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NFVIaaS Architectural Framework for Policy Based Resource Placement  
and Scheduling

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Abstract

One of the goals of Network Functions Virtualization (NFV) is to offer the NFV infrastructure as a service to other SP customers - this is called NFVIaaS. Virtual Network Function (VNF) deployment in this paradigm will drive support for unique placement policies, given VNF's stringent service level specifications (SLS) required by customer SPs. Additionally, NFV DCs often have capacity, energy and other constraints - thus, optimizing the overall resource usage based on policy is an important part of the overall solution. The purpose of this document is to depict an architectural framework for policy based resource placement and scheduling in the context of NFVIaaS.

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#### Conventions used in this document

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1. Introduction

One of the goals of NFV [ETSI-NFV-WHITE] is to offer the NFV infrastructure as a service to other SP customers - this is called NFVIaaS [ETSI-NFV-USE-CASES]. In this context, it may be desirable for a Service Provider to run virtual network elements (e.g., virtual routers, virtual firewalls, and etc. - these are called Virtual Network Functions - VNF) as virtual machine instances inside the infrastructure of another Service Provider. In this document, we call the former a customer SP and the latter an NFVIaaS SP.

There are many reasons for a customer SP to require the services of an NFVIaaS SP, including: to meet performance requirements (e.g., latency or throughput) in locations where the customer SP does not have physical data center presence, to allow for expanded customer reach, regulatory requirements, and etc.

As VNFs are virtual machines, their deployment in such NFVIaaS SPs would share some of the same placement restrictions (i.e., placement policies) as those intended for Cloud Services. However, VNF deployment will drive support for unique placement policies, given VNF's stringent service level specifications (SLS) required/imposed by customer SPs. Additionally, NFV DCs or NFV PoPs [ETSI-NFV-TERM] often have capacity, energy and other constraints - thus, optimizing the overall resource usage based on policy is an important part of the overall solution.

The purpose of this document is to depict an architectural framework for policy based resource placement and scheduling in the context of NFVIaaS.

2. NFVIaaS Architectural Framework for Policy Based Resource Placement and Scheduling

The policy engine performs policy-based resource placement and scheduling of Virtual Machines (VMs) in support for NFVIaaS. It determines optimized placement and scheduling choices based on the constraints specified in the policy. The NFVIaaS Architectural Framework for Policy Based resource placement and scheduling is based on the NFV policy architectural framework [IRTF-NFV-POLICY-ARCH]. This is depicted in Figure 1.

In one instantiation of this architecture, the policy engine would interface with the Measurement Collector to periodically retrieve instantaneous per-server CPU utilization, which it would then use to compute a table of per-server average CPU utilization. In an alternative instantiation of this architecture, the measurement collector could itself compute per-server average CPU utilization. The latter approach reduces overhead, since it avoids too frequent pulling of stats from Ceilometer. The policy engine evaluates such policies based on an event trigger or a based on a programmable timer.

Other average utilization parameters such as VM CPU utilization, VM Memory utilization, VM disk read IOPS, Network utilization/latency etc. could be used by the policy engine to enforce other types of placement policies.

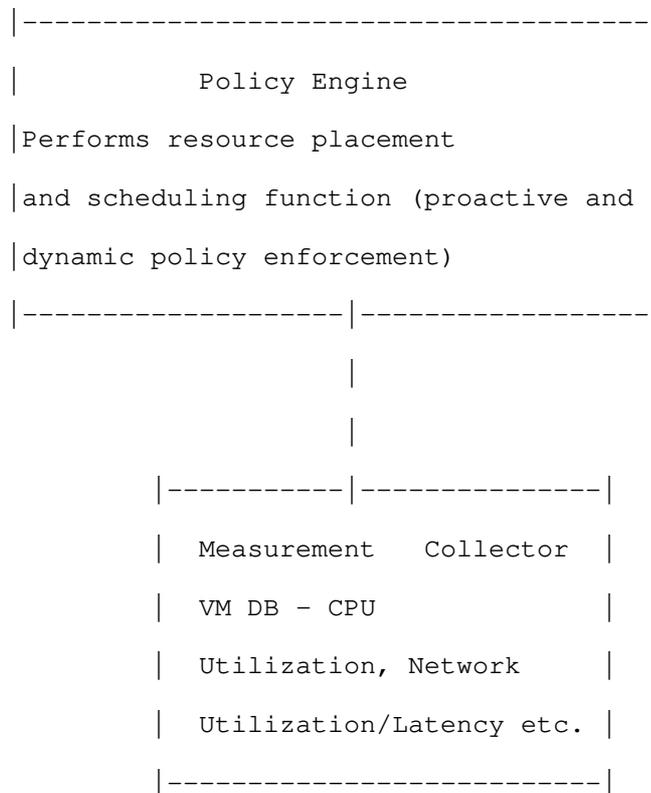


Figure 1: NFVIaaS Architecture for Policy Based Resource Placement and Scheduling

In an ETSI NFV Architectural Framework [ETSI-NFV-ARCH] [NFV-MANO-SPEC], Policy Engine is part of the Orchestrator and the Measurement Collector is part of the Virtual Infrastructure Manager (VIM).

### 3. System Analysis in a OpenStack Framework

#### 3.1. Compute Monitoring with OpenStack - Use Case and Example

Consider an NFVIaaS SP that owns a multitude of mini NFV data centers managed by OpenStack [OPENSTACK] where,

- The Policy Engine function is performed by OpenStack Congress [OPENSTACK-CONGRESS-POLICY-ENGINE]
- The Measurement Collector function is performed by OpenStack Celiometer [OPENSTACK-CELIOMETER-MEASUREMENT]
- The Policy Engine has access to the OpenStack Nova database that stores records of mapping of virtual machines to physical servers.

Exemplary Mini NFV DC configuration:

An exemplary mini NFV DC configuration is depicted below.

- There are 210 physical servers in 2U rack server configuration spread over 10 racks.
- There are 4 types of physical servers each with a different system configuration and from a particular manufacturer. It is possible that the servers are from the same or different manufacturer. For the purpose of this example, server type 1 is described further. Server type 1 has 32 virtual CPUs and 128GB DRAM from manufacturer x. Assume 55 physical servers of type 1 per mini NFV DC.
- There are 2 types of instances large.2 and large.3, which are described in the table below. Each parameter has a minimum guarantee and a maximum usage limit.

Instance Type	Virtual CPU Units	Memory (GB)	Minimum/Maximum
Type	Minimum Guarantee	Minimum Guarantee	Physical Server
	/Maximum Usage	/Maximum Usage	Utilization (%)

-----	-----	-----	-----
large.2	0/4	0/16	0/12.5
large.3	0/8	0/32	0/25
-----	-----	-----	-----

Table 1: NFVIaaS Instance Types

For the purpose of this example, the Mini NFV DC topology is considered static -- the above topology, including the network interconnection, is available through a simple file-based interface.

Policy 1 (an exemplary NFV policy):

Policy 1 is an exemplary NFV policy. In a descriptive language, Policy 1 is as follows - "For physical servers of type 1, there can be at most only one active physical server with average overall utilization less than 50%."

The goal of this policy is to address the energy efficiency requirements described in the ETSI NFV Virtualization Requirements [ETSI-NFV-REQ].

Policy 1 is an example of reactive enforcement.

Policy 2 (another exemplary NFV policy):

Policy 2 is necessary to protect NFV servers from failures. In this example we consider failures of physical servers. Policy 2 is as follows - "Not more than one VM of the same HA group must be deployed on the same physical server".

Note: There may be conditions (according to current Mini DC usage and policies of type 2 that are currently active) when there may not be any placement solution respecting both policies. It may be better to reformulate Policy 1? For example, "Minimize the number of physical servers with average overall utilization less than 50%"

Policy 2 is an example of proactive and reactive enforcement. Various Module Interactions for Policy 1:

The various module interactions with respect the architectural framework in Figure 1 for Policy 1 is described below.

The policy calls for the identification of servers by type. OpenStack Congress would need to support server type, average CPU utilization, and be able to support additional performance parameters (in the future) to support additional types of placement policies. OpenStack Congress would run the policy periodically or based on events such as deleting/adding VMs etc. Initially, we could use a periodic timer based approach. In case OpenStack Congress detects a violation, it determines optimized placement and scheduling choices so that the policy is not violated.

OpenStack Congress could interface with OpenStack Celiometer to periodically retrieve instantaneous per-server CPU utilization, which it would then use to compute a table of per-server average CPU utilization. Alternatively, OpenStack Celiometer could itself compute per-server average CPU utilization which could be used by OpenStack Congress.

The proposed module interactions in this NFVIaaS placement policy example are as depicted in the architectural framework in Figure 1.

A key goal of Policy 1 above is to ensure that servers are not kept under low utilization, since servers have a non-linear power profile and exhibit relatively higher power wastage at lower utilization. For example, in the active idle state as much as 30% of peak power is consumed. At the physical server level, instantaneous energy consumption can be accurately measured through IPMI standard. At a customer instance level, instantaneous energy consumption can be approximately measured using an overall utilization metric, which is a combination of CPU utilization, memory usage, I/O usage, and network usage. Hence, the policy is written in terms of overall utilization and not power usage.

The following example combines Policy 1 and Policy 2.

For an exemplary maximum usage scenario, 53 physical servers could be under peak utilization (100%), 1 server (server-a) could be under partial utilization (62.5%) with 2 instances of type large.3 and 1 instance of type large.2 (this instance is referred as large.2.X1), and 1 server (server-b) could be under partial utilization (37.5%) with 3 instances of type large.2. Call these three instances large.2.X2, large.2.Y and large.2.Z

One HA-group has been configured and two large.2 instances belong to this HA-group. To enforce Policy 2 large.2.X1 and large.2.X2 that belong to the HA-group have been deployed in different physical servers, one in server-a and a second in server-b.

When one of the large.3 instances mapped to server-a is deleted from physical server type 1, Policy 1 will be violated, since the overall utilization of server-a falls to 37,5%, since two servers are underutilized (below 50%)

OpenStack Congress, on detecting the policy violation, uses various constraint based placement techniques to find the new placement(s) for physical server type 1 to address Policy 1 violation without breaking Policy 2. Constrained based placement will be explored in a convex optimization framework [CONVEX-OPT]; some of the algorithms which would be considered are linear programming [LINEAR-PROGRAM], branch and bound [BRANCH-AND-BOUND], interior point methods, equality constrained minimization, non-linear optimization etc.

Various new placement(s) are described below.

1) New placement 1: Move 2 of three instances of large.2 running on server-b to server-a. Overall utilization of server-a - 62,5%. Overall utilization of server-b - 25%. large.2.X2 must not be one of the migrated instances.

2) New placement 2: Move 1 instance of large.3 to server-b. Overall utilization of server-a - 12,5%. Overall utilization of server-b - 62.5%.

A third solution consisting of moving 3 large.2 instances to server-a cannot be adopted since this breaks Policy 2. Another policy minimizing the number of migrations could allow choosing between solution (1) and (2).

New placements 2 and 3 could be considered optimal, since they achieve maximal bin packing and open up the door for turning off server-a or server-b and maximizing energy efficiency.

To detect violations of Policy 1, an example of a classification rule is expressed below in Datalog, the policy language used by OpenStack Congress.

Database table exported by the Resource Placement and Scheduler for Policy 1 and Policy 2:

The database table exported by the Resource Placement and Scheduler for Policy 1 is below.

```
server_utilization (physical_server, overall_util)
```

- Each database entry has the physical server and the calculated average overall utilization.

vm\_host\_mapping(vm, server)

- Each database entry gives the physical server on which VM is deployed.

anti-affinity\_group(vm, group)

- Each entry gives the anti-affinity group to which a VM belongs.

Policy 1 (in Datalog [DATALOG] policy language):

Policy 1 in a Datalog policy language is as follows.

error (physical\_server) :-

nova [OPENSTACK-NOVA-COMPUTE]: node (physical\_server, "type1"),

resource placement and scheduler: server\_utilization  
(physical\_server, overall\_util < 50)

Policy 2 (in Datalog policy language):

error(vm) :-

anti-affinity\_group(vm1, grp1),

anti-affinity\_group(vm2, grp2),

grp1 != grp2,

nova: vm host mapping(vm1, server-1),

nova: vm host mapping(vm2, server-2),

server-1 == server-2

### 3.2. Joint Network and Compute Awareness with OpenStack - Use Case

There are several NFV DCs such as mobile base stations, small central offices, small branch office locations etc. Having an OpenStack Controller in each of these locations increases the management complexity and the DC capacity needs. The idea is to have the OpenStack compute and network nodes in these DC locations and manage them centrally through an OpenStack Controller node through a

larger central office location in the same metro area. The key considerations here are that the OpenStack management network extends over the metropolitan area network (MAN) and is an in-band network where the data and management traffic use the same physical pipe; typical MAN distances are within 100 miles but could have a geographic variation.

Across MAN, some of the key management network considerations are latency and bandwidth impacting various operations such as configuration, VM image transfer, monitoring data collection, backing up of logs etc. OpenStack Neutron can provide the hooks for reporting MAN bandwidth and latency which will be abstracted by the enhanced OpenStack Nova scheduler. The network connection between NFV DCs can be modelled as Neutron end-points. During the validation phase, the enhanced OpenStack Nova scheduler (part of the OpenStack Controller node) in the central DC can determine if the compute/network nodes in the small DC are manageable remotely based on the service SLA requirements specified by the Orchestrator; each of the small DCs could have different bandwidth/latency depending on the network topology. During runtime, the enhanced OpenStack Nova scheduler periodically monitors the MAN bandwidth and latency variations and reports any exceptions. The enhanced scheduler can measure the overall bandwidth usage across MAN so that it can determine the optimized time window(s) during the day for backing up logs, detailed monitoring data etc. The enhanced scheduler can also measure overall latency usage across MAN so that it can place the high availability instances across DCs meeting the service SLA requirements. Dynamic measurement of MAN bandwidth and latency can be implemented using a vendor specific OpenStack Neutron plugin which typically interfaces with an SDN Controller [LAYERED-SDN]. [Y.1731-monitoring] is typically used by switches for performance monitoring across physical/logical Ethernet network end points.

#### 4. Related Work

A related proof of concept in ETSI NFV on placement and scheduling is [ETSI-NFV-POC-PLACEMENT].

#### 5. Summary

#### 6. Future Work

TBD

#### 7. IANA Considerations

This draft does not have any IANA considerations.

## 8. Security Considerations

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Resource Management in Service Chaining  
draft-lee-nfvrg-resource-management-service-chain-01

Abstract

This document specifies problem definition and use cases of NFV resource management in service chaining for path optimization, traffic optimization, failover, load balancing, etc. It further describes design considerations and relevant framework for the resource management capability that dynamically creates and updates network forwarding paths (NFPs) considering resource constraints of NFV infrastructure.

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The resource placement problem in service chains matters not only to the quality of NFPs but also to the optimized use of NFVI resources. For example, if some of the VNF instances and VFs are selected to constitute a NFP but the others are not, the processing and bandwidth burden will converge on those VNF instances and VFs, which results in scalability problem.

This document addresses resource management problem in service chaining to optimize the NFP quality and resource usage. It provides the relevant use cases of the resource management such as traffic optimization, failover, load balancing and further describes design considerations and relevant framework for the resource management capability that dynamically creates and updates NFPs considering resource state of VNF instances.

This document mainly focuses on the resource capability in the ETSI NFV framework [ETSI-NFV-ARCH] but also studies its applicability to the control plane of SFC architecture [I-D.ietf-sfc-architecture].

## 2. Terminology

This document uses the following terms and most of them were reproduced from [ETSI-NFV-TERM].

- o Network Functions (NF): A functional building block within a network infrastructure, which has well-defined external interfaces and a well-defined functional behavior.
- o Network service: A composition of network functions and defined by its functional and behavioural specification.
- o NFV Framework: The totality of all entities, reference points, information models and other constructs defined by the specifications published by the ETSI ISG NFV.
- o Virtualised Network Function (VNF): An implementation of an NF that can be deployed on a Network Function Virtualisation Infrastructure (NFVI).
- o NFV Infrastructure (NFVI): The NFV-Infrastructure is the totality of all hardware and software components which build up the environment in which VNFs are deployed.
- o NF Forwarding Graph: A graph of logical links connecting NF nodes for the purpose of describing traffic flow between these network functions.

- o VNF Forwarding Graph (VNF-FG): A NF forwarding graph where at least one node is a VNF.
- o Virtual Link: A set of connection points along with the connectivity relationship between them and any associated target performance metrics (e.g. bandwidth, latency, QoS). The Virtual Link can interconnect two or more entities (VNF components, VNFs, or PNFs).
- o Scaling: Ability to dynamically extend/reduce resources granted to the Virtual Network Function (VNF) as needed.

### 3. Resource management in service chain

The goal of the resource management is to optimize the quality of network services and resource usage of NFVI. To meet this goal, NFPs of the network services need to consider the state of NFV resources (such as VNF instances or virtual links) at construction. The NFPs also need to dynamically adapt to the changes of the resource state at run-time, such as availability, load, and topological locations of VNF instances; latency and bandwidth of virtual links. The adaptation of NFPs can be executed by monitoring the resource state of VNF instances and VNs and replacing the original VNF instances of the NFP with new VNF instances that constitute a NFP with better performance. This functionality can be a part of Orchestrator functional building block in the NFV framework [ETSI-NFV-MANO] but it needs further study.

#### 3.1. Use cases

In this section, several (but not exhausted) use cases for resource management in service chaining are provided: fail-over, path optimization, traffic optimization, load balancing, and energy efficiency.

##### Fail-over

When one of VNF instances in a NFP gets failed to run due to failure of its VM or underlying network, the whole chain of network service also gets failed. For service continuity, the failure of VNF instance needs to be detected and the failed one needs to be replaced with the other one which is available to use. Figure 1 presents an example of the fail-over use case. A network service is defined as a chain of VNF-A and VNF-B; and the service chain is instantiated with VNF-A1 and VNF-B1 which are instances of VNF-A and VNF-B respectively. In the meantime, failure of VNF-B1 is detected so that VNF-B2 replaces the failed one for fail-over of the NFP.

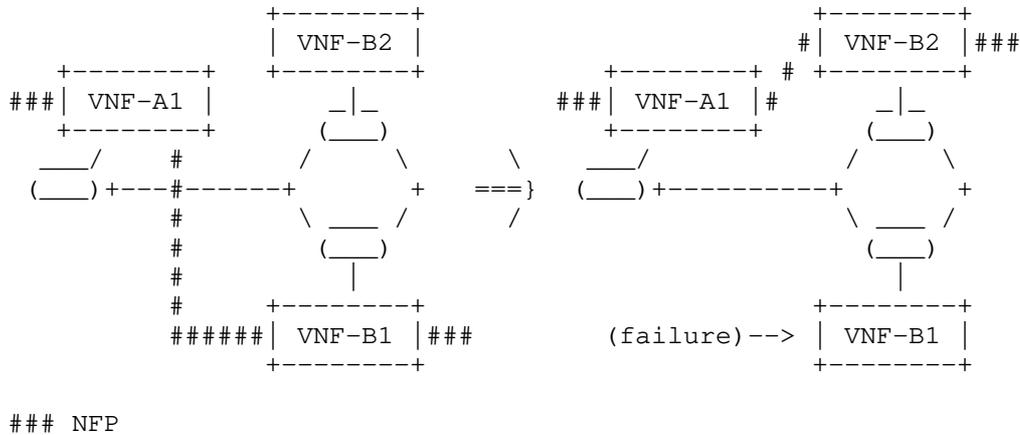


Figure 1: A fail-over use case

Path optimization

Traffic for a network service traverses all of the VNF instances and the connecting VLs given by a NFP to reach a target end point. Thus, quality of the network service depends on the the resource constraints (e.g., processing power, bandwidth, topological locations, latency) of VNF instances and VLs. In order to optimize the path of the network service, the resource constraints of VNF instances and VLs need to be considered at constructing NFPs. Since the resource state may vary in time during the service, NFPs also need to adapt to the changes of resource constraints of the VNF instances and VLs by monitoring and replacing them at run-time.

Traffic optimization

A network operator may provide multiple network services with different VNF-FGs and different flows of traffic traverse between source and destination end-points along the VNF-FGs. For efficiency of network management resource usage, the NFPs need to be built as to localize the traffic flows or as to avoid bottleneck links shared by multiple traffic flows. In this case, multiple NFV instances of different NFPs need to be considered together at constructing a new NFP or adapting one.

Load balancing

A single VNF instances may be shared by multiple traffic flows of the same of different network services. In order to avoid bottleneck

points due to overloaded NFV instances, NFPs need to be constructed or maintained to distribute workloads of the shared VNF instances.

#### Energy efficiency

Energy efficiency in the network is getting important to reduce impact on the environment so that energy consumption of VNF instances using VNFI resources (e.g., compute, storage, I/O) needs to be considered at NFP construction or adaptation. For example, a NFP can be constructed as to make traffic flows aggregated into a limited number of VNF instances as much as its performance is preserved in a certain level.

### 3.2. Design considerations

To support the aforementioned use cases, it is required to support resource management capability which provides service chain (or NFP) construction and adaptation by considering resource state or constraints of VNF instances and virtual links among them. The resource management operations for service chain construction and adaptation can be divided into several sub-actions:

- o Select a VNF instance
- o Evaluate a VNF instance and a virtual link
- o Replace a VNF instance to update a NFP
- o Monitor state or resource constraints of a VNF instance and a virtual link
- o Migrate a VNF instance to another ones in different locations

Note: While scaling-in/out or -up/down of VNF instances is one of the essential actions for NFV resource management, it is a different approach with a finer granularity than service chain adaptation. The scaling approach may be integrated together with the service chain adaptation but it is still under study.

As listed above, VNF instances are selected or replaced according to monitoring or evaluation results of performance metrics of the VNF instances and virtual links. Studies about evaluation methodologies and performance metrics for VNF instances and NFVI resources can be found at [ETSI-NFV-PER001] [I-D.liu-bmwg-virtual-network-benchmark] [I-D.morton-bmwg-virtual-net]. The performance metrics of VNF instances and virtual links specific to service chain construction and adaptation can be defined as follows:

- o availability (or failure) of a VNF instance and a virtual link
- o a topological location of a VNF instance
- o a utilization rate of a VNF instance
- o a throughput of a VNF instance
- o energy consumption of VNF instance
- o bandwidth of a virtual link
- o latency of a virtual link

### 3.3. Framework

The resource management functionality for dynamic service chain adaptation takes role of NFV orchestration with support of VNF manager and Virtualised Infrastructure Manager (VIM) in the NFV framework [ETSI-NFV-ARCH]. Detailed functional building block and interfaces are still under study.

## 4. Applicability to SFC

### 4.1. Related works in IETF SFC WG

IETF SFC WG provides a new service deployment model that delivers the traffic along the predefined logical paths of service functions (SFs), called service function chains (SFCs) with no regard of network topologies or transport mechanisms. Basic concept of the service function chaining is similar to VNF-FG where a network service is composed of SFs and deployed by making traffic flows traversed instances of the SFs in a pre-defined order.

There are several works in progress in IETF SFC WG for resource management of service chaining. [I-D.ietf-sfc-architecture] defines SFC control plane that selects specific SFs for a requested SFC, either statically or dynamically but details are currently outside the scope of the document. There are other works [I-D.ww-sfc-control-plane] [I-D.lee-sfc-dynamic-instantiation] [I-D.krishnan-sfc-oam-req-framework] [I-D.aldrin-sfc-oam-framework] which define the control plane functionality for service function chain construction and adaptation but details are still under study. While [I-D.dunbar-sfc-fun-instances-restoration] and [I-D.meng-sfc-chain-redundancy] provide detailed mechanisms of service chain adaptation, they focus only on resilience or fail-over of service function chains.

4.2. Integration in SFC control-plane architecture

In SFC WG, [I-D.ww-sfc-control-plane] defines a generic architecture of SFC control plane with well-defined functional building blocks and interfaces as follows:

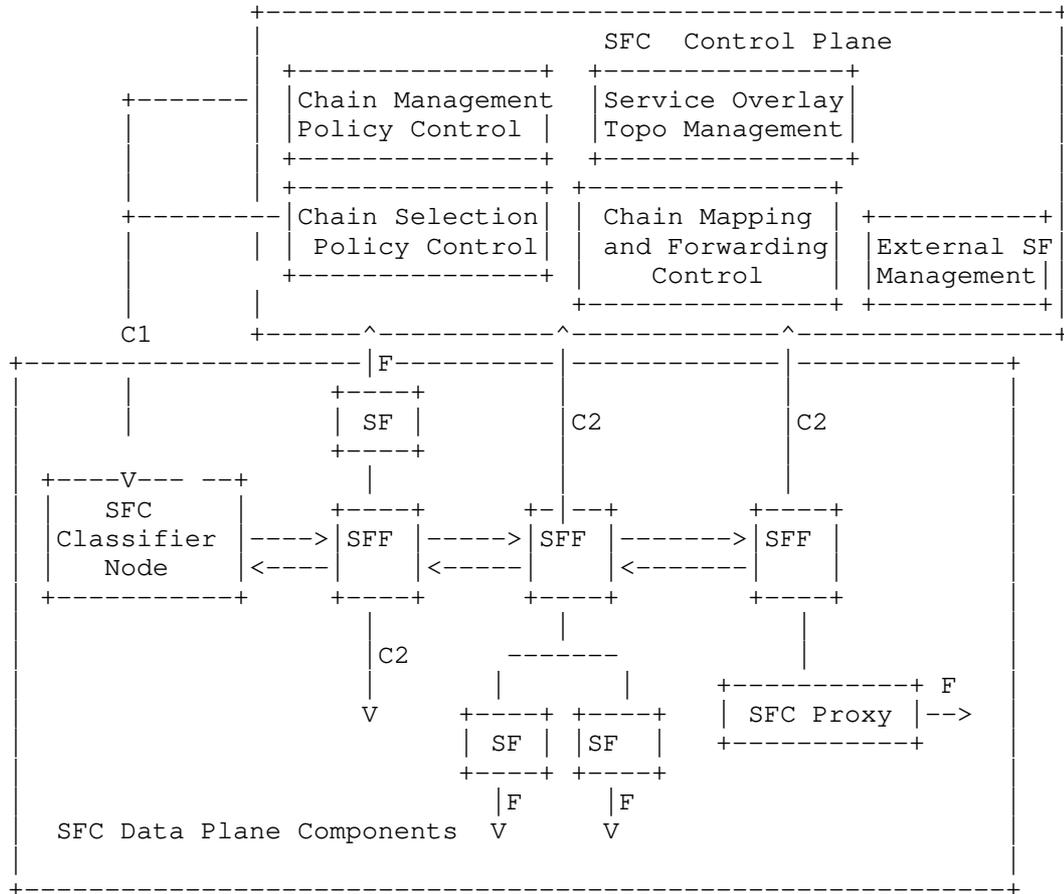


Figure 2: SFC control plane architecture

The service chain adaptation addressed in this document may be integrated into the Chain Mapping and Forwarding Control functional block and may use the C2 and F interfaces for monitoring or collecting the resource constraints of VNF instances and VFs.

Note that SFC does not assume that Service Functions are virtualized. Thus, the parameters of resource constraints may differ, and it needs further study for integration.

## 5. Security Considerations

TBD.

## 6. IANA Considerations

TBD.

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Policy Architecture and Framework for NFV Infrastructures  
draft-norival-nfvrg-nfv-policy-arch-04

Abstract

A policy architecture and framework is discussed to support NFV environments, where policies are used to enforce business rules and to specify resource constraints in a number of subsystems. This document approaches the policy framework and architecture from the perspective of overall orchestration requirements for services involving multiple subsystems. The framework extends beyond common orchestration constraints across compute, network, and storage subsystems to include energy conservation. This document also analyses policy scope, global versus local policies, policy actions and translations, policy conflict detection and resolution, interactions among policies engines, and a hierarchical policy architecture/framework to address the demanding and growing requirements of NFV environments, that could also be applicable to cloud infrastructures in general.

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The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119.

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## 1. Introduction

This document discusses the policy architecture and framework to support Network Function Virtualization (NFV) [3] infrastructures. In these environments, policies are used to enforce business rules and to specify resource constraints, e.g., energy constraints, in a number of subsystems, e.g., compute, storage, network, and etc., and across subsystems. These subsystems correspond to the different "infrastructure domains" identified by the NFV ISG Infrastructure Working Group [6][7].

The current work in the area of policy for NFV is mostly considered in the framework of general cloud services, and typically focused on individual subsystems and addressing very specific use cases or environments. For example, [3] addresses network subsystem policy for network virtualization, [14] and [15] are open source projects in the area of network policy as part of the OpenDaylight [16] software define networking (SDN) controller framework, [13] specifies an information model for network policy, [9] focuses on placement and migration policies for distributed virtual computing, [18] is an open source project proposal in OpenStack [17] to address policy for general cloud environments.

This document approaches policy, policy framework, and policy architecture for NFV services from the perspective of overall orchestration requirements for services involving multiple subsystems, and can be applied to the general case of any cloud-based service. The analysis extends beyond common orchestration constraints across compute, network, and storage subsystems to also include energy conservation constraints applicable to NFV and other environments. The analysis in this document also extends beyond a single virtual Point of Presence (vPoP) or administrative domain to include multiple data centers and networks forming hierarchical domain architectures [8]. The focus of this document is not general policy theory, which has already been intensively studied and documented on numerous publications over the past 10 to 15 years (see [13], [21], [12], [22], and [1] to name a few). This document's purpose is to discuss and document a policy architecture that uses known policy concepts and theories to address the unique requirements of NFV services including multiple vPoPs and networks forming hierarchical domain architectures [8].

With the above goals, this document analyses policy scope, global versus local policies, policy actions and translations of actions, policy conflict detection and resolution, the interactions among policies engines from the different vPoPs and network subsystems, demanding and growing requirements of NFV environments.

## 2. Policy Intent Statement versus Subsystem Actions and Configurations

Policies define which states of deployment are in compliance, and, by logic negation, which ones are not. The compliance statement in a policy may define specific actions, e.g., "a given customer is [not allowed to deploy VNF X]", where VNF refers to a Virtual Network Function, or quasi-specific actions, e.g., "a given customer [must be given platinum treatment]." Quasi-specific actions differ from the specific ones in that the former requires an additional level of translation or interpretation, which will depend on the subsystems where the policy is being evaluated, while the latter does not require further translation or interpretation.

In the previous examples, "VNF X" defines a specific VNF type, i.e., "X" in this case, while "platinum treatment" could be translated to an appropriate resource type depending on the subsystem. For example, in the compute subsystem this could be translated to servers of a defined minimum performance specification, while in the network subsystem this could be translated to a specific Quality of Service (QoS) level treatment.

The actions defined in a policy may be translated to subsystem configurations. For example, when "platinum treatment" is translated to a specific QoS level treatment in a networking subsystem, one of the outcomes (there can be multiple ones) of the policy could be the configuration of network elements (physical or virtual) to mark that customer's traffic to a certain DSCP (DiffServ Code Point) level (Figure 1). Some may refer to the QoS configuration above as a policy in itself, e.g., [21], [22], [2], and [12]. In this document, such domain configurations are called policy enforcement technologies to set them apart from the actual policy intent, e.g., "a given customer must be given platinum treatment" as in the above example.

Describing intent using a high-level policy language instead of directly describing configuration details allows for the decoupling of the desired intent from the actual configurations, which are subsystem dependent, as shown in the previous example (Figure 1). The translation of a policy into appropriate subsystem configurations requires additional information that is usually subsystem and technology dependent. Therefore, policies should not be written in terms of policy enforcement technologies. Policies should be translated at the subsystems using the appropriate policy provides a few examples where the policy "a given customer must be given platinum treatment" is translated to appropriate configurations at the respective subsystems.

The above may sound like a discussion about "declarative" versus "imperative" policies. We are actually postulating that "imperative

policy" is just a derived subsystem configuration using an appropriate policy enforcement technology to support an actually intended policy.

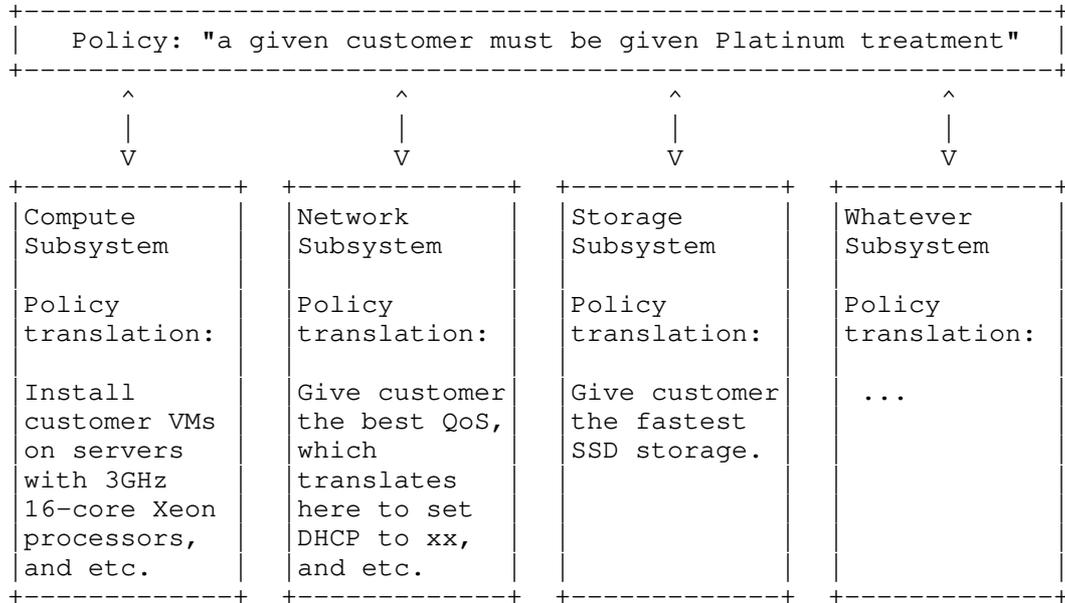


Figure 1: Example of Subsystem Translations of Policy Actions

### 3. Global vs Local Policies

Some policies may be subsystem specific in scope, while others may have broader scope and interact with multiple subsystems. For example, a policy constraining certain customer types (or specific customers) to only use certain server types for VNF or Virtual Machine (VM) deployment would be within the scope of the compute subsystem. A policy dictating that a given customer type (or different implications on different subsystems. As shown in Figure 1, that "platinum treatment" could be translated to servers of a given performance specification in a compute subsystem and storage of a given performance specification in a storage subsystem.

Policies with broader scope, or global policies, would be defined outside affected subsystems and enforced by a global policy engine (Figure 2), while subsystem-specific policies or local policies, would be defined and enforced at the local policy engines of the respective subsystems.

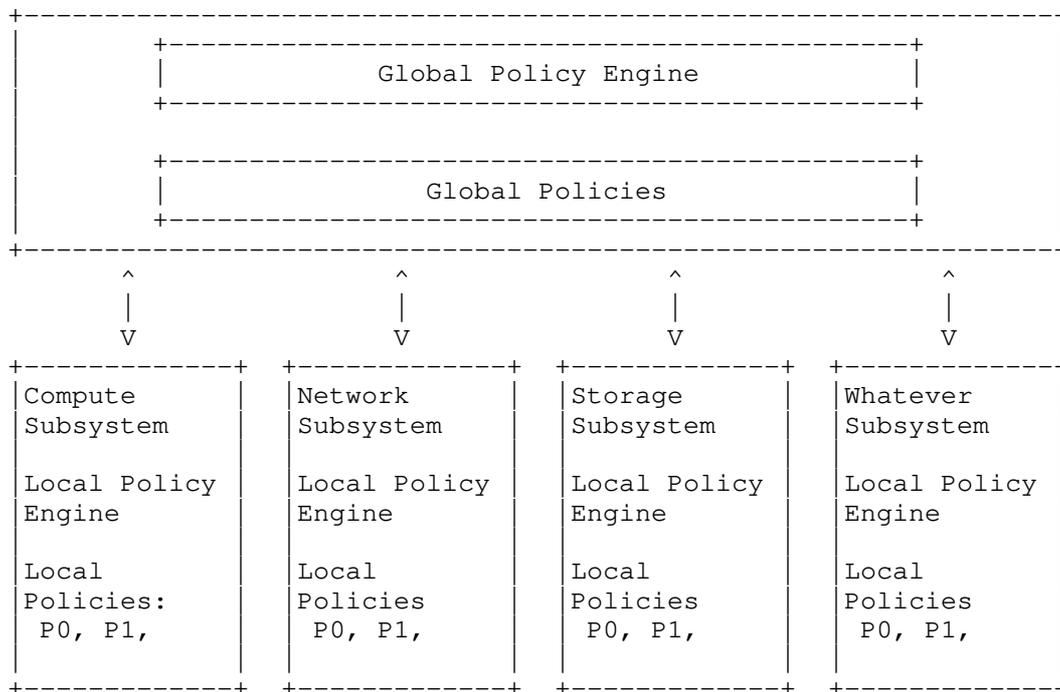


Figure 2: Global versus Local Policy Engines

So far, we have referenced compute, network, and storage as subsystems examples. However, the following subsystems may also support policy engines and subsystem specific policies:

- SDN Controllers, e.g., OpenDaylight [16].
- OpenStack [17] components such as, Neutron, Cinder, Nova, and etc.
- Directories, e.g., LDAP, ActiveDirectory, and etc.
- Applications in general, e.g., standalone or on top of OpenDaylight or OpenStack.
- Physical and virtual network elements, e.g., routers, firewalls, application delivery controllers (ADCs), and etc.
- Energy subsystems, e.g., OpenStack Neat [19].

Therefore, a policy framework may involve a multitude of subsystems. Subsystems may include other lower level subsystems, e.g., Neutron [20] would be a lower level subsystem in the OpenStack subsystem. In other words, the policy framework is hierarchical in nature, where the policy engine of a subsystem may be viewed as a higher level policy engine by lower level subsystems. In fact, the global policy

engine in Figure 2 could be the policy engine of a Data Center subsystem and multiple Data Center subsystems could be grouped in a region containing a region global policy engine. In addition, one could define regions inside regions, hierarchically, as shown in Figure 3.

Metro and wide-area network (WAN) used to interconnect data centers would also be independent subsystems with their own policy engines.

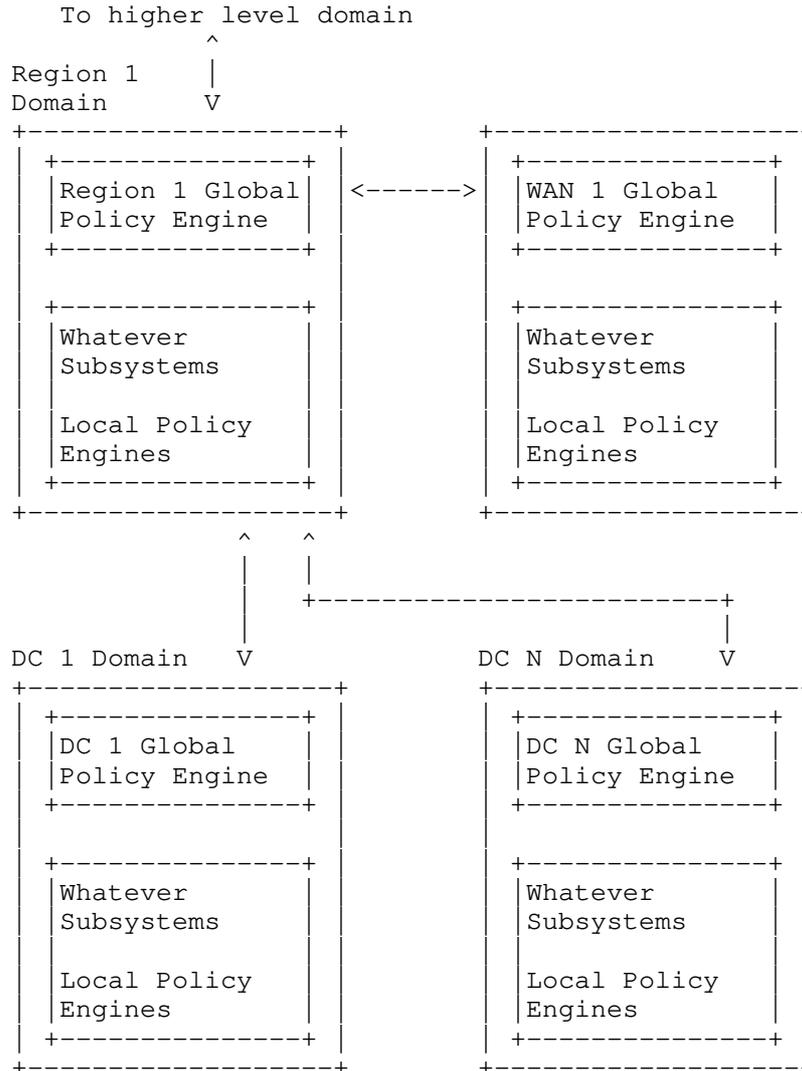


Figure 3: A Hierarchical Policy Framework

## 5. Policy Conflicts and Resolution

Policies should be stored in databases accessible by the policy engines. For example, the local policies defined for the Compute subsystem in Figure 2 would be stored in a database accessible by the local policy engine in that subsystem.

As a new policy is added to a subsystem, the subsystem's policy engine should perform conflict checks. For example, a simple conflict would be created if a new policy states that "customer A must not be allowed to use VNF X", while an already existing policy states that "customer A is allowed to use VNF X". In this case, the conflict should be detected and an appropriate policy conflict resolution mechanism should be initiated.

The nature of the policy conflict resolution mechanism would depend on how the new policy is being entered into the database. If an administrator is manually attempting to enter that policy, the conflict resolution could entail a warning message and rejection of the new policy. The administrator would then decide whether or not to replace the existing policy with the new one.

When policies are batched for later inclusion in the database, the administrator should run a preemptive conflict resolution check on those policies before committing to include them in the database at a future time. However, running a preemptive conflict resolution check does not guarantee that there will be no conflicts at the time the batched policies are actually included in the database, since other policies could have been added in the interim that cause conflicts with those batched policies.

To avoid conflicts between batched policies waiting for later inclusion in the database and new policies being immediately added to the database, one could run a preemptive conflict resolution check against database policies and also batched policies every time new policies are added to the database. However, this may not be sufficient in case of separate administrative domains. A region administration could define batched policies to be pushed to the Compute subsystem of a Data Center at a later time. However, the Compute subsystem may be a separate administrative domain from that of the region administrative domain. In this case, the Compute subsystem may not be allowed to run preemptive policy conflict checks against the batched policies defined at the region administrative domain. Thus, there is a need for a reactive policy conflict resolution mechanism besides preemptive techniques.

The above discussions implicitly assumed that policies are individually evaluated for conflicts and individually committed

without regard to other policies. However, a set of policies could be labeled as part of a same "Commit Group", where the whole set of policies in the Commit Group must be committed for a desired result to be obtained. In this case, the conflict resolution mechanism would need to verify that none of the policies in the Commit Group conflicts with currently committed policies before the Commit Group is added (in other words, committed) to the policy database.

The Commit Group conflict detection mechanism and subsequent addition to the database should be implemented as an atomic process, i.e., no changes to the policy database should be allowed by other processes until either the whole Commit Group is checked and committed or a conflict is detected and the process stopped, to avoid multiple writers issues.

The above described atomic Commit Group conflict detection and policy commit mechanism would eliminate the need for Commit Group rollback. A rollback could be required if policies in a Commit Group were to be checked for conflicts and committed one by one, since the detection of a subsequent policy conflict in the Commit Group would require the rollback of previously committed policies in that group.

## 6. Policy Pub/Sub Bus

In the previous section, we considered policy conflicts within a same level subsystem. For example, new local policies added to the Compute subsystem conflicting with existing local policies at that subsystem. However, more subtle conflicts are possible between global and local policies.

A global policy may conflict with subsystems' local policies. Consider the following Compute subsystem local policy: "Platinum treatment must be provided using server of type A."

The addition of the Global policy "Platinum treatment must be provided using server subtype A-1" would intrude into the Compute subsystem by redefining the type of server to be used for a particular service treatment. While one could argue that such global policy should not be permitted, this is an event that requires detection and proper resolution. A possible resolution is for the Compute subsystem to import the more restrictive policy into its local database. The original local policy would remain in the database as is along with the new restrictive policy. The local policy engine would then enforce the more restricted form of the policy after this policy change, which could make already existing resource allocations non-compliant and requiring corrective actions, e.g., Platinum treatment being currently provided by a server of type A instead of a server of type A-1.

If the new Global policy read "Platinum treatment must be provided using server of types A or B" instead, the Compute subsystem would not need to do anything different, since the Compute subsystem has a more restrictive local policy in place, i.e., "Platinum treatment must be provided using server of type A."

The above examples demonstrate the need for subsystems to subscribe to policy updates at the Global policy level. A policy publication/subscription (pub/sub) bus would be required as shown in Figure 4.

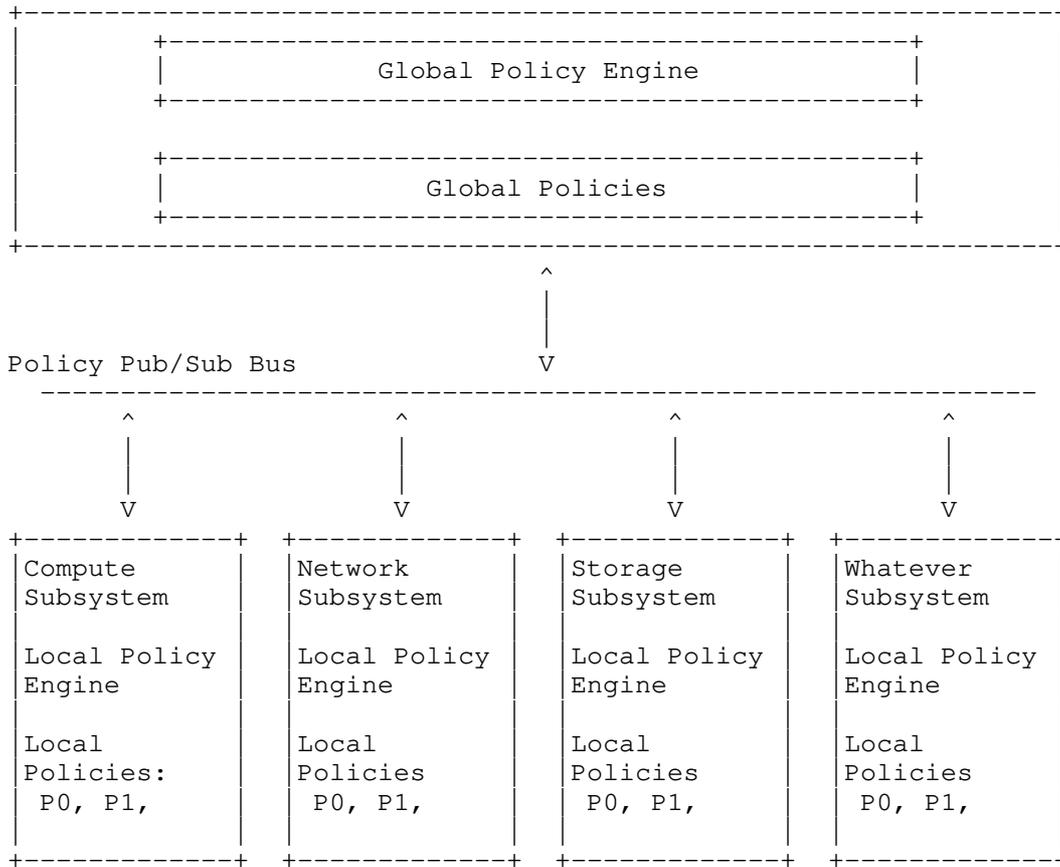


Figure 4: A Policy Pub/Sub Bus

A policy conflict may force policies to change scope. Consider the following existing policies in a Data Center:

Compute subsystem policy: "Platinum treatment requires a server of

type A or B."

Storage subsystem policy: "Platinum treatment requires a server storage of type X or Y."

Now consider the outcome of adding the following new Global policy: "Platinum treatment requires a server of type A when storage of type X is used or a server of type B when storage of type Y is used."

This new Global policy intrudes into the Compute and Storage subsystems. Again, one could argue that such global policy should not be permitted. Nevertheless, this is an event that would require detection and proper resolution. This Global policy causes a conflict because the Compute and Storage subsystems can no longer independently define whether to use a server of type A or B or storage of type X or Y, respectively. If the Compute subsystem selects server of type A for a customer and the Storage subsystem selects storage of type Y for that same customer service the Global policy is violated. In conclusion, if such global policy is permitted, the Compute and Storage subsystems can no longer make such selections. A possible conflict resolution is for the Compute and Storage subsystems to relegate policy enforcement for such resources to the Global policy engine. In this example, the Global Policy engine would need to coordinate with the Compute and Storage subsystems the selection of appropriate resource types to satisfy that policy.

That suggests that the policy pub/sub bus should in fact be an integral part of the northbound service interfaces (NBI) of the subsystems in the hierarchy. Such issue was analyzed in [8], where the concepts of service capability, service availability, and service instantiation were introduced to enable a higher-level subsystem to properly select services and resources from lower-level subsystems to satisfy existing policies.

The above example demonstrates again the need for subsystems to subscribe to policy updates at the higher policy level (the Global policy level in this example) as shown in Figure 4.

If, as demonstrated, a Global policy may "hijack" or "nullify" local policies of subsystems, what exactly makes the scope of a policy local versus global then?

Proposition: A Local Policy does not affect the compliance state imposed by global Policies or the local policies of other subsystems.

The above non-exhaustive examples demonstrate that global and local policies may conflict in subtle ways. Policy conflicts will also

policy framework requires a policy pub/sub bus between all levels to allow for conflict detection, conflict information propagation, and conflict resolution (Figure 5).

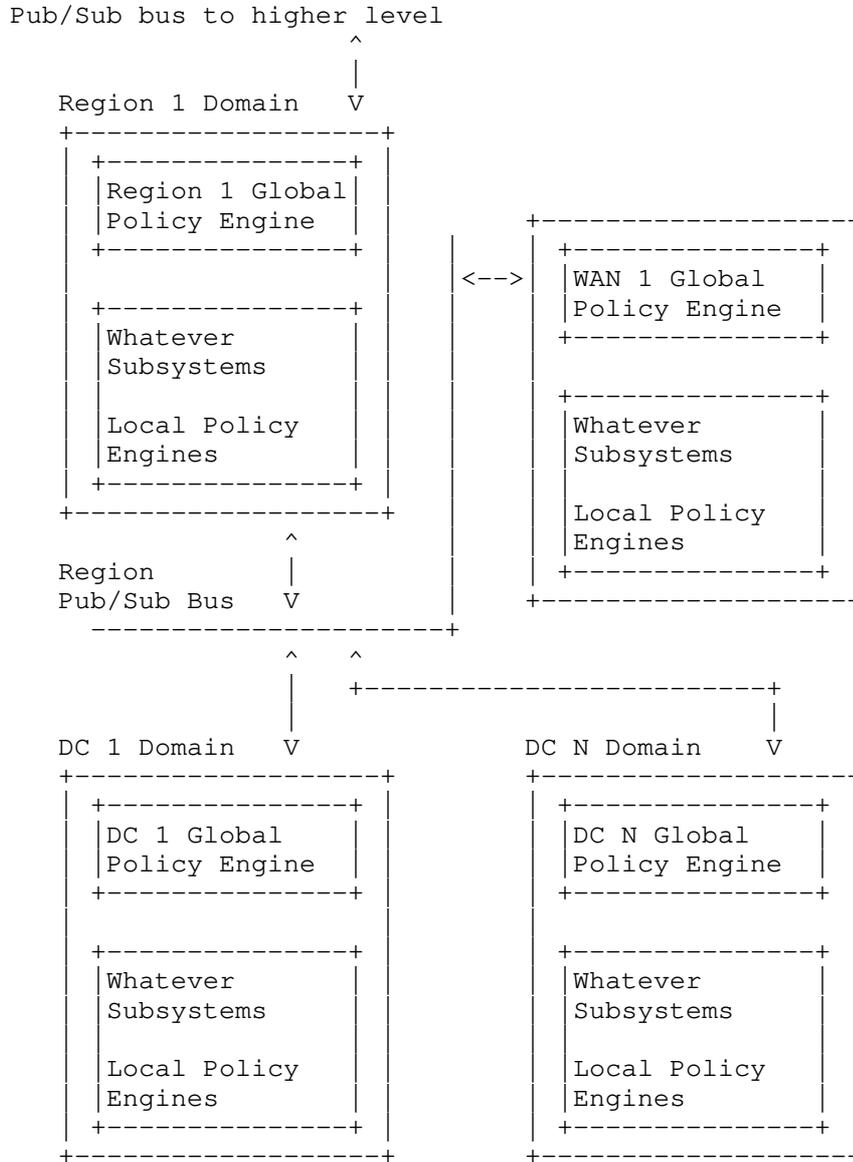


Figure 5: Pub/Sub Bus - Hierarchical Policy Framework

## 7. Examples

### 7.1 Establishment of a Multipoint Ethernet Service

Consider a service provider with an NFV infrastructure (NFVI) with multiple vPoPs, where each vPOP is a separate administrative domain. A customer "Z" requests the creation of a "multipoint Silver Ethernet service" between three of its sites, which are connected to service provider's vPoPs A, B, and C. The customer request is carried out using a service provider self-service web portal, which offers customers multiple service type options, e.g., point-to-point and multipoint Ethernet services, and multiple service levels per service type, e.g., Platinum, Gold, and Silver Ethernet services, where the different service levels may represent different service specifications in terms of QoS, latency, and etc. The web portal relays the request to a service provider's OSS/BSS. The service request is stored as a service policy that reads as: "multipoint Silver Ethernet service between vPoPs A, B, and C for customer Z".

The OSS/BSS subsystem communicates the service request and requirements as a policy to a global NFV Orchestrator (NFVO) subsystem. The service provider's vPOP NFV infrastructure architecture may vary depending on the size of each vPOP and other specific needs of the service provider. For example, a vPOP may have a local NFVO subsystem and one or more local Virtual Infrastructure Manager (VIM) subsystems or it may simply have a VIM, but no local NFVO subsystem. For simplicity of exposition, assume that the service provider has a VIM and no NFVO per vPOP (as in Figure 6). In this case, the global NFVO subsystem communicates the service request and requirements as a policy to the VIMs of vPoPs A, B, and C.

At each vPOP, the local VIM will carry out the requested service policy based on the local configuration of respective subsystems and current availability of resources. For example, Silver service type, as specified in the policy, may translate in vPOP A to use a specific vCPE VNF type, say vCPE\_X, while Silver service type in vPOP B may translate to a different vCPE VNF type, say vCPE\_Y, due to local subsystem configurations (refer to Section 2 for a discussion on subsystem actions and configurations). Similarly, the local VIM interaction with the vPOP's compute, network, and storage subsystems may lead to local configurations of these subsystems driven by the translation of the policy by the respective subsystems (see Section 3 for a discussion on global versus local policies).

The global NFVO subsystem would potentially communicate the service policy to a WAN infrastructure management (WIM) subsystem (not shown in Figure 6), to provision a multipoint Silver Ethernet service between vPoPs A, B, and C. The WIM subsystem could oversee a

hierarchy of other subsystems, e.g., SDN multi-domain architecture of controllers deployed as a hierarchy of network regions (see [8]). Network subsystems would translate the Silver type requirement to a local configuration (again, refer to Section 2 for a discussion on subsystem actions and configurations).

As depicted in Figure 6, service policy communications should employ a policy pub/sub bus between the subsystems' policy engines in the policy hierarchy (see Section 6 for a discussion on policy pub/sub bus). The global NFVO subsystem should have visibility into the policies defined locally at each vPoP to be able to detect any potential global policy conflicts, e.g., a local vPoP administrator could add a local policy that violates or conflicts with a global policy. In addition, the global NFVO subsystem would benefit from being able to import the currently configured services at each vPoP. For example, each vPoP could publish a table of currently configured services. The global NFVO would use such information to monitor global policy conformance and also to facilitate detection of policy violations when new global policies are created, e.g., a global level administrator is about to add a new global policy that, if committed, would make certain already configured services a violation of the policy. The publication of subsystem service tables for consumption by a global policy engine is a concept used in the Congress [18] OpenStack [17] project.

In the hierarchical policy framework described in this document, a subsystem's currently configured services table could be published to higher tier policy engines using the policy pub/sub bus. The subsystem's currently configured services table would describe configured services based on the configured policy name space for the respective policy pub/sub bus. The name space of a policy pub/sub bus refers to the name space available to communicate policies between the subsystems connected to the particular policy pub/sub bus. In this example, Ethernet services use the name space "Platinum", "Gold", and "Silver". A policy can then specify Silver Ethernet service. The policy name space would be an attribute associated with a particular policy pub/sub bus and should be pre-defined/pre-configured in the respective subsystems for each policy pub/sub bus.

Note that in a hierarchical policy framework a policy engine may use more than one policy pub/sub bus, e.g., a policy pub/sub bus to communicate with higher tier policy engines and another policy pub/sub bus to communicate with lower tier policy engines. For example, Figure 6 shows a policy pub/sub bus between the global NFVO subsystem and the vPoPs. Each vPoP could have an internal hierarchy of policy engines, e.g., VIM policy engine communicating with network (e.g., SDN controller), compute (VM orchestration), and storage subsystems' policy engines.

The amount of information that would be reported by a subsystem's currently configured services table would then depend on the pre-defined name space of a particular policy pub/sub bus. In this example, the vPoPs would communicate that customer Z is assigned/configured a vCPE VNF of type Silver.

Note that the described policy framework does not mandate or preclude use of detailed name spaces. However, to promote scalability and limit complexity, one should preferably use a name space hierarchy where the name spaces used by higher tier policy engines would be limited to higher level details. For example, suppose that vPoP A supports VNF types Silver.vCPE\_X1 and Silver.vCPE\_X2, that is, vCPE\_X1 and vCPE\_X2 are VNFs that were configured at vPoP A as supporting Silver services. Local policies in vPoP A would be used for the selection of vCPE\_X1 or vCPE\_X2 VNF when a service request requires a Silver vCPE VNF. vPoP A would report customer Z as using Silver.vCPE\_X1 vCPE VNF (instead of simply Silver vCPE VNF) only when the name space between vPoP A and the global NFVO defines this granularity of Ethernet services. Note that one would want to define Silver.vCPE\_X1 and Silver.vCPE\_X2 as part of the policy name space between vPoP A and the global NFVO if the capability to specify such policy specificity is desired at the global level. However, the higher the degree of specificity allowed at the higher tiers of the policy hierarchy the higher the operational complexity.

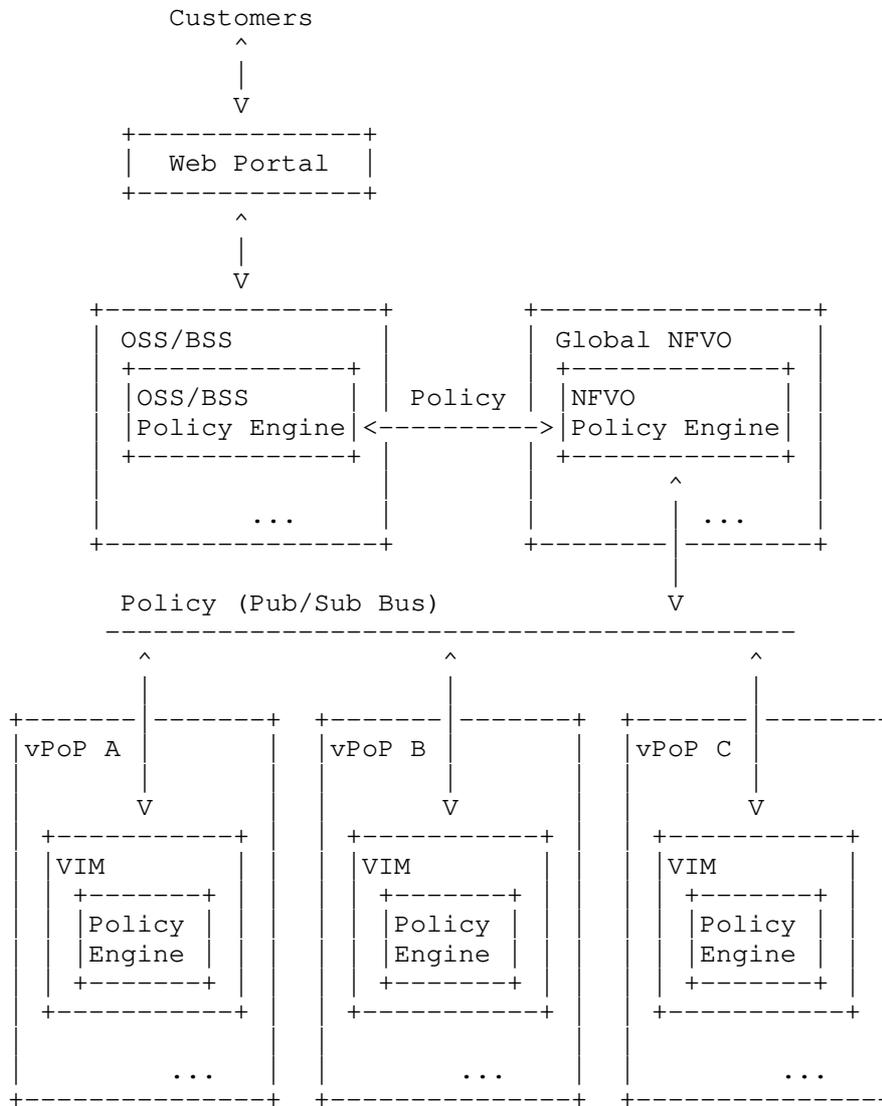


Figure 6: Simplified view of a service provider's NFV Architecture:  
Multipoint Ethernet Service Example

## 7.2 Policy-Based NFV Placement

IRTF draft [10] describes a detailed example of a global policy written in Datalog [1] applicable to compute to promote energy conservation for the NFVIaaS use case [4] in an OpenStack framework. The goal of that policy is to address the energy efficiency requirements described in the ETSI NFV Virtualization Requirements [5].

Related to the above, energy efficiency using analytics-driven policies in the context of OpenStack Congress [18] policy as a service was presented and demonstrated at the Vancouver OpenStack summit [11], where the Congress policy engine delegates VM placement to a VM placement engine that migrates under-utilized VMs to save energy.

## 8. Summary

This document approached the policy framework and architecture from the perspective of overall orchestration requirements for services involving multiple subsystems. The analysis extended beyond common orchestration for compute, network, and storage subsystems to also include energy conservation constraints. This document also analyzed policy scope, global versus local policies, policy actions and translations, policy conflict detection and resolution, interactions among policies engines, and a hierarchical policy architecture/framework to address the demanding and growing requirements of NFV environments, applicable as well to general cloud infrastructures.

The concept of NFV and the proposed policy architecture is applicable to service providers and also enterprises. For example, an enterprise branch office could have capacity and energy constraints similar to that of many service provider NFV vPoPs in constrained environments. This is an aspect that would be worth examining in detail in future work.

## 9. IANA Considerations

This draft does not have any IANA considerations.

## 10. Security Considerations

Security issues due to exchanging policies across different administrative domains are an aspect for further study.

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Verification of NFV Services : Problem Statement and Challenges  
draft-shin-nfvrg-service-verification-04

Abstract

NFV relocates network functions from dedicated hardware appliances to generic servers, so they can run in software. However, incomplete or inconsistent configuration of virtualized network functions (VNF) and forwarding graph (FG, aka service chain) could cause break-down of the supporting infrastructure. In this sense, verification is critical for network operators to check their requirements and network properties are correctly enforced in the supporting infrastructures. Recognizing these problems, we discuss key properties to be checked on NFV-enabled services. Also, we present challenging issues related to verification in NFV environments.

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## 1. Introduction

NFV is a network architecture concept that proposes using IT virtualization related technologies, to virtualize entire classes of network service functions into building blocks that may be connected, or chained, together to create network services. NFV service is defined as a composition of network functions and described by its functional and behavioral specification, where network functions (i.e., firewall, DPI, SSL, load balancer, NAT, AAA, etc.) are well-defined, hence both their functional behavior as well as their external interfaces are described in each specifications.

In NFV, a VNF is a software package that implements such network functions. A VNF can be decomposed into smaller functional modules or APIs for scalability, reusability, and/or faster response [ETSI-NFV-Arch], [ETSI-NFV-MANO]. This modular updates or composition for a network function may lead to many other verification or security issues. In addition, a set of ordered network functions which build FGs may be connected, or chained, together to create an end-to-end network service. Multiple of VNFs can be composed together to reduce management and VNF FGs. While autonomic networking techniques could be used to automate the configuration process including FG updates, it is important to take into account that incomplete and/or inconsistent configuration may lead to verification issues. Moreover, automation of NFV process with integration of SDN may lead the network services to be more error-prone. In this sense, we need to identify and verify key properties to be correct before VNFs and FGs are physically placed and realized in the supporting infrastructure.

### 1.1. Terminology

This document draws freely on the terminology defined in [ETSI-NFV-Arch].

## 2. Problem statement

The verification services should be able to check the following properties:

### 2.1. Dependencies of network service components in NFV framework

In NFV framework, there exist several network service components including NFVI, VNFs, MANO, etc. as well as network controller and switches to realize end-to-end network services. Unfortunately, these components have intricate dependencies that make operation incorrect. In this case, there is inconsistency between states stored and managed in VNF FGs and network tables (e.g., flow tables), due to

communication delays and/or configuration errors. For example, if a VNF is replicated into the other same one for the purpose of load balance and a new FG is established through the copied one, but all the state/DBs replication is not finished yet due to delays, this can be lead to unexpected behaviors or errors of the network service. Therefore, these dependencies make it difficult to correctly compose NFV-enabled end-to-end network services.

## 2.2. Invariant and error check in VNF FGs

In VNF FGs, an infinite loop construction should be avoided and verified. Let us consider the example. Two VNF A and VNF B locate in the same service node X whereas another VNF C resides in other service node Y [SIGCOMM-Gember]. Also, the flow direction is from X to Y, and the given forwarding rule is A->C->B. In such a case, service node Y can receive two ambiguous flows from VNF A: 1) one flow processed by VNF A and 2) another flow processed by VNF A, B, and C. For the former case, the flow should be processed by VNF C whereas the latter flow should be further routed to next service nodes. If these two flows cannot be distinguished, service node Y can forward the flow to service node X even for the latter case and a loop can be formed. To avoid the infinite loop formation, the forwarding path over VNF FG should be checked in advance with the consideration of physical placement of VNF among service nodes. Also, reactive verification may be necessary, since infinite loop formation may not be preventable in cases where configuration change is happening with live traffic.

In addition, isolation between VNFs (e.g. confliction of properties or interference between VNFs) and consistent ordering of VNF FGs should be always checked and maintained.

## 2.3. Load balancing among VNF instances

In VNF FG, different number of VNF instances can be activated on several service nodes to carry out the given task. In such a situation, load balancing among the VNF instances is one of the most important considerations. In particular, the status in resource usage of each service node can be different and thus appropriate amount of jobs should be distributed to the VNF instances. To guarantee well-balanced load among VNF instances, the correctness of hash functions for load balancing needs to be verified. Moreover, when VNF instances locate in physically different service nodes, simple verification of load balancing in terms of resource usage is not sufficient because different service nodes experience diverse network conditions (e.g., different levels of network congestion) [ONS-Gember]. Therefore, it is needed to monitor global network condition as well as local resource condition to achieve the network-wide load balancing in VNF

FGs. Also, whether the monitoring function for network/compute/storage resources is correctly working should be checked.

#### 2.4. Policy and state consistency on NFV services

In VNF FG, policy to specific users can be dynamically changed. For example, a DPI VNF can be applied only in the daytime in order to prohibit from watching adult contents while no DPI VNFs applied during the nighttime. When the policy is changed, the changed policy should be reconfigured in VNF service nodes as soon as possible. If the reconfiguration procedure is delayed, inconsistent policies may exist in service nodes. Consequently, policy inconsistency or confliction needs to be checked. Also in some situations, states for VNF instances may be conflicted or inconsistent. Especially when a new VNF instance is instantiated for scale-up and multiple VNF instances are running, these multiple VNF instances may have inconsistent states owing to inappropriate instantiation procedure [SIGCOMM-Gember]. In particular, since the internal states of VNF instances (e.g., the instantaneous state of CPU, register, and memory in virtual machine) are not easily-visible, a new way to check the VNF internal states should be devised.

#### 2.5. Performance

In VNF FG, VNF instances can locate in different service nodes and these service nodes have different load status and network conditions. Consequently, the overall throughput of VNF FG is severely affected by the service nodes running VNF instances. For example, if a VNF instance locates in a heavily loaded service node, the service time at the service node will be increased. In addition, when a VNF FG includes a bottleneck link with network congestion, the end-to-end performance (e.g., latency and throughput) in the VNF FG can be degraded. Therefore, the identification of bottleneck link and node is the first step for performance verification or guarantee of the VNF FG [ONS-Gember]. After detecting the bottleneck link/node, the VNF requiring scale up or down can be identified and the relocation of VNF instance among service nodes can be determined

#### 2.6. Security

How to verify security holes in VNF FG is another important consideration. In terms of security services, authentication, data integrity, confidentiality, and replay protection should be provided. On the other hand, several VNFs (e.g., NAT) can modify or update packet headers and payload. In these environments, it is difficult to protect the integrity of flows traversing such VNFs. Another security concern in the VNF FG is distributed denial of service (DDoS) to a

specific service node. If an attacker floods packets to a target service node, the target service node cannot perform its functions correctly. Therefore, such security attacks in the VNF FG should be detected and handled in an efficient manner. In the case of DDoS, adding a DDoS appliance as the first element in the service chain would help alleviate the problem. Moreover, unknown or unauthorized VNFs can run and thus how to identify those problems is another security challenge.

### 3. Examples - NS policy conflict with NFVI policy

Another target of NFV verification is conflict of NS policies against global network policy, called NFVI policy.

NFV allocates and manages NFVI resources for a network service according to an NS policy given in the network service descriptor (NSD), which describes how to govern NFVI resources for VNF instances and VL instances to support KPIs of the network service. Example factors of the NS policy are resource constraints (or deployment flavor), affinity/anti-affinity, scaling, fault and performance management, NS topology, etc.

For a network-wide (or NS-wide) management of NFVI, NFVI policy (or global network policy) can be provided to describe how to govern the NFVI resources for optimized use of the infrastructure resources (e.g., energy efficiency and load balancing) rather than optimized performance of a single network service. Example factors of the NFVI policy are NFVI resource access control, reservation and/or allocation policies, placement optimization based on affinity and/or anti-affinity rules, geography and/or regulatory rules, resource usage, etc.

While both of the policies define the requirements for resource allocation, scheduling, and management, the NS policy is about a single network service; and the NFVI policy is about the shared NFVI resources, which may affect all of the given network services globally. Thus, some of NS and NFVI policies may be inconsistency with each other when they have contradictive resource constraints on the shared NFVI resources. Examples of the policy conflicts are as follows:

<Example conflict case #1>

- o NS policy of NS\_A (composed of VNF\_A and VNF\_B)
  - Resource constraints: 3 CPU core for VNF\_A and 2 CPU core for VNF\_B
  - Affinity rule between VNF\_A and VNF\_B

- o NFVI policy
  - No more than 4 CPU cores per physical host
- o Conflict case
  - The NS policy cannot be met within the NFVI policy

<Example conflict case #2>

- o NS policy of NS\_B (composed of VNF\_A and VNF\_B)
  - Affinity rule between VNF\_A and VNF\_B
- o NFVI policy
  - Place VM whose outbound traffic is larger than 100Mbps at POP\_A
  - Place VM whose outbound traffic is smaller than 100Mbps at POP\_B
- o Conflict case
  - If VNF\_A and VNF\_B generate traffic in 150Mbps and 50Mbps, respectively,
  - VNF\_A and VNF\_B need to be placed at POP\_A and POP\_B, respectively according to the NFVI policy
  - But it will violate the affinity rule given in the NS policy

<Example conflict case #3>

- o NS policy of NS\_C (composed of VNF\_A and VNF\_B)
  - Resource constraints: VNF\_A and VNF\_B exist in the same POP
  - Auto-scaling policy: if VNF\_A has more than 300K CPS, scale-out
- o NFVI policy
  - No more than 10 VMs per physical host in POP\_A
- o Conflict case
  - If CPS of VNF\_A in POP\_A gets more than 300K CPS,
  - and if there is no such physical host in the POP\_A whose VMs are smaller than 10,
  - VNF\_A need to be scaled-out to other POP than POP\_A according to the NFVI policy
  - But it will violate the NS policy

#### 4. Requirements of verification framework

A verification framework for NFV-based services needs to satisfy the following requirements:.

- o R1 : It should be able to check global and local properties and invariants. Global properties and invariants relate to the entire VNFs, and local properties and invariants relates to

the specific domain or resources that some of the VNFs are using. For example, Loop-freeness and isolation between VNFs can be regarded as global. The policies that are related only to the specific network controllers or devices are local.

- o R2 : It should be able to access to the entire network states whenever verification tasks are started. It can directly manage the states of network and NFV-based services through databases or any solution that specializes in dealing with the network topology and configurations, or can utilize the functions provided by NFV M&O and VNFI solutions to get or set the states at any time.
- o R3 : It should be independent from specific solutions and frameworks, and provide standard APIs.
- o R4 : It should process standard protocols such as NetConf, YANG, OpenFlow, and northbound and southbound interfaces that are related network configurations, and used by OSS.

## 5. Challenging issues

There are emerging challenges that the verification services face with.

### 5.1. Consistency check in distributed state

Basically, NFV states as well as SDN controllers are distributed. writing code that works correctly in a distributed setting is very hard. Therefore, distributed state management and consistency check has challenging issues. Some open source project such as ONOS offers a core set of primitives to manage this complexity. RAFT algorithm [RAFT] is used for distribution and replication. Similarly, Open daylight project has a clustering concept to management distributed state. There is no "one-size-fits-all" solution for control plane data consistency.

### 5.2. Intent-based service composition

Recently, Intent-based high-level language is newly proposed and discussed in open source project. The Intent allows for a descriptive way to get what is desired from the infrastructure, unlike the current NFV description and SDN interfaces which are based on describing how to provide different services. This Intent will accommodate orchestration services and network and business oriented SDN/NFV applications, including OpenStack Neutron, Service Function

Chaining, and Group Based Policy. A Intent compiler that translates and compiles it into low level instructions (e.g., SDN controller/OpenStack primitives) for network service components. In this sense, error checking and debugging are critical for reliable Intent-based service composition.

### 5.3. Finding infinite loops

General solutions for the infinite loop can lead to intractable problem (e.g. the halting problem). To make the verification practical and minimize the complexity, some of the restrictions are required. Finding cycle can be processed in polynomial time but the restriction could be too much for some cases that service functions or network flows requires finite loops.

### 5.4. Live traffic verification

It is known fact that the complexity of verification tasks for the real and big problem is high. A few invariants can be checked in real-time but it would be impossible if the size of VNFs increases or properties to be checked are complex.

### 5.5. Languages and their semantics

For the verification, configurations and states of VNFs need to be precisely expressed using formal semantics. There are many languages and models, and it is impractical for the verification frameworks to support all of the existing languages and models. Languages and semantic models optimized to the verification framework need to be selected or newly developed.

## 6. Gap analysis - open source projects

Recently, the Open Platform for NFV (OPNFV) community is collaborating on a carrier-grade, integrated, open source platform to accelerate the introduction of new NFV products and services [OPNFV]. Open Daylight (ODL) is also being tightly coupled with this OPNFV platform to integrate SDN controller into NFV framework [ODL].

This clause analyzes the existing open source projects including OPNFV and ODL related to verification of NFV services.

### 6.1. OPNFV

#### 6.1.1. Doctor

The Doctor project provides a NFVI fault management and maintenance

framework on top of the virtualized infrastructure. The key feature is to notify unavailability of virtualized resources and to recover unavailable VNFs.

While the Doctor project focuses only on faults in NFVI including compute, network, and storage resources, the document discusses broader fault management issues such as break-down of the supporting infrastructure due to incomplete or inconsistent configuration of NFV services.

#### 6.1.2. Prediction

The Prediction project provides a data collection for failure prediction framework. The failure prediction framework diagnoses or verifies which entity is suspected to be progressing towards a failure and which VNFs might be affected due to the predicted anomaly.

While the Prediction project focuses only on fault prediction in NFVI compute, network, and storage resources, the document includes broader fault management and prediction issues such as faults in the NFV service deployment and operation.

#### 6.1.3. Resource Scheduler

The Resource Scheduler project provides an enhanced scheduler for optimizing the performance of the VNFs. In particular, this project supports resource isolation. For example, when a VNF strictly requires low latency, strongly isolated compute resources can be allocated to the VNF.

The Resource Scheduler project only focuses on optimizing the performance of individual VNFs without considering the end-to-end performance (e.g., latency and throughput) in NFV services.

#### 6.1.4. Moon

The Moon project implements a security management system for the cloud computing infrastructure. The project also enforces the security managers through various mechanisms, e.g., authorization for access control, firewall for networking, isolation for storage, and logging for tractability.

Note that the main interest of the Moon project is the DDoS attack to a service node and the IDS management for VNFs. A wider range of security issues in the NFV service verification need to be discussed.

#### 6.1.5 Bottlenecks

The Bottlenecks project aims to find system bottlenecks by testing and verifying OPNFV infrastructure in a staging environment before committing it to a production environment. Instead of debugging the deployment in production environment, an automatic method for executing benchmarks to validate the deployment during staging is adopted. For example, the system measures the performance of each VNF by generating workload on VNFs.

The Bottlenecks project does not consider incomplete or inconsistent configurations on NFV services that might cause the system bottlenecks. Furthermore, the Bottlenecks project aims to find system bottlenecks before committing it to a production environment. Meanwhile, the draft also considers how to find bottlenecks in real time.

### 6.2. ODL

#### 6.2.1. Network Intent Composition

The Network Intent Composition project enables the controller to manage and direct network services and network resources based on intent for network behaviors and network policies. Intents are described to the controller through a new northbound interface, which provides generalized and abstracted policy semantics. Also, the Network Intent Composition project aims to provide advanced composition logic for identifying and resolving intent conflicts across the network applications.

When the reconfiguration upon the policy (i.e, intent) is delayed, policy inconsistency in service nodes may occur after the policy is applied to service nodes. While the Network Intent Composition project resolves such intent conflicts only before they are translated into service nodes, this document covers intent conflicts and inconsistency issues in a broader sense.

#### 6.2.2. Controller Shield

The Controller Shield project proposes to create a repository called unified-security plugin (USecPlugin). The unified-security plugin is a general purpose plugin to provide the controller security information to northbound applications. The security information could be for various purposes such as collating source of different attacks reported in southbound plugins and suspected controller intrusions. Information collected at this plugin can also be used to configure firewalls and create IP blacklists for the network.

In terms of security services, the document covers authentication, data integrity, confidentiality, and replay protection. However, the Controller Shield project only covers authentication, data integrity, and replay protection services where the confidentiality service is not considered.

### 6.2.3. Defense4All

The Defense4All project proposes a SDN application for detecting and mitigating DDoS attacks. The application communicates with ODL controller via the northbound interface and performs the two main tasks; 1) Monitoring behavior of protected traffic and 2) Diverting attacked traffic to selected attack mitigation systems (AMSS).

While the Defense4All project only focuses on defense system at the controller, this document includes broader defense issues at the service node as well as the controller.

### 6.3. Summary

The verification functions should spread over the platforms to accomplish the requirements mentioned in clause 3. The correctness of NFV-based services and their network configurations can be checked in the NFV MANO layer which has the entire states of the VNFs. Each NFVI needs to provide verification layer which composed of policy manager, network database and interfaces (e.g. REST APIs). Local properties and invariants can be verified inside the specific NFVI, and the global properties and invariants can be checked by merging local verification results from the related NFVIs.

The verification service provides verification functions to NFV MANO, NFVI, and any other low-level modules such as SDN controllers. For the platform independency, it provides standard APIs to process the verification tasks. It also uses standard APIs provided by OSS such as OpenStack (Neutron) and Open Daylight. The compiler and interpreter translate standard description languages and protocols into the internal model which optimized to the verification tasks. It can process user-defined properties to be checked as well. The properties to be checked whether they are user-defined or pre-defined invariants are managed by property library. The verifier maintains a set of verification algorithms to check the properties. The network database inside the verification service manages the global network states directly or indirectly.

A PoC can be implemented using OpenStack (Neutron) and Open Daylight. The modules related to verification framework can reside in between network virtualization framework (e.g. OpenStack Neutron) and SDN controller (e.g. Open Daylight). Neutron and Open Daylight uses

standard APIs provided by verification service to accomplish verification tasks. The initial use case for the PoC could be, in particular, any of security, performance, etc as mentioned in clause 2.

## 7. Security Considerations

As already described in clause 2.6, how to verify security holes in VNF FG is very important consideration. In terms of security services, authentication, data integrity, confidentiality, and replay protection should be provided. On the other hand, potential security concern should be also carefully checked since several VNFs (e.g., NAT) can modify or update packet headers and payload.

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Unifying Carrier and Cloud Networks: Problem Statement and Challenges  
draft-unify-nfvrg-challenges-04

Abstract

The introduction of network and service functionality virtualization in carrier-grade networks promises improved operations in terms of flexibility, efficiency, and manageability. In current practice, virtualization is controlled through orchestrator entities that expose programmable interfaces according to the underlying resource types. Typically this means the adoption of, on the one hand, established data center compute/storage and, on the other, network control APIs which were originally developed in isolation. Arguably, the possibility for innovation highly depends on the capabilities and openness of the aforementioned interfaces. This document introduces in simple terms the problems arising when one follows this approach and motivates the need for a high level of programmability beyond policy and service descriptions. This document also summarizes the challenges related to orchestration programming in this unified cloud and carrier network production environment. A subsequent problem is the resource orchestration. This is handled separately in [I-D.caszpe-nfvrg-orchestration-challenges] and will be merged in the next iteration of this document.

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#### 1. Introduction

To a large degree there is agreement in the network research, practitioner, and standardization communities that rigid network control limits the flexibility and manageability of speedy service

creation, as discussed in [NSC] and the references therein. For instance, it is not unusual that today an average service creation time cycle exceeds 90 hours, whereas given the recent advances in virtualization and cloudification one would be interested in service creation times in the order of minutes [EU-5GPPP-Contract] if not seconds.

Flexible service definition and creation start by formalizing the service into the concept of network function forwarding graphs, such as the ETSI VNF Forwarding Graph [ETSI-NFV-Arch] or the ongoing work in IETF [I-D.ietf-sfc-problem-statement]. These graphs represent the way in which service end-points (e.g., customer access) are interconnected with a set of selected network functionalities such as firewalls, load balancers, and so on, to deliver a network service. Service graph representations form the input for the management and orchestration to instantiate and configure the requested service. For example, ETSI defined a Management and Orchestration (MANO) framework in [ETSI-NFV-MANO]. We note that throughout such a management and orchestration framework different abstractions may appear for separation of concerns, roles or functionality, or for information hiding.

Compute virtualization is central to the concept of Network Function Virtualization (NFV). However, carrier-grade services demand that all components of the data path, such as Network Functions (NFs), virtual NFs (VNFs) and virtual links, meet key performance requirements. In this context, the inclusion of Data Center (DC) platforms, such as OpenStack [OpenStack], into the SDN infrastructure is far from trivial.

In this document we examine the problems arising as one combines these two formerly isolated environments in an effort to create a unified production environment and discuss the associated emerging challenges. Our goal is the definition of a production environment that allows multi-vendor and multi-domain operation based on open and interoperable implementations of the key entities described in the remainder of this document.

## 2. Terms and Definitions

We use the term compute and "compute and storage" interchangeably throughout the document. Moreover, we use the following definitions, as established in [ETSI-NFV-Arch]:

**NFV:** Network Function Virtualization - The principle of separating network functions from the hardware they run on by using virtual hardware abstraction.

NFVI PoP: NFV Infrastructure Point of Presence - Any combination of virtualized compute, storage and network resources.

NFVI: NFV Infrastructure - Collection of NFVI PoPs under one orchestrator.

VNF: Virtualized Network Function - a software-based network function.

VNF FG: Virtualized Network Function Forwarding Graph - an ordered list of VNFs creating a service chain.

MANO: Management and Orchestration - In the ETSI NFV framework [ETSI-NFV-MANO], this is the global entity responsible for management and orchestration of NFV lifecycle.

Further, we make use of the following terms:

NF: a network function, either software-based (VNF) or appliance-based.

SW: a (routing/switching) network element with a programmable control plane interface.

DC: a data center network element which in addition to a programmable control plane interface offers a DC control interface

LSI: Logical Switch Instance - a software switch instance.

CN: an element equipped with compute and/or storage resources.

UN: Universal Node - an innovative element that integrates and manages in a unified platform both compute and networking components.

### 3. Motivations

Figure 1 illustrates a simple service graph comprising three network functions (NFs). For the sake of simplicity, we will assume only two types of infrastructure resources, namely SWs and DCs as per the terminology introduced above, and ignore appliance-based NFs for the time being. The goal is to implement the given service based on the available infrastructure resources.

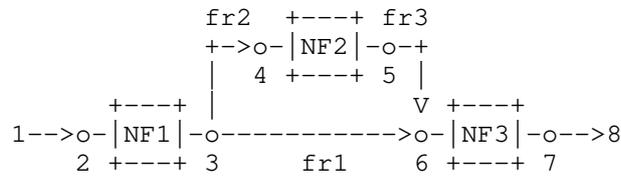


Figure 1: Service graph

The service graph definition contains NF types (NF1, NF2, NF3) along with the

- o corresponding ports (NF1:{2,3}; NF2:{4,5}; NF3:{6,7})
- o service access points {1,8} corresponding to infrastructure resources,
- o definition of forwarding behavior (fr1, fr2, fr3)

The forwarding behavior contains classifications for matching of traffic flows and corresponding outbound forwarding actions.

Assume now that we would like to use the infrastructure (topology, network and software resources) depicted in Figure 2 and Figure 3 to implement the aforementioned service graph. That is, we have three SWs and two Points of Presence (PoPs) with DC software resources at our disposal.

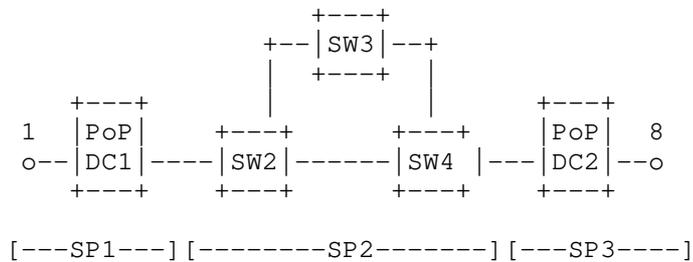


Figure 2: Infrastructure resources

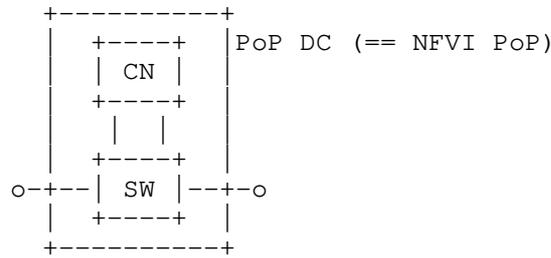


Figure 3: A virtualized Point of Presence (PoP) with software resources (Compute Node - CN)

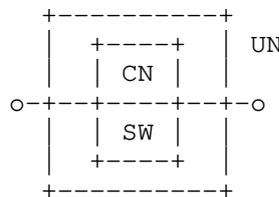


Figure 4: Universal Node - an innovative element that integrates on the same platform both compute and networking components

In the simplest case, all resources would be part of the same service provider (SP) domain. We need to ensure that each entity in Figure 2 can be procured from a different vendor and therefore interoperability is key for multi-vendor NFVI deployment. Without such interoperability different technologies for data center and network operation result in distinct technology domains within a single carrier. Multi-technology barriers start to emerge hindering the full programmability of the NFVI and limiting the potential for rapid service deployment.

We are also interested in a multi-operation environment, where the roles and responsibilities are distributed according to some organizational structure within the organization. Finally, we are interested in multi-provider environment, where different infrastructure resources are available from different service providers (SPs). Figure 2 indicates a multi-provider environment in the lower part of the figure as an example. We expect that this type of deployments will become more common in the future as they are well suited with the elasticity and flexibility requirements [NSC].

Figure 2 also shows the service access points corresponding to the overarching domain view, i.e., {1,8}. In order to deploy the service graph of Figure 1 on the infrastructure resources of Figure 2, we

will need an appropriate mapping which can be implemented in practice.

Figure 3 shows the structure of a PoP DC that presents compute and network resources while Figure 4 shows the structure of the Universal Node (UN), an innovative element that integrates on the same platform both compute and networking components and that could be used in the infrastructure as an alternative to elements depicted in Figure 2 for what concerns network and/or compute resources.

In Figure 5 we illustrate a resource orchestrator (RO) as a functional entity whose task is to map the service graph to the infrastructure resources under some service constraints and taking into account the NF resource descriptions.

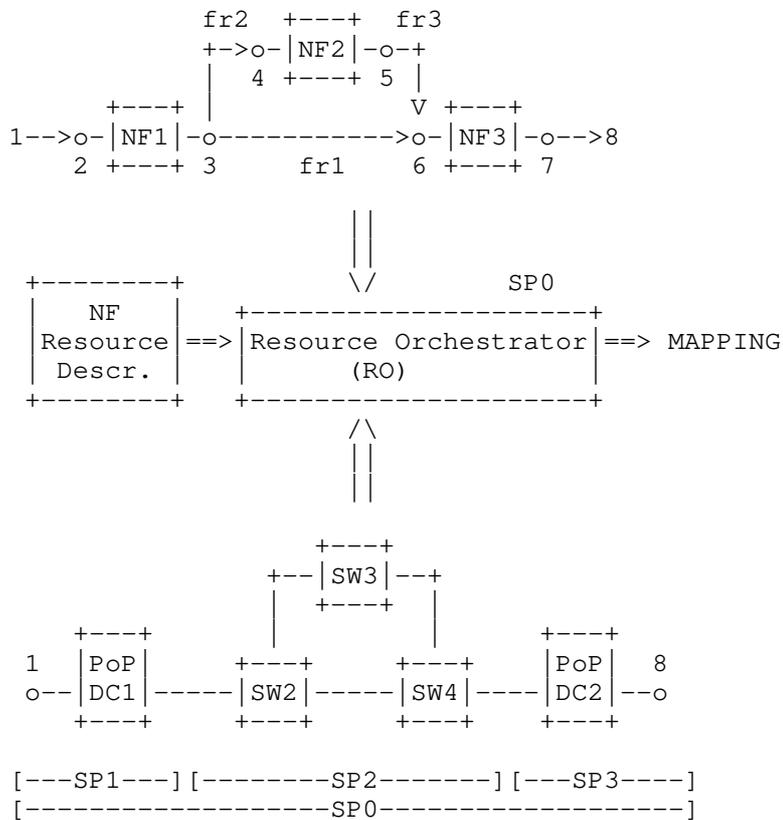


Figure 5: Resource Orchestrator: information base, inputs and output

NF resource descriptions are assumed to contain information necessary to map NF types to a choice of instantiable VNF flavor or a selection of an already deployed NF appliance and networking demands for different operational policies. For example, if energy efficiency is to be considered during the decision process then information related to energy consumption of different NF flavors under different conditions (e.g., network load) should be included in the resource description.

Note that we also introduce a new service provider (SP0) which effectively operates on top of the virtualized infrastructure offered by SP1, SP2 and SP3.

In order for the RO to execute the resource mapping (which in general is a hard problem) it needs to operate on the combined control plane illustrated in Figure 6. In this figure we mark clearly that the interfaces to the compute (DC) control plane and the SDN (SW) control plane are distinct and implemented through different interfaces/APIs. For example, Ic1 could be the Apache CloudStack API, while Ic2 could be a control plane protocol such as ForCES or OpenFlow [RFC7426]. In this case, the orchestrator at SP0 (top part of the figure) needs to maintain a tight coordination across this range of interfaces.

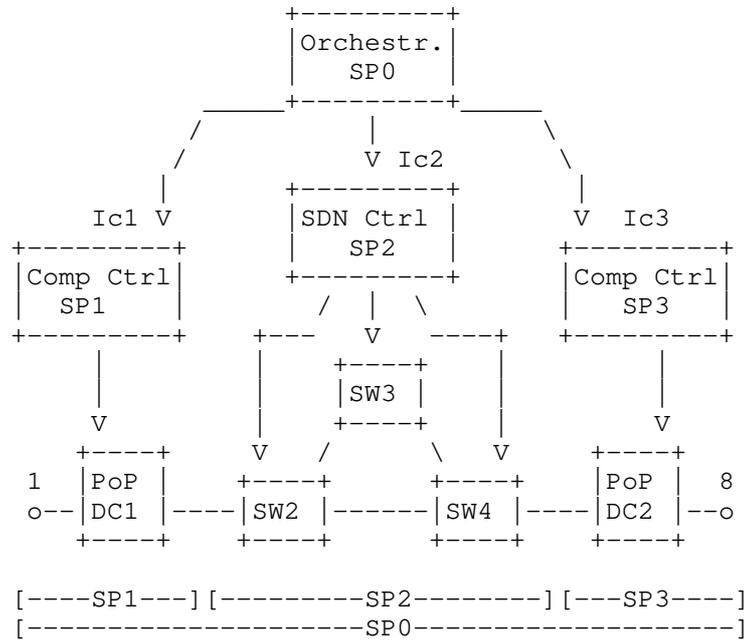


Figure 6: The RO Control Plane view. Control plane interfaces are indicated with (line) arrows. Data plane connections are indicated with simple lines.

In the real-world, however, orchestration operations do not stop, for example, at the DC1 level as depicted in Figure 6. If we (so-to-speak) "zoom into" DC1 we will see a similar pattern and the need to coordinate SW and DC resources within DC1 as illustrated in Figure 7. As depicted, this edge PoP includes compute nodes (CNs) and SWs which in most of the cases will also contain an internal topology.

In Figure 7, IcA is an interface similar to Ic2 in Figure 6, while IcB could be, for example, OpenStack Nova or similar. The Northbound Interface (NBI) to the Compute Controller can use Ic1 or Ic3 as shown in Figure 6.

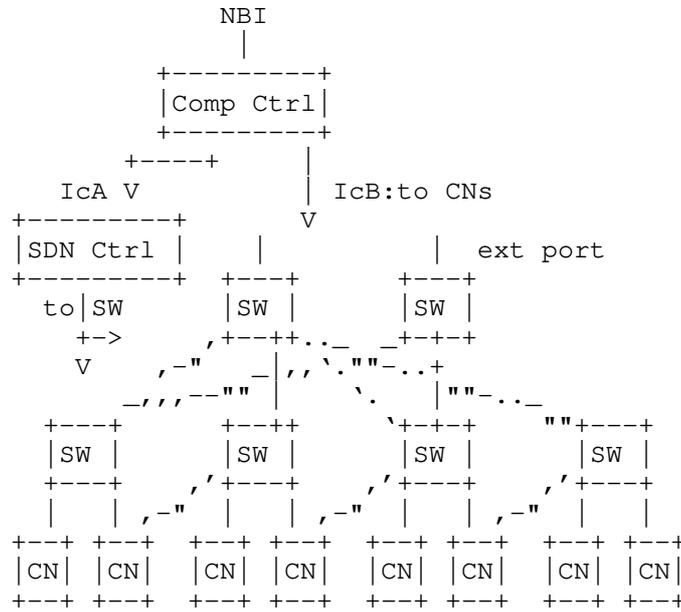


Figure 7: PoP DC Network with Compute Nodes (CN)

In turn, each single Compute Node (CN) may also have internal switching resources (see Figure 8). In a carrier environment, in order to meet data path requirements, allocation of compute node internal distributed resources (blades, CPU cores, etc.) may become equivalently important.

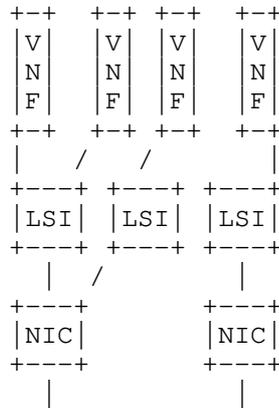


Figure 8: Compute Node with internal switching resource

Based on the recursion principles shown above and the complexity implied by separate interfaces for compute and network resources, one could imagine a recursive programmatic interface for joint compute, storage and network provisioning as depicted in Figure 9.

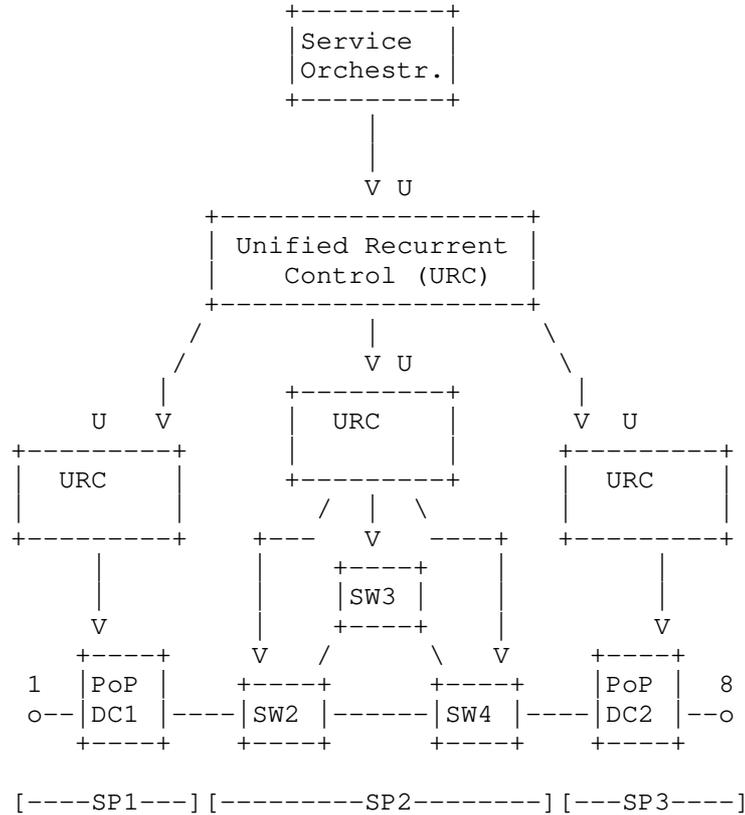


Figure 9: The RO Control Plane view considering a recursive programmatic interface for joint compute, storage and network provisioning

In Figure 9, Ic1, Ic2 and Ic3 of Figure 6 have been substituted by the recursive programmatic interface U to use for both compute and network resources and we find also the Unified Recurrent Control (URC), an element that performs both compute and network control and that can be used in a hierarchy structure.

Considering the use of the recursive programmatic interface U and the Unified Recurrent Control, the PoP DC Network structure with Compute Nodes view changes as reported in Figure 10.

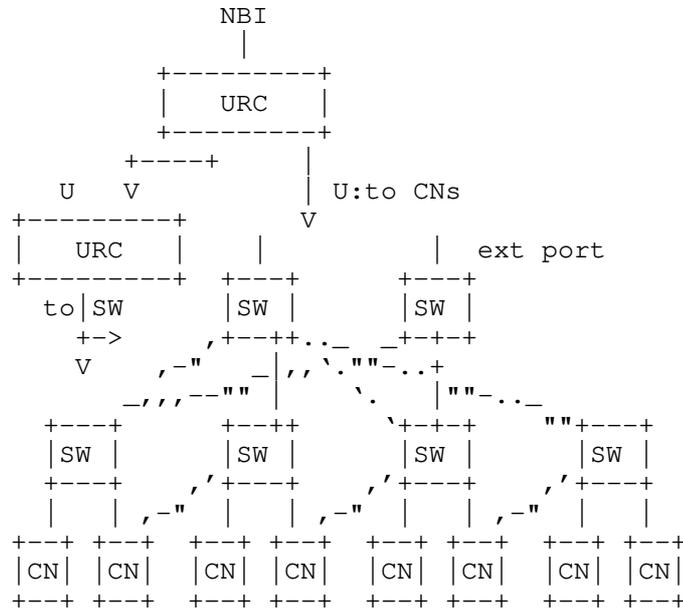


Figure 10: PoP DC Network with Compute Nodes (CN) considering the U interface and the URC element

4. Problem Statement

The motivational examples of Section 3 illustrate that almost always compute virtualization and network virtualization are tightly connected. In particular Figure, 3 shows that in a PoP DC there are not only compute resources (CNs) but also network resources (SWs), and so it illustrates that compute virtualization implicitly involves network virtualization unless we consider the unlikely scenario where dedicated network elements are used to interconnect the different virtual network functions implemented on the compute nodes (e.g.: to implement Flexible Service Chaining). On the other hand, considering a network scenario made not only of just pure SDN network elements (SWs) but also of compute resources (CNs) or SDN network nodes that are equipped also with compute resources (UNs), it is very likely that virtualized network resources, if offered to clients, imply virtualization of compute resources, unless we consider the unlikely scenario where dedicated compute resources are available for every virtualized network.

Furthermore, virtualization often leads to scenarios of recursions with clients redefining and reselling resources and services at different levels.

We argue that given the multi-level virtualization of compute, storage and network domains, automation of the corresponding resource provisioning could be more easily implemented by a recursive programmatic interface. Existing separated compute and network programming interfaces cannot easily provide such recursions and cannot always satisfy key requirement for multi-vendor, multi-technology and multi-provider interoperability environments. Therefore we foresee the necessity of a recursive programmatic interface for joint compute, storage and network provisioning.

## 5. Challenges

We summarize in this section the key questions and challenges, which we hope will initiate further discussions in the NFVRG community.

### 5.1. Orchestration

Firstly, as motivated in Section 3, orchestrating networking resources appears to have a recursive nature at different levels of the hierarchy. Would a programmatic interface at the combined compute and network abstraction better support this recursive and constraint-based resource allocation?

Secondly, can such a joint compute, storage and network programmatic interface allow an automated resource orchestration similar to the recursive SDN architecture [ONF-SDN-ARCH]?

Thirdly, can such a joint compute, storage and network programmatic interface realize the functionality of an SFC Control plane [I-D.ietf-sfc-control-plane]? Our initial mapping and proof of concept experimentations are documented in [I-D.unify-sfc-control-plane-exp].

### 5.2. Resource description

Prerequisite for joint placement decisions of compute, storage and network is the adequate description of available resources. This means that the interfaces (IcA, IcB etc. in Figure 6 and Figure 7) are of bidirectional nature, exposing resources as well as reserving. There have been manifold attempts to create frameworks for resource description, most prominently RDF of W3C, NDL, the GENI RPC and its concept of Aggregate Managers, ONF's TTP and many more.

Quite naturally, all attempts to standardize "arbitrary" resource descriptions lead to creating ontologies, complex graphs describing relations of terms to each other.

Practical descriptions of compute resources are currently focusing on number of logical CPU cores, available RAM and storage, allowing, e.g., the OpenStack Nova scheduler to meet placement decisions. In heterogeneous network and compute environments, hardware may have different acceleration capabilities (e.g., AES-NI or hardware random number generators), so the notion of logical compute cores is not expressive enough. In addition, the network interfaces (and link load) provide important information on how fast a certain VNF can be executed in one node.

This may lead to a description of resources as VNF-FGs themselves. Networking resource (SW) may expose the capability to forward and process frames in, e.g., OpenFlow TableFeatures reply. Compute nodes in the VNF-FG would expose lists of capabilities like the presence of AES hardware acceleration, Intel DPDK support, or complex functions like a running web server. An essential part of the compute node's capability would be the ability to run a certain VNF of type X within a certain QoS spec. As the QoS is service specific, it can only be exposed by a control function within the instantiated VNF-FG.

### 5.3. Dependencies (de-composition)

Salt [SALT], Puppet [PUPPET], Chef [CHEF] and Ansible [ANSIBLE] are tools to manage large scale installations of virtual machines in DC environments. Essentially, the decomposition of a complex function into its dependencies is encoded in "recipes" (Chef).

OASIS TOSCA [TOSCA] specification aims at describing application layer services to automate interoperable deployment in alternative cloud environments. The TOSCA specification "provides a language to describe service components and their relationships using a service topology".

Is there a dependency (decomposition) abstraction suitable to drive resource orchestration between application layer descriptions (like TOSCA) and cloud specific installations (like Chef recipes)?

### 5.4. Elastic VNF

In many use cases, a VNF may not be designed for scaling up/down, as scaling up/down may require a restart of the VNF which the state data may be lost. Normally a VNF may be capable for scaling in/out only. Such VNF is designed running on top of a small VM and grouped as a pool of one VNF function. VNF scaling may crossing multiple NFVI PoPs (or data center)s in order to avoid limitation of the NFVI capability. At cross DC scaling, the result is that the new VNF instance may be placed at a remote cloud location. At VNF scaling,

it is a must requirement to provide the same level of Service Level Agreement (SLA) including performance, reliability and security.

In general, a VNF is part of a VNF Forwarding Graph (VNF FG), meaning the data traffic may traverse multiple stateful and stateless VNF functions in sequence. When some VNF instances of a given service function chain are placed / scaled out in a distant cloud execution, the service traffic may have to traverse multiple VNF instances which are located in multiple physical locations. In the worst case, the data traffic may ping-pong between multiple physical locations. Therefore it is important to take the whole service function chain's performance into consideration when placing and scaling one of its VNF instance. Network and cloud resources need mutual considerations, see [I-D.zu-nfvrg-elasticity-vnf].

#### 5.5. Measurement and analytics

Programmable, dynamic, and elastic VNF deployment requires that the Resource Orchestrator (RO) entities obtain timely information about the actual operational conditions between different locations where VNFs can be placed. Scaling VNFs in/out/up/down, VNF execution migration and VNF mobility, as well as right-sizing the VNFI resource allocations is a research area that is expected to grow in the coming years as mechanisms, heuristics, and measurement and analytics frameworks are developed.

For example, Veitch et al. [IAF] point out that NFV deployment will "present network operators with significant implementation challenges". They look into the problems arising from the lack of proper tools for testing and diagnostics and explore the use of embedded instrumentation. They find that in certain scenarios fine-tuning resource allocation based on instrumentation can lead to at least 50% reduction in compute provisioning. In this context, three categories emerge where more research is needed.

First, in the compute domain, performance analysis will need to evolve significantly from the current "safety factor" mentality which has served well carriers in the dedicated, hardware-based appliances era. In the emerging softwarized deployments, VNFI will require new tools for planning, testing, and reliability assurance. Meirosu et al. [I-D.unify-nfvrg-devops] describe in detail the challenges in this area with respect to verification, testing, troubleshooting and observability.

Second, in the network domain, performance measurement and analysis will play a key role in determining the scope and range of VNF distribution across the resources available. For example, IETF has worked on the standardization of IP performance metrics for years.

The Two-Way Active Measurement Protocol (TWAMP) could be employed, for instance, to capture the actual operational state of the network prior to making RO decisions. TWAMP management, however, still lacks a standardized and programmable management and configuration data model [I-D.ietf-ippm-twamp-yang]. We expect that as VNFI programmability gathers interest from network carriers several IETF protocols will be revisited in order to bring them up to date with respect to the current operational requirements. To this end, NFVRG can play an active role in identifying future IETF standardization directions.

Third, non-technical considerations which relate to business aspects or priorities need to be modeled and codified so that ROs can take intelligent decisions. Meirosu et al. [I-D.unify-nfvrg-devops] identify two aspects of this problem, namely a) how high-level network goals are translated into low-level configuration commands; and b) monitoring functions that go beyond measuring simple metrics such as delay or packet loss. Energy efficiency and cost, for example, can steer NFV placement. In NFVI deployments operational practices such as follow-the-sun will be considered as earlier research in the data center context implies.

#### 6. IANA Considerations

This memo includes no request to IANA.

#### 7. Security Considerations

TBD

#### 8. Acknowledgement

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Abstract

Carrier-grade network management was optimized for environments built with monolithic physical nodes and involves significant deployment, integration and maintenance efforts from network service providers. The introduction of virtualization technologies, from the physical layer all the way up to the application layer, however, invalidates several well-established assumptions in this domain. This draft opens the discussion in NFVRG about challenges related to transforming the telecom network infrastructure into an agile, model-driven environment for communication services. We take inspiration from data center DevOps on the simplification and automation of management processes for a telecom service provider software-defined infrastructure (SDI). A number of challenges associated with operationalizing DevOps principles at scale in software-defined telecom networks are identified in relation to three areas related to key programmable management processes.

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## 1. Introduction

Carrier-grade network management was developed as an incremental solution once a particular network technology matured and came to be deployed in parallel with legacy technologies. This approach requires significant integration efforts when new network services are launched. Both centralized and distributed algorithms have been developed in order to solve very specific problems related to configuration, performance and fault management. However, such algorithms consider a network that is by and large functionally static. Thus, management processes related to introducing new or maintaining functionality are complex and costly due to significant efforts required for verification and integration.

Network virtualization, by means of Software-Defined Networking (SDN) and Network Function Virtualization (NFV), creates an environment where network functions are no longer static or strictly embedded in physical boxes deployed at fixed points. The virtualized network is dynamic and open to fast-paced innovation enabling efficient network management and reduction of operating cost for network operators. A significant part of network capabilities are expected to become available through interfaces that resemble the APIs widespread within datacenters instead of the traditional telecom means of management such as the Simple Network Management Protocol, Command Line Interfaces or CORBA. Such an API-based approach, combined with the programmability offered by SDN interfaces [RFC7426], open opportunities for handling infrastructure, resources, and Virtual Network Functions (VNFs) as code, employing techniques from software engineering.

The efficiency and integration of existing management techniques in virtualized and dynamic network environments are limited, however. Monitoring tools, e.g. based on simple counters, physical network

taps and active probing, do not scale well and provide only a small part of the observability features required in such a dynamic environment. Although huge amounts of monitoring data can be collected from the nodes, the typical granularity is rather static and coarse and management bandwidths may be limited. Debugging and troubleshooting techniques developed for software-defined environments are a research topic that has gathered interest in the research community in the last years. Still, it is yet to be explored how to integrate them into an operational network management system. Moreover, research tools developed in academia (such as NetSight [H2014], OFRewind [W2011], FlowChecker [S2010], etc.) were limited to solving very particular, well-defined problems, and oftentimes are not built for automation and integration into carrier-grade network operations workflows. As the virtualized network functions, infrastructure software and infrastructure hardware become more dynamic [NFVSWA], the monitoring, management and testing approaches also need to change.

The topics at hand have already attracted several standardization organizations to look into the issues arising in this new environment. For example, IETF working groups have activities in the area of OAM and Verification for Service Function Chaining [I-D.aldrin-sfc-oam-framework] [I-D.lee-sfc-verification] for Service Function Chaining. At IRTF, [RFC7149] asks a set of relevant questions regarding operations of SDNs. The ETSI NFV ISG defines the MANO interfaces [NFVMANO], and TMForum investigates gaps between these interfaces and existing specifications in [TR228]. The need for programmatic APIs in the orchestration of compute, network and storage resources is discussed in [I-D.unify-nfvrg-challenges].

From a research perspective, problems related to operations of software-defined networks are in part outlined in [SDNsurvey] and research referring to both cloud and software-defined networks are discussed in [D4.1].

The purpose of this first version of this document is to act as a discussion opener in NFVRG by describing a set of principles that are relevant for applying DevOps ideas to managing software-defined telecom network infrastructures. We identify a set of challenges related to developing tools, interfaces and protocols that would support these principles and how can we leverage standard APIs for simplifying management tasks.

## 2. Software-Defined Telecom Infrastructure: Roles and DevOps principles

There is no single list of core principles of DevOps, but it is generally recognized as encompassing:

- . Iterative development / Incremental feature content
- . Continuous deployment
- . Automated processes
- . Holistic/Systemic views of development and deployment/operation.

With Deployment/ Operations becoming increasingly linked with software development, and business needs driving more rapid deployments, agile methodologies are assumed as a basis for DevOps. Agile methods used in many software focused companies are focused on releasing small interactions of code to implement VNFs with high velocity and high quality into a production environment. Similarly, Service providers are interested to release incremental improvements in the network services that they create from virtualized network functions. The cycle time for DevOps as applied in many open source projects is on the order of one quarter year or 13 weeks.

The code needs to undergo a significant amount of automated testing and verification with pre-defined templates in a realistic setting. From the point of view of software defined telecom infrastructure management, the of the network and service configuration is expected to continuously evolve as result of network policy decomposition and refinement, service evolution, the updates, failovers or re-configuration of virtual functions, additions/upgrades of new infrastructure resources (e.g. whiteboxes, fibers). When troubleshooting the cause of unexpected behavior, fine-grained visibility onto all resources supporting the virtual functions (either compute, or network-related) is paramount to facilitating fast resolution times. While compute resources are typically very well covered by debugging and profiling toolsets based on many years of advances in software engineering, programmable network resources are a still a novelty and tools exploiting their potential are scarce.

### 2.1. Service Developer Role

We identify two dimensions of the "developer" role in software-defined infrastructure (SDI). The network service to be developed is captured in a network service descriptor (e.g. [IFA014]). One dimension relates to determining which high-level functions should be part of a particular service, deciding what logical interconnections are needed between these blocks and defining a set of high-level constraints or goals related to parameters that define, for instance, a Service Function Chain. This could be determined by the product owner for a particular family of services offered by a telecom provider. Or, it might be a key account representative that adapts an existing service template to the requirements of a particular customer by adding or removing a small number of functional entities. We refer to this person as the Service Developer and for simplicity (access control, training on technical background, etc.) we consider the role to be internal to the telecom provider.

### 2.2. VNF Developer role

Another dimension of the "developer" role is a person that writes the software code for a new virtual network function (VNF). The VNF then needs to be delivered as a package (e.g.[IFA011]) that includes various metadata for ingestion/integration into some service. Note that a VNF may span multiple virtual machines to support design objectives (e.g. for reliability or scalability). Depending on the actual VNF being developed, this person might be internal or external (e.g. a traditional equipment vendor) to the telecom provider. We refer to them as VNF Developers.

### 2.3. System Integrator role

The System Integrator role is to some extent similar to the Service Developer: people in this role need to identify the components of the system to be delivered. However, for the Service Developer, the service components are pre-integrated meaning that they have the right interfaces to interact with each other. In contrast, the Systems Integrator needs to develop the software that makes the system components interact with each other. As such, the Systems Integrator role combines aspects of the Developer roles and adds yet another dimension to it. Compared to the other Developer roles, the System Integrator might face additional challenges due to the fact that they might not have access to the source code of some of the components. This limits for example how fast they could address issues with components to be integrated, as well as uneven workload depending on the release granularity of the different components that need to be integrated. Some system integration activities may take

place on an industry basis in collaborative communities (e.g. OPNFV.org).

#### 2.4. Network service Operator role

The role of a Network Service Operator is to ensure that the deployment processes were successful and a set of performance indicators associated to a particular network service are met. The network service is supported on infrastructure specific set of infrastructure resources that may be owned and operated by that Network Service Operator, or provided under contract from some other infrastructure service provider. .

#### 2.5. Customer role

A Customer contracts a telecom operator to provide one or more services. In SDI, the Customer may communicate with the provider in real time through an online portal. From the customer perspective, such portal interfaces become part of the service definition just like the data transfer aspects of the service. Compared to the Service Developer, the Customer is external to the operator and may define changes to their own service instance only in accordance to policies defined by the Service Developer. In addition to the usual per-service utilization statistics, in SDI the portal may enable the customer to trigger certain performance management or troubleshooting tools for the service. This, for example, enables the Customer to determine whether the root cause of certain error or degradation condition that they observe is located in the telecom operator domain or not and may facilitate the interaction with the customer support teams.

#### 2.6. DevOps Principles

In line with the generic DevOps concept outlined in [DevOpsP], we consider that these four principles as important for adapting DevOps ideas to SDI:

\* Automated processes: Deploy with repeatable, reliable processes: Service and VNF Developers should be supported by automated build, orchestrate and deploy processes that are identical in the development, test and production environments. Such processes need to be made reliable and trusted in the sense that they should reduce the chance of human error and provide visibility at each stage of the process, as well as have the possibility to enable manual interactions in certain key stages.

\* Holistic/systemic view: Develop and test against production-like systems: both Service Developers and VNF Developers need to have the opportunity to verify and debug their respective SDI code in systems that have characteristics which are very close to the production environment where the code is expected to be ultimately deployed. Customizations of Service Function Chains or VNFs could thus be released frequently to a production environment in compliance with policies set by the Operators. Adequate isolation and protection of the services active in the infrastructure from services being tested or debugged should be provided by the production environment.

\* Continuous: Monitor and validate operational quality: Service Developers, VNF Developers and Operators must be equipped with tools, automated as much as possible, that enable to continuously monitor the operational quality of the services deployed on SDI. Monitoring tools should be complemented by tools that allow verifying and validating the operational quality of the service in line with established procedures which might be standardized (for example, Y.1564 Ethernet Activation [Y1564]) or defined through best practices specific to a particular telecom operator.

\* Iterative/Incremental: Amplify development cycle feedback loops: An integral part of the DevOps ethos is building a cross-cultural environment that bridges the cultural gap between the desire for continuous change by the Developers and the demand by the Operators for stability and reliability of the infrastructure. Feedback from customers is collected and transmitted throughout the organization. From a technical perspective, such cultural aspects could be addressed through common sets of tools and APIs that are aimed at providing a shared vocabulary for both Developers and Operators, as well as simplifying the reproduction of problematic situations in the development, test and operations environments.

Network operators that would like to move to agile methods to deploy and manage their networks and services face a different environment compared to typical software companies where simplified trust relationships between personnel are the norm. In software companies, it is not uncommon that the same person may be rotating between different roles. In contrast, in a telecom service provider, there are strong organizational boundaries between suppliers (whether in Developer roles for network functions, or in Operator roles for outsourced services) and the carrier's own personnel that might also take both Developer and Operator roles. Extending DevOps principles across strong organizational boundaries e.g. through co-creation or collaborative development in open source communities) may be a commercial challenge rather than a technical issue.

### 3. Continuous Integration

Software integration is the process of bringing together the software component subsystems into one software system, and ensuring that the subsystems function together as a system. Software integration can apply regardless of the size of the software components. The objective of Continuous Integration is to prevent integration problems close to the expected release of a software development project into a production (operations) environment. Continuous Integration is therefore closely coupled with the notion of DevOps as a mechanism to ease the transition from development to operations.

Continuous integration may result in multiple builds per day. It is also typically used in conjunction with test driven development approaches that integrate unit testing into the build process. The unit testing is typically automated through build servers. Such servers may implement a variety of additional static and dynamic tests as well as other quality control and documentation extraction functions. The reduced cycle times of continuous enable improved software quality by applying small efforts frequently.

Continuous Integration applies to developers of VNF as they integrate the components that they need to deliver their VNF. The VNFs may contain components developed by different teams within the VNF Provider, or may integrate code developed externally - e.g. in commercial code libraries or in open source communities.

Service developers also apply continuous integration in the development of network services. Network services are comprised of various aspects including VNFs and connectivity within and between them as well as with various associated resource authorizations. The components of the networks service are all dynamic, and largely represented by software that must be integrated regularly to maintain consistency.

Some of the software components that Service Developers integrate may be sourced from VNF Providers or from open source communities. Service Developers and Network Service Operators are increasingly motivated to engage with open Source communities [OSandS]. Open source interfaces supported by open source communities may be more useful than traditional paper interface specifications. Even where Service Providers are deeply engaged in the open source community (e.g. OPNFV) many service providers may prefer to obtain the code through some software provider as a business practice. Such software providers have the same interests in software integration as other

VNF providers. An open source integration community (e.g. OPNFV) may resolve common integration issues across the industry reducing the need for integration issue resolution specific to particular integrators.

#### 4. Continuous Delivery

The practice of Continuous Delivery extends Continuous Integration by ensuring that the software (either a VNF code or code for SDI) checked in on the mainline is always in a user deployable state and enables rapid deployment by those users. For critical systems such as telecommunications networks, Continuous Delivery may require the advantage of including a manual trigger before the actual deployment in the live system, compared to the Continuous Deployment methodology which is also part of DevOps processes in software companies.

Automated Continuous deployment systems in may exceed 10 updates per day. Assuming an integration of 100 components, each with an average time to upgrade of 180 days then deployments on the order of every 1.8 days might be expected. The telecom infrastructure is also very distributed - consider the case of cloud RAN use cases where the number of locations for deployment is of the order of the number of cell tower locations ( $\sim 10^4..10^6$ ). Deployments may need to be incremental across the infrastructure to reduce the risk of large-scale failures. Conversely, there may need to be rapid rollbacks to prior stable deployment configurations in the event of significant failures.

#### 5. Consistency, Availability and Partitioning Challenges

The CAP theorem [CAP] states that any networked shared-data system can have at most two of following three properties: 1) Consistency (C) equivalent to having a single up-to-date copy of the data; 2) high Availability (A) of that data (for updates); and 3) tolerance to network Partitions (P).

Looking at a telecom SDI as a distributed computational system (routing/forwarding packets can be seen as a computational problem), just two of the three CAP properties will be possible at the same time. The general idea is that 2 of the 3 have to be chosen. CP favor consistency, AP favor availability, CA there are no partition. This has profound implications for technologies that need to be developed in line with the "deploy with repeatable, reliable processes"

principle for configuring SDI states. Latency or delay and partitioning properties are closely related, and such relation becomes more important in the case of telecom service providers where Devs and Ops interact with widely distributed infrastructure. Limitations of interactions between centralized management and distributed control need to be carefully examined in such environments. Traditionally connectivity was the main concern: C and A was about delivering packets to destination. The features and capabilities of SDN and NFV are changing the concerns: for example in SDN, control plane Partitions no longer imply data plane Partitions, so A does not imply C. In practice, CAP reflects the need for a balance between local/distributed operations and remote/centralized operations.

Furthermore to CAP aspects related to individual protocols, interdependencies between CAP choices for both resources and VNFs that are interconnected in a forwarding graph need to be considered. This is particularly relevant for the "Monitor and Validate Operational Quality" principle, as apart from transport protocols, most OAM functionality is generally configured in processes that are separated from the configuration of the monitored entities. Also, partitioning in a monitoring plane implemented through VNFs executed on compute resources does not necessarily mean that the dataplane of the monitored VNF was partitioned as well.

## 6. Stability and Real-Time Change Challenges

The dimensions, dynamicity and heterogeneity of networks are growing continuously. Monitoring and managing the network behavior in order to meet technical and business objectives is becoming increasingly complicated and challenging, especially when considering the need of predicting and taming potential instabilities.

In general, instability in networks may have primary effects both jeopardizing the performance and compromising an optimized use of resources, even across multiple layers: in fact, instability of end-to-end communication paths may depend both on the underlying transport network, as well as the higher level components specific to flow control and dynamic routing. For example, arguments for introducing advanced flow admission control are essentially derived from the observation that the network otherwise behaves in an inefficient and potentially unstable manner. Even with resources over provisioning, a network without an efficient flow admission control has instability regions that can even lead to congestion collapse in certain configurations. Another example is the instability which is

characteristic of any dynamically adaptive routing system. Routing instability, which can be (informally) defined as the quick change of network reachability and topology information, has a number of possible origins, including problems with connections, router failures, high levels of congestion, software configuration errors, transient physical and data link problems, and software bugs.

As a matter of fact, the states monitored and used to implement the different control and management functions in network nodes are governed by several low-level configuration commands. There are several dependencies among these states and the logic updating the states in real time (most of which are not synchronized automatically). Normally, high-level network goals (such as the connectivity matrix, load-balancing, traffic engineering goals, survivability requirements, etc) are translated into low-level configuration commands (mostly manually) individually executed on the network elements (e.g., forwarding table, packet filters, link-scheduling weights, and queue-management parameters, as well as tunnels and NAT mappings). Network instabilities due to configuration errors can spread from node to node and propagate throughout the network.

DevOps in the data center is a source of inspiration regarding how to simplify and automate management processes for software-defined infrastructure. Although the low-level configuration could be automated by DevOps tools such as CFEngine [C2015], Puppet [P2015] and Ansible [A2015], the high-level goal translation towards tool-specific syntax is still a manual process. In addition, while carrier-grade configuration tools using the NETCONF protocol support complex atomic transaction management (which reduces the potential for instability), Ansible requires third-party components to support rollbacks and the Puppet transactions are not atomic.

As a specific example, automated configuration functions are expected to take the form of a "control loop" that monitors (i.e., measures) current states of the network, performs a computation, and then reconfigures the network. These types of functions must work correctly even in the presence of failures, variable delays in communicating with a distributed set of devices, and frequent changes in network conditions. Nevertheless cascading and nesting of automated configuration processes can lead to the emergence of non-linear network behaviors, and as such sudden instabilities (i.e. identical local dynamic can give rise to widely different global dynamics).

## 7. Observability Challenges

Monitoring algorithms need to operate in a scalable manner while providing the specified level of observability in the network, either for operation purposes (Ops part) or for debugging in a development phase (Dev part). We consider the following challenges:

- \* Scalability - relates to the granularity of network observability, computational efficiency, communication overhead, and strategic placement of monitoring functions.

- \* Distributed operation and information exchange between monitoring functions - monitoring functions supported by the nodes may perform specific operations (such as aggregation or filtering) locally on the collected data or within a defined data neighborhood and forward only the result to a management system. Such operation may require modifications of existing standards and development of protocols for efficient information exchange and messaging between monitoring functions. Different levels of granularity may need to be offered for the data exchanged through the interfaces, depending on the Dev or Ops role. Modern messaging systems, such as Apache Kafka [AK2015], widely employed in datacenter environments, were optimized for messages that are considerably larger than reading a single counter value (typical SNMP GET call usage) - note the throughput vs record size from [K2014]. It is also debatable to what extent properties such as message persistence within the bus are needed in a carrier environment, where MIBs practically offer already a certain level of persistence of management data at the node level. Also, they require the use of IP addressing which might not be needed when the monitored data is consumed by a function within the same node.

- \* Common communication channel between monitoring functions and higher layer entities (orchestration, control or management systems) - a single communication channel for configuration and measurement data of diverse monitoring functions running on heterogeneous hard- and software environments. In telecommunication environments, infrastructure assets span not only large geographical areas, but also a wide range of technology domains, ranging from CPEs, access-, aggregation-, and transport networks, to datacenters. This heterogeneity of hard- and software platforms requires higher layer entities to utilize various parallel communication channels for either configuration or data retrieval of monitoring functions within these technology domains. To address automation and advances in monitoring programmability, software defined telecommunication infrastructures would benefit from a single flexible communication channel, thereby supporting the dynamicity of virtualized environments. Such a channel should ideally support propagation of

configuration, signalling, and results from monitoring functions; carrier-grade operations in terms of availability and multi-tenant features; support highly distributed and hierarchical architectures, keeping messages as local as possible; be lightweight, topology independent, network address agnostic; support flexibility in terms of transport mechanisms and programming language support.

Existing popular state-of-the-art message queuing systems such as RabbitMQ [R2015] fulfill many of these requirements. However, they utilize centralized brokers, posing a single point-of-failure and scalability concerns within vastly distributed NFV environment. Furthermore, transport support is limited to TCP/IP. ZeroMQ [Z2015] on the other hand lacks any advanced features for carrier-grade operations, including high-availability, authentication, and tenant isolation.

\* Configurability and conditional observability - monitoring functions that go beyond measuring simple metrics (such as delay, or packet loss) require expressive monitoring annotation languages for describing the functionality such that it can be programmed by a controller. Monitoring algorithms implementing self-adaptive monitoring behavior relative to local network situations may employ such annotation languages to receive high-level objectives (KPIs controlling tradeoffs between accuracy and measurement frequency, for example) and conditions for varying the measurement intensity. Steps in this direction were taken by the DevOps tools such as Splunk [S2015], whose collecting agent has the ability to load particular apps that in turn access specific counters or log files. However, such apps are tool specific and may also require deploying additional agents that are specific to the application, library or infrastructure node being monitored. Choosing which objects to monitor in such environment means deploying a tool-specific script that configures the monitoring app.

\* Automation - includes mapping of monitoring functionality from a logical forwarding graph to virtual or physical instances executing in the infrastructure, as well as placement and re-placement of monitoring functionality for required observability coverage and configuration consistency upon updates in a dynamic network environment. Puppet [P2015] manifests or Ansible [A2015] playbooks could be used for automating the deployment of monitoring agents, for example those used by Splunk [S2015]. However, both manifests and playbooks were designed to represent the desired system configuration snapshot at a particular moment in time - they would now need to be generated automatically by the orchestration tools instead of a DevOps person.

\* Actionable data

Data produced by observability tools could be utilized in a wide category of processes, ranging from billing and dimensioning to real-time troubleshooting and optimization. In order to allow for data-driven automated decisions and actuations based on these decisions, the data needs to be actionable. We define actionable data as being representative for a particular context or situation and an adequate input towards a decision. Ensuring actionable data is challenging in a number of ways, including: defining adaptive correlation and sampling windows, filtering and aggregation methods that are adapted or coordinated with the actual consumer of the data, and developing analytical and predictive methods that account for the uncertainty or incompleteness of the data.

\* Data Virtualization

Data is key in helping both Developers and Operators perform their tasks. Traditional Network Management Systems were optimized for using one database that contains the master copy of the operational statistics and logs of network nodes. Ensuring access to this data from across the organization is challenging because strict privacy and business secrets need to be protected. In DevOps-driven environments, data needs to be made available to Developers and their test environments. Data virtualization collectively defines a set of technologies that ensure that restricted copies of the partial data needed for a particular task may be made available while enforcing strict access control. Further than simple access control, data virtualization needs to address scalability challenges involved in copying large amounts of operational data as well as automatically disposing of it when the task authorized for using it has finished.

## 8. Verification Challenges

Enabling ongoing verification of code is an important goal of continuous integration as part of the data center DevOps concept. In a telecom SDI, service definitions, decompositions and configurations need to be expressed in machine-readable encodings. For example, configuration parameters could be expressed in terms of YANG data models. However, the infrastructure management layers (such as Software-Defined Network Controllers and Orchestration functions) might not always export such machine-readable descriptions of the runtime configuration state. In this case, the management layer itself could be expected to include a verification process that has the same challenges as the stand-alone verification processes we outline later in this section. In that sense, verification can be considered as a set of features providing gatekeeper functions to

verify both the abstract service models and the proposed resource configuration before or right after the actual instantiation on the infrastructure layer takes place.

A verification process can involve different layers of the network and service architecture. Starting from a high-level verification of the customer input (for example, a Service Graph as defined in [I-D.unify-nfvrg-challenges]), the verification process could go more in depth to reflect on the Service Function Chain configuration. At the lowest layer, the verification would handle the actual set of forwarding rules and other configuration parameters associated to a Service Function Chain instance. This enables the verification of more quantitative properties (e.g. compliance with resource availability), as well as a more detailed and precise verification of the abovementioned topological ones. Existing SDN verification tools could be deployed in this context, but the majority of them only operate on flow space rules commonly expressed using OpenFlow syntax.

Moreover, such verification tools were designed for networks where the flow rules are necessary and sufficient to determine the forwarding state. This assumption is valid in networks composed only by network functions that forward traffic by analyzing only the packet headers (e.g. simple routers, stateless firewalls, etc.). Unfortunately, most of the real networks contain active network functions, represented by middle-boxes that dynamically change the forwarding path of a flow according to function-local algorithms and an internal state (that is based on the received packets), e.g. load balancers, packet marking modules and intrusion detection systems. The existing verification tools do not consider active network functions because they do not account for the dynamic transformation of an internal state into the verification process.

Defining a set of verification tools that can account for active network functions is a significant challenge. In order to perform verification based on formal properties of the system, the internal states of an active (virtual or not) network function would need to be represented. Although these states would increase the verification process complexity (e.g., using simple model checking would not be feasible due to state explosion), they help to better represent the forwarding behavior in real networks. A way to address this challenge is by attempting to summarize the internal state of an active network function in a way that allows for the verification process to finish within a reasonable time interval.

## 9. Testing Challenges

Testing in an NFV environment does impact the methodology used. The main challenge is the ability to isolate the Device Under Test (DUT). When testing physical devices, which are dedicated to a specific function, isolation of this function is relatively simple: isolate the DUT by surrounding it with emulations from test devices. This achieves isolation of the DUT, in a black box fashion, for any type of testing. In an NFV environment, the DUT become a component of a software infrastructure which can't be isolated. For example, testing a VNF can't be achieved without the presence of the NFVI and MANO components. In addition, the NFVI and MANO components can greatly influence the behavior and the performance of the VNF under test.

With this in mind, in NFV, the isolation of the DUT becomes a new concept: the VNF Under Test (VUT) becomes part of an environment that consists of the rest of the necessary architecture components (the test environment). In the previous example, the VNF becomes the VUT, while the MANO and NFVI become the test environment. Then, isolation of the VUT becomes a matter of configuration management, where the configuration of the test environment is kept fixed for each test of the VUT. So the MANO policies for instantiation, scaling, and placement, as well as the NFVI parameters such as HW used, CPU pinning, etc must remain fixed for each iterative test of the VNF. Only by keeping the configurations constant can the VNF tests can be compared to each other. If any test environment configurations are changed between tests, the behavior of the VNF can be impacted, thus negating any comparison of the results.

Of course, there are instances of testing where the inverse is desired: the configuration of the test environment is changed between each test, while the VNF configuration is kept constant. As an example, this type of methodology would be used in order to discover the optimum configuration of the NFVI for a particular VNF workload. Another similar but daunting challenge is the introduction of co-located tenants in the same environment as the VNF under test. The workload on these "neighbors" can greatly influence the behavior and performance of the VNF under test, but the test itself is invaluable to understand the impact of such a configuration.

Another challenge is the usage of test devices (traffic generator, emulator) that share the same infrastructure as the VNF under test. This can create a situation as above, where the neighbor competes for resources with the VUT itself, which can really negate test results. If a test architecture such as this is necessary (testing east-west traffic, for example), then care must be taken to configure the test devices such as they are isolated from the SUT in terms of allowed

resources, and that they don't impact the SUT's ability to acquire resources to operate in all conditions.

NFV offers new features that didn't exist as such previously, or modifies existing mechanisms. Examples of new features are dynamic scaling of VNFs and network services (NS), standardized acceleration mechanisms and the presence of the virtualization layer, which includes the vSwitch. An example mechanism which changes with NFV how fault detection and fault recovery are handled. Fault recovery could now be handled by MANO in such a way to invoke mechanisms such as live migration or snapshots in order to recover the state of a VNF and restore operation quickly. While the end results are expected to be the same as before, since the mechanism is very different, rigorous testing is highly recommended to validate those results.

Dynamic scaling of VNFs is a new concept in NFV. VNFs that require more resources will have them dynamically allocated on demand, and then subsequently released when not needed anymore. This is clearly a benefit arising from SDI. For each type of VNF, specific metrics will be used as input to conditions that will trigger a scaling operation, orchestrated by MANO. Testing this mechanism requires a methodology tailored to the specific operation of the VNF, in order to properly reach the monitored metrics and exercise the conditions leading to a scaling trigger. For example, a firewall VNF will be triggered for scaling on very different metrics than a 3GPP MME. Both VNFs accomplish different functions. Since there will normally be a collection of metrics that are monitored in order to trigger a scaling operation, the testing methodology must be constructed in such a way as to address all combinations of those metrics. Metrics for a particular VNF may include sessions, session instantiations/second, throughput, etc. These metrics will be observed in relation to the given resources for the VNF.

#### 10. Programmable management

The ability to automate a set of actions to be performed on the infrastructure, be it virtual or physical, is key to productivity increases following the application of DevOps principles. Previous sections in this document touched on different dimensions of programmability:

- Section 5 approached programmability in the context of developing new capabilities for monitoring and for dynamically setting configuration parameters of deployed monitoring functions

- Section 7 reflected on the need to determine the correctness of actions that are to be inflicted on the infrastructure as result of executing a set of high-level instructions
- Section 8 considered programmability in the perspective of an interface to facilitate dynamic orchestration of troubleshooting steps towards building workflows and for reducing the manual steps required in troubleshooting processes

We expect that programmable network management - along the lines of [RFC7426] - will draw more interest as we move forward. For example, in [I-D.unify-nfvrg-challenges], the authors identify the need for presenting programmable interfaces that accept instructions in a standards-supported manner for the Two-way Active Measurement Protocol (TWAMP) protocol. More specifically, an excellent example in this case is traffic measurements, which are extensively used today to determine SLA adherence as well as debug and troubleshoot pain points in service delivery. TWAMP is both widely implemented by all established vendors and deployed by most global operators. However, TWAMP management and control today relies solely on diverse and proprietary tools provided by the respective vendors of the equipment. For large, virtualized, and dynamically instantiated infrastructures where network functions are placed according to orchestration algorithms proprietary mechanisms for managing TWAMP measurements have severe limitations. For example, today's TWAMP implementations are managed by vendor-specific, typically command-line interfaces (CLI), which can be scripted on a platform-by-platform basis. As a result, although the control and test measurement protocols are standardized, their respective management is not. This hinders dramatically the possibility to integrate such deployed functionality in the SP-DevOps concept. In this particular case, recent efforts in the IPPM WG [I-D.cmzrjp-ippm-twamp-yang] aim to define a standard TWAMP data model and effectively increase the programmability of TWAMP deployments in the future.

Data center DevOps tools, such as those surveyed in [D4.1], developed proprietary methods for describing and interacting through interfaces with the managed infrastructure. Within certain communities, they became de-facto standards in the same way particular CLIs became de-facto standards for Internet professionals. Although open-source components and a strong community involvement exists, the diversity of the new languages and interfaces creates a burden for both vendors in terms of choosing which ones to prioritize for support, and then developing the functionality and operators that determine what fits best for the requirements of their systems.

## 11. Security Considerations

DevOps principles are typically practiced within the context of a single organization ie a single trust domain. Extending DevOps practices across strong organizational boundaries (e.g. between commercial organizations) requires consideration of additional threat models. Additional validation procedures may be required to ingest and accept code changes arising from outside an organization.

## 12. IANA Considerations

This memo includes no request to IANA.

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Towards recursive virtualization and programming for network and cloud  
resources  
draft-unify-nfvrg-recursive-programming-02

## Abstract

The introduction of Network Function Virtualization (NFV) in carrier-grade networks promises improved operations in terms of flexibility, efficiency, and manageability. NFV is an approach to combine network and compute virtualizations together. However, network and compute resource domains expose different virtualizations and programmable interfaces. In [I-D.unify-nfvrg-challenges] we argued for a joint compute and network virtualization by looking into different compute abstractions.

In this document we analyze different approaches to orchestrate a service graph with transparent network functions relying on a public telecommunication network and ending in a commodity data center. We show that a recursive compute and network joint virtualization and programming has clear advantages compared to other approaches with separated control between compute and network resources. In addition, the joint virtualization will have cost and performance advantages by removing additional virtualization overhead. The discussion of the problems and the proposed solution is generic for any data center use case; however, we use NFV as an example.

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#### 1. Introduction

To a large degree there is agreement in the research community that rigid network control limits the flexibility of service creation. In [I-D.unify-nfvrg-challenges]

- o we analyzed different compute domain abstractions to argue that joint compute and network virtualization and programming is needed for efficient combination of these resource domains;
- o we described challenges associated with the combined handling of compute and network resources for a unified production environment.

Our goal here is to analyze different approaches to instantiate a service graph with transparent network functions into a commodity Data Center (DC). More specifically, we analyze

- o two black box DC set-ups, where the intra-DC network control is limited to some generic compute only control programming interface;
- o a white box DC set-up, where the intra-DC network control is exposed directly to for a DC external control to coordinate forwarding configurations;
- o a recursive approach, which illustrates potential benefits of a joint compute and network virtualization and control.

The discussion of the problems and the proposed solution is generic for any data center use case; however, we use NFV as an example.

## 2. Terms and Definitions

We use the terms compute and "compute and storage" interchangeably throughout the document. Moreover, we use the following definitions, as established in [ETSI-NFV-Arch]:

NFV: Network Function Virtualization - The principle of separating network functions from the hardware they run on by using virtual hardware abstraction.

NFVI: NFV Infrastructure - Any combination of virtualized compute, storage and network resources.

VNF: Virtualized Network Function - a software-based network function.

MANO: Management and Orchestration - In the ETSI NFV framework [ETSI-NFV-MANO], this is the global entity responsible for management and orchestration of NFV lifecycle.

Further, we make use of the following terms:

NF: a network function, either software-based (VNF) or appliance-based.

SW: a (routing/switching) network element with a programmable control plane interface.

DC: a data center is an interconnection of Compute Nodes (see below) with a data center controller, which offers programmatic resource control interface to its clients.

CN: a server, which is controlled by a DC control plane and provides execution environment for virtual machine (VM) images such as VNFs.

### 3. Use Cases

Service Function Chaining (SFC) looks into the problem how to deliver end-to-end services through the chain of network functions (NFs). Many of such NFs are envisioned to be transparent to the client, i.e., they intercept the client connection for adding value to the services without the knowledge of the client. However, deploying network function chains in DCs with Virtualized Network Functions (VNFs) are far from trivial [I-D.ietf-sfc-dc-use-cases]. For example, different exposures of the internals of the DC will imply different dynamisms in operations, different orchestration complexities and may yield for different business cases with regards to infrastructure sharing.

We investigate different scenarios with a simple NF forwarding graph of three VNFs (o->VNF1->VNF2->VNF3->o), where all VNFs are deployed within the same DC. We assume that the DC is a multi-tier leaf and spine (CLOS) and that all VNFs of the forwarding graph are bump-in-the-wire NFs, i.e., the client cannot explicitly access them.

#### 3.1. Black Box DC

In Black Bock DC set-ups, we assume that the compute domain is an autonomous domain with legacy (e.g., OpenStack) orchestration APIs. Due to the lack of direct forwarding control within the DC, no native L2 forwarding can be used to insert VNFs running in the DC into the forwarding graph. Instead, explicit tunnels (e.g., VxLAN) must be used, which need termination support within the deployed VNFs. Therefore, VNFs must be aware of the previous and the next hops of the forwarding graph to receive and forward packets accordingly.

### 3.1.1. Black Box DC with L3 tunnels

Figure 1 illustrates a set-up where an external VxLAN termination point in the SDN domain is used to forward packets to the first NF (VNF1) of the chain within the DC. VNF1, in turn, is configured to forward packets to the next SF (VNF2) in the chain and so forth with VNF2 and VNF3.

In this set-up VNFs must be capable of handling L3 tunnels (e.g., VxLAN) and must act as forwarders themselves. Additionally, an operational L3 underlay must be present so that VNFs can address each other.

Furthermore, VNFs holding chain forwarding information could be untrusted user plane functions from 3rd party developers. Enforcement of proper forwarding is problematic.

Additionally, compute only orchestration might result in sub-optimal allocation of the VNFs with regards to the forwarding overlay, for example, see back-forth use of a core switch in Figure 1.

In [I-D.unify-nfvrg-challenges] we also pointed out that within a single Compute Node (CN) similar VNF placement and overlay optimization problem may reappear in the context of network interface cards and CPU cores.

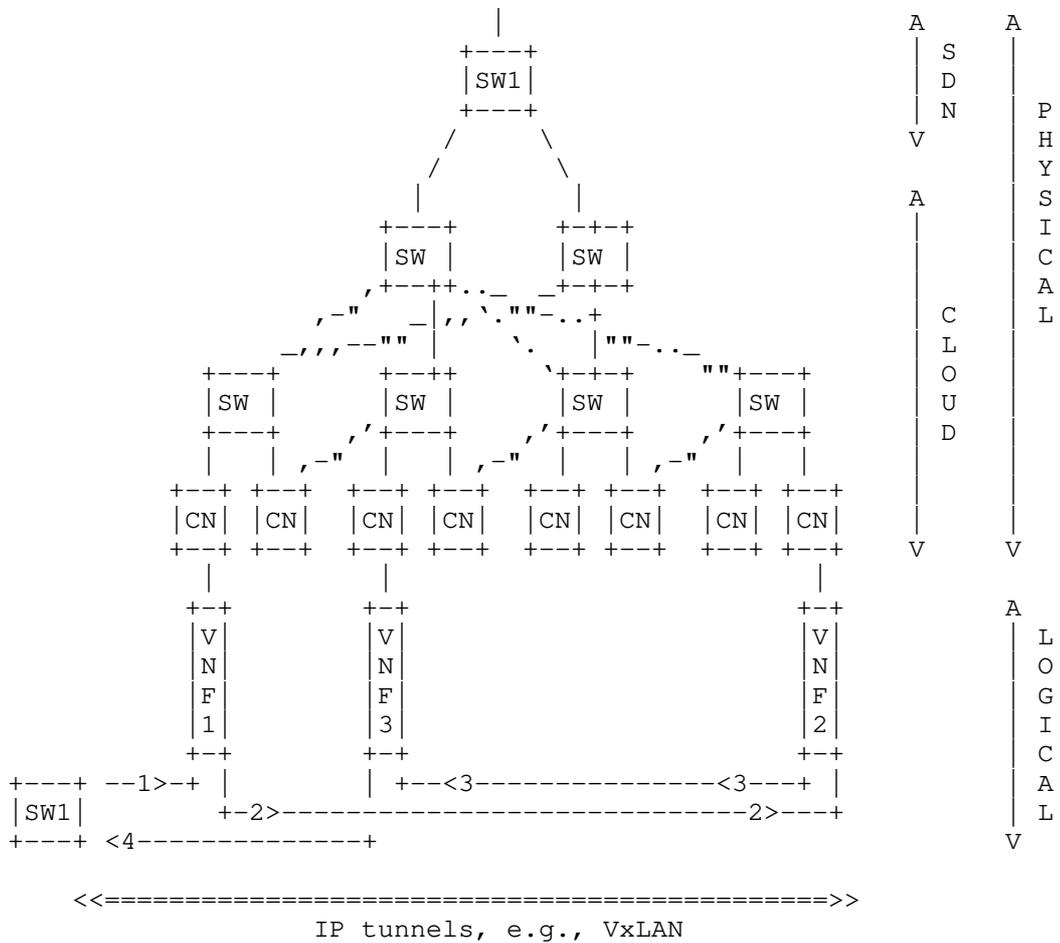


Figure 1: Black Box Data Center with VNF Overlay

3.1.2. Black Box DC with external steering

Figure 2 illustrates a set-up where an external VxLAN termination point in the SDN domain is used to forward packets among all the SFs (VNF1-VNF3) of the chain within the DC. VNFs in the DC need to be configured to receive and send packets between only the SDN endpoint, hence are not aware of the next hop VNF address. Shall any VNFs need to be relocated, e.g., due to scale in/out as described in [I-D.zu-nfvrg-elasticity-vnf], the forwarding overlay can be transparently re-configured at the SDN domain.

Note however, that traffic between the DC internal SFs (VNF1, VNF2, VNF3) need to exit and re-enter the DC through the external SDN switch. This, certainly, is sub-optimal and results in ping-pong traffic similar to the local and remote DC case discussed in [I-D.zu-nfvrg-elasticity-vnf].

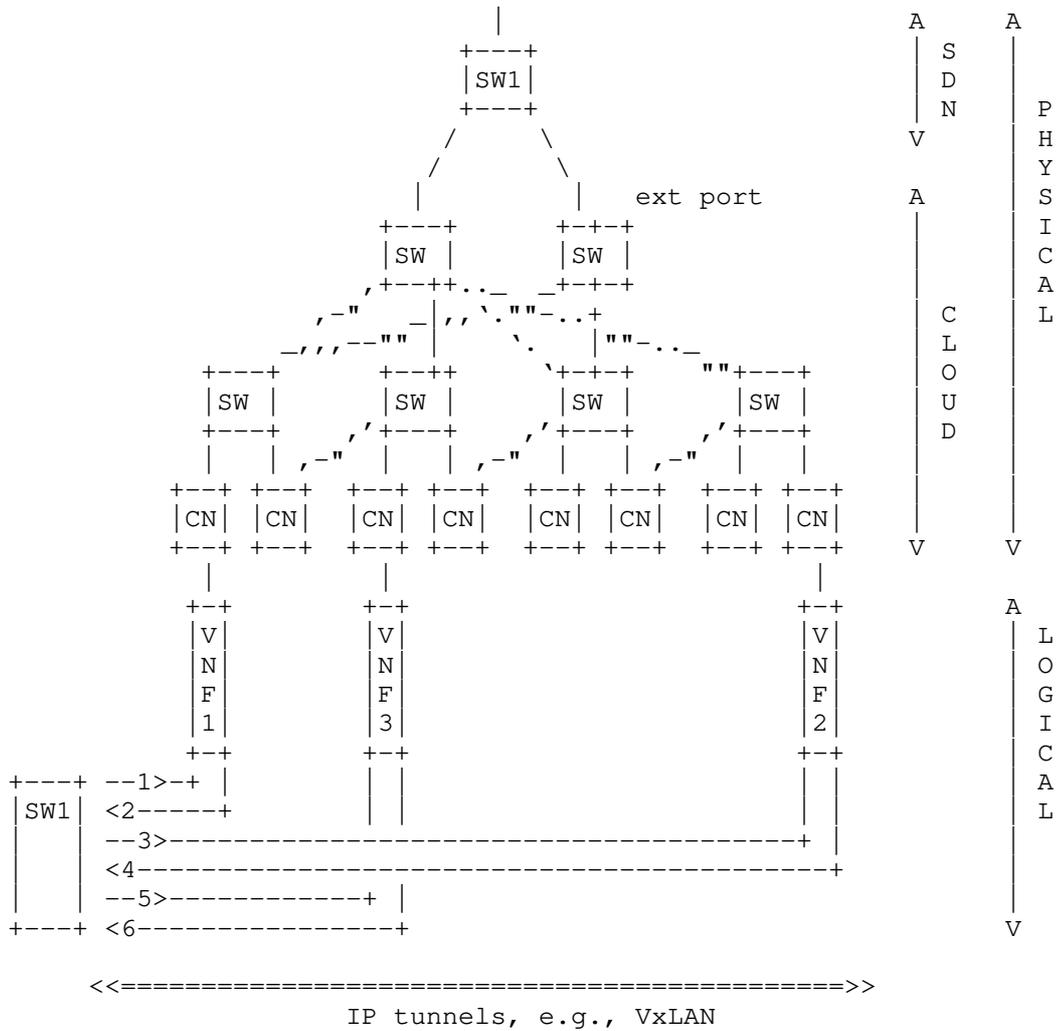


Figure 2: Black Box Data Center with ext Overlay

### 3.2. White Box DC

Figure 3 illustrates a set-up where the internal network of the DC is exposed in full details through an SDN Controller for steering control. We assume that native L2 forwarding can be applied all through the DC until the VNFs' port, hence IP tunneling and tunnel termination at the VNFs are not needed. Therefore, VNFs need not be forwarding graph aware but transparently receive and forward packets. However, the implications are that the network control of the DC must be handed over to an external forwarding controller (see that the SDN domain and the DC domain overlaps in Figure 3). This most probably prohibits clear operational separation or separate ownerships of the two domains.

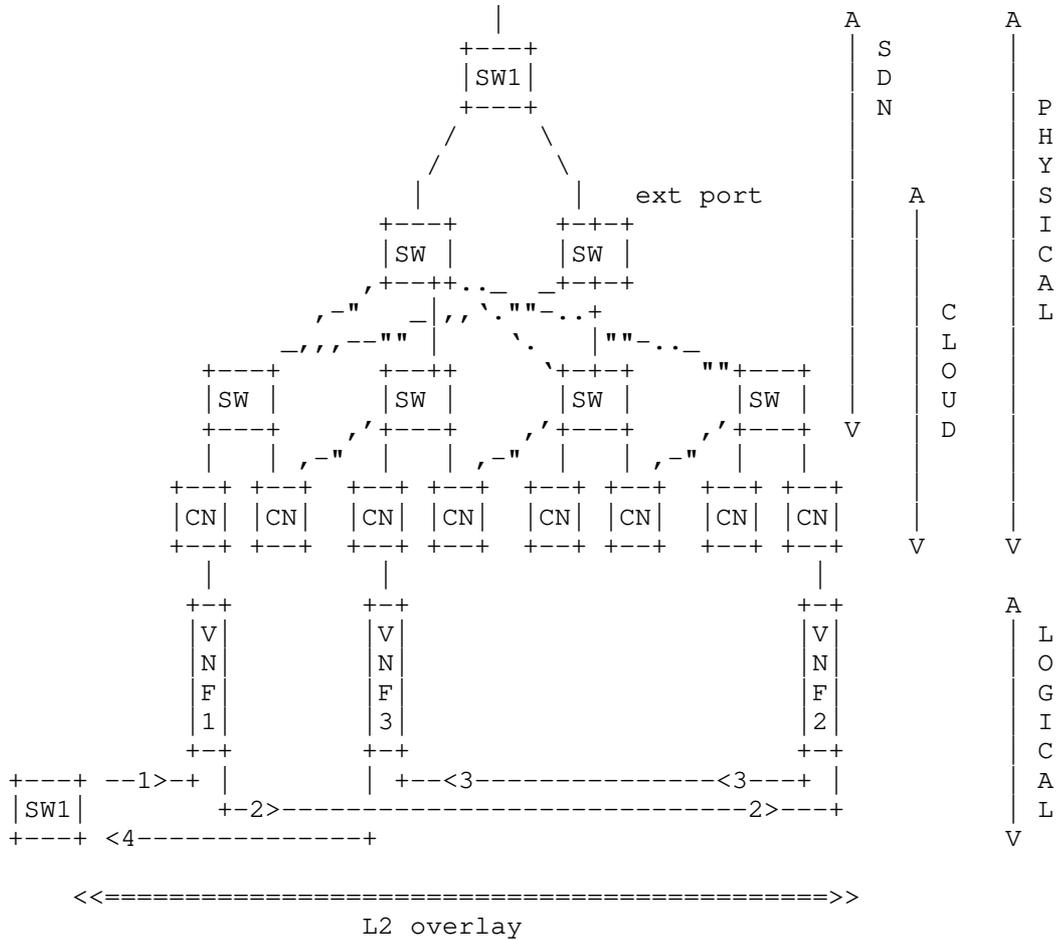


Figure 3: White Box Data Center with L2 Overlay

### 3.3. Conclusions

We have shown that the different solutions imply different operation and management actions. From network operations point of view, it is not desirable to run and manage similar functions several times (L3 blackbox DC case) - especially if the networking overlay can be easily managed upfront by using a programmatic interface, like with the external steering in black and whitebox DC scenarios.



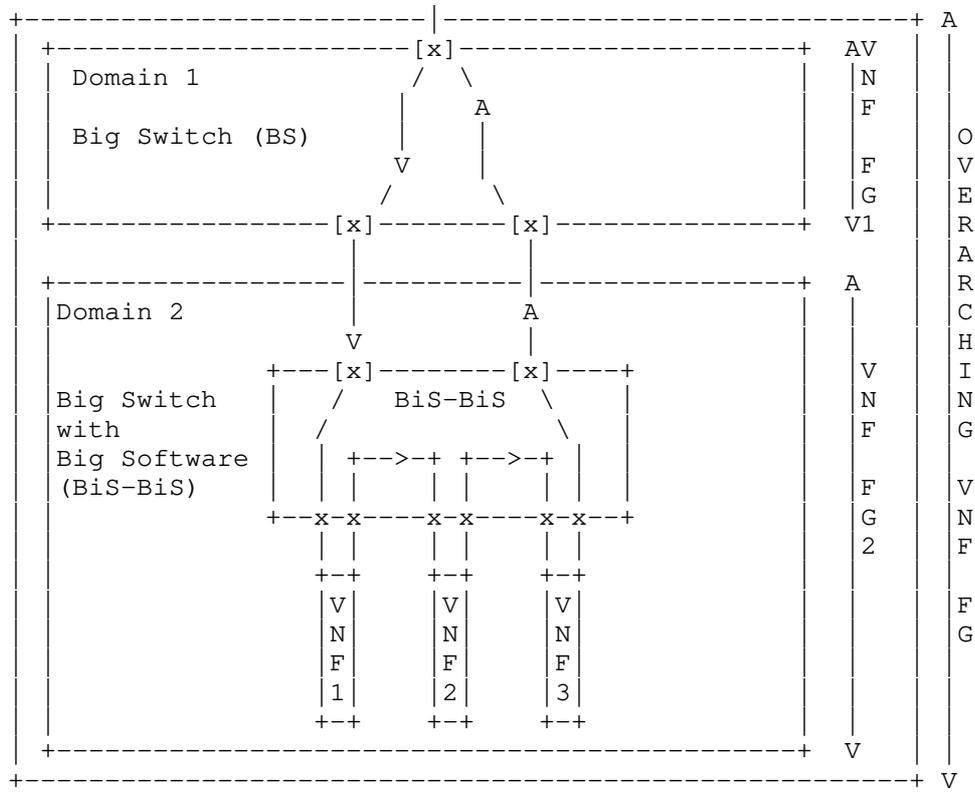


Figure 5: Recursive Domain Virtualization and Joint VNF FG programming: Domain Views

#### 4.1. Virtualization

Let us first define the joint software and network abstraction (virtualization) as a Big Switch with Big Software (BiS-BiS). A BiS-BiS is a node abstraction, which incorporates both software and networking resources with an associated joint software and network control API (see Figure 6).

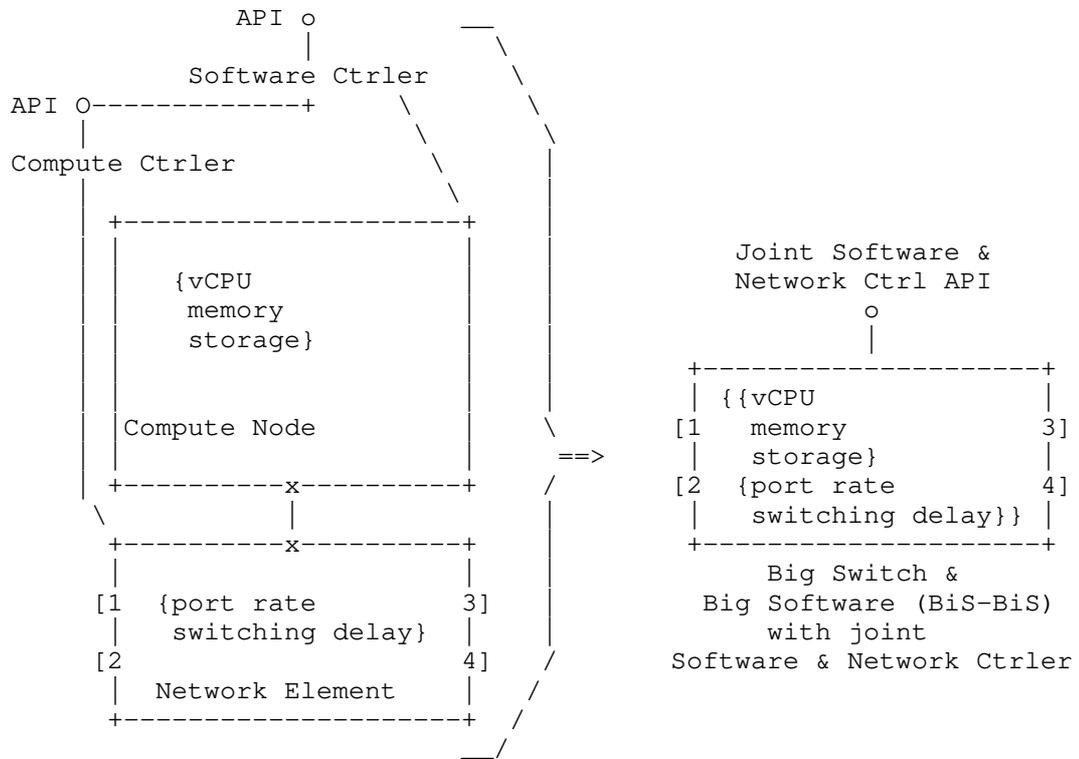


Figure 6: Big Switch with Big Software definition

The configuration over a BiS-BiS allows the atomic definition of NF placements and the corresponding forwarding overlay as a Network Function - Forwarding Graph (NF-FG). The embedment of NFs into a BiS-BiS allows the inclusion of NF ports into the forwarding overlay definition (see ports a, b, ..., f in Figure 7). Ports 1, 2, ..., 4 are seen as infrastructure ports while NF ports are created and destroyed with NF placements.



```

    +--rw id?          string
    +--rw name?       string
    +--rw src         port-ref
    +--rw dst         port-ref
    +--rw resources
      +--rw delay?    string
      +--rw bandwidth? string
+--rw resources
  +--rw cpu          string
  +--rw mem          string
  +--rw storage      string
+--rw NF_instances
  +--rw node* [id]
    +--rw id          string
    +--rw name?       string
    +--rw type        string
    +--rw ports
      +--rw port* [id]
        +--rw id          string
        +--rw name?       string
        +--rw port_type  string
        +--rw port_data? string
    +--rw links
      +--rw link* [src dst]
        +--rw id?        string
        +--rw name?      string
        +--rw src        port-ref
        +--rw dst        port-ref
        +--rw resources
          +--rw delay?    string
          +--rw bandwidth? string
    +--rw resources
      +--rw cpu          string
      +--rw mem          string
      +--rw storage      string
+--rw capabilities
  +--rw supported_NFs
    +--rw node* [id]
      +--rw id          string
      +--rw name?       string
      +--rw type        string
      +--rw ports
        +--rw port* [id]
          +--rw id          string
          +--rw name?      string
          +--rw port_type  string
          +--rw port_data? string
    +--rw links

```

```

    |--rw link* [src dst]
        |--rw id?          string
        |--rw name?       string
        |--rw src         port-ref
        |--rw dst         port-ref
        |--rw resources
            |--rw delay?   string
            |--rw bandwidth? string
    |--rw resources
        |--rw cpu         string
        |--rw mem         string
        |--rw storage     string
    |--rw flowtable
        |--rw flowentry* [port match action]
            |--rw port     port-ref
            |--rw match     string
            |--rw action    string
            |--rw resources
                |--rw delay?   string
                |--rw bandwidth? string
    |--rw links
        |--rw link* [src dst]
            |--rw id?          string
            |--rw name?       string
            |--rw src         port-ref
            |--rw dst         port-ref
            |--rw resources
                |--rw delay?   string
                |--rw bandwidth? string

```

Figure 8: Virtualizer's YANG data model: tree view

## 4.1.1.2. YANG Module

```

<CODE BEGINS> file "virtualizer.yang"

module virtualizer {
  namespace "http://fp7-unify.eu/framework/virtualizer";
  prefix virt;
  organization "EU-FP7-UNIFY";
  contact "Robert Szabo <robert.szabo@ericsson.com>";
  description "data model for joint software and network
  virtualization and resource control";

  revision 2015-06-27 {
    reference "Initial version";
  }
}

```

```
// REUSABLE GROUPS
grouping id-name {
  description "used for key (id) and naming";
  leaf id {
    type string;
    description "For unique key id";}
  leaf name {
    type string;
    description "Descriptive name";}
}

grouping node-type {
  description "For node type defintion";
  leaf type{
    type string;
    mandatory true;
    description "to identify nodes (infrastructure or NFs)";
  }
}

// PORTS
typedef port-ref {
  type string;
  description "path to a port; can refer to ports at multiple
  levels in the hierarchy";
}

grouping port {
  description "Port definition: used for infrastructure and NF
  ports";
  uses id-name;
  leaf port_type {
    type string;
    mandatory true;
    description "Port type identification: abstract is for
    technology independent ports and SAPs for technology specific
    ports";}
  leaf port_data{
    type string;
    description "Opaque data for port specific types";
  }
}

grouping ports {
  description "Collection of ports";
  container ports {
    description "see above";
    list port{
```

```
        key "id";
        uses port;
        description "see above";
    }
}
// FORWARDING BEHAVIOR
grouping flowentry {
    leaf port {
        type port-ref;
        mandatory true;
        description "path to the port";
    }
    leaf match {
        type string;
        mandatory true;
        description "matching rule";
    }
    leaf action {
        type string;
        mandatory true;
        description "forwarding action";
    }
    container resources{
        uses link-resource;
        description "network resources assigned to forwarding entry";
    }
    description "SDN forwarding entry";
}

grouping flowtable {
    container flowtable {
        description "Collection of flowentries";
        list flowentry {
            key "port match action";
            description "Index list of flowentries";
            uses flowentry;
        }
    }
    description "See container description";
}

// LINKS
grouping link-resource {
    description "Core networking characteristics / resources
(bandwidth, delay)";
    leaf delay {
        type string;
    }
}
```

```
        description "Delay value with unit; e.g. 5ms";
    }
    leaf bandwidth {
        type string;
        description "Bandwithd value with unit; e.g. 10Mbps";
    }
}

grouping link {
    description "Link between src and dst ports with attributes";
    uses id-name;
    leaf src {
        type port-ref;
        description "relative path to the source port";
    }
    leaf dst {
        type port-ref;
        description "relative path to the destination port";
    }
    container resources{
        uses link-resource;
        description "Link resources (attributes)";
    }
}

grouping links {
    description "Collection of links in a virtualizer or a node";
    container links {
        description "See above";
        list link {
            key "src dst";
            description "Indexed list of links";
            uses link;
        }
    }
}

// CAPABILITIES
grouping capabilities {
    description "For capability reporting: currently supported NF
types";
    container supported_NFs { // supported NFs are enumerated
        description "Collecction of nodes as supported NFs";
        list node{
            key "id";
            description "see above";
            uses node;
        }
    }
}
```

```
    }
    // TODO: add other capabilities
}

// NODE

grouping software-resource {
  description "Core software resources";
  leaf cpu {
    type string;
    mandatory true;
    description "In virtual CPU (vCPU) units";
  }
  leaf mem {
    type string;
    mandatory true;
    description "Memory with units, e.g., 1Gbyte";
  }
  leaf storage {
    type string;
    mandatory true;
    description "Storage with units, e.g., 10Gbyte";
  }
}

grouping node {
  description "Any node: infrastructure or NFs";
  uses id-name;
  uses node-type;
  uses ports;
  uses links;
  container resources{
    description "Software resources offer/request of the node";
    uses software-resource;
  }
}

grouping infra-node {
  description "Infrastructure nodes wich can contain other nodes
as NFs";
  uses node;
  container NF_instances {
    description "Hosted NFs";
    list node{
      key "id";
      uses node;
      description "see above";
    }
  }
}
```

```

    }
    container capabilities {
        description "Supported NFs as capability reports";
        uses capabilities;
    }
    uses flowtable;
}

//===== Virtualizer =====

container virtualizer {
    description "Definition of a virtualizer instance";
    uses id-name;

    container nodes{
        description "infra nodes, which embeds NFs and report
        capabilities";
        list node{
            key "id";
            uses infra-node;
            description "see above";
        }
    }
    uses links;
}
}
<CODE ENDS>

```

Figure 9: Virtualizer's YANG data model

## 5. Relation to ETSI NFV

According to the ETSI MANO framework [ETSI-NFV-MANO], an NFVO is split into two functions:

- o the orchestration of NFVI resources across multiple VIMs, fulfilling the Resource Orchestration functions;
- o The NFVO uses the Resource Orchestration functionality to provide services that support accessing NFVI resources in an abstracted manner independently of any VIMs, as well as governance of VNF instances sharing resources of the NFVI infrastructure

Similarly, a VIM is split into two functions:

- o Orchestrating the allocation/upgrade/release/reclamation of NFVI resources (including the optimization of such resources usage), and

- o managing the association of the virtualised resources to the physical compute, storage, networking resources.

The functional split is shown in Figure 13.

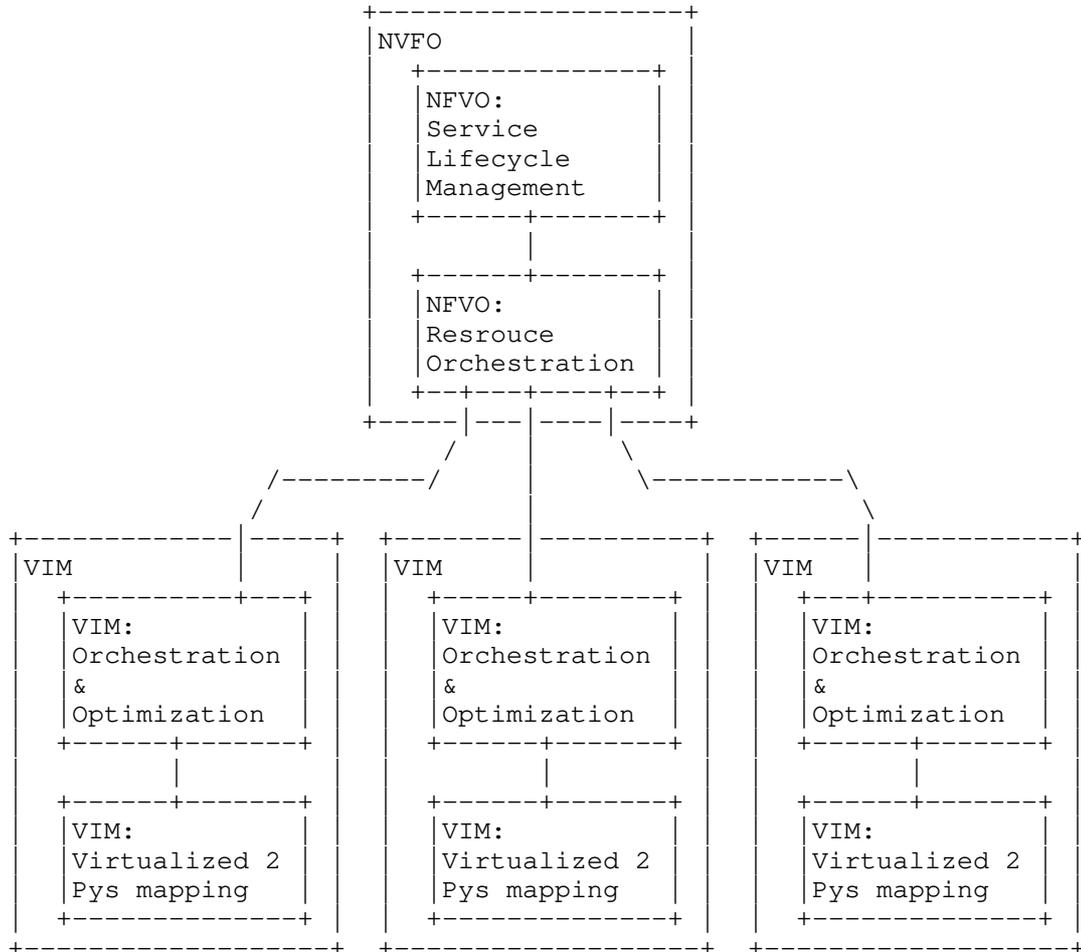


Figure 10: Functional decomposition of the NFVO and the VIM according to the ETSI MANO

If the Joint Software and Network Control API (Joint API) could be used between all the functional components working on the same abstraction, i.e., from the north of the VIM Virtualized physical mapping component to the south of the NFVO: Service Lifecycle

Management as shown in Figure 11, then a more flexible virtualization programming architecture could be created as shown in Figure 12.

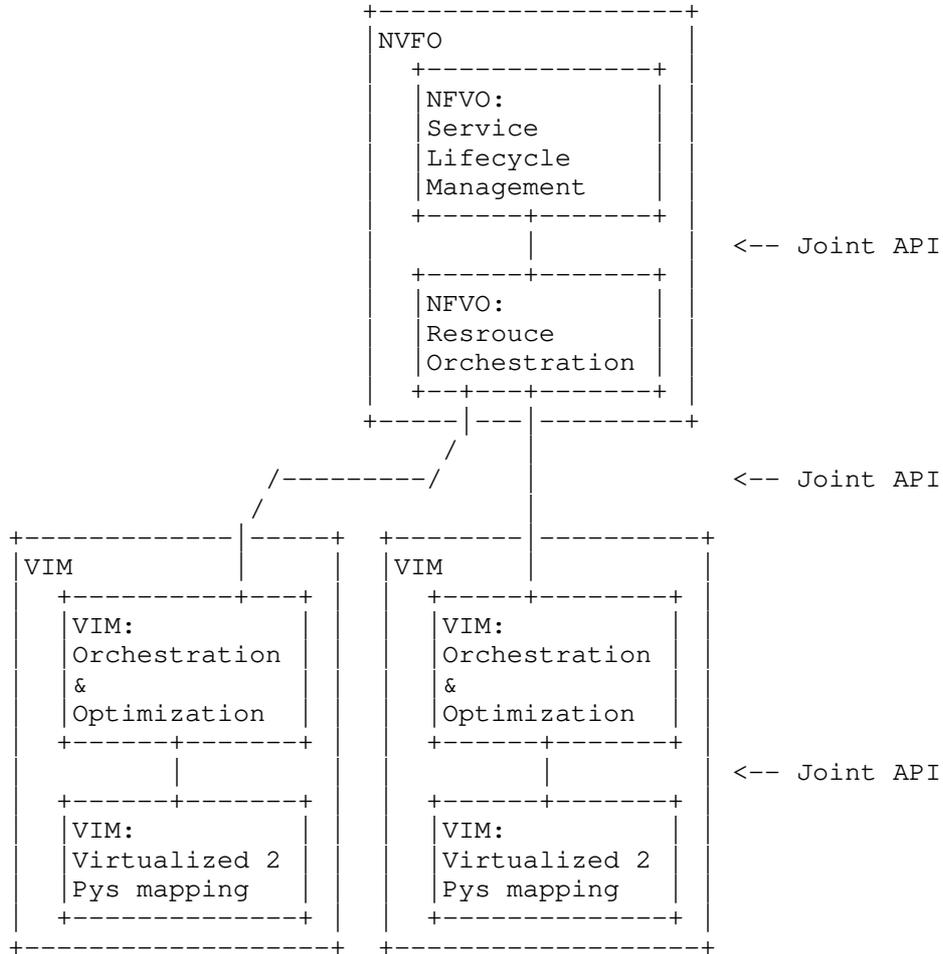


Figure 11: Functional decomposition of the NFVO and the VIM with the Joint Software and Network control API





```

<virtualizer xmlns="http://fp7-unify.eu/framework/virtualizer">
  <id>UUID001</id>
  <name>Single node simple infrastructure report</name>
  <nodes>
    <node>
      <id>UUID11</id>
      <name>single Bis-Bis node</name>
      <type>BisBis</type>
      <ports>
        <port>
          <id>0</id>
          <name>SAP0 port</name>
          <port_type>port-sap</port_type>
          <vxlan>...</vxlan>
        </port>
        <port>
          <id>1</id>
          <name>North port</name>
          <port_type>port-abstract</port_type>
          <capability>...</capability>
        </port>
        <port>
          <id>2</id>
          <name>East port</name>
          <port_type>port-abstract</port_type>
          <capability>...</capability>
        </port>
      </ports>
      <resources>
        <cpu>20</cpu>
        <mem>64 GB</mem>
        <storage>100 TB</storage>
      </resources>
    </node>
  </nodes>
</virtualizer>

```

Figure 14: Single node infrastructure report example: xml view

Figure 15 and Figure 16 show a 3-node infrastructure report with 3 BiS-BiS nodes. Infrastructure links are inserted into the virtualization view between the ports of the BiS-BiS nodes.

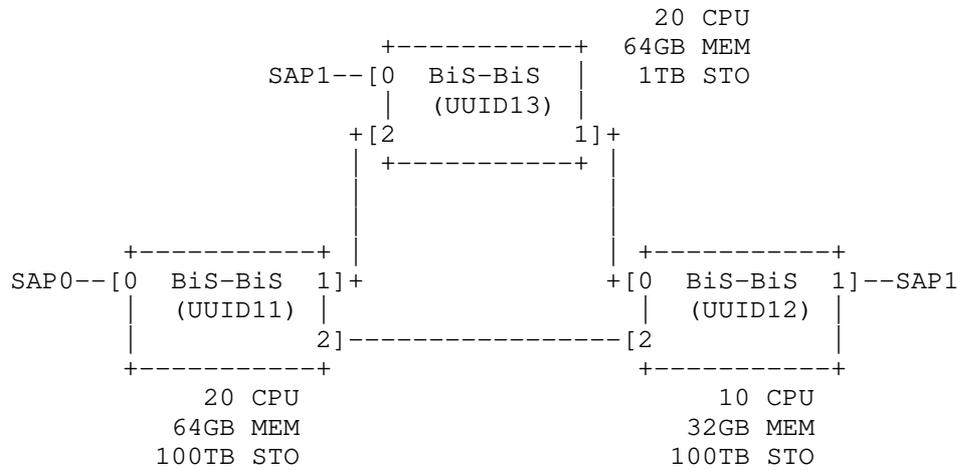


Figure 15: 3-node infrastructure report example: Virtualization view

```

<virtualizer xmlns="http://fp7-unify.eu/framework/virtualizer">
  <id>UUID002</id>
  <name>3-node simple infrastructure report</name>
  <nodes>
    <node>
      <id>UUID11</id>
      <name>West Bis-Bis node</name>
      <type>BisBis</type>
      <ports>
        <port>
          <id>0</id>
          <name>SAP0 port</name>
          <port_type>port-sap</port_type>
          <vxlan>...</vxlan>
        </port>
        <port>
          <id>1</id>
          <name>North port</name>
          <port_type>port-abstract</port_type>
          <capability>...</capability>
        </port>
        <port>
          <id>2</id>
          <name>East port</name>
          <port_type>port-abstract</port_type>
          <capability>...</capability>
        </port>
      </ports>
    </node>
  </nodes>
  <resources>

```

```

        <cpu>20</cpu>
        <mem>64 GB</mem>
        <storage>100 TB</storage>
    </resources>
</node>
<node>
    <id>UUID12</id>
    <name>East Bis-Bis node</name>
    <type>BisBis</type>
    <ports>
        <port>
            <id>1</id>
            <name>SAP1 port</name>
            <port_type>port-sap</port_type>
            <vxlan>...</vxlan>
        </port>
        <port>
            <id>0</id>
            <name>North port</name>
            <port_type>port-abstract</port_type>
            <capability>...</capability>
        </port>
        <port>
            <id>2</id>
            <name>West port</name>
            <port_type>port-abstract</port_type>
            <capability>...</capability>
        </port>
    </ports>
    <resources>
        <cpu>10</cpu>
        <mem>32 GB</mem>
        <storage>100 TB</storage>
    </resources>
</node>
<node>
    <id>UUID13</id>
    <name>North Bis-Bis node</name>
    <type>BisBis</type>
    <ports>
        <port>
            <id>0</id>
            <name>SAP2 port</name>
            <port_type>port-sap</port_type>
            <vxlan>...</vxlan>
        </port>
        <port>
            <id>1</id>

```

```

        <name>East port</name>
        <port_type>port-abstract</port_type>
        <capability>...</capability>
    </port>
    <port>
        <id>2</id>
        <name>West port</name>
        <port_type>port-abstract</port_type>
        <capability>...</capability>
    </port>
</ports>
<resources>
    <cpu>20</cpu>
    <mem>64 GB</mem>
    <storage>1 TB</storage>
</resources>
</node>
</nodes>
<links>
    <link>
        <id>0</id>
        <name>Horizontal link</name>
        <src>../../../../nodes/node[id=UUID11]/ports/port[id=2]</src>
        <dst>../../../../nodes/node[id=UUID12]/ports/port[id=2]</dst>
        <resources>
            <delay>2 ms</delay>
            <bandwidth>10 Gb</bandwidth>
        </resources>
    </link>
    <link>
        <id>1</id>
        <name>West link</name>
        <src>../../../../nodes/node[id=UUID11]/ports/port[id=1]</src>
        <dst>../../../../nodes/node[id=UUID13]/ports/port[id=2]</dst>
        <resources>
            <delay>5 ms</delay>
            <bandwidth>10 Gb</bandwidth>
        </resources>
    </link>
    <link>
        <id>2</id>
        <name>East link</name>
        <src>../../../../nodes/node[id=UUID12]/ports/port[id=0]</src>
        <dst>../../../../nodes/node[id=UUID13]/ports/port[id=1]</dst>
        <resources>
            <delay>2 ms</delay>
            <bandwidth>5 Gb</bandwidth>
        </resources>

```

```

    </link>
  </links>
</virtualizer>

```

Figure 16: 3-node infrastructure report example: xml view

## 6.2. Simple requests

Figure 17 and Figure 18 show the allocation request for 3 NFs (NF1: Parental control B.4, NF2: Http Cache 1.2 and NF3: Stateful firewall C) as instrumented over a BiS-BiS node. It can be seen that the configuration request contains both the NF placement and the forwarding overlay definition as a joint request.

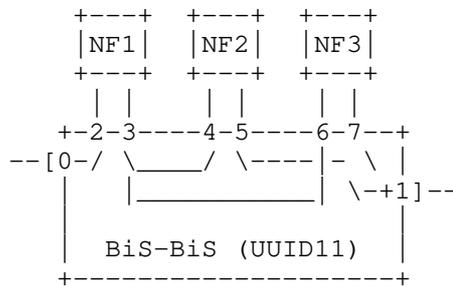


Figure 17: Simple request of 3 NFs on a single BiS-BiS: Virtualization view

```

<virtualizer xmlns="http://fp7-unify.eu/framework/virtualizer">
  <id>UUID001</id>
  <name>Single node simple request</name>
  <nodes>
    <node>
      <id>UUID11</id>
      <NF_instances>
        <node>
          <id>NF1</id>
          <name>first NF</name>
          <type>Parental control B.4</type>
          <ports>
            <port>
              <id>2</id>
              <name>in</name>
              <port_type>port-abstract</port_type>
              <capability>...</capability>
            </port>
            <port>
              <id>3</id>

```

```

        <name>out</name>
        <port_type>port-abstract</port_type>
        <capability>...</capability>
    </port>
</ports>
</node>
<node>
    <id>NF2</id>
    <name>cache</name>
    <type>Http Cache 1.2</type>
    <ports>
        <port>
            <id>4</id>
            <name>in</name>
            <port_type>port-abstract</port_type>
            <capability>...</capability>
        </port>
        <port>
            <id>5</id>
            <name>out</name>
            <port_type>port-abstract</port_type>
            <capability>...</capability>
        </port>
    </ports>
</node>
<node>
    <id>NF3</id>
    <name>firewall</name>
    <type>Stateful firewall C</type>
    <ports>
        <port>
            <id>6</id>
            <name>in</name>
            <port_type>port-abstract</port_type>
            <capability>...</capability>
        </port>
        <port>
            <id>7</id>
            <name>out</name>
            <port_type>port-abstract</port_type>
            <capability>...</capability>
        </port>
    </ports>
</node>
</NF_instances>
<flowtable>
    <flowentry>
        <port>.../.../ports/port[id=0]</port>

```

```

        <match>*</match>
        <action>output:.../..NF_instances/node[id=NF1]
            /ports/port[id=2]</action>
    </flowentry>
    <flowentry>
        <port>.../..NF_instances/node[id=NF1]
            /ports/port[id=3]</port>
        <match>fr-a</match>
        <action>output:.../..NF_instances/node[id=NF2]
            /ports/port[id=4]</action>
    </flowentry>
    <flowentry>
        <port>.../..NF_instances/node[id=NF1]
            /ports/port[id=3]</port>
        <match>fr-b</match>
        <action>output:.../..NF_instances/node[id=NF3]
            /ports/port[id=6]</action>
    </flowentry>
    <flowentry>
        <port>.../..NF_instances/node[id=NF2]
            /ports/port[id=5]</port>
        <match>*</match>
        <action>output:.../..ports/port[id=1]</action>
    </flowentry>
    <flowentry>
        <port>.../..NF_instances/node[id=NF3]
            /ports/port[id=7]</port>
        <match>*</match>
        <action>output:.../..ports/port[id=1]</action>
    </flowentry>
    </flowtable>
</node>
</nodes>
</virtualizer>

```

Figure 18: Simple request of 3 NFs on a single BiS-BiS: xml view

## 7. IANA Considerations

This memo includes no request to IANA.

## 8. Security Considerations

TBD

## 9. Acknowledgement

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March 2, 2015

Elasticity VNF  
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## Abstract

This draft is an analysis of Network Function Virtualization (NFV) applications based on the NFV architecture, use cases and requirements. The purpose of this analysis is to identify any NFV characteristics related issues. The analysis is focusing on elastic VNF with predicable performance, reliability and security. Only the issues which are unique to NFV are discussed in this document.

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## 1. Introduction

Network Functions Virtualization (NFV) is a network architecture concept that proposes using IT virtualization related technologies, to virtualize entire classes of network node functions into building blocks that may be connected, or chained, together to create communication services. NFV aims to transform the traditional operator architect networks by evolving standard IT virtualization technology to consolidate network equipment types onto industry standard high volume services, switches and storage, which could be located in a variety of NFV Infrastructure Point of Presences (NFVI PoPs) including Data Center (DC), network nodes and in end user premises. It is also indicated that an important part of controlling the NFV environment should be done through automation network management and orchestration.

This draft is an analysis of NFV applications based on the NFV architecture, use cases and requirements. The purpose of this analysis is to identify any NFV characteristics related issues. The analysis is focusing on elastic VNFs with predicable performance, reliability and security. Only the issues which are unique to NFV are discussed in this document. The intention is to identify what is missing, and what is needed to be addressed in terms of protocol / solution specifications which may be the potential work for IETF.

The reader is assumed to be familiar with the terminology as defined in the NFV document [nfv-tem].

## 2. Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC-2119 [RFC2119].

In this document, these words will appear with that interpretation only when in ALL CAPS. Lower case uses of these words are not to be interpreted as carrying RFC-2119 significance.

### 3. Terminology

This document uses the same terminology as found in the NFV end to end architecture [nfv-tem]:

**Network Function Consumer:** a Network Function Consumer (NFC) is the consumer of virtual network functions. It can be either an individual user, home user or the enterprise user.

**NFV:** network function virtualization. NFV technology uses the commodity servers to replace the dedicated hardware boxes for the network functions, for example, home gateway, enterprise access router, carrier grade NAT and etc. So as to improve the reusability, allow more vendors into the market, and reduce time to market. NFV architecture includes a NFV Control and Management Plane (orchestrator) to manage the virtual network functions and the infrastructure resources.

**NF:** A functional building block within an operator's network infrastructure, which has well-defined external interfaces and a well-defined functional behavior. Note that the totality of all network functions constitutes the entire network and services infrastructure of an operator/service provider. In practical terms, a Network Function is today often a network node or physical appliance.

**Network Function Provider:** a Network Function Provider (NFP) provides virtual network function software.

**Network Service Provider (NSP):** a company or organization that provides a network service on a commercial basis to third parties. A network service is a composition of network functions and defined by its functional and behavior specification. The NSP operates the NFV Control Plane.

**NFV Infrastructure (NFVI):** NFV Infrastructure indicates the computing, storage and network resources to implement the virtual network function. High performance acceleration platform is also part of it.

**VNF:** virtual network function, an implementation of an executable software program that constitutes the whole or a part of an NF that can be deployed on a virtualization infrastructure.

**VM:** virtual machines, a program and configuration of part of a host computer server. Note that the Virtual Machine inherits the

properties of its host computer server e.g. location, network interfaces.

NFV Control and Management Plane (NFVCMP): a NFV Control and Management Plane is operated by a NSP and orchestrates the NFV NFV Overview

#### 4. Network Function Virtualization

##### 4.1. NFV Requirements

There are many virtualization requirements described by NFV in [nfv-req]. The followings are highlights of a few NFV requirements which are related to this document:

- Portability: VNF portability is a reasonable generic virtualization requirement. It allows VNF mobility across different but standard multi-vendor environment. However, moving a VNF within the NFV framework with the Service Level Specification (SLA) requirements including performance, reliability and security could be a challenge.
- Performance: Virtualization adds additional processing overhead and increases the latency. For latency-sensitive VNFs, it is a big concern for NFV on how to achieve predictable low-latency performance.
- Elasticity: NFV elasticity requirement allows the VNF to be scaled within NFVI. Within the NFV framework, it is important to support VNF scaling with the SLA requirements including performance, reliability and security.
- Resiliency: NFV resiliency is a must requirement for NFV network, including both the control plane and data plane. Necessary mechanisms must be provided to improve the service availability and fault management.
- Security: The traditional telecom network functions are developed in dedicated hardware located in an isolated network. Security is provided by underlay network. When moving VNF into a DC network with shared Infrastructure, security becomes a big concern.
- Service Continuity: At VNF failure over, migration, mobility, and upgrading, service downtime may not be avoided. In NFV, service continuity must be supported which means the provided service must be restored at the VNF instance updated / replaced / recovered. This procedure includes the restoration of any ongoing data sessions. And it shall be transparent to the user of NFV service.

## 4.2. NFV Use Cases

Multiple use cases are described by NFV in [nfv-uc]. The followings are a highlight of the NFV use cases.

### 4.2.1. Network Function Virtualization Infrastructure

Network Function Virtualization Infrastructure as a Service (NFVIaaS), Virtual Network Function as a Service (VNFaaS) and Virtual Network Platform as a Service (VNPaaS) are the NFV use cases which describe how the telecom operators would like to build up their telecom cloud infrastructure using virtualization.

Network Function Virtualization Infrastructure (NFVI) is the totality of all hardware and software components which build up the environment in which VNFs are deployed. The NFVI can span across several locations. The network providing connectivity between these locations is regarded to be part of the NFVI.

NFVIaaS is a generic IaaS plus NaaS requirement which allows the telecom operator to build up a VNF cloud on top of their own DCs Infrastructure and any external DCs Infrastructure. This will allow a telecom operator to migrate some of its network functions into a 3rd party DC when it is needed. Furthermore, a larger telecom operator may have multiple DCs in different geography locations. The operator may want to setup multiple virtual data center (vDC), where each vDC may cross several of its physical DCs geography locations. Each vDC is defined for providing one specific function, e.g. Telco Cloud.

VNFaaS is more focusing on enterprise network which may have its own cloud infrastructure with some specific services / applications running. VNFaaS allows the enterprise to merge and/or extend its specific services / applications into a 3rd party commercial DC provided by a telecom operator. With this VNFaaS, the enterprise does not need to manage and control the NFVI or the VNF. However, NFV Performance & portability considerations will apply to deployments that strive to meet high performance and low latency considerations.

With VNPaaS, the mobile network traffic, including WiFi traffic, is routed based on the APN to a specific packet data service server over the mobile packet core network. Applications running at the packet data service server may be provided by the enterprise. And it is possible to have an interface to route the traffic into an enterprise network. But the infrastructure hosting the application is fully under controlled by the operator. However, the enterprise

has full admin control of the application and needs to apply all configurations on its own, potentially via a vDC like management interface with support of the hosting operator.

All the above use cases need solutions for the operator to share the infrastructure resources with 3rd parties. Therefore cross domain orchestration with access control is needed. Besides, the infrastructure resource management needs to provide a mechanism to isolate the traffic, not only based on the traffic type, but also from different operators and enterprises.

#### 4.2.2. Telecom Network Functions Migration

Virtualization of telecom network functions, including Mobile Core Network functions, IMS functions, Mobile base station functions, Content Delivery Networks (CDN) functions, Home Environment functions, and Fixed Access Network functions, are described in the NFV use case document [nfv-uc]. In addition, VNF forwarding Graphs is another use case which describes how the user data packets are forwarded by traversing more than one operator service chain functions, such as DPI, Firewall, Content Filtering, before reaching the service server.

Migrate the telecom functions includes moving the control plane, data plane and service network into a cloud based network and using cloud based protocol to control the data plane. Service continuity, network security, service availability, resiliency in both control plane and data plane must be ensured at this migration.

### 5. Elasticity in a Distributed Cloud

Today the usage of personal devices, e.g. smartphones, for internet service traffic, telecom specific service access, and accessing the corporate network, is increased significantly. At the same time, telecom operators are under pressure to accommodate the increased service traffic in a fine-grained manner. Services provided by telecom network must be done in an environment of increased security, compliance, and auditing requirements, along with traffic load may be changed dramatically overtime. Providing self-service provisioning in telecom cloud requires elastic scaling of the VNF based on the dynamic service traffic load and resource management e.g. computing, storage, and networking.

The existing telecom network functions may not be cloud technologies ready yet. Most of the NFV functions are stateful and running on either specific hardware or a big VM. It is not designed to tolerate

any system failure in many VMs. The network functions are very difficult in term of configuration, scale updating, etc.

Re-engineering may be needed for virtualization enabling, e.g. software adaption for software and hardware decoupling. For cloud technologies readiness, telecom network functions need to be re-designed to run on small VMs with multiple instances which can provide higher application availability. Such VMs may be stateless in operations or may need to support state migration (e.g., OpenNF <http://opennf.cs.wisc.edu/>). With cloud ready network functions, applications' dynamic scaling can be achieved by adding more VMs into the service.

Virtualization provides the elasticity ability to scale up / down, scale out / in with guaranteed computational resources, security isolation and API access for provisioning it all, without any of the overhead of managing physical servers. However, there are still many optimizations which can be used to avoid the increasingly overhead.

#### 5.1. NFV Infrastructure

Virtualized Network Function (VNF) is an implementation of a network function that can be deployed on Network Function Virtualization Infrastructure (NFVI).

For a large telecom operator, multiple NFVI Point of Presences (NFVI PoPs) may be created according to multiple physical data centers. As NFVI PoPs may be located in different geography locations, networking characteristics should be taken into account when selecting an NFVI PoP to host a VNF.

#### 5.2. Elastic VNF

In many cases, a VNF may not be designed for scaling up/down. As scaling up/down may require a restart of the VNF which the state data may be lost. In that case either stateless operation is needed, or the support of state information migration procedure is required, which will increase the complexities of the VNF implementation.

Normally a VNF may be capable for scaling in/out only. Such VNF is designed running on top of a small VM and grouped as a pool of one VNF function.

VNF capacity may be limited if it only can be scaled within one NFVI PoP, e.g., within one DC in a geography location. As an NFVI which may be crossing multiple NFVI PoPs (or data center)s, it is possible

to scale an elastic VNF crossing different network zones if it is needed. At cross DC scaling, the result is that the new VNF instance may be placed at a remote cloud location. It is a must requirement to provide the same level of SLA including performance, reliability and security.

### 5.3. VNF Forwarding Graphs

In NFV network, a VNF Forwarding Graph (VNF FG) (an application) may consist of multiple VNFs, where each VNF may consist of multiple VNF instances. Normally the VNFs are working as such that the services provided by the VNFs may need to process the user data packets with several selected VNF instances before delivering it to its destination

For instance, when mobile users setup a PDN connection for IMS services, there are multiple network entities involved along the PDN connection, including eNB, Serving GW, PDN GW, P-CSCF, S-CSCF, etc. Another example is service function chaining, where a service chain is referring to one or more service processing functions in a specific order which are chained to provide a composite service.

In telecom cloud, a service session may traverse multiple stateful and stateless VNF functions of a VNF set. And with an NFVI consisting of multiple NFVI PoPs, it may be crossing multiple DCs. In such cloud, an incoming data packet may be processed by multi-VNF instance before delivering to the final destination. Therefore the east-west traffic (i.e. data traffic between VNFs within the DC) is much heavier comparing to the north-south traffic (i.e. data traffic in/out from the DC).

When placing VNF Forwarding Graphs, it is better spread the VNF components across many NFVI PoPs, which may give a better availability. However, multiple NFVI PoPs may also increases the network latency, which can be considerably big compared to latencies within a single NFVI PoP. Therefore, the whole VNF Forwarding Graph should be taken into account instead of a single VNF component during orchestration. Furthermore, during VNF scaling, dependencies (interconnection) with other service instances of the VNF Forwarding Graph shall also be considered.

When scaling, VNFs are not scaled only in relation to compute and storage PoPs. VNF instances may need to be grouped together according to the VNF FG and subjected to auto-scaling techniques to the entire group. The scaling policies, e.g., ratio between the

different VNFs, need to be applied on the VNF FG in aggregate to control the scaling process.

5.4. VNF scaling across multiple NFVI PoPs

Since in general, a VNF is part of a VNF Forwarding Graph (or a service function chain), meaning the data traffic may traverse multiple stateful and stateless VNF functions in sequence. When some VNF instances of a given service function chain are placed / scaled out in a distant cloud execution, the service traffic may have to traverse multiple VNF instances which are located in multiple physical locations. In the worst case, the data traffic may ping-pong between multiple physical locations.

Therefore it is important to take the whole service function chain's performance into consideration when placing and scaling one of its VNF instance. Network and cloud resources need mutual considerations [unify1].

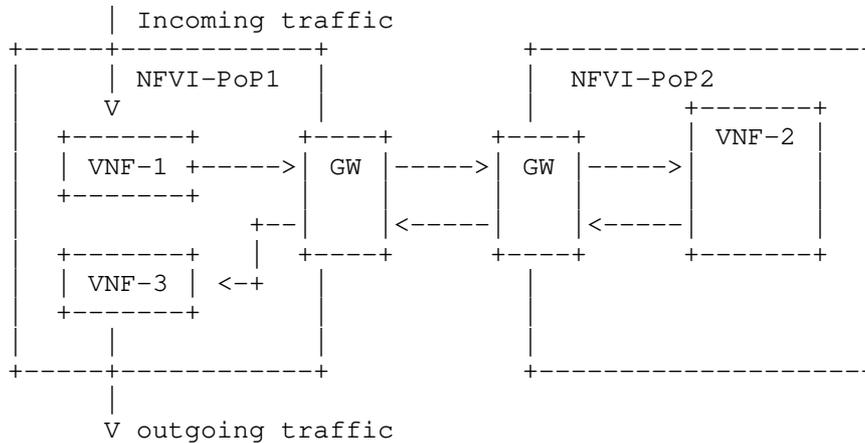


Figure 1 a data traffic flow traversing distributed VNF cloud

6. Elasticity with Predicable Performance

6.1. Predicable Performance

High performance with low-latency VNF is expected in the NFV framework. The NFVI metrics are related to any kind of metrics generated by the NFVI, including not only CPU load on a VM, CPU load

on a host, but also interrupt rate handled by the hypervisor or network latency/packet loss.

Virtualization adds additional overhead which impacts the performance. This additional extra distortion shall be avoided or, at least, minimized. It is a big concern for NFV on how to achieve predictable and low-latency performance, not only at placing a VNF into the DC, but also at VNF scaling.

Operator may wish to run standard test and use the result to provide KPIs of the VNF. A significant part of a VNF vendor's performance guarantees will depend on the choice of the virtualization technology.

Network latency may not be at the same level if the physical connections between the servers are various. Furthermore, geography location of the physical servers also increases the network latency. When placing or moving a VNF, the location of other VNFs of the same VNF set shall be considered to avoid network latency issue. For instance, VNF-a, VNF-b, and VNF-c are grouped as one VNF set. When moving VNF-b into a new location, the network connection between the new location and the existing location may be a concern. As the traffic may traverse from VNF-a to VNF-b, then VNF-c, moving the VNF-b into a new location may create Ping-Pong type of traffic, which the network latency may be doubled. The best choice would be to move the whole VNF set into the new location instead of only one VNF.

## 6.2. Hardware virtualization features

Virtualization layer adds minimal overhead and delivers a predictable performance between a minimum and maximum threshold for latency and jitter which are far more important. Light weight virtualization, e.g. container or bare metal, may be considered for performance sensitive VNF applications. In addition, hardware virtualization features (e.g. SR-IOV) are important to be supported in order to provide some performance improvement. Many VNF requires direct access to the device hardware so that they can offload functionality with throughput rates of millions of packets a second. Another alternative, which may be more attractive for latency-sensitive applications, is using non-hypervisor virtualization, including bare metal and Linux container.

Optimization to drive high-throughput network workloads associated with such functions as traffic filtering, NATing and firewalling. Avoiding performance bottleneck, the virtualization layer shall have a suitably-architected I/O stack.

### 6.3. Network Overlay

Network overlay adds additional overhead when forwarding the data packets. Reference [vxlan-p] is a VXLAN performance testing report which indicates the overlay performance is a concern. Avoiding overlay connections may be one option which is more attractive for latency-sensitive applications.

Furthermore, additional network latency may be added when traversing the cross-DC overlay connections. To avoid any additional network latency, all the functions of a VNF set may be placed in the same low-latency network zone, e.g. same host or same DC. However, when the capacity limitation the network zone is reached, scaling-out one VNF into another network zone may be needed. In this case, as the service session has to traverse the same path, the Ping-Pong traffic between the network zones cannot be avoided. Depends on the network overlay technologies used for the cross network zone connection, the overhead network latency can be various. In another words, the network performance may become unpredictable.

### 7. Elasticity with Reliability

NFV resiliency is a must requirement for NFV network, including both the control plane and data plane. Necessary mechanisms must be provided to improve the service availability and fault management.

With virtualization, the use of VNFs can pose additional challenges on the reliability of the provided services. For a VNF instance, it typically would not have built-in reliability mechanisms on its host (i.e., a general purpose server). Instead, there are more factors of risk such as software failure at various levels including hypervisors and virtual machines, hardware failure, and instance migration that may make a VNF instance unreliable. Even for cloud ready NFV applications, a HA may still be needed as the storage, load balancer may be failure. Service restoration solution is still needed.

One alternative to improve the VNF resiliency is to take snapshot of the VM periodically. At VNF failure, the network can restore the VM at same or different host using the stored snapshot. However, there is a downtime of the provided service due to the snapshot recovering. And the downtime is much longer than the expected value which could be tolerated by NFV. NFV has a completely different level of reliability requirements, e.g. recovering time, comparing to enterprise cloud applications.

To improve the network function resiliency, some kind high availability (HA) solutions may be needed for NFV network, which has the potential to minimize the service downtime at failure. However, in most of the telecom use cases, there are application level restoration procedures available which makes the high availability solution less important.

The VNF reliability can be achieved by eliminating any single points of failure by creating a redundancy of resources, normally, including enough excess capacity in the design to compensate for the performance decline and even failure of individual resources; that is, a group of VNF instances providing the same function works as a network function cluster or pool, which provides protection (e.g. failover) for the applications and therefore an increased availability.

## 8. Elasticity with Security

TDB

## 9. Security Considerations

This is a discussion paper which provides inputs for NFV related discussions and in itself does not introduce any new security concerns.

## 10. IANA Considerations

No actions are required from IANA for this informational document.

## 11. References

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