Information on total consumption or consumption per appliance is available in the CEMS	The Smart Appliance / generator executed the load management command and Actor A or Actor B received the feedback with a load curve recorded for this period

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Scenario Name :							
Step No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Zones / domains	Ref.
1a		Actor A sends a load management command to Energy Management Gateway	Actor A	Energy Management Gateway	Load management command	Enterprise – field / Customer premise	DKE0020
1b	Energy Management Gateway receives a load management command from Actor A	Energy Management Gateway forwards the load management command to CEMS	Energy Management Gateway	CEMS	Load management command	Field/ Customer premise	DKE0020
2a	Actor B wants to send a load management command to the market (alternative)	Actor B sends a load management command to MDM	Actor B	MDM	Load management command	Enterprise / Customer premise	ESMIG0017
2b	MDM receives a load management command from Actor B	MDM decides on which loads to adjust and sends an announcement of the load adjustment notification to CCM	MDM	CCM	Announcement of load adjustment	Enterprise / Customer premise	FINS-0048 3.5.4 p30, ESMIG0014
2c	MDM receives a load management command from Actor B	MDM decides on which loads to adjust and sends a load management command to HES	MDM	HES	Load management command	Enterprise - operation/ Customer premise	DKE-0020 ESMIG0017
2d	HES receives the load management command from MDM	HES forwards the load management command to Smart Metering Gateway (LNAP) (optional: signal is sent through NNAP)	HES	Smart Metering Gateway (LNAP)	Load management command	Operation - station - field/ Customer premise	FINS-0048 3.5.4 p30
2e	Smart Metering Gateway (LNAP) receives the load management command from HES	Smart Metering Gateway (LNAP) forwards the load management command to CEMS	Smart Metering Gateway (LNAP)	CEMS	Load management command	Field/ Customer premise	
3	CEMS receives the load management command from Energy Management Gateway or Smart Metering Gateway (LNAP)	CEMS sends the start of load management notification to Display	CEMS	Display	Load management command	Field/ Customer premise	FINS-0048 3.5.4 p30

Scenario Name :							
Step No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Zones / domains	Ref.
4	CEMS receives the load management command from Energy Management Gateway or Smart Metering Gateway (LNAP)	CEMS decides which Smart Appliances needs to be adjusted and sends an order of load adjustment to the Smart Appliances / generators	CEMS	Smart Appliances / generators	Order of load adjustment	Field/ Customer premise	DKE-0021p8 TC205 – 0001 to 0043 p80
5	Smart Appliances / generators receive the order of load adjustment	The Smart Appliances / generators decide to switch on/off based on the consumer's settings and send feedback to CEMS	Smart Appliances / generators	CEMS	Load adjustment feedback	Field/ Customer premise	FINS-0048 3.5.4 p30 DKE-0021p8 TC205 – 0001 to 0043 p80
6a	CEMS receives feedback from smart appliances / generators	CEMS informs Energy Management Gateway on which change in consumption to expect. (alternative)	CEMS	Energy Managemen t Gateway	Change in consumption	Field/ Customer premise	DKE0020
6b	Energy Management Gateway receives the change in consumption from CEMS	Energy Management Gateway forwards the change in consumption to Actor A	Energy Managemen t Gateway	Actor A	Change in consumption	Field - enterprise / Customer premise	DKE0020
7a	CEMS receives feedback from smart appliances	CEMS informs Smart Metering Gateway on which change in consumption to expect. (alternative)	CEMS	Smart Metering Gateway	Change in consumption	Field/ Customer premise	FINS-0048 3.5.4 p30
7b	Smart Metering Gateway receives the change in consumption from CEMS	Smart Metering Gateway forwards the change in consumption to HES (optional: signal is sent through NNAP)	Smart Metering Gateway	HES	Change in consumption	Field – station - operation/ Customer premise	
7c	HES receives the change in consumption from Smart Metering Gateway	HES forwards the change in consumption to MDM	HES	MDM	Change in consumption	Operation - enterprise / Customer premise	ESMIG0017
7d	MDM receives the change in consumption from HES	MDM forwards the change in consumption to Actor B	MDM	Actor B	Change in consumption	Enterprise / Customer premise	ESMIG0017
8	Load adjustment period is finished	CEMS sends an end of load adjustment to Smart Appliances	CEMS	Smart Appliances / generators	End of load adjustment	Field/ Customer premise	FINS-0048 3.5.4 p30
9	Smart Appliances / generators receive the end of load adjustment from CEMS	The Smart Appliances / generators switch on/off and send feedback to CEMS	Smart Appliances / generators	CEMS	End of load adjustment feedback	Field/ Customer premise	FINS-0048 3.5.4 p30

Scenario Name :							
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Zones / domains**	**Ref.**
10	CEMS receives the feedback from Smart Appliances / generators	CEMS sends the end of load adjustment notification to Display	CEMS	Display	End of load adjustment	Field/ Customer premise	FINS-0048 3.5.4 p30
11a	CEMS receives the feedback from Smart Appliances	CEMS sends the end of load adjustment period to Energy Management Gateway and sends a load curve recorded for this period (alternative)	CEMS	Energy Management Gateway	Load adjustment feedback	Field/ Customer premise	FINS-0048 3.5.4 p30
11b	Energy Management Gateway receives the feedback from CEMS	Energy Management Gateway forwards the feedback to Actor A	Energy Management Gateway	Actor A	Load adjustment feedback	Field - enterprise / Customer premise	FINS-0048 3.5.4 p30
12a	CEMS receives the feedback from Smart Appliances	CEMS sends the end of load adjustment period to Smart Metering Gateway (LNAP) and sends a load curve recorded for this period (alternative)	CEMS	Smart Metering Gateway (LNAP)	Load adjustment feedback	Field/ Customer premise	FINS-0048 3.5.4 p30
12b	Smart Metering Gateway (LNAP) receives the feedback from CEMS	Smart Metering Gateway (LNAP) forwards the feedback to HES (optional: signal is sent through NNAP)	Smart Metering Gateway (LNAP)	HES	Load adjustment feedback	Field – station - operation/ Customer premise	
12c	HES receives the feedback from Smart Metering Gateway (LNAP)	HES forwards the feedback to MDM	HES	MDM	Load adjustment feedback	Operation - enterprise / Customer premise	FINS-0048 3.5.4 p30 ESMIG0017
12d	MDM receives the feedback from HES	MDM forwards the feedback to Actor B	MDM	Actor B	Load adjustment feedback	Enterprise / Customer premise	FINS-0048 3.5.4 p30 ESMIG0017

Alternative scenarios

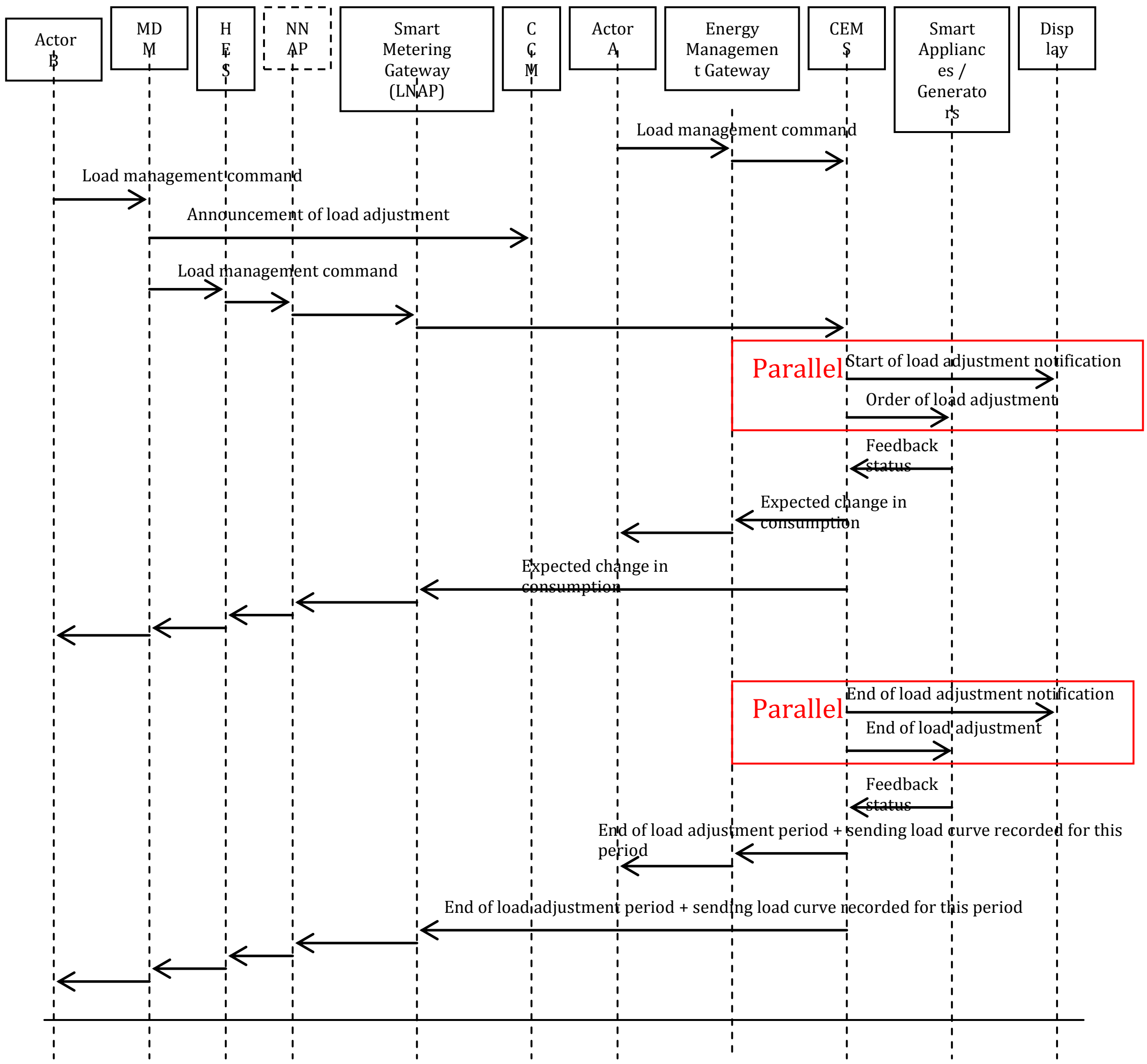
1. Customer derogates before the start of the load management period (*FINS-0048 3.5.4 p30)*
2. Customer derogates during the load management period (*FINS-0048 3.5.4 p30)*
   a. CEMS sends an end of load management to Smart Appliances (*FINS-0048 3.5.4 p30)*
   b. Smart Appliances send feedback to CEMS

5.1.1.7.3 Use case scenario 2: Direct load management – the appliance has no control over its own load adjustment

Note: initially for this Use Case only “load management” and “changes in consumption” are described. Please note that this use case is equally applicable on generation management or storage management.

Drawing or Diagram of Use Case

DIRECT LOAD MANAGEMENT – appliance has end-decision about its load adjustment



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2576 ***Step by Step Analysis of Use Case***

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S.No	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
	Actor A or Actor B	Actor A or Actor B wants to send a load management command to the market	Communication between all actors can be established The consumer configured the CEMS and/or the participating devices (appliances and generators). The consumer configured the device settings and thresholds Information on total consumption or consumption per appliance is available in the CEMS	The appliance executed the load management command and Actor A or Actor B received the feedback

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Scenario Name :							
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Require-ments ID***	***Ref.***
1a	Actor A wants to send a load management command to the market (alternative)	Actor A sends a load management command to Energy Management Gateway	Actor A	Energy Managemen t Gateway	Load management command	Enterprise - field/ Customer premise	DKE0020
1b	Energy Management Gateway receives a load management command from Actor A	Energy Management Gateway forwards the load management command to CEMS	Energy Managemen t Gateway	CEMS	Load management command	Field/ Customer premise	DKE0020
2a	Actor B wants to send a load management command to the market (alternative)	Actor B sends a load management command to MDM	Actor B	MDM	Load management command	Enterprise/ Customer premise	ESMIG00 17
2b	MDM receives a load management command from Actor B	MDM decides on which loads to adjust and sends a load management command to HES	MDM	HES	Load management command	Enterprise - operation/ Customer premise	FINS-0048 3.5.4 p30, ESMIG00 14
2c	HES receives the load management command from MDM	HES forwards the load management command to Smart Metering Gateway (LNAP) (optional: signal is sent through NNAP)	HES	Smart Metering Gateway (LNAP)	Load management command	Operation – station - field/ Customer premise	
2d	Smart Metering Gateway (LNAP) receives the load management command from HES	Smart Metering Gateway (LNAP) forwards the load management command to CEMS	Smart Metering Gateway (LNAP)	CEMS	Load management command	Field/ Customer premise	FINS-0048 3.5.4 p30 TC205 – 0001 to 0043 p60
3	CEMS receives the load management command from Energy Management Gateway or Smart Metering Gateway	CEMS sends the start of load adjustment notification to Display	CEMS	Display	Load adjustment notification	Field/ Customer premise	FINS-0048 3.5.4 p30
4	CEMS receives the load management command from Energy Management Gateway or Smart Metering Gateway	CEMS decides which generator/smart appliance needs to be adjusted and sends an order of load adjustment	CEMS	Smart Appliance/G enerators	Order of load adjustment	Field/ Customer premise	DKE-0021p8 TC205 – 0001 to 0043 p60

Scenario Name :								
Step No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Technical Require-ments ID	Ref.
5	Smart Appliance/generator receives the order of load adjustment	The Smart Appliance/generator switches on/off and sends feedback to CEMS	Smart Appliance/Generator	CEMS	Load adjustment feedback	Field/ Customer premise	FINS-0048 3.5.4 p30 DKE-0021p8 TC205 – 0001 to 0043 p60
6	Smart Appliance / generator adjustment period is finished	CEMS sends an end of load adjustment to Smart Appliance/generator	CEMS	Smart Appliance/Generator	End of load adjustment	Field/ Customer premise	FINS-0048 3.5.4 p30
7	Smart Appliance/Generator receives the end of load adjustment from CEMS	The Smart Appliance/Generator switchs on/off and sends feedback to CEMS	Smart Appliance/Generator	CEMS	End of load adjustment feedback	Field/ Customer premise	FINS-0048 3.5.4 p30
8	CEMS receives the feedback from Smart Appliance/Generator	CEMS sends the end of load adjustment notification to Display	CEMS	Display	End of load adjustment	Field/ Customer premise	FINS-0048 3.5.4 p30
9a	CEMS receives the feedback from Smart Appliance/Generator	CEMS sends the end of load adjustment period and a load curve recorded for this period to the Energy Management Gateway (alternative)	CEMS	Energy Management Gateway	Load adjustment feedback	Field/ Customer premise	FINS-0048 3.5.4 p30
9b	Energy Management Gateway receives the end of load adjustment period with feedback from CEMS	Energy Management Gateway forwards the end of load adjustment period with feedback to Actor A	Energy Management Gateway	Actor A	Load adjustment feedback	Field - enterprise/ Customer premise	FINS-0048 3.5.4 p30
10a	CEMS receives the feedback from Smart Appliance/Generator	CEMS sends the end of load adjustment period and a load curve recorded for this period to the Smart Metering Gateway (LNAP) (alternative)	CEMS	Smart Metering Gateway (LNAP)	Load adjustment feedback	Field/ Customer premise	FINS-0048 3.5.4 p30
10b	Smart Metering Gateway (LNAP) receives the end of load adjustment period with feedback from CEMS	Smart Metering Gateway (LNAP) forwards the end of load adjustment period with feedback to HES (optional: signal is sent through NNAP)	Smart Metering Gateway (LNAP)	HES	Load adjustment feedback	Field-station-operation/ Customer premise	
10c	HES receives the end of load adjustment period with feedback from Smart Metering Gateway (LNAP)	HES forwards the end of load adjustment period with feedback to MDM	HES	MDM	Load adjustment feedback	Operation - enterprise/ Customer premise	ESMIG0017

Scenario Name :								
Step No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Technical Require-ments ID	Ref.
10d	MDM receives the end of load adjustment period with feedback from HES	MDM forwards the end of load adjustment period with feedback to Actor B	MDM	Actor B	Load adjustment feedback	Enterprise/ Customer premise	ESMIG0017

5.1.2 Distribution Automation FLISR

5.1.2.1 FLISR: Fault Location Isolation and Service Recovery

5.1.2.1.1 High level overview

FLISR automates the management of faults in the distribution grid. It supports the localization of the fault, the isolation of the faulty equipment(s) from the healthy equipment and the restoration of the healthy equipment. FLISR is typically applied in the MV network. During disturbances the automatic fault handling shortens outage time and offloads the operators in the distribution control center for more complicated situations. Therefore FLISR may help to improve performance indexes like SAIDI (System Average Interruption Duration Index).

Utilities that operate networks have a need for fast fault awareness, faulty section identification, rapid information gathering and analysis of switching options to restore service when a part of the consumers, attached to the concerned feeder is lost. Without this capability, it makes 8 hours or more to restore power should an inner city substation be lost. This application runs at a control centre level, with tight connection with field devices acting either as sensors or actuators.
Implementing FLISR helps Utility to improve the performance based rates (PBR) and reduce the risk of penalties. The rules for PBR will vary from country to country, or even from state to state, however most include the performance measures of SAIDI and often system average interruptions per mile of line.
Another business approach can be to measure the quantity of Non-Distributed-Energy due to un-availability of power at consumer side. The quicker the restoration is performed after a fault, the less is the quantity of non-distributed energy.

5.1.2.1.2 Communications requirements

The FLISR use case is divided into four sequences:

1. Fault detection and clearance – The protection devices in the grid are detecting the fault and issuing suitable breaker tripping.
2. Fault localization – Identify the physical location of the fault by analysing the telemetered alarms received from protection devices in the grid
3. Fault isolation – Determine switching actions which will isolate the faulty equipment(s) from the rest of the grid
4. System restoration (optional) – Re-supply those healthy parts of the grid, which are de-energized during the fault clearing.

The execution within these steps is typically highly automated, while the continuation with the next sequence typically requires a control room operator interaction.

Data flow:

- Intelligent Electronic Devices / Programmable Logic Controllers / Relays communicate through serial, Ethernet or RF Mesh
- Centralized or Distributed Intelligence reachable through the WAN
- Potentially P2P traffic between reclosers, sensors, feeders.
- Fault Intelligence Application receiving traffic from IED/PLC
- Grid State Database – collect all data
- Distribution Management System – Real-Time information
- Time synchronization
- Support of legacy devices: Serial to IP translation
- Data volume could be bytes (or higher) depending on field automation penetrations and density and inclusion of other systems such as AMI data for resolution.

Table 6: FLISR communication requirements

	Data use Category	
Parameter	Control/Protection Data	Monitoring/Management Data
Latency	Low (20 ms to 2 seconds)	Medium (<10 S
Data occurrence interval	Millisecond	Seconds
Method of Communication	Unicast, Multicast/Broadcast	Unicast /multicast
Reliabilit	High	Medium
Data security	High	High
Data volume	Bytes/Kilo bytes	Kilobyte
Priorit	High	Medium
Level assurance	High	Low

5.1.2.1.3 Proposed communication architecture setup

Scenario I

In this scenario it is assumed that a communication network allows for a hop by hop communication between the primary substation and all the secondary substation in between. A field area router allows the communication to the central application. The field router is typically placed in one of the primary substations although not show as such in the figure 5.1 below.

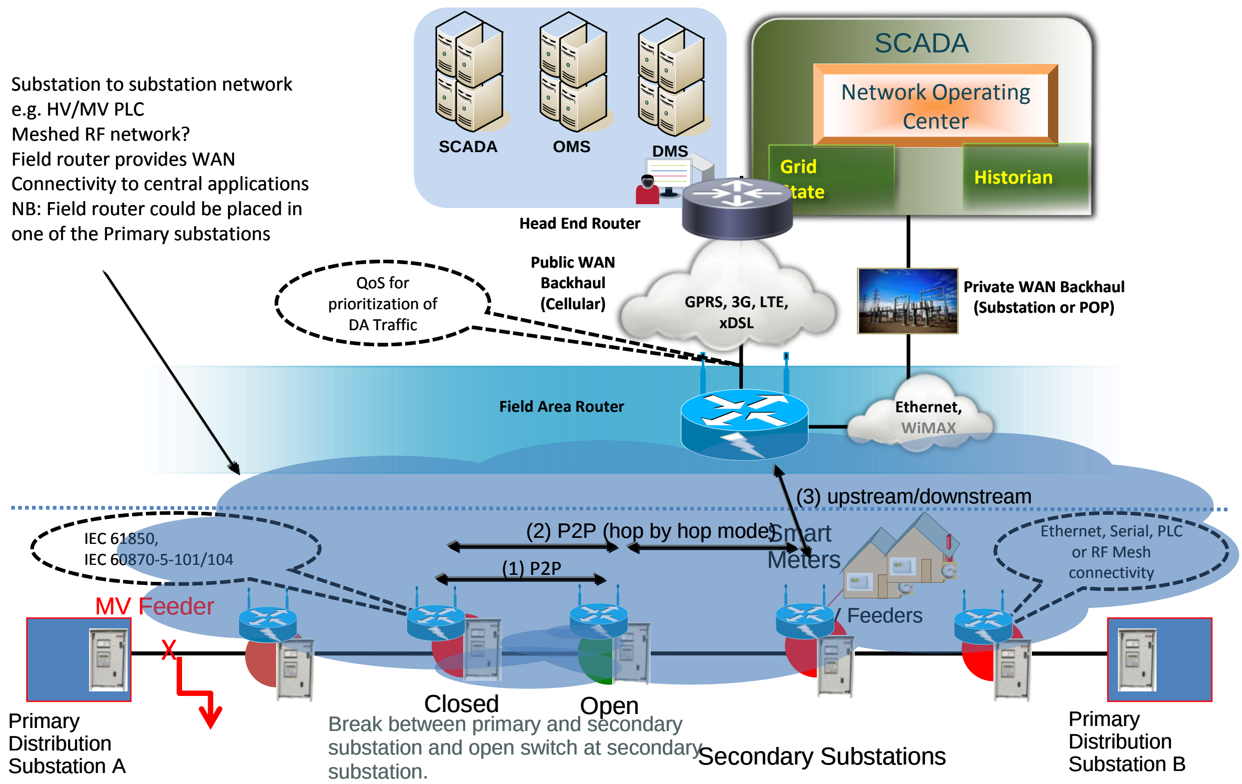


Figure 19: FLISR (1) Example architecture

In this scenario in Figure 5.1 above, 3 modes of communication are depicted:

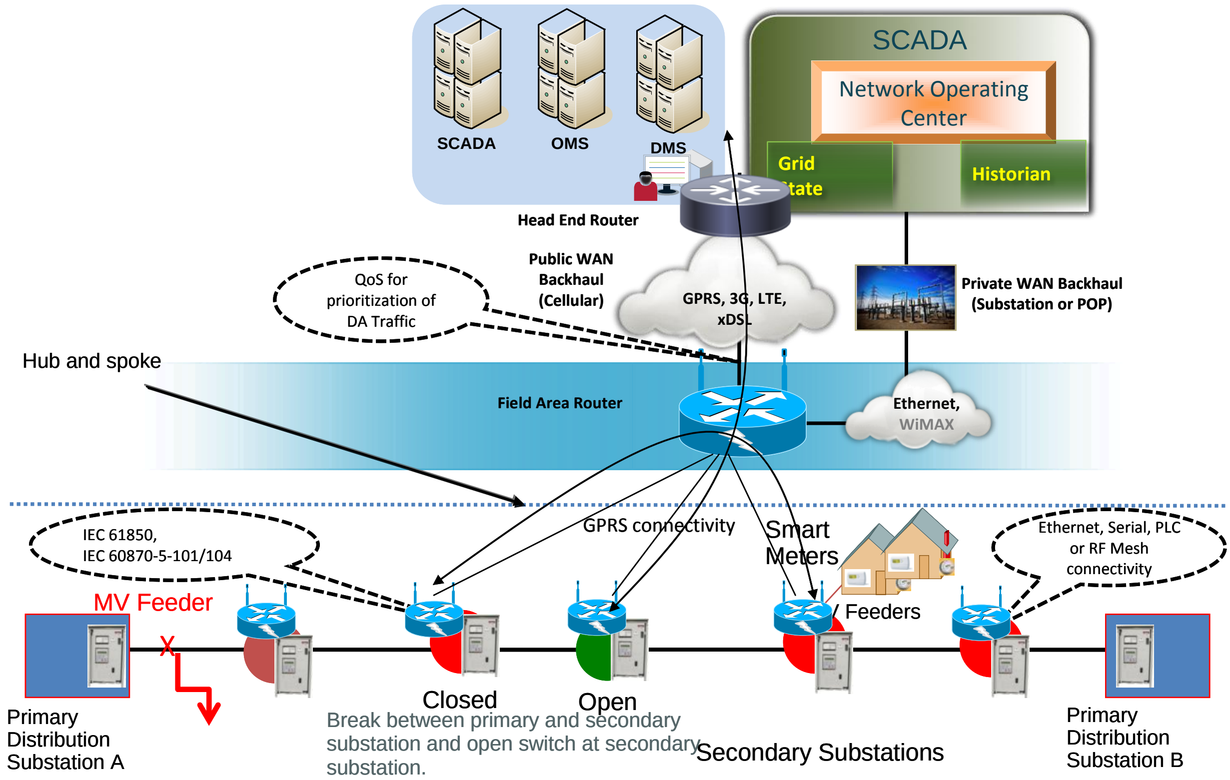
- (1) P2P communication (1hop): secondary substation to adjacent secondary substation
- (2) P2P communication (multi-hop): secondary substation to non adjacent secondary substation where an intermediate substation allows to router the traffic
- (3) Upstream and downstream communication to a central control system via a field area router which is typically equipped with a WAN communication interface and an area network communication interface. Any of the secondary or primary substations could communicate to the central applications via this router, and the area network that connects this router.

For the purpose of robustness it could be recommended to deploy two field area routers: one in each substation. Dynamic IP routing allows rerouting the traffic in case of failure of one of the WAN interfaces.

Scenario II

In this scenario, in figure 5.2, each of the secondary substations implement a (typically WAN) point to point communication interface toward the field area router: typically this can be achieved through the deployment of a cellular communication module (e.g. GPRS).

In this scenario the traffic from a secondary substation to a secondary substation needs to go via the field area router in a hub and spoke mode. The traffic to a central application is routed via the field area router.



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2663 **Figure 20: FLISR (2) Example architecture**

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2665 Mapping to the SGAM model:
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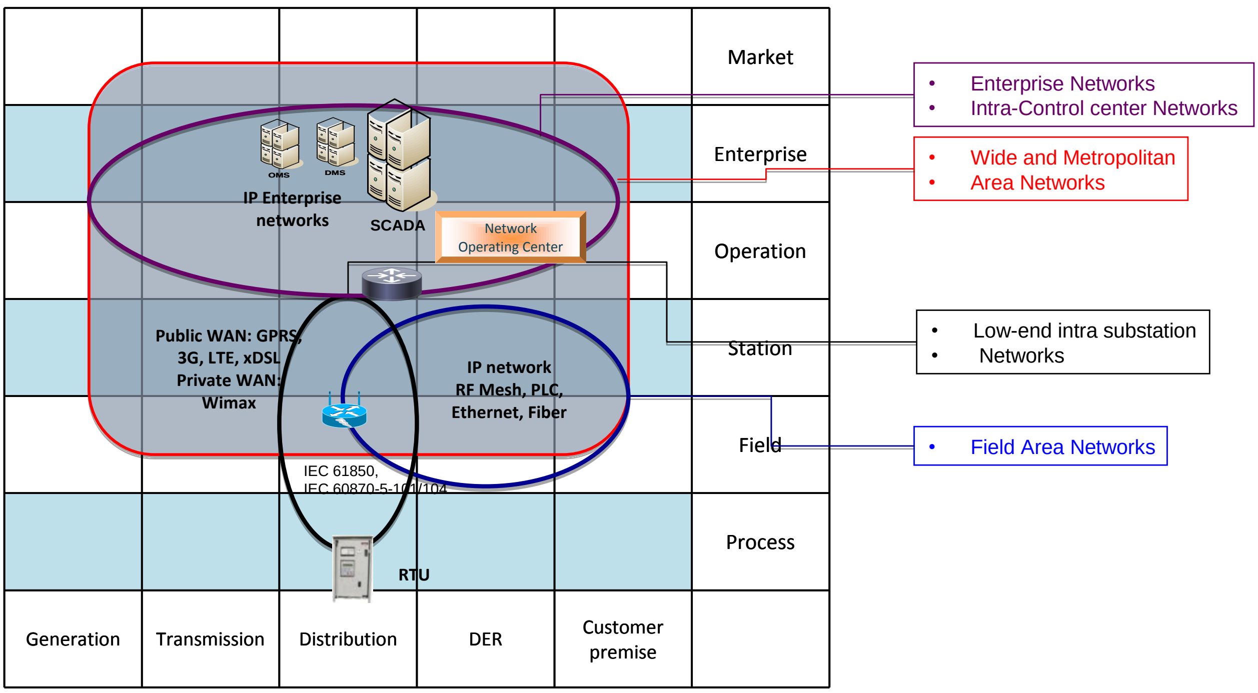

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2668 **Figure 21: FLISR Communication networks mapping to the SGAM model**

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5.1.3 Tele-protection using an IP/MPLS network

5.1.3.1 High level overview

What is protected: lines and devices.

Tele-protection consists in quickly and reliably detecting a (power) network fault and then ensuring the faulty equipment is isolated before the fault has a greater effect on the power grid. Tele-protection typically applies to protection implemented between substations within the high voltage network.

Tele-protection systems monitor and compare conditions with distance relays at the two high voltage line ends to determine if there is a fault on the protected line section. When a fault is detected, TPR (tele-protection relay) tripping signals will activate the protection equipment (typically a circuit breaker) to isolate the affected part in the adjacent substation to prevent damages to expensive substation equipment and instability in the power system. To ensure the power system is protected, relay signals need to be transferred between distance relays without a sufficient delay so as to prevent the fault to not propagate to the other equipment & substations before the telecommunications signals reach **the target equipment**.

The end-to-end delay tolerance for relay signals with the **number of cycles that can vary depending on the distance, types of relays, etc.** of the electricity transmission at 60Hz (NA) or 50Hz (Europe). This translates to 10msnode top node delay including time for propagation from substation to substation.
This end-to-end delay includes the latency of the telecom network (IP/MPLS for the purpose of this use case) as well as the detection and activation time of the protection circuits.

The interface from the TPR can be G.703, E&M, RS-232, X.21, IEEE c33.67, etc.

Use Case Diagram

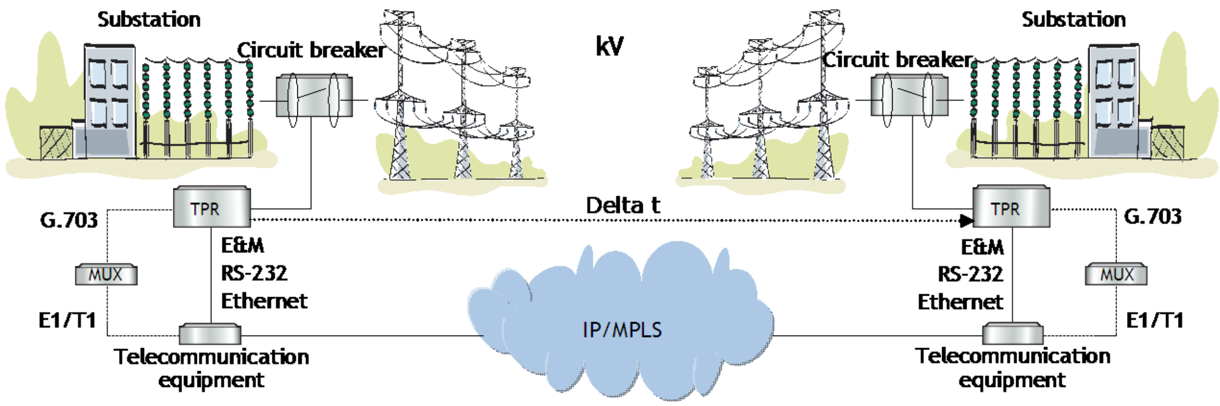


Figure 22: Tele-protection Example architecture

Use Case Stakeholders

1. Circuit breaker: is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to detect a fault condition and, by interrupting continuity, to immediately discontinue electrical flow.
2. Tele-protection Relay (TPR): activate the protection equipment to isolate the affected part in adjacent substation to prevent damages to expensive substation equipment and instability in the power system

3. Telecommunication Equipment: interface to TPR in order to adapt and transfer control signals between the TPRs. Provides circuit emulation services in order to transport TDM based interfaces over a Packet Switched Network (PSN)
4. Telecommunication network (IP/MPLS): provides packet-based communication between the Telecommunication Equipment end points. It supports the QoS and path protection mechanisms needed by the targeted services.

5.1.3.2 Communications requirements

The table below lists the network communication requirements for the Tele-protection scenario.

Table 7: Tele-Protection communication requirements

	Data Category	
Parameters	Control/Protection Data	Monitoring/Management Data
Latency	Less than 10ms	100ms
Data occurrence interval	Unpredictable (based on Network conditions)	Periodic
Method of Communication	Unicast	Unicast
Reliability	Very High	High
Data security	High	High
Data volume	Few Kilo bytes	Kilobytes
Priority	Very High	Medium
Level assurance	High	High

The following provides additional clarifications as regards the communication requirements:

- The end to end latency of 10 ms includes the TDM-related packetization delay
- Symmetry: The end to end delay in one direction shall not exceed the end to End delay in the other direction by more than 2ms
- Resiliency: All traffic paths shall be protected, where the protection delay shall not take more than 100ms (50ms is preferred)
- Denial of service: the IP/MPLS network shall support denial of service protection mechanisms in order to avoid disrupting the control plane and incurring excessive delay for the tele-protection signals
- Time synchronization: The IP/MPLS network shall provide accurate time synchronization needed to support TDM services (1ms granularity)
- QoS: The IP/MPLS network shall implement a Strict Priority scheduling algorithm that allow minimal delay per IP/MPLS node: the delay incurred by each traversed node shall be less than 250µs

5.1.3.3 Proposed communication architecture setup

Teleprotection over IP/MPLS	Mechanisms for detecting a (power) network fault and then ensuring the faulty equipment is isolated through sending teleprotection signals via an IP/MPLS network

High level functions

0	Substation detect a fault detection
1	Substation isolates a fault by acting upon a circuit breaker
2	A Teleprotection relay sends teleprotection signals to another teleprotection relay located at another substation
3	Telecommunication equipment provides adaptation of a TDM signal to a packet based IP/MPLS network (and vice versa)
4	IP/MPLS network transports packetized TDM traffic
5	Circuit breaker at peer substation activated

Communications requirements

- End to end latency between the egress port of the TPR and the ingress port of the other TPR shall not exceed 10 ms including the TDM packetization delay (when applicable)
- Symmetry: The end to end delay in one direction (TPR1 to TPR2) shall not differ from the end to End delay in the other direction (TPR2 to TPR1) by more than 2ms (750 micro seconds may be preferred by some deployments)
- Resiliency: All traffic paths shall be protected, where the protection delay shall not take more than 100ms (50ms is preferred)
- Denial of service: the IP/MPLS network shall support denial of service protection mechanisms in order to avoid disrupting the control plane and incurring excessive delay for the tele-protection signal
- Time synchronization: The IP/MPLS network shall provide accurate time synchronization needed to support TDM services (1ms granularity)
- QoS: The IP/MPLS network shall implement a Strict Priority scheduling algorithm that allow minimal delay per IP/MPLS node: the delay incurred by each traversed node shall be less than 250µs

Proposed communications architecture setup

The figure below provides the proposed communication architecture setup.

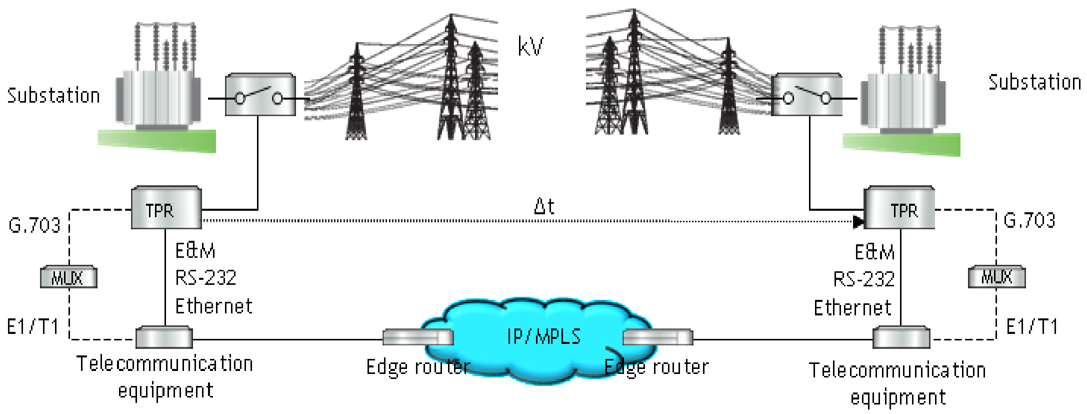


Figure 23: Tele-Protection Architecture example

In this figure the Telecommunication equipment provide TDM over packet and vice versa communication. The Edge router allows for traffic marking in order to ensure that the teleprotection traffic gets the highest scheduling priority. Additionally the Edge router allows routing the teleprotection IP packets over specific LSPs (Label Switched Paths) that are reserved for high priority traffic. Those LSPs are path protected by the Fast Reroute mechanism as described in IETF RFC 4090.

The total end-to-end latency is calculated by summing the packetization delay (PD), network delay (ND) and jitter buffer delay (JBD) as shown in the below figure.

Assuming a PD of 2ms, a JBD of 4ms, the network shall be dimensioned in order to provide the remaining delay budget.

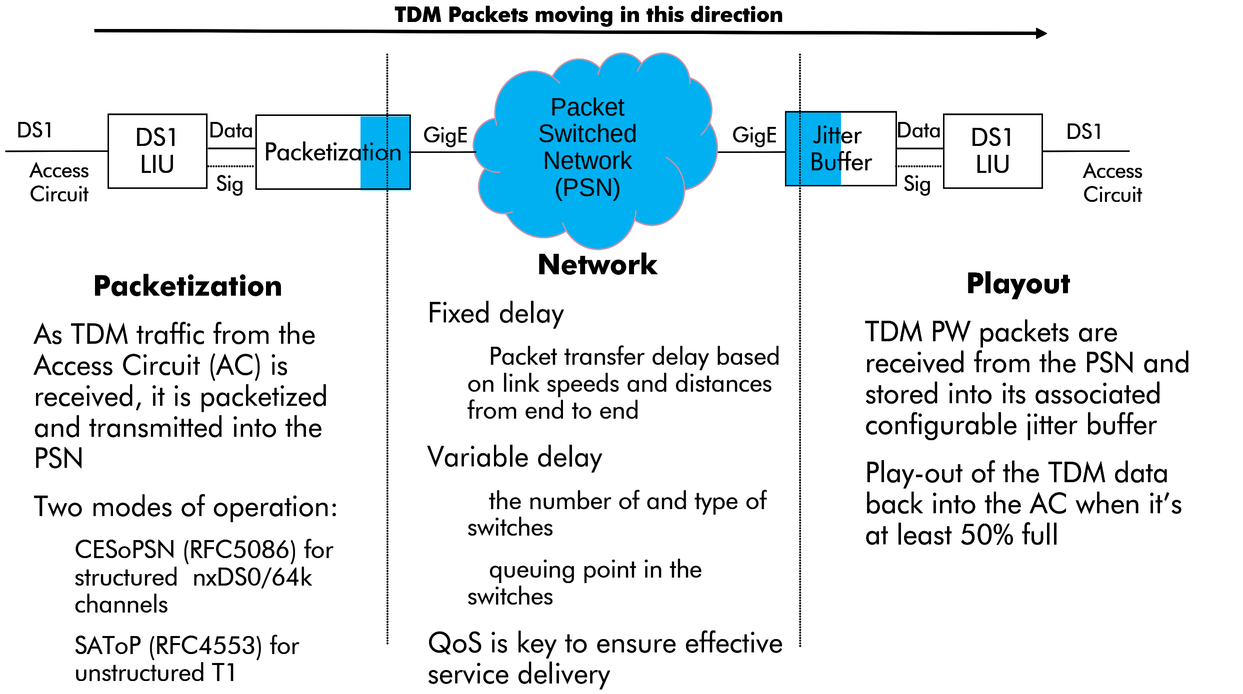


Figure 24: Delay incurred by the telecommunication equipment and the IP/MPLS network

- Circuit emulation: RFC 5086, RFC4553
- Specific LSP(s) for tele-protection traffic: primary + backup path
- Traffic marking: done at the telecommunication equipment

Mapping of communication networks to the SGAM model:

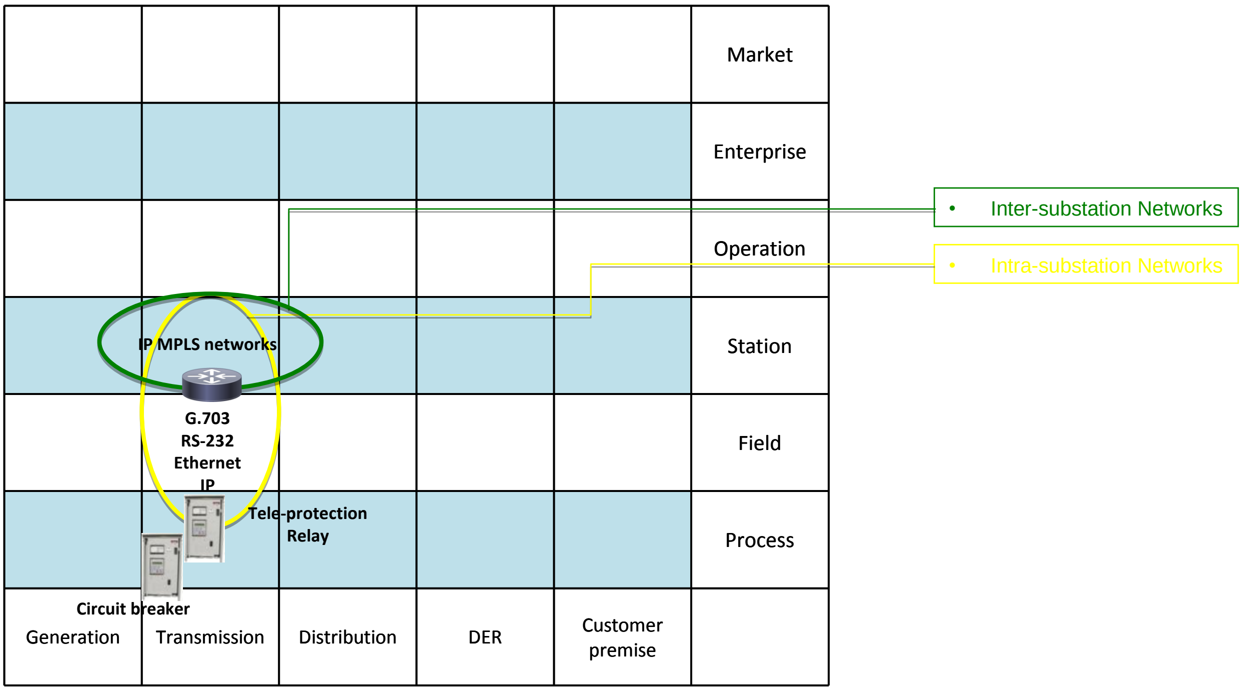


Figure 25: Tele-Protection: Mapping of communication networks to the SGAM model

5.1.4 Workforce communication

This use case will be developed in a subsequent release.

5.1.4.1 Proposed communication architecture setup

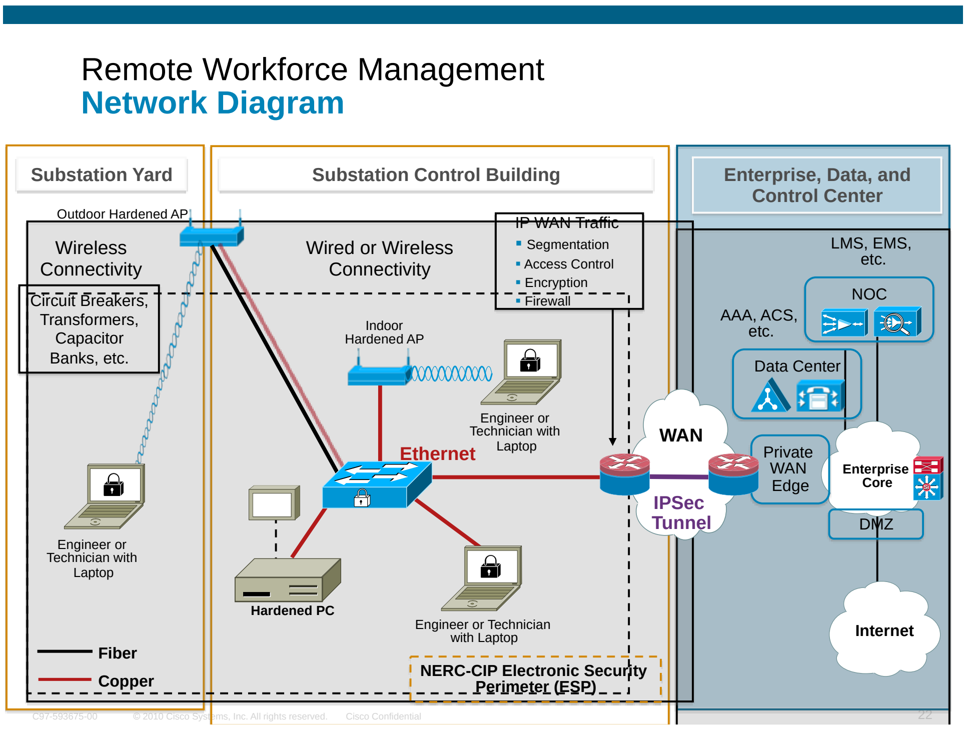


Figure 26: Workforce management example architecture

5.2 Mapping Example Use Cases to the Conceptual Model

Here is a mapping of the above Use Case examples chosen for the Communications to the Smart Grid Conceptual Model Domains, “x” means that the domain is involved in the use case.

Table 8: Mapping Example use Cases to the Conceptual Model Domains

Use Case	Markets	Operations	Services	Bulk Generation	DER	Transmission	Distribution	Customer
Demand Response	2x Use Cases emerging							
- via gateway and Energy Manager	x	x	x maybe. Depending on national split of ops. & BSS deregulation.		(x) maybe. Depending DER in Customer Domain (2 meter solutions) & on national deregulation.		x maybe. Depending on communication technology used.	x
- Smart appliances	x	x	x varies on national split of ops. & BSS deregulation. Also 3rd party Appliance Service providers.		(x) maybe, depending DER in Customer Domain (2 meter solutions) & on national deregulation.		x maybe, depending on communication technology used.	x
Distributed source of Energy		x	x for billing & accounting		x		x	x
Substation Automation (Primary)	Use Case not specified: covered in the Architecture							
Electric Vehicles	2x Use Cases emerging							
- Adhoc		x	x for eBilling				x	x
- Smart Charging	x	x	x maybe depending on national split of ops. & BSS deregulation.		x maybe depending EV Storage & on national deregulation.		x	x
Energy Trade Market	Use Case not specified							
Distribution Automation (Secondary)/FLISR		x					x	x
Wide Area Situation Awareness - Recent				x	x	x	x	
Teleprotection						x		
Remote workforce management- Recent				x	x	x	x	x

This table is based on the use cases in clause 3.1 above, these are a subset of the 450 use cases that exist in the Sustainable Process use cases repository. The items in this table are aligned with the descriptions in the repository; no attempt was made to survey all 450 use cases. There is a close relationship between the cases in this table and the descriptions in clause 3.1 above. This mapping could be viewed as a summary of the chosen use cases above. These use cases were selected as they are demonstrating the communications requirements.

5.3 QoS requirements for different Smart Grid Applications

This will be elaborated in the next version.

6 Description of selected communication profiles for the Smart Grid communications

6.1 Introduction

Generally a profile defines a subset of an entity (e.g. standard, specification or a suite of standards/specifications). Profiles enable interoperability and therefore can be used to reduce the complexity of a given integration task by:

- Selecting or restricting standards to the essentially required content, e.g. removing options that are not used in the context of the profile
- By setting specific values to defined parameters (frequency bands, metrics, etc.)

A standard profile for communications standards may contain a selection of communication capabilities applicable for specific deployment architecture. Furthermore a profile may define instances (e.g. specific device types) and procedures (e.g. programmable logics, message sequences) in order to support interoperability.

It may also provide a set of engineering guidelines to ease the deployment of new technologies.

A standard profile may contain the following information:

- Communication profile name
- Communication requirements and boundary
  Delay / Latency, Jitter
  Routing convergence time
  Bi directional jitter
  Nb of nodes
  BER
  Admissible Packet loss rate
  …
- Network diagram
  Drawings / Schema
- List of use cases / systems if relevant
- List of technologies
  Specifications / standards
- Security considerations
  Standards
  AAA
  Overall diagram
- Configuration parameters
- Best current practice

The following paragraphs are giving 2 examples of communication profiles. These profiles have been developed to illustrate the concept. This should be considered as example only, no validation have been performed and some pieces have not been fully developed.

6.2 Profile Example 1: Field Area Network

6.2.1 Communication profile name: Field Area Network

The FAN may serve the following systems: smart metering, feeder automation, FLIR (Fault Location, Registration, Isolation and Restoration), EHV charging, demand response, voltage regulation, distributed generation.

The following profile will primarily focus on 2 of these systems: Smart metering and Feeder automation. This is a multiservice network; the profile should combine the requirements from both use cases.

Feeder automation:

A Feeder automation system refers to the system and all the elements needed to perform automated operation of components placed along the MV network itself (feeders), including (but not limited to) fault detectors, pole or ground mounted MV-switches, MV-disconnectors and MV-circuit-breakers - without or with reclosing functionality (also called reclosers) between the HV/MV substation (MV side included) and the MV/LV substations.

The typical considered operations are protection functionalities (from upwards and/or distributed), service restoration (after fault conditions) or feeder reconfiguration.

Advanced Metering Infrastructure:

This network may connect meter concentrator (NNAP) and smart meters (LNAP) in this sense, it could overlap with the Neighborhood Network. It is also use to connect the MNAP to the HES via the uplink. The AMI system or the feeder automation system may benefit from each other and share the same network infrastructure but using QOS and/or VPN technologies to differentiate the flow of data.

6.2.2 Communication requirements and boundaries

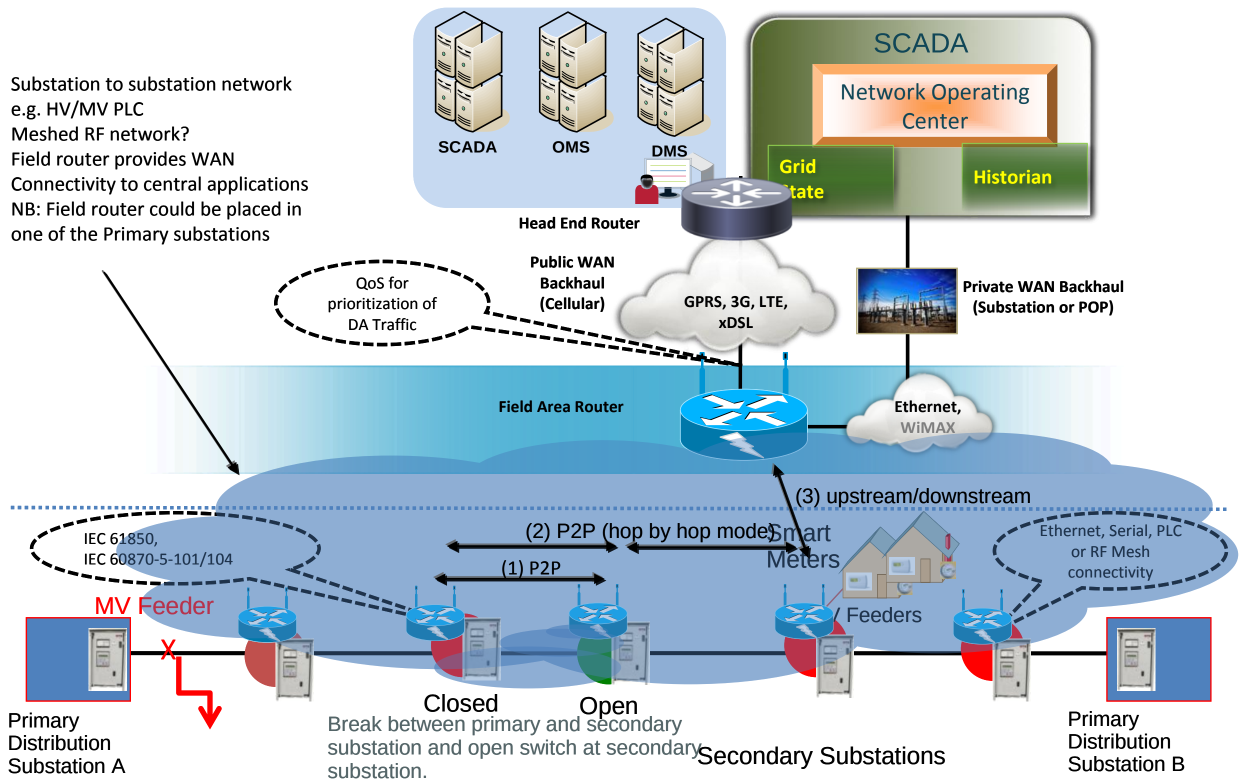
	Data use Category	
Parameter	Control/Protection Data	Monitoring/Management Data
Latency	Low (20 ms to 2 seconds)	Medium (<10 S
Data occurrence interval	Millisecond	Seconds
Method of Communication	Unicast, Multicast/Broadcast	Unicast/multicast
Reliabilit	High	Medium
Data security	High	High
Data volume	Bytes/Kilo bytes	Kilobyte
Priorit	High	Medium
Level assurance	High	Low

6.2.3 Scalability:

Feeder automation: tens of nodes

Smart metering: 10,000

6.2.4 Network diagram



6.2.5 List of systems if relevant

- Smart metering (NNAP, LNAP, HES communication)
- Feeder automation

6.2.6 List of technologies

UP-link connectivity:

- GPRS, 3G, LTE, xDSL, Wimax, Fiber, Ethernet

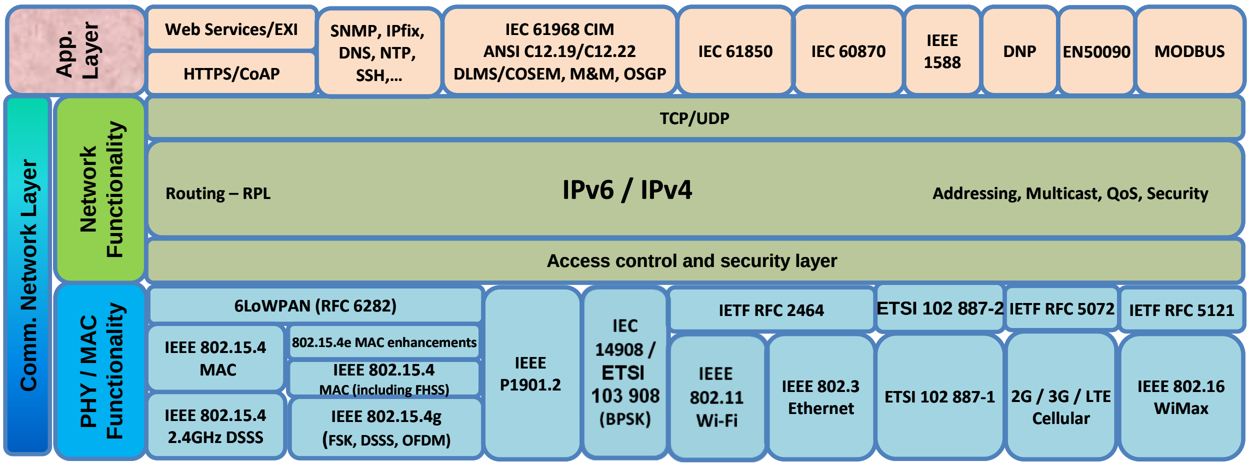
This profile will focus on device connectivity, which is the lower part of the network. The up-link technologies are only listed for the sake of a good understanding. It is to be noticed that some up-link technologies may be used for low-end inter-substation connectivity (802.16 for instance)

IPv6 is recommended due to the large number of devices to be connected.

Layer 3 routing: RPL (Routing over Low power and lossy network)

MAC/Phy: 802.15.4g (RF), P1901.2 (PLC), ETSI TS 103908 (PLC), EN 14908 (PLC)
QOS
VPN
Multicast

FAN Protocol stack:



The profile is focusing on the light orange part of the figure. The different MAC/PHY may imply the development of different sub-profiles as MAC/PHY specificities may lead to different configuration parameters in the upper communication layers.

6.2.7 Specifications / standards

This paragraph should give the list of all relevant standards used for implementing the profile.

6.2.8 Security considerations

Access control:
- 802.1x
- EAP

Security encryption:
- TLS
- DTLS

6.2.9 Configuration parameters

6.2.9.1 IPv6 addressing scheme

Manual configuration
This is appropriate for Head-End and NMS servers that never change their address, but is inappropriate to millions of end-points, such as meters, in regards to the associated operational cost and complexity. This may be used for the feeder automation as the number of devices will be limited but not recommended.

Stateless auto-configuration
An IPv6 prefix gets configured on a router interface (interface of any routing device such as a meter in a mesh or PLC AMI network), which is then advertised to nodes attached to the interface. When receiving the prefix at boot time, the node can automatically set-up its IPv6 address

Stateful auto-configuration
Through the use of DHCPv6 Individual Address Assignment, this method requires DHCPv6 Server and Relay to be configured in the network but benefits of a strong security as the DHCPv6 process can be coupled with AAA authentication, population of Naming Services (DNS) available for Head-End and NMS applications. The list above is the minimum set of tasks to be performed, but as already indicated; you must also establish internal policies and operational design rules. This is particularly true when considering security and management tasks such as registering IPv6 addresses and names in DNS (Domain Name System) and in NMS (network management station(s) or setting-up filtering and firewalling across the infrastructure.

6.2.9.2 Routing protocol:

RPL Profile

This section outlines a RPL profile for a representative AMI and Feeder automation deployment.

(Source: Applicability Statement for the Routing Protocol for Low Power and Lossy Networks (RPL) in AMI Networks draft-ietf-roll-applicability-ami-05)

6.2.9.2.1 RPL Features

6.2.9.2.1.1 RPL Instances

RPL operation is defined for a single RPL instance. However, multiple RPL instances can be supported in multi-service networks where different applications may require the use of different routing metrics and constraints, e.g., a network carrying both Smart Metering data and feeder automation traffic.

We may need to define one instance per application. This allows taking into account the specific requirements of each application (QOS, delay, jitter…) and allowing RPL to establish one topology per RPL instance (i.e. application).

6.2.9.2.1.2 Storing vs. Non-Storing Mode

In most scenarios, electric meters are powered by the grid they are monitoring and are not energy-constrained. Instead, electric meters have hardware and communication capacity constraints that are primarily determined by cost, and secondarily by power consumption. As a result, different AMI deployments can vary significantly in terms of memory size, computation power and communication capabilities.

For this reason, the use of RPL storing or non-storing mode SHOULD be deployment specific. When meters are memory constrained and cannot adequately store the route tables necessary to support hop-by-hop routing, RPL non-storing mode SHOULD be preferred. On the other hand, when nodes are capable of storing such routing tables, the use of storing mode may lead to reduced overhead and route repair latency.

However, in high-density environments, storing routes can be challenging because some nodes may have to maintain routing information for a large number of descendants. When the routing table size becomes challenging, it is RECOMMENDED that nodes perform route aggregation, similarly to the approach taken by other routing protocols, although the required set of mechanism may differ.

6.2.9.2.1.3 DAO Policy

Two-way communication is a requirement in AMI systems. As a result, nodes SHOULD send DAO messages to establish downward paths from the root to them.

6.2.9.2.1.4 Path Metrics

Smart metering deployments utilize link technologies that may exhibit significant packet loss and thus require routing metrics that take packet loss into account. To characterize a path over such link technologies, AMI deployments can use the Expected Transmission Count (ETX) metric as defined in [I-D.ietf-roll-routing-metrics]. For water- and gas-only networks that do not rely on powered infrastructure, simpler metrics that require less energy to compute would be more appropriate. In particular, a combination of hop count and link quality can satisfy this requirement.

As minimizing energy consumption is critical in these types of networks, available node energy should also be used in conjunction with these two metrics. The usage of additional metrics specifically designed for such networks may be defined in companion RFCs, e.g., [I-D.ietf-roll-routing-metrics] .

6.2.9.2.1.5 Objective Function

RPL relies on an Objective Function for selecting parents and computing path costs and rank. This objective function is decoupled from the core RPL mechanisms and also from the metrics in use in the network. Two objective functions for RPL have been defined at the time of this writing, OF0 and MRHOF, both of which define the selection of a preferred parent and backup parents, and are suitable for AMI deployments.

Neither of the currently defined objective functions supports multiple metrics that might be required in heterogeneous networks (e.g., networks composed of devices with different energy constraints) or combination of metrics that might be required for water- and gas-only networks. Additional objective functions specifically designed for such networks may be defined in companion RFCs

6.2.9.2.1.6 DODAG Repair

To effectively handle time-varying link characteristics and availability, AMI deployments SHOULD utilize the local repair mechanisms in RPL. Local repair is triggered by broken link detection and in storing mode by loop detection as well. The first local repair mechanism consists of a node detaching from a DODAG and then re-attaching to the same or to a different DODAG at a later time. While detached, a node advertises an infinite rank value so that its children can select a different parent. This process is known as poisoning and is described in Section 8.2.2.5 of [I-D.ietf-roll-rpl].

While RPL provides an option to form a local DODAG, doing so in AMI deployments is of little benefit since AMI applications typically communicate through a LBR. After the detached node has made sufficient effort to send notification to its children that it is detached, the node can rejoin the same DODAG with a higher rank value. The configured duration of the poisoning mechanism needs to take into account the disconnection time applications running over the network can tolerate. Note that when joining a different DODAG, the node need not perform poisoning. The second local repair mechanism controls how much a node can increase its rank within a given DODAG Version (e.g., after detaching from the DODAG as a result of broken link or loop detection). Setting the DAGMaxRankIncrease to a non-zero value enables this mechanism, and setting it to a value of less than infinity limits the cost of count-to-infinity scenarios when they occur, thus controlling the duration of disconnection applications may experience.

6.2.9.2.1.7 Multicast

RPL defines multicast support for its storing mode of operation, where the DODAG structure built for unicast packet dissemination is used for multicast distribution as well. In particular, multicast forwarding state creation is done through DAO messages with multicast target options sent along the DODAG towards the root. Thereafter nodes with forwarding state for a particular group forward multicast packets along the DODAG by copying them to all children from which they have received a DAO with a multicast target option for the group. Multicast support for RPL in non-storing mode will be defined in companion RFCs.

6.2.9.2.1.8 Security

AMI deployments operate in areas that do not provide any physical security. For this reason, the link layer, transport layer and application layer technologies utilized within AMI networks typically provide security mechanisms to ensure authentication, confidentiality, integrity, and freshness. As a result, AMI deployments may not need to implement RPL's security mechanisms and could rely on link layer and higher layer security features.

6.2.9.2.1.9 P2P communications

Distribution Automation and other emerging applications may require efficient P2P communications. Basic P2P capabilities are already defined in the RPL RFC [I-D.ietf-roll-rpl]. Additional mechanisms for efficient P2P communication are being developed in companion RFCs.

6.2.9.2.2 Recommended Configuration Defaults and Ranges

6.2.9.2.2.1 Trickle Parameters

Trickle was designed to be density-aware and perform well in networks characterized by a wide range of node densities. The combination of DIO packet suppression and adaptive timers for sending updates allows Trickle to perform well in both sparse and dense environments. Node densities in AMI deployments can vary greatly, from nodes having only one or a handful of neighbors to nodes having several hundred neighbors. In high density environments, relatively low values for Imin may cause a short period of congestion when an inconsistency is detected and DIO updates are sent by a large number of neighboring nodes nearly simultaneously.

While the Trickle timer will exponentially backoff, some time may elapse before the congestion subsides. While some link layers employ contention mechanisms that attempt to avoid congestion, relying solely on the link layer to avoid congestion caused by a large number of DIO updates can result in increased communication latency for other control and data traffic in the network. To mitigate this kind of short-term congestion, this document recommends a more conservative set of values for the Trickle parameters than those specified in [RFC6206]. In particular, DIOIntervalMin is set to a larger value to avoid periods of congestion in dense environments, and DIORefundancyConstant is parameterized accordingly as described below.

These values are appropriate for the timely distribution of DIO updates in both sparse and dense scenarios while avoiding the short-term congestion that might arise in dense scenarios. Because the actual link capacity depends on the particular link technology used within an AMI deployment, the Trickle parameters are specified in terms of the link's maximum capacity for transmitting link-local multicast messages. If the link can transmit m link-local multicast packets per second on average, the expected time it takes to transmit a link-local multicast packet is 1/m seconds. DIOIntervalMin: AMI deployments SHOULD set DIOIntervalMin such that the Trickle Imin is at least 50 times as long as it takes to transmit a link-local multicast packet.

This value is larger than that recommended in [RFC6206] to avoid congestion in dense urban deployments as described above. In energy-constrained deployments (e.g., in water and gas battery-based routing infrastructure), DIOIntervalMin MAY be set to a value resulting in a Trickle Imin of several (e.g. 2) hours. DIOIntervalDoublings: AMI deployments SHOULD set DIOIntervalDoublings such that the Trickle Imax is at least 2 hours or more. For very energy constrained deployments (e.g., water and gas battery-based routing infrastructure), DIOIntervalDoublings MAY be set to a value resulting in a Trickle Imax of several (e.g., 2) days. DIORedundancyConstant: AMI deployments SHOULD set DIORedundancyConstant to a value of at least 10. This is due to the larger chosen value for DIOIntervalMin and the proportional relationship between Imin and k suggested in [RFC6206].

This increase is intended to compensate for the increased communication latency of DIO updates caused by the increase in the DIOIntervalMin value, though the proportional relationship between Imin and k suggested in [RFC6206] is not preserved. Instead, DIORedundancyConstant is set to a lower value in order to reduce the number of packet transmissions in dense environments.

6.2.9.2.2.2 Other Parameters

- AMI deployments SHOULD set MinHopRankIncrease to 256, resulting in 8 bits of resolution (e.g., for the ETX metric).

- To enable local repair, AMI deployments SHOULD set MaxRankIncrease to a value that allows a device to move a small number of hops away from the root. With a MinHopRankIncrease of 256, a MaxRankIncrease of 1024 would allow a device to move up to 4 hops away.

6.2.10 MAC / PHY configuration parameters:

According to the MAC/PHY chosen, you will find here the frequency band, the different parameters to configure the MAC and Physical layer with the default values.

6.2.11 Best current practice:

This paragraph may describe some largely deployed solutions using this profile with the parameter's default values, the scalability number and any useful information.

6.3 Profile Example 2: IP MPLS

6.3.1 Introduction

This communication profile considers the case where an IP/MPLS network is used as WAN communications network to interconnect substations (to each other), Utility control center and Bulk power stations.

In particular the focus of this profile is on the use of the IP/MPLS network for the purpose of inter-substation Teleprotection. The same IP/MPLS network can be used for other smart grid communications.

The communication architecture considered for this profile is depicted in the figure below:

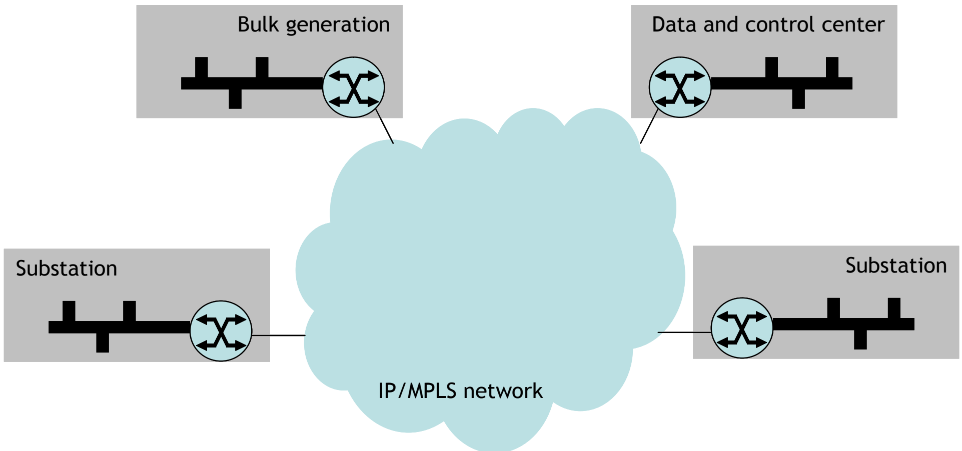


Figure 27: Architecture for IP/MPLS based teleprotection

For the sake of simplicity only two substations are depicted in this architecture; however the described profile is applicable to an arbitrary number of substations sharing the same IP/MPLS infrastructure.

The IP/MPLS network can either be owned operated and managed by the Energy provider or communication network operator.

6.3.2 Communication requirements and boundaries

The following requirements shall be fulfilled by the communications network.

- The End to end latency between the egress port of the TPR and the ingress port of the other TPR shall not exceed 10 ms. This delay includes the TDM packetization delay (when applicable).

- Symmetrical delay: The end to end delay in one direction (TPR1 to TPR2) shall not differ from the end to End delay in the other direction (TPR2 to TPR1) by more than 2ms.

- Security/Denial of service attacks: the IP/MPLS network shall support denial of service protection mechanisms in order to avoid disrupting the control plane and incurring excessive delay for the tele-protection signal

- Time synchronisation: The IP/MPLS network shall provide accurate time synchronisation needed to support TDM services

- QoS: The IP/MPLS network shall implement a Priority scheduling algorithm that allows for minimal delay per IP/MPLS node

6.3.3 Detailed Network diagram for the profile

End-to-End Layer 1 and Layer 2 communications services over MPLS are shown in the figure below:

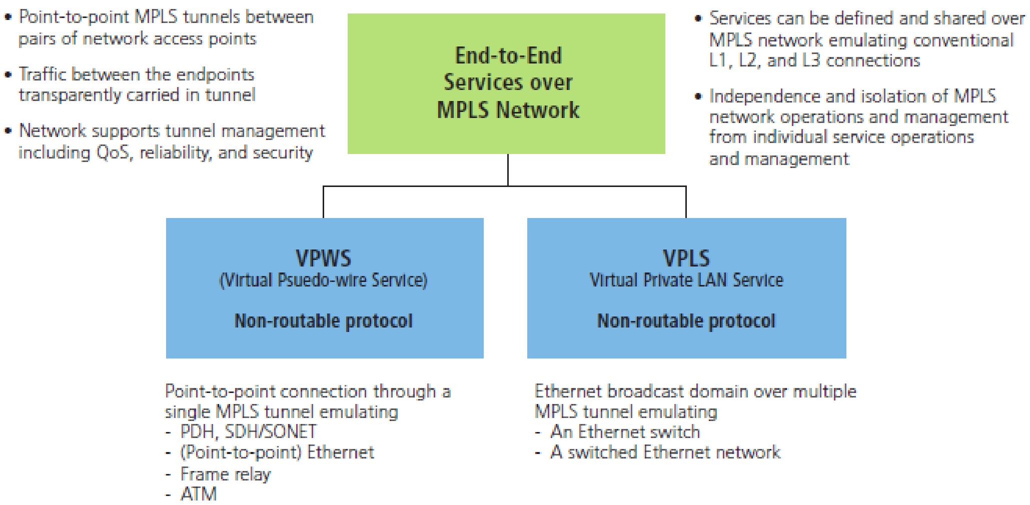


Figure 28: MPLS services

The choice of VPLS or VPWS for the purpose of our profile depends on the interface that is implemented by the TPR.

6.3.3.1 The TPR implements an Ethernet interface

In case the TPR implements an Ethernet Interface, a **VPLS (Virtual Private LAN Service) service** as defined in RFC 4762 is preferred because it allows a multipoint to multipoint connectivity. VPLS is a Layer 2 VPN (Virtual Private Network) service and is used to provide multi-point to multi-point Ethernet connectivity between the TPRs (for the purpose of teleprotection) and for the overall communication between the substations, the data and control center and the bulk generation sites. VPLS emulates an Ethernet bridge connecting these endpoints. In a converged MPLS network, this Layer 2 VPN is achieved using a full mesh of LSPs between the participating sites. Conceptually, a number of secure tunnels are constructed, allowing multipoint connectivity.

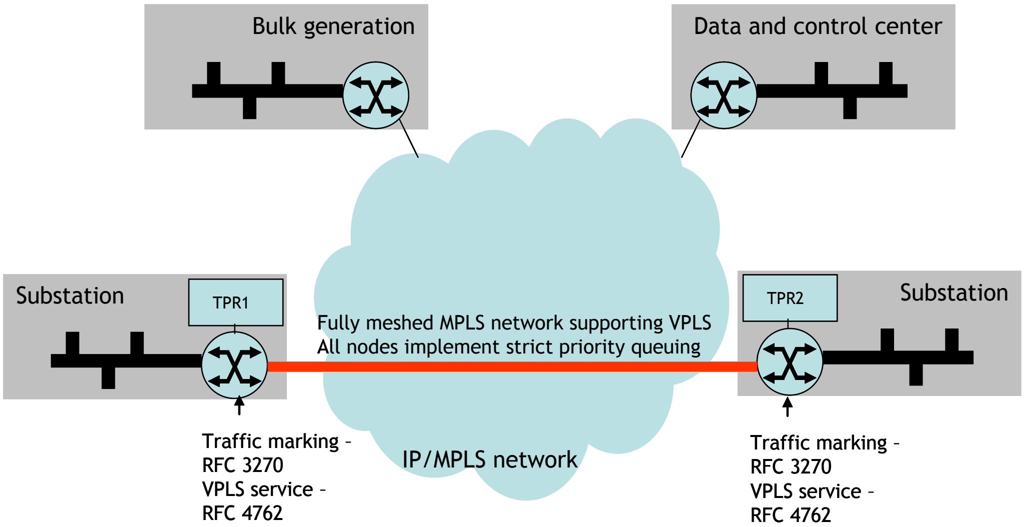


Figure 29: Teleprotection using VPLS (Ethernet TPRs)

For the sake of simplicity, Figure 4 shows a partial view representing a point to point VPLS connecting the substation TPRs.

6.3.3.2 The TPR implements a TDM interface

In case the TPR implements a TDM interface, a circuit emulation service is required. Two modes of circuit emulation can be supported (depending on the TDM interfaces): unstructured and structured.

- Unstructured mode is supported for DS1 and E1 channels per RFC 4553, Structure-Agnostic Time Division Multiplexing (TDM) over Packet (SAToP).
- Structured mode is supported for n*64 kbps circuits as per RFC 5086, Structure-Aware Time Division Multiplexed (TDM) Circuit Emulation Service over Packet Switched Network (CESoPSN).

Both circuit emulation services (structured and unstructured), a VPWS (Virtual Pseudo Wire Service) service as defined in RFC 4447 should be used. In VPWS a pseudo-wire is a point-to-point connection between two end points: the TPRs in this case. Circuit/TDM services can be carried over MPLS pseudo wires.

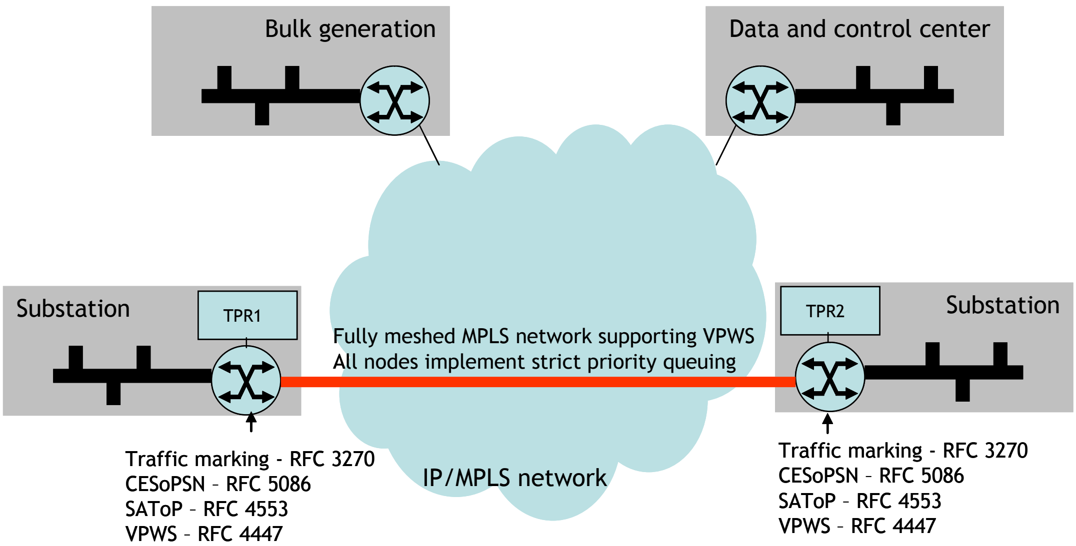


Figure 30: Teleprotection using VPWS (TDM TPR)

In Figure 30, the MPLS edge router (also referred to as Provide Edger - PE- router) must implement a circuit emulation mechanism to allow the transport of a circuit/TDM interface over the IP/MPLS network. Depending on the type of the TDM interface RFC 4553 or RFC 5086 can be used.

6.3.3.3 Path protection

MPLS Fast Reroute provides path protection mechanisms where the switching time is estimated at 50 ms. For the purpose of Teleprotection which mandates a delay bound of 10 ms, Fast Reroute does not provide an adequate answer.

To provide 10 ms protection, two separate MPLS LSP paths should be provisioned and used by the TPRs to send teleprotection signals simultaneously over the two LSPs. The same protection mechanism can be used for both the VPLS and the VPWS as depicture in Figure 31 below:

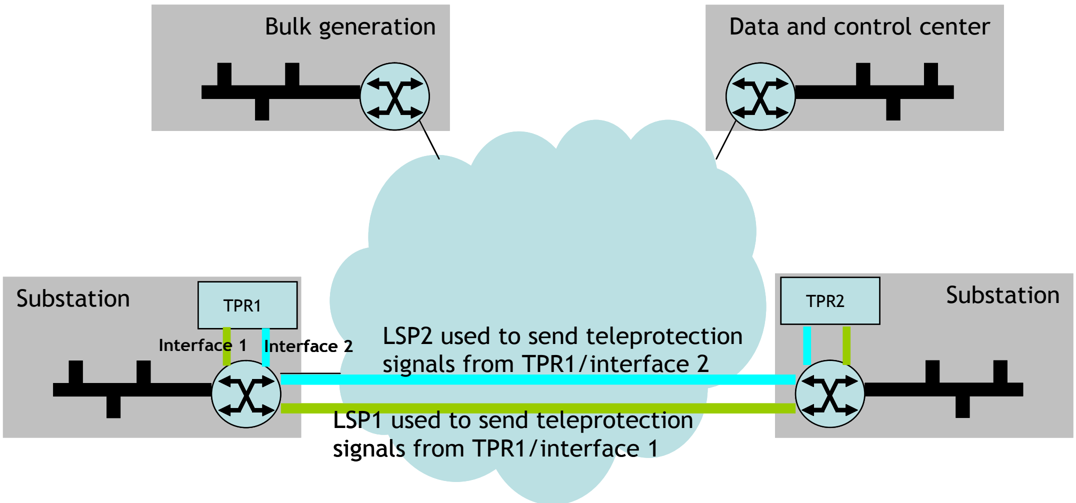


Figure 31: Achieving protection for Teleprotection services.

6.3.3.4 Quality of Service and scheduling

The IP/MPLS network shall support the DiffServ QoS architectural model mapped to MPLS as defined in RFC 3270

6.3.3.5 Achieving path symmetry

To achieve path symmetry the network should support IP/MPLS traffic engineering capabilities as defined in RFC 3209 for RSVP-TE.

The path in each directed is determined (traffic engineered) offline and provided to the ingress PE (Provider Edge) routers to set the LSP according to an explicit route. The explicit route in one direction and in the other direction shall provide comparable end to end delay (with a tolerance of 2ms) and shall take into account the packetization delay if applicable (VPWS case).

Editor’s note: optionally OSPF-TE as defined in RFC 3639 and IS-IS TE as defined in RFC 3784 can be used to allow for Shared Risk Link Group (SRLG) based LSP path diversity. This use if for further study

6.3.3.6 Timing and synchronisation

In order to support TDM service (TPRs supporting TDM interfaces) the PE router must support timing and synchronization as specified in: ANSI T1.403 and ITU-T G.2861

6.3.3.7 System reliability

System reliability is generally achieved through redundancy; therefore, the network equipment must provide redundant cooling, and redundant power.

For continuity of service, functions such as non-stop-signaling and non-stop routing and an intra-nodal high availability control plane failover mechanism must be supported for all active services. The deployed system shall support both hardware and software redundancy.

Hardware redundancy:

- Component redundancy
- Dual switching fabric
- Redundant cooling system
- Redundant power

Software redundancy

- Configuration Redundancy
- Service Redundancy
- Accounting Configuration Redundancy
- Synchronization

6.3.3.8 Network reliability

The network equipment forming the solution must embody the following reliability traits.

- Inter-nodal failover with multi-chassis APS for CES, IP/MPLS and MLPPP (IP)
- Multiple link, card, and node fault restoration scenarios
- Pseudowire redundancy protection for IP/MPLS, as specified in RFC 5254
- CES, ETH over redundant pseudowires

With the evolution towards IP/MPLS, devices providing the aggregation layer for a significant proportion of revenue generating services, having a single point of failure at the core layer may cause a significant loss of revenue. Multi-chassis developments have effectively removed that single point of failure. Multi-chassis support can be extended to both Ethernet and SDH interfaces.

6.4 Initial list of profiles for future development by SDOs

The following list gives a first outlook of different communication profiles. This list is not exhaustive and do not represent the complete scope of smart grid system needs:

- Neighborhood Area: smart metering, EHV charging, demand response, voltage regulation, street lighting, transformer management, distributed generation

- FAN: smart metering, feeder automation, FLIR (Fault Location, Registration, Isolation and Restoration), EHV charging, demand response, voltage regulation, distributed generation

- Low-end intra substation Ethernet: Substation automation, Distributed Energy Resources, asset management, energy storage

- Intra substation Ethernet based: Substation automation, Distributed Energy Resources, asset management, energy storage, synchrophasor, WAMS, WASA

- Inter substation: Transmission Grid Management, Distribution Grid Management, Distributed Energy Resources, asset management, energy storage, synchrophasor, WAMS, WASA
- …

6.5 Interoperability consideration/recommendations

The goal of developing communication profiles is to ensure interoperability as defined in the Reference Architecture document (SG CG RA document paragraph 5.1 “Interoperability in the context of the Smart Grid”). It is aligned with the GridWise Alliance GWAC stack.

7 Communication architecture topologies for the Smart Grid

This section aims at providing detailed architecture topologies for the communications networks as listed in section 1.3.

7.1 Subscriber Access Network

To be developed in a subsequent release

7.2 Neighborhood Network

To be developed in a subsequent release

7.3 Field Area Network

To be developed in a subsequent release

7.4 Low-end intra-substation network

To be developed in a subsequent release

7.5 Intra-substation network

Currently communication within most substations is limited to SCADA. IEDs and RTUs in the substation use point-to-point communication between them, often through a “data concentrator”. Most protocols are proprietary. The SCADA communication link between the substation and the SCADA control center are often point to point TDM connections.

If there are other applications located at the substations (such as teleprotection, synchrophasors, and CCTV), they each have a separate communication links to their respective counterparts.

The substation LAN evolution will be on two different levels. At one level, the substation architecture of the utility operations applications such as SCADA and teleprotection will evolve to the architecture specified in the IEC 61850 standard [4]. On another level, traffic generated by many new smart grid and other applications that will be resident at the substation such as the meter concentrators and CCTV will be aggregated at the substation router along with the SCADA and other operations traffic. The substation router is an ER in our integrated architecture of Figure 32. The router at a (large) substation may additionally aggregate traffic generated in the vicinity of the substation.

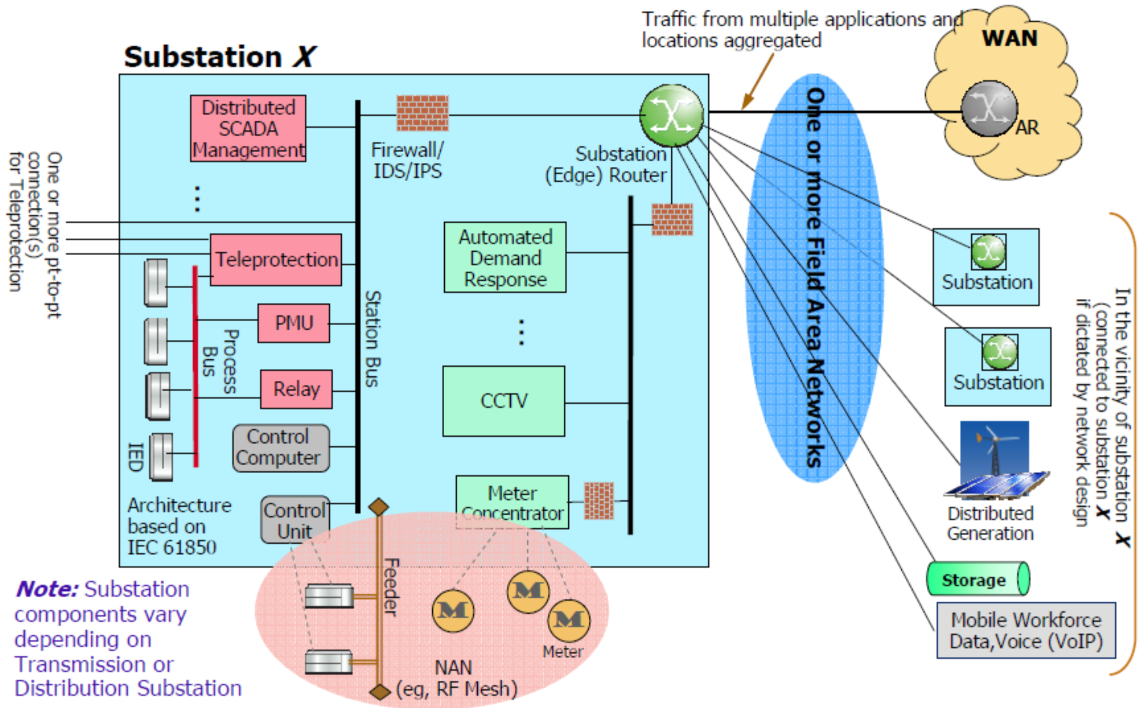


Figure 32: Substation communication architecture example

IEC 61850 define a process bus that is an Ethernet bus. All SCADA IEDs and optionally the teleprotection IEDs and PMUs connect to the process bus. For legacy equipment gateways may be used to connect into the process bus. There may be more than one process bus.

The station bus is used to connect the process busses as well as other operation systems such as the distribution automation traffic concentration from the feeder IEDs (if thus designed).

Access to all these operation elements are protected by protecting the station bus behind firewall and/or Intrusion detection and protection (IDS/IPS) systems.

The substation may use another Ethernet network for connecting other smart grid and utility systems such as the CCTV, meter concentrators, and demand response systems; access to these systems is protected by another firewall and/or IDS/IPS system.

Finally the substation router aggregates all traffic generated at the substation and possibly traffic generated at (smaller) substations in the vicinity as well as traffic from other endpoints in the vicinity – examples of which are shown in Figure 32.

7.6 Inter substation network

7.6.1 High voltage teleprotection network

To be developed in a subsequent release.

7.6.2 Medium voltage inter-substation network

The following figure provides a typical European Grid topology, source KEMA report.

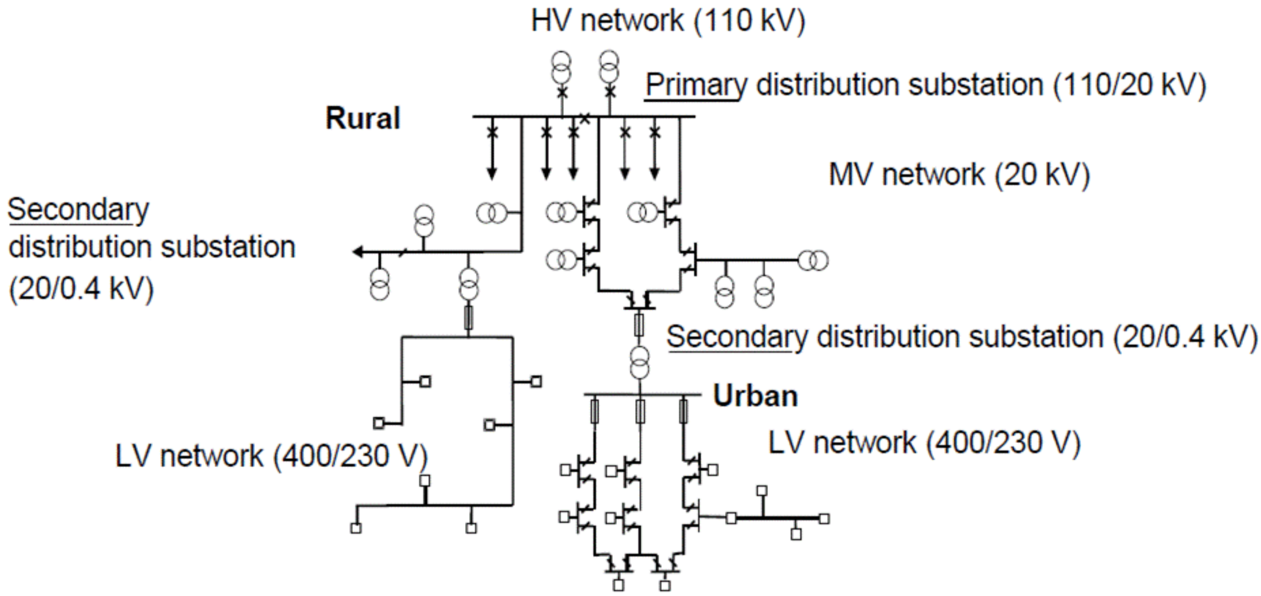


Figure 33: Distribution grid: typical substation topology for European markets (Source Kema)

In this topology one can distinguish the ring topology that connects a primary distribution substation as part of the distribution network together with the secondary substations. Two cases can be distinguished:

- Urban areas: The primary substation connects to the secondary substations using a ring topology. Often the ring is based on an **open ring**, through acting on a breaker switch connecting a secondary substation.
- Rural areas: the primary substation connects to the secondary substation using a bus topology.

7.6.3 MV Substation to substation communication topology: Point to Multipoint (P2MP) using BPL

Figure X below provides an example of a Point to Multipoint topology that can be used for communication between a primary substation and the secondary substation. This topology uses MV BPL standards where each substation is equipped with a single MV BPL modem. This architecture assumes that a L2 frame sent on the communication bus is received by the entire substation but handled only by the substation has the correct destination address of the L2 frame (similar to Ethernet in bus topologies).

The advantage of such a topology is the reduced cost because a single MV BPL is deployed. However, it has two main disadvantages:

- Disconnection of the power cable will cut the communication
- Switching will change the impedance of the cable and degrades the communication performance

It can be advocated for Hub and Spoke topologies (star) or in bus technologies (rural areas).

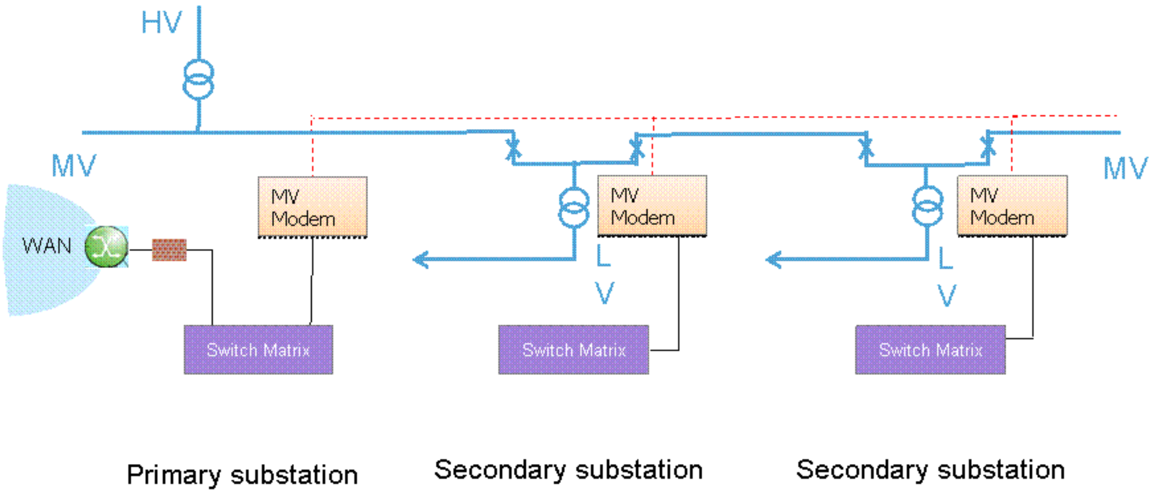


Figure 34: MV communication using MV BPL model, Point to multipoint topology

7.6.4 MV Substation to substation communication topology: Point to Point (P2P) using BPL

Figure X below provides an example of a Point to Point topology that can be used for communication between a primary substation and the secondary substation. This topology uses MV BPL standards where each substation is equipped with a two MV BPL modems.

Compared to the topology presented in 7.6.3, this incurs additional cost pertaining to the use of an additional BPL modem. The main advantages of this topology are:

- Disconnection of the power cable will NOT cut the communication
- No degrades to the communication performance on switching

It can be advocated for ring (including open ring) topologies for urban deployments.

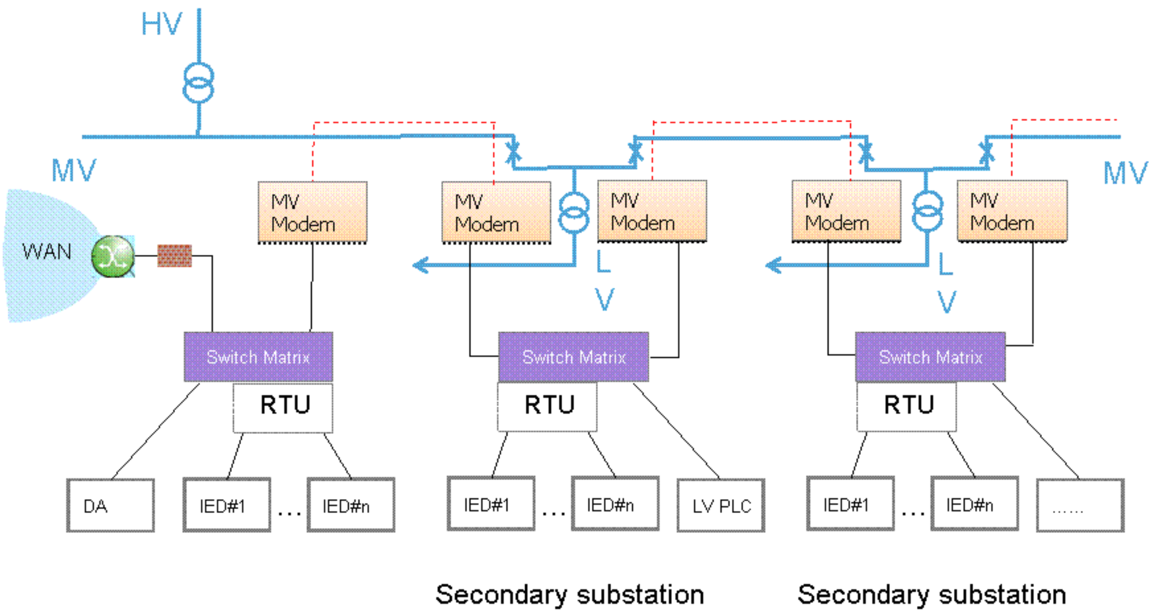


Figure 35: MV communication using MV BPL model, Point to point topology

7.7 Intra Control Centre / Intra Data centre Network

To be developed in a subsequent release

7.8 Enterprise Network

To be developed in a subsequent release

7.9 Balancing Network

To be developed in a subsequent release

7.10 Interchange Network

To be developed in a subsequent release

7.11 Trans-Regional – Trans-National Network

To be developed in a subsequent release

7.12 Wide and Metropolitan Area Network

To be developed in a subsequent release

8 Security

Coupling data communications capabilities with the power transmission, distribution, and consumption infrastructures increases the efficiency of the power grid, but also creates a long list of operational challenges— Security tops that list. Thus, security represents a key challenge for enabling a successful rollout of Smart Grids and AMIs. It needs to be addressed in a holistic, end-to-end fashion, leveraging the concept of “Security by Design”.

In the past it was sometimes claimed that the use of open standards and protocols may itself represent a security issue, but this is overcome by the largest possible community effort, knowledge database and solutions available for monitoring, analyzing and fixing flaws and threats—something a proprietary system could never achieve.

Said otherwise, a private network, IP-based architecture based on open standards has the best understood and remedied set of threat models and attack types that have taken place and have been remedied against, on the open Internet. This is the strongest negation of the now deprecated concept of “security by obscurity” that argues that the use of non-standard networking protocols increases security and which is unanimously rejected by the network security expert community. Security per se is not a new topic to utilities as they are already operating and maintaining large-scale data communication networks. Using IP as a common technology in the core of Smart Grids and AMIs will help to ensure security knowledge is available within the involved organizations.

It is important to note that IPv6 security has at least the same strengths as IPv4, but both IPv4 and IPv6 are certainly not worse than proprietary networking protocols. We recommend people focusing on FAN security to review documents such as NISTIR 7628, Guidelines for Smart Grid Cyber Security or UCAIUG, AMI System Security Requirements. In Europe, Smart Grid Information Security requirements are currently under definition by the standardization organizations; several guidelines and requirements have been issued or are under definition by the Member States. All are asking for open standards. With Security being a multi-layer challenge, it is important to review some additional features that provide nodes authentication and data integrity and privacy on a FAN deployment.

Strong authentication of nodes can be achieved by leveraging a set of open standards mechanisms. For example, after a node discovered a RF or PLC Mesh network leveraging IEEE 802.15e enhanced Beacon frames, it can get properly authenticated through IEEE 802.1x, PKI, certificate and AAA/Radius mechanisms before beginning to communicate using a Link-local IPv6 address. From there, the node can join its RPL domain before getting a global IPv6 address through DHCPv6 as well as other information (DNS server, NMS, etc.).

Data integrity and privacy leverages the encryption mechanisms available at various layers of the communication stack. For example, an IPv6 node on a last mile subnet has options to encrypt data at layer 2 (AES-128 on IEEE 802.15.4g or IEEE P1901.2), layer 3 (IPsec), layer 4 (DTLS) or per application at layer 7, i.e.: encryption of ANSI C12.22 or DLMS/COSEM for the metering traffic. While multiple levels of encryption may be implemented on a constraint node, the processing resources (processor speed and memory, energy consumption) requirements must be evaluated in regards of the additional hardware cost this could generate. With multiple options available it can be assured that nodes can be integrated into existing security architectures, relying on Link, Transport and/or Application Layer encryption. Furthermore, this will ease the integration and enhancement of existing Application Layer protocols (i.e. ANSI C12.22 or DLMS/COSEM) where certain security functions could convert at a lower layer, e.g. by providing a secured end-to-end path, and where other functionalities (i.e. message integrity / proof of origin) can remain at the Application Layer.

The choice of a given layer for data encryption and devices performing the encryption also impact the network services, performances and scalability of a deployment. For example, when software upgrade, demand/response or dynamic pricing should use Multicasting, the choice of encrypting data at transport layer (L4 DTLS) precludes leveraging the replication capabilities of IP Multicast routers on the infrastructure.

Whatever the encryption layer selected on the NAN devices, an IP Edge router can also perform Layer 3 encryption (IPsec) for all traffic forwarded over the backhaul links. Therefore, hardware cost and resources may limit to layer 2 authentication and encryption and potentially encryption at layer 3 or 7 on constrained devices while Layer 3 encryption on the IP Edge router takes care of all traffic sent over the WAN without loosing network services capabilities.

Combined with more traditional security features such as digital signatures for firmware images or data objects on devices (i.e. for meter reads or critical commands), traffic filtering, firewalling and intrusion prevention on the IP Edge routers, the last mile of a Smart Grid deployment can get strong security reinforcement whatever the traffic patterns.

With IP offering the possibility of end-to-end communication down to the last mile, also, in case this is required, end-to-end encryption can be established in an efficient manner. Moreover, Application Layer protocol translation would not be required within the communication network. Multiple protocols do not have to be maintained, this would represent a clear advantage for the efficiency and security of the network.

In addition, IP, as well known technology, offers already available, tested, certified software stacks, implementing proven security algorithms and Computer Security Incident Response Teams (CSIRTs) and Computer Emergency Response Team (CERT)). Thus, the Security of Smart Grids and AMIs can directly benefit from security findings within the Internet Community, now and in the future.

Appendix A
Industry Fora and Alliances References

This Appendix references Industry Fora and Alliances documentation for information purpose only.

Power Line Technologies:

Narrow band:

SDOs-Alliance-Industry	Standard Name	Frequency Bands	Power Line Segment
Industry	INSTEON	131.65kHz	Low Voltage
Industry	HomePlug C&C	FCC (120-400kHz) CENELEC A, B	Low Voltage
Industry	Meters and More	CENELEC A 20kHz-95kHz	Low Voltage
Industry	OSGP	CENELEC A 20kHz-95kHz	Low Voltage
Industry	PRIME	CENELEC A (~42kHz-~89kHz) FCC 159kHz to 490kHz	Low Voltage
Industry	G3 PLC	35.9-90.6kHz CENELEC A Field tested (capable up to 180kHz)	Low Voltage
Industry	UPB	4-40kHz	Low Voltage
Industry	X10	120kHz	Low Voltage
Industry	A10	120kHz	Low Voltage
Industry	G3 Lite MAX2990 (FCC band extension being developed)	CENELEC & FCC 10kHz-490kHz	Low Voltage
Industry	TDA5051A	FCC within 95kHz-145kHz (132.5kHz typical)	Low Voltage
Industry	PLM-1	50-500kHz (262kHz expected)	Low Voltage
Industry	C&C Turbo (fully comply with HomePlug C&C)	FCC (120-400kHz) CENELEC A, B	Low Voltage

Broadband:

SDOs-Alliance-Industry	Standard Name	Frequency Bands	Power Line Segment
Industry	Home Plug AV	2-30MHZ	Low Voltage
Industry	Home Plug GreenPHY	2-30MHZ	Low Voltage
Industry	Home Plug AV Extended	2-75MHz	Low Voltage
Industry	Home Plug AV Mediaxtreme	2-30MHz 50-300MHz	Low Voltage
Industry	WPCLRWB5	2-4MHz	Low Voltage

Appendix B
Relationship to the SGAM model

This section provides a mapping of the communication architecture to the SGAM model. Such a mapping is performed using the tele-protection use case.

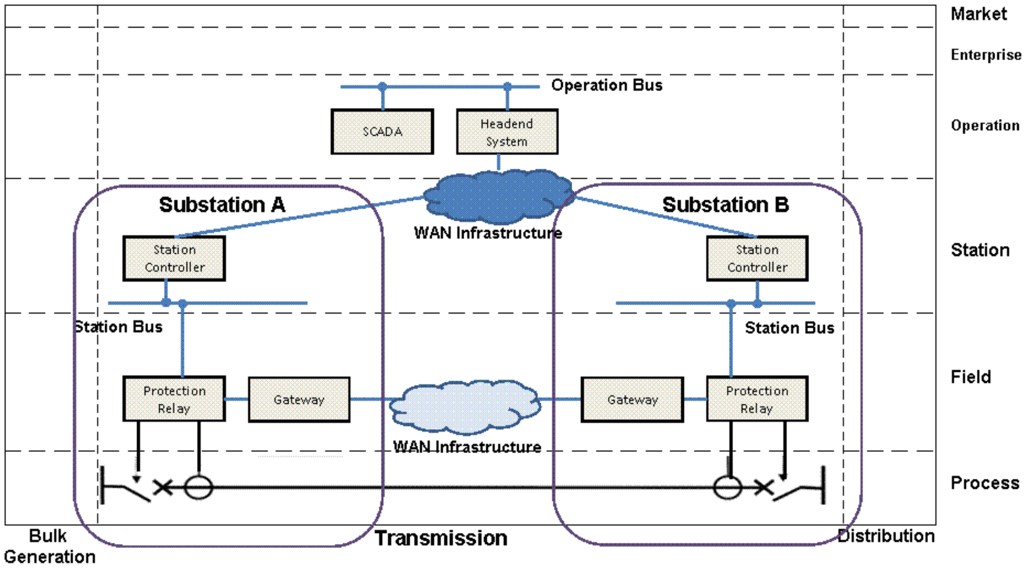
The SGAM is a framework for:

- Hosting functional and information architectures in appropriate layers
- Identify top-level elements
- Fit in EU high level functions
- Map architectures to smart grid plane (domains/zones)

The component layer of SGAM is the physical distribution of all participating components in the smart grid context. This includes power system equipment (typically located at process and field level), protection and tele-control devices, network infrastructure (wired / wireless communication connections, routers, switches, servers) and any kind of computers

The Figure below provides the **component layer** pertaining to the Tele-protection use case. The Figure depicts the following main components

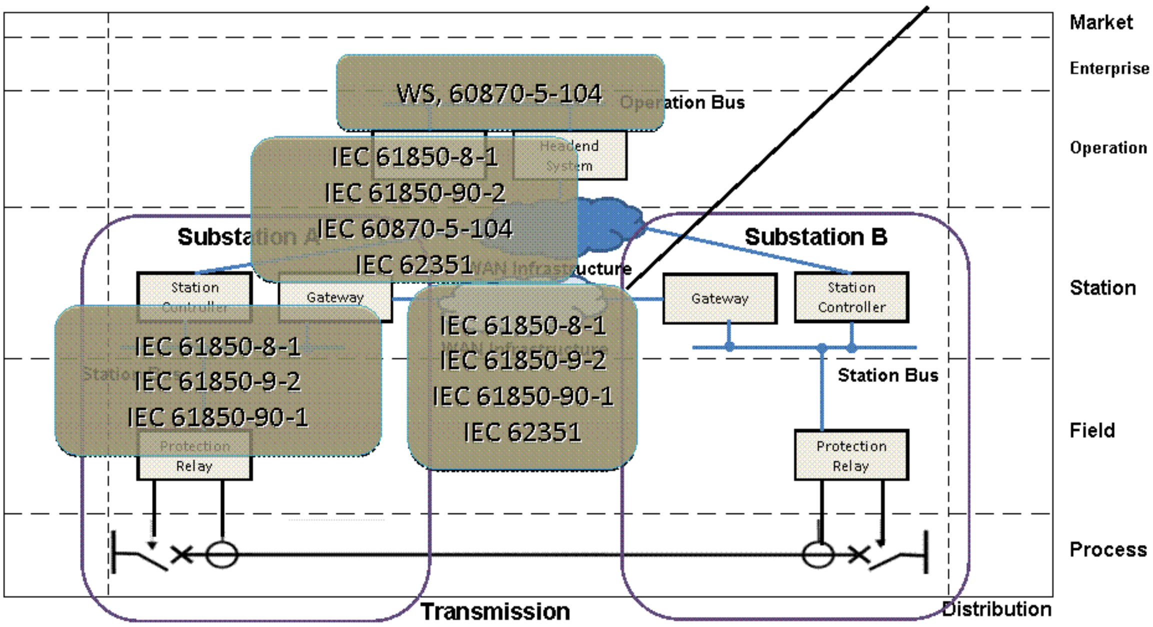
- Process components:
    - The circuit breaker: an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to detect a fault condition and, by interrupting continuity, to immediately discontinue electrical flow.
- Field components:
    - Protection Relay: activate the protection equipment to isolate the affected part in adjacent substation to prevent damages to expensive substation equipment and instability in the power system
    - Gateway: interface to Protection Relay in order to adapt and transfer control signals between the Protection Relays. Provides circuit emulation services in order to transport TDM based interfaces over a Packet Switched Network (PSN), in the case of IP WAN infrastructure
    - WAN infrastructure: Provides reliable and low delay/jitter transport of the protection signals. This WAN infrastructure might be different from the one used to connect a substation to central control systems.
- The Station components:
    - Station controller: provide communication toward the central operation systems via a WAN infrastructure.



The **Communication layer** as depicted in the figure below provides the list of standards applicable for the communication stack of the Teleprotection use case.

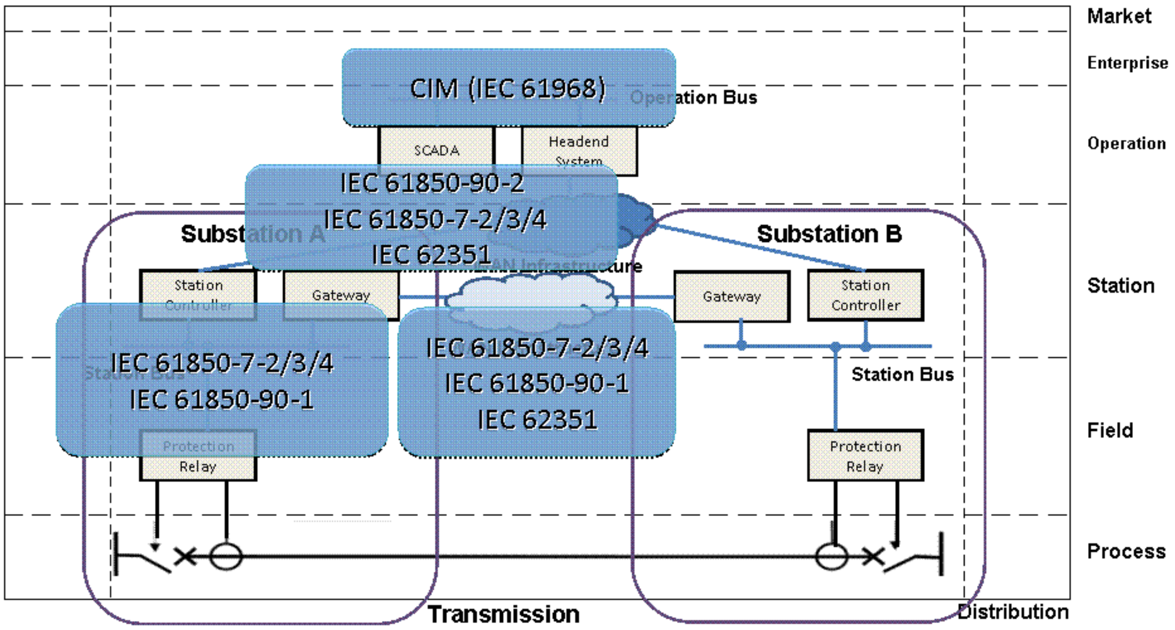
The Figure depicts the following list of applicable standards:

- IEC 61850-8-1 (Goose)
- IEC 61850-9-2 (Sampled Values)
- IEC 61850-90-1 (SS-SS Com.)
- IEC 62351 (E2E Security)



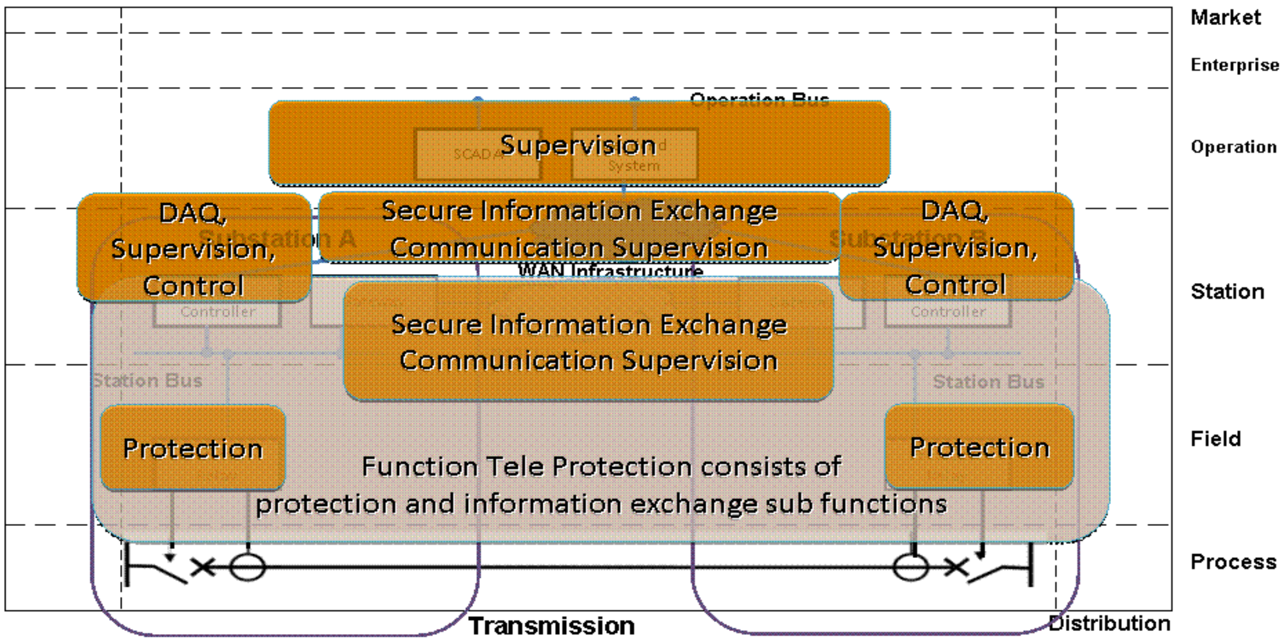
The figure below provides the **Information layer** pertaining to the Teleprotection use case. These are:

- IEC 61850-7-2/3/4 (Services, Data Models)
- IEC 61850-90-1 (SS-SS Com.)
- IEC 62351 (E2E Security)

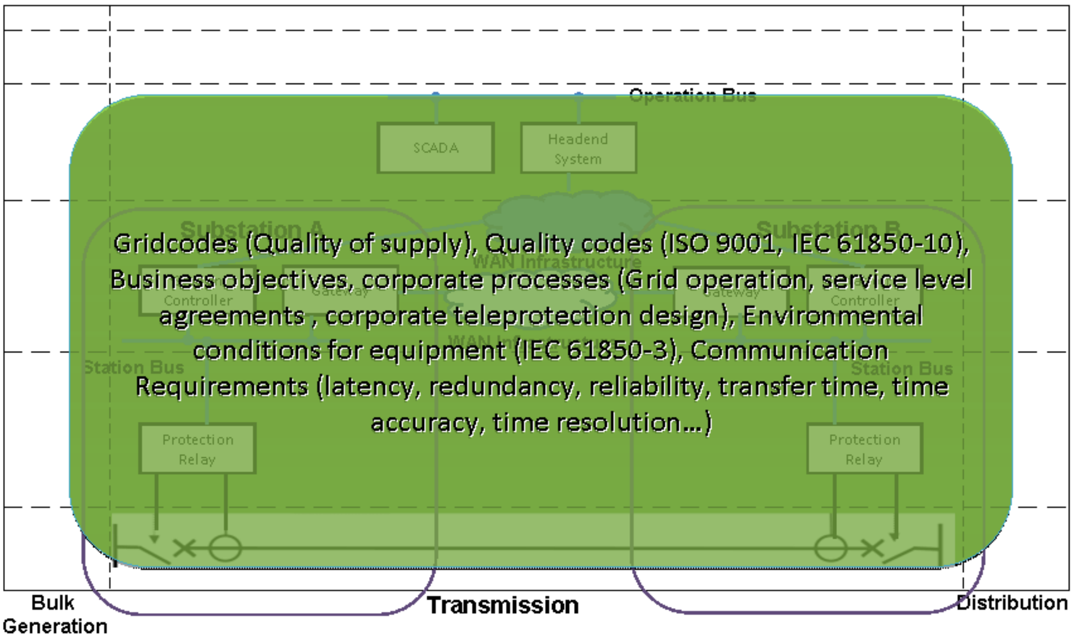


The figure below provides the **function layer** pertaining to the Teleprotection use case. The different functions shown are:

- Supervision performed at the central operations systems
- DAQ, Supervision and Control
- Secure Information exchange
- Protection



Finally, the **Business layer** provides the business objectives pertaining to the use case.



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