An Implementation of Network Service Chaining for SDN-enabled Mobile Packet Data Networks

Yekta Turk
Ericsson Research,
Istanbul, Turkey, 34396.
yekta.turk@ericsson.com

Engin Zeydan
Centre Technologic de Telecomunicacions de Catalunya,
Barcelona, Spain, 08860.
engin.zeydan@cttc.cat

***Abstract*—Mobile Network Operators (MNOs) are on the path towards designing flexible architectures. The main goal is to improve the end-to-end system performance responses and at the same time generate more revenue streams thanks to easier and faster service deployments. For this reason, traditional mobile network infrastructure needs to evolve towards a data center oriented infrastructure where services can be initiated on demand. Software Defined Networks (SDN) in combination with Service Function Chaining (SFC) have great potentials for MNOs in terms of flexible and scalable rich service deployment. This paper investigates the setting up an SDN-based SFC experimental implementation that is based on application of SDN concept for mobile core networks. During our experiments, we build a SDN-based Gi-LAN mobile core architecture solution using SFC and evaluate its performance compared to traditional mobile core network service. Our results validate that by dynamically adjusting defined virtual network functions as well as directions and policies of flows with Open Network Operating System (ONOS) controller, SDN-based SFC mechanism is capable of forwarding traffic data flows into each compute nodes having different virtual network functionality.**

***Index Terms*—SDN, mobile operator, service function chain, core network.**

I. Introduction

Mobile IP video data traffic is expected to reach 82 percent of all IP traffic in 2020 [1]. For this reason, Mobile Network Operators (MNOs) are looking for cost-effective solutions that can meet the increased demands of this kind of traffic and respond quickly to increased service requests from users. Software-Defined Networking (SDN) and Network Function Virtualization (NFV)-based network architectures are one of the most promising and important solutions to provide a flexible network infrastructure that can satisfy the needs of MNOs. With the advantages of service virtualization with NFV and SDN on standard hardware, MNOs can offer enriched services to end-users at very low cost and with little risk. Some of the benefits of an SDN and NFV-based architecture to MNOs' infrastructure include: (i) removing hardware dependency (the OpenFlow switch infrastructure, which can perform the same functions as the high-cost service router, can be provided at much lower cost). (ii) achieving a high-performance, low-cost and expandable switching fabric infrastructure with SDN-based leaf-spine architecture (compared to existing spine key investments, CapEx and OpEx can be reduced significantly). (iii) achieving faster service provisioning (end-user services can be delivered much more quickly based on SDN). (iv) providing new business potential for MNOs (management and operation of NFV-based network services (vEPC, vFW, vDPI, vCGNAT, etc.) can be simplified). (v) providing complete control over network and service management for MNOs.

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Ever increasing changes in requirements, technologies and trends in data processing pipeline are also putting MNOs under constant pressure. Together with explosive growth in demand for wireless services, new and innovative approaches that can enable flexible and elastic service orchestration are necessary. For this reason, MNOs are not only willing to provide a data pipeline infrastructure but also intend to provide a dynamic service-oriented architecture for their users. Moreover, MNOs are poised to have complete control and management of their data. In a typical data flow pipeline, a data flow traverses through a "service graph" involving Network Address Translation (NAT), Access Control Lists (ACLs) and firewalls before reaching to a target destination. However in SDN-enabled Service Function Chaining (SFC) networks, services are formed by chaining various service functions in a concert. Together with the flexible and scalable architecture that SFC can provide, MNOs can benefit from virtualized SDNs solution.

A. Related Works

Current trends of service orchestration and management are evolving towards an open software approach where distributed and decentralized architecture design based on SDN and NFV is becoming mainstream in both literature and industry [2], [3], [4]. The white paper by Heavy Reading in [5] has described the benefits and description of Gi-LAN solution. Another white paper in [6] focuses on how a SFC-based Gi-LAN implementation can be applied using open source and vendor-specific solutions. Concepts, principles, and components of a service function chaining architecture are described in [7]. The authors in [8] provide a use case for SFC when implemented on mobile packet data networks challenging traditional architectural concepts. A

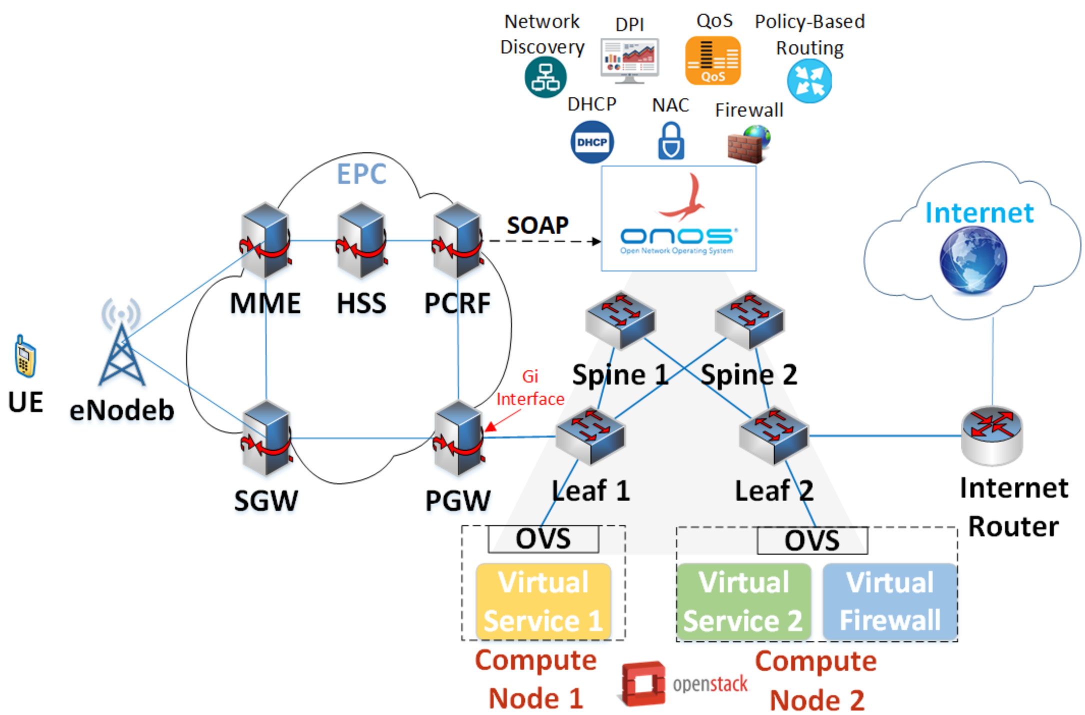

Fig. 1: High level test network architecture of SDN-enabled Gi-LAN and corresponding components for service chaining.

telco viewpoint and some virtual models for SFC are identified in [9]. New user deployment and readjustment of in-service users in SFC environment are studied in [10].

B. Our Contributions

In this paper, we demonstrate the advantages that the service function chaining paradigm can deliver in emerging network infrastructures. Although SFC-based solutions has been already largely investigated in the literature, the validation of the theoretical solutions is yet to be investigated on real infrastructure. Different than above works, we build an SDN-enabled SFC testbed implementation for testing suitability and evaluating performance aspects of the SFC concept in SDN-enabled mobile packet data networks which is referred as a Gi-LAN solution. The studied Gi-LAN solution can provide MNOs the necessary enablers to deliver SDN-NFV based network services in accordance with the ETSI-NFV's architecture as well. This study also provides a solution based on open source applications and systems for MNOs in general terms. Through experimental results, we demonstrate dynamic service instantiating of SFC feature inside Gi-LAN and compare it with traditional network solution in test-lab environment of a mobile infrastructure provider.

The rest of the paper is organized as follows. Section II is presenting the proposed SDN controlled network architecture. Section III is describing the SFC feature scenario details in mobile core network. Section IV provides the experimental results and finally Section V gives the conclusions and future work.

II. SDN Controlled Network Architecture

Fig. 1 and Fig. 2 provide the SDN-enabled Gi-LAN architecture and mobile packet core network with traditional architecture that are used in evaluation purposes respectively. In Fig. 1, Open Network Operating System (ONOS) controller controls the underlying Gi-LAN between the Internet router and Packet Gateway (P-GW). On top of ONOS controller runs different network management applications such as network discovery, Deep Package Inspection (DPI), Quality-of-Service (QoS) management, policy based routing, Dynamic Host Configuration Protocol (DHCP), Network Access Control (NAC) and firewall features. Fig. 2 provides the components of a legacy Evolved Packet Core (EPC) based mobile network architecture.

Gi-LAN inside mobile core network is an emerging service chaining use case. It enables traffic steering from Gi/SGi interface through various service nodes [11]. In fact, Gi-LAN represents the interconnection point between external network and mobile network [12]. Thus, a local area network (LAN) is created by connecting the devices such as firewall, Carrier Grade NAT (CGN) equipment, TCP optimizer, etc. in cascade, through the Gi interface, which is the point of presence of EPC, so different services can be provided to the subscribers by MNOs. The main benefit of Gi-LAN is easier and faster function addition or removal over the data path. End-user's service policy is based on configurations on Policy and Charging Rules Function (PCRF). In summary, Gi-LAN approach can provide a data-center oriented solution to service provider's network infrastructure. Traditional (legacy) architecture is providing a legacy service and is mostly static. However, SDN-enabled SFC architecture is dynamic and services can be initiated on demand.

Benefits and limitations of Gi-LAN network architecture: An SDN-enabled SFC follows a different path from traditional forwarding or routing where the traffic is steered according to service/subscriber policy. In SFC, each chain performs a specific service execution per user traffic. Gi-LAN is the application of SFC in mobile core network's architecture. It is mainly the softwarization and virtualization of Gi-LAN routers to transform services into Virtual Network Functions (VNFs). The virtual functions are chained together instead of vendor specific hardware based appliances. The idea behind creating a Gi-LAN using SFC is to deploy a *SDN controlled service execution* so that each user's traffic is maintained via *service chaining*. Subscriber aware dynamic SFC promises automatized instantiation and plumbing of needed virtual functions on the back-end virtualization system, classifying packets flowing through at Gi speed with respect to subscriber profile, and processing flows through proper function chains. Virtual functions are decided and purchased by the customer. Subscriber IP addresses and profiles are learned from policy server (such as PCRF) of the service provider network. Table I shows the comparisons of the traditional and Gi-LAN based architectures in terms of their characteristics, benefits and limitations.

III. SDN BASED SERVICE-CHAINING IN MOBILE CORE NETWORKS

To illustrate the advantages of the proposed architecture of Fig. 1 on SDN-enabled EPC, we conduct an experimental case study using SFC in this section. The utilized SFC-based service instantiating mechanism in mobile core network (i.e. Gi-LAN) can be summarized as instances where the instances containing VNF and/or Physical Network Function (PNF) functions are configured as a function on the controller and the corresponding functions are selected to form a chain. In this structure, any physical server in the topology for PNFs can be selected. VNFs are instances of Virtual Machines (VMs) that have been instantiated by a software platform, e.g. OpenStack [13]. New customer profiles are created for different service chains in PCRF. There is a SOAP/ XML Application Programming Interface (API) in PCRF to interface to external systems. The information of subscriber PCRF profile is transmitted to the ONOS controller via Simple Object Access Protocol (SOAP) messaging by this interface. The ONOS controller must resolve the incoming profile type from these SOAP messages and assign services related to the specified customer profile. Thanks to this communication, so the ONOS can assign the corresponding subscribers to the related service chains that they are using according to their defined profiles. By this way, the services assigned to this PCRF profile are provided to the subscriber.

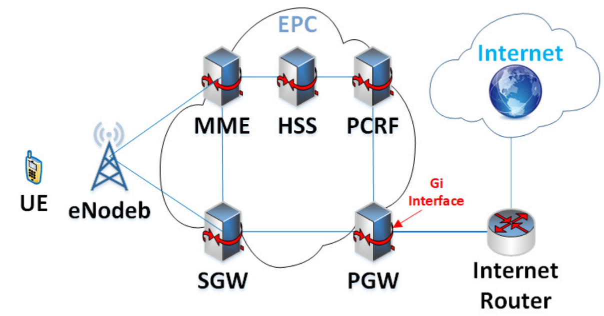

Fig. 2: Legacy test network architecture

The test scenarios used in our evaluation results are summarized in Fig 2 and Fig 3. Two compute nodes (compute node 1 and compute node 2), each with virtual services, are created using OpenStack. Transmission Control Protocol (TCP) optimizer VNF (named as virtual service 1 and virtual service 2) and one Firewall VNF has been created and monitored in the system in Fig 3. Virtual service 1 and 2 are responsible for the optimization of TCP flows and virtual firewall VNF is used by ONOS controller to update these flows based on defined rules. On the ONOS Command Line Interface (CLI), SFC is created in download direction and is assigned to an PCRF-Profile. Fig 2 shows the traditional static network scenario for video service. In this scenario, user equipment (UE) only uses fixed and pre-assigned static service to access Internet and download video content from remote servers. Fig 3 shows dynamic service orchestration with SFC where UE uses different compute nodes with different VNFs. In first step, video flow is directed towards compute node 1 and virtual service one is instantiated. In second step, video flow is redirected towards compute node 2 where virtual service 2 and virtual firewall functions are activated. In this step, firewall service function is assigned to the SFC for download. Later, the generated SFC is assigned to the PCRF-profile. Hence, during this step, no video content can be downloaded by test UE. In third step, marked by green line, firewall rules are updated to allow video traffic to resume towards UE. In fourth step, firewall deny service is activated again. Finally in fifth step, video traffic is redirected to compute node 1 for regular video transmission service.

Our aim is to build a system where video content session is traversed through either paths of two compute nodes with corresponding VNFs as given in Fig. 1. The SDN controlled SFC in mobile core network solution components are given as follows.

Data Plane: The data layer (fabric) consists of SDN-based switches located in the leaf-spine structure managed by the control Layer. Leaf switches are 40 GbE in uplink ports and 10 GbE on downlink ports.

Service Functions: Some prior assumptions regarding VNFs in the SDN controlled Mobile Core SFC solution are given below:

TABLE I
COMPARISONS OF TRADITIONAL AND SDN BASED GI-LAN ARCHITECTURES.

Architectures	Characteristics	Benefits	Limitations
Traditional	- Each service function should be connected as a separate physical equipment. - Equipment placing between PGWand Internet must be in order and in a parallel structure.	The common usage of equipment by network operators is more convenient in terms of operation.	- Service functions are not easily moved, created or removed for not only existing physical services but also when virtualized service functions are deployed. - In order to increase the capacity, new equipment must be purchased. - For operational point of view, when an equipment has problems, it can affect total availability of services because of the parallel connected network structure. - Redundancy will solve this problem, but it will create cost.
SDN Based	- Architecture is based on a hardware environment that includes leaf and spine switches and servers between PGW and Internet. - Each service is positioned as a separate VNF.	- Leaf and spine structure provides a redundancy inherently. - Capacity increases can be done easily by increasing the virtual machine capacity. - When one of the services is interrupted, this service does not affect the others. - In case of operational failures, services can be easily transported to different virtual or physical machines. - Operational costs are less. - Open source based solutions can be used without any additional cost.	- There can be licensing fees for purchased services and these fees are not needed in traditional networks. - For operators who have worked mostly in traditional networks, the management of the SDN based structure can be difficult.

- VNFs are network applications running in VMs that are mounted on OpenStack compute nodes.
- VNF applications should be transparent applications. That is, all the traffic of VM's network interfaces can be visible. After required functionalities are fulfilled, packets are sent back into the network without dropping the packet headers.
- VNFs can send packets from a network interface back to the same network interface (single-branch case) or packets from a network interface to other networks (double-branch case).
- VNFs do not need to address the packets they process. In other words, destination IP or MAC addresses in packets destined to a VNF do not have to be IP and MAC address of VNF.

Control Plane: The control layer of SDN controlled mobile core SFC solution is built on top of solution components in Trellis architecture of ONOS [14] and the necessary SDN controlled solution components. ONOS underlay control manages the data layer consisting of leaf-spine switches with segment routing application. ONOS overlay control provides overlay network management with CORD VTN application [15]. The ONOS vRouter application, along with Quagga [16], manages the traffic route at the point of access to Internet i.e. on Gi interface.

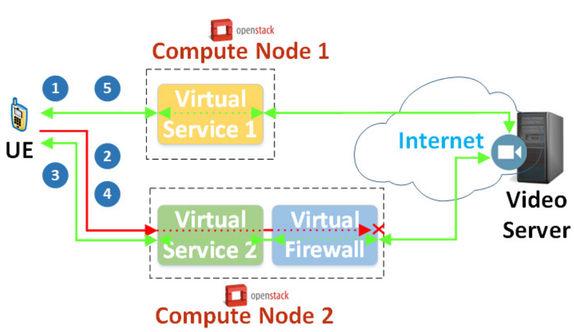

Fig. 3: SFC-enabled network scenario

SFC on mobile core: The flow path where mobile traffic will be directed to (either virtual or physical services (VNF/PNF)) is determined by the ONOS controller on mobile core network. Traffic is routed based on preconfigured SFC that matches the VLAN tag. On egress of mobile core network, P-GW traffic will be routed through the data layer at the leaf level at Internet ingress of mobile core network.

IV. EVALUATION OF SFC SCENARIOS

In this section, we provide the evaluation results of the considered SFC and legacy network architectures. We implemented the SDN controlled SFC in mobile core network solution scenario in R&D test lab of the major infrastructure provider in Turkey. As SDN controller, we have used ONOS controller [17]. For evaluations, our Gi-LAN solution is implemented with virtual functions that are modeled as VMs. As a first precondition, a test UE used in our experiments are predefined into our system. For this, we have defined a PCRF profile value for the test UE used in our experiments. Mobile video traffic is generated

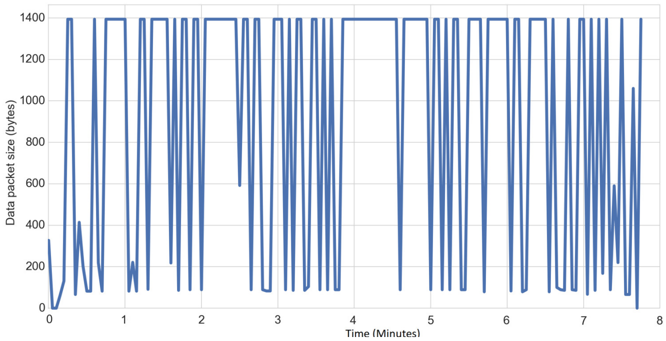

Fig. 4: Video download packet size versus time index without SFC.

by Youtube video service using protocol for emulating end-user traffic in Proof of Concept (PoC) environment. Statistics of the video download traffic generated during the test are collected directly from the test UE via TEMS pocket application [18]. Proposed SFC test scenario of Fig. 3 is implemented. A typical Youtube video streaming traffic spanning over eight minutes that flows in our SFC-based architecture is used to test the performance. For evaluating the performance, we measured the data size of Quick UDP Internet Connections (QUIC) protocol [19] flowing between UE and video server.

Fig. 4 illustrates the traditional network scenario of Fig. 2 for video download packet size over the observed time interval. In this scenario, Internet service is provided once after appropriate configurations. This architecture is an example of a traditional network with static "service graph". Fig. 4 shows that the packet size varies between 0 and 1394 bytes and normal video service continues without interruption. However, this configuration is static and cannot be dynamically adjusted based on the varying service requirements of the UE.

Fig. 5 shows the graphic for packet size versus time in minutes for the considered scenario of Fig. 3. In this figure, compared to traditional networks, data traffic flow is dynamically redirected between compute nodes by ONOS controller, hence virtual services (which are dynamically assigned for each flow) differ. For example, changes in firewall rule updates by ONOS controller affect video traffic flow from video server to test UE. When traffic is directed to compute node 1 which has only virtual service 1, regular video traffic is streaming. When traffic is directed towards compute node 2 with two active VNFs, video traffic of test UE is directed through virtual service 2 and virtual firewall service in the download direction. During time intervals of first and second as well as sixth and seventh minutes, test UE cannot have access to Internet due to new flow rule updates by SDN controller on firewall service function. Therefore, the traffic flowing through virtual firewall is denied according to flow rule updates which are based on IP address restriction policy. During second and sixth minute time intervals, test UE is accessing the video content where QUIC protocol data size changes between 0 and 1400 bytes observed. Later during seventh and eight minute intervals, video traffic is redirected again to compute node 1 that only counts the packet numbers and the video service resumes again.

Main insights and challenges from empirical evaluations: The above evaluation results signify that services provided by legacy architectures are static configurations and require more effort in terms of reconfiguration. Hence, SDN-SFC framework is more flexible compared to fixed pre-configured architecture. Switching between different compute nodes demonstrates the change in the service profile of the user. The accept-reject rule changes within the virtual firewall indicates the change of service content received by the subscriber in the same service profile. However, dynamic service initiation by creating a Gi-LAN with SFC can also be a cost efficient alternative for executing customized carrier-grade services. Although SDN based system can provide some benefits, there are also some trade-offs of deploying this new architecture. In legacy systems, PCRF database contains the profile information of subscribers based on the speed and quota package information that they are subscribed with. For the SDN based system, a different profile ID need to be given for each service received by the subscriber profiles. This can cause additional problems as the capacity increases compared to the legacy system of the SDN based system. Moreover, ONOS controller needed to be upgraded to communicate with core network elements such as the subscriber PCRF profile is communicated via SOAP messaging service. Therefore, PCRF database structure may need to be updated to service based structure in case of Gi-LAN solution compared to legacy networks.

V. Conclusions and Future Work

Delivering an end-to-end service requires flexible management and dynamic orchestration of services due to several network function requirements in a MNO network infrastructure. For this reason, applying SFC using an SDN-enabled mobile core infrastructure is a promising solution that can provide this functionality together with advantages of SDNs. This paper is studying a test-bed implementation of an SDN-based mobile core network with SFC scenario. A Gi-LAN testbed is created inside mobile core network of a MNO. The proposed SDN-enabled mobile core infrastructure with SFC is experimentally tested and compared with traditional network's fixed service solution. At the same time, we have shown the effect of the SFC implementation on the user with the test results that are received directly through the UE. The comparisons are done using video content distribution. The experimental results validate that by dynamically adjusting defined virtual network functions as well as directions and policies of flows with ONOS controller, SDN-based SFC mechanism is capable of forwarding traffic data flows into each compute nodes having different virtual network functionality. Our results also

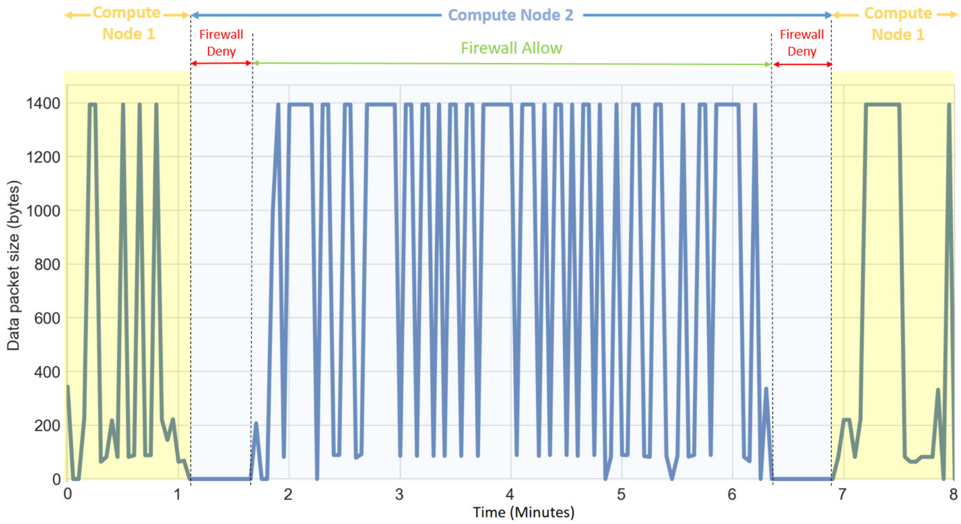

Fig. 5: Video download packet size versus time index with SFC.

reveal that different services are rapidly applied to user profile via SFC and the effect on the user video traffic are observed. As a future work, evaluation of SFC scenarios is planned to be implemented with large number of VMs in a test-bed to replicate a real-world scenario where many different VNFs are active in the chain. Moreover, other services that need to be inside a Gi network can also be created in different compute nodes. Within each compute node, one or more of the services such as DPI, carrier-grade NAT, Domain Name System (DNS) and video or TCP optimization can be enabled.

VI. Acknowledgements

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