DOI: 10.1007/s10922-020-09534-z

Applicability of SDN and NFV techniques for a virtualization-based roaming solution

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Abstract

Network programming and virtualization are technological trends being incrementally introduced in operational networks. This creates an environment where new innovations can be incorporated, facilitating also the evolution of the way in which existing services are delivered. These changes, however, are not only motivated by technical reasons. External factors, such as regulation, can trigger the evolution of existing services. Roaming services are an example of this two-sided situation. From the technical perspective, roaming users typically experiment worst performance than local users on the same network, since their traffic is usually routed through the home network. Besides that, due to recent regulation changes introduced in Europe for roaming services, known as *Roam Like at Home* (RLAH), roaming is charged at domestic prices. Both aspects are severely challenging the current mode of operation of roaming services as delivered nowadays by mobile operators. This paper presents the design of a virtualized based roaming solution, including an experimental assessment, as well as an economic insight of the concept.

Keywords

Roaming; multi-domain; programmability; orchestration; slicing

1 Introduction

Traditionally, technological innovations are introduced in the network for satisfying new service demands, for enhancing existing service, or for delivering the same services in a more cost-efficient manner. However, it may happen that factors external to the pure technological domains, e.g., new regulations, foster the development and the adoption of technological innovations to cope with new market landscapes.

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An example of a service influenced by both technical and non-technical aspects is the case of the roaming service. When roaming, an end user from Operator A in Country X (i.e., the home network) is allowed to use the infrastructure of Operator B in Country Y (i.e., the visited network) for accessing mobile services (e.g., for voice, messaging and data). Specifically focusing on data services, a roaming end user typically accesses the home operator specific data services, creating a situation where data traffic must be routed from/to the home network up to the visited network where the end user is connected to (which is commonly known as *home routing*). This fact does not only generate a large amount of interconnection traffic, but also a poorer user experience given by the larger latency in delivering traffic.

In addition to that, recent regulation changes have been introduced by the European Union (EU) with respect to roaming in the European single digital market. This new regulation, known as *Roam Like at Home* (RLAH), has been effective since June 15th, 2017. According to RLAH, roaming is charged at domestic prices, then benefiting the end users that previously were usually billed with expensive roaming tariffs.

This positive change in the end user side has not been accompanied yet by a transformation in the way the roaming services are provisioned by network operators, which maintain the already established interconnection architecture and cost structure. On the other hand, the advent of RLAH promoted new habits among the end users resulting in an ever-increasing demand of data intensive services. Such situation is severely challenging the current mode of operation of roaming services as delivered nowadays by mobile operators. Since roaming users are charged at domestic rates, the extra costs due to the provision of roaming versus domestic services compromise the sustainability of the service when using existing solutions. Different strategies have been proposed to mitigate the economic and business impacts foreseen [1].

Figure 1-1 [2] presents the evolution of the average data consumption per subscriber in roaming in the European Economic Area (EEA)[2]. Looking at the reported data, the total increase on the average Gigabyte (GB) consumed per end user after the activation of the RLAH regulation is of 397% for the period Q2 2017 - Q3 2019. Comparing Year-on-Year (YoY) growth, for avoiding seasonal impacts, it can be found that the YoY increase for Q1 2017-2018 is 280%, while the YoY increase for Q1 2018-2019 represents an additional increment of 54%. It is therefore clear that the new regulation has had a significant impact on the overall demand of roaming services, particularly on the data consumption while the end user is abroad.

Looking at the impressive growth percentages triggered by RLAH, it is hence necessary to evolve the way roaming services are provided, transitioning towards a future mode of operation that could easily scale in line with the growth perceived in the users' demand.

To this respect, the advent of Software Defined Networking (SDN) and Network Function Virtualization (NFV) techniques bring a new possible strategy to evolve existing interconnection scenarios for roaming services towards more dynamic and better

[2] The EEA includes the countries forming the EU plus the countries of the European Free Trade Association (EFTA), all of them being part of the EU's single market.

performance scenarios. In this sense, a potential solution to be considered is the deployment of virtualized mobile packet core entities from the home operator into the visited operator premises. This work extends the technical proposition in [3] for a virtualized LTE roaming solution by providing experimental results of prototype implementation of the virtualization-based roaming solution as well as some techno-economic insights of this approach.

The paper is structured as follows: Section 2 describes how data roaming is accomplished nowadays in operational mobile networks, while Section 3 introduces the virtualization-based approach as new value proposition for mobile operators. Next, Section 4 details how to apply such virtualization approach specifically to the roaming service case. Section 5 presents the experimental assessment through the description of the prototype used to validate the proposed concept. Section 6 elaborates on the techno-economic dimension of the solution. Finally, Section 7 draws the conclusions and some closing remarks.

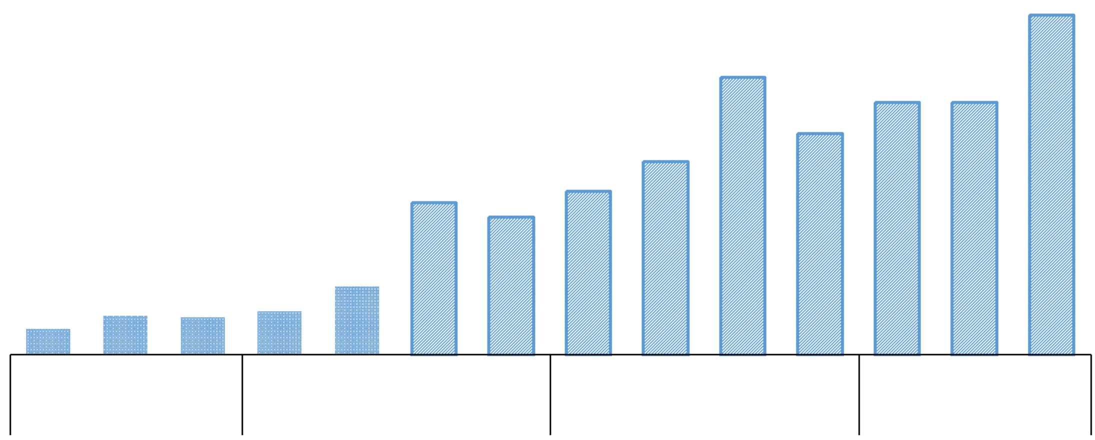

Figure 1-1. Monthly average consumption in GB per roaming subscriber [2] (solid columns show consumption in quarters previous to the applicability of RLAH)

2 Roaming in existing mobile networks

The roaming service allows an end user to use the infrastructure of the visited network for accessing mobile services. This paper focuses on the access to data services, i.e. Internet and associated content-related services as subscribed by the end user to the home network operator. It is also important to note that we look only to 4G/LTE networks. While 5G networks have been largely standardized, their deployment is not yet commercially available in the majority of the countries. Nevertheless, 5G networks adopt the same approach as LTE for roaming and they do not envisage any substantial change in the way roaming services are delivered. Finally, the experimental validation, described later in Section 4, leverages a commercial software-based LTE network, implementing the necessary LTE components and replicating the scenario below.

2.1 *Roaming architecture*

In the LTE architecture, the Evolved Packet Core (EPC) [4] is in charge of providing IP connectivity and session continuity to the mobile terminal or User Equipment (UE) as it moves around. Figure 2-1 represents the basic entities of the EPC involved in the roaming procedure [5]. Once the UE of an end user moving to another country attempts to attach to a visited network, the Mobility Management Entity (MME) of the visited network identifies the newly connected device and tries to register it into the system. During this process, the MME is able to detect through signaling procedures that the UE belongs to a foreign network. In case that the two operators have a valid roaming agreement, the MME of the visited network retrieves the information of the service subscriptions associated to that UE from the Home Subscriber Server (HSS) of the home network. With such information, the UE becomes registered in the home HSS as located in the visited network and the roaming subscriber can start using the home network services from the visited network infrastructure.

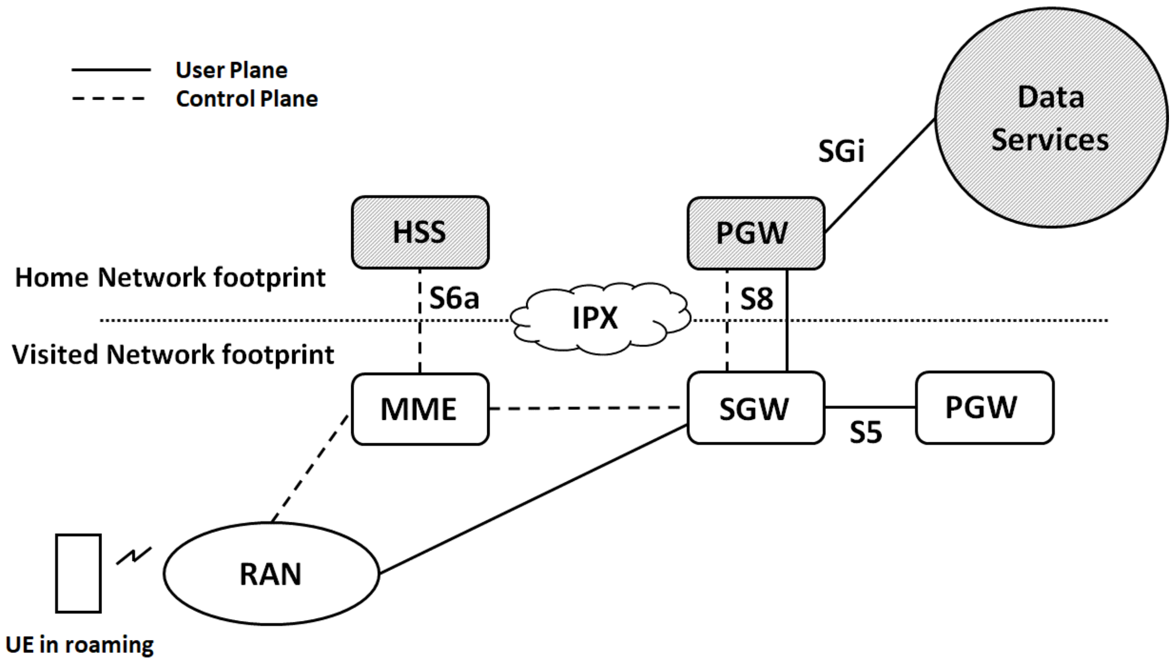

Figure 2-1. LTE roaming architecture (shadowed boxes represent home network elements)

The S5/S8 interface identifies the logical connection between the Serving Gateway (SGW) and the Packet Data Network Gateway (PGW) in the EPC, with the S5 referring to the case when this connection is done to a PGW of the local network while S8 relates to the logical connection to a PGW of a visited network as needed for enabling the roaming services. Usually, when an end user is in roaming and thus attached to a visited network, the connectivity to external networks (e.g., the Internet) via the SGi interface is gained through its home network (home routing). The motivations for that are basically that the local breakout option presents incompatibility issues, such as different billing systems, and *lawful* interception obligations.

The logical interconnection represented by the S8 interface is typically arranged by leveraging on an Internetwork Packet Exchange (IPX) provider which enables the interconnection of network operators for the interchanging of IP services with committed QoS. Figure 2-2 depicts a simplified architecture of the IPX interconnection model [6].

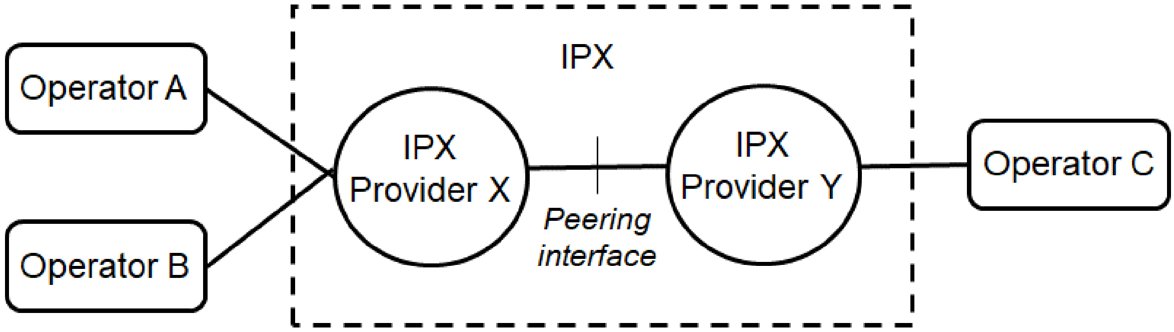

Figure 2-2. Simplified IPX model

In case network operators do not have a direct interconnection, the access to data services (e.g., Internet) by a roaming end user implies the delivery of the data from the home network to the visited network via the IPX infrastructure. In this way, the home operator incurs in costs due to the usage of the visited network and the IPX infrastructure, which is proportional to the volume of traffic transited among providers. Thus, the sustainability of the service gets compromised as the data traffic demanded by the roaming users increases.

2.2 Literature overview on performance implications of existing roaming architecture

A number of recent studies have been reported in the literature assessing the performance of the current mode of operation for roaming users. This section provides an overview of reported experiments and results in the literature. In [7], an extensive analysis using 16 different European mobile operators' networks in 6 distinct countries is provided observing very interesting behaviors, common to all tested networks. First, it is corroborated that home routing is the common pattern on the enabling of roaming services across operators, implying that the roaming user accesses data content through the home network. Second, as a consequence of that, it is reported a poorest experience in terms of latency for the roaming users because of the fact of getting the data contents from the home network instead of doing closer to the real roaming user location. The performance implications identified are around 60 ms of delay penalty for roamers. Such delay penalty depends on the geographical location of the roaming users and the content server, as also confirmed by the analysis in [8]. The work in [9] considered also roaming users from two distinct European mobile operators in the characterization of the performance in the access to applications from major Cloud Service Providers. For instance, in one of the roaming cases it is observed a delay inflation of 20% for CloudFront or Google services. Finally, a Europe wide (more than 39 countries) measurement campaign comparing in-country and abroad latency is provided in [10] based on Speedtest data from Android devices on 4G LTE cellular connections (more than 30 samples) during the second half of 2018, revealing an average difference of 76 ms between local and roaming latency for all the reported values.

Similar analysis has been performed one year later [11] in similar conditions (but limited to 28 countries in this case) showing an average difference of 71 ms.

All these studies indicate a loss of performance experienced by the roaming users mainly due to the fact of the home routing. In this sense a virtualization-based roaming solution, as introduced in the next section, can help on reducing the delay observed by the roaming users when accessing contents by making the home network environment closer to the real user location.

3 Virtualization and programmability in mobile networks

Service providers have for a long time focused on facilitating the best connectivity to their customers, with reliable connectivity as the base of the networking business during the past decades. Value added services accessed through the SGi interface have been typically offered by the same service providers using manual configuration of static infrastructure, tailoring services according to the specific needs of the customers. However, this way of service delivery has shown its limitations in terms of adaptability and scalability to the ever-increasing demand faced by mobile operators. The advent of network programmability and virtualization has opened the door to more flexible and cost-efficient deployments.

NFV enables mobile operators to compose network services as needed whilst providing the required elasticity to instantiate on-demand the network functions on generic computing facilities and to scale them in/out and up/down according to real service demand. The dedicated and specialized hardware is substituted by computing elements (typically x86 servers) with a virtualization layer (hypervisors) executing the same kind of service function as supported by the traditional specialized network equipment. Those computing resources are constituted in the form of Network Function Virtualization Infrastructure Points of Presence (NFVI-PoPs). Though, in its initial conception, those PoPs are intended to be under a unique administration.

It is worth noting that major telecom operators are starting to deploy their own NFVI environments (e.g.,[12]) that can be opened to other operators and vertical customers to exploit new business prospects enabled by such new technology ecosystem. Evolutionary services like Virtual Network Functions as a Service (VNFaaS) or Slice as a Service (SlaaS) are the target, favored by the advent of 5G networks, with strict requirements of flexibility and performance. It is interesting to consider that cloud computing providers are also entering in this direction by offering computing capabilities for a diversity of services, including significantly EPC-based services [13]. These trends confirm the exploitability of the approach considered in this paper.

3.1 Review of virtualization proposals for the Enhanced Packet Core

These new technological trends related to network programmability and virtualization are being introduced step by step in operational networks since they present an environment that can be widely benefit from deployment flexibility and automated operation. The analysis of applicability of these new paradigms to the EPC has been extensively addressed in [14] where a survey of a variety of mobile packet core architectural options based on the application of SDN and NFV is presented. Those options range from a fully NFV-based

EPC architecture, with all the packet core entities deployed as simple virtual machines, to a fully SDN-based EPC architecture, with all the functional packet core entities running as applications on top of an SDN controller handling data plane forwarding entities. Other intermediate options (e.g., with virtualized data plane) are also described, showing the rich number of alternatives enabled by these techniques. For instance, the work in [15] presents a software-defined control architecture of a virtualized combination of SGW and PGW separating control and user planes as well as decoupling the mobile service from the specific encapsulation protocol (i.e., GTP). In the case of [16] a software-defined approach is proposed for the functionality in the S5/S8 interfaces between SGW and PGW to implement the mobility management procedures without introducing changes to the rest of the standard 3GPP defined interfaces, ensuring compatibility with deployed infrastructure. Precisely related to the mobility procedures, in [17] the optimization of mobility management is addressed by using NFV and service function chaining (SFC) with the decomposition of the MME into multiple components. Finally, reference [18] presents the implementation of a solution for virtualizing the services through the SGi interface by using NFV and SDN, thus complementing the previous approaches from the application and service provision perspectives.

Network slicing dedicated to roaming services is considered [19] as a potential solution by allowing the extension of the footprint of the home operator into the geographical domain of the visited operator. Essentially, the home operator requests a network slice to the visited operator where deploying virtualized network functions while retaining the control and management capabilities over such functions. Those functions will be the ones needed to offer a roaming service to the home network's end user, such as the PGW and other complementary services that could be required (e.g., CDN end point for delivering subscribed video services), thus eliminating the need of transitioning intensive data traffic, and with that, avoiding costs. In addition to that, by shortening the delivery paths, better user experience is achieved since latency can be also significantly reduced. Furthermore, some other concerns as content distribution rights, lawful interception, etc., can be managed in a more simplistic way.

All these operations for constituting a network slice between multiple administrative domains require from the existence of inter-operator interfaces or APIs between the management and orchestration systems of both the home and visited operators for permitting the trading and operation of the functions and resources involved in the service.

3.2 Virtualized solution for the support of roaming users

The feasibility of virtualizing EPC components, including functions for complementary services deployed on the SGi interface, offers new possibilities for reconsidering the existing roaming architecture. The concept behind was already described in [3]. The main idea consists then in the instantiation by the home operator of a PGW (and complementary content delivery points, when needed) in the form of a virtual network function (VNF) within premises of the visited operator. Figure 3-1 depicts the prospected solution.

This can be done by leveraging on the NFVI facilities made available by visited operators to home operators. However, it is yet necessary to define mechanisms that could allow the orchestration of VNFs through administrative domain boundaries, as well as additional configuration actions (e.g., in the DNS of the home network) for a full enablement of the roaming service. The following section describes how these challenges are accomplished.

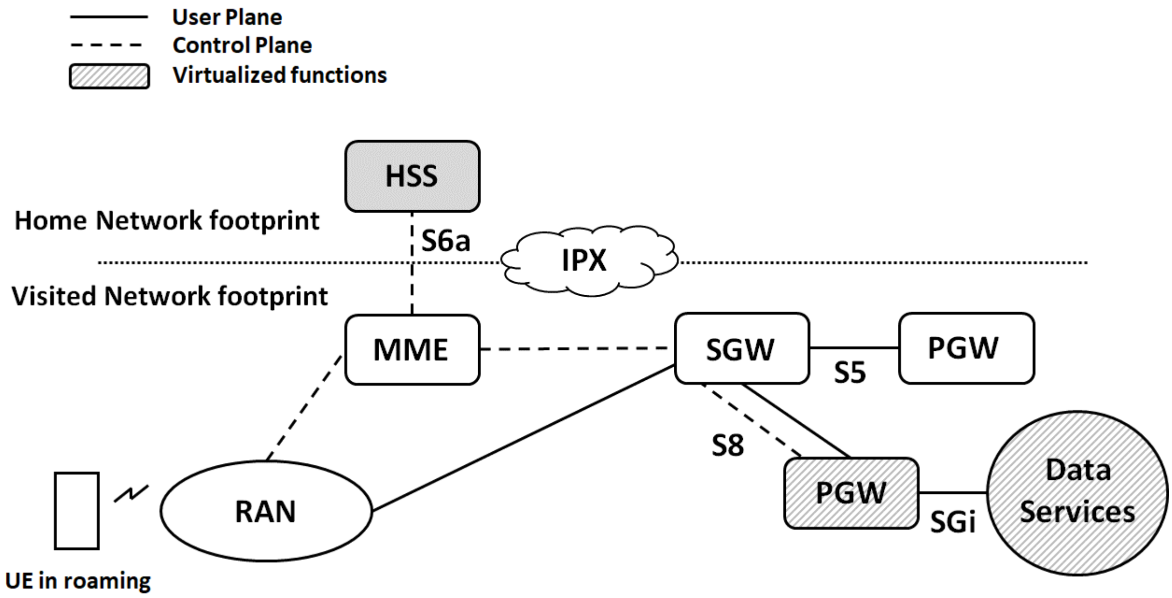

Figure 3-1. Virtualized-based LTE roaming architecture proposal (shadowed boxes represent home network elements, being virtualized the stripped ones)

4 Virtualization-based roaming service

The roaming service intrinsically involves multiple providers. In the case of employing virtualization techniques, with the home network using the NFVI facilities of the visited network, this implies the need of deploying, configuring and operating a set of VNFs in a different administrative domain (the one of the visited network, in this case), as well as the capability of properly signaling the creation of the roaming service among home and visited network operators.

4.1 Multi-domain orchestration

The VNFs can be pushed to different locations within a single administrative domain or even exceeding the frontier between administrative domains by means of multi-provider orchestration, as reported in [20] and further elaborated in [21]. That is the case for service providers offering their NFVI-PoPs to host third party service functions or even offering VNFs to be consumed by others. Thus, the service can be decoupled from the hosting infrastructure.

Both home and visited networks represent different administrative domains. Whatever orchestration action implies a multi-domain orchestration where some level of information exposition between providers is expected, as well as the availability of interfaces or APIs for control and management operations.

Two distinct levels of orchestration could be considered. On one hand, Resource Orchestration (RO), where one operator makes available resources to another operator for instantiating services in the form of interconnected VNFs. On the other hand, Service Orchestration (SO), in which one operator directly offers the instantiated VNFs for composing an end-to-end service together with its own functions. The SO manages the lifecycle of network services, while the RO provides an overall view of the resources present in the administrative domain to which it provides access.

Assuming that the orchestration domains are based on the ETSI MANO architecture, a suitable architecture for accomplishing a multi-domain scenario is the architecture defined by the 5GEx project [22]. Such architecture allows resources such as networking, connectivity, computing and storage in one operator's domain to be traded among federated operators using this exchange, and thus enabling service provisioning on a global basis. In this vision, 5GEx is the enabler, which facilitates operators to buy, sell, and integrate infrastructure services. It provides the ability to automatically trade resources, verify requested services, and leading to clear billing and charging aligned to resource consumption. An insight on specific use cases and the business dimension of 5GEx can be found in [23].

A set of APIs and interfaces protocols implement the exchange from the control plane perspective. Also, from the data plane, it is not necessary for a static and direct connection of physical appliances. Intermediate, transit networks participants of the end-to-end service (and its control procedures) providing the connecting paths between both parties.

One of the key features inherited by NFV is the separation of services from resources. The NFV architectural model describes a network service (as well as its component VNFs) as a packaging of virtual and physical resources plus an application utilizing them to implement network functions usually executed by a network appliance. The description of the VNFs and services is typically an offline function, eventually populated via a catalog of available services. At operation time, it is possible to select a network service and invoke its provisioning. The key element for accomplishing it is the Orchestrator that decides which infrastructure node is the more convenient for the service deployment counting with the necessary logical resources needed by the service. For that, dynamic information is interchanged among operators with the invoked service description, which contains detailed information about the requirements of the different VNFs (not only in terms of resources, but also geographic affinity, redundancy, etc.). Also, information from the underlying interconnected infrastructure(s) is advertised. This resource allocation is dynamically controlled and adapted, based on the monitoring of service performance, SLA enforcement, availability or security triggered reallocations, etc.

Figure 4-12 highlights the scope of 5GEx system by presenting a logical interworking architecture, showing not only functional entities but also the different APIs and operational interfaces between them. This same architecture has been considered as a solution for multi-domain programmability through SDN [24] or for the VNF composition across multiple administrative domains [25].

The core of 5GEx system is composed of *(i)* the Multi-domain Orchestrator (MdO), *(ii)* various domain orchestrators and *(iii)* collaboration with domain orchestrators and controllers that are in charge of enforcing the requested services on the underlying network, compute, and storage components.

Co-operation between providers takes place at the higher level through the inter-operator orchestration API (I2) that exchanges information, functions and control. This interface also serves for the Business-to-Business relation between operators in complement to the Business-to-Customer API (I1), through which customers request service deployment. The MdO maps service requests into its own resource domains and/or dispatches them to other operators through interface (I2). This interaction is performed at MdO level: each operator MdO can expose to other operators' MdOs an abstract view of its resource domains and available service functions.

The MdO enforces the decision through interface (I3) as exposed by Domain Orchestrators, each one orchestrating and managing resource domains through the northbound interfaces (I5) exposed by technology-specific controllers. Interface (I4) facilitates interaction among different Domain Controllers. 5GEx scope is focused on interfaces I1, I2 and I3. Full 5GEx architecture details can be found in [26].

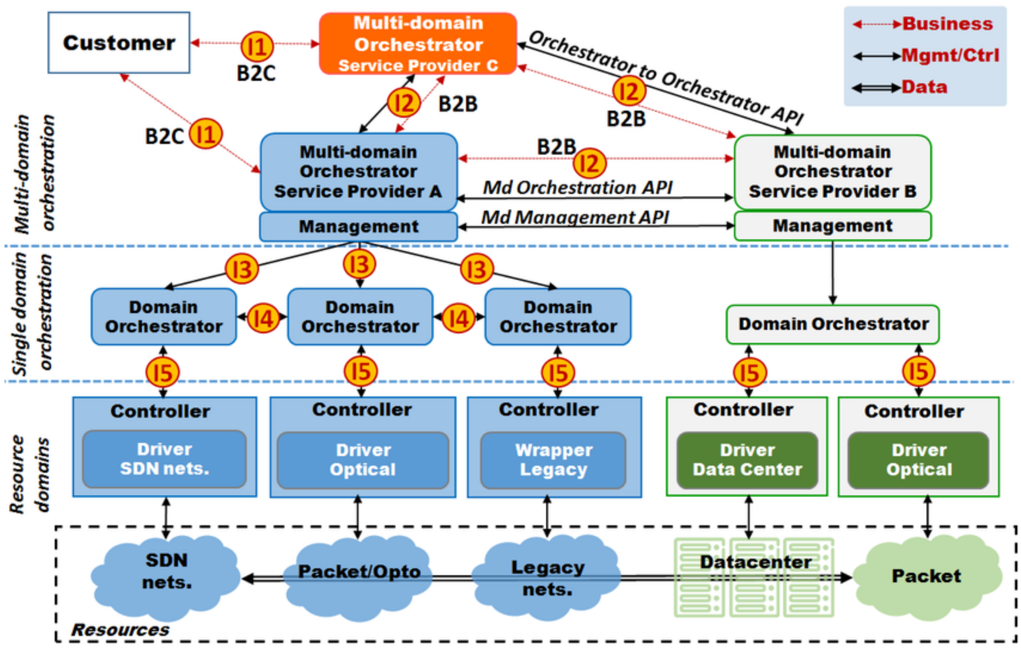

Figure 4-1. 5GEx architecture

Using such an interworking architecture for multi-domain orchestration will make possible use cases such as the roaming case, hard to tackle due to the interaction requirements of multiple heterogeneous actors and technologies.

4.2 Complementary functionality for service creation through network slicing management capabilities

Despite the 5GEx architecture enables the orchestration across multiple administrative domains, the solely multi-provider orchestration, as defined in [21], is not enough in most cases since basically it focuses on VNF instantiation and lifecycle management.

On one hand, additional functionality for this kind of environments is needed, as capabilities for performing negotiation, charging, etc., in an automated fashion. On the other hand, for some services there is a need of having some other functional modules handling aspects of the service itself which are out of the logic of the multi-domain orchestration.

This is the case of the virtualized roaming solution here proposed. In this case, the overall roaming service, besides the instantiation and deployment of a virtualized PGW (vPGW) instance as a VNF (and associated VNFs like CDN end point, if applicable) requires additional configuration such as the configuration of DNS entries for proper re-direction from the SGW of the visited network to the vPGW of the home network (deployed at the visited network's premises). That additional functionality is out of scope of the multi-domain orchestration tasks but have to be accomplished in order to properly deliver the service, but with the context and the logic related to them laying outside the MdO.

With that purpose, it is possible to leverage on the management functions needed to manage network slices to support communication services as defined by 3GPP [27]. Despite the concept of network slicing has emerged with the development of 5G, its applicability is agnostic of the technology being contained in the slice, and thus applicable also for LTE. Those functions are:

- *Communication Service Management Function* (CSMF), which is responsible for translating the communication service-related requirement to network slice related requirements.
- *Network Slice Management Function* (NSMF), that results responsible for management and orchestration of an instance of a network slice
- *Network Slice Subnet Management Function* (NSSMF), which performs the same task at sub-instance level

Both NSMF and NSSMF can be considered aggregated as part of the same Network Service realized by means of a slice. This management functions have been mapped [28] to the ETSI MANO framework. The resulting mapping locates this functionality as part of the broader OSS/BSS part of the framework, as shown in Figure 4-23.

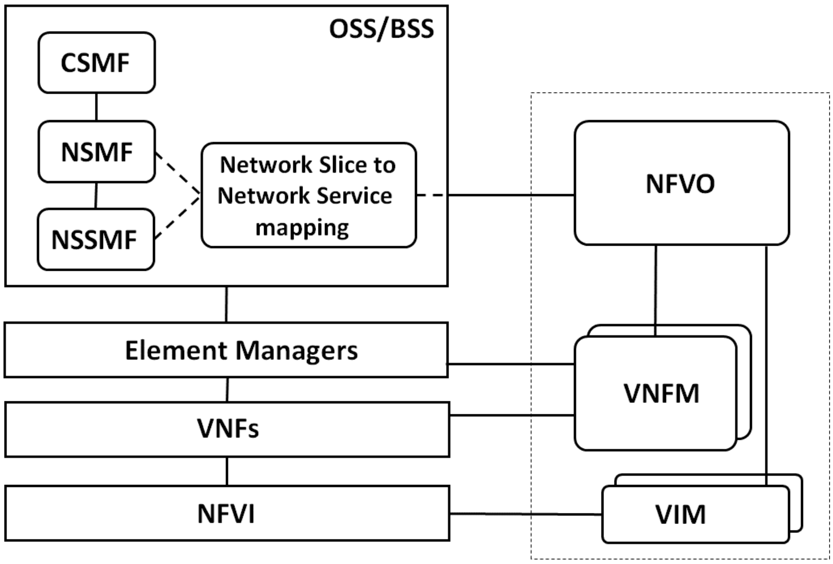

Figure 4-2. Mapping of the 3GPP network slicing concept to the ETSI MANO framework

According to the management functions described above, the CSMF could play the functionality of managing the required service logic for the virtualized roaming service (e.g., handling the DNS re-configuration in the visited network as triggered by the home network operator) to complement the multi-domain orchestration. This kind of action cannot be performed from the logic of the multi-domain orchestration since the service logic could not be fully incorporated at that level. In addition to that, the configuration and management of the services and resources offered by the visited network, once allocated and deployed, can be part of the NSMF (and NSSMF). Figure 4-34 shows the complementary functionality from an architectural point of view.

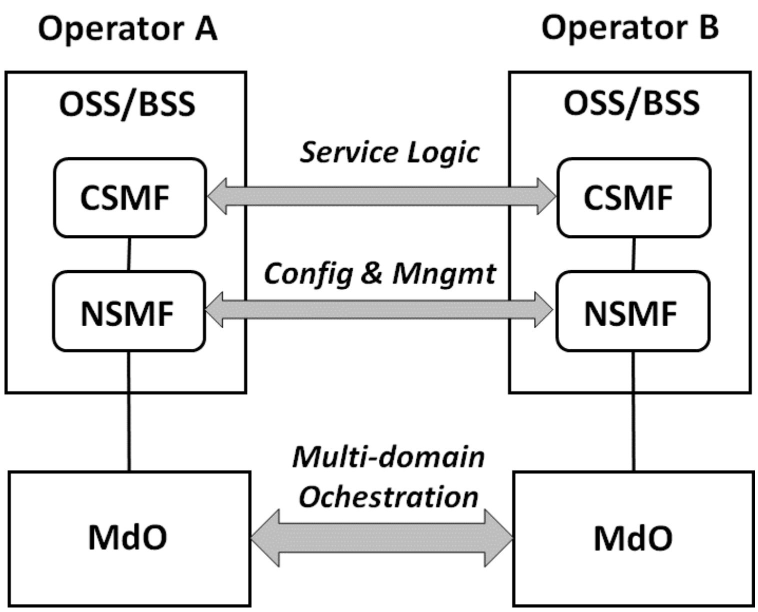

Figure 4-3. Complementary functionality for virtualized roaming service creation

4.3 Proposed solution

The proposed solution was already anticipated in [3]. Here, further details on the design are provided, spanned later on in the experimental description. Three phases can be distinguished in the provision and execution of the virtualized roaming service between Operator A (the home network) and Operator B (the visited network), namely the service preparation, service creation and service activation phases. Figure 4-45 shows a generic flowchart of these three phases, summarizing the main result for each phase, which are described next.

4.3.1 Phase I – Advertisement of capabilities between operators and service preparation

Before any kind of service interaction, the operators have to interchange information about the capabilities supported. Specifically, for the virtualized roaming service, potential visited operators will have to advertise aspects such as resource availability, geographical location, product offerings (e.g., NFVI or VNF as a service), orchestration features (e.g., versioning, supported interfaces), etc.

In these scenarios of multi-provider orchestration, this interchange can be published in the form of a service catalog per administrative domain, accessed by potential home operators.

This first phase would also include a number of business-related actions, such as service pricing and SLA negotiation, which are out of scope of this paper.

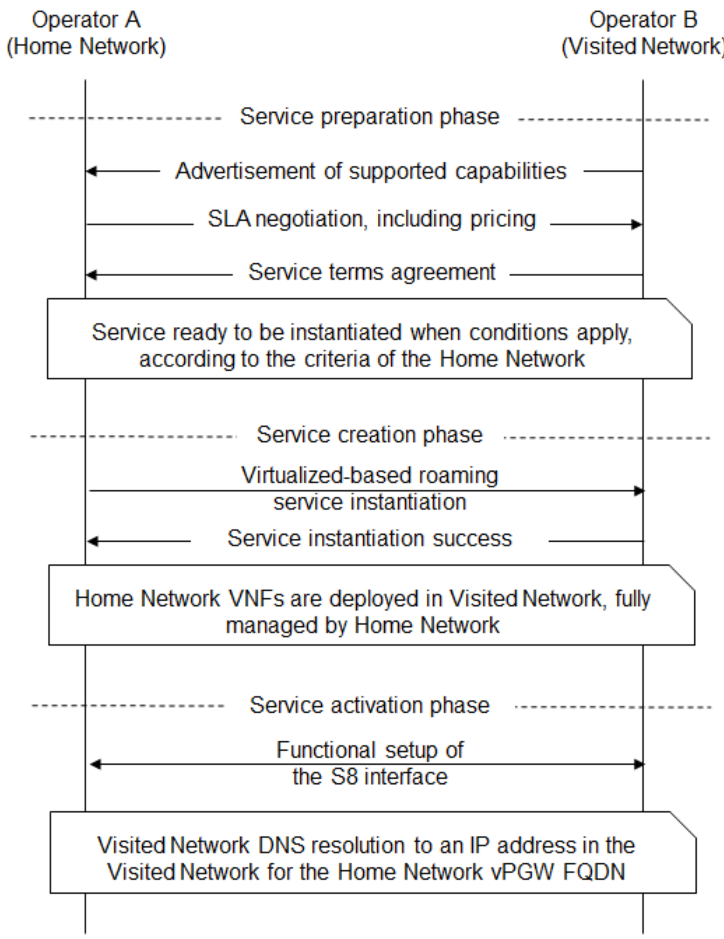

Figure 4-4. Service preparation, creation and activation phases for the virtualized-based roaming service

4.3.2 Phase II – Virtualized roaming service orchestration

Figure 4-56 graphically describes a detailed view of the workflow for the creation of the service between Operator A (the home network) and Operator B (the visited network).

Once the home and visited network operators agree on the terms of provision of the virtualized roaming service, the orchestration is triggered under a number of conditions. In this case, the trigger for orchestrating a vPGW in the visited network is considered to be the number of end users from Operator A roaming in Operator B network.

Step 1. The home network will continuously monitor the number of roaming users attached to the visited network. In the event of crossing a given threshold on the number of roaming users, the OSS of Operator A will notify that case to its corresponding BSS.

Step 2. The BSS will then instruct the OSS to initiate the provision of the virtualized roaming service.

Step 3. The OSS will request the MdO to deploy the vPGW (and associated virtual functions, noted as $vService_A$) in the visited network, including the necessary connectivity among operators. At this stage Operator A has intelligently decided when and where to deploy the VNFs of the roaming service with the information previously shared by Operator B.

Step 4. The multi-domain orchestration is initiated. The MdO of the home network request to its counterpart, the MdO of the visited network to deploy the VNFs of the service on its premises.

Step 5. Once deployed, the MdO of the visited network indicates success of operation to the MdO of the home network, including information (i.e., identifiers) of the interfaces to access the deployed VNFs for configuration and operation.

Step 6. The MdO of the home network will forward that information to its OSS in such a way that Operator A can configure and monitor the deployed VNFs by OSS, as if they were part of domestic assets.

Step 7. The final configuration of the VNFs involves interaction among OSSs of both operators since the access to the network functions is indirect (i.e., OSS of the visited network mediates in that access).

Step 8. The success of the configuration is confirmed by the OSS of the visited network.

As result, the VNFs of the roaming service have been instantiated and are up and running in the visited network.

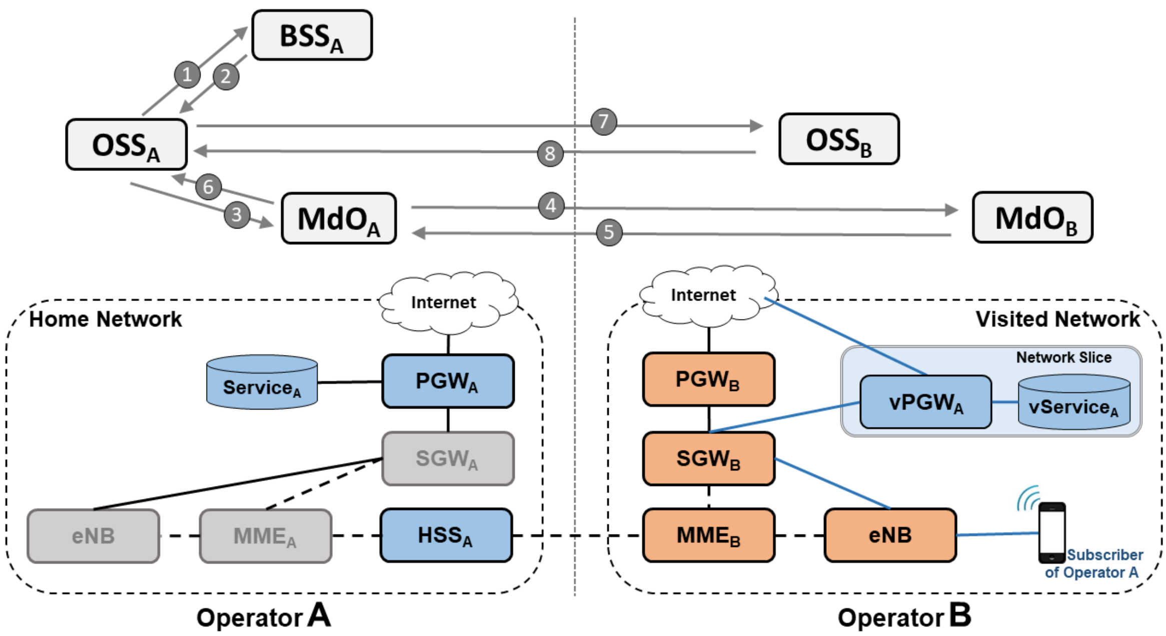

Figure 4-5. Workflow for virtualized roaming service creation

4.3.3 Phase III – Virtualized roaming service activation

As mentioned before, pure orchestration is not sufficient for activating the virtualized roaming service. Part of the logic of the service activation exceeds the purpose of the multi-domain orchestration.

The additional action to accomplish is basically to configure the PGW selection process and the functional setup of the S8 interface between the SGW of the visited operator and the vPGW.

The procedure follows the guidelines of [5]. When a roaming UE from Operator A sends an attachment request using the visited network, the MME of Operator B identifies and registers such UE into the visited network based on the information acquired from the home network HSS. During this process, the home network HSS provides to the visited network MME the identifier of the home network PGW that the roaming UE must connect to. Typically, that identifier is coded as a Fully Qualified Domain Name (FQDN) [29], requiring this FQDN to be translated into an IP address by a DNS server within the visited network.

In this case of virtualized roaming service, the home network HSS will provide to the visited network MME an FQDN for the vPGW. The mapping of that FQDN and the actual IP address of the vPGW (and IP address of the visited network) should be configured in the DNS server as part of the service creation. With such mapping, once the PGW procedure concludes, the roaming UE will be able to connect to the vPGW, completing the virtualized roaming service activation.

5 Experimental implementation of a virtualized roaming service

This section reports the experimental results achieved during the validation of the virtualized based roaming concept.

5.1 Experimental setup

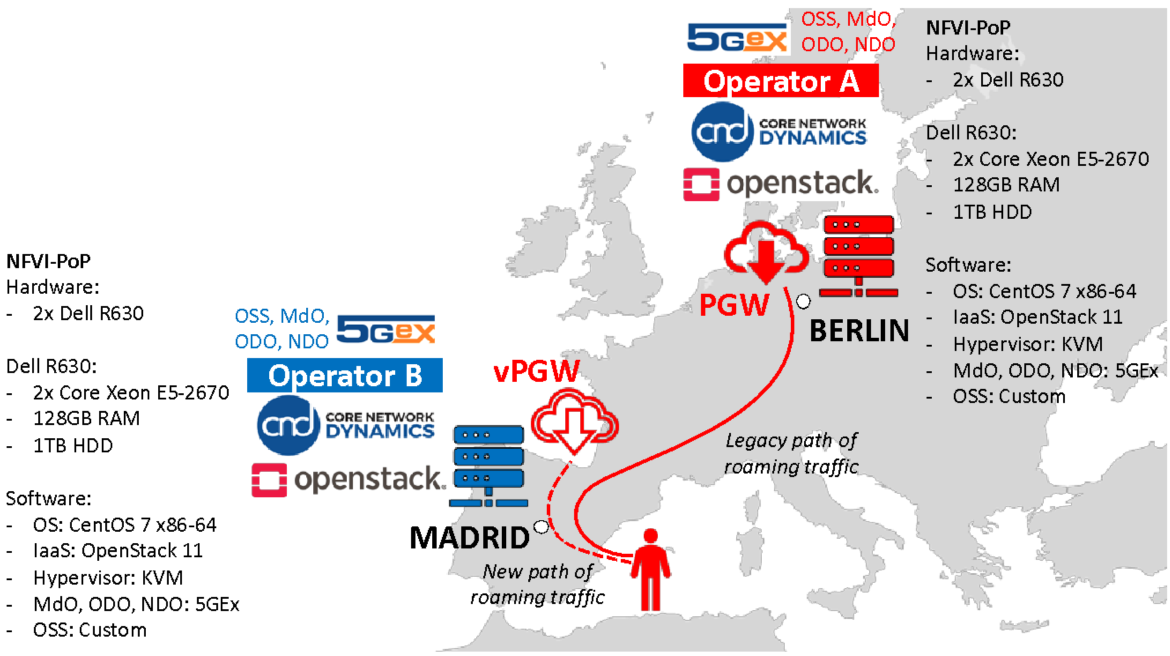

Figure 5-1: Experimental roaming setup consisting of two test-sites: Madrid and Berlin

For the experiment, a real-life prototype is built and two different operators are considered. Figure 5-1 shows the geographical location and the hardware and software setup of each of these operators, namely Operator A and Operator B. Specifically, Operator A envisages an NFVI-PoP physically located in Berlin, Germany, while Operator B envisages an NFVI-PoP physically located in Madrid, Spain. Each NFVI-PoP is composed of two Intel-based servers running CentOS 7 as Linux-based operating system while OpenStack 11 is employed as Infrastructure-as-a-Service (IaaS) for handling the underlying hypervisor – Kernel-based Virtual Machine (KVM).

Moreover, each NFVI-PoP is equipped with the 5GEx implementation of the MdO in charge of the multi-provider orchestration. In addition to this, two domain orchestrators are considered, namely the OpenStack Domain Orchestrator (ODO) and the Network Domain Orchestrator (NDO). The 5GEx implementation of the ODO is in charge of interacting with the virtualized infrastructure for the deployment of the virtual machines supporting the VNFs to be deployed by the home operator, while the 5GEx implementation of the NDO is in charge of resolving the connectivity needed for the new S8 interface.

Each operator also has some OSS/BSS functions that assists on the provision and activation of the service by monitoring the number of roaming users to trigger the deployment of the virtual machines, as described before. The OSS/BSS implementation used in this experiment consists of a mockup of the functionalities required to support the roaming service. Particularly, in this experiment Operator A plays the role of home network while Operator B plays the role of visited network.

Finally, each operator has its own running EPC in advance with a conventional active roaming interconnection established between them emulating an IPX environment. The EPC solution in the experiment is based on OpenEPC (from Core Network Dynamics), which permits the deployment of EPC entities as virtual machines, including virtualized UEs and eNBs. As a result, each NFVI-PoP runs an end-to-end virtualized LTE network (from the RAN to the Core) with a fully compliant 3GPP signaling. It is worth noting that in this virtualized version of OpenEPC, the only layer being emulated is the physical layer, all the others strictly follow the specifications by 3GPP.

In this manner, both the nominal EPC and the VNFs needed for the virtualized roaming services can be deployed and operated in a similar way. The deployment of the EPC on the NFVI-PoPs is done by using an OpenStack Heat Orchestration Template (HOT). Additionally, since the virtualized solution is complementary to the conventional roaming infrastructure, backward compatibility is ensured, and incremental deployment of the virtual solution can be prospected.

It is assumed that through the advertisement phase, the operators have agreed on the possibility of activating the virtualized roaming service, ensuring that there are enough resources available for such service. Those resources refer not only to networking and computing resources (CPU/Storage) but also to EPC specific resources like the number of supported roaming users.

5.2 *Experiment execution*

Figure 5-2 represents the execution operations of the experimental setup described before. The starting point considers that the advertisement phase has been already accomplished through the interaction of the MdOs from Operator A (located in Berlin) and B (located in Madrid), and the service, that was part of the Operator B catalog, has been agreed.

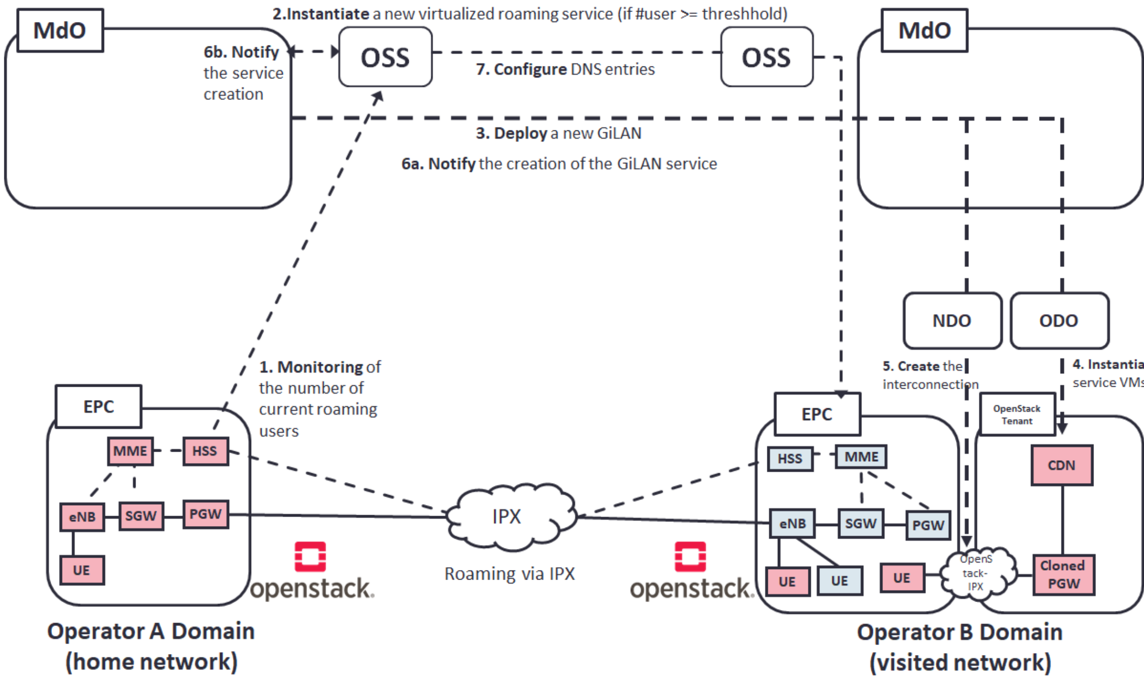

Figure 5-2. Experiment setup of the virtualized roaming service

The detailed workflow is as follows:

Step 1. The monitoring of the number of roaming users in the target visited network is done by checking the HSS of the home network EPC. This can be performed as a management action in the EPC being an internal process of the home network (e.g., performed through OSS).

Step 2. Once the threshold fixed for triggering the virtualized roaming service is exceeded, the OSS/BSS in the home network request its MdO to invoke the instantiation of the VNFs in the visited network.

Step 3. The home network MdO launches the instantiation of the service by interacting with the visited network MdO according with what has been previously agreed.

Step 4. The MdO of the visited network instantiates the creation and deployment of the VNFs of the virtualized roaming service via its ODO. The ODO spawns the required service virtual machines as associated to a particular tenant of Operator B, being the tenant the Operator A. The VNFs to be deployed consists of a vPGW (cloned from the PGW as facilitated by OpenEPC) and whatever other service that the home network could require to locate in proximity to the roaming users (for instance a CDN end point caching specific contents distributed by Operator A).

Step 5. The MdO of the visited network orchestrates the action of the NDO to creates the required service interconnections, i.e. the connection of the vPGW to the external data services (i.e., the Internet), the setup of the new S8 interface by connecting the SGW with the vPGW, and a tunnel (via the IPX) between the tenant space and the home network EPC to allow the synchronization of non-user related data, e.g. used for the CDN.

Step 6. Once the service has been provisioned, the MdO of the visited network confirms the MdO of the home network the success of the operation. As part of such notification, the MdO of the visited network sends the information about the configuration interface for the recently created VNFs.

Step 7. After the proper configuration of the VNFs, Operator A activates the virtualized roaming service by requesting the configuration of the proper DNS entry in the SGW of Operator B. As consequence of that, the DNS will start forwarding the requests for new roaming users to the vPGW, in the visited network, instead of forwarding them to the PGW in the home network.

From this point on, the new roaming users attaching to Operator B network will use the virtualized roaming service.

5.3 Experimental results

5.3.1 Service creation and activation

Figure 5-3 shows the deployment and termination time for the virtualized roaming service, providing details on the time incurred per each component as well as the total time for the service after running 100 experiments. The granularity of the polling request for collecting time information is 1 second, with the figure reports the average 95th percentile of the different contributions.

For the service deployment phase, the MdO contribution in Figure 5-3 reports the time spent from the point in which the OSS in the home network instructs its MdO to launch the service up to the point in which the MdO in the visited network informs back that instantiation has started from the ODO. The OpenStack (OS) contribution considers the time since the OSS starts polling the OpenStack domain until it reports that the vPGW virtual machine has been created. Finally, the VM contribution contains the time it takes to the vPGW virtual machine to perform the boot up. At the end of this time, the service is up.

For the service termination phase, the MdO contribution reports the time between the request of termination up to the instant in which the visited network MdO notifies back that the termination has been requested to the ODO. Finally, the OS contribution considers the time from the point in which the OSS starts a polling OpenStack asking if the vPGW VM and the instant in which all the related networks have been removed.

According to the results, the virtualized roaming service can be deployed in an automated manner on average in 46 seconds and terminated on average in 12.5 seconds. These figures shown that the service can be created and terminated easily for reacting certain service conditions in a dynamic manner. OpenStack operation is the most time-consuming contribution to the overall process. This is due to the time involved in the creation of the vPGW that implies the disk to be copied, and the time spent in the creation of the interconnection this same vPGW with the rest of the EPC inside OpenStack.

5.3.2 Improvement on latency

A relevant effect of deploying a vPGW in the visited network is the possibility of a faster provision of the data services demanded by the roaming user, either a simple access to the Internet or more complex services such the access to specific subscribed content from the home network (if this content is co-located with the vPGW).

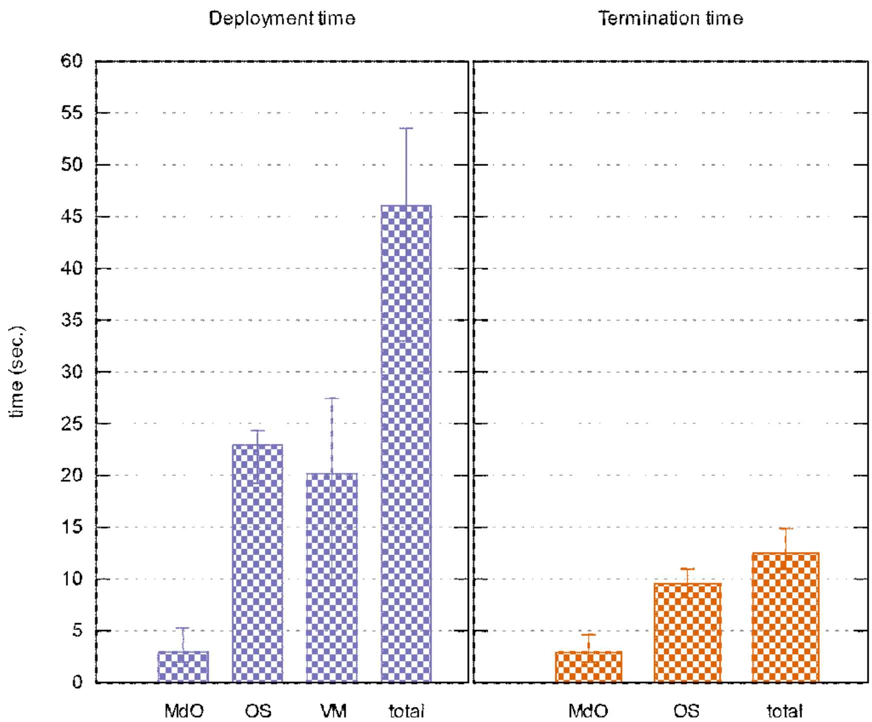

Figure 5-3. Virtualized roaming service deployment and termination time (in total and per involved components)

During the experiments, the home network components were deployed in Berlin, Germany, while the visited network ones were deployed in Madrid, Spain. The connectivity among home and visited network was established via a basic VPN. Both EPCs at Berlin and Madrid were connected to Internet.

Under these conditions the experiments were run collecting ping traces for an Internet access to google.com from a roaming UE. Figure 5-4 shows the Graphical User Interface (GUI) of the UE implementation as provided by OpenEPC package [30].

The average ping latency in the traditional scenario is ~67 ms. However, by deploying the new proposed solution, the average ping latency drops to ~6 ms. That is, an improvement on latency of an order of magnitude was observed when moving to the virtualized solution. The real gain however will depend on the conditions for the conventional roaming, since inherent distance and connectivity conditions between home and visited networks will affect in the observed latency, as reported in [8]. Anyway, for the virtualized solution it can be assumed a latency similar to the one observed in whatever domestic network and similar to the experienced by the local users. Table 6-1 presents a comparison with the related work described in Section 2.2. The trend shown is the same, reflecting a penalization in terms of delay for roaming users because of the home routing access to contents, including Internet.

Thus, the ability of deploying a home network environment close to the roamers in a virtualized manner can be an important improvement in the quality of experience of the roaming user that can be translated to a commercial advantage, as well.

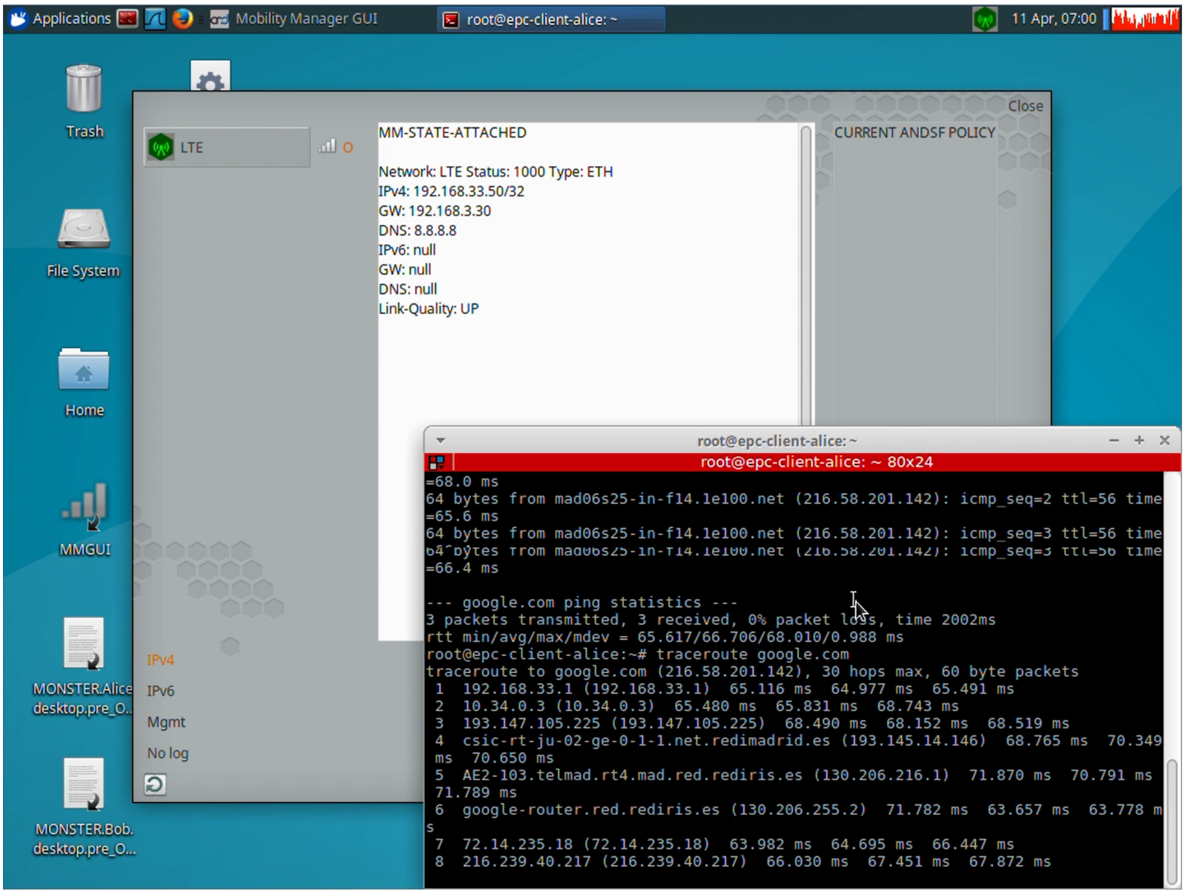

Figure 5-4: OpenEPC Graphical Interface of the UE showing ping and traceroute results in case of traditional roaming between Madrid and Berlin.

6 Techno-economic insight

The previous sections have shown the technical feasibility of the virtualized roaming solution. The economic viability of it will depend on a number of variables to quantify, as the number of roaming users (and from that, the traffic growth), the seasonal effect (or how the roaming users distribute along the time), the geographical footprint (concentration of roaming users per country and within a country), the content offerings and subscriptions of the home network, the evolution of regulation in terms of pricing, the cost evolution of the technology, etc. This makes the calculation complex and particular to each scenario defined.

In order to get a primary insight on economic viability, here a very simplistic model will be assumed, just focusing on the impact due to the growth of traffic incentivized by the new regulation. The monetary flows to consider are as follows:

- In the existing mobile data roaming scenario, the home network operator pays a regulated wholesale fee to the visited operator. Wholesale payments by home operator should allow the visited operator to recover both mobile data service origination costs plus transit costs for the home routing. Apart from that, the home operator has to cover the cost of the physical PGW.
- In the proposed virtualization-based roaming solution the home network pays a fee to the visited operator for hosting the virtual PGW. Apart from that, the home operator has to cover the cost of the virtual PGW.

Table 6-1. Result comparison to related work.

Study (Date of the experiment)	Latency penalty for roaming users [ms]	Conditions	Main takeaways	Traffic type
Mandalari et al. [7] (not detailed)	~ 60	Real measurements over sixteen European mobile operators from 6 different countries (thus, five different roaming destinations).	Home routing is generalized among mobile operators. The delay penalty varies as a function of the location of the home country. There is variety on the visited network when using 3G or 4G.	HTTP
Michelinakis et al. [9] (2017)	~ 20	Real measurements involving two Nordic operators (Swedish roamer in Norway).	Experiment on accessing CDNs and Cloud service providers. Due to the home routing, TCP connection time for roamers increases when compared to local users because of the country distance inflation. Roaming users do not benefit from existing local peering or cache agreements.	TCP
Speedtest [10] (2018), [11] (2019)	~ 76 ~ 71	Real measurement collected across 39 (28) different European countries by end of 2018 (2019). The measurements were performed through based on Speedtest data from Android devices on 4G LTE cellular connections during Q3-Q4	The provided value reflects the average increment on latency suffered by residents of European countries while roaming in Europe. Roaming agreements vary widely per operator, as well as the roaming destinations per country. Thus, uniform values for a resident across different	ICMP

		period (with at least 30 samples).	countries cannot be guaranteed.	
Work in this paper (2019)	~ 61 (when no local instantiation of vPGW, no penalty when instantiated)	Real measurements through a fully operational prototype consisting on an experimental OSS mock-up together with a virtualization-based solution, between Spain and Germany	The local instantiation of a vPGW from the home network removes the impact of distance inflation observed in conventional home routing solutions.	ICMP

This leads to an analysis where basically compare the incremental cost of the conventional solution, leveraging on higher capacity in both IPX and PGW, versus the incremental cost in the virtualized one, considering the instantiation of the vPGW fitted to the capacity required in the visited network plus the associated costs for hosting it.

An industry analyst forecast [31] states the declining on the average spend per roaming user in Western Europe in a 60% in the 2016-2023 time frame (moving from $125 to $50). This basically implies that any costs in CAPEX and OPEX derived by the traffic increase as motivated from the RLAH regulation will not be covered by a corresponding increase on revenues. Any increase on incomes will come only from an increment on the number of roaming users. With the new regulation the data consumption by roamers in EU will increase, while the average spend per active roamer will decline in the short term. The same forecast states that the rise in revenues will flatten over the next 2-3 years, starting to decline towards the end of 2021.

Figure 6-1 presents the evolution of the data roaming traffic during the last quarters in the EEA. This evolution on traffic evidences the need of an increase on IPX interconnection capacity for traffic transit in the conventional roaming scenario. Assuming a bandwidth based IPX charging model [32], such increase implies higher OPEX, even if the price per unit of traffic counts some annual erosion. As reference, the EU has established a wholesale roaming data cap of 4,50 € per GB (plus VAT) in 2019. The price caps act as benchmark prices in wholesale roaming negotiations and any discount on the wholesale roaming market is made from these reference prices. It is expected a decrease of the cap in the next years, according to [33].

The increment on traffic also implies the need of investing on PGW capacity. The dimensioning of the EPC entities depends on the number of users to be supported (dimension related to the signaling capabilities of the specific entity) and on the traffic that it can deliver (depending on the throughput supported). The PGW is a data intensive entity which provides connectivity to the external data services, thus usually being more limited by traffic than by the number of users (especially in situations when the average traffic per user increases).

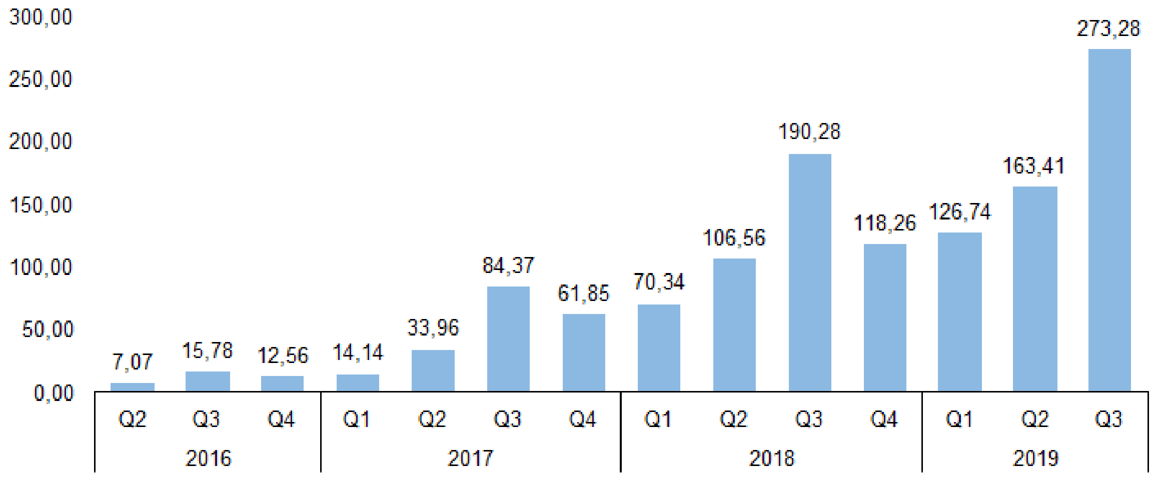

Figure 6-1. Data roaming traffic (in millions of GB) in EEA [2]

Then, an increment in the overall roaming traffic will also force CAPEX investments on PGW. To this respect, the adoption of virtualized solutions for PGW (and EPC in general) is expected to reduce CAPEX and OPEX. For instance, in [34] a TCO analysis show a significant cost reduction of 69% for the virtualized option. Similar findings are reported in [35], with savings due to the virtualized solution over the physical one between 49,2% (for a NFVI as a service approach) and 34,2% (for a VNF as a service case). All these calculations, however, are dependent on the particular scenario of analysis. It is worthy to note that the savings reported incorporate the cost of the virtualized infrastructure that in the case of the virtualized roaming solution will be offered by the visited network (translating it into an income).

For the sake of simplicity in the analysis, the following assumptions are considered:

- For both the conventional and the virtualized case, the costs of the existing infrastructure is considered as equivalent. This applies for instance to the cost of the rest of EPC entities, the cost of connection to Internet in either home or visited network (similar in a single market as the one under analysis), etc.
- It is assumed that the SDN and NFV capabilities are already in place at both the home and the visited network and are not only dedicated to the roaming case. This is the general trend, as described before, with previous analysis supporting its viability (e.g., [36]). In other words, the roaming case would be an incremental case to apply by leveraging on the SDN and NFV capabilities of the operators involved.
- In line with the studies of savings for virtualized EPC, the savings here considered will embed the cost in the usage of the virtualized infrastructure, in this case offered by the visited network.
- By moving towards virtualization, the seasonality of the roaming traffic can be better managed adapting the vPGW capacity to the demand in a dynamic way. This implies the possibility of activating vPGW only when needed. This is not the case for PGW and IPX capacity which has to be properly planned and deployed in advance attending the expected peak demand within a given time frame. For

instance, in Figure 6-1 there is a clear trend of seasonality showing huge traffic increments on the third quarter each year (comprising Q3 the traditional annual vacation period in Europe). In a usual planning exercise, capacity for the physical PGW and the IPX interconnection should take into account the potential peak reached along the year, without possibility of reducing the capacity in less demanding periods. This dynamicity, however, will not be consider here. Instead, comparison for the same capacity will be performed in a static manner (dynamicity implies an extra level of cost savings).

- Also leveraging on virtualization (in a similar way as in [18]), some of the service subscribed by the end user could be provided locally, at the visited network, while roaming, for instance by deploying virtual CDN endpoints with home network contents, actually facilitating a service "like at home", that otherwise is not possible (e.g., distribution rights). This contribution would lower the traffic increase in the virtualized solution versus the conventional one. However, this is not accounted as depends on the specific offerings of each home network operator.

Thus, the analysis can be reduced to the impact of the traffic growth on the PGW platform and the wholesale costs. According to that, it is possible to assume an incremental cost due to the traffic increase for the conventional roaming scenario as

$$\alpha \times T_u + \beta \times T_u \quad (1)$$

being T_u the incremental traffic unit (in GB), and both α the PGW and β the wholesale cost (including service originating and transit IPX costs) per traffic unit respectively.

Similarly, in the virtualized roaming case, the incremental cost can be stated as

$$\alpha \times (1 - \gamma) \times T_u \quad (2)$$

representing ϒ the percentage of cost savings of the virtualized option of the PGW (including hosting costs) versus the physical one.

Then, the cost ratio between the virtualized and the conventional solutions due to the traffic growth can be established as

$$\frac{\alpha \times (1-\gamma) \times T_u}{\alpha \times T_u + \beta \times T_u} = \frac{1-\gamma}{1+\frac{\beta}{\alpha}} \quad (3)$$

Table 6-21 summarizes the parameters used for cost comparison and their values. Figure 6-2 shows the potential savings that could be achieved through the deployment of the virtualized roaming solution.

Table 6-2. Parameters considered for cost comparison

Parameter	Symbol	Values
PGW cost per traffic unit (€/GB)	α	[100 – 35000]
Wholesale cost per traffic unit (€/GB)	β	4,50
Percentage of cost savings of virtual versus physical PGW	ϒ	20% / 40% / 60%

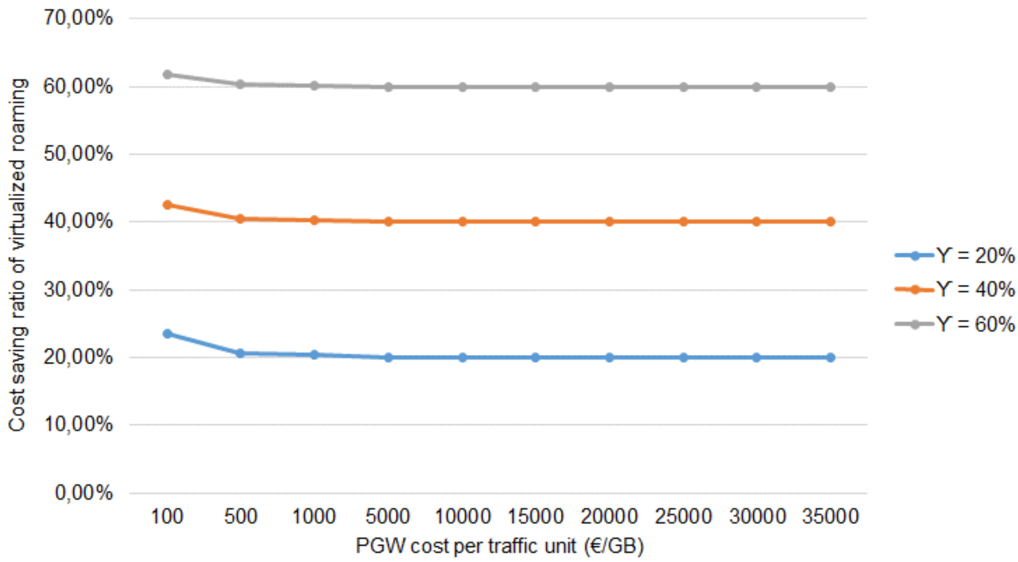

Figure 6-2. Savings of the virtualized roaming solution

What can be observed is that the cost level of the virtualized roaming solution with respect the conventional one due to the increase of traffic is dominated by the savings that the vPGW could bring with respect to the physical PGW, since $\alpha \gg \beta$. From this it could be inferred that similar gains could be similarly obtained by absorbing the new demand in the conventional case simply deploying vPGW capabilities in the home network. However, an additional advantage of the virtualized roaming solution is the minimization of the home network cash-out since no (annually growing) OPEX is payed to third party IPX providers. It is worthy to note that such an OPEX would be typically fixed and uniform along each year since the capacity is dimensioned for the annual expected peak, independently of the actual demand.

7 Conclusions

This paper has presented the design of a virtualized-based roaming solution that consists on the deployment of virtual elements in the visited network redirecting roaming users to them for implementing a true local breakout. Existing local breakout options are not practical since they present incompatibility issues, such as with billing systems, and lawful interception obligations. This virtualized-based approach allows to alleviate the inter-domain transit traffic while keeping compatibility with the 3GPP architecture.

On top of the proposed design, the paper presents some experimental results as well as some economic insights for the solution. The following conclusions are obtained:

- Multi-domain orchestration opens new business ecosystem but also can facilitate a smart evolution of existing services, as the roaming case. It enables ways of deploying services with the necessary automation between providers. Here, evolutions of ETSI NFV towards multi-domain provision have been considered as exemplified with the usage of the 5GEx project architecture.

- Orchestration is not enough in some cases for a full-service provision. There are some actions that lay out of the scope of the pure orchestration. Certain service logic could be required as in the roaming case.
- Compatibility has to be ensured for an easy transition to future mode of operation. Here the virtualized based solution coexists with the conventional one, complementing it, making possible to absorb the excess demand (once a threshold of roaming users in visited domain is passed).
- The virtualized solution allows to instantiate VNFs on demand, when needed. This permits the necessary flexibility to instantly adapt to the real demand.
- The quality of experience can be improved, and the service portfolio can be enlarged while retaining compatibility with systems and obligations (e.g., lawful interception).
- The traffic growth in roaming raised by the new tariff scheme together with the new habits in data service consumption are challenging the current way of implementing the roaming service, leveraging on third party infrastructures like the IPX. Here, in the simplistic economic analysis performed, the savings obtained with the virtualization-based solution are dominated by the expected savings due to the virtualized functions involved, but other advantages emerge such as the reduction in the cash-out to third parties, such as IPX.

The introduction of SDN and NFV is being extended in operational networks. In the particular case of the EPC, even cloud providers [13] are proposing solutions for leveraging in computing capabilities in the Internet. The dependencies to foster the deployment of solutions like the virtualized based roaming lay in the roll-out of NFVI infrastructure in network operators, the deployment of standard multi-domain orchestration environments, and the development of corresponding bilateral business models.

8 Acknowledgement

This work has been supported by the European Community through the 5GEx project within the H2020 programme (grant agreement no. 671636). Special thanks to the teams of Deutsche Telekom and BISDN involved in H2020 EU 5GEx project that were part of the design and execution of this use case.

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