Experimental Demonstration of Distributed Multi-tenant Cloud/Fog and Heterogeneous SDN/NFV Orchestration for 5G Services

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***Abstract*—It is expected that in 5G networks billions of smart devices will generate huge aggregated volumes of data that will be processed in distributed cloud/fog infrastructure. To this end, it is required an integrated management of the network and the cloud resources forming a converged end-to-end system. Software Defined Networking (SDN) and Network Function Virtualization (NFV) architectures are the key enablers to integrate both network and cloud resources, enabling cross-optimization in both sides.**

This paper presents the experimental activities related to 5G services using the ADRENALINE testbed located at CTTC premises in Castelldefels (Barcelona, Spain). SDN orchestration is presented as a feasible and scalable solution for providing end-to-end connectivity between heterogeneous networks and cloud/edge computing. Moreover, we present the demonstration of an SDN/NFV orchestrator to dynamically create virtual backhaul tenants over a multi-layer (packet/optical) aggregation network and deploy virtual network functions to better adapt the capacity increase of Mobile Network Operators.

I. Introduction

The fifth generation of mobile networks technology (5G) is not only focused on the evolution of the radio technologies, but with the design of a new End-to-End (E2E) converged network and cloud infrastructure.

This converged infrastructure, illustrated in Fig. 1, is composed of: E2E heterogeneous network segments covering radio and fixed access, metro aggregation, and core transport involving heterogeneous wireless and optical technologies; massive distributed cloud computing and storage infrastructure; and large amounts of heterogeneous smart devices and terminals for traditional mobile broadband services (e.g., smartphones, tablets, etc.) and IoT services (e.g. sensors, actuators, robots, cars, drones, etc.).

From the network perspective, the 5G architecture needs to provide high flexibility, low-latency, and high-capacity in order to support the forecasted 1000x growth in mobile data traffic with sub-millisecond latency [1]. On the control/management side, E2E connectivity services need to be provisioned between distributed cloud infrastructures and end users. These requirements can only be met by efficiently integrating heterogeneous access (RAN, fixed access, satellite, Wi-Fi, personal area networks), optical/wireless crosshaul (fronthaul/backhaul), metro aggregation packet networks and high-capacity optical core transport networks.

For this integration, SDN Orchestration is proposed to coordinate, in a hierarchical, logically centralized manner, the heterogeneous control plane technologies of the different network segments, which may remain separated as independent administrative domains. Moreover, the current SDN controllers northbound interface (NBI) is highly heterogeneous and technology and vendor dependent. The STRAUSS project has defined the first Transport API named Control Orchestration Protocol (COP), that abstracts the particular control plane technology of a given transport domain. COP provides a research-oriented multi-layer approach using YANG/RESTconf [2].

At the cloud level, the demand of massive computing and storage will dramatically be increased by new 5G services, which will require processing and storage capabilities (e.g., Big Data). In addition, the impending growth of Network Function Virtualization (NFV) [3] and Mobile Edge Computing (MEC) [4] also require cloud services for the deployment of software functions (e.g., mobile Evolved Packet core (EPC), local cache, firewalls). Originally, cloud services have been implemented in core data centers (DCs) for high-computational or long-term processing. However, the cloud is being spread to the edge of the network (e.g., in edge DCs located in the metro network, or even in network nodes or mobile base stations with cloud capabilities) in order to reduce the latency of services for the end user. This concept is referred to as fog computing [6]. Therefore, 5G networks need a global orchestration for the distributed cloud/fog implementation and the management of heterogeneous networks.

The ongoing efforts carried out by CTTC towards the aforementioned integration architecture are condensed in the presented 5G SDN/NFV experimental platform for testing advanced end-to-end IoT and mobile services [5]. In this paper, we present in detail three different use cases available for real-life demonstration in our platform:

- End-to-End SDN Orchestration of IoT Services Using an SDN/NFV-enabled Fog Node
- Hierarchical SDN Orchestration of Wireless and Optical Networks
- Integrated SDN/NFV Orchestration for the Dynamic Deployment of Mobile Virtual Backhaul Networks

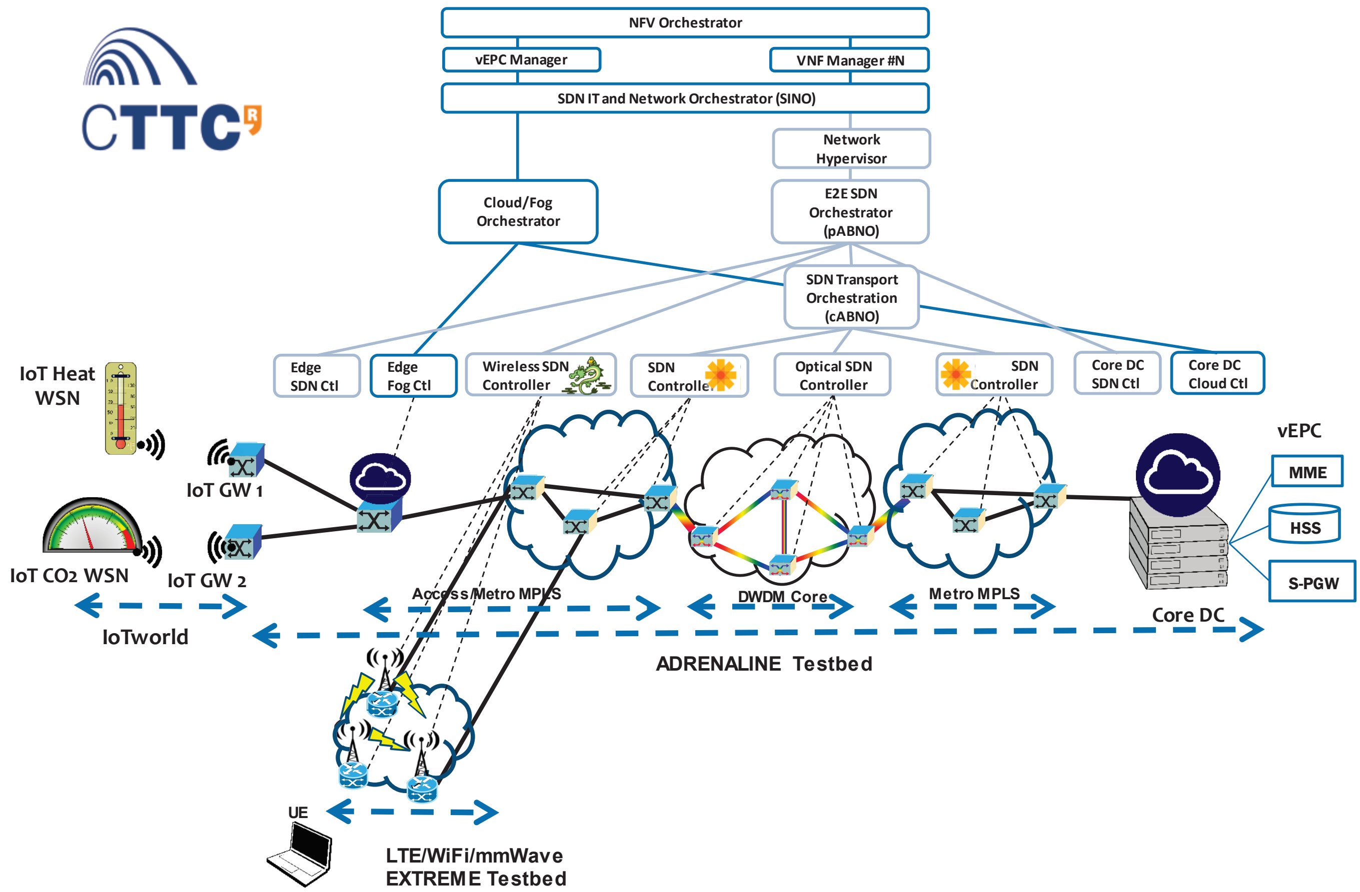

Fig. 1: ADRENALINE Testbed for 5G services

This paper is organized as follows, section 2 introduces the implementation details of the CTTC 5G experimental tested; section 3 includes the detailed description of the three 5G use cases available for real-life demonstration in our testbed; and finally section 4 summarizes the conclusions and future work.

II. Experimental setup description

The cloud computing platform and transport network of the ADRENALINE Testbed (Fig. 1) is composed by the Cloud/Fog infrastructure, the intra-DC networks, the multi-domain heterogeneous Wireless/Optical networks and the control/management planes, all physically installed at CTTC premises in Castelldefels (Barcelona, Spain). The presented demonstrations exploit the ADRENALINE testbed system features, as well as they also integrate EXTREME testbed (SDN-enabled wireless domain) and IoTworld testbed (based on wireless sensor networks).

For the cloud/fog computing platform, we have deployed OpenStack Liberty into Commercial Off The Shelf (COTS) servers. Two availability zones have been defined in order to emulate distributed DC locations, which are interconnected as depicted in Fig. 1. The Fog/Edge node has been implemented using an Intel Next Unit of Computing (NUC) on top of which is deployed an OpenStack compute node instance running in a third availability zone.

For the intra-data center network, OpenFlow switches have been employed. All inter-DC traffic is aggregated to the core through the access/metro segments which are composed of OpenFlow 1.4 switches deployed on COTS hardware with several 1G NICs implemented by xDPD software switch. Each Metro/Core border node includes a 10 Gb/s XFP tunable transponder interface. Both the intra-data center networks, and the access/metro segments are controlled with OpenDayLight (ODL) SDN Controller, Hydrogen Service Provider release instances using OpenFlow.

The inter-data center interconnection traverse across the core GMPLS-controlled optical network segment. This is composed of an all-optical WSON with 2 ROADMs and 2 OXCs providing re-configurable (in space and in frequency) end-to-end lightpaths, deploying a total of 610 km of G.652 and G.655 optical fiber, with six DWDM wavelengths per optical link. The optical SDN controller is responsible for the inter-data center network connectivity and it has been implemented following the Active Stateful Path Computation Element (AS-PCE) architecture.

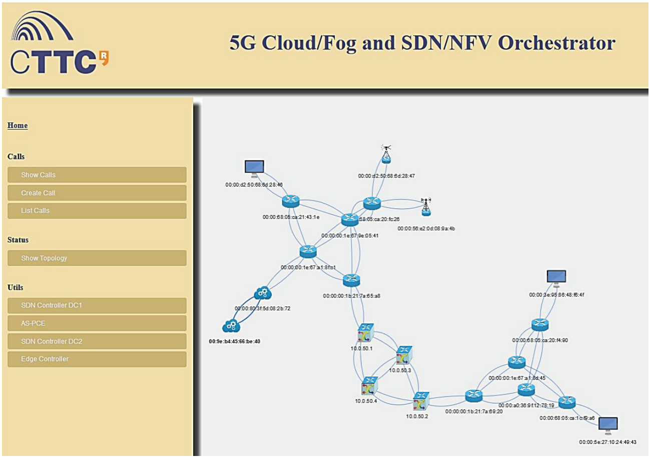

Fig. 2: 5G Cloud/Fog and SDN/NFV orchestrator

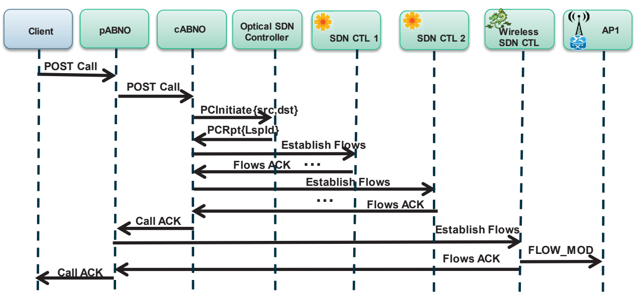

Fig. 3: a) Message exchange for hierarchical SDN orchestration; b) Network Topology abstraction at the E2E SDN orchestrator level

Fig. 2 shows the user interface for the overall 5G Cloud/Fog and SDN/NFV orchestrator software stack. It is composed of the NFV orchestrator, several VNF managers, an SDN IT and Network Orchestrator (SINO), a network hypervisor and an hierarchical SDN orchestrator. The 5G Cloud/Fog and SDN/NFV orchestrator software stack has been developed entirely in Python by CTTC and it is able to provide multi-tenancy over SDN/NFV-enabled multi-vendor multi-technology network and cloud/fog computing resources.

III. 5G SDN/NFV Experimental Platform Demonstrations

Following subsections include the architectural and functional description of the 5G SDN/NFV experimental platform through the three different use cases presented in this paper.

A. Hierarchical SDN orchestration of Wireless and Optical Networks

Hierarchical SDN Orchestration has been proposed as a feasible solution to handle the heterogeneity of different network domains, technologies, and vendors. It focuses on network control and abstraction of several control domains, whilst using standard protocols and modules. The need of hierarchical SDN orchestration has been previously justified in [7] with two basic purposes: the ability to scale and the increase of security.

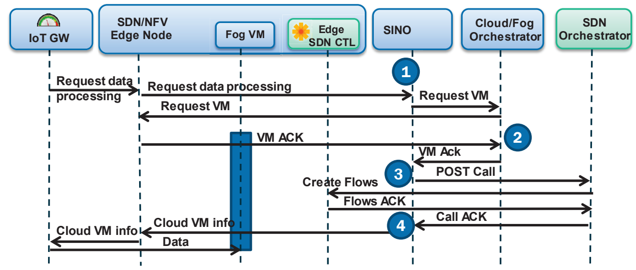

Fig. 4: E2E conectivity provisioning workflow between IoT gateway and virtual machine running at Edge node

In this use case, the hierarchical SDN Orchestration is applied for the integration of wireless and optical transport networks [8], to provide E2E connectivity between the User Equipment (UE) and a cloud service deployed in the Core DC location. In the wireless segment (Fig. 1), implemented over the EXTREME Testbed, an SDN controller is in charge of the programming of the wireless network (access and backhaul). This SDN controller tackles the specifics of the wireless medium, implementing the proper extensions to control wireless devices. In the optical segment, implemented over the ADRENALINE Testbed, we consider an SDN-enabled MPLS-TP aggregation network, while the control of the core network relays on an AS-PCE over a GMPLS distributed control plane.

A parent E2E SDN Orchestrator, based on the IETF ABNO architecture in [9] (pABNO), is responsible of the E2E provisioning across the different network segments. The pABNO orchestrates several network segments: an SDN-enabled wireless segment and the MPLS/Metro and Core network segments orchestrated by a child ABNO (cABNO). The cABNO is responsible for abstracting the multi-domain transport segments, and it offers a simplified view to the pABNO, thus improving scalability and security.

Fig. 3.a shows the orchestration workflow. It can be observed that an E2E connection is requested (POST Call) to the pABNO. The pABNO computes the involved network controllers (Wireless SDN/cABNO) and requests the underlying connection to them. We can observe how the workflow follows inside a cABNO, which is responsible for another level of hierarchy of the SDN orchestration process.

B. End-to-End SDN Orchestration of IoT Services Using an SDN/NFV-enabled Fog Node

SDN is a key technology to address all the technical networking challenges posed by the IoT. SDN aims to overcome the limitations of traditional IP networks, which are complex and hard to manage in terms of network configuration and reconfiguration due to faults and changes. An SDN controller can be viewed as a network operating system which interacts with the data plane and the network applications by means of Application Programmable Interfaces (APIs). In this regard, also the different needs in networking resources such as bandwidth and delay can be managed more easily thanks to the software programmability approach facilitated by SDN in the network control. Another important benefit of SDN is that it paves the way for the integration of smart objects with fog and cloud computing. More specifically, thanks to the flexibility

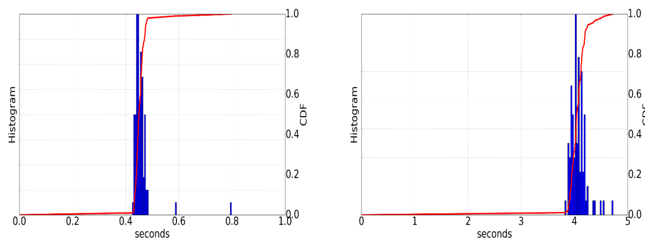

Fig. 5: Setup delay. (left) Edge node, (right) Core DC

provided by SDN, the data flows of information between IoT nodes and fog or cloud computing can be easily managed. This enables collaborative analytics between geo-distributed smart things.

Integrating IoT and SDN can also increase the efficiency of the network by responding to changes or events detected by the IoT which might imply network reconfiguration. For example, SDN can be used in IoT applications where the data are transmitted from the sensors periodically in specific time frames to schedule the requested bandwidth on the transmission paths only during the active duty cycles. Such dynamic reconfiguration of the forwarding devices is only possible via centralized applications which orchestrate IoT collected information and network resources information jointly.

We have deployed an SDN/NFV-enabled Edge Node in ADRENALINE Testbed for integrating wired IoT gateways from the IoTWorld Testbed by means of E2E SDN Orchestration of integrated Cloud/Fog and network resources [6]. E2E SDN orchestration provides network connectivity between IoT gateways and deployed virtual machines (VMs) which might be allocated in the proposed edge node or in a DC located in the core network.

The SDN IT and Network Orchestrator (SINO) is responsible for handling Virtual Machine (VM) and network connectivity requests, which are processed through the Cloud and SDN orchestrators. The orchestration process consists of two different steps: the VM creation and network connectivity provisioning (see Fig. 4). The SINO requests the creation of virtual instances (VMs) to the Cloud Orchestrator, which, is responsible for the creation of the instances. It is also responsible to attach the VMs to the virtual switch inside the host node (at the edge node or in a core DC). When the VMs creation is finished, the Cloud Orchestrator replies the VMs networking details to the integrated Cloud/Fog and network orchestrator (MAC address, IP address and physical computing node location). The SDN orchestrator is the responsible to provision E2E network services. The SDN orchestrator will provide the E2E connectivity between the requested IoT gateway and the deployed VM. Finally, data from IoT gateway will flow to the processing resources located in the proposed SDN/NFV-enabled edge node.

E2E connectivity setup delay has been measured 100 times between IoT GW and edge node (Fig. 5.a) or core DC (Fig. 5.b). The histograms and CDFs are showed. In average the setup delay between the IoT GW and the edge node is 456 ms, while towards the core DC is 4070 ms, due to the fact that a bidirectional optical lightpath needs to be dynamically established.

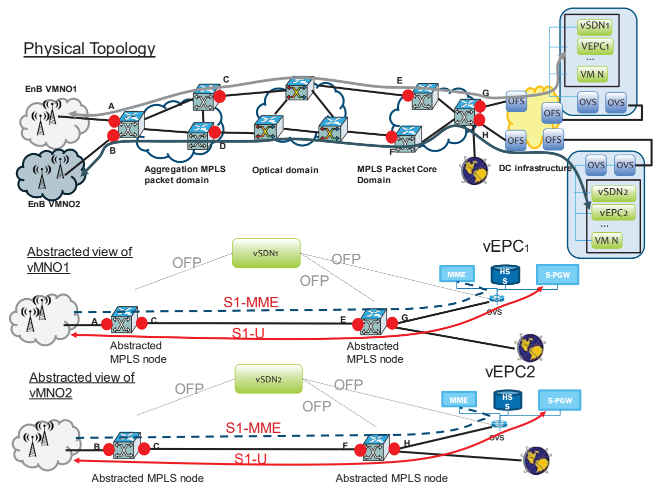

Fig. 6: Multi-layer aggregation network connecting RANs and DCs and abstracted view of the backhaul networks per MNO (left).

C. Integrated SDN/NFV Orchestration for the Dynamic Deployment of Mobile Virtual Backhaul Networks

In order to cope with the augmenting data traffic, MNOs expect that virtualization of network functions (NFV) and infrastructure (SDN) are appealing to obtain a more scalable, cost-efficient and flexible MNO deployment, in particular, in the backhaul infrastructure. We assume that a number of MNOs owning their radio area network (RAN) are connected to a common physical multi-layer (packet and optical) aggregation infrastructure. This shared physical infrastructure is partitioned to compose individual virtual backhaul tenants on top of it. Furthermore, the MNO Evolved Packet Core (EPC) functions are as well virtualized into the cloud connected to the aggregation network. This model enables MNOs to flexibly adjust their virtual backhaul and EPC necessities to the actual traffic loads.

This demonstration use case experimentally assess the dynamic computation and automatic deployment of a MNO virtual backhaul along with a virtual EPC (vEPC) [10]. The 5G Cloud/Fog and SDN/NFV orchestrator coordinates the virtualization of heterogeneous transport technologies within the aggregation segment as well as compute cloud resources at the DCs.

Fig. 6 shows the physical multi-layer aggregation network to connect MNO's RAN and DC domains wherein virtual SDN controller (vSDN) and vEPC are instantiated. The aggregation network leverages the statistical multiplexing provided by MPLS packet switching and the huge transport capacity of optical switching applying multi-layer grooming techniques. An MNO creating/increasing its backhaul capacity is built upon the aggregation network as interconnected virtual packet domains. The MNO SDN controller's vision is an abstraction of a set of connected packet domains (via an optical connection) providing the connectivity between the RAN and vEPC. Each abstracted packet domain is represented by a virtual packet node whose interfaces are mapped to the physical incoming/outgoing links of a packet flow.

The network topology and packet resource status are used

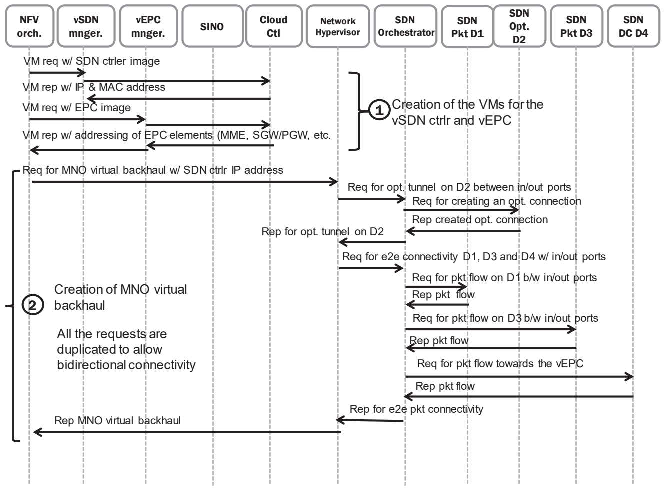

Fig. 7: Workflow for provisioning MNO virtual backhaul network and VNFs

to dynamically set up packet MPLS tunnels for backhauling upcoming mobile LTE signaling and data bearers (i.e., S1-MME and S1-U interfaces) between the RAN and vEPC [12]. The vSDN controller for the virtual backhaul is provided as a VNF in the DC. Last but not least, the connectivity within the DC network is virtualized connecting the core packet domain and the deployed cloud VNFs.

Fig. 7 shows the workflow between the involved functional blocks of the SDN/NFV orchestrator to manage the creation of an SDN-controlled virtual backhaul and the corresponding vEPC.

Step 1 allows the NFV orchestrator to request the provisioning of the vSDN controller (for the virtual backhaul) and the vEPC. This is handled by the corresponding VNF managers sending requests to the Compute controller of VMs with the respective implementation (image) of the VNFs (vSDN and vEPC). Next, in step 2, the creation of the MNO virtual backhaul is conducted allowing the connectivity of the created vSDN controller to configure such an infrastructure. To do that, the MNH receives the request and computes the domain sequence within the aggregation network in order to connect at the packet level the MNO RAN and the vEPC. This requires that at first the traversed packet domains are interconnected via an optical connection which is triggered by the SDN orchestrator. When the optical connection is set up (by the network hypervisor [11]) at the packet level all the domains are interconnected. For those packet domains the SDN Orchestrator subsequently requests the packet flow provisioning specifying ingress/egress links of those domains to derive the abstracted (virtual) packet node forming the targeted virtual backhaul.

Finally, a L2 flow in the DC infrastructure (e.g., Ethernet) is created to connect the virtual (MPLS) node with the vEPC. Once the virtual backhaul connectivity is ready, this is notified to the NFV orchestrator, and at that time, the vSDN has a view of the virtual packet backhaul used to transport LTE bearers between the RAN and the vEPC.

IV. Conclusion

Conducting real-life demonstrations of an end-to-end 5G scenario including both IoT and mobile broadband services, requiring the integration of heterogeneous wireless access and optical transport networks, distributed cloud computing, and wireless sensor and actuators networks is a very challenging task.

CTTC has been working on the development of the first-known end-to-end 5G platform capable of reproducing such an ambitious scenario. This paper has described the existing demonstrations, supported functionalities, use cases, and preliminary results among the different experimental facilities available at CTTC.

Further research will consist on introducing service function chainning in the ADRENALINE testbed, as well as optimal resource allocation algorithms which based on constraints (e.g., latency) decide the optimal allocation of virtualized network functions.

Acknowledgment

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