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Hierarchy of IP Controllers (HIC)
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Abstract

This document describes the interactions between various IP controllers in a hierarchical fashion to provide various IP services. It describes how the Abstraction and Control of Traffic Engineered Networks (ACTN) framework is applied to the Hierarchy of IP controllers (HIC) as well as document the interactions with other protocols like BGP, Path Computation Element Communication Protocol (PCEP) to provide end to end dynamic services spanning multiple domains and controllers (e.g. Layer 3 Virtual Private Network (L3VPN), Seamless MPLS etc).

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1. Introduction

Software-Defined Networking (SDN) refers to a separation between the control elements and the forwarding components so that software running in a centralized system called a controller, can act to program the devices in the network to behave in specific ways. A required element in an SDN architecture is a component that plans how the network resources will be used and how the devices will be programmed. It is possible to view this component as performing specific computations to place flows within the network given knowledge of the availability of network resources, how other forwarding devices are programmed, and the way that other flows are routed. The Application-Based Network Operation (ABNO) [RFC7491] describes how various components and technologies fit together.

A domain [RFC4655] is any collection of network elements within a common sphere of address management or path computation responsibility. Specifically within this document we mean a part of an operator’s network that is under common management. Network elements will often be grouped into domains based on technology types, vendor profiles, and geographic proximity and under a domain controller.

Multiple such domains in the network are interconnected, and a path is established through a series of connected domains to form an end-to-end path over which various services are offered. Each domain is under the control of the domain controller (or lower-level controller), and a "super controller" (or high-level controller) takes responsibility for a high-level view of the network before distributing tasks to domain controllers (or lower-level controllers). It is possible for each of the domain to use a different tunneling mechanism (eg RSVP-TE, Segment Routing (SR) etc).

[I-D.ietf-teas-actn-framework] describes the framework for Abstraction and Control of Traffic Engineered Networks (ACTN) as well as a set of management and control functions used to operate multiple TE networks. This documents would apply the ACTN principles to Hierarchy of IP controllers (HIC) and focus on the applicability and interactions with other protocol and technologies (specific to IP packet domains).

Sometimes, service (such as Layer 3 Virtual Private Network (L3VPN), Layer 2 Virtual Private Network (L2VPN), Ethernet VPN (EVPN), Seamless MPLS) require sites attached to different domains (under the control of different domain controller) to be interconnected as part of the VPN service. This require multi-domain coordination between domain controllers to compute and setup E2E path for the VPN service.

This document describes the interactions between various IP controllers in a hierarchical fashion to provide various IP services. It describes how the Abstraction and Control of Traffic Engineered Networks (ACTN) framework is applied to the Hierarchy of IP controllers (HIC) as well as document the interactions with control plane protocols (like BGP, Path Computation Element Communication Protocol (PCEP)) and management plane aspects (Yang models) to provide end to end dynamic services spanning multiple domains and controllers (e.g. L3VPN, Seamless MPLS etc).

2. Overview

Figure 1 show examples of multi-domain IP domains under hierarchy of IP controllers.

```
                             |
                       +------------+
                       |  SuperCo   |
                       +------------+
                             |
             ----------------------------------
             |               |                |
      +------------+   +------------+   +------------+
      |   DoCo#1   |   |   DoCo#2   |   |   DoCo#3   |
      +------------+   +------------+   +------------+


      +--Domain#1--+   +--Domain#2--+   +--Domain#3--+
      |            |   |            |   |            |
      |     B------+---+---D-----E--+---+------J     |
      |    /       |   |    \   /   |   |       \    |
      |   /        |   |     \ /    |   |        \   |
      |  A         |   |      H     |   |         L  |
      |   \        |   |     / \    |   |        /   |
      |    \       |   |    /   \   |   |       /    |
      |     C------+---+---F-----G--+---+------K     |
      |            |   |            |   |            |
      +------------+   +------------+   +------------+
```

Figure 1: Example: Hierarchy of IP controllers (HIC)

The IP "Super Controller" receives request from the network/service orchestrator to setup dynamic services spanning multiple domains. The IP "Super Controller" breaks down and assigns tasks to the domain controllers, responsible for communicating to network devices in the domain. It further coordinates between the controller to provide a unified view of the multi-domain network.

2.1. Mapping to ACTN

As per [I-D.ietf-teas-actn-framework], ACTN has following main functions -

- o Multi-domain coordination
- o Virtualization/Abstraction
- o Customer mapping/translation
- o Virtual service coordination

These functions are part of Multi Domain Service Coordinator (MDSC) and/or Provisioning Network Controller (PNC). Further these functions are part of the controller / orchestrator.

The HIC is an instantiation of ACTN framework for IP packet network. The IP domain (lower-level) controllers implements the PNC functionalities for configuring, controlling and monitoring the IP domain. The "super controller" (high-level controller) implements the MDSC functionalities for coordination between multiple domains as well as maintaining an abstracted view of multiple domains. It also takes care of the service related functionalities of customer mapping/translation and virtual service coordination.

The ACTN functions are part of the IP controllers and responsible for the TE topology and E2E path computation/setup. There are other functions along with ACTN that are needed to manage multiple IP domain networks.

2.2. Interface between Super Controller and Domain Controller in HIC

The interaction between super controller and domain controller in HIC is a combination of Control Plane and Management Plane interface as shown in Figure 2. BGP [RFC4271] and PCEP [RFC5440] are example of the control plane interface; where as NETCONF [RFC6241] and RESTCONF [RFC8040] are example of management plane interface.

```
      +----------------------------------------------+
      |                Super Controller              |
      |                                              |
      |                                              |
      +------------------*------#---------------------+
                         *      #
                         *      #
                      *************************
                      *         #             *
                ######*###############        *
                #     *              #        *
      +---------#-----*--+        +--#--------*------+
      | Domain           |        | Domain           |
      | Controller       |        | Controller       |
      +--#------------*--+        +--#------------*--+
         #            *              #            *
         #            *              #            *


       * -> Control Plane Interface
       # -> Management Plane Interface
```

Figure 2: Interface between Super Controller and Domain Controller

Note that ACTN's MDSC-PNC Interface (MPI) could be implemented via management plane interface using Yang models [I-D.ietf-teas-actn-yang] or via PCEP control plane interface [I-D.ietf-pce-applicability-actn].

3. Key Concepts

3.1. Topology

The Domain Controller is expected to be aware of the topology of the network devices in its domain. The domain controller could participate in the IGP ([RFC3630] and [RFC5305]) or use BGP-LS [RFC7752] by which link-state and TE information is collected and shared with domain controller using the BGP routing protocol.

An alternate approach would be to rely on the management plane interface which uses the YANG model for network/TE Topology as per [I-D.ietf-i2rs-yang-network-topo] and [I-D.ietf-teas-yang-te-topo].

The domain controller is expected to share the domain topology to the Super Controller as aligned to ACTN (where PNC abstract the topology towards MDSC). A level of abstraction is usually applied while presenting the topology to a higher level controller. Topology abstraction is described in [RFC7926] as well as [I-D.ietf-teas-actn-framework]. BGP-LS, PCEP-LS [I-D.dhodylee-pce-pcep-ls] or management plane interface based on the abstracted network/TE Topology could be used to carry the abstract topology to the super-controller. At minimum the border nodes and inter-domain links are exposed to the super-controller.

3.2. Path Computation/Path instantiation

The Domain Controller is responsible for computing and setup of path when the source and destination is in the same domain, otherwise the Super Controller coordinates the multi-domain path computation and setup with the help of the domain controller. This is aligned to ACTN.

PCEP [RFC5440] provides mechanisms for Path Computation Elements (PCEs) [RFC4655] to perform path computations in response to Path Computation Clients (PCCs) requests. Since then, the role and function of the PCE has grown to allow delegated control [RFC8231] and PCE-initiated use of network resources [RFC8281].

Further, [RFC6805] and [I-D.ietf-pce-stateful-hpce] describes a hierarchy of PCE with Parent PCE coordinating multi-domain path computation function between Child PCE(s). This fits well with HIC as described in this document.

Note that a management plane interface which uses the YANG model for path computation/setup ([I-D.ietf-teas-yang-path-computation] and [I-D.ietf-teas-yang-te]) could be used in place of PCEP.

3.3. BGP considerations

[RFC4456] describes the concept of route-reflection where a "route reflector" (RR) reflects the routes to avoid full mesh connection between Internal BGP (IBGP) peers. The IP domain controller can play the role of RR in its domain. The super controller can further act as RR to towards the domain controller.

[Editor’s Note: To do - BGP policy, BGP Flowspec. Maybe a BGP expert can add details here!]

[Editor’s Note: Is there a role of BMP here?]

4. VPN Service

4.1. L3VPN

A Layer 3 IP VPN service is a collection of sites that are authorized to exchange traffic between each other over a shared IP infrastructure. [RFC4110] provides a framework for Layer 3 Provider-Provisioned Virtual Private Networks (PPVPNs). [RFC8299] provides a L3VPN service delivery YANG model for PE-based VPNs. The Super controller is expected to implement the L3SM model and translate it to network models towards the domain controller, which in terns translate it to the device model. See [RFC8309] for more details.

```
                          | L3SM
                          V
                 +--------------------+
                 |  Super Controller  |
                 +--------------------+
                          |
             +--------------------------------+
             |                                |
             V                                V
          +---------+                      +---------+
          | DoCo#1 |                      | DoCo#2 |
          |         |                      |         |
          +---------+                      +---------+

      CE                                                     CE
       \     AS 100                          AS 200       /
        \                                                /
         A----B----C----ASBR1------ASBR2----D----E----F
        /    /    /       /          /     /    /    /
       /    /    /       /          /     /    /    /
   CE----G----H----I----ASBR3------ASBR4----J----K----L------CE
```

Figure 3: L3VPN

Based on the user data in L3SM model, the network configurations need to be trickle down to the network device to setup the L3VPN.

Based on the QoS or Policy requirement for the L3VPN service, the Super Controller may -

- o Set the tunnel selection policy at the PE/ASBR routers so that they could select the existing tunnels

- o Select an existing tunnels at the controller level and bind it to the VPN service

- o Initiate the process of creating a new tunnel based on the QoS requirement and bind it the VPN service

- o Initiate the process of creating a new tunnel based on the the policy

Refer [I-D.lee-teas-te-service-mapping-yang] for more details from ACTN perspective.

Apart from the Management plane interface based on respective YANG models, the control plane interface PCEP could be used for path computation and setup.

4.2. Seamless MPLS

Seamless MPLS [I-D.ietf-mpls-seamless-mpls] describes an architecture which can be used to extend MPLS networks to integrate access and core/aggregation networks into a single MPLS domain.In the seamless MPLS for mobile backhaul, since there are multiple domains including the core network and multiple mobile backhaul networks, for each domain there is a domain controller. In order to implement the end-to-end network service provision, there should be coordination among multiple domain controllers.

```
                                |
                                |
                                |
                             +----------+
              |--------------|Super     |---------|
              |              |Controller|         |
              |              +----------+         |
              |                 |                 |
              |                 |                 |
              |                 |                 |
          +------+           +------+          +------+
     |----|DoCo  |----|  |---|DoCo  |--|  |----|DoCo  |---|
     |    |#X1   |    |  |   |#Y    |  |  |    |#X2   |   |
     |    +------+    |  |   +------+  |  |    +------+   |
     |                |  |             |  |               |
     |                |  |             |  |               |
     |                |  |             |  |               |
     |               +----+           +----+              |
     |           ....|ABR1|...........|ABR3|....          |
   +----+   .....    +----+           +----+    .....   +----+
   | PE |...                                         ...| PE |
   +----+   .....                                       +----+
                 ....+----+           +----+    .....
                     |ABR2|...........|ABR4|....
                     +----+           +----+

     |      IGP-X1     |      IGP-Y      |       IGP-X2      |
     |       (MBH)     |      (Core)     |       (MBH)       |
     |                 |                 |                   |
     |-----BGP LSP-----|-----BGP LSP----|------BGP LSP-----|
     |                 |                 |                   |
     |---LDP/TE LSP----|----LDP/TE LSP--|-----LDP/TE LSP---|
     |                 |                 |                   |
```

Figure 4: Seamless MPLS

Super Controller is responsible for setting the seamless MPLS service. It should break down the service model to network configuration model [RFC8309] and the domain controller further break it to the device configuration model to the PE/ASBR to make the E2E seamless MPLS service. The selection of appropriate ASBRs and handling of intra-domain tunnels is coordinated by the Super Controller in the similar fashion as shown in Section 4.1.

By enabling BGP sessions between Domain Controller and Super Controller, BGP labeled routes can also be learned at Super

Controller. As super Controller is aware of the (abstract) topology, it could make intelligent decisions regarding E2E BGP LSP to optimize based on the overall traffic information.

4.3. L2VPN and EVPN service

There are two fundamentally different kinds of Layer 2 VPN service that a service provider could offer to a customer: Virtual Private Wire Service (VPWS) and Virtual Private LAN Service (VPLS) [RFC4664]. A VPWS is a VPN service that supplies an L2 point-to-point service. A VPLS is an L2 service that emulates LAN service across a Wide Area Network (WAN). A BGP MPLS-based Ethernet VPN (EVPN) [RFC7432] addresses some of the limitations when it comes to multihoming and redundancy, multicast optimization, provisioning simplicity, flow-based load balancing, and multipathing etc.

The handling of L2VPN/EVPN service is done in a similar fashion as shown in Section 4.1.

5. Possible Features/Extensions

This sections list some of the possible features or protocol extensions that could be worked on to deploy HIC in a multi-domain packet network.

1. Simplify the initial configurations needed to setup the relationship between the super controller and the domain controllers. Note that this could be done via exchanges during initial session establishment, discovery via other protocols, service discovery (such as DNS) etc.

2. The (higher-level controller, lover-level controller) relationship or the the role of the controller.

3. The learning and handling of various capabilities of the Super Controller and Domain Controller.

4. Handling of multiple instances of controller at each level for high availability.

5. TBD

6. Other Considerations

6.1. Control Plane

6.1.1. PCE / PCEP

The Path Computation Element communication Protocol (PCEP) [RFC5440] provides mechanisms for Path Computation Elements (PCEs) [RFC4655] to perform path computations in response to Path Computation Clients (PCCs) requests.

The ability to compute shortest constrained TE LSPs in Multiprotocol Label Switching (MPLS) and Generalized MPLS (GMPLS) networks across multiple domains has been identified as a key motivation for PCE development.

A stateful PCE [RFC8231] is capable of considering, for the purposes of path computation, not only the network state in terms of links and nodes (referred to as the Traffic Engineering Database or TED) but also the status of active services (previously computed paths, and currently reserved resources, stored in the Label Switched Paths Database (LSPDB).

[RFC8051] describes general considerations for a stateful PCE deployment and examines its applicability and benefits, as well as its challenges and limitations through a number of use cases.

[RFC8231] describes a set of extensions to PCEP to provide stateful control. A stateful PCE has access to not only the information carried by the network’s Interior Gateway Protocol (IGP), but also the set of active paths and their reserved resources for its computations. The additional state allows the PCE to compute constrained paths while considering individual LSPs and their interactions. [RFC8281] describes the setup, maintenance and teardown of PCE-initiated LSPs under the stateful PCE model.

[RFC8231] also describes the active stateful PCE. The active PCE functionality allows a PCE to reroute an existing LSP or make changes to the attributes of an existing LSP, or a PCC to delegate control of specific LSPs to a new PCE.

Computing paths across large multi-domain environments require special computational components and cooperation between entities in different domains capable of complex path computation. The PCE provides an architecture and a set of functional components to address this problem space. A PCE may be used to compute end-to-end paths across multi-domain environments using a per-domain path computation technique [RFC5152]. The Backward recursive PCE based path computation (BRPC) mechanism [RFC5441] defines a PCE-based path computation procedure to compute inter-domain constrained MPLS and

GMPLS TE networks. However, both per-domain and BRPC techniques assume that the sequence of domains to be crossed from source to destination is known, either fixed by the network operator or obtained by other means.

[RFC6805] describes a Hierarchical PCE (H-PCE) architecture which can be used for computing end-to-end paths for inter-domain MPLS Traffic Engineering (TE) and GMPLS Label Switched Paths (LSPs) when the domain sequence is not known. Within the Hierarchical PCE (H-PCE) architecture, the Parent PCE (P-PCE) is used to compute a multi-domain path based on the domain connectivity information. A Child PCE (C-PCE) may be responsible for a single domain or multiple domains, it is used to compute the intra-domain path based on its domain topology information.

[I-D.ietf-pce-stateful-hpce] state the considerations for stateful PCE(s) in hierarchical PCE architecture. In particular, the behavior changes and additions to the existing stateful PCE mechanisms (including PCE- initiated LSP setup and active PCE usage) in the context of networks using the H-PCE architecture.

[I-D.ietf-pce-applicability-actn] examines the applicability of PCE/ PCEP to the ACTN framework in detail.

6.1.2. BGP

[Editor’s Note - TBD, maybe some one who is expert in BGP can add details on BGP-LS, BGP-Flowspec, RR handling, BGP Policy etc]

6.2. Management Plane

6.2.1. YANG Models

This is an non-exhaustive list of possible yang models developed or in-development that could be used for HIC.

Topology: [I-D.ietf-i2rs-yang-network-topo] defines a generic YANG data model for network topology. [I-D.ietf-teas-yang-te-topo] defines a YANG data model for representing, retrieving and manipulating Traffic Engineering (TE) Topologies.

Tunnel: [I-D.ietf-teas-yang-te] defines a YANG data model for the configuration and management of Traffic Engineering (TE) interfaces, tunnels and Label Switched Paths (LSPs).

L3VPN: The Layer 3 service model (L3SM) is defined in [RFC8299], which is a YANG data model that can be used for communication between customers and network operators and to deliver a Layer 3 provider-provisioned VPN service. [I-D.ietf-bess-l3vpn-yang] defines a YANG data model that can be used to configure and manage BGP Layer 3 VPNs at the device. Note that a network configuration model at the Domain Controller level needs to be developed.

L2VPN/EVPN: [I-D.ietf-l2sm-l2vpn-service-model] defines a YANG data model that can be used to configure a Layer 2 Provider Provisioned VPN service. This model is intended to be instantiated at management system to deliver the overall service. [I-D.ietf-bess-l2vpn-yang] and [I-D.ietf-bess-evpn-yang] defines a YANG data model to configure and manage L2VPN and EVPN service respectively. Note that a network configuration model at the Domain Controller level needs to be developed.

OAM: TBD

[Editor’s Note - the above list should be extended.]

6.2.2. Protocol Considerations

The Network Configuration Protocol (NETCONF) [RFC6241] provides mechanisms to install, manipulate, and delete the configuration of network devices. The RESTCONF [RFC8040] describes an HTTP-based protocol that provides a programmatic interface for accessing data defined in YANG, using the datastore concepts defined in NETCONF.

Some other mechanism like gRPC/gNMI could also be used between controllers using the same YANG data models.

7. IANA Considerations

There are no IANA concerns in this document.

8. Security Considerations

There are no new security concerns in this document.

9. Acknowledgments

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