Smart Energy as a Service Network Architecture

Matching NRG-5 and 5G-PPP Architectural Group approaches

Th. Zahariadis, P. Trakadas, D.Skias,
H.C. Leligou, A.Gikaki, S.Voliotis
Electrical Engineering Department
TEISTE
Chalkida, Greece
zahariad@teiste.gr

Spada Maria Rita
Network Architecture Department
WIND TRE SPA
Trezzano Sul Naviglio Mi, Italy
MariaRita.Spada@windtre.it

A. Gonos, E.Kanakis
Research and Development
Optimum S.A.
N. Chalkidona, Greece
AGonos@optimum.gr

***Abstract*— The 5G network innovations aim to enable massive capacity, zero delay, faster service development, flexibility, elasticity and optimal deployment, less energy consumption, enhanced security, privacy by design and connectivity to billions of devices with less predictable traffic patterns. Many application areas, such as smart cities, e-health, intelligent transport, education or entertainment & media, have been proposed to demonstrate the 5G potential. Among them, one of the most challenging is the smart energy vertical, from Energy auto-configuration and Demand-Response to preventive maintenance of transmission and distribution electricity network. NRG-5 is a project that has received financial support by the European Commission to analyze the smart energy requirements from the 5G network and provide solutions towards 5G architecture. This paper presents the NRG-5 network architecture extensions to 5G-PPP Architectural Group work on 5G Network Architecture.**

Keywords—Energy Vertical, 5G Networks, Demand-Response, Network Architecture

I. Introduction

The massive deployment of IoT devices, mobile broadband and mission critical services along with a huge variety of scenarios, ranging from smart city to Virtual and Augmented Reality (VAR) are paving the way for a novel and disruptive 5G communication network. The 5G network innovations aim to enable massive capacity, zero delay, faster service development, flexibility, 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 the increasingly diverse set of new and yet unforeseen services, all of them with extremely diverging requirements, which will push mobile network performance and capabilities to their extremes. Additionally, it should provide flexible, yet smart and scalable adaptation and/or association of the available network resources to the specific requirements of the supported services, enabling a dramatic paradigm shift from CAPEX to the OPEX "Everything-as a-Service" driven business models.

To meet the 5G challenges, the European ICT industry has moved fast, developing a number of breakthrough innovations. The European vendors try to bring the new technology in the market but most products are still in the development phase, while global consensus is progressing slowly on how 5G will proceed with respect to technological barriers, regulatory restrictions and standardization activities. With respect to the technological barriers, it is clear that 5G networks will not be based on a single specific technology. Instead, 5G must be considered as a portfolio of access, connectivity and flexibility solutions addressing the demands and requirements of mobile communications beyond 2020. In order to cover the requirements from different application domains, technologies promoted in the 5G landscape range from advances on the radio access network, such as ultra-lean radio access design, device-to-device communications, MIMO antennas, along with the benefits of slicing management. Large consortia promote solutions for the softwarization of networks and virtualization of federated cloud environments, while large European operators and leading institutions build their own solutions, following ETSI NFV standards and open source community around OPNFV. Additionally, mobile and fiber operators are striving to reduce OPEX and CAPEX and looking for technological solutions that would allow them on one hand to extend their profit while on the other hand address the 5G requirements (increased bandwidth, billions of devices, zero-latency applications and fast services development).

To support and accelerate 5G development and deployment in Europe, the European Commission and the European ICT industry (ICT manufacturers, telecommunications operators, service providers, SMEs and researcher Institutions) have created the 5G Infrastructure Public Private Partnership (5G PPP) joint initiative. The 5G-PPP is now in its second phase where 21 new projects were launched in Brussels in June 2017. The 5G PPP will deliver solutions, architectures, technologies and standards for the next generation communication infrastructures of the coming decade, securing Europe's leadership in particular areas, where Europe is strong or where there is potential for creating new markets such as smart cities, e-health, intelligent transport, education or entertainment & media.

One of the most challenging domains, especially with respect to delay and response time, reliability and service continuity, to be supported by 5G networks is the energy

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transmission and distribution service. The energy domain (both electricity and gas) requires response delay in the range of millisecond and self healing features to overcome service disruption.

The NRG-5 ("Enabling Smart Energy as a Service via 5G Mobile Network advances") project is selected by the EC (Contract No. 762013) to design and develop a novel 5G solution for the energy vertical context. NRG-5 will analyze the smart energy requirements from the 5G network point of view and provide solutions towards an energy vertical oriented 5G architecture. This paper presents the NRG-5 network architecture extensions to the 5G-PPP Architectural Group work on 5G Network Architecture.

II. ENERGY VERTICAL COMMUNICATION CHALLENGES

According to the 5G PPP Architecture Working Group and ITU, 5G networks aim to natively meet the requirements of three groups of communications [1]:

a) *Massive Machine Type Communications (mMTC)* expected to connect a large number of M2M devices with a range of performance and operational requirements, with further improvement of low-cost and low-complexity device types as well as extension of coverage.

b) *Extreme Massive broadband (eMBB)* achieving higher data rates and improvements in capacity, supporting high quality video (i.e. 3D, UHD/4K/8K/12K), and

c) *Ultra-reliable and low-latency communications (URLLC)* that allows critical machine-type communication and immediate feedback with high reliability and enables for example remote control over robots and autonomous driving.

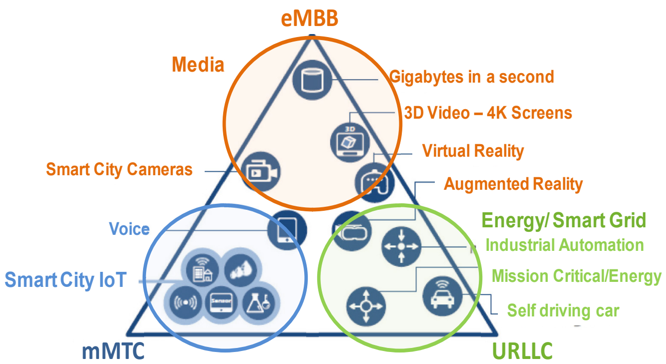

Fig. 1. 5G main communication types.

For examples as it is shown in Fig. 1, Energy/Smart Grid mainly fit in the URLLC category, media including Augmented and Virtual Reality are positioned in the eMBB category, while Smart City IoT are in the mMTC category.

Targeting the Smart Energy vertical domain, NRG-5 has defined use cases covering all three groups of 5G communications. In more details, NRG-5 defines the following use case:

A. *Smart Meter identification and 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, terminal auto-discovery, and authorization. However, for security, cost and operational reasons, full implementations of the above features is impractical, while cost should remain low. On the other hand, self discovery and auto configuration should enable customers to avoid utilities lock-in.

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. The challenge that 5G has to face is to offer remote flight control of drones (or swarms of drones) based on video analysis of drones' cameras [2].

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. There are estimations that when Electrical Vehicles (EV) 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 [3]. 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.

In summary, NRG-5 use cases change all three category types of 5G communications. The dense deployment of Smart meters, EVs and PMUs challenge the mMTC service type, the PMUs operations, the energy rerouting in DDR (below 5ms requirements) and the remote flight control of drones challenge the URLLC category, while the real-time video transmission from the (swarm of) drones challenge the eMBB service type.

III. 5G-PPP ARCHITECTURE GROUP PROPOSAL

The 5G PPP Architecture Group has proposed a quite complete 5G Network Architecture [4]. From a pure and high level technological point of view, the proposed architecture is shown at Fig. 2. In a left to right approach, we consider at the lower layer the RAN, Edge, Transport and Core infrastructure, various radio, satellite and IoT 5G radio interfaces along with optical/metro access networks. Moreover, we consider xMEC nodes, edge and core routers, SDN switches and controllers, along with complete Data Centres.

At the logical Network Infrastructure layer, we consider various PNFs (Physical Network Functions) and VNF (Virtual Network Functions), including functions such as AMF (Access & Mobility Management Function) and UPF (User Plane Functions) offering UE-based Authentication, Authorization and Mobility Management and packet routing and forwarding functions respectively. In this layer, we also consider Application specific Virtual Functions (AVF), such as media processing or blockchains' processing, which are offloaded from User Equipment (UE) that take advantage of the Edge or core computational power.

At the higher layer, we consider the Software Defined Mobile Network (SDM) Control and Network Slice Layer, which is responsible for the end-to-end network slicing. This layer creates groups of network resources, connects the physical and virtual network and service functions as appropriate and instantiates all network and service functions assigned to the slice. The SDM-C and SDM-X entities control and coordinate respectively the resources translating decisions of control applications into commands to VNFs and PNFs.

At the Management and Network Orchestration (MANO) layer we consider multiple MANO functions, including the VIM (Virtual Infrastructure Manager), the NFVO (NFV Orchestrator), the VNF Manager, along with domain specific application management functions, such as 3GPP Element Management and Network (sub-)slice Management functions and ETSI NFV MANO. At this layer, we also consider an Inter-slice Broker and Network Slice Selection Function that transforms consumer-facing service description into resource-facing service description and vice versa. Last but not least, this layer also hosts the Multi-domain Service Management and Orchestrator (SMO) component, which bridges the service layer with the Inter-slice broker.

At the service layer, we consider various multi-tenant applications and services. Within facility architecture, we also foresee DevOps tools, including SDKs, programming and proofing tools and an Experimentation Toolboxes, which will initiate experimentation over the 5G facility at local or pan-European level.

IV. NRG-5 ARCHITECTURE DESIGN PRINCIPLE

Aiming to offer Smart Energy as a Service utilizing 5G communication networks, NRG-5 project adopts and contributes to the 5G-PPP Architecture Working group proposal and extends it to meet specific requirements. As a first step we define and adopt a number of design principles:

a) *The terminals should be as simple and low cost as possible.* To meet this requirement we decided to move all intelligence from the terminals to the infrastructure network.

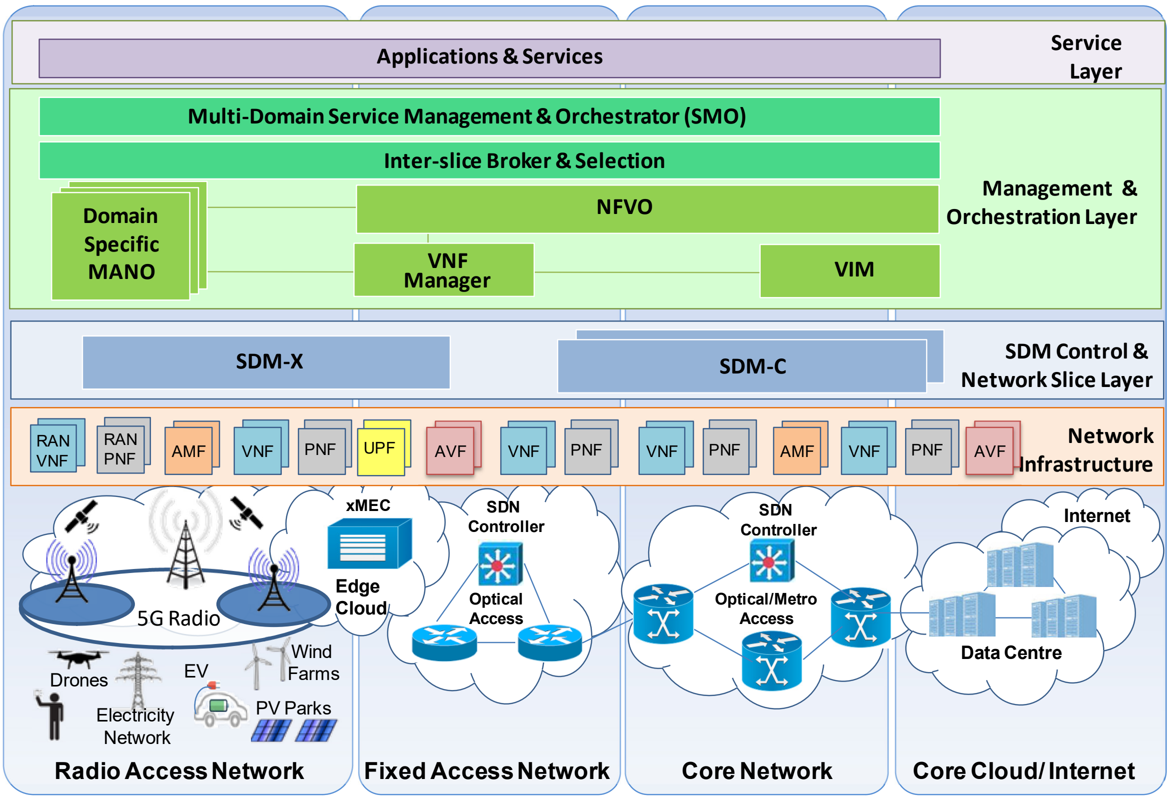

Fig. 2. A high level view of 5G-PPP Architectural proposal

b) *The service should be flexible but the security high*. This requirements is somewhat conflicting NRG-5 need to offer flexible terminal discovery and self-organizing functions, without locking any devices with a specific utility or telecom operator. As a coincidence, beyond an comprehensive Authentication and Authorization, business models based on distributed and trusted accounting and smart contracts should be introduced.

c) *Response time and delay should be minimal.* To meet the very strict requirements of electricity rerouting and drones' control, the functionality must be moved as close to the terminal as possible (to the edge cloud if possible).

d) *Accurate Mobility is mandatory.* As various terminals (i.e. drones) and energy storage devices (i.e. Electrical Vehicles) will be moving, their accurate position well more accurate than the 5G cell that are located is needed. As such, Mobility Management Entity (MME) should provide information in a range of meters.

V. Focus on the Mobile Edge Cloud

In order to meet the above Smart Energy as a Service requirements and respect the design principles, NRG-5 has decided to focus on the infrastructure edge and offload as much functionality as possible to an extended Mobile Edge Cloud (xMEC). As shown in Fig. 3 we consider at the lower lay various physical interfaces in a multi-Radio Access Technology (multi-RAT) and over that a virtualized MEC computing/networks layer followed by a NFV Infrastructure (NFVI). On top, the proposal NRG-5 architecture enriches the capabilities of the 5GPPP approach offering new virtualized functions tailored to offer the expected capabilities according to the requirements of the Energy vertical context organized in different logical groups:

A. Group 1: General Core VNFs:

This group of VNFs includes all the virtual functions requested to discover devices and services in the network, to allow the self-organize and self-optimize the communication and the routing services between devices that have limited network, along with virtual functions requested to recognize and authorize the different elements and allow a secure connection for the data exchange according to the requested services. In this group we foreseen the following VNFs:

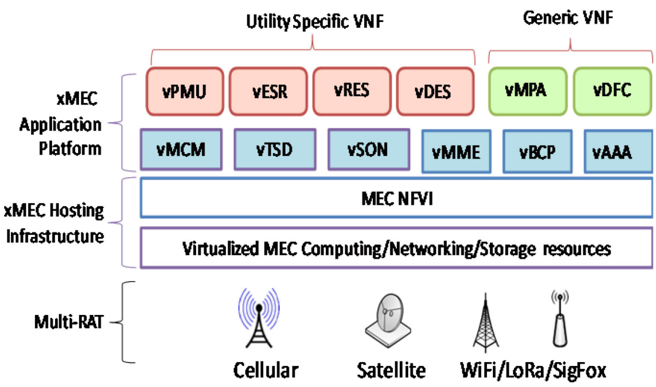

Fig. 3. NRG-5 Extended Mobile Edge Cloud

- ***vTSD*** (virtual Terminals Self-Discovery): this VNF, offers device and services discovery services at local area level (depending on the area covered by the base station hosting the xMEC stack)
- ***vSON*** (virtual Self-Organizing Networks): offers device topology determination as well as optimized routing services to groups of devices that have limited network connectivity capabilities
- ***vMCM*** (virtual Machine-Cloud-Machine): allows utility resources to be stored in the cloud and accessed by multiple users with any scaling issues
- ***vMME*** (virtual Mobility Management Entity): an extension to the standard LTE MME, which provides for idle mobile devices paging and tagging including GPS location (e.g. safeguarding the location of EVs, mobile terminals or drones)
- **vBCP** (virtual Blockchains Processing): offers an easy-to-use and universal API gateway allowing multiple applications to benefit from the security, immutability and transparency properties of the Blockchain technology
- ***vAAA*** (virtual Authentication, Authorization, Accounting): provides services related to the administration of the field devices at the level of AAA.

B. Group 2: General Applications VNFs:

Within NRG-5, we consider that drones will be the smart phone of the future, seamlessly integrated and receiving integral support from the 5G network. To support remote drones flight control, we introduce two application specific VNFs namely:

- ***vMPA*** (virtual Media Processing & Analysis): performs near-real-time video streams processing and analysis so that e.g. results of the drones-transmitted video data are managed in real time
- ***vDFC*** (virtual Drone Flight Control) performs real time autonomous remote control of drones

C. Group 3: Smart Energy Specific VNFs:

In this group, we consider VNFs specialized to meet the smart energy functionality, including.

- ***vPMU*** (virtual Phasor Measurement Unit) monitors the state of the grid by measuring voltage levels and frequency values of selected locations of the grid
- ***vESR*** (virtual Electricity Substation & Rerouting): enables control of the local substation and electricity rerouting activities.

- ***vRES*** (virtual Renewable Energy Sources): provides low-latency flexibility services to the grid operator that can be used in DR campaigning to keep the grid balanced
- **vDES** (virtual Distributed Energy Storage): provides energy flexibility in a certain time interval; the function deals with flexibility provisioning services to the grid operator that can use it to issue demand response (DR) campaigning

VI. CONCLUSIONS

The 5G network innovations aim to enable massive capacity, zero delay, faster service development, flexibility, elasticity and optimal deployment, less energy consumption, enhanced security, privacy by design and connectivity to billions of devices with less predictable traffic patterns. Many application areas, such as smart energy, which is one of the most demanding vertical.

In this paper, we have presented the generic 5G-PPP Architecture Group proposal for the 5G Network Architecture, along with extension from NRG-5 mainly at the edge cloud to meet the specific Smart Energy as a Service 5G Network Architecture.

ACKNOWLEDGMENT

This paper has been funded by the European Commission H2020/5G PPP NRG-5 Project under the contract No. 762013.

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