# Smart Grid: a demanding use case for 5G technologies

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***Abstract*— The energy sector represents undoubtedly one of the most significant "test cases" for 5G enabling technologies, due to the need of addressing a huge range of very diverse requirements to deal with across a variety of applications (stringent capacity for smart metering/AMI versus latency for supervisory control and fault localization). However, to effectively support energy utilities along their transition towards more decentralized renewable-oriented systems, several open issues still remain as to 5G networks management automation, security, resilience, scalability and portability. To face these issues, we outline a novel 5G PPP-compliant software framework specifically tailored to the energy domain, which combines i) trusted, scalable and lock-in free plug 'n' play support for a variety of constrained devices; ii) 5G devices' abstractions to demonstrate mMTC (massive Machine Type Communications), uMTC (critical MTC) and xMBB (Extended Massive BroadBand) communications coupled with partially distributed, trusted, end-to-end security and MCM to enable secure, scalable and energy efficient communications; iii) extended Mobile Edge Computing (xMEC) micro-clouds to reduce backhaul load, increase the overall network capacity and reduce delays, while facilitating the deployment of generic MTC related NFVs (Network Function Virtualisation) and utility-centric VNFs (Virtual Network Functions).**

***Keywords—Smart energy grids; 5G; preventive maintenance, resilience; demand response; Machine Type Communications; Virtual Network Functions.***

## I. INTRODUCTION

The wide deployment of IoT devices, broadband and mission critical services along with a large variety of scenarios, ranging from smart city to factory automation, are paving the way for a novel and disruptive 5G communication network, which will enable huge capacity, zero delay, faster service development, elasticity and optimal deployment, less energy consumption, enhanced security, privacy by design and connectivity to billions of devices with less predictable traffic patterns. Accordingly, the next generation network should be capable of handling the complex context of operations and support an increasingly diverse set of new and emerging services, all of them with extremely diverging requirements, which will push mobile network performance and capabilities to their limits. Furthermore, it should provide flexible, smart and scalable adaptation and/or association of the available network resources to the requirements of the supported services, enabling a dramatic paradigm shift from legacy CAPEX to the OPEX "Everything-as-a-Service" driven business models.

Although a variety of software frameworks and reference architectures have already made available for 5G enabling technologies, there is still a clear gap to bridge for 5G seamless deployment within a number of "vertical" sectors such as smart grid and smart city, which pose significant new requirements. Among others, the energy "vertical" represents one of the most demanding "use/test case" for 5G enabling technologies, mainly due to the need of addressing a huge range of very diverse requirements to deal with across a variety of applications (stringent capacity for massive smart metering/AMI (Advanced Manufacturing Infrastructure) services versus stringent latency for supervisory control and fault localization) [1]. As a matter of fact, the combined effect of growing penetration of distributed Renewable Energy Sources (RES) in the generation portfolio together with the European Union's "Customer Centric Energy Systems" vision, which aims at turning energy consumers into active "prosumers", are dramatically changing the way in which energy distribution grids operate. To underline the penetration of RES with unpredictable energy generation patterns integration, please consider that on 15 May 2016, RES supplied nearly all of German domestic electricity demand[2] while the political importance is evident by the agreement that took place on 6 June between the North Sea region countries (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway and Sweden) to create good conditions for the development of offshore wind energy [3].

Technological advances, political visions and market liberation are transforming the energy network from a closed, monolithic and highly predictable infrastructure to an open, multi-owned, decentralized ecosystem and pose huge

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challenges, both in functional (i.e. stability, resiliency and highly availability) and in non-functional (i.e. sustainability, security, privacy and CAPEX/OPEX) directions. In this new and time varying energy landscape, 5G initiative is challenged to guarantee optimal communications of the energy grid, which is believed to be the most complex, heterogeneous and gigantic machine ever made in human history.

In particular "last mile" of the smart energy network has the highest potential for demonstrating the added value of the 5G unified approach. While smart energy grids observability (in particular in the case of smart electricity grid) is already in place in the High and mostly in the Medium Voltage branches of the energy networks, situational awareness of Low Voltage/Low Pressure branches is lagging behind. The state of the art is actually for substation-level/pumps monitoring via SCADA, without considering real time energy consumption or energy production feedback from prosumer, which would allow a finer-grained prediction of the demand and an improved load balancing of the energy networks. Hence smart energy "last mile" network represents an ideal vertical for extensive 5G deployment, where different applications with different requirements have to be managed:

- Smart Grid applications, such as supervisory monitoring (cyber monitoring and physical/aerial surveillance), fault localization, isolation/self-healing and energy re-routing, requiring more stringent latency, highest availability and security (Mission Critical)
- Advanced metering applications enabling the massive and lock-in free integration of end-users' infrastructure requesting more stringent capacity and privacy (Massive IoT application)
- A combination of the above such as smart Electric Vehicle charging, where 5G technology should be able to incorporate and address both latency and capacity more stringent requirements.

Beyond applications requirements, significant challenges are posed from the energy infrastructure complexity and heterogeneity. The huge diversity in variables such as population density, service territory size, control and monitoring technology, terrain and topology, power plants location and fuel, RES capabilities and budget of utilities for new deployments, as well as the different bandwidth and latency requirements of applications within each utility, has resulted in the deployment and management of several, legacy communication solutions. Only 24% of utilities manage just one communications network, with 58% of utilities have between 2 to 6 operating networks, 14% between 7 to 10, and 4% have 10 or more networks[4], with a significant complexity and financial burden to manage.

In this paper, we focus on the exploration of requirements and identification of innovative concepts to be contributed to the 5G PPP/5G Initiative research and development activities towards the realization of a Smart Energy as a Service use case that will stress 5G current results. We aim to advance beyond state-of-the-art in virtualization-based communication networks technologies, making them suitable to support Smart Energy as a Service at large Scale, placing emphasis on security, privacy, trust and high availability. This work was developed in the framework of H2020 -NRG-5 project which aims to additionally deliver innovative open-source prototypes, state of the art laboratory experiments and heterogeneous real-life trials to draw valuable.

The rest of the paper is organized as follows: in section II we explore the main challenges that smart grid operations impose on 5G technologies. These challenges have been validated by smart grid operators from the NRG-5 consortium. Then, in section III, we define novel concepts that can efficiently address these challenges and are in line with the 5G technology principle and vision. In section IV we propose a novel architecture that proposes concrete developments that are required to make 5G technology a perfect enabler for next generation smart grid operations. Finally, section V concludes the article.

## II. UTILITIES' COMMUNICATION CHALLENGES

Starting from the communication challenges that smart energy faces in view of the Smart Grids establishment, we investigate the stringent Machine to Machine (aka M2M) and Machine Cloud Machine (MCM) Machine Type Communications (MTC) networking requirements of a range of today's smart (electricity and gas) meters, intelligent energy devices sensor/actuator devices and drones, identifying and handling current and anticipated limitations of communication networks. These challenges and associated requirements will drive the definition of research concepts that relate to achieving Smart Energy-as-a-Service by applying generic Network Function Virtualisation (NFVs) and domain-specific Virtual Network Functions (VNFs), leveraging on extended Mobile Edge Computing (xMEC) and distributed energy flexibility.

According to the 5G PPP Architecture Working Group, 5G networks aim to natively meet the requirements of three groups of use cases[5] :

*a)* Massive broadband (xMBB) that delivers gigabytes of bandwidth on demand

*b)* Massive machine-type communication (mMTC) that connects billions of terminals.

*c)* Critical machine-type communication (uMTC) that allows immediate feedback with high reliability and enables for example remote control over robots and autonomous driving.

Targeting the Smart Energy vertical domain, we define use cases covering all three groups of MTC communications and aim to examine how already defined 5G radio features could be used in Energy use cases and define NFV concepts as contributions to 5G studies which would optimise the performance for 5G network in the upper layers, to support the use case requirements.

### *A. Device identification and network autoconfiguration*

According to the Smart Grid paradigm, customers will play an active role in energy flexibility, being equipped with components for decentralized energy generation and local (possibly moving) energy storage. In such a framework, smart metering devices are quickly proliferating in number and need to exhibit a far more complex profile than today, offering services beyond traditional 15 minutes reporting, including support for real-time measurements, service discovery, infrastructure automation and AAA. However, for security, cost and operational rationality reasons, implementing the above features at full scale at smart meters level is, usually, impractical, also due to the high numbers of devices that need to access the network; smart metering should be kept at low cost, hence resource constrained. In turn, the currently employed smart meters' authentication solutions and centralized key management repositories create an informal customers' lock-in.

The challenge that 5G technologies has to face is to provide a framework that will allow for easy, real-time, automated devices identification so that network auto-configuration can be achieved automatically. Unified AAA should be achieved in a homogeneous manner, to reduce the chances of AAA misconfigurations among different services of the same or different tenant, to address multi-tenancy under geographically unbound mobility scenarios. Last, secure communications should be achieved irrespectively of the network service provided and the physical entity initiating the connection.

### *B. Predictive Maintenance for utility infrastructures*

Predictive Maintenance of distributed generation plants, energy transmission and distribution networks, like electricity cables and isolators, and gas/LNG tanks, pumps and pipelines, is an activity of utmost importance in achieving highest power network reliability. Especially in case of electrical isolators and the transmission lines along the electricity grid or the natural gas storage tanks, pumps or pipelines is critical with high accompanying cost.

Recently, the Energy industry started to adopt manually driven UAVs/Drones to perform visual inspections, but, again, special flight control certification has been necessary and the time required for such operations is, still, hindering wide adoption; using manually driven drones, an electricity transmission network may need to be traversed three or four times as each electricity transmission network has at least one power line for each electrical phase and a safety lightning protection cable, often with fibre optics inside, for communication purposes.

The challenge that 5G initiative has to face is to offer low-delay, 5G-enabled predictive maintenance for more efficient operation, accidents avoidance and fast restoration of energy networks, leading to reduced maintenance costs and increasing the QoE offered by the Utilities to the citizens.

### *C. Resilience and high availability via Dispatchable Demand Response (DDR)*

Energy cannot be easily stored at large scale, so utilities have traditionally matched demand and supply by shaping demand through Demand Response campaigns, inserting (very expensive) peaking plants to cover peak demand, or importing power from other utilities. The FP7 FINESCE Project has estimated that when EVs take-up reaches even 10% in the EU, the load will peak in the evenings at about 38GW, introducing very severe stability risks to the Utilities due to the mobility patterns of the EVs that introduce uncertainty in the grid management. As the penetration of EV rises above 10% the risk will further increase, demanding that solutions be researched and tested and to be ready for deployment before the volume of EVs becomes too large, and the cost of retro-fitting solutions become prohibitive.

In the same context, low cost, Phasor Measurement Unit (PMU), enabling precise state measurements to be made across an entire gird, support fast monitoring of distribution feeders, with data refresh of 10 to 50 times per second. However, such update frequencies open up vast new possibility for the fine-grained network control needed to manage the complex future grid, but also permitting potentially devastating attacks though manipulation and data mirages.

Last but not least, the increasing proliferation of EVs has been paving the way for the massive deployment of smart EV chargers, which will offer near real time communicating and interfacing with EV driver, with EV battery management system and with DSO, with a view to determine what appropriate scheduling of EVs may provide flexibility benefits to DSO (Vehicle to Grid service).

The challenge that 5G technologies has to face is to support fast response. Given that most of the times, storage is not available on-site, ultra-low (below 5ms) response from the energy operation centre is of vital importance. The enablement of large scale DDR requires extreme (for today's standards) communication requirements as metering and associated computational processes should be performed at very high frequencies.

## III. APPROACHES TO MEET THE CHALLENGES

To meet the described challenges, we have outlined novel approaches as follows. To meet the challenge for device identification and network autoconfiguration, our approach is grounded on a basic analysis of the considered use case which shows the need for efficient mMTC communications. We propose the realization of the "plug & play vision" in metering resources by implementing a novel and scalable xMEC paradigm. Beyond edge computing acceleration, we propose the design of a group of VNFs to facilitate distributed, scalable and trusted plug 'n' play functionality of hardware constrained devices. In more details, we focus on:

*a)* A virtual Terminals Self-Discovery (vTSD) VNF which, whenever needed, will initiate and broadcast discovery beacons and messages to identify nearby nodes and MEC nodes.

*b)* A virtual Self-Organizing Networks (vSON) VNF, which will realize a lightweight path selection paradigm in a multi-RAT landscape by selecting and establishing networking paths between the nodes and the edge-routers based on functional and non-functional requirements, e.g. trust metrics, expected transmission count (ETX), Expected Transmission Time (ETT) and explicit policy rules.

*c)* A virtual Machine-Cloud-Machine (vMCM) VNF, which will provide caching services for the smart meter values on the xMEC, enabling scalable remote access and significant reduction of the device energy consumption, as the devices may remain more at sleep mode and consuming less energy.

*d)* A virtual Mobility Management Entity (vMME) VNF, which will provide for idle mobile devices paging and tagging (e.g. safeguarding the location of EVs or mobile terminals in proximity).

*e)* A trust-service provisioning VNF based on Blockchains Processing (vBCP), which will provide a truly distributed key management mechanism based on the blockchains technology.

*f)* A virtual Authentication, Authorization, and Accounting (vAAA) VNF, which will combine novel, low complexity cryptographic approaches implemented on the smart meter with blockchains implemented by the vBCP. As blockchains offer a truly distributed keys repository, combination with inherited physical functions may create an AAA that overcomes utilities lock-in.

It is important to note that all proposed VNFs may be applied well beyond utility networks to any type of mobile hardware constrained terminal.

To meet the challenge for predictive maintenance of the energy infrastructures, we propose the use of semi-autonomous swarms of drones and parallel survey from different views/cameras. The UAVs/Drones swarms need to run complex, bandwidth demanding, computationally heavy and time critical applications, meeting a) operational requirements, such as to define the flight plan for each drone in a swarm, so that they have optimal coverage with minimal resources, taking into account the flight capability of each UAV/drone and the remaining energy, b) communication requirements, either by cellular or satellite links controlling the drones flight and uploading captured video and c) mission requirements, such as object (i.e. lines, pipes, tanks, blades, towers) video analysis and inspection.

Towards an energy infrastructure Predictive Maintenance as a Service (PMaaS) application, integration of application specific logic with a complex forwarding graph of VNFs is needed, such as:

*a)* A virtual Media Processing & Analysis (vMPA) VNF able to perform real time video streams processing and analysis. Though this VFV will be specialized for energy infrastructures-related video processing, it will be generic enough to be used for generic video processing and analysis, complementing existing VNFs such CISCO's Virtualized Video Processing VNF

*b)* A virtual Drones Flight Control (vDFC) VNF able to perform real time autonomous control of drones. This VNF will also be quite generic, as it may be used for applications such as precision agriculture, security monitoring of critical infrastructures and crown management.

Both VNFs will utilise the xMEC so that applications hosted on drones may migrate tasks from their embedded processor to a dedicated edge cloud accelerator, sense the traffic demand and the mobility/distribution of the drone swarms. Additional vMPA and vDFC instances may be deployed and/or their resources may be dynamically scaled-up in locations where there is an increased traffic processing demand. In this way, the access and especially the backhaul network capacity is preserved, thus offering the capability to the network infrastructure to allow remote control and conserve more users/terminals, while mobile operators monetize on their access/edge resources. Here we addresse: a) xMBB communications via the vMPA VNF for video streaming from the drones and analysis to the xMEC and the utilities control centre, and b) uMTC communications via the vDFC VNF for controlling the flight of drones.

To meet the challenge for resilience and high availability, we propose the realization of decentralized, communication demanding services such as AMI as a Service (AMIaaS), Dispatchable Demand Response as a Service (DDRaaS), Energy Infrastructure Fault Localization as a Service (FLaaS). All these services may be realized as closed loop applications, integrating application specific logic with a complex forwarding graph of collaborating utility-specific VNFs, such as:

*a)* A virtual Phasor Measurement Unit (vPMU) VNF, enabling precise state measurements to be made across an entire gird. In principle, fast sampling will be enriched with software based synchronization algorithms. To ensure reusability, this VNF will be a result of combined SFC and VNFFG techniques. VNF

*b)* A virtual Electricity Substation & Rerouting (vESR) VNF, enabling control of the local substation and electricity rerouting activities.

*c)* A virtual DER (vDER) VNF, enabling the optimized management and local control of distributed energy storage resources (like second life batteries, EVs on the move and EVs chargers), which will be in charge for providing low-latency flexibility provisioning services to the grid operator.

Pursuing this approach, we address: a) mMTC communications via the huge number of RES, DES and controlling units and b) uMTC communications as most VNFs require real-time control of the smart energy services.

## IV. THE PROPOSED FRAMEWORK

Our vision is shown in figure 1. At the lower level we may see the smart energy (electricity & gas) layer, composed of varying energy infrastructure assets. Over this layer, we consider the telecommunications network, consisting of cellular and mini-cells, IoT and satellite communications. The proposed (NRG-5) framework is positioned over these layers. Following the 5G Architecture vision, it consists of a number of VNFs offering IaaS, Self* functions and smart energy specific VNFs. At the higher later, we introduce mechanisms for xMEC offloading, elastic VNF sizing and chaining, M2M/MCM communications and trusted/scalable Plug 'n' play. All these activities are coordinated and supervised by a CI-SLA monitor and enforcement entity. As proof of context,

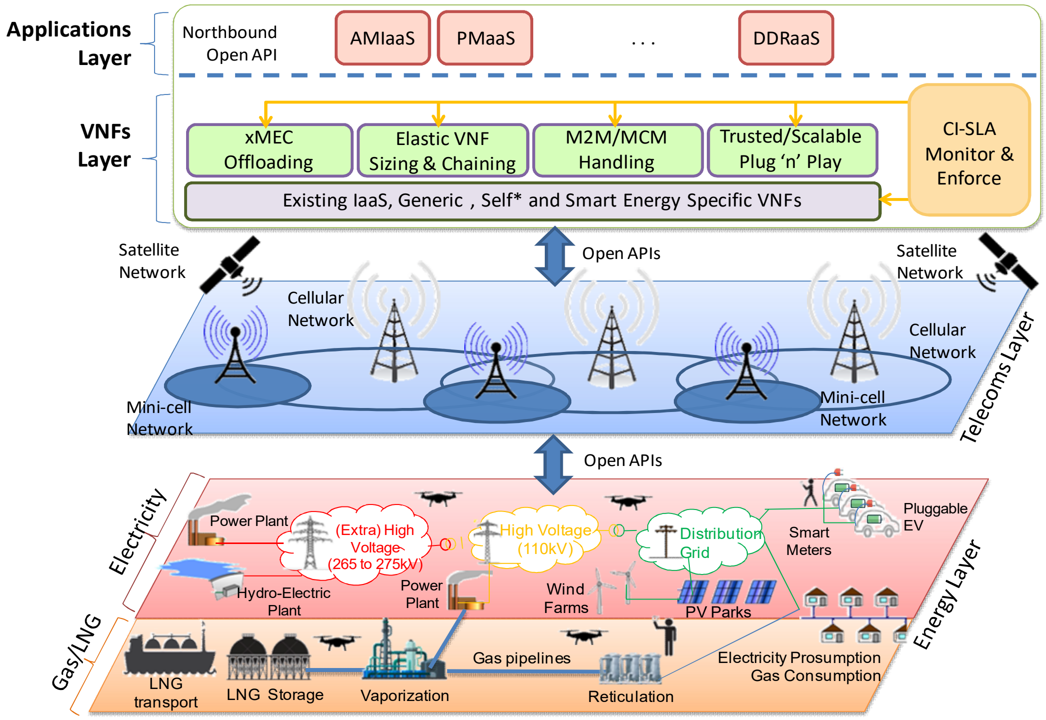

Fig. 1. The proposed framework which exploits 5G concepts to build an enhanced smart energy grid

we consider many novel utility functions offered following the "X as a Service" approach, separated by an Open Northbound API (NBI).

With respect to *decentralized trust & identity management*, we proposed the development of a smart meter device and software protocol stack as a generic 5G terminal to validate decentralised trust and identity management. The idea of using the Smart Meters for delivering value-added services, beyond just billing (e.g. Demand Side Management [6], power quality monitoring [7] and fault detection [8]) is not new. Currently, efforts on developing the NORM (Next Generation Open Real Time Smart Meter) are in place. Yet, little effort has been placed so far in services requiring high accuracy and precise time-tagging. So, we propose to leverage the H2020 SUCCESS unbundled smart meter architecture and introduce a scalable cloud-based stack, optional multi-RAT access interface and enriched security and trust features, to provide a next generation smart meter as 5G device prototype. PUF encryption will be combined with Blockchains to offer a decentralized trust & identity management mechanism, supporting end-users' privacy by design. In parallel, the self-* features will accelerate deployment. An abstraction layer will hide metering specific functionality (e.g. legacy meter for electricity or gas, hard real-time features such as PMU functionality) and physical network interfaces (offering event satellite access in case cellular coverage is not available). In this way, we will offer a novel, open solution, applicable not only for smart meters but any hardware constrained device, with built in trusted and vendor/ utilities lock-in free Plug 'n' Play functionality.

With respect to traceable Critical Infrastructures SLAs (CI-SLAs) and Extended MEC, trust and security are considered to play a major role in 5G systems. Especially critical infrastructures such as electricity and gas storage and distribution infrastructures request for high availability and resilience. We introduce the Critical Infrastructures SLAs (CI-SLAs) as the ability of the network, from a security and resilience perspective, to provide explicit, measurable and enforceable capabilities enabling the network to behave consistently in a prescribed way. Such CI-SLAs will specify the relevant security constraints for traffic, such as traffic isolation and network slicing requirements, desired levels of availability or the level of security assurance of network elements, while taking into account the energy asset severity, the cascading effect versus the time to recover from a malfunction (incident, accident or attack) and the relevant CAPEX and OPEX.

To enable traceability and enforcement of the CI-SLA, we introduce the concept of Blockchains technology based VNF Descriptors (VNFDs) and expand the ETSI MEC concept to become a trusted Multi-RAT MEC (xMEC) enabling process offloading from hardware constrained devices to the edge-cloud infrastructure. By utilizing blockchains VNFDs as processes tags, we introduce a traceable mechanism to monitor and enforce CI-SLAS. At execution time, an offloading decision will be taken, based on the remote node and xMEC status (e.g. CPU load, memory, network delay, etc), policies and license agreements. xMEC will employ fault-tolerant replication techniques, to re-execute any failing task execution, if this is feasible due to time constraints. Likewise, NRG-5 will be able to recall any incident, and modify the permissions granted to a migrated service or even revoke access to previously stored data. The combination of self-identifiable/traceable VNFDs and CI-SLAs monitoring play a crucial role in the considered use cases and exploitation potential, as they guarantee a realistic business model. We propose the support of novel business models via migration micro-contracts, which could be negotiate and unexceptionably monitored, while protecting the hosting node from malware, as it could directly identify and quarantine malicious nodes and applications at any time.

Turning our attention to elastic VNF optimal sizing, placing and chaining which is crucial to achieve smart energy requirements, beyond development of generic and utility specific VNFs, we propose the development of an automated, machine-learning based VNF handling mechanism for either automatically sizing the deployed VNFs to much operational needs, or automatically deciding the correct VNF architecture and size to operate under the CI-SLA required. In a multi-tenant environment, the machine learning VNF handling mechanism will interface the northbound interface NBI of both the single- and the multi-tenant MANOs so that hierarchical state-awareness is achieved. In this framework, elasticity of the network services will be able, even when collaboration of multiple communication service providers is mandatory. To support high flexibility, instead of relying on static definition of VNFDs, a mix of machine learning (e.g. K-Means Clustering combined with singular value decomposition and principal component analysis) and regression techniques (e.g. logistic regression and support vector machines for regression) will be employed to reduce data dimensionality, cluster the terminals based on their characteristics and forecast their behaviour in terms of communication requirements.

## V. CONCLUSIONS

This paper explores the requirements imposed by smart grid operations on 5G designs and it was found that smart grids place real and diverse challenges on 5G technologies. We proposed novel concepts and approaches as well as a concrete architectural framework that constitutes 5G an enabling technology for the next generation of smart grids. The proposed architecture will be implemented under the 5G Public Private Partnership (5G-PPP) framework and the EC funded project H2020 ICT-762013 NRG-5 (http://www.nrg5.eu). The complete framework will be validated in laboratory environment and in real life trials offered by ASM Terni (electricity network) and ENGIE (Gas/LNG network).

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