           Framework for Abstraction and Control of Transport Networks

                  draft-ceccarelli-actn-framework-07.txt

Status of this Memo

Copyright Notice

Abstract

   This draft provides a framework for abstraction and control of
   transport networks.

Table of Contents

1. Introduction

   Transport networks have a variety of mechanisms to facilitate
   separation of data plane and control plane including distributed
   signaling for path setup and protection, centralized path
   computation for planning and traffic engineering, and a range of
   management and provisioning protocols to configure and activate
   network resources. These mechanisms represent key technologies for
   enabling flexible and dynamic networking.

   Transport networks in this draft refer to a set of different type of
   connection-oriented networks, primarily Connection-Oriented Circuit
   Switched (CO-CS) networks and Connection-Oriented Packet Switched
   (CO-PS) networks. This implies that at least the following transport
   networks are in scope of the discussion of this draft: Layer 1(L1)

and Layer 0 (L0) optical networks (e.g., Optical Transport Network
(OTN), Optical Channel Data Unit (ODU), Optical Channel
(OCh)/Wavelength Switched Optical Network (WSON)), Multi-Protocol
Label Switching - Transport Profile (MPLS-TP), Multi-Protocol Label
Switching - Traffic Engineering (MPLS-TE), as well as other emerging
technologies with connection-oriented behavior. One of the
characteristics of these network types is the ability of dynamic
provisioning and traffic engineering such that resource guarantees
can be provided to their clients.

One of the main drivers for Software Defined Networking (SDN) is a
decoupling of the network control plane from the data plane. This
separation of the control plane from the data plane has been already
achieved with the development of MPLS/GMPLS [GMPLS] and PCE [PCE]
for TE-based transport networks. One of the advantages of SDN is its
logically centralized control regime that allows a global view of
the underlying network under its control. Centralized control in SDN
helps improve network resources utilization from a distributed
network control. For TE-based transport network control, PCE is
essentially equivalent to a logically centralized control for path
computation function.

Two key aspects that need to be solved by SDN are:

   . Network and service abstraction
   . End to end coordination of multiple SDN and pre-SDN domains
       e.g. NMS, MPLS-TE or GMPLS.

As transport networks evolve, the need to provide network and
service abstraction has emerged as a key requirement for operators;
this implies in effect the virtualization of network resources so
that the network is "sliced" for different tenants shown as a
dedicated portion of the network resources

Particular attention needs to be paid to the multi-domain case,
where Abstraction and Control of Transport Networks (ACTN) can
facilitate virtual network operation via the creation of a single
virtualized network or a seamless service. This supports operators
in viewing and controlling different domains (at any dimension:
applied technology, administrative zones, or vendor-specific
technology islands) as a single virtualized network.

Network virtualization, in general, refers to allowing the customers
to utilize a certain amount of network resources as if they own them
and thus control their allocated resources in a way most optimal
with higher layer or application processes. This empowerment of
customer control facilitates introduction of new services and

applications as the customers are permitted to create, modify, and
delete their virtual network services. More flexible, dynamic
customer control capabilities are added to the traditional VPN along
with a customer specific virtual network view. Customers control a
view of virtual network resources, specifically allocated to each
one of them. This view is called an abstracted network topology.
Such a view may be specific to the set of consumed services as well
as to a particular customer. As the Customer Network Controller is
envisioned to support a plethora of distinct applications, there
would be another level of virtualization from the customer to
individual applications.

The framework described in this draft is named Abstraction and
Control of Transport Network (ACTN) and facilitates:

  - Abstraction of the underlying network resources to higher-layer
    applications and users (customers); abstraction for a specific
    application or customer is referred to as virtualization in the
    ONF SDN architecture. [ONF-ARCH]

  - Slicing infrastructure to connect multiple customers to meet
    specific customer's service requirements;

  - Creation of a virtualized environment allowing operators to
    view and control multi-subnet multi-technology networks into a
    single virtualized network;

  - Possibility of providing a customer with abstracted network or
    abstracted services (totally hiding the network).

  - A virtualization/mapping network function that adapts customer
    requests to the virtual resources (allocated to them) to the
    supporting physical network control and performs the necessary
    mapping, translation, isolation and security/policy
    enforcement, etc.; This function is often referred to as
    orchestration.

  - The multi-domain coordination of the underlying transport
    domains, presenting it as an abstracted topology to the
    customers via open and programmable interfaces. This allows for
    the recursion of controllers in a customer-provider
    relationship.

The organization of this draft is as follows. Section 2 provides a
discussion for a Business Model, Section 3 ACTN Architecture,
Section 4 ACTN Applicability, and Section 5 ACTN Interface
requirements.

2. **Business Model of ACTN**

The traditional Virtual Private Network (VPN) and Overlay Network
(ON) models are built on the premise that one single network
provider provides all virtual private or overlay networks to its
customers. This model is simple to operate but has some
disadvantages in accommodating the increasing need for flexible and
dynamic network virtualization capabilities.

The ACTN model is built upon entities that reflect the current
landscape of network virtualization environments. There are three
key entities in the ACTN model [ACTN-PS]:

  - Customers
  - Service Providers
  - Network Providers

 2.1. Customers

Within the ACTN framework, different types of customers may be taken
into account depending on the type of their resource needs, on their
number and type of access. As example, it is possible to group them
into two main categories:

Basic Customer: Basic customers include fixed residential users,
mobile users and small enterprises. Usually the number of basic
customers is high; they require small amounts of resources and are
characterized by steady requests (relatively time invariant). A
typical request for a basic customer is for a bundle of voice
services and internet access. Moreover basic customers do not modify
their services themselves; if a service change is needed, it is
performed by the provider as proxy and they generally have very few
dedicated resources (subscriber drop), with everything else shared
on the basis of some SLA, which is usually best-efforts.

Advanced Customer: Advanced customers typically include enterprises,
governments and utilities. Such customers can ask for both point to
point and multipoint connectivity with high resource demand
significantly varying in time and from customer to customer. This is
one of the reasons why a bundled services offer is not enough but it
is desirable to provide each of them with customized virtual network

services. Advanced customers may own dedicated virtual resources, or
share resources, but shared resources are likely to be governed by
more complex SLA agreements; moreover they may have the ability to
modify their service parameters directly (within the scope of their
virtualized environments. As customers are geographically spread
over multiple network provider domains, the necessary control and
data interfaces to support such customer needs is no longer a single
interface between the customer and one single network provider. With
this premise, customers have to interface multiple providers to get
their end-to-end network connectivity service and the associated
topology information. Customers may have to support multiple virtual
network services with different service objectives and QoS
requirements. For flexible and dynamic applications, customers may
want to control their allocated virtual network resources in a
dynamic fashion. To allow that, customers should be given an
abstracted view of topology on which they can perform the necessary
control decisions and take the corresponding actions. ACTN's primary
focus is Advanced Customers.

Customers of a given service provider can in turn offer a service to
other customers in a recursive way. An example of recursiveness with
2 service providers is shown below.

   - Customer (of service B)
   - Customer (of service A) & Service Provider (of service B)
   - Service Provider (of service A)
   - Network Provider

```
  +--------------------------------------------------------------+   ---
  |                                                              |    ^
  |                                  Customer (of service B)|    .
  | +----------------------------------------------------------+ |    B
  | |                                                          | |--- .
  | |Customer (of service A) & Service Provider(of service B)| | ^  .
  | | +------------------------------------------------------+ | | .  .
  | | |                                                      | | | .  .
  | | |                        Service Provider (of service A)| | | A  .
  | | |+--------------------------------------------+        | | | .  .
  | | ||                                            |        | | | .  .
  | | ||                          Network provider|        | | | v  v
  | | |+--------------------------------------------+        | | |------
  | | +------------------------------------------------------+ | |
  | +----------------------------------------------------------+ |
  +--------------------------------------------------------------+
```
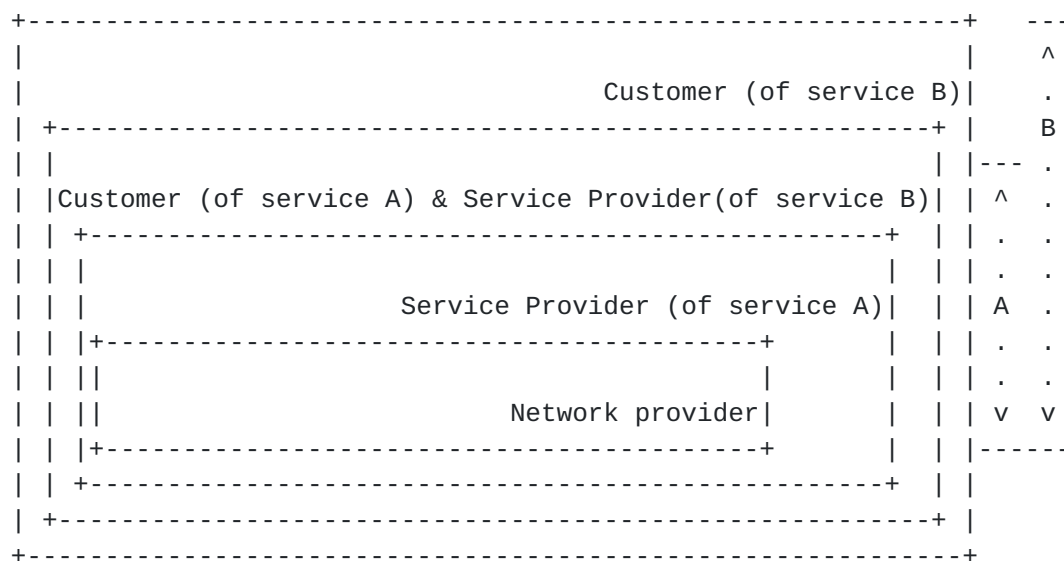
Figure 1: Network Recursiveness.

2.2. Service Providers

Service providers are the providers of virtual network services to
their customers. Service providers may or may not own physical
network resources. When a service provider is the same as the
network provider, this is similar to traditional VPN models. This
model works well when the customer maintains a single interface with
a single provider. When customer location spans across multiple
independent network provider domains, then it becomes hard to
facilitate the creation of end-to-end virtual network services with
this model.

A more interesting case arises when network providers only provide
infrastructure while service providers directly interface their
customers. In this case, service providers themselves are customers
of the network infrastructure providers. One service provider may
need to keep multiple independent network providers as its end-users
span geographically across multiple network provider domains.

```
Customer            X ----------------------------------X

Service Provider A  X ----------------------------------X

Network Provider B                      X----------------X

Network Provider A  X-----------------X
```

The ACTN network model is predicated upon this three tier model and
is summarized in figure below:

```
                    +---------------------+
                    |      customer       |
                    +---------------------+
                              |
                              |   /\  Service/Customer specific
                              |   ||  Abstract Topology
                              |   ||
                    +---------------------+  E2E abstract
                    |  Service Provider   | topology creation
                    +---------------------+
                    /         |          \
```

```
                  /           |              \  Network Topology
                 /            |               \ (raw or abstract)
                /             |                \
   +------------------+   +------------------+   +------------------+
   |Network Provider 1|   |Network Provider 2|   |Network Provider 3|
   +------------------+   +------------------+   +------------------+
```
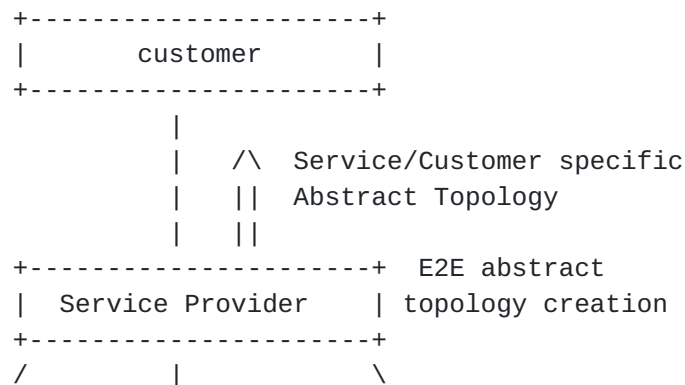
Figure 2: Three tier model.

There can be multiple types of service providers.

   . Data Center providers: can be viewed as a service provider type
      as they own and operate data center resources to various WAN
      clients, they can lease physical network resources from network
      providers.
   . Internet Service Providers (ISP): can be a service provider of
      internet services to their customers while leasing physical
      network resources from network providers.
   . Mobile Virtual Network Operators (MVNO): provide mobile
      services to their end-users without owning the physical network
      infrastructure.

The network provider space is the one where recursiveness occurs. A
customer-provider relationship between multiple service providers
can be established leading to a hierarchical architecture of
controllers within service provider network.

 2.3. Network Providers

Network Providers are the infrastructure providers that own the
physical network resources and provide network resources to their
customers. The layered model proposed by this draft separates the
concerns of network providers and customers, with service providers
acting as aggregators of customer requests.

[3]. ACTN architecture

This section provides a high-level control and interface model of
ACTN.

The ACTN architecture, while being aligned with the ONF SDN
architecture [ONF-ARCH], is presenting a 3-tiers reference model. It
allows for hierarchy and recursiveness not only of SDN controllers
but also of traditionally controlled domains. It defines three types
of controllers depending on the functionalities they implement. The
main functionalities that are identified are:

. Multi domain coordination function: With the definition of
  domain being "everything that is under the control of the same
  controller",it is needed to have a control entity that oversees
  the specific aspects of the different domains and to build a
  single abstracted end-to-end network topology in order to
  coordinate end-to-end path computation and path/service
  provisioning.

. Virtualization/Abstraction function: To provide an abstracted
  view of the underlying network resources towards customer,
  being it the client or a higher level controller entity. It
  includes computation of customer resource requests into virtual
  network paths based on the global network-wide abstracted
  topology and the creation of an abstracted view of network
  slices allocated to each customer, according to customer-
  specific virtual network objective functions, and to the
  customer traffic profile.

. Customer mapping function: In charge of mapping customer VN
  setup commands into network provisioning requests to the
  Physical Network Controller (PNC) according to business OSS/NMS
  provisioned static or dynamic policy. Moreover it provides
  mapping and translation of customer virtual network slices into
  physical network resources

. Virtual service coordination: Virtual service coordination
  function in ACTN incorporates customer service-related
  knowledge into the virtual network operations in order to
  seamlessly operate virtual networks while meeting customer's
  service requirements.

  The functionality is covering two types of services:

  - Service-aware Connectivity Services: This category includes
    all the network service operations used to provide
    connectivity between customer end-points while meeting
    policies and service related constraints. The data model for
    this category would include topology entities such as

virtual nodes, virtual links, adaptation and termination
points and service-related entities such as policies and
service related constraints. (See Section 4.2.2)

- Network Function Virtualization Services: These kinds of
services are usually setup between customers' premises and
service provider premises and are provided mostly by cloud
providers or content delivery providers. The context may
include, but not limited to a security function like
firewall, a traffic optimizer, the provisioning of storage
or computation capacity where the customer does not care
whether the service is implemented in a given data center or
another. These services may be hosted virtually by the
provider or physically part of the network. This allows the
service provider to hide his own resources (both network and
data centers) and divert customer requests where most
suitable. This is also known as "end points mobility" case
and introduces new concepts of traffic and service
provisioning and resiliency. (e.g. Virtual Machine
mobility)." (See Section 4.2.3)

About the Customer service-related knowledge it includes:

- VN Service Requirements: The end customer would have
specific service requirements for the VN including the
customer endpoints access profile as well as the E2E
customer service objectives. The ACTN framework
architectural "entities" would monitor the E2E service
during the lifetime of VN by focusing on both the
connectivity provided by the network as well as the customer
service objectives. These E2E service requirements go beyond
the VN service requirements and include customer
infrastructure as well.

- Application Service Policy: Apart for network connectivity,
the customer may also require some policies for application
specific features or services. The ACTN framework would take
these application service policies and requirements into
consideration while coordinating the virtual network
operations, which require end customer connectivity for
these advanced services.

While the "types" of controller defined are shown in Figure 3 below
and are the following:

. CNC - Customer Network Controller

      . MDSC - Multi Domain Service Coordinator
      . PNC - Physical Network Controller

```
   VPN customer          NW Mobile Customer      ISP NW service Customer
       |                         |                         |
   +-------+                 +-------+                 +-------+
   | CNC-A |                 | CNC-B |                 | CNC-C |
   +-------+                 +-------+                 +-------+
       _____               |               _____/
        ----------               |               ------------
                 \               |              /
              +-----------------------+
              |          MDSC         |
              +-----------------------+
              _____/      |       _____
             ----------       |        ------------____
            /                 |                     \
       +-------+          +-------+                 +-------+
       | PNC   |          | PNC   |                 | PNC   |
       +-------+          +-------+                 +-------+
           | GMPLS            /      |                 /    \
           | trigger         /       |                /      \
        --------       __----     +-----+  __      +-----+     \
       (        )     (    )_    | PNC |__     | PCE |      \
        -        -    ( Phys )   +-----+          +-----+    -----
       (  GMPLS   )    (Netw)       |              /       (      )
       ( Physical  )   ----         |             /       ( Phys. )
        ( Network )                -----        -----       ( Net )
         -        -               (     )    (      )        -----
        (        )               ( Phys. )   ( Phys  )
         --------                 ( Net )    ( Net )
                                   -----      -----
```
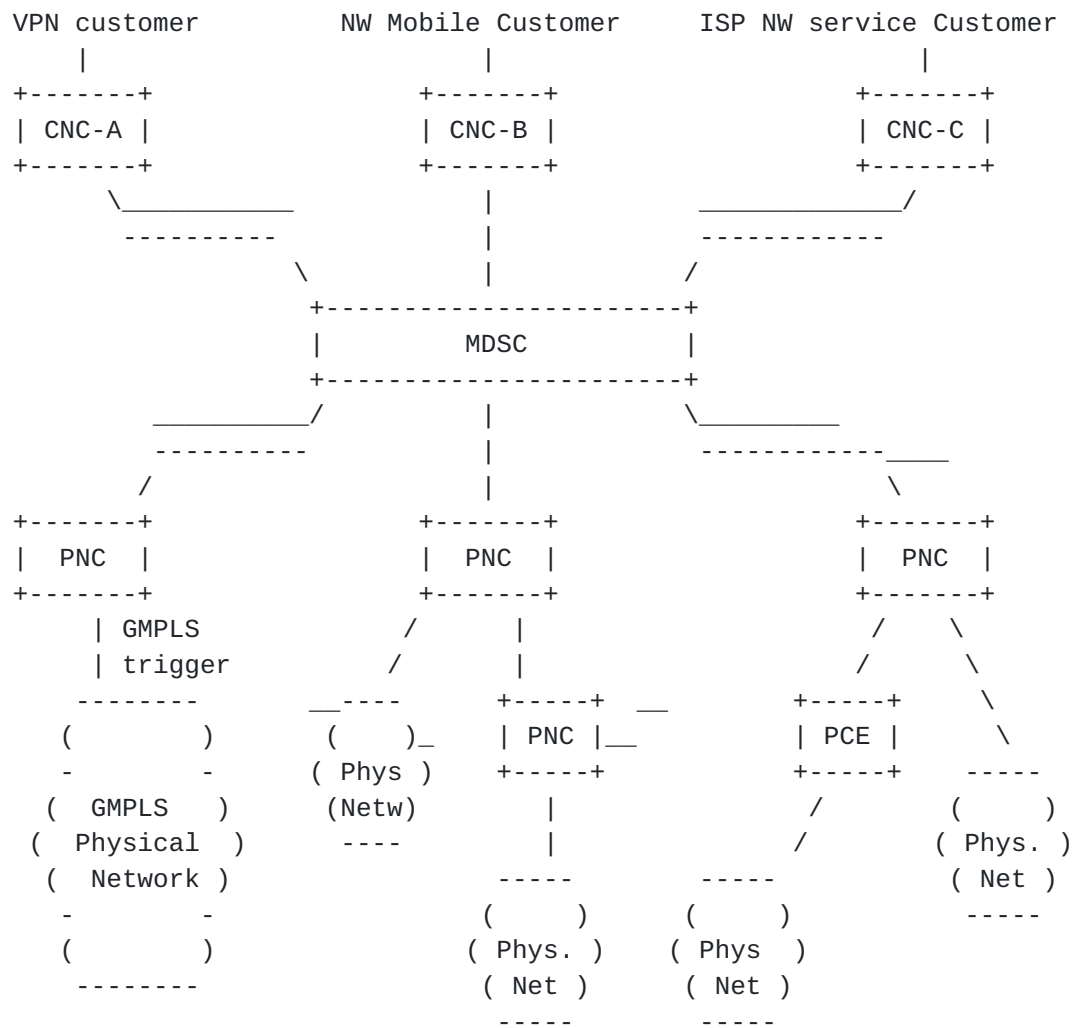
                    Figure 3: ACTN Control Hierarchy

  3.1. Customer Network Controller

 A Virtual Network Service is instantiated by the Customer Network
 Controller via the CMI (CNC-MDSC Interface). As the Customer Network
 Controller directly interfaces the application stratum, it
 understands multiple application requirements and their service
 needs. It is assumed that the Customer Network Controller and the
 MDSC have a common knowledge on the end-point interfaces based on
 their business negotiation prior to service instantiation. End-point
 interfaces refer to customer-network physical interfaces that
 connect customer premise equipment to network provider equipment.
 Figure 10 in Appendix shows an example physical network topology
 that supports multiple customers. In this example, customer A has

three end-points A.1, A.2 and A.3. The interfaces between customers
and transport networks are assumed to be 40G OTU links.

In addition to abstract networks, ACTN allows to provide the CNC
with services. Example of services include connectivity between one
of the customer's end points with a given set of resources in a data
center from the service provider.

 3.2. Multi Domain Service Coordinator

The MDSC (Multi Domain Service Coordinator) sits between the CNC
(the one issuing connectivity requests) and the PNCs (Physical
Network Controllersr - the ones managing the physical network
resources). The MDSC can be collocated with the PNC, especially in
those cases where the service provider and the network provider are
the same entity.

The internal system architecture and building blocks of the MDSC are
out of the scope of ACTN. Some examples can be found in the
Application Based Network Operations (ABNO) architecture [ABNO] and
the ONF SDN architecture [ONF-ARCH].

The MDSC is the only building block of the architecture that is able
to implement all the four ACTN main functionalities, i.e. multi
domain coordination function, virtualization/abstraction function,
customer mapping function and virtual service coordination.
A hierarchy of MDSCs can be foreseen for scalability and
administrative choices.

```
      +-------+               +-------+               +-------+
      | CNC-A |               | CNC-B |               | CNC-C |
      +-------+               +-------+               +-------+
          _____            |           _____/
           ----------            |           ----------
                   \             |          /
                +----------------------+
                |         MDSC         |
                +----------------------+
             _____/        |         _____
             ----------        |        -----------____
            /                  |                  \
      +-----------+        +-----------+        +--------+
      |   MDSC    |        |   MDSC    |        |  MDSC  |
      +-----------+        +-----------+        +--------+
           |                /      |              /    \
           |               /       |             /      \
        +-----+         +-----+  +-----+      +-----+  +-----+
        | PNC |         | PNC |  | PNC |      | PNC |  | PNC |
        +-----+         +-----+  +-----+      +-----+  +-----+
```
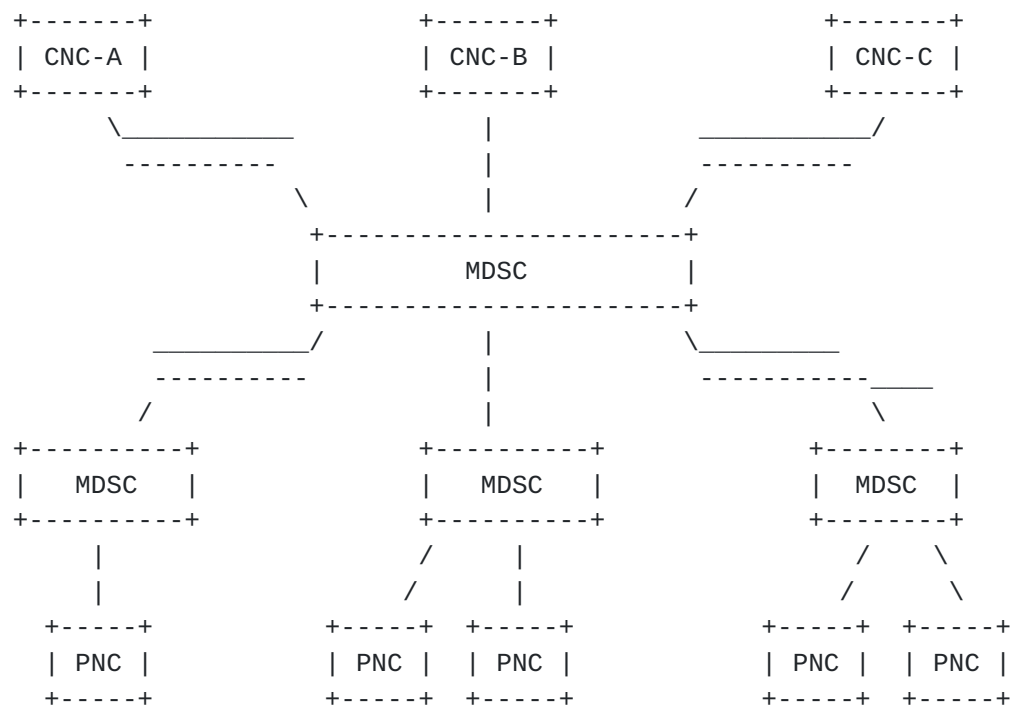
                   Figure 4: Controller recursiveness

   A key requirement for allowing recursion of MDSCs is that a single
   interface needs to be defined both for the north and the south
   bounds.
   In order to allow for multi-domain coordination a 1:N relationship
   must be allowed between MDSCs and between MDSCs and PNCs (i.e. 1
   parent MDSC and N child MDSC or 1 MDSC and N PNCs). In addition to
   that it could be possible to have also a M:1 relationship between
   MDSC and PNC to allow for network resource partitioning/sharing
   among different customers not necessarily connected to the same MDSC
   (e.g. different service providers).
   It should be noted that the interface between the parent MDSC and a
   child MDSC does not introduce any complexity as it is "internal" and
   "transparent" from the perspective of the CNCs and the PNCs and it
   makes use of the same interface model and its primitives as the CMI
   and MPI.

  3.3. Physical Network Controller

   The physical network controller is the one in charge of configuring
   the network elements, monitoring the physical topology of the
   network and passing it, either raw or abstracted, to the MDSC.

The internal architecture of the PNC, his building blocks and the
way it controls its domain, are out of the scope of ACTN. Some
examples can be found in the Application Based Network Operations
(ABNO) architecture [ABNO] and the ONF SDN architecture [ONF-ARCH]

The PNC, in addition to being in charge of controlling the physical
network, is able to implement two of the four ACTN main
functionalities: multi domain coordination function and
virtualization/abstraction function
A hierarchy of PNCs can be foreseen for scalability and
administrative choices.

 3.4. ACTN interfaces

To allow virtualization and multi domain coordination, the network
has to provide open, programmable interfaces, in which customer
applications can create, replace and modify virtual network
resources and services in an interactive, flexible and dynamic
fashion while having no impact on other customers. Direct customer
control of transport network elements and virtualized services is
not perceived as a viable proposition for transport network
providers due to security and policy concerns among other reasons.
In addition, as discussed in the previous section, the network
control plane for transport networks has been separated from data
plane and as such it is not viable for the customer to directly
interface with transport network elements.

While the current network control plane is well suited for control
of physical network resources via dynamic provisioning, path
computation, etc., a multi service domain controller needs to be
built on top of physical network controller to support network
virtualization. On a high-level, virtual network control refers to a
mediation layer that performs several functions:

Figure 4 depicts a high-level control and interface architecture for
ACTN. A number of key ACTN interfaces exist for deployment and
operation of ACTN-based networks. These are highlighted in Figure 4
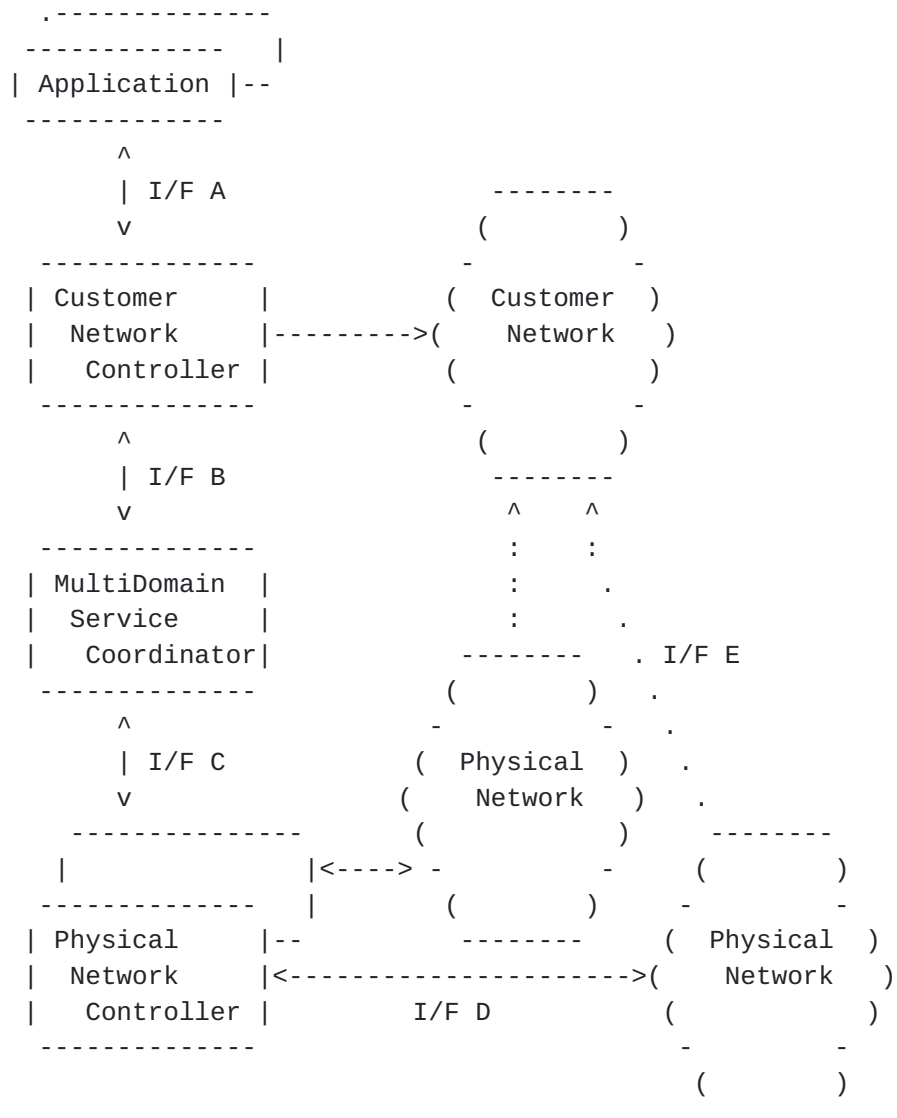(ACTN Interfaces) below:

```
                     .--------------
                    -------------   |
                   | Application |--
                    -------------
                          ^
                          | I/F A             --------
                          v                  (          )
                    --------------          -            -
                   | Customer     |        (  Customer  )
                   |  Network     |-------->(    Network    )
                   |   Controller |        (              )
                    --------------          -            -
                          ^                  (          )
                          | I/F B             --------
                          v                       ^     ^
                    --------------                :     :
                   | MultiDomain  |               :      .
                   |  Service     |               :       .
                   |   Coordinator|            --------    . I/F E
                    --------------            (        )   .
                          ^                  -          -   .
                          | I/F C           (  Physical  )   .
                          v                (    Network   )    .
                    ---------------        (              )      --------
                    |             |<----> -          -      (        )
                    --------------   |      (          )    -          -
                   | Physical     |--          --------    (  Physical  )
                   |  Network     |<---------------------->(    Network   )
                   |   Controller |         I/F D          (              )
                    --------------                          -            -
                                                           (          )
                                                            --------
```

                       Figure 4: ACTN Interfaces

   The interfaces and functions are described below:

      . Interface A: A north-bound interface (NBI) that will
         communicate the service request or application demand. A
         request will include specific service properties, including:
         services, topology, bandwidth and constraint information.

  . Interface B: The CNC-MDSC Interface (CMI) is an interface
    between a Customer Network Controller and a Multi Service
    Domain Controller. It requests the creation of the network
    resources, topology or services for the applications. The
    Virtual Network Controller may also report potential network
    topology availability if queried for current capability from
    the Customer Network Controller.

  . Interface C: The MDSC-PNC Interface (MPI) is an interface
    between a Multi Domain Service Coordinator and a Physical
    Network Controller. It communicates the creation request, if
    required, of new connectivity of bandwidth changes in the
    physical network, via the PNC. In multi-domain environments,
    the MDSC needs to establish multiple MPIs, one for each PNC, as
    there are multiple PNCs responsible for its domain control.

  . Interface D: The provisioning interface for creating forwarding
    state in the physical network, requested via the Physical
    Network Controller.

  . Interface E: A mapping of physical resources to overlay
    resources.

   The interfaces within the ACTN scope are B and C.

3.5. Work in Scope of ACTN

   This section provides a summary of use-cases in terms of two
   categories: (i) service-specific requirements; (ii) network-related
   requirements.

   Service-specific requirements listed below are uniquely applied to
   the work scope of ACTN. Service-specific requirements are related to
   virtual service coordination function defined in Section 3. These
   requirements are related to customer's VNs in terms of service
   policy associated with VNs such as service performance objectives,
   VN endpoint location information for certain required service-
   specific functions (e.g., security and others), VN survivability
   requirement, or dynamic service control policy, etc.

Network-related requirements are related to virtual network
operation function defined in Section 3. These requirements are
related to multi-domain and multi-layer signaling, routing,
protection/restoration and synergy, re-optimization/re-grooming,
etc. These requirements are not inherently unique for the scope of
ACTN but some of these requirements are in scope of ACTN, especially
for coherent/seamless operation aspect of multiple controller
hierarchy.

The following table gives an overview of service-specific
requirements and network-related requirements respectively for each
ACTN use-case and identifies the work in scope of ACTN.

Details on these requirements will be developed into the information
model in [ACTN-Info].

Use-case	Service-specific Requirements	Network-related Requirements	ACTN Work Scope
[Cheng]	- E2E service provisioning - Performance monitoring - Resource utilization abstraction	- Multi-layer (L2/L2.5) coordination - VNO for multi-domain transport networks	- Dynamic multi-layer coordination based on utilization is in scope of ACTN - YANG for utilization abstraction
[Dhody]	- Service awareness/ coordination between P/O.	- POI Performance monitoring - Protection/ Restoration synergy	- Performance related data model may be in scope of ACTN - Customer's VN survivability policy enforcement for protection/res toration is unique to ACTN.
[Fang]	- Dynamic VM migration (service), Global load balancing (utilization efficiency), Disaster recovery - Service-aware network	- On-demand virtual circuit request - Network Path Connection request	- Multi-destination service selection policy enforcement and its related primitives/inf ormation are unique to

	query - Service Policy Enforcement		ACTN. - Service- aware network query and its data model can be extended by ACTN.
-------	--------------	----------------	--------------
[Klee]		- Two stage path computation E2E signaling coordination - Abstraction of inter-domain info - Enforcement of network policy (peering, domain preference) - Network capability exchange (pull/push, abstraction level, etc.)	- Multi-domain service policy coordination to network primitives is in scope of ACTN
-------	--------------	----------------	--------------
[Kumaki]	- On-demand VN creation - Multi- service level for VN - VN survivability /diversity/con fidentiality		- All of the service- specific lists in the left column is unique to ACTN.
-------	--------------	----------------	--------------
[Lopez]	- E2E accounting and resource usage data	- E2E connection management, path provisioning - E2E network	- Escalation of performance and fault management

	- E2E service policy enforcement	monitoring and fault management	data to CNC and the policy enforcement for this area is unique to ACTN.
-------	--------------	----------------	--------------
[Shin]	- Current network resource abstraction Endpoint/DC dynamic selection (for VM migration)	- LB for recovery - Multi-layer routing and optimization coordination	- Multi-layer routing and optimization are related to VN's dynamic endpoint selection policy.
-------	--------------	----------------	--------------
[Xu]	- Dynamic service control policy enforcement - Dynamic service control	- Traffic monitoring - SLA monitoring	- Dynamic service control policy enforcement and its control primitives are in scope of ACTN - Data model to support traffic monitoring data is an extension of YANG model ACTN can extend.

4. References

4.1. Informative References

[PCE]   Farrel, A., Vasseur, J.-P., and J. Ash, "A Path
          Computation Element (PCE)-Based Architecture", IETF RFC
          4655, August 2006.

   [PCE-S]   Crabbe, E, et. al., "PCEP extension for stateful
              PCE",draft-ietf-pce-stateful-pce, work in progress.

   [GMPLS]   Manning, E., et al., "Generalized Multi-Protocol Label
              Switching (GMPLS) Architecture", RFC 3945, October 2004.

   [NFV-AF]   "Network Functions Virtualization (NFV); Architectural
              Framework", ETSI GS NFV 002 v1.1.1, October 2013.

   [ACTN-PS] Y. Lee, D. King, M. Boucadair, R. Jing, L. Contreras
              Murillo, "Problem Statement for Abstraction and Control of
              Transport Networks", draft-leeking-actn-problem-statement,
              work in progress.

   [ONF]   Open Networking Foundation, "OpenFlow Switch Specification
              Version 1.4.0 (Wire Protocol 0x05)", October 2013.

   [ABNO]   King, D., and Farrel, A., "A PCE-based Architecture for
              Application-based Network Operations", draft-farrkingel-
              pce-abno-architecture, work in progress.

   [ACTN-Info] Y. Lee, S. Belotti, D. Dhody, "Information Model for
              Abstraction and Control of Transport Networks", draft-
              leebelotti-teas-actn-info, work in progress.

   [Cheng] W. Cheng, et. al., "ACTN Use-cases for Packet Transport
              Networks in Mobile Backhaul Networks", draft-cheng-actn-
              ptn-requirements, work in progress.

   [Dhody] D. Dhody, et. al., "Packet Optical Integration (POI) Use
              Cases for Abstraction and Control of Transport Networks
              (ACTN)", draft-dhody-actn-poi-use-case, work in progress.

   [Fang] L. Fang, "ACTN Use Case for Multi-domain Data Center
              Interconnect", draft-fang-actn-multidomain-dci, work in
              progress.

   [Klee] K. Lee, H. Lee, R. Vilata, V. Lopez, "ACTN Use-case for On-
              demand E2E Connectivity Services in Multiple Vendor Domain
              Transport Networks", draft-klee-actn-connectivity-multi-
              vendor-domains, work in progress.

   [Kumaki] K. Kumaki, T. Miyasaka, "ACTN : Use case for Multi Tenant
            VNO ", draft-kumaki-actn-multitenant-vno, work in
            progress.

   [Lopez] D. Lopez (Ed), "ACTN Use-case for Virtual Network Operation
            for Multiple Domains in a Single Operator Network", draft-
            lopez-actn-vno-multidomains, work in progress.

   [Shin] J. Shin, R. Hwang, J. Lee, "ACTN Use-case for Mobile Virtual
            Network Operation for Multiple Domains in a Single
            Operator Network", draft-shin-actn-mvno-multi-domain, work
            in progress.

   [Xu] Y. Xu, et. al., "Use Cases and Requirements of Dynamic Service
            Control based on Performance Monitoring in ACTN
            Architecture", draft-xu-actn-perf-dynamic-service-control,
            work in progress.

[5](). Contributors

Authors' Addresses

   Daniele Ceccarelli (Editor)
   Ericsson
   Torshamnsgatan,48
   Stockholm, Sweden
   Email: daniele.ceccarelli@ericsson.com

   Young Lee (Editor)
   Huawei Technologies
   5340 Legacy Drive
   Plano, TX 75023, USA
   Phone: (469)277-5838
   Email: leeyoung@huawei.com

   Luyuan Fang
   Email: luyuanf@gmail.com

   Diego Lopez
   Telefonica I+D
   Don Ramon de la Cruz, 82
   28006 Madrid, Spain
   Email: diego@tid.es

   Sergio Belotti
   Alcatel Lucent
   Via Trento, 30
   Vimercate, Italy
   Email: sergio.belotti@alcatel-lucent.com

   Daniel King
   Lancaster University
   Email: d.king@lancaster.ac.uk

   Dhruv Dhoddy
   Huawei Technologies
   dhruv.ietf@gmail.com