Engineering Simplicity

Port Fan-Out—Juniper Validated Design (JVD)

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Juniper Networks Validated Designs provide customers with a comprehensive, end-to-end blueprint for deploying Juniper solutions in their network. These designs are created by Juniper's expert engineers and tested to ensure they meet the customer's requirements. Using a validated design, customers can reduce the risk of costly mistakes, save time and money, and ensure that their network is optimized for maximum performance.

About this Document

Juniper Validated Design (JVD) is a cross-functional collaboration between Juniper solution architects and test teams to develop coherent multidimensional solutions for domain-specific use cases. The JVD team is comprised of technical leaders in the industry with a wealth of experience supporting complex customer use cases. The scenarios selected for validation are based on industry standards to solve critical business needs with practical designs that are fully supported at publication.

This document provides JVD for implementing Juniper Network's port fan-out solution. In general, the port fan-out approach is widely used in network designs to achieve cost savings, port flexibility, and a higher density of ports. At the same time, a port fan-out solution usually introduces additional complexity due to the need of provisioning more network devices - a PE-node along with multiple fan-out (FO) nodes. In this document, we introduce a foundational port fan-out reference architecture based on open standards protocols. It includes implementation choices for port fan-out transparency, control plane and class of service (CoS) considerations, which combines traditional benefits of the port-fan out approach and minimizes operation costs associated with extra FO-nodes in the network.

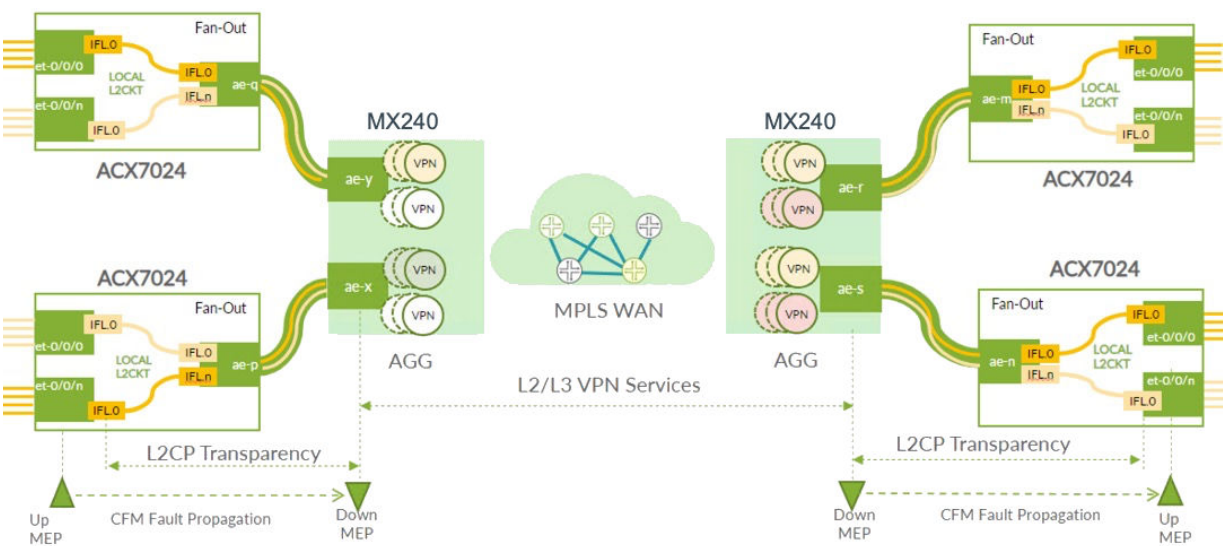
The validations are done using Juniper's ACX7024 Cloud Metro Router as a fan-out device and MX240 (with MPC10E and MPC7) as edge routers. The forwarding ASIC in the ACX7024 router has throughput of 360 Gbps and 300 Mpps. The demonstrated fan-out design patterns and methodology is applicable to other combinations of routers and switches if they possess the required capabilities. With the combination of an ACX7024 router and an MX Series router, we have successfully performed extensive tests for a 100GE port fan-out solution and confirmed that the solution works flawlessly.

Solution Benefits

IN THIS SECTION

Since the early days of data networking, equipment manufacturers are striving to make bigger, better, denser (in terms of speeds and feeds as well as features), and faster switches and routers. Although these goals are being consistently achieved, fast, dense, and feature rich network equipment presents specific scalability and flexibility challenges. These challenges are more pronounced at, but not limited to, the edges of a network where customer's equipment connects (or attaches) to the provider's equipment. These challenges are best addressed by network design through port fan-out architectures.

Figure 1: Port Fan-Out Solution Architecture



Cost Effective

Attachment circuits at the edges of a network are often (maybe even most of the time) running at a fraction of their native or design capacity (both speeds and features). This is because they are dedicated to a specific customer who rarely consumes a port's abilities in their entirety and typically transmits and receives traffic. This is usually considered inefficient because there is excess capacity (speeds and features) that is not being consumed, which leads to higher capital and operating costs.

In an effort to drive higher capacity utilization and reduce costs in the world of compute and storage, virtualization was invented and is now widely deployed. A port fan-out architecture does to network design what virtualization does to compute and storage – drives higher capacity utilization and reduces costs of fast, capable, and expensive edge router ports.

Flexible Port Options

A fan-out design addresses the need to provide slower Ethernet attachment circuits, for example, 1/10/25/40GbE, as well as their sub-rates and multiples, while preserving features and capabilities available to a customer on an edge router's port.

Higher Port Density

There are several significant benefits of a fan-out design for edge routers. The customer density per fast, feature-reach, and expensive port increases from a ratio of 1:1 to N:1, where N ranges from a few ports to hundreds of ports, depending on the type and model of the fan-out device being used. The ratio gets even bigger if we consciously allow oversubscription, which works well for bursty traffic. This increase of customer and service density per edge router port allows network operators to maximize use of their investment in hardware and licenses.

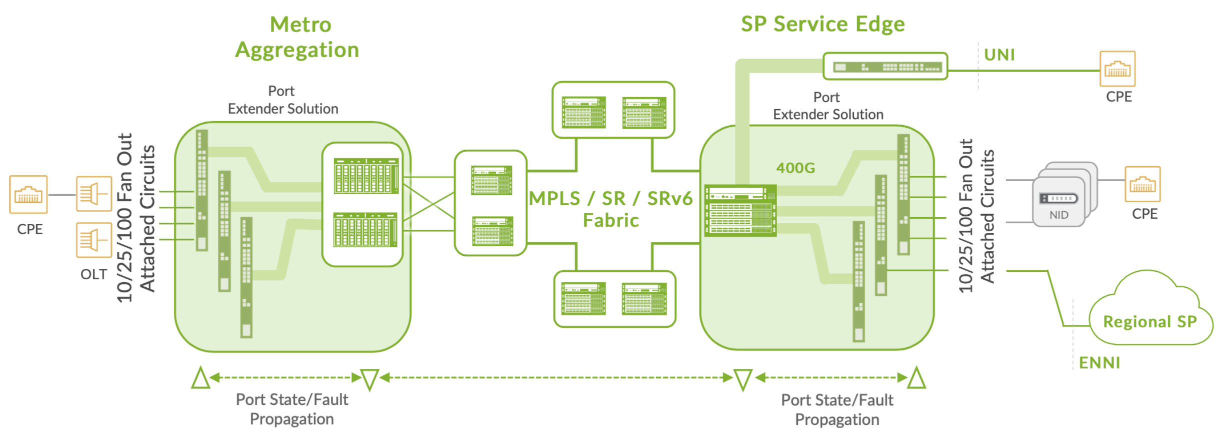
Minimum Provisioning Efforts and Transparency

The fundamental benefit of the proposed solution is the minimal provisioning effort required to maintain connections at fan-out devices during the life cycle of the provided network services. This is possible due to the full transparency and port state synchronization between the customer-facing physical port of the FO-node and the logical interfaces of the PE-device for the Layer 2 (L2) protocols. In other words, connecting a new attached circuit to the fan-out device would look like attaching it directly to the port of the PE-node and requires zero configuration changes to be done at FO-node at the time of connecting a new or swapping existing attached circuits.

Use Case Overview

In the modern WAN networks, 100G/400G port speeds are a common requirement in the service providers' multiservices edge (MSE) and metro aggregation scenarios and even in enterprise class networks. Nonetheless, lower speed ports continue to be extensively utilized. While achieving the necessary port diversity within a single chassis system is feasible, it often falls short of being optimal in terms of total cost of ownership (TCO), performance, and power consumption. Introducing distribution or preaggregation network segments or layers emerges as the natural solution to consolidate traffic from lower speed attached circuits and route it towards centrally located aggregation nodes equipped with 100G/400G ports. With this JVD, we introduce a solution for a simple port-extender that addresses the need for efficient management and configuration of high-speed aggregation networks.

Figure 2: Port Fan-Out in the Multiservice and Metro Use Cases of the Service Provider Network



This JVD presents a network design that encompasses both the data and control planes for the port fan-out solution, utilizing the MX Series router as the aggregation PE device and the ACX Series router as the port fan-out device. The solution works best for use cases where the MSE PE-node or metro nodes aggregate traffic from access or preaggregation nodes or interconnects with another service provider through External Network-Network Interface (ENNI). Use cases with directly connected CPE devices to the FO-ports can be also conditionally addressed by the introduced fan-out solution. More specifically, the solution works best for aggregating and delivering traffic flows end-to-end from attached circuits, which already carry a service VLAN tag (S-VLAN) in the Ethernet frames.

This solution proves particularly beneficial for enabling the fan-out approach within a metro aggregation or within multi-service edge network segments of a service provider network, where the MX router's

Nx100G ports are fanned-out into lower port speeds with the ACX7024 router serving as the fan-out device.

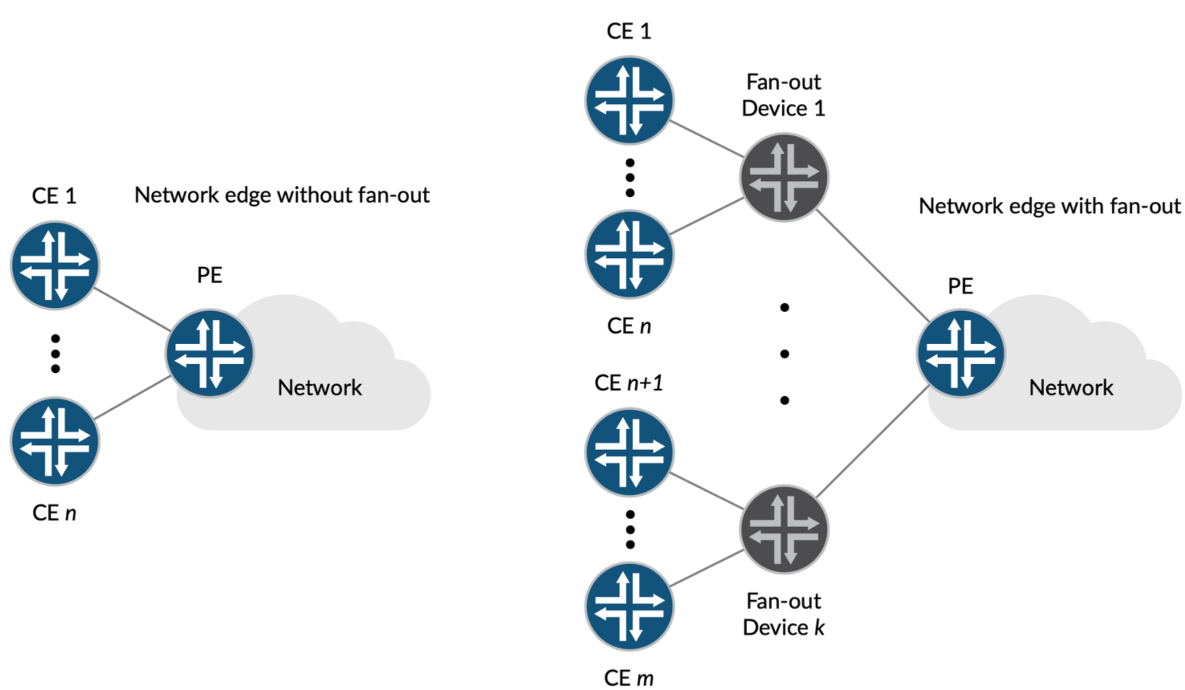
The key characteristics of this solution include:

- A full extender's physical port and optics laser status propagation to the aggregation node
- Full transparency for the L2 control traffic
- Streamlined operations and provisioning

This proposed solution needs a one-time provisioning of the fan-out device at day 0, with its configuration remaining unchanged as new attached circuits are connected to the ports of the fan-out device. Furthermore, the solution is entirely based on open standard protocols and can be readily extended for use with other variations of the Juniper Networks platforms if needed.

The port fan-out solution is an application of hierarchical network design principles at the network's edge, as depicted in Figure 3 on page 5. The port fan-out architecture creates an unobtrusive abstraction layer over the physical hardware that now sits between the customer's and the provider's equipment. This abstraction layer is transparent from the customer's perspective. In most deployments, it requires a minimal and localized configuration change on a provider's edge port, which doesn't affect or propagate to the rest of the network. Configuration of a fan-out device is also localized, straightforward, and doesn't change throughout its lifetime.

Figure 3: Network Edge Design with and Without Port Fan-Out



Solution Architecture

IN THIS SECTION

Solution Technical Overview

In the proposed solution the ACX7024 router acts as a fan-out device and the MX Series router is our choice for the PE-node and performs the following functions:

- **Aggregation and multiplexing of traffic** between multiple attached circuits at FO–PE link(s). Attached circuits may be either a plain Ethernet link or an aggregated Ethernet bundle.
- **Transparent L2 extension of a CE–PE link**. Transparency of a fan-out device manifests itself in both the data plane and the control plane:
  - In the data plane, the fan-out device is oblivious to *VLAN tags* that are either locally significant between CE and PE (on what previously was a direct Layer 1 (L1) CE–PE connection), or globally significant between local and remote CEs (for example, when PE provides L2 bridging of the customer's frames with L2 circuits or other means).
  - In the control plane, the fan-out device is oblivious to L2 control protocols (L2CPs) that have significance or meaning to either the CE or the PE or both. The fan-out device does not interact with the customer's L2CPs and transparently forwards their protocol data units (PDUs) between the CE–FO link and the FO–PE link.

    Note that there are L2CPs that are meant to be locally significant between link partners on an Ethernet link, this is discussed below.
  - L2CP transparency is what differentiates the fan-out design from generic hierarchical network designs where the network elements at different levels of network hierarchy actively interact with each other in the control plane for various purposes such as topology discovery, maintenance, and

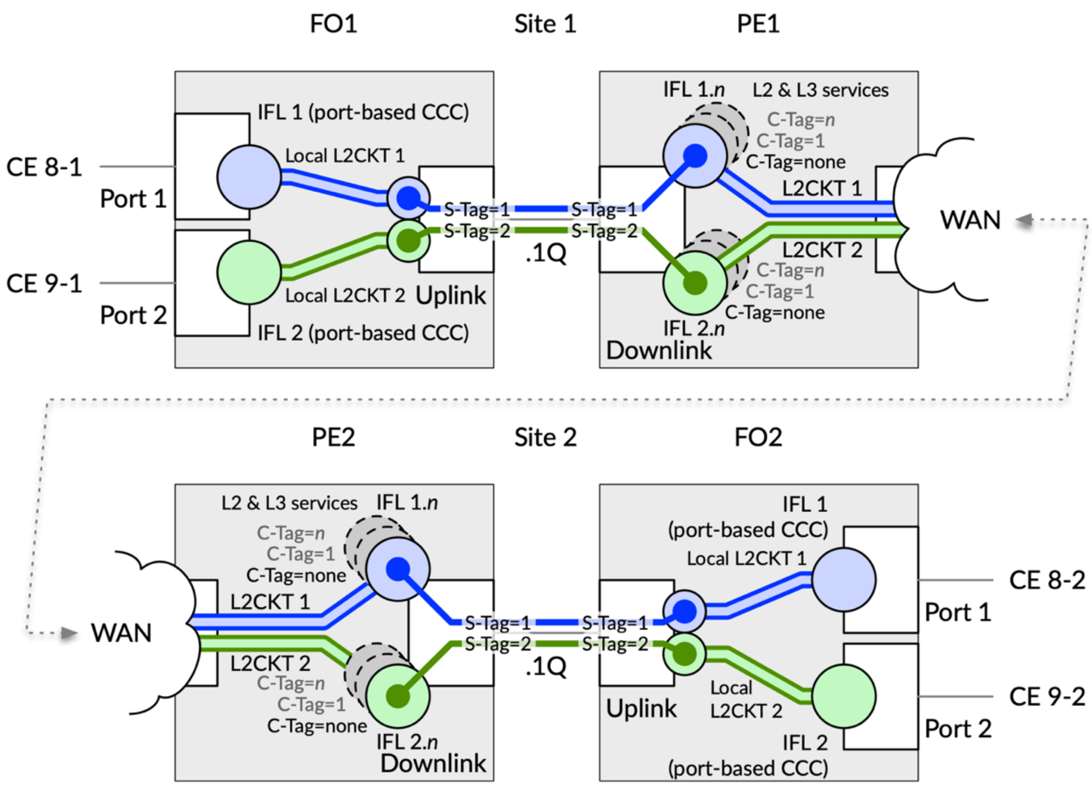
recovery (LACP, STP, link state routing protocols), disseminating reachability information (routing protocols), active in-band connectivity monitoring (BFD, CFM, protocol keepalives), and so on.

- Propagation of L1 link state between CE and PE, and between local and remote CEs.

The following list of features and design decisions represent the technical summary of the solution which can be used as a basis for a deployment and extension of the solution towards other Juniper platforms if needed:

- The L1 state of a local CE-facing interface propagates to remote CE-facing interface, and vice versa.
- The CE-facing interface is agnostic of customer's VLAN tags.
- The FO–PE link that carries traffic from multiple customers uses the simplest link virtualization technique available, without a control channel.
- The fan-out device is reasonably transparent for L2 and other control protocols.
- The data plane is implemented in a segmented manner: CE–FO, FO–PE, PE–PE. That is, there are no end-to-end tunnels, L2 circuits, and that hop over the top of the network.
- Fault propagation is implemented in a segmented manner: CE–FO, FO–PE, PE–PE. That is, there is no targeted FO-to-FO propagation.
- PE–PE fault propagation uses existing underlying network's signaling such as a status TLV in LDP-signaled L2 circuits, route advertisement and withdrawal by routing protocols where L3 routed services are used, and so on.

Figure 4: Data Plane Forwarding



- The fan-out device is an L2 extension of a PE (or PEs), thus doesn't perform local switching between CE facing ports, CE to CE communication always takes place through a PE device.

- Services provided on PEs can be point-to-point or multipoint L2 or L3 services. For example, vanilla IP routing, bridging, L2 VPNs (VPWS, VPLS, EVPN), and so on.

- Both in-band and out-of-band management options are available to manage the fan-out device.

- The FO's CE-facing physical interface (IFD) uses port-based CCC encapsulation.

- Asynchronous notification (means laser-off is allowed) is enabled on the FO's CE-facing IFD. This allows the L2 circuit and CFM MEP to control the CE-facing port's laser when it needs to signal a failure towards the CE.

- On the fan-out device, the local point-to-point L2 circuit bridges customer frames between the CE-facing the logical interface (IFL) on the attachment circuit and PE-facing IFL on the FO-PE link. There is no MAC address learning.

- Frames that traverse FO–PE link belong to multiple customers. 802.1Q VLAN tagging is used on the FO–PE link as a link-level virtualization technique. Think of them as S-TAGs. The fan-out device employs VLAN manipulation to push a multiplexing outer VLAN tag onto a customer's frame on egress towards the PE and pops the multiplexing outer VLAN tag from a customer's frame on ingress from the PE.

- The PE's IFLs pop the multiplexing outer VLAN tag from a customer's frame on ingress from the fan-out device and push a multiplexing outer VLAN tag onto a customer's frame on egress towards a fan-out device. An existing customer's PE IFL configuration needs to be adjusted to account for multiplexing outer VLAN tag on the FO–PE link. Note that Juniper's devices can process up to two outermost VLAN tags when deciding which IFL should accept a frame.

- Services on PE's IFLs are orthogonal to port fan-out and can be any point-to-point or multipoint L2 and/or Layer 3 (L3) services. PE's IFL is a demarcation line between fan-out domain and the rest of the provider's network, and multiplexing VLAN tag glues them together in a continuous end-to-end data plane.

Port Mapping and Traffic Multiplexing

On the fan-out device, the customer's L2 frame information is preserved. The frame's original VLAN tags are not manipulated (although this is possible if needed through the CLI). The fan-out device is indifferent (agnostic) of the L2 and L3 technology headers of traffic that needs to be transported between CE and PE, and services provided by the PE.

The fan-out device pushes a VLAN tag onto the customer frame which might be untagged, single-tagged, or multiple-tagged on ingress to the fan-out device from the CE. It is common to refer to the outer and inner tags as Service VLAN (S-VLAN) and Customer VLAN (C-VLAN) tags respectively. On the FO–PE link, the S-VLAN identifies one CE device. This is the only VLAN tag that the fan-out device cares about, and S-VLAN tag acts as a pure locally significant multiplexing field on FO–PE link. The fan-out device is just a transparent cross-connect between an attachment circuit and PE interface. The C-VLAN identifies one customer service such as a circuit on the PE.

This is achieved by the following configuration on the fan-out device:

1. The CE-facing interface is configured to use port-based mode for cross-connect local L2 circuit. See configuration in "Example 1" on page 10.

2. The PE-facing interface is configured to use VLAN-tagged mode. Because the FO–PE link carries traffic of multiple customers. We need to somehow multiplex them. This is also known as link virtualization. There are several alternatives that allow virtualization of a point-to-point link: GRE or VXLAN tunneling, VPWS, or tagging with VLAN tags or MPLS labels. VLAN tagging is the simplest and easiest of them all and doesn't require a dedicated control channel between the ends of the link. For this reason, the port fan-out solution uses VLAN tagging as a FO–PE link virtualization method.

3. Local cross-connects (think local pseudowire, which are internally in the device) transparently bridge Ethernet frames between pairs of interfaces, CE-facing and PE-facing, as shown in "Example 3" on page 11 . There is no MAC address learning during this process.

Note that the fan-out device doesn't perform local switching between CE-facing ports. Thus, CE to CE communication always takes place through a PE device, similarly to what it was when the CE and PE were directly connected.

Example 1: Fan-Out Device—Customer Facing Interface (CE–FO link)

```
interfaces {
    /* Facing CUSTOMER 81 */
    et-0/0/10 {
        encapsulation ethernet-ccc;
        unit 0;
    }
    /* Facing CUSTOMER 91 */
    et-0/0/12 {
        encapsulation ethernet-ccc;
        unit 0;
    }
}
```

Example 2: Fan-Out device—Network Facing Interface (FO–PE link)

```
interfaces {
    /* Facing PE - AE member link */
    et-0/0/17 {
        ether-options {
            802.3ad ae1;
        }
    }
    /* Facing PE */
    ae1 {
        flexible-vlan-tagging;
        encapsulation flexible-ethernet-services;
        aggregated-ether-options {
            minimum-links 1;
            /* Inactive because of PR 1713849 */
            inactive: lacp {
                active;
                periodic fast;
```

```
            }
        }
        unit 1 {
            encapsulation vlan-ccc;
            vlan-id 81;
            input-vlan-map pop;
            output-vlan-map push;
        }
        unit 2 {
            encapsulation vlan-ccc;
            vlan-id 91;
            input-vlan-map pop;
            output-vlan-map push;
}}}
```

Example 3: Fan-Out device—Local Cross-Connect Between Customer and Network-Facing Interfaces

```
protocols {
    l2circuit {
        local-switching {
            /* CUSTOMER 81 - CE-facing to PE-facing cross-connect */
            interface et-0/0/10.0 {
                end-interface {
                    interface ae1.1;
                }
            }
            /* CUSTOMER 91 - CE-facing to PE-facing cross-connect */
            interface et-0/0/12.0 {
                end-interface {
                    interface ae1.2;
                }
            }
}}}
```

Firstly, on a PE device, we need to configure customer facing IFLs to accept customer frames. As soon as an IFL accepts a frame, the PE processes it in accordance with the services configured on that IFL. This essentially makes PE's IFL a demarcation line between the fan-out domain and the rest of the network with its services. As a result, the port fan-out compartment is completely agnostic of services provided on a PE or in the network in general.

Recall that on the FO–PE link, the outer VLAN tag (S-TAG from the PE's perspective) is used as a locally significant multiplexing field and an outer tag's VLAN ID identifies one CE device. The outer tag protocol

ID (TPID) is by default set to 0x8100 by the fan-out and PE devices, and there isn’t a need to change this default behavior. The inner tag (C-TAG from the PE's perspective, with its C-VLAN and C-TPID) identifies one customer service on the PE.

Each IFL is configured with either a vlan-id <S-VLAN> or vlan-tags outer <S-VLAN> inner <options>.

"No Link Title" on page 12 illustrates how the IFL demultiplexes and accepts frames before they are sent to respective services for further processing:

- All traffic with S-TAG = 81 and any C-TAG (including no C-TAG, or an arbitrary long stack of tags) belongs to Customer 81.
- The IFL ae0.8101 accepts frames with S-TAG = 81 and C-TAG = 2001. Note that on a CE–FO link these frames are single-tagged with VLAN ID = 2001.
- The IFL ae0.8102 accepts frames with S-TAG = 81 and C-TAG = 2002.
- The IFL ae0.8103 accepts frames with S-TAG = 81 and C-TAG = 2003.
- The IFL ae0.8198 illustrates L2 service configuration with the inner-range option; it accepts frames with S-TAG = 81 and C–TPID.TAG of 0x88a8.666–667.
- The IFL ae0.8199 illustrates L2 service configuration. This time with the inner-list option; it accepts frames with S-TAG = 81 and C-TAGs of 1–665, 668–2000, 2010–4094.
- The IFL ae.8100 accepts frames with S-TAG = 81 and either no C-TAG at all or a C-TAG that did not match any other IFL with the same S-TAG. Some people find this to be quite unexpected.

The VLAN manipulation input-vlan-map pop and the output-vlan-map push is what pushes an outer locally significant multiplexing S-TAG to customer's frame on egress towards the fan-out device and pops it on ingress from the fan-out device.

The FO-PE link in the "Example 4" on page 12 is an aggregated Ethernet bundle configured in static mode to match fan-out device's configuration in the "Example 2" on page 10.

Example 4: PE Device—Fan-Out Facing Interface (FO–PE link), with Dummy IFLs for Ingress Admission Control

```
interfaces {
    /* Facing FO - AE member link */
    xe-0/0/1:0 {
        gigether-options {
            802.3ad ae0;
        }
    }
    ae0 {
```

```
        /* Facing FO */
        flexible-vlan-tagging;
        encapsulation flexible-ethernet-services;
        aggregated-ether-options {
            minimum-links 1;
            /* Deactivated as a temporary workaround for PR 1713849 */
            inactive: lacp {
                active;
                periodic fast;
            }
            ethernet-switch-profile {
                tag-protocol-id [ 0x8100 0x88a8 ];
            }
        }
        /* Facing CUSTOMER 81 via FAN-OUT: CE-untagged or priority-tagged service + non-explicit
VIDs */
        unit 8100 {
            encapsulation vlan-ccc;
            vlan-id 81;
            input-vlan-map pop;
            output-vlan-map push;
        }
        /* Facing CUSTOMER 81 via FAN-OUT: CE-single-tagged service 1 (L2) */
        unit 8101 {
            encapsulation vlan-ccc;
            vlan-tags outer 81 inner 2001;
            input-vlan-map pop;
            output-vlan-map push;
        }
        /* Facing CUSTOMER 81 via FAN-OUT: CE-single-tagged service 2 (L2) */
        unit 8102 {
            encapsulation vlan-ccc;
            vlan-tags outer 81 inner 2002;
            input-vlan-map pop;
            output-vlan-map push;
        }
        /* Facing CUSTOMER 81 via FAN-OUT: CE-single-tagged service 3 (L3) */
        unit 8103 {
            vlan-tags outer 81 inner 2003;
            /* Vlan-maps are not needed on L3 IFLs  */
            family inet {
                address 169.254.81.254/24;
            }
```

```
            family inet6 {
                address 2001:db8:169:254:81::fffe/112;
            }
        }
        /* Facing CUSTOMER 81 via FAN-OUT: CE-single-tagged service - Etype/VID example */
        unit 8198 {
            encapsulation vlan-ccc;
            /* vlan-tags valid only with ccc/vpls/bridge encapsulation */
            vlan-tags outer 0x8100.81 inner-range 0x88a8.666-667;
        }
        /* Facing CUSTOMER 81 via FAN-OUT: CE-single-tagged service - VID list example */
        unit 8199 {
            encapsulation vlan-ccc;
            vlan-tags outer 81 inner-list [ 1-665 668-2000 2010-4094 ];
        }
        /* Rinse and repeat for other customers; mind the outer VLAN tag */
    }
}
```

For a detailed configuration guide, contact your Juniper Networks representative.

Fault Detection and Propagation

Fault detection and propagation is one of the differentiating components of the solution. Fault propagation is implemented in segmented fashion: CE-FO, FO-PE, PE-PE. That is, there is no FO-to-FO CFM MA over the top of the network. The CFM MA is the connectivity fault management maintenance association. When implementing fault detection and propagation, remember the following:

- The Propagation method is a local matter on each segment.
- The CE-FO segment uses the fan-out device local cross-connect ability to drive IFL/IFD state (logically down or laser off) alone, or in combination with the CFM maintenance association end point (MEP).
- The FO–PE segment uses the CFM MEP's Interface Status TLV and/or adjacency events, depending on direction of propagating fault.
- The PE-PE segment is independent of and unrelated to the port fan-out solution. We suggest that you use the underlying network's fault detection and propagation signaling such as the status TLV in the LDP-signaled L2 circuit, BFD, and so on.

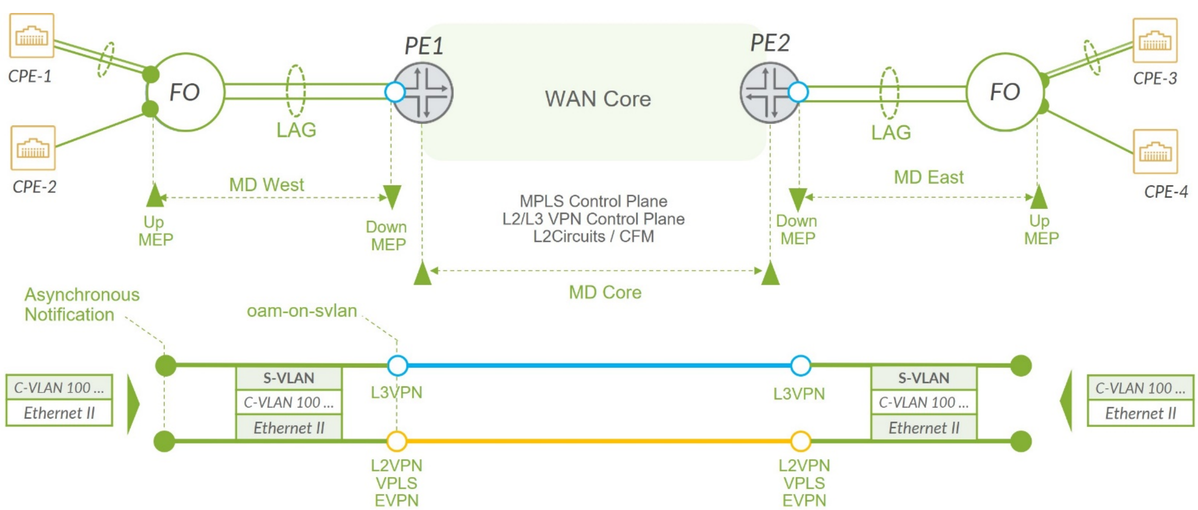
- In case of point-to-multipoint connectivity between PE IFLs, consider using end-to-end CFM MA between FO's CE-facing ports.

With the introduction of a fan-out device, there is no longer L1 continuity between the CE and PE which impacts the link state propagation between the CE-facing and PE-facing interfaces on fan-out device. The port fan-out solution employs CFM as CFM (IEEE 802.1g, ITU-T G.8013 / Y.1731) offers the necessary capabilities to operate and maintain the network and service aspects of the Ethernet layer in point-to-point and multipoint topologies.

CFMs *continuity check* capability is used to detect loss of continuity between a pair of MEPs. When a MEP does not receive continuity check information from a peer MEP, in the list of its peer MEPs, within an interval of 3.5 times the continuity check transmission period, it detects loss of continuity (called loss of adjacency in Junos OS) to that peer MEP. The interval corresponds to a loss of three consecutive frames carrying continuity check information from the peer MEP.

MEPs make use of the Interface Status TLV that indicates the status of the interface on which the MEP transmitting the connectivity check message (CCM) is configured.

Figure 5: CFM Up–Down MEP Design and Fault Propagation



Note that the CFM session between the FO and PE pair (MD West and MD East in the Figure 5 on page 15) are integral part of the solution. The MD Core shown in Figure 5 on page 15 is agnostic to fan-out solution. The choice of a protocol used for connectivity control and state propagation between PE-nodes depends on the type of network service implemented in the network. The protocol could be the status TLV in LDP-signaled L2 circuits, IGP or MP-BGP signaling for L3VPN control plane and so on.

Eight maintenance domains (MD) in Junos OS speak, or maintenance entity groups (MEG) in ITU-T speak levels are available to accommodate different network deployment scenarios. The ITU-T recommends this default MD level assignment amongst customer, provider, and operator roles:

- The customer role is assigned three MD levels: 7, 6, 5
- The provider role is assigned two MD levels: 4, 3
- The operator role is assigned three MD levels: 2, 1, 0

The specific MD level assignment in the production network is a matter of mutual agreement among customer, provider and/or operator, and might differ from what we have used during our validation.

Fault detection and propagation in the port fan-out solution adheres to modular hierarchical design principles and handles faults in a segmented and compartmentalized manner, similar to how we approached the problem of building an end-to-end data path in the previous section. The PE's IFLs create a demarcation line between the fan-out fault domain and the rest of the network. As a result, the port fan-out compartment is completely agnostic of faut detection and propagation methods and procedures used in the network between PEs.

Figure 5 on page 15 illustrates the CFM design and end-to-end fault propagation in the port fan-out solution. In a real deployment, some CEs may connect to their PEs through fan-out devices while others may not, this does not affect proposed fault propagation design nor its operation.

On the fan-out device, Up MEP is configured on the CE-facing IFL. Up MEP actively probes connectivity through the packet forwarding engines (PFEs) on the fan-out device and its local cross-connect between CE-facing and PE-facing IFLs, on a per customer basis. If connectivity between a CE facing port on fan-out device and a PE becomes non-operational for any reason, this will be detected by the Up MEP which shuts down the laser of the CE facing port on the PO device, which in turn, signals the event to the CE. Respectively, the Down MEP configured on the S-VLAN logical interface on the PE device controls the states of corresponding customer IFL's.

Note that in most cases the PE will have multiple CE-facing IFLs per customer (one IFL per deployed service). When the physical port on fan-out device goes down, we must assure that the failure state is accurately signaled to each service-IFL on the PE-device. To achieve that a special oam-on-svlan function is enabled on the MX PE-node to propagate the state of the S-VLAN to all logical interfaces which are configured with a given S-VLAN tag. Think of them as parent IFL and children IFLs. Parent and children IFLs in turn propagate their state throughout the rest of core network as usual, through underlying network's signaling such as a status TLV in LDP-signaled L2 circuits, route advertisement and withdrawal in the case of a L3 IFL, and so on. At the release of this JVD with Junos OS Release 23.4R2 the OAM state propagation only happens in the parent to children direction, from SVLAN to all CVLANs. State propagation in the opposite direction, from children to their parent, may be considered in future releases of Junos OS software.

This solution provides a consistent fault detection and state propagation and synchronization between physical ports of the fan-out device and mapped logical interfaces (IFL's) of the PE-device for the following failure events:

1. CE-facing on PO device is down

2. FO-PE link is down

3. FO to PE connectivity failure (any reason other than FO-PE link failure)

4. CE facing IFL on PE device is down (driven by the Core MD control plane)

To illustrate the state propagation workflow, consider a CE-facing link failure where the CE brings its interface down or a fiber cable gets cut.

In this situation the FO's interface registers an Rx loss of line (LOL)/loss of service (LOS) event and shortly thereafter brings CE-facing IFL down. From this moment, two concurrent chains of events begin to unfold:

1. The Local L2 circuit on the fan-out device propagates the fault to its PE-facing IFL, brings it down and keeps it down until the Rx LOL/LOS condition clears on CE-facing interface.

2. Concurrently, the Up MEP on the CE-facing IFL ceases to receive connectivity check messages (CCMs) from its Down MEP peer on the PE, because its underlying IFLs has been brought down in response to the Rx LOL/LOS on the physical CE-facing interface. Within an interval of 3.5 times the configured continuity check transmission period, it detects loss of continuity (adjacency-loss in Junos speak) to the peer MEP on the PE and sends a laser off command to an interface (known as an asynchronous-notification in Junos). The CE-facing interface turns its laser off.

NOTE: IMPORTANT: If the CE implements the exact same logic, then even when it becomes operational again, it will have to keep its laser off in response to the LOL/LOS caused by the MEP's action. At this point, we have a deadlock and manual intervention is required to clear it. To avoid a deadlock, ensure CE does not turn its laser off in response to Rx LOL/LOS at its end.

On the PE device, the Down MEP similarly ceases to receive connectivity check messages (CCMs) from its Up MEP peer on the fan-out, because fan-out’s local cross-connect circuit brought down its respective IFL when it propagated the fault. Within an interval of 3.5 times the configured continuity check transmission period, The Down MEP detects loss of continuity (adjacency-loss in Junos OS speak) to the peer MEP on the PE and performs the action defined in its action-profile (for example, interface-down) of the parent IFL, which thanks to oam-on-svlan automagically brings down its children IFLs.

Finally, the fault propagates throughout the network to the far end PEs through respective signaling mechanisms. A parent IFL on a far end PE goes down. The Down MEP configured on this IFL originates interface status TLV = down to its peer Up MEP on the fan-out device, which then turns the laser off on the CE-facing interface. The CE registers Rx LOL/LOS faults and processes in accordance with its configuration. That completes the propagation cycle of the CE-FO failure.

For the complete configuration details for fan-out failure detection and state propagation, contact your Juniper Networks representative.

Port Fan-Out L2CP Transparency

Transparency in the data plane is relatively easy to achieve. While different switches and routers and software versions demonstrate various degrees of L2CP transparency and offer different controls to an operator, It is impractical to aim at absolute L2CP transparency because some L2CPs are designed to be locally significant between link partners on an Ethernet link. Notable examples are IEEE 802.3 Ethernet PAUSE, IEEE 802.1Qbb priority flow control (PFC), and micro-BFD.

Table 1 on page 18 has a summary of L2CP and other control protocol transparency test results for the ACX702 device and the MX480 MPC10E router.

Table 1: L2 and Other Control Protocols Transparency Results, ACX7024, MX480 MPC10E

Layer 2 and Other Control Protocol	Result
01:00:0c:cc:cc:cc 0xaa 0xaa 0x00000c 0x2004 DTP	PASS
01:00:0c:cc:cc:cd 0xaa 0xaa 0x3 0x010b PVST+	PASS
01:80:c2:00:00:00 0x42 0x42 0x3 STP	PASS
01:80:c2:00:00:00 0x8809 0x01 LACP alt. DMAC (Nearest Customer Bridge)	PASS
01:80:c2:00:00:00 0x888e EAPOL/MKA alt. DMAC (Nearest Customer Bridge)	PASS
01:80:c2:00:00:00 0x88cc LLDP alt. DMAC (Nearest Customer Bridge)	PASS
01:80:c2:00:00:01 0x8808 0x0001 802.3x PAUSE	PEER (1)
01:80:c2:00:00:01 0x8808 0x0101 802.1Qbb PAUSE	PEER (1)
01:80:c2:00:00:02 0x8809 0x01 LACP default DMAC (Slow Protocols)	PASS | PEER | DROP
01:80:c2:00:00:02 0x8809 0x02 LAMP default DMAC (Slow Protocols)	PASS | PEER | DROP
01:80:c2:00:00:02 0x8809 0x03 Link OAM	PASS
01:80:c2:00:00:02 0x8809 0x0a ESMC	DROP
01:80:c2:00:00:03 0x8809 0x01 LACP alt. DMAC (Nearest Non-TPMR Bridge)	PASS
01:80:c2:00:00:03 0x8809 0x02 LAMP alt. DMAC (Nearest Non-TPMR Bridge)	PASS

Table 1: L2 and Other Control Protocols Transparency Results, ACX7024, MX480 MPC10E *(Continued)*

Layer 2 and Other Control Protocol	Result
01:80:c2:00:00:03 0x888e EAPoL/MKA default DMAC (Nearest Non-TPMR Bridge)	PASS
01:80:c2:00:00:03 0x88cc LLDP alt. DMAC (Nearest Non-TPMR Bridge)	PASS
01:80:c2:00:00:04 802.1Q MAC-specific Ctrl Protos	PASS
01:80:c2:00:00:05 802.1Q Reserved for future	PASS
01:80:c2:00:00:06 802.1Q Reserved for future	PASS
01:80:c2:00:00:07 0x88ee MEF E-LMI	PASS
01:80:c2:00:00:08 Provider Bridge Group	PASS
01:80:c2:00:00:09 802.1Q Reserved for future	PASS
01:80:c2:00:00:0a 802.1Q Reserved for future	PASS
01:80:c2:00:00:0b 0x888e EAPOL/MKA alt. DMAC (EDE-SS PEP Address)	PASS
01:80:c2:00:00:0c 802.1Q Reserved for future	PASS
01:80:c2:00:00:0d 0x88f5 Provider Bridge MVRP	PASS
01:80:c2:00:00:0e 0x888e EAPOL.MKA alternate DMAC (Nearest Bridge)	PASS
01:80:c2:00:00:0e 0x88cc LLDP default DMAC (Nearest Bridge)	PASS
01:80:c2:00:00:0e 0x88f7 PTP	PASS
01:80:c2:00:00:0f 802.1Q Reserved for future	PASS
01:80:c2:00:00:1f 0x888e EAPOL/MKA alt. DMAC (EDE-CC PEP Address)	PASS
01:80:c2:00:00:20-2f GARP/MRP	PASS
01:80:c2:00:00:30 0x8902 CFM Level 0	PASS or DROP (2)

Table 1: L2 and Other Control Protocols Transparency Results, ACX7024, MX480 MPC10E *(Continued)*

Layer 2 and Other Control Protocol	Result
01:80:c2:00:00:31 0x8902 CFM Level 1	PASS or DROP (2)
01:80:c2:00:00:32 0x8902 CFM Level 2	PASS or DROP (2)
01:80:c2:00:00:33 0x8902 CFM Level 3	PASS or DROP (2)
01:80:c2:00:00:34 0x8902 CFM Level 4	PASS or DROP (2)
01:80:c2:00:00:35 0x8902 CFM Level 5	PASS or DROP (2)
01:80:c2:00:00:36 0x8902 CFM Level 6	PASS or DROP (2)
01:80:c2:00:00:37 0x8902 CFM Level 7	PASS or DROP (2)
micro-BFD 01:00:5e:90:00:01 udp/6784	DROP

Legend:

- DROP—A frame is dropped on ingress without any further processing.
- PASS—A frame is transparently forwarded, without processing in the control plane.
- PEER—A frame is trapped on ingress and sent to control plane for local processing.

Notes in Table 1 on page 18:

(1) 802.3 MAC Control frames with DMAC 01-80-C2-00-00-01 and EtherType 0x8808 are discarded in hardware as these packets are considered Rx control packets by the DNX Jericho 2 chipset of the FO deice and consumed in hardware irrespective of their subtype. Due to this hardware behavior, all types of 802.3 MAC Control frames such as Pause, Priority Flow Control, Multipoint MAC control and Organization Specific Extensions are discarded in hardware.

(2) In ITU-T G.8013/Y.1731 OAM functions and mechanisms for Ethernet based networks, OAM transparency refers to the ability to allow transparent carrying of OAM frames belonging to *higher-level* MEGs across other lower-level MEGs when the MEGs are nested. OAM frames belonging to an administrative domain originate and terminate in MEPs present at the boundary of that administrative domain. A MEP prevents OAM frames corresponding to a MEG in the administrative domain, from leaking outside that administrative domain. However, when a MEP is not present or is faulty, the associated OAM frames could leave the administrative domain. Similarly, a MEP present at the boundary of an administrative domain protects the administrative domain from OAM frames belonging to other administrative domains. The MEP allows OAM frames from outside administrative domains belonging to

higher-level MEs to pass transparently, while it blocks OAM frames from outside administrative domains belonging to *same or* lower-level MEs.

QoS/CoS Considerations

CoS config is a critical part of the solution which enables the network to avoid false positive interface failure detection in congestion scenarios: FO-CE interface congestion and FO-PE interface congestion. High level design principals and solution requirements for quality of service are:

1. The oversubscription of a fan-out device should be avoided or reduced to a reasonable and acceptable level
2. Contention of FO—PE link must be under check
3. Prevent overwhelming of a customer's attachment circuit FO➜CE
4. Minimal and localized alterations to an already existing QoS architecture, design, and deployment

Class of Service Design

Oversubscription of fan-out can be eliminated by sizing fan-out device appropriately during network design. Choose a fan-out device model that has adequate forwarding capacity for aggregate bandwidth on its customer-facing interfaces plus FO-PE links. For example, forwarding ASIC in ACX7024 has throughput of 360 Gbps and 300 Mpps:

1. On a fan-out device:
    - Ingress from CE
        - Traffic conditioning by envelope policing of transit/revenue traffic on a customer's attachment circuit. (Traffic is received or sent in regulated amounts to ensure that it fits within the acceptable or promised/agreed traffic profile for a particular set of flows. We call this traffic profile an envelope. There are many ways to define a set of flows such as per subscriber or group of subscribers, per service, logical interface, and so on. Conformance to a traffic envelope is enforced by input policing and output queueing and scheduling (incl. shaping). This limits surges that may congest a network and/or violate a service level agreement (SLA). The port fan-out solution makes use of these concepts and tools at various levels of the Hierarchical QoS architecture.
        - The MEF 10.4 Subscriber Ethernet Service Attributes has the following definition: An Envelope is a set that contains one or more bandwidth profile flows that can share bandwidth resources that are represented by tokens. This avoids oversubscribing the FO-PE link in a

deployment that is prone to such oversubscription because of deliberately or incorrectly sized fan-out device interfaces facing customers and the PE. Also, if there is a possibility of a customer exceeding their contractual traffic rate, ingress envelope policing can be moved from IFLs on the PE to a customer facing interface on the fan-out device, so that excess traffic never traverses FO-PE link.

  - Assign your own CFM Up MEP's PDUs to a dedicated forwarding class, with its own egress queue (think of it as a super network control class and its queue). Up MEP's PDUs appear as they have entered fan-out device through a front panel port. They undergo exact same treatment as any other ingress packet. This is by OAM/CFM design.

  - Assuming that the fan-out device and its interfaces are sized such that there is no potential for oversubscription of the FO-PE link, all transit traffic ingressing from a CE is treated as belonging to the same forwarding class and enqueued in the same egress queue on a PE facing interface.

- Egress to PE

  - Separate own real-time and near-real-time control traffic from transit/revenue traffic by enqueueing them in different queues.

  - Do not mix [near-]real-time (own CFM PDUs) and bulk control or management traffic.

  - Optional. Increase priority of the network control queue to minimize jitter for [near-]real-time control traffic. Inconsistent arrival times of CFM continuity check messages are known to cause loss of MEP adjacency on a peer MEP at short continuity check intervals and with low loss-threshold setting.

- Ingress from PE

  - Assign peer's CFM PDUs to a dedicated forwarding class, with its own egress queue (a super network control class and its queue).

  - If egress envelope shaping (envelope shaping, in Juniper terminology refers to hierarchical shaping which is available on MX Series routers) to a contractual or attachment circuit's rate is implemented on a PE towards a customer, all transit traffic ingressing from a PE is treated as belonging to the same forwarding class and enqueued in the same egress queue on a CE-facing interface.

- Egress to CE

  - If egress envelope shaping to a contractual or attachment circuit's rate is implemented on a PE towards a customer, all transit traffic ingressing from a PE is treated as belonging to the same forwarding class and enqueued in the same egress queue on a CE-facing interface.

2. On a PE:

- Ingress from fan-out (and customer)

- Apply your usual traffic conditioning (for example, policing), QoS classification, filters, and so on. Ensure that while doing so you are not inadvertently punishing incoming peer's CFM PDUs.

- Egress to network
  - Apply your usual scheduling and queueing, ToS re-write, and so on.

- Ingress from network
  - Classify ingressing control and management traffic into a traffic class other than default network-control class. This is to avoid mixing transit control and management traffic with own CFM Down MEP's PDUs that are sensitive to jitter and loss and are enqueued in the default network-control queue (explained why later in this section).

- Egress to fan-out (and customer)
  - Envelope shaping to the attachment circuit's rate or a contractual rate, whichever is lower.
  - Increase priority of the default network-control queue to minimize jitter for [near-]real-time control traffic. Recall that transit control ad management traffic has been classified in a different class on ingress from the network. Inconsistent arrival times of CFM continuity check messages are known to cause loss of MEP adjacency on a peer MEP at short continuity check intervals and with low loss-threshold setting.

- Self-originated (a.k.a. host-outbound, locally originated, or RE traffic) is being treated in a default manner.
  - For a complete list of self-originated control and management protocols and their queue assignment on Juniper's routers and switches, see: https://www.juniper.net/documentation/us/en/software/junos/cos/topics/example/cos-host-outbound-traffic-default-classification-and-dscp-remarking.html

Validation Framework

IN THIS SECTION

In the solution validation topology, the MX Series routers act as PE1 and PE2, configured MPLS WAN between them. Table 2 on page 24 outlines the list of protocols configured.

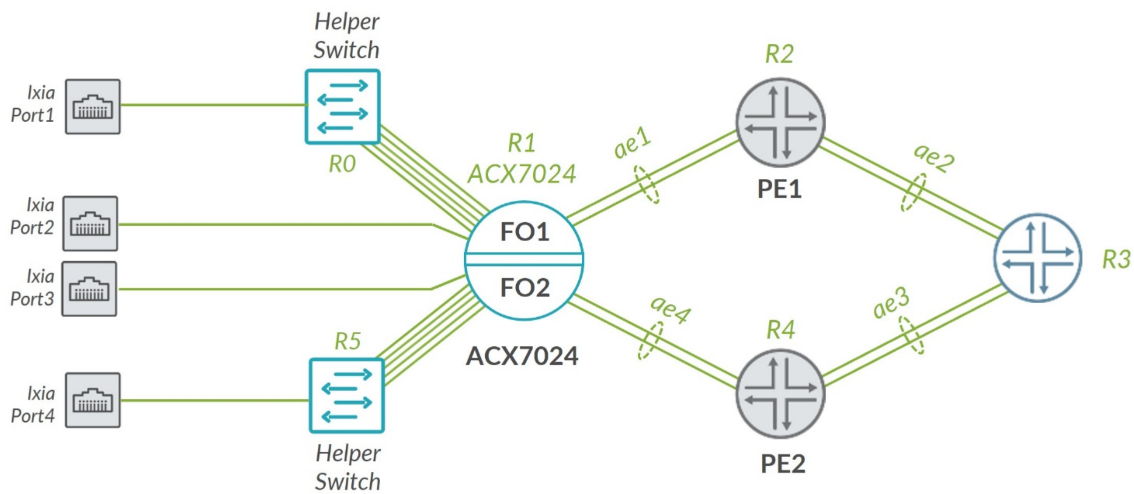
For fan-out, ACX7024 is used at both ends. A single ACX7024 is shared for both sides as shown in Figure 6 on page 25 . Customer traffic is emulated through Ixia.

Table 2: Protocol Scale Parameters

Protocol	Scale Number	Device Role/Name
L3VPN routes per VRF	2000	PE1,PE2
L2VPN Instances	12	PE1,PE2
EVPN Instances	12	PE1,PE2
L2VPN Instances	12	PE1,PE2
VPLS Instances	12	PE1,PE2
L2CKT Neighbors	12	PE1,PE2
iBGP Peers	1	PE1,PE2
LDP Sessions	1	PE1,PE2
OSPF Neighbors	1	PE1,PE2
CFM Sessions	12	PE1,PE2
Local-switching	24	Fan-out
Customers (asynchronous notification)	24	Fan-out
CFM Sessions	24	Fan-out

Test Bed

Figure 6: Validation Test-Bed Topology



Platforms / Devices Under Test (DUT)

To review the software versions and platforms on which this JVD was validated by Juniper Networks, see the Validated Platforms and Software section in this document.

Test Bed Configuration

Contact your Juniper Networks representative to obtain the full archive of the test bed configuration used for this JVD.

Test Objectives

IN THIS SECTION

JVDs are a cross-functional collaboration between Juniper solution architects and test teams to develop coherent multidimensional solutions for domain-specific use cases. The JVD team comprises technical leaders in the industry with a wealth of experience supporting complex customer use cases. The scenarios selected for validation are based on industry standards to solve critical business needs with practical network and solution designs.

The key goals of the JVD initiative include:

- Test iterative multidimensional use cases.
- Optimize best practices and address solution gaps.
- Validate overall solution integrity and resilience.
- Support configuration and design guidance.
- Deliver practical, validated, and deployable solutions.

A reference architecture is selected after consultation with Juniper Networks global theaters and a deep analysis of customer use cases. The design concepts that are deployed use best practices and leverage relevant technologies to deliver the solution scope. Key performance indicators (KPIs) are identified as part of an extensive test plan that focuses on functionality, performance integrity, and service delivery.

Once the physical infrastructure that is required to support the validation is built, the design is sanity-checked and optimized. Our test teams conduct a series of rigorous validations to prove solution viability, capturing, and recording results. Throughout the validation process, our engineers engage with software developers to quickly address any issues found.

The port fan out solution validates that PE's IFL is a demarcation line between the fan-out domain and the rest of the provider's network and is completely agnostic of services provided on a PE. The PE device is configured with customer facing IFLs to accept customer's frames and the PE processes it in accordance with services configured on that IFL. Hence, the services on PE's IFLs are orthogonal to port fan-out and can be any point-to-point or multipoint L2 and/or L3 services.

Validation Goals

The focus of the testing is to validate that the port fan-out Solution includes, but not limited to, the following features:

- L2circuit for point-to-point services between CEs
- L2VPN (VPWS, VPLS and EVPN-MPLS) for multipoint L2 services
- L3VPN for L3 VPN services
- QoS/CoS—Policing, QoS classification, filters, scheduling, and queueing
- OAM's Connectivity Fault Management (CFM) (IEEE 802.1g, ITU-T G.8013 / Y.1731) with UP MEP on FO and DOWN MEP on PE's
- CFM's continuity check Message (CCM) to detect loss of continuity between a pair of MEPs
- Asynchronous notification (laser-off) on fan-out’s CE-facing IFD
- PE–PE fault propagation using underlying status TLV in an LDP-signaled L2 circuit

The validation confirms that solution provides:

- A consistent traffic steering between fan-out device and service logical interfaces of the adjacent PE device
- A consistent fault and state propagation between fan-out and adjacent PE for failure and restore events
- A consistent fault propagation between local and remote FO nodes
- A consistent fault propagation between local and remote PE nodes
- A consistent system behavior on restoration events

Additional validations were performed to measure impact of:

- Restart/Kill of critical Junos OS or Junos OS Evolved processes and assess its impact
- Device reboot to evaluate impact in the network
- Interface flap events to evaluate impact on network traffic
- Deletion or configuration of various configuration stanzas to evaluate impact of node and network stability
- Clearing of protocol sessions to simulate protocol session flap and assess its impact on service and traffic

Validation Non-Goals

The following items were not part of the solution validation goals:

- Fan-out and PE devices' management plane integration
- Traffic steering based on three VLAN tags: C-VLAN, S-VLAN, FO-PE Multiplexing VLAN
- Protocols other than mentioned in the "Validation Goals" section

Results Summary and Analysis

IN THIS SECTION

Known Issues, Limitations, Restrictions, Caveats

- When implementing VLAN tagging on a Juniper device that uses service provider style interface configuration, you have the option to work with no tag, single tag (including what's known as a priority tag when VID is set to 0), dual tag, or a combination of them on the same interface. If prior to deployment of the port fan-out solution the PE used both outer and inner tags to identify one customer service, ability to work with no more than two VLAN tags on an IFL may be a limiting factor. Note that a frame can carry an arbitrarily deep stack of VLAN tags, a router or a switch is simply oblivious to anything beyond first two levels.
- OAM state propagation with oam-on-svlan is currently unidirectional, from S-VLAN to C-VLANs (parent IFL to children IFLs). We are working on adding state propagation in C-VLANs to their parent S-VLAN direction in future versions of Junos software.
- When several MEPs are attached to an IFL, only one should have its action profile configured with interface-down action, otherwise there will be races, contention and indeterministic results.
- State propagation like MEP1 ➜ IFL ➜ MEP2 is not possible between multiple MEPs configured on an IFL. Configuration commit fails when you attach more than one MEP with an action profile to an IFL.

- Neither CFM-driven nor L2 circuit (RPD) driven have any effect on AE interfaces. They only work on non-AE interfaces.

Recommendations

The landscape of modern WAN is rapidly evolving, driven by the relentless demand for higher speeds and more efficient data transmission methods. In this dynamic environment, the port fan-out solution, as tested and validated in the scope of this JVD, stands out as a beacon of innovation, flexibility, and cost efficiency.

Our extensive validation process has conclusively demonstrated that the proposed port fan-out solution, leveraging Juniper Networks' MX Series for aggregation and the ACX Series router for fan-out, meets the rigorous demands of contemporary network environments. The port fan-out solution achieves this by offering a scalable, efficient, and operationally simplified approach to network design, which is critical in today's fast-paced and cost-conscious market.

The successful validation of key features such as L2VPN, L3VPN, QoS/CoS, and OAM's CFM asynchronous notification, alongside the robust fault propagation mechanisms, underscores the solution's readiness for deployment in diverse networking environments. The system's resilience and consistent behaviour during critical events, such as process restarts or interface flaps, further reinforce its reliability and operational excellence.

While the solution, as validated, specifically utilizes Juniper Networks' ACX and MX Series devices, its underlying principles and design are based on open standards, allowing for potential extension to other Juniper devices and even third-party routers and switches. Such extensions, however, should be approached with careful consideration and validation to ensure compatibility and to maintain the solution's core benefits. For example, propagation of S-VLAN OAM state to C-VLANs that have the same S-VLAN (outer) tag on PE-to-FO interface with oam-on-svlan feature is available only on MX Series routers which makes it a unique choice for the PE role as of release time of this JVD. Thanks to the openness of the solution, the fan-out device and its validated scope can be combined with other custom deployment scenarios requiring advanced capabilities, like local FO traffic replication, egress multicast replication and so on, which we are open to consider for the future validations.

Given these findings, it is our recommendation that the port fan-out solution be considered for deployment within both service provider and enterprise network infrastructures. It offers a compelling alternative to traditional fan-out approaches by simplifying provisioning, optimizing operational efforts, and enabling cost.