SDN/NFV Orchestration of Multi-technology and Multi-domain Networks in Cloud/Fog Architectures for 5G Services

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Abstract: *This paper presents an SDN/NFV architecture for delivery of future 5G services across multiple technological and administrative networks, including massive computing resources, which might be centralized or distributed, which are able to offer virtualized functions.*
Keywords: *Orchestration, Transport Networks, SDN, NFV, Cloud, Fog, IoT, 5G*

I. Introduction

End-to-End (E2E) converged network and cloud/fog infrastructure becomes of the essence for the fifth generation of mobile networks technology (5G). This converged infrastructure, illustrated in Fig.1.a, is composed of: E2E heterogeneous network segments covering radio and fixed access, metro aggregation, core transport involving heterogeneous wireless and optical technologies; centralized cloud and distributed fog computing/storage/networking infrastructure; and large amounts of heterogeneous smart devices and terminals for traditional mobile broadband services and IoT services.

5G architecture needs to deliver high flexibility, low-latency, and high-capacity networks for supporting the estimated 1000x increase in mobile data traffic while providing sub-millisecond latency [1]. From the perspective of Management and Control Continuum, E2E connectivity services need to be provisioned between distributed cloud and fog infrastructures and end users. These requirements can only be fulfilled by efficiently integrating in using the Software Defined Networking (SDN) paradigm the heterogeneous access, metro aggregation packet networks and high-capacity optical core transport networks. For this integration, SDN Orchestration is proposed to coordinate [2], in a hierarchical/peer, logically centralized manner, the heterogeneous control plane technologies of the different network segments, which may remain separated as independent administrative domains.

From the centralized cloud and distributed fog infrastructure perspective, the demand of massive and decentralized computing/storage/network 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) and Mobile Edge Computing (MEC) also require the delivery of generalized Virtualized Functions (VFs) on top of cloud /fog infrastructure for the deployment of software functions (e.g., mobile Evolved Packet core (EPC), local cache, firewalls, databases, video analytics). Originally, cloud services have been implemented in core data centers (DCs) for high-computational or long-term processing.

This paper presents the necessary SDN/NFV architecture and how it has been deployed on top of ADRENALINE testbed. Special focus on hierarchical SDN orchestration and virtualized function orchestration at the edge of the network is given.

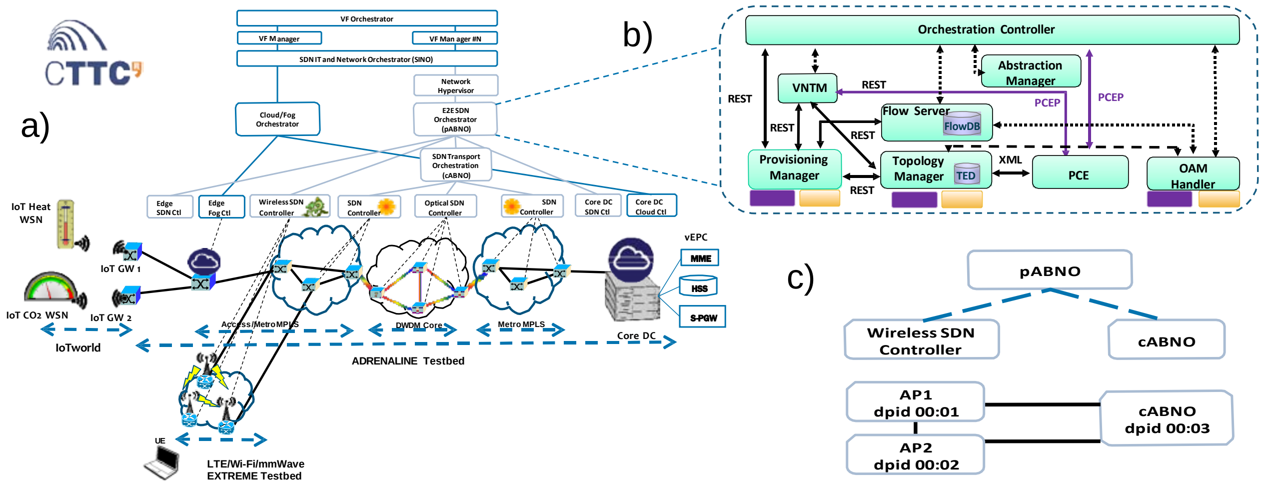

Fig. 1. a) Proposed SDN/NFV orchestration architecture, b) Detailed components of an SDN orchestrator (parent/child), c) Abtracted topological view as seen by E2E SDN orchestrator (pABNO).

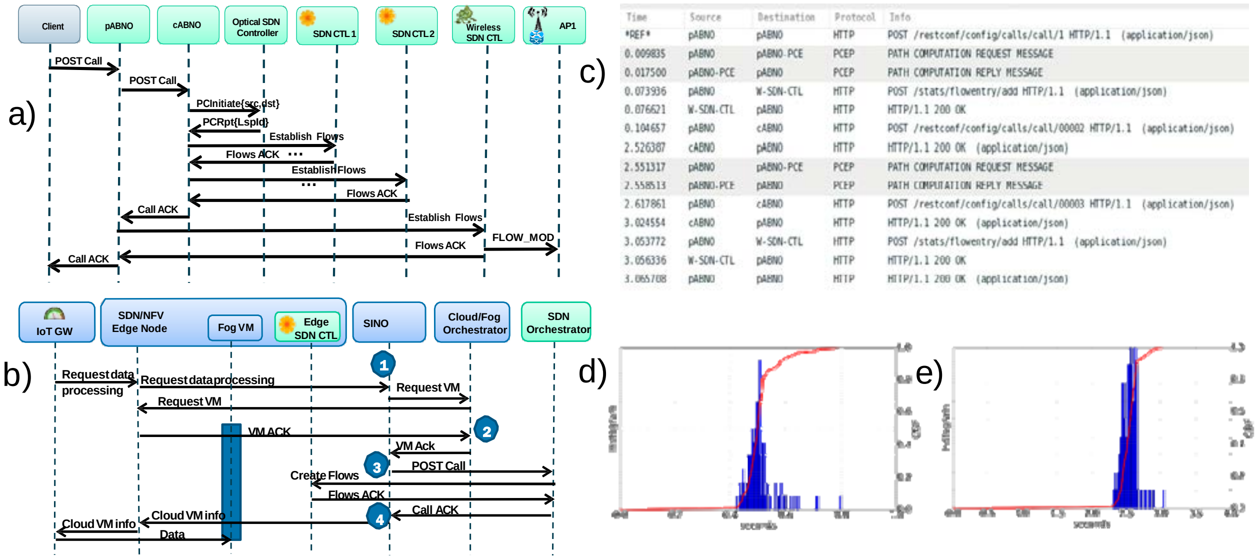

Fig. 2. a) Workflow for hierarchical SDN orchestration, b) Workflow for Virtualized Function Orchestration, c) Wireshark captures between pABNO-cABNO, d) Packet response time between IoT GW and edge VM, e) or core DC VM

II. SDN/NFV ORCHESTRATION AND THE ADRENALINE TESTBED

The SDN/NFV proposed architecture consists of four main building blocks: a Virtualized Functions Orchestrator (VF-O), a SDN IT and Network Orchestrator (SINO), a Cloud/Fog orchestrator, and an SDN Orchestrator (SDN-O) for control of heterogeneous networks. The VF-O is the responsible for the dynamic orchestration of generalized virtualized functions, which might include NFV, MEC and IoT services. The VF-O is responsible for allocating the necessary resources for the deployed services through the usage of the SINO. The SINO is the responsible for the joint orchestration of cloud/fog and network resources. The cloud/fog orchestrator enables the deployment of computing, storage and networking resources in distributed data centers and fog nodes. As networks are expected to span across several domains and technologies, a hierarchical SDN-O is introduced to manage this complexity.

The SDN-O follows a hierarchical approach where there is a parent SDN orchestrator (E2E SDN-O), child SDN-O, and SDN controllers for each domain. Each SDN controller might be in charge of the specifics of the underlying data plane technology. The SDN-O is based on the ABNO architecture proposed at IETF [3]. The main building blocks are shown in Fig.1.b. and they have been described previously in [4]. The Orchestration Controller handles all the processes (workflows) involved inside the NO to satisfy the provisioning of end-to-end connectivity. The Topology Server is the component responsible of gathering the network topology from each control domain and building the whole network topology which it is stored in the Traffic Engineering Databased (TED), which is used by the Path Computation Element (PCE) for calculating routes across the network. The Virtual Network Topology Manager (VNTM) is the responsible of the multilayer management. The Provisioning Manager implements the different provisioning interfaces to push the forwarding rules into the data plane. Flow server stores the connections established in the network into a FlowDB. Abstraction Manager is the responsible for providing network abstractions. Finally, OAM handler handler receives asynchronous notifications, such as topology updates, flow statistics, or failure alarms.

This proposed architecture has been deployed on top of the cloud computing platform and transport network of the ADRENALINE Testbed, located at CTTC premises in Castelldefels (Barcelona, Spain). The Cloud Computing platform of the ADRENALINE Testbed (Fig.1.a) includes OpenStack Havana release, which has been deployed into servers with 2 x Intel Xeon E5-2420 and 32GB RAM each. A fog server has been developed using Intel NUC NUC5i5RYH, with 16Gb RAM and 120 Gb SSD. Four OpenFlow switches have also been deployed. Each Data Center border switch has a 10 Gb/s XFP tunable transponder. Finally, the ADRENALINE transport network is controlled with an optical SDN controller, which interacts to a GMPLS-controlled optical network is composed of an all-optical WSON with 2 ROADMs and 2 OXCs providing reconfigurable end-to-end lightpaths.

III. HIERARCHICAL SDN ORCHESTRATION

In order to provide a feasible solution to handle the heterogeneity of different network domains, technologies, and vendors, we propose the introduction of hierarchical SDN Orchestration. 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 presented in [5] to serve two basic purposes: the increase of security and scalability.

In this use case, the hierarchical SDN Orchestration is applied for the integration of wireless and optical transport networks, in order to provide E2E connectivity between the User Equipment (UE) and a cloud service deployed in the Core DC location. In the wireless segment, an SDN controller is in charge of the programming of the wireless network (access and backhaul). 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 optical SDN controller over a GMPLS distributed control plane.

A parent E2E SDN Orchestrator (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 child SDN-O (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.1.c shows the abtracted topological view as seen by pABNO.

The workflow is shown in Fig.2.a. 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. Fig.2.c shows the wireshark captures of the exchanged messages at both the pABNO and cABNO. The bidirectional E2E service call request is received at the pABNO. The pABNO PCE is responsible for computing an E2E path. The pABNO VNTM decomposes the computed E2E path in order to request a call service to the cABNO. The cABNO is responsible for SDN orchestration towards the underlying network domains (SDN-CTL-1, AS-PCE, and SDN-CTL-2). After the cABNO provisions the requested call service, the pABNO requests the necessary flows to the wireless SDN controller. The setup delay for an E2E service call is around 3.06s.

IV. VIRTUALIZED FUNCTION ORCHESTRATION AT THE EDGE OF THE NETWORK

In this use case, we propose to extend the scope of NFV and introduce virtualized functions. As an example, we propose the deployment of a database services for the storage of Wireless Sensor Network (WSN) data that traverses the IoT gateways. We propose to analyze the necessary orchestration workflows for deploying the database services at the edge of the network (Fig.2.b).

The IoT gateway acts as the client which requests a database service to VF-O, which interacts with the SINO to request the creation of VMs to the Cloud/Fog Orchestrator (1). It is responsible for the creation of the instances. It will select the proper allocation of the computing and storage resources depending on the requested services. 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/Fog Orchestrator replies the VM's networking details to the integrated Cloud/Fog and network orchestrator (MAC address, IP address and physical computing node location) (2). The E2E SDN-O is responsible for provisioning of E2E network services (3). It will provide the E2E connectivity between the requested IoT gateway and the deployed VM (4). Finally, data from IoT gateway will flow to the processing resources, located in the proposed edge node.

We define packet response time as the necessary time it takes for a certain amount of data to travel from point A to point B and back (round trip). It can be observed that the average packet response time between the IoT GW and an edge VM is of 506 ms (2 switch hops) (Fig.2.d), while the average packet response time between the IoT GW and a VM located at the core DC is of 2552 ms (9 hops) (Fig.2.e). The allocation of processing resources at the edge results in better packet response time.

V. CONCLUSIONS

In this paper, we have presented an SDN/NFV orchestration architecture for the delivery of future 5G services. A Virtualized Function Orchestrator has been presented in order to generalize the necessity of orchestrating generic purpose applications and services (e.g., a database) through distributed cloud and fog resources, which are interconnected through heterogeneous network domains.

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