Analysis of State-of-the-art Smart Metering Communication Standards

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***Abstract*—Currently, utility companies in Europe are trying to overcome new challenges, such as generation diversification, greenhouse gas emissions regulation, energy conservation, demand response and a new liberalized market system. It is clear that these cannot be resolved with the current infrastructure. A next-generation grid, commonly referred to as "the smart grid" is expected to be the solution to these issues. Effectively, a smart grid is the convergence of ICT with power systems engineering. A lot of ideas and techniques concerning smart grids are already in use, albeit quite isolated (such as IEDs (Intelligent Electronic Devices), "supervisory control and data acquisition" (SCADA) and AMR (Automated Meter Reading)) and thus can't be considered a breakthrough. For a grid to be "smart", a well designed layer of intelligence placed over the assets of a utility should provide the basis for new fundamental grid applications. For example, demand response and VPPs (virtual power plants) would require tight integration of smart meters, home networks and distribution transformers or substations. This illustrates the importance of an appropriate communication infrastructure on multiple levels. In this paper an architectural overview of the smart grid is presented along with an overview of existing ICT standards related to the smart grid.**

I. Introduction

AMR (Automatic Meter Reading) can be considered as the predecessor of AMI (Advanced Metering Infrastructure) and allows utilities to perform some basic readout functions of a customers' meter. It does not allow control of the meter itself (e.g. disconnect or the uploading of new tariff tables), let alone enable demand-side management. Together with new generation challenges (DER and intermittent), the next logical step will be the emergence of AMI systems under distributed control: the smart grid. The rise of the smart grid will very likely follow an evolutionary trajectory. New wind farms, solar installations and substations will be equiped with distributed control and monitoring features, enabling utility automation. At the consumer side, the installation of smart meters will trigger a (slow) adoption of "energy aware" devices that can communicate with it.

II. Smart Grid Communication Architecture

Figure 1 shows a generic smart metering system outlining the basic system components. It is very similar to the "system components and interfaces" defined in the Open Meter project [1] and the "Metering installation description" from the Dutch Smart Meter Requirements document [2]. A short overview of the main components:

1) Electr. meter & Comm. hub: This device functions as the gateway to the smart grid. Most of the time, the house's main electricity meter will be integrated with it, as well as a externally controllable breaker switch (e.g. for contract control). Being also a communication hub, the device will communicate with other metering devices and home appliances connected to a HAN (Home Area/Automation Network).
2) Multi-utility meter: A meter measuring e.g. gas, water or heat, or an electricity submeter such as for a residential PV installation.
3) End-customer device: Appliances that communicate with the hub using a HAN. Examples include HVAC units, lighting and major appliances, but also P(H)EVs.
4) Data concentrator: In between the smart meter and the central system an intermediate data concentrator can be present. Its main purpose is to manage the connected meters and act as a relay for the central system.
5) Central system: The task of the central system is to provide the core communication functions of the smart grid. It interfaces with the supplier and grid companies which can query customer meters for billing purposes or issue tariff commands and demand response alarms. It is possible that the central system will be operated by new service providers, which then grant access to the various market players. Eventually, the control center of the TSO and DSO is still responsible for the management of the legacy grid infrastructure as well as its centralized and distributed energy sources.
6) Handheld units (HHUs): An extra port on the meter/hub and concentrator allows service technicians to locally read and change parameters during installation or maintenance. It is also useful in case problems arise that cannot be remedied remotely.

The relevant communication channels and relations that arise are marked I1 to I6.

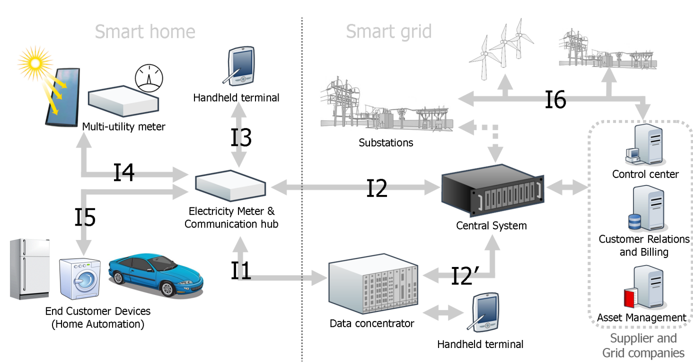

Fig. 1. Smart grid system architecture

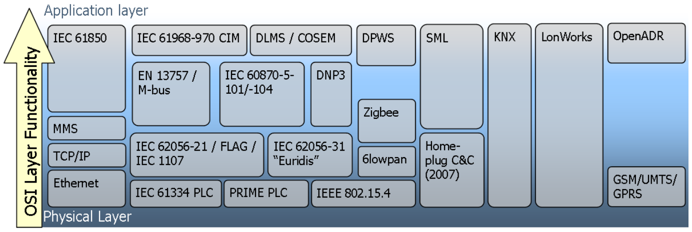

Fig. 2. OSI layer placement of the analyzed standards

III. Available Standards

In this section, a short introduction to each analyzed standard is presented. The relevant criteria for selection are:

1) Openness of the standard. Because of the smart grid context, interoperability and extendibility must be guaranteed across different devices and manufacturers. Therefore, only open standards have been considered in this overview. (For example Z-wave and Insteon are proprietary, LonWorks was standardized officially later on and SITRED is in the process of being opened).
2) OSI layer position. Does the standard mostly concern hardware aspects (such as IEC 61334-5 or IEC 62056-21) or is it a data-model (e.g. DLMS/COSEM) or both (such as KNX and LonWorks)? A rough sketch of this is shown in figure 2.
3) The intended use case of the standard and what functionality it provides. This leads to a separation between the smart home and the smart grid, with the former focusing on in-home communication and automation (such as domotics) and the latter more on long-range and management aspects. Accordingly, sections III-A up to III-I describe standards pertaining the grid while sections III-J to III-P are more related to the smart home. This is also illustrated in figure 3, which will be explained in section IV.
4) The maturity and if applicable, the performance and scalability.

A. IEC 61850 and UCA 2.0

The Utility Communications Architecture was developed by the EPRI at the beginning of the '90s. In '97 the IEC and the EPRI harmonized their efforts to develop a common international standard which led to the IEC 61850 specification. IEC 61850 can therefore be considered as a superset of UCA 2.0 and is primarily designed with intra-substation communication in mind [3], but it can also be used between substations or control centers (IEC 62445-1 and -2) and for metering applications. IEC 61850 is placed at the application layer. All services and models are designed in an abstract form called ACSI (Abstract Communication Service Interface) and thus independent of the underlying medium. ACSI is then mapped to protocols such as MMS2 and TCP/IP over Ethernet. In addition to ACSI, IEC 61850 provides the multicast based GSE (Generic Substation Events) as a way to quickly transfer event data over an entire substation network. Furthermore, part 9-1 and -2 specify a process bus for use with IEDs. The basic concept of IEC 61850 consists of a hierarchical and object-oriented information model with devices, nodes and classes that can hold different attributes and data [4]. These are self-describing and every vendor is required to publish their extensions. Since January 2009, part 7-420 has been added to IEC 61850 and covers distributed energy sources and storage. It could even be used for V2G (Vehicle to grid) activities. Also of interest is IEC 61400-25, an adaptation of 61850 for wind-turbines. IEC 61850 is a flexible, mature and future-proof standard that is most likely to follow through in the utilities sector.

B. IEC 61334 PLC

Part 5 of the 61334 suite of standards defines several narrowband PLC (Power Line Communication) systems, part 5-1 S-FSK being the most used. The upper OSI layers (including the DLMS protocol in part 4-41) are also specified but optional. Because the allowed frequency range (3 kHz to 148.5 kHz in Europe) and transmission power is small [5], so is the bandwidth, limiting suitability for (e.g.) TCP/IP communication. A typical PLC system consists of a backbone-coupled concentrator close to a MV/LV transformer. All traffic on the line is initiated by the concentrator, which acts as a "local relay" for a management center. More recent narrowband PLC technology include sophisticated techniques such as OFDM (Orthogonal Frequency-Division Multiplexing) to provide higher data rates, and focuses on broadband solutions operating in the 1-30 MHz band [6]. Also worth mentioning is the installation of filters to improve SNR ratios. Despite the difficulties, PLC technologies are at a clear advantage for utility companies as they can have full control over the network and are relatively cheap [7].

C. PRIME PLC

PRIME stands for Powerline Related Intelligent Metering Evolution and defines the lower layers of an OFDM based PLC narrowband system that operates within the CENELEC A-band. Raw data rates of up to 130 kbps are possible and an IPv4 convergence layer should allow efficient transfer of TCP/IP traffic [8]. There are however still some rough edges:

1) As development started at the end of 2007 and the PRIME alliance was founded in 2009, PRIME is still an immature standard.
2) The standard still lacks conformance tests.
3) IEC 61334-5 and PRIME are not designed to coexist on the same network segment.
4) No test results yet about real-world operation, interference and meshed network performance.

Alliance coordinator Iberdrola, a Spanish utility, is developing an open smart metering architecture around PRIME and has commenced a pilot project in 2009 [9].

D. IEC 62056-21 / IEC 61107

The IEC 62056-21 standard is sometimes referred to as "Flag" or by its old name IEC 1107 [10]. Part 21 "direct local data exchange" was published mid 2002 and describes software protocols and hardware suitable for data exchange with utility meters [11]. It is similar in nature to US standard ANSI C12.18. At the hardware side, an optical interface and a two-wire system are described. On top of this, asynchronous half-duplex ASCII-based RS232 data transfer is used. Different operating modes are specified, labeled from A to D, which differ in baud rate, directionality and security. A special mode E allows the use of DLMS/COSEM via HDLC (High-Level Data Link Control, IEC 62056-46). As one of the first meter data exchange standards, IEC 62056-21 is widely used today. However it does not use a data model or uniform memory mapping. Therefore meter communication requires manufacturer specific information, limiting interchangeability.

E. SITRED / Telegestore

At the beginning of the '90s [12], Italy's largest distribution company, ENEL, developed a transmission system called SITRED to read and manage meters remotely. A large test proved that remote management via the LV network was technically viable but the use of Ferraris meters equipped with electronics was not cost effective enough. At the end of the '90s, technology had advanced enough and ENEL concluded that changing all the low voltage meters for electronic ones would soon be profitable and in October 1999 the Telegestore project was started [13]. At the consumer side fully electronic meters communicate with a concentrator close to a transformer via PLC. The concentrator communicates with the acquisition center through an access server using GSM, PSTN or satellite. In the future it is possible that also MV grids and BPL (Broadband Power Line) communication will be incorporated. Two communication protocols (using PLC) are used: an enhanced version of LonTalk and more recently ENEL reintroduced its proprietary SITRED protocol that was used in the original project. SITRED uses a simple narrowband FSK-based solution (similar to IEC 61334-5-2, in CENELEC band A) that is relatively reliable throughout their whole diverse grid, reducing the cost of transceivers and coupling devices but limiting the attainable speed to about 2400 baud. LonTalk and SITRED differ in the PHY and MAC layers but the same proprietary application layer is used on top of both, ensuring transparency for the acquisition center. During the peak of deployment, more than 40000 meters were installed a day totaling 29,8 million by the end of 2006. Recently, ENEL has announced to make its system open to the market. Spanish utility company Edesa has plans to begin rollout of a SITRED based AMM solution in 2010.

F. SML (Sym^2 project)

The Smart Message Language [14] is a communication protocol for data acquisition and parameterization developed by the German utility companies RWE, EON and EnBW. The main idea is to have a simple structure that is usable in low-power embedded devices. The application layer defines a file and document structure to carry data between the measuring point and a collection center. Push and pull operation is supported. For the presentation layer, SML provides two options: readable XML encoding or more efficient SML binary coding. In typical metering applications SML messages will then be transported using TCP/UDP over IP networks. But for serial links such as GSM/PSTN or direct readout the SML transport protocol is available. SML is tailored specifically towards electricity metering and has to be viewed alongside the SyM^2 project. This is a joint venture between RWE, EON and Landis+Gyr to develop an industry standard specification for load profile meters in Germany. SML only defines a message structure, but not a data model nor a standard functions list or interface classes. This is the task for companion specifications. Also, CENELEC standardization is still underway and version 1.03 from November 2008 has yet to be translated to English.

G. EN 13757 / M-Bus

EN 13757 (Meter bus) is an European standard [15] for the remote interaction with utility meters and various sensors and actuators which was developed at the University of Paderborn. M-Bus uses a reduced OSI layer stack. Part 2 describes the physical and link layers, while part 3 specifies the application layer [16]. Several physical media are supported including twisted pair and wireless M-Bus (in the ISM band). The twisted pair medium typically operates at 2400 to 9600 baud and a single segment can be up to a few km's long. Primary focus of the standard is on simple, low-cost, battery powered devices. Noteworthy is the support for DLMS/COSEM in the lower layers. The DSMR (Dutch Smart Meter Requirements) [2] specifies wired and wireless M-Bus as the means of communication between a metering installation and other (gas, water, ...) meters, albeit with improved security (AES instead of DES). As this standard is already widely used in meters and reasonably future proof it is a good contender for local data exchange in the smart grid.

H. DLMS/COSEM or IEC 62056

DLMS (integrated in IEC 62056 [17]) stands for Device Language Message Specification and is an application layer protocol, specifying general concepts for the modeling of object-related services, communication entities and protocols. COSEM is the Companion Specification for Energy Metering. It comprises metering specific objects based on OBIS (Object Identification System) codes for use with (x)DLMS. xDLMS is an extension to DLMS and describes how to access attributes and methods of COSEM objects. COSEM defines a number of standard interface classes, called objects when instantiated, containing attributes and methods to describe some required functionality. An attribute is used to describe the aspects of some data, while methods are used to read or modify it. There are four groups of COSEM interface classes, relating to storage, access control, time and scheduling and communication. Standardized building blocks can be combined to model a metering device in a hierarchical structure, thus allowing the construction of complex metering systems. Two mandatory objects per device regulate access control and identification. When a meter is read, the necessary attributes of certain objects are accessed using an xDLMS service and transformed into a series of bytes, called APDUs (Application Protocol Data Units). OBIS naming is used to identify COSEM objects to make them self-describing. A full list of standard OBIS codes and valid combinations of standard values in each group is maintained by the DLMS User Association. To support future functionality and enable innovation and competition, specific elements such as new OBIS codes, attributes, methods and interface classes are allowed. However the information on such elements has to be made available by the manufacturer. DLMS/COSEM is based on a client/server structure in which the data collection system acts as a client requesting data from the servers (pull operation), in this case the meters. The communication protocol stack (called a profile) is completely independent of the application layer so servers and clients may independently support one or more communication profiles to communicate over various media. The COSEM model - modeling the application process - and the application layer - making use of this model - remain the same. Future additions will provide push operation (client to server) and more efficient data exchanges by using compression techniques. DLMS/COSEM is positioning itself as the all round contender for smart grid communication. The support for DLMS/COSEM in a lot of other standards (such as M-Bus, IEC 62056-21, -31 and recently Zigbee), projects (Dutch DSMR) and existing meters illustrate this.

I. IEC 62056-31 ”Euridis”

Euridis [18] is a standard for remote and local meter reading introduced at the beginning of the 90s and in 1999 it was integrated into IEC 62056 as part 31. Euridis uses a twisted-pair cabling system, the local bus, onto which all meters in a building can be linked. A magnetic coupler then allows to connect a handheld unit for readout or programming. The bus can be up to 500m or 100 devices and allows a data rate of 1200 baud half-duplex. Today, nearly 10 million devices, mostly in francophone countries, communicate using Euridis. At the beginning of 2009, the Euridis+ protocol stack was announced, supporting DLMS and allowing 9600 baud, while retaining backwards compatibility. Publication of Euridis+ is expected at the end of 2010. The scope of Euridis is clearly local meter reading with HHUs. As with part 21, Euridis does not have a common data model, but the upcoming Euridis+ will correct for this.

J. KNX

KNX [19] is the result of the joint effort of three European consortia working on home and building control, namely Batibus, EIB and EHS. KNX was made into standard ISO/IEC 14543-3-x in November 2006. KNX provides application models for distributed automation, configuration and management schemes, device profiles and a communication system (media and protocol stack). Possible communication media are twisted pair cabling, RF, IP/Ethernet or sometimes PLC. Each bus device has some sort of certified BCU (Bus coupler unit) that is typically flush mounted for switches, displays and sensors. To manage network resources, KNX uses both point-to-point and multicast communication. When a device publishes a data-point (an input, output or parameter), it is assigned a multicast group address. A data-point in another device having the same address will then receive updates and be able to notify the local application. Thus all local applications in a group form a so-called “distributed application”. For the configuration, KNX specifies three modes: system, easy and automatic. System mode allows sophisticated building setups but needs a separate Configuration Master (such as the association’s own ETS software) and well-trained installers, while Automatic mode is suitable for end-user installation. Some devices support more than one configuration mode. The KNX standard also has predefined sets of features for many common applications, called profiles. KNX aims to provide a complete solution for home and building automation and is backed by a lot of manufacturers worldwide. It must be noted that most KNX success stories about reduced energy consumption involve a complex interaction of KNX enabled boilers, lighting, etc. making the installation costs very high, especially for retrofitting.

K. LonWorks/LonTalk

The heart of the LonWorks technology (Local Operating Network) is the proprietary LonTalk protocol, developed by Echelon. The goal of LonWorks is to make it easy and cost effective to build open control systems, but because a protocol specification alone is not sufficient for interoperability, Echelon created LonWorks as a whole platform by offering the hardware (Neuron chips), firmware and tools (Neuron ANSI C) as well. The LonTalk protocol itself is a layered, packet-based, peer-to-peer communications protocol designed to be medium-independent but some widely used channels are twisted pair and PLC. Just as KNX, LonTalk implements a form of network variables (NVs). The application program in a device does not need to know where input and output NVs come from or go to as this is the task of the LonWorks firmware. Altogether LonWorks is similar to KNX, but is used in a much wider range of applications, well outside the home and building space. At the end of 2008, ISO and IEC made the LonTalk technology into standard ISO/IEC 14908-x [20].

L. BACnet

BACnet stands for Building and Automation Control Networking and became ISO standard 16484-5 [21] in 2003. Furthermore, BACnet is an entirely non-proprietary system, with typical applications in the HVAC, lighting and security domain. A number of network technologies can be used, including Ethernet, LonTalk, ARCnet, ZigBee networks and BACnet/IP. The latter allows the use of BACnet over virtually any medium. BACnet has a Smart Grid Working Group (SG-WG) focused on enabling buildings to interact in the grid. Standard BACnet objects such as the LCO (Load Control Object) can already be used to track consumption and execute preprogrammed actions accordingly. The BACnet/WS (Web Services) specification allows external applications to interact with a building automation system and is already used in the OpenADR project. Future additions will include a standard meter object and energy profiles. LonWorks and BACnet have overlapping scopes but the latter has become the first choice at the system management level.

M. ZigBee (Smart Energy Profile)

ZigBee is a low-power wireless communications technology designed for monitoring and control of devices, and is maintained and published by the ZigBee Alliance [22]. Home automation is one of the key market areas. Zigbee works on top of the IEEE 802.15.4 standard [23], in the unlicensed 2.4 GHz or 915/868 MHz bands. An important feature of ZigBee is the possibility to handle mesh-networking, thereby extending the range and making a Zigbee network self-healing. The Zigbee Smart Energy Profile [24] (numbered 0x0109) was defined in cooperation with the Homeplug Alliance in order to further enhance earlier HAN (Home Area Network) specifications. The profile defines device descriptions for simple meter reading, demand response, PEV charging, meter prepayment, etc. Recently a collaborative effort between the Zigbee Alliance and the DLMS UA was announced to define a method to tunnel standard DLMS/COSEM messages with metering data through ZigBee Smart Energy networks. Considering the low power requirements, robustness, availability of cheap Zigbee "kits" and the specific profile for metering applications, Zigbee has a lot of potential in home area networks.

N. Homeplug (Command & Control)

The Homeplug 1.0 standard was published in 2001 by the Homeplug Powerline Alliance and allows communication over power lines at 14 Mbps half-duplex. In 2005 it was succeeded by Homeplug AV, allowing over 100 Mbps and meant for HD multimedia applications. In 2007, version 1.0 of Homeplug Command & Control was announced, providing a PHY and MAC specification for low-speed (up to 5Kbps), low-cost PLC usable in house-control applications (lighting, HVAC, security and metering) [25]. Work on network, transport and session layers is still ongoing. Device profiles will provide a description language to define supported services and actions. On another level, the Homeplug Alliance is also seeking to standardize a Broadband over Power Line technology. In January 2010, the IEEE P1901 draft was published, defining a standard for high speed (>100 Mbps at the physical layer) communications devices, using transmission frequencies up to 100MHz [26]. Currently, Homeplug C&C or Homeplug BPL products have not yet hit the market.

O. 6LoWPAN

The 6LoWPAN is a standard under development [27] [28] from the IETF designed from the ground up to be used in small sensor networks, on top of low power wireless (mesh) networks, specifically IEEE 802.15.4 (thus directly competing with ZigBee). Implementations of 6LoWPAN will easily fit into a few kbs of memory. Highlights include support for the Zero-Conf and Neighbor Discovery capabilities of IPv6 and stateless header compression that allows the packets to be as small as 4 bytes. 6lowpan could realize the main concept of the "Internet of Things" by making it feasible to assign an IP address to the smallest of devices, sensors and actuators.

P. DPWS

DPWS stands for Devices Profile for Web Services and its goal is to integrate devices with internet web services. DPWS 1.1 [29] was approved as an OASIS Standard in June 2009. The full protocol stack is composed of several web standards, such as WSDL, XML, SOAP and a host of WS-standards. DPWS is similar to UPnP (Universal Plug And Play) but puts more focus on web services technology. DPWS enables secure Web Service messaging, discovery, description, and eventing on embedded, resource-constrained devices.

IV. Suitability in the SG Architecture

The mentioned standards in section 3 all serve varying purposes, reflecting different needs and applications throughout a smart grid. In the end, a smart grid will be an integration of complementary components and subsystems that will coexist with (rather than replace) the current electricity grid. Thus a topology is needed that facilitates continuous expansion by the inclusion of upward compatible technology while ensuring full backward compatibility with existing legacy systems. In figure 3, most of the legacy systems are situated within the dotted area marked as "supplier and grid companies" and the transmission and substation systems pictured above them. On the lower levels of the net, command-and-control systems are less common. A typical system for smart meters contains the following interfaces:

- I1: The communication between a data concentrator and a consumer's electricity meter. Data concentrators are used when a direct connection from the central server to the meter is not possible (for example PLC systems). A handheld unit can be connected for maintenance.
- I2: Direct communication between the meter and the central system. This will typically be based on GPRS/UMTS/LTE or an already available broadband internet connection.
- I3: Connection between the meter and a local terminal (for installation and configuration). It is comparable to the case of the data concentrator, with wireless functionality making cost-effective "drive-by meter reading" possible.
- I4: Communication between the central meter and secondary meters (for e.g. domestic solar panel arrays) or multi-utility meters for gas, water or heat.
- I5: Communication between the meter and a HAN (Home Area Network) for home automation and domotics, enabling advanced demand response and load shedding functionality. In-home displays and controllers will communicate with the meter via this interface.

V. Conclusions

The pending rollout of smart meters in most European countries necessitates the need for interoperable and future proof solutions that are available today. In this paper, an overview was given of communication standards relevant to the smart grid and smart house concepts. Of course, many more technologies are out there, but most of them lack wide acceptance, flexibility, or are still nascent or vendor-controlled. The latter is especially true in the home and building automation space. When talking strictly about meter data exchange itself, the leading standard would be DLMS/COSEM. As an application layer protocol it can be used over virtually any medium and more importantly, commercial solutions are available today.

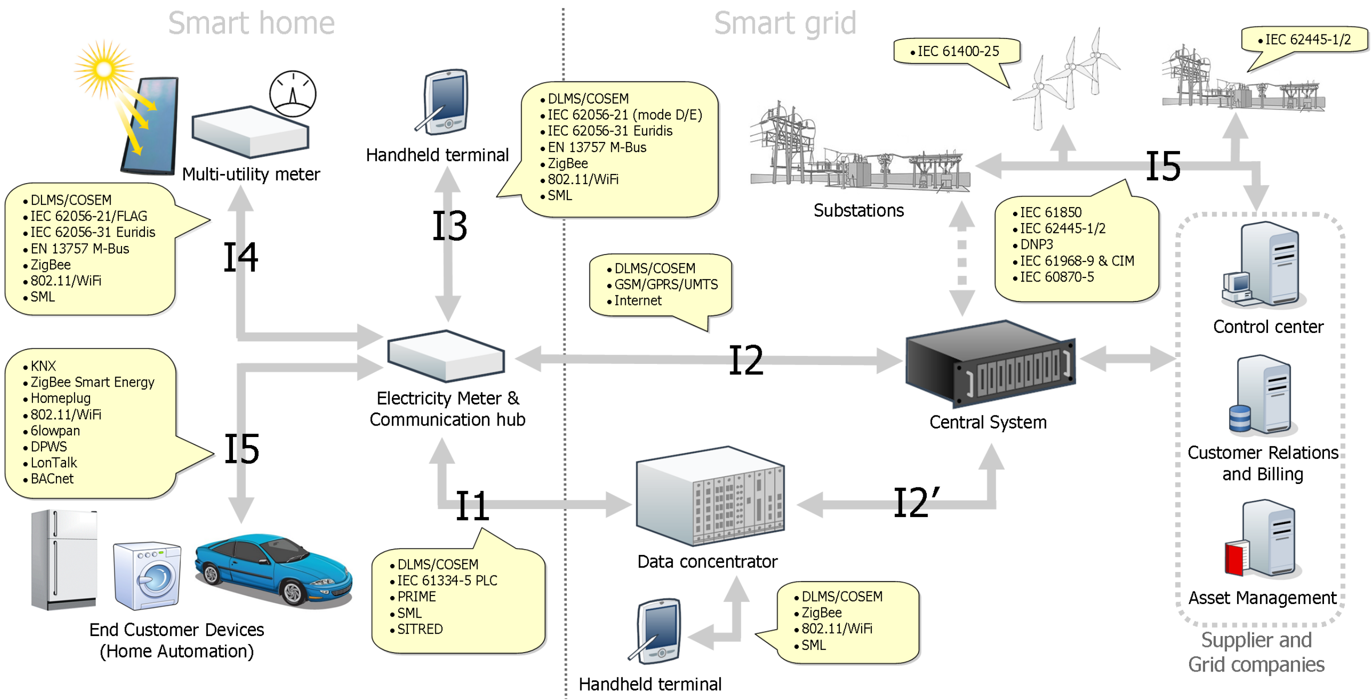

Fig. 3. Placement of the analyzed standards in the smart grid architecture

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