D4.1.4.3: Optimal Concepts for Smart Grid Communication

Revision History

Edition	Date	Status	Editor
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Abstract

This document analyses communication requirements related to Smart Grid applications, which are either evolving or appear to need reassessment.
It focuses on the investigation of certain application use cases in the Smart Grid, which were selected to challenge known methods and implementations of communication networks and technologies.
By spanning a wide space of applications in the core and at the edge of the Smart Grid, we were able to analyze an adequate set of communication requirements.

In the Smart Grid use case examination we describe properties and limitations of applicable communication solutions, also taking into account relevant aspects of their character of commercial implementation. We limited our scope to future oriented wired and wireless communication solutions, which appear as most suitable to support new Smart Grid applications.

Transforming the spanned area of Smart Grid use case requirements into an area of Smart Grid Communication requirements yields the basis to determine optimal concepts for communication.
This methodology indicates that public wireless networks based on 3GPP standards (2G/GPRS/EDGE, 3G/UMTS and 4G/LTE) emerge as most optimal in the further implementation of Smart Grids.

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1 Preface

This report was done as a part of the Finnish national research project "Smart Grid and Energy Market" SGEM.

It was funded by Tekes – the Finnish Funding Agency for Technology and Innovation and the project partners.

The report was generated based on an analysis of the ongoing public world-wide Smart Grid use case discussion, performed during 2010 at Nokia Siemens Networks. Information for this study were provided by the various Smart Grid related documents, namely from NIST, IEC, DKE and others. As the Smart Grid is an evolution of today's grid also sources related to currently existing use cases and communication solutions have been used, some of them in German language related to DER integration and DA, where appropriate. In particular, the MV/LV DER interconnection and related communication requirements [34,35,36,39,40] were used as example specifications from a country with relatively high DER penetration and the resulting network integration challenges. The motivation for this was to get a better 'grounding' of the utilities communication requirements in critical areas such as availability, reliability, latency, etc.

We would like to thank our colleagues who supported and discussed during the preparation of the document, providing specific information and valuable comments, namely Nils Heldt, Seppo Yrjölä and Timo Knuutila in the NSN organization and the previous contributors in the CLEEN SGEM WP4 workgroup. We would also like to thank our partner Vattenfall for providing helpful background information on the practices of some of today's use cases.

2 Scope

This document is based on the previously provided sub-document "SGEM document SGC Use Case Evaluation", V1, from September, 30th 2010, embedded in "Collection of Smart Grid communication requirements [2] as well as "Interfaces of consumption metering infrastructures with the energy consumers - Review of standards" [1].

It contains a further selection of the therein described use cases for the purpose of a quantitative judgment on optimal concepts for Smart Grid communications.

These use case specific concepts are sighted later on and concluded for oversight.

3 Introduction to Methodology and Motivation

In order to determine the Optimal Concepts for Smart Grid Communication we chose to analyze a set of certain use cases or applications in the Smart Grid environment for their individual communication requirements. In a number of cases we considered communication requirements and solutions as used already today, from which Smart Grid Communication is expected to evolve.

It should be noted that we restricted the area of Grid communication applications to such use cases, which can be operated under regular IP-based network conditions.
Special grid communication implementations, like today's intra-substation direct Ethernet or PDH/SDH-based HV-line protection switching, which allow only for single-digit milli-second delays, have been excluded.

By describing and discussing applicable use cases' communication requirements from a "non-functional" (in terms of communication requirements, but "functional" in terms of application requirements) as well as from the "functional" communication perspective, we tried to embrace a complete plane of evolving Smart Grid Communications.

This "seed and harvest" approach visualizes the big picture by "seeding" all the different viewing angles, which become apparent throughout the single use cases' discussion and then "harvesting" the details into a condensed view in the latter chapters.

While discussing the individual Smart Grid use cases in the first instance in the SGEM contribution "Collection of Smart Grid Communication Requirements" [2], it became apparent that different requirements in an individual use case influence the communication characteristics quite significantly. Therefore we decided to discuss the following use cases one by one in more detail, to cover, display and document their individual characteristics to obtain a panoramic view per use case.

Selected representative communication solutions were further documented as "commonly-used" ones, to reference the respective details, which influence the "available network parameters' table".
This table was generated per use case, to serve as a quick look-up of results from the preceding discussions concerning a certain use case. It condenses numeric parameters in a holistic way into a more useful +/0/- scheme, to derive an overview for the latter combining chapters as far as possible.

It should be noted already here that various communication solutions are usually available to serve a distinct Smart Grid Communication task. One or the other unfold certain arguments, which favor its application in a specific use case. Nevertheless, arguments superimposed from the other use cases (like technology availability, applicability, cost, etc.), might let a certain communication solution look less favorable in the overall context. We were constantly trying to control such effects by maintaining a common overall judgment throughout the use cases' descriptions.

As an outlook, we tried to suggest an "evolutionary view", how an anticipated future environment will influence each individual use case scenario and what impact this may have on the optimal communication concept.

Later, the "synopsis" chapter tries to harvest and distill common learning in terms of communication requirements from the discussed Smart Grid use cases. This is achieved by holistic analysis of the individual case tables.

Finally, we "concluded" all findings into a generic recommendation, how to approach Smart Grid Communication implementation, not only from a telecommunication equipment vendor's perspective, but taking into account as much Smart Grid know-how, as it was possible to gain (also through the SGEM partnership) by a telecommunication equipment vendor.

4 Selection of the use cases

The selection of the use cases was originally done to cover a thematic overview about the various areas of the Smart Grid from power plant generation via transmission and distribution down to the consumer. In the light of the anticipated interest of our project partners and the public discussion, we chose to have the use cases described in this order.
As outlined before, the selection of the cases shall generate a maximized area of possible Smart Grid communication requirements to support a conclusive view at the end.

Our selection:

- Distribution Automation (DA / relevant in the Smart Grid Core)
- Smart Metering (AMR - Advanced Meter Reading / relevant in the Smart Grid Edge)
- Demand Response (DR) control
  (for large scale applications / relevant in the Smart Grid Core)
- Distributed Energy Resources (DER) control
  (for large scale applications / relevant in the Smart Grid Core)
- Wide Area Measurement Systems
  (WAMS / relevant in the Smart Grid Core)
- Home-Demand Response applications – Home Appliances
  (Home-DR / relevant in the Smart Grid Edge)

Throughout the discussion of the first DA use case, we have added an extended view on the evolution of 3GPP/other wireless communication towards 4G, which also serves as a knowledge repository for the following cases.

5 Distribution Automation

The considered key uses cases for Distribution Automation beyond the primary substation which require some means of communication are:

1. acceleration of Fault Detection, Isolation and Restoration (FDIR) for rural and urban feeders in order to improve customer interruption time related metrics
2. improving asset management, such as condition monitoring of the primary equipment such as switchgear, transformers, batteries, etc.
3. DER Feed-in reduction due to congestion of interconnected HV transmission network
4. monitoring and control of power quality such as the voltage profile along MV and LV feeders within the context of Smart Grid applications such as DER integration

These goals can be met by remote measurement, fault indication, monitoring and control functions. This in turn will require cost effective and reliable communication between SCADA/DMS and the assets of the distribution network such as re-closers, sectionalizers, disconnectors and secondary MV/LV substations. In case of 3.), a currently existing use case in Germany, the DSO’s SCADA/DMS needs to communicate with RTUs of DER resources connected to the LV/MV feeders

These use cases will be analyzed in more detail within the following sections.

Communication requirements which are specifically applicable for primary substations such as related to automation within the primary substation or for protection of inter-substation 110 kV lines are more stringent and are not covered in this UC analysis.

5.1 Rural Feeder Automation

5.1.1 Non functional requirements

Background information regarding system design issues for rural MV and LV feeders and the benefits related to introducing feeder automation can be found from [21,22,24].

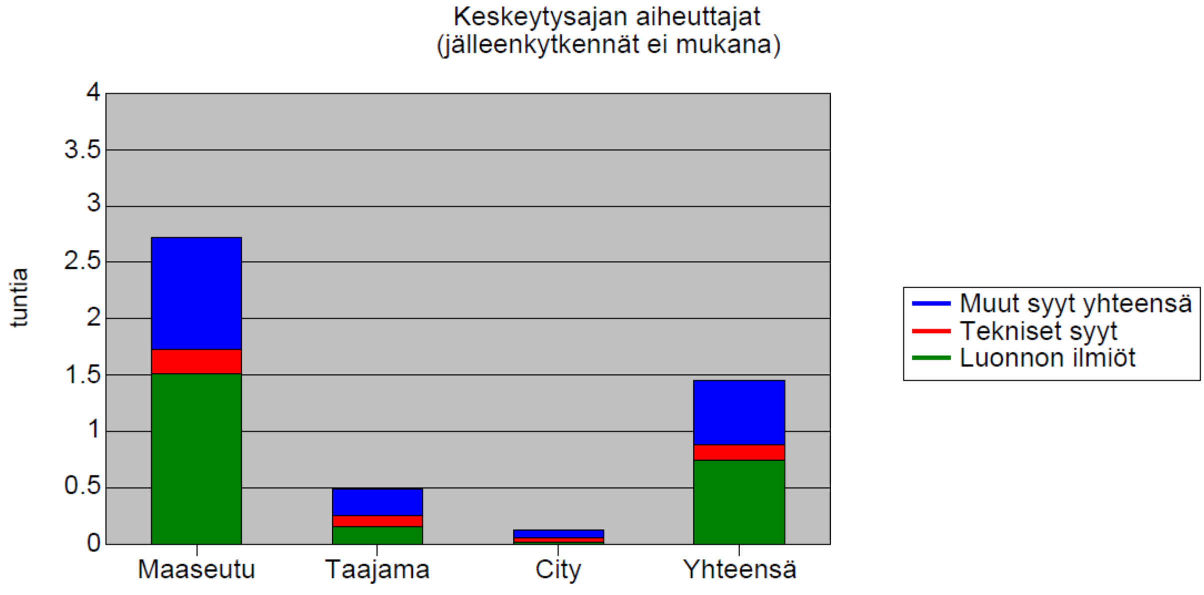


Fig. 5.1. Finland 2009 System average interruption duration index (SAIDI), from [23]

Fig 5.1 from [23] shows the system average interruption duration index (SAIDI) in Finland for the year 2009. Rural distribution networks and in particular the radial MV overhead lines suffer significantly more from faults than suburban or urban feeders. Further detailed fault related statistics, also for other metrics, can be found in [23].

Today, the regulatory framework in Finland and elsewhere sets monetary incentives for the DSO to reduce customer interruption [25]. There is hence an economic motivation for the DSO to introduce rural MV feeder automation (FA) with the targets of

- improving customer interruption metrics (SAIFI, SAIDI, …), reducing the cost due to energy not delivered
- avoid penalty payments (increase DSO profits) as per regulation
- increase profits due to more efficient work force management for FDIR (less site visits)

Generally speaking, introducing rural FA with remote controlled switchgear is most effective when the times to detect, isolate and (partially) restore power are of the same order as the time required clearing the fault. More information related to this use case can be found from [21,22,24,25,26] and is not repeated here. Fig. 5.2 shows a remote controlled pole mounted disconnector station.

Radio communications, either by dedicated VHF radios or, more popular, by public land mobile networks (PLMNs) such as GSM/GPRS within the 900 MHz bands are feasible means to provide the remote monitoring and control link in rural areas. The key is to provide ubiquitous radio coverage at low cost and sufficient availability.

Fig. 5.2. Remote controlled pole mounted disconnectors station, Foto ABB

5.1.2 Functional requirements

Information elements to be communicated between the IEDs of remote controlled recloser/disconnector stations and SCADA/DMS may be as follows:

- fault indicators, alarms and related measurements ((directional) earth faults, OC, auto-re-closure, zero sequence fault current Io, fault currents, voltage sags/under-voltage …)
- measurements (3U, 3I, power quality power factor, THD,…)
- states of disconnectors, circuit breakers (CB, status of AR shots)

- measurements and alarms related to condition monitoring (gas density of GIS (CB), battery condition, CB electric wear, transformer temperatures, …)
- switchgear commands (open, close, ..)

One example for the functionality of an IED used in rural FA is the one described in [27]. Information elements which can be exchanged between this IED and SCADA/DMS can be found from the IEC 60870-5-101 protocol specification in [28]. A typical[1] implementation in FA is to connect such IED to a RTU which provides the functions of protocol conversion IEC 101 <-> 104 and a GPRS modem such as e.g. the RTU described in [29]. The IEC 60870-5-104 protocol runs on top of TCP/IP conveyed over GPRS connectivity between the RTU and SCADA in a secured manner e.g. using VPN, firewalls and private IP address spaces.

It shall be noted that in rural MV FA applications aimed at speeding up FDIR the radio communications are not required to support ‘safety critical’ functions such as signaling for selective (differential) line protection schemes known for HV. Feeder protection is provided by the OC and earth-fault relays which do not require (radio) communication of signals in order to trip. As a consequence, the communications delay and availability requirements are quite ‘lenient’ and can be generally fulfilled by commercial cellular systems such as GPRS, 3G and 4G (LTE).

The most important radio communications related requirements of the rural FA use case are as follows:

1. delay: in the order of seconds. Delays related to communications should be small compared to delays due to e.g. motor operation of disconnectors, operator intervention at DMS on received alarms etc.
2. bandwidth: low, in the order of one … few tens of kbps as the amount of information to be exchanged is very limited and delay times are not critical.
3. coverage (rural): good radio coverage even at remote locations is essential. In practice this requires radio coverage in a frequency band < 1 GHz due to lower propagation losses.
4. communication system’s availability: In order for rural FA to be economically beneficial, the communication system should have a high availability so that FDIR operations succeed for a large proportion of isolated faults. In case communications are unavailable, re-closer/disconnector locations would need to be visited by utility service crews increasing the average service interruptions times and utility OPEX. Provided that there is radio coverage, an availability figure of ~99.5% seems reasonable with a goal to evolve towards more stringent requirements such as > 99.9%.
5. protection from power outage, battery backup: in the order of 1 … 6 h. IEDs may have battery backup in the order of some 48 h, however, a glance at the statistics of fault interruption times Fig. 5.3 from [23] suggests that a large proportion of isolated faults in rural areas can be cleared already within 4 h:

[1] for European, Asian markets. In N.A. alternative standards are used: DNP3, …

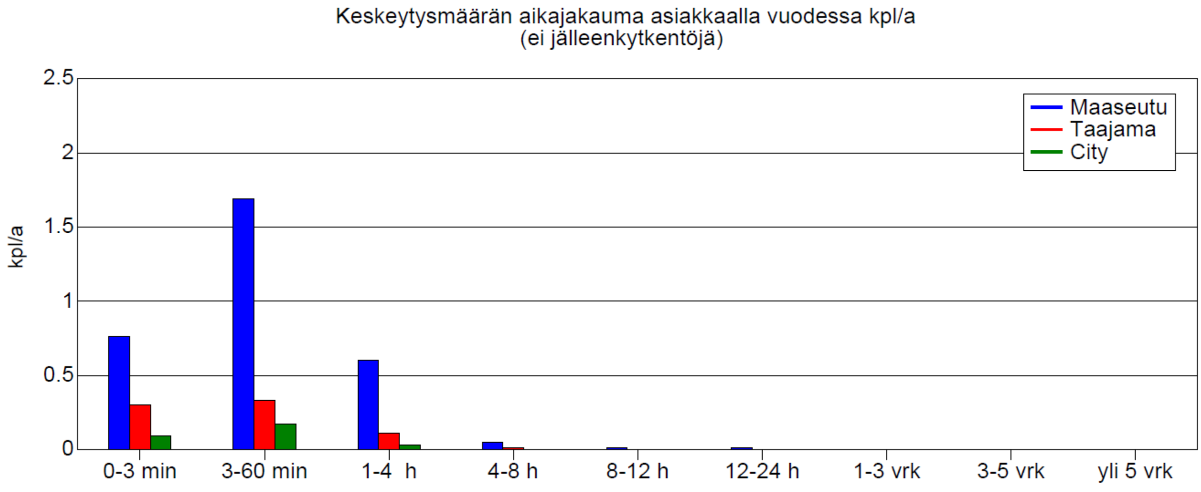


Fig. 5.3. Finland 2009 distribution of customer interruption times per year, from [23]

It can be assumed that fault isolation will typically take less time than fault clearance, perhaps in the order of ½ h. Hence, only those BS which happen to be power fed from the faulty section will need to switch to their batteries and may ultimately exhaust their battery and fail in case of very long fault clearance / restoration times.

6. Availability under large scale storms, outages:

Rural MV FA investment makes economic sense when the time (without automation) for fault detection & isolation + feeder reconfiguration is of the same order as times for fault clearance. In case of majors storms and related large scale power outages the potential benefit of remote controlled FA, when compared to isolated faults, will be much diminished due to:

- in case of a large amount of faults there is much less scope for remote controlled FA to be effective for fault isolation and switching of alternative power connections (such as closing of N.O. disconnectors)
- a larger amount of utility service crews will have to be in the affected area anyway
- in this case customer interruption times are dominated by fault repair times
- also the battery back-up of the IEDs is limited to some 48 h, hence outage/repair times in the order of days cannot be bridged.

While there might still be some benefit for remote controlled FA in case of storms in terms of reducing FDIR times for some customers, it appears that it is not reasonable and economically justified to design the communication system (+IED) availability and power backup requirements for wide scale and long lasting (~days) power outages.

7. requirement for communication backup systems, resilience: Given the above discussion for the availability requirements 4. and 5., there appears very little justification for redundant radio communication systems at the level of individual (pole-mounted) FA locations. However, there is a need to safeguard critical communication system components higher up in the network hierarchy (e.g. RNCs, subscriber databases, GGSN,…) in order to

prevent large scale outages. A possibility for alternative routes from the RTU to/fro SCADA throughout the communications network may be considered to meet very stringent availability (> 99.9%).

8. scalability: the communication system shall be able to scale with the traffic to/fro thousand(s) of RTUs in the field. It has to cope with emerging, smart grid related, applications of DA e.g. extension of FA to sub-/urban areas (like RMUs, additional sensors,…), fusing available power quality data from AM, supporting communications related to integrating DER into the distribution network etc. These will increase the number of RTUs under control of the DSO and the communication system shall be able to scale accordingly, both in terms of traffic in the user data plane as well as control (=signaling) plane. The communication system must be able to handle signaling loads related to managing a large number of intermittent and/or ‘always-on’ radio connections. Nevertheless, when compared to the density and traffic volumes of cellular broadband subscribers, the impact from RTU M2M traffic is likely to be low.

9. support of IP based protocols: the communication system must efficiently and reliable support TCP/IP protocols as commonly used in the stack for standardized remote control protocols such as IEC 60870-5-104 or a future evolution of IEC 61850 for SG DA. The radio system shall offer low packet loss ratios by means of physical (L1) / MAC (L2) layer error correction and re-transmission schemes. Migration towards IPv6 must be supported.

10. Security: the communication system must facilitate secure connections and be resilient against cyber attacks. Common IP related security mechanisms such as VPN, IPsec shall be supported, not excluding an additional e2e security layer between SCADA gateway and RTUs deployed by the DSO (e.g. tunneled VPN connection, TLS,…).

11. cost for implementation (CAPEX/OPEX): investments for remote controlled FA need to be economically justified. The cost of the RTU (radio modem, IEC protocol conversion) would need to be a small fraction (e.g. well below 10 %) of the cost of the primary equipment (e.g. disconnector, ~15kEUR). Radio system CAPEX and OPEX would need to be low, as FA is an application requiring mainly coverage with only little transported traffic and little other uses of the communication system. While a certain amount of CAPEX may be justified by the utility as part of a distribution network modernization project, low OPEX as recurrent cost item is important as the OPEX needs to be recovered from the avoided regulatory penalties each year. Nevertheless, cost for RTU modem functionality must not be ‘high’ due to possible upgrades as radio communication technology goes through shorter innovation / replacement cycles compared to the primary / secondary equipment of power systems. This points towards shared use of widely available packet radio systems (lower OPEX) using radio modem technology which is established elsewhere in other M2M ‘verticals’ (lower CAPEX), i.e. leveraging emerging M2M eco-systems.

12. multi-purpose use, integration of DSO communications: the communication system shall be able to integrate a wide range of DA communication applications with RTUs in the field in order to limit the number of dedicated systems the DSO needs to inter-connect towards or operate. Dealing with a larger number of specialized communication systems with limited application scope leads to high CAPEX/ OPEX, challenges in security, scalability and

flexibility for evolution towards new use cases. There will always be an economic scale benefit when using a single integrated communication system compared to the use of multiple systems.

13. future proofness: the radio system shall be future-proof and enable evolution towards more demanding emerging ADA/SG applications. Related requirements are:
    - the radio system should be packet based and support IP convergence
    - enable evolution towards better radio performance which might become necessary with new SG applications (lower delays, higher bandwidth, managed QoS)
    - support scalability, for both, user and control plane traffic to a much higher number of RTUs and changing traffic patterns which may be required for smart grids
    - should be based on widely available standardized commercial radio technology components which have price-competitive ‘eco-system’
    - should be within ‘mainstream’ of the developing M2M device / solution markets

5.2 Automation of urban secondary substations

5.2.1 Non functional requirements

The motivation for automating urban secondary substations is essentially the same as for rural FA: improving MV related FDIR related operation and workforce management in light of regulatory financial incentives related to energy supply reliability. Even though in urban areas cable networks with lower failure rates are used (refer to Fig. 5.1), there appears still an economic benefit to bring remote monitoring and/or control down to the secondary substations, in particular the ring main units (RMUs) in MV distribution networks with ring topology. Further additional uses cases related to smart grid functions (integration of DER resources, AM) are described below in section 5.3.

General background information regarding urban MV distribution networks can be found in [21] and examples for specific projects in RMU automation can be found in [30,31,32]. Examples for potential remotely controlled sensors and actors at a RMU are shown in Fig. 5.4 copied from [31].

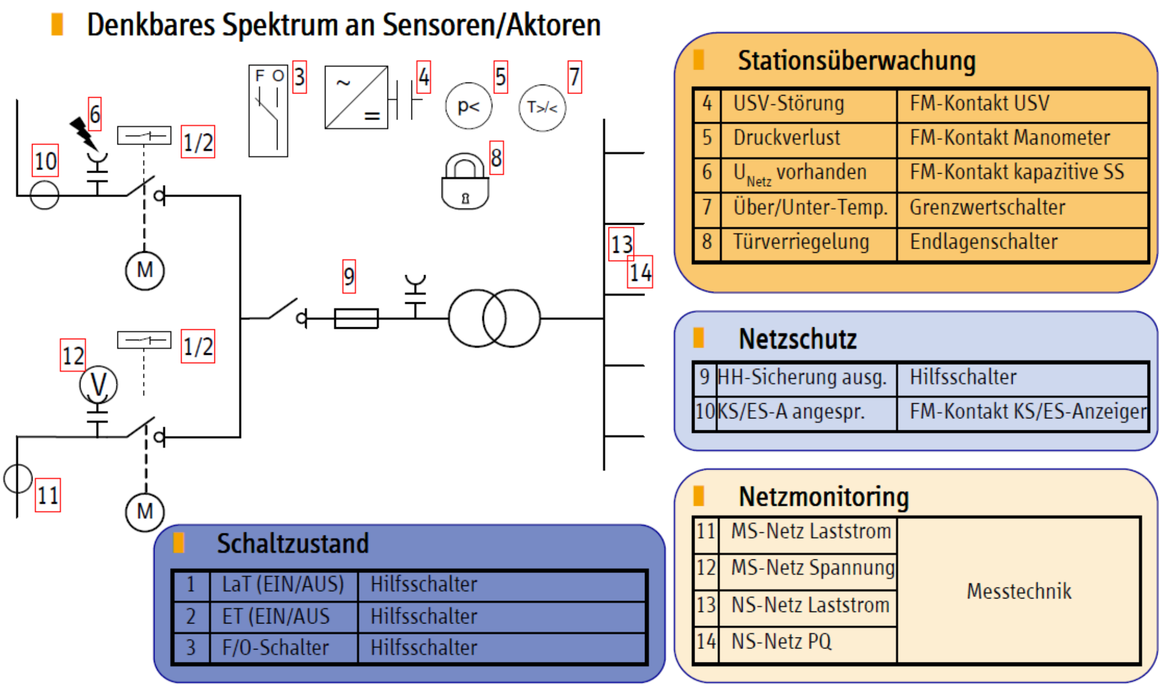


Fig. 5.4. Potential sensors and actors at a RMU, from [31]

Also at the RMUs wireline communications are generally not available, with possible exception of occasional availability of DSL access. Hence radio communications is, in most cases, the only viable option.

5.2.2 Functional requirements

The functional requirements are largely the same as discussed in 5.1.2 for rural FA and are not repeated here. The following differences may be observed:

- coverage: in urban areas also bands > 1 GHz are viable due to their general availability and the higher density of RMUs.
- scalability: will be more important compared to rural FA due to the higher density of RMUs with the number of RMU nodes in the order of thousands. Nevertheless, when compared to the density and traffic volumes of cellular broadband subscribers, the impact from RTU M2M traffic is likely to be low.
- cost for implementation (CAPEX/OPEX): low cost of the radio communication equipment and operations is here even more important as faults occur less often on urban cable feeders and hence the economic benefits from remote control must be generated from fewer events, putting even higher pressure on recurrent OPEX. If only remote monitoring and FI is implemented, the cost of the RTU and modem functionality would need to be a fraction of the sensors and interfacing IEDs. This, together with a large number of RMUs will drive towards low communication related CAPEX/OPEX with radio modem price points in the order of perhaps 100+EUR and very low network usage fees (or operational cost) from shared use.

- multi-purpose use, integration of DSO communications: If the AMI related communications are managed by the DSO there will be an economic scale benefit when using a single integrated radio communication system compared to dedicated systems for AM and FA

5.3 Other Smart Grid use cases impacting Distribution Automation

In this section other SG use cases which impact Distribution Automation related communication requirements are briefly discussed. Some of these may lead to more stringent requirements than FA.

5.3.1 Automatic metering (AM)

There is a connection of measurements at the secondary substations on the LV-side (voltage, power quality) with data points available from customer AM. Making these data points available at the DMS and fusing them with data points received from the secondary substations will enable more sophisticated monitoring and control of e.g. voltage drop profiles and power quality along the LV-feeders [37].

The communication requirements for AM are discussed in section 6. Performance related requirements such as radio coverage, delay and availability are more lenient compared to the DA use case, whereas the requirements for cost and scalability are more stringent. PLMNs based on 2G/3G/UMTS or later 4G/LTE technology display themselves as preferred default-choice solutions for a broad range of deployment scenarios of Smart Meter communication as shown in section 6.

If the AM related communications are managed by the DSO there will be an economic scale benefit when using a single integrated radio communication system compared to dedicated systems for AM and FA. This holds true for FA, especially when considering the fact that the order(s) of magnitude larger amount of AM nodes will necessitate low cost modems for the AM RTUs as well as scalable ICT architectures for managing their large amount of generated data points. Hence it will be beneficial for the FA application to take advantage of the emerging AM related communication M2M 'eco-system'.

5.3.2 DER Feed-in reduction due to congestion of the HV transmission network

Already in today's grid with high DER penetration (e.g. in Germany), the DSO participates in signaling of DER feed-in reduction due to local congestion of the next higher level(s) of the power transmission network (110 kV and higher). This use case is motivated by existing HV transmission network capacity bottlenecks[2] (e.g. violation of the *n-1* principle) in regions of high DER feed-in and at times of high DER generation (e.g. strong wind) and low demand (e.g. night time). This requires communications between the TSO and DSO and then in turn between the DSO and DER resources connected to the MV and LV distribution network. It is an already existing DER related use case from which additional SG requirements will evolve from.

On request of the TSO, which is responsible for power flows on the HV grid, the DSO (and DER operator) is obliged (subject to local regulation) to provide the means to reduce the feed-in from DER plants in order to prevent the overloading of HV transmission lines. The DER operator is obliged to provide the remote control interface towards the DSO and corresponding functionality in

[2] in countries with highly subsidized DER generation (such as Germany) it is a fact that the upgrade of the HV transmission networks does not keep pace with the rapid increase in DER generation capacity

the DER plant. The controlled parameters today are the feed-in real power, with future extensions to cover also reactive power. Typically the DER plant shall report the actual feed-in real power back to SCADA.

This use case should not be confused with a requirement of DER feed-in reduction due to power system over-frequency: this additional requirement, important for global grid stability, is captured typically within the DER interconnect requirements (see [39,40] for Germany) by means of a specified over-frequency vs power reduction curve and does not require any communications with the DER plant.

Neither should this use case be confused with voltage profile management across MV/LV feeders due large DER power feed-in– this is a local distribution network problem to be managed by the DSO itself and may or may not require any communications with the DER plant and/or MV/LV secondary substation, depending on the chosen technical solutions, see section 5.3.3.

This use case is a special case of controlling DER plants which is considered more generally in chapter 8.

Actual implementations of the DER Feed-in reduction use case can be found in Germany for DER plants > 100 kW and/or connected to the MV network [35,47]. The regulatory and operational requirements for the DSO and DER operator can be found from [34,39]. Examples of the resulting technical requirements from a DSO including compulsory communication interfaces towards the DER plant can be found in [36,47].

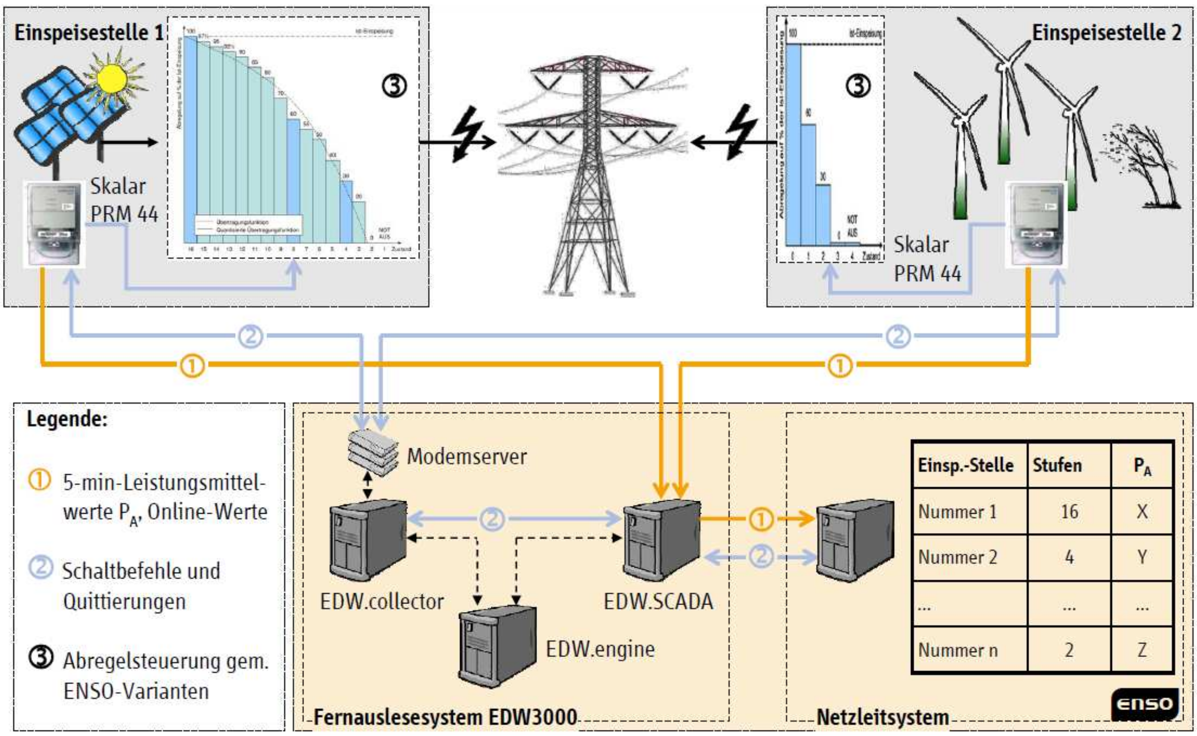


Fig. 5.5. Example for a GPRS based DER Feed-in management due to congestion of the transmission network, from [47]

The key functional requirements of this use case related to communications can be summarized as follows:

1. <u>delay:</u> in the order of tens of seconds

2. coverage: good coverage in the affected DSO region is desirable, use of external antennas, if needed, is viable. It appears that it is not essential to cover all DER plant locations, as only excessive power flows (i.e. much above the demand in the impacted DSO region) into the HV network needed to be curtailed; this does not necessarily require a working connection to each and every DER plant.
3. availability: Due to the implications on the HV network, it is important that the large bulk of excessive power flows from the impacted DSO region towards the TSO interconnection can be reliably curtailed. This requires very high availability of the involved central ICT components (such as the DSO management component, SCADA, gateways towards the communication network and it's central network elements). The option for alternative radio access (this could be another PLMN) is worth considering safeguarding against large scale communications outages. However, communication system availability at individual DER locations can be more lenient (e.g. comparable to PLMN services). Obviously, this function is not needed in areas affected by power outage.
4. scalability, use of quasi-simultaneous transmission mode (‘broadcast') from SCADA -> RTUs: it is important that a large number of the DER plants within the impacted DSO region can be reliably reached within a short timeframe (in the order of tens of seconds). No signaling congestion shall occur when a large number of reduction commands is sent quasi-simultaneously (‘broadcast') from the SCADA / DSO gateway to a large number of RTUs. Depending on the scenario parameters and chosen radio technology, this may necessitate ‘always-on' radio connections in order to reduce peak signaling loads related to radio link establishment when this function activates. Note that this ‘quasi-broadcast' requirement is somewhat unique to this use case as in most other instances the communications with the end-nodes can be decorrelated in time without impacting the required functionality.
5. cost for implementation (CAPEX/OPEX): cost of the RTU shall be a small fraction of the cost of small DER installations and should be in balance with e.g. the DER controller. A price point of ~150 EUR for the radio modem has been mentioned as an indication [35]. Also the OPEX must be very low, as there is no economical benefit, neither for the DSO nor DER operator, in supporting this function (it's a system related obligation originating from the TSO).
6. multi-purpose use, integration of DSO communications: the economic scale benefit when the DSO can use a single integrated radio communication system compared to dedicated systems should be exploited.

In actual implementations of this use case in Germany the required communications method and modem devices are mandated by the DSO. Communication methods mandated by the DSO for DER plants with a maximum power P of 100 kW < P < 2 MW (typically connected to the LV network) are among the following:

- long wave broadcasting in the 130 … 150 kHz range using EFR [46]
- PLC
- GSM/GPRS [47].

EFR and PLC with their inherent broadcast mode allow the DSO to reach a larger number of DER plants nearly simultaneously, however, EFR does not comprise any uplink channel, hence yet another communication system is required if the DER plant is to report the actual feed-in real power back to SCADA (which is indeed required for larger DER plants by the DSO).

Larger DER plants (> 2 MW), connected to the MV network, are typically connected to the DMS SCADA via bi-directional channels using, for example, GPRS for this use case [36,47]. Additional considerations related to the communication options applicable to DER plants can be found in section 8.3.

5.3.3 Voltage control in Distribution networks due to DER

EN 50160 is one important standard defining RMS voltage requirements at the customer's point of connection. In today's distribution networks, without DER, automatic voltage regulation (AVR) is mainly an issue of appropriate line-drop compensation of MV/LV feeders under conditions of dynamically changing load and 'floating' primary busbar voltages at the HV/MV station. For this on-load tap changing transformers (OLTC) are utilized at the primary substation. For an introduction to this topic and an outline of current practices see [21].

Introduction of DER into the distribution networks will lead to the additional issue of preventing over-voltage conditions due to DER in-feed, in particular in weak (rural) feeders. For a synopsis of the issues, see e.g. [57] and for examples of the actual discussions due to high PV in-feed in Germany, see e.g. [37,38]. The motivation to deploy 'smarter' AVR at distribution system elements (transformers, DER plants, STATCOMs,…) is to avoid more costly upgrades of the distribution network such as additional / larger feeders, additional primary / secondary substations, etc.

AVR in DER plants is essentially the control of reactive power generation/consumption subject to parameters such as the generated real power and/or voltage at the point of interconnection, etc. For example, in the MV and LV interconnection requirements in Germany [39,40], (new) DER plants are required to have the functionality of not only a statically configurable but also remotely and dynamically adjustable reactive power characteristics. However, this functionality appears currently not to be in general use by the DSOs. It also increases I^2R power losses due to reactive currents and may therefore only be actively used when the AVR of the OLTC transformer(s) alone are not sufficient to prevent generation curtailment of DER plants due to overvoltage conditions.

In this context the Adine project studied decentralized and centralized voltage control schemes, see the summary report [57] and the references therein. Centralized voltage control schemes require communications between SCADA/DMS and the nodes with AVR capability in order to exchange the set-points related to the AVR control loops as well as the actual measured voltage values, see Fig. 5.6 copied from [57]. Note, that there is an option to utilize the AMR data for more robust state estimation. Not shown in this figure is the additional option of MV/LV OLTC transformers for AVR as suggested in [37].

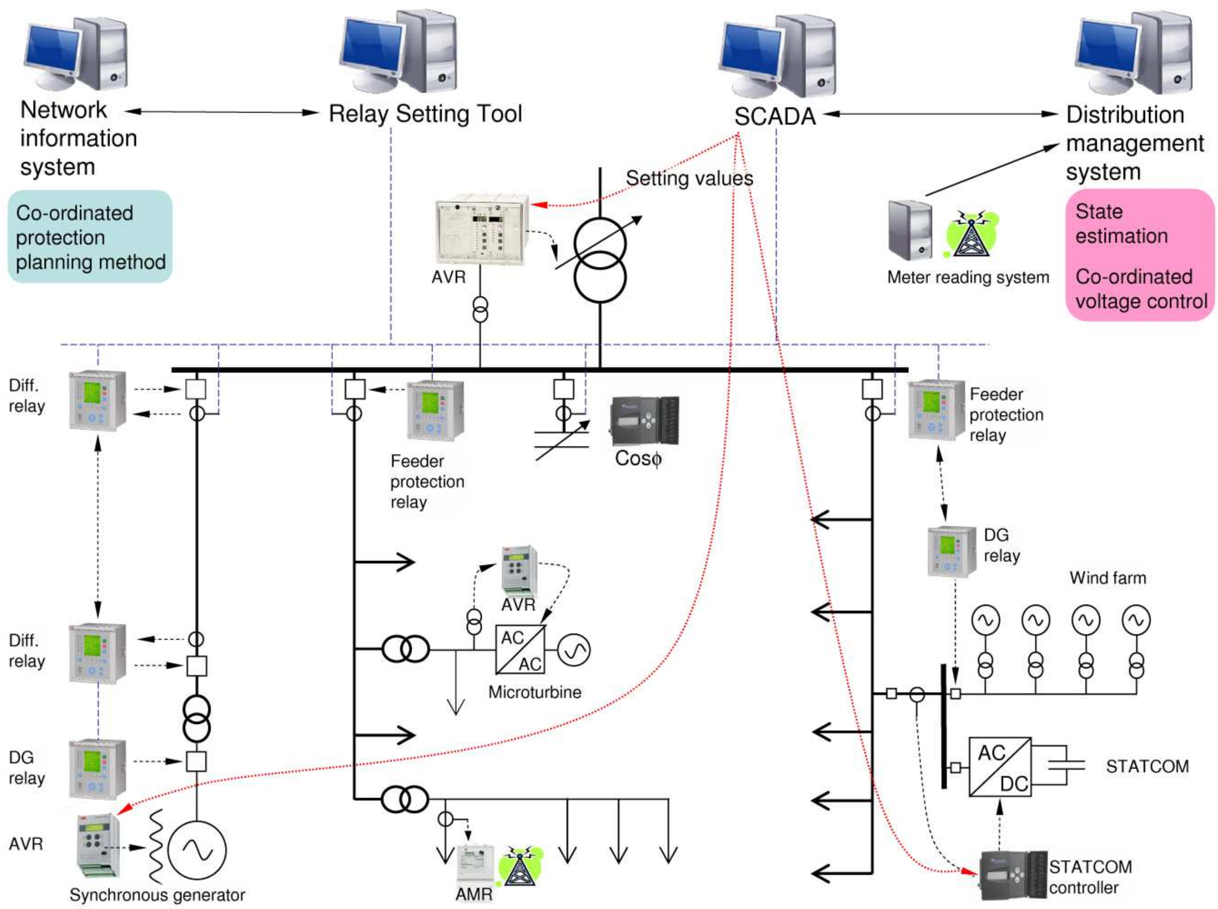


Fig. 5.6. Overview of the active distribution network in the ADINE project, from [57]

The key functional requirements of this use case related to communications can be summarized as follows:

1. delay: in the order of seconds to tens of seconds in line with gradual changes in generated power. This is reflected, for example, in the MV and LV interconnection requirements in [39,40],
2. coverage: good coverage in the affected DSO region is desirable as DER plants may be located in rural areas at sites without existing communications. The use of external antennas at the DER plant location, if needed, is viable. IEDs involved in AVR and located at the primary substation may share existing communication links towards SCADA/DMS.
3. availability: it's difficult to derive an exact availability figure, but the fact that this functionality is not 'mission critical' but rather intended to maximize the DER generation (within the capacity constraints of the distribution network) suggests that similar availability as for FA might be appropriate. It is reasonable to assume that in case failure of the communication link is detected within an IED the AVR will revert to a 'default', statically configured characteristic, i.e. perform in the same manner as 'decentralized' AVR, see also the

discussion in [57]. This may potentially require signaling to some[3] of the involved AVR IEDs not affected by communication outage in order to have them also revert into the decentralized (default) AVR mode. Any overvoltage conditions at the DER plant will always be prevented according to the interconnection requirements, also without communication links. However, the decentralized (default) AVR control loops at OLTC transformers would need to be configured in such a way as to reliably prevent over/-under voltages across the LV feeders, at least under the conditions of no or little DER generation[4], i.e. they would need to function in the 'conventional' manner. All in all, it appears that centralized AVR can be implemented with a robust fallback in case of communication failures ensuring that the DSO can fulfill voltage limits across LV feeders as required.

4. scalability: the amounts of traffic scales with the number of AVR capable nodes and the necessary 'keep-alive' (heartbeat) signals exchanged with SCADA. Voltage / VAR control is inherently a local problem (no signaling storms across DSO region) and the required control signaling instants are infrequent (likely orders of minutes) and can be decorrelated in time. When compared to the density and traffic volumes of cellular broadband subscribers, the impact from AVR M2M traffic is likely to be low.
5. cost for implementation (CAPEX/OPEX): cost of the RTU shall be a small fraction of the cost of small DER installations and should be in balance with e.g. the DER IED (controller).
6. multi-purpose use, integration of DSO communications: the economic scale benefit when the DSO and especially the DER operator can use a single integrated radio communication system compared to multiple, dedicated systems for each control function, should be exploited.

In Germany, for example, the required communication method and protocol for DER plants is mandated by the DSO. A concrete example specification for DER reactive power control for plants with P > 2 MW connected to the MV network is [36] which is on the basis of IEC 60870-5-104 on top of GPRS. DSOs and DER operators have a clear incentive to create synergies with the communication methods required for DER Feed-in reduction due to congestion of the HV transmission network, see 5.3.2.

5.3.4 LOM protection in Distribution networks with AR

Loss-of-mains (LOM) protection when DER generators become islanded in conjunction with Auto-Reclosing (AR) is a great challenge and may require low delay (~100 ms) signaling based schemes in the future. A brief synopsis of this issue can be found in [60,61,62], more research results in [57,58,59] and a survey of islanding detection methods in [63]. As LOM protection has system safety and well as system stability implications it shall be considered here in order to examine communication related requirements.

In a nutshell, the issue is as follows:

- DER plants connected to feeders with AR should be disconnected already before the first reclosing attempt; however,
- typically used islanding detection methods work too slow for this, in particular when Low Voltage Ride Through (LVRT) is required; hence

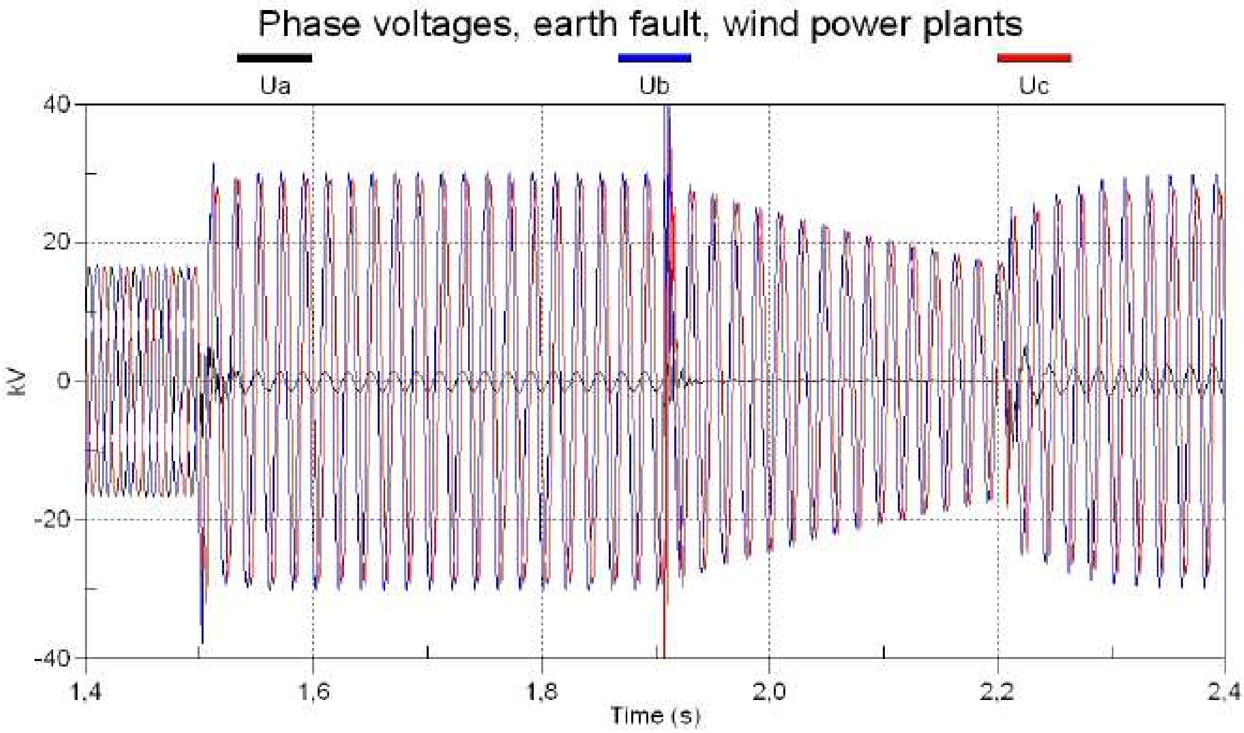
[3] e.g. OLTC transformers

[4] the transition towards the 'default' mode may or may not lead to disconnection of DER plants due to overvoltage conditions, but this appears acceptable within the probabilities of communication outages

- the DER generator continues to feed the arc in the open period of the AR and consequently the first reclosing attempt has a fair chance to fail. Furthermore the generator my loose the synchronization at re-closure. These result in
- additional wear and stresses on equipment (AR, transformers, generator…) and prolonged interruption times

The critical aspect here is the very short duration of the first AR open period: e.g. in Finnish MV networks this is only ~300 ms. The duration from fault occurrence to the AR trip can be ~400 ms.

The following simulation results copied from [62] of a failed first AR due to 3 wind power plants with asynchronous generators continuing to feed the arc (while spooling down) illustrate the issue: the fault occurs at 1.5 s, the AR opens at 1.9 s and re-closes at 2.2 s. Also shown, below, is a current spike due to phase reversal at the time of re-closure as a result of the generators getting out-of-sync during the 300 ms open time.



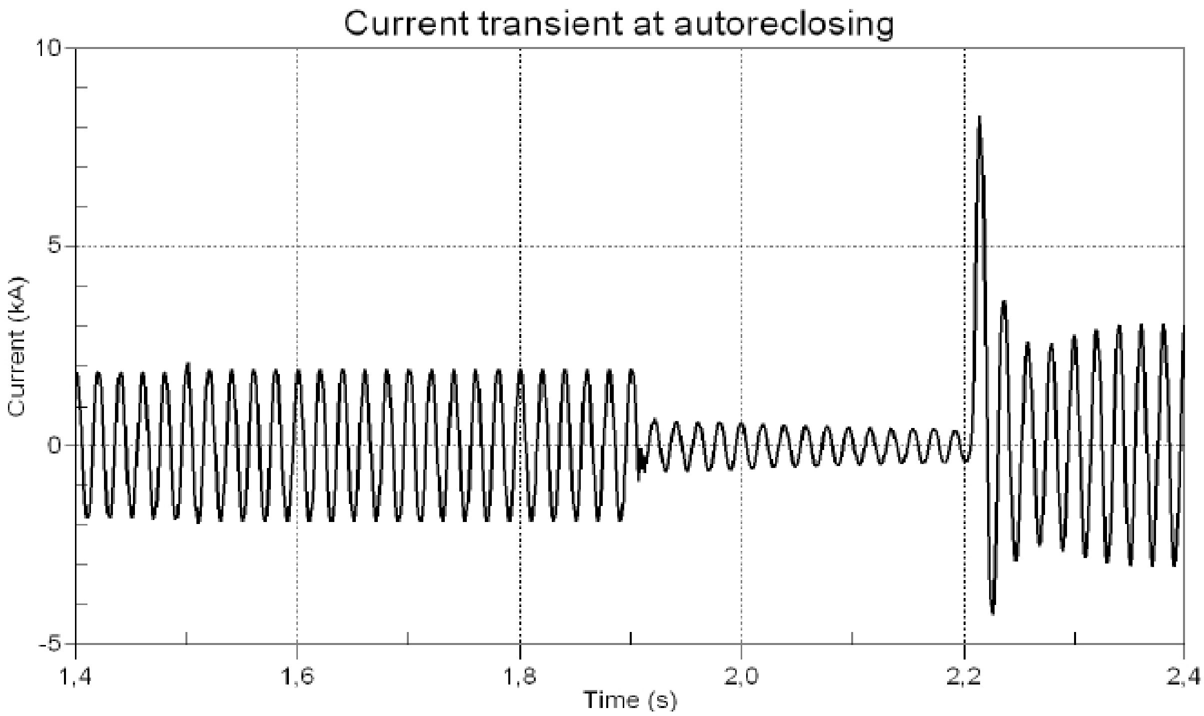


Fig. 5.7.Failed AR due to 3 wind power plants (asynchronous generators), copied from [57]

Such scenarios depend of course on many variables such as fault / generator location, type of generator, relay settings and, importantly, on the difference between load and generated power within the island at the time of the trip. More results regarding statistics of failed AR attempts can be found in [57,58].

In the, for example, German interconnection requirements DER plants connected to *LV feeders* are currently *not* required to support LVRT [40]; this means the use of passive islanding detection based on under voltage during the fault can be more effective[5]. In the following we focus therefore on DER plants connected to MV feeders.

In the, for example, German interconnection requirements DER plants connected to *MV feeders* are required to use passive islanding detection based on over/under voltages and frequencies [39]. However, the LVRT voltage requirements (red curves) have priority, as they are related to the overall power system stability and required by the TSOs. A fault in the HV network using AR will lead to geographically widespread voltage dips (with duration < 150 ms) and DER plants must not disconnect as otherwise this could result in a large loss of generation power.

[5] but not foolproof within the very short duration before 1st re-closure, see [60]. There is a requirement, using other (active) methods as well, to reliably detect islanding and disconnect after 5 s even under conditions of balanced load – this is primarily in order to protect utility worker's safety when islanding, not to facilitate 1st AR.

Based on the voltage dips alone, the DER plant has no means to locate the origin of the fault (HV or MV network) and often cannot[6], by virtue of the LVRT requirement, use voltage dips to trip on faults in the MV network before the first re-closure. This is illustrated in Fig. 5.8, showing two failed AR attempts in the MV network together with LVRT requirements (red curves), copied from [39]:

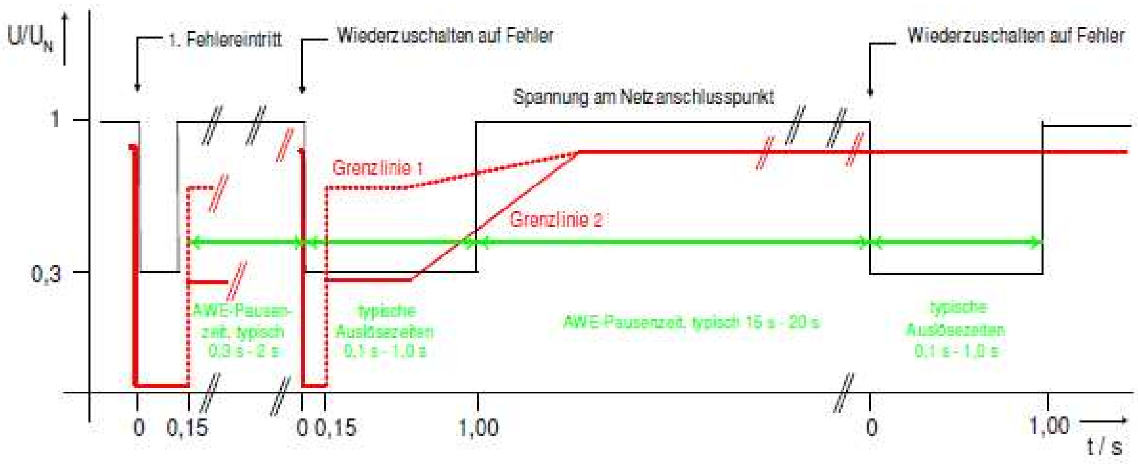


Fig. 5.8. Two failed AR attempts in MV network and LVRT requirements (red curves) from [39]

Unlike in HV networks, there may be multiple AR shots in MV networks, however, the duration of the 2nd opening may be much longer, perhaps ~15 … 20 s as in Fig 5.8. Hence the DER plant has much higher chances to detect the islanding and disconnect prior to the 2nd re-closure (this is allowed in [39], regardless of LVRT, as this leads only to local DER trips).

[39] contains a scenario in which the sustained in-feed from DER plants supporting LVRT may cause even the failure of the AR on the HV line as shown in Fig. 5.9. The suggested remedy is signaling between IEDs: after the distance protection IEDs in primary substations A and B tripped[7] the CBs, the distance protection IED within primary substation C can locate the fault and command the IED at the CB of the DER feeder to open and stop feeding the arc. This is a case of intra-substation signaling and could be done, for example, with fast IEC 61850 GOOSE messages [64] – all this prior to the 1st re-closing on the 110 kV line.

Furthermore [39] states for the corresponding case that the DER plant supporting LVRT is connected along the MV feeder (rather than SS busbar) that the DSO has the right to request a (fast[8]) signaling connection to the CB at the DER's point of interconnection.

[6] actually, in order to ease this fundamental conflict between LVRT and fast AR, [39] relaxes the LVRT requirement for DER plants connect to MV feeders *with AR.* This is a trade-off in favor of the DSO and DER operator on the expense of the TSO responsible for system stability.

[7] short circuit current from HV network >> DER plant(s)

[8] Binary Signal Transfer (BST) is mentioned as an example implementation

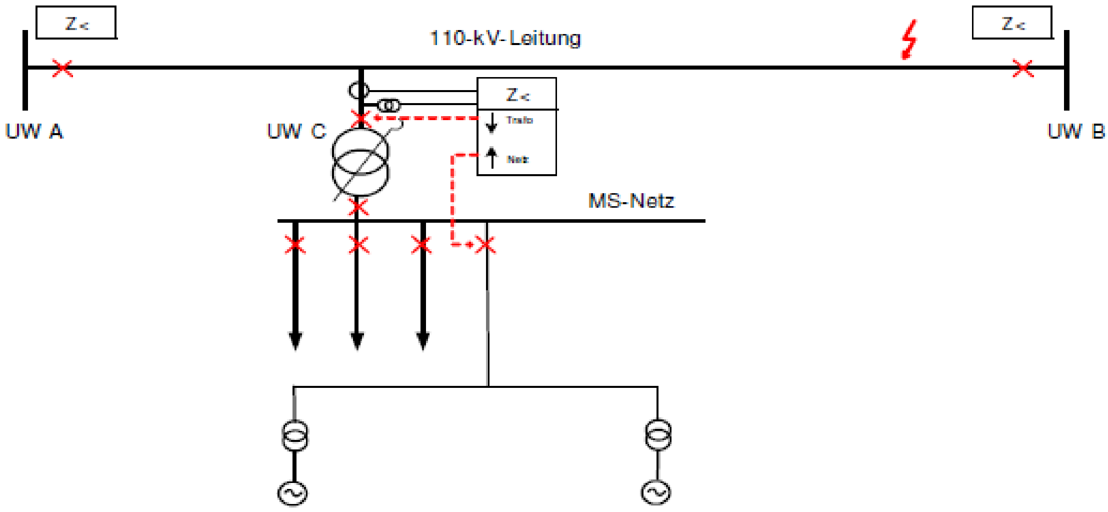


Fig. 5.9. AR attempts in HV network facilitated by signaling, from [39]

The above discussion motivates the use of signaling based schemes to facilitate LOM protection. Not only would this alleviate the above AR related issues, but would also support further functions such as blocking of DER trips due to faults of adjacent MV feeders, controlled islanding (if so supported by the MV network) and many more cases. These is discussed in more detail in [57,58,60]. Fig. 5.10 shows an example of the tests conducted in Adine in which total signaling transfer times between the IEDs of 30 ms based on IEC 61850 GOOSE messaging across Ethernet were achieved[9] [57,58].

[9] of which 5 ms were used on the BST optical lin

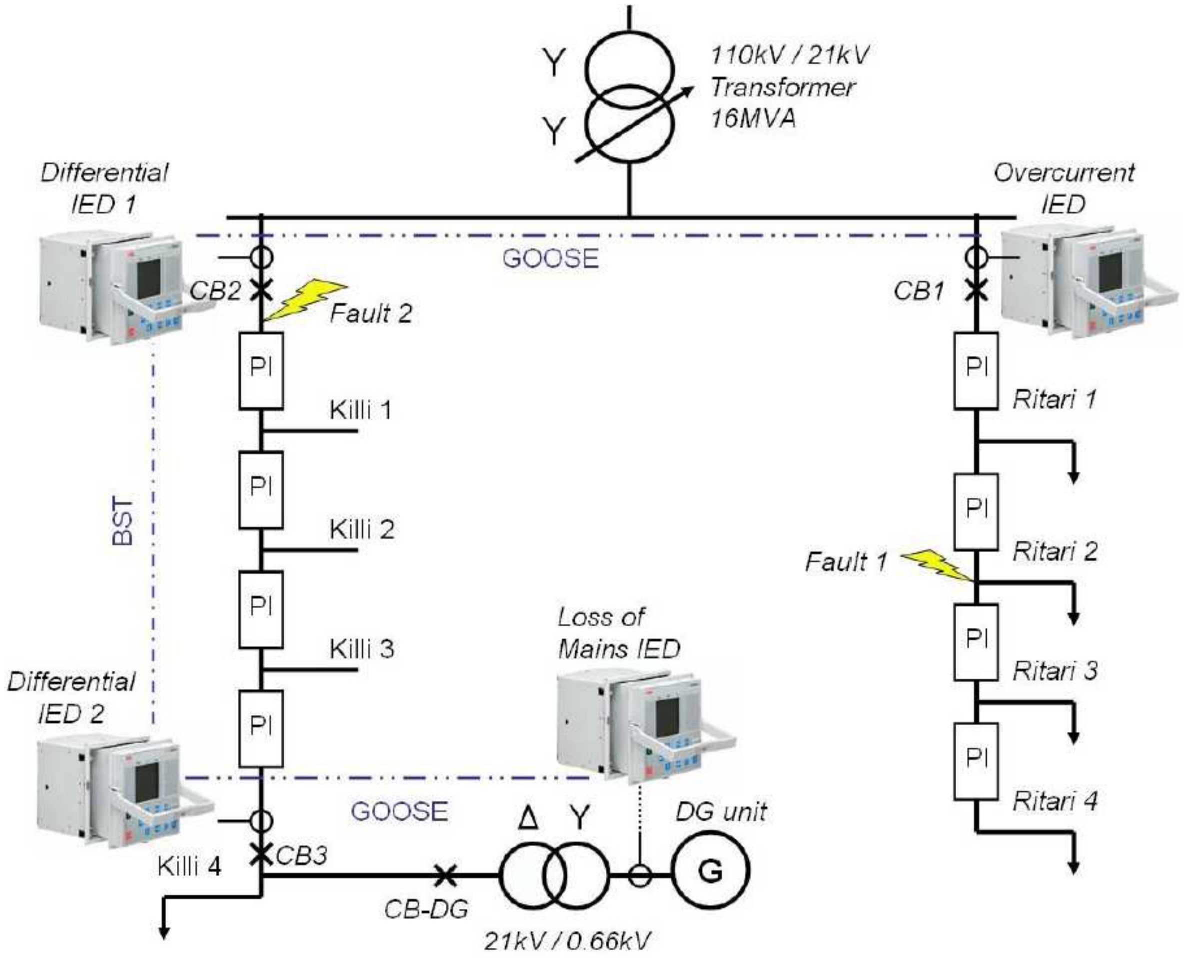


Fig. 5.10. Communication arrangement between feeder and DER unit protection, copied from [57]

A few remarks to this when considering real deployments:

- signaling towards a LOM IED may augment conventional passive (or active) islanding detection methods rather than replace them, thus creating another layer of defense in LOM protection [61]. This will facilitate stringent LVRT requirements not compromised by the requirements due to, for example, AR.
- the signaling towards the LOM IED cannot be carried via GOOSE/Ethernet, but has to be carried on top of TCP/IP via an IEC 61850 substation gateway and further IP gateways of the utility proving access to the IP network the LOM IED is attached to.
- unlike the other DA use cases with SCADA/DMS ←→ RTU 'hub and spoke' connectivity, we have here a IED ←→ IED 'meshed' connectivity (due to the low latency requirement). This will have implications regarding managing network configuration and security. E.g. in the above Figure, IED2 protecting the MV feeder needs to be aware of the IP addresses of all connected LOM IEDs and also needs the access rights to control them.
- IP routing rather than PVCs may facilitate the required connectivity in a flexible manner
- due to the often rural geographical localization, especially of smaller DER plants, mostly located in the vicinity of existing MV-lines, the access to such stations by available wire-

bound communication networks is not a given (e.g. subscriber lines for DSL, fiber connection, leased lines). A mix of radio and fixed line access needs to be considered for the LOM IEDs.

The key functional requirements of this use case related to communications can be summarized as follows:

1. delay: the exact maximum E2E delay requirements between the IEDs would need to be elaborated further; naturally they depend on the AR relay dead time settings (300 … 500 ms) acceptable for MV networks. As a starting point 50 … 150 ms could be considered. This is an area FFS. Delay and delay variation across the involved IP networks would need to be guaranteed by suitable QoS mechanisms.
2. coverage: good radio coverage in the affected DSO region is desirable as DER plants may be located in rural areas at sites without existing communications. The use of external antennas at the DER plant location, if needed, is viable.
3. availability: it's difficult to derive an exact availability figure, so let's look first at the implications of communication failure. If this is detected by the LOM IED, the stand-by passive (or active) islanding detection methods may be re-configured into a specific 'fall' back mode. For example, those LOM IEDs of DER plants connected to MV lines with AR could be re-configured towards more relaxed LVRT under-voltage requirements in order to trip with high probability on voltage dips during fault occurrence. The remaining LOM IEDs affected by the outage could retain their 'default' stand-by settings as islanding detection with times in the order of seconds may be acceptable during the short time durations of communication outages.

   The LVRT requirement is mainly aimed at preventing large-scale tripping of DER plants in case of faults in the HV networks, hence they are resilient against local non-compliance as a consequence of local communications outage. On the other hand, AR failures may have detrimental impact on the DER generator and DSO equipment.

   Due to the stability implications on the HV network, it is important though that the large bulk of DER plants within the DSO region comply with strict LVRT requirement. Assuming that communication failures could lead to some DER plants being configured with less stringent LVRT settings, large scale communication outages may become critical and must have a very low probability of occurrence. This requires very high availability of the involved central ICT components (such as the DSO management component, SCADA, gateways towards the communication network and it's central network elements). The option for alternative communication access (this could be another PLMN in case of radio access) is worth considering safeguarding against large scale communications outages. However, communication system availability at individual DER locations can be more lenient (e.g. comparable to PLMN services). This is an area FFS.

4. scalability: The number of end nodes scales with the number of DER plants requiring this signaling. Even when considering extension towards DER plants connected to the LV network in the future, the impact from LOM IED M2M traffic is likely to be low when compared to the density and traffic volumes of cellular broadband subscribers. Nevertheless, the bandwidth/resources consumed per connection might be relatively higher as stringent QoS priorities need to be applied to meet low delay requirements. Implementation of the IED – IED connectivity (configuration, routing) should scale properly (e.g. IP routing may be beneficial).

5. cost for implementation (CAPEX/OPEX): This use case may be not so cost sensitive as the other DA use cases, as the functionality is network protection related and less exposed to economic trade-offs. It's also more likely to be used on larger, isolated DR plants (power rating in the order of MW) with high CAPEX/OPEX; hence the communications related expenses are relatively less important.
6. multi-purpose use, integration of DSO communications: the economic scale benefit when the DSO and the DER operator can use a single integrated IP based communication system compared to multiple, dedicated systems for each control function, should be exploited.

5.4 Descriptions of commonly-used communication solutions

5.4.1 Dedicated Radio systems in VHF/UHF bands

5.4.1.1 RADIUS

Radius [45] is a proprietary radio system operating in the VHF bands which is being used in some rural feeder automation projects. Due to its proprietary nature, lack of inherent support of TCP/IP protocols and IP related security mechanisms, lack of scalability, bandwidth and future proofness it is not considered as viable for smart grid communications related to DA.

5.4.1.2 TETRA

Use of TETRA [44] as radio modem has been suggested for RMU automation projects [32]. However, TETRA has been optimized for public safety (PS) related mobile field crew operations (police forces, fire brigades,…) and has therefore special voice features such as support of dispatching, fast setup of group calls, mobile-to-mobile calls (DMO) etc. None of these H2H features is relevant for the M2M communications required for DA.

The claimed higher availability, reliability and 'ruggedness' of TETRA under 'crisis situations' will add little benefit to FA use case due to:

- TETRA reliability is mainly connected to sustaining H2H calls in BS island mode and DMO operation. In both instances the required connectivity between RTU and SCADA/DMS would be lost anyway.
- TETRA's higher physical site protection, longer battery back-up times and/or alternative power feeds improve availability, however, very high availability (>99.9%), while desirable, is not an essential requirement for FA use case to make economic sense as discussed above.
- Features to manage system congestions and overload under 'crisis situations' such as priority access, call barring and pre-emption are not unique to TETRA and also possible in PLMNs such as LTE, see e.g. [55].

Furthermore, TETRA terminals (modems) are few and expensive compared to devices for public cellular systems [44].

Finally, all established TETRA system vendors have announced support of LTE for the evolution towards broadband PS radio and formed alliances with LTE system vendors.

5.4.2 WiMAX

While WiMAX has some common features as LTE, e.g. the OFDM radio access method, it's use for rural FA and DA related applications appears limited. This is due to:

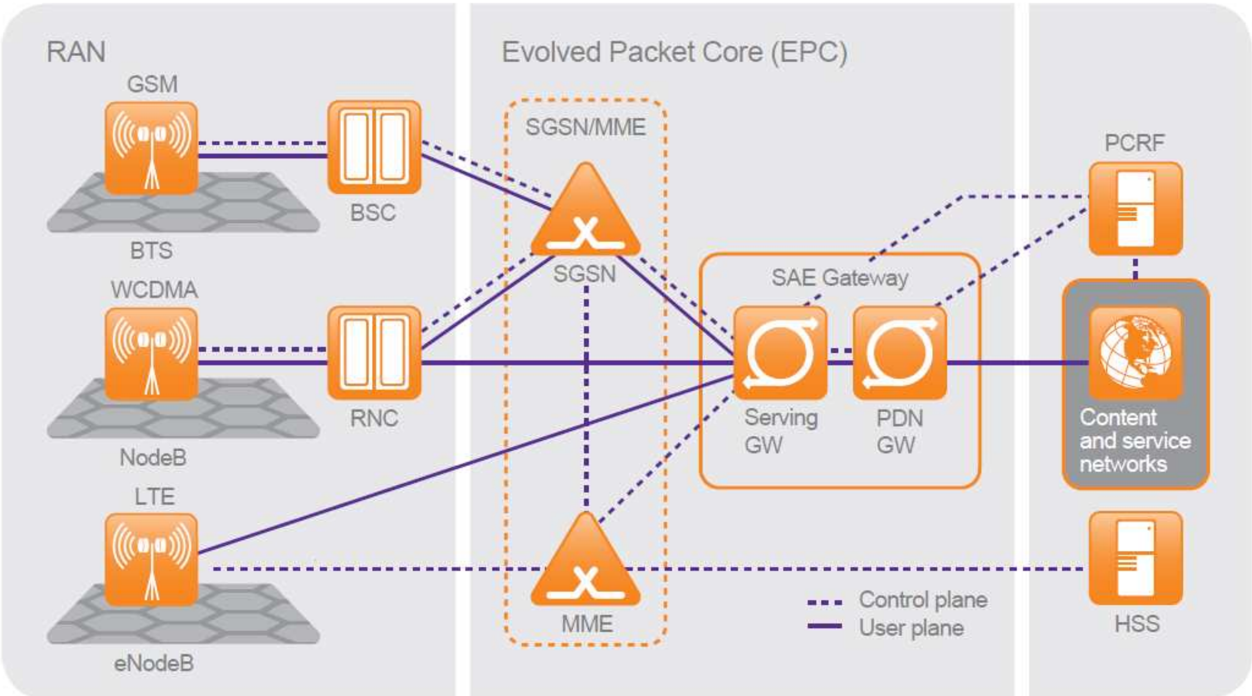
- no widespread availability from CSPs in licensed bands ➔ little possibility to share utility traffic with public users ➔ higher CAPEX/OPEX
- not implemented in bands < 1 GHz ➔ poor coverage in rural areas
- when implemented in license exempt bands ➔ low TX powers, possible interference issues ➔ poor coverage
- no evolution from existing GSM/GPRS DA applications
- relatively small eco-system and not considered as future proof when compared to LTE ➔ risk of stranded investments

5.4.3 3GPP defined PLMNs

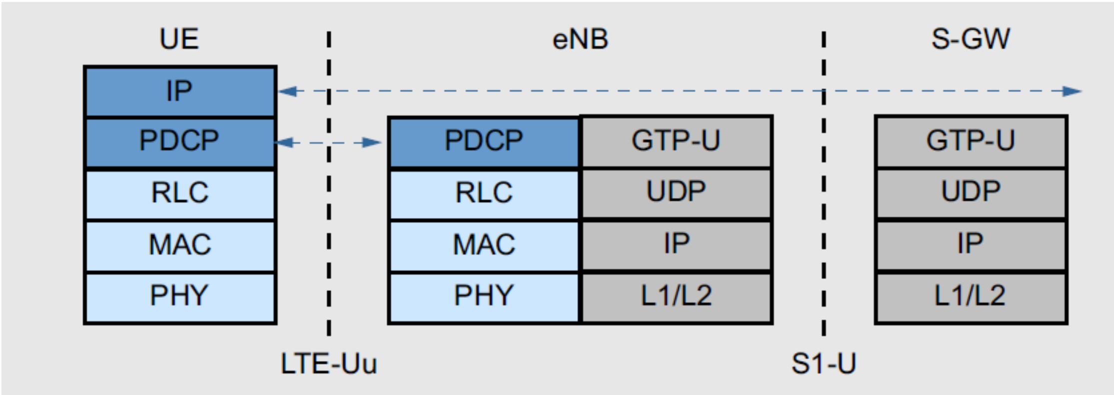
3GPP defined radio solutions (PLMNs) include GSM/GPRS/EDGE, HSPA and LTE. M2M modem / RTU devices used for remote controlled FA are currently based on multi-band GPRS/EDGE modules and will in the shorter term evolve towards GPRS/ HSPA multi-mode/band devices and in the longer term also support LTE radio access. Even though all 3 generations of 3GPP radios can certainly meet the above radio communications requirements for DA, the focus of this section will be on exploring the potential of LTE to meet or exceed these requirements. LTE is widely considered a future-proof, scalable and high performance IP based broadband radio access [49,50] with high potential for capturing many if not most of the emerging smart grid related communication needs.

A good technical summary of LTE technology and its key radio performance characteristics can be found from [43].

The following Figure shows the 3GPP network architecture evolution from 2G➔3G➔4G. LTE network architecture is flat and optimized for IP protocols [49]. Implementation of the EPC requires requiring only few, highly scalable, core network elements.



Optimization for IP-protocols can be noted from the following Figure showing the user plane protocol stack. Migration towards IPv6 is supported.



5.4.3.1 Available frequency bands for LTE

The frequency bands currently specified within 3GPP for LTE FDD are as follows:

3GPP Supported FDD Frequency Bands

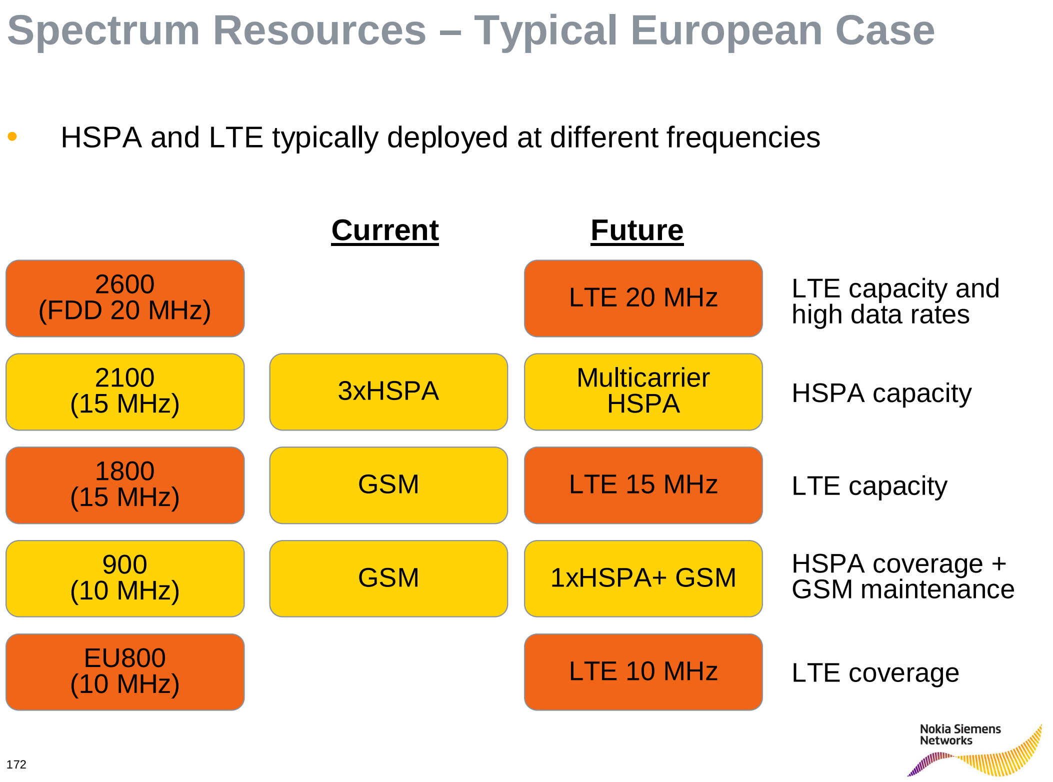
Band	Total [MHz]	Uplink [MHz]	Downlink [MHz]	Europe /Asia	Japan	Americas	
1	2x60	1920-1980	2110-2170	●	●		UMTS core
2	2x60	1850-1910	1930-1990			●	US PCS
3	2x75	1710-1785	1805-1880	●			1800
4	2x45	1710-1755	2110-2155			●	US AWS
5	2x25	824-849	869-894			●	US 850
6	2x10	830-840	875-885		●		Japan 800
7	2x70	2500-2570	2620-2690	●			2600
8	2x35	880-915	925-960	●			900
9	2x35	1749.9-1784.9	1844.9-1879.9		●		Japan 1700
10	2x60	1710-1770	2110-2170			●	Extended AWS
11	2x20	1427.9-1447.9	1475.9-1495.9		●		Japan 1500
12	2x18	698-716	728-746			●	US700
13	2x10	777-787	746-756			●	US700
14	2x10	788-798	758-768			●	US700
17	2x12	704-716	734-746			●	US700
18	2x15	815-830	860-875		●		Japan new 800
19	2x15	830-845	875-890		●		Japan new 800
20	2x30	832-862	791-821	●			EU800
21	2x15	1447.9-1462.9	1495.9-1510.9		●		Japan 1500 ext
22	2x90	3410-3500	3510-3600	●			3500
23	2x20	2000-2020	2180-2200			●	S-band
24	2x34	1626.5-1660.5	1525-1559			●	L-band

Within the US, early deployments of LTE are in Bands 13 and 17 as these frequencies became recently available and hence are not occupied by 2G/3G legacy systems. Furthermore the 700 MHz band has favorable propagation characteristics. Band 14 comprises the lower ‘D-Block’ (2x5 MHz) which is up to re-auction and has relevance for Public Safety (PS) applications subject to FCC ruling. Use of LTE is also expected for the upper ‘broadband PS’ block (2x5 MHz) within Band 14 which will be licensed to PS operators throughout municipalities.

Yet another band with good potential for CSPs to address utility related communications is Band 24 (L-band) which is available nationwide and exhibits better propagation than the bands around 2

GHz such as Bands 2,4 and 10. Band 24 will also see early LTE deployments and is commercialized by Lightsquare under a new ‘wholesale’ business model.

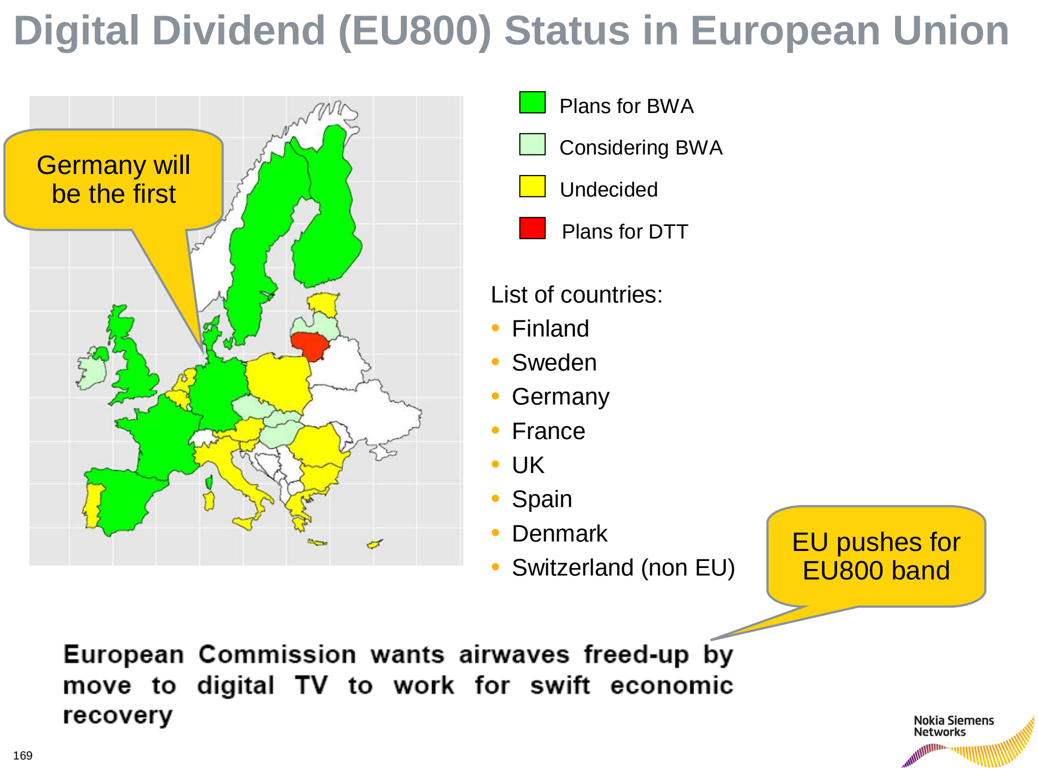
From a European perspective, the evolution towards LTE is expected to follow this broad general pattern, subject to country specific licensing and commercial plans of the CSPs:



For urban / sub-urban environments Band 7 and Band 3 will be primarily used for LTE, with first deployments in Band 7 (when available).

For DA and FA related applications bands < 1 GHz will be required in order to get economically coverage for rural areas. For these bands, LTE will typically start in Band 20 (EU800, when available), only at a later stage will the GSM 900 MHz (Band 8) be used.

The situation regarding Band 20 is as follows:



Regarding the use of Band 20 in Finland co-existence with the Russian Aeronautical Radionavigation (ARNS) remains to be a challenge. The currently claimed 420 km coordination distance means that all base stations would need to be coordinated which makes this band in practice unusable for the time being. Status of this service will be discussed in the next WRC 2012. Given a positive outcome for mobile usage, Band 20 could become available for LTE deployment around 2015.

In Finland use of GSM in the 900 MHz band is expected to last at least until ~2017 and the use of HSPA within this band certainly much longer, all this is subject to commercial plans of the CSPs.

To summarize, in Finland a likely evolution towards LTE capable M2M radio modems in bands <1 GHz may be as follows: GPRS900➔add HSPA900➔ add LTE800➔LTE800/900. Naturally, in urban areas LTE2600 (+LTE1800) will become available earlier.

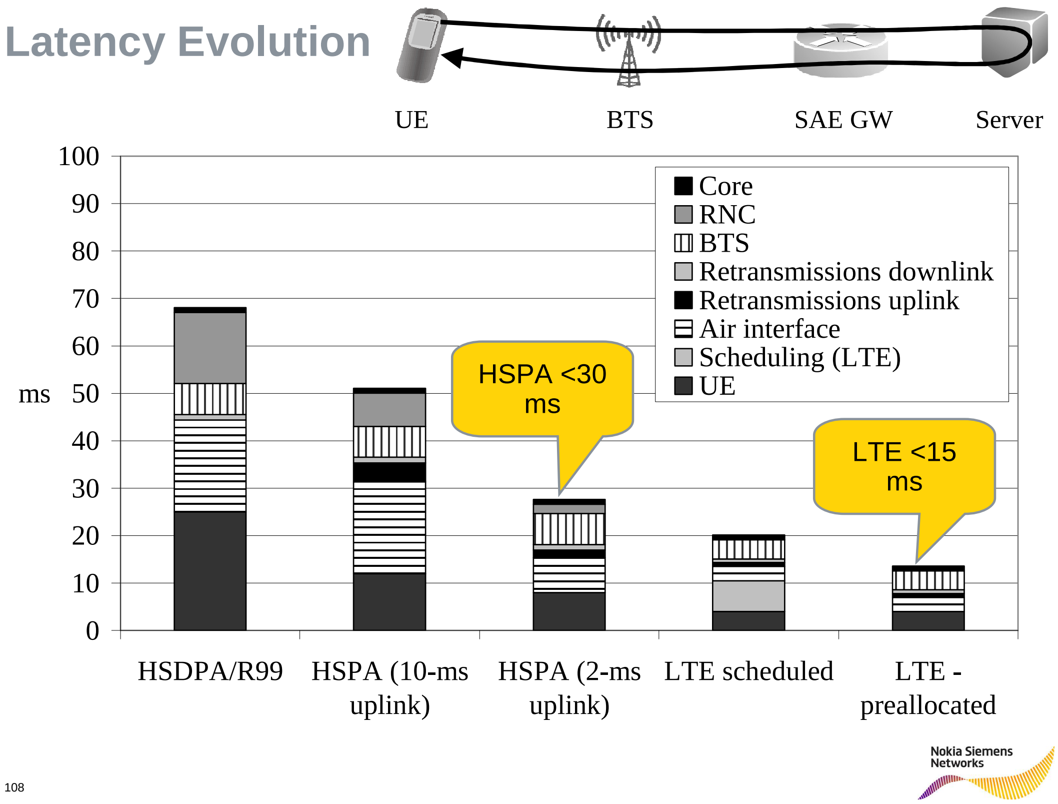
Support for the 450 MHz bands is currently not specified for LTE, nevertheless it is expected that TETRA and cdma450 will eventually evolve towards LTE, hence these bands may be added some point in time.

5.4.3.2 Delay, round trip time (RTT)

The delay requirements for the above discussed DA use cases are in the order of seconds and can already be met with GPRS today.

Only signaling related to line protection (e.g. between substations) would require much lower and guaranteed delays as well as jitter. The following provides some indications how delay times can be reduced by 3G and 4G systems in case stringent delay requirements would need to be met in future DA related applications.

The following figure shows the minimum *average* round trip time (RTT) which can be achieved for 3G HSPA evolution and LTE:



The following caveats need to be kept in mind when looking at these figures:

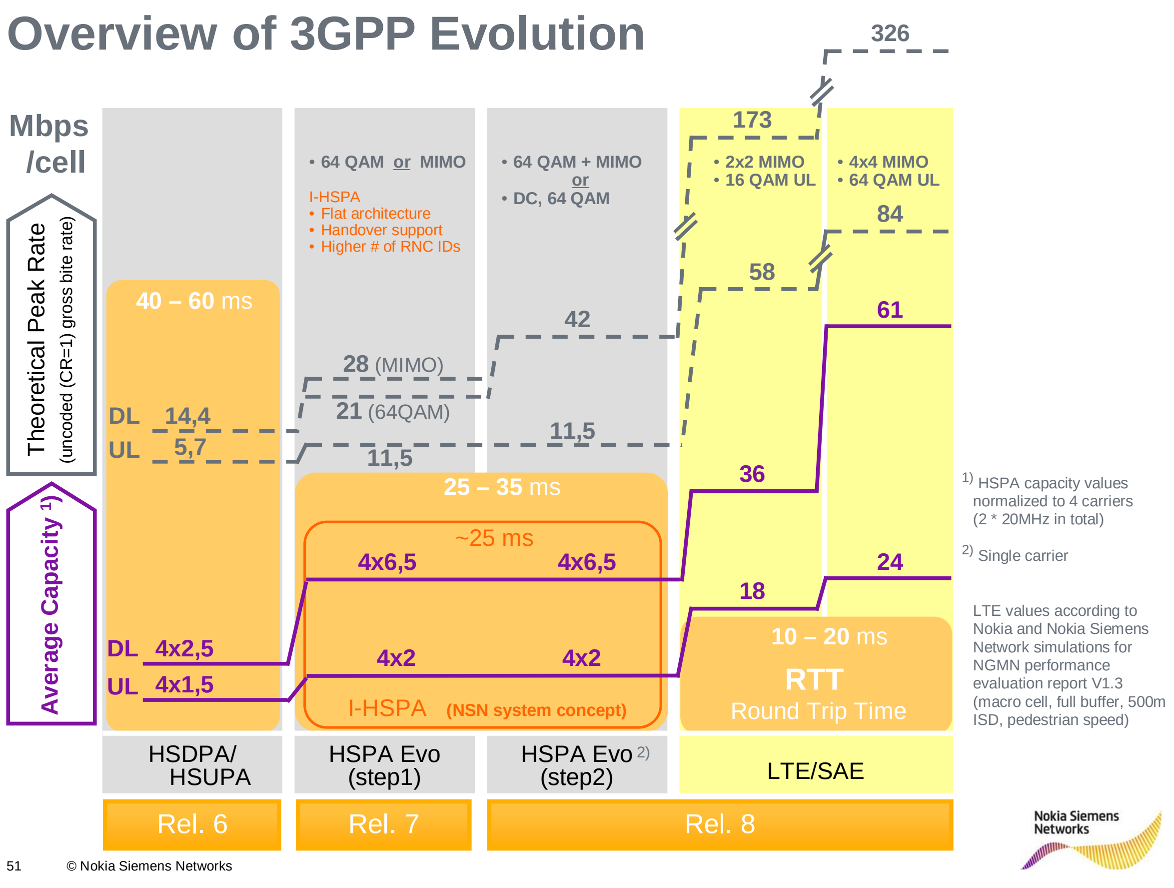
- for 3G HSPA the RTT depends on the features supported by the network (peak bit rate, HSUPA, TTI length,..) and may differ therefore from network to network.
- the RRC_CONNECTED state was assumed (i.e. an active radio link). The corresponding RTT for GPRS/EDGE would be ~190 ms. In LTE no dedicated radio links and resources are maintained in the RRC_CONNECTED state, unlike for HSPA in which air-interface capacity is consumed. Hence the LTE device can be kept longer in his state without impact on radio system capacity. With LTE also very low RTT (~15 ms) can be achieved if radio resources are persistently allocated for the device. A DSL connection would have a RTT of ~20 … 50 ms depending on the operator.
- if the terminal is in LTE RRC_IDLE state (or HSPA cell_PCH state), e.g. when no heartbeat signal was received for prolonged time, the RRC connection would first need to be set up which will increase the RTT for LTE to some 125 ms and for HSPA to some 500 ms.
- due to possible multiple L1 HARQ re-transmissions the delay times come with a certain statistical distribution, however, the radio link parameters could be configured by the network for M2M devices in such as way as to minimize these L1 re-transmissions (also stationary of the RTU will help). Also cell loading will impact the delay distribution, unless QoS is enforced.
- delay (RTT) will depend on the configured QoS parameters for the radio bearer such as the delay budget in the LTE QoS Class Identifier (QCI), priority etc. The radio packet scheduler

is ‘QoS-aware’ and the parameterization could be optimized for stationary M2M devices requiring low delays: as terminal battery saving and handovers are not a relevant issue in this use case, the RRC timers used for maintaining the radio link states could be set to larger values, so as to minimize delays (and signaling loads).

- depending on the network topology additional delays may occur due to the mobile backhaul and the transition through intermediate IP networks to SCADA.

5.4.3.3 Bandwidth, cell capacity

The following Figure shows the 3G→4G evolution of user peak throughput rates and average cell capacities expressed in Mbps and normalized to 20 MHz of available spectrum:



5.4.3.4 Coverage:

An uplink radio budget comparison between GSM voice and HSPA, respectively LTE 64 kbps packet data is shown in the following figure. The calculation principles are the same as described in detail in [43].

Uplink Radio Link Budget
GSM voice vs HSPA, LTE 64 kbps packet data

	Uplink	GSM voice	HSPA	LTE	
	Data rate [kbps]	12.2	64	64	
	Transmitter - UE				
a	Max tx power [dBm]	33.0	23.0	23.0	
b	Tx antenna gain [dBi]	0.0	0.0	0.0	other sheet
c	Body loss [dB]	3.0	0.0	0.0	Body loss for voice terminal 3 dB
d	EIRP [dBm]	**30.0**	**23.0**	**23.0**	=a+b-c
	Receiver - Node B				
e	Node B noise figure [dB]	-	2.0	2.0	
f	Thermal noise [dBm]	-119.7	-108.2	-118.4	=k(Boltzmann)*T(290K)*B. Note 1.
g	Receiver noise floor [dBm]	-	-106.2	-116.4	=e+f
h	SINR [dB]	-	-17.3	-7.0	From simulations / measurements. Note 2
i	Receiver sensitivity [dBm]	-114.0	-123.4	-123.4	=g+h. Note 7
j	Interference margin [dB]	0.0	3.0	1.0	Note 3
k	Cable loss [dB]	0.0	0.0	0.0	
l	Rx antenna gain [dBi]	15.0	15.0	15.0	in 900 MHz
m	Fast fade margin [dB]	0.0	1.8	0.0	Note 4
n	Soft handover gain [dB]	0.0	2.0	0.0	Note 5
	Maximum path loss	**159.0**	**158.6**	**160.4**	=d-i-j-k+l+m-n+o
	Delta [dB]	Reference	**-0.4**	**1.4**	

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We note that the link budget for HSPA and LTE 64 kbps packet data is approximately the same as for GSM voice when considering the 3 dB body losses for the latter service. The downlink radio link budget shows a similar relative behavior and is not copied here.

However, in installations for FA, the overall radio link budget is actually significantly more advantageous when compared to the radio network design criteria used by commercial cellular system providers, this is due to:

- higher gain antennas at the RTU compared to mobile terminals, especially for pole mounted installation higher gain (e.g. 5 dB) omni antennas are possible. Mobiles have poor antenna gain for bands < 1 GHz due to limited space.
- larger antenna height at the RTU than for mobile terminals (e.g. 4.5 m height possible)
- no in-building (or in-car) penetration losses need to be considered at the RTU with external antennas which is always possible in rural and perhaps also very often in suburban

environments. In urban environments wall penetration losses for the RMU hut cannot be neglected.

The following Figure illustrates this and shows the resulting cell radius, in [km], for LTE 64 kbit/s vs. GSM voice reference case when considering FA RTU site antenna parameters accordingly. The calculation also shows the dependency on the frequency band (results are shown for LTE Bands 1, 3, 7 and 8):

Cell radius, in [km], for LTE 64 kbit/s vs. GSM voice reference case when considering FA RTU site antenna parameters

	LTE Urban	LTE Suburban	LTE Rural	GSM900 voice Ref Rural	
Base station antenna height [m]	30	50	80	80	
RTU antenna height [m]	1.5	2.5	4.5	1.5	
RTU antenna gain [dBi]	2.0	3.0	5.0	-5.0	(external) omni ant for RTU
Slow fading standard deviation [dB]	8.0	8.0	8.0	8.0	
Location probability	95 %	95 %	95 %	95 %	
Correction factor [dB]	0	-5	-15	-15	
Indoor loss [dB]	15	0	0	10	in SU, Ru RTU antenna is external
Slow fading margin [dB]	8.8	8.8	8.8	8.8	
Max path loss at 1800/2100/2600 [dB]	162.4	161.4	161.4	164	UE ant gain, BS ant gain + cable loss
Max path loss at 900 [dB]	160.4	160.4	160.4	159	UE ant gain, BS ant gain + cable loss

UL center frequency [MHz]	LTE Urban	LTE Suburban	LTE Rural	GSM900 voice Ref Rural	Relative cell area
897.5	**1.95**	**11.52**	**45.45**	**11.76**	100 %
1747.5	**1.20**	**6.64**	**26.81**	**8.61**	38 %
1950	**1.08**	**5.97**	**24.18**		31 %
2535	**0.84**	**4.63**	**18.90**		19 %

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The following can be observed:

- in 900 MHz, the combined ~20 dB difference due to larger terminal antenna gains, antenna heights and lack of wall penetration losses provides the FA application with a very advantageous link budget compared to GSM900 voice. Therefore finding radio coverage from public cellular systems for FA RTUs is not considered a challenge in bands < 1 GHz.
- if LTE would be deployed in bands < 1 GHz as a dedicated system for the utility to provide coverage for rural FA, very large cell sizes in the order of up to ~45 km could be used indeed. Actually, the earth's curvature would be the factor limiting the cell size in this regime [43].
- coverage can also be competitively provided to RMUs in suburban areas when using external antennas at the RMU housing, in fact, the resulting cell ranges are comparable with cells dimensioned for *rural* GSM voice (radius > 10 km).

- the results also show the advantage of bands < 1 GHz in terms of the cell *area*. LTE cells in 800 ... 900 MHz are up to 4x … 5x larger than in 2.6 GHz with corresponding impacts on the #of sites and cost required for providing coverage. LTE (or 3G) in bands < 1 GHz is therefore more competitive than any other broadband radio system deployed in the unlicensed 2.4 GHz ISM band (or above) such as WiMAX or dedicated mesh networks.

5.4.3.5 System availability, resilience:

As mentioned in Section 5.1.2 a radio communications system availability figure of ~99.5% at the modem / RTU seems reasonable for DA related use cases with a goal to evolve towards more stringent requirements such as > 99.9%.

CSPs implement measures for resilience, fault tolerance and redundancy into their networks; e.g. alternative transmission paths maybe used within the backbone transport and furthermore, critical network elements such as databases (HSS, MME, PDN-GW…) are required to have very high availability 99.999%, i.e. comparable to utility communications availability requirements for safety critical protection functions.

In any given location there is typically radio coverage provided from multiple PLMNs, i.e. 2 or more CSPs provide coverage within each available frequency band (900, 1800, 2600 MHz). M2M modems are typically multi-standard and multi-band devices enabling access to multiple PLMNs, hence this will allow to add additional layers of redundancy all within the 3GPP radio family at comparable low additional OPEX. This can be done by having multiple SIMs in the modem / RTU or by arranging roaming agreements with the CSPs providing coverage in an area. An example of such an arrangement by a Spanish utility was presented in [48] and is shown in Fig. 5.6:

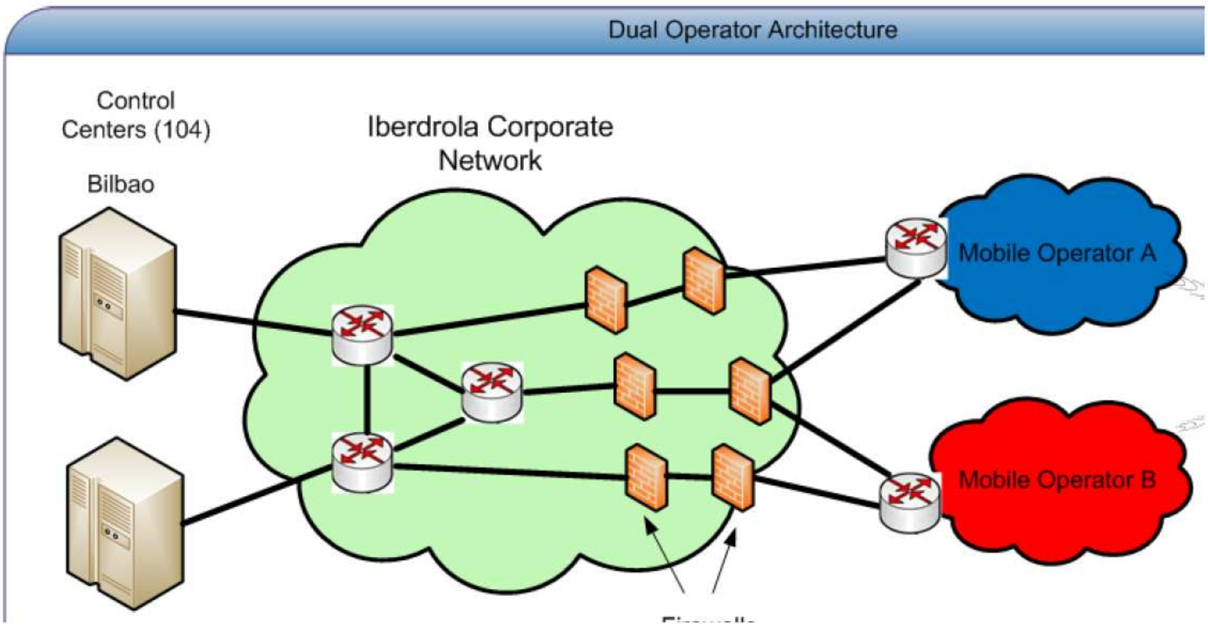


Fig. 5.6. Use of multiple PLMNs to provide redundancy, from [48]

Assuming a single PLMN availability of 0.995 (99.5%) and that PLMN outages are uncorrelated events among CSPs (isolated failures) we would obtain the combined availability using 2 PLMNs as 1 – (1-0.995)^2) = 0.999975 or 99.9975 %.

5.4.3.6 Power outage, battery backup:

As discussed in 5.1.2 battery backup in the order of 1 … 6 h covers the time needed for fault isolation and to a large extent also the time needed for restoration in FA applications. The data presented in 5.1.2 showed that a large proportion of isolated faults in rural areas can be cleared already within ~4 h.

Typically there exists country specific regulation w.r.t. requirements for resilience and power backup. In Finland these requirements are set by the Finnish Communications Regulatory Authority (Ficora) and can be found in [41,42]. The key requirements from [41] are extracted as follows:

Taulukko 1: Tärkeysluokat

Tärkeysluokka	Viestintäverkon tai -palvelun komponentti
1	Komponentti, joka vaikuttaa viestintäpalveluihin erittäin suurella maantieteellisellä alueella tai komponentti, joka vaikuttaa suuruusluokaltaan • ≥ 200 000 käyttäjän puhelinpalveluun tai • ≥ 200 000 käyttäjän laajakaistapalveluun tai • ≥ 500 000 käyttäjän sähköpostipalveluun tai • ≥ 300 000 käyttäjän joukkoviestintäpalveluun tai • ≥ 500 000 käyttäjän muuhun viestintäpalveluun.
2	Komponentti, joka vaikuttaa viestintäpalveluihin suurella maantieteellisellä alueella tai komponentti, joka vaikuttaa suuruusluokaltaan • ≥ 50 000 käyttäjän puhelinpalveluun tai • ≥ 50 000 käyttäjän laajakaistapalveluun tai • ≥ 200 000 käyttäjän sähköpostipalveluun tai • ≥ 100 000 käyttäjän joukkoviestintäpalveluun tai • ≥ 200 000 käyttäjän muuhun viestintäpalveluun.
3	Komponentti, jota vaikuttaa • ≥ 150 GSM-verkon puhekanavan toimintaan tai • ≥ 1000 käyttäjän puhelinpalveluun tai • ≥ 1200 käyttäjän laajakaistapalveluun tai • ≥ 50 000 käyttäjän sähköpostipalveluun tai • ≥ 50 000 käyttäjän joukkoviestintäpalveluun tai • ≥ 100 000 käyttäjän muuhun viestintäpalveluun.
4	Joukkoviestintäverkon päälähetin tai komponentti, joka vaikuttaa • ≥ 75 GSM-verkon puhekanavan toimintaan tai • ≥ 250 käyttäjän puhelinpalveluun tai • ≥ 250 käyttäjän laajakaistapalveluun tai • ≥ 10 000 käyttäjän sähköpostipalveluun tai • ≥ 50 000 käyttäjän muuhun viestintäpalveluun.
5	• Matkaviestinverkon peruspeiton tukiasema tai • kiinteän puhelinverkon keskitin tai • laajakaistakeskitin tai • kiinteän langattoman laajakaistaverkon tukiasema tai • maanpäällisen televisioverkon täytelähetin, joka palvelee yli 50 kotitaloutta tai • radiotoiminnan täytelähetin tai • komponentti, joka vaikuttaa yleisessä puhelinverkossa toimiviin puhelinpalveluihin tai • komponentti, joka vaikuttaa yli 1 000 käyttäjän sähköpostipalveluun.

Taulukko 2: Tehonsyötön varmistaminen

Tärkeysluokka[7)]	Akuston [1)] varmistusaika	Varavoimalaitos ja muut vaatimukset
1	≥ 3 tuntia	Kiinteä varavoimalaitos, jonka varmistuksena on: [2)] - kiinteän varavoimalaitoksen N+1 -varmistus tai - vähintään 6 tunnin akustovarmistus tai - käytettävissä oleva siirrettävä varavoimalaitos liitäntämahdollisuuksineen
2	≥ 6 tuntia [3)]	Kiinteä varavoimalaitos tai käytettävissä oleva siirrettävä varavoimalaitos liitäntämahdollisuuksineen
3	≥ 12 tuntia [3), 4)]	Siirrettävän varavoimalaitoksen liitäntämahdollisuus, mikäli varavoimalaitoksen käyttö on kohteessa mahdollista
4	≥ 6 tuntia [3), 5)]	Siirrettävän varavoimalaitoksen liitäntämahdollisuus, mikäli varavoimalaitoksen käyttö on kohteessa mahdollista
5	≥ 3 tuntia [6)]	Siirrettävän varavoimalaitoksen liitäntämahdollisuus, mikäli varavoimalaitoksen käyttö on kohteessa mahdollista

1) Maanpäällisen joukkoviestintäverkon lähettimille ei vaadita akustoa, mikäli lähettimen tehonsyöttö on varmistettu kiinteällä varavoimalaitoksella.
2) Kiinteän varavoimalaitoksen varmistusta ei vaadita maanpäällisen joukkoviestintäverkon lähettimiltä, mikäli varmistusta ei ole toteutettavissa kohtuullisin kustannuksin.
3) Jos viestintäverkon tai -palvelun komponentti on kytketty voimalaitejärjestelmään, jossa tehonsyötön varmistuksena on kiinteä varavoimalaitos, akuston minimivarmistusajaksi riittää 3 tuntia.
4) Jos viestintäverkon tai -palvelun komponentti sijaitsee taajamassa, akuston minimivarmistusajaksi riittää 6 tuntia.
5) Mikäli vähintään kolme taajaman ulkopuolella sijaitsevaa tärkeysluokan 4 viestintäverkon tai -palvelun komponenttia käyttää yhteistä yleisen sähköverkon liitäntää, ja komponenttien tehonsyötön varmistuksena ei ole kiinteää varavoimalaitosta, tulee akuston minimivarmistusaika pidentää 12 tuntiin.
6) Mikäli laitetilaan ei ole mahdollista päästä akuston 3 tunnin minimivarmistusajan puitteissa laitetilan kaukaisen sijainnin, maasto-olosuhteiden tai odotettavissa olevien keliolosuhteiden vuoksi, tulee akuston minimivarmistusaika pidentää 6 tuntiin.
7) Tärkeysluokalla tarkoitetaan 3 §:ssä määriteltyä viestintäverkon tai -palvelun komponentin tärkeysluokkaa.

As long as GSM provides the ‘baseline coverage’, i.e. prior to replacement by UMTS900, UMTS RNCs have ‘importance class 3’ whilst the UMTS BS has a requirement of 15 min battery backup and LTE at the moment none[10] [41]. The following key points related in particular to the BS sites, can be noted from [41,42]:

- the philosophy is to set stringent requirements for the radio system components providing *baseline radio coverage* which is, today, GSM BS and BSC. More lenient requirements are set for system components providing *additional capacity* (e.g. UMTS cells overlaid on a GSM system, GSM microcells, etc.). However, it is mentioned in [42] that should UMTS become the radio to provide baseline coverage (this could happen e.g. when GSM900 migrates to UMTS900) then the above more stringent requirements will need to be considered for UMTS BS and RNC and updates of this regulation are expected. This means that M2M devices (RTUs) with multi-band/mode functionality can always expect to find a fall-back to a battery protected baseline system.
- central network elements 'higher up' in the importance hierarchy have to fulfill the backup requirements in above Table 2 regardless of the radio access method (i.e. this applies also to UMTS, LTE central databases, etc.)
- the BS battery backup times mandated in [41] appear to be very well matched to the FA requirements mentioned above.

When it comes to isolated faults in the distribution network not all BS will be affected, hence there is an inherent 'redundancy' against communications outage at work:

- Only those BS which happen to be power fed from the faulty feeder section will need to switch to their batteries whereas all other BS will be available also for prolonged fault clearance times.
- The RTU might be able to connect to another cell which is fed from a healthy part of the feeder. In fact, looking at the above link budget analysis *it is very likely* that the RTU will 'see' and be able to connected to another BS of the same network: the ~20 dB more advantageous link budget of RTUs compared to the typical public cellular cell design criteria will enable the RTU to 'see' way beyond the best serving site, providing an inherent 'site diversity'. The precise statistics of this to happen is an interesting area for further work in SGEM II.
- Yet another layer of redundancy is to enable the modem / RTU to access multiple PLMNs. This can be done by having multiple SIMs in the RTU or by arranging roaming agreements with the CSPs providing coverage in an area, see Fig. 5.6. BS sites are typically not co-located which means that isolated power outage events can be considered uncorrelated among different operators BS sites, hence providing a redundant layer of protection. In particular in urban areas are typically > 2 networks (across several bands), so a very high level of protection against power outage is expected.
- Finally it shall be noted there will be utility service personal available in the area of the faulted feeder section which can operate the switches also manually should the battery backup times be exceeded and no other communications fall-back be available.

These considerations may not always apply in the event of large scale storms and prolonged (~days) power outages. In this case also one or more PLMNs may fail in case a sufficient number of movable power generators cannot be brought into action to the affected BS sites. However it was noted already in Section 5.1.2 that it is not reasonable and economically justified to design FA

[10] LTE has not yet been considered in [21,22]

radio communication system availability and power backup requirements for wide scale and long lasting power outages due to:

- in case of a large amount of faults there is much less scope for remote controlled FA to be effective for fault isolation and switching of alternative power connections (such as closing of N.O. disconnectors)
- a larger amount of utility service crews will have to be in the effected area anyway
- in this case customer interruption times are dominated by fault repair times
- also the battery back-up of the IEDs is limited to some ~48 h

In summary, the regulatory requirements stipulated by e.g. Ficora for public cellular communication system power backup requirements appear well matched to the requirements of the FA use case. In fact, PLMNs could even exceed these requirements when considering the inherent possibilities of ‘site diversity’ within one PLMN and the possible additional diversity among PLMNs in case of multiple subscription/roaming agreements.

In passing, we note that [41,42] also stipulate requirements for physical protection of communication sites and related cabling.

5.4.3.7 Signaling congestion due to ‘always-on’ connections, resilience to ‘signaling storms’

Generally, the spatial density of RTUs in the FA automation case is very low compared to the subscriber densities assumed for PLMNs: in Finland’s rural FA the distance between RTUs may be in the order of ~15 km and in urban FA in the order of perhaps a few hundreds of meters. Consequently, the resulting additional load due to traffic and signaling from FA will be low compared to the overall traffic carried by the network with little risk for causing congestion.

Nevertheless the existing German use case described in section 5.3.2 implied that a large number of the DER plants across the DSO region may need to be reliably reached within a short timeframe (in the order of tens of seconds) – i.e. the situation of a quasi-simultaneously (‘broadcast’) from the SCADA / DSO gateway to a large number of RTUs. Depending on the scenario parameters, this may or may not lead to peak signaling loads from radio link (RRC or even PDP context) establishment procedures in the higher nodes of the system (e.g. MME, P-GW, HSS) and is an area FFS.

A related situation would be the quasi-simultaneous reporting of measurement and conditioning data from e.g. secondary substations, say at 24:00 due to poor design of the application process. Generally, the design of SG related communication applications may be ignorant of or not optimized for the characteristics of the underlying radio system.

Another issue is when the DA related communication application is forced into an ‘always-on’ connection mode, e.g. by SCADA sending a regular ‘heartbeat’ (poll) signal in the order of seconds to the RTUs. This may be done to ensure low delay downstream connectivity from SCADA-> RTU, without any prior poll request via SMS. Hence the heartbeat signal ensures that none of the intermediate stateful NAT and firewall related timers will expire in order to maintain the PDP context at the P-GW [54].

However, running a ‘heartbeat’ signal every few seconds to maintain the PDP ‘always-on’ does not always prevent high signaling load caused by frequent transitions of the RRC states (RRC_IDLE <-> RRC_CONNECTED state), i.e. the frequent buildup and tear down of the radio link: CSPs operating poor 3G network implementations, experienced congestion due to signaling overload from Smartphones running ‘always-on’ apps such as IM, see [52,53].

Now, regarding the signaling load of DA related ‘always-on’ connections, there are 3 mitigating factors at work:

1. low spatial density of RTUs compared to regular BB user density
2. RTUs do not need to conserve battery
3. RTUs do not make handovers

Items 2. and 3. would suggest to set RRC timers used for maintaining the radio link states to much larger values, so as to minimize the related signaling loads. There are several mechanisms by which the PLMN can recognize the presence of a DA related M2M device as opposed to a mobile device, e.g. based on subscription records or by inspection of the traffic. Here, LTE is in particular advantageous as, unlike 3G, no dedicated radio resources are consumed in the RRC_CONNECTED state. Hence the RTU could be kept for long durations (i.e. longer than the higher layer motivated heartbeat interval) in RRC_CONNECTED state, minimizing both, delays (RTT) and RRC related signaling loads. This ensures good scalability to a very high number of RTU devices should SG related extensions of DA require so.

Finally, there is the issue when a large population of M2M devices of a M2M MVNO would be roaming within operators A’s network whilst having also a subscription to operators B’s network in same area for reasons of redundancy as shown in Fig. 5.6. Now if operators A’s network fails the M2M devices would quasi simultaneously access operators B’s network and this may lead to congestion of B’s and the M2M MVNO central databases (MME, HSS,…). Even if the number of M2M devices operated by the DSO may be small (compared to the # of BB subscribers) a larger population of M2M devices from other ‘verticals’ may suffer from the same failure and trigger the congestion. This is an area FFS.

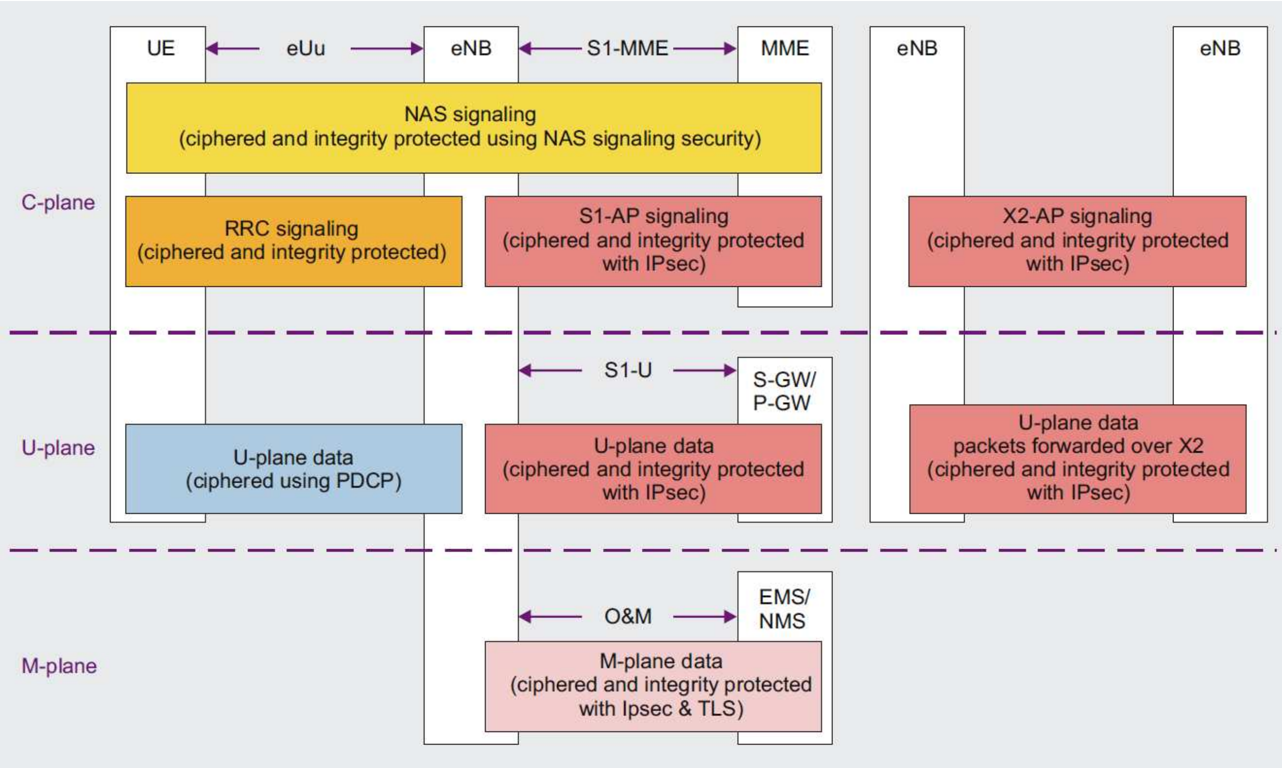
These and other M2M related aspects have been recognized by 3GPP and work is underway to optimize the 3GPP RAN (2G/3G/4G) and EPC also for machine-type-communications (MTC). A number of items relevant for SG use cases have been identified in the 3GPP technical report [51] such as:

- Overload and congestion control for MTC devices in RAN and CN
- MTC group concept
- MTC monitoring
- MTC time controlled
- MTC low mobility
- MTC small data transmission
- Signaling message reduction
- Alternatives for usage of MSISDN in machine type communication

Hence, future versions of 3GPP standards are expected to support even more robust and efficient MTC for a wide range of use cases, including those with a high density of M2M devices.

5.4.3.8 Security

Security related aspects are considered in other SGEM work packages. In here, we only show the LTE/EPC security architecture for the C-, U-, and M-plane as specified by 3GPP:



C-plane security protects NAS signaling, RRC signaling over the LTE-Uu, and S1-AP/X2-AP signaling between eNB and MME/other eNBs respectively. U-plane security protects the transfer of user data over the LTE-Uu, S1-U and X2 reference points. Secure processing environment of the eNB provides a Secure Processing Environment for U-plane and C-plane traffic. Security for eNB setup and configuration provides protection from 'rogue' or invalid modifications.

Of course this does not exclude an additional e2e security layer between SCADA gateway and RTUs deployed by the DSO (e.g. tunneled VPN connection, TLS,…) so that the DSO can keep his traffic confidential and securely protected in relation to the CSP. Examples for such concept on top of GPRS can be found in [26,29,48].

5.4.3.9 CAPEX/OPEX

Comparisons for CAPEX + OPEX between systems (or even for a single system) are difficult to obtain and require definition of detailed scenario parameters. Here only some principle dynamics for the cost of LTE broadband service are copied from [50]. Some more detail regarding the made assumptions can be found in [50] and the results are summarized below in figures 5.7 and 5.8. The following principal observations were made in [50] for the selected scenario:

1. The most important factor in the cost calculations is network OPEX because it is typically higher than CAPEX over the depreciation time. The largest contributors to OPEX are backhaul transport, site rental, network maintenance and electricity. In the example calculation of [50] cumulative OPEX over the depreciation time was ~1.6 higher than CAPEX.

2. The CAPEX + OPEX per subscriber are relatively high when the subscriber density is low. The cost reduces when there are more subscribers sharing the costs.

3. The cost of delivering a GB of data is highly dependent on the network utilization. If total data use is high, either due to a high number of subscribers or to high use per subscriber, the cost per GB can be below 1 EUR.

4. The relationship between cost and traffic per subscriber is not linear. If the traffic per subscriber grows ten-fold, the cost will increase only two- to three-fold. This is because the radio networks must always provide basic coverage even in low traffic areas. When the traffic increases, the low traffic areas do not need capacity upgrades.

5. Many cost elements in the high traffic areas remain similar or grow only moderately with traffic volumes. Such costs include site rental and backhauling costs. In other words, high data penetration and high data usage leads to lower cost per GB. Therefore, CSPs with a large market share will benefit from economies of scale.

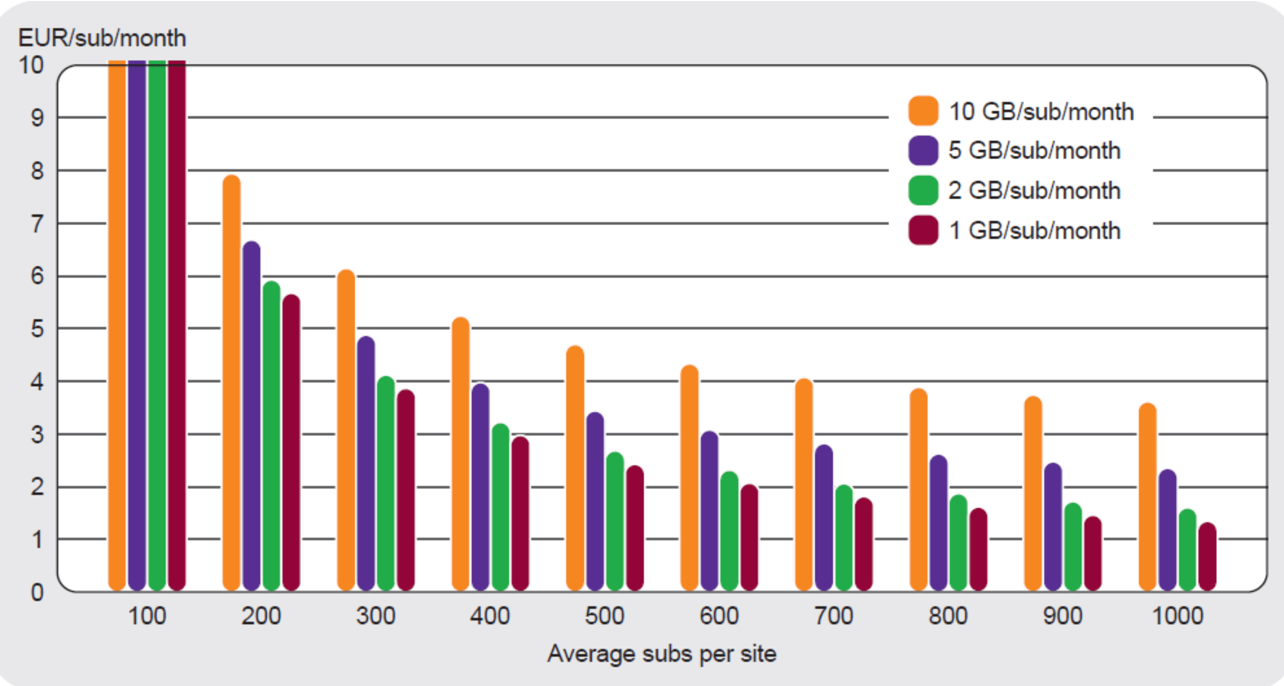


Figure 5.7. Network CAPEX + OPEX per sub per month

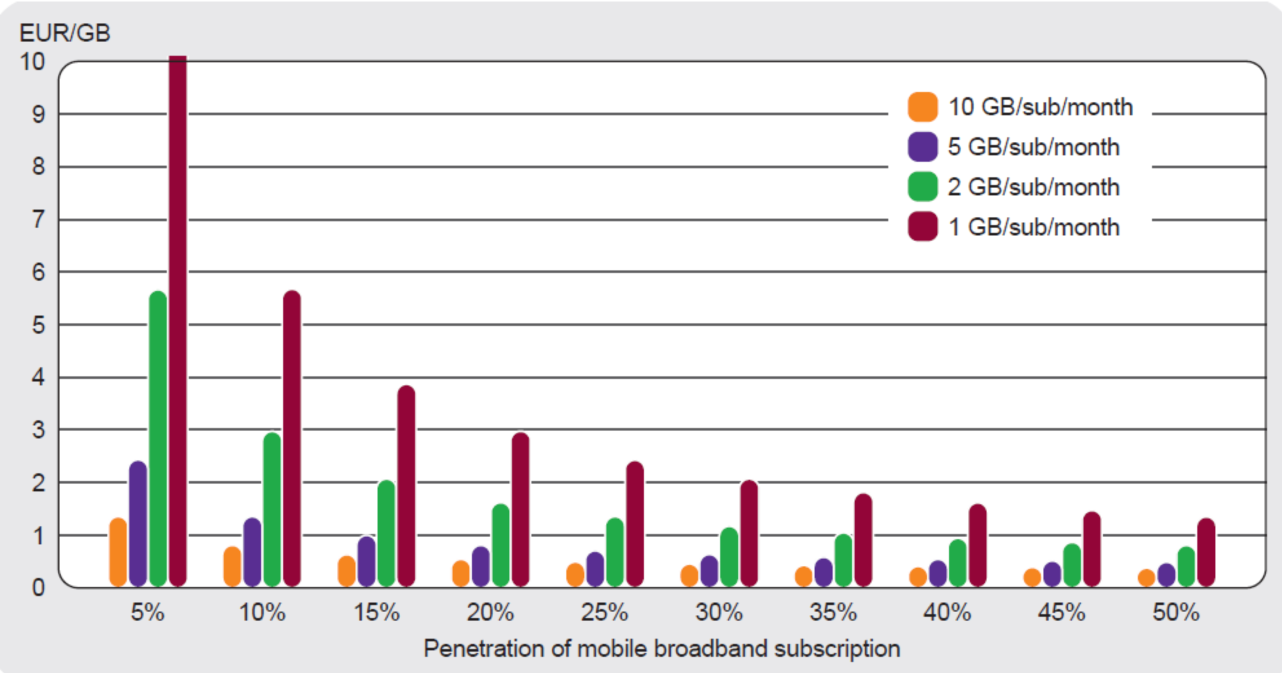


Figure 5.8. Network CAPEX + OPEX per gigabyte of data

FA and DA automation is clearly a low traffic volume, low subscriber density use case which most essentially requires basic coverage in low traffic areas, together with high system availability (and security).

In order to obtain low OPEX required for the economic justification of remote controlled FA, the above 5 observations strongly point towards shared use of the radio communications system.

The FA and DA automation use case with its few measurement and control data points will simply never provide the large data amounts required to fill up a stand alone wireless *broadband* system while the system availability targets can be met by commercial PLMNs.

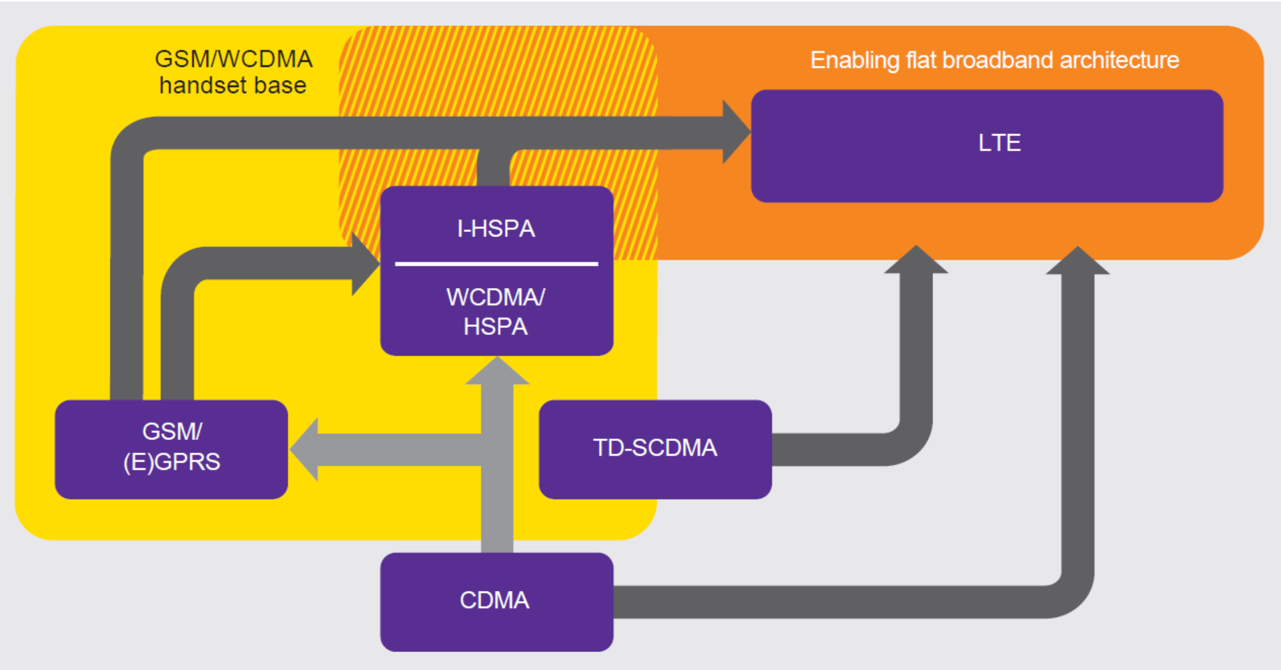
Dominated by the OPEX anyway, any additional CAPEX which might be due to migration from 2G➔(3G)➔4G, depending on the scenario, can be absorbed without changing the fundamentals.

5.4.3.10 Future proofness, evolution towards new ADA/SG applications

The following figure shows the evolution of existing 2G/3G networks to LTE. This includes also the non-3GPP cdma track (including cdma450 systems). LTE FDD and TDD modes share large parts of the specifications and implementations (80 … 90 %) hence, provide mutual synergies.

In addition, to these public cellular systems also the following dedicated/private/governmental cellular radio systems will evolve in their next generation towards LTE:

- TETRA
- GSM-R



Given the above communication requirements of this use case and the cost benefits of licensed band shared operation with public services offered by a CSP, it's quite obvious that evolution from 3GPP 2G➔(3G)➔4G will provide the most comprehensive and future proof ecosystem for the machine-type-communications (MTC) required for this use case.

5.5 Mapping req's to available N/W parameters

Within the DA domain radio communication systems other than 3GPP defined radios, such as Radius, TETRA, EFR (broadcasting solution based on Long Wave Radio), … are typically used only in very specific use cases and not as converged SGC solutions. Moreover, there may be considerable variation of the used radio communication systems across different countries and even DSOs within a country.

For example, the use of EFR has been limited to DER Feed-in reduction by some German DSOs. EFR is not applicable to use cases in which a feedback channel towards SCADA is required. Radius has been limited to rural FA whilst TETRA has not been suggested for rural FA applications. WiMax, with no support for licensed bands < 1 GHz, will make coverage provision for rural FA difficult.

Rather than providing a comprehensive, but necessarily 'sparse' mapping of comparison criteria for each use case against all of the radio technologies we focus specifically on 3GPP 2G (GPRS) / 3G (WCDMA) / 4G (LTE) radio access for which this mapping can be carried out for the studied use cases in a more meaningful way. This will allow assessing the strengths and weaknesses of 3GPP radio access for the considered DA use cases.

Whilst it is not precluded that 3GPP radio access will be used as a private mobile system in frequency bands dedicated to a utility (or, more general, to a licensee offering communications for public safety operations) we focus here on bands used for commercial public use, as this will be by far the dominant case.

Table 5.1 shows the mapping of the DA use case requirements to 3GPP defined radio access operated by a CSP.

Use case Requirement	Rural Feeder Automation	Automation of urban secondary substations	DER Feed-in reduction due to congestion of the HV transmission network	Voltage control in Distribution networks due to DER	LOM protection in Distribution networks with AR
Delay, Latency	can be met by 2G/3G/4G	can be met by 2G/3G/4G	can be met by 2G/3G/4G	can be met by 2G/3G/4G	could be met by 4G if connection is kept in RRC_Connected state, strict QoS needed for low scheduling delays. Requires further validation.
Bandwidth	can be met by 2G/3G/4G	can be met by 2G/3G/4G	can be met by 2G/3G/4G	can be met by 2G/3G/4G	low delay requires sufficient bandwidth to be available on demand at all times; strict QoS attribute needed
Coverage	can be met by 2G/3G/4G using available bands < 1 GHz	can be met by 2G/3G/4G	can be met by 2G/3G/4G; for DER located in rural areas available bands < 1 GHz are advantageous	can be met by 2G/3G/4G; for DER or secondary SS located in rural areas available bands < 1 GHz are advantageous	can be met by 2G/3G/4G; for DER located in rural areas available bands < 1 GHz are advantageous
Availability	can be met by 2G/3G/4G	can be met by 2G/3G/4G	can be met by 2G/3G/4G on cell level, but due to impact on TSO's network stability redundancy against large-scale outages by enabling access to a 2nd MNO should be considered	can be met by 2G/3G/4G, but redundancy by enabling access to a 2nd MNO may be considered	can be met by 2G/3G/4G on cell level, but due to potential impact on TSO's network stability redundancy against large-scale outages by enabling access to a 2nd MNO should be considered
Protection from power outage, battery backup	Central 2G/3G/4G network elements are covered by regulatory power back-up requirements. Longer battery backup times (in the order of hours) are currently met by 2G BS only. However, fallback from (3G,4G) → 2G access in case of power outage is viable from service point of view (delay, data rates,…). If this fall-back to 2G is not desired, then enabling 3G (or 4G) access to a 2nd MNO's network can be considered. In the future, changes to regulation for 3G, 4G are expected to ensure sufficient BS battery backup for areas in which baseline coverage is provided by 3G or 4G instead of 2G (e.g. for 900 MHz bands). Redundancy against power outages can be obtained from inherent multi-site hearability or by enabling access to a 2nd MNO.			Fallback to 2G/3G not viable, therefore vulnerable to BS power outages without special arrangements, as 4G would typically have only ~15 min BS battery backup. Enabling 4G access to a 2nd MNO's network can be considered.	
Scalability	can be met by 2G/3G/4G. Signaling load due to 3G/4G 'heartbeat' signaling can be reduced further if required	can be met by 2G/3G/4G. Signaling load due to 3G/4G 'heartbeat' signaling can be reduced further if required	likely be met by 2G/3G/4G, the potential impact from simultaneous signaling towards a larger number of DER in relation to	can be met by 2G/3G/4G. Signaling load due to 3G/4G 'heartbeat' signaling can be reduced further if required	can be met by 4G. Low signaling load due to staying in RRC_Connected state

			the 'background' signaling load due to BB traffic should be studied further		
Support of IP protocols	running IEC protocols (61850, 60870) on top of TCP/IP is fully supported. Support for IPv6.				
Integration of DSO communications	3G/4G has good potential as converged IP access network		4G required		
Future proofness	seamless migration from 2G→(3G, 4G). Migration towards 4G (LTE) expected also for a number of non-3GPP radio access (TETRA, WiMax). Optimization of M2M communications which are also relevant for SGC in DSO use cases is under work in 3GPP				
CAPEX, OPEX TCO	lowest TCO due to shared use of sites (coverage) and bandwidth (capacity). In particular ubiquitous rural coverage is possible in the available bands < 1 GHz. The traffic / signaling volume from the DA use cases is low compared to BB users with resulting low incremental cost of provision. CSPs have a large amount of frequency resources (multiple bands, up to ~50 MHz) and existing site location to leverage. DSO can lower cost by streamlining the number of used communications solutions.				

Table 5.1. Mapping of the DA use case requirements to 3GPP 2G (GPRS) / 3G (WCDMA) / 4G (LTE) radio access operated by a CSP

To summarize Table 5.1., it can be observed that 3GPP 2G (GPRS) / 3G (WCDMA) / 4G (LTE) radio access operated by a CSP in licensed frequency bands can generally meet the relevant use case requirements.

Some of the criteria such as enabling future-proof convergence towards IP based universally available access and low TCO can be met very well indeed.

Less obvious is how communications system availability requirements can be met by 3GPP radio. As for the studied DA use cases, availability requirements have to be met in order to ensure economic benefit of FA or to fulfill obligations towards the TSO with implications to system stability. Nevertheless, it was found that public 3GPP radio access operated by a CSP can address these requirements due to the following mitigating factors:

- the regulator sets specific requirements for physical protection, resilience and power backup for the various network elements according to their importance in the network hierarchy (regardless of radio access technology)
- whilst in current regulation sufficiently long times for power backup may only be required for GSM base station sites, GPRS service capabilities are sufficient for most DA use cases. Hence the fall-back to a GPRS network of the same operator is generally viable should 3G(4G) base station power fail. If this fall-back to 2G is not desired, then enabling 3G (or 4G) access to a 2nd MNO's network can be considered – this however, *may* not be needed if the MNO consistently uses a single *multi-standard radio* (MSR) BS for providing 2G/3G (same battery back-up may be used, depending on the case).
- the very favorable radio link budget available at sites related to DA provide additional site diversity against isolated failure of BSs
- also use cases may possess an inherent tolerance against isolated (local) failures. E.g. the mentioned use cases related to TSO obligations are not sensitive to communications failure at a single (or isolated few) sites
- large-scale communication outages can have system stability implication for the TSO. While CSPs are expected to provide redundancy and high availability (in the 99.999% range) of central network elements, the DSO can use additional safeguards against large

scale communications outages such as access of the RTUs to multiple operators (PLMNs), see discussion in 5.4.3.5.

Another challenge for communication systems are low latency and very high availability requirements related to protection which are typically implemented using BST over optical lines. The studied special DSO use case of LOM protection in context of DER and AR cannot be met with 2G or 3G, but might be feasible with 4G/LTE due to it's possible low latency when strict QoS is enabled; this is subject to further validation. It's quite clear that in general 3GPP radio solutions are not appropriate for (inter-substation) differential protection schemes requiring low delay (~5 ms) and highly reliable, redundant (99.999% availability) communication channels.

5.6 Recommendation for most reasonable communication solutions

Based on the requirement analysis of the considered use cases in section 5.5 it is evident that utilizing public 3GPP 2G (GPRS) / 3G (WCDMA) / 4G (LTE) radio networks is a very attractive option for the DSO to converge the various communications systems used today towards future-proof IP based universally available SGC at low TCO.

CSPs have a large amount of licensed (interference free) frequency resources in use, spanning multiple frequency bands, in particular bands < 1 GHz which are essential in providing economical coverage in rural areas. As the traffic and signaling volume from the DA use cases are expected to be low when compared to wireless BB this results in low incremental cost of service provision for the DSO. The essential advantage is the possibility of leveraging the already existing radio coverage at the many new site locations envisioned for SGC. Furthermore, many more M2M application from other 'verticals' are expected to materialize which will provide a favorable 'eco-system' in terms of standardized M2M network features, devices and services.

This recommendation, however, holds only as long as the critical DSO availability requirements can be properly addressed. Based on the analysis in sections 5.4.3.5 and 5.5 it appears that the availability requirements can be reasonably fulfilled, possibly by enabling access to a 2nd PLMN at some increase in system complexity. In this context we also note that the regulatory requirements related to power backup of 3G/4G base station sites providing baseline radio coverage would need to be updated as public systems evolve from 2G->3G->4G.

5.7 Suggested evolution

Today various communication systems are used in the area of DA. Regarding 3GPP radio access, it is likely that these SGC radio access methods will be concurrently used. There will be GPRS legacy FA application, together with more recent installations utilizing HSPA900 multi-mode/band capable RTUs. It will be in the interest of MNOs to push new M2M applications to use 2G/3G multi-mode M2M decices in order to avoid requests for maintaining legacy GPRS M2M applications with long life-cycles in the future, even though there are currently no regulatory requirements regarding the time span to keep GSM networks up and running.

DA related use cases are somewhat less price sensitive than SGC use cases closer to the consumer such as AM. This may allow for faster migration from 2G ➔ (3G and/or 4G) in order to simplify and rationalize network operation.

As discussed in section 5.4.3.1, a likely evolution in Finland towards ultimately LTE capable M2M radio modems in bands <1 GHz for rural SGC may be as follows: GPRS900➔add HSPA900➔ add LTE800➔LTE800/900 with the caveat that in urban areas LTE2600 (+LTE1800) will be available as an earlier option for LTE.

Note, that the discussion on 3GPP radio access migration is also connected to BS power backup considerations, see section 5.5 (ref. fall-back to GPRS with guaranteed longer power back-up times).

Naturally, also fixed access (e.g. DSL) maybe be in use at some locations of RMUs or DER, either by legacy or choice. Hence managed connectivity from SCADA/DMS would need to be able to deal in addition to 3GPP radio access also with DSL or any other legacy IP access, complicating network operation (identity management, service provisioning, QoS management, security …).

From the perspective of simplified and rationalized network operation, it makes sense to target evolution towards CSP provided LTE for most DSO related SGC with exception of protection schemes requiring communication channels with the most stringent QoS.

5.8 Items for further study

During the requirement analysis of the considered use cases in section 5.5 the following items for further study were identified:

- traffic modeling (including signaling) related to DA SGC use cases and comparing it to BB traffic in mobile networks
- quantitative results regarding the radio system outage probability when considering additional resilience due to same-operator 'site-diversity' under the conditions of the favorable M2M link budgets as discussed in section 5.4.3.6
- network architectures, interfaces and reduction of outage probabilities when using multi-operator access in order to increase availability (section 5.4.3.5 and [48])
- detailed investigations on the delay (latency) requirements for the LOM protection use case 5.3.4.

6 Smart Metering

In several aspects Smart Metering appears as the most challenging use case for Smart Grid communication. Even though the functionality of Smart Meters seems quite limited, their scale of deployment, requirements on privacy and against manipulation are challenging.
Furthermore Smart Meters are installed in difficult to reach locations, not only by service personnel, but as well as in the sense of communication with limited network access options at minimum cost. It is assumed that they will run with untouched operation for around 15 years.

6.1 Non functional requirements

Next to the obvious Smart Meter requirement to count and rate used electricity as before, there are several other detailed requirements to be fulfilled.

The most prominent one is to support customers in Smart Energy utilization. This means that mainly residential and enterprise consumers have to be enabled by the Smart Grid infrastructure to cognize their energy consumption behavior in a real time experience. According to the Pew Center for Global Climate Change [3] this promises the largest potential in energy saving today.
On the other hand, energy generation will adopt renewable sources to a high degree, requiring conscious consumers' households to utilize energy in an interactive way, depending on Time of Use (ToU) schemes or even event triggered instances.

These requirements are best incentivized by a variable price of electricity, which needs to be understood and easily utilized by the consumer.

Furthermore Smart Meters shall optionally fulfill additional operational tasks, like embedding the capability to remotely turn off/on electricity feeding, monitor and control connected equipment or provide meter reading information to remotely connected In-Home-Displays (IHD).

Apparently ancillary objectives around the above task must not be neglected in the implementation of Smart Grid Communication. Poor consumer acceptance is the consequence, currently faced in the U.S. for several reasons.
Consumer energy usage profile privacy is an important objective, which is most stringently described by the German Federal Data Protection Act [4], but its underlying basics become more and more understood all over the world, due to the potential of malicious utilization of personal data. For instance such privacy concerns caused a hold in large scale Smart Meter deployment in the Netherlands in 2009, leaving it as non-compulsory for citizens to opt for installation [56].

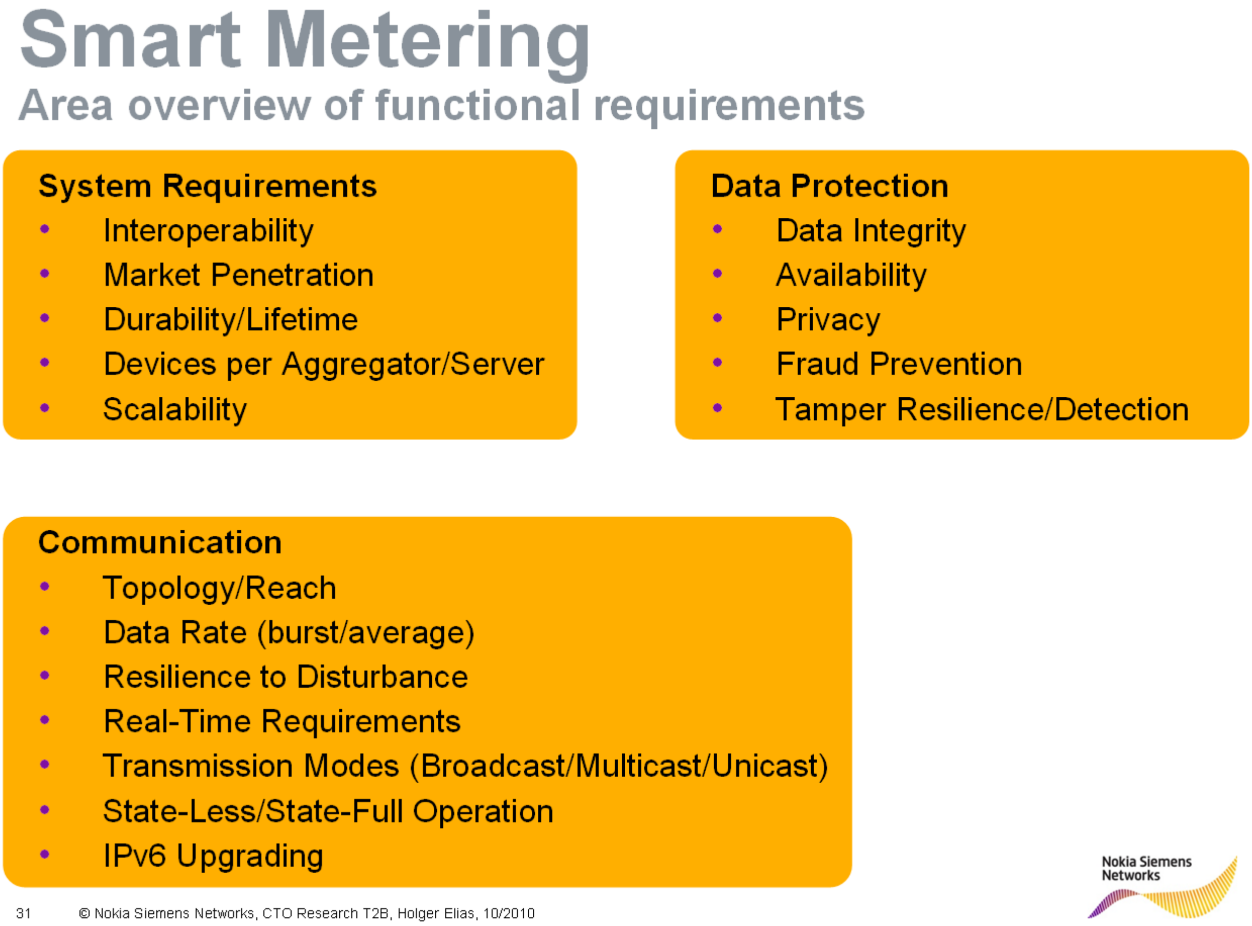
Other objectives are around the business case for Smart Metering and smart energy utilization as a whole. Smart Meters need to comply with current cost expectations for metering. Their initial price as well as the regular communication, data processing/maintenance and intrinsic electricity cost (for the complete smart energy utilization scheme) needs to be covered by the enabled energy-saving applications.

6.2 Functional requirements

6.2.1 Overview

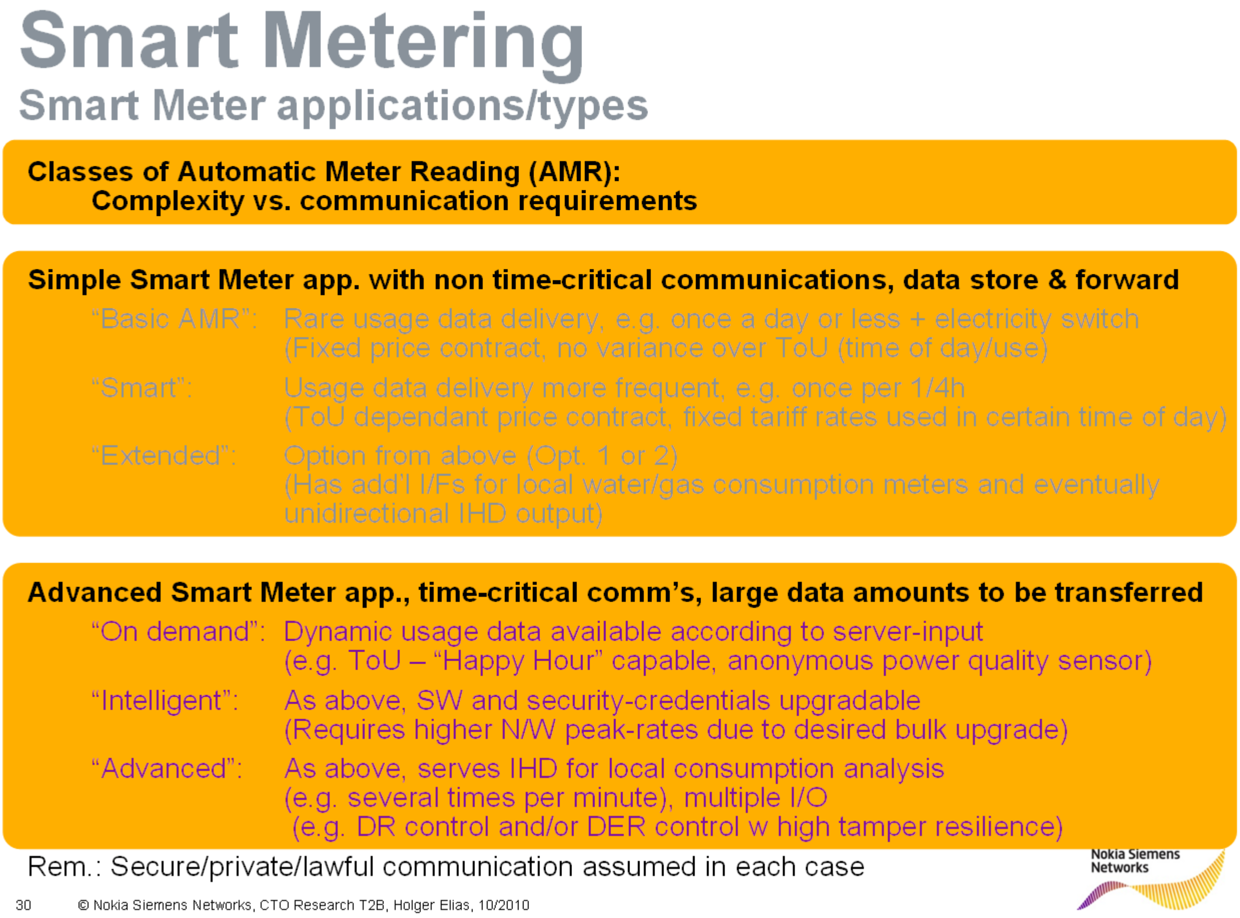
As outlined above, the Smart Metering use case faces a broad range of functional requirements in several areas. Many of them do have an impact on the optimal concept for communication with the metering device. Not all of these functional requirements can be discussed here, but those ones identified to impact the communication concept directly, are focused and discussed.

As an overview some generic functional requirements to operate Smart Meters are listed below



6.2.2 Range of applications

Another dimension for functional requirements is the desired range of applications to be supported in a Smart Meter rollout (please see below).
In general, one may divide Smart Meters into 2 groups: Simple and Advanced.



Depending on the expectations over lifetime, it is useful to invest into a more versatile metering device platform as required from begin of installation.
Considering the operational stability, without physical attendance of service personnel asks for some reserves in device processor power and memory. (Please consider operating PCs or computer equipment as well as software designed 10 years ago). Smart Meter platforms fulfilling advanced requirements with 32 bit processors are already on the market [8].

In a recent interview, Vint Cerf, as a VP of Google, admitted that the Smart Grid will probably not be sustainable without relying on Public Key Cryptography based communication [5] for authentication. Obviously necessary encryption bears a twofold implication on the communication requirements.

- Encryption may extend the initial message size of Smart Meters in terms of bytes to multiples of the cryptographic block length (e.g. 128 or optionally 192 or 256 bits in case of AES).
  From NIST references [6] message length is indicated from around 25 to a few hundred bytes and cryptographic key size of 128bit in case of AES utilization was considered as sufficient [65].
  In certain cases, like in multi-dwelling buildings, several (few dozen) rather simple meters (as described above) may also be connected to a local master-node, as for instance described in the M-Bus concept [7], which builds on the "Trust-by-Wire" principle in a building thus avoiding encryption and even IP-Layer transport in such sub-systems. After all, the local master node, in combination with the communication interface, need to fulfill the above privacy requirements, when connected to a Wide Area Network (WAN).

- Software upgrading, as probably required several times during the lifecycle, accounts for some 400 to 2000 Kilobytes per meter [6] or master node in the above sense.
  Unfortunately, relying on an underlying IP protocol stack makes the utilization of Multicast or Broadcast mechanisms as known from IPTV networks (e.g. Protocol Independent Multicast, PIM) difficult, especially on the last mile of the communication connection.
  The last mile of the network usually exhibits the lowest bandwidth in the network and may not be able to support multicast protocols like PIM in its routing instances.
  Since intrinsic multicast properties of certain shared media communication solutions (e.g. as defined by 3GPP, ZigBee and eventually in PLC/BPL) differ in implementation and operation, they should be regarded as a critical success factor during initial communication network planning and implementation.
  Our first calculations show that e.g. smart meter upgrade tasks may be supported already safely in a 3G/UMTS point-to-point / one-by-one application without blocking too much network capacity carried out in a reasonable timeframe.
  Due to transmission errors or network outages, a successful process of SW/FW upgrading needs to be checked and repeated anyway for several times, even if multicast mechanisms are available.

6.2.3 Conclusion to functional requirements

Based on the discussion above, the communication concept dimensioning for Smart Meters shall be based on the utilization of Public Key Infrastructure (PKI) and implies only a 1-to-1 WAN connection scheme between server and device.

In addition, as Nokia Siemens Networks, neither being involved in the design of home area networks, nor in the required diversity of Home Area Network (HAN) solutions, we will mainly concentrate on communication solutions which are directly connected to the WAN. These may be wire-bound or wireless solutions, operated publicly (by Communication Service Providers - CSP) or privately (by Dedicated Network Providers). The reasoning for this is the variety of in-home communication solutions, may they be wire-bound, as for instance the new G.hn (ITU Recommendation G.9960) standard which specifies 3 ways of communication via power-line, coaxial or twisted pair cable or wire-less ones, like ZigBee, Z-Wave or WiFi. All of these communication technologies will transport IP and need to fulfill the throughput and latency requirements for the above discussed Smart Meter functions up to an in-house aggregation point, which connects to the WAN.
The selection of an appropriate in-house communications technology depends on the structure of the building. For instance, Smart Meters installed in the basement cannot rely on 3GPP defined methods of communication, requiring an aggregator or proxy node having sufficient radio field-strength.
On the other hand, when installed above ground with sufficient radio field-strength, the meter may be directly connected into the 3GPP network without aggregator node, even in multi-dwelling buildings.

In case of a wire-bound WAN-communication for Smart Metering, it needs to be considered, when a private WAN communication connection (e.g. via Home-DSL/Cable-Router), will be switched off for a rather long period (over night or during absence).
A wire-bound Broadband-Power-Line (BPL) or outdoor wireless ZigBee WAN-connection into a so-called Neighborhood-Area-Network (NAN), which can be described as a local Dedicated Network, overcomes the above mentioned non-availability of communication, but may be prone to disturbance from interference of other communication devices operating in the same unlicensed frequency bands.

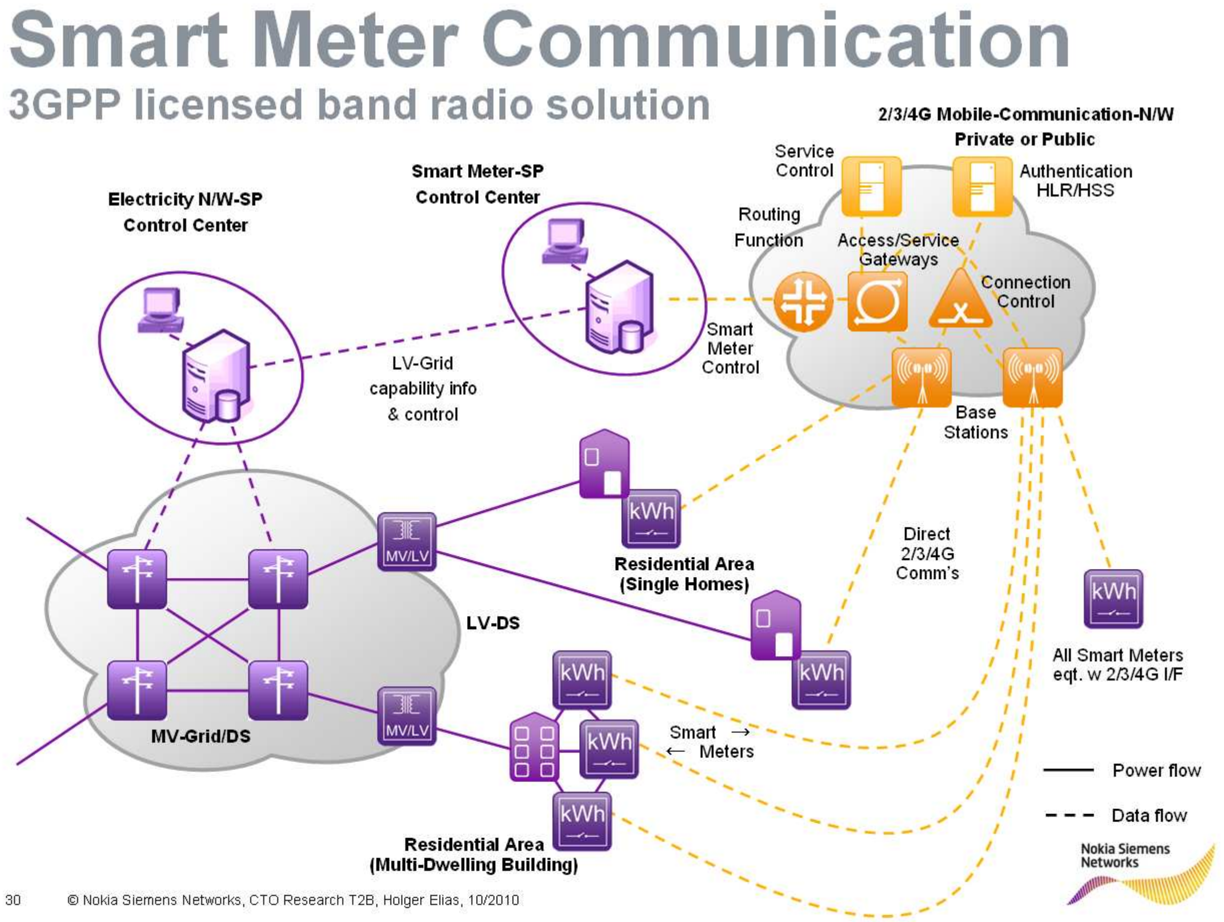
In essence, the operational availability for an installed WAN communication service may be regarded as sufficient in general, but the practical availability may be disturbed for the above mentioned reasons. Operational availability and the other communication requirements from above are reflected in the table in chapter 6.4 below, using communication technology related terms.

6.3 Descriptions of commonly-used communication solutions

Considering the above discussion, we see 3 major suitable communication network solutions to connect Smart Meters (single or in a secure cluster formation) over "wide areas".

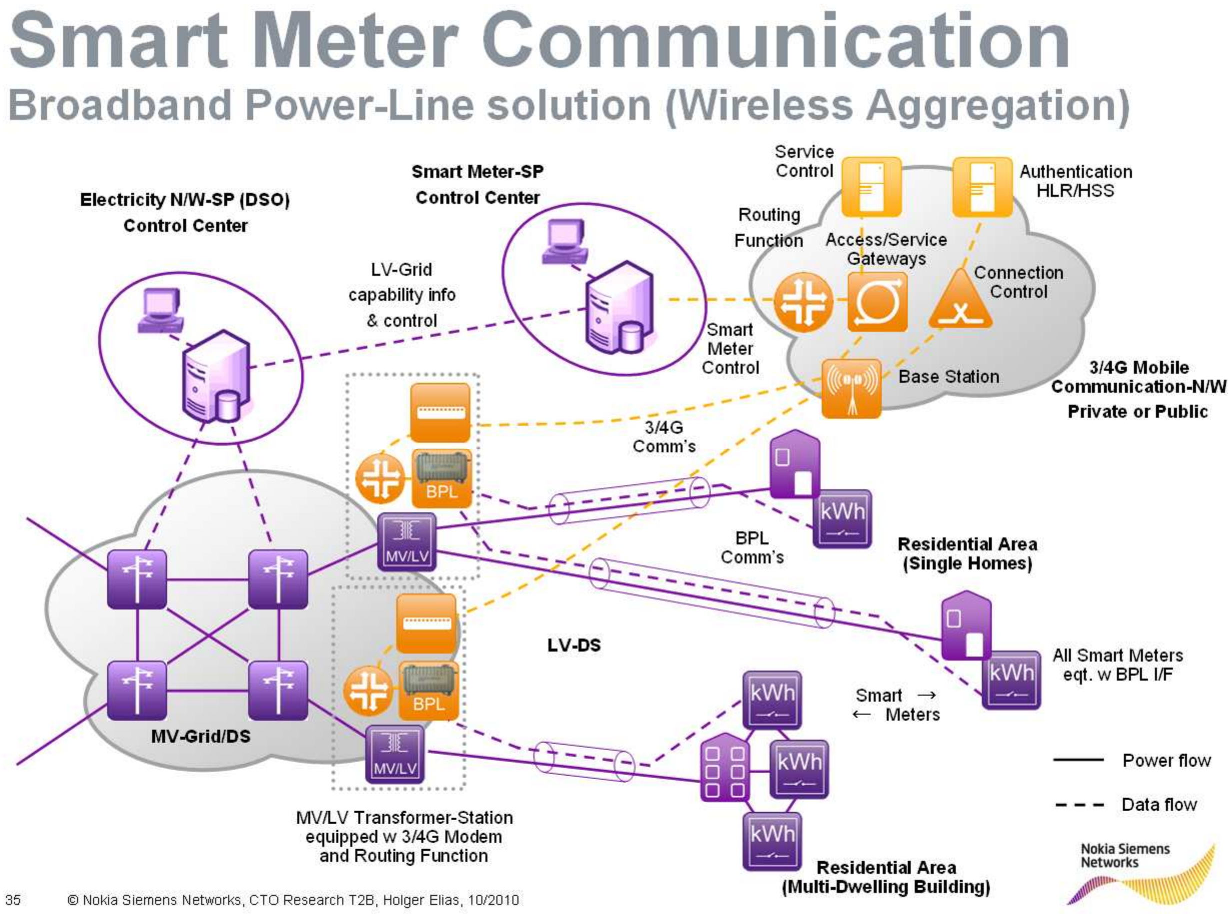
6.3.1 3GPP defined licensed band radio solutions

3GPP defined licensed band radio solutions, like 2G/GSM/GPRS/Edge, 3G/UMTS or 4G/LTE or in some cases also WIMAX solutions (WiMax tends to migrate into a standardized 4G solution over time).
These may be operated as public networks by CSPs (mainly 3GPP oriented) or as dedicated networks (some WIMAX oriented, also in unlicensed bands), e.g. by utility or service companies. Please see below:



6.3.2 Broadband Power-Line solutions

Broadband Power-Line solutions in the neighborhood area in combination with aggregator nodes (due to reach limitation) are typically installed on utility premises (like MV to LV transformer locations). These aggregator sites are usually connected either via the above described wireless WAN solutions or again by independent "WAN"-type BPL solutions operating on the MV network (both BPL solutions will not interfere, since the MV-to-LV transformer will separate both signals). In the “WAN”-type BPL network, a repeater spacing of <1Km needs to be realized. A dedicated fiber connection at transformer sites seems rather the un-probable case in the medium term future, when the Smart Grid will be enabled. Please see below:



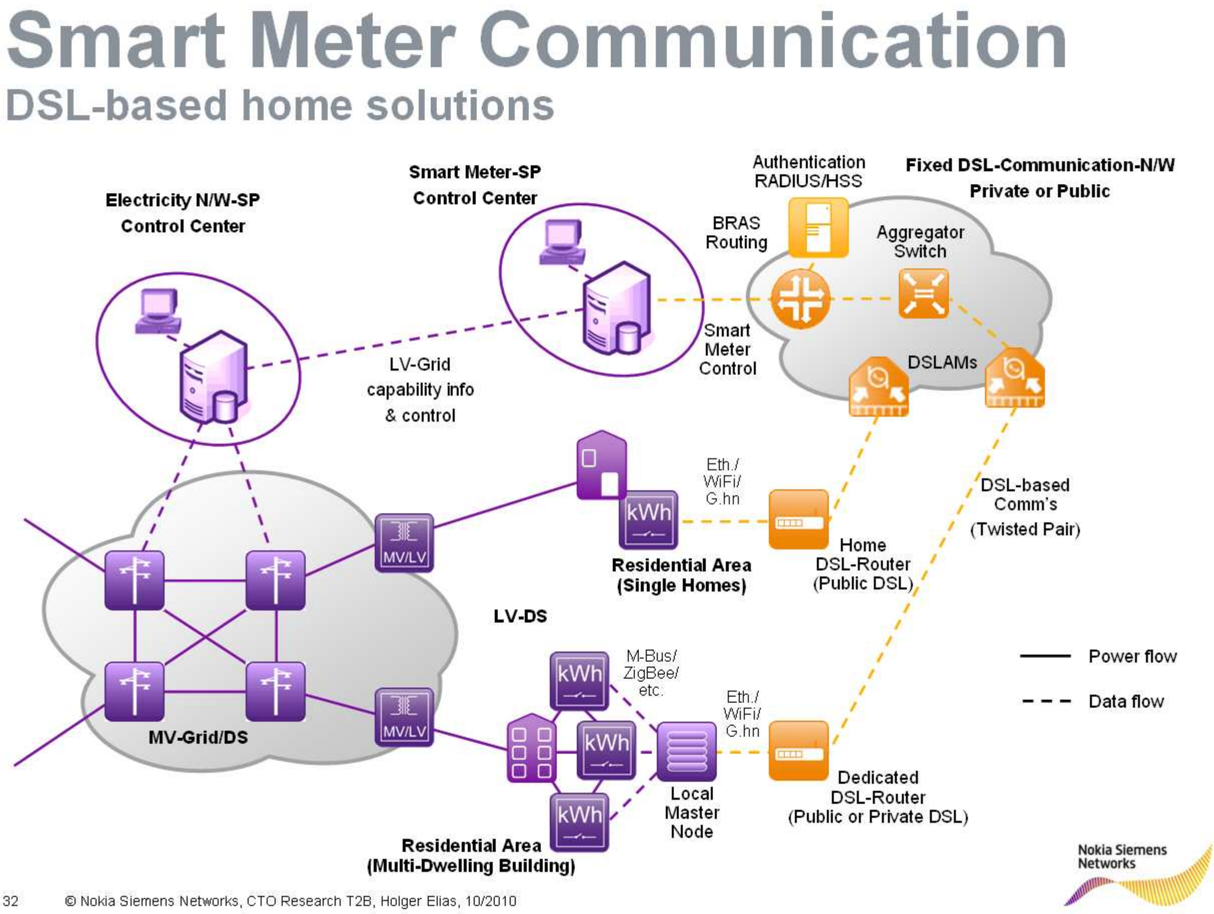
6.3.3 DSL/Cable-based home solutions

DSL/Cable-based home solutions, which are widely available, may be preferably used for multi-dwelling buildings, since only one more twisted pair will be used to connect several meters in a building.

In principle, private DSL or Cable may also be used, but as discussed above, there is no permanent communication availability guaranteed, limiting a broad range of applications initially only to conscious consumers.

One need to observe that intentional electricity power cutting via the Smart Meter may be avoided by breaking the communication link and also re-establishing power is not possible without mains power at the DSL/Cable-Home-Router!

Please see below:



6.4 Mapping req's to available N/W parameters

Different WAN solutions to connect Smart Meters to suitable communication network solutions, based on their relevant network parameters are being analyzed in detail in the table below, to derive the relevance of available communication solutions to Smart Grid Communications.
An interpretation of the table, recommending reasonable communication solutions for Smart Meters can be found in the next paragraph.

As outlined above, secondary in-house communication solutions are not discussed in here.

4G/LTE licensed band WAN offering was split into "Digital Dividend" (<1GHz) and "Regular" (>2GHz) band operation, because (intended) propagation characteristics are different, as outlined in chapter 5.4.3.4 (Coverage/Cell Cadius).
Furthermore, the rating for 4G/LTE in the following table was projected to 2015 onwards, to gain a future-proof valuation.

For WiMax it was assumed that operation will take place above 2GHz, particularly in unlicensed, but undisturbed bands.

Dedicated Network operation is named as Private Wired/Wireless.

To map all relevant N/W parameters into a single two-dimensional table, it was necessary to differ between Smart meter communication solutions which are directly connected to the device and solutions which include a concentrator or aggregator node, collecting data from several meters, before connecting into the WAN. This was reflected in a double rating field, where a significant difference in rating is visible. Otherwise, a single rating describes a similar suitability for both solutions (to maintain better visibility).

As discussed above, Smart Meter classes were differentiated into simple and advanced types as well, to maintain a better overview. As one can see, differences are limited to the feasibility of the 2G/3G and BPL communication solution.

The rating was done in a relative way, according to the relevance of certain parameter requirements for the noted Smart Meter types. The distinct display of numeric values for Smart Meter communication parameters was therefore avoided, but can be reviewed in reference [6] which is appended and from discussion in reference [2].

The distinction between ratings (+/0/-/N/?) shall be understood in way that:

(+) Indicates a fault-free operation within practical boundaries of installed metering network.

(0) Means that certain constraints in the boundaries of the deployment need to be observed.

(-) Shall indicate that problems in the operation of the metering deployment may not be avoided.

(N) Indicates situations in which functionality may not be reasonably maintained on a broad basis.

(?) Shows the relevance of secondary communication solutions, which may impact the functionality of the complete E2E solution

Meter/Communication	Public Wireless					Private Wireless			Public Wired	Private Wired	
	2G/GPRS/EDGE	3G/UMTS	4G/LTE <1G	4G/LTE >2G	WiMax	4G/LTE <1G	4G/LTE >2G	WiMax	DSL/Cable	BPL	DSL/Cable (*1)
General Network Availability	+	+	0 (*2)	0 (*2)	-	-	-	-	0	-	-
Concentrator Utilisation	See below ↓ Double field rating: Without Concentrator/With Concentrator ↓ Single field rating: Similar rating for both solutions										
Simple Smart Meter Type											
Bandwidth	0/N	+/0	+	+	+	+	+	+	+	0/-	N/+
Latency	-/N	+/0	+	+	+	+	+	+	+	0	N/+
Operational Availability	+	+	+	+	+	+	+	+	-	0	N/+
Cluster-size	+/N	+	+	+	+	+	0	0	0/+	0	N/+
Reach	+/N	+	+	0	0	+	0	0	+	0	N/+
Accessibility											
Basement	-	N	-	N	N	-	N	N	-/+	+	N/+
Inside Above Ground	+/N	+	+	0	0	+	0	0	0/+	+	N/+
Security/Privacy	+/?	+/?	+/?	+/?	+/?	+/?	+/?	+/?	?	N/?	N/?
Function Support (*3)	+	+	+	+	+	+	+	+	-/+	+	N/+
Future Upgrade	-/N	+/0	+	+	+	+	+	+	+	0	N/+
TCO (*2)	+/N	0/+	0	0	-/0	-	-	-	0/+	-	N/+
Advanced Smart Meter Type											
Bandwidth	N	0	+	+	+	+	+	+	+	-	N/+
Latency	-	+	+	+	+	+	+	+	+	-	N/+
Operational Availability	+	+	+	+	+	+	+	+	-	0	N/+
Cluster-size	+	+	+	+	+	+	0	0	0/+	0	N/+
Reach	+	+	+	0	0	+	0	0	+	0	N/+
Accessibility											
Basement	-	N	-	N	N	-	N	N	-/+	+	N/+
Inside Above Ground	+/N	+	+	0	0	+	0	0	0/+	+	N/+
Security/Privacy	+/?	+/?	+/?	+/?	+/?	+/?	+/?	+/?	?	+/?	N/?
Function Support (*3)	+	+	+	+	+	+	+	+	-/+	+	N/+
Future Upgrade	N	0	+	+	+	+	+	+	+	0	N/+
TCO (*2)	N	0/+	+	+	-/0	-/0	-/0	-	0/+	-	N/+

Rating: (+) = Good
(0) = Fair
(-) = Poor
(N) = Not feasable
(?) = Depending on Solution

Remarks:
*1 → (N/+) Not enough twisted-pairs available, but one from concentrator feasable
*2 → TCO rating and availability for 4G/LTE beyond 2015
*3 → Functions depending on independant meter communication G/W powering (i.e DSL-Router or Cable.Modem)

6.5 Recommendation for most reasonable communication solutions

As can be concluded from the above table, from a concrete technological perspective, there are several reasonable communication solutions possible.

Actually they tend to be country specific, i.e. depending on existing local loop infrastructure (E. g. certain limitations in Eastern European States of the EU vs. perfectly built structures in middle Europe), or speed of 3G/4G network deployment in other states, as well as structures of population density and regulatory conditions. Please refer also to chapter 5.4.3.1 for details

Therefore probably all discussed solutions will have their generic place in deployment.

Observing cost constraints on a broad basis (expected monthly cost for pure metering purpose is less than 1€/month, Smart Metering may add some value), the influence of scaling effects in device and service pricing will certainly play a selective role.
Considering the cost of silicon for communication purposes (e.g. ICs & ASICs for 3G/4G or DSL) as a major one, those ones used in residential applications promise an advantage over low volume “special solutions” (e.g. ICs & ASICs for WiMax or BPL) over time.
Ongoing deregulation in the energy sector will continue to further split former “utility-giant” organizations into legally independently operating units, which also need to perform independent business in all geographical areas. This leads to a pressure to avoid high CAPEX investments into Dedicated or Private Networks, giving Public CSPs a chance to grow such e-Energy business on the basis of OPEX oriented offering, while observing specific network availability requirements.

In parallel to the above, the ratio of labor cost to install devices and device cost (Smart Meters) will continue to increase. Therefore stand-alone Smart Meter solutions (e.g. in single homes) will prosper, which are less time consuming to install. Such solutions may be 3GPP and BPL based ones where no additional in-house communication needs to be installed or configured.

Projecting bandwidth and real-time communication requirements for the next years, which are based on Demand Response and ToU service offerings (including upgrading metering device firmware and software), certain bandwidth limited communication solutions, like 2G networks (which may even be phased out during the Smart Meter life-cycle) or the usage of BPL in densely populated areas need to be questioned.

A special issue is the utilization of existing residential infrastructure, like DSL or Cable. Since they do not offer non-interrupted and independent operation, neither from the premises’ primary power connection, nor free access/control for utility companies, their advantage is limited to incentive triggered residential offerings. These go beyond the Smart Meter application, but their importance may arise in future (Please see next chapter).

Based on the above one may draw the following conclusions:

Public wireless networks based on 3G/UMTS or later 4G/LTE technology display themselves as preferred default-choice solutions for a broad deployment of Smart Meter communication.
This will be accompanied by wired BPL or DSL/Cable solutions in cases where there is no wireless network access, or in case of the opportunity to install concentrators in multi-dwelling buildings (Single meter or multiple meters located in basements).

6.6 Suggested evolution

Two main drivers for the evolution of the Smart Meter communication case may be expected.

- One is about communication network technology and its scaling effect on cost. We expect to see a broad introduction of 4G/LTE as a standard and widely available multi-purpose communication technology in both frequency bands, whereas DSL/Cable and BPL communication will rather stagnate in bandwidth offering and pricing.
- The other driver is the opportunity for new business players. Today, deregulation has barely started to distract residential consumers from changing their local electricity vendor. This potential may be exploited by new companies, not only offering the legally required Smart Metering according to measurement and weight laws (as solely done by today’s utilities), but in addition or independently by offering services for refunding money by smart electricity

utilization. This opens a whole new field of Demand Response applications, which may be legally ruled in a different way than today's pure electricity metering. In the light of such applications, any residential communication network capability may be used.
The paradigm to switch off residential communication infrastructure to save money would be altered in way to an "always on" scenario for the same purpose. This would pave the way for the broad utilization of existing DSL/Cable infrastructure plus the incentive for the end-user to connect as many smart devices to the home network at his own or shared cost together with the refunding partner (similar to Kofler Energies offering in Germany [9]).

On the other hand such "Refunding Companies" will also see the advantage of avoiding home network configuration problems, therefore pushing integral solutions with 3G/4G communication I/Fs into the market.
One needs to observe that they may pick their customers in selected areas in a similar way from today's established electricity vendors/utilities, as alternative Fixed-Network DSL-Operators did 5-10 years ago (so-called "cherry-picking" in Germany), thus setting the technology trend in Smart Meter communication.

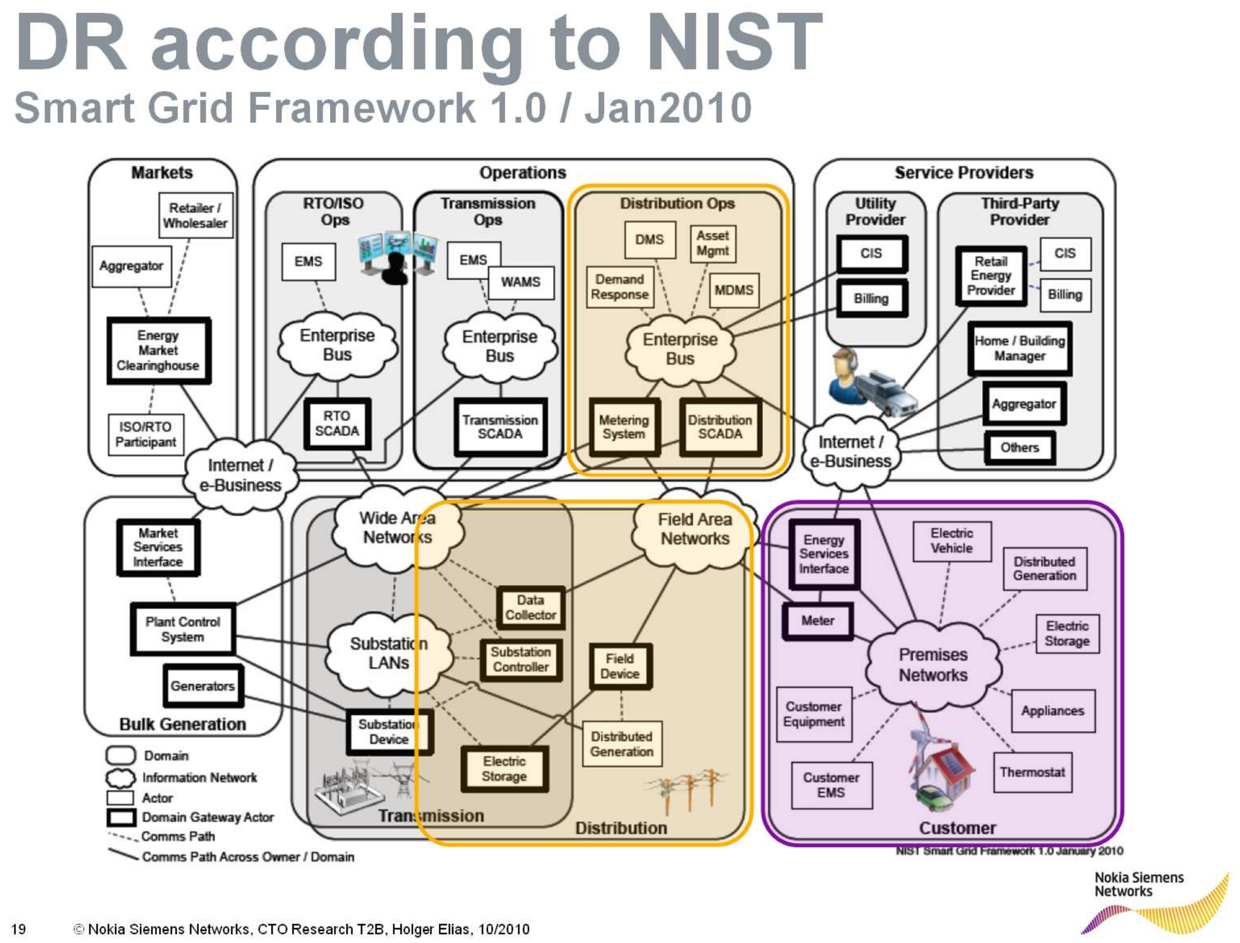
These expectations may underpin the findings from the above chapter in a way that the importance of unlimited public wireless broadband communication, especially in 4G/LTE networks will rise at the expense of Fixed-Network/wired solutions, which eventually have to be considered only as a catalyst for Smart Meter communication.

7 Demand Response for large scale application

Demand Response for large scale application (industrial and enterprise management – Large Industrial and C&I type) shall be understood in contrast to Demand Response in Consumer or Prosumer areas, including Small & Medium Enterprises (SME), which will be covered later in this document.

For further understanding, Berkeley National Laboratory had issued a scoping study, which details the business background of the Demand Response scenario [11]

NIST [10] has described the Smart grid ecosystem in which Demand Response is settled in the framework drawing below.



The upper part includes Demand Response operations (orange) for both areas (large scale and consumer) within Distribution System Operators (DSO) responsibility, the lower part (orange) shows the area of Distribution Networks addressed in here. The customer network part (purple) is more related to consumer applications.

As a coarse guideline for the following discussions, large scale Demand Response applications shall be understood as rather connected directly to the Medium Voltage Distribution System, originating from Substations.
Based on a recent U.S. based demand response and energy management solutions provider publication from ENERNOC [12], the desired customer application range for Demand Response becomes obvious spanning Large Industrial and C&I customers.
Please see excerpt below:

Comparison of Types of Dispatchable Demand Response Programs

	Interruptible Tariff	EnerNOC Demand Response	Direct Load Control
Customer Segment	Large industrial	Commercial, Institutional and Industrial (C&I)	Residential
Resource Profile	Usually manual; full facility shut down or customized curtailment plan	Manual or automated; typically requires customized curtailment plan	Utility has automated control of common applications (e.g., air conditioning, pool pumps)
Customer Profile	Generally, more sophisticated energy users	Some energy sophistication, most require guidance	Little energy interest or sophistication
Capacity	1 MW and up	100 kW and up	1-2 kW
Incentive	Reduced electricity rates	Capacity and energy payments	Nominal credit or other incentive
Reliability	Reliability varies	Metering and control technology enables high reliability	Limited visibility into performance

Source: ENERNOC, please see explanations above

7.1 Non functional requirements

Non-functional requirements for Demand Response communications originate mainly from insuring the operational stability of the Distribution System, throughout the ongoing introduction of Renewable Energy Sources.
This evolution requests a higher degree of flexibility in Demand Response as in the past, due to the un-deterministic and variable nature of power generation from renewable sources (e.g. Wind-Turbines, Photo-Voltaic and Wave-Power-Plants).

Basically scheduled demand response operations as they exist today (e.g. for industrial and factory plants) need to be extended towards instant controlled negotiation and response.

Compared to the situation in the past, where a simple communication channel from the DSO was sufficient to control consumption on a previously agreed basis with the customer, nowadays ancillary automated processes become necessary to increase flexibility in demand response.

Simple communication channels using SCADA-type interfaces (Supervisory Control And Data Acquisition), e.g. transported via low bit-rate transmission modems, need to be supplemented by Demand Response Management interfaces (e.g. metering and administration of curtailment plan, please see table above) to close the circle of demand response automation. Usually these interfaces rely on browser-type protocols (HTTP, HTML, XML, etc.).
Simple communication in this circumstance does not mean that the reliability of this control communication link should be underestimated, since the efficiency of production processes in general will depend on fulfilled Service Level Agreements (SLA) of demand response operations, but certain limitations apply (see next chapter).

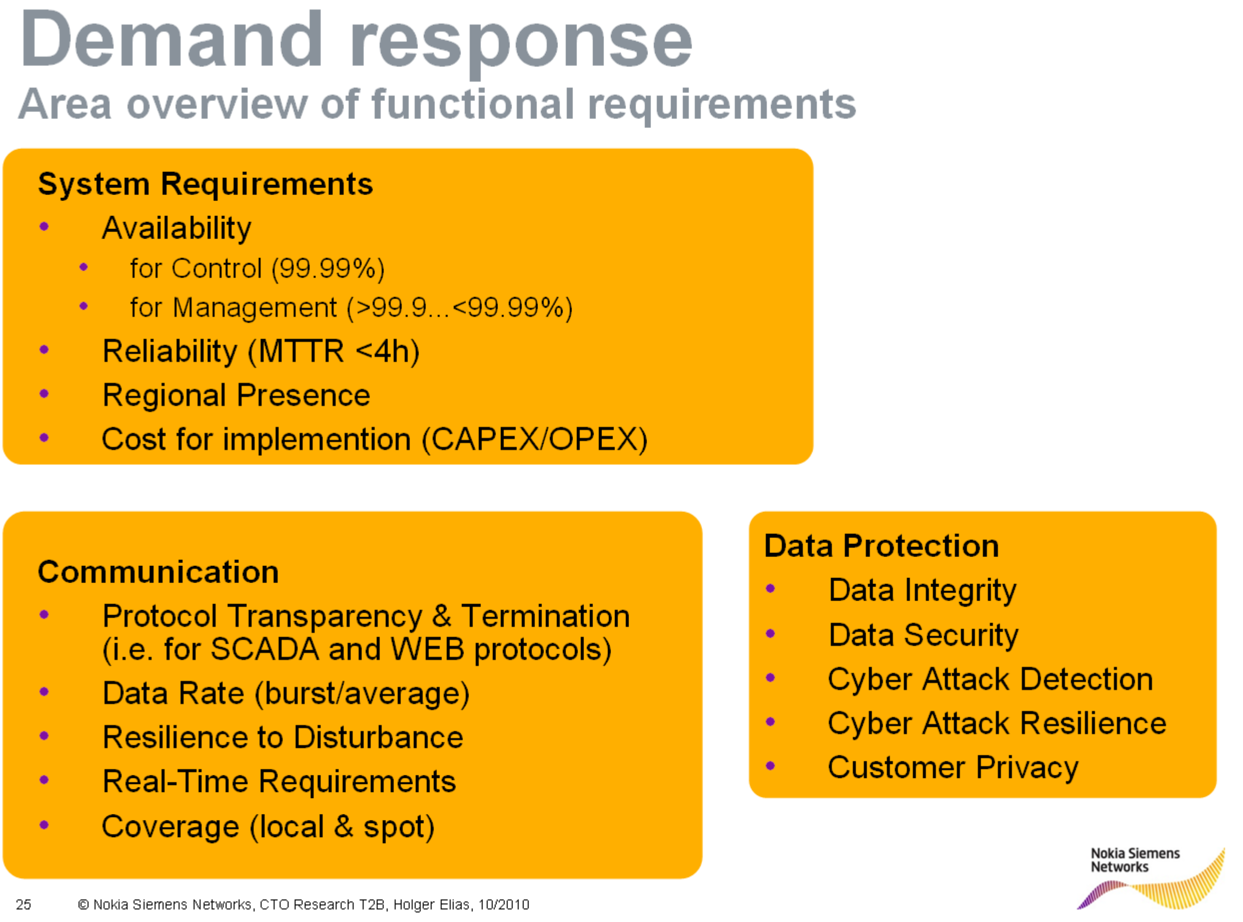
Please also note that the control-type interface may be provided by the local DSO, whereas the management interface for Demand Response may be provided by a dedicated company, other than the DSO (in the example above by ENERNOC).

7.2 Functional requirements

Following the above, judging from a business fulfillment background, estimated Demand Response functional availability of 99.99% (app. 1h outage per year) would require initially comparable availability on demand response concerning communication links.

This would require similar high availability of the control channel (please see the table below), actually turning on and off power sources or consumption devices, which are relevant to business or production fulfillment. Usually these control & measurement links require relatively low bandwidth (<100Kbps) and relaxed latency (<100ms in dialed-up mode, <1min for dialing-up). Security may be maintained by “trust-by-wire” for dial-up connections or router-based secure VPNs, when operating via IP networks. On the other hand, demand response management may have somewhat relaxed availability requirements, since evaluation and modification of demand response programs may not be that critical, compared to the execution, accomplished through control mechanisms. Therefore 99.9% availability (app. 10h outage per year) seems a reasonable requirement.

Please see below:



Reliability figures with a 4h Mean-Time-to-Repair (MTTR) rely on the assumption that a hardware or software related failure, which cannot be fixed remotely, happens only once within several years of continued operation and typical repair service actions may be fulfilled in such timeframe.
Considering much longer times to repair communication cable-breaks, no matter if located in the local loop or metro area, precautions for manual override of local demand response control need to be taken into account to achieve the desired figures from above.
From this discussion it becomes obvious, that it is not reasonable to demand such service availability figures directly from one communication network itself, neither for control nor management channels. Therefore the communications availability will need to orient itself to the announced CSPs’ commercial availability figures, ranging around 99%, i.e. 4 days of possible network failure per year. Back-up communication systems or manual control will need to solve this challenge.

A combination of the below discussed commonly used communication solutions may be also applied to increase communication network availability.

Resilience to disturbance is specifically important to SCADA-type communication protocols for control channels, which operate directly on top of transmission layers 1 and 2. Therefore Bit Error Rate (BER) becomes important to maintain resilience. Typical BER requirements in transmission links would be <10E-6 bit errors per second (BER).

In parallel, management channel links typically exhibit similar or higher standards (BER < 10E-8), even though higher communication layers (4 to 7, e.g. TCP on layer 4) would maintain operational functionality even at worse transmission conditions.

Coverage is of practical importance, since general regional presence of a CSP may be given, but white spots on local level may still exist.

Furthermore coverage on spot level needs is essential, i.e. resilience to fading effects, like observed in cellular radio (2G CSD/GPRS) e.g. vehicles passing by, causing multipath disturbance.
In general, such disturbance becomes less prominent when utilizing 3G or 4G mobile broadband connections, which are less prone to multipath fading in critical antenna placement situations.

As outlined in chapter 5.4., external antenna placement will increase field strength significantly, even without directional antennas, making it possible to connect to more than one base-station in case of temporary disturbance.

Data Protection needs to be maintained by standard mechanisms like HTTPS or IP-SEC on IP-links or modem authentication using dial-up links on trusted lines, which is not too difficult to achieve and may be even enhanced by intrusion detection and integrity surveillance.

Finally the cost for setting up a Demand Response solution needs to be observed.
From a DR-SP's perspective, investments to enable will vary indirectly by differing mutual agreements with local DSOs. Their cost depends mainly on the regional structure and the way how the SCADA communication is implemented. Differences are discussed later in chapter 7.5.

7.3 Descriptions of commonly-used communication solutions

Since demand response customers will probably always have an Enterprise Communication Network in operation, the above discussed DR-Management channel may be obtained through the company-LAN, e.g. by tunneling Internet-Access from the Demand Response Service Provider (DR-SP) to the appropriate Servers or Workstations, utilizing well-known protocols.
As SCADA via IP (for control purposes) has somewhat different requirements,
primarily from an administrative point of view (Enterprise vs. DSO communication policy), secondarily also from LAN and Internet-Access network design,
it makes sense to assume separate communication channels for both tasks.
The local DSO would operate the SCADA link independently from the Enterprise LAN installation either wire-bound or wireless.

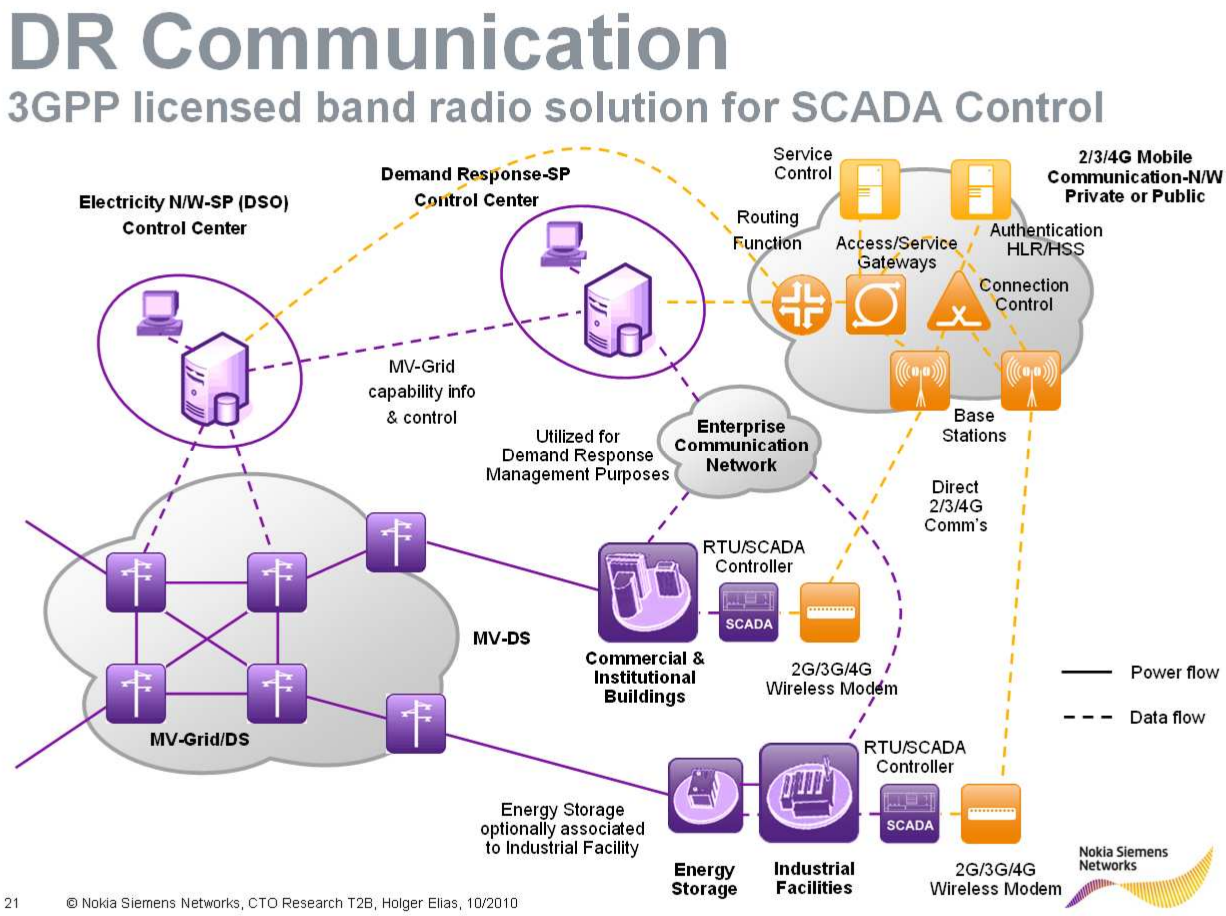
Therefore our descriptions of commonly-used communication solutions will focus on the latter only.
Nevertheless the physical connection to the demand response site could well be provided by the same CSP, but on different logical levels, e.g. a different L2 or L3 connection (VLAN or VPN), originating from the same CSP-owned termination switch or router (see MAN scenario below).

7.3.1 3GPP defined licensed band radio solutions for SCADA Control

In general a DSO will try to simplify his SCADA network as much as useful.
Given the fact that DR-applications will predominantly appear in developed areas like cities, business

parks or industrial zones, but Distributed Energy Resources will need to be connected rather in rural areas, wireless communication is the common denominator to serve both purposes.

Effective wireless network design will build on point to multipoint architectures which can be offered by publicly or privately operated network operators, based on 3GPP licensed band radio solutions or eventually also via alternative WiMax WAN-radio-network installations.
After all, the differences in network design for both solutions are not so relevant for the control channel functionality, so we concentrate on 3GPP solutions network based discussion below.



Considering the legal relationship between the involved partners, the DR-SP will have to have a separate SLA with the local DSO, to offer DR-services to the C&I customer. Therefore the DSO will operate equipment under demand response regime himself, also to maintain DS-N/W stability.
This is reflected in the above solution drawing, where the DR-SP serves the C&I customer directly via Internet and Enterprise-LAN for DR management purposes, whereas the DSO controls consumption curtailment via his SCADA-N/W operated by a public or private wireless-CSP. DR-sites are connected via wireless modems and SCADA controllers, i.e. so called Remote Terminal Units (RTU). As discussed before, the necessary network parameters can be fulfilled by all network types in principle (2G, 3G, 4G or WiMax), differences are mainly determined by local network availability. Even Circuit Switched Data (CSD) connections on 2G networks are possible, due to the connectionless requirements of the SCADA control.

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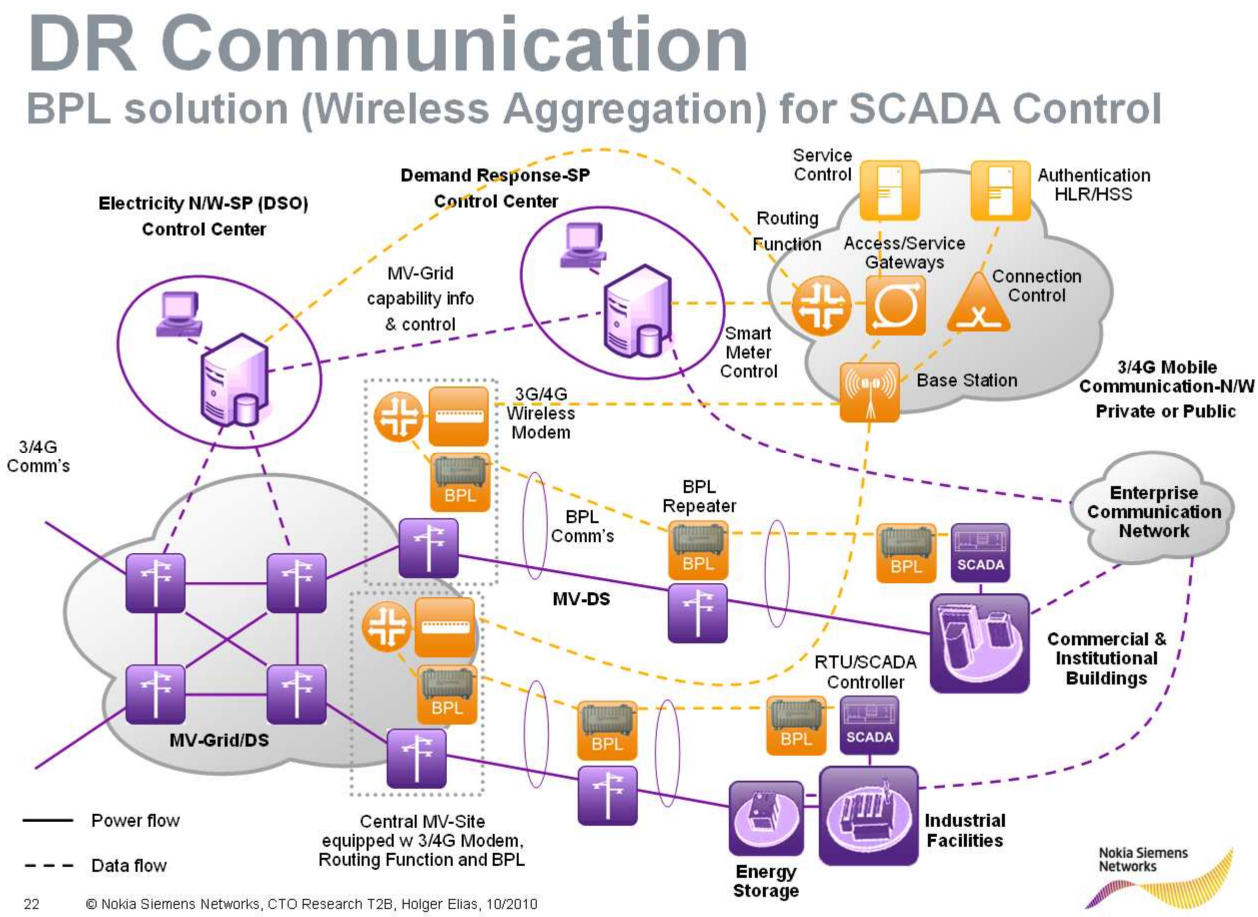
7.3.2 Broadband Power-Line solutions

Demand Response solutions using Broadband Power-Line solutions are in principle set up similar to the above described. The Demand Response management channel is as well delivered separately from the control channel via the Enterprise network.
Please see below:



The architecture in the control channel differs quite significantly though, even if the displayed solution uses a wireless WAN connection from a central site as well as the solution above. Such a site must not be a Sub-Station, it can be set up remotely, also in the vicinity of the demand response customer (e.g. a MV Recloser or branching site).
Please note that this MV-BPL equipment differs from the low voltage one, described in the Smart metering use case. Both are transmission-wise isolated from each other by MV to LV transformers. Typical reach for such BPL equipment is around 500-1000m on a MV-line. Repeaters need to be placed along the line at this distance. Practical bitrates, which can be achieved in such a scenario, are ranging at some few ten Mbps. This serves certainly all possible customers to be connected to such a network in a given area. In fact, the network capacity will hardly be used up, so additional services may be run in parallel (surveillance, access control, etc.). This will reduce the DR-application specific upfront investment cost burden, to set up the BPL aggregating station and repeaters.

The driver behind utilizing Broadband Power-Line solutions is therefore at least fourfold.

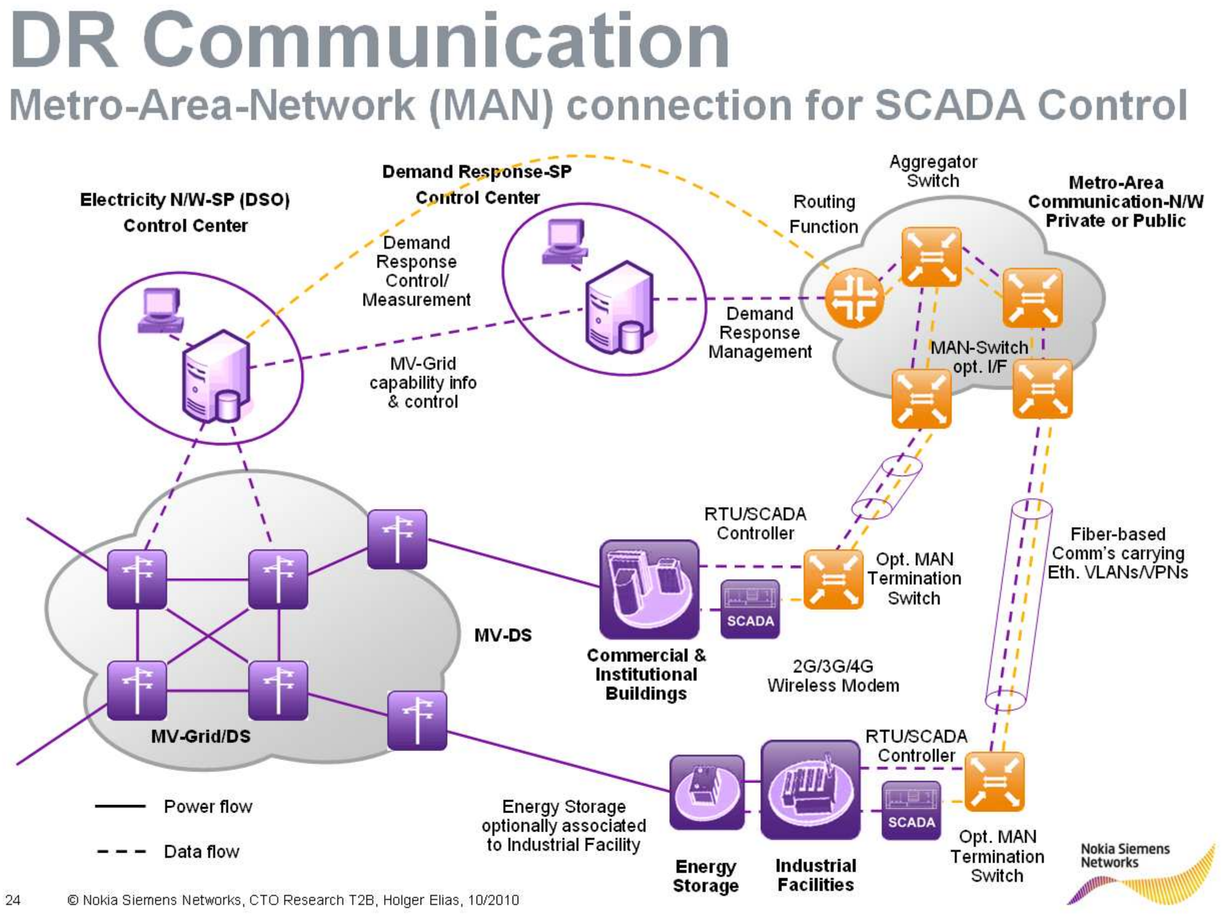
- Firstly Broadband Power-Line acts as Point-to-Multipoint distribution system, so several customers in an industrial zone may be addressed by one aggregating node.

- Secondly there is no need for separated data access at the customer site, assuming the equipment to be controlled is located in the vicinity of the MV-termination. This does not apply as good as the above wireless solution for DER applications in rural sites, because of the high BPL repeater count, but from an integration point of view it has still some advantages over split communication solutions.
- Thirdly system maintenance can be controlled in an aggregated way as well and expansions to more customers may rather be achieved under own regime, without involving other CSPs as 3rd parties.
- Fourthly the BPL system can be considered as a trust-by-wire solution due to the nature of the transmission media (MV!)

At the BPL aggregation site, in the generic case, a wireless WAN-link is foreseen to limit the necessity for a general full-scale BPL rollout in the MV-Grid. In specific cases, the Demand Response control channel aggregator may be also connected to existing LANs, e.g. in Sub-Stations. To avoid data traffic congestion from several demand response sites, a 3G or later 4G wireless connection should be foreseen initially. To mention it again, WiMax networks may also be utilized instead.

7.3.3 Directly connected communication solution via Metro-CSP

Since the DR customer will probably operate his own Enterprise LAN with connection to a local CSP, presumably via Metro-Area-Networks (MAN) and Ethernet over fiber (Direct Ethernet as shown below but also SDH), it seems rather obvious to utilise the same link for SCADA-DR-control and DR-management. Due to the different requirements for both services, different termination points seem necessary at the customer site. Both termination points may be physically located in one termination-switch, but in logically separated way. This may be achieved by Virtual-LANs (L2 – Ethernet-Switch, as shown below) or VPNs (L3 IP/MPLS-Router as an alternative). The termination device will be operated by the local CSP to maintain and monitor the SLA.
As introduced for the financial community, certain MAN CSPs are offering even high reliability solutions, based on fiber-optic ring networks which incorporate automatic protection switching and route diversity. Utilizing such a carrier, service and maintenance schedules may be even relaxed from the above mentioned 4h of MTTR to deactivate DR functionality manually after a major communication link fault.



Disadvantage of such a solution is certainly the requirement for the local DSO to negotiate with the CSP, chosen by the Enterprise, to host the DSO's control communication link as well and to connect to the CSP's main site.
Due to common roots of such MAN CSP and DSO enterprises in the same former utility company in certain city areas (e.g. Munich, but many others as well) such solutions are realistic as well.

7.3.4 Other legacy communication methods

In addition to the above more future oriented communication methods, remote SCADA communication is today mainly realized by dial-up modem connections via public (or also private) branch exchanges on voice (or in Europe also on ISDN) lines.
With the introduction of Voice over IP, some voice networks did as well introduce voice compression, which makes modem communication sometimes problematic, due to the required modem detection, which should switch voice compression off. Furthermore long VoIP voice packet generation delay may cause as well unforeseeable communication problems.

CSPs' DSL offering (consumer or professional services) may be another viable solution to reach DR-customer's locations. In principle, in the lower part of the drawing in chapter 6.3.3, the shown DSL solution based on the Dedicated DSL-Router may be utilized as well, then connecting to a SCADA RTU. ADSL or SHDSL service offerings for dedicated customers may be used, due to the limited bandwidth requirements.

7.4 Mapping req’s to available N/W parameters

Based on the above exemplary mapping of communication solutions to Demand Response needs, the below table shall yield a quantitative view on their feasibility and efficiency.

Discussing technical network parameters for the DR control channel solely (the DR management channel realized via the enterprise’s internet connection), not much differentiation can be derived from Bandwidth, Latency and Resilience to Disturbance, except some limitations using 2G/GSM or (Voice-)Modem communication in an aggregating application.
Concerning coverage within a small and dedicated area, like shadowing behind elevations (i.e. hills → “local”) or fading (i.e. metal walls → “spot”) for wireless (or concerning reach for wire-bound), those wireless technologies are in favor, which utilize spread-spectrum mechanisms to cope with “spot” field-strength dips (3G/4G/WiMax, please see also remarks in chapters 7.2 and 5.4).

Accessibility means the place of installation of the communication device, and thus the extension of the Ethernet data link to the local (SCADA-) controller. Assuming that the local controller is usually located in the basement inside the building, LAN-cable may be used to displace the communication device to where needed (e.g. outside, in the wireless case). In the case of BPL, a link needs to be established from a distant MV/LV transformer station (assuming it outside of the building) to the building where the DR controller is located. This might require a more complex way to connect.

As discussed above, all of the practically known applied transmission technologies are prone to cable cuts, which take their time to repair (including wired feeders). Actually only protected transmission links, like in the dual-homed MAN case or communication devices with different uplinks (e.g. wired and wireless) could meet the initially required reliability of the DR-service, limiting production outages just to power failures, but not to communications failures.
On the other hand, manual override of DR may solve transmission disturbance problems on a different level of operation and relativize availability requirements for the communication channel.

Future-proofness analyses mainly the availability of services and communication device components over the expected life-time of the solution. Expectations are in the range of 5-10years of unchanged DR operation, until changes in the infrastructure may cause upgrading of the communication structure as well.

Solution unification for the similarly applied Demand Response and Distributed Energy Resources communication give an advantage to networks, which are also present in rural areas. This is rather the case for wireless services, where reach can also be enhanced by beam antennas.
The disadvantage of beam antennas connecting to just one base-station may be turned into advantageous alternate path routing in 3GPP networks, by a second wireless modem with a separate beam antenna, prioritized on TCP-IP level in a local router or the local DR-controller.

DR Control Channel Communication	Public Wireless				Private Wireless			Public Wired	Private Wired		
	2G/GPRS/EDGE	3G/UMTS	4G/LTE <1G	4G/LTE >2G	4G/LTE <1G	4G/LTE >2G	WiMax	DSL/Modem	BPL	MAN	DSL/Modem
Regional Network Presence	+	+	0 (*1)	0 (*1)	-	-	-	+	-	0	-
Technical Parameters											
Bandwidth	0	+	+	+	+	+	+	+/- (*3)	+	+	+/0 (*3)
Latency	0	+	+	+	+	+	+	+/0 (*3)	+	+	+/0 (*3)
Resilience to Disturbance	+	+	+	+	+	+	+	+	0	+	+
Coverage (local&spot) (*2)	0	0	+	0	+	0	-	+	0	+	+
Accessibility (where installed)	+	+	+	+	+	+	+	+	-	+	+
Reliability (beyond 4h MTTR)	0	0	0	0	0	0	0	0	0	+	0
Future-Proofness	0	+	+	+	+	+	0	+/- (*3)	0	+	+/- (*3)
Security/Privacy	+	+	+	+	+	+	+	+	+	+	+
Comm's solution Integrity (with DER App's)	+	+	+	+	+	+	+	-	0	-	-
TCO (*1)	+	+	+	+	0	0	-	0	0	-	-

Rating: (+) = Good
(0) = Fair
(-) = Poor
(N) = Not feasable
(?) = Depending on Solution

Remarks:
*1 → TCO rating and availability for 4G/LTE beyond 2015
*2 → Wireless: White Spot/Fading dependant - Wired: Building cabling Issues
*3 → First Rating: DSL; Second Rating: Voice-Modem

The regional network presence also influences the total cost of ownership for a communications solution significantly (e.g. providing twisted pair or fiber in white spots).
Anyway, costs for communications provisioning (network and terminal devices) need to be distributed to each connected device, especially in case of wireless networks. In case of utilization of concentrators or aggregating devices, this explicit wireless cost penalty for 3G or 4G networks (in comparison to BPL terminals) becomes irrelevant.

7.5 Recommendation for most reasonable communication solutions

As discussed before, there are several communication solutions possible to build DR-control from a technology perspective. As found in the Smart metering case above, a ubiquitous communication means may be identified in 2G and 3G (as well 4G later on) public wireless technologies. Comparing the DR cost reduction potential with the cost of communication, the installation and operation of wireless communication technology seems rather negligible.

Considering the practical availability of other communication methods and certain limitations (as discussed before) in their practical application, public wireless communication based on 3GPP recommendations is certainly the default choice for DR-control communication.
Relating costs of communication with communication flexibility and stability, 3G and 4G technologies may be the preferred choices to stay future proof in a mainstream DR (and DER -please see next chapter-) solution approach.

Other communication technologies may be used in parallel and where applicable, or when upfront infrastructure investments have been made before (BPL, DSL, MAN cases).

7.6 Suggested evolution

Whether public or private wireless 3GPP defined networks are to be utilized, may not be the ultimate question in the future, since recent discussions about network virtualization or segregation, also for wireless networks, may yield purpose optimized network slices, e.g. serving the M2M business specifically.

Virtualization may take place at different levels or layers of the network.

- Starting at the logical network level, several “Access-Points” may be defined in one certain wireless network, allowing access only to authorized devices, while setting and maintaining certain QoS attributes.
- A formal layer of virtualization may be the sharing of commonly operated network equipment in the field, between legally independent network operators.

This may involve radio access network components (RAN sharing - [13] Infrastructure Sharing for Mobile Network Operators), i.e. complete base stations or only site infrastructure like powering, masts or antennas.
The sharing of network core components like gateways or controllers has been discussed on a technical level as well.

While the M2M and eEnergy communication markets and requirements will evolve, these network virtualization options will certainly gain influence on the CSPs' business of the future.

8 Distributed Energy Resources in large scale application

Distributed Energy Resources (DER) and Demand Response processes (see chapter 7) need to work hand in hand to complement each other for the sake of a stable Smart Grid. Therefore it makes sense to assume similar localization in the Smart Grid, namely in the MV-Grid of the Distribution System, which was as well discussed in the Distribution Automation sub-chapter 5.3.3, covering “Voltage control in Distribution networks due to DER”.
Please visualize also the NIST drawing in chapter 7, it covers DER sources as well.

Due to legal and technical differences in the operation of DER in the consumer/prosumer area and in large scale application (as discussed in here), consumer/prosumer solutions are handled separately.

From a communication perspective, DR and DER almost share the same basic requirements, since their functional control requirements are based mainly on the same underlying SCADA protocols.

Examples for DER are:

- Highly variable regenerative sources like wind, photo-voltaic and wave enabled stations/parks
- Flexible ramp-up/down sources like Micro-Turbines (bio or natural gas driven), water storage power stations and local chemical (e.g. battery, fuel-cell based) or mechanical (e.g. flywheel) energy based power storage solutions.
- Continuous, but nevertheless also controllable distributed sources like river or geothermal power stations

The common denominator for these sources is their geographical distributed character, typically in rural areas, and their individual limitation in power generation.
In parallel, and in contrast to DR management, DER management centers (here in the sense of operational enabling and maintenance) are probably much less often associated to their (rural) location.

DER supply, in combination with DR needs to be commonly controlled to satisfy actual power demand and avoid power blackout or over-voltages. Controlled interactions as described in DR scenarios above, need to be more flexible and reliable in the DER case, compared to the DR case. This does not necessarily require different properties of the control channel though.

8.1 Non functional requirements

Non-functional DER requirements tend to be very similar in principle to the DR case described in chapter 7.1.
TSOs and DSOs will need to have a sensitive on-demand control over power generation to maintain a generation to demand balance. In a way, DER power control processes need to be under tighter control than DR power control processes, i.e. the DER control loop needs to react faster and more precise than DR control to influence Distribution System power parameters like voltage, frequency/phase and therefore stability. Practically this means reaction times of a few minutes to order e.g. an altered DER power output and/or reactance setting, instead of turning it completely on or off. Concerning the communication links (for control and management purposes), the amount of control information exchanged, will therefore increase to allow a quantitative control of power and VAR generation as well as data reporting on a continuous basis.

8.2 Functional requirements

Basically boundary requirements collected in chapter 7.2 for Demand Response communication will apply for DER as well. From the non-functional requirement area, 2 differences shape the communication requirements in a more demanding way.

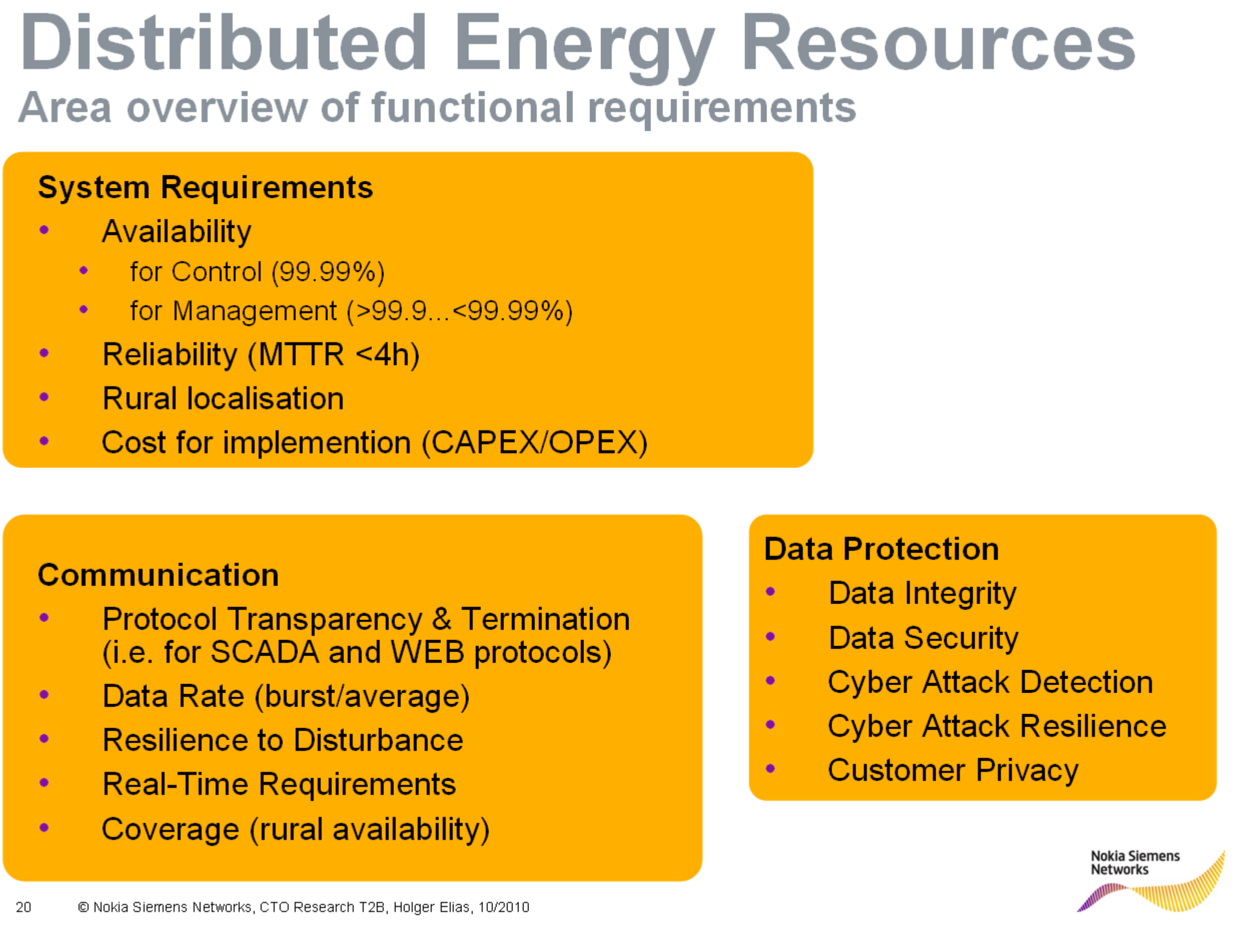
- Due to tighter control requirements, the data to be transmitted will increase from a rather hourly event driven communication basis to a quasi continuous flow of information. As discussed

before, net data rates in the range of some Kbps can be expected in the control channel. When transmitting over the air or via the internet, message encryption overhead needs to be considered, maybe doubling the bit-rate due to the short and efficient SCADA message character. Typical transmission path round trip delay or latency will not harm the undisturbed information flow.
Note: There are also other alternative protocols than SCADA/IEC61850 to control DER sources. Especially smaller DER stations, also connected to the LV-grid may be controlled via IEC60870-5 protocol suites via various communication interfaces, like direct 2G/GPRS (e.g. based on IEC60870-5-101) or via TCP-IP (IEC60870-5-104) capable data links. It is worth to note that IEC60870-5-104-based communication and SCADA-type communication may coexist in a single IP-network.

- Due to the rural geographical localization, especially of smaller DER stations, mostly located in the vicinity of existing MV-lines, the access to such stations by available wire-bound communication networks is not very probable (e.g. subscriber lines for DSL). Nevertheless newly build onshore or offshore wind-turbine farms are already often equipped with dedicated fiber communication access, on top of an extension of the MV-Grid. The reason for this extension of existing dedicated communication networks may be found in the DSO's increased control requirements for power generation.
  As 3G wireless coverage can be easily extended by high-gain beam antennas (as well as 4G later on), mounted at significant height in the case of wind-turbines, there is always a good chance to connect such stations without the financial burden of landline communication investment.
  Please see also general information in chapter 5.4.3 and coverage remarks in chapters 7.2 and 7.4.

Considering the ownership and responsible operation of such DER sources, they will probably not be owned by the connecting DSO, who is in operational duty for the Smart Grid, so control links need to terminate in the DSO's communication network. Management control for DERs though lies in the hand of the owner or his representatives. Considering the mostly rural character, the management control center will be located far off of the actual DER location. Since many more parameters need to be supervised to maintain the proper operation of DERs, there is a second communication channel needed to operate such stations. Management will often be supported by a custom-designed web-server access type, which will originate from the station's controller/server directly, but not via standardized SCADA messaging. Higher data throughput requirements compared to the above DR management may apply here, but usually no common Enterprise LAN will be installed in such locations. Therefore, a second communication path, similar to the physical control channel needs to be made available. As this does not directly relate to the operation of the Smart Grid, such legacy Internet/Web-access shall not be quantified further in here.

Functional requirements, derived from the DR case in chapter 7.2, but slightly adapted are shown below



Due to the higher impact of uncontrolled operation of DER stations compared to DR applications, dual way fail-safe mechanisms need to be in place to cope with limited communication availability.

- In case of complete loss of control of the DER, the DSO needs to be able to cut off and afterwards reestablish power lines in the Smart Grid, preferably by remotely controlled Distribution Automation.
- In case of temporary loss of control communication, the station's controller/server needs to maintain operation while monitoring grid parameters like power, voltage and frequency boundaries and automatically ramp down the station in case of their violation.

Therefore the availability requirements of communication channels may be left un-altered --compared to standard communication network SLA offerings.

8.3 Descriptions of commonly-used communication solutions

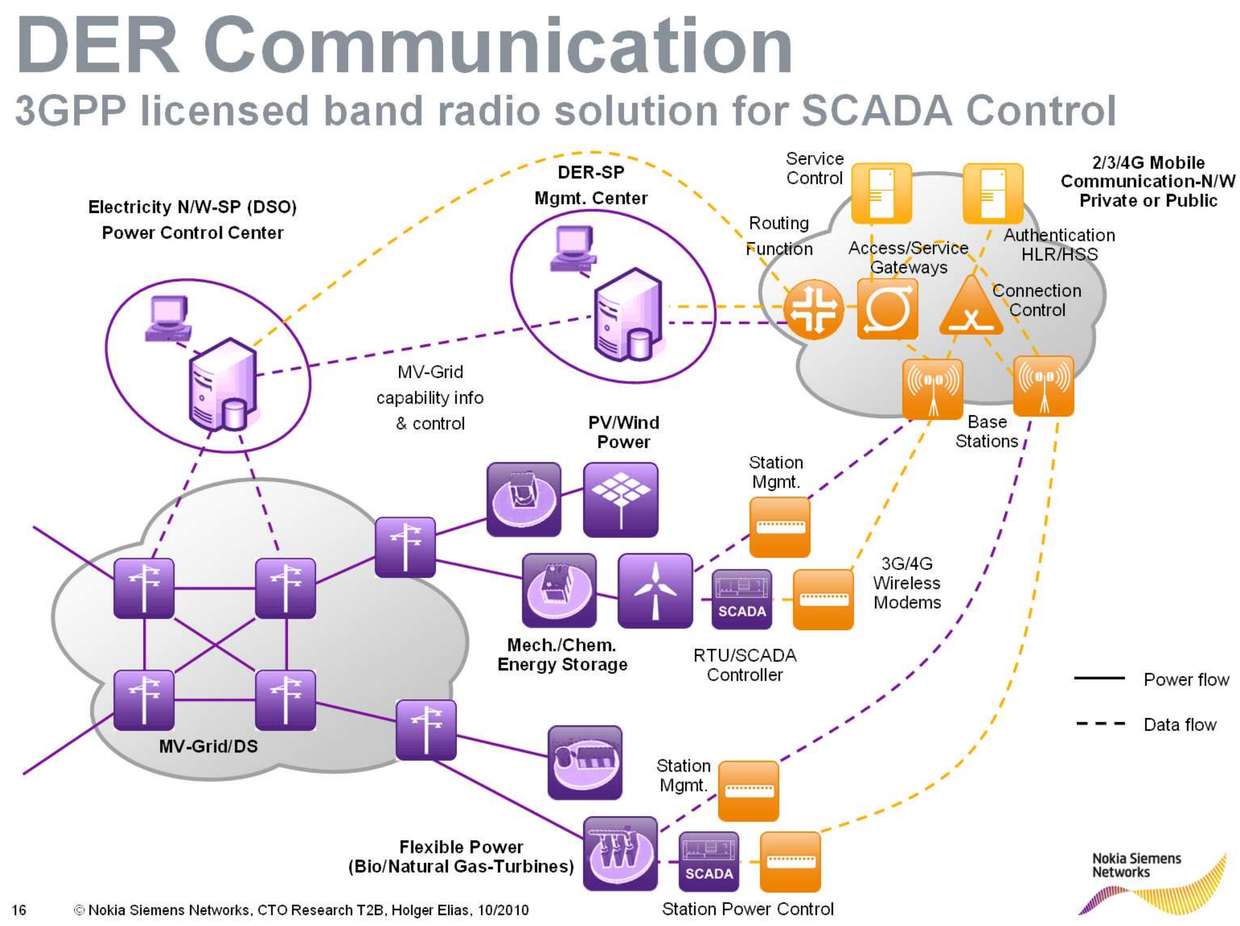
Considering the often rural localization of DERs, the selection of suitable communication technologies focuses on wireless and fiber solutions to bridge larger distances, to avoid repeaters in case of onshore and offshore underground cable. Dedicated point to point radio solutions may make sense in case of wind-parks, connecting an array of wind-turbines altogether.

8.3.1 3GPP defined licensed band radio solutions for SCADA Control

3GPP based radio solutions exhibit their advantages in the DER communication case in several ways:

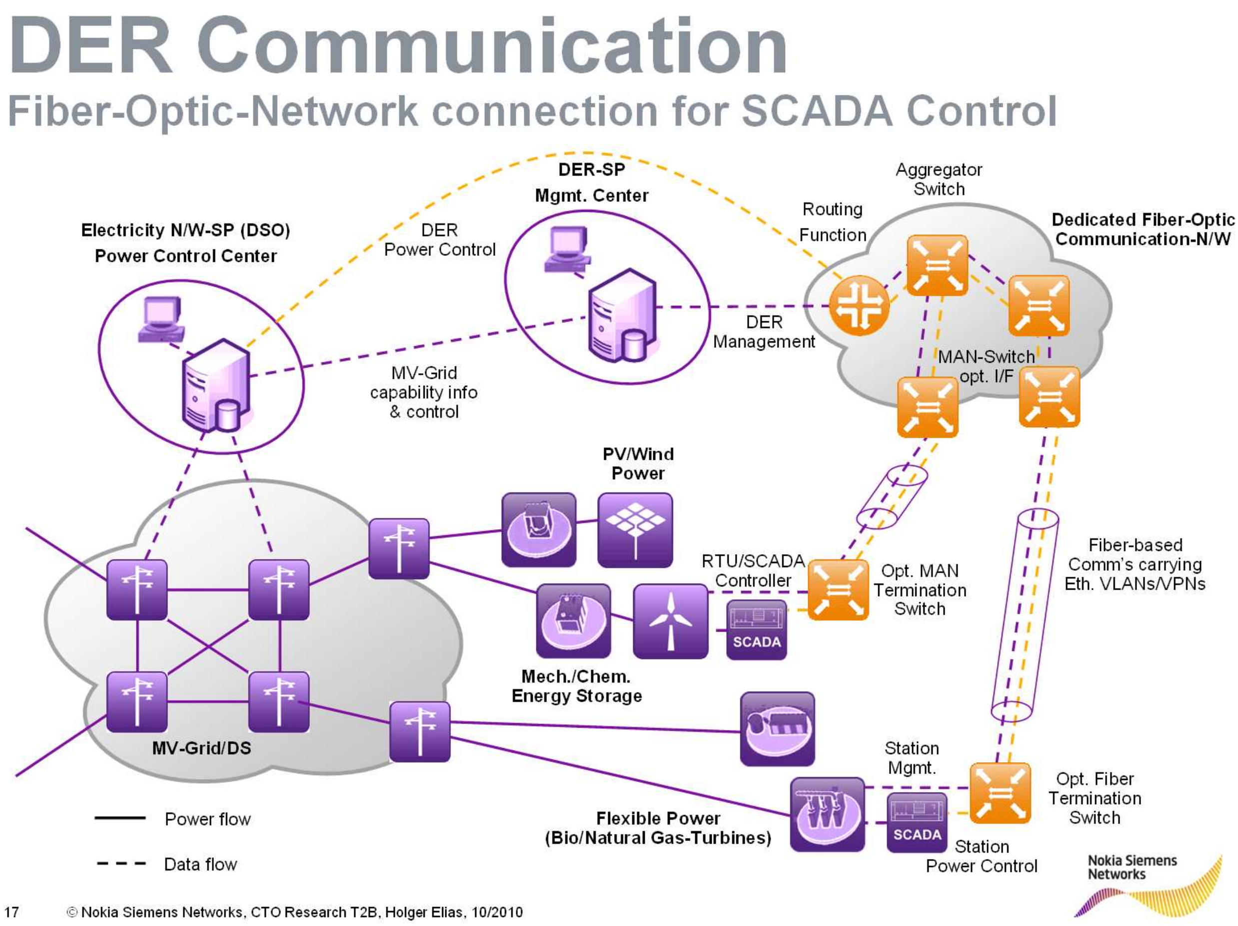
- The existing network availability maintained by public operators, even in off-shore areas offers immediate connectivity options without situational network upgrade, as it would be required in case of WiMax Point to Multi-Point (PtMP) or “Leased Line” type PtP radios.
- Shared network utilization for SCADA and power station management and maintenance bears no contractual problems, as they may arise in case of any dedicated communication network (i.e. separate legal entities for control and management of power stations).
- Expandable data transmission capacity in the case of 3G/4G networks and network reach extension with beam antennas to 2-digit kilometer range (according to chapter 5.4.3.4.)
- Alternate path routing by a second wireless modem with a separate beam antenna, prioritized on TCP-IP level in a local router or the local DER-controller
- Lowest possible CAPEX for enablement, even utilization of different 3GPP radio links for control and management purposes without significant relative cost increase.
- Ideal for stand-alone power stations, which will connect directly to existing MV lines.
- Integration with Demand Response scenarios into one standardized default solution. Therefore less planning and engineering effort to set up.
- Wireless Modems may be physically separated for station management and power control purposes at low cost, e.g. utilizing different Access Point Names (APN) connecting to the 3GPP base station, but sharing common infrastructure like antennas and masts. This has the advantage of separating management responsibilities for both areas, while allowing independent QoS handling and maintaining individual security credentials

Please see the network drawing below.



8.3.2 Directly connected communication solution via Fiber-Optic Network

As discussed before, large DER projects, e.g. off-shore wind parks will require new MV/HV or even HVDC power cable installation. In such cases, an empty tube for fiber-optic transmission purposes generates no significant overhead for utilities. Also carrying additional traffic on such fibers by means of Layer 2 VLANs or L3 VPNs to accommodate management data traffic bears no capacity problem. Considering the connection of such to the communication network at sub stations, the further aggregation and handover of this remote traffic, inside and outside of the DSO's enterprise network appears reasonable from a capacity and general networking perspective as long as the sub station is connected via optical fiber. Capacity problems may arise, if the sub station data traffic is carried only via limited transmission resources (PtP radio, BPL) towards the DSO's core network. These shall not be discussed here, since they are case dependant



8.3.3 Other communication network solutions

As alternative methods of communication based on dedicated networks, Broadband Power Line (BPL) or Point to Point Radio (PtP) should be mentioned.

- In principle BPL was identified as viable method of communication in the Demand Response scenario in chapter 7. DR is situated rather in populated areas, where 240V AC power supply for BPL head-end and repeater stations may be expected along the MV lines.
  In the rural DER case, associated to the MV line, some AC power needs to be made available. Considering a span of 500m to 1Km between BPL repeaters on overhead landlines, local transformation from MV to LV (AC) voltage level needs to be achieved. Such transformers are quite bulky (35Kg) due to isolation requirements, even at low power levels as required by BPL.
  The drawing shows an exemplary transformer from Arteche [15].
  (MV connection made from the top, LV connection made from inside the lower die cast box)

  Such transformers need to be pole-mounted, probably on a separate platform, raising the cost for BPL installation along overhead landlines lines significantly.

In case of underground/on or offshore cables, the installation becomes unreasonable in effort, due to water-proof sealing requirements.

- Dedicated Point to Point radio may be a reasonable choice to communicate with remote clusters of power stations, like wind parks for instance, especially bridging large distances (>20Km).
  Similar radio technologies (Ethernet/SDH/PDH) as for the aggregation of 3GPP radio base stations may be used.
  Due to their fixed bandwidth assignment, they need to be dimensioned for burst data transmission cases, without statistical multiplex gain advantage.
  Considering a 3GPP or WiMax base station within reach, connected to the CSP's network with a similar PtP radio solution, statistical gain and shared utilization can be realized, thus operational expenditures are lowered.

8.4 Mapping req's to available N/W parameters

Due to the different selection of viable DER transmission technologies, the table below was restricted from the DR case towards realistic solutions.

- The fiber-based MAN from the DR case was altered into a similar dedicated network architecture, named FON, Fiber Optic Network, as outlined in chapter 8.3.2 above.
- WiMax technologies where removed as well, because their existence on a broader regional scale may not be probable. From a technology perspective, WiMax will behave similar to 4G/LTE in the according frequency band.

DER Control Channel Communication	Public Wireless				Private Wireless			Private Wired	
	2G (*2)	3G	4G/LTE <1G	4G/LTE >2G	4G/LTE <1G	4G/LTE >2G	PtP Radio (*2)	BPL (*3)	FON (*2)
Regional Network Presence	+	+	0 (*1)	0 (*1)	-	-	-	-/N	0
Technical Parameters									
Bandwidth	0/-	+	+	+	+	+	+	+	+
Latency	0/-	+	+	+	+	+	+	0	+
Resilience to Disturbance	+	+	+	+	+	+	+	0	+
Reach/Coverage	+	+	+	0	+	0	+	-/N	+
Reliability (beyond 4h MTTR)	0	0	0	0	0	0	0	0	0
Future-Proofness	0	+	+	+	+	+	0	0	+
Security/Privacy	+	+	+	+	+	+	+	+	+
Comm's solution integrity (with DR App's)	+	+	+	+	+	+	0	0	+
TCO (*1)	+	+	+	+	-	-	-/0	-/N	-/0

Rating: (+) = Good
(0) = Fair
(-) = Poor
(N) = Not feasable
(?) = Depending on Solution

Remarks:
FON: Fiber Optic Network (e.g. Gigabit Ethernet)
*1 → TCO rating and availability for 4G/LTE beyond 2015
*2 → 1st Rating: Direct Comm's (1 RTU per Modem)
2nd Rating: Aggregated Comm's (several RTUs per Modem)
*3 → 1st Rating corresponds to overhead MV lines
2nd Rating corresponds to underground MV lines

8.5 Recommendation for most reasonable communication solutions

As discussed in the cases above, fiber-based and public 3GPP wireless communication solutions seem to be the most suitable communication solutions from a technical perspective.

In case of fiber to be laid out in addition to existing MV lines, fiber communications will become rather expensive compared to public 3GPP mobile broadband or PtP radio.

On the other hand, reach of higher frequency band 3GPP radio (4G >2GHz), the relative reach will suffer, compared to 2G or 4G transmitting below 1GHz. 3G reach behaves somewhat in between, but due to the higher density of base stations will be still a good choice (please see coverage table in chapter 5.4.3.4.).
Judged on the basis of a majority of expected DER communication scenarios, 3G or later 4G (especially <1GHz) communication solutions appear to be the preferred default choice, in case no fiber is available.

8.6 Suggested evolution

Similar findings as for DR communication (described in chapter 7.5) suggest an evolution of DER communication into the same direction, i.e. the utilization of pervasive multi-purpose/multi-stakeholder mobile broadband networks, offering a communication solution with the least administrative and upfront installation cost overhead, while staying future-proof over life-time.

9 Wide Area Measurement System application

HV Transport & Distribution Network stability threats, caused by volatile regional energy generation, become increasingly important when introducing power stations relying on volatile 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. Therefore so-called Wide Area Measurement Systems, covering international, national or regional power transmission networks are being introduced to supervise the momentary power network status. An introduction to Wire Area Monitoring may be found in the ABB repository [16]

9.1 Non functional requirements

Proper state information about the initial network health can be obtained from Phase Measurement Units (“PMUs, aka Synchrophasors”). Due to their exact GPS-based time marking measurement, high resolution phase information can be made available to TSO and also 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.

Today, PMUs are generally installed where data communication access is available at decent speed, e.g. in Sub-Stations accessed by Fiber-Optic-Networks (FON) or by PtP microwave radio. In the case of PDH microwave radio (2Mbps), transmission capacity might already be quite limited (please see chapter 9.2)
In advanced PMU deployment scenarios, their placement is expected also outside of Sub-Stations, e.g. close to power stations or at geographical power network borders, like national borders. In such locations, FONs are generally not available. Therefore 3GPP wireless mobile broadband connections are an interesting alternative, even to PtP microwave radio.

9.2 Functional requirements

As outlined before, functional communication requirements of PMUs and their associated servers are depending on the way of application in the power network. Three major cases may be anticipated.

- Continuously on-line monitoring of a wide area transmission network. The required data rate per device was e.g. determined by ERLPhase Power Technologies Ltd.: Phasor Measurement Unit Communication, Experience in a Utility Environment [17].
  Please see the following table:

Baud rate, (bps)	Reporting rate (frames / second)							
	10	12	15	20	25	30	50	60
9,600	12	12*	10*	6*	4*	2	0	0
19,200	12	12	12	12	12	10	4*	2
38,400	12	12	12	12	12	12	12	10
56,700	12	12	12	12	12	12	12	12
115,200	12	12	12	12	12	12	12	12

Table 1.0 : Estimated number of phasor channels that can be transmitted at various baud rates and PMU reporting rates over serial port.

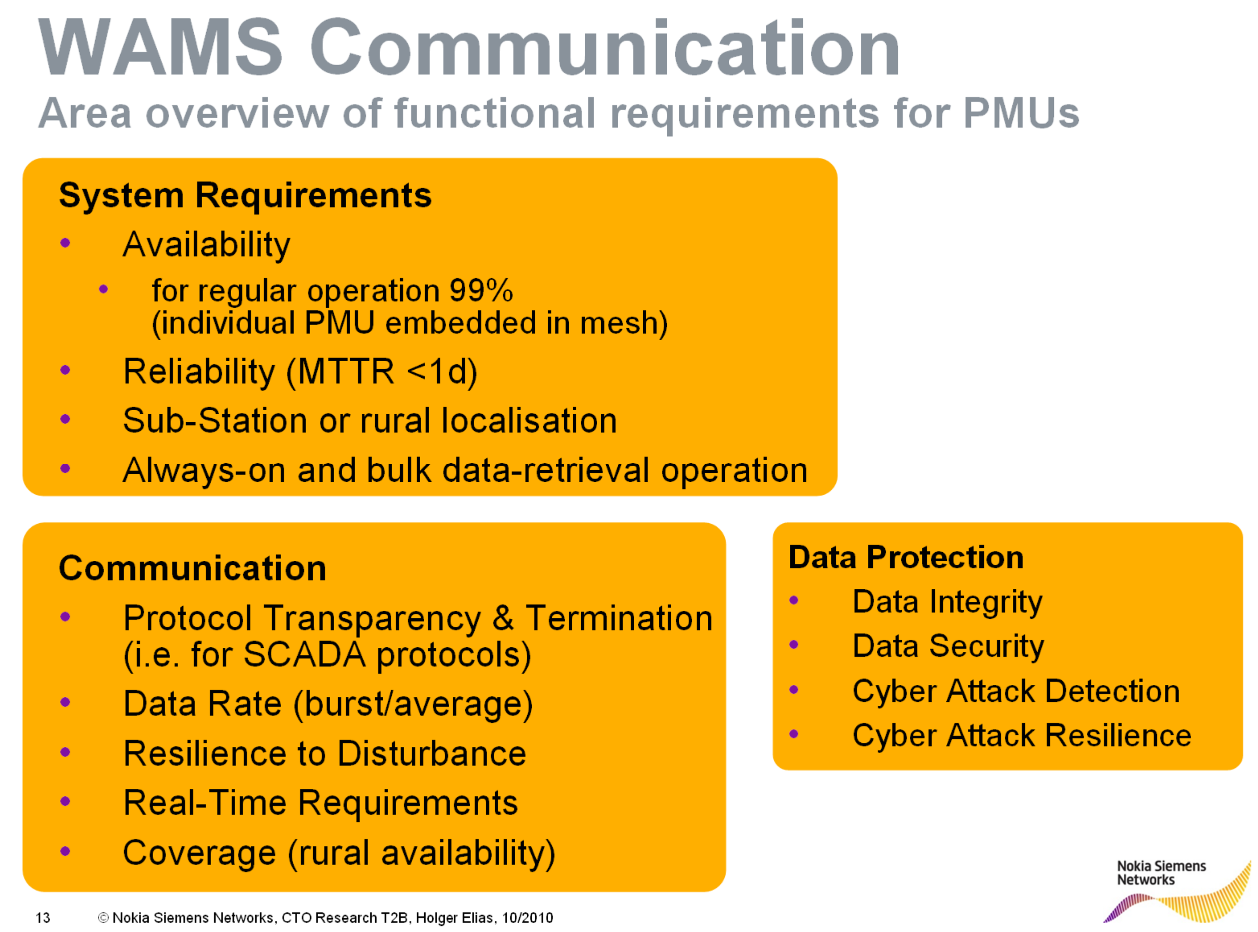
  This shows that the on-line traffic requirements from PMUs are quite low in principle, even satisfied by voice modem speed.

- Data collection in a quasi off-line mode, interrogating certain devices on demand and individually or on a scheduled basis to obtain bulk data. Data rates capable of transporting 45 MB of data in 5 minutes or on average 150 KB/s are required [17], see also above.
- PMU maintenance, remotely loading new firmware to the devices in the field.
  This is usually done individually per device, but may be carried out for several devices in parallel, requiring some MB per device.

Basically in all cases the expected total volume of data transferred in a longer timeframe lies in the range of many MB per device. The significant differentiation is the required peak data rate handling capability in the 2nd and 3rd case, whereas in the 1st case the availability of the communication connection matters most.

Since communication service availability is not necessarily related to HV power outage events, or only up the moment, when a blackout occurs, the major task of a PMU is to be on-line for power monitoring when power is also available. Therefore we expect that the already above discussed (chapter 7.2) commercial communication service availability of 99% for an individual PMU should be sufficient to fulfill even advanced monitoring tasks. PMUs, placed in a logical mesh to monitor the grid, will increase the availability of representative grid information.
As suggested above, this opens the path for the application of 3GPP-defined communication access, predominantly with 3G or 4G technologies.

Please see the requirement overview below:

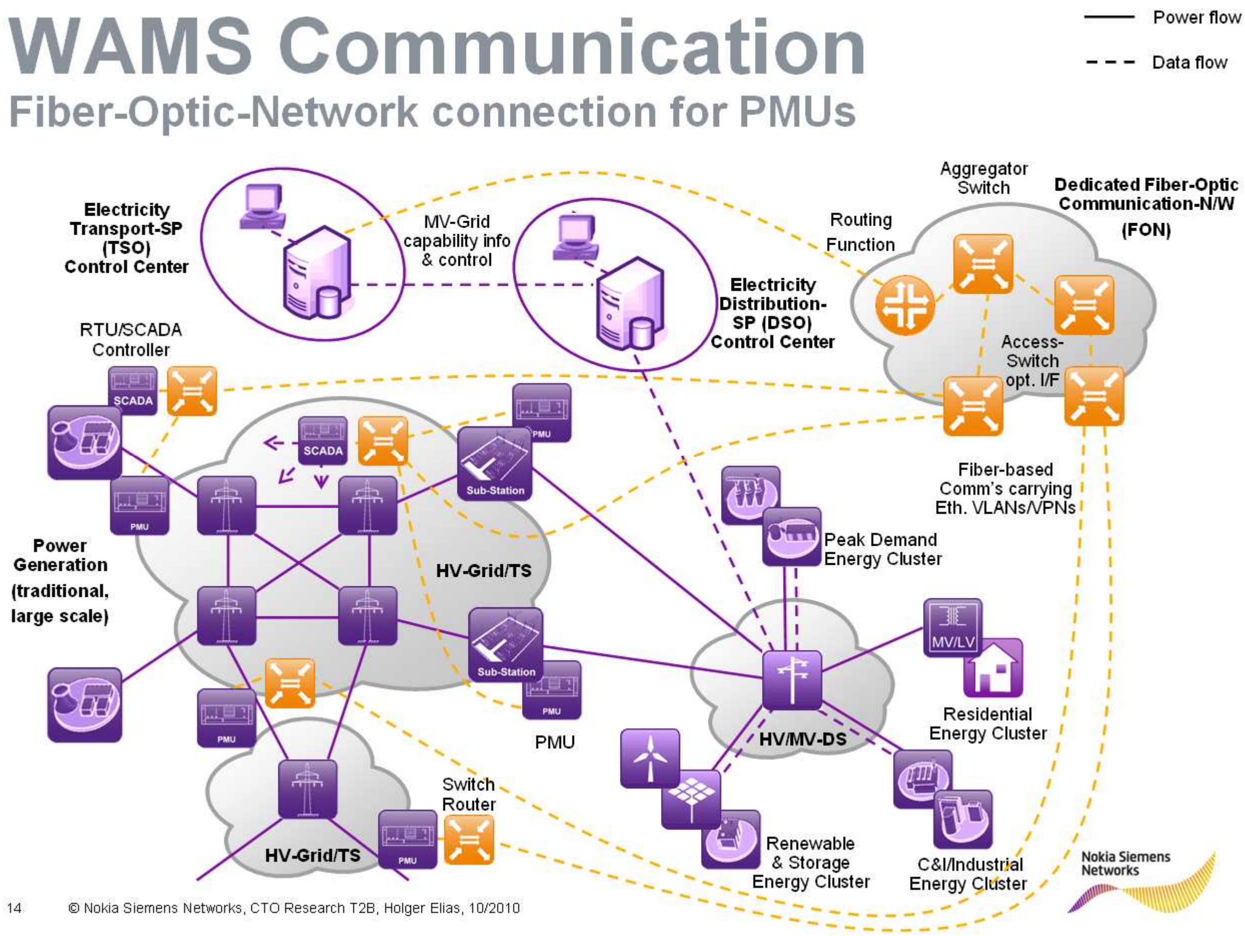


9.3 Descriptions of commonly-used communication solutions

Commonly installed communication solutions based on Fiber-Optic-Networks, recently also upgraded from SDH to direct Ethernet transmission are certainly the first choice for PMU application. SDH PtP radio may offer sufficient capacity as well.
In the case of PDH PtP radio with nx2Mbps, a purpose specific upgrade with 3GPP-defined public mobile broadband service is a viable add-on option.
These both methods of traditional FON and alternatively 3G/4G radio are being discussed below.

9.3.1 Directly connected communication solution via Fiber-Optic Network

Due to the existence of SCADA networks in TSOs installations, PMUs may be directly connected to Sub-Station LANs via dedicated VLANs or via routers on certain VPNs. This is depicted in the lower drawing left by existing local Ethernet-Switches in the HV-Grid cloud. Communication termination is done at the TSO’s control center being connected to its FON.
Certain remote locations may be reached via FON as well, considering the utilization of optical fibers carried in the HV-lines’ ground wire on top. This applies also for newly built remote Sub-Stations belonging to the HV DS, connecting e.g. offshore wind parks.
Similar to mobile network base stations, a ground shelter may house the fiber optic termination, the PMU and a local AC-power installation with or without battery back-up.



Please note that electrical HV-transmission and communication links will geographically run mostly in parallel, despite it is drawn separately below, for the sake of better visibility and understanding of logical association (orange dotted lines). Therefore the HV-grid cloud and the FON cloud need to be understood as geographically overlapping.

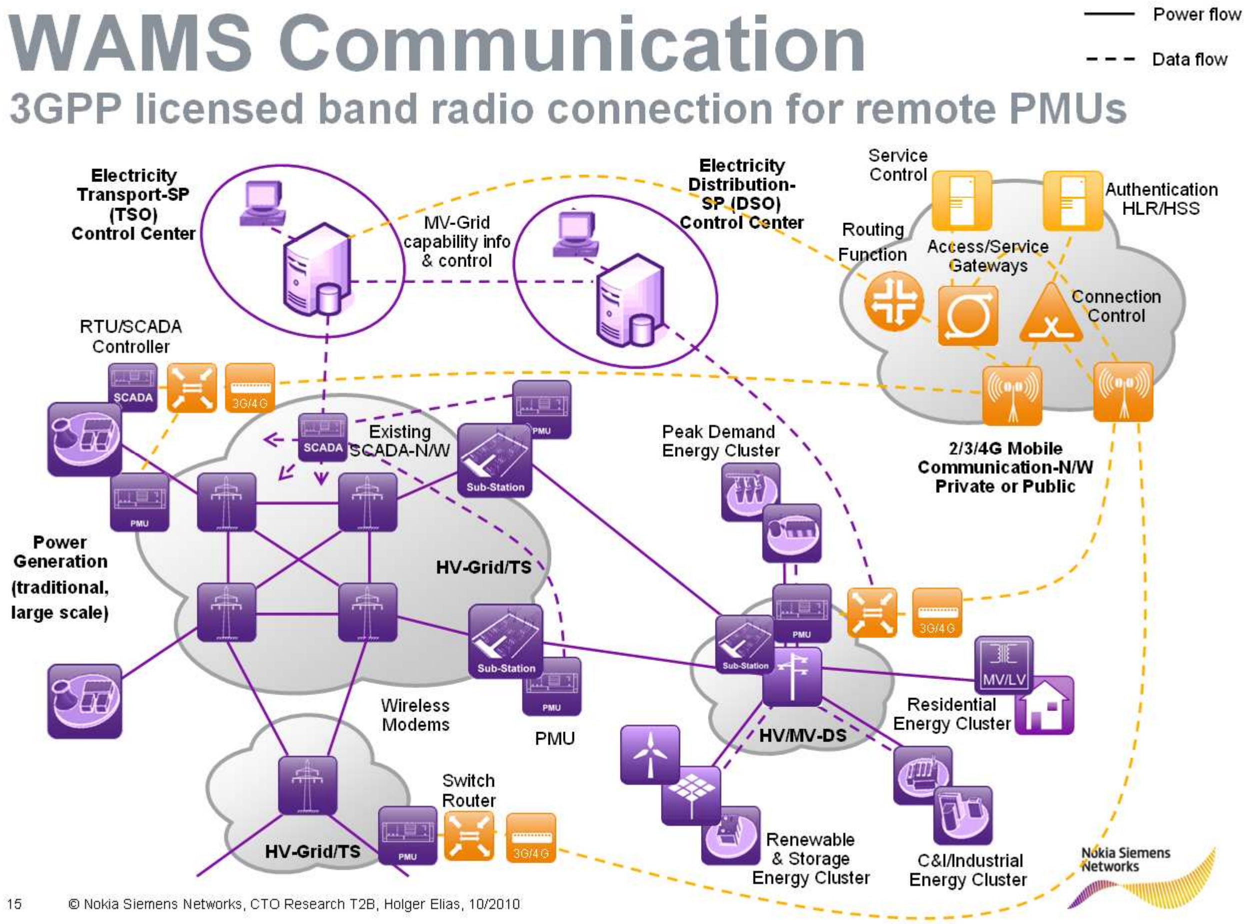
PMUs may be even installed in DSOs networks, e.g. where large scale MV power generation takes place or at HVDC feeder stations. In such cases, the DSO's communication network (purple dotted lines) needs to provide the necessary data connections to the TSO's control center and vice versa.

9.3.2 3GPP defined licensed band radio solutions for remote PMU communication

For the task of Smart Grid supervision, PMUs may be placed also outside their original domain in and around the HV transmission grid. In locations, e.g. belonging to adjacent HV-grids or power generation from wind-parks in the DS, data communication facilities for PMUs might not be existent or to weak for their application. In these cases, additional 3GPP-based communication solutions provide an interesting alternative to wire-bound or wireless PtP communication networks.

A local router/switch in combination with a 3G or later 4G modem connects in an always-on mode into the TSO/DSO's control center, via a secure VPN tunnel. Such solution provide enough bandwidth in the single digit (today) and two digit (future) Mbps range to upload collected bulk data or allows real-time software upgrading of the local measurement equipment.
Connecting existing communication links through the local router enables even diverse-path routing backup capabilities as shown in the below HV/MV-DS.

Regarding coverage and path protection of 3GPP links, please note the remarks in chapters 8.2 and 8.3.1 as well.



9.4 Mapping req's to available N/W parameters

Not neglecting other possible communication methods for WAMS, the below table includes more solutions into the discussion.

BPL suffers from the short repeater-spacing requirements and the unreasonable effort to regenerate transmission signals under water in off-shore situations.

WiMax, operated in unlicensed frequency-bands, especially along coastal lines with international borders and other frequency plans, bear some risk of being disturbed by unforeseen transmission.

In general, private wireless tends to be too expensive in to be deployed in wide areas (e.g. in Finland). One exception is PtP radio, but usually limited in bandwidth to a very few Mbps.

WAMS / PMU Communication	Public Wireless				Private Wireless				Private Wired	
	2G/GPRS/EDGE	3G/UMTS	4G/LTE <1G	4G/LTE >2G	4G/LTE <1G	4G/LTE >2G	WiMax un-lic. Band	PtP Radio	BPL (*2)	FON
Network Presence	+	+	0 (*1)	0 (*1)	-	-	-	-	-/N	0
Technical Parameters										
Bandwidth / Capacity	-	+	+	+	+	+	+	0	+	+
Latency (Always-On)	-	0	+	+	+	+	+	+	0	+
Resilience to Disturbance	+	+	+	+	+	+	0	+	0	+
Reach/Coverage	+	+	+	0	+	0	-	+	-/N	+
Reliability (beyond 1d MTTR)	0	0	0	0	0	0	0	+	0	0
Future-Proofness	0	+	+	+	+	+	0	0	0	+
Security/Privacy	+	+	+	+	+	+	+	+	+	+
TCO (*1)	+	+	+	+	-	-	-	0	-/N	-

Rating: (+) = Good
(0) = Fair
(-) = Poor
(N) = Not feasable
(?) = Depending on Solution

Remarks:
FON: Fiber Optic Network (e.g. Gigabit Ethernet)
*1 → TCO rating and availability for 4G/LTE beyond 2015
*2 → 1st Rating corresponds to overhead MV lines
2nd Rating corresponds to underground MV lines

9.5 Recommendation for most reasonable communication solutions

Public wireless services for PMU application, based on 3G or 4G present themselves as a good communication system extension to existing FON solutions, both from financial and technological judgment.

Dedicated FONs, which are the basis for existing communication network solution, certainly fulfill most of TSO/DSO requirements to a high degree and are administratively under their control.
In situations of newly built power stations, supervision of existing remote Sub-Stations or preventive control of adjacent grids, 3G and later on 4G are suitable and cost-effective communication technologies to utilize. 2G/GPRS/Edge is capable in principle to support continuous PMU measurements, but since it is a shared transmission media and burst data transmission requirements are persistent, such solution cannot be regarded as future-proof enough.
It should be noted that public wireless communication may also be utilized for alternate-path / diverse-route protection solutions. In cases of mechanical failure of the HV pylon infrastructure due to icing (Northern Germany, Winter 2005) the embedded FON infrastructure is harmed as well. In such cases protected communication routes are essential.

9.6 Suggested evolution

Our recommendation to improve grid supervision and black-out prevention is to extend existing communication infrastructures by 3G and later 4G transmission solutions as a general means. Advanced Distribution Automation supported by WAMS, connected through a fault resilient and future-proof communication network, will support the deployment of a high degree of regenerative and variable energy sources in the HV/MV grids.

Communication route diversification, relying on dedicated and public infrastructures in parallel, supported by suitable IP routing protocols is an effective means to achieve optimal grid communication availability in the future.

10 Home-DR applications for Home Appliances

This chapter addresses future Demand Response solutions which are set-up in private homes or also in small and medium enterprises. Home appliances (mainly white and red goods) shall be understood in a way that they have been installed in the premises by the consumer at a later point in time, after erection of the building. These appliances are able to control energy consumption during a certain time-frame. Postponing or preponing energy consumption towards a time-slot when "cheap" energy is available or avoiding consumption during expensive peak demand times saves OPEX.

"Fixed-Gear" installations like originally built-in water heating or HVAC, attached to the building, shall not be discussed in here. Energy control mechanisms for the latter might differ substantially today and may be realized similar as described in the chapter 7, Demand Response for large scale application.

Furthermore the business model for Home-DR enables other stakeholders and players as discussed in chapter 7 for Demand Response for large scale application.

- Based on enabled Time of Use (ToU) billing by a Smart Meter Service Provider (SM-SP), the SM-SP may offer Home-DR service by himself.
- Due to the ongoing integration task of new appliances and other business reasons (e.g. scaling and bundling effects), Home-DR may be offered also from new specialized vendors, namely Home-DR-SPs, who integrate the necessary functionality and contract several SM-SPs to expand the area where they offer their service.
- A future evolution of the Home-DR business model implementation is supported by law (like in Germany). A new founded Home-DR-SP may also apply for a license to deploy his own Smart Meters and become a combined DR/SM-SP. In such a case, the premise's meter needs to be exchanged and formally "sealed with leads" by the DR/SM-SP to fulfill Measurement and Weights Acts as required by national law.

  The new Smart Meter device might include the additional functionality, like a communication G/W for the appliances and Home-DR control in one unit, instead of the separated approach shown below, evolving it towards a Smart Home-G/W-Controller.
  Since the appliance device communication may be difficult to achieve in certain premises (like an apartment building, with a metering room in the basement), this case is not discussed in greater detail here.
  Caution is also advised from national legal perspectives, when implementing complex additional functions inside the Smart Meter with regard to the above mentioned national Measurement and Weights Acts (on top of legal security/privacy requirements).
  Law may not allow or require certain functionality from the Smart Meter implementation, which is not compatible with the desired additional functions inside.

10.1 Non functional requirements

Non functional requirements concerning any aspects other than the communication from the home premises to the Home-DR-SP cover several areas.

- The basic requirement is to swiftly consume energy according to ToU or "Happy Hour" offerings announced by the DSO (or to release current energy consumption during supply shortfall – as a value added service).
  Considering reasonable billing intervals of about15 min, announced with little time advance (option for immediate grid reaction), total reaction time of the involved systems need to be rather less than 5 min's.
  Most of the processing and its associated delay will occur in the proper (i.e. equitable and contract-conform) assignment of the available excess energy to the respective consumers
- Reliable communication to each local Home-DR-controller needs to be achieved rather in a one-to-one communication way, than in a broadcast mode which would need to have complicated geographical and customer tailoring options on top of the difficult to achieve secure broadcasting communication plus eventually individual acknowledgements.
  This requires enough (communication and processing) capacity at the Home-DR-SP to address

e.g. a 5-digit amount of premises within the assumed 5 min's timeframe. Traffic related background calculations show also that the Home-DR-SP can achieve such task utilizing a standard 100Mbps internet connection.

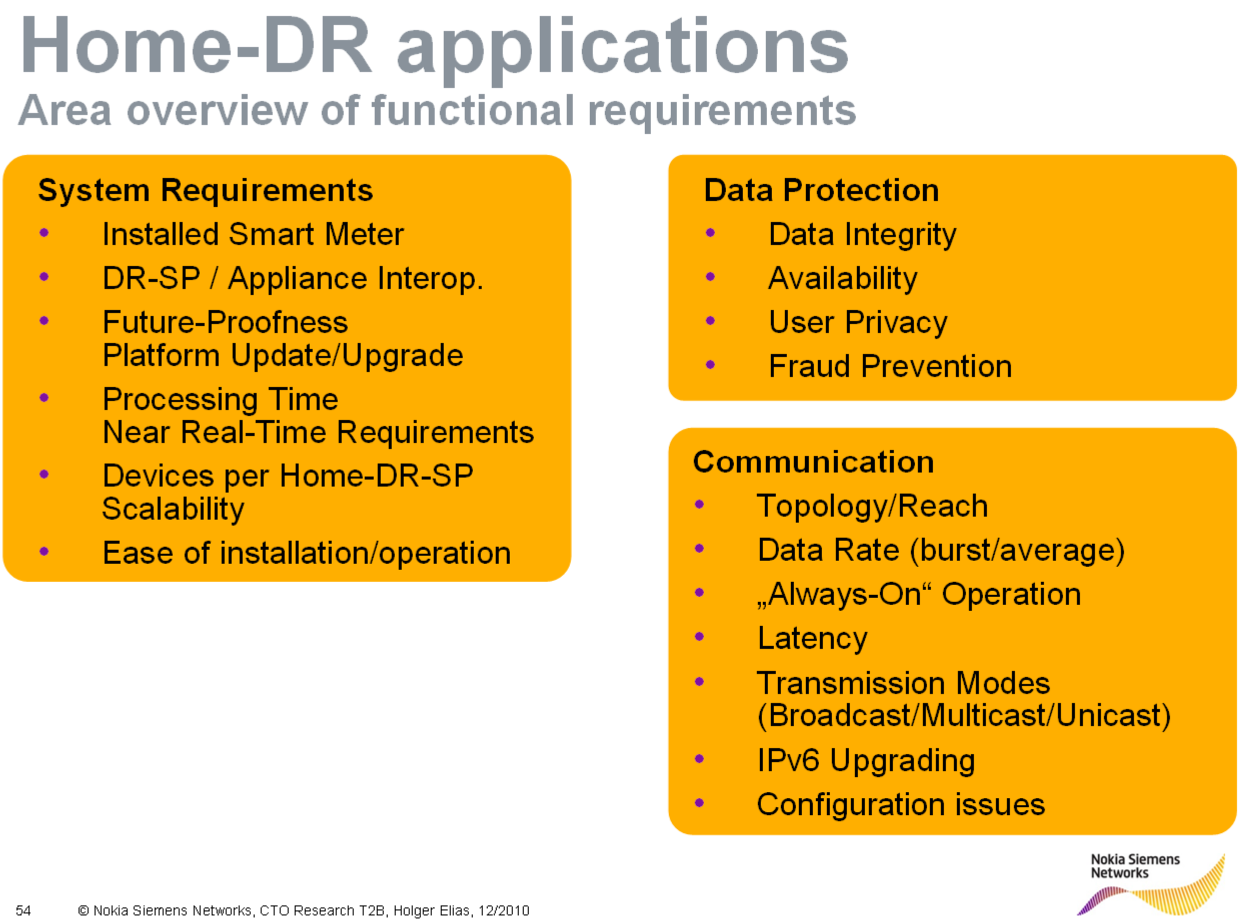
- In order to control a wide range of different appliance vendor's equipment, not only a DR-communication G/W, but a DR-controller (Energy Management Gateway) is required to enable new equipment functionality in the Home-DR scenario.
  Appliance-specific Management Information Bases (MIB) or Information Models are being developed to control their functionality in a standardized way by the Home-DR-SP.
  According to B/S/H [18], two similar streams are visible, driven by the "American Association of Home Appliance Manufacturers, AHAM" (White Paper, 2009/12) and 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 parallel, the German Ministry of Economics and Technology (BMWi) is suggesting the EEBUS [20], based upon KNX, ZigBee und TCP/IP communication stacks to enable also white and red goods manufacturers to connect to a DR-Controller. UML based information base data exchange was recently suggested as descriptive language towards the Home-DR-SP. Appliance specific MIB definitions are still open, but might e.g. come from the above organizations or communication stack providers like KNX or ZigBee.

  Appliance Information Models in general will evolve over time, therefore remote updating/upgrading capabilities for the DR-controller are required.
- As a value added function and to actively include and motivate the consumer in energy conservation and control, interactive home display devices play an important role.
  The local Home-DR-controller may act as a local server for them and eventually retrieve relevant information from the Home-DR-SP's data base, which might have been even forwarded on demand from the local SM-SP. This scenario includes the functionality of the widely discussed In-Home Display (IHD).

Home-DR service availability is regarded as rather uncritical, since the business case for the consumer works in a cumulative way. Commercial communication network availability is regarded as sufficient.

10.2 Functional requirements

Functional requirement areas for communication, derived from the above system requirements can be found in the below table.



Due to the in-home location of Home-DR, suitable communication methods with the Home-DR-SP may be assumed as existing.
E.g. DSL or cable-based internet connections are suitable in bandwidth and latency. Also quick response times, not so much related to latency, but “Dial-In” characteristics are well covered by these wire-bound communication methods, as they can be considered as “Always-On” for the Home-DR purpose.
In case of 3GPP based radio access, 2G/GPRS technology seems too limited in terms of bandwidth and connection set-up for swift and smooth Home-DR operation.
3G/UMTS has sufficient bandwidth for multiple Home-DR operation (please see the bandwidth discussion below).
Operational delays may be also caused by mass “Dial-In” when the Home-DR-SP addresses many recipients, respectively “Always-On” connections by keeping many connections alive, which will cause significant signaling overhead.

4G/LTE will remove any limitation to Home-DR service since it may be operated in “Always-On” mode without capacity limitations.

3G and 4G based Home-DR solution may be preferred by Home-DR-SPs, because they operate in a closed dedicated environment, avoiding home network interworking problems and their costly remedy by call centers.

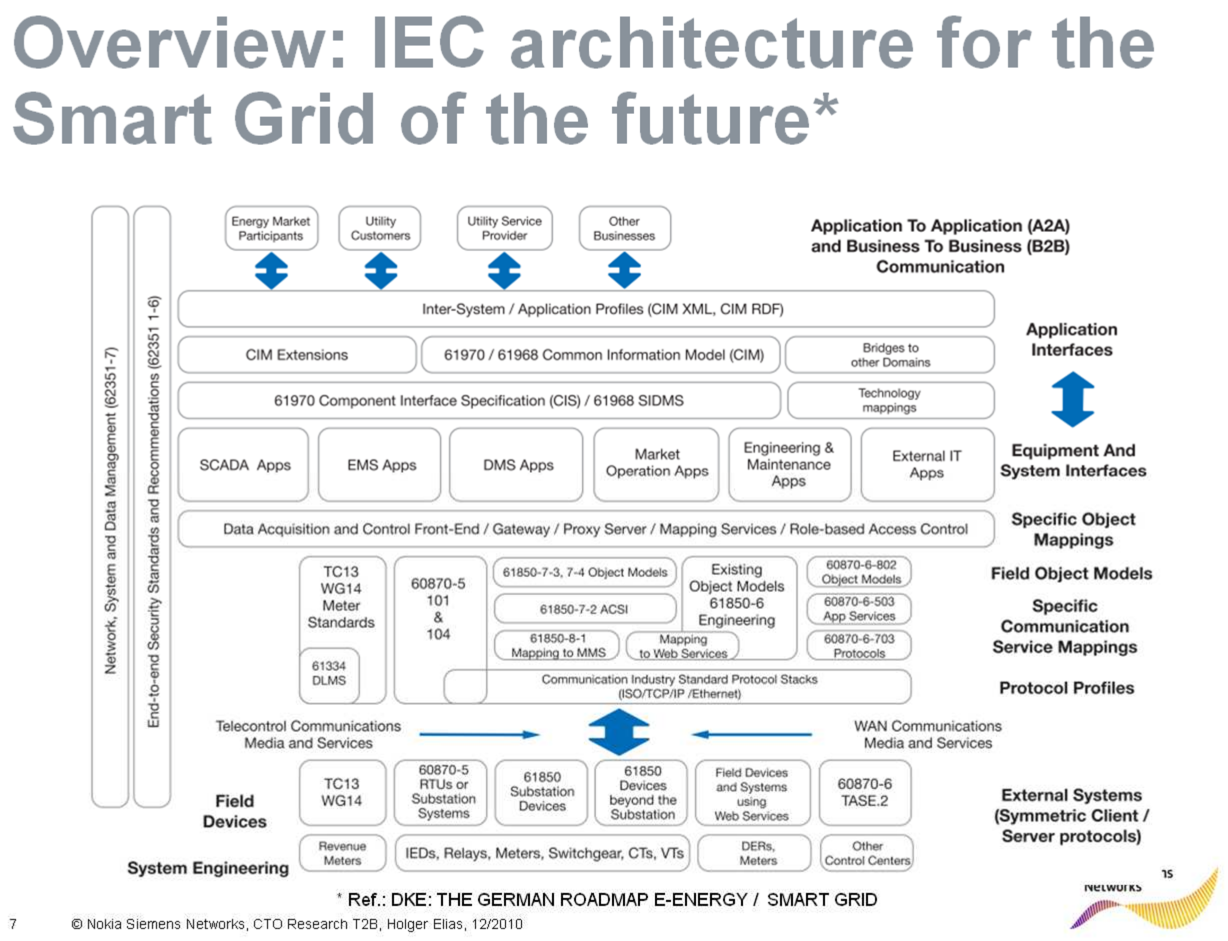
As discussed before, a secure broadcasting mode shall not be assumed, so instantaneous parallel unicast transmission capacity for a high number of customer sites is required.

As a guideline and proof-point for the number of addressed sites for Home-DR by wireless and wire-line communications, the following assumptions shall apply.

Considering a densely inhabited area in a large European city as the most challenging scenario, addressed by a public CSP with 1/3rd market share for Home-DR,

- For the wireless case, e.g. a 3G sector (e.g. one BS serving 3 sectors) needs to serve about 700 consumers, offering 7.2Mbps in total today. To protect the M2M data traffic contingent against mobile devices' data traffic, it shall be assumed that 10% of the total cell data rate is dedicated to M2M requirements. This may be achieved by a different APN setting in the BS for M2M data traffic and consequential dedicated queuing.
- In case of wire-line DSL service, one CO DSLAM will serve about 300 consumers sharing an uplink of 1Gbps today, from which 1% shall be dedicated to M2M data traffic without specific prioritization.

Considering these M2M/Home-DR consumer sites connected to one aggregation node as of above, the wireline case offers >10 times the bandwidth, compared to the wireless case.
Therefore the wireless case is critical to analyze first.
Sharing some 700Kbps among 700 remote sites, offers about 1Kbps of effective data rate per site.
Further considering a 5 min's (300s) interval to process all 700 Home-DR sites, about 35KB of information may be exchanged with each Home-DR site.
This seems sufficient, considering the amount of data exchanged via an effective control protocol, e.g. designed according to the IEC Smart grid architecture suggestion (see below, above and below of the WAN communications borderline) and quantitatively confirmed by NIST in the Smart Meter case [6] as an analogy for this new control domain.



This task of data transfer maybe also compared to remote IP router mgmt., in the case of SNMP. vs. CLI or Web-based mgmt.

As a consequence, it should be noted that dedicated control protocols seem necessary to fulfill the task to control Home-DR in densely populated areas, at least via 3G/UMTS wireless networks.
Web based protocols containing a large fraction of ancillary data (graphical descriptions or bulk page data) should be avoided.
For instance, instead of XML as a native Web-protocol, UML was recently proposed (2nd German E-Energy Congress in Jan 2011) as a communications protocol by the EEBus consortium to increase transmission efficiency.
A later 4G/LTE introduction will relieve potential 3G/UMTS bottleneck situations and lead to faster reaction times in Home-DR service.

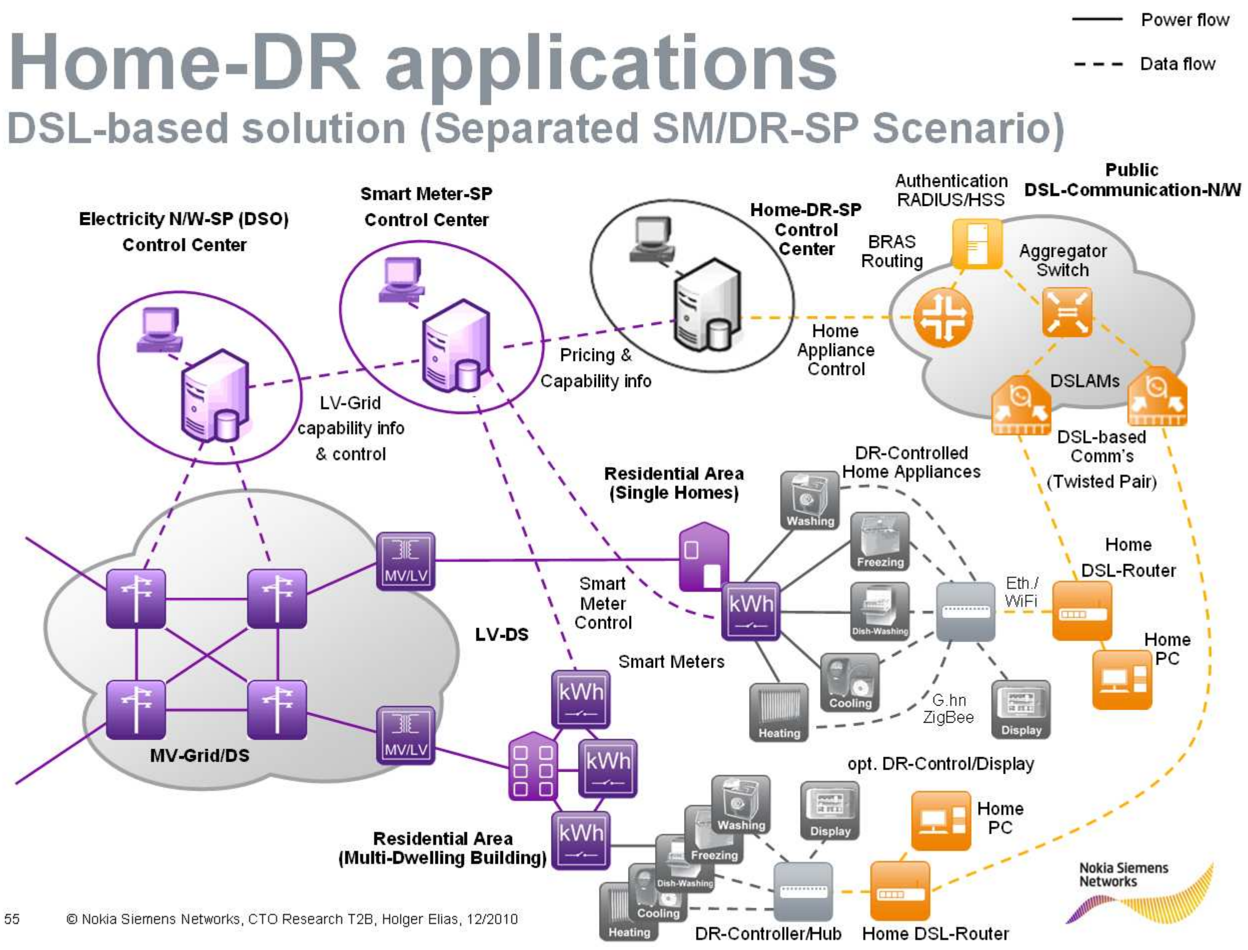
10.3 Descriptions of commonly-used communication solutions

10.3.1 Communication solution via Public DSL-Network

The DSL-based communication solution for Home-DR builds on available Internet connections in a residential home or SMEs. In case of residential Home-DR application, not only single homes but also apartments in multi-dwelling-buildings may be addressed.
The paradigm of disabled internet access due to energy saving reasons is not really relevant in this use

case, since the consumer as an operator must be interested to keep the Home-DR service up and running.

As discussed above, appliances will not be connected directly to the home router, since transmission and logical protocol conversion is required. Therefore a Home-DR controller, connected to the DSL-router via standard links (Ethernet/WiFi) is required. This device is preferably logically connected to the Home-DR-SP in a secured and encrypted "Always-On" mode. The Home-DR-SP receives instant and scheduled pricing information from relevant Smart Meter-SPs.
Grid alert functions may be received and processed from relevant local DSOs.
In cases where the consumer's Electricity-SP is not identical with the Smart meter-SP, actual pricing information is received from this provider.
Therefore the functionality of the Home-DR scenario relies on the synchronization of available pricing information and appliance control.
Typical appliance interfaces to be connected will be wireline (powerline, coax or twisted pair), as described by the G.hn standard, or wireless-mesh interfaces like ZigBee, Z-wave, etc.
In case of G.hn, it is foreseen that Home-Routers/Switches or switched Ethernet home networks may seamlessly incorporate G.hn interfaces as well, since they rely on standard MAC-address forwarding mechanisms.

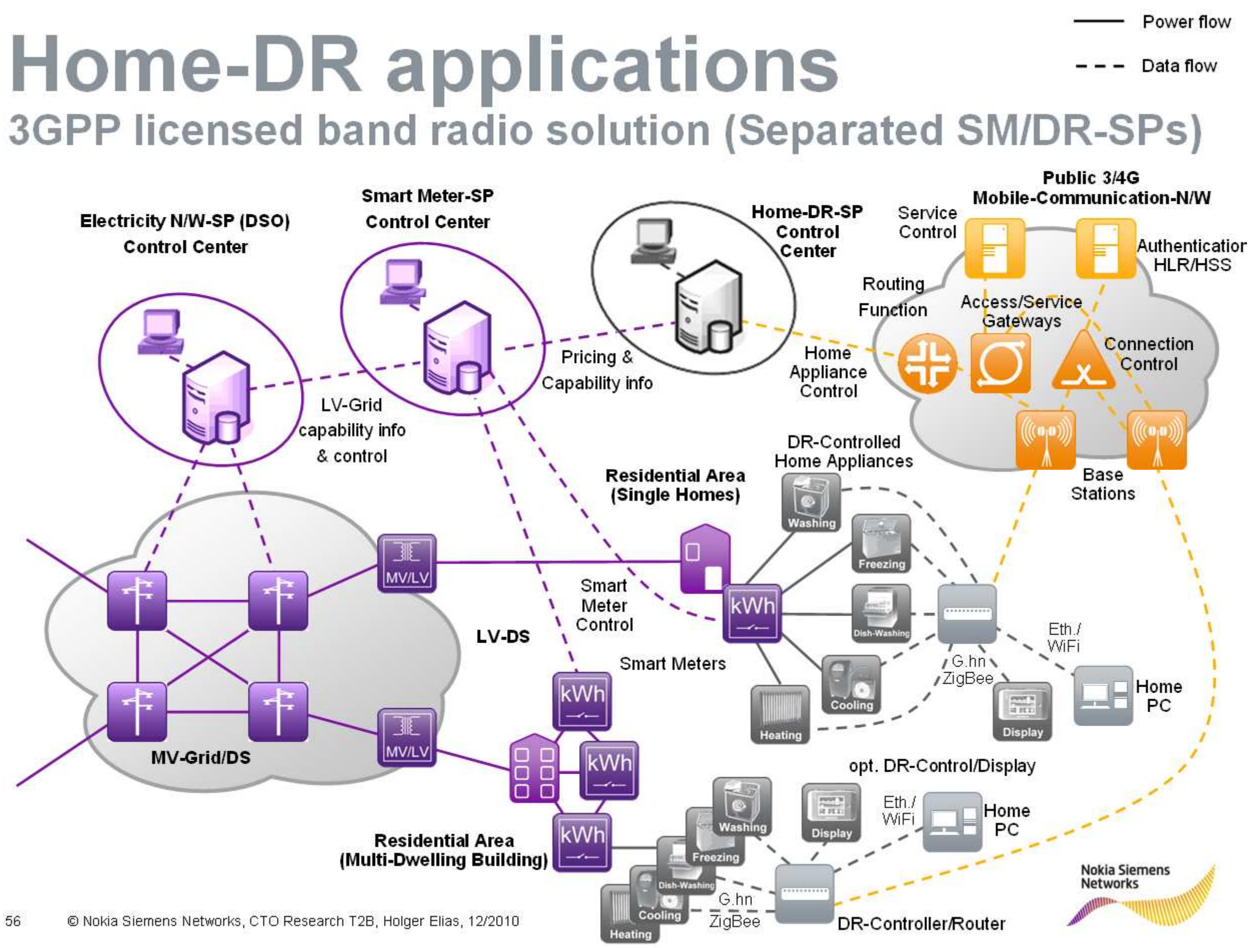


Whether the home PC will have direct Web-access to a DR-controllers Web-server or via the Home-DR-SP depends on the implementation and presence of relevant data bases for pricing and history information. It may be assumed though that the DR-controller will incorporate at least a Web-server for local management purposes.

Instead of a DSL-network connection, Cable-based access (based DOCSIS 2.0 / 3.0 standards) will also provide suitable internet connectivity for Home-DR purposes.

10.3.2 Communication solution via 3GPP defined licensed band radio

Unlike in the above DSL-based communication solution, involving the consumer in the Home-DR communications configuration set-up, a 3GPP based public communication solution may act as a “pre-configured” solution, avoiding communication network set-up by the consumer.
To control and supervise relevant Home-DR settings, a Display-Unit with some menu control buttons might avoid the below shown local PC connection for control purposes.



Solution control may be achieved in greater detail by an independent home-PC, connected to the Home-DR-SP’s server via the internet (as shown in chapter 10.3.1). Therefore the 3GPP connection is not loaded with any Web-based data traffic, keeping operational cost as low as possible.

10.3.3 Other private communication solutions

In principle, Home-DR service offering is possible also via private communication networks.

- This is true for dedicated wireless networks, e.g. building on WiMax technology. In this case, the set-up and functionality is similar to the public 3GPP case, as discussed in the chapter 10.3.2 above.
- In case of the existence of BPL wireline communication over the LV grid, as discussed for Smart Metering in chapter 6.3.2, the attainable data transmission bandwidth is not exactly foreseeable and is regarded as critical low for added Home-DR application. Also due to the unclear application situation of the Smart Meter as a home communication G/W, this solution is not further discussed in here.

10.4 Mapping req's to available N/W parameters

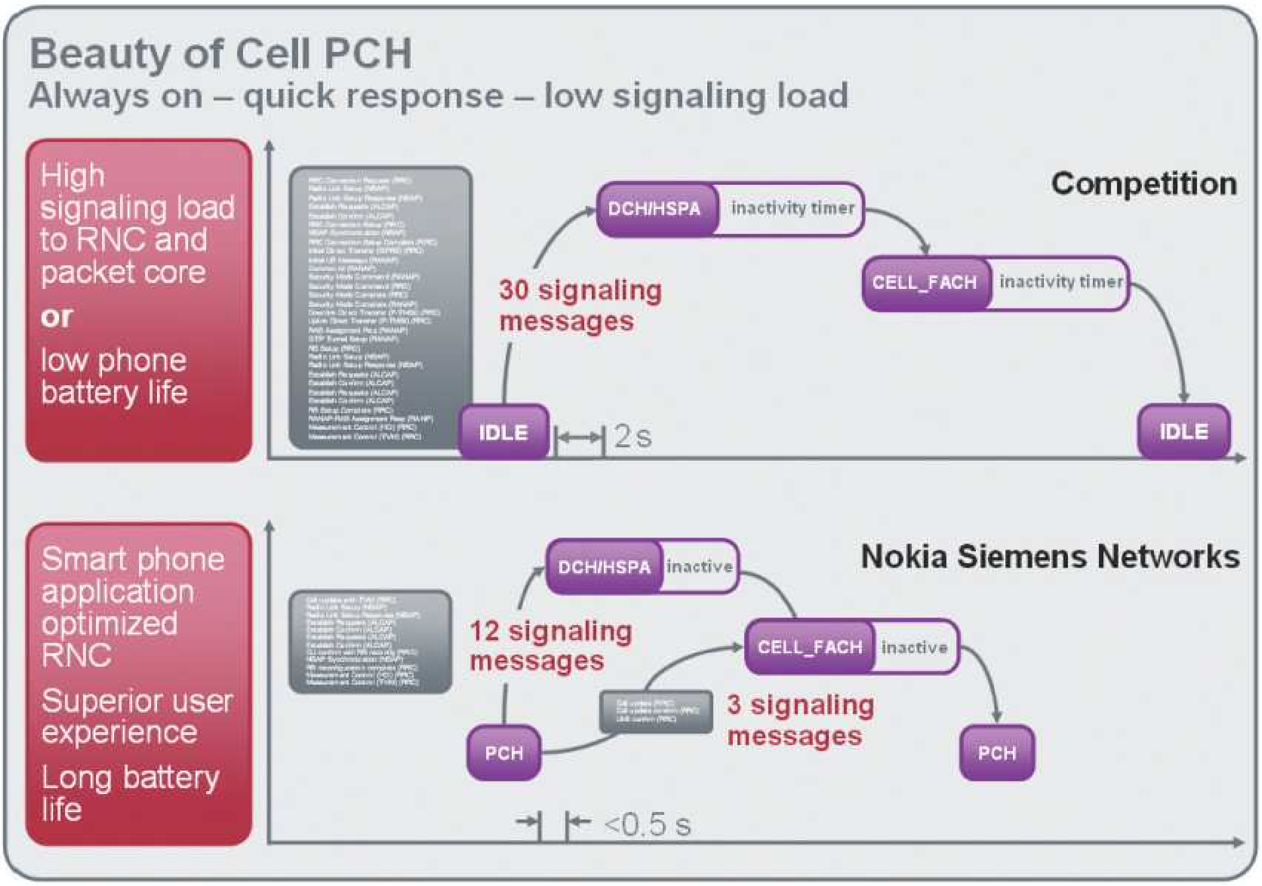
Home-DR communication primarily has to rely on available internet connections in the premises, therefore the General Network Availability appears as the primary indicator for a possible market penetration. Due to the low probability to find private WiMax or BPL communication network implementations, the focus of this application will evolve on public communication networks. This will drive down device costs due to scaling effects, which are also coupled to the mobile broadband equipment case (e.g. PC-cards, ASICs, RF-circuitry) or already available wireline installations, which can be considered as a cost-neutral internet access already, due to widely spread flatrate tariffing.
In case of 2G/GPRS/Edge though, the scalability due to data aggregated cell throughput and latency requirements per cell in densely populated is not given.

Home-DR Communication	Public Wireless			Public Wired	Private Wireless	Private Wired
	2G/GPRS	3G/UMTS	4G/LTE	DSL/Cable	WiMax	BPL
General Network Availability	+	+	0 (*)	0	-	-
Comm's N/W Perfomance						
Bandwidth	0	+	+	+	+	-
Latency/Always-On Operation	-	0	+	+	+	0
Operational Availability	+	+	+	+	+	0
Scalability	N	+	+	+	0	0
Reach	+	+	0	+	0	0
Security/Privacy	+	+	+	+	+	+
Future-Proofness	N	+	+	+	-	-
WAN Configuration Issues	+	+	+	0	+	+
TCO (*)	N	0	0	+	-	0

Rating:
(+) = Good
(0) = Fair
(-) = Poor
(N) = Not feasable
(?) = Depending on Solution

Remarks:
(*) → TCO rating and availability for 4G/LTE beyond 2015

3G/UMTS may be configured in quasi "always-on" mode or better described as stateful operation in router context. Recent improvements configuring application (App's) communication in mobile devices by Cell_PCH [19] improve scalability significantly.
Cell_PCH is a 3G radio signaling mechanism, which handles excessive device signaling differently, compared to releasing and waking-up devices from the Idle state (please see below).



Battery life is one important aspect for mobile devices, but for Home-DR devices, session activation delay reduction from 2s to 0.5s and reduced signaling traffic are the solution enablers in densely populated areas for 3G/UMTS networks.

10.5 Recommendation for most reasonable communication solutions

From the solution discussion above, existing DSL/Cable wireline or 3G/UMTS and later 4G/LTE wireless communication solutions will play the major role as communication links for Home-DR, since they do not exhibit any major deficiencies, while being widely available and cost effective.

In parallel, it can be foreseen that specific extensions to deployed and dedicated networks may play a local role in Home-DR communication as well.
By leveraging otherwise justified investments in dedicated communication infrastructure, a counterbalance to operational expenses from the utilization of public networks may manifest in certain cases. In the long run though, less volume in specific dedicated communication technology will limit especially associated home devices' deployment for cost reasons.

10.6 Suggested evolution

From the discussion above, it seems probable that Home-DR will evolve in an independent organizational environment other than coming from traditional DSOs. Legal pressure from deregulation (and limited local presence) will force DSOs to split up into dedicated business units in their own legal frameworks, making it difficult to bundle various interests to build a Home-DR solution from the DSO via the Smart Meter operator, the consumer's contracted electricity provider and finally the Home-DR provider. Therefore each business segment will decide independently about their necessary

communication requirements and choose a different suitable communication solution, as discussed in the other chapters as well.
Further considering a trend towards low CAPEX pre-investment in new business areas, public communication will be the expected choice for Home-DR providers.
With this perspective, a strong interest may arise in a developed Home-DR market by these players, to engage in the Smart Metering operation to create a business control point by a combined Smart Meter and Home-DR HW-device offering. This may bind the consumer tighter to such a combined provider. In turn, communication service for this bundle offering will probably come from a public CSP.
Understanding the operational limitation of wireline communication (DSL/twisted pair are powered behind the meter, thus turning on/off power is not possible! - As discussed in the Smart Metering case, chapter 6), 3G/UMTS, followed by network upgrading to 4G/LTE exhibit the best chances to lead the communication market for Home-DR and Smart Metering in the future.

11 Synopsis of use case descriptions

This chapter will structure and analyze commonalities and differences of the discussed use cases with a focus on applicable communication solutions. Again, a table of the condensed relevant communication parameters helps to detect “sweet spots” or identify “un-attractive” communication solutions. In order to judge about the applicability of specific communication solutions, a holistic judgment across the relevant communication network parameters condensates into a singular solution rating.
We also tried to minimize the use case specific columns to increase the expressiveness of the table.
It was found that ratings for 4G/LTE operated below 1GHz for rural application and above 2GHz for urban application yielded similar results in their specific use case application. One column covering all 4G/LTE frequency bands was therefore found to be sufficient, assuming the later existence of appropriate 4G/LTE installations per use case.

Please see the below table.

Synopsis for Use Case Communication Solutions	Public Wireless			Private Wireless			Public Wired			Private Wired				
	2G/GPRS/EDGE	3G/UMTS	4G/LTE	4G/LTE	WiMax	PtP	DSL	MODEM	Cable	BPL	MAN	FON	DSL	MODEM
Use Cases (SG Core)														
WAMS (Wide Area Measurement Systems):	-	+	+	+	0	+				0		+		
Distribution Automation (DA)														
Rural Feeder Automation	+	+	+	0	0	0								
Automation of Urban Secondary Substations	+	+	+	0	0	-	0							
Voltage Ctrl in Distribution N/Ws	+	+	+	0	0	-								
LOM protection	-	-	+	0	0		+					+		
Demand Response (DR) control	0	+	+	+	0		+	-		0	+		0	-
Distributed Energy Resources (DER) control	0	+	+	0	0	0				0		+		
Use Cases (SG Edge)														
Smart Metering (AMR - Advanced Meter Reading)	-/N	+	+	+	0		0/+		0/+	0			N/+	
Home-DR applications – Home Appliances	N	+	+		0		+		+	0				

Rating: (+) = Good
(0) = Fair
(-) = Poor
(N) = Not feasable
(?) = Depending on Solution

Remarks:
- Blank fields shall be understood as not relevant, resp. not applicable or negatively rated
- Double rating, e.g. 0/+
First: Direct individual connection / Second: Connection via Data Concentrator
- Rating for 4G/LTE is projected from 2015

In order to understand our key influencing factors to the individual ratings, there are some remarks available below.

Concerning the core of the Smart Grid:

- Wide Area Measurement Systems (WAMS)
  Except the 2G public service for bandwidth and latency reasons, the other 3GPP based public service offerings show an acceptable performance in all areas to support the intended HV/MV grid-surveillance tasks described in chapter 9.
  In case of dedicated private wireless services, the situation is viewed as less positive for

coverage vs. cost reason, e.g. forcing a communication network rollout with an unreasonable high density to reach remote stations. This is especially true for higher frequencies, whereas the cell size below 1GHz may stay large enough to neutralize this argument.
On the other hand, reasonably priced PtP radio solutions, installed only for a certain location will not generate a too high cost burden for a limited set of applications.
Dedicated private wired services like BPL or FON are as well use case compatible communication solutions, whereas the transmission performance and upfront installation cost of BPL limits the benefit significantly.
Considering FON fiber deployment cost, laid out together with the power lines themselves, enables reasonable high upfront cost in combination with lower cost optical Ethernet interfaces, avoiding expensive transmission equipment investment.

- Distribution Automation (DA)
  The main trends which can be observed are as follows:
  - Given the moderate availability / reliability requirements for DA use cases, there is a advantage lowering TCO in using public wireless over private wireless
  - There is a clear advantage using bands < 1 GHz when connectivity in rural environments is needed
  - Operating PtP radios from RMUs in urban environments with complex topologies is cumbersome
  - If optical fiber or DSL links happen to be available, they can be alternatively used
- Demand Response control for large scale applications (DR)
  Keeping in mind that DR applications are located in places where public communication is regularly available and communication bandwidth is not too demanding, other factors like future-proofness and cost become more decisive.
  Cost needs to be analyzed from CAPEX and OPEX perspective, where installation originated costs need to be set in relationship to monthly operational expenses. This is especially problematic for the upfront investment in dedicated private network solution like WiMax and BPL in combination with less decreasing technology cost, compared to mass deployed network solutions.
- Distributed Energy Resources control for large scale applications (DER)
  As discussed above for DR, the communication bandwidth of DER during regular operation is not too demanding either, but locations tend to be rather rural. Therefore dedicated private network installation will be quite expensive, to achieve a regional presence.
  In case of optical fibers deployed alongside the power line cable, FON may be a reasonable communication solution, especially when network installation costs can be shared with an independently required station management control communication by the owner of the DER.

Concerning the edge of the Smart Grid:

- Smart Metering (AMR - Advanced Meter Reading)
  Even some today's Smart Meter installations rely on 2G/GPRS/EDGE based wireless communication, we question the future-proofness in the light of the new application range in the Smart Grid strongly.
  In the field of wired communication, concentrating solutions based on DSL or Cable exhibit their strength in multi-dwelling buildings only.
  Connecting Smart Meters via private Internet access, limits their functionality in case of forced power control requirements.
  In general, BPL is viewed to solve several problems in the Smart Metering application sphere and bring additional value when the BPL aggregator is mounted in the MV/LV transformer station The network communication in there may enable also other Smart Grid functionality for

the DSO, but technological, commercial and legal (ownership) limitations of BPL lead us to a neutral judgment.

- Home-Demand Response (DR) applications – Home Appliances
  Dedicated private network use for Home-DR is not seen as too favorable here, since we excluded "Fixed-Gear" appliances, which might be operated out of (management) control of the resident/consumer. Therefore Home-DR is seen as a voluntary application service offering and therefore already existing public communication services (under the control of the resident/consumer) are sufficient in general, while usually no additional Telco cost is added. To avoid extensive home router/LAN configuration, a separate wireless modem may be compensated in total cost by avoiding extensive call center configuration support in case of home network integration.
  On top of this argument it needs to be realized that dedicated private networks' cost position might be worse than public ones (WiMax case), especially if the Home-DR-SP is not the network owner.

12 Conclusion

Analyzing the table of available communication methods in the above chapter 11 in a holistic way, which is reflecting several representative Smart Grid use cases, it becomes obvious that public wireless technologies based on 3GPP standards display themselves as a viable communication solution in most cases.

We excluded certain HV-line grid protection schemes from this discussion, which require low signal transmission delay and extended communication equipment protection, which can only be achieved by dedicated Layer 2 transmission technology. Nevertheless, some protection related schemes in the area of DA (LOM protection) were considered and may seem to have more relaxed delay requirements so that QoS enabled "always-on" solutions based on 4G/LTE become viable.
Data security and associated customer privacy aspects were raised in the Smart Metering use case and discussed to a limited extent, as they are depending on regional (e.g. EU/U.S.) and national requirements.
Both are subject for further investigation.

Looking closer at the use cases requirements, it becomes obvious that the more participants or devices to be controlled or interrogated in the field, the more challenging the sustainability of Smart Grid communication network operation and maintenance over a long depreciation period gets.
Since the rate of new communication technology deployment has accelerated even more in the last years, compared to new grid infrastructure deployment, both energy and associated communication technologies need to be synchronized in terms of solution perspective.

The energy sector did so far insure its operability from a closed view scheme, trying to maintain and operate all relevant technologies (energy and communication related) over the anticipated lifespan of more than a decade.

Reflecting the rate of technological change in the telecommunication sector, (e.g. in semiconductor components or software maintenance) and the associated cost to hedge them for the desired timeframe suggest a re-thinking of present strategies.
This has to be viewed in the light of today's utility availability requirements for communication systems .
In some new use cases, especially the edge centric Smart Grid (Smart Metering and Home-DR), but also to a certain degree in DR and DER control in the Smart Grid's core, today's public communication service availability appears as sufficient.
When it comes to distribution grid infrastructure conservation during energy infrastructure malfunction, more careful communication service availability considerations are required. Some of the issues are

discussed in the distribution network (DA) related use cases.
An increase in availability, based on public wireless networks may be achieved by:

- Device multi-mode operation (e.g. 3G to 2G fallback options)
- Roaming between CSPs
- A combination of wired and wireless communication technologies.

Also regulatory requirements and suitable power back-up strategies in public CSP's networks related to power backup of 3G/4G base station sites would need to be considered further, while public communication systems evolve from 2G to 3G and 4G.

The above synopsis table displays the utilization of public communication technology as the most forthcoming solution. It is foreseeable to be available as a future proof basis over decades.

The nature of the grid communication requirements is rapidly changing from addressing only discrete energy infrastructure towards basically each consumer's or prosumer's premises The burden to install pervasive communication for all smart grid related tasks becomes almost overstraining, considering utilization for energy-related applications only.

Further industrial trends, caused by deregulation and general market adaptation requirements, result in an ongoing legal structuring of formerly bulk organizations in the field of energy utilities. This seems to leave less opportunity for the implementation of dedicated wide area telecommunication networks in the future.

CSPs have a large amount of licensed (interference free) frequency resources in use, spanning multiple frequency bands, in particular bands < 1 GHz which are essential in providing economical coverage in rural areas. As the traffic volume from the smart grid use cases are expected to be low compared to wireless BB, this results in low incremental cost of service provision for the DSO.
Another essential advantage is the possibility of leveraging the already existing radio coverage at the many new site locations envisioned for the SG. Furthermore, many more M2M application from other 'vertical organized businesses' (Transportation, Medicine, Building Mgmt., etc.) are expected to materialize. which will provide a favorable 'eco-system' in terms of standardized M2M network features, devices and services.

Public CSPs and telecommunication equipment vendors are therefore in the most ideal position to cover effective communication solutions, thoroughly enabling new Smart Grid functionality. Proximity to consumers, prosumers, enterprises as well as to the energy infrastructure industry, will support optimum concepts for Smart Grid Communication.

13 Abbreviations

3G	Third Generation of standards for mobile communications and services
3GPP	Third Generation Partnership Project
4G	Fourth Generation of standards for mobile communications and services
AC	Alternating current
ACSI	Abstract Communication Service Interface
ADA	Advanced Distribution Automation
ADSL	Asymmetric Digital Subscriber Line
AES	Advanced Encryption Standard

AIPN	All IP Networks
AMI	Advanced Metering Infrastructure
AMIS	Automated consumption data acquisition and information system
AMR	Automated Meter Reading
ANSI	American National Standards Institute
AP	Access Point
API	Application Program Interface
APN	Access Point Name
AR	Auto-Reclosing
ASCII	American Standard Code for Information Interchange
ASDU	Application Service Data Unit
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASN.1	Abstract Syntax Notation
ATM	Asynchronous Transfer Mode
ATU	ADSL Terminal Unit
AVR	Automatic Voltage Regulation
BAS	Building Automation System
BPEL	Business Process Execution Language
BPL	Broadband over Powerline (see also PLC)
BPMN	Business Process Modeling Notation
BS	Base-Station (3GPP)
CAPEX	Capital expenditure
CATV	Cable TV
CDM	Code Division Multiplexing
CDMA	Code Division Multiple Access
CdTe	Cadmium telluride
CEA	Consumer Electronics Association
CERT	Computer emergency response team
CGR	Connected Grid Router
CGS	Connected Grid Switch
CHP	Combined heat and power
CIGRE	International Council On Large Electric Systems
CIM	Common Information Model for energy management applications
CIP	Critical Infrastructure Protection
CIS	Component Interface Specification
CM	Configuration Management
CO	Central Office (Telecom)
COTS	Commercial off-the-shelf

CPP	Critical Peak Pricing
CRC	Cyclic Redundancy Check
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
CSP	Communication Service Provider
Cu	Copper
DA	Distribution Automation
DC	Direct current
DEMS	Decentralized energy management system
DER	Distributed Energy Resources (distributed generation and storage)
DES	Data Encryption Standard
DG	Distributed generation
DHCP	Dynamic Host Configuration Protocol
DHS	Department of Homeland Security (USA)
DIN	German Institute for Standardization
DisCo	Distribution company
DIY	Do It Yourself
DKE	Deutsche Kommission Elektrotechnik
DMS	Distribution management system
DMT	Discrete-Multi-Tone
DMZ	Demilitarized zone
DNP/3	Distributed network protocol
DNS	Domain Name System
DOD	Department of Defense (USA)
DOE	Department of Energy (USA)
DP	Dynamic Pricing
DR	Demand Response
DS	Distribution System
DSL	Digital subscriber line
DSLAM	Digital Subscriber Line Access Multiplexer
DSO	Distribution System Operators
EAI	Enterprise Application Integration
EAN/EDIEL	Business process model for invoicing in downstream electricity power market
ebIX	European forum for energy Business Information eXchange
ebXML	Electronic Business (eBusiness) eXtensible Markup Language
EDGE	Enhanced Data rates for GSM Evolutions
EDI	Electronic Data Interchange

EDL	Exchange Data Language
EDP	Electronic data processing
EFR	Europäische Funk-Rundsteuerung: Long-wave radio broadcast
EHV	Extra high voltage
EIA	Electronic Industries Alliance
EIB	European Installation Bus
EISA	Energy Independence and Security Act
ELCOM	Electricity utilities communication
EMC	Electromagnetic compatibility
EMI	ElectroMagnetic Interference
EMS	Energy Management System
EN	European Standard
EPRI	Electric Power Research Institute
ES	Energy Storage
ESP	Energy Service Provider
ETC	ebIX Technical Committee
ETSI	European Telecommunications Standards Institute
ETSO	European Transmission System Operators
EU	European Union
EV	Electric Vehicle
EWG	Electricity Working Group
FA	Feeder Automation
FACTS	Flexible AC transmission system
FCC	Federal Communications Commission
FDD	Frequency Division Multiplexing
FEC	Forward Error Correction
FERC	Federal Energy Regulatory Commission
FO	Fiber optic
FON	Fiber optic network
FTP	File Transfer Protocol
GenCo	Generation company
GHG	Greenhouse Gases
GID	Generic interface definition
GIS	Geographic Information System
GOOSE	Generic Object Oriented Substation Events
GPRS	General packet radio service
GPS	Global Positioning System (time source)
GRS	General Radio Service

GSM	Global system for mobile communications
GTIN	Global Trade Item Number
GUI	Graphical user interface
GWAC	GridWise Architecture Council
G/W	Gateway (e.g. for communication stack adaptation)
HCC	Home Control Center
HDSL	High Data Rate Digital Subscriber Line
HDTV	High Definition TV
HF	High frequency
HMI	Human Machine Interface
HSDPA	High-Speed Downlink Packet Access
HSxPA	High Speed Xlink Packet Access
HTTP/HTTPS	Hypertext transfer protocol/ hypertext transfer protocol secure
HV	High voltage
HVAC	Heating Ventilating and Air Conditioning
HVDC	High voltage direct current
HVDCT	High voltage direct current transmission
HW	Hardware
ICCP	Inter-control center communication protocol
ICT	Information and Communication Technologies
IDS	Intrusion Detection Systems
IEC	International Electrotechnical Commission
IED	intelligent electronic device
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IHD	In-Home Display
IMT	International Mobile Telecommunications
IO	Input Output
IOS	Internetwork Operating System
IP	Internet Protocol
IS	International Standard
ISDN	Integrated services digital network
ISM	Industrial, Scientific and Medical band
ISO	International Organization for Standardization, Independent Systems Operator
IT	Information Technology
ITU	International Telecommunication Union
KNX	Network communications protocol for intelligent buildings

LAN	Local Area Network
LCD	Liquid crystal display
LED	Light emitting diode
LOM	Loss of Mains
LTE	Long Term Evolutions
LV	Low voltage
LVMD	Low voltage main distribution
M2M	Machine to Machine
MAC	Message Authentication Code
MD	Main distribution
MIB	Management Information Base
MIME	Multipurpose Internet Mail Extensions
MIMO	Multiple Input Multiple Output
MMS	Manufacturing Messaging Specification ISO 9506
MSCONS	Metered Services Consumption
MTBF	Meantime between failures
MTTF	Meantime to Failure
MUX	Multiplexer
MV	Medium voltage
NEMA	National Electrical Manufacturers Association
NERC	North American Electric Reliability Council / Corporation
NFC	Near Field Communication
NGMN	Next Generation Mobile Networks
NIST	National Institute of Standards and Technology
N.C.	Normally closed (disconnector)
N.O.	Normally open (disconnector)
NOAA	National Oceanic and Atmospheric Administration
NSA	National Security Agency
NTP	Network time protocol
NTT	Nippon Telegraph and Telephone
OASIS	Open Access Same Time Information System
OASIS	Organization for the Advancement of Structured Information Standards
OC	Overcurrent
OFDM	Orthogonal Frequency Division Multiplexing
OID	Object Identifier
OLTC	On load tap changer (transformer)
OMG	Object management Group
OpenSG	Open Smart Grid

OPEX	Operational expenditure
OSGi	Open Services Gateway Initiative
OSI	Open Systems Interconnection (Basic Reference Model)
PABX	Private Automatic Branch Exchange
PCM	Pulse code modulation
PDH	Plesiochronous digital hierarchy; an international multiplexing standard
PDU	Protocol Data Unit
PEV	Plug-in Electric Vehicles
PLMN	Public Land Mobile Network
PLC	Power-line carrier
PMU	Phasor Measurement Unit
POTS	Plain Old Telephone Service
PPPoE	Point-to-Point Protocol over Ethernet
PROFIBUS	Process Field Bus
PS	Public Safety (US)
PSTN	Public Switched Telephone Network
PUC	Public Utility Commission
PV	Photo-Voltaics
QOS	Quality Of Service
RAN	Radio Access Network
RES	Renewable energy sources
RF	Radio Frequency
RFC	Request for Comments; Remote Feedback Controller
RFID	Radio Frequency Identification
RJ	Registered Jack
RMU	Ring Main Unit
RMS/ rms	Root mean square
RSA	Rivest, Shamir, Adelman
RSTP	Rapid spanning tree protocol
RTO	Regional Transmission Operator
RTP	Real-Time Pricing
RTU	Remote Terminal Unit
SAE	System Architecture Evolution
SAS	Station automation system
SCADA	Supervisory Control And Data Acquisition
SCL	Substation Configuration description
SDH	Synchronous digital hierarchy; multiplexing protocol for transferring multiple bit streams over the same optical fiber

SDO	Standards Development Organization
SDSL	Synchronous Digital Subscriber Loop
SFPs	Small Form-Factor Pluggable
SHA	Secure Hash Algorithm
SHA-1	Secure-Hash-Algorithm Version 1
SHDSL	Symmetrical High Data Rate Digital Subscriber Line
SIMs	Subscriber Identity Module
SLA	Service Level Agreement
SME	Small and Medium Enterprises
SMTP	Simple Mail transfer Protocol
SNCP	Sub-network connection protection
SNMP	Simple network management protocol
SNTP	Simple Network Time Protocol
SOA	Service-Oriented Architecture
SONET	Synchronous optical network
SP	Service-Provider
SQL	Structured Query Language
SSH	Secure Shell
STATCOM	Static synchronous compensator
STM	Synchronous transport module
SVC	Static var compensator
TCP/IP	Transmission Control Protocol/Internet
TDD	Time Division Duplexing
TDM	Time Division Multiplexing
TETRA	TErrestrial Trunked RAdio (ealier: Trans European Trunked RAdio)
TFTP	Trivial File Transfer Protocol
TLS	Transport Layer Security
TOGAF	The Open Group Architecture Framework
TOU	Time-of-Use
TransCo	Transmission company
TSO	Transmission System Operator
UHF	Ultra high frequency
UHVDC	Ultra-high-voltage direct-current
UI	User Interface
UID	Universal Identifier
UMB	Ultra Mobile Broadband
UML	Unified Modeling Language
UMTS	Universal Mobile Telecommunications System

UPnP	Universal Plug and Play
UPS	Uninterruptible power supply
USB	Universal serial bus; serial bus standard to interface devices
UTRAN	UMTS Terrestrial Radio Access Network
VDSL	Very high bit-rate Digital Subscriber Line
VHF	Very high frequency
VID	VLAN Identifier
VLAN	Virtual LAN
VLF	Very Low Frequency
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
VPP	Virtual power plant
VT	Voltage transformer
W3C	World Wide Web Consortium
WAMS	Wide-Area Measurement System
WAN	Wide area network
WAP	Wireless Application Protocol
WASA	Wide Area Situational Awareness
WCDMA	Wideband Code Division Multiple Access
WDM	Wavelength division multiplex
WDS	Wireless Distribution System
WEP	Wired Equivalent Privacy
WiFi	Wireless Fidelity
WiMAX	Worldwide interoperability for microwave access
WLAN	Wireless local area network
WP	Work Package
WPAN	Wireless Personal Area Network
WS	Web Services
WSDL	Web Services Description Language
XML	Extensible markup language

14 References

[1] VTT Publication; Koponen, Pekka; Pykälä, Marja-Leena; Peltonen, Janne; & Ahonen, Pasi; Interfaces of consumption metering infrastructures with the energy consumers - Review of standards, 2010, http://www.vtt.fi/inf/pdf/tiedotteet/2010/T2542.pdf

[2] SGEM D4.1.4.1: Collection of Smart Grid communication requirements

[3] Pew Center for Global Climate Change, Steve Caldwell:
Electricity Demand in a Low-Carbon Energy Future,
IEEE Power & Energy Society - General Meeting (July 25-29, 2010)

[4] The German Federal Commissioner for Data Protection and Freedom of Information:
English translation of the German Federal Data Protection Act
Bundesdatenschutzgesetz in englischer Fassung (BDSG, english version)

[5] ConnectivityWeek, Vint Cerf, June 2010 IST;
http://www.smartmeters.com/the-news/1010-cerf-believes-in-smart-grids-eventual-success.html

[6] NIST, Oct. 2010 SG Network System Requirements Specification v4.1-draft4.xls
SG Network System
Requirements Specific

[7] Homepage of M-Bus Usergroup,
http://www.m-bus.com/

[8] Texas Instruments processors for Smart Meters: Stellaris 32-bit ARM Cortex-M3 MCUs
www.ti.com/stellaris and www.ti.com/430metering

[9] Homepage of Kofler Energies (in German language only)
http://www.koflerenergies.com/

[10] NIST: Framework and Roadmap for Smart Grid Interoperability Standards 1.0,
January 2010
http://www.nist.gov/public_affairs/releases/upload/smartgrid_interoperability_final.pdf

[11] Berkeley Lab study: Estimating Demand Response Market Potential among Large Commercial and Industrial Customers (2007)
http://eetd.lbl.gov/ea/emp/reports/61498.pdf

[12] ENERNOC: Commercial, Institutional, and Industrial Demand Response (2009)
http://www.enernoc.com/resources/files/utilitysalesbrch-web.pdf

[13] IEEE Library: Infrastructure Sharing for Mobile Network Operators
http://ieeexplore.ieee.org/iel5/4470165/4472737/04472768.pdf?arnumber=4472768

[14] http://www.wind-energy-the-facts.org/en/part-i-technology/chapter-4-wind-farm-design/infrastructure/scada-and-instruments.html

[15] MV/LV transformer example from Arteche, Italy,
PLC comm on MV
lines.pdf

[16] Paper provided by ABB:
Under observance, International Power Generation - November 2004
http://www.google.com/url?sa=t&source=web&cd=1&sqi=2&ved=0CBUQFjAA&url=http%3A%2F%2Fwww05.abb.com%2Fglobal%2Fscot%2Fscot221.nsf%2Fveritydisplay%2Fc8209d795bf3f49cc1257019002bb27c%2F%24File%2FUnder%2520observance.pdf&rct=j&q=EDITORIAL_2004_03_en_Under_observance.pd&ei=vmbuTM3CBoiUOry-iJMK&usg=AFQjCNGcrpDwBT6_pKTC50F6sHpYWfbdSQ&cad=rj

[17] CIGRÉ Canada, Conference on Power Systems, Winnipeg, October 19-21, 2008:
Phasor Measurement Unit (PMU) Communication Experience in a Utility Environment
by KRISH NARENDRA, TONY WEEKES

[18] B/SH contribution to: Sino-EU SMART GRID Technology and Standardization Forum 2010 Bejing Standardization Forum 2010, May 2010:
Dr. Claudia Häpp, Uwe Kampet: Smart Home, Smart Appliances and Smart Building
http://www.docin.com/p-56134798.html

[19] Nokia Siemens Networks contribution, Smart Networks for Smart Devices
http://www.nokiasiemensnetworks.com/sites/default/files/document/Smart_Networks_for_Smart_Devices_15072010_final.pdf
and the theme overview:
http://www.nokiasiemensnetworks.com/portfolio/products/mobile-broadband/smart-networks-for-smart-devices

[20] EEBUS background information:
http://www.e-energy.de/de/827.php (german),
http://www.kellendonk.de/GB/eebus.htm (english)

[21] Lakervi, Holmes: Electricity Distribution Network Design, The Institution of Engineering and Technology

[22] Lakervi, Partanen: Sähkönjakelutekniikka, OTATIETO / YLIOPISTOKUSTANNUS 2008

[23] Energiateollisuus: KESKEYTYSTILASTO 2009,
http://www.energia.fi/fi/tilastot/keskeytystilastot/keskeytystilasto%202009.html

[24] VTT TIEDOTTEITA: Verkkovisio 2030, Jakelu- ja alueverkkojen teknologiavisio
http://www.vtt.fi/inf/pdf/tiedotteet/2006/T2361.pdf

[25] Lågland, Kauhaniemi, Hakola, Rintamäki: Impacts of quality improvement incentives on automation investments in the Finnish new regulation model, CIRED 2009, Paper 0141
http://search.abb.com/library/Download.aspx?DocumentID=CIRED-09-0141&LanguageCode=en&DocumentPartId=&Action=Launch

[26] Viola Systems: CASE VATTENFALL: AUTOMATING THE DISTRIBUTION NETWORK
http://www.automation.com/pdf_articles/Vattenfall_Viola.pdf

[27] ABB: Technical Reference Manual , Remote Monitoring and Control Unit REC 523
http://www05.abb.com/global/scot/scot229.nsf/veritydisplay/a2f02873a80ef9c6c125756300478261/$File/REC523_trm_750881_ENn.pdf

[28] ABB: IEC 60870-5-101 Remote Communication Protocol for REC 523
http://www05.abb.com/global/scot/scot229.nsf/veritydisplay/f466922a02ab837bc2256fc600361bc8/$File/rec523_IECprotENe.pdf

[29] Viola Systems: Arctic IEC-104 Gateway
http://www.violasystems.com/products/products_arctic_iec-104_gateway.htm

[30] M HYVÄRINEN et al.: A COMPREHENSIVE SECONDARY SUBSTATION MONITORING SYSTEM, 20th International Conference on Electricity Distribution Prague, 8-11 June 2009 http://www.cired.be/CIRED09/pdfs/CIRED2009_0687_Paper.pdf

[31] M Grosse, ENSO Netz GMBH: Stationsautomatisierung bei Enso
http://www.vde.com/de/Regionalorganisation/Bezirksvereine/Thueringen/Facharbeit%20regional/Arbeitskreise/Informationstechnik/Documents/Symposium2010/Martin.Grosse.pdf

[32] B Küchau, Vattenfall Europe Distribution Berlin: Umsetzung der Stationsautomatisierung in einem EVU, VDE-Symposium, Jena 08.09./09.09.2010
http://www.vde.com/de/Regionalorganisation/Bezirksvereine/Thueringen/Facharbeit%20regional/Arbeitskreise/Informationstechnik/Documents/Symposium2010/Bernd.Kuechau.pdf

[33] Puolustustaloudellinen suunnittelukunta: VIESTINTÄ- JA SÄHKÖNJAKELUVERKKOJEN KESKINÄISET RIIPPUVUUDET, PTS Tietoyhteiskuntasektori 1/2006

http://www.huoltovarmuus.fi/documents/3/TYS_2006-1_Viestinta_ja_sahkonjakeluverkkojen_keskinaiset_riippuvuudet.pdf

[34] VDN: Erzeugungsmanagement zur Umsetzung des § 4 Abs. 3 EEG, 27. Februar 2006 http://www.transpower.de/pages/tennettso_de/EEG__KWK-G/Erneuerbare-_Energien-Gesetz/Links_und_Downloads/Grundsatz_Erzeugungsmanagement.pdf

[35] S Dorendorf, E.DIS AG: Netzsicherheitsmanagement und seine Konsequenzen für Verteilnetzbetreiber, Innovationstag 2005 am 01.06. und 02.06.05 http://www-docs.tu-cottbus.de/cebra/public/DownloadDokumente/Innovationstag/2005/Do_II_1_Dorendorf.pdf

[36] EWE Netz: Technische Anforderungen zur Umsetzung des Einspeisemanagements im Verteilnetz Strom der EWE Netz GmbH http://www.ewe-netz.de/data/Anlagen_groesser_100_kW_bis_2_MW.pdf

[37] J Schmiesing, E.On: Neue Herausforderungen für ländliche Verteilnetzbetreiber durch dezentrale EEG - Einspeisung, Fachtagung BNetzA / efzn; Göttingen 15. – 16.April 2010 http://www.efzn.de/fileadmin/Veranstaltungen/2010_Elektrizitaetsnetze/Vortraege/03_Schmiesing.pdf

[38] Auswirkungen des Photovoltaik-Ausbaus auf die Verteilernetze, Studie von Roland Berger Strategy Consultants, Berlin, 04. November 2010 http://www.solarwirtschaft.de/fileadmin/content_files/rol_berger_verteiln.pdf

[39] BDEW: Technische Richtlinie Erzeugungsanlagen am Mittelspannungsnetz, Juni 2008 http://www.vde.de/de/fnn/dokumente/documents/rl_ea-am-ms-netz_bdew2008-06.pdf

[40] VDE/FNN: E VDE-AR-N 4105, Erzeugungsanlagen am Niederspannungsnetz – Technische Mindestanforderungen für Anschluss und Parallelbetrieb von Erzeugungsanlagen am Niederspannungsnetz http://www.vde.com/de/fnn/dokumente/documents/e-vde-ar-n-4105_2010-07.pdf

[41] Ficora: Viestintävirasto 54/2008 M, VIESTINTÄVERKKOJEN JA -PALVELUJEN VARMISTAMISESTA, helmikuuta 2008 http://www.ficora.fi/attachments/suomiry/5vB4GW4xt/Viestintavirasto542008M.pdf

[42] Ficora: MÄÄRÄYKSEN 54 PERUSTELUT JA SOVELTAMINEN VIESTINTÄVERKKOJEN JA PALVELUIDEN VARMISTAMISESTA, 14.2.2008 http://www.ficora.fi/attachments/5kAoklazG/MPS54.pdf

[43] Holma, Toskala: LTE for UMTS - OFDMA and SC-FDMA Based Radio Access

[44] Wikipedia: Terrestrial Trunked Radio, http://en.wikipedia.org/wiki/Terrestrial_Trunked_Radio

[45] Radius: http://www.radius.net/Products/distribution-automation.html

[46] EFR: http://www.efr.de/en/CMS/services/frs_functional_principles_of_energy_management_1032.aspx

[47] M Damm, Enso Netz GmbH: Umsetzung der Anforderungen nach § 6 und § 11 EEG bei ENSO Netz GmbH http://www.vde.com/de/Regionalorganisation/Bezirksvereine/Thueringen/Facharbeit%20regional/Arbeitskreise/Informationstechnik/Documents/Symposium2010/Marco.Damm.pdf

[48] ARZUAGA, A., OJINAGA, Z., LLANO, A.: Implementation of a distributed RTU monitoring system using the IEC60870-5-104 protocol over GPRS networks, CIGRE 2008 http://www.usyscom.com/LinkClick.aspx?fileticket=%2FrSKrgfMv2k%3D&tabid=122&mid=493&language=en-GB

[49] Nokia Siemens Networks: Heading Towards High-Performance All-IP with LTE/SAE, http://www.nokiasiemensnetworks.com/portfolio/products/mobile-broadband/long-term-evolution-lte

[50] Nokia Siemens Networks: Mobile broadband with HSPA and LTE – capacity and cost aspects, http://www.nokiasiemensnetworks.com/portfolio/products/mobile-broadband/long-term-evolution-lte

[51] 3GPP TR 23.888 V1.0.0 (2010-07), 3GPP System Improvements for Machine-Type Communications

[52] GSMA: Fast Dormancy Best Practices V1.0, 26th May 2010 http://www.gsmworld.com/documents/fast_dormancy_best_practices.pdf

[53] Signals Research Group, LLC: Smartphones and a 3G Network by http://www.nokiasiemensnetworks.com/portfolio/products/mobile-broadband/smart-networks-for-smart-devices

[54] H Haverinen et al.: Energy Consumption of Always-On Applications in WCDMA Networks, IEEE, 2007 http://www.pasieronen.com/publications/haverinen_siren_eronen_vtc2007.pdf

[55] Public Safety Communications Research (PSCR): Priority, Preemption and QoS http://www.pscr.gov/projects/broadband/700mhz_demo_net/inaug_stakeholder_mtg_042010/day_2/5_Priority_Preemption_and_QoS-final.pdf

[56] NRC Handelsblad article: The 'smart energy meter' will not be compulsory in the Netherlands. Minister of economic affairs Maria van der Hoeven backed down after consumer groups raised privacy concerns. http://vorige.nrc.nl/international/article2207260.ece/Smart_energy_meter_will_not_be_compulsory

[57] ADINE Deliverable 63, Final definition of ANM, 1.12.2010, http://hermia-fi-bin.directo.fi/@Bin/feac52ce4679128c37f60589e632c22b/1294835624/application/pdf/761570/ADINE_D63_01122010_rev1.pdf

[58] Adine workshop, Sami Repo: Protection of distribution network including distributed generation, http://www.hermia.fi/@Bin/756249/ADINE_SP2.ppt

[59] Kari Mäki: Novel Methods for Assessing the Protection Impacts of Distributed Generation in Distribution Network Planning, Tampere University of Technology. Publication 701, http://webhotel2.tut.fi/units/set/raportteja/dg/yleiset/thesis_net.pdf

[60] O. Samuelsson: Islanding detection and connection requirements, IEEE 2007

[61] Rintamaki, Kauhaniemi: Applying modern communication technology to loss-of-mains protection, CIRED 2009, Paper 0759, http://www05.abb.com/global/scot/scot229.nsf/veritydisplay/f18eda4c63485819c12575ed00479480/$File/ABB_whitepaper_CIRED_2009_0759.pdf

[62] L. Kumpulainen, K. Kauhaniemi: Analysis of the impact of distributed generation on automatic reclosing, IEEE 2004

[63] Bower, W., Ropp, M.: Evaluation of Islanding Detection Methods for Photovoltaic Utility-Interactive Power Systems, Report IEA PVPS T5-09: 2002, http://www.iea-pvps.org/products/download/rep5_09.pdf

[64] ABB special report IEC 61850 http://www05.abb.com/global/scot/scot271.nsf/veritydisplay/ba5c0d1cacc015a7c12577840033f1a2/$file/abb_sr_iec_61850_72dpi.pdf

[65] NIST Special Publication 800-57 March, 2007, Recommendation for Key Management – Part 1: General (Revised).

http://www.google.de/url?sa=t&source=web&cd=1&ved=0CBsQFjAA&url=http%3A%2F%2Fcsrc.nist.gov%2Fpublications%2Fnistpubs%2F800-57%2Fsp800-57-Part1-revised2_Mar08-2007.pdf&rct=j&q=sp800-57-part1-revised2_mar08-2007&ei=4RUwTbbyPJWSjAfNoYjECg&usg=AFQjCNGTQfktaE8pQxZL_2AYw1rj_IQeAQ&cad=rja