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SGEM/Task 4.1.4 Tools and methods for telecommunication

SGC Use Case Evaluation

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SGC Use Case Evaluation

Contents/Overview:

1 Scope

1.1 This document shall determine and describe certain use cases in the field of Smart Grid related M2M communications (focus on suitability for LTE)

1.2 Special focus is on Distribution Automation and Prosumer applications

2 **Introductory overview**

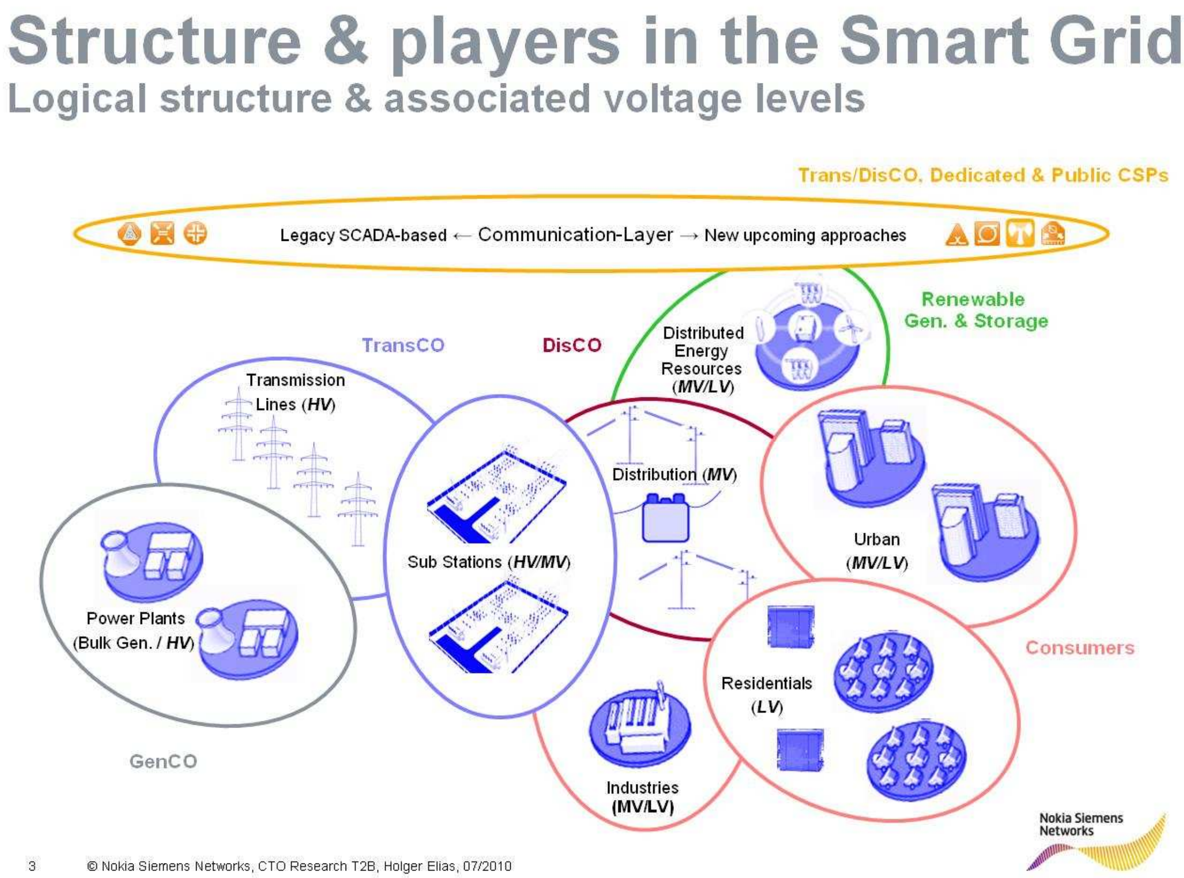
2.1 Structure and players in the Smart Grid

The structure of the Smart Grid may be viewed from several dimensions.

- Most important is of course the logical structure concerning the building blocks the Smard Grid consists of, such as main electricity generating Power Plants, Transmission Lines, Sub Stations to interconnect generation and demand on a high level, as well as the distribution network layer to supply electricity to the end users (please see below).
A new venue is the “Renewable Generation & Storage” area.

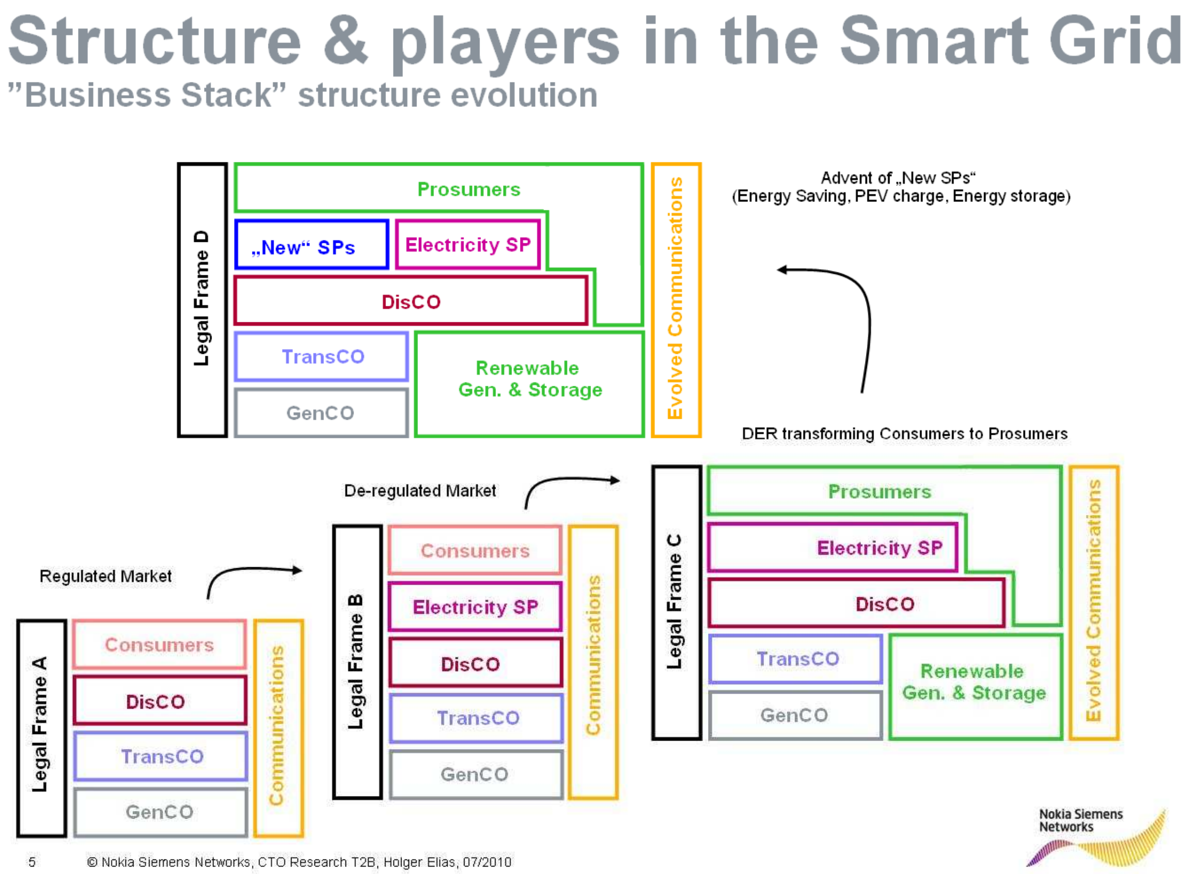
This logical structure is interconnected by the Communication-Layer, which has different roots (SCADA / Internet) and is currently evolving into a new versatile infrastructure.

- A second dimension are the involved companies, performing the task of delivering electricity to enterprises and residential customers, as there are Generation companies (GenCo, Please see below, also for the following), Transmission or Transportation companies (TransCo), Distribution companies (DisCo), new Service Providers facing the various groups of end-users and End-Users themselves.



On top of these “generic” players there are legal requirements in place, to allow for effective competition (please see below), at least in the field of electricity end usage, to force Distribution-N/W owners to open their infrastructure (deliver electricity) to competitive offering from additional service providers, to overcome local monopolies. Along the following use cases in this document,

this intended structure does have a significant impact on the structure of the use cases´ realisation and also on the way, how electricity will be marketed in the future by service providers.
This leaves room for specific new service providers, who might rather offer energy savings services, in contrast to delivering energy.

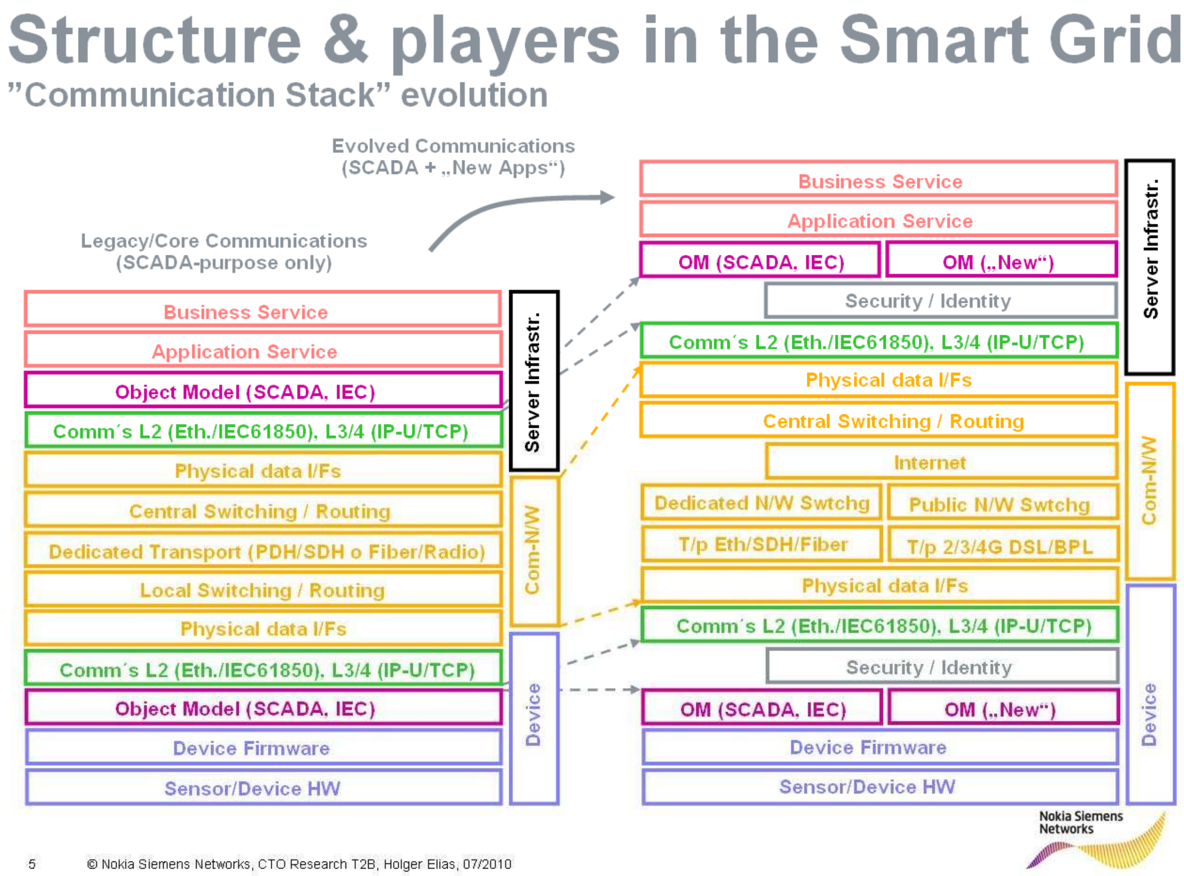


- Associated, but not identical with logical structure on the technical side, is the voltage level dimension in the network. In the past, bulk electricity generation was always associated with the High Voltage-Network (HV-N/W), and local generation was rather an exceptional case. Due to politically and publicly intended focus on local alternative and renewable electricity generation (based on Wind, Sun, Water, Natural Heat), the Medium Voltage-Network (MV-N/W) migrates from its unidirectional distribution character to a bidirectional meshed generation and demand-type N/W. This idea expands even in the Low-Voltage-Network (LV-N/W), e.g. due to extensive Photo-Voltaic generation in the residential and small/medium enterprise area, already causing a reversal of the load-flow in MV-to-LV transformers in certain cases, endangering locally connected home-devices by over-voltage.

2.2 Communication requirements from today's perspective

As a consequence from the multi-dimensional character of the Smart Grid, enhanced control, especially in the Distribution-N/Ws (MV/LV), is required to provide optimum electricity availability for all users and to offer as well an effective business environment to enable all players.
Whereas the control task is very much related to the electricity N/W installation, and therefore installation of measurement devices goes hand-in-hand with this, the communication task to interconnect sensors with their central control, becomes a task which is more and more detached from the ownership of the above.

This is due to the common interest of various players in obtaining the measured information, therefore there is a common sense between the players, to share the burden of the communication cost, wherever possible.
Therefore an opening of the previously dedicated network structure towards existing and evolving communication networks is required. This will have some impact on the communication stack of the applications, which is displayed below.



The issue is not only about transporting SCADA control over an evolved infrastructure, but also about integrating non-SCADA devices in the Smart Grid communication.
A very crucial point for both is the loss of "Trust By Wire" principle, which needs to be rebuilt by a "Trust By Identification And Encryption" scheme, when data is travelling on shared networks.
Please also note that not all comm´s is (device)client / (application)server related, but proxies in the form of simple transmission and switching/routing gateways (e.g. DSL-Routers in residential installations) or more complex ones, which aggregate (or distribute) non-SCADA or SCADA object model data into SCADA compatible format, will widen the above stack even more (As depicted in the DR/DER use cases below).

Since the criticality of certain communication features, like latency and ultimate availability is dependant on the amount and the concentration of energy generated or used in one place, the HV and Sub Station areas have not been so much in focus for alternative communication methods (please see the protection case requirements in the table below)

Communication requirements of different types of functions

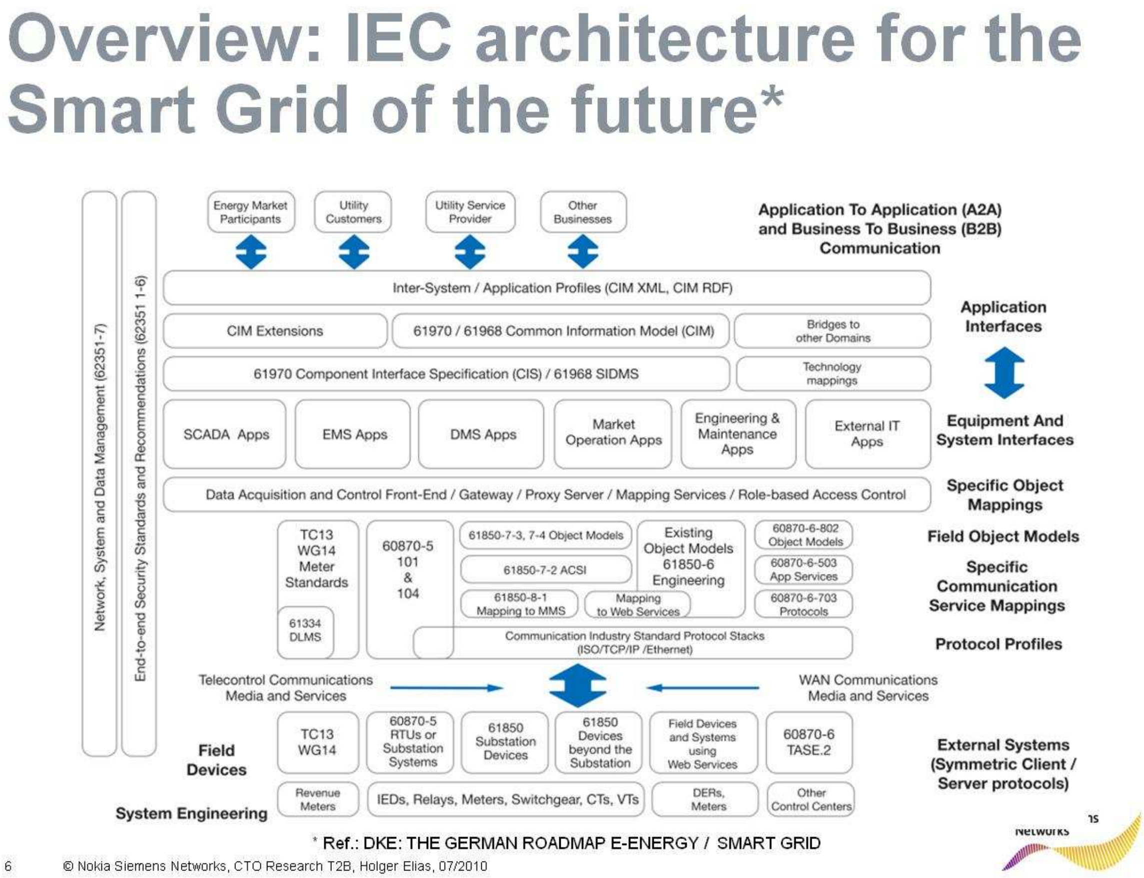
Function	Typical response time	Data amount	No of Comm. Nodes	Technologies
Protection	1 - 10 ms	Bytes	1-10	Fiber; copper ; 4G; Proprietary radio
Control	100 ms	Bytes	10-100	Fixed BB; Cellular:3G/ 4G; Proprietary radio
Monitoring	1 s	kBytes	1k	Fixed BB; Cellular: 2G/ 3G/ 4G; Proprietary radio
Metering / Billing	1 h – 1 d	MBytes	1M	Fixed BB; Cellular: 2G/ 3G/ 4G; Proprietary radio
Reporting	1 d – 1 y	GBytes	1M	Email, www

Rem: Derived from ABB Group proposal

But new evolving demand to increase network behavioural knowledge by connecting more remote sites causes some interest to avoid the installation of costly fixed (Fiber or licensed PtP-Radio) communication N/Ws to those sites.
This is reflected in the Wide Area Measurement System use case, which rather requires less transmission performance (please see Control case requirements above and the discussion in the respective use case chapter below).
Basically, the underlying idea is to discuss the co-utilisation of public N/Ws (or N/Ws built from public N/Ws technology, operated by dedicated communication providers) case by case.
Considering the more and more distributed architecture of generation and demand in the Smart Grid, the Smart Grid as a N/W will behave also more predictable in a somewhat larger time window, than concentrated bulk generation and transmission (with dedicated protection schemes in place, to overcome faults in fractions of seconds) since minute-trends of distributed generation and demand leave enough time for communicating electrical N/W-measurements and process them respectively.
Of course the long-term (hours, days and months) variability will increase, due to the increased in-deterministic generation, but this is exactly to be solved by intelligent demand control (Demand Response) build on an appropriate communication-N/W infrastructure.

2.3 Existing standardisation landscape and outlook

It is not the focus of this paper to discuss standardisation in much detail, but there is a quite good overview available, published by the DKE (German Commission for Electrical, Electronic & Information Technologies of DIN and VDE) in the German Roadmap for e-Energy, which is appended as a quick reference (please see below)



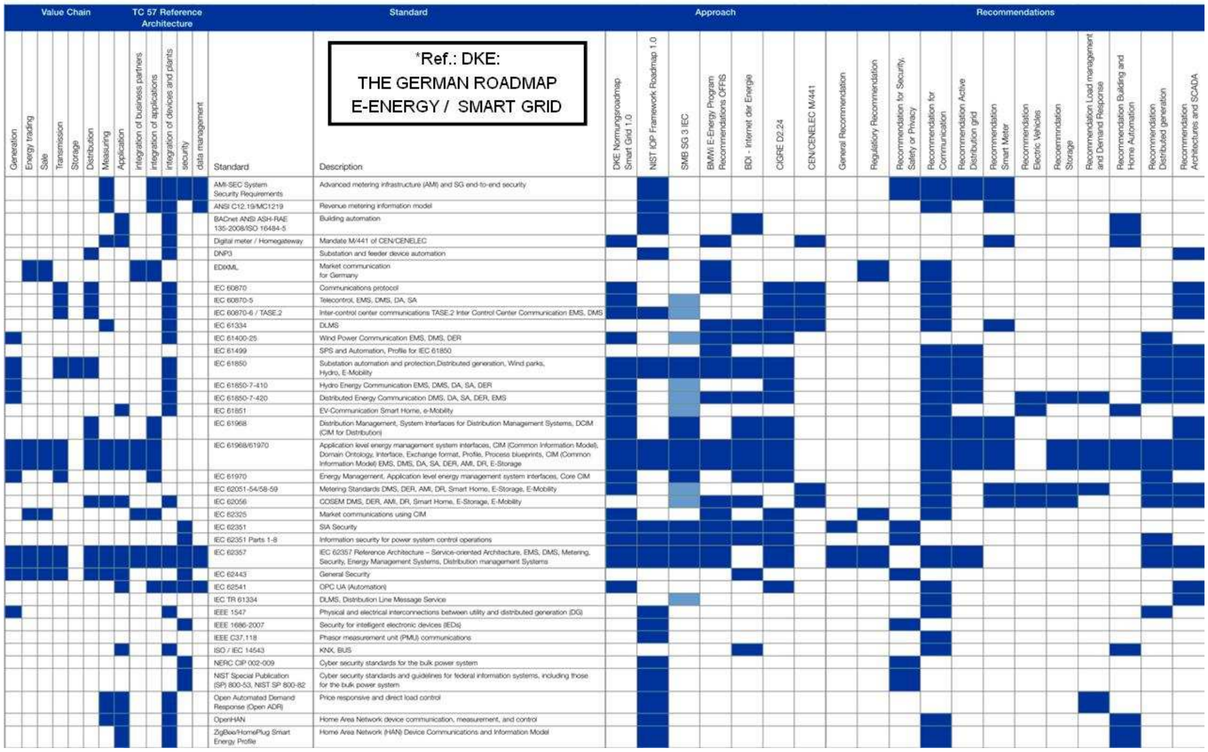
It shows mainly IEC´s view on the existing and ongoing standardisation in the field of Smart Grids. Of course there are overlapping standards from other bodies, but due to the energy related footprint IEC has achieved so far, it is reasonable to explore from here.

This becomes especially important in the field of Home Demand Response applications, discussed below, since the concerned White and Red Ware Industry needs standardisation support to deliver their contribution to the Smart Grid in the field of energy savings and control, instead of tedious competition in a fragmented multi-standard environment.
A standardised object model approach for these devices will enable service providers to mediate between Distribution-N/W operators (who are relying on IEC today) and home devices more effectively.

2.4 Involved parties in Smart Grid standardisation and overview of implementing institutions

DKE also gives an insight into some basic standardisation bodies activities (please see below; vertical middle column) vs. the field of standards application (left hand horizontal) in the Smart Grid. Institutions and application groups or just generic advisory, which is trying to build reproducible solutions for the Smart Grid from this are listed on the right hand horizontal, showing the focal roots in standardisation.
Please enlarge or printout the table below to DIN A3 format for a better overlook and for reference.

Overview: Comparsion of various studies on Smart Grid standardization*



3 Overview of important and interesting Smart Grid areas
(for the purpose of use case selection)

Three areas have been identified, in which Smart Grid Communication may differ from legacy utility communications´ implementation or simply has to be newly defined and implemented.
This leaves room for discussion of comm´s alternatives, which is part of the use case descriptions below.
The 4 areas are:

- The traditional area of Distribution Automation (DA), which is enhanced by certain functionality in the Smart Grid, therefore now called Advanced Distribution Automation (ADA).
- One aspect is DA in Transformer Stations, which is the linkage between the new functionality in the ADA area and the new functionality in the Distributed Energy Resources (DER) and Demand Response (DR) areas. One may count these towards the ADA area itself, but due to the focus in the LV area, it has been kept separately here.
- Another aspect comes from the Prosumer area, the extension of Consumer towards Producer area, not meant to be limited to residential and SME consumers, but especially dedicated to small generating or storage enterprises. This involves future Plug-in Electrical Vehicle (PEV) charging and power feeding scenarios.
- As an ubiquitous element, Sensor Networks need to be understood in a way of a pervasive capability to monitor and supervise TS and DS networks, but not necessarily to operate them, i. e. mainly fulfilling environmental or functional sensing (see also 3.1.7 - Sub Station site control). Sensor Networks will probably be embedded in (newly) installed communication networks with other primary tasks (e.g. from the DA area), which differ from the task to monitor and supervise certain elements. Therefore they are not covered in each use-case, but only as one stand-alone example, which is the DS supervision (Distribution System) use-case 4.

The following lists and discusses some parts of the above areas of interest, to give an overview and assemble a repository from which use cases have been be selected from.

3.1 (Advanced) Distribution Automation (ADA)

3.1.1 Substation Automation (HV to MV, via SCADA)

3.1.2 Teleprotection/HV-oriented supervision, measurement and control (also on FACTS and HVDC - rather not in scope, due to reaction time and availability req´s)

3.1.3 MV-oriented supervision, measurement and control

3.1.4 Control of large scale Distributed Energy Resources (DER; e.g. Wind/Wave/Solar-Energy farms, Intermediate Energy Storage facilities)

3.1.5 Demand Response control of large campuses or connected building areas

3.1.6 Reactive Power (VAR) control in conjunction with DER

3.1.7 Sub Station site control (diagnostics, temperature sensing, video surveillance, motion tracking, remote access control)

3.1.8 Wide Area Measurement System (WAMS, power flow monitoring over a very large area, via synchrophasor measurement data)

3.1.9 DSO supervision
E.g. Voltage Dip sensing

3.2 DA in Transformer Stations (MV to LV)

3.2.1 LV-oriented distribution supervision, measurement and control

3.2.2 Smaller scale Distributed Energy Resources (DER) control

3.2.3 Smaller scale Demand Response (DR) control

3.2.4 MicroGrid control (basically subsuming small scale DER, DR)

3.2.5 Transformer site control (diagnostics, temperature sensing tamper alarming, remote access)

3.3 Prosumer (Consumer/Enterprise)

3.3.1 Smart Metering (Electricity, others)

3.3.2 Photo Voltaic (PV) Generation

3.3.3 Other Generation (Wind, Water, BioGas, etc.)

3.3.4 Plug-In Electric Vehicle (PEV) related

3.3.4.1 PEV charging

3.3.4.2 Demand Response controlled charging (charge-duration contracts)

3.3.4.3 Distribution Network power feeding by PEVs

3.3.5 Other Demand Response applications

3.3.5.1 HVAC related (Water heater, Room heating, Air-condition)

3.3.5.2 Appliance related like Washing machine, Dish washer or Recreational facilities (e.g. Sauna, Pool appliances)

4 Selection criteria for concrete use cases

In order to be able to choose concrete use cases for further evaluation from the above list, there are certain criteria's which have been used to identify the below selection.
The main criteria's are listed below:

4.1 Suitability of LTE as a comm´s technology

4.1.1 Financial driven selection criteria (CAPEX, OPEX)

4.1.2 Other selection criteria (e.g. timeframes)

4.2 Transmission Delay

4.3 Transmission throughput capabilities (peak, average)

4.3 Power backup

4.4 Network availability

4.5 Security (IdM, Encryption, Key-based cryptography support)

4.6 Privacy (pseudonymous and/or anonymous data processing)

5 Selection of the Use Cases

Recommended Use Case(s) for further evaluation and selection by Demo, Trial and financial analysis

5.1 From (A)DA area

5.1.1 Use-Case 1
WAMS (Wide Area Measurement System)

5.1.2 Use Case 2
DER control (Distributed Energy Resources)

5.1.3 Use-Case 3
DR control (Demand Response)

5.1.4 Use-Case 4
DS supervision (Distribution System)

5.2 From DA in Transformer Stations (MV to LV) area

5.2.1 Use-Case 5
DER, DR/Microgrid control

5.3 From Prosumer (Producer & Consumer) area

5.3.1 Use-Case 6
Smart Metering

5.3.2 Use-Case 7
PV generation (Photo-Voltaic)

5.3.3 Use-Case 8
Home-DR applications (Demand Response) for consumer appliances

5.3.4 Use-Case 9
PEV charging and power feed

6. **Description of the Use-Cases**

6.1 From (A)DA area

6.1.1 Use-Case 1
WAMS (Wide Area Measurement System)

Abstract:

HV Transport & Distribution Network stability threats, caused by volatile regional energy generation, becomes increasingly important when introducing power plants relying on sun or wind energy in large scale.

As can be seen from recent nation-wide failure events, black-out causes are propagating within minutes and sometimes only seconds through entire national and even international transport & distribution networks.

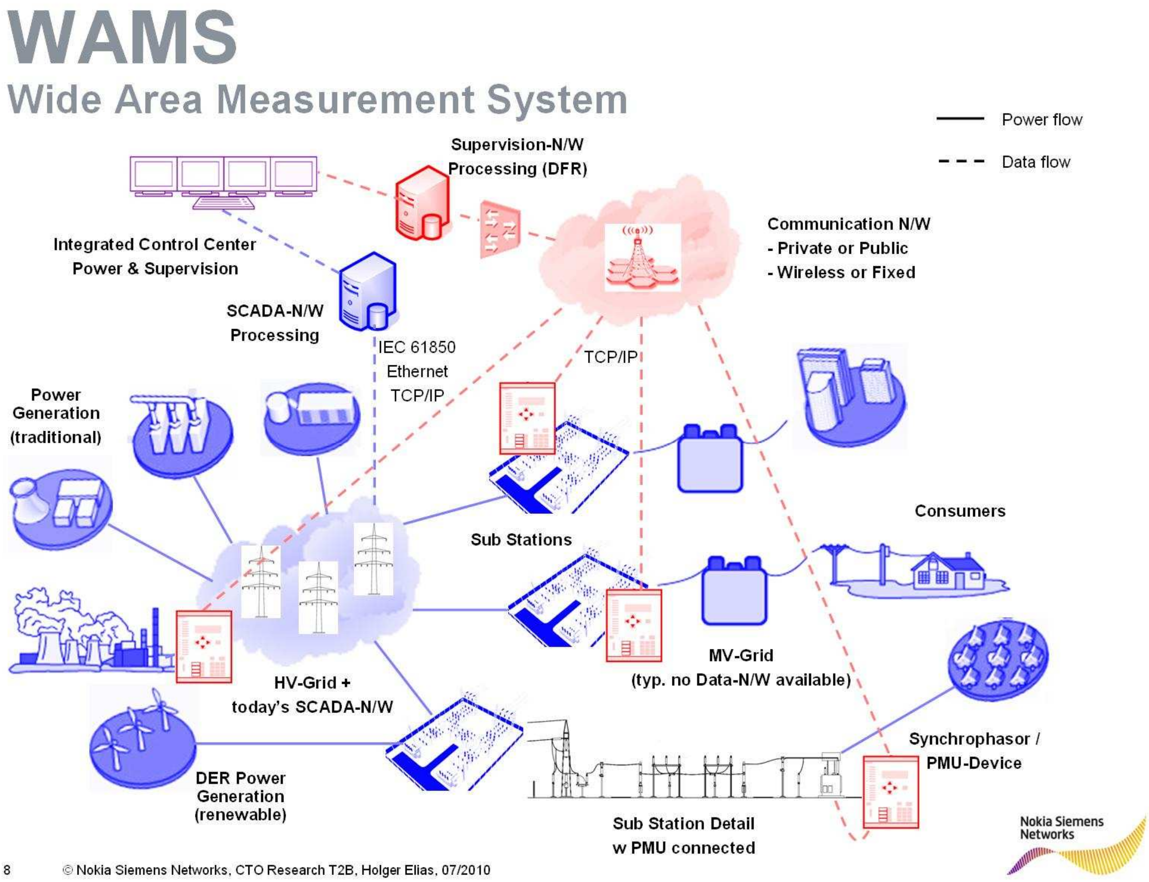
Proper state information about the initial network health can be obtained from Phase Measurement Units ("PMUs, aka Synchrophasors") over a whole country or even beyond. Due to their exact measurement time marking, high resolution phase information can be made available to TSO/DSO control centers to initiate automatic counter measures within seconds, to protect a whole wide-area network from black-out events.

Whereas PMUs usually generate bulk statistical information transmitted hourly or daily, they are capable of continuously monitoring the wide-area network status on-line. In this use case there will be continuous information streaming data available to control centers from hundreds of PMUs at once. This requires a stable communication network with sufficient capacity and quality, wherever PMUs are installed.

Details of the WAMS use case:

According to the below picture, PMUs (red boxes) are positioned across the High-Voltage transmission and distribution network (HV-Grid, operated by Transmission and Distribution System operators – TSO/DSOs), typically in Sub Stations, where network node connections are made and the distribution of load flow is of importance.

Whereas in Sub Stations typically broadband data connections via optical fibers are available, there may be other locations (e.g. handover or remote sites) where external communications means are required. Therefore the red cloud depicts a public or private broadband communication network which is typically capable of transporting IP traffic. In this use case PMUs are connected via this communication network to show the applicability of HV network supervision especially via Mobile Broadband networks, thus not requiring any additional TSO/DSO-internal network extensions. Of course, when utilising a public 3G or later 4G communication infrastructure, sufficient power back-up resources should be available to the network, but this is of course true for dedicated networks as well.
One might argue that the utilisation of public communication infrastructure is not as suitable as to utilise private TSO/DSO infrastructure via optical fibers, laid-out in hollow top earthing-wires of HV electricity lines, but recent catastrophic events like broken pylons of HV electricity lines due to ice load (Northern Germany, 2005) relativise this thinking.



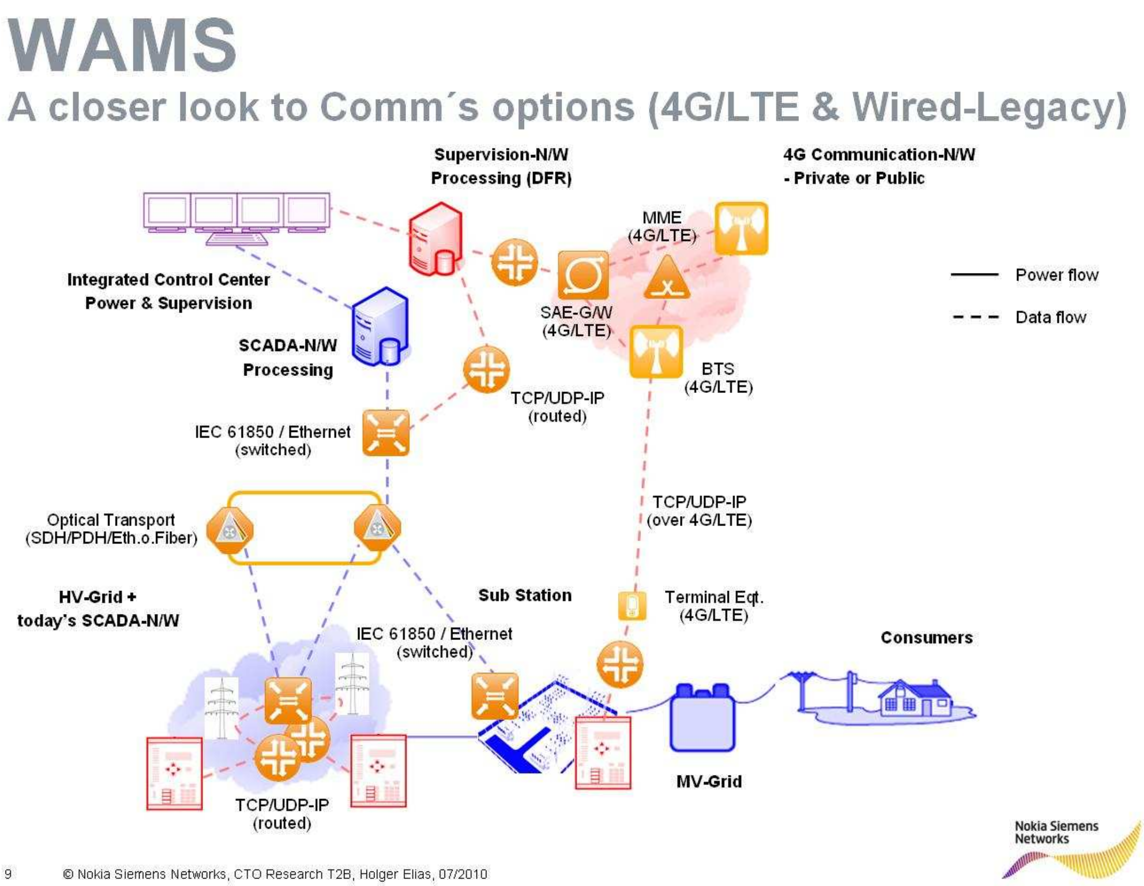
In contrast to legacy electricity communications infrastructure equipment, PMUs are designed to operate in a routed IP-network as well (on top of IEEE Standard 1344), instead of requiring a dedicated data transport network capable of frame oriented forwarding and switching (IEC61850 compliant Ethernet-type networks). Considering transmission delays of <1s in the depicted red communication network, especially electricity network phase information may be transported in near real time to the control center.

By correlation of wide-area phase, current and voltage information in TSO-control centers, immediate decisions may be enforced to shut down regional networks to protect nation-wide or even international networks from being overloaded, thus avoiding black-out-spreading as initialised e.g. by a controlled shutdown of a HV-line in northern Germany (2006), in combination with unexpected transmission capacity bottlenecks, harming wide areas of Europe for hours.

On the other hand DSOs may supervise their regional distribution networks in their control centers to work around critical situations caused locally, by local intervention, with the aim to avoid catastrophic influences on the electricity transmission network.

Therefore discussions are going on to extend this quite expensive PMU-technology to a broader area in the distribution networks, especially considering the extended utilisation of renewable photo-voltaic or wind-turbine-based electricity generation. Short term load and generation trend analysis may be supported by PMUs in the DSO´s network to control peak demand scenarios as local as possible.

Coming back to data transmission network implementation, an always-on connection scenario for PMUs is reasonable. This may be achieved with 3G (UMTS) or in the future even better by 4G/LTE networks (see below), considering existing load situations in public comm´s networks. To insure a sufficient quality of service a specific UDP/TCP-port assignment needs to be negotiated with the Mobile Broadband SP.
Individual data traffic from a PMU is rather low, compared to other mobile broadband usage (e.g. private file download, even internet surfing), but it is continuous. As described in a CIGRE paper* continuous PMU operation covering 12 channels each 50Hz cycle, will generate <50Kb/s net frame data rate.
Considering continuous UDP-IP transmission, the air data rate will stay below <100Kb/s and typically below <1Mb/s for a Sub Station location.
Considering intended burst transmission, e.g. transmission of bulk daily or hourly data, e.g. from a transient fault recorder (TFR), data volume may reach into the 3-digit MB range causing a high-bandwidth-burst of transmitted data.
Based on 3G capacity, such an application will jam the Mobile-N/W for minutes.
(I.e. with ~3Mb/s dedicated transmission bandwidth 50MB of data will occupy the Mobile-N/W for more than 2minutes, with TCP transmission even longer)
From this, one can easily see the advantages of a 4G/LTE network, which will allow much higher burst bandwidth (>20Mb/s) and offer lower delay, speeding up TCP acknowledgements and connection set-up as well.



Summarising the above, we believe in the vision of enhancing currently installed fiber-based IEC61850 transmission equipment infrastructure by suitable wireless infrastructures, especially 4G/LTE networks, which may be designed from a QoS & Availability perspective to fully support advanced TS/DS-N/W quality measurements, not only in remote sites, but also offering an alternate transmission pathes to overcome combined failures of the Energy and Transmission N/Ws in case of infrastructural damage.
The principle of relying on the statistical independence of failure occurrences may improve Energy-N/W availability significantly.
This leaves open the decision to rely on 3rd party wireless providers, may it be either dedicated or public Communication Service Providers. Especially focusing on new installed public 4G/LTE networks, the necessary Comm´s-N/W resilience may be designed right into the newly rolled-out infrastructure, to support such services right from scratch.

Final remark:
It needs to be understood that the above does not cover all of today's high speed line protection switching schemes, which are currently supported by IEC61850 (Fast Ethernet over direct-Fiber or SDH/PDH). This is used to protect humans and the Energy-infrastructure from fatal damages in limited areas.
But considering a highly meshed network, reactions on load changes, need to be evaluated by complex simulation tools anyway, relativising the transmission requirements in the intended cases from above.

*Ref.: Phasor Measurement Unit (PMU) Communication, Experience in a Utility Environment
CIGRÉ Canada Conference on Power Systems, Winnipeg, October 19-21, 2008

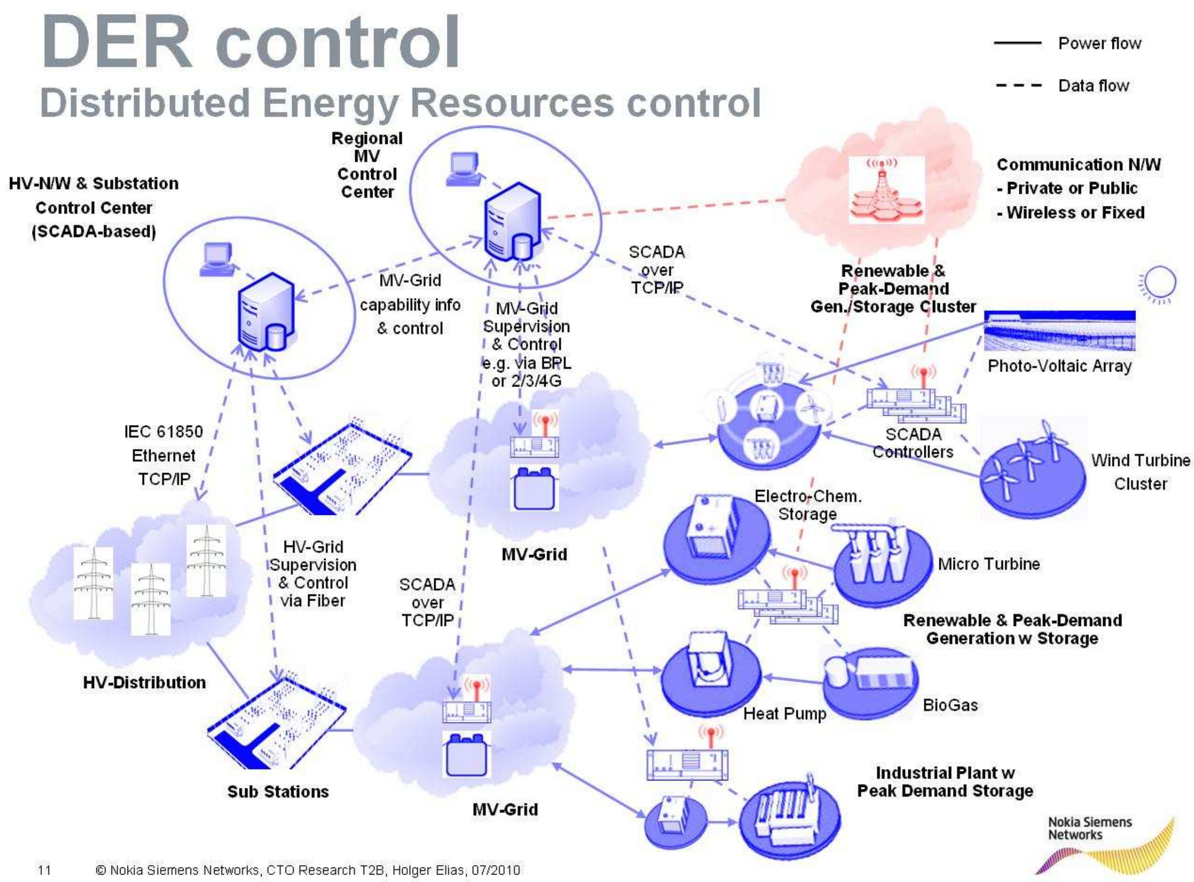
6.1.2 Use Case 2
DER control (Distributed Energy Resources)

Abstract:

When dealing with many Distributed Energy Resources in an Energy-N/W, most of the resources will be connected to the MV-Distribution-N/W due to their distributed nature, as well as their power-class in the lower MW range (E.g. Wind-Turbines, large PV-Arrays, etc.).
Since Comm´s-N/W capabilities are rather limited in today's MV-Distribution-N/Ws, an efficient and flexible Comm´s-N/W overlay implementation is crucial for local DER-rollout.
With the help of regional energy management, generation may be controlled according to demand and better Distribution-N/W protection becomes possible on a regional, instead of a local basis.

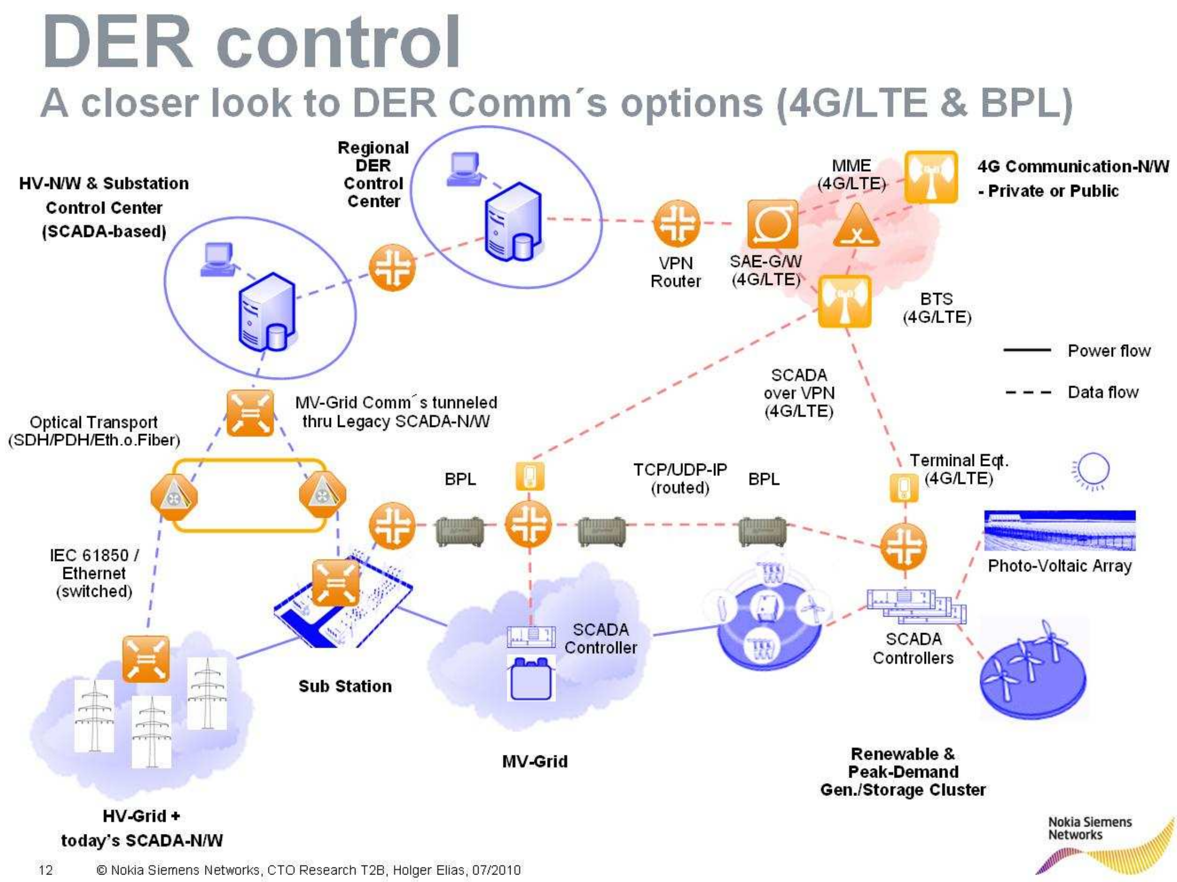
Details of the DER control use case:

Two main technologies are envisaged for DER-Comm´s.
One is Broadband Powerline (BPL), utilising the MV-Electricity-N/W itself, thus avoiding expensive civil works for new fiber ducts. Data rates in the range of a few 10Mb/s are obtainable over distances of several hundred meters. Distortion from other sources or crosstalk from other BPL systems is considered not to be dominating, since residential BPL home equipment is well attenuated by MV-to-LV transformers. A drawback is the intrinsic low reach of BPL-technology, making it necessary to place a high number of regenerators in line in rural areas, thus reducing the overall availability of the system and cost for maintaining a large number of installations in the field. This becomes relativised in more densely populated areas, where many MV-to-LV transformer station sites shorten the MV-distribution distances. On the other hand, DER is rather not that predominant in populated areas due to expensive site costs and various objections from local citizens.
Alternative comm´s technologies are wireless, offered by dedicated or public Communication Service Providers. Technology-wise existing or new Comm´s-N/W implementations with 3G/UMTS or 4G/LTE and maybe even 2G/Edge are suitable.
This is due to the limited amount of continuous control needed and data generated by these DER installations. As discussed in the WAMS use case before, alternate routing for energy and comm´s will not only increase N/W-availability, but also enable local MicroGrid operation in case of distribution-N/W-detachment from a Sub Station (Which would be the node point in the case of BPL-based comm´s).



The basic control task for DER control builds on standardised IEC61850/SCADA-N/W implementation, with the relief that TCP-IP routing is suitable for this comm´s purpose, compared to HV-Distribution N/W-protection-management, which requires very fast Ethernet-switching. DERs, communicating with their regional MV control center via public wireless networks, seem to be the most viable solution, from the aspects of comm´s availability and data throughput as well. Comm´s CAPEX and OPEX-wise, a clear cut between the different players (i.e. the Distribution-N/W and the DER-operator) concerning the write-off of comm´s infrastructure installation burden, also speaks for utilising a public wireless CSP offering.

SCADA-based control offers very efficient message exchange between devices and their control center. In the case of a public-CSP comm´s solution, setting up a dedicated VPN with moderate QoS requirements will also fulfil operational security requirements. A local VPN-router will improve SCADA security to the necessary degree and also improve comm´s resilience.
An envisaged number of DER devices in such a network reach from a few to several dozens (e.g. Wind-Turbine farms) contributing with an average of some Kb/s in continuous operation, requiring comm´s acknowledgement in the several-second range.
One data-comm´s exemption may be the bulk transfer of power generation data or SW-upgrade during maintenance. In these cases, a 3G/UMTS or in future a 4G/LTE N/W would reduce operational downtimes significantly, from several minutes to just seconds per device.
Please see the Comm´s-N/W set-up alternatives below.


DER control
A closer look to DER Comm´s options (4G/LTE & BPL)
Regional DER Control Center
HV-N/W & Substation Control Center (SCADA-based)
MME (4G/LTE)
4G Communication-N/W - Private or Public
VPN Router
SAE-G/W (4G/LTE)
BTS (4G/LTE)
Power flow
Data flow
SCADA over VPN (4G/LTE)
Optical Transport (SDH/PDH/Eth.o.Fiber)
MV-Grid Comm´s tunneled thru Legacy SCADA-N/W
BPL
TCP/UDP-IP (routed)
BPL
Terminal Eqt. (4G/LTE)
Photo-Voltaic Array
IEC 61850 / Ethernet (switched)
SCADA Controller
SCADA Controllers
Sub Station
MV-Grid
Renewable & Peak-Demand Gen./Storage Cluster
HV-Grid + today's SCADA-N/W
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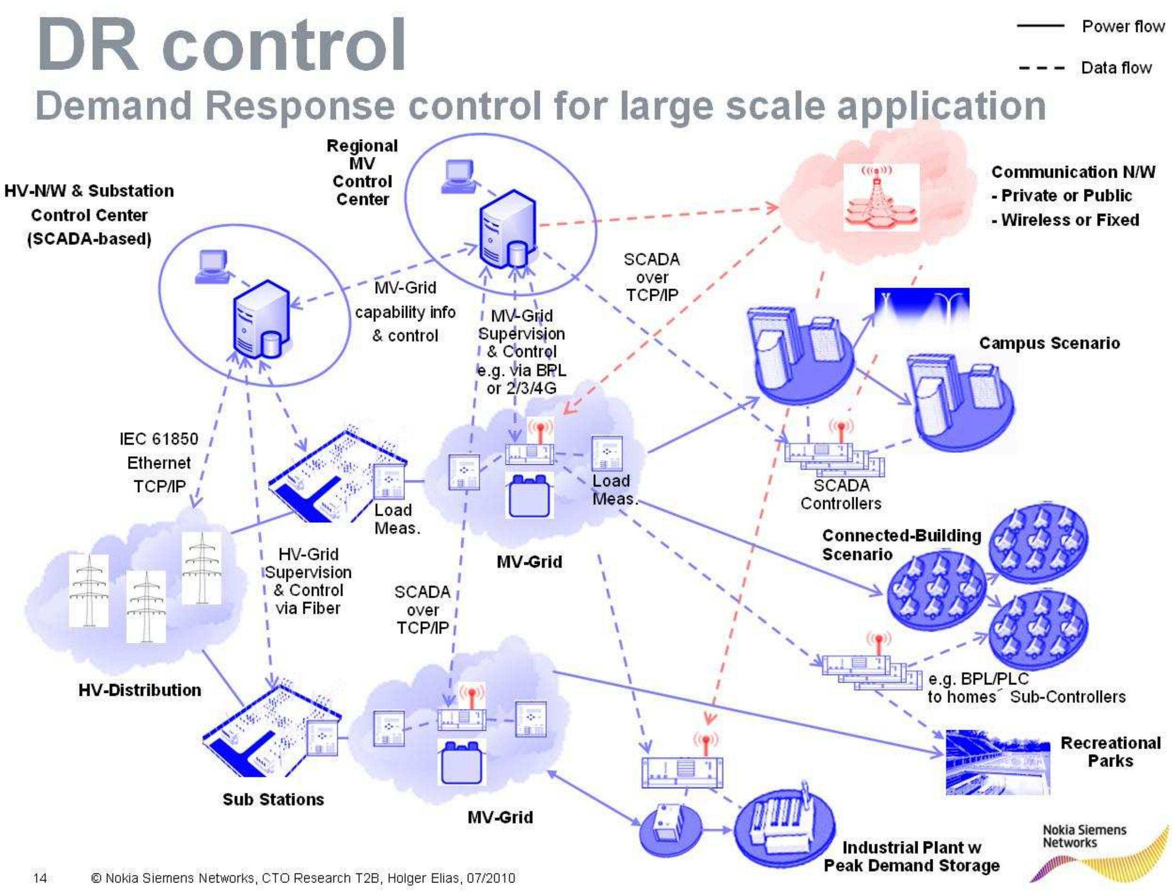
6.1.3 Use-Case 3
DR control (Demand Response) for large scale application

Abstract:

Similar to the above Distributed Energy Resources scenario, the Demand Response scenario for large scale applications (displayed below) is very much located in the MV-Distribution-N/W due to its distributed nature, as well as its power-class in the medium KW range (e.g. aggregated Home/Campus-DR, Street Lighting, Recreational Parks, etc.).
Please note that DR applications in this use case are dedicated to “fixed-gear” home appliances (like HVAC, Pool & Sauna appliances), which are enabled for bulk control directly from the utility, rather than from a separate service provider, as described in the Home-DR applications section for consumer appliances (please see Prosumer area; Use Case 8).
The basic goal in this DR use case is to stabilise the network, by equalising peak energy demand over short times (quarter hours range) and to protect the Distribution-N/W against black-out situations or support the recovery process following a black-out.

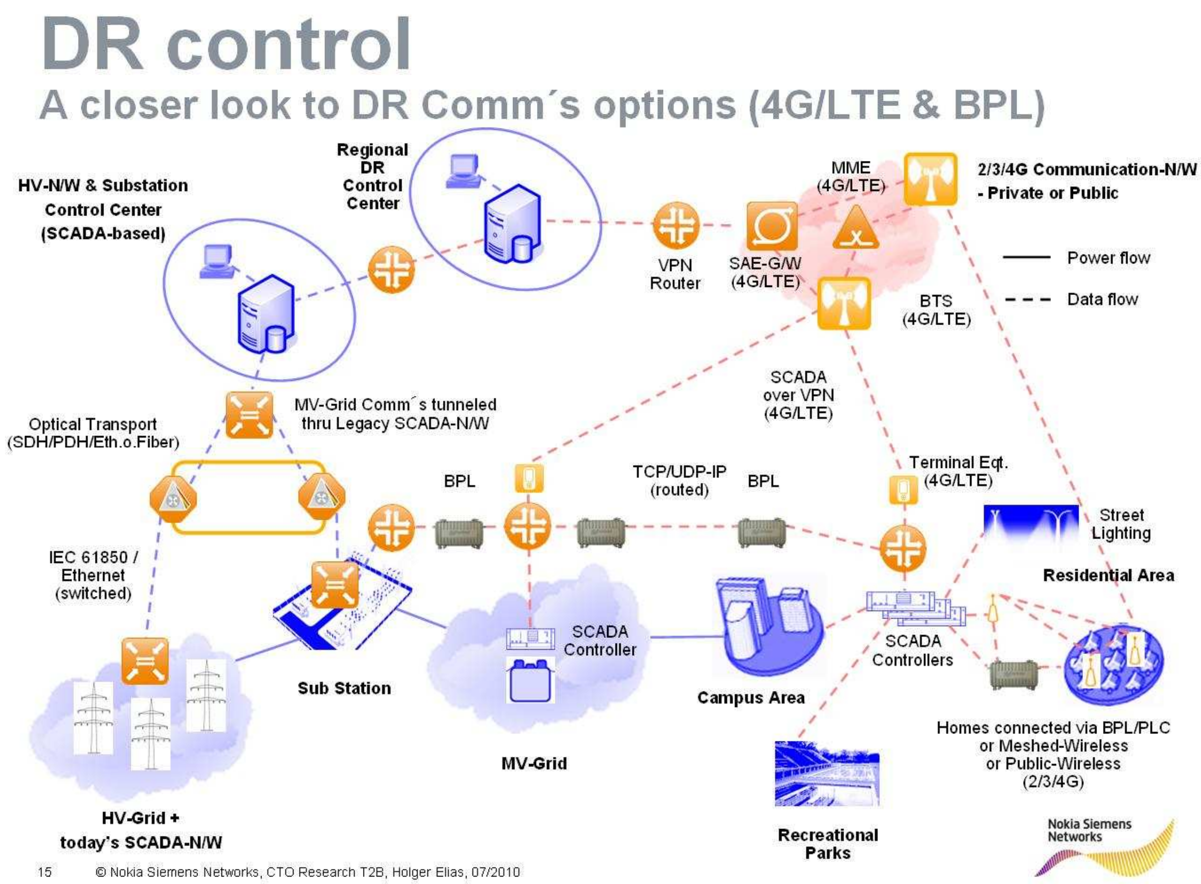


Details of the DR control use case:

Please see the discussion for the Comm´s N/W in the above DER scenario (Use Case 2), which is applicable here as well, including expected data traffic throughput and latency expectations.
Please note also the various load measuring points in the MV-Distribution-N/W, which are supporting the load measurement accuracy derived in the Sub Stations. The information is

aggregated in the Regional MV Control Center, processed and will yield control commands for the attached SCADA controllers for DR purposes.

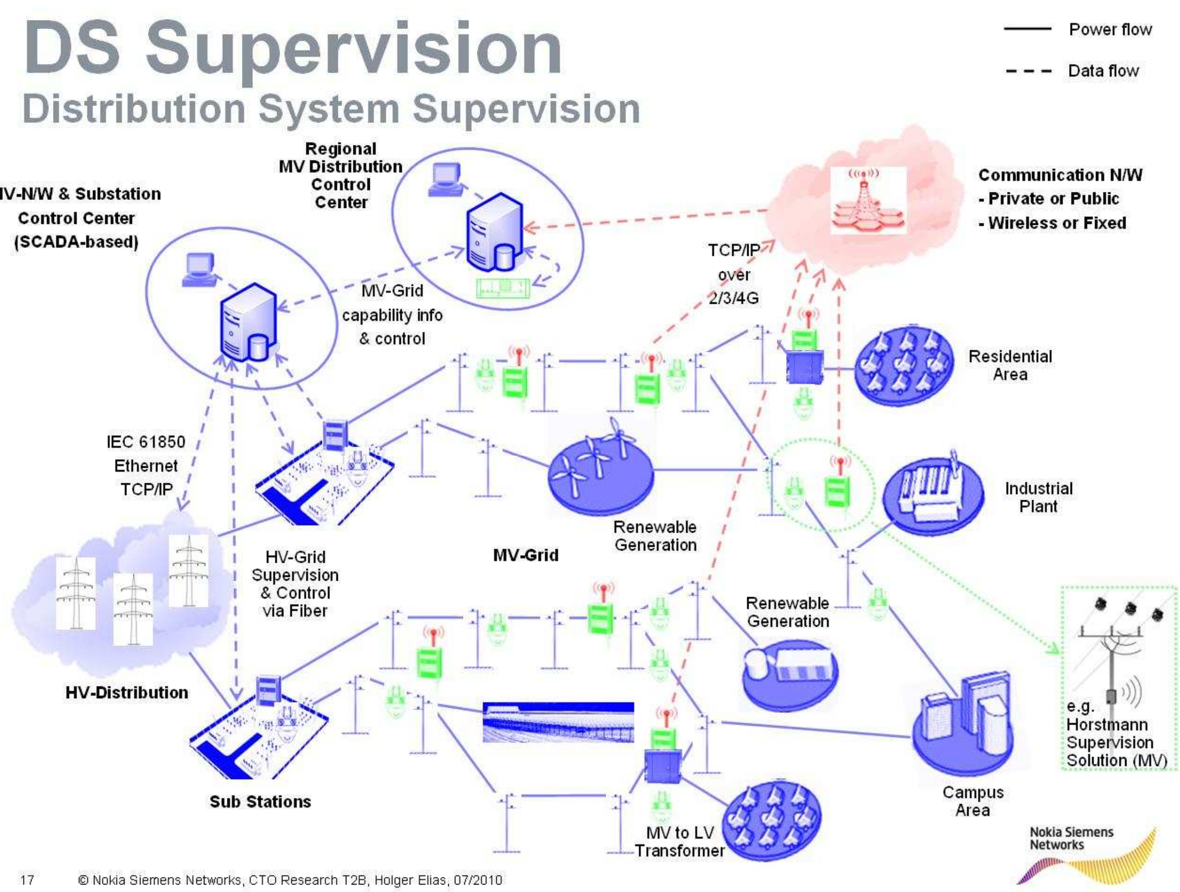
One important difference though is the distribution of demand response signalling in the Home area. The below shown SCADA controller, dedicated to the residential area, needs a communication and protocol front-end to control a large amount (dozens) of households, probably connected to the same MV-to-LV transformer for infrastructure reasons.
Privacy concern are of less interest in this application, due to the primarily unidirectional way of “broadcast” communication.
This is described in more detail in the DA for Transformer Stations (MV to LV) section for DER, DR/Microgrid control (Use-Case 5)



6.1.4 Use-Case 4
DS supervision (Distribution System)

Abstract:

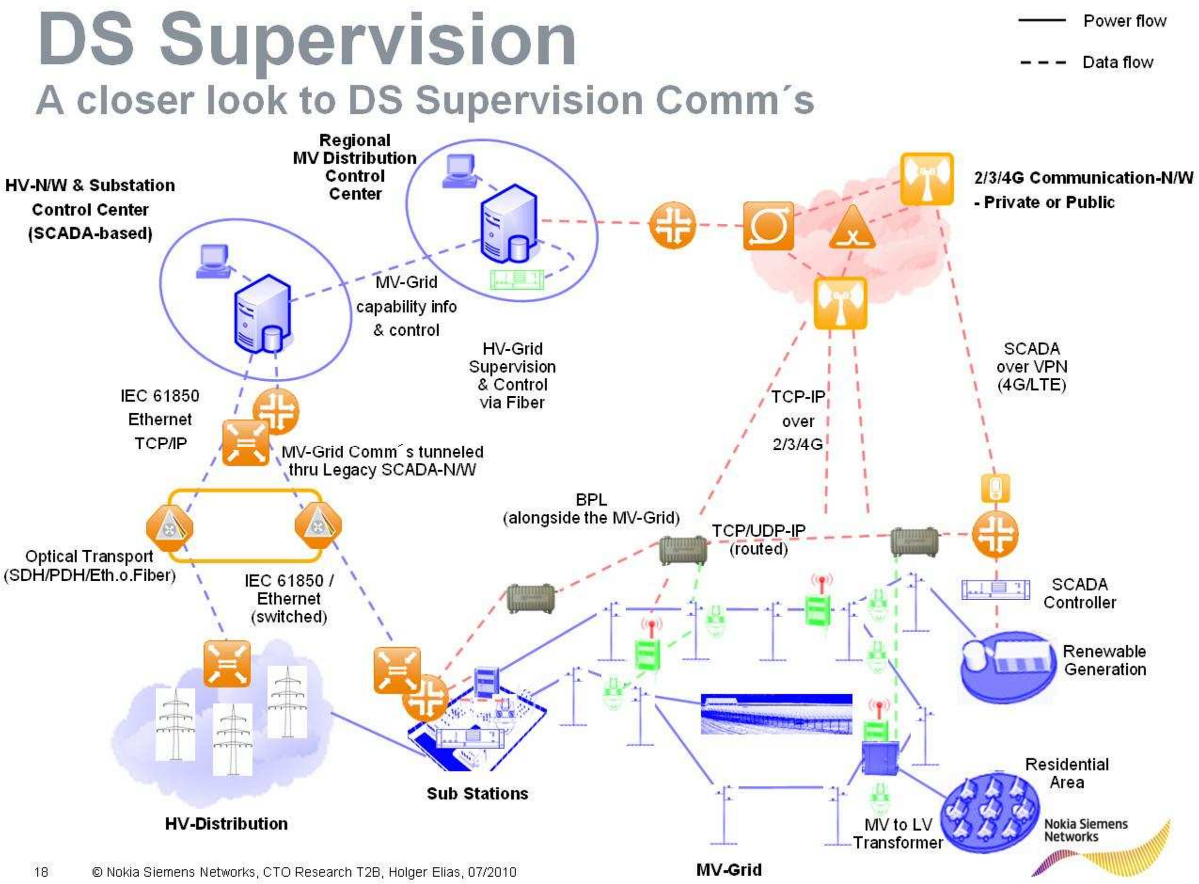
The aim of Distribution System Supervision is primarily to notify faults in Distribution-N/W faster than end users would do and to analyse the fault situation in more detail from remote. In combination with better focused field force activity, this leads to an increase of Distribution-N/W availability.
Different to the sensing and measuring in the DR control use case above, which is related to certain infrastructure points in the Distribution-N/W, the DS Supervision relates more to a distributed task, supervising passive infrastructure, like lines, cables and branching points alongside, plus the information gathered from specific premises.



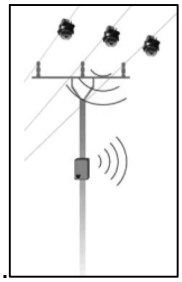
Details of the Distribution System Supervision use case:

Unlike the measurement tasks underlying the above Demand Response control scenario, which must be of a quantitative nature to control the Distribution-N/W, the Distribution System Supervision rather yields qualitative information about the N/W-status along the lines, i.e. where electricity is still available and whether Voltage Dips did occur (e.g. caused by automatic Recloser actions). Of course, the installations for DR and DER-control will support the situational analysis with their measurement capabilities, but the Distribution System Supervision allows for fast status checking in between.

As discussed before (DER & DR control, Use Cases 2 & 3), wireless and wired comm´s solutions are possible options to reach certain stations in the Distribution-N/W (like MV-to-LV transformer sites).
In these locations, the effort which may be spend from a space and cost perspective, fundamentally differs from sites, which which are not associated with ground installations (like MV poles and masts or subsurface branching sites, please see below).



In case when a BPL-line is installed alongside a MV-line, e.g. pole installations may be equipped with current and voltage sensors, which then are connected to the BPL-system. The effort to install such a solution is depending on the technical preparation of the chosen BPL system (e.g. Corinex vs. Amperion).
In any case, it needs to be insured that the BPL power feeding offers some reserve to operate the line during black-out situations to accomplish the desired supervision task.
A more effective supervision solution may be a wireless one, relying on a public CSP.
Since the datarates and the message frequency are rather low, a battery powered system is suitable.
Today, 2G/GSM-Radio Reporting Systems are available on the market (e.g. from Horstmann).
Completely isolated and self-sustained voltage and current measurement probes attached on the 3 wires of the MV-line will transmit their incident triggered measurement results towards the reporting

system via short reach unlicensed radio.
Battery lifetime of the above systems depends on the usage or incident frequency, but reaches several years under typical operating conditions.

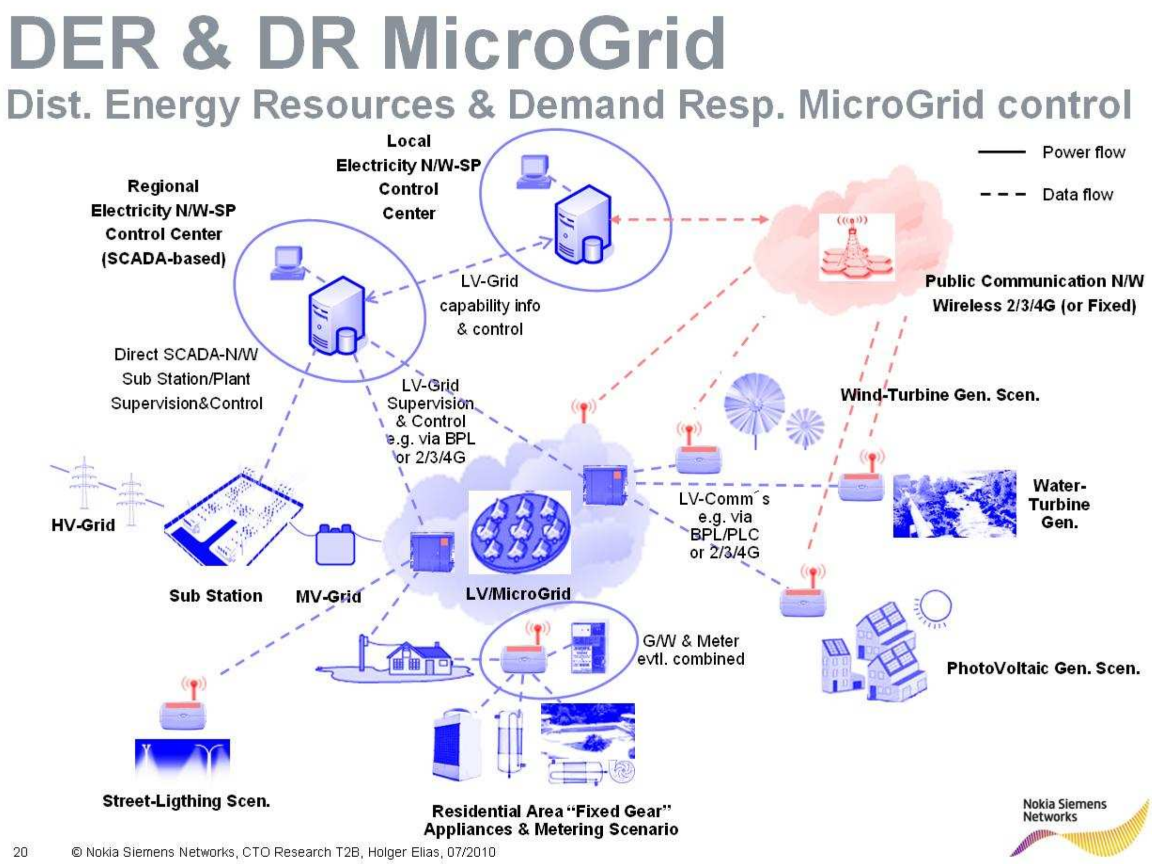
In both cases, incident measurement data is transferred to the regional MV Distribution Management System for further processing, via BPL or radio-based.

6.2 From DA for Transformer Stations (MV to LV) area

6.2.1 Use-Case 5
DER, DR/Microgrid control

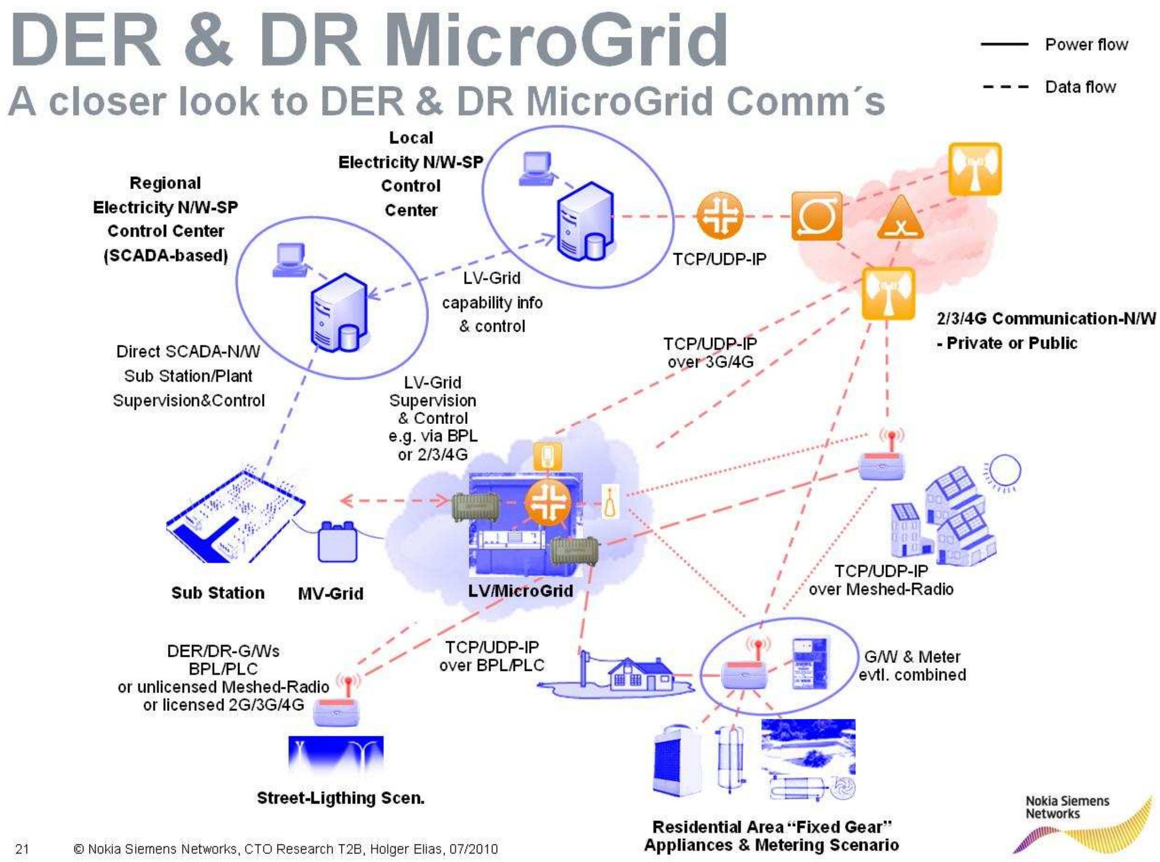
Abstract:

DER, DR/Microgrid control is focused around the handover point at the MV-to-LV transformer sites, where the LV-distribution and generation takes place (please see below).
As outlined in the DR control description for large scale application (please see Use Case 3), this task is about stabilising the network, by
- Equalising peak energy demand over short times (hours range) and to
- Protect the LV-Distribution-N/W against overload or excessive voltage situations (caused by strong local sun or wind-based generation),
- Actively compensate Reactance with enabled devices (e.g. PV-Inverters) as well as to
- Support the recovery process following a black-out.
Please note that DR applications in this use case are dedicated to “fixed-gear” home appliances (like HVAC, Pool & Sauna appliances), which are enabled for bulk control directly from the Local Electricity N/W-SP Control Center, rather than from a separate service provider, as described in the Home-DR applications section for consumer appliances (please see Prosumer area; Use Case 8).



Details of the DER, DR/Microgrid control use case:

There are 3 applicable ways to accomplish the comm´s task with individual homes ("fixed gear" appliances), demand or generation (e.g. street lighting, PV generation) sites as shown below.



- One is physically connected via the MV-to-LV transformer site, utilising BPL/PLC towards the LV-Grid.
Please note that the MV-to-LV transformer separates the MV and LV BPL/PLC N/Ws not only physically but also logically for their different comm´s purposes.
Another aspect concerning the public BPL/PLC installation are interferences which might be generated by home-based BPL eqt., therefore only a limited QoS must be expected
- Second is a proprietary Meshed-Radio-N/W solution like ZigBee or Z-Wave which allows hop-to-hop-meshing to extend and stabilise the comm´s-N/W. The root station would be co-located with the transformer station. Since such radios predominantly operate in unlicensed frequency bands, there exists as well only a limited QoS expectation.
- Third depicts a wireless solution, based on public or private CSP offering, which operates in licensed frequency bands and will offer a suitable QoS, when properly set-up (2G/3G/4G).
Such a solution may be used also as a feeder, in combination with the previously described local comm´s solutions, installed in the transformer station. Suitable bandwidth and latency is available via 3G and 4G networks.

An independent feeder for the transformer station also ensures MicroGrid operation from a communication perspective, when the MV-feeder is down. All attached distributed generating contributors are then still within control of the Local Electricity N/W-SP Control Center, thus enabling an "Island" or "MicroGrid" mode of operation, when generating enough local power and

DR-enabled devices acting accordingly.

The “last mile” comm´s link, connecting the residential homes, will terminate in fixed installed devices in the homes (e.g. G/Ws located in fuse-boxes). Either in a direct way, in a dedicated device (e.g. relay circuit control or in an advanced HVAC-controller) or in an indirect way, via installed smart meters´ relay control outputs, using the same comm´s infrastructure.
In any case, the installed home or DER-G/W needs to be compatible with the Local Electricity N/W-SP´s basic installations, not only in terms of communication stack (Authentication, Authorisation) but also in terms of Object-Data Modelling.
Since the Object-Data modelling definition and standardisation is still ongoing, a solution, defined & operated by the Local Electricity N/W-SP, is rather mandatory today. Therefore it is likely that this SP will provide the necessary control and comm´s equipment to the DR/DER partners.
In the U.S., the Smart Grid Interoperability Panel (SGIP) is currently setting up a Priority Action Plan (PAP17) to define the necessary elements to support this definition phase.

Reference for the non-shown Sub Station and MV comm´s details are available from the descriptions of the previous Use Cases 2 or 3.

6.3 From Prosumer (Producer & Consumer) area

6.3.1 <u>Use-Case 6</u>
Smart Metering

Abstract:

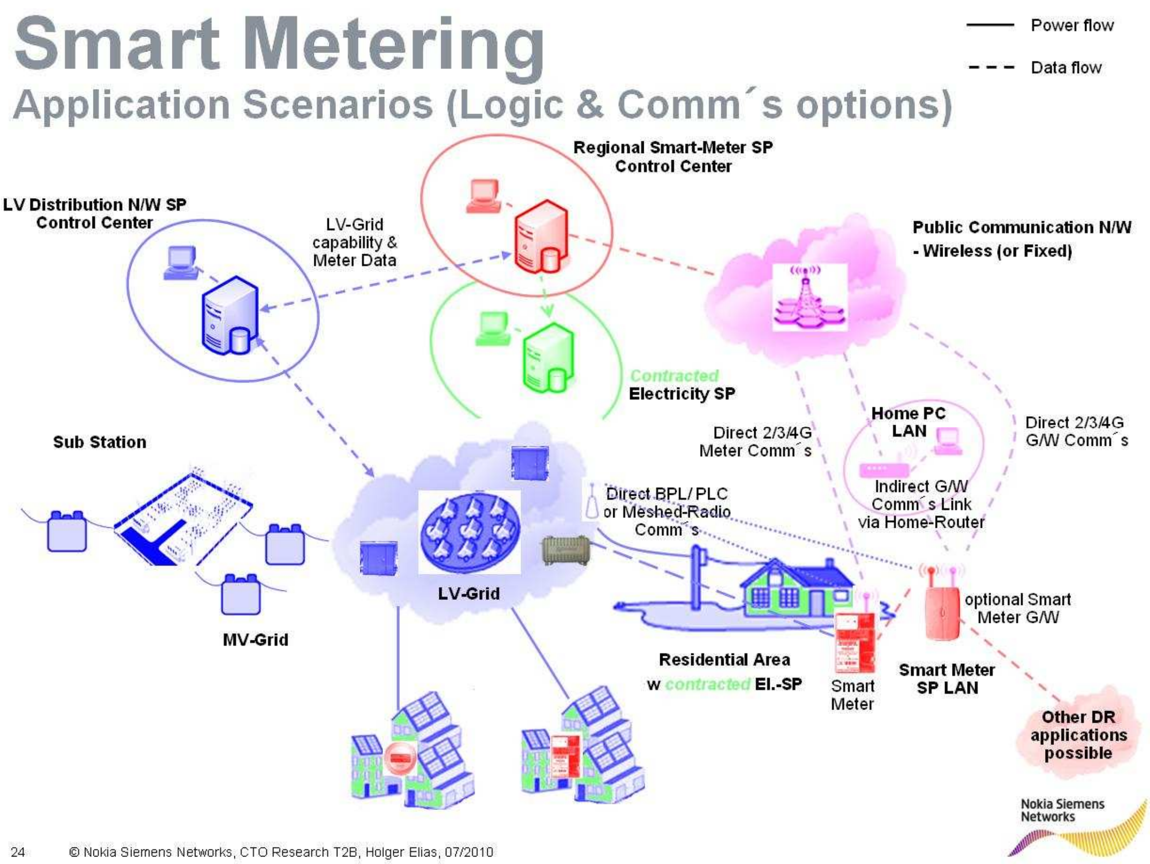
Smart Metering is one of the most challenging use cases for the associated comm´s infrastructure, due to its urgence, large quantity rollout, price pressure and security, resp. privacy requirements. Several different comm´s technologies, for accessing Smart Meters from the Control Center, are being discussed. “Direct” ones, which rely on a dedicated comm´s link and “indirect” ones, relying on existing home comm´s installation, like DSL/Cable-routers. Whereas
- “Direct” enables comm´s with the Smart Meter in principle at any time
(good for real time data exchange),
- “Indirect” relies on the availability of the comm´s link from time to time
(good for batch data exchange),
resulting in time-wise flexible and inflexible tariffing models (please see below).
This drawback is leveraged in conjunction with the Home-DR applications´ requirements for consumer appliances (Use Case 8), when the consumer is interested in special tariffs, while operating his home DR appliances. Therefore he will have his Home-LAN switched on, when he is interested in saving expenses. In this case, the Smart Meter is able to record special tariffs as well. Another limitation of “indirect” comm´s is the lack of the option to shut down the electricity supply in case of lacking consumer payments.

As an option, a Smart Meter G/W placed in front of the Meter, may support further services in the residential home like DR application control or just energy In-Home Displays (IHD).
Vice versa, the Smart Meter might act as a G/W with limited control functionality as well. This is shown in the DER, DR/Microgrid control scenario (Use Case 5).

From a legal perspective though, Smart Meters should be very much “closed” or “trusted” devices with a single secure and private link to their application server, to cope with national requirements on that.
Any additional (local) interface may intentionally or non-intentionally leak private information to 3rd parties, which is at least illegal in Germany. A local interface may also create infringement problems with the metering accuracy (Measurement and Weights Acts), when local attacks are imposed to the device.
Such a “closed” architecture looks as if it would create a severe drawback for the utilisation of In-Home Displays. Today, IHDs are considered as an immediate source for energy savings (e.g. acc. to the Pew Center for Global Climate Change, 2010 IEEE PES conference), based on the feedback they give to the consumers for consequent energy saving actions (In fact, the energy saving potential by analysing the consumption is considered as today’s most effective solution!).
Therefore a reasonable proposal is, to operate IHDs over the internet(-connection) and not directly from the Smart Meter. This has 4 main advantages.
- Single sourcing of the metering data provided through the Regional Smart-Meter SP (fulfilment of applicable Measurement and Weights Acts)
- Fulfilment of privacy laws, letting the consumer decide, whether his personal meter data is made available through a reasonably secure internet-based link.

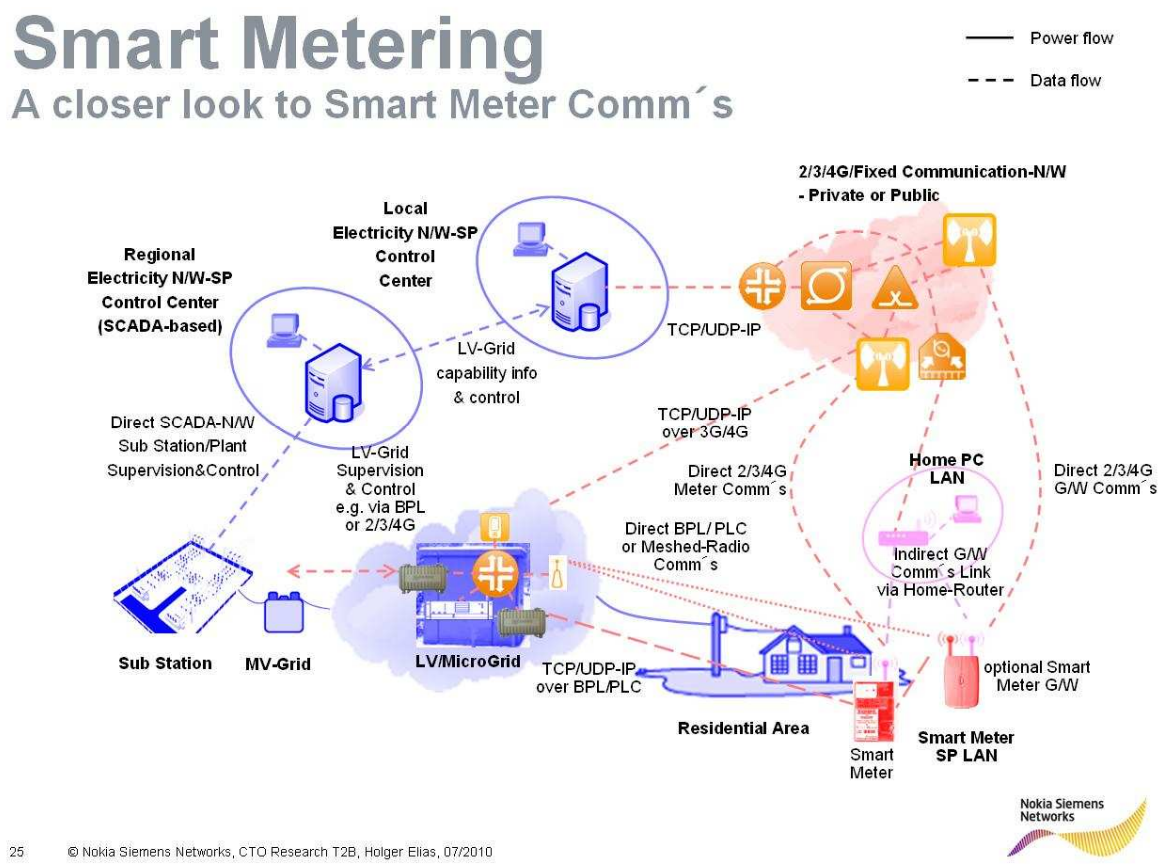
- “Educate” the consumer to keep his smart meter online for energy saving purposes, when connected via his Home-LAN (as explained above).
- Enable the IHD also for near-real-time financial (consumption) data display, which is generated by the billing server.

Finally, based on a legal requirement, the consumer may choose a third party Electricity Service Provider, whom he may contract. In this case, the Regional Smart-Meter SP needs to supply a trusted data I/F to the Electricity SP to support his business with the consumer. This is as well true for the IHD data provisioning, suggesting that the IHD data is generated and marketed by the Electricity-SP and may as well be available on secure web-page-format in parallel.



Details of the Smart Metering use case:

The Smart Meter use case may be best understood from the comm´s visualisation below.
The generic core-N/W comm´s-functions are similar to the one of the DER, DR/Microgrid control scenario (Use Case 5) with the extension of an “indirect” comm´s option, via the purple home router section below.
As discussed before (please see description for Use Case 5), the BPL/PLC and Meshed-Radio comm´s options do have their limitations in terms of QoS. This may be overcome by “direct” comm´s via 2G/3G/4G for the Smart Meter application solely.



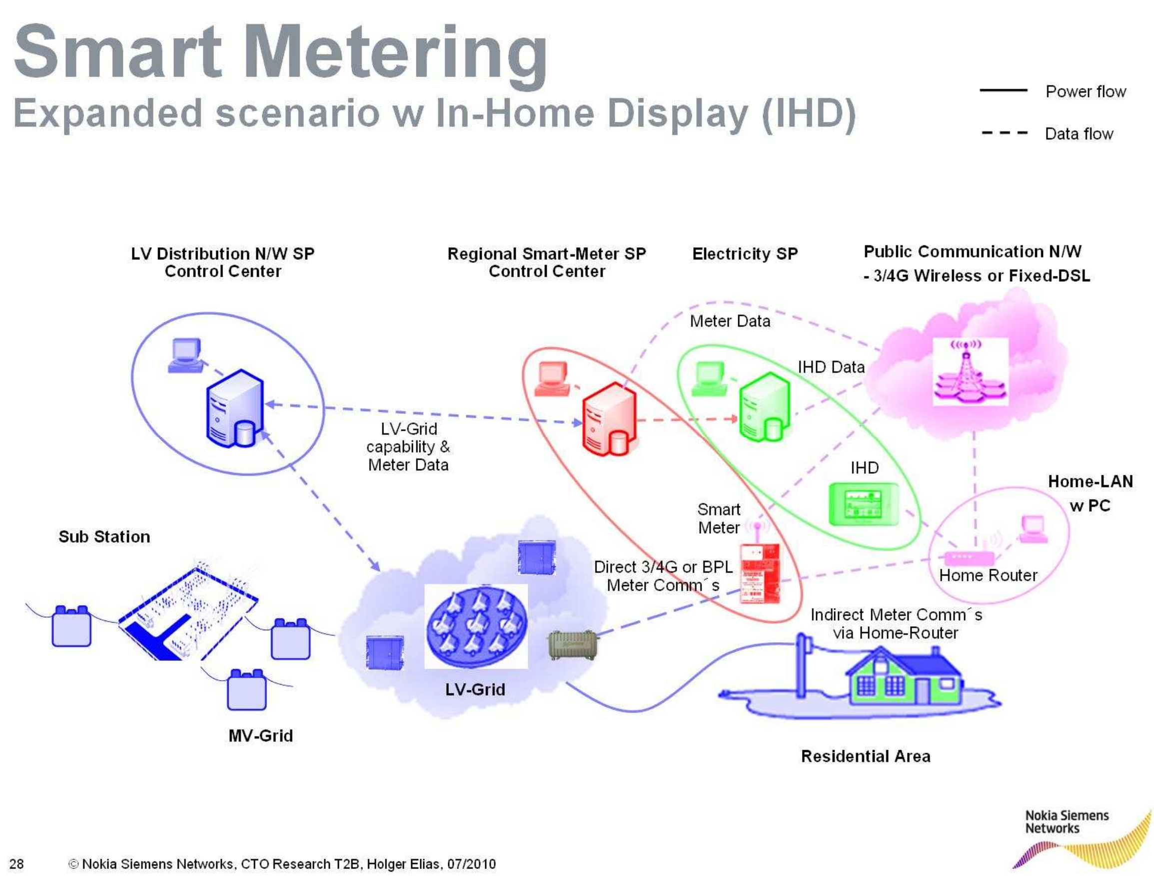
For the native Smart Meter application, where "invariable over day" tariffs are used, the least performing comm´s solution is sufficient in principle, due to the low read-out frequency and limited amount of data. From this perspective, a narrowband link like PLC, unlicensed Meshed-Radio or licensed 2G are convenient. Especially a 2G/GPRS/SMS link might create the least costs, due to the limited data-size of the messages, fitting in a SMS, or generating some KB via GPRS.
Such a solution is very much limited and will probably not support any tariffing-related DR applications. In parallel, such devices are not really upgradable, considering many thousands of devices in the network to receive MB´s of data in parallel.
Therefore a "burst bandwidth" capable comm´s scenario with a reasonable speed around 100Kb/s, also offering a suitable latency <100ms, would enable control functions. This would narrow down the comm´s options towards 3G/UMTS, BPL or the Home-Router solution (with limited availability, s. a.). It would also leave some capacity for the option to connect additional devices to a Smart Meter G/W solution.
A Smart Meter G/W concept could solve the problem of 3G attenuation in the basements of stone-built homes, when positioned above ground. The connection to the Smart Meter could be supported by various in-house wireless solutions (unlicensed, short reach) or wire-bound (G.hn, Eth., BPL/PLC).

One important issue is the operational cost for the above installation from the perspective of a consumer.
- Operating the Smart Meter itself does not create additional billing, since the meter´s consumption is not counted. This speaks for self-contained solutions with 3G/UMTS (for flats, multi-dwelling buildings) or with BPL (feasible for basement installation).
- Operating additional infrastructure like a detached Smart Meter G/W and/or a Home-Router will

count for about 10 to 20€ electricity cost per year (@10W power consumption, valid for various countries in Europe).

One way to overcome operating cost discussions with the consumer is to advertise an In-Home Display (IHD) in conjunction with the installation of a Smart Meter.
This will help the consumer to conserve more energy, than the extra stand-by power of his installations (Home-Router or Smart Meter G/W, IDH) will consume.
Below, the above mentioned IHD scenario is shown in conjunction with the involved parties. Smart Meter data is securely and privately collected by the Regional Smart-Meter SP (red circle) and handed over similarly to the consumer's Electricity SP.
The Electricity SP may enrich the electrical consumption data by near-real-time financial data and send it securely and privately to the IHD (green circle) or to the consumers PC via the Internet. By this method, the acquisition of meter data will stay completely (electrically and legally) undisturbed from the in-home display process. Just one source of meter data (smart meter data incl. processing on the SP layer) will insure consistent electricity billing to IHD reading.

Required data rates and volumes depend very much on the IHD settings.
Assuming a fade-out of the actualised display after 10min with 20s update interval and an initial 1h per day usage time for a web-page-update display scenario of the IHD, about 100KB of data transfer per 10min interval are required. 1mio consumers served by such a solution, would generate about 220TB of data p.a. This will distribute to a medium data flow of less than 100Mb/s, handed over from the Electricity SP to the ISP, which is cost wise negligible, compared to the expected energy savings.



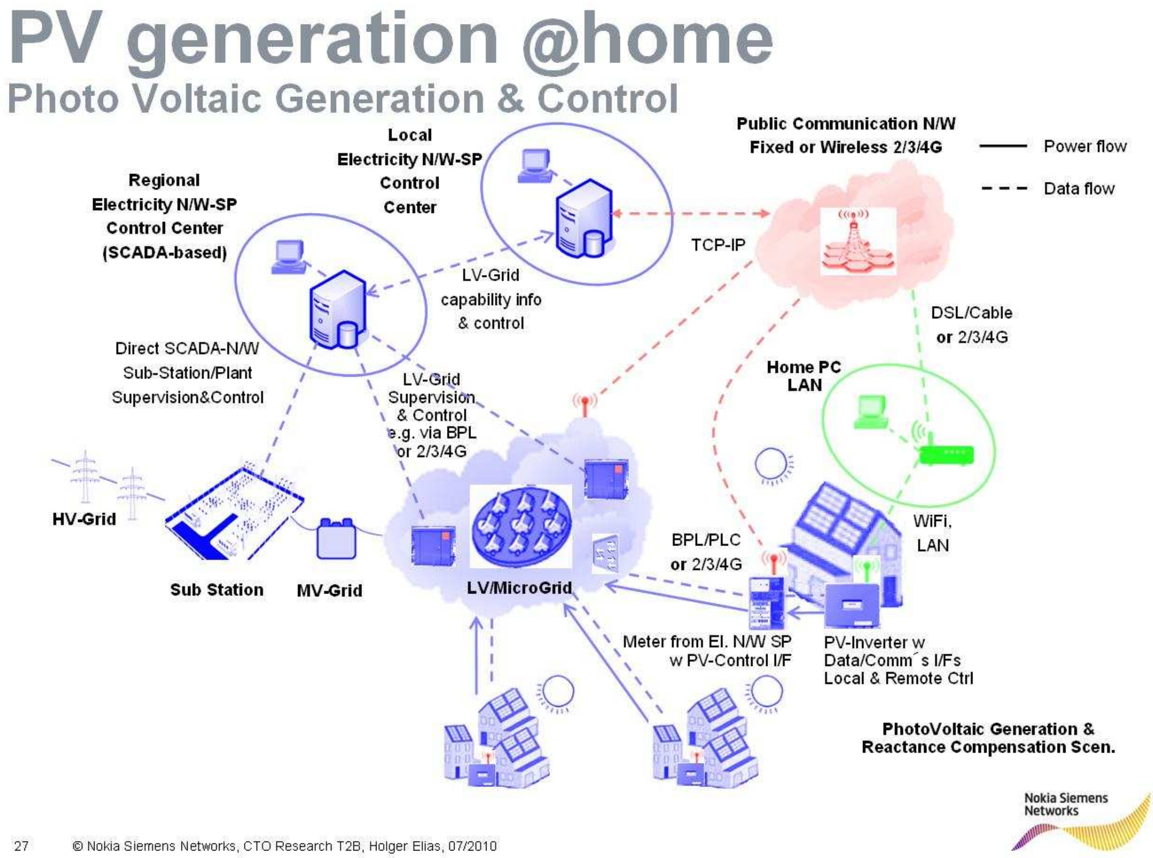
6.3.2 Use-Case 7
PV generation (Photo-Voltaic)

Abstract:

The PV Generation & Control use case is architecture-wise very similar to the DER, DR/Microgrid control scenario (Use Case 5), actually it can be seen as a subset of it, but due to the specific character, it has a different utilisation focus.
In this advanced use case not only
- PV-based electricity generation shall be possible, but also
- Limited Reactance control in the local distribution layer. Furthermore
- Power control to stabilise the LV-Grid and to
- Enable MicroGrid operation

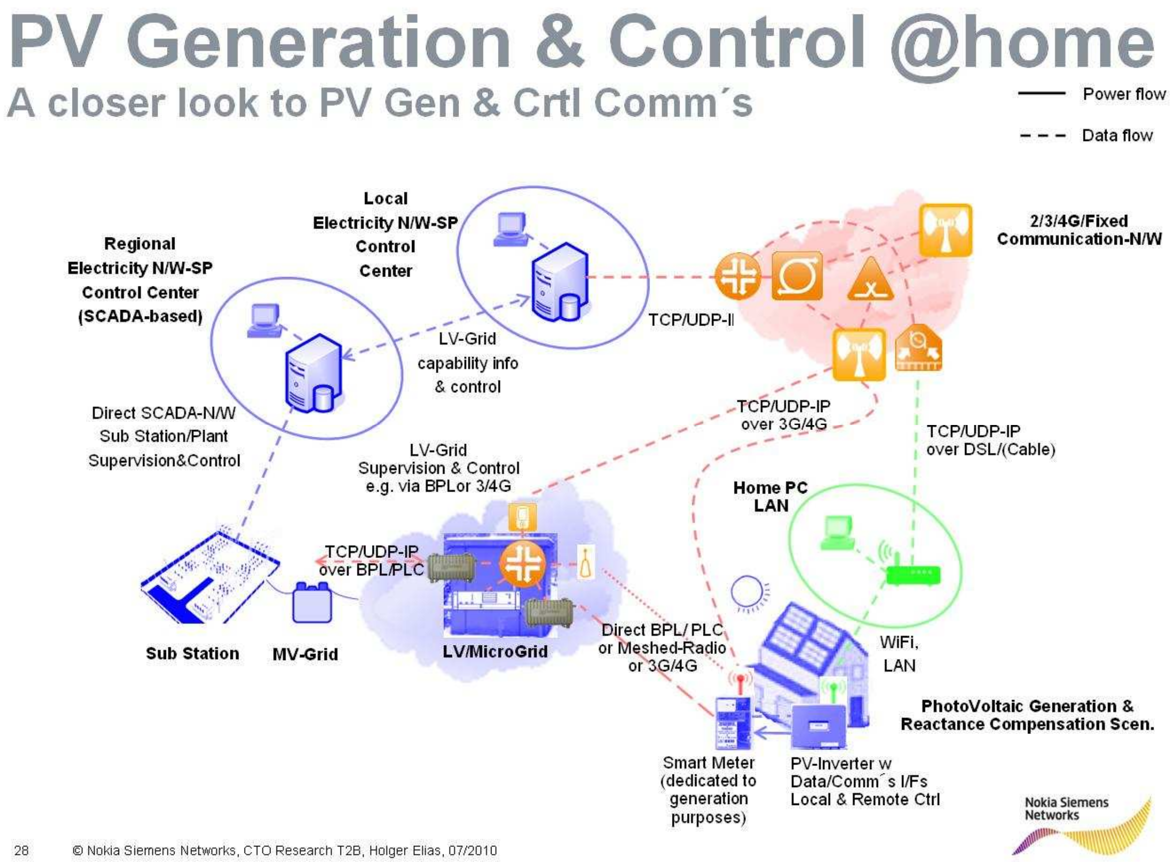
The displayed Smart Meter below is dedicated for electricity generation measurement purposes and may therefore differs from regular Smart Meters for consumption measurement.
Another advantage is the capability to support weighted electricity generation refunding, based on time-of-day tariffing (e.g. intended off-optimum-axis PV-panel placement to equalise the regional generation characteristic over the course of the day).
The Home-LAN shown is primarily dedicated to configure, monitor and maintain the PV-installations. There is no control foreseen from the Local Electricity N/W-SP via this link.
PV-Inverter-control shall be enforced via the dedicated Smart Meter for generation purposes. Considering the lesser importance in terms of data privacy in the generation case, such a meter device may incorporate a control interface for the PV-Inverter.

This architecture may be extended to other DERs´ control schemes (Wind, Water, BioGas, etc.) to enable an independent local LV-MicroGrid operation, reinforced by other MicroGrid areas through connection via the MV-Distribution-N/W and controlled by a Local Electricity N/W-SP.



Details of the PV Generation use case:

The comm´s architecture of the PV Generation & Control use case is identical to the beforehand described DER, DR/Microgrid core comm´s implementation (Use Case 5: LV/MicroGrid + superior MV/HV-N/W comm´s architecture). Differences exist in the local control architecture, as outlined in the Abstract section. A standards-based protocol I/F (basically IEC-homed), incl. object-data-format definition, will later enable not only PV-Inverters but also other DERs to become part of a controlled MicroGrid (please see below).



Controlling such an architecture requires reliable comm´s link with reasonable throughput and latency (per device in the N/W). Due to the lesser price pressure on these applications, wireless 3G or later 4G I/Fs are arguable, especially when utilising BPL or Meshed-Radio based central control from the LV-Grid. In this case all local control traffic will be aggregated at the LV-transformer sites and transmitted via this central site.

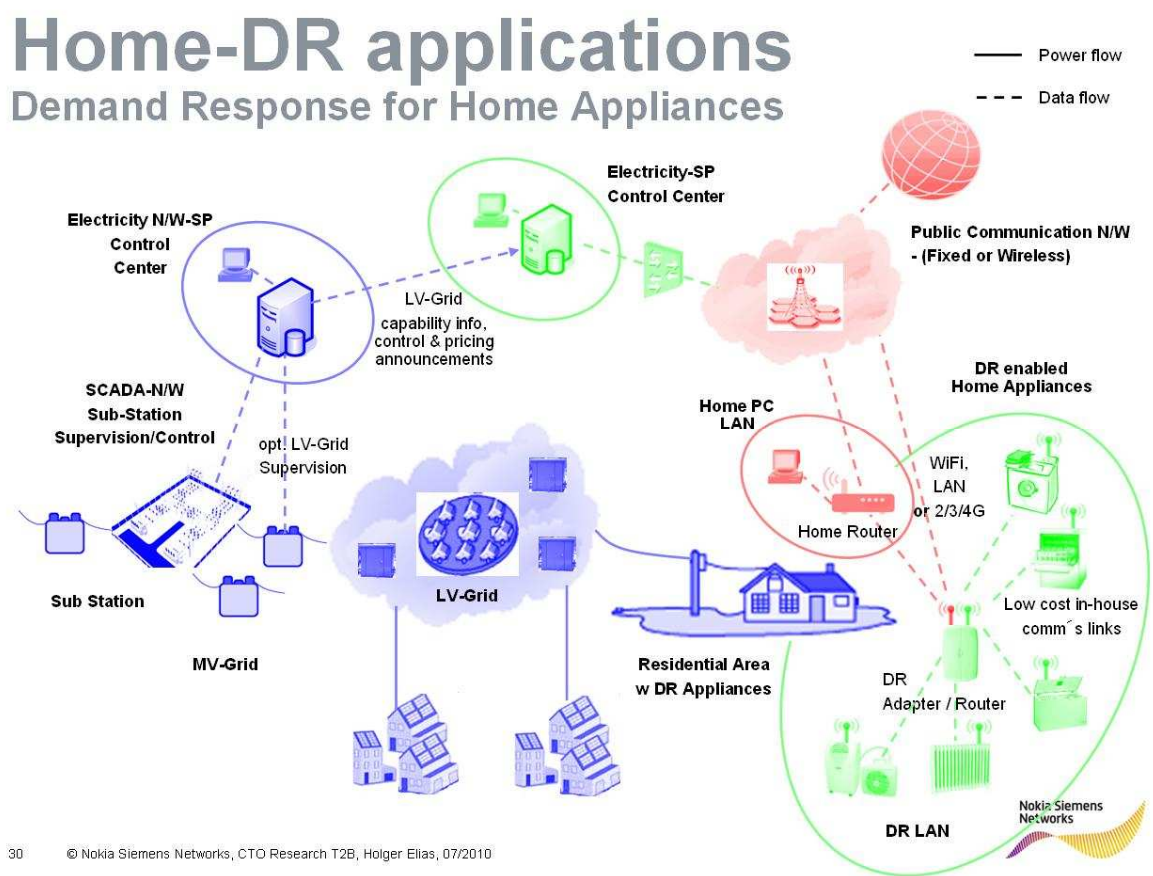
A 3G/4G connection to the LV-Grid also yields the advantage of independent MicroGrid operation w/o MV-Distribution-N/W connection (on which the BPL is transmitted). In order to reduce the control traffic and make the local LV-Grid even more resilient, some power control could be "sourced-out" from the Local Electricity N/W-SP´s control center to a partial independent local control instance, to allow limited autarkic operation. Such an "Pre-Aggregation-Controller" could be co-located on the LV-transformer premises.

6.3.3 Use-Case 8
Home-DR applications (Demand Response) for consumer appliances

Abstract:

Home-DR applications are not yet completely standardised and also follow another stream of standardisation than the original energy-sector driving-forces, like the IEC coming from the electricity-N/W field.
According to B/S/H two similar streams are visible, in the U.S., driven by the “American Association of Home Appliance Manufacturers, AHAM” (White Paper, 2009/12) and in the EU by the “European Committee of Domestic Equipment Manufacturers, CECED” (Position Paper, 2010/02), building on CENELEC´s “Appliance Interworking Specification V1.0 (EN 50523-1)”.

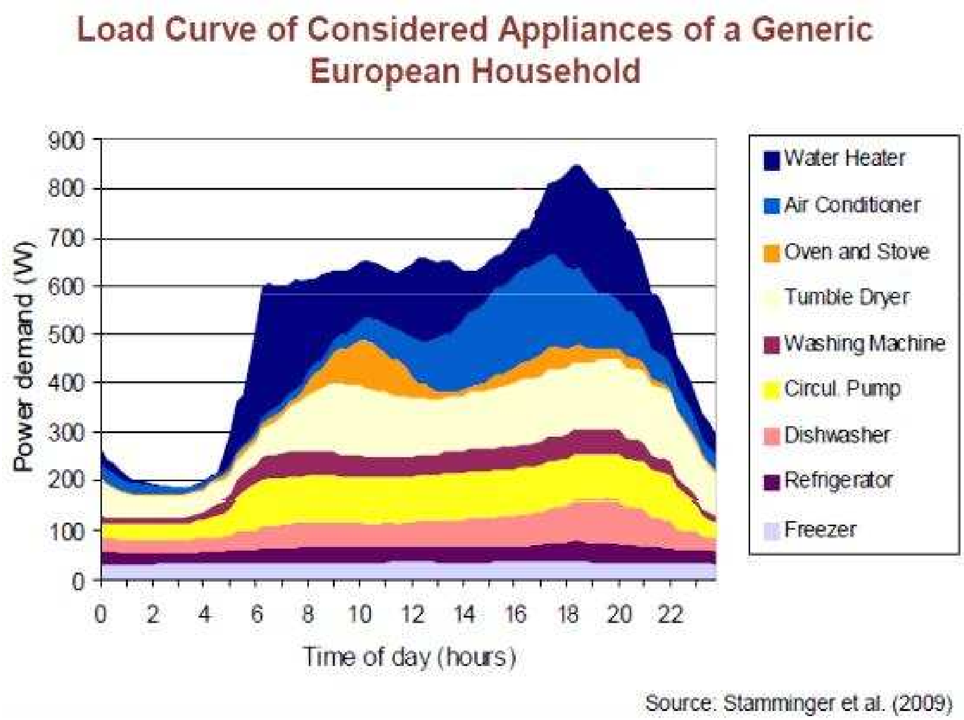
In this use case, Home-DR applications are defined through White and Red Ware equipment, which the user sets up himself, i.e. these devices are connected to a regular outlet, located wherever suitable in the home and are suitable for Home-DR application (please see below). Suitable means that the benefit to save energy at a certain time of day, during the lifetime of the devices, will overcome the additional cost of enabling this functionality.
This price pressure requires a very cost effective implementation, as known from consumer electronics and home networking.



In addition, operation of such devices must flexible enough to fulfil consumer’s requirements. Examples are deep freezers, which are capable of delaying cooling intervals until a suitable time of

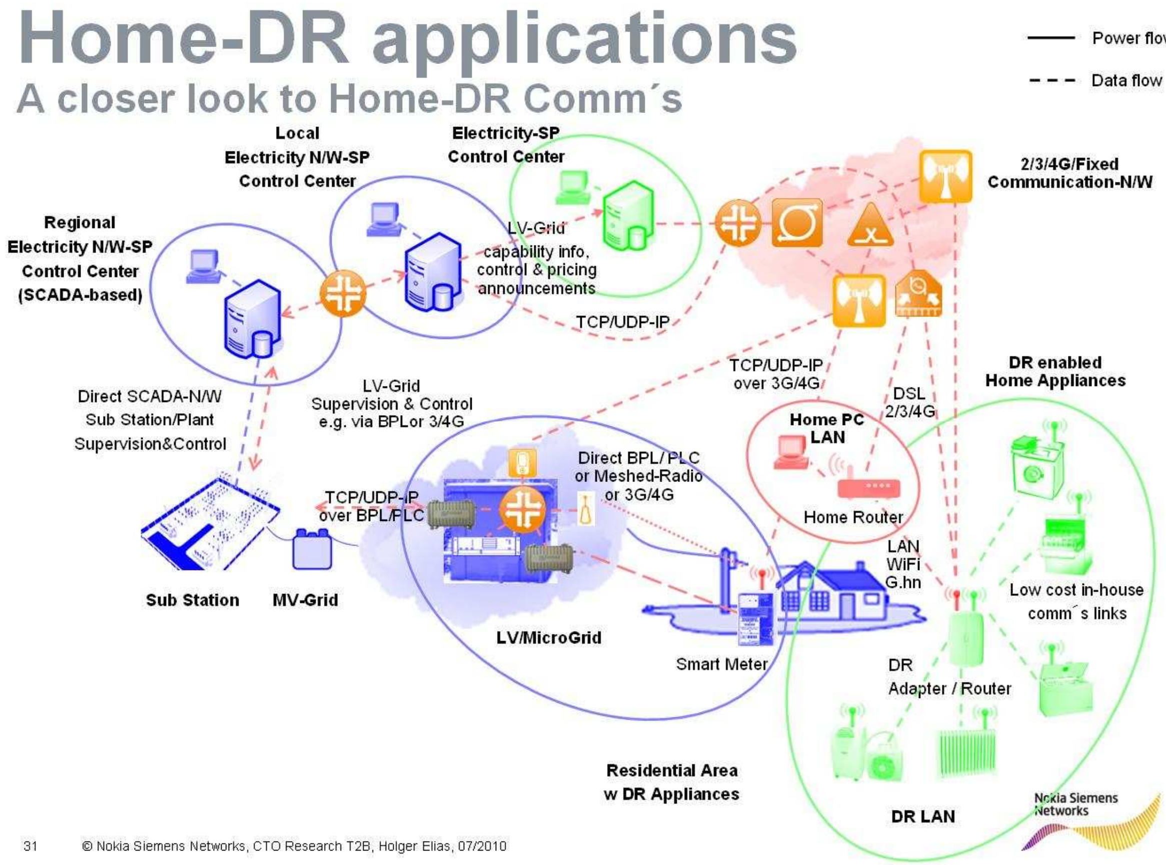
day, when the electricity-N/W SP is able to offer a relatively low price for electricity. In case of the freezer, cooling may be activated at noon, when the sun shines most (high generation from PV) or when there is strong wind energy available, otherwise at default times of day, off the recurring peak demand hours.
Further examples are washing machines, tumble dryers and dish washers, where the customer may agree on a proposed scheduled runtime or movable heating/cooling devices to simply reduce high priced time of day operation.

The average potential for diverse appliances is shown below. It should be noted that the main potential to be influenced lies in electric HVAC, which is covered above as “fixed gear” home appliances in use-case 5 (DER, DR/Microgrid control), nevertheless app. half of the average consumption in a European household is due to White and Red Ware equipment
(Please also note that the averaging does not imply a singular appliance device´s max. consumption, i.e. tumble dryers are quite visible, because they run a long time at high power. A washing machine´s peak consumption is as high, but occurs only for a short time, e.g. when heating up water or during fast spin.)



Details of the Home-DR applications use case:

This proposal is forward looking, since the LV-Distribution-N/W needs to be prepared for flexible tariff accounting. Therefore it is required that the Local Electricity N/W-SP (please see below) did install a Smart Meter infrastructure before in his LV-Grid, as decribed in the Smart Metering Use-Case 6 above.
As outlined above and for privacy control reasons as well as implementation cost reasons, it is proposed to keep the Smart Metering comm´s N/W separate from this Home-DR comm´s-N/W. Another advantage of this proposal is to fulfil the legal requirement to be able to choose a suitable local Electricity-SP separately.



It is anticipated that the Electricity-SP is interested to offer Home-DR services to differentiate himself from the competition. The associated main parts, this Home-DR-N/W is built from, are shown in green colour.
The El.-SP Control Center receives LV-Grid capability, control and pricing information from the Local El.-N/W-SP. This information is harmonised by the Local El.-N/W-SP with the Smart Meter tariff, accounted in the consumers´ residential home.
Via the 2/3/4G/Fixed Communication-N/W (and evtl. including the consumer's Home-N/W, when operating via Fixed Network) the El.-SP announces this pricing information to a G/W supplied by him, designated as DR-Adapter/Router.
This is a new device class in the residential home, at best logically comparable with a set-top box (for e-Energy management purposes, instead for multimedia). The DR Adapter/Router receives and stores the control and pricing information. On demand, the subsequently connected devices ask for currently available options, when the consumer communicates with ("programs") them or as in case of the freezer, upon internal demand planning by the device's controller.
This requires a simple low profile object model for each device to be connected and controlled, which shall be supplied by the White or Red Ware manufacturer and adapted to the DR-Adaptor/Router by the El.-SP, on a forward-looking basis and downloaded to it on a regular update basis.

End-to-End comm´s protocol security between the El.-SP and the DR Adapter/Router (including the comm´s N/W path) shall meet at least high consumer requirements (if not national law requirements as in the Smart Meter comm´s case), which is comparable to home–banking application standards, due to the financial analogy.
This advises strong data encryption, which should be administered and guaranteed by the El.-SP. In order to keep up a responsive "always-on" service, the communication I/F in case of a wireless

connection should be at least a broadband 3G/UMTS (or later 4G) type, considering object-device-table und upgrade downloads in the MB range.

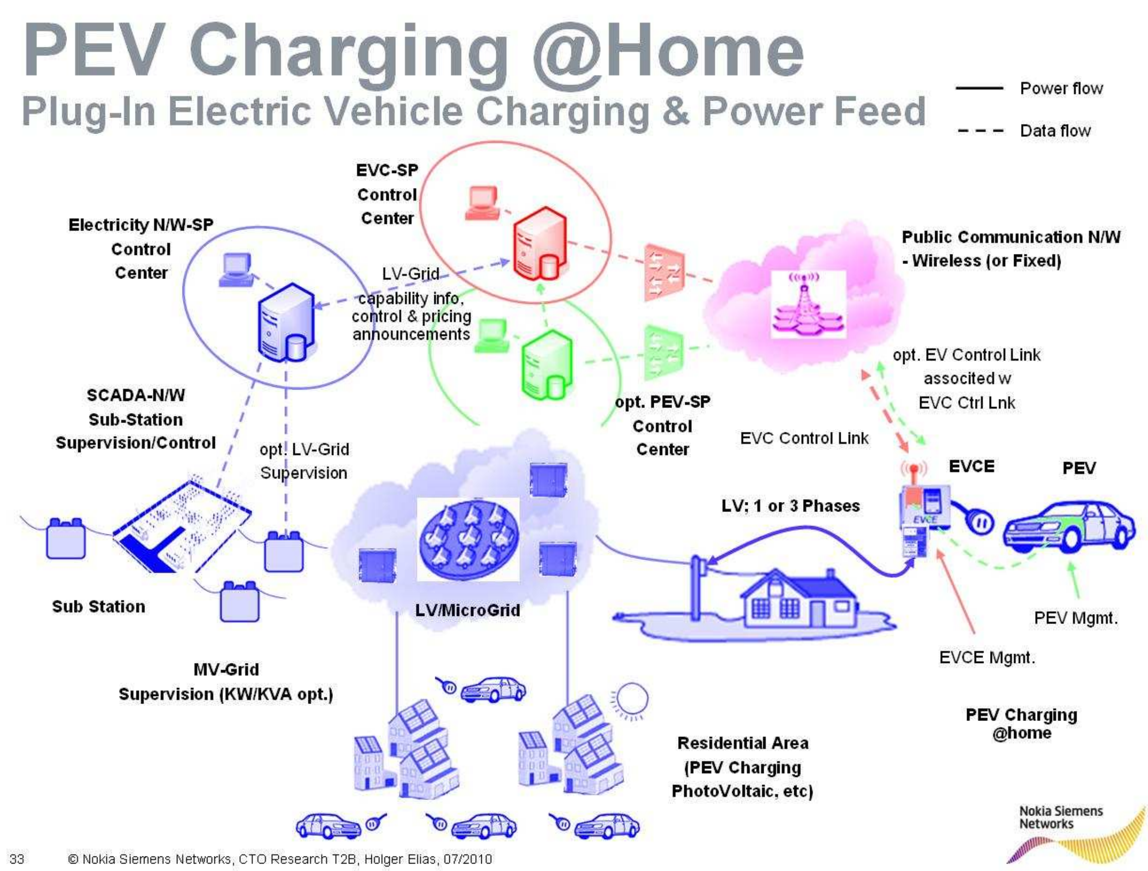
Comm´s protocols between the DR-Adapter/Router and the White & Red Ware are predominantly of the low cost type, like wired ones from the G.hn portfolio or wireless ones like ZigBee, Z-wave, etc. Data security and encryption requirements are moderate, since a practical local security (symmetrical password, e.g. like Bluetooth) should be regarded as sufficient, implying the consent of the consumer and the limited possible access to the DR-Adapter/Router control-software part via this I/F.

Important to note is the limited independence of the generic operation of the Home-DR system, when communication links are temporarily down or not activated, since the DR-Adapter/Router may offer a “best practice” offline-mode, which may be pre-programmed by the El.-SP to avoid regular peak pricing consumption.

6.3.4 Use-Case 9
PEV charging and power feed

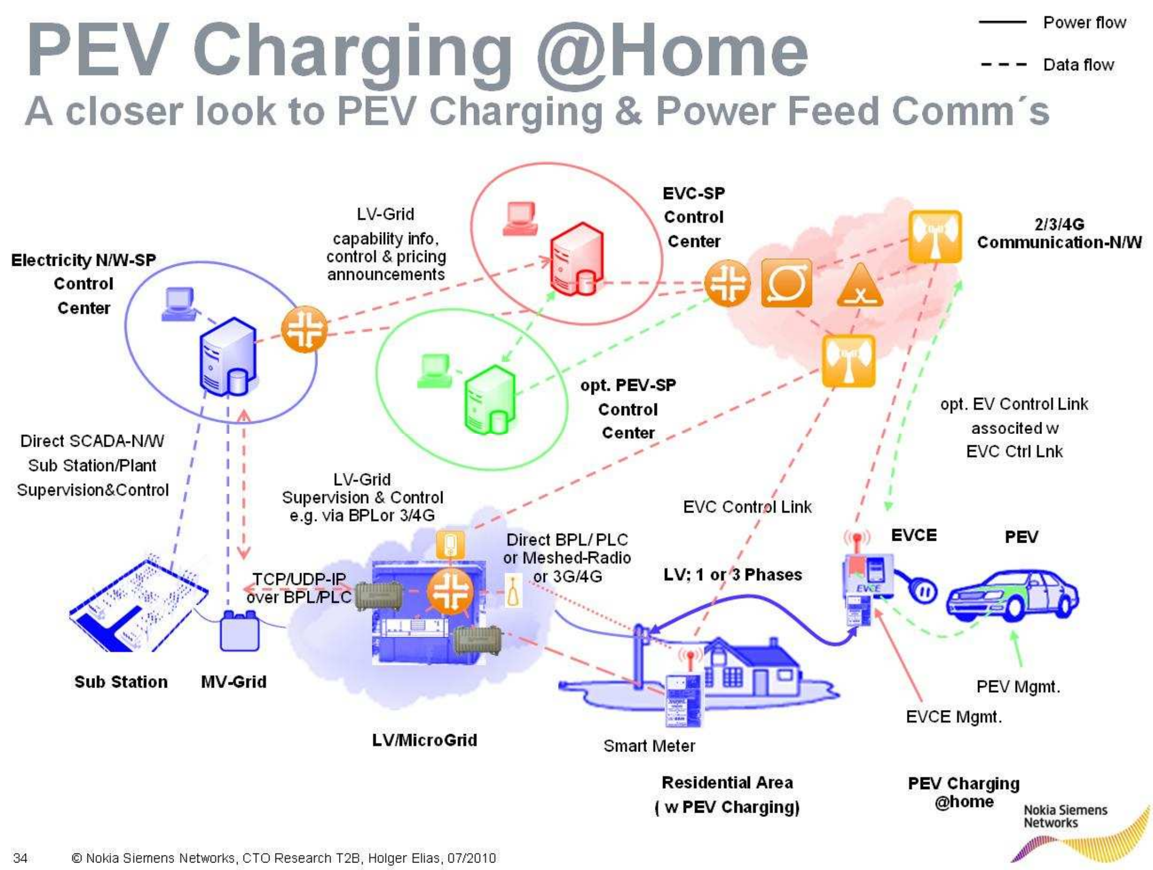
Abstract:

Plug-In Electric Vehicle (PEV) Charging at home will be a large volume application in the upcoming decades, compared to public PEV charging, which will always have additional overhead cost, at least rental fees for setting up such Electric Vehicle Charging Eqt. (EVCE) in public places. Therefore there will be a market for privately set up EVCE on residential premises (please see below).
Such EVCEs will be connected separately to the homes primary electricity supply, because of power requirements (e.g. fast 3 phase charging for more than one car).
In parallel, a Power Feed(back) option from the PEV´s battery into the Electricity-N/W may reduce the cost of ownership for the complete PEV eco-system.
Similar to the legal option to engage an Electricity-SP (El.-SP) next to the delivering Electricity-N/W-SP (El.-N/W-SP), it is reasonable to obtain an EVCE solution from a dedicated Electric Vehicle Charging SP (EVC-SP), who takes care of special functions like the DR enablement (cost effective PEV Charging and Power Feed) and functions in conjunction with PEV service and maintenance (providing a data connection for PEV health purposes, e.g. managing Power Feed cycles, PEV-SW upgrading & remote fault analysis, etc.) by the PEV-SP (the PEV-SP must not be identical to the PEV manufacturer, options like independent Fleet Management SPs are possible).



Details of the PEV charging and Power Feed use case:

From the drawing below, it becomes clear that the El.-N/W-SP is responsible for the residential homes (smart) metering. Depending on local laws, the metering for the EVCE may be independent and might be a physical part of the EVCE. This yields also the advantage that the branching from the residential homes primary power supply can be utilised in front of the homes fuse box, even from the outside, if the electricity is delivered above ground via poles.
Assuming no broadband data connection in the garage, where the EVCE shall be located, it is reasonable to rely on public wireless data service (2G/3G/4G) for this purpose. Since garages are located mostly above ground in residential areas, radio coverage is also assumed as quite sufficient.



Depending on the PEV´s brand, a parallel wired data connection may be included in the EVCE charging plug to enable the PEV´s controller to access its agreed service and maintenance provider (PEV-SP). In case of no wired connection (high data rate, e.g. Ethernet), a short reach link, e.g. via ZigBee or even Bluetooth may be established (medium data rate ~2Mb/s). This connection will then be routed via the EVCE´s mobile broadband link to the PEV-SP´s control center in parallel to the charging and power feed control data, which is routed to the EVC-SP´s control center.