Main Challenges on WAN due to NFV and SDN: Multi-layer and Multi-domain Network Virtualization and Routing

Paola Iovanna, Fabio Ubaldi, Teresa Pepe, Luis M. Contreras, Victor Lopez, Juan Pedro Fernandez-Palacios Gimenez

***Abstract*—This paper describes the requirements and challenges on WAN due to NFV in case of datacenter interconnections crossing heterogeneous domains for technology, control and vendors. It is presented a new architecture with novel functional building blocks between transport and service layers named E2E harmonization. Such architecture allows efficient virtualization for the service layer including novel elasticity parameters, while allow optimization for the transport resource. The solution allows evolving the transport network with new domains such as SDN, EON step by step that can be included as “plug-and-play” with easy interwork with existing transport domains. The solution is validated on a relevant network scenario provided from Telefonica showing the capability to following the dynamic traffic behavior without wasting bandwidth and guarantee 100% of traffic requests.**

***Index Terms*—SDN, NFV, Datacenter, Elasticity, resource optimization**

I. INTRODUCTION

Cloud computing is one a key drivers for the evolution of telecommunication networks. In this context Network Function Virtualization (NFV) [1] proposes a new model based on the “as a service” concept that allows simplifying the organization and manipulation of resources and services at different levels to create smart and fast services.

Cloud computing will evolve according two main trends. The first one is the “centralization” where most of network functions are moved in centrally placed data centers to allow resources pooling and the reduction of operation costs by concentrating site visit and competence. The second trend, instead, is to decentralize the location of some functions to reduce the transport cost, increase the performance of services especially in case tight requirements are required such as the mobile services. For example the growth of smart phones and tablet applications deployed in public data centers, and the rising use of cloud services by enterprises push for distributed data centers towards regional areas.

In such context distributed datacenters (DC) are becoming an important network infrastructure for efficient service provisioning, both for the ability to share resources in a flexible and cost-effective way and for the capability to virtualize and distribute existing network functionalities on general purpose platforms for fixed and mobile services. According to such evolution, it will be necessary to provide ubiquitous network connectivity and virtualization. In most of cases, the connectivity among distributed DCs crosses heterogeneous transport domains made of nodes from different vendors, employ different technologies, and are managed in different ways including domains managed just by Network Management System (NMS), or by distributed control plane.

DC interconnection requires large bandwidth and an effective and dynamic provisioning of connections. Thus, the traditional transport network architecture is unsuitable since it is too static if compared to the elastic and virtualized DC resources connected to it. In principle Software Defined Networking (SDN) paradigm is a valuable enabler of the NFV paradigm thanks to the capability to separate control and data-plane, facilitate the abstraction of the network resources and simplify the multi-vendor and multi-technology interworking. Practically the E2E multi-domain transport network will evolve towards SDN smoothly and only in some portions of the networks at the time, in order to prevent operators to realize their entire transport infrastructure from scratch once. Moreover, also in case of SDN implementation, it is reasonable to consider that the transport network will be organized in SDN domains for several reasons such as scalability or because different vendors provides different implementations.

The interworking among heterogeneous domains is a well-known problem that has not found a concrete and practical solution. In line with the NFV model, the transport network (called Wide Area Network or WAN) should be represented by a suitable network virtualization (NV) where the service orchestrator should easily manipulate the WAN resources to compose E2E services unaware of the transport domains

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Paola Iovanna is with Ericsson, via Giuseppe Moruzzi, 1, 56214, Pisa, Italy (e-mail: paola.iovanna@ericsson.com).
Teresa Pepe is with Ericsson, via Giuseppe Moruzzi, 1, 56214, Pisa, Italy (e-mail: teresa.pepe@ericsson.com).
Fabio Ubaldi is with Ericsson, via Giuseppe Moruzzi, 1, 56214, Pisa, Italy (e-mail: fabio.ubaldi@ericsson.com).
Victor Lopez is with Telefonica, Core Network And Transport I+D, Ronda Della Comunicatiòn, 28050, Madrid, Spain (e-mail: victor.lopezalvarez@telefonica.com)
Luis M. Contreras is with Telefonica, Core Network And Transport I+D, Ronda Della Comunicatiòn, 28050, Madrid, Spain (e-mail: luismiguel.contrerasmurillo@telefonica.com)
Juan Pedro Fernandez-Palacios Gimenez is with Telefonica, Core Network And Transport I+D, Ronda Della Comunicatiòn, 28050, Madrid, Spain (e-mail: juanpedro.fernandez-palaciosgimenez@telefonica.com)

heterogeneity, and this seems not considered in current solutions. Elasticity support is one of peculiar requirement for efficient DC interconnection, but how to provide that in an E2E heterogeneous environment has not been defined yet. Moreover, due to the fact that the cost of transport is one of the critical aspects with respect to storage and computing cost, how to provide that with optimization of the transport resources is a very key challenge. The main standardization bodies that deal with virtualization in NFV and routing in SDN analyzed the two topics from two different points of view without considering that some links are necessary between the two areas. In fact ETSI NFV [1] faces the virtualization from the view of the "service provider" defining the requirement of telecommunication services, while IETF [2] faces the virtualization from the view of the "transport vendor" defining the requirement of the transport network. What is missing is the link between the two approaches that allow better conjugating the requirements coming from transport and service.

This paper proposes a solution that "glues" the service with the transport requirements in a multi-domain scenario. We present the requirements and challenges on WAN due to NFV, and define a new architecture with novel functional building blocks between transport and service layers named E2E harmonization. New parameters for elasticity support that are transport domain agnostic are presented. That parameters enable new E2E services and the E2E harmonization methods assures transport resource optimization. The solution is validated on a relevant network scenario provided from Telefonica.

II. MAIN REQUIREMENTS ON WAN

According to NFV paradigm, the main requirement for the multi-domain transport is the capability to operate and manage the E2E network automatically, simplifying the multi-vendor and multi-technology inter-working. The target is to move towards a service-driven configuration management scheme facilitating and improving the completion of configuration tasks, by means of highly automated, service-wise, global configuration procedures. Currently, in a network composed of heterogeneous domains automatic provisioning of E2E connection is very complex and requires long time and high operational costs for configuration, management and adaptation to each particular technology implementation. Thus it is the first issue to fix, then virtualization and resource optimization is the second task.

In the following the main requirements on WAN to apply NFV principles are reported.

Fast & automatic carrier grade connection. The transport layer should provide "on demand" E2E connectivity hiding the specific technology and implementation issues. Moreover, in order to provide all services, including real time ones, tight requirements in terms of resiliency, delay, latency must be guaranteed.

Elasticity. It should be possible providing "real time" and "on-demand" elastic services at E2E level even if the E2E connection crosses domains with different ways to provide elasticity, including the case of some domains could not support elasticity capability at all.

Efficient resource optimization. Both routing and elasticity at the E2E level in the service layer should be provided guaranteeing resource optimization in each domain of the transport layer to reduce the cost per bit of the transport [3].

The resource optimization in a multi-domain network scenario could be challenging because, even though each domain is organized to optimize its own resources, such advantage could be loosen when combined in the E2E connectivity. Each domain could provide elasticity in different ways or some domains could not support elasticity at all. Optimization in each domain could require longer time in terms of computation and configuration time with respect the very fast requirements to support E2E real time services. Thus, an E2E harmonization of such heterogeneous domains is required both to automate the E2E provisioning and to optimize the resource usage. This function could be considered as part of the transport layer and part on the service layer, and we name "E2E harmonizer". It represents the capability to harmonize all transport domains in order to provide suitable virtualization to the service layer and meet optimization requirements on the transport layer. Such E2E harmonization should allow including new domains with different capability in terms of data-plane, control plane, and elasticity as plug-and-play without impacting the other domains. This allows guaranteeing the operator to smoothly evolve the transport network and keeping the separation between the transport and the service layers. Actually, in case a domain with better performance in terms of elasticity and resource optimization is included, the E2E solution performance are improved as well, but without any impact on the other domains composing the E2E connectivity. Moreover, according to NFV model, it should be possible to provide a suitable virtualized view of the E2E transport, with parameters that are technology agnostic, that the service orchestrator will use, for example to optimize the storage, computing and transport resources. In projects like UNIFY [4], service abstraction model to enable dynamic and automatic placement of networking, computing, and storage, is provided but low attention is dedicated to the multi-domain transport networks to meet the requirements described in the previous points. The elasticity support is something that has not been included in the virtualized representation of the multi-domain transport network according technology agnostic parameters. The parameters reported in the virtualized view could be part of a Service Level Agreement (SLA) that the transport layer guarantees to the upper service layer. In addition the virtualized view should be quite stable in the time limiting the variation of parameters and facilitating the task of the service orchestrator. Again, this could be in contrast with the resource optimization techniques applied on the transport layer where, continuous change of information and data could be necessary. In [5] and [6] are described solutions for multi-domain path computation, but the multi-vendor extension has not concretely provided. The challenge is to meet all previous requirements concurrently taking into account NFV and SDN reference paradigm.

III. E2E HARMONIZATION: ROUTING & VIRTUALIZATION

In this section, the E2E harmonization solution is explained by its main two functions that are the multi-domain network virtualization and the E2E routing.

The proposed solution is based on two main principles. The first one is to provide a sort of umbrella on the top of the transport layer that "translates" in common service parameters the technology parameters of each network domain to provide a homogenous view (i.e. abstraction). The second principle is the separation of the E2E routing performed at service level on the virtualized view with respect the intra-domain routing performed to build up the virtualized view. In Figure 1, the architectural model for the proposed solution is reported. The Figure represents the connectivity between DCs controlled by SDN control, crossing heterogeneous domains. Each DC domain exposes proper virtualization of computing and storage resource to the service layer that is named in the paper as service control. According to the separation between service and transport layers, the transport is in charge to expose the parameters to the virtualized view, while the service control uses the virtualized view as proper resources.

The main building blocks of the solution are the following:

a) *Multi-domain transport layer*. It is composed by domains with a proper control. It could be a traditional control (e.g., GMPLS or NMS in case of domains without control plane) or a SDN control. Each domain could have a local PCE for path computation as well. Moreover the domains can belong to different vendor.

b) *Local Virtualizer*. It is one for each domain and performs abstraction of transport resources. Each domain provides the information about the connectivity according the specific language of the domain (e.g. GMPLS, etc.). The "Local Virtualizer" translates the technology parameters in service parameters including elasticity and summarized the physical paths in virtual links. In [7] an algorithm that performs such summarization is described in detail.

c) *E2E Harmonizer*. It combines the information provided by the "Local Virtualizer" with those related to the interconnections between the domains to build a virtual network topology for an efficient path handling in the service-layer. It could be duplicated in intra-vendor and inter-vendor building block.

d) *Service Controller (SC).* It manages E2E resources, including storage and computing at service layer. It validates and authorizes resource requests. The E2E path computation is performed by a Virtual Network PCE (V-PCE) that may be part of the Service control or implemented as an external application.

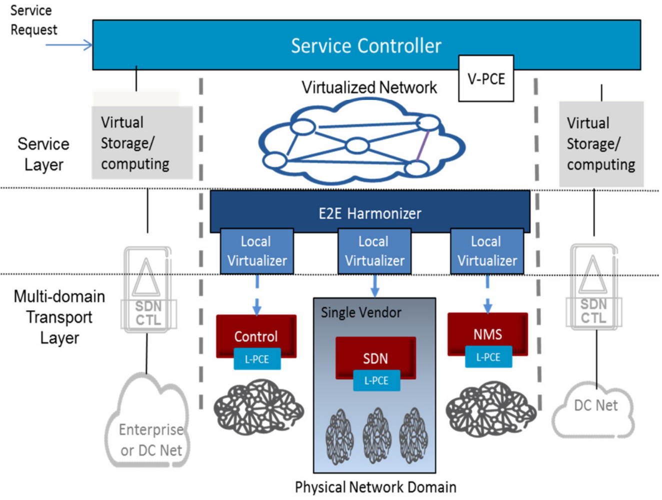


Fig. 1 Functional building blocks of the proposed architecture

A. Network virtualization model

In order to represent the virtualized view in a common language suitable for the service control, the parameters of the domain are described using a common set of service parameters. The type of E2E service to be supported could be statically configured or dynamically requested from the SC to the "E2E Harmonizer". An example of E2E service could be a point-to-point Ethernet service and the corresponding parameters could be Guaranteed Bandwidth, Peak Bandwidth, Delay, Jitter, and Loss.

The "E2E harmonizer" performs two operations when a service is requested by SC. First the V-PCE is triggered to compute the E2E path for the service on the virtual network topology available in that moment. Then all "Local Virtualizers" that manage the virtual links selected by the "V-PCE, select a corresponding physical path that is internal to the domain area controlled by the "Local Virtualizer". A possible example of such selection is shown in [7].

The main advantage of such architecture is that the service operations, like the E2E path computed by V-PCE, can be real time because the computation is performed on the virtual topology information available at the time of the service request. At the same time such real time operation are asynchronous with respect to the transport operations that could be time consuming. For example the computation and the configuration of the physical paths for each domain that corresponding to each virtual path could be performed in advance and in a different time with respect the computation of the virtual path. An example of such decoupling is the virtual link monitoring performed by the "Local Virtualizer" on the summarized virtual link as explained in [7]. According to such method there is a phase where the physical resources of each domain are summarized and put at disposal of the E2E path computation. While the physical resources are used, there is some criterion to compute or modify the summarization before that such resources are not available.

In addition on the virtualized view novel parameters are defined to provide E2E elasticity. Such parameters are the *Maximum elastic bandwidth with traffic interruption (Max-E in)*, and the *Maximum elastic bandwidth without traffic interruption (Max-E out).*

“Max-E in” associated to a link, indicates the maximum increase of bandwidth that such virtual link can provide without guaranteeing any traffic disruption, while “Max-E out” indicates the amount of bandwidth that such virtual link can provide guaranteeing no traffic disruption.

This method allows providing three different types of service by the service control. The first one is a static negotiation of SLA that can be associated to a service type by a contract stipulated off-line. The second type of service could be based on a dynamic negotiation of the SLA for the customer. In such model the service control can accept the negotiation and allocate the resource in elastic way by modify the bandwidth of the path, re-route the traffic in alternative links, or split them in more links. The third service type could be the “management of out of SLA”, that allows the customer to send exceeding traffic without renegotiate SLA, and the service controller can serve this traffic taking advantage of unused resources. According to the elasticity parameters and the service type service control could decide the level of elasticity to provide (e.g. with or without interruption).

SC manages the allocation of virtual resource for the transport by using a virtualized PCE. Several implementations can be considered for such PCE (e.g. internal to SC, external application). According to the service requests, the SC can decide to increase the bandwidth associate to the service exploiting the elasticity parameter on each link. This means to increase the bandwidth keeping the same path or provides a new path. The aim is to take into account the elastic capability of the physical resources due to an elastic reconfiguration of nodes. For examples, EON elasticity techniques could be implemented or the elasticity could be provided with a bandwidth variation of a Label Switched Path (LSP) in a Multiprotocol Label Switching (MPLS) network. This type of representation is technology agnostic and allows to define elasticity as SLA in the E2E connection.

In more detail, the proposed solution consists of the following steps. In the first one each domain provides the lists of available paths between the border nodes according proper policy and rules. That could be done on request from “Local Virtualizer” by standard (e.g. PCEP, NETCONF) or proprietary protocols. In the second step each “Local Virtualizer” organizes such list of paths belonging to the same source and destination in databases called baskets. In addition, if class of services (CoS) is defined, the list of paths belonging to the same source and destination can be organized in different baskets, one for each CoS. Thus, a basket is a database of paths, connecting same source and destination of border nodes of a domain, belonging to the same CoS, that is, paths that have bandwidth, delay, jitter, and loss within a specific range of values, and elasticity parameter. When a transport domain computes a new path, it is associated to a basket based on the CoS it belongs to.

The creation of a basket is done according an asynchronous operation, with respect to the E2E routing in order to decouple the E2E routing that should be very fast with respect the intra-domain routing that could be slower.

Note that each domain cannot pre-calculate all the possible paths but only a portion of paths according to an estimation of the traffic request. The time to do that could be different for each domain and the paths could be configured when are communicated to the “Local Virtualizer” or just pre-computed according to the local transport domain policy. Finally, in the third step the “Local Virtualizer” associates the virtual parameters to be exposed. For sake of simplicity we consider the bandwidth value that is used for optimizing the resource usage. Each virtual link for the basket with i paths is represented by the following values:

- VBw = bandwidth of the path with maximum value
- $VE1$= min (Ei) elasticity of the path with minimum value
- $VE2$ = max (B_i+ E_i)

In more detail, *VE1* represents the elasticity that the network may provide without requiring to move the traffic to another path causing traffic interruption. *VE2* instead is the maximum bandwidth that the network is able to provide on a path in the basket considering elasticity. Note that the specific value assumed by *VE1* and *VE2* depends on the particular elasticity capabilities of the domains. For example, in a MPLS domain the elasticity parameters can be set to the difference between the available link bandwidth and the bandwidth allocated to the given LSP. In this way, it is possible to change, by using RSVP, the bandwidth associated to the LSP until the maximum link capacity is reached. Gathering the virtualized information from each domain with the inter-domain information, the “E2E harmonizer” constructs the virtual topology as virtual nodes (i.e., border nodes of the physical network domain) connected by VLs and exposes that to the service control. The transport layer and the Harmonization are responsible for the information exposed in the virtualized view, while the service control work only on the virtualized view as proper resource.

B. E2E Routing Solution

A service request is described by two values: the bandwidth that is currently required (B_r) and the capability to modify its bandwidth value (E_r). The service can require this modification allowing traffic interruption or without interruption. When a new E2E service request arrives to the SC, the V-PCE computes the E2E path on the virtual topology available in that time. If the service is without traffic interruption, V-PCE routes the traffic if the request is minor the sum between *VBw* and *VE1*. Moreover, if traffic interruption is allowed by the service, V-PCE routes the traffic if the request is minor of *VE2*. After the E2E path has been computed, the V-PCE asks the “E2E Harmonizer” to provide the physical resources. The "E2E Harmonizer" manages the inter-domain resources, while each "Local Virtualizer" selects in suitable way the resources from the basket according to the following criterion:

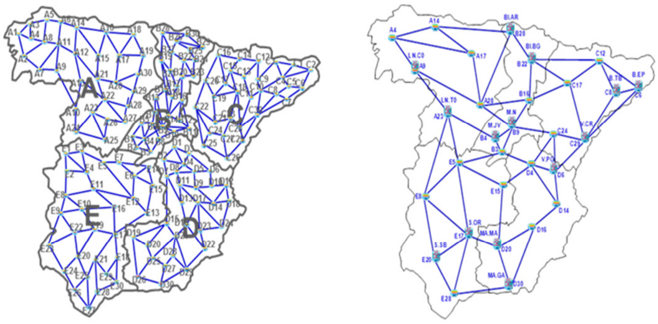
$$\begin{array}{ll} \min (B_i) \geq (B_r + E_r) & \text{if } VBw \geq (B_r + E_r) \\ \min (B_i + E_i) \geq (B_r + E_r) & \text{if } VBw < (B_r + E_r) \end{array}$$

This choice allows limiting the use of bandwidth and aims at optimizing the mapping of the requests on the physical path. Moreover, the method aims to limit the use of the physical paths with the maximum value of bandwidth, in order to maximize the probability to accept E2E requests with high bandwidth value. While the physical resources are used, a mechanism is introduced to fill the basket before they are empty. This method has a twofold objective: the first one is to avoid that all domains must compute all resources for basket once; the second is to follow dynamically the behavior of the traffic and fill the basket accordingly. In more detail, a method for basket usage monitoring has been introduced. Details about the method are in [7].Such monitoring method is based on the measurement of the paths utilization in the basket. Whenever the number of available physical paths into a basket reaches a critical prefixed threshold (*Th*), the corresponding transport domain is triggered in order to provide further paths for that basket. The path computation is performed taking into account the residual available resources inside the domain. Moreover, all the baskets are monitored to check how many times the threshold is reached in a fixed time window (*Ti*), and consequently, the system updates the paths in the basket. The baskets that reach *Th*, more times than a prefixed value (*Th1*), are considered critical. After a time equal to Ti, critical baskets are filled with more physical connectivity. Instead, in non-critical basket N (number of paths in the basket) paths are released. The monitoring, as the path computation, is performed by the "Local Virtualizer", independently and asynchronously to how V-PCE works. This allows the execution of time consuming operation (e.g., physical impairment validation) asynchronously with respect to the E2E routing of the service control. In addition, this makes the solution able to fit the virtualization to unpredictable network variation; also it allows avoiding stability and scalability issues due to the absence of continuous communication between the different network layers (i.e., physical, virtual) because the filling of the basket does not change the VL.

IV. RESULT

A. *Topology description and traffic model*

The reference network topology is the Spanish IP/WDM backbone, shown in Figure 2 provided by Telefonica. It consists of five regional domains based on IP/MPLS technology (Figure 2a) and one national domain (Figure 2b), providing interconnections between the regional domains, based on IP and optical technology.



a. Regional domains

b. National domains

Fig. 2 Spanish backbone topology

An expected traffic matrix for the topology is provided by Telefonica and it is used for basket dimensioning at the starting point.

B. *Traffic model*

It is assumed that E2E traffic demand consists of traffic related to different service requests types (voice, video, data, and datacenter). The bandwidth request is represented as a product between the mean requested bandwidth for each single user and the number of user formed the aggregated request.

The type of traffic, typically carried in a backbone network, the relative mean bandwidth ranges for single user and the number of user are reported in Table I.

TABLE I
TRAFFIC DESCRIPTION

Service Type	Mean Bandwidth for Single User	Number of Users
Voice	4Kbps-64Kbps	100-3000
Video	2Mbps – 15Mbps	5-20
Data	1Kbps – 10Kbps	1000-10000
Datacenter	2Mbps-15Mbps	20-200

Each service request is generated (Birth) according to a Poisson process with rate λ and served in an exponential time with mean $1/\mu$. At the end of the service time the request goes out of the servant (this occurs with probability p) or it goes back into the servant and the bandwidth request is modified (this occurs with probability 1-p).

C. *Simulation results*

In [7] the network virtualization model has been analyzed and the results are summarized in Figure 3. In this Figure is compared the case where the "Local Virtualizer" only selects the physical paths to the services (called Hierarchical Static Routing or HRS) with the case where the "Local Virtualizer" selects the physical paths and exploiting the decoupling of transport and service operations, perform the monitoring of the virtualized links (called Hierarchical Dynamic routing or HDR.

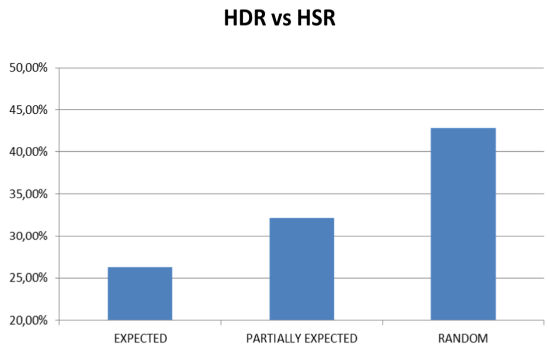


Fig. 3 Bandwidth accommodation gain

In “Expected” case the same traffic matrix is used for dimensioning and dynamic routing; in “Partially Expected” the two matrices have the same traffic volume but 25% of requests have different source-destination nodes and bandwidth; in “Random” only the total traffic volume is the same. The figure shows that HDR allows accommodating always more bandwidth than the HSR approach (at least more than the 25%). Moreover, when there is unexpected traffic, the dynamic approach allows to follows the network request earning the 43% of allocated bandwidth, while the static approach is not able to optimize the network resources.

In this paper it is also evaluated the elasticity solution described in section III.

Two traffic cases are considered: in the first one the amount of traffic is smallest respect to the amount used for dimensioning the network (i.e. 2000 traffic requests equally divided for each service type). In the second one, named “high-load” the amount of traffic requests is 30% higher than the one used for dimensioning (e.g. 10000 traffic requests equally divided for each service type. The proposed solution (called “elastic policy”) is compared with two other policies of service allocation. In the “allocation policy 1” method, the peak bandwidth is allocated; while in the “allocation policy 2” method, the guarantee bandwidth is allocated according to a certain percentage respect to the peak value. The evaluation of the solution is performed using two performance parameters: i) *Wasted bandwidth* (B_{wast}) that represents the amount of bandwidth allocated by the network and not used by the services; it is evaluated as percentage respect to the total allocated bandwidth; ii) *Unreserved Bandwidth* (B_{unr}) that represents the amount of bandwidth requests by the service and not allocated by the network (service dropping). The comparison results for “low-load” profile are reported in Table II. It shows that the proposed solution is able to serve all the requests for the entire service time allocating the right amount of network resources, without dropping service traffic. On the other hand, “allocation policy 2” has a percentage of traffic dropped (this percentage increase when the threshold of guaranteed bandwidth decrees). At the same time the “elastic method” does not waste network resources as performed by the other two allocation policies.

TABLE II
SIMULATION RESULTS

Allocation Policy	“Low-Load” Profile		“High-Load” Profile	
	B_{wast} (%)	B_{unr} (%)	B_{wast} (%)	B_{unr} (%)
Elastic Policy	0%	0%	0%	0%
Allocation Policy 1	78%	0%	88%	0%
Allocation Policy 2 25%	0.9%	45%	6%	44%
Allocation Policy 2 50%	24%	20%	22%	19%
Allocation Policy 2 75%	47%	4%	48%	4%

V. CONCLUSION

This paper report a novel architecture with related solution to provide efficient data-center interconnection crossing heterogeneous multi-domain WAN. The work defines new functions to better conjugate the virtualization model of NFV and efficient routing of SDN including new services model for supporting elasticity. That enables the application of NFV principle in current infrastructure favoring the evolution of SDN control step by step and allow high performing domain, such as EON, to be included smoothly in the E2E transport with very efficient interworking with domain with different features. A validation of the solution has been performed on Spanish backbone networks considering realistic traffic matrix demonstrating the capability to support elasticity with optimization for the transport resources.

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