                  Resource Management in Service Chaining
            draft-irtf-nfvrg-resource-management-service-chain-03

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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1. Introduction

   Network Functions Virtualisation (NFV) [ETSI-NFV-WHITE] offers a new
   way to design, deploy and manage network services. The network
   service can be composed of one or more network functions and NFV
   relocates the network functions from dedicated hardware appliances to
   generic servers, so they can run in software. Using these
   virtualized network functions (VNFs), one or more VNF forwarding
   graphs (VNF-FGs; a.k.a. service chains) can be associated to the
   network service, each of which describes a network connectivity
   topology, by referencing VNFs and Virtual Links that connect them.
   One or more network forwarding paths (NFPs) can be built on top of
   such a topology, each defining an ordered sequence of VNFs and
   Virtual Links to be traversed by traffic flows matching certain
   criteria.

   The network service is instantiated by allocating NFVI resources for
   VNFs and VLs which constitute the VNF-FGs. Thus, the capacity and
   performance of the network service depends on the state and
   attributes of the network resources used for its VNF and VL
   instances. While this brings a similar problem to the VM placement
   optimization in a cloud computing environment, it differs as one or
   more VNF instances are interconnected for a single network service.
   For example, if one of the VNF instances in the VNF-FG gets failed or
   overloaded, the whole network service also gets affected. Thus, the
   VNF instances need to be carefully placed during NS instantiation
   considering their connectivity within NFPs. They also need to be
   monitored and dynamically migrated or scaled at run-time to adapt to
   changes in the resources.

   The resource management problem in VNF-FGs matters not only to the
   performance and capacity of network services but also to the
   optimized use of NFVI resources. For example, if processing and
   bandwidth burden converges on the VNF instances placed in a specific
   NFVI-PoP, it may result in scalability problem of the NFV
   infrastructure. Thus care is encouraged to be taken in distributing
   load across local and external VNF instances at run-time.

   This document addresses resource management problem in service
   chaining to optimize the NS performance and NFVI 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 NFP
   instances considering NFVI resource states for VNF instances and VL
   instances.

Note that this document mainly focuses on the resource management capability based on the ETSI NFV framework [ETSI-NFV-ARCH] but also studies contribution points to the work for control plane of SFC architecture [I-D.ietf-sfc-architecture] [I-D.ietf-sfc-control-plane].

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 NFVI-PoP: A location or point of presence that hosts NFV infrastructure

o VNF Forwarding Graph (VNF-FG): A NF forwarding graph where at least one node is a VNF.

o Network Forwarding Path (NFP): The sequence of hardware/software switching ports and operations in the NFV network infrastructure as configured by management and orchestration that implements a logical VNF forwarding graph "link" connecting VNF "node" logical interfaces.

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 (e.g., VNF components, VNFs, or PNFs).

3. Resource management in service chain

   This section addresses several issues for considerations in NFV
   resource management of service chain.

3.1. Resource scheduling among network services

   In the NFV framework, network services are realized with NS
   instantiation procedures at which virtualized NFVI resources are
   assigned to the VNFs and VLs which constitute VNF-FGs of the network
   service. The NFVI resources are placed and located along the VNF-FG
   by NFV Orchestrator (NFVO) dynamically according to:

   o Resource availability,

   o Deployment templates which define resource requirements of NS
      instances and VNF instances to support KPIs (e.g., capacity and
      performance) of the network service, and

   o Resource policies which define how to govern NFVI resources for NS
      instances and VNF instances (e.g., affinity/anti-affinity rules,
      scaling, and fault management) to support an efficient use of NFVI
      resources as well as KPIs of the network service.

   In order to satisfy the deployment templates and resource policies,
   VNF-FGs of the network services need to be built by considering the
   state of NFVI resources for VNF instances (e.g., availability,
   throughput, load, disk usage) and VL instances (e.g., bandwidth,
   delay, delay variation, packet loss).

   However, since the NFVI resources are shared by different network
   services and their deployment constraints are very different from
   each other, it is required to carefully schedule the NFVI resources
   for multiple network services to optimize their KPIs.

3.2. Performance guarantee within a service chain

   In NFV, a network service is composed of one or more virtualized
   network functions which are connected via virtual links along NFPs
   specified for a traffic flow for the network service. Thus, the
   performance of a network service is determined by the performance and
   capability of a coupling of VNF instances and VL instances. For
   example, if one of the VNF instances or VL instances of an NFP gets
   failed or overloaded, the whole network service also gets affected.
   Thus, the VNF instances need to be carefully placed during NS
   instantiation considering their connectivity within NFPs.

This performance coupling can be handled by considering deployment
rules for affinity/anti-affinity, geography, or topological locations
of VNFs; and QoS of virtual links.

Another important factor for virtual links is the inter-connectivity
between different NFVI-PoPs, which is an enabler of resource sharing
among different NFVI-PoPs. When the VNF instances of a network
service are allocated at different NFVI-PoPs, the NFVI-PoP
interconnect may be a bottleneck point which needs to be monitored to
support KPIs of the service chain.

3.3. Multiple policies and conflicts

The NFVI resources for a network service should be allocated and
managed according to a 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. The examples of NS policy are affinity/anti-affinity,
scaling, fault and performance, geography, regulatory rules, NS
topology, etc. Since network services may have different NS policies
for their own deployment and performance, this may cause resource
management difficult within the shared NFVI resources.

For network-wide (or NS-wide) resource management, NFVI policy (or
network policy) can be also provided. It may describe the resource
management policy for optimized use of infrastructure resources
rather than the performance of a single network service. The
examples of 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.

Multiple administrative domains or subsystems may have different NFVI
policies so that it may bring some conflicts when enforcing them in a
global infrastructure. There could be a similar problem among NS
policies and NFVI policies.

Note that the similar topics are being studied in
[I-D.irtf-nfvrg-nfv-policy-arch]

3.4. Dynamic adaptation of service chains

The performance and capability of NFVI resources may vary in time due
to different uses and management policies of the resources. If some
changes in the resources make the service quality unacceptable, the
VNF instances can be scaled according to the given auto-scaling
policies. But it's only for local quality of the VNF.

In order to provide optimized KPIs to network services, the NFP
instances need to dynamically adapt to the changes of the resource
state at run-time. The performance of the whole NFP instance should
be measured by monitoring the resource state of VNF instances and VL
instances. Based on the monitoring results, some VNF instances may
be determined and relocated at different virtualized resources with
better performance and capabilities.

4. Use cases

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

4.1. Fail-over

For service continuity, failure of a VNF instance needs to be
detected and the failed one needs to be replaced with the other one
which is available to use as per redundancy policy. 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.

```
                      +--------+                        +--------+
                      | VNF-B2 |                       #| VNF-B2 |###
       +--------+     +--------+              +--------+ # +--------+
    ###| VNF-A1 |        _|_             ###| VNF-A1 |#        _|_
       +--------+       (___)              +--------+        (___)
     ___/    #         /     \        \  ___/              /     \
    (___)+---#------+        +    ===}  (___)+----------+        +
         #        \ ___ /        /                      \ ___ /
         #         (___)                                 (___)
         #           |                                     |
         #       +--------+                            +--------+
         ######| VNF-B1 |###       (failure)--> | VNF-B1 |
               +--------+                            +--------+


    ### NFP
```
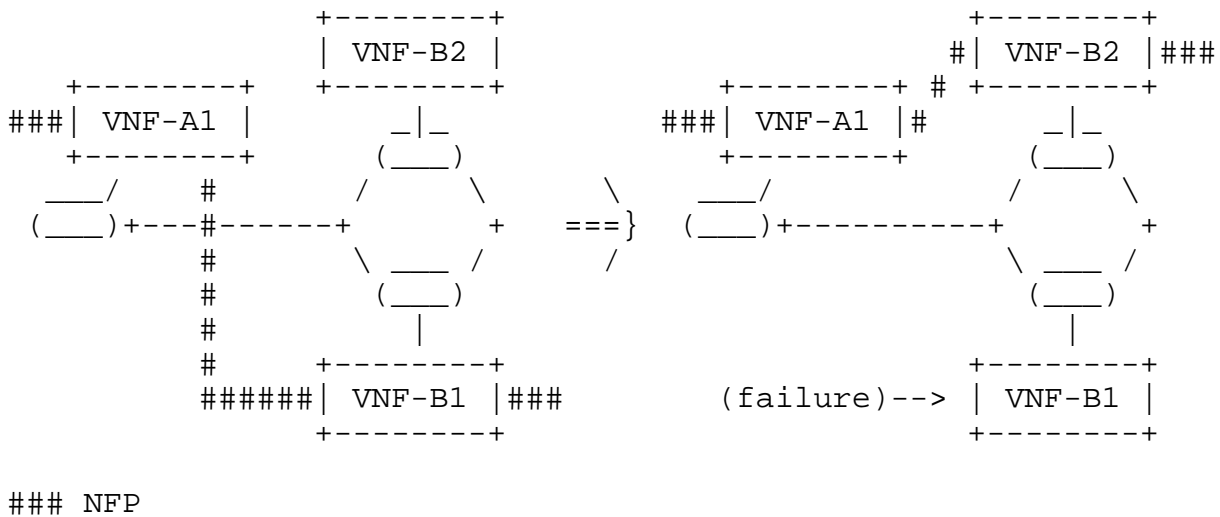
                    Figure 1: A fail-over use case

The above is in the case where there is a 1+1 or 1:N redundancy
scheme. In event that VNF instance overloads before NFVO has time to

scale out, or when resources do not permit a scale-out then we can route the service chain deterministically to a remote VNF instance. This adaptation may be revertive or non-revertive dependent on service provider policy and resource availability.

4.2. Load balancing

A single VNF instance may be a bottleneck point of a service chain due to its overload. It may affect the performance of the whole service chain consequently so that an NFP instance needs to be built to avoid bottleneck points or maintained to distribute workloads of overloaded VNF instances.

With NFVI-PoP Interconnect, service chains can be balanced between NFVI-PoPs in a way that best utilises NFV infrastructure and ensures service integrity. The wide area conditions can be monitored in real-time to provide KPIs, such as BW, delay, delay variation and packet loss per QoS class to the service chaining application which may enable use of external VNF instances when there is an overload or failure condition in the local NFVI-PoP. In this way the service chaining application can make a service chain reroute decision (in the event of failure and/or overload) that is network and platform- aware. The service chaining application understands the state of external VNFs and WAN conditions per QoS class between the local NFVI-PoP and remote NFVI-PoP in real-time.

4.3. Path optimization

Traffic for a network service traverses all of the VNF instances and the connecting VL instances given by a NFP instance to reach a target end point. Thus, quality of the network service depends on the resource constraints (e.g., processing power, bandwidth, topological locations, latency) of VNF instances, VL instances including NFVI-PoP interconnects. 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, NFP instances also need to adapt to the changes of resource constraints of the VNF instances and VL instances by monitoring and replacing them at run-time.

4.4. 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 resource usage, the NFP instances need to be built by default to localize the traffic flows and to avoid processing and network bottlenecks. It is only in the case of local failure or overload

(whereby the NFVO is unable or has not completed a scale-out of on-site resources) that NFP instances would be constructed between NFVI-PoPs. In this case, multiple VNF instances of different NFVI-PoPs need to be considered together at constructing a new NFP instance or adapting one.

4.5. Energy efficiency

Energy efficiency in the network is getting important to reduce impact on the environment so that energy consumption of VNF instances using NFVI resources (e.g., compute, storage, I/O) needs to be considered at NFP instantiation or adaptation. For example, a NFP can be instantiated as to make traffic flows aggregated into a limited number of VNF instances as much as its performance is preserved in a certain level. Policy may vary between centralized or distributed NFV applications, and could include policies for even energy distribution between sites, time-of-day etc.

5. Evaluation Model

To derive specific algorithms for use cases discussed in Section 4, an evaluation model for a service chain (or a NFP) needs to be developed, which can address two problems for a given network topology and input parameters (e.g., VL/VNF capacity, incoming traffic flows, etc.) : 1) how much traffic flows pass on each VL instance and 2) how much processing capacity is needed for the installed VNF instance. This section first describes the system model and then presents main objectives for the evaluation model.

5.1. System Model

The system model considers the following network topology. The network topology under consideration is composed of start/end points and multiple NFVI-PoPs where multiple VNF instances locate. On the other hand, VL instances inter-connect VNF instances in NFVI-PoPs.

Start and end points are incoming and outgoing points of traffic flow for a given network service, respectively. Specifically, the amount of incoming traffic flows for a network service (i.e., a VNF-FG) at the start point is given as an input parameter in the model.

Under the network topology, the network traffic is processed by one or more VNF instances and delivered via VL instances. Thus, the VNF processing capacity can be defined as the maximum amount of traffic flows that a VNF instance can process according to the resource allocation policies defined in its deployment template. The VL capacity can be also defined as the maximum amount of traffic flows

that can pass on a VL instance according to the resource allocation
policies defined in the deployment template.

In NFV, traffic flows for a VNF-FG should be processed according to
the VNF order described in the given VNF-FG. Accordingly, traffic
flows at the start point should not be processed by any VNF.
Meanwhile, traffic flows at the end point should be processed by all
VNFs specified in the given VNF-FG.

In a given VNF-FG, VNFs should be individually placed on multiple
NFVI-PoPs. Therefore, a decision variable, VNF placement indicator
function (VPIF), is defined as:

o VNF placement indicator function (VPIF): indicator function (i.e.,
   0 or 1) to represent the location (i.e., a NFVI-PoP) where the VNF
   instance is placed.

Intuitively, the amount of traffic flows that pass a VL instance
should not exceed the VL capacity to avoid any overload at the VL
instance. Likewise, the amount of incoming traffic flows to a VNF
instance should not exceed the VNF processing capacity. (These
constraints will be covered in the following paragraphs) Therefore,
traffic flows for a network service (i.e., a VNF-FG) should be
distributed to multiple NFPs depending on resource and capacity
constraints for VNF and VL instances. Moreover, multiple network
services can be supported by distributing traffic flows for each
network service. Therefore, another decision variable, traffic flow
ratio (TFR), is defined as:

o Traffic flow ratio (TFR): the ratio of the traffic flows
   distributed to each NFP. Therefore, the amount of traffic flows
   that passes on each NFP is the product of TFR and the amount of
   incoming traffic flows for a network service. Note that TFR and
   the amount of incoming traffic flows can be computed by measuring
   the amount of traffic flows that passes on each VL.

The constraints regarding the amount of network traffic and capacity
of VNF and VL instances can be specified as follows.

o Network traffic conservation constraints: In the VNF-FG system
   model, the amount of network traffic should be conserved within a
   VNF-FG. That is, 1) the amount of incoming network traffic to a
   VNF instance should be equal (more or less in case of packet
   manipulation) to the amount of outgoing network traffic from the
   VNF instance; and 2) the amount of incoming network traffic to a
   VNF instance should not exceed the flow rate of the corresponding
   NFP which can be determined by TFR.

o Network traffic processing order constraints: As defined in the
   VNF-FG, the network traffic can be processed by a VNF instance
   only after being processed by the preceding VNF instances along
   the NFP. Similarly, the incoming network traffic to a NFP should
   be firstly processed by the VNF instance which is located at the
   ingress point of the NFP; and the outgoing network traffic from a
   NFP should be the result of processing by every VNF instance in
   the order defined by the NFP.

o Link and processing capacity constraints: The amount of incoming
   network traffic to a VL instance should not exceed the given link
   capacity of the VL to avoid any congestion at the link. Likewise,
   the amount of incoming network traffic to a VNF instance should
   not exceed the processing capacity of the VNF.

This system model can be exploited to obtain the optimal solutions of
network resource (i.e., VNF and VL instances) placement for network
resource usage, network service throughput, and so on. This
optimization problem can be solved, for example with linear
programming (LP), by defining different objective functions.

5.2. Objective functions

   In the evaluation model, three objectives are considered including,
   but not limited to, 1) load balancing, 2) flow throughput
   maximization, and 3) energy efficiency.

5.2.1. Load balancing

   For load balancing for a network service, the remaining capacity for
   VNF instances and VL instances should be balanced to avoid any
   bottlenecks. To this end, the minimum remaining processing capacity
   for VNF instances and the minimum remaining link capacity for VL
   instances should be maximized.

5.2.2. Throughput optimization

   On the other hand, the flow throughput considers both throughputs for
   VNF processing and for VL instance. Then, the throughput of an NFP
   can be calculated as the product of TFR and the sum of capacities,
   and the total throughput is the sum of computed throughputs for all
   NFPs. By maximizing the total flow throughput, it is possible to
   reduce the network service time.

5.2.3. Energy efficiency

   Since each VNF instance consumes an amount of energy for processing
   its function and transmitting/receiving traffic flows across VL
   instances, the energy consumption for each VNF instance should be
   minimized for energy efficiency of network services. Detailed model
   is under construction.

6. Framework

   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 VL instances which connect them.
   The resource management operations for service chain construction and
   adaptation can be divided into several sub-actions:

   o Locate VNF instances

   o Evaluate the performance of VNF instances and VL instances

   o Relocate (or scale) VNF instances to update a NFP instance

   o Monitor state or resource constraints of a VNF instance, VL
      instances including NFVI-PoP interconnects

   As listed above, VNF instances are relocated according to monitoring
   or evaluation results of performance metrics of the VNF instances and
   VL instances. 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.ietf-bmwg-virtual-net]. The performance metrics of VNF
   instances and VL instances specific to service chain construction and
   adaptation can be defined as follows:

   o availability (or failure) of a VNF instance and a VL instance

   o a topological location of a VNF instance

   o CPU and memory utilization rate of a VNF instance

   o a throughput of a VNF instance

   o energy consumption of a VNF instance

   o bandwidth of a VL instance

   o packet loss of a VL instance

o latency of a VL instance

o delay variation of a VL instance

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

7. Applicability to SFC

7.1. 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.ietf-sfc-control-plane] [I-D.lee-sfc-dynamic-instantiation]
[I-D.krishnan-sfc-oam-req-framework] [I-D.ietf-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.

7.2. Integration in SFC control-plane architecture

In SFC WG, [I-D.ietf-sfc-control-plane] describes requirements for
conveying information between Service Function Chaining (SFC) control
elements (including management components) and SFC functional
elements. It also identifies a set of control interfaces to interact
with SFC-aware elements to establish, maintain or recover service
function chains.

```
              +-----------------------------------------------+
              |                                               |
              |      SFC   Control & Management Planes         |
      +-------|                                               |
      |       |                                               |
      |  C1   +------^-----------^-------------^-------------+
+-----------------------|C3---------|-------------|-------------+
|       |               +----+      |             |             |
|       |               | SF |      |C2           |C2           |
|       |               +----+      |             |             |
| +----V--- --+           |         |             |             |
| |   SFC     |         +----+    +-|--+        +----+           |
| |Classifier |---->|SFF |----->|SFF |------->|SFF |           |
| |  Node     |<----|    |<-----|    |<-------|    |           |
| +----------+        +----+      +----+        +----+           |
|       |               |           |             |             |
|       |               |C2     -------           |             |
|       |               |       |     |    +-----------+ C4     |
|       |               V     +----+ +----+ | SFC Proxy |-->    |
|       |                     | SF | |SF  | +-----------+       |
|       |                     +----+ +----+                     |
|       |                       |C3    |C3                      |
|  SFC Data Plane Components     V      V                        |
+--------------------------------------------------------------+
```
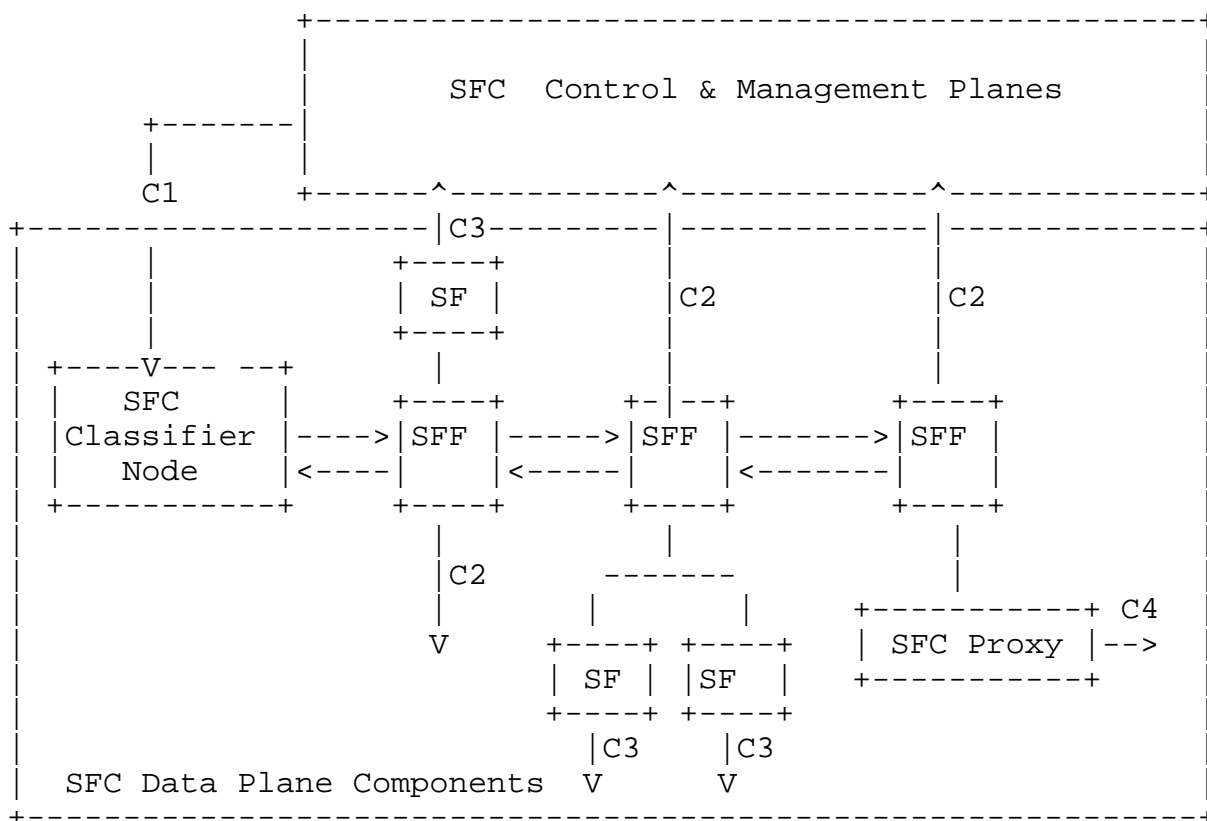
                  Figure 2: SFC control plane overview

   The service chain adaptation addressed in this document may be
   integrated into the SFC Control & Management Planes and may use the
   C2 and C4 interfaces for monitoring or collecting the resource
   constraints of VNF instances, NFVI-PoP interconnects and VL
   instances.

   To prevent constant integration between the application and probing
   functions we would propose a 3-tier architecture per NFVI-PoP.

   o Top level application control at the SFC Control & Management
      Planes

   o An abstraction layer between the application layer and the probing
      layer. This would decouple NFVI and link monitoring methods from
      the application layer

   o A probing layer that monitors VNF, physical and virtual link
      resources

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.

8. Security Considerations

TBD.

9. IANA Considerations

TBD.

10. Contributors

In addition to the authors, the following individuals contributed to the content.

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