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5G and Energy

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Executive Summary

5G is envisioned to be more than just a refined version, an evolution of the current telecom standards. Its ambition is to cover all types of communications including machine type usage and must therefore be very flexible and also support completely new business models. In 5G, verticals like energy, manufacturing, healthcare and automotive are envisioned as the new user space, enabling new applications, markets and businesses. This Whitepaper assesses the needs of the energy vertical, both from the technical and business perspective, and proposes measures to achieve a win-win situation needed for a successful adoption of 5G.

The energy vertical has some very specific requirements on the supporting communication solutions going beyond what can be provided by current generic telecoms' solutions. One specific aspect regards how the technology is deployed and used. In this industry longevity of 20 years is normal, plug and play, deploy once and operate "forever" is assumed to be given. On the performance side concerning latencies the requirement is not about the best case, not even average case, but concerns the worst case, since the failure to deliver a single message within its guaranteed delivery time can have a severe impact on the process that is controlled. Additionally, 5G needs to compete with existing wired solutions when it comes to performance, cost and usability.

On the plus side the business potential of introducing 5G in the energy domain is exceptionally high, as it is expected to provide the necessary support not only to the critical machine type communication (MTC) applications of energy grid protection and control, but also to the massive volume of MTC type applications of the emerging smart metering. In summary, the anticipated performance and flexibility of 5G will enable a communication infrastructure which is able to support the emerging energy use-cases of 2020 and beyond. The ongoing evolution of the power grid into a grid supporting a much more distributed generation and storage of power as well as micro-grids would be a clear beneficiary of the high performance, but still very flexible communication architecture provided by 5G.

In order to overcome remaining challenges and cash in on opportunities for the benefit of Europe the ICT industry and vertical players need to jointly address issues both on the technical and business levels, to shape up a 5G that fulfills the vertical needs using the ICT solutions in the most cost efficient way. An important element accomplishing this is to further strengthen collaborative research fostering exchange of ideas and alignment e.g. through the 5G PPP work program.

The needs to further develop the business models, as well as the detailed technical requirements required are described and explored in this Whitepaper and should preferably be further addressed in the ongoing standardization work carried out in 3GPP.

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List of acronyms

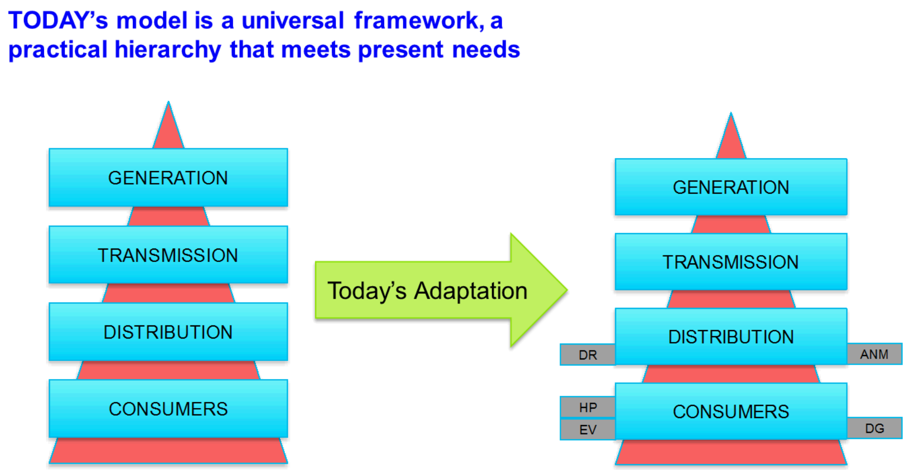
CAPEX	Capital expenditures
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
DR / DER	Distributed Resources / Distributed Energy Resources
DNO	Distribution Network Operator
ETSI	European Telecommunications Standards Institute
E2E	End to End
EUTC	European Utilities Telecom Council
GOOSE	Generic Object Oriented Substation Events, IEC 61850 8-1
IoT	Internet of Things
ITU	International Telecommunication Union
LPWAN	Low Power Wide Area Network
MIMO	Multiple Input Multiple Output
MTC	Machine Type Communication
NGMN	Next Generation Mobile Networks Alliance
OPEX	Operating Expense
PLC	Power Line Communication
PVNO	Private Virtual Network Operator
SLA	Service Level Agreement
TNO	Transmission Network Operator
TSO	Transmission System Operator

1. Socio-economic drivers of Energy at the horizon 2020

The Energy system has developed over a prolonged period (in excess of 100 years) and has evolved in many different "silos"; Primary fuels for Generation, Transport, Heat, etc, Transmission systems to deliver bulk oil, gas, electricity, etc., and Distribution to deliver to end users while the demand side has been largely separate from the supply side. With the rising cost of energy to end users and the need for energy security of supply to national economies combined with environmental concerns a major change in the energy system is underway.

Nowhere is this more evident than in the electricity supply industry. Where historically predictable end user profiles would allow scheduling of appropriate levels of generation to meet demand via large central thermal and hydro generation stations, we are now faced with unpredictable small generation stations (solar, wind, etc. in their thousands) combining with changing end-user energy use patterns (such as mobile large demand/storage units such as Electric Vehicles). In order to manage these changes new "Smart Grids" will be needed to resolve these new challenges. Data and the communications to drive this new smart grid will be of paramount importance. In Europe Utilities have for many years developed robust and efficient infrastructure, especially at the transmission voltage level, to provide observability and control. Distribution Networks have lagged behind this due to the nature of the original design principles of building to meet the biggest peak demand expected. This is no longer affordable or appropriate. Smart Grids are therefore focused between the transmission grid and beyond the meter to end consumers who are now becoming producers as well. Communication infrastructures will be needed to extend the observability and control to this level. New connectivity is already being implemented via smart metering but as the Internet of Things, large mobile demand/storage (Electric Vehicles) and stakeholders appear with new business models the challenge for coherent and secure communications as a whole system becomes a major challenge.

The traditional stakeholders involved in the production, delivery and coordination of these functions is also changing. From state-owned monopolies we have moved to regulated and market driven independent companies. The structure below describes today's world. Generators, Transmission Network Operators (TNO), Distribution Network Operators (DNO) deliver to Consumers.



DR=Distributed Resources, ANM=Active Network Management, HP=Heat Pumps, DG=Distributed Generation

Figure 1.1. Power grid structure

And now new requirements are being added to the system almost daily at all levels of the system.

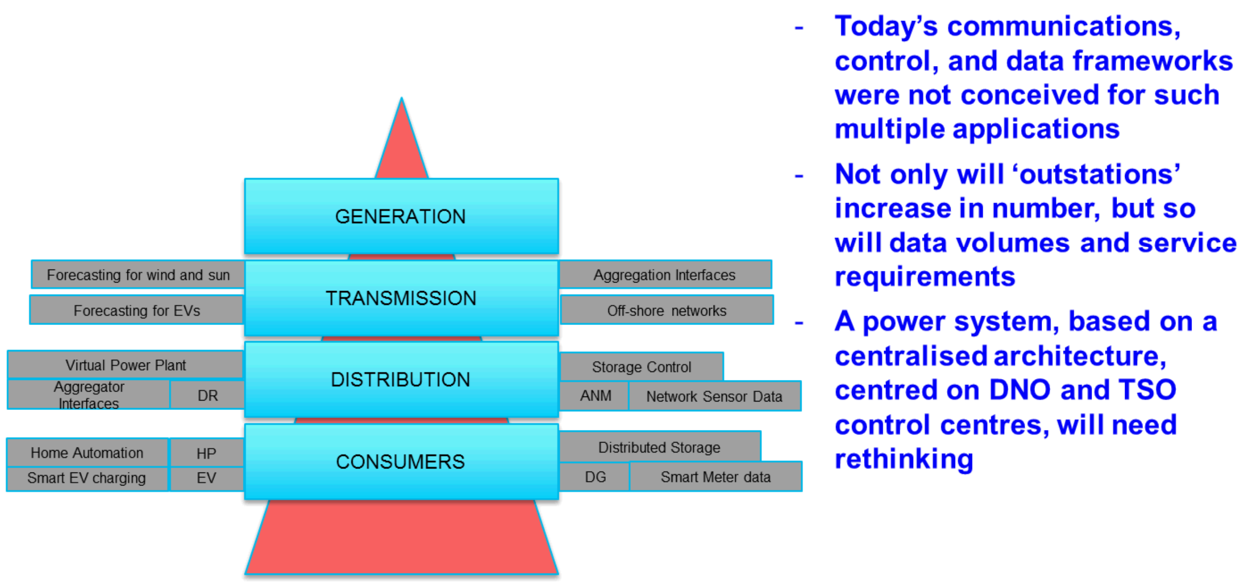


Figure 1.2. New requirements for the power grid

1.1. Socio-economic drivers

Due to changes in the social, commercial, technical and market landscape, the European energy industry needs to adapt to the changing nature of both supply side and demand side requirements. Individual users, local communities and regions will be able to take their own decisions regarding power generation and usage independently from the incumbent strategies. The physical infrastructure will likely not change that much but the way we use it and the fundamental overlays of communications, intelligence, business models and market structure will enable new possibilities. The Internet of Things, home automation, social media and smart users will mean that much of the centralised functions of command and control will move towards a hybrid of central and distributed intelligence having to work seamlessly together. The Power grid will see planning tools that once only catered for defined known user profiles and geographically stable loads giving way to loads that not only move but can also become generators (Electric Vehicles for instance, that can move a plug back into the network at unknown times or places).

1.2. Whole system perspective

In the past very little value was placed on the socio-economic cost of a proposed solution. This is changing due to the realisation that unless the costs of integration into the overall **whole system** is considered (market structure, technical, commercial, environment, health and safety, social, etc.) the hidden costs could be higher than the business cases predicted. A whole systems perspective requires that ALL aspects are considered and is normally tested by the generation of use cases that will drive out these unforeseen inter-related issues and can be tested against a range of scenarios to ensure the extremes as well as the 'central' scenario is considered.

Most technologies rely on electricity being available to power them and control them, communications is needed to ensure this is achieved. This symbiotic relationship means that there is an inter reliance between them and most developed societies see them both as a right not a luxury. In terms of socio-economic benefits, society demands that these elements; electricity and communications are as much a right as air, water and security. The importance of this can be seen if electricity or communications is lost for a prolonged period, such as many of the natural disasters cause. Societal pressure on politicians is unbearable, law and order is challenged and restoration required immediately.

1.3. Key aspects of technical changes in societal usage

The Electricity industry has remained for many years a stable and unchanging industry with tried and tested methods, operational and maintenance regimes and dependable infrastructure. In the last decade the European electricity industry has transformed from a highly predictable and secure power delivery medium to a much more dynamic and unpredictable environment where intermittent and variable power sources are replacing dispatchable and controllable base load generation. Large centralised generation delivered via transmission and distribution networks is starting to be challenged by small, distributed generation embedded close to communities. The advent of affordable storage solutions and demand side response mechanisms has introduced a new and additional aspect to grid stability – instead of generation flexing to meet maximum demand – demand is flexing to meet available generation. This all requires highly secure and available communications for both sensing and control.

The key aspects of technical changes are summarized below:

- Produce economy
  - The electricity sector used to be centered on production constraints and possibilities – it is changing to become user-centric, as users will not only consume electricity but they will produce some of it, be the source of critical usage data and have a choice regarding quality of service. This is leading to a highly decentralized system including millions of small producers in parallel to the large utility companies.
  - Both production and usage will be less stable and predictable than it used to be, integrating various production technologies and a larger number of independent producers.
  - Large consumption users (industry, data centers, etc.) may choose to produce their own electric power.
- Shared economy
  - Users will not only produce their own electricity power, they will probably share their production at the local or regional level requiring sophisticated network management methods.
- Electric power storage
  - Electricity power storage system cost is decreasing to levels affordable to consumers. It may ultimately get commoditized to the advantage of end-users. Management of the stored energy at micro-grid level is a serious challenge for centralized and hierarchly built European electric grid.
- User nomadic electric power consumption, IoT
  - There is a fantastic growth of electric powered nomadic and connected devices, from cars to home appliances, including for critical applications. Disruptive technologies are needed to manage, control the energy consumption of these devices, and ensure their energy efficiency at a micro/macro scale.
- IoT & Big data mining shift services offering
  - Data becomes a key resource for the electricity industry. On one side, we have the development of the Internet of Things (IoT) delivering an enormous amount of production and consumption data, some in real-time, possibly made public as open data; on the other side we have Big Data technologies enabling the processing, analysis of this wealth of data up to individual user profiling. The combination of these technologies allows the introduction of high added-value - possibly low-cost - services associated with energy efficient operations.
- User favour environment friendly [green] technologies – matching energy efficient solutions selection, in Europe, user energy consumption choices will be guided by two main considerations:
  - A growing concern regarding the environment, strong incentives to reduce the use of fossil fuels and non-renewable natural resources, promises to reduce carbon dioxide emission at national and international levels
  - The search for the most economical solutions, with maximum valorization of local resources and the promotion of a circular economy.

- User concern on privacy & security
    - Privacy & security embezzlements cause users' increased concern on the limitation of digital & communications services offerings, obliging further European & state involvement & regulations.
- Electric Energy HFT
    - Electric Energy high-frequency trading market movement may call-up telecommunications advanced features and requirements such as low network latency.

As a conclusion on the smart grid challenges, opportunities and transformation; the evolving market context represents major challenges for energy actors and their value chain (generator, TSO, DSO, aggregator/retailer) - they risk losing control over the whole system or they may get obliged to redesign themselves at a time when:

- the energy ecosystem has to integrate new players (energy producers, IT companies, brokers, customers, etc.) entering the field due to sector deregulation and the addition of new technologies;
- Incumbent utilities have to face massive investments to switch to environmentally sustainable production technologies, with strong incentives to reduce the use of fossil fuels and non-renewable natural resources as well as the promise to reduce carbon dioxide emissions at national and international levels.

Figure 1.3. Future vision of the energy ecosystem[1]

1.4. Key aspects of commercial changes in societal usage

The advent of new and innovative business models in the utility sector is a development that has occurred with new service provision and the search for cost efficiencies. This has led to challenges in areas such as data quantity and use (Big Data and data analytics), data privacy, cybersecurity and public or private provision of communication solutions amongst many other new and emerging challenges. New business models are key to unlocking value for many stakeholders.

A business model "describes the rationale of how an organization creates, delivers, and captures value[2] in economic, social, cultural or other contexts. The process of business model construction is part of the business strategy[3].

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[1] Steve Lippman, 2010 Mid-America Regulatory Conference, http://www.marc-conference.org/2010/presentations.php

[2] Business Model Generation, Alexander Osterwalder, Yves Pigneur, Alan Smith, and 470 practitioners from 45 countries, self published, 2010

[3] Wikipedia, https://en.wikipedia.org/wiki/Business_model

A good business model provides:

- Affordable and attractive services for customers ("value for money")
- Profitability for all players down the value chain in a stable way

The traditional electricity business model in Europe is still subscription-based, ensuring stability for both suppliers and customers: stable income for utilities; stable supply for customers at predictable and affordable prices. We notice a paradigm shift that started with the deregulation of the sector, still smaller customers have little choice regarding quality of service and limited flexibility as regards to supply.

The key aspects of commercial changes are summarized below:

- 5G Technology enable Smart Grid new business models
    - There is a complex web of interactions between the electricity smart grid and the communications networks, each one in need of the other. The smart grid becomes more flexible and efficient but critically depends on the availability of high-quality data collection, transmission and analysis for operations and marketing. All this results in a customer-centered industry, possibly a shared economy for electric power. 5G features are expected to contribute to the smart grid new business models enablement.
- Electric Power Value-Chain Actors Value Transfer & Disintermediation
    - A variety of business models will be proposed to accommodate production and regulatory constraints on one side and customer demands on the other side:
        - Providing various quality levels for electricity supply[4], such as traditional supply, low-cost, back-up only, environmentally-friendly supply, etc.
        - Providing various levels of associated services and data management (bundling pricing schemes; data monetization), and
        - More flexible pricing schemes, integrating the value of customer-produced electricity. Pay-as-you-go, bartering, real-time peak pricing could be offered;
    - New business models will also emerge in the value chain linking the traditional utilities and the myriad of services providers in the ecosystem: market places, innovative revenue split schemes, incentive schemes, etc. All these will be explored by the proponent actors.
- Demand Response affecting Business Models, in the new paradigm, two majors changes are expected:

[4] For a more detailed discussion, see: Netbeheer Nederland, Action Plan Sustainable Energy, p. 9. Available at: http://www.netbeheernederland.nl/publicaties/position-papers-factsheets/

- Electricity supply and prices may vary considerably over time and space; interconnection of electricity networks becomes tricky from a technical and economic point of view. Customers will have to deal with this new situation, choosing the quality level they require or can afford regarding supply;
- Additional services will be offered, based on the data accumulated through smart metering and customer smart home applications: optimization of consumption, predictive maintenance, home surveillance, etc.

2. How can 5G be a catalyzer for Energy?

In this chapter, first we provide a brief overview of different energy use cases covering the areas of smart grid, renewable production and smart assets. Then we discuss about how these use cases can be enabled by the introduction of 5G.

2.1. Energy use cases

The energy uses cases that we are going to discuss in this section address both smart grid and smart assets areas as illustrated with some examples in Figure 2.1.

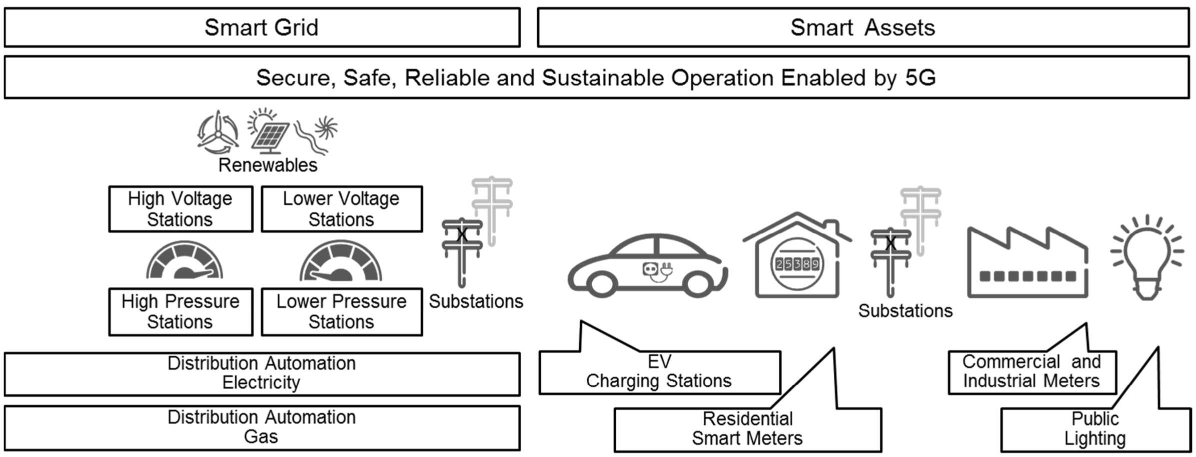


Figure 2.1. The energy uses cases highlighting the smart assets use cases and the energy distribution use case from smart grids.

The representative future use cases related to Smart Grid can be summed up as follows:

- Self-healing networks and ultra-fast fault location, isolation and power restoration are essential to existing as well as future Smart Grids. Fast response to fault situation in active networks require that protective functions can communicate with each other with very short latencies. Self-healing networks is a wide topic and contains many different features: blocking other protective devices during the operation time of the protection, so that the area disconnected by the fault will be minimized already before opening the circuit breaker. Also more selective protection applications such as line differential protection belong to this category
- Disconnecting nearby distributed generation should be enabled so that they do not feed fault current.
- More distant distribution generation units should be forced to remain connected in the grid if they do not belong to the area that needs to be disconnected.
- The topology of the grid during fault time can be easily restructured so that power restoration can happen as fast as possible.

- In power distribution automation, switchgear interlocking across bays is of paramount importance. Substation wide switchgear interlocking must be performed in a distributed way through the exchange of messages, in the same or similar way as IEC-61850 8-1 GOOSE messages today. Hardwiring between bay control units can thus be replaced by the reliable transmission of these messages.
- The integration of Distributed Energy Resources (DERs) requires the control of the feed-in of renewable energy, like photovoltaic, in order to avoid system overload and ensure the system reliability through protective messages.
- Micro-grids have a massive impact on the future electricity smart grid architecture and the associated control network. They provide a new way to manage and deliver electricity to a local user base, enabling the integration of renewable resources on the community level and customer participation in the electricity enterprise. Their management and regular operation in grid-connected or island mode requires extensive message signalling.
- The voltage profile and power flows are optimized to maintain stable voltage at customer site.
- Forecast generation and consumption can help DSOs plan for possible imbalance situations in advance. This requires that the operator has detailed information about short and long-term generation and consumption profiles and expected consumer consumption during absence periods.

Due to the development of renewables, new challenges are appearing for the energy distribution networks. Indeed, renewable production is uncertain and variable during the day by nature due to weather conditions (e.g., sun, wind). In addition, renewable production is much more distributed than central power plants that are based on e.g. nuclear or fossil fuel. In order to avoid black-outs and to optimize the use of renewables a real time dynamic routing of electricity flows will be needed. This routing will require new electrical equipment but also a renewed supervision and control network for electricity distribution networks. This supervision and control network will be required to transmit and process distributed data such as measures from meters (for production units but also demand units or even weather sensors) in real time. It could make sense to mutualize infrastructures with other sectors to execute this distributed transmission and processing of data. Indeed, this requirement is also appearing for water or gas distribution networks and also in some manufacturing transformations, as well as more broadly in the Cloud industry and in the Internet of Things domain. 5G technology could support efficiently all these services and sectors within a unified infrastructure while providing sufficient flexibility in order to deploy specific virtual network functions and ensure dedicated technical performances (with related SLA) such as constant latency for each sector/domain.

Smart meters and aggregator gateways are constantly evolving towards ever shorter measurement intervals leading to the requirement on the future networks to carry short data packages from thousands of users. They will reach near real time application in coming years, enabling near real time optimisations of sections of the low and medium voltage infrastructure with impacts on the communications requirements of utilities towards the customers (residential and business) particularly in urban areas where 5G will become available and can address the communication needs of smart meters if the design targets are accordingly set.

The need to integrate electric vehicles into the energy systems is another reason why 5G can be a catalyser for energy sector. For instance, in the geographical regions where e-Cars can be charged with renewable energy, as in Ireland which has an abundance of wind power, the impact of transport on CO2 production drops radically. To integrate the charge needs of e-Cars into the energy infrastructure, near real time communications with charging stations and e-Cars will enable a wide range of new options for service provision and optimisation of the energy infrastructure.

2.2. 5G Summary

5G is the next step in the evolution of mobile communication. 5G research is currently ongoing in several research projects around the world in private companies, universities and research institutes. Early test beds are also emerging from several vendors. Standardization is expected to start during 2016 in 3GPP[5] where new services and markets technology enablers are currently investigated[6]. Commercial systems based on standardized solutions are expected to appear around 2020.

Several organizations have presented visions for 5G, including ITU-R[7], 5GPPP[8] and NGMN[9]. These visions outline a system that provides significantly enhanced performance for mobile broadband services with improvements in e.g. capacity, bit rate, throughput, latency and energy efficiency. The expectation is also that 5G will provide connectivity for a wide range of new applications and use cases, including industrial use cases in various vertical sectors. These use cases span from Internet of Things applications requiring low cost devices and long battery life time to mission critical applications requiring ultra-reliable low latency communication.

An overview of the requirements currently envisioned for 5G[7] is shown in the figure below.

[5] 3GPP, The 3rd Generation Partnership Project. http://www.3gpp.org/
[6] 3GPP TR 22.891 1.0.0 “Study on New Services and Markets Technology Enablers”
[7] ITU-R, “Framework and overall objectives of the future development of IMT for 2020 and beyond”
[8] 5GPPP white paper, 5G Vision: the 5G Infrastructure Public Private Partnership: the next generation of communication networks and services, Feb. 2015
[9] NGMN 5G white paper, Feb. 2015

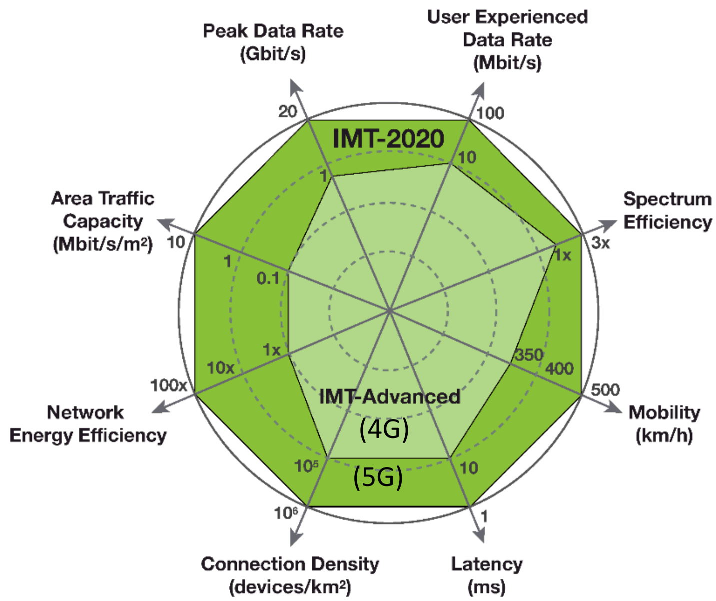


Figure 2.2. Overview of design targets for 5G[7]

To meet these requirements it is expected that 5G will provide:

- A new flexible radio interface or interfaces to meet the challenging performance requirements
- Integration of currently existing and evolved radio access technologies into a coherent end to end system (e.g. LTE and WiFi)
- Support for a broad range of vertical industry segments both in terms of technical capabilities, business- and deployment models

2.3. 5G as a Catalyzer for Energy

Communication networks for *Smart Grids*, *Smart Meters* and other use cases such as *Electric Vehicles (i.e., e-Cars)* need to be able to serve the needs of various applications from automated meter reading, and control of distributed energy resources to integration of e-Cars to the energy systems. Taking smart grid as an example, the demand for efficient and reliable communication solutions is expected to grow due to the emergence of smart grids, and a lion share of the growth will take place in the medium-voltage and low-voltage domain towards secondary substations and distributed energy resources as well as between secondary substations and primary substation. Since these assets in a smart grid network currently have no communications or measurement equipment in the medium; 5G can provide economically viable wireless solutions, with respect to purely fiber-based communication systems, decentralising the energy networks with increased resilience compared to LTE. This way, future smart grids can be provided with an increased usage of protection, control and monitoring leading to improved power quality, fewer power outages, smaller power outage areas, and easier grid deployments with less environmental impact in urban areas. Decentralized Smart Grids with increased resilience will also enable micro-grid solutions that will become important in black-out recovery as the threat of cyber-attacks on the power network increases.

Three European Standards Organizations (ESOs), CEN, (European Committee for Standardization), CENELEC (European Committee for Electrotechnical Standardization) and ETSI (European Telecommunications Standards Institute) have been developing a framework to enable ESOs to provide interoperability, continuous standard enhancement and development in the Smart Grid and Smart Metering fields of the energy market[10,11]. Yet, due to the above-mentioned constraints, the communication networks for Smart Grids and Smart Meters usually consist of a variety of communication technologies that need to be engineered and integrated to form an end-to-end communication solution.

As discussed in Section 2.2, 5G is envisioned to be the first global technology standard that will in mind address the variety of future use cases from energy sector, where even more data is predicted to be generated and smartly used, by ensuring that the both radio and core network performance requirements can be met in terms of (end to end) latency, reliability, availability for different services. Robust and reliable handling of data traffic offered to the 5G network by the multitude of supported services will be achieved from data plane and control plane isolation. Flexible association of network resources to different services, which are characterized by heterogeneous and sometimes incompatible requirements, lead to the definition of 5G network slicing, where a slice corresponds to the collection of interconnected logical network functions[12].The new concept such as network slicing and mobile edge computing (distributed computing and storage capabilities) will facilitate the mutualization of distributed data transmission and processing capabilities which are required by the energy use case. The energy use cases in particular are subject to mission critical machine-to-machine communication, which issues requirements that hardly comply with general purpose network architectures. The end to end control and data plane architecture covered by a network slice incorporates configuration in radio access, fronthaul, backhaul as well as core network to achieve the requirements associated with the energy use cases. Moreover, control and data plane procedures, such those related to network attachment, service request, location update and reachability, may be considered network slice-specific to achieve ultra-reliable low-latency radio access for variable bandwidth traffic (in a unified 5G network). In addition to the foreseen capabilities of 5G that can be commonly utilized by different sectors, the new standard has to respond to the more specific needs from energy sector's stakeholders. The new needs are resulted from the fundamental changes faced by the energy sector, where the current communication network is unable to support the transformation to the user-centric and distributed energy grid and wired connection operated today cannot be flexible/temporarily deployed and with high CAPEX. The energy use cases will need to increasingly require secure communications in near real-time with the customer premises. In this way the efficiency of the energy network can be maximised by allowing finer grained control of loads in the power network and with increasing use of power to generate heat in homes along with increasing use

[10] CEN-CENELEC Sector: Smart grids http://www.cencenelec.eu/standards/Sectors/SustainableEnergy/SmartGrids/Pages/default.aspx

[11] CEN-CENELEC Sector: Smart meters http://www.cencenelec.eu/standards/Sectors/SustainableEnergy/SmartMeters/Pages/default.aspx

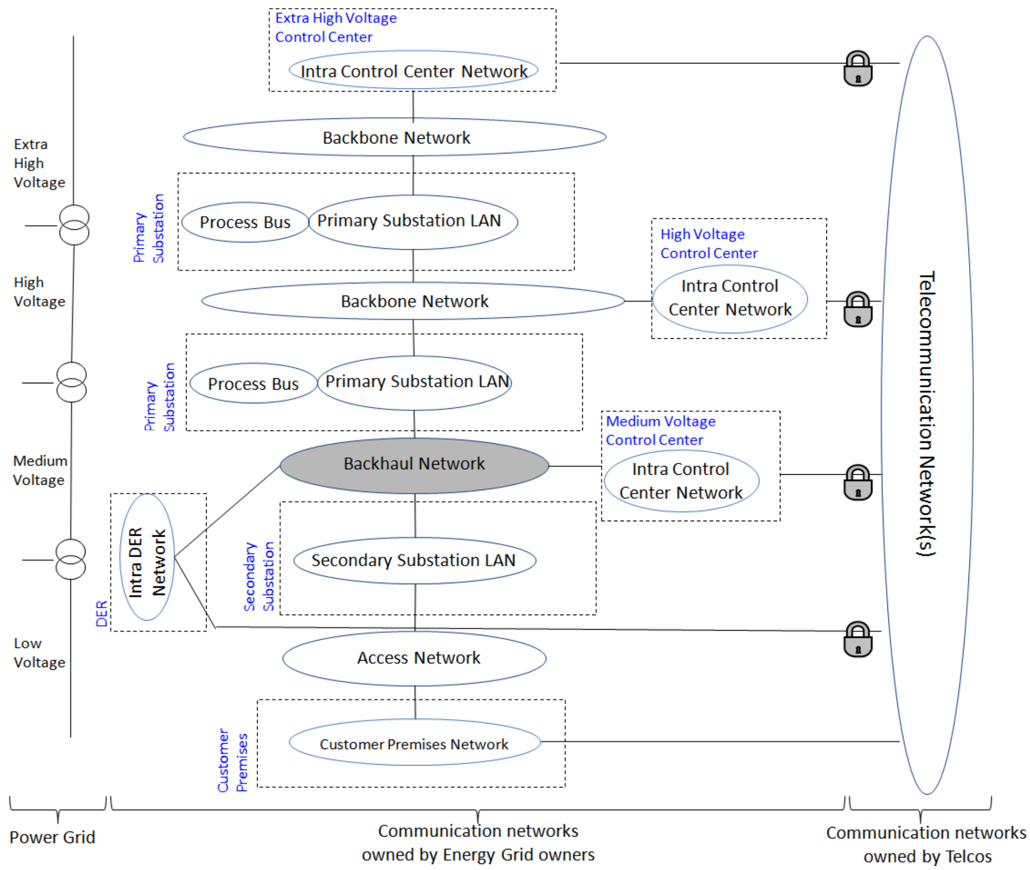
[12] R. Trivisonno, R. Guerzoni, "Requirements and Design Principles for Next Generation Networks", IEEE COMSOC MMTC E-letter, July 2015

of batteries for storage by customers, as well as allowing the better deployment of energy and reductions in CO_2 generation. Furthermore, the agile deployment and fast market penetration of 5G with its advanced features associated with technologies such as big data will certainly offer a leeway to the electricity companies to transform and sustain the socio-economic challenges we have identified.

In the next chapter, we will discuss the technical requirements primarily focusing on the Smart Grids as the primary and exemplary use case.

3. Technical requirements for 5G

Smart Grid communication networks consist of multiple domains. Each of these domains serves a specific area e.g. a distribution network or location like a secondary substation (transformation between medium and low voltage). It has to support individual requirements driven by the applications it has to serve. The communication network architecture, visualized in the figure below, is derived from and mapped to the Power Network it serves.



The border elements of these voltage levels are of major relevance for the Smart Grid communication domains as they have their own very specific requirements:

- *Primary Substation*: the medium voltage to high voltage transformation point, resp. the high voltage to extra high voltage transformation point.
- *Secondary Substation*: low voltage to medium voltage transformation point

The following communication network domains can be distinguished:

- *Grid Backbone Communication Network*: Communication network which connects the Primary Substation LANs amongst each other and with regional control centers (often co-located) and central control centers.
- *Primary Substation LAN*: A Primary Substation LAN is quite complex and requires an own communication infrastructure that distinguishes between a Process Bus and a Station Bus. It is mainly based on a Gigabit Ethernet infrastructure.
- *Grid Backhaul Communication Network*: Communication network which connects the Secondary Substation LANs with each other and with a control center. This network domain might also connect to the respective Primary Substation LAN.
- *Secondary Substation LAN*: Network inside the secondary substation (today this network is quite trivial and may consist of just one single Ethernet switch / IP router). The Secondary Substation LAN is implemented in US-Style regions more in a distributed manner whereas in Europe the Secondary Substation LAN is very often located in an encapsulated enclosure.
- *Grid Access Communication Network*: Communication network which connects the customer premises or e.g. low-voltage sensors to a specific Secondary Substation.
- *Customer Premises LAN*: In-building communication network whereas a customer is characterized by consumption and production of energy (Prosumer) and the customer can be residential, public or industrial prosumer.
- *Intra DER Network*: For medium-sized DERs like wind/solar parks a dedicated LAN is required for control, management and supervision purposes.
- *Intra-Control-Center Network*: LAN within a Distribution System Operator's or Transmission System Operator's control center.
- *External Network*: Fixed or Mobile Network Operator owned communication network which offers different connectivity services either via dedicated services or via the open Internet.

The communication network domains in the Smart Grids context where 5G is immediately expected to play a significant role are the access networks (connecting the elements in the low voltage power grid) and the backhaul networks (connecting the elements in the medium voltage power grid). For the far future 5G might also play a role in other network domains like the backbone network domain (connecting the elements in the high voltage and extra high voltage power grid), which has the most stringent requirements in terms of real-time and reliability.

The communication network domains present a logical structure of the overall communication network required in parallel to the power infrastructure to establish the Smart Grid. Nevertheless several of these domains might be realized as virtual instances on the same physical infrastructure, e.g. the Grid Access Communication Network and the Grid Backhaul Communication network can be virtual instances (so-called slices) on the same 5G network infrastructure – it will anyway be the Distribution System Operator who is responsible for both, Grid Access and Backhaul communication network.

The non-functional requirement aspects are:

- “*Service guarantees*”: part of the future important Smart Grid applications are mission/business critical (like e.g. protection in case of a power grid fault). 5G technologies and networks will only be an option in these cases, if service guarantees can be given. From a technical perspective this means that guarantees for average values are not sufficient but there need to be guarantees for max/min values as well. Form a regulatory viewpoint, net neutrality needs to allow for such specific Smart Grid – grade communication services.
- “*Cost efficiency*”: the communication solutions provided by 5G do not only need to assure technical feasibility, but also suitable from a business viewpoint. I.e. even if the offering of an advanced 5G communication solution is technically possible and standardized, it still needs to be able to be offered for a suitable price tag – from CAPEX and OPEX viewpoint – which the Smart Grid players are able and ready to pay. This is e.g. important for solutions offered in rural areas as well as when more than one Mobile Network Operator has to be involved.
- “*SLA Handling*”: Due to the criticality of some Smart Grid applications and the respective communication solutions 5G needs to foresee appropriate SLA monitoring and management, when the communication solutions are (partially) provided by a third party. Provider and user need to be enabled to verify and monitor the communication solution
- “*Provisioning times*”: For remote services there might be the need to spontaneously setup a communication path towards a dedicated station which provides specific QoS. The time to setup such high quality connectivity should be in the range of 10min to 1 hour.
- “Asset Management”: Due to the increasing number of connected devices (mainly sensors like Smart Meters) there is the need for efficient asset handling, e.g. done by bulk provisioning and alike.
- “Coverage”: Many more Smart Grid elements will need to be connected with each other from a communication perspective even if they are in the rural area (e.g. secondary substations). 5G needs to assure ubiquitous coverage including all relevant Smart Grid elements.

3.1. Grid access communication network domain

The access network domain is characterized by the communicating end points in the low voltage area (i.e. Smart Meters, secondary substations). The diameter of the region to be covered is typically <10km. The applications running through this area are typically less critical than in other domains (see below). Just for those end-points which shall be dispatched (in terms of load or generation) in case of a power grid stability problem some real-time capability is required. Otherwise the requirements[13] are less stringent:

- Bandwidth: 1 kbps per residential user (even if the user is positioned in the basement)
- E2E Latency (guaranteed upper bound): <1s from the control center / meter data management center/ secondary substation to the Smart Meters

[13] Siemens Whitepaper, “Smart Communications for Smart Grids”, 2012

- Packet-loss: no specific requirement as long as E2E Latency requirement can be covered (TCP-based communication is dominant)
- Availability: 99% equal to 9 h downtime p.a.
- Failure Convergence Time: <1s
- Handling of crisis situations (surviving medium power down-times on a large scale, assuring black start capability): not required.

3.2. Grid backhaul communication network domain

The backhaul network domain is characterized by the communicating end points in the medium voltage area (i.e. secondary substations). The diameter of the region to be covered is typically <100km. Due to critical applications like protection (automating fault detection and isolation to prevent large scale power outage [14]) stable, reliable secure and real-time capable communication is required with service guarantees:

- Bandwidth: in the range of several Mbps between the secondary substations amongst each other and towards a control center
- E2E Latency (guaranteed upper bound): <50ms between the secondary substations as well as towards the control center
- Packet-loss: < 10^{-6} (E2E Latency requirement has to be covered, as well as non-acknowledged status information distribution – e.g. GOOSE-based – has to function properly).
- Availability: 99,99%, equal to 50 min downtime p.a.
- Failure Convergence Time: <1s
- Handling of crisis situations (surviving medium power down-times on a large scale, assuring black start capability): mandatory. This can be realized by suitable battery backup or other 5G technical solutions which allows switching between different communication technologies which can be guaranteed to not fail at the same time.

3.3. Grid backbone communication network domain

The backbone network domain is characterized by the communicating end points in the high and extra high voltage area (i.e. primary substations). The diameter of the region to be covered is typically <1000km. The most important applications in this arena are protection functions (so-called Teleprotection, Differential Protection) which require ultra stable, reliable secure and real-time capable communication amongst the primary substations and towards the control center. Therefore these networks are today dedicated optical wireline networks. The specific requirements are:

- Bandwidth: in the range of Mbps to Gbps between the primary substations and towards the control center
- E2E Latency (upper bound): <5ms between the primary substations and towards the control center[15]

[14] 3GPP S1-150111, SMARTER: Use case for reliable communications, Qualcomm, Feb. 2015.
[15] IEC, "IEC 61850 Part 5: Communication requirements for functions and device models," 2002

- Packet-loss: < 10^{-9} (E2E Latency requirement has to be covered, as well as non-acknowledged status information distribution – e.g. GOOSE-based – has to function properly, which is more demanding for high/extra high voltage than for medium voltage applications).
- Availability: >99,999% equal to 5 min downtime p.a.
- Failure Convergence Time: Seamless failover required, i.e. no loss of information in case of a failure while keeping real-time delivery of the information (i.e. within a small number of milliseconds)
- Handling of crisis situations (surviving long power down-times on a large scale, assuring black start capability): mandatory.

Summarizing, Smart Grid services are often associated with stringent requirements in terms of reliability, tolerating only short packet dropouts. Therefore, 5G has to incorporate a wide range of diverse use case characteristics that are associated with a complex set of requirements as described above. To accommodate these under a common network topology, novel technology components are needed, as well as some disruptive techniques. The design of the new radio access network involves the interplay among various radio interfaces that are seamlessly integrated and results in a radical paradigm shift on the connectivity concept in the future 5G vision. Efficient integration of the 5G access technologies include multi-connectivity approaches where the user equipment is simultaneously connected to several access technologies or frequency bands which could help to address the requirements in terms of crisis situation handling.

4. Capabilities which are not yet supported by existing technologies

After the summary of 5G requirements for the energy sector in the previous chapter, we will now briefly analyse the capabilities of existing wireless and fixed access technologies and identify the main limitations.

4.1. Wireless access technologies

In contrast to fixed access, wireless technologies provide to a high degree flexible connectivity for various equipment deployment scenarios (point-to-point, point-to-multipoint, etc.). While short-range radio technologies based on 802.11 (WLAN) and 802.15 (Bluetooth, ZigBee) standard families are limited to local networks only without quality of service guarantees, 3GPP LTE is a cellular mobile radio system providing wide area coverage. However its original primary design targets were efficient support for mobile broadband services requiring very high user data rates and for high velocities.

Reliability-of-service will have to be orders of magnitude higher than in current wireless access networks, usually in combination with stringent E2E latency requirements, e.g. for the grid backbone communication network domain below 5 ms, while the acceptable downtime per year must not exceed 5 minutes, and data rates in the order of Mbps or even Gbps are required. Existing LTE may not be able to guarantee packet loss probabilities below 10^{-6} when at the same time demanding latency requirements set by critical applications have to be met,. The problem with existing 2G, 3G and 4G technologies like LTE is for sure not the fulfilment of one single of these performance metrics, but the simultaneous support of low latency, ultra high reliability and availability as well as high data rates. This is because LTE design choices were not originally designed for critical applications.

The achievement of the required reliability may come along with an additional delay, e.g. through multiple repetitions of the same information. Generally, reasons for delay in LTE include a static subframe structure, HARQ retransmissions, processing times, random access procedure and connection setup signalling. For instance, the current subframe structure does not allow transmission times that are shorter than 1 ms, and the HARQ retransmission protocol adds 8 ms for each required retransmission. In addition, random access, which is a multi-stage protocol with several signalling messages in uplink and downlink, may result in a delay until the actual payload can be transmitted if the radio synchronization is lost or does not exist. Another source for additional delay may be the need for many re-transmissions due to a high collision probability on the random access channel when the traffic load increases. This becomes critical for event-driven applications when a big number of devices start to transmit simultaneously, e.g., equipment protection in case of a thunderstorm. Therefore delay optimized access schemes and a configurable network architecture designed to minimize delays are needed in order to guarantee the required reliability within a given overall transmission and processing time. To enable the expected massive traffic increase and the number of simultaneous active connections per cell, connectivity states for devices need to be simplified while channel access must be provided with minimal signalling.

Most of these devices are fixed at specific locations and thus, do not need elaborate mobility handling as provided natively by LTE network. Support of mobility comes at a cost for mobile network and the device in terms of extra signalling messages, processing resources and delay in setup & data message transaction. Thus, a flexible network which can provide mobility on demand to reduce device complexity & cost on one hand and makes better use of network resources on other hand is required. Short burst intermittent access from Smart Grid applications also leads to high radio in-efficiency due to signalling overhead and thereby, making non-optimized use of highly scarce radio spectrum resources.

Smart Metering application necessitates support of a wireless network that can provide wide area connectivity but which is optimized for low data rates, can penetrate to reach basements and enable substantially lower cost and longer battery life of smart meters. As LTE was primarily designed to serve smart phones and improve users' wireless internet experience, it is not optimized to handle such requirements. Evolutions in LTE are being adopted and alternatively, few dedicated IoT networks are being designed and deployed across the world but these LTE evolutions or dedicated IoT network technologies may not fulfil long-term requirements of Smart Grid or Smart Meter applications.

Smart Grid includes diverse use cases ranging from system protection that requires ultra reliable and low latency communication to smart meters that require support of massive number of network connected devices with relaxed latency and reliability requirements. LTE Radio Access Network (RAN) and Evolved Packet Core (EPC) are not designed flexible enough to simultaneously meet requirements of such diverse use cases economically and technically. Thus, programmable and flexible network architecture is required which can enable handling reliability, security and performance (including QoS) requirements of diverse subset or even each Smart Grid application over a single platform. As consequence, the increasing demand for low round trip latency and ultra-high reliability appears as a decisive factor for 5G implementation with respect to mission-critical communication within the smart grid.

4.2. Fixed access technologies

The fibre-optical links used today for envisaged smart energy use cases cannot provide required deployment flexibility and cost figures. In densely populated urban areas fixed fibre-optical links might also not be possible due to restricted construction limitations, so the limitations are not only economical but in some cases also related to construction permits.

5. Business and policy aspects

Wireless cellular networks such as GPRS, UMTS or LTE, referred to in the market as 2G, 3G, and 4G, respectively, are a natural communication solution for Internet of Things deployments such as the smart grid and smart meter. They are standardized and proven, provide the required technical performance, are easy to install (anywhere anytime) and wireless connectivity is usually the most economical solution (lower installation costs, several vendors and operators). 5G, with even more performance, will answer those applications growing data needs and enable even more use-cases not yet covered by wireless communications.

Most Internet of Things (IoT) solutions cannot be considered as nice-to-have anymore. They are of critical importance as they directly impact people's lives and companies' processes. It's even more true for the smart grid and the smart meter which act as digital skin to the electricity, gas and water grids, the very building blocks of our society and economy.

As telecommunications are used not only to monitor but also to control the power grids, they become of mission-critical nature and of strategic importance to DSO's, to the point that the telecom network can be considered a ”third net”, next to the electricity and gas nets.

Trust over these communications is essential, as the stability of the grids depends on them. This requires energy actors to be able to take enough control on their telecommunications, thus leading to interesting new business models and business roles between energy and telecom/IT actors.

5.1. Transformation of business models in the future

5G technology, with improved performance compared to 2G/3G/4G, will answer the growing smart grid and smart meter data needs and enable even more smart solutions not yet covered by wireless technologies [see chapter 3 for more details on the use-cases technical requirements].

But a number of requirements are of non-technical nature and even more critical to the success of smart grid and smart meter deployments on the long term. The telecom infrastructure needs to be future-proof, secure, robust, reliable and the telecom costs under control and stable for the long term:

- Life-cycle / Longevity
  - Smart grid and smart metering application are typically installed for periods longer than 15 years. Therefore the telecom solution should have a guaranteed supply over an extended period of time. Exchanging the telecom solution could mean swapping millions of devices with removal and installation costs often exceeding the telecom costs themselves.
  - Commercial wireless operators have different primary drivers: their main business is to compete with each other based on network performance, bandwidth and the latest trendy smartphones. Most of the time they cannot guarantee technology longevity or if they do, at the cost of price increase. With

other words telecommunication “longevity” comes at the cost of business case “longevity.

- Security
  - Malicious threats can be disastrous to electricity supply due to the mission-critical nature of the smart grid connected entities (sub-stations for example). Therefore the highest possible security levels must be used by the smart grid telecom infrastructure.
  - Security is also a focus of commercial wireless operators. However, the security risks and vulnerabilities of a smartphone or set top box are not the same than those of a critical electricity sub-station. The standard security measures and priorities are not optimal for the electricity and gas grids critical elements.
- Resilience
  - Telecommunication is monitoring and controlling mission-critical smart grid applications therefore it is expected to work without any interruption, even in case of power outage. The required time for resiliency range from 8-12 hours up to 72 hours for the most critical services and sites.
  - Most commercial operators cannot deliver this kind of resiliency, especially not end-to-end, and do not want to commit to SLA’s for long power outage situations.
- Costs stability
  - The telecom solution should not only guarantee the technology longevity but also its costs level over the long term. With other words the communication cost, per asset and for a specific telecommunication solution, should not increase over the years. Smart grid and smart meter business cases are made for very long-term (more than 15 years) and any significant communication cost increase could be disastrous for grid operators, considering the number of assets.

As currently available commercial cellular operators do not fulfil energy grids long-term needs, utilities are building new business models based on taking partial of total ownership of the wireless network, and therefore partial or total control. Two examples of such new business models can be given as illustration:

- PVNO (Private Virtual Network Operator): in this technical and business construction, utilities can manage the provisioning of the communication devices (for example SIM card) and customize part of the core network and information systems (at least customer databases and eventually more). Utilities are signing a contract with the wholesale department of the wireless operator instead of the retail department. In this model radio network and frequency license remain in full control of the telecom operator.
- Private dedicated network: Dutch DSO’s have rolled-out a fully dedicated wireless network to support their smart grid and smart meter assets. In this model they fully own the wireless radio and core networks, as well as the frequency license in the band 450 MHz. They are fully in charge of deciding how to move forward with their telecom strategy over the years.

It is good to notice that operators are not standing still and also realize that the life-cycle of their current main business –smartphones- is not in line with the longevity of machines. A few interesting developments are taking place:

- Creation of machine “profiles” as part of existing or future cellular technologies. For example LTE-M2M is meant to optimize the wireless network resources used by machines. This represents a gain for the operator (not wasting expensive bandwidth) but also for the communication device (less signalling and therefore using less energy). However this scenario does not solve the longevity mismatch as the M2M profile (i.e. LTE-M2M) remains dependent on the life-cycle of the main network (LTE).
- Dedicated IoT networks. A few initiatives based on LPWAN (Low Power Wide Area Network) technologies have recently taken place. Wireless operators acknowledge the specific technical (low power and low data rate) as well as business (long longevity) requirements of the IoT and are rolling-out dedicated networks. However those are often based on proprietary technologies with limited number of product suppliers, which for the long-term represents both a technical and a vendor lock-in. Also the technical performance of those solutions is not sufficient for the smart grid e.g. their latency is in the order of the second whereas for backhaul electricity networks we need less than 50 ms.

Utilities on their side are also deploying dedicated telecommunication solutions based on RF Mesh or PLC (Power Line Communications). Their motivation is the same: take control by taking ownership. However those technologies are often proprietary, which results in technical and vendors lock-in.

5G technology and operators could give more control to energy customers, by providing for example:

- True “machine” profiles creation and activation. IoT customers such as the smart grid/meter could customize their data communication needs: for some more bandwidth, for others less signalling and less power consumption etc. For operators the benefit would be to optimize network resources and performance according to the user profile.
- Wireless network virtualization and slicing. Energy customers could receive harder guarantees from cellular operators about telecommunications availability and performance.
- Forward and/or backward compatibility of 5G technology. Cellular networks longevity, compared to that of the energy grids, is one of the biggest mismatch and challenge for the deployment of long term IoT solutions. By applying a forward and/or backward compatibility to the technology (or at least “IoT part” of the technology), could wireless network operators guarantee longer longevity of their network to IoT customers?

Such capabilities would allow the energy sector to truly benefit of the standardization and economy of scale of 5G without having to make concessions on control. This would also allow 5G operators to provide dedicated IoT products and networks and allow them to compete with new dedicated IoT networks based for example on LPWAN.

5.2. Evolution of business roles between players from the vertical sector and ICT industry

Energy generation, transport or distribution are fully entering into the digital world. Telecom and data are becoming mission-critical to support primary processes such as the smart grid. Utilities have growing needs for IT (Information technology) and OT (Operational Technology) expertise, which they fulfil with their own experts or by hiring external companies. In both cases they need to remain in control and to guarantee the quality of the digital solutions.

Wireless operators, on their side, are facing a dilemma. On one side every object on the planet is getting a connection, which should open huge opportunities, but on the other side IoT connectivity cannot be expensive to guarantee a positive IoT business case. Wireless operators are facing an even larger challenge, independently of the IoT. More and more added value services are run by music and video content providers, confining them to basic connectivity providers, and taking over most of the financial profits. Wireless operators have to reinvent their business model and their role to avoid the trap of remaining only connectivity vendors.

This situation opens the door to new business roles and responsibilities on both sides. In principle different roles scenarios are possible, as long as utilities keep enough control on the digital solution on the long term.

In the traditional situation utilities are responsible for electricity, gas and water grids, telecom operators for all elements of the telecom connectivity, and IT companies for the gathering and processing of the data.

The digital revolution is shifting those roles, for example:

- Energy utilities are taking more ownership on the telecom network. In this scenario national wireless service operators are transforming into network operators. In The Netherlands for example, although DSO’s decided to become owner of a private dedicated wireless network for the smart grid and the meter, the main national wireless service operator still fulfils the primary role in the design, roll-out and management of this network.
- Most wireless network operators are looking at getting higher in the value chain by proposing IT / big data services in addition to telecom connectivity. This can be seen as a natural move as most of them have adequate IT expertise in house, but their challenge remains that business leaders do not necessarily see them yet as the first choice to provide ICT services.

By providing the capabilities mentioned in previous paragraph –“machine” profiles, virtualization, slicing, forward/backward compatibility-, 5G could support energy players and operators to achieve those ambitions.

5.3. Spectrum considerations

Spectrum is the most critical component of a wireless network. Without spectrum no wireless network. 5G will be designed to operate in a large range of frequency bands and licensing regimes, including both licensed and unlicensed frequency bands. Licensed band operation has the benefit that there is regulated low level of interference from other wireless systems which leads to higher resilience against disturbances and is more suitable for mission critical applications. Unlicensed bands may be accessed more easily without licence fee and may be adequate for some use cases.

5G is envisioned to support a wide range of services and requirements in the same frequency band, with mechanisms to logically separate resources between industries if needed.

5G should be able to operate, and become fully standardized, in the maximum number of frequency bands. The EUTC (European Utilities Telecom Council), for example, recommends the use of dedicated spectrum in its position paper[16], and lists a certain number of spectrum parts to be considered. 5G would be a good candidate as technology of choice in this proposed spectrum, if it supports those bands.

It is also the expectation that 5G will make the internet of things more effective and more efficient from a spectrum efficiency point-of-view. Machines should use 5G network resources and associated spectrum only when needed, in the most efficient way. This would have obvious benefits for the network operator (efficient use of expensive spectrum) and for the devices (using less energy).

5.4. Required standardization approach

ETSI[17] summarizes why we need standards.

Standards provide:

- Safety and reliability – Adherence to standards helps ensure safety, reliability and environmental care. As a result, users perceive standardized products and services as more dependable – this in turn raises user confidence, increasing sales and the take-up of new technologies.
- Support of government policies and legislation – Standards are frequently referenced by regulators and legislators for protecting user and business interests, and to support government policies. Standards play a central role in the European Union's policy for a Single Market.
- Interoperability – the ability of devices to work together relies on products and services complying with standards.
- Business benefits – standardization provides a solid foundation upon which to develop new technologies and to enhance existing practices. Specifically standards:
    - Open up market access
    - Provide economies of scale
    - Encourage innovation
    - Increase awareness of technical developments and initiatives

[16] EUTC position paper – spectrum needs for Utilities
[17] ETSI "Why we need standards" http://www.etsi.org/standards/why-we-need-standards

- Consumer choice - standards provide the foundation for new features and options, thus contributing to the enhancement of our daily lives. Mass production based on standards provides a greater variety of accessible products to consumers.

Regarding smart grid and smart meter standardization, the European Commission is standardizing the smart grid and smart meter under the M/490 mandate for the smart grid[18] and M/441 for the smart meter[19].

Utilities recognize the need for standardization but are also dependent on their implementation by suppliers.

Regarding telecom standardization, cellular technologies such as 2G-3G-4G, and 5G in the future, are examples of standardization success story. These technologies have been deployed worldwide, by most of the telecom operators. This is probably one of the main reason, aside from the technical performance, that it is considered a natural choice for smart grid and smart meter, compared to more proprietary technologies.

5.5. Regulatory barriers

Extracts[20] of chapter 2 "The Regulatory Challenges Related to Smart Grids"

[…]In their 2010 Conclusions Paper, European Energy Regulators observed that while high-level principles for smart grids can be applied across Europe, detailed implementation will vary from country to country. The results from the 2011 Status Review showed that smart grids are at different stages of development in Europe, and as a consequence, the regulatory activity for smart grids within Member States is evolving in different phases. As smart grids progressively become a more significant topic of discussion in Europe, the challenges to their implementation are increasingly examined in more detail by energy regulators. This investigation is important for regulators in order for them to identify challenges and to ensure mitigation through appropriate action at the national level.

[…] a range of possible issues that will help to identify challenges to smart grid regulation, according to the following categories:

- Stakeholder involvement in the development of smart grids (e.g. demand side response, demand side response for domestic customers, incentivising demand side response);
- Regulatory challenges to the development of smart grids (e.g. technical and commercial arrangements, barriers, regulatory instruments); and
- Emerging regulatory issues for the development of smart grids (e.g. new arrangements, electrical storage, and smart meter data).

[18] http://www.cencenelec.eu/standards/Sectors/SustainableEnergy/SmartGrids/Pages/default.aspx
[19] http://www.cencenelec.eu/standards/Sectors/SustainableEnergy/SmartMeters/Pages/default.aspx
[20] CEER Council of European Energy Regulators, "CEER Status Review on European Regulatory Approaches enabling Smart Grid Solutions (" Smart Regulation"), Ref. C13-EQS-57-04, 18-Feb-2014)

[…]There was no clear consensus between NRAs on the existence of regulatory and commercial barriers to the development of smart grids, but the majority of respondents did not consider barriers to be evident.

Norway noted that it will be necessary to continually develop regulation as thinking on smart grids evolves. Several NRAs (Belgium, Cyprus, Czech Republic, France, Great Britain, Italy, Poland, Portugal and the Netherlands) identified a number of different barriers. Examples of these barriers relate to the following areas:

- Encouraging system operators to play a more active role in addressing future challenges;
- High electricity prices and limited network development funds;
- Uncertainty around the direction of planned national action plans;
- The integration of Electric Vehicles (EV), storage, demand response and renewable energy strategies (RES) into the market;
- Charging methodologies and current settlement processes;
- Data protection laws;
- The lack of clear responsibilities for the role of stakeholders; and
- Standardisation.

[…]CEER asked its members to rank a series of issues with regards to their importance for smart grid development:

- Incentives to encourage network operators to choose investment options that offer the most cost effective solutions was rated as 'very important' by the majority of countries (61%);
- Incentives to encourage network operators to choose innovative solutions/ incentives for network operators to encourage efficient use of electricity and renewable electricity production was rated as 'important' by most countries (52%), as was active participation in the development of smart grids by stakeholders (48%), the roles and relationships of relevant stakeholders to encourage the introduction of new services or markets (44%), and the introduction of new tariffs to incentivise more efficient network use (52%);
- A number of countries (35%) rated standards on smart technologies as of 'medium importance';

Regarding telecom regulations, the following 5G implications are identified:

- Competition: licensing, market power and regulation of dominant position; network interconnection – There are several issues regarding players' lock-in strategies, for example:
    - Regulatory authority should allow the development of a competitive market by ensuring the always-possible introduction of innovative, disruptive, or efficient technologies. In other words, the champion technology should not be defined ex-ante. In this line, it is recommended to consult with the stakeholders to identify the best way to give access to spectrum.

- Use of scarce resources: spectrum allocation, numbering schemes, right of way, and privacy issues – these are few concerns for the 5G development within the DSO value chain:
    - Network data will provide a wealth of information enabling detailed tracing of user activity (via smart metering for example).
    - User-centred system can increase the potential security risks associated with private data collection. Besides raising the awareness of the users for privacy issues, privacy-by-design enforcement could be essential to ensure the user privacy without interfering with the smart grid system.
- Ubiquitous service – or provision of digital energy services everywhere – 5G promises significant new opportunities in terms of user experience and social life e.g. better connectivity coverage while moving at high speeds. Associated with the 5G technologies development, there should be a commitment to provide 5G everywhere, or at least everywhere we find electricity networks. This would allow the ubiquitous access to digital energy services.

6. What is needed in terms of research and innovation?

Experimentations on smart metering and power grid monitoring for the energy sector have already started a few years ago with both 3G and 4G technologies. Within the home area we are already beyond experimentation with large scale trials or even up and running services in different countries in the world (see e.g. Google Nest in the USA or Issy Grid in France, http://issygrid.com/en/). However, experimentations should be conducted beyond these domains regarding the real time command, control, protection and monitoring system of the energy distribution and transport grid at the regional level. 5G technologies could be a good fit for these applications due to their flexible performances and their ability to deliver network slices and distributed cloud resources.

Before the actual experimentation setups can start, the challenging requirements on 5G needs to be addressed by going towards a joined design between vertical and ICT players including collaborative research fostering exchange of ideas and alignment. Derived from the use-cases in chapter 2 and the requirements in chapter 3, the following areas can be foreseen of particular interest in terms of research and innovation:

- *Improvement on latency*, which can unlock use cases currently not supported by existing mobile communication technologies. More importantly than latency reduction, latency needs to be guaranteed, meaning that the packets needs to fulfil an upper latency bound in the access, backhaul distribution and grid backbone networks. Instant uplink access – where uplink transmissions can take place without a prior request-grant phase – and a shorter transmission-time interval could be considered as enabling mechanisms for smart grid operations.
- *Reliability boost*, which can match the existing wired solutions but also supersede them by e.g. using the inherent flexibility of 5G to improve the reliability of mobile communication substantially. Combining several wireless technologies (including satellite) should also be investigated.
- *Business models*, which can transform the system advantages into business and allow potentially new models on ownership, operation, maintenance as well as usage.
- *Security and confidentiality solutions*, which prevents cyber-attacks, still maintaining the latency requirements, is a critical function for the future power grid communication network.
- *Use of unlicensed spectrum*, which is receiving a lot of attention in current standardization efforts. Currently, the carrier-aggregation framework is used to aggregate licensed and unlicensed spectrum and forms the basis for downlink-focused license-assisted access in LTE release 13. In practice, carrier aggregation implies that the same node is handling licensed as well as unlicensed spectrum. A natural enhancement is to extend license-assisted access to build upon the dual-connectivity framework. This will provide additional deployment flexibility as physically separate nodes can handle the two spectrum types. Full support for uplink transmissions in unlicensed spectrum is also considered as a potential option.

- *Massive machine-type communication* (MTC) is a vital part of the overall 5G vision. Research efforts are required to further improve the MTC capacity as well as look into new features for MTC devices, such as device-to-device relaying as well as interoperability with satellite/High Altitude Platforms based system as a mean for coverage extension, data off-loading, and latency reduction. This capacity to extend coverage especially indoor and in rural areas would be useful for smart grid applications.
- *Massive MIMO*, or full-dimension MIMO as it is called in 3GPP, is about using a large number of antenna elements, e.g. for two-dimensional beamforming and/or multi-user MIMO. Potential extensions of the current massive MIMO framework refer to an even larger number of antennas (more than 16) while the development of requirements and test methodologies to facilitate real-life deployment of these technologies needs to be secured. MIMO can be used for better reliability of the link and to extend the coverage. As a result, it fits well the need of smart grid applications.
- *Accurate time synchronization*, provided by the mobile communication infrastructure, will be an important topic for research and innovation, both in the communication infrastructure and for the power applications. An alternative time source to GPS and other satellite based solutions could be an important success factor for the energy domain.

Finally, as discussed in the previous sections, the evolution of the energy and ICT sectors toward a shared economy is opening the door to new business roles and responsibilities on both sides. In this respect, the large energy consumption of 5G networks will probably include eco-friendly elements, like base stations supplied by renewable sources, which can be integrated as new generation players in the grid. Such integration fosters the use of 5G architecture and interfaces to control the smart grid.