Dual Management of Open XR pluggable modules in P2MP Applications Hosted in Various Routers with Transmission over Multiple Line Systems Proof of Concept Demonstration

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ABSTRACT:

Here we report on the proof of concept of the Open XR Dual Management approach in P2MP applications where pluggables are hosted in various routers and signals transmitted over multiple line systems. The proof of concept demonstrates:

1. Compatibility of XR signals with a variety of line systems in
    a. Point-to-point configuration and
    b. Point-to-multipoint configuration
2. Compatibility of XR pluggable transceivers with a variety of host systems (Juniper, DriveNets & Ufispace, SONiC & Edgecore, Infinera TM301, and Infinera NDU)
3. Advanced management functionality of smart pluggable transceivers, demonstrating the capability of modern routers to seamlessly support remote management of pluggable transceivers through the Open XR Management Architecture.

This shows the viability of XR to transform the network, while being able to seamlessly integrate with legacy network infrastructure.

The Open XR Optics Forum
www.openxropticsforum.org

Open XR Optics Forum

The Open XR Optics Forum is the multi-source agreement (MSA) working group for XR optics, the industry's first point-to-multipoint coherent pluggable transceiver technology. The Open XR Optics Forum's mission is to foster collaboration that will advance development of XR optics-enabled products and services, accelerate adoption of intelligent coherent transceivers ,coherent point-to-multipoint network architectures, and drive standardization of networking interfaces to ensure ease of multi-vendor interoperability and an open, multi-source solution ecosystem.

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1 Executive Summary

1.1 Proof of Concept

Open XR promises to simplify the network architecture with long-reach coherent optics supporting point-to-point and point-to-multipoint connectivity, provide advanced transponder like functionality in a pluggable form factor, while being able to be deployed in existing optical fiber infrastructure and network equipment. This comes with a wide variety of challenges, from co-existence in deployed line systems and PON networks to being deployed in a variety of different types of hosts, all while providing full operational management functionality for advanced pluggable transceivers without full featured support by the diverse host system infrastructure.

In this Open XR Proof of Concept, we demonstrate the capabilities of Open XR transceivers to excel in such diverse environments by showing:

- The Coexistence of Open XR signals in a variety of line systems and networks, tested line systems from Ciena and Infinera, and Point to Multipoint deployment of XR in a legacy PON environment.
- Compatibility of Open XR transceivers with a variety of hosts, tested routers: Juniper / Evo, Ufispace / DriveNets, Infinera, and Edgecore / SONiC.
- Advanced management capabilities of Open XR transceivers and the Open XR controller, offering unambiguous control of the Optical Line Side independently from the (disaggregated) hosts [1], here tested in operating anJuniper / Evo and UfiSpace / DriveNets.

Open XR forum members Liberty Global, Infinera, Juniper, UfiSpace, and DriveNets supported this demonstration of a network with diverse hosts. Demonstrating interoperability of Open XR signals and multiple Optical Line Systems currently in use in Liberty Global networks, as well as Interoperability of Open XR modules with a diverse set of 400G routers (Juniper, Ufispace, …). Both, 400G point-to-point and 400G to 4 x 100G point-to-multipoint are shown.

In addition, coexistence of the Open XR signals and the Liberty Global XGS-PON signals on the same PON single fiber infrastructure is demonstrated.

2 Demonstration Objectives

2.1 Interoperability with Deployed Line Systems in the Liberty Global Optical Network

First, the interoperability of the Open XR signal and deployed Liberty Global Optical Line Systems was demonstrated.

Liberty Global has deployed the Infinera XTM line system widely in the metro layer of the network in various countries.

The Ciena OME 6500 line-system supports the Liberty Global international network as well as the national network of the various countries Liberty Global operates in.

Interoperability between these line systems and the Open XR signal is crucial for brownfield deployments. This is key for the rapid adoption of Open XR in existing network infrastructures.

To demonstrate compatibility, the following scenarios are investigated for each line system:

1. 100GHz and 112.5GHz AWG Line System passband compatibility of a 16-subcarrier wide signal and 50GHz AWG Line System passband compatibility of an 8-subcarrier wide signal.
2. Ability of the Line System to read optical signal power level and regulate it to required power level at the line side.
3. Ability of the Rx side of the Open XR module to recover the signal after being transported across the line system.
4. Support for Open XR P2MP connectivity after the signal is transported over a Line System and an optical splitter.
5. In a final test, interoperability of Open XR signals with current Liberty Global XGS-PON systems is tested, demonstrating the deployment of an Open XR signal in a single fiber point-to-multipoint Liberty Global PON testbed to show coexistence with XGS-PON signals in the same fiber tree.

For this evaluation, the pluggable transceivers were hosted in 400G EdgeCore Whitebox switch running SONiC or Infinera TM301 system equipped with CFP2 Open XR modules.

2.2 Interoperability with a variety of Routers and diverse Hosts supporting 400G pluggables

The interoperability of the Open XR transceivers with 400G routers at Liberty Global is demonstrated. This is done by varying the host systems throughout the trials.

Host systems tested in the Liberty Global labs were Juniper PTX10K 400G routers and DriveNets UfiSpace 400G routers, 400GE EdgeCore Whitebox switches, Infinera TM301, and an Infinera Network Demarcation Unit (NDU) connected to a Nokia SR-7s. The Infinera NDU facilitates connectivity between XR pluggables and QSFP28 pluggables.

Table 1: Tested Host Devices

Verified Host Devices
Juniper PTX10K 400G routers
DriveNets UfiSpace 400G router
400GE EdgeCore Whitebox switch with Sonic
Infinera TM301
Infinera NDU connected to Nokia SR-7s through QSFP28

Compatibility of these routing platforms with Infinera Open XR compliant pluggable transceivers was tested:

1. Successfully power up the module,
2. start up the module through MDIO or CMIS management interface,
3. establish data connectivity though the module, verified by traffic test set,
4. and enable IP connectivity between the pluggable transceiver and an external Open XR Controller.

2.3 Demonstration of Advanced Open XR Management Functionality with the Open XR Controller

Open XR modules provide advanced functionalities beyond the capabilities of currently deployed host systems. The Open XR management architecture [1] mitigates this mismatch by providing host independent management capabilities of advanced functionalities through the Open XR controller. These features include inventory and monitoring but also configuring advanced functionalities for point-to-point high performance transmission, point to multipoint (establishing point to multipoint module connectivity, assigning subcarriers, …).

3 Interoperability with a variety of 400G Routers and diverse Hosts

3.1 Introduction

A variety of host systems were tested in both P2P and P2MP configurations throughout the following two chapters.

Table on which host is tested in which section.

Host	**Section and application**
Juniper PTX10K v23.1-EVO	5.4 - 5.5 p2p Dual Mgmt
DriveNets v17.3 & UfiSpace S9702-23D	4.6 p2mp single fiber, 5.2 p2p, 5.3 p2p Dual Mgmt, 5.6 p2p Dual Mgmt remote, 5.7 p2mp Hub
SONiC 2011-11 & EdgeCore	4.2 p2p, 4.3 p2
Infinera XR-NDU	4.5 p2mp Leaf, 5.7 p2mp Leaf
Infinera TM301	4.4 p2p, 4.5 p2mp Hub

4 Interoperability with Deployed Line Systems in the Liberty Global Optical Network

4.1 Introduction

Compatibility with multiple line systems was investigated and successfully demonstrated. The line systems and utilized host devices are listed in the Table below. The line systems were representative of line systems deployed in the Liberty Global networks.

Table 2: Tested combinations of line systems and host devices for line system interoperability tests.

	Line System	Scenario	Host Device
4.2	Infinera XTM 100GHz Flex Grid WSS	1×400G point-to-point	400GE EdgeCore Whitebox switch running SONiC
4.3	Ciena OME 6500 112.5GHz Flex Grid WSS	1×400G point-to-point	400GE EdgeCore Whitebox switch running SONiC
4.4	Infinera XTM 50GHz, Fixed Grid WSS, and DCU	2×100G P2P point-to-point	Infinera TM301 system

4.5	Infinera XTM 100GHz Flex Grid WSS with P2MP breakout after transmission	2×100G point-to-multipoint	Infinera TM301 and Infinera NDU
4.6	PON single fiber overlay scenario	2x100G point-to-multipoint	UfiSpace DriveNets and Infinera NDU

4.2 Open XR 400G P2P signal and Infinera XTM 100GHz Flex Grid WSS

The Infinera XTM line system is widely used inside the metro layer of Liberty Global network. This line system is currently mostly in combination with transponders and muxponders, extending the usage of this infrastructure with Open XR technology would make it much more valuable for Liberty Global.

To demonstrate the interoperability an XTM line system setup with two optical nodes interconnected with 40 km of SMF-28E+ fiber was used. The XTM line system software version used was v35.0.

The line system was equipped with 100GHz AWG filters, 1x9 Route & Select WSS modules, and twin EFDA amplifiers. To control the optical signal power an OCM was deployed at the amplifier to measure the per channel signal power and control the VOA attenuation level inside the WSS module.

Connecting to the line system was a 400GE EdgeCore Whitebox switch running SONiC version SONiC.ec202111.0-dirty-20220928.150408. This device acted as the host for two XR modules running software version v0.2.2. One XR module was acting as the XR Hub module and the other as XR Leaf module.

The connection across the line system was established on 100GHz port 940 with optical signal center frequency 194.00GHz.

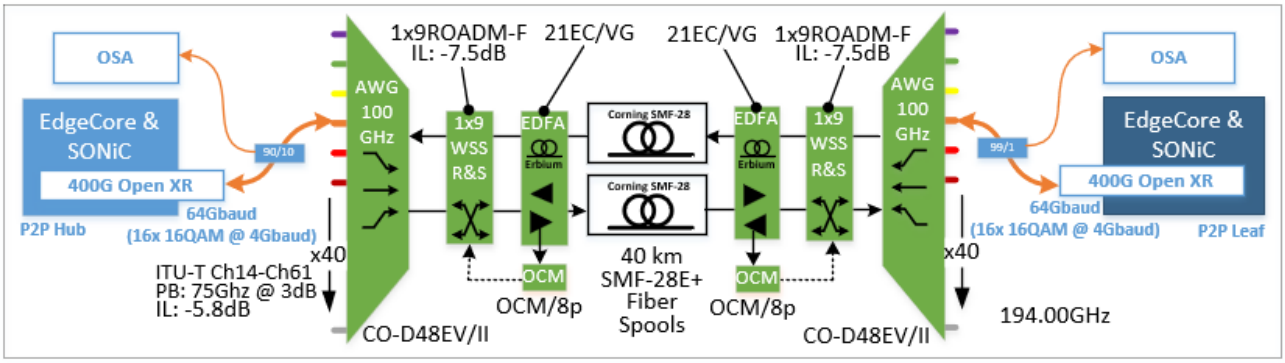

Figure 1 - Logical diagram of testbed 1 – Infinera XTM 100GHz

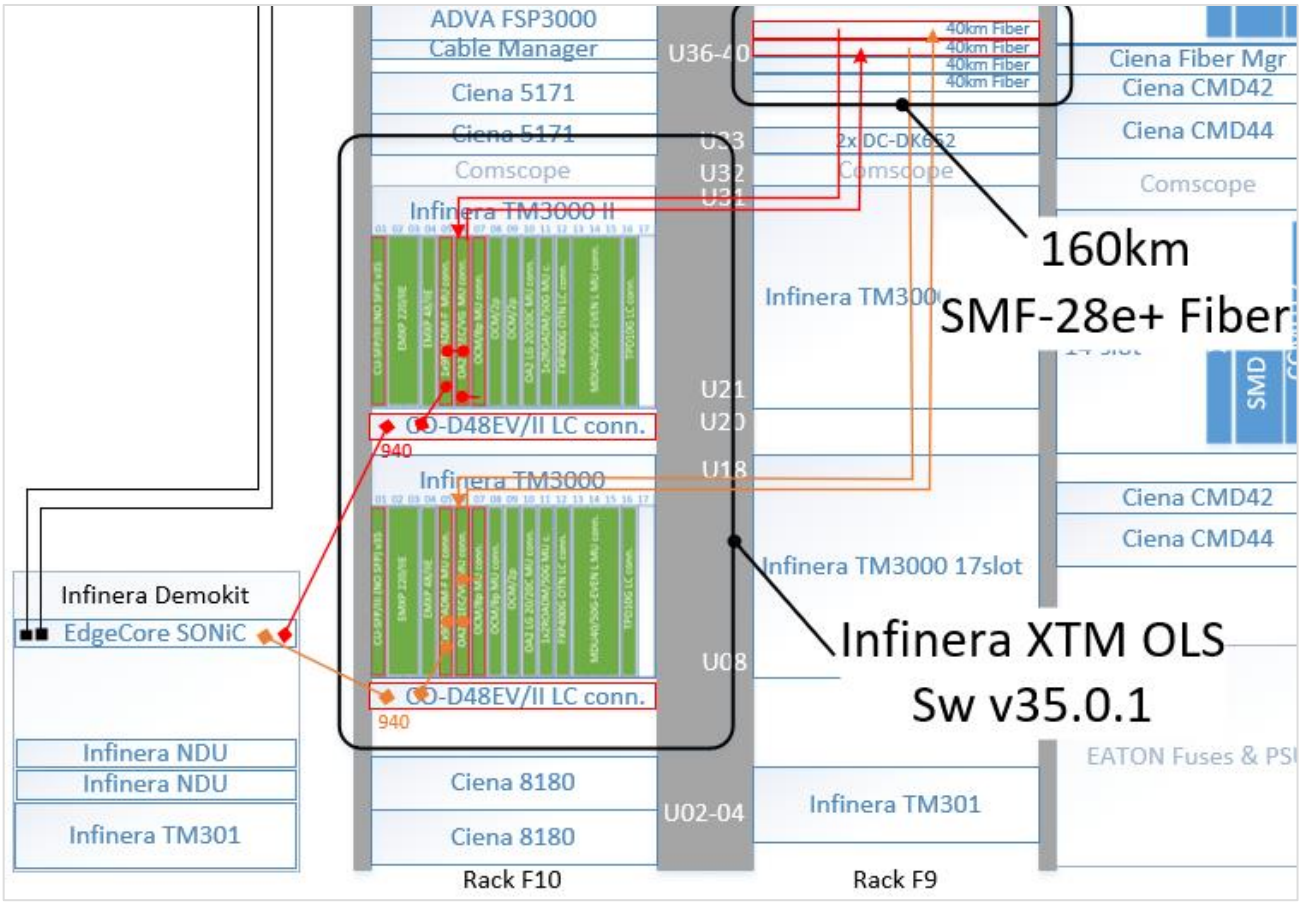

Figure 2 - Rack layout and cabling of testbed 1

4.2.1 Test results

Using testbed 1 a 400G P2P connection was successfully established between the two XR modules and across the Infinera XTM line system.

The OSA readings from the transmitted XR signals and the received XR signals indicated that the full 16 XR subcarriers fit through the AWG filter. The attenuation curve of the AWG was showing on the AWG, but the signal could be recovered on the outer subcarriers.

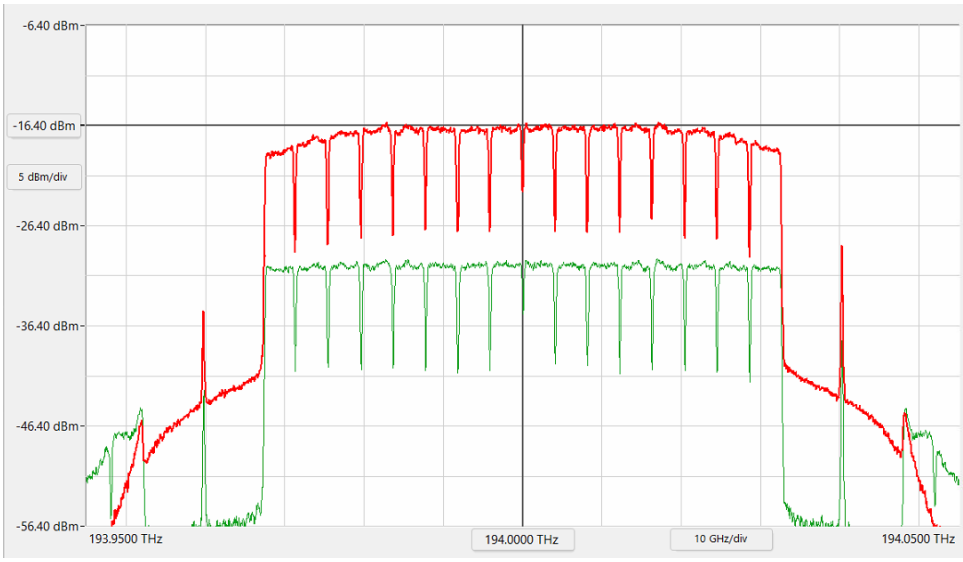

Figure 3 - P2P Hub Tx (Green) and P2P Leaf Rx (Red) Optical Spectrum Analyzer readings

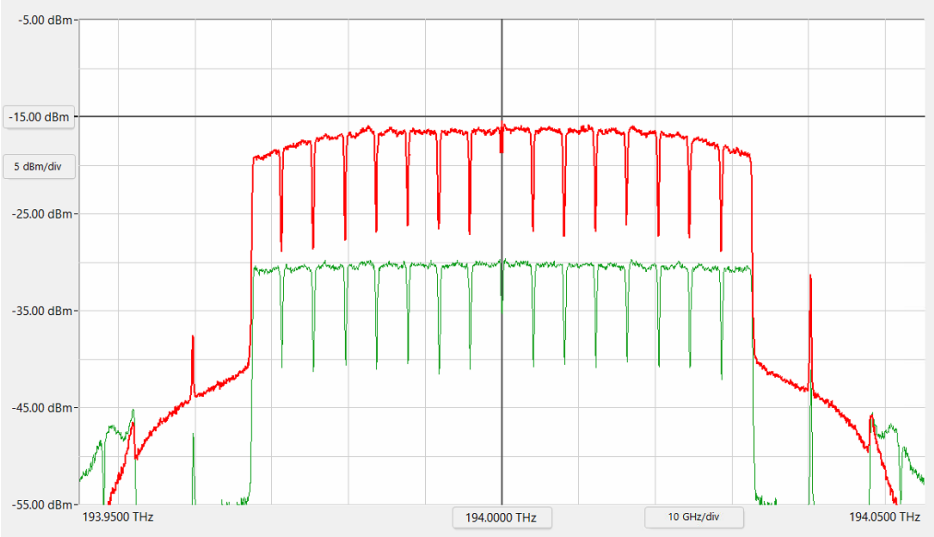

Figure 4 - P2P Leaf Tx (Green) P2P Hub Rx (Red) Optical Spectrum Analyzer readings

Liberty Global has deployed most of its XTM line systems as 40 channel systems. To achieve the best performance, the line side optical signal power per channel is set to 3.5 dB. During the test it was possible to achieve this power level of 3.5dB as shown in the XTM element manager screenshot. Also the XR signal was established successfully across the line system with Regulation switched on.

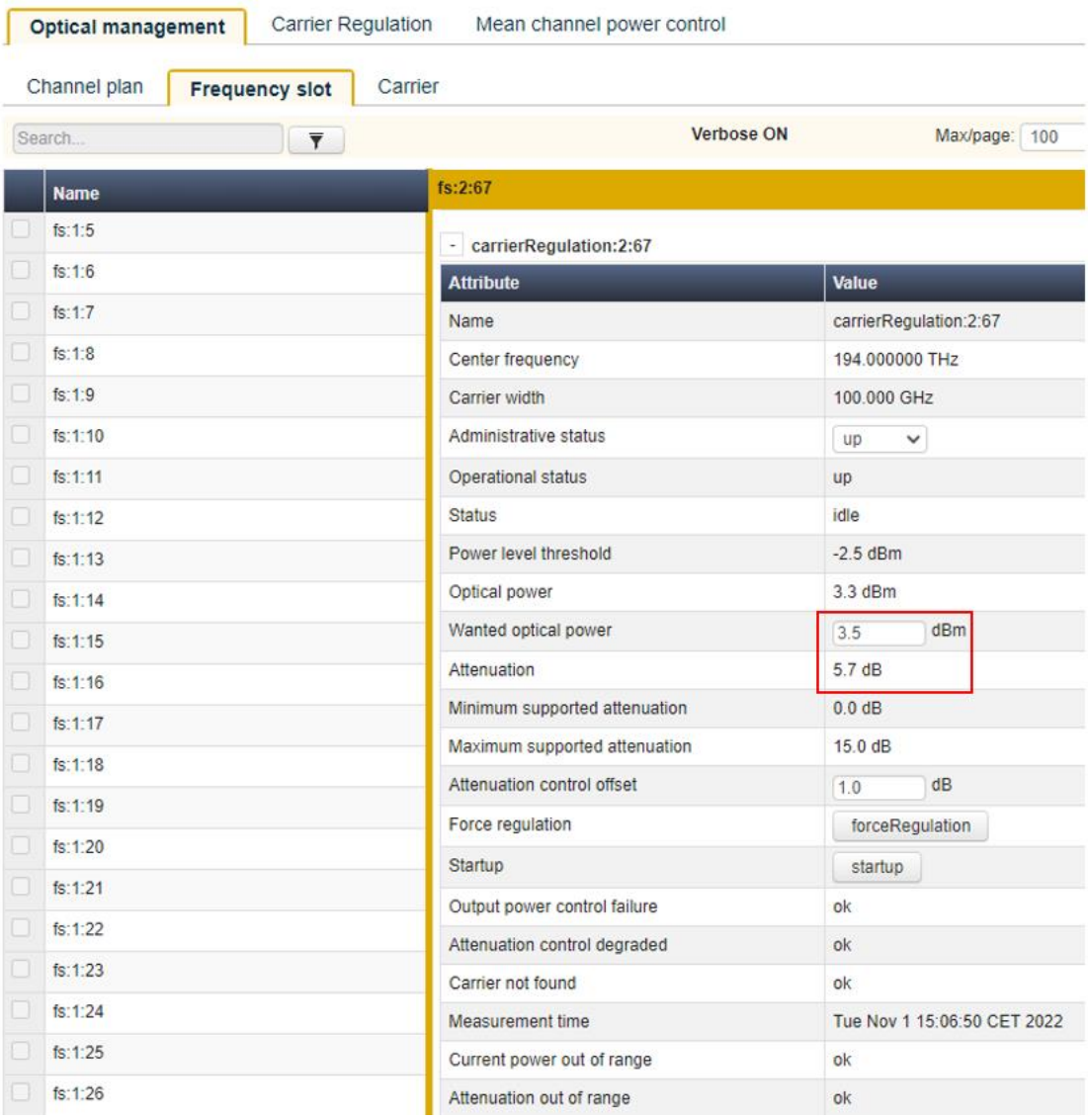

Figure 5 - Infinera XTM 3.5dBm line side & regulation

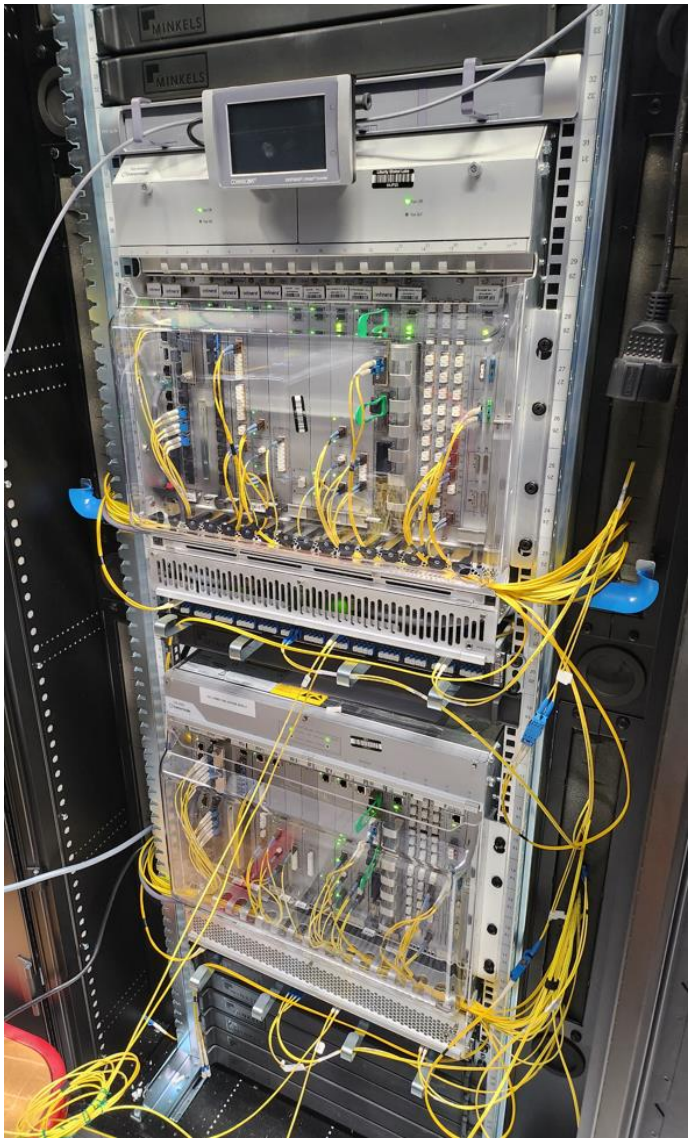

Figure 6 - Infinera XTM line system of testbed 1

4.3 Open XR 400G P2P signal and Ciena OME 6500 112.5GHz Flex Grid WSS

The Ciena OME 6500 line system is widely used inside the core and international layer of the Liberty Global network. This line system is currently mostly in combination with transponders and muxponders, extending the usage of this infrastructure with Open XR technology would make it much more valuable for Liberty Global.

To demonstrate the interoperability a two node Ciena OME 6500 line system setup with two optical nodes interconnected with 10dB attenuators was used. The Ciena OME 6500 line system software version used was v12.72.

The line system was equipped with 112.5GHz AWG filters, 1x9 Broadcast & Select WSS modules, and two stages of twin EFDA amplifiers. To control the optical signal power an OCM was deployed at the amplifier to measure the per channel signal power and control the VOA attenuation level inside the WSS module.

Connecting to the line system was a 400GE EdgeCore Whitebox switch running SONiC version SONiC.ec202111.0-dirty-20220928.150408. This device acted as the host for two XR modules running software version v0.2.2. One XR module was acting as the XR Hub module and the other as XR Leaf module.

The connection across the line system was established on 112.5GHz with optical signal center frequency 195.0188GHz.

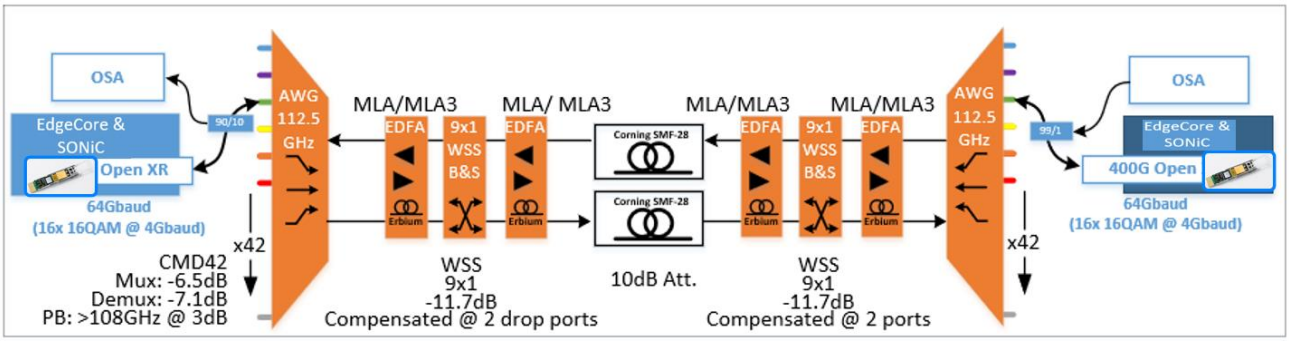

Figure 7 - Logical diagram of testbed 2 – Ciena OME6500 112.5GHz

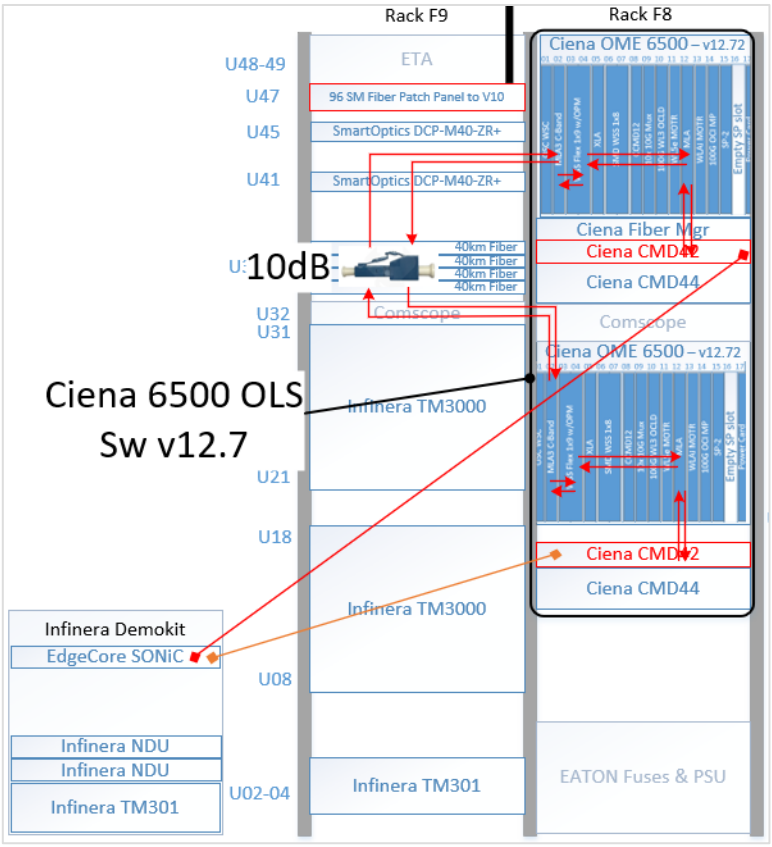

Figure 8 - Rack layout and cabling of testbed 2

4.3.1 Test results

Using testbed 2 a 400G P2P connection was successfully established between the two XR modules and across the Ciena OME 6500 line system.

The OSA readings from the transmitted XR signals and the received XR signals indicated that the full 16 XR subcarriers fit easily through the 112.5GHz AWG filter. The attenuation curve of the AWG was showing on the AWG, but the signal could be recovered on the outer subcarriers.

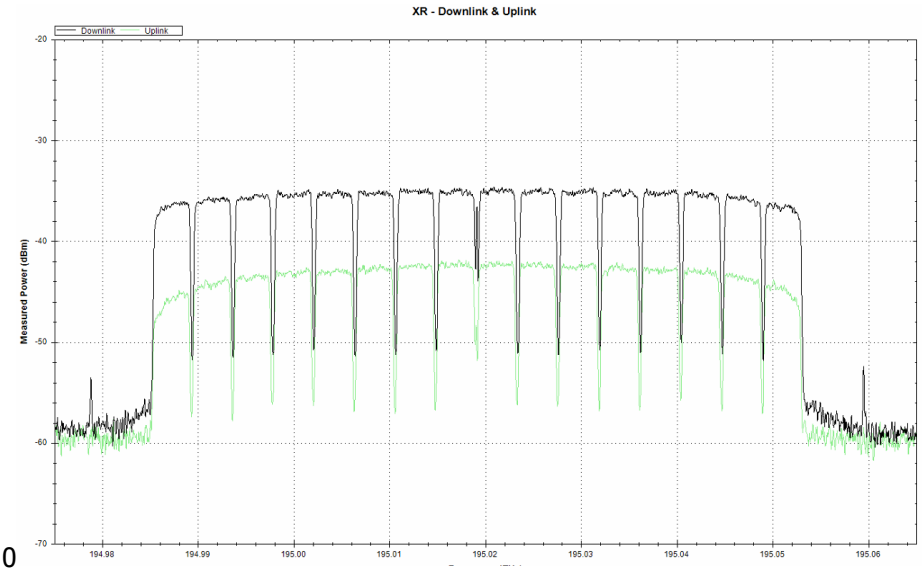

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Figure 9 - XR Downlink (Green) and Uplink (Black) Optical Spectrum Analyzer readings

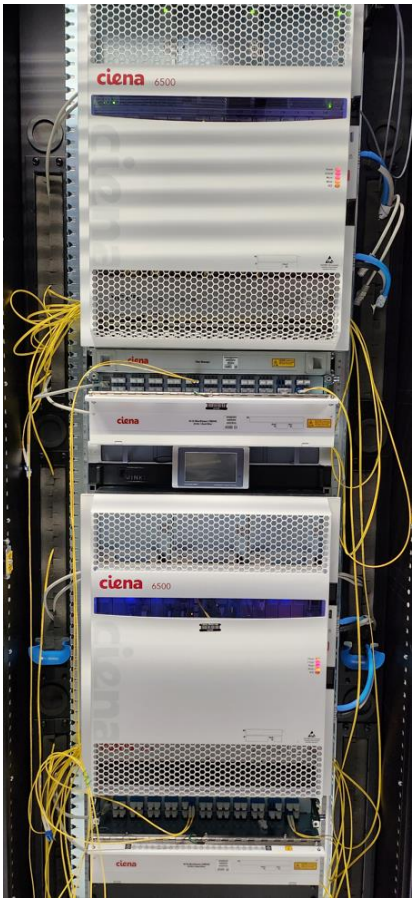


Figure 10 - Ciena OME 6500 line system of testbed 2

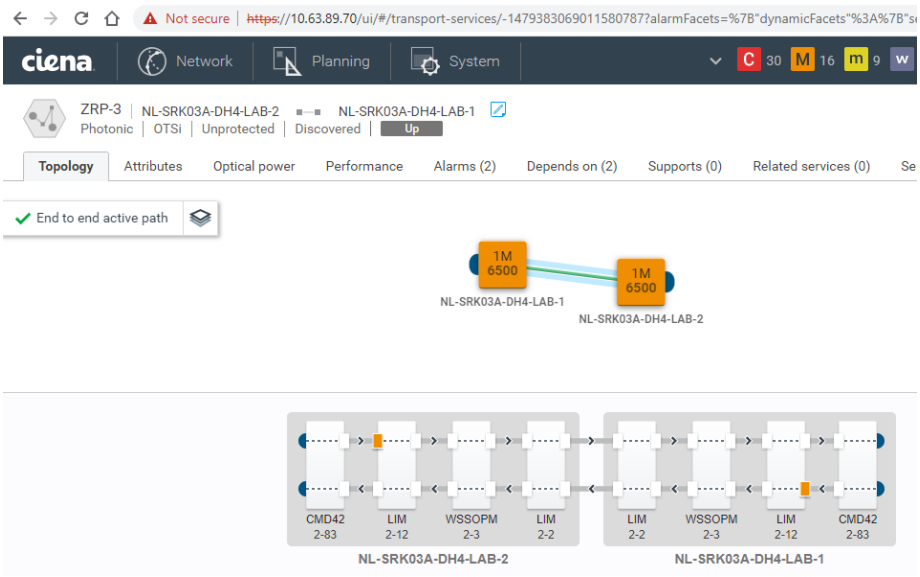


Figure 11 - Ciena MCP Topology view of testbed 2

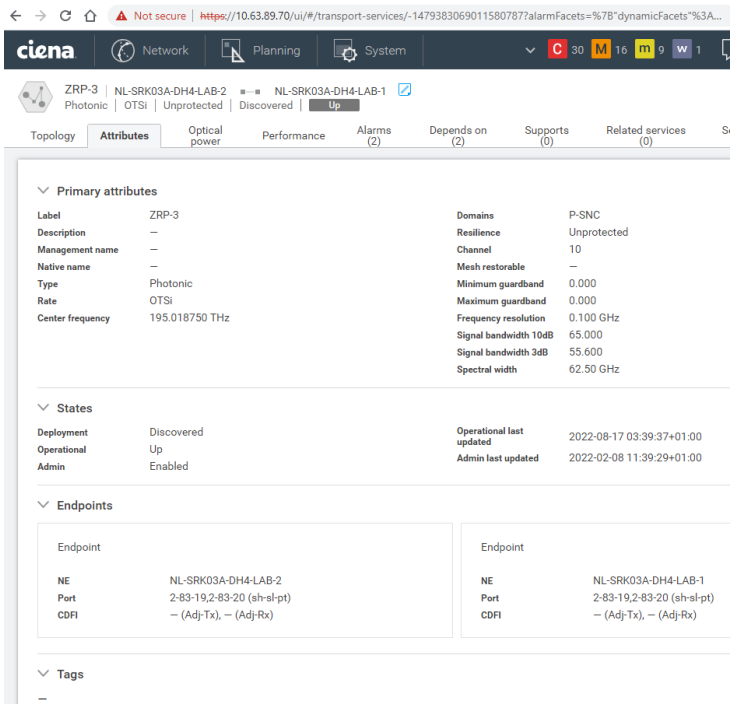


Figure 12 - Ciena MCP Photonic Service view of testbed 2

4.4 Open XR 2x100G P2P signal and Infinera XTM 50GHz, Fixed Grid WSS, and DCU

The Infinera XTM line system is widely used inside the metro layer of Liberty Global network. This line system is currently mostly in combination with transponders and muxponders, extending the usage of this infrastructure with Open XR technology would make it much more valuable for Liberty Global.

In its most common setup, the XTM is equipped with a 50GHz fixed grid system, which includes a 1x2 WSS and Dispersion Compensation Units. These systems are 10G signal optimized but lack support for 400G coherent signals. The passband should allow for up to 8 Open XR subcarriers which allows for the delivery of 200G worth of capacity on a single 50GHz channel.

To demonstrate the interoperability an XTM line 50GHz system setup with two optical nodes interconnected with 40 km of SMF-28E+ fiber was used. The XTM line system software version used was v35.0.

The line system was equipped with 50GHz AWG filters, 1x2 Route & Select WSS modules, and twin EFDA amplifiers. To control the optical signal power an OCM was deployed at the amplifier to measure the per channel signal power and control the VOA attenuation level inside the WSS module.

Together with the Open XR signal a 100G QPSK optical signal and a 10G optical signal were transported by the XTM line system.

Connecting to the line system was an Infinera TM301 system equipped with CFP2 Open XR modules. One XR module was acting as the XR Hub module and the other as XR Leaf module.

The connection across the line system was established on 50GHz with optical signal center frequency 194.00GHz. The Open XR modules were configured to send 8 subcarriers with 16QAM modulation by switching off 4 of the outer subcarriers on both sides.

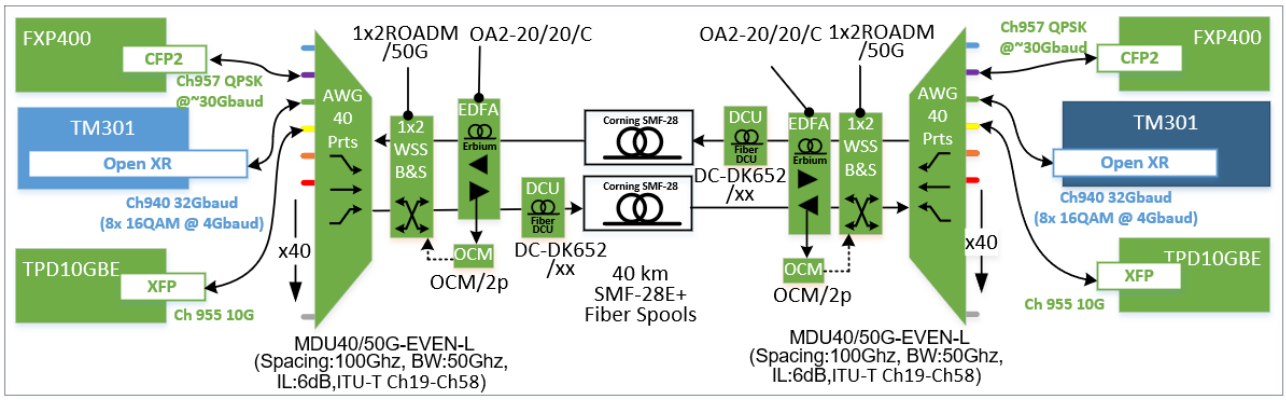


Figure 13 - Logical diagram of testbed 3 – Infinera 50GHz

4.4.1 Test results

Using testbed 3 eight 25G subcarriers were successfully transported across the 50GHz XTM line system with one subcarrier margin on both sides.

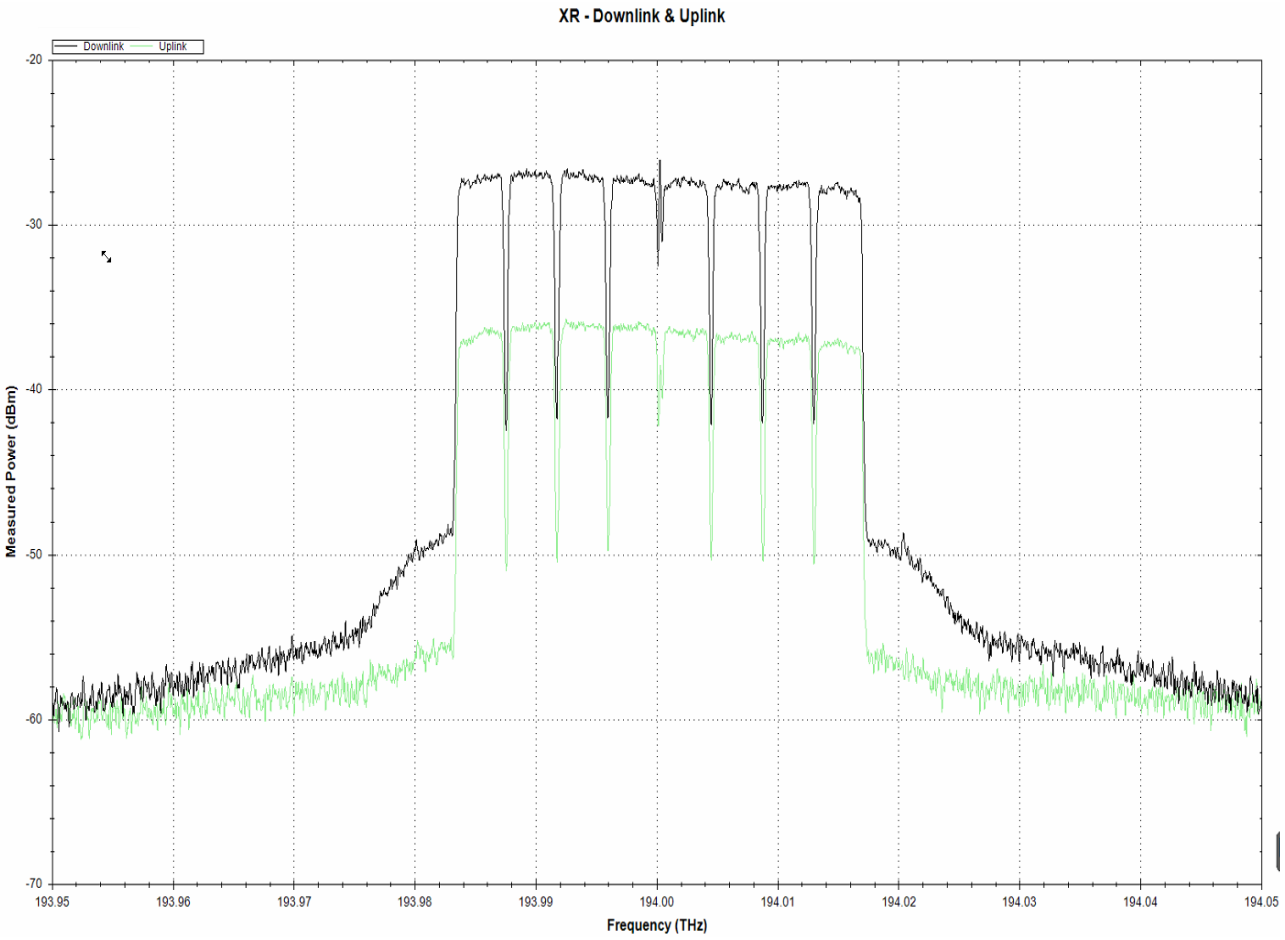


Figure 14 - XR Downlink (Green) and Uplink (Black) Optical Spectrum Analyzer readings

4.5 Open XR 2x100G P2MP signal and Infinera XTM 100GHz Flex Grid WSS

The Infinera XTM line system used in testbed 1 was extended with a 4x4 Coupler for Open XR 2x100G P2MP signal interoperability testing as part of testbed 4.

Connecting to the line system were an Infinera TM301 with CFP2 Hub and CFP2 Leaf module, as well as a NDU with CFP2 Leaf module.

The connection across the line system was established on 100GHz port 940 with optical signal center frequency 194.00GHz.

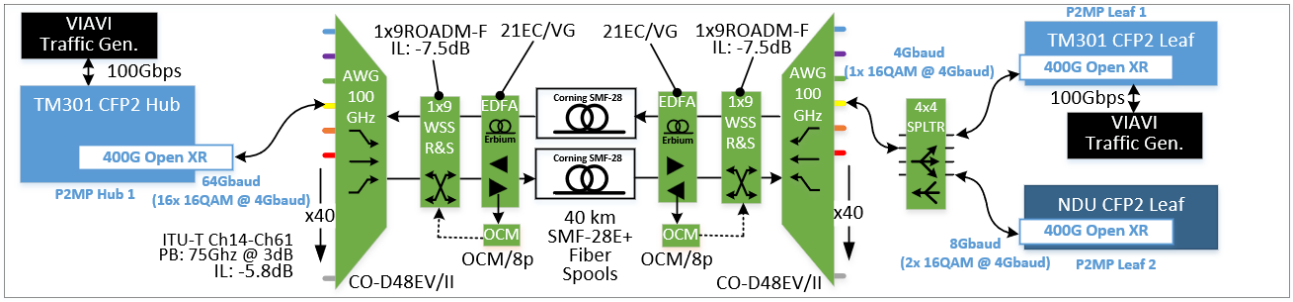


Figure 15 - Logical diagram of testbed 4 – Infinera 100GHz with 4x4 Coupler

4.5.1 Test results

The 2x100G P2MP signal was successfully transported across the 100GHz XTM line system and the 4x4 Coupler. The optical signal was also received, demodulated, and decoded successfully at the Hub and the two Leaf sides.

The XTM had to be configured for a 0.5dBm line side power to successfully regulate the XR signal.

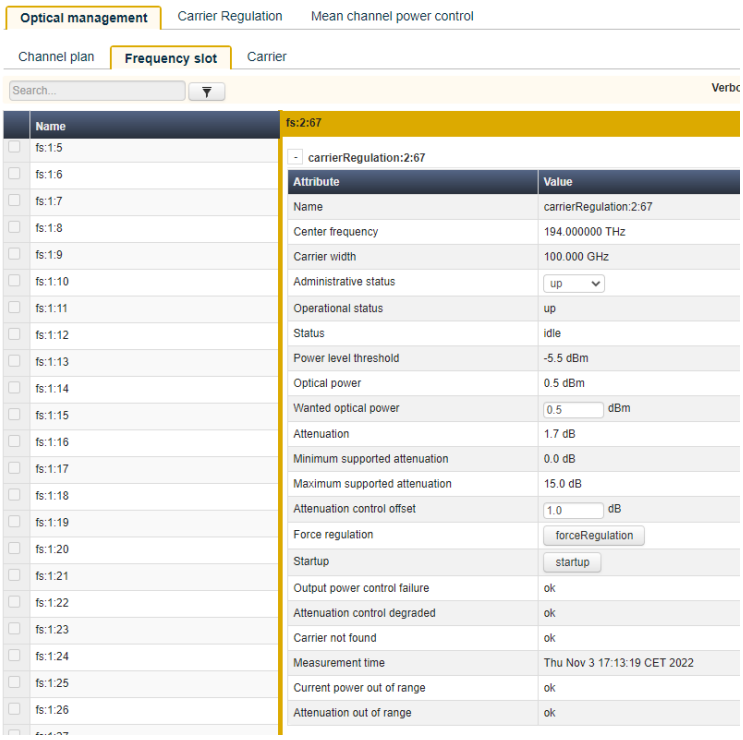


Figure 16 - Infinera XTM 0.5dBm line side & regulation

4.6 Single fiber p2mp with XGS-PON coexistence with UfiSpace DriveNets 400G router

The Nokia XGS-PON test network in Liberty Global's lab facility was extended with a circulator and multiple splitters. This allows for testing the coexistence of the XGS-PON optical signal and the Open XR signal on the same single fiber tree.

The Open XR hub side was set up in a p2mp fashion connecting to two leafs with 100G full duplex speed for each. In parallel to this a single XGS-PON ONU device was connecting with a 10G speed to an OLT using the same fiber.

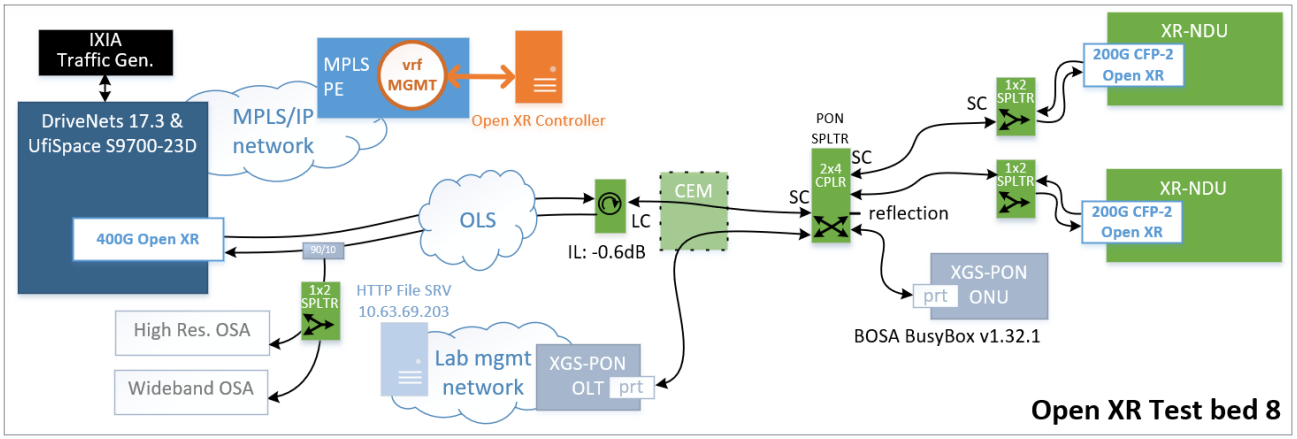


Figure 17 - Logical diagram of the Open XR and XGS-PON coexistence testbed

4.6.1 Test results

The 2x100G P2MP signal was successfully transported across the single fiber tree including the circulators and splitters. At the same time the XGS-PON signal was also transmitted successfully and the working of the IP packet forwarding function was successfully verified.

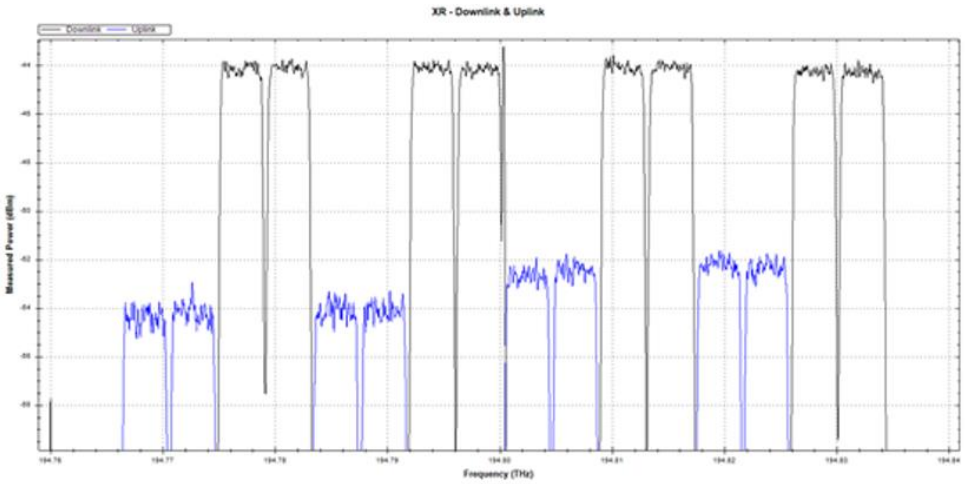


Figure 18 - High Resolution OSA graph of the Single Fiber XR signal from hub and leaf interleaved

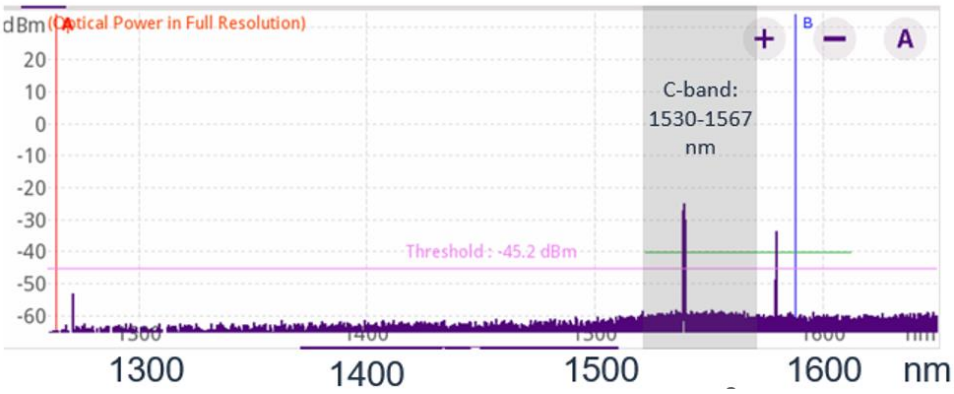


Figure 19 - Wideband OSA graph showing both XGS-PON and Open XR signal.

5 Advanced Management of Smart Pluggable Transceivers in a Variety of Hosts

5.1 Introduction

The Advanced management capabilities of the smart pluggable transceivers were tested in a variety of scenarios and hosts, carefully selected to represent the most promising use cases of the Open XR technology as identified by Liberty Global. Connectivity was verified using a Viavi traffic tester and additional telemetry was obtained through a high-resolution optical spectrum analyzer and the Open XR Controller.

In these investigations, connectivity for the remote management of smart pluggable transceivers was facilitated by virtual routing and forwarding (VRF), which is a standard feature available in modern routers.

In the following sections, we show different management concepts up to the zero-touch provisioning in section 5.7.

The selected use cases were:

1. Initial verification of connectivity between pluggable, host, and Open XR controller
2. 400G Transmission through a line system with local management by host system
3. 400G Transmission through a line system with remote management by the Open XR controller and static configuration of the IP connectivity in a UfiSpace/DriveNets 400G router as the host system
4. 400G Transmission through a line system with remote management by the Open XR controller and static configuration of the IP connectivity in a Juniper PTX10K 400G router as the host system
5. 400G Transmission through a line system with remote management by the Open XR controller and zero touch provisioning of the IP connectivity in a Juniper PTX10K 400G router as the host system
6. 400G Transmission through a line system with remote management by the Open XR controller and zero touch provisioning of the IP connectivity through a supervisory channel on the line side of a module in a UfiSpace/DriveNets 400G router as the host system

7. Point to Multipoint commissioning through VRF in a UfiSpace/DriveNets host to multiple Infinera XR NDUs, one connected to a Nokia SR-7s.

5.2 CMIS managed Open XR Modules in UfiSpace and DriveNets 400G router

Liberty Global is using UfiSpace hardware with DriveNets software as a 400G routing platform for its Core Network. This testbed is used to confirm interoperability between this router platform and the Open XR Modules running in point-to-point mode.

In this test bed the Open XR modules are configured with a center frequency and Tx power using the DriveNets CLI. The Open XR Controller was placed in monitoring mode, which is identified by the "Discovered" text in the Constellations and Services pages.

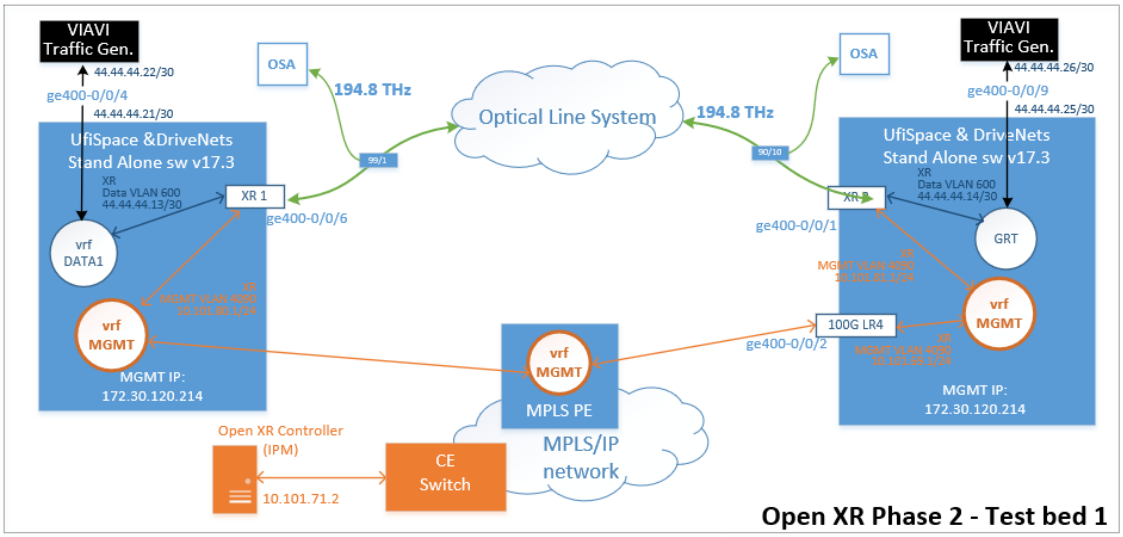


Figure 20 - CMIS Management test bed logical diagram

DriveNets DNOS 17.3 configuration:

```
ge400-0/0/1
  admin-state enabled
  transceiver
    optical-transport
      center-frequency 194800 ghz
      target-output-power -2000

ge400-0/0/6
  admin-state enabled
  transceiver
```

```
optical-transport
  center-frequency 194800 ghz
  target-output-power -2000
```

The 400GE connection availability was successfully verified using a VIAVI tester.

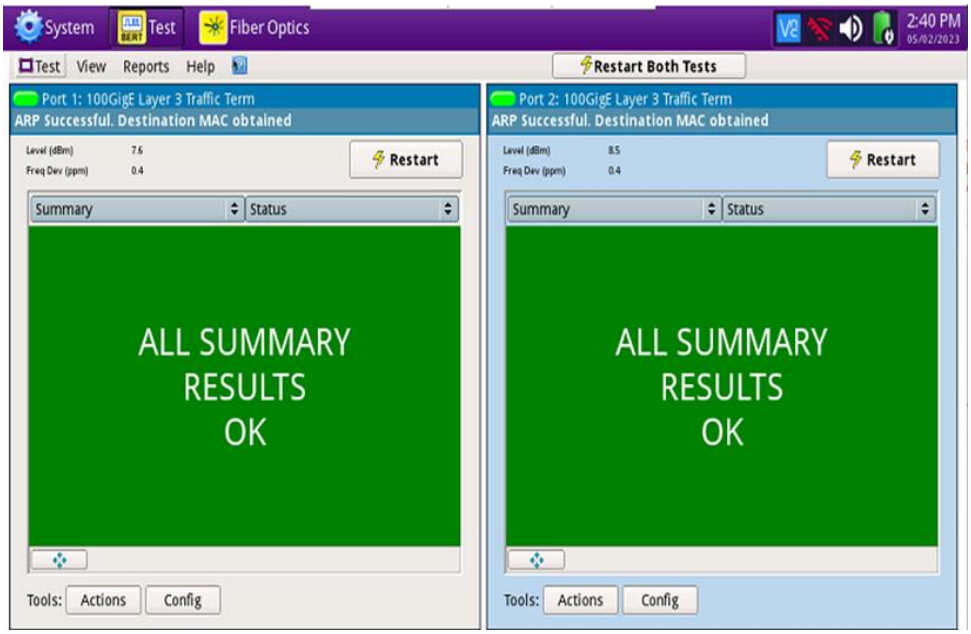


Figure 21 - CMIS Management test bed Viavi test results

The High resolution OSA readings from the Hub and Leaf side with all 16 digital subcarriers:

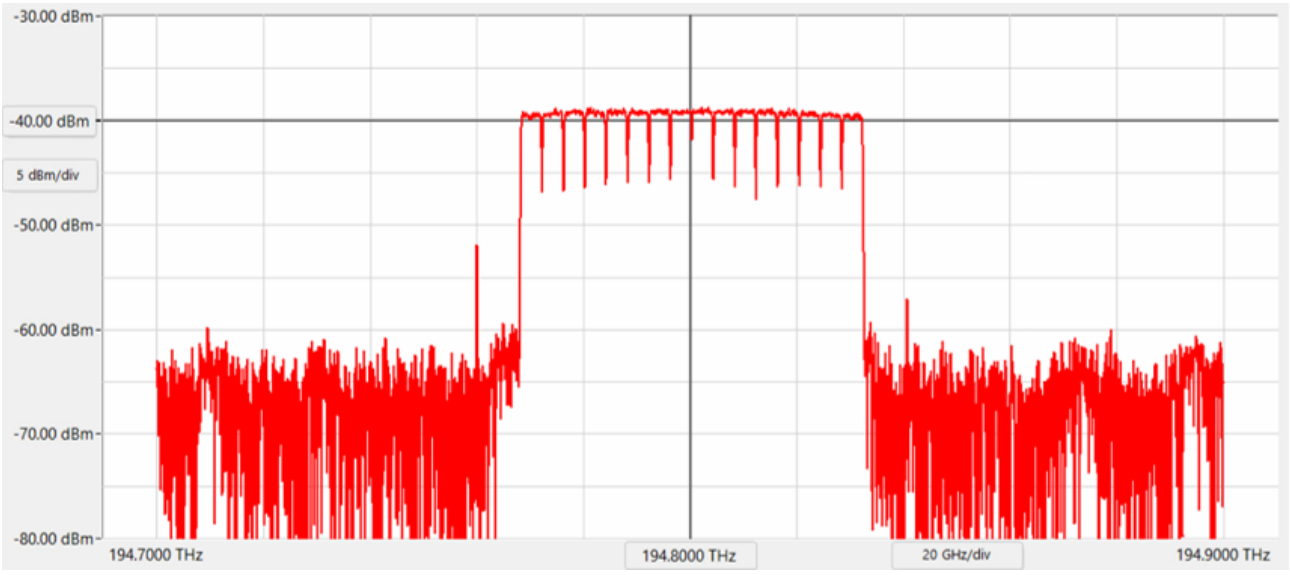


Figure 22 - CMIS Management test bed Hub Tx OSA 90/10

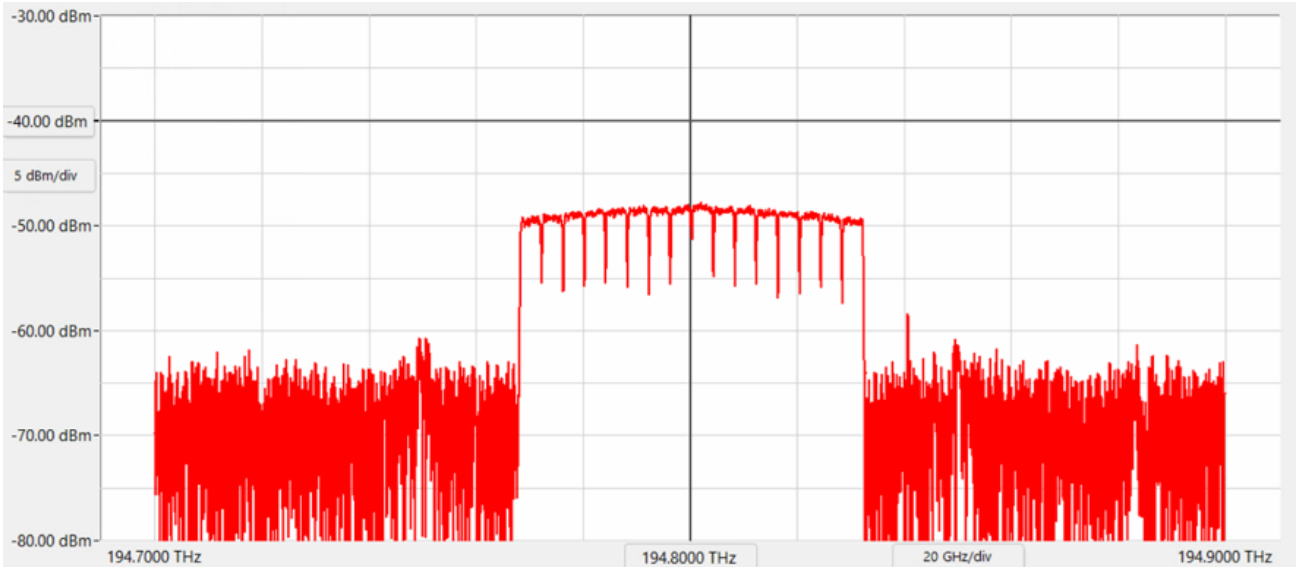
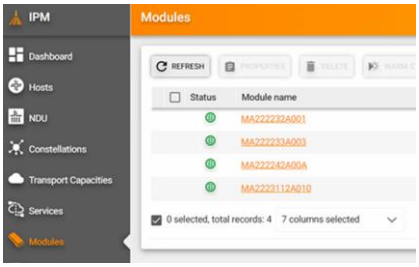
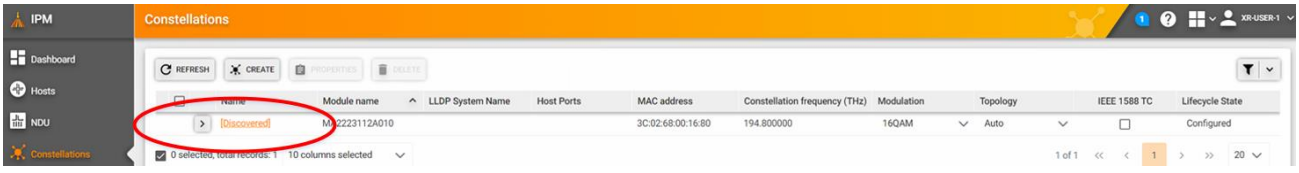
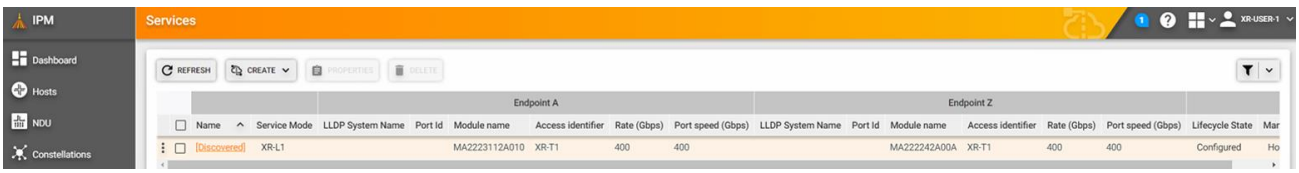


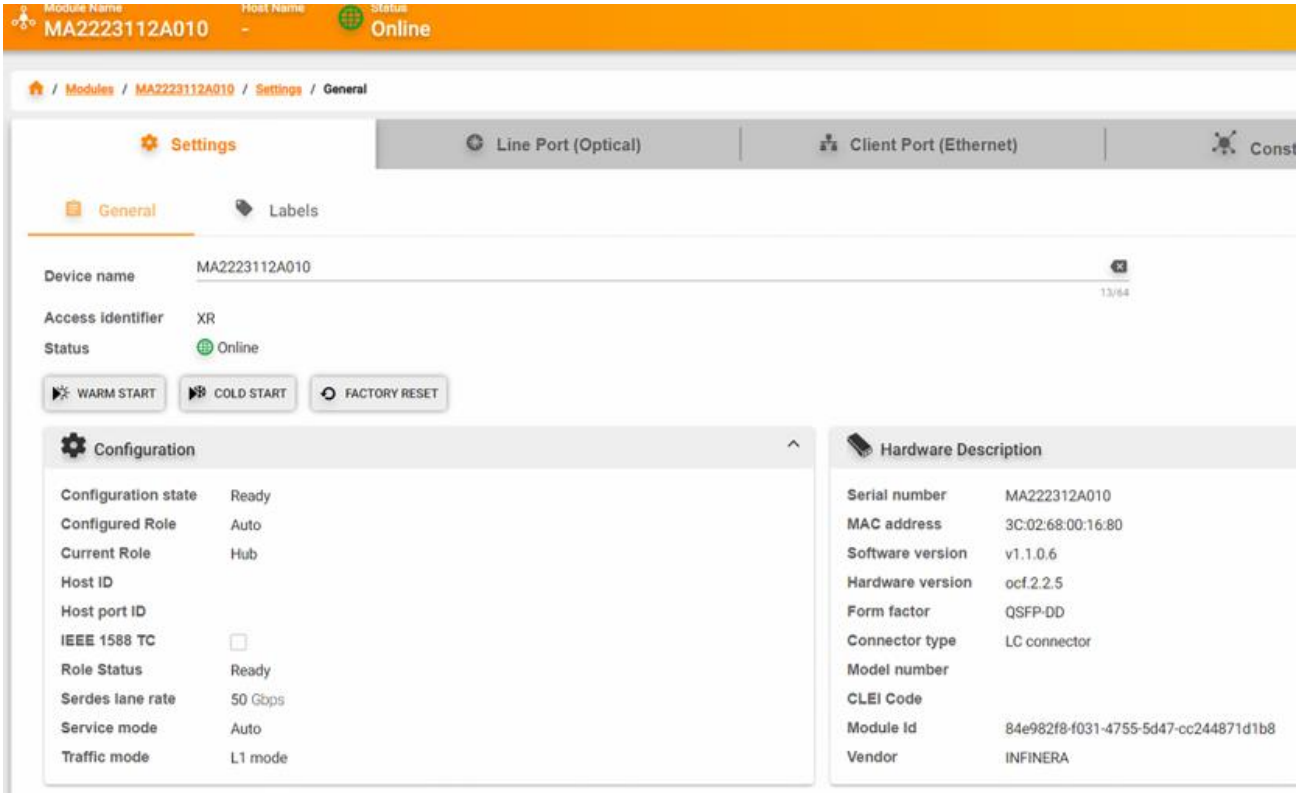
Figure 23 - CMIS Management test bed Leaf Tx OSA 99/1

Several different Open XR Controller screenshots:









DriveNets DNOS 17.3 CLI show command output:

```
OpenXR1# show interfaces counters ge400-0/0/1

Interface ge400-0/0/1:
Operational state: up

Ethernet counters:
        RX octets:                          6212702501261 ( 80952256985 bps / 80952.26 Mbps)
        RX frames:                            91363272132 (   148809136 fps /  148.81 Mfps)
        RX unicast frames:                    91363272127 (   148809136 fps /  148.81 Mfps)
        RX broadcast frames:                          0 (           0 fps /       0 Mfps)
        RX multicast frames:                          5 (           0 fps /       0 Mfps)
        TX octets:                          6212702437283 ( 80952059710 bps / 80952.06 Mbps)
        TX frames:                            91363270799 (   148808912 fps /  148.81 Mfps)
        TX unicast frames:                    91363270779 (   148808912 fps /  148.81 Mfps)
        TX broadcast frames:                          0 (           0 fps /       0 Mfps)
        TX multicast frames:                         20 (           0 fps /       0 Mfps)

Ethernet control counters:
        RX pause frames:                              0
        TX pause frames:                              0
        RX PFC frames:                                0
        TX PFC frames:                                0

Ethernet drop counters:
        RX errors:                                    0
        RX too short:                                 0
        RX too long:                                  0
        RX FCS errors:                                0
        RX internal MAC errors:                       0
        RX pipeline MAC drops:                        0
        TX errors:                                    0

FEC counters:
        FEC corrected errors:                    169862
        FEC uncorrected errors:                       0
        FEC symbol errors:                       169888
        FEC bit errors:                          161308

Forwarding drops summary of logical and sub-IF:
        RX VLAN mismatch:                             0
        Destination MAC mismatch:                     5
        Invalid IP header:                            0
        Total RX dropped packets:                     5
        Total TX dropped packets:                     0

OpenXR1# show interfaces counters ge400-0/0/6
```

```
Interface ge400-0/0/6:
Operational state: up

Ethernet counters:
        RX octets:                          6232996758315 ( 80939516954 bps / 80939.52 Mbps)
        RX frames:                            91661721369 (   148786250 fps /  148.79 Mfps)
        RX unicast frames:                    91661721345 (   148786250 fps /  148.79 Mfps)
        RX broadcast frames:                          0 (           0 fps /       0 Mfps)
        RX multicast frames:                         24 (           0 fps /       0 Mfps)
        TX octets:                          6232997965295 ( 80940472373 bps / 80940.47 Mbps)
        TX frames:                            91661736825 (   148787856 fps /  148.79 Mfps)
        TX unicast frames:                    91661736825 (   148787856 fps /  148.79 Mfps)
        TX broadcast frames:                          0 (           0 fps /       0 Mfps)
        TX multicast frames:                          0 (           0 fps /       0 Mfps)

Ethernet control counters:
        RX pause frames:                              0
        TX pause frames:                              0
        RX PFC frames:                                0
        TX PFC frames:                                0

Ethernet drop counters:
        RX errors:                                    0
        RX too short:                                 0
        RX too long:                                  0
        RX FCS errors:                                0
        RX internal MAC errors:                       0
        RX pipeline MAC drops:                        0
        TX errors:                                    0

FEC counters:
        FEC corrected errors:                        29
        FEC uncorrected errors:                       0
        FEC symbol errors:                           29
        FEC bit errors:                              28

Forwarding drops summary of logical and sub-IF:
        RX VLAN mismatch:                             0
        Destination MAC mismatch:                     1
        Invalid IP header:                            0
        Total RX dropped packets:                     1
        Total TX dropped packets:                     0

OpenXR1#
```

More DriveNets DNOS 17.3 CLI show command output:

```
OpenXR1# show interfaces transceiver ge400-0/0/6

Interface ge400-0/0/6
Identifier                                : QSFP_DD
Connector                                 : 0x7 (LC type fiber connector)
Length (SMF,km)                           : 63km
Length (OM3 50um)                         : 0m
Length (OM2 50um)                         : 0m
Length (OM1 62.5um)                       : 0m
Length (Copper or Active cable)           : 0m
Transmitter technology                    : 0x10 C-band tunable laser
Optical transport info                    : Grid 6.25GHz, Frequency 194.8 THz
Tx Power                                  : -2.0 dBm
Laser wavelength                          : 1547 nm
Laser wavelength tolerance                : 0 nm
Vendor name                               : INFINERA
Vendor OUI                                : 00:0B:F8
Vendor PN                                 :
Vendor rev                                :
Vendor SN                                 : MA222242A00A
Firmware version                          : 1.1
Revision compliance                       : QSFP-DD or QSFP-DD CMIS Rev 5.1
Module temperature                        : 62.4 degrees C / 144.3 degrees F
Module voltage                            : 3.2 V
Alarm/warning flags implemented           : Yes
Laser tx bias current (Channel 0)         : 100.0 mA
Transmit avg optical power (Channel 0)    : -3.1 dBm / 0.5 mW
Rcvr signal avg optical power (Channel 0) : -2.5 dBm / 0.6 mW
Laser bias current high alarm (Chan 0)    : off
Laser bias current low alarm (Chan 0)     : off
Laser bias current high warning (Chan 0)  : off
Laser bias current low warning (Chan 0)   : off
Module temperature high alarm             : off
Module temperature low alarm              : off
Module temperature high warning           : off
Module temperature low warning            : off
Module voltage high alarm                 : off
Module voltage low alarm                  : off
Module voltage high warning               : off
Module voltage low warning                : off
Laser tx power high alarm (Channel 0)     : off
Laser tx power low alarm (Channel 0)      : off
Laser tx power high warning (Channel 0)   : off
Laser tx power low warning (Channel 0)    : off
Laser rx power high alarm (Channel 0)     : off
Laser rx power low alarm (Channel 0)      : off
Laser rx power high warning (Channel 0)   : off
Laser rx power low warning (Channel 0)    : off
Laser bias current high alarm threshold   : 105.0 mA
Laser bias current low alarm threshold    : 95.0 mA
Laser bias current high warning threshold : 102.5 mA
Laser bias current low warning threshold  : 97.5 mA
Laser output power high alarm threshold   : 4.0 dBm / 2.5 mW
Laser output power low alarm threshold    : -19.0 dBm / 0.0 mW
Laser output power high warning threshold : 3.0 dBm / 2.0 mW
Laser output power low warning threshold  : -18.0 dBm / 0.0 mW
Module temperature high alarm threshold   : 75.0 degrees C / 167.0 degrees F
Module temperature low alarm threshold    : -5.0 degrees C / 23.0 degrees F
Module temperature high warning threshold : 70.0 degrees C / 158.0 degrees F
Module temperature low warning threshold  : 0.0 degrees C / 32.0 degrees F
Module voltage high alarm threshold       : 3.6 V
Module voltage low alarm threshold        : 3.0 V
Module voltage high warning threshold     : 3.5 V
Module voltage low warning threshold      : 3.1 V
Laser rx power high alarm threshold       : 4.0 dBm / 2.5 mW
Laser rx power low alarm threshold        : -18.0 dBm / 0.0 mW
Laser rx power high warning threshold     : 2.0 dBm / 1.6 mW
Laser rx power low warning threshold      : -16.0 dBm / 0.0 mW
Chromatic dispersion (min / avg / max)    : 108 / -250689 / 188017 ps/nm
Pre-fec-ber (curr / min / avg / max)      : 8.430e-04 / 1.451e-03 / 3.240e-04 / 2.360e-02
Post-fec-ber (FERC) (curr / min / avg / max) : 0.000e+00 / 3.800e+06 / 0.000e+00 / 2.380e+08
Osnr (min / avg / max)                    : 210.000 / 260.000 / 276.000 dB

Active application                        : ZR400-OFEC-16QAM
Supported applications:
1. 100GBASE-ZRplus
2. ZR200-OFEC-QPSK
3. ZR300-OFEC-8QAM
4. ZR400-OFEC-16QAM

Configuration:
  Application                             : N/A
  Frequency                               : 194.8 THz
  Grid spacing                            : N/A
  Target output power                     : -2.0 dBm
```

```
OpenXR1# show interfaces transceiver ge400-0/0/1

Interface ge400-0/0/1
Identifier                                : QSFP_DD
Connector                                 : 0x7 (LC type fiber connector)
Length (SMF,km)                           : 63km
Length (OM3 50um)                         : 0m
Length (OM2 50um)                         : 0m
Length (OM1 62.5um)                       : 0m
Length (Copper or Active cable)           : 0m
Transmitter technology                    : 0x10 C-band tunable laser
Optical transport info                    : Grid 6.25GHz, Frequency 194.8 THz
Tx Power                                  : -2.0 dBm
Laser wavelength                          : 1547 nm
Laser wavelength tolerance                : 0 nm
Vendor name                               : INFINERA
Vendor OUI                                : 00:0B:F8
Vendor PN                                 :
Vendor rev                                :
Vendor SN                                 : MA222312A010
Firmware version                          : 1.1
Revision compliance                       : QSFP-DD or QSFP-DD CMIS Rev 5.1
Module temperature                        : 48.8 degrees C / 119.8 degrees F
Module voltage                            : 3.2 V
Alarm/warning flags implemented           : Yes
Laser tx bias current (Channel 0)         : 100.0 mA
Transmit avg optical power (Channel 0)    : -2.0 dBm / 0.6 mW
Rcvr signal avg optical power (Channel 0) : -3.1 dBm / 0.5 mW
Laser bias current high alarm (Chan 0)    : off
Laser bias current low alarm (Chan 0)     : off
Laser bias current high warning (Chan 0)  : off
Laser bias current low warning (Chan 0)   : off
Module temperature high alarm             : off
Module temperature low alarm              : off
Module temperature high warning           : off
Module temperature low warning            : off
Module voltage high alarm                 : off
Module voltage low alarm                  : off
Module voltage high warning               : off
Module voltage low warning                : off
Laser tx power high alarm (Channel 0)     : off
Laser tx power low alarm (Channel 0)      : off
Laser tx power high warning (Channel 0)   : off
Laser tx power low warning (Channel 0)    : off
Laser rx power high alarm (Channel 0)     : off
Laser rx power low alarm (Channel 0)      : off
Laser rx power high warning (Channel 0)   : off
Laser rx power low warning (Channel 0)    : off
Laser bias current high alarm threshold   : 105.0 mA
Laser bias current low alarm threshold    : 95.0 mA
Laser bias current high warning threshold : 102.5 mA
Laser bias current low warning threshold  : 97.5 mA
Laser output power high alarm threshold   : 4.0 dBm / 2.5 mW
Laser output power low alarm threshold    : -19.0 dBm / 0.0 mW
Laser output power high warning threshold : 3.0 dBm / 2.0 mW
Laser output power low warning threshold  : -18.0 dBm / 0.0 mW
Module temperature high alarm threshold   : 75.0 degrees C / 167.0 degrees F
Module temperature low alarm threshold    : -5.0 degrees C / 23.0 degrees F
Module temperature high warning threshold : 70.0 degrees C / 158.0 degrees F
Module temperature low warning threshold  : 0.0 degrees C / 32.0 degrees F
Module voltage high alarm threshold       : 3.6 V
Module voltage low alarm threshold        : 3.0 V
Module voltage high warning threshold     : 3.5 V
Module voltage low warning threshold      : 3.1 V
Laser rx power high alarm threshold       : 4.0 dBm / 2.5 mW
Laser rx power low alarm threshold        : -18.0 dBm / 0.0 mW
Laser rx power high warning threshold     : 2.0 dBm / 1.6 mW
Laser rx power low warning threshold      : -16.0 dBm / 0.0 mW
Chromatic dispersion (min / avg / max)    : 155 / -250689 / 213692 ps/nm
Pre-fec-ber (curr / min / avg / max)      : 9.800e-05 / 8.230e-04 / 7.800e-05 / 2.600e-02
Post-fec-ber (FERC) (curr / min / avg / max) : 0.000e+00 / 1.540e+07 / 0.000e+00 / 1.669e+08
Osnr (min / avg / max)                    : 207.000 / 288.000 / 305.000 dB

Active application                        : ZR400-OFEC-16QAM
Supported applications:
1. 100GBASE-ZRplus
2. ZR200-OFEC-QPSK
3. ZR300-OFEC-8QAM
4. ZR400-OFEC-16QAM

Configuration:
  Application                             : N/A
  Frequency                               : 194.8 THz
  Grid spacing                            : N/A
  Target output power                     : -2.0 dBm
```

5.3 Static IP Dual mgmt. with Open XR Modules in UfiSpace/DriveNets 400G router

This test bed has the same physical setup as the previous one. But in this test bed the Open XR modules are fully under the control of the Open XR Controller. The connectivity between the Open XR modules and the Open XR Controller is established through an MPLS L3VPN to a remote PE router. This

demonstrates the flexibility in the deployment of a centralized Open XR Controller that manages all Open XR Modules deployed in different routers throughout the network.

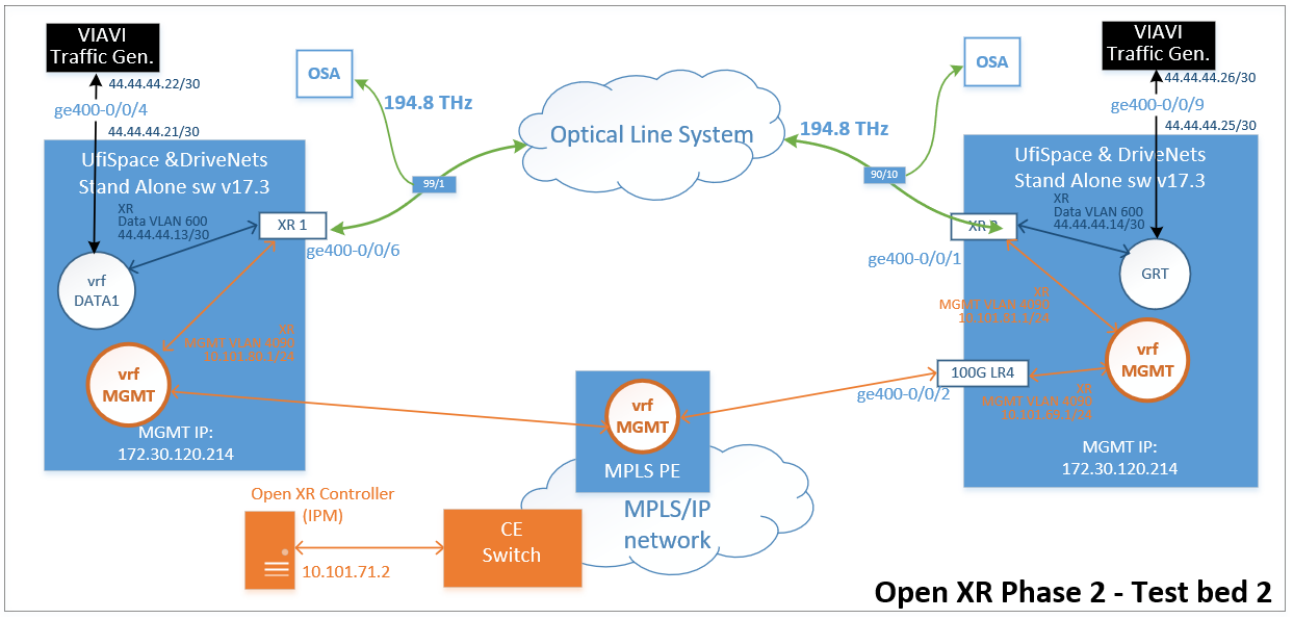


Figure 24 - Static IP Dual Mgmt test bed logical diagram

DriveNets DNOS 17.3 configuration:

```
interfaces
  ge400-0/0/1
    admin-state enabled
  !
!
interfaces
  ge400-0/0/6
    admin-state enabled
    ipv6-admin-state enabled
```

The 400GE connection availability was successfully verified using a VIAVI tester.

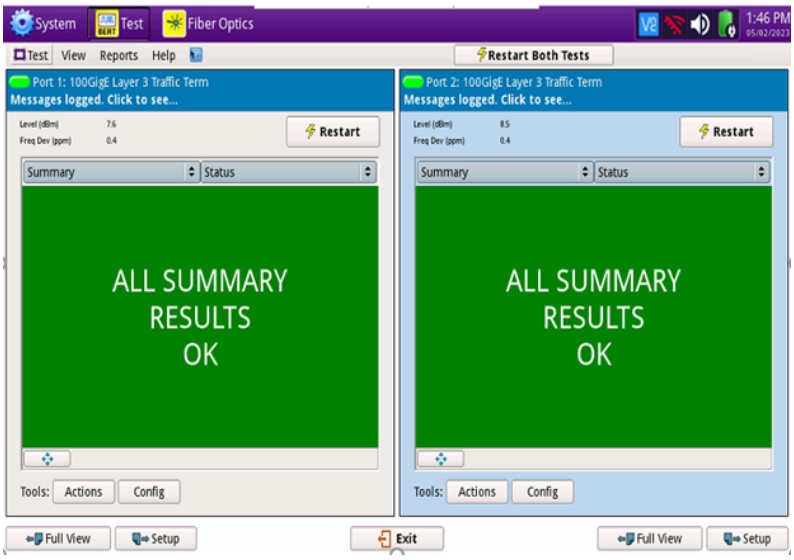


Figure 25 - Static IP Dual Mgmt test bed Viavi test results

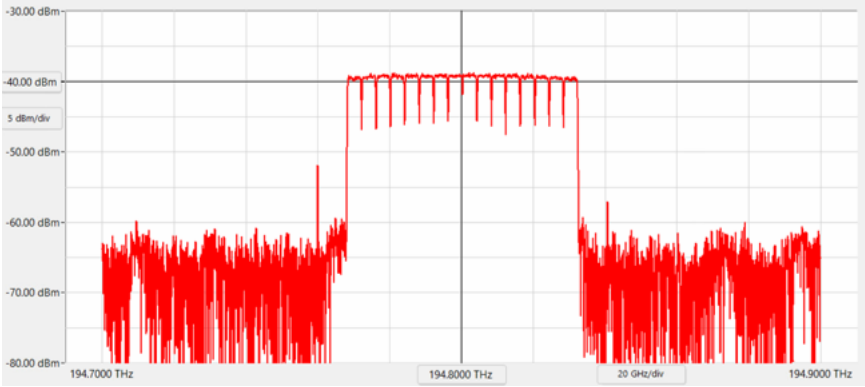


Figure 26 - Static IP Dual Mgmt test bed Hub Tx OSA 90/10

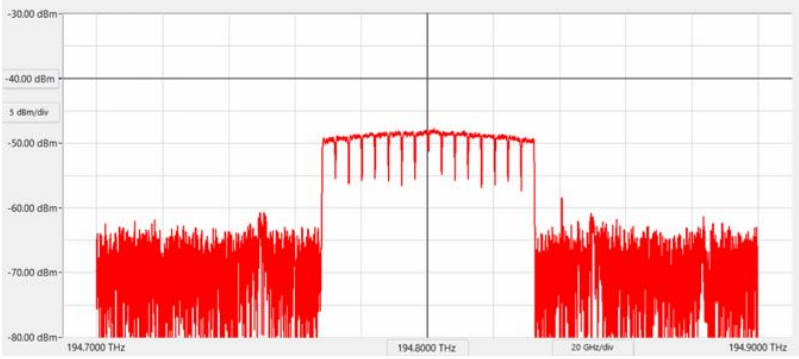


Figure 27 - Static IP Dual Mgmt test bed Leaf Tx OSA 99/1

Open XR Controller screenshots showing the Open XR modules:

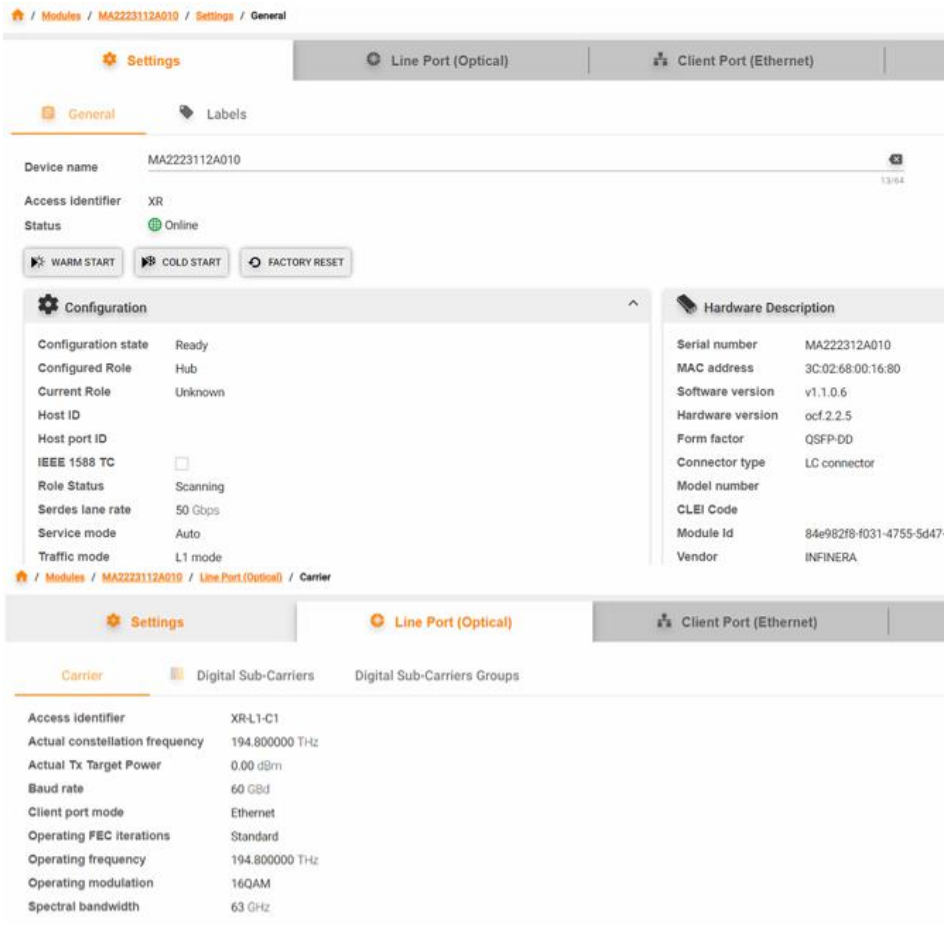


Figure 28 - Hub Open XR Controller

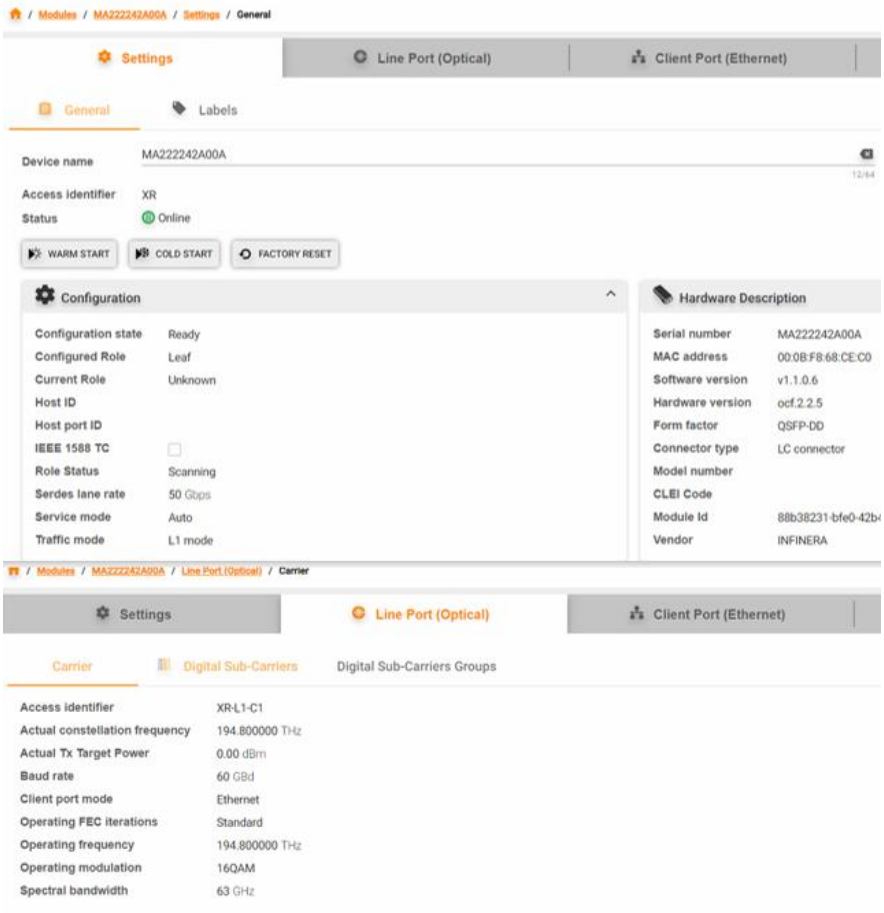


Figure 29 - Leaf Open XR Controller

DriveNets DNOS 17.3 CLI show command output:

```
OpenXR1# show interfaces counters ge400-0/0/6

Interface ge400-0/0/6:
Operational state: up

Ethernet counters:
        RX octets:                          1650652255472 ( 80944365020 bps / 80944.37 Mbps)
        RX frames:                            24274255534 (   148794694 fps /  148.79 Mfps)
        RX unicast frames:                    24274255525 (   148794694 fps /  148.79 Mfps)
        RX broadcast frames:                          0 (           0 fps /       0 Mfps)
        RX multicast frames:                          9 (           0 fps /       0 Mfps)
        TX octets:                          1008013765002 ( 80944380557 bps / 80944.38 Mbps)
        TX frames:                            14823727726 (   148794856 fps /  148.79 Mfps)
        TX unicast frames:                    14823727726 (   148794856 fps /  148.79 Mfps)
        TX broadcast frames:                          0 (           0 fps /       0 Mfps)
        TX multicast frames:                          0 (           0 fps /       0 Mfps)

Ethernet control counters:
        RX pause frames:                              0
        TX pause frames:                              0
        RX PFC frames:                                0
        TX PFC frames:                                0

Ethernet drop counters:
        RX errors:                                    0
        RX too short:                                 0
        RX too long:                                  0
        RX FCS errors:                                0
        RX internal MAC errors:                       0
        RX pipeline MAC drops:                        0
        TX errors:                                    0

FEC counters:
        FEC corrected errors:                         6
        FEC uncorrected errors:                       0
        FEC symbol errors:                            6
        FEC bit errors:                               6

Forwarding drops summary of logical and sub-IF:
        RX VLAN mismatch:                             0
        Destination MAC mismatch:                     0
        Invalid IP header:                            0
        Total RX dropped packets:                     0
        Total TX dropped packets:                     0

OpenXR1# show interfaces counters ge400-0/0/1

Interface ge400-0/0/1:
Operational state: up

Ethernet counters:
        RX octets:                          1129501749403 ( 80948323874 bps / 80948.32 Mbps)
        RX frames:                            16610284256 (   148802329 fps /  148.8 Mfps)
        RX unicast frames:                    16610284256 (   148802329 fps /  148.8 Mfps)
        RX broadcast frames:                          0 (           0 fps /       0 Mfps)
        RX multicast frames:                          0 (           0 fps /       0 Mfps)
        TX octets:                          1772110212735 ( 80948712302 bps / 80948.71 Mbps)
        TX frames:                            26060435945 (   148802736 fps /  148.8 Mfps)
        TX unicast frames:                    26060435935 (   148802736 fps /  148.8 Mfps)
        TX broadcast frames:                          0 (           0 fps /       0 Mfps)
        TX multicast frames:                         10 (           0 fps /       0 Mfps)

Ethernet control counters:
        RX pause frames:                              0
        TX pause frames:                              0
        RX PFC frames:                                0
        TX PFC frames:                                0

Ethernet drop counters:
        RX errors:                                    0
        RX too short:                                 0
        RX too long:                                  0
        RX FCS errors:                                0
        RX internal MAC errors:                       0
```

```
        RX pipeline MAC drops:                          0
        TX errors:                                      0

FEC counters:
        FEC corrected errors:                      127840
        FEC uncorrected errors:                         0
        FEC symbol errors:                         127867
        FEC bit errors:                            121006

Forwarding drops summary of logical and sub-IF:
        RX VLAN mismatch:                               0
        Destination MAC mismatch:                       0
        Invalid IP header:                              0
        Total RX dropped packets:                       0
        Total TX dropped packets:                       0

OpenXR1#
```

More DriveNets DNOS 17.3 CLI show command output:

```
OpenXR1# show interfaces transceiver ge400-0/0/1

Interface ge400-0/0/1
Identifier                                  : QSFP_DD
Connector                                   : 0x7 (LC type fiber connector)
Length (SMF,km)                             : 63km
Length (OM3 50um)                           : 0m
Length (OM2 50um)                           : 0m
Length (OM1 62.5um)                         : 0m
Length (Copper or Active cable)             : 0m
Transmitter technology                      : 0x10 C-band tunable laser
Optical transport info                      : Grid 6.25GHz, Frequency 194.8 THz
Tx Power                                    : 0.0 dBm
Laser wavelength                            : 1547 nm
Laser wavelength tolerance                  : 0 nm
Vendor name                                 : INFINERA
Vendor OUI                                  : 00:0B:F8
Vendor PN                                   :
Vendor rev                                  :
Vendor SN                                   : MA222312A010
Firmware version                            : 1.1
Revision compliance                         : QSFP-DD or QSFP-DD CMIS Rev 5.1
Module temperature                          : 47.9 degrees C / 118.2 degrees F
Module voltage                              : 3.2 V
Alarm/warning flags implemented             : Yes
Laser tx bias current (Channel 0)           : 100.0 mA
Transmit avg optical power (Channel 0)      : 0.0 dBm / 1.0 mW
Rcvr signal avg optical power (Channel 0)   : -3.0 dBm / 0.5 mW
Laser bias current high alarm (Chan 0)      : off
Laser bias current low alarm (Chan 0)       : off
Laser bias current high warning (Chan 0)    : off
Laser bias current low warning (Chan 0)     : off
Module temperature high alarm               : off
Module temperature low alarm                : off
Module temperature high warning             : off
Module temperature low warning              : off
Module voltage high alarm                   : off
Module voltage low alarm                    : off
Module voltage high warning                 : off
Module voltage low warning                  : off
Laser tx power high alarm (Channel 0)       : off
Laser tx power low alarm (Channel 0)        : off
Laser tx power high warning (Channel 0)     : off
Laser tx power low warning (Channel 0)      : off
Laser rx power high alarm (Channel 0)       : off
Laser rx power low alarm (Channel 0)        : off
Laser rx power high warning (Channel 0)     : off
Laser rx power low warning (Channel 0)      : off
Laser bias current high alarm threshold     : 105.0 mA
Laser bias current low alarm threshold      : 95.0 mA
Laser bias current high warning threshold   : 102.5 mA
Laser bias current low warning threshold    : 97.5 mA
Laser output power high alarm threshold     : 4.0 dBm / 2.5 mW
Laser output power low alarm threshold      : -19.0 dBm / 0.0 mW
Laser output power high warning threshold   : 3.0 dBm / 2.0 mW
Laser output power low warning threshold    : -18.0 dBm / 0.0 mW
Module temperature high alarm threshold     : 75.0 degrees C / 167.0 degrees F
Module temperature low alarm threshold      : -5.0 degrees C / 23.0 degrees F
Module temperature high warning threshold   : 70.0 degrees C / 158.0 degrees F
Module temperature low warning threshold    : 0.0 degrees C / 32.0 degrees F
Module voltage high alarm threshold         : 3.6 V
Module voltage low alarm threshold          : 3.0 V
Module voltage high warning threshold       : 3.5 V
Module voltage low warning threshold        : 3.1 V
Laser rx power high alarm threshold         : 4.0 dBm / 2.5 mW
Laser rx power low alarm threshold          : -18.0 dBm / 0.0 mW
Laser rx power high warning threshold       : 2.0 dBm / 1.6 mW
Laser rx power low warning threshold        : -16.0 dBm / 0.0 mW
Chromatic dispersion (min / avg / max)      : -2147483648 / -2147483648 /
2147483647 ps/nm
Pre-fec-ber (curr / min / avg / max)        : 9.300e-05 / 2.930e-04 / 6.500e-05
/ 2.300e-02
Post-fec-ber (FERC) (curr / min / avg / max) : 0.000e+00 / 3.320e+06 / 0.000e+00
/ 1.901e+08
Osnr (min / avg / max)                      : 210.000 / 300.000 / 309.000 dB

Active application                          : ZR400-OFEC-16QAM
Supported applications:
1. 100GBASE-ZRplus
2. ZR200-OFEC-QPSK
3. ZR300-OFEC-8QAM
4. ZR400-OFEC-16QAM

Configuration:
  Application                               : N/A
  Frequency                                 : N/A
  Grid spacing                              : N/A
  Target output power                       : N/A

OpenXR1# show interfaces transceiver ge400-0/0/6

Interface ge400-0/0/6
Identifier                                  : QSFP_DD
Connector                                   : 0x7 (LC type fiber connector)
Length (SMF,km)                             : 63km
Length (OM3 50um)                           : 0m
Length (OM2 50um)                           : 0m
Length (OM1 62.5um)                         : 0m
Length (Copper or Active cable)             : 0m
Transmitter technology                      : 0x10 C-band tunable laser
Optical transport info                      : Grid 6.25GHz, Frequency 194.8 THz
Tx Power                                    : 0.0 dBm
Laser wavelength                            : 1547 nm
Laser wavelength tolerance                  : 0 nm
Vendor name                                 : INFINERA
Vendor OUI                                  : 00:0B:F8
Vendor PN                                   :
Vendor rev                                  :
Vendor SN                                   : MA222242A00A
Firmware version                            : 1.1
Revision compliance                         : QSFP-DD or QSFP-DD CMIS Rev 5.1
Module temperature                          : 62.4 degrees C / 144.3 degrees F
Module voltage                              : 3.2 V
Alarm/warning flags implemented             : Yes
Laser tx bias current (Channel 0)           : 100.0 mA
Transmit avg optical power (Channel 0)      : -3.0 dBm / 0.5 mW
Rcvr signal avg optical power (Channel 0)   : -0.6 dBm / 0.9 mW
Laser bias current high alarm (Chan 0)      : off
Laser bias current low alarm (Chan 0)       : off
Laser bias current high warning (Chan 0)    : off
Laser bias current low warning (Chan 0)     : off
Module temperature high alarm               : off
Module temperature low alarm                : off
Module temperature high warning             : off
Module temperature low warning              : off
Module voltage high alarm                   : off
Module voltage low alarm                    : off
Module voltage high warning                 : off
Module voltage low warning                  : off
Laser tx power high alarm (Channel 0)       : off
Laser tx power low alarm (Channel 0)        : off
Laser tx power high warning (Channel 0)     : off
Laser tx power low warning (Channel 0)      : off
Laser rx power high alarm (Channel 0)       : off
Laser rx power low alarm (Channel 0)        : off
Laser rx power high warning (Channel 0)     : off
Laser rx power low warning (Channel 0)      : off
Laser bias current high alarm threshold     : 105.0 mA
Laser bias current low alarm threshold      : 95.0 mA
Laser bias current high warning threshold   : 102.5 mA
Laser bias current low warning threshold    : 97.5 mA
Laser output power high alarm threshold     : 4.0 dBm / 2.5 mW
Laser output power low alarm threshold      : -19.0 dBm / 0.0 mW
Laser output power high warning threshold   : 3.0 dBm / 2.0 mW
Laser output power low warning threshold    : -18.0 dBm / 0.0 mW
Module temperature high alarm threshold     : 75.0 degrees C / 167.0 degrees F
Module temperature low alarm threshold      : -5.0 degrees C / 23.0 degrees F
Module temperature high warning threshold   : 70.0 degrees C / 158.0 degrees F
Module temperature low warning threshold    : 0.0 degrees C / 32.0 degrees F
Module voltage high alarm threshold         : 3.6 V
Module voltage low alarm threshold          : 3.0 V
Module voltage high warning threshold       : 3.5 V
Module voltage low warning threshold        : 3.1 V
Laser rx power high alarm threshold         : 4.0 dBm / 2.5 mW
Laser rx power low alarm threshold          : -18.0 dBm / 0.0 mW
Laser rx power high warning threshold       : 2.0 dBm / 1.6 mW
Laser rx power low warning threshold        : -16.0 dBm / 0.0 mW
```

```
Chromatic dispersion (min / avg / max)        : -2147483648 / -2147483648 /
2147483647 ps/nm
Pre-fec-ber (curr / min / avg / max)          : 9.180e-04 / 1.089e-03 / 2.680e-04
/ 2.300e-02
Post-fec-ber (FERC) (curr / min / avg / max)  : 0.000e+00 / 4.250e+06 / 0.000e+00
/ 2.200e+08
Osnr (min / avg / max)                        : 210.000 / 260.000 / 279.000 dB

Active application                            : ZR400-OFEC-16QAM
Supported applications:
                                              1. 100GBASE-ZRplus
                                              2. ZR200-OFEC-QPSK
                                              3. ZR300-OFEC-8QAM
                                              4. ZR400-OFEC-16QAM

                                              Configuration:
                                                Application                    : N/A
                                                Frequency                      : N/A
                                                Grid spacing                   : N/A
                                                Target output power            : N/A
```

5.4 Static IP Dual mgmt. with Open XR Modules in Juniper 400G router

To make it possible to take advantage of all the innovative XR Module features in existing 400G routers, the Open XR Module Dual Management feature is required. This capability avoids two integration points which are hard to do. First of all, the CMIS implementation of the router must be complete and supporting the CMIS implementation and the CMIS vendor extensions available on the Open XR Module. Secondly the router mgmt. interface must support all the functionality needed to manage the Open XR Modules, which is currently not available for the enhanced p2mp features of Open XR.

For the Open XR Module to expose its IP management interface to the Open XR Controller, several different approaches exist. The approach taken for this test bed is using functionality that exists in most Service Provider 400G routers sold today. In this case the physical 400GE port is configured with one additional IP interface that is associated with a particular VLAN tag. This enables the Open XR Module to redirect Ethernet Frames with the VLAN tag to its own management plane, as illustrated in the Figure below.

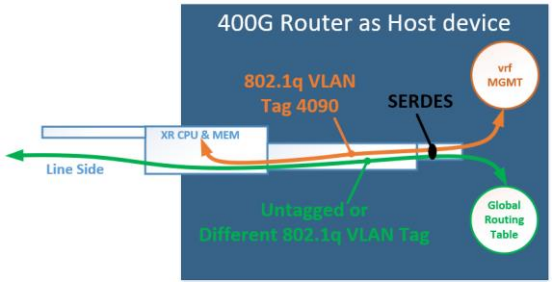


Figure 30 - Open XR Module MGMT VLAN redirect to Module control plane

This additional IP interface can then be considered an Open XR Module management interface, which can be connected into a separate MPLS VPN isolating it from other traffic. Based on this principle the test bed as shown below is implemented. The Open XR Module that is used for this test is a module with Serial Number MA222312A00B and IP address 10.101.70.2.

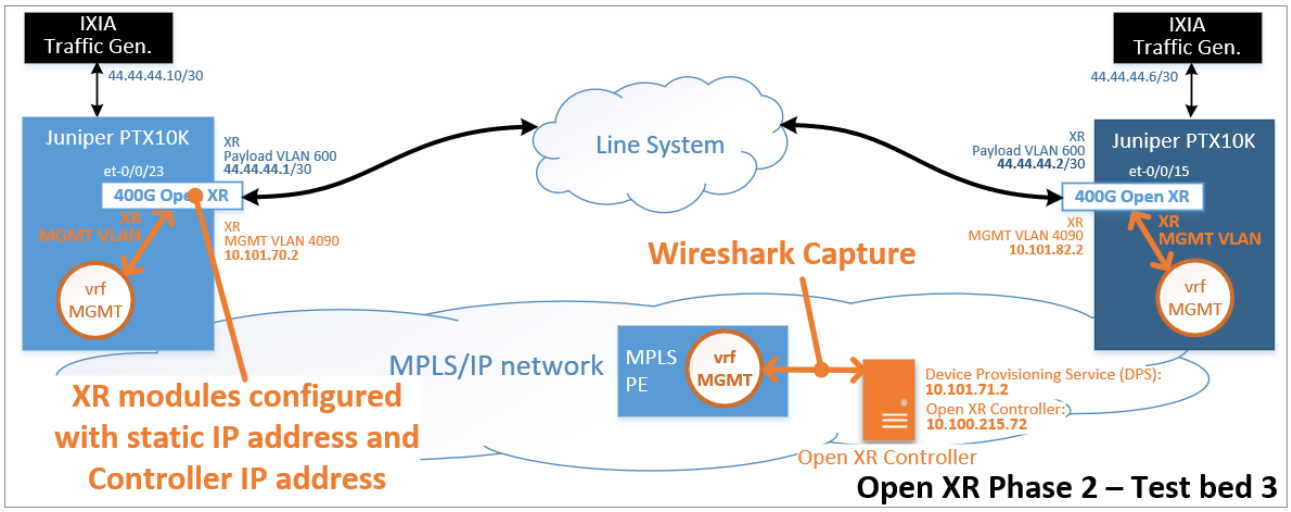


Figure 31 - Static IP Dual Management test bed logical diagram

Below is displayed the Juniper Junos configuration of the physical interface with the payload and the mgmt. logical interfaces. The logical interface with VLAN tag 600 is used for carrying traffic between the routers, while the interface with VLAN tag 4090 is used for the Open XR management traffic. Please note that the payload traffic can also be carried untagged to increase the available bandwidth for IP packets on the 400G link.

```
set interfaces et-0/0/23 description "OpenXR Testing - connection to XR 1"
set interfaces et-0/0/23 flexible-vlan-tagging
set interfaces et-0/0/23 speed 400g
set interfaces et-0/0/23 mtu 9192
set interfaces et-0/0/23 encapsulation flexible-ethernet-services
set interfaces et-0/0/23 unit 600 vlan-id 600
set interfaces et-0/0/23 unit 600 family inet address 44.44.44.1/30
set interfaces et-0/0/23 unit 4090 vlan-id 4090
set interfaces et-0/0/23 unit 4090 family inet mtu 1500
set interfaces et-0/0/23 unit 4090 family inet address 10.101.82.1/24
set interfaces et-0/0/23 unit 4090 family inet6
set routing-instances OpenXR-Testing-MGMT interface et-0/0/23.4090
```

The CLI output below shows on top the state of IP interfaces on the Open XR Module during the test. Below this CLI output from the Juniper router it is showing how the router has detected the Open XR module and registered it as OpenZR+ transceiver type.

```
root@xr:~# ip addr show dev br0
47: br0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP group default qlen 1000
    link/ether 3c:02:68:00:17:0d brd ff:ff:ff:ff:ff:ff
    inet 10.101.70.2/24 scope global br0
       valid_lft forever preferred_lft forever
    inet 169.254.82.72/16 brd 169.254.255.255 scope global noprefixroute br0
       valid_lft forever preferred_lft forever
    inet6 fe80::c8b7:65ff:fe4e:71fb/64 scope link
       valid_lft forever preferred_lft forever


lab@prod-lab03d-rc1-re0> show chassis pic fpc-slot 0 pic-slot 0 |match "INFINERA |Wave-"
                         Fiber                  Xcvr vendor       Wave-                          Xcvr          JNPR     MSA
  15   400G-ZR-M          SM     INFINERA                          1528.77 nm - 1567.13 nm   0.1           XXXX     CMIS 5.1

lab@prod-lab03d-rc1-re0> show chassis hardware | match "Xcvr 15 |Item"
Item             Version  Part number  Serial number     Description
    Xcvr 15      XXXX     NON-JNPR     MA222312A00B      QSFP56-DD-400G-ZR-M
```

The CLI output below shows the output of a Python script that is used to configure the Open XR Module via its CMIS interface. As shown by the output, the module is statically configured with IP addresses and DCHP is disabled.

```
# ./sfputil_dn.py show mgmt -p 6
  Port  DHCP      ND       debugport    ip address      ip gateway    NTP server    ip call home    mvlan channel    oui etype    sgmii       mvlan id
------  --------  -------  -----------  --------------  ------------  ------------  --------------  ---------------  -----------  --------  ----------
     6  disabled  enabled  open         10.101.70.2/24  10.101.70.1   0.0.0.0       0.0.0.0:0       manual           enabled      disabled        4090
```

To understand how the Open XR Modules connect to the Open XR Controller a Wireshark traffic capture was made using the Tcpdump application feature that allows writing to a .pcap file. This capture was made in the IP subnet the Open XR Controller connected to.

The packet capture shows that the Open XR Module (10.101.70.2) initially establishes a connection to the Device Provisioning Service server (DPS) (10.101.71.2). This allows the Open XR Module to obtain the contact information of the Open XR Controller and collect the needed certificate to securely connect to it.

The packet capture shows the initial TCP session establishment, which is followed by a TLS session setup. This is a relatively short-lived connection.

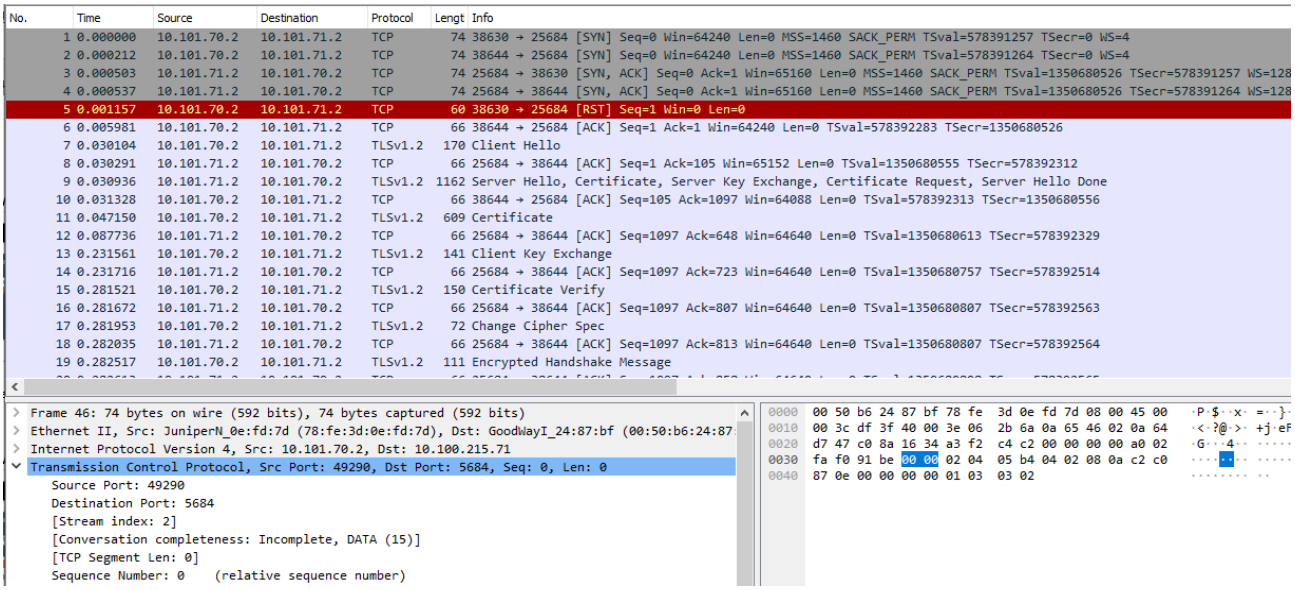


Figure 32 - Wireshark capture of TCP traffic between Open XR Module and Devices Provisioning Service

Once the Open XR Module has collected all needed data from the Device Provisioning Service, then the TLS session is terminated, and the Module will initiate a new TLS session to the Open XR Controller server IP address being 10.100.215.71. This stage in the Open XR Module management communication is shown in the Wireshark screenshot included below.

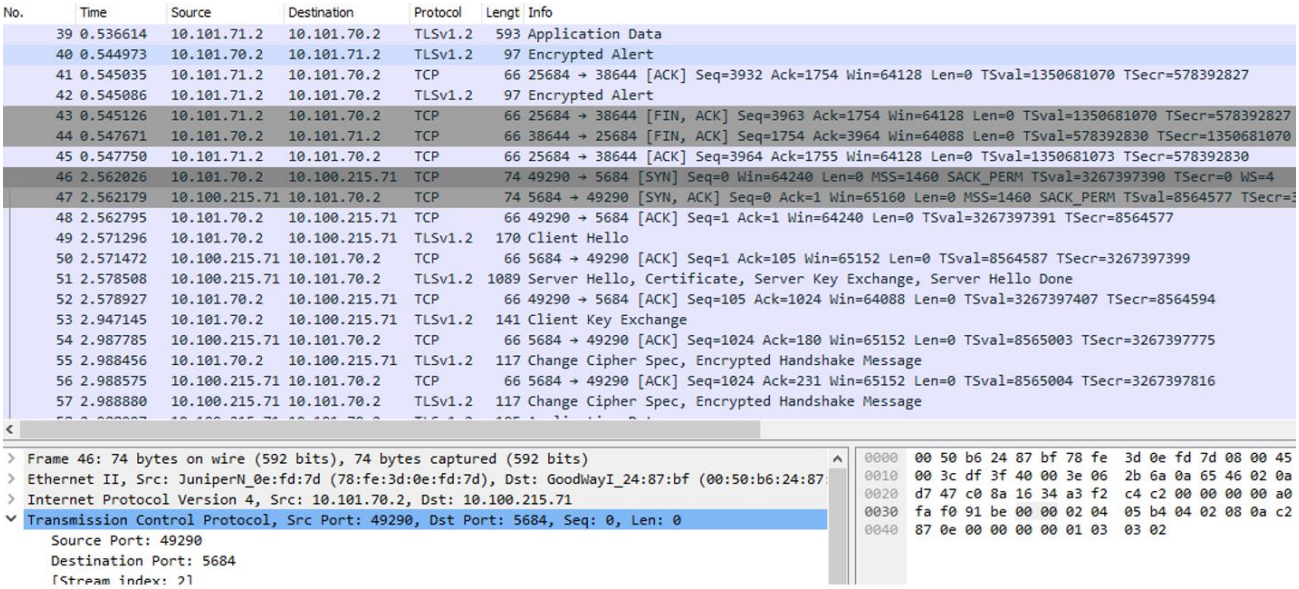


Figure 33- Wireshark capture of TCP traffic between Open XR Module and the Open XR Controller

After the TLS session with the Open XR Controller is setup and all data has been exchanged, then the Open XR Controller web portal shows the Open XR Module as online and managed by the controller.

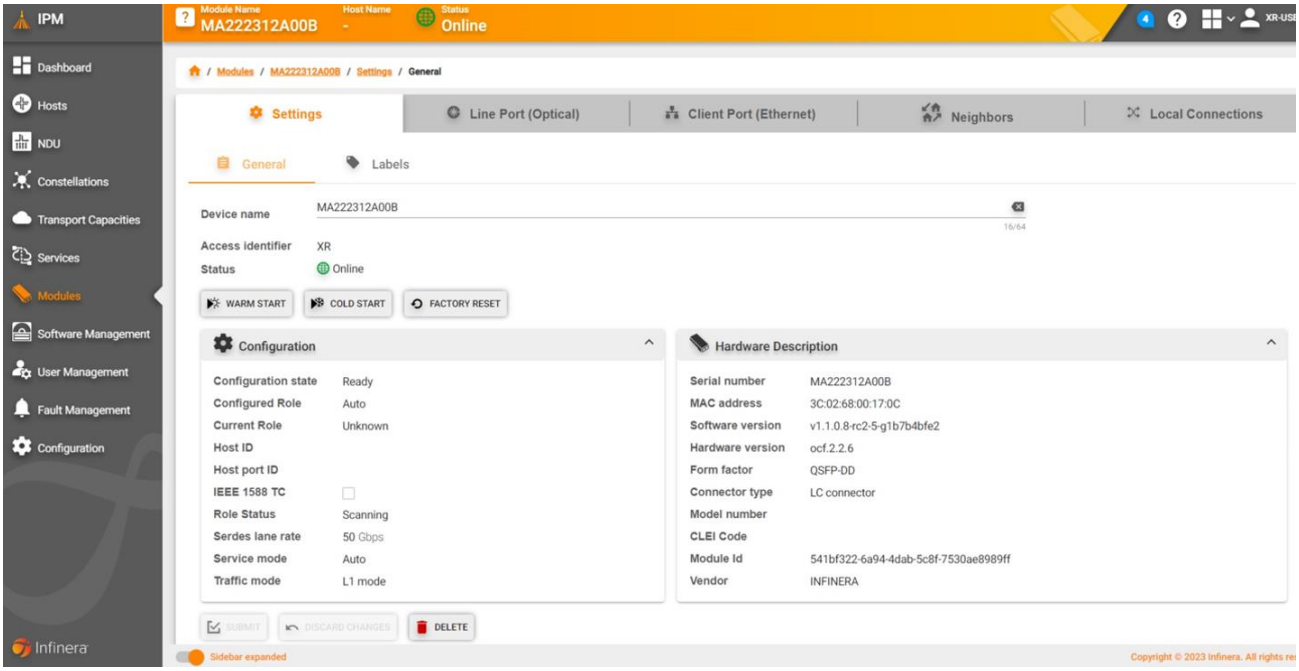


Figure 34 - Open XR Controller web portal with Open XR Module reported as Online

5.5 Dynamic IP Dual mgmt. with Open XR Modules in Juniper 400G router

This test extends the previous test bed with a DCHP server and client added to it. In this case the Open XR Module has a DHCP client activated, as opposed to manually configuring the IP address of the Module and the DPS server. This allows for using Open XR Modules in any router port without first manually configuring them. The Open XR Module that is used for this test is a module with Serial Number MA222312A00B and Dynamically assigned IP address 10.101.70.3.

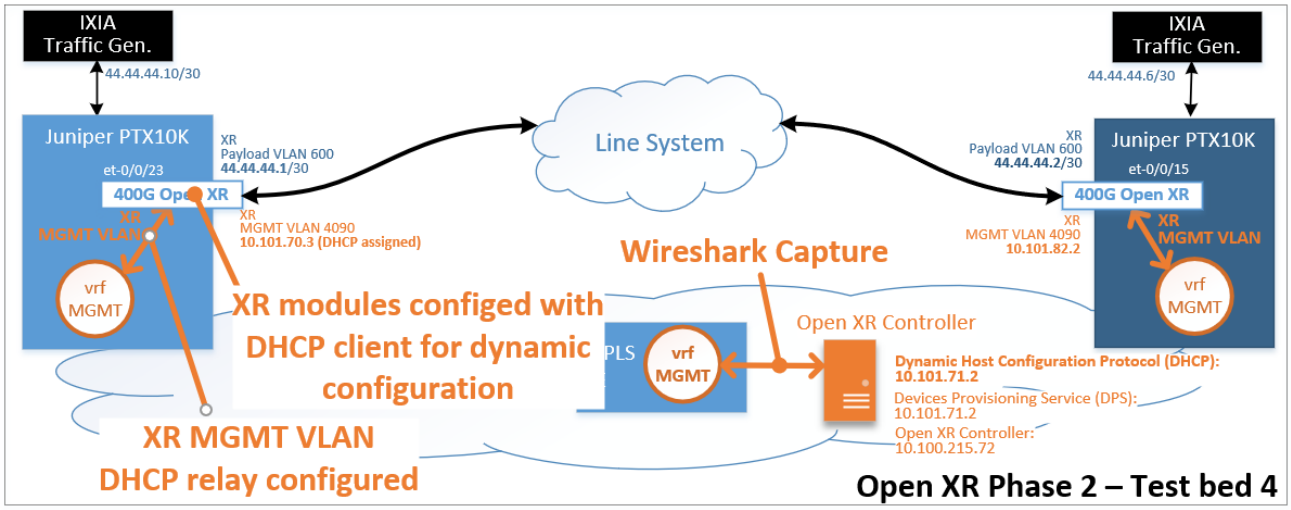


Figure 35 - Dynamic IP Dual Mgmt test bed logical diagram

To support the DHCP client on the Open XR Module the 400G router must be configured with DHCP message forwarding/relaying to a centralized DHCP server. This is configured as follows:

```
set routing-instances OpenXR-Testing-MGMT forwarding-options dhcp-relay group
OpenXR_Group interface et-0/0/23.4090
set routing-instances OpenXR-Testing-MGMT forwarding-options dhcp-relay server-
group OpenXR_IPM_servers 10.101.71.2
set routing-instances OpenXR-Testing-MGMT forwarding-options dhcp-relay group
OpenXR_Group active-server-group OpenXR_IPM_servers
```

The Open XR Module for this test bed also configured with an active DHCP client.

```
XR module DHCP configured through CMIS script
# ./sfputil_dn.py show mgmt -p 6
  Port  DHCP     ND       debugport    ip address    ip gateway    NTP server    ip call home    mvlan channel    oui etype    sgmii       mvlan id
------  -------  -------  -----------  ------------  ------------  ------------  --------------  ---------------  -----------  --------  ----------
     6  enabled  enabled  open         0.0.0.0/0     0.0.0.0       0.0.0.0       0.0.0.0:0       manual           enabled      disabled         4090
```

After the Open XR Module has requested an IP address from the DHCP server, the IP addresses active on the Open XR Module looks as follows:

```
root@xr:~# ip addr show dev br0
47: br0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP group default qlen 1000
    link/ether 3c:02:68:00:17:0d brd ff:ff:ff:ff:ff:ff
    inet 169.254.99.79/16 brd 169.254.255.255 scope global noprefixroute br0
       valid_lft forever preferred_lft forever
    inet 10.101.70.3/24 brd 10.101.70.255 scope global dynamic noprefixroute br0
       valid_lft 487sec preferred_lft 417sec
    inet6 fe80::94b7:57ff:fe9c:5e4/64 scope link
       valid_lft forever preferred_lft forever
```

The Wireshark screenshot below shows the DHCP messages that are exchanged between the client and server. Also visible is the IP addressing information provided by the DHCP server including the URL of the DPS service as DHCP option 114 (CoAPs URL).

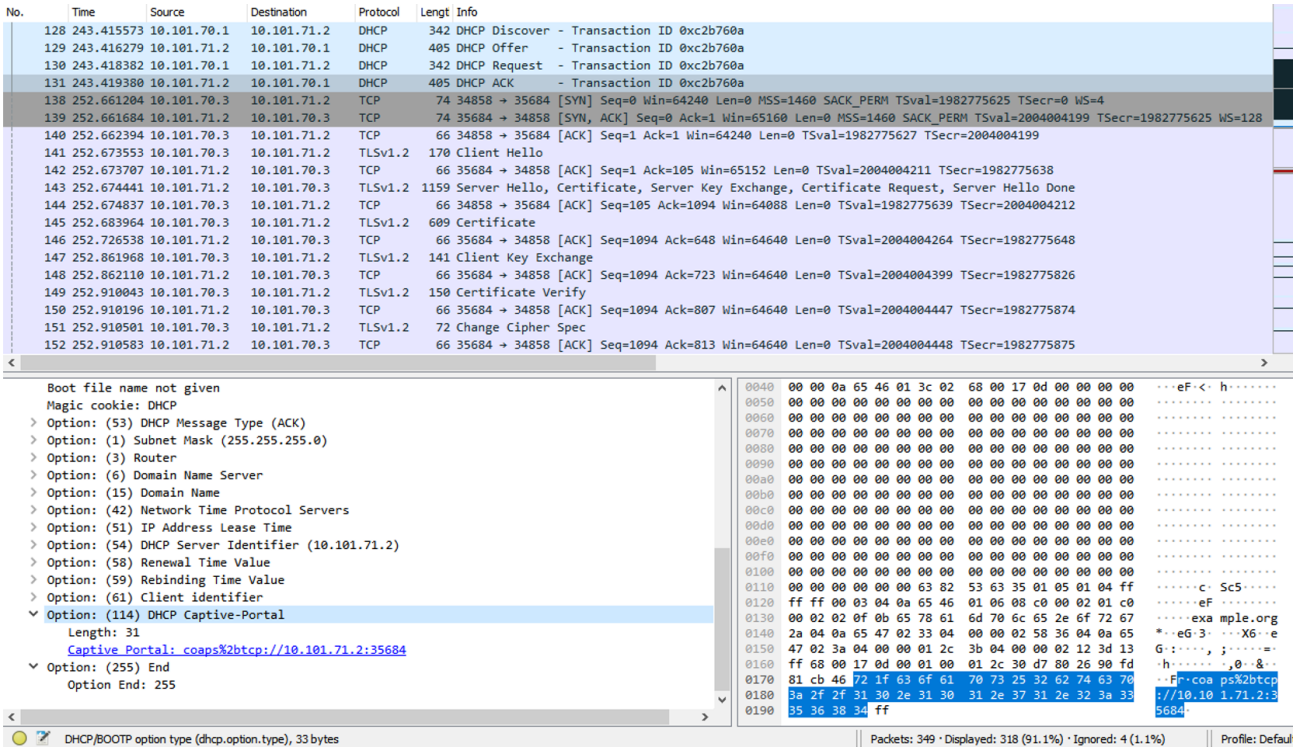


Figure 36 - Wireshark capture of DHCP messages and TCP traffic between Open XR Module and Devices Provisioning Service

Once the DPS data exchange is completed the TLS session to 10.101.71.2 is terminated and the TLS session to the Open XR Controller at 10.100.215.7 is initiated.

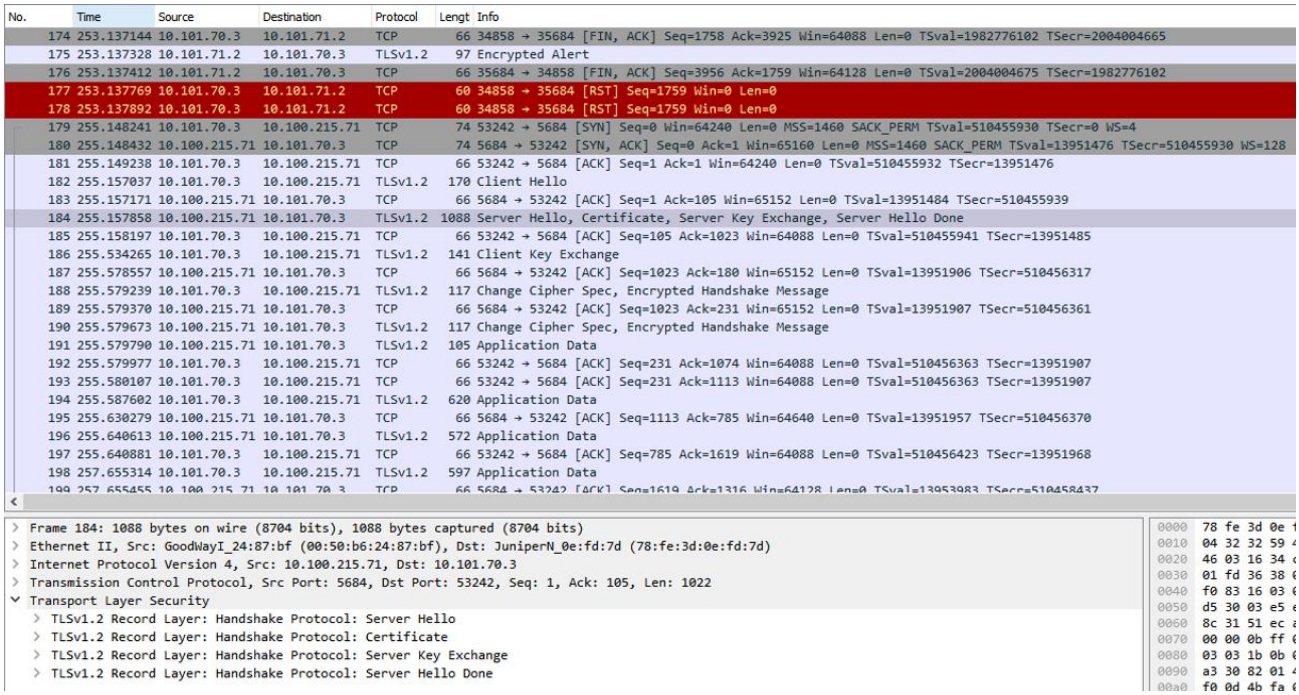


Figure 37 - Wireshark capture of TCP traffic between Open XR Module and the Open XR Controller

Just as with the previous test bed, after the TLS session with the Open XR Controller is setup and all data has been exchanged, then the Open XR Controller web portal shows the Open XR Module as online and managed by the controller.

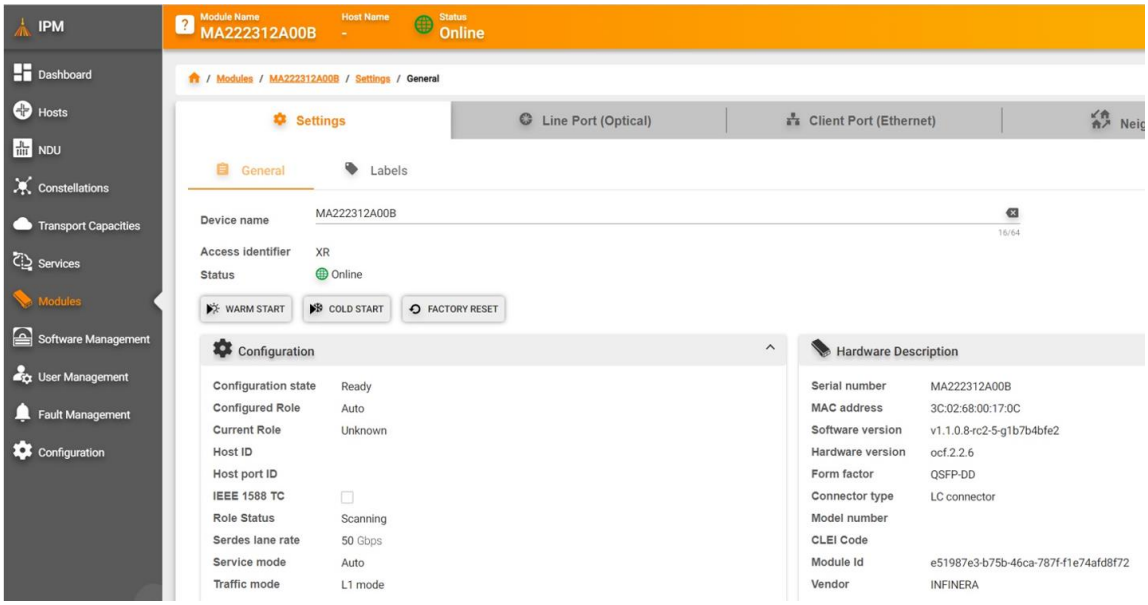


Figure 38 - Open XR Controller web portal with Open XR Module reported as Online

5.6 Line Side Dynamic IP Dual mgmt. with Open XR Modules in 400G router

When a Service Provider extends the network footprint to a new technical site, then the router deployed and connected to the network via a new DWDM link might not yet have management connectivity. For this reason, it is possible to enable a DHCP client on the line side of the Open XR Module. See the diagram for the connectivity path that is used in this case. This functionality is being tested in Test Bed 5.

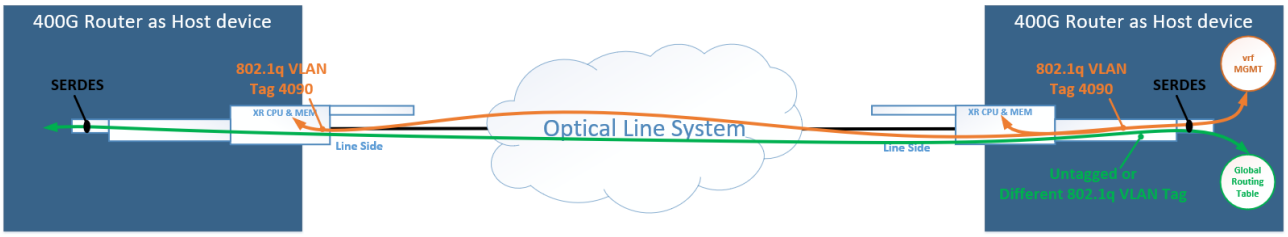


Figure 39 - Open XR Module MGMT VLAN redirect to Module control plane on a remote 400G router

The logical diagram of the test bed is shown in the Figure below. The Open XR Modules used for this test is a module with Serial Number MA222312A00B as local and a module with Serial Number MA122244A003 on the remote end.

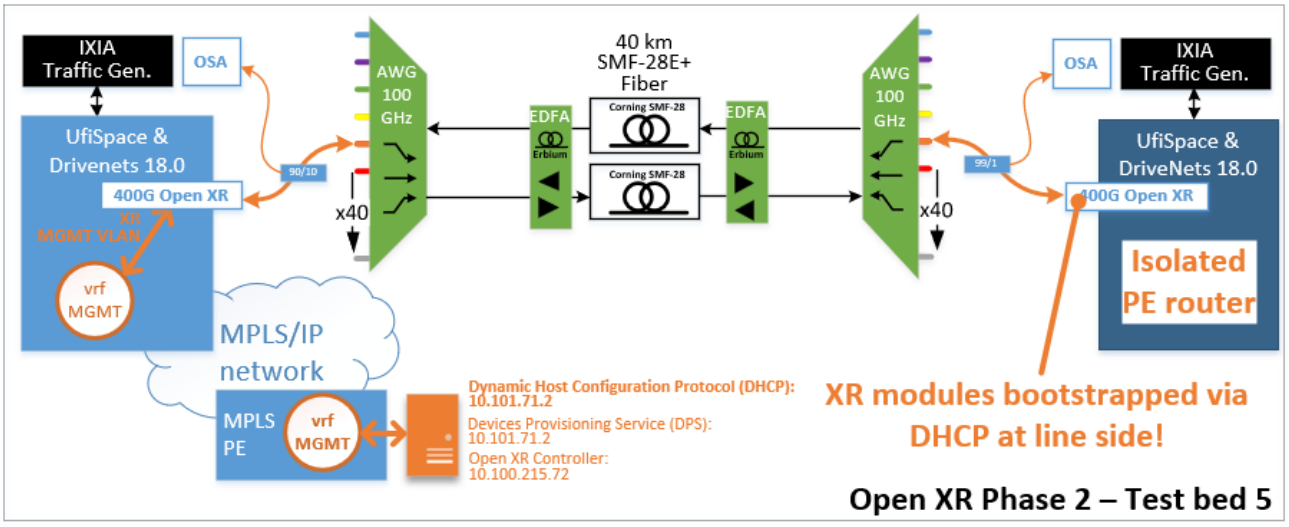


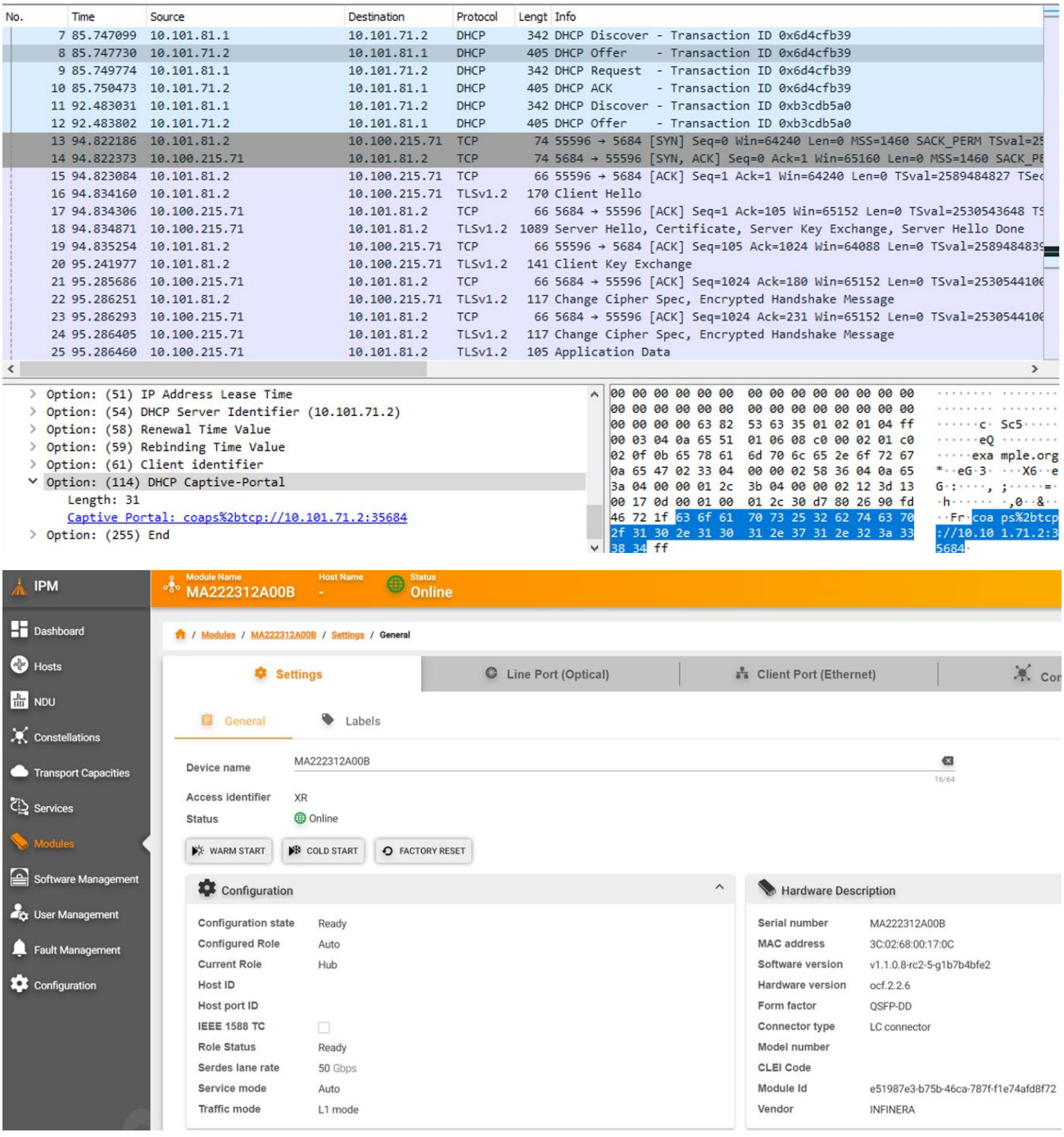
Figure 40 – Line Side Dynamic IP Dual Mgmt test bed logical diagram

In this test bed the 400G router that is used is the DriveNets/UfiSpace router running DNOS v18.0. This is configured as follows:

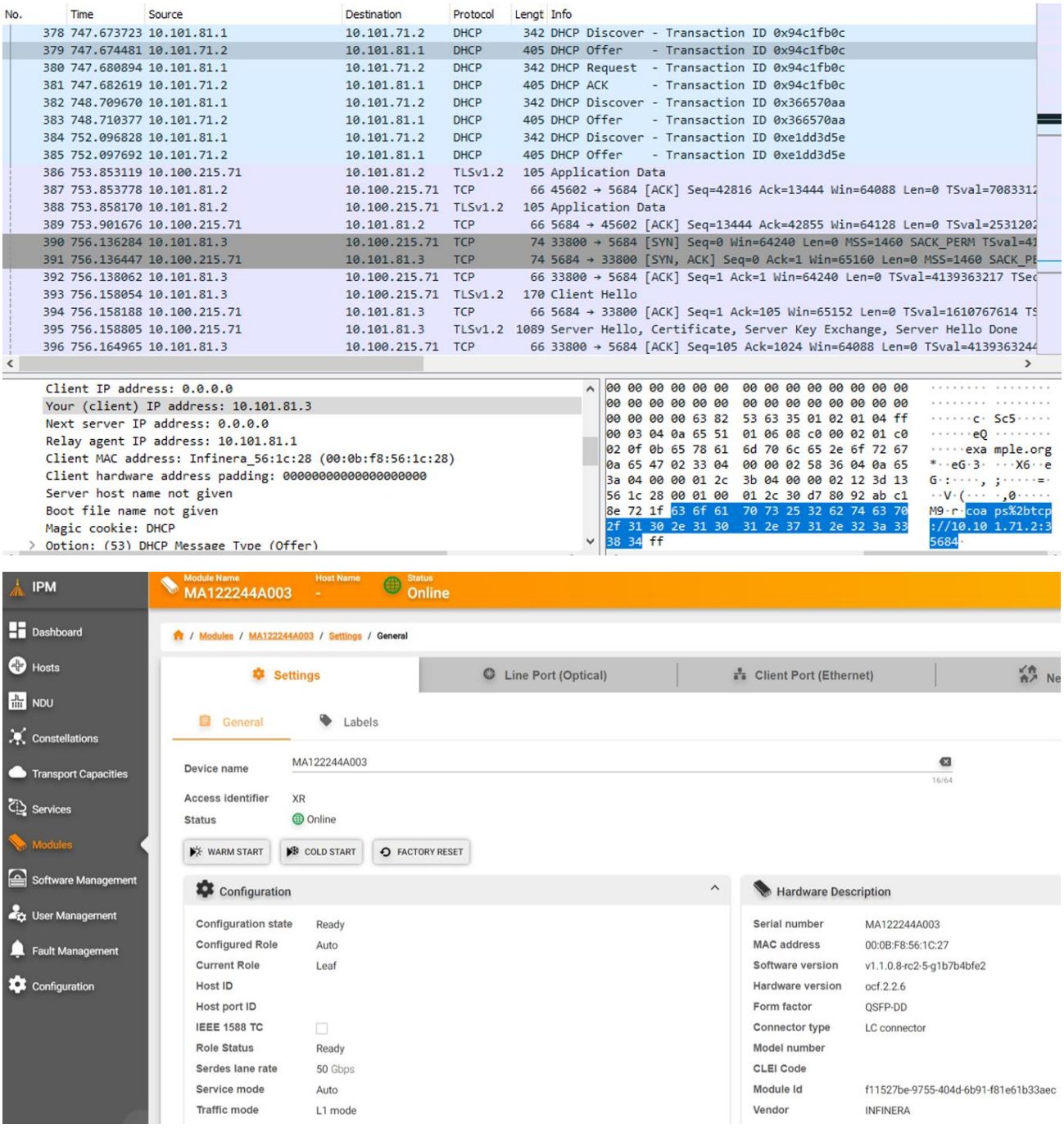
```
interfaces
  ge400-0/0/1
    admin-state enabled
```

```
  transceiver
    optical-transport
      center-frequency 194200 ghz
      target-output-power -3
    !
  !
!
ge400-0/0/1.4090
  admin-state enabled
  ipv4-address 10.101.81.1/24
  vlan-id 4090 tpid 0x8100
  dhcp relay-agent
    admin-state enabled
    server 10.101.71.2
  !
!
ge400-0/0/6
  admin-state enabled
  transceiver
    optical-transport
      center-frequency 194200 ghz
      target-output-power -3
    !
  !
!
ge400-0/0/6.4090
  admin-state enabled
  ipv4-address 10.101.80.1/24
  vlan-id 4090 tpid 0x8100
```

The Wireshark screen capture below shows how the local Open XR Module obtains its DHCP lease (IP address 10.101.81.2 is provided) and then registers at the Open XR Controller.



After the local Open XR Module is registered the remote module also manages to obtain its DHCP lease (IP address 10.101.81.3 is provided) and then also registers at the Open XR Controller.



400G router CLI ARP output showing the two DHCP assigned IP addresses for the local and the remote module associated with the same interface ge400-0/0/1.4090.

```
OpenXR1# show arp

VRF: default
| IPv4 Address    | MAC Address       | Origin   | State     | Age             | Interface         |
|-----------------+-------------------+----------+-----------+-----------------+-------------------|
| 10.101.69.1     | fc:96:43:aa:70:42 | dynamic  | reachable | 0 days, 0:57:30 | ge400-0/0/9.4090 |
| 10.101.69.2     | e8:c5:7a:b7:25:48 | local    |           |                 | ge400-0/0/9.4090 |
| 10.101.80.1     | e8:c5:7a:b7:25:30 | local    |           |                 | ge400-0/0/6.4090 |
| 10.101.81.1     | e8:c5:7a:b7:25:08 | local    |           |                 | ge400-0/0/1.4090 |
| 10.101.81.2     | 3c:02:68:00:17:0d | dynamic  | reachable | 0 days, 0:04:29 | ge400-0/0/1.4090 |
| 10.101.81.3     | 00:0b:f8:56:1c:28 | dynamic  | reachable | 0 days, 0:02:52 | ge400-0/0/1.4090 |
```

5.7 P2MP with Open XR Modules in NDU and UfiSpace DriveNets router

This test bed is built to test the ability of an Open XR Module inside a UfiSpace DriveNets router to act as a Hub module connecting to multiple NDU devices with Open XR Modules as leaf. The test setup is as follows:

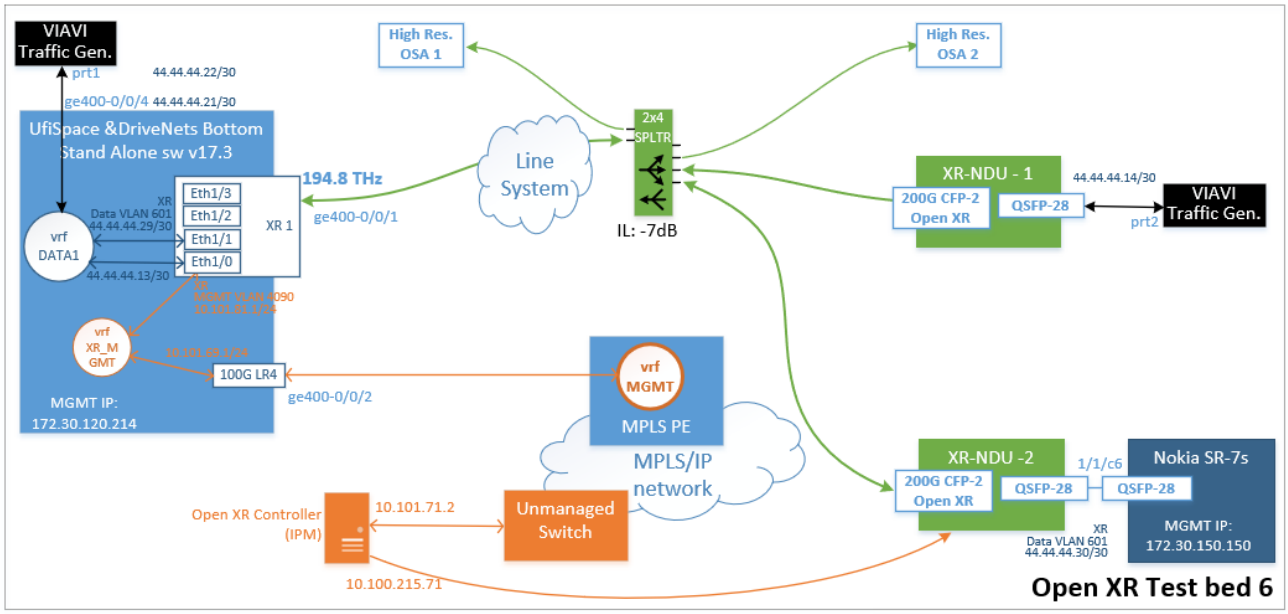


Figure 41 - Test bed 6 logical diagram

The interface configuration of the Open XR Hub Module for the traffic forwarding:

```
interfaces
  ge400-0/0/4
    admin-state enabled
    fec none
    ipv4-address 44.44.44.21/30
    speed 100
  !
!
```

```
OpenXR1# show config interfaces ge100-0/0/1/0
interfaces
  ge100-0/0/1/1
    admin-state enabled
    fec rs-fec-544-514
  !
!
OpenXR1# show config interfaces ge100-0/0/1/1.601
interfaces
  ge100-0/0/1/1.601
    admin-state enabled
    ipv4-address 44.44.44.29/30
    vlan-id 601 tpid 0x8100
  !
```

The interface configuration of the Nokia 100G router with a 100G grey client optic connecting to the NDU:

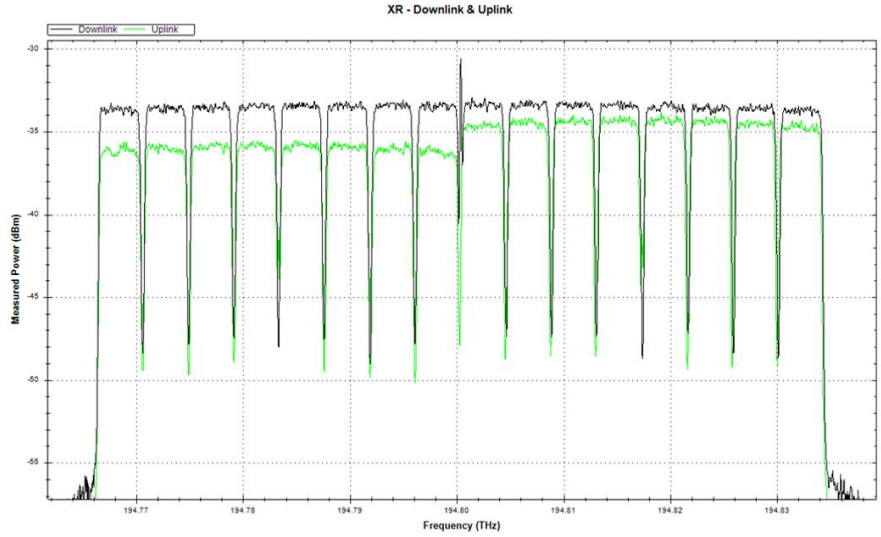
```
A:admin@prod-lab03c-ra1# info flat | match 1/1/c6
    port 1/1/c6 { }
    port 1/1/c6 { admin-state enable }
    port 1/1/c6 { description "** In use for Open XR testing - 100G LR4 **" }
    port 1/1/c6 { connector }
    port 1/1/c6 { connector breakout c1-100g }
    port 1/1/c6/1 { }
    port 1/1/c6/1 { admin-state enable }
    port 1/1/c6/1 { description "** In use for Open XR testing - 100G LR4
transceiver **" }
    port 1/1/c6/1 { ethernet }
    port 1/1/c6/1 { ethernet mode hybrid }
    port 1/1/c6/1 { ethernet mtu 9192 }
    router "Base" { interface "OpenXR_c6_tag_1" port 1/1/c6/1:601 }

[pr:/configure]
A:admin@prod-lab03c-ra1# info flat | match "OpenXR_c6_tag_1"
    router "Base" { interface "OpenXR_c6_tag_1" }
    router "Base" { interface "OpenXR_c6_tag_1" port 1/1/c6/1:601 }
    router "Base" { interface "OpenXR_c6_tag_1" ipv4 }
    router "Base" { interface "OpenXR_c6_tag_1" ipv4 primary }
    router "Base" { interface "OpenXR_c6_tag_1" ipv4 primary address 44.44.44.30 }
    router "Base" { interface "OpenXR_c6_tag_1" ipv4 primary prefix-length 30 }

[pr:/configure]
```

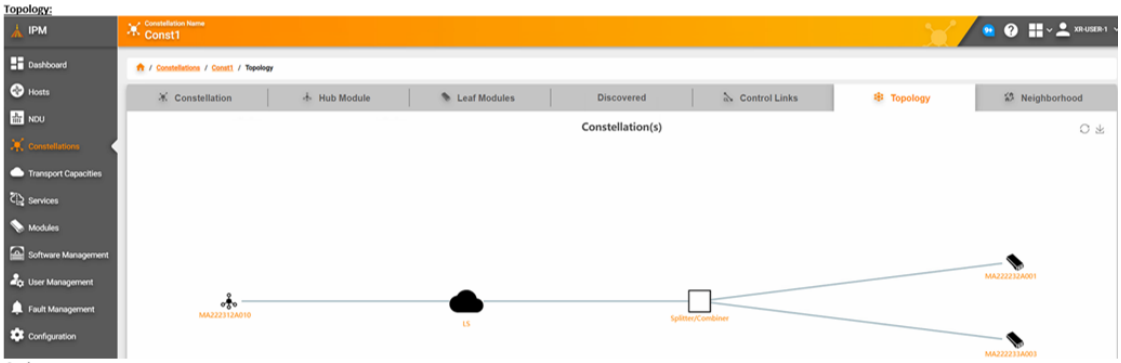
The High Resolution OSA devices reading from both the Hub (black) and the two Leaf modules (green):

OSA Screen shots:
Black trace: Hub TX
Green trace: Hub RX

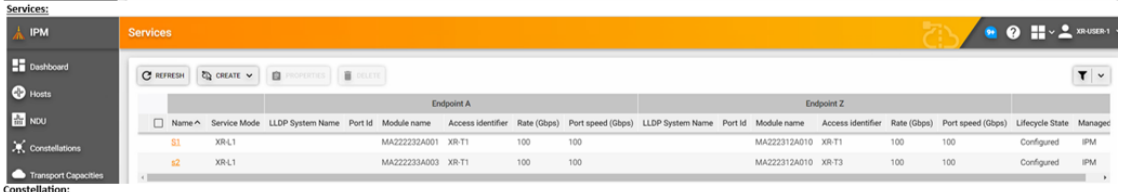


The Hub and Leaf modules are fully registered and controlled by the Open XR Controller:

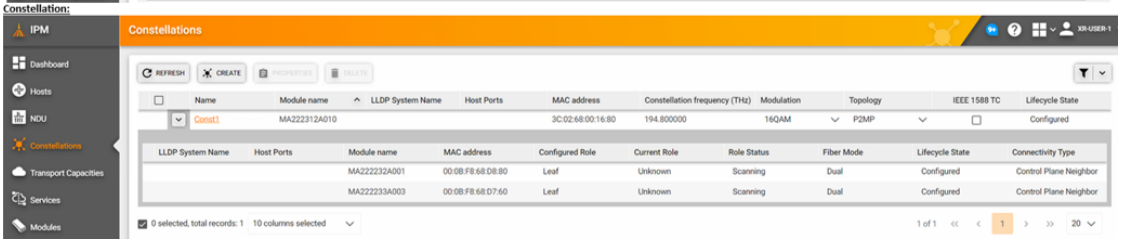
Topology:



Services:



Constellation:



6 Summary and Conclusion

In this Proof of concept, we have successfully demonstrated:

1. Coexistence of XR signals with a variety of brownfield DWDM and XGS-PON line systems in:
    a. Point-to-point configuration and
    b. Point-to-multipoint configuration
2. Compatibility of XR pluggable transceivers with a variety of host and NOS systems (Juniper, DriveNets & Ufispace, SONiC & Edgecore, Infinera TM301, and Infinera NDU).
3. Host independence of optical management when XR coherent optics are deployed in a packet host demonstrating the Open XR Management Architecture's dual management paradigm.
4. Advanced management functionality of smart pluggable transceivers, demonstrating the capability of modern routers to seamlessly support remote management of pluggable transceivers through the Open XR management architecture.

This demonstrates the viability of XR to transform the network architecture with long-reach coherent optics supporting both P2P and P2MP connectivity, while being able to seamlessly integrate with legacy network management and installed infrastructures.

7 References

[1] Open XR Forum, "Open XR Management Architecture Specification," March 2022. [Online]. Available: https://www.openxrforum.org/documents.