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Communication technologies and networks for Smart Grid and Smart Metering

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Introduction

Climate policy has substantial repercussions on the value chain of power markets. To emit less carbon, an energy supply system requires the addition of intermittent renewable energy sources (e.g., wind, solar). The challenge of integrating these renewable energy sources (RES) is made harder by the fact that most distribution networks are characterized by a low degree of automation and monitoring. Thus, the transformation of the energy system must encompass new instruments and automated processes aimed at synchronizing the demand and supply of electricity. Otherwise, the stability of power grids cannot be guaranteed (VDE 2012).

In order to transform the power markets, Information and Communication Technologies (ICT) are needed to provide the energy market with the functionalities to monitor and operate electricity grids. The implementation of ICT and intelligent devices in the field turns a conventional power grid into a Smart Grid - the next generation power grid.

Since ICT plays a vital role in deploying a Smart Grid (Wissner 2011), research has been carried out on various aspects of ICT for Smart Grid, and with a broader focus, on machine-to-machine (M2M) communication[1] (Gungor et al. 2011, Zhong Fan et al. 2012). With regard to communication technologies facilitating Smart Grid, both academic studies and pilots performed by utilities have tried to evaluate wired (fiber, DSL, PLC) and wireless (GSM, UMTS, LTE, CDMA) communication technologies for last mile and wide area network connectivity (Gao et al. 2012). However, most studies compare technologies only with a constrained set of qualitative parameters. Hence, when analyzing wireless technologies, neither the impact of the frequency band used (Lundborg et al. 2012) nor the ability of commercial networks to cover both mobile mass market and Smart Grid applications have been fully taken into account. For instance, the fact that only frequencies below 1 GHz can efficiently support Smart Grid (which in most cases requires indoor coverage) is still to some extend neglected in literature (e.g., Raquet/Liotta 2013). Wireless technologies using

[1] M2M-communication leads to the Internet of Things. The trend to connect multiple devices can be observed in logistics, automotive, public transport and in the health sector. Each of these sectors has different requirements, but also similarities.

frequencies at 2 GHz (e. g., UMTS) are less if not at all adapted to enable wide or local area networks for Smart Grid due to their propagation characteristics. Looking at wired communication technologies (fiber, DSL), regulatory aspects as well as penetration levels have been underestimated.

This paper tries to fill this gap. Additionally, contrary to approaches proposing that utilities should rely on already existing commercial broadband infrastructures (Kurth 2012), this paper does not exclude the option that a new infrastructure might offer better efficiency.

The paper is based on desk research and discussions with experts in the German power market.[2] The first section describes briefly the European legal framework and functionalities of Smart Grid. The second section covers the communication requirements. In the last section, communication technologies able to support Smart Grid are analyzed qualitatively. Section 6 presents the conclusions.

Legal and technical aspects of Smart Grid

1. Legal aspects of Smart Grid

What is Smart Grid? Smart Grid is nowadays a very popular catchphrase for many different aspects of the future supply chain in power markets (Müller/Schweinsberg 2013).

From a formal point of view this study refers to the definition provided by the European Commission: a Smart Grid "*means an upgraded energy network to which two-way digital communication between the supplier and consumer, smart metering and monitoring and control system have been added*."[3] The Smart Grid therefore can be conceived as an end-to-end system which can manage direct interaction and communication among multiple entities like consumers, devices, other grid users and energy suppliers. Smart Grid, as commonly understood, covers three out of four major components in power markets: generation, distribution and consumption. Transmission as the fourth element of the power market is not included because at this level the Transmission System Operators (TSO) have already deployed ICT, i.e., the transmission side of the grid has been “smart” for some time.[4]

[2] The author is member of industry working groups dealing with the transition of the power market.
[3] European Commission, Recommendation on 9.3.2012 on preparations for the roll-out of smart metering systems, C(2012) 1342 final.
[4] That does not preclude that TSOs might assume responsibility for Smart Grid.

From an architectural point of view, a Smart Grid can be seen as a communication layer that is virtually overlaid on the electricity grid (Wang et al. 2011, NIST 2009, VDE 2012). The communication layer thereby enables new services which are realized in the application layer and allows interactions with the power grid. This architecture follows the idea that the communication layer should not restrict services.

Functionalities of Smart Grid

Taking this formal definition, three main functionalities of Smart Grid can be identified (see also Khan/Khan 2013):

a.) Smart network management

Smart network management comprises data acquisition, protection, switching and control of energy flows, and quality of supply within the network. Herewith, ICT is the basis of innovative control and monitoring concepts which are required to operate renewable energy sources in a reliable and safe way. The U.S. technology agency NIST (National Institute of Standards and Technology) speaks of wide area situational awareness (WASA) (NIST 2009), i.e., providing utilities with real time information on current power flows and quality of supply, supporting power grid operation and predicting near time development within the grid.

b.) Smart integrated generation

This category encompasses energy storage solutions, distributed generation, integration of electric vehicles and other elements which will be integrated into a future grid.

c.) *Smart Market*

Herewith functions like demand response (DR), load control, dynamic pricing, among others, are covered. These (customer-oriented) services require a new, advanced metering infrastructure. Today, standard electricity meters lack the feedback capabilities that are necessary to (1) balance energy supply and demand, (2) influence customers' behavior, and (3) enable variable tariffs. Therefore, electricity meters must be linked to gateways which support two-way communication. These meters are called Smart Meters. Implementation of Smart Meters is the precondition for dynamic participation of end customers in the energy market (Gangale et al. 2013).

Legal aspects of the advanced metering infrastructure (AMI)

Smart Meters have been promoted by European law since 2006. According to the Energy Service Directive 2006/32/EC smart meters should be installed when an existing meter is replaced, a new building is connected to the power grid or when an existing building is significantly renovated as far as the installation is technically feasible and economically reasonable. Directive 2009/72/EC requires Member States to ensure the implementation of intelligent metering systems to assist the active participation of consumers in the electricity supply market. The implementation of those metering systems can be determined based on an economic assessment of the long-term costs and benefits to the market and the individual consumer. The assessment should further conclude which forms of intelligent metering are economically reasonable and cost-effective and which timeframe is feasible for rolling out intelligent meters. Where the roll-out of Smart Meters is assessed positively, at least 80 per cent of consumers shall be equipped with a Smart Meter by 2020. Since the advanced metering system is politically sensitive in terms of data protection and data security, the European Commission advocates a European-wide common approach of assessing the implications of Smart Grids. The cost benefit analysis has already been carried out in various Member States. In the following countries the respective analysis recommends a nationwide roll-out: e.g., in the Netherlands, Austria, France, UK and Switzerland.

In some EU Member States, the decision has already been made to go beyond the threshold of 80 per cent. In the UK, for example, all "old" meters in households will be replaced by 2020 (AT Kearny 2010). In Germany, where for the time being a market driven approach towards the deployment of smart meters has been pursued (Hierzinger et al. 2012), the roll-out is subject to the above mentioned economic assessment which was published in July 2013. The study concludes that the European target (80 per cent by 2020) is not economically beneficial for Germany. However, the study recommends a roll-out plan for Smart Meters according to which 11.9 Mio. Intelligent Metering Systems (Smart Meters connected to a communication gateway) (37 per cent) have to be installed between 2014 and 2022 (Ernst & Young 2013, 117).

Although the studies on the costs and benefits of the AMI are not fully comparable, the majority supports the thesis that the concept of Smart Grid reduces the consumption of electricity (e.g., Schleich et al. 2013) and subsequently has, in sum, positive effects on economic welfare. Apart from this empirical evidence, the studies reveal another interesting point: market participants will not introduce smart metering without government guidance and support. The reason for this market failure is twofold: on the one hand the benefits of the new infrastructure are widely distributed among the relevant stakeholders (DSO, retailers, and customers) (Römer et al. 2012). Empirical research reveals that in order to increase consumer acceptance the introduction of a new metering system must be accompanied by information on the benefits of the new system (Gerportt/Paukert 2013, Kranz/Picot 2011). Furthermore customers are concerned about security and privacy aspects of the new infrastructure (McHenry 2013). On the other hand the introduction of metering is unattractive for the incumbent utilities as it results in direct and indirect costs. Utilities will likely lose revenue due to lower consumption (Baeriswyl et al. 2012) or an increase of competition. Moreover the introduction of Smart Metering incurs costs that have to be borne by some party and so far it is not clear that the utilities can cross-charge all cost to the end user.

Requirements for communication technologies and networks

A Smart Gird is an upgraded energy grid which enables sensing, monitoring, communication and control of middle and low voltage grids. Against this background, the communication infrastructure must address the following requirements (Yan 2013, Khan/Khan 2013, Plückebaum/Wissner 2013):

a.) Scalability

A study for the UK revealed that compared to 2011 the increase in connected end points in an electricity grid was forecast to grow 775 per cent by 2021 and 1199 per cent by 2031.[5] The vast majority of sites requiring communication facilities are identified at the level of the end user and at the low voltage level (11kV) of the electricity grid. The communication infrastructure must provide utilities with the capability to accommodate a fast growing and ultimately very high number of M2M devices that are widely distributed in the field. Accordingly, the communication network needs to provide both comprehensive coverage and sufficient network capacity.

b.) Performance: Latency, data throughput and reliability

[5] According to EUTC.

For the performance of a Smart Grid, data volumes of only a few Kbytes per data transfer, and latency less than 100ms are critical for network-oriented applications. End-customer-oriented services, like metering, are less demanding. Here, higher latency rates can be accepted. For network-oriented applications the suggested time for resiliency ranged from 8-12 hours up to 72 hours for the most critical services and sites.

c.) Availability

End-to-end service availability for Smart Grid and smart metering applications depends on location and time availability. Whereas location availability of fixed networks only depends on homes connected and implemented redundancy, the location availability of wireless networks is connected to radio coverage.

Some Smart Grid applications, for instance connecting secondary subsystems, require a service availability ranging from 99.5 to 99.9 per cent. In a commercial network this can only be achieved by reserving capacity for or prioritizing Smart Grid services.[6] Furthermore, the dependency on power supply is a crucial element here.

Service availability for the advanced metering infrastructure is less demanding in respect to time. Since data will be stored on customer devices for a certain time period, availability below 90 per cent could be acceptable.

d.) Costs

The Smart Grid, with its unprecedented communication capabilities, should not significantly increase the price of electricity. Here, two categories of costs are relevant: (1) the price of the single communication service (e.g., connectivity costs for transport of 1kByte). The cost per application thereby depends on the cost of coverage, the cost of capacity and the cost of operation with different technologies having advantages and disadvantages in the one or other cost category. It is therefore important to look at the average unit cost per application for the expected number of smart assets in the grid taking into account coverage of all assets, capacity for all applications and the operation thereof. (2) The costs incurred with the installation of a communication interface at the customer premises. Main cost drivers are communication device and installation effort, in particular related to in-house cabling, power supply and house owner consent. The latter is especially relevant for the AMI. The installation costs could be around 40 per cent of the total capital costs of the Smart Meter

[6] This issue is related to the debate on net neutrality.

(CapGemini 2008). Regarding the communication service, utilities are under pressure to keep the costs of the Smart Grid as low as possible. From an economic point of view that means that utilities have to achieve an efficient allocation of the resources needed for Smart Grid.[7] These low cost requirements do thereby apply not only to Smart Grid appliances. They are equal to other M2M appliances characterized by low complexity, vast number of devices and low data volumes.

e.) Security

One of the emergent requirements facing the deployment of Smart Grid is related to security issues. Firstly, the design of a Smart Grid has to ensure that consumer related data cannot be misused. Secondly, the interconnection of the multiple entities in a Smart Grid might attract cyber-attacks. To mitigate the risk, there is a need for a security system especially when commercial networks enable Smart Grids. Finally, all data in a Smart Grid must be subject of a secure and guaranteed message delivery. Governments generally prescribe security features/implementation requirements for Smart Metering, which in principle are independent of the communication technology and can be implemented in public and private networks. However, private networks provide an additional layer of security which enhances security substantially and may reduce the need for additional security features to be implemented on higher layers, lowering cost and complexity.

f.) Technology life-cycle/system availability

Once the metering infrastructure is in place or a substation is equipped with ICT, the hardware for the communication technology should have a lifetime and system availability of at least 15 years. Otherwise, the communication technology has a negative impact on midterm costs. Swapping millions of devices might easily exceed capital and operation expenditures for the whole communication infrastructure. Furthermore, the main underlying technology should be standardized and established so that there is no lock-in-effect with any single supplier but a large enough ecosystem to ensure long-term supply alternatives.

g.) Control

Even though certain commercial solutions are technically compliant, some utilities take the standpoint that they cannot rely on commercial operators due to a lack of end-to-end control.

[7] The role of radio spectrum in facilitating the introduction is recognized in Art. 7 of the European Spectrum Policy Program.

Contractual negotiated guarantees concerning power autonomy, redundancy and availability are considered insufficient in this respect. This line of reasoning relates in particular to the increasing demand for broadband connections and (managed) services. If the demand for broadband services exceeds the expectations of the telecommunication operator, the question of how to allocate the scarce resources becomes important. Since network-oriented Smart Grid applications are critical to the stability of the electricity grid for which the distribution service operator is legally responsible, it is considered to be burdensome to delegate the operation of the Smart Grid to a third party. Utilities argue here that it is beneficial for society if in case of disturbances caused by a deficient Smart Grid, there is clear (legal) responsibility which is not subject to contractual interpretations or disputes over service level agreements. These considerations lead to the question whether utilities should rely on commercial networks or deploy communication infrastructures under their control such as power line or dedicated wireless networks.

Interim conclusions

The requirements can be summarized and classified as follows:

Firstly, the communication network should match the technical requirements. Secondly, the communication network should not be exposed to external effects like consumer behavior, policy of access providers or unstable regulatory aspects[8]. Only if the chosen technology is secured against these effects can a stable environment needed to attract investments in Smart Grid be expected. Thirdly, the costs to achieve the required coverage, installation and operation should be as low as possible.

Based on the requirements described above we will analyze in the next chapter how and to what extent the different communication technologies and networks can meet the needs of the power market At first glance we expect that the shortcomings of wired technologies relate to costs, availability (both area covered and system reliance), and strategic issues (e.g., control). The challenges of commercial wireless networks result from their network design and use cases; these networks are neither equipped to support services with an availability of 99.9 per cent nor can they effectively and efficiently handle the massive amount of M2M devices on top of the mass market personal communication (Clark/Pavlovski 2010).

[8] For instance, the debate on wholesale rates for local loop unbundling.

Qualitative analysis of wired technologies

Fiber optics communication

Given the requirements of mission-critical applications and the objective of politicians to get fiber connections as soon as possible to almost all households, fiber optical networks appear to be the preferred solution for Smart Grid. Optical fiber is the fastest and highest bandwidth network available, supporting a wide range of communication protocols and services (Evens et al. 2011). Furthermore, Fiber to the Home (FTTH) networks are future proof. However, this communication infrastructure does not play a significant role in the European broadband markets yet. The low penetration of fiber as an access technology relates to the costs of deploying FTTH-networks. The costs range between € 500 in dense urban areas and € 2000 in rural areas (Casier et al. 2008). Even more intensified cooperation between utilities and telecommunication operators (Tahon et al. 2013) cannot change the expectation that FTTH-networks will not be an option in the upcoming years to support end-user oriented Smart Grid appliances to a considerable degree. The same applies to network oriented appliances in the electricity grid. Here, the network elements (e.g. substations) are usually not equipped with access to optical fiber networks. From a cost point of view, it is far too expensive to deploy fiber networks only for Smart Grid purposes. Looking at the requested data throughputs, one has to acknowledge that the large bandwidth that fiber optical networks provide is simply not needed.

A concluding remark refers to the above mentioned link between national broadband plans and the deployment of Smart Grid (Mayrhofer/Römer 2012). Against the background of the costs of FTTH-networks we can hardly expect an availability of these access networks at locations where typically renewable energy sources feed the electricity grid. Current developments show that wireless technologies like LTE or LTE Advanced using frequencies at 700 MHz (digital dividend part two) are more likely to close the geographical digital divide.

xDSL

Today the majority of broadband connections are based on xDSL, although in some countries cable is growing faster. Access to xDSL is available in dense urban areas, whereas in some rural areas the infrastructure is still less developed. At first glance, xDSL technologies are viewed to offer low cost services for Smart Grid because the physical infrastructure is already available and the bandwidth required for Smart Grid applications is marginal. However, the use of xDSL faces significant challenges in terms of access line regulation, dependence on the customer and installation cost. The wholesale price for local loop unbundling, i.e., the use of copper line to each house, is regulated. If an additional service is offered, a new allocation of costs must be carried out to determine the wholesale price. Smart Grid applications need transmission resources which are comparable to those that retail customers use for voice telephony. Today, even if these retail customers have subscribed only to such limited voice services, they have to pay the full price. According to regulatory considerations, using xDSL technology for Smart Grid means first of all to open up the controversial discussion on wholesale prices for local loop unbundling. Because this part of the regulatory landscape is highly disputed, we can expect legal proceedings which can have negative repercussions on the deployment of Smart Grid. In the event, that the regulatory authority is able to re-allocate the costs in a way that the involved stakeholders agree, another challenge remains. What happens to the customer-independent Smart Grid services if the end-customer terminates his DSL contract? In that case, the function of the advanced metering infrastructure will be interrupted. Consequently, from a functional perspective any kind of Smart Grid access must be independent of customer behavior. xDSL will also likely incur higher installation costs compared to power line or certain wireless technologies. Usually, the wired infrastructure needs an additional wired or wireless link to the Smart Meter for which the consent of the owner of the premises is needed. Both the additional infrastructure and the requirement to involve the owner increase the one-time costs of installation. With regard to the DSO's interest to avoid a lock-in effect, it could be a shortcoming that DSL providers usually offer a product bundle comprising connectivity and IT services, such as data management which is primarily aimed at smaller utilities which do not have their own resources.

Power line communication

Power line communication is widely used by utilities for remote metering in many countries around the world (Galli et al. 2010). The deployment of power line is motivated by both the shortcomings of commercial offerings and the interest of DSOs to exert control over the communication infrastructure given that they have responsibility for grid operation.

The power line technology operates by sending modulated carrier signals on the power transmission wires. Typically, data signals cannot propagate through transformers and hence communication is limited within each line segment between transformers (Wang et al. 2011, 3610).

Until recently, utilities chiefly deployed single carrier narrowband solutions. Narrowband power line is now being upgraded to broadband systems operating in higher frequency bands. Hereby data rates up to 200 Mb/s can be achieved. Whereas power line technology was not able to compete with wired broadband technologies (e.g., DSL, cable) in the mass market for broadband connections, this is not the case in the Smart Grid giving new market opportunities to this technology. Advocates of power line (Schönberg 2012) highlight the fact that the physical lines needed for PLC already exist. This could lead to lower (operating) costs, although we have to bear in mind that the cost structure depends on the number of connected devices. As mentioned above, due to lower external cost and general line availability, the power line technology is often used in smart meter pilots. Additionally, power line can be used for home area network (HAN) purposes. Furthermore, the data rates required for the different applications are within the broadband power line capabilities.

The shortcomings of traditional narrowband power line are as follows: A critical feature of Smart Grid is the capability to transfer data in real-time. That applies primarily to the frequency stability and power flow status in low and medium voltage grids. Here, the DSO needs reliable data in order to keep the network stable. Pilots revealed that, especially when narrowband power line is used, the technology does not always fulfill this requirement. Another shortcoming of power line relates to interference. In the event that power line technology is used nationwide to connect up to 80 per cent of smart meters, it is not clear how power line will affect radio applicants (e.g., broadcasting services). According to the German security profile defined by BSI, the capacity of narrowband power line is not sufficient to carry the metering traffic with required security features.

As a consequence, broadband power line seems to be the more relevant technology for Smart Grid. However, broadband power line uses the same frequency spectrum as in-house power line for LANs and also for some radio applications (i.e., emergency services). Therefore, interference on same grid communications caused by other usage as well as disturbances of other users can occur, especially in the case of an extensive use of broadband power line for smart metering. Since broadband power line uses higher frequencies, the signal attenuation is much higher than for narrow band power line. Furthermore, the regulatory emission limits for the protection of radio applications limits power line operation to relatively small signal levels as a result of which line amplifiers are often required if distances between substations and smart meters are too long. Moreover, the signal coupling between the power line modem and power grid, and thus signal strength, is highly unpredictable because of unknown and time varying impendency of the power grid for higher frequencies. This also can lead to implementation of additional line amplifiers for higher availability.

In addition, in the event of an outage, communication over power line is not available, a highly undesirable situation. Consequently, power line is not easily equipped for critical applications in the power grid. And finally, broadband power line is a relatively early stage and non-standardized technology.

Choosing broadband power line solutions for smart metering and critical network oriented applications appears at least risky.

Qualitative analysis of wireless technologies

This chapter analyses how radio spectrum and wireless technologies enable Smart Grid functionalities. Utilities have two alternatives:

a.) The first alternative is to use the services of public, commercial mobile networks, where it is doubtful whether operators can offer a dedicated service with high SLA in principle (issue of net neutrality) and at an acceptable price level.

b.) The second alternative is to realize Smart Grid in a private wireless network. A private network could either be deployed (owned and controlled) by utilities or by third parties who offer dedicated capacity to market players in the power market. The difference of the latter to the first alternative is that within a private network there will be no competition with radio resources.

The study does not focus on all kinds of spectrum available for Smart Grid applications. Firstly, unlicensed spectrum is not the subject of the analysis; the operator has no exclusive use which could lead to congestion, making performance of the network potentially unreliable. License-exempt spectrum is therefore not regarded as a viable option for the wide area communication network (WAN). As a consequence, RF Mesh is not analyzed in this paper. However, RF Mesh may be an option to connect gas, water and electricity meters within a building to the WAN network. Secondly, due to propagation characteristics, only spectrum below 1 GHz provides the opportunity for indoor coverage (in particular basements). Spectrum above 1 GHz has weaker in-building penetration and is used primarily to increase capacity which is less relevant in the context of Smart Grids. Below 1 GHz the following spectrum bands are traditionally used and available for mobile services and therefore considered in more detail: 450 MHz, 800 MHz and 900 MHz.

900 MHz band and GSM/GPRS (General Packet Radio System)

Although the European Law provides for the possibility of operating mobile technologies other than GSM/GPRS in the 900 MHz band, the majority of mobile operators have not switched to another technology (like UMTS or LTE). For example, the German mobile operators have constantly repeated that from a short-term perspective GSM/GPRS remains the prevailing technology in this frequency band. Hence, Smart Grid in the 900 MHz frequencies uses GSM/GPRS. Other technologies might be deployed after 2020.

Currently, trials in Germany and in other EU Member States use GSM/GPRS as the WAN for the Smart Grid.[9] The use of this technology reflects primarily the fact that GPRS is currently the only mobile technology which is accessible almost everywhere in the country. Furthermore, GSM/GPRS networks at 900 MHz are able to provide reasonable indoor-coverage and data services are available at reasonable cost.

However, observing the requirements outlined above and taking into account results from trials (Ernst & Young 2013, 49) it becomes obvious that GPRS has some significant limitations; certain performance requirements are not met by GPRS (e.g., latency). The indoor coverage of GSM networks is probably the best of any commercial networks, given its 900 MHz spectrum band and comprehensive area coverage, but pilots have shown that the coverage is often insufficient for Smart Meters. Since in the 900 MHz band all frequencies dedicated for mobile telephony (or mobile access to the internet) have already been allocated, there is no possibility to deploy a private network. As a consequence, GSM/GPRS in 900 MHz is only available as a service on commercial networks with shortfalls in terms of security, control, availability and resilience.

Here we have to bear in mind that GSM/GRPS networks have been designed, dimensioned and deployed to offer mobile voice telephony to end users. The networks are ill prepared to handle the signaling traffic of millions of devices which occurs with the advanced metering infrastructure on top of mass market voice services. Service guarantees and dedicated quality of service to ensure priority message delivery cannot be guaranteed by mobile operators. In

[9] www.e-energy.de

addition it is expected that GSM/GPRS will be substituted by other technologies in the mid-term which are more efficient. Thus, it can be assumed that mobile operators will not invest in this technology to improve the network quality for just one class of service.

In summary, although the use of GSM/GPRS is the simplest alternative available to utilities, as it avoids any further decision on communication solutions and related investments and deployments, there is a mismatch between the utilities' requirements and the capabilities and lifecycle of GSM/GPRS. While GSM/GPRS is dominant in current trials because of its wide availability, it appears that GSM/GPRS is generally seen as an inferior solution when a full-fledged roll-out of the AMI is considered.

800 MHz and Long Term Evolution (LTE)

LTE as a new global standard for mobile (broadband) data has attracted considerable attention in the context of Smart Grid (Brown/Kahn 2013). LTE networks are currently operated in the frequency bands at 800 MHz, 1800 MHz and 2,6 GHz. In light of the increasing demand for mobile data services it is assumed that mobile operators will ask for additional frequencies in a mid-term perspective (Kürner 2013). Due to propagation characteristics only LTE at 800 MHz offers the opportunity to provide the necessary indoor coverage in most cases. But, for the time being, LTE at 800 MHz does not provide nationwide coverage in most European countries. Furthermore, in some regions LTE is or will be the only technology which gives access to the Internet. Consequently, network capacity is limited.

Although LTE 800 fulfills broadly the performance requirements (e.g., latency), we have to take into account, that LTE 800 is firstly being rolled-out by commercial operators only[10] and secondly will not be designed and optimized for M2M traffic. The current use cases of LTE differ significantly from the use case we have identified in Smart Grid. The opportunity costs arising in the event Smart Grid traffic crowds out mass market applications in the retail market will impact pricing of the Smart Grid traffic making it more expensive. The better LTE succeeds in the market, the higher the opportunity costs which subsequently have to be reflected in the wholesale prices for Smart Grid services. The telecommunication operator has to bear in mind that M2M traffic with a high number of installed devices, like the Smart Meter, uses a large part of network resources. Congestion in commercial networks can only

[10] Due to the scarcity of available spectrum, it is at least from an economical point of view (price for the spectrum) almost impossible to deploy a private network in the 800 MHz frequency band.

be avoided if the network concerned is operating with sufficient resources in frequency bands below 1 GHz and is optimized for M2M traffic pattern.

In summary, although LTE 800 fulfills some requirements there are doubts whether it is technically and economically feasible for mobile operators to enter the market for Smart Gird communication. Furthermore, choosing commercial LTE 800 services for Smart Grid communication faces several of the shortcomings of GSM/GPRS 900: chiefly no control over the network and therefore a lock-in to providers which will first service the mass consumer market for revenue reasons. .

450 MHz and Code Division Multiple Access (CDMA), and LTE in the future

The 450 MHz frequency band is available in many European countries (being either underutilized or unassigned) and has in comparison with 800 MHz and 900 MHz a striking benefit: due to its lower frequency range, the propagation characteristics enable much better building penetration than GSM 900 and LTE 800. Moreover, mobile networks in the 450 MHz spectrum require approximately four times less base stations than mobile networks at 800 and 900 MHz (irrespectively of the technology deployed), thereby offering much better stand-alone economics.

Currently, the standardized CDMA (3G) technology is available at 450 MHz. In the mid-term, LTE technology will become an alternative. Standardization of LTE for 450 MHz is on the way and first suppliers have LTE equipment available. It is likely that operators in Brazil will deploy LTE in this frequency band starting in 2014. However, LTE has yet to be optimized for M2M use cases. CDMA EV-DO Rev. A provides a data throughput of 1.8 Mb/s in the uplink and 3.1 Mb/s in the downlink. The latency criteria of network-oriented applications are also met. Existing CDMA450 networks in more than 60 countries and a well-developed supply ecosystem ensure longer term equipment availability. CDMA technology is being further optimized for M2M use by new standard developments such as CDMA 1X Rev F. A recent analysis of the economics of a Greenfield CDMA450 network revealed low unit cost making the CDMA450 solution not only technically superior but also cost competitive with power line and GSM/GPRS (Sörries 2013).

In summary, as spectrum is available in many countries, CDMA (or alternatively LTE) at 450 MHz is a valid opportunity for the deployment of Smart Grid communication. Compared to the alternatives of GSM/GPRS 900 and LTE 800, the 450MHz band is not widely used in Western Europe for mass market deployment for mobile services. In many countries the spectrum is either unassigned or currently underutilized, making it available for Smart Grid communication. It is not only technically, but also from a spectrum/network availability standpoint, very well suited for deploying/operating networks that are wholly or partially dedicated to Smart Grid.

Conclusions

The Smart Grid is an electrical grid that communicates. The idea behind Smart Grid is to make our electrical system far more resilient to problems like blackouts, better accommodate unconventional power sources, and ease energy demand by providing instant information about retail prices to consumers. Future communication requirements for Smart Grid targets can be met in various ways.

The comparison of technologies and networks reveals that technologies which are well equipped to facilitate the deployment of Smart Grid are less exposed to external effects (e.g., customer behavior, regulated wholesale prices, control issues), meet the technical requirements (e.g. data throughput, latency) and can provide connectivity at a low unit cost where the costs of area coverage, installation and operation all have to be taken into account.

Against the background of these qualitative parameters, a wireless technology using frequencies at 450 MHz appears to be very efficient for Smart Grid communication. This assumption applies even in a Greenfield approach. It is therefore rational that some DSOs (e.g., Alliander in the Netherlands) intend to deploy a new wireless infrastructure over its own licensed spectrum and set an example for other DSOs to do the same A dedicated communication infrastructure clearly separated from commercial networks can be a significant advantage; it avoids competition for bandwidth with other market players during critical events.

The following table summarizes the findings of this analysis.

Parameter	GSM at 900 MHz	LTE at 800 MHz	CDMA at 450 MHz	Fiber optics	DSL	Power line
Scalability	Competition on resources	Competition on resources	No competition on resources	No competition on resources	No competition on resources	No competition on resources
Low latency	No	Yes	Yes	Yes	Yes	Narrowband no
Data rates are sufficient	Problematic	Yes	Yes	Yes	Yes	Narrowband no

Enhanced Resilience	Not available	Not available	Available	Available	Only limited SLAs	Not available
Indoor penetration/ availability	Fair	Fair	Good	Good	Good	Good
System availability	Constrained	Constrained	Yes	Yes	Yes	Constrained
Network and system optimization for M2M applications	No	No	Yes	No	No	No
Interference with other services (e.g. broadcasting)	No	No	No	No	No	Expected
Cost effective nationwide coverage available/possible	Yes	Yes	Yes	Very limited	Partially limited	Limited
Installation / rollout	Simple	Simple	Simple	Difficult	Difficult	Simple
Security	Public Grid	Public Grid	Closed Network	Public grid	Public grid	Closed network
Long-term system availability	No	Yes	Yes	Yes	Yes	Yes
Exposure to customer behavior	No	No	No	Yes	Yes	No
Exposure to developments in the broadband market	no	Yes	No	No	Yes	No

Table 1: Qualitative evaluation of communication technologies

In addition, a wireless infrastructure for the advanced metering system can cope with the fact that in rural or less populated areas any wired solutions will be unavailable or too costly. Generally speaking, there is no necessity to link the deployment of Smart Grid to the various national broadband plans and the availability of next generation networks. The use cases of the Smart Grid illustrate that fiber optical networks are simply not needed in terms of bandwidth and given their costs are detrimental to the deployment of Smart Grid. A wireless communication infrastructure using frequencies at 450 MHz is in contrast considered very suitable for connecting a large number of smart connections (in houses), as a back-up system or as a primary solution in cases where wired solutions are too expensive or not feasible for distribution automation.

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