Towards an SDN/NFV-based multi-tenant network and cloud testbed for end-to-end 5G services

Raul Muñoz, Josep Mangues-Bafalluy, Nikolaos Bartzoudis, Ricard Vilalta, Ricardo Martínez, Ramon Casellas, Nicola Baldo, José Nuñez-Martínez, Manuel Requena-Esteso, Oriol Font-Bach, Miquel Payaró, Pol Henarejos, Ana Perez-Neira.
Centre Tecnològic de Telecomunicacions de Catalunya, CTTC
Av. Carl Friedrich Gauss 7, 08860 Castelldefels (Barcelona), Spain
Email: raul.munoz@cttc.es

***Abstract*—5G has a main requirement of highly flexible, ultra-low latency and ultra-high bandwidth virtualized infrastructure in order to deliver end-to-end services. This requirement can be met by efficiently integrating all network segments (radio access, aggregation and core) with heterogeneous wireless and optical technologies (5G, mmWave, LTE/LTE-A, Wi-Fi, Ethernet, MPLS, WDM, software-defined optical transmission, etc.), and massive computing and storage cloud services (offered in edge/core data centers). This paper introduces the preliminary architecture aiming at integrating three consolidated and standalone experimental infrastructures at CTTC, in order to deploy the required end-to-end top-to-bottom converged infrastructure pointed out above for testing and developing advanced 5G services. The existing experimental facilities cover complementary technologies from terminals to radio access, aggregation/core and cloud, and are namely: the three experimental facilities are the GEDOMIS®testbed (LTE/5G PHY testbed), the EXTREME Testbed®(wireless HetNet and backhaul, and edge data-center), and the ADRENALINE Testbed®(packet aggregation and optical core network, core data-center). Two uses cases addressing Fixed Mobile Convergence (FMC) developed in ADRENALINE and EXTREME, and virtual mobile network function splitting and deployment, involving EXTREME and GEDOMIS, are also presented.**

I. Introduction

Software Defined Networking (SDN) [1] and Network Functions Virtualization (NFV) [2] architectures are the key enablers to federate heterogeneous experimental facilities and to integrate both network and cloud resources to offer advanced end-to-end 5G services upon multi-domain heterogeneous networks and distributed data centers (DC).

SDN has emerged as the most promising candidate to improve network programmability and dynamic adjustment of the network resources. SDN is defined as a control framework that supports the programmability of network functions and protocols by decoupling the data plane and the control plane, which are currently integrated vertically in most network equipment. SDN proposes a logically centralized architecture where the control entity (SDN controller) is responsible for providing an abstraction of network resources through Application Programming Interfaces (API). One of the main benefits of this architecture resides on the ability to perform control and management tasks of different wireless and wired network forwarding technologies (e.g., packet/flow switching or circuit switching) by means of the same network controller. The OpenFlow protocol is the most commonly deployed protocol for enabling SDN. It offers a logical switch abstraction, mapping high-level instructions of the protocol to hide vendor-specific hardware details, which mitigates inter-operability issues commonly found in multi-vendor deployments [3]. This abstraction enables SDN to perform network virtualization, that is, to slice the physical infrastructure and create multiple co-existing network slices (virtual networks) independent of the underlying wireless or optical technology and network protocols. In a multi-tenant environment, these virtual networks can be independently controlled by their own instance of SDN control plane (e.g., virtual operators) [4].The notion of NFV relates to deploying network functions that are typically deployed in specialized and dedicated hardware servers, as software instances (named virtual network functions - VNF) running on commodity servers in data-centers (DCs) through software virtualization techniques. Examples of VNFs include IP network functions such as load balancers, firewalls, security or Authentication, Authorization and Accounting (AAA), LTE/EPC network functions, such as Mobility Management Entity (MME), Serving Gateway (SGW), and PDN Gateway (PGW), or transport network functions [5] [6].

5G will enable the collection of a huge amount of data generated at the terminals, sensors, machines, nodes, etc., that will be transported through networks to data-centers in order to be processed (Big Data) and make the proper decisions (Cognition). Additionally, the recent rise of NFV services will also require investments in cloud/DC [7]. Originally, cloud computing services have been offered in centralized DCs. However, there is a general trend to spread the DCs to the edge of the network in order to reduce services' latency to the end user. The extension of cloud computing and services to the edge of the network is known as fog computing, and it will lead to an exponential growth on the inter-data center traffic requiring high-bandwidth and low-latency 5G networks to interconnect them and offer global end-to-end cloud services. Current Distributed/Federated cloud computing solutions does not take advantage of the dynamicity and flexibility of the network. The network is considered a commodity providing fixed bandwidth pipes for bulk data. A real integration and orchestration of distributed cloud and heterogenous network resources across multi-domain multi-layer wireless/optical network infrastructures (5G, mmWave, LTE/LTE-A, Wi-Fi, Ethernet, MPLS, WDM, software-defined optical transmission, etc.) is required for deploying end-to-end 5G services.

This paper introduces in Sec.II the preliminary architecture aiming at integrating three consolidated and stand alone experimental infrastructures developed by CTTC, in order to deploy the required end-to-end top-to-bottom converged platform for testing and developing advanced end-to-end 5G services. These experimental facilities cover complementary technologies from terminals to radio access, aggregation/core and cloud. The three experimental facilities are the GEDOMIS®testbed (LTE/5G PHY testbed) [**?**], the EXTREME Testbed®(wireless HetNet and backhaul, and edge data-center) [**?**], and the ADRENALINE Testbed®(packet aggregation and optical core network, core data-center) [**?**], as shown in Fig.1. Section III presents a use case addressing Fixed Mobile Convergence (FMC) developed in ADRENALINE and EXTREME, and Section IV depicts a use case on virtual mobile network function splitting and deployment, involving EXTREME and GEDOMIS.

II. SDN/NFV NETWORK AND CLOUD COMPUTING PLATFORM ARCHITECTURE

Ideally, the SDN architecture is based on a single control domain comprising multiple network nodes featuring diverse technologies provided by different vendors that are controlled through standard interfaces. However, network operators usually fragment their networks into multiple domains to cope with administrative and regional organizations. Each domain can be provided by a different vendor with its own control plane technology (SDN/OpenFlow with some proprietary extensions, legacy GMPLS/PCE, MPLS control, etc.). In our 5G experimental platform, the RAN provided by EXTREME and GEDOMIS is controlled by an SDN controller, and the MAN and WAN provided by ADRENALINE are controlled by an SDN controller and a distributed GMPLS control plane with an Active Stateful PCE, respectively. Thus, a multi-domain network orchestration mechanism is required, as proposed in Fig.1. The network orchestration mechanism acts as unified network operating system (or controller of controllers) allowing the composition, at a higher, abstracted level, of end-to-end virtual infrastructures [8] as well as end-to-end provisioning services [9] across multiple domains with heterogeneous control and network technologies. SDN is a suitable candidate for end-to-end network service orchestration due to its centralized control nature and the standard and open northbound APIs.

In our 5G end-to-end experimental platform shown in Fig.1, EXTREME contributes with edge DCs close to the end users connected to the RAN, and ADRENALINE with core DCs connected the optical core network. In our approach, global virtualization of IT resources in distributed DCs is provided by means of a Distributed-DC Cloud Orchestrator, responsible of logically managing multiple distributed Cloud Controllers in a federation of multi-cloud testbeds [10], where each Cloud

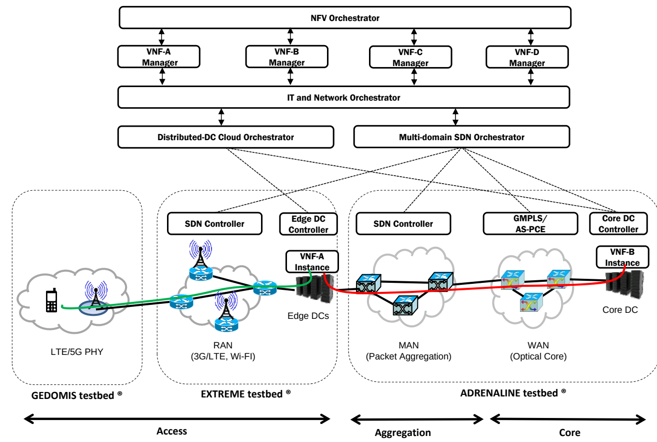

Fig. 1: CTTC SDN/NFV-based multi-tenant network and cloud testbed for end-to-end 5G services

Controller provides Infrastructure as a Service and may be deployed with different cloud computing software platforms, such as OpenStack, CloudStack or OpenNebula. The Cloud Orchestrator takes over the creation/ migration/ deletion of VM instances (computing service), disk images storage (image service), and the management of the VM network interfaces (networking service) from any DC.

The interconnection of different DC sites that are physically dispersed, but logically centralized is one of the major challenges to face in order to provide global end-to-end cloud and NFV services. VNFs running on top of a VM can be located in the most appropriate DC, and can be interconnected between them and with the end users (i.e., terminals) in a certain way (forwarding graph) in order to achieve the desired overall end-to-end functionality or service. This is known as ”service chaining”. Thus, VNFs can be distributed over several DCs connected through multiple heterogeneous wireless and optical networks. Consequently, there is the need to perform an integrated orchestration of cloud (IT) and network resources to dynamically deploy virtual machines and provide the required network connectivity between DCs and between DCs and end-users [11]. In our architecture, this function is provided by the IT and Network Orchestrator, as shown in Fig.1, and is responsible of effectively coordinating the management of the IT resources in the distributed DCs, and the network resources in the heterogeneous optical and wireless networks, providing a unified operating system towards the applications, such as the VNF managers. The VNF manager is responsible for the lifecycle management (i.e., creation, configuration, and removal) of a Virtual Network Function. Finally, the NFV Orchestrator is the responsible for managing the life cycle of the different VNFs and the required network resources in order to deploy end-to-end NFV forwarding graphs.

III. USE CASE 1: FIXED MOBILE CONVERGENCE.

Ricardo + Nicola

IV. USE CASE 2: VIRTUAL MOBILE NETWORK FUNCTION SPLITTING AND DEPLOYMENT

Josep + Nikos

V. CONCLUSIONS

This paper has presented the preliminary architecture of an SDN/NFV network and cloud computing platform for end-to-end 5G services. This platform integrates ADRENALINE, GEDOMIS and EXTREME testbeds, three complementary testbeds developed by CTTC, spanning from terminals to radio access network, aggregation/core networks and cloud. One of the challenges to face is to deploy a multi-domain network orchestration mechanism to offer dynamic and flexible end-to-end connectivity and virtual network provisioning services across multi-domain and multi-technology networks, integrating all network segments (radio access, aggregation and core) with heterogeneous wireless and optical technologies. The second main challenge is to perform an integrated orchestration of distributed cloud resources (virtual compute and storage)and network resources to dynamically deploy virtual machines or VNF instances and provide the required network connectivity between DCs and between DCs and end-users. Two prelim integration scenarios have been defined and the preliminary results have presented. The former integrates ADRENALINE and EXTREME to deploy a Fixed Mobile Convergence use case. The latter integrates EXTREME and GEDOMIS to deploy a use case on virtual mobile network function splitting and deployment.

VI. ACKNOWLEDGEMENTS

The GEDOMIS®testbed, the EXTREME Testbed®, and the ADRENALINE Testbed®, are partially financed by the Operational European Regional Development Fund Programme Catalonia 2007-2013.

REFERENCES

[1] "Sdn architecture 1.0," *Open Networking Foundation (ONF), https://www.opennetworking.org/images/stories/downloads/sdn-resources/technical-reports/TR_SDN_ARCH_1.0_06062014.pdf*, 2014.

[2] "Network function virtualization (nfv): Architectural framework," *ETSI GS NFV 002 v.1.1.1,*, 2013.

[3] N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, and J. Turner, "Openflow: enabling innovation in campus networks," *ACM SIGCOMM Computer Communication Review*, vol. 38, no. 2, pp. 69–74, 2008.

[4] A. Autenrieth, T. Szyrkowiec, K. Grobe, J.-P. Elbers, P. Kaczmarek, P. Kostecki, and W. Kellerer, "Evaluation of virtualization models for optical connectivity service providers," in *Optical Network Design and Modeling, 2014 International Conference on*. IEEE, 2014, pp. 264–268.

[5] R. Vilalta, R. Muñoz, R. Casellas, R. Martínez, V. López, and D. López, "Transport network function virtualization."

[6] R. Vilalta, R. Muñoz, R. Casellas, R. Martínez, T. Szyrkowiec, V. Autenrieth, A.and López, and D. López, "Sdn/nfv orchestration for dynamic deployment of virtual sdn controllers as vnf for multi-tenant optical networks," in *In Proc. Optical Fiber Communication Conference (OFC)*. OSA, 2015.

[7] M. Chiosi, D. Clarke, P. Willis, A. Reid, J. Feger, M. Bugenhagen, W. Khan, M. Fargano, C. Cui, H. Denf *et al.*, "Network functions virtualisation: An introduction, benefits, enablers, challenges and call for action," in *SDN and OpenFlow World Congress*, 2012, pp. 22–24.

[8] R. Vilalta, R. Muñoz, R. Casellas, Rm abnd Martinez, F. Francois, S. Peng, R. Nejabati, D. Simeonidou, N. Yoshikane, T. Tsuritani, I. Morita, V. Lopez, T. Szyrkowiec, and A. Autenrieth, "Network virtualization controller for abstraction and control of openflow-enabled multi-tenant multi-technology transport networks," in *In Proc. Optical Fiber Communication Conference (OFC)*. OSA, 2015.

[9] R. Muñoz, R. Vilalta, R. Casellas, R. Martínez, F. Francois, M. Channegowda, A. Hammad, S. Peng, R. Nejabati, D. Simeonidou *et al.*, "Experimental assessment of abno-based network orchestration of end-to-end multi-layer (ops/ocs) provisioning across sdn/openflow and gmpls/pce control domains," in *Optical Communication (ECOC), 2014 European Conference on*, 2014.

[10] J. A. L. d. Castillo, K. Mallichan, and Y. Al-Hazmi, "Openstack federation in experimentation multi-cloud testbeds," in *Cloud Computing Technology and Science (CloudCom), 2013 IEEE 5th International Conference on*, vol. 2. IEEE, 2013, pp. 51–56.

[11] A. Mayoral, R. Vilalta, R. Muñoz, R. Casellas, and R. Martinez, "Experimental seamless virtual machine migration using an integrated sdn it and network orchestrator," in *In Proc. Optical Fiber Communication Conference (OFC)*. OSA, 2015.