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CISCO

Advances in IP+Optical and Multi-Layer Integration

BRKOPT-2661

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Housekeeping

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- Please switch off our mobile phones
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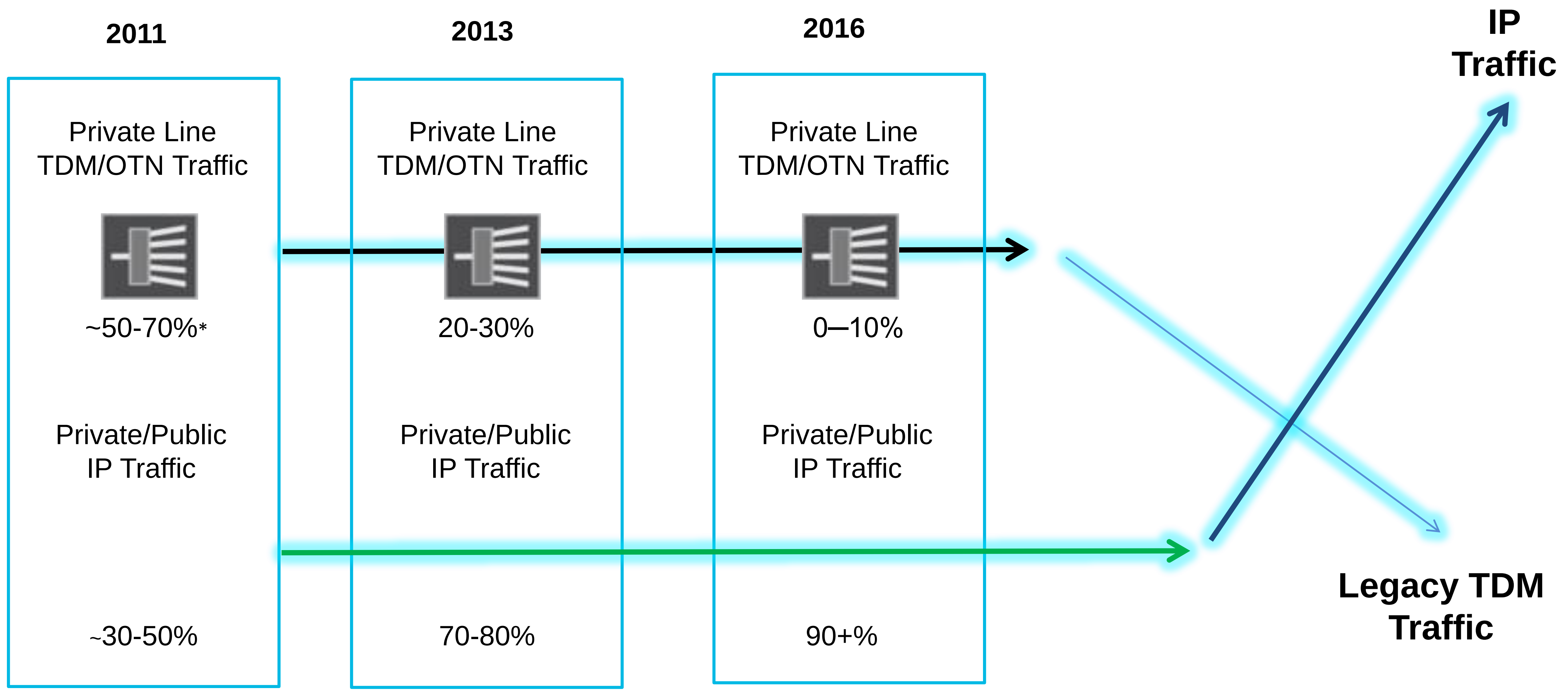
Agenda

- Introduction to IP+Optical
- New ROADM Trends to support seamless integration
- Multi-layer Control Planes
- IP+Optical Architectures and Management
- Conclusion

Introduction to IP+Optical

Circuit to Packet Migration

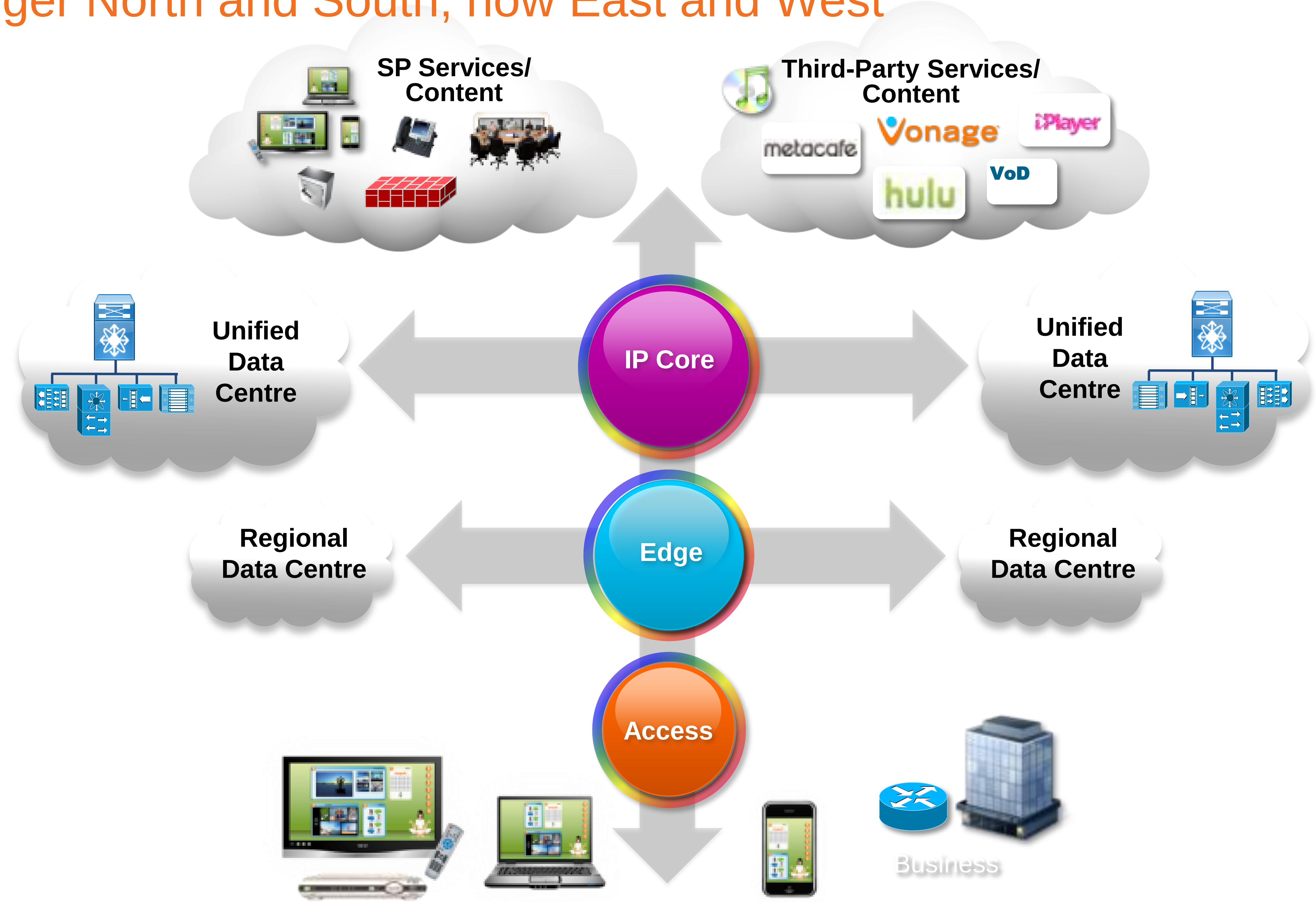


- Massive change in SP traffic make-up in next 5 years*
- SP revenue shifting from circuits to packet services**
  - 5 yrs → ~80% revenue derived from packet services
  - Packet traffic increasing at 34% CAGR*** (mobility, video and cloud)

**ACG Research 2011, ** Cisco Research 2010, ***Cisco VNI 2011*

Changing Traffic Patterns Drive Architecture Evolution

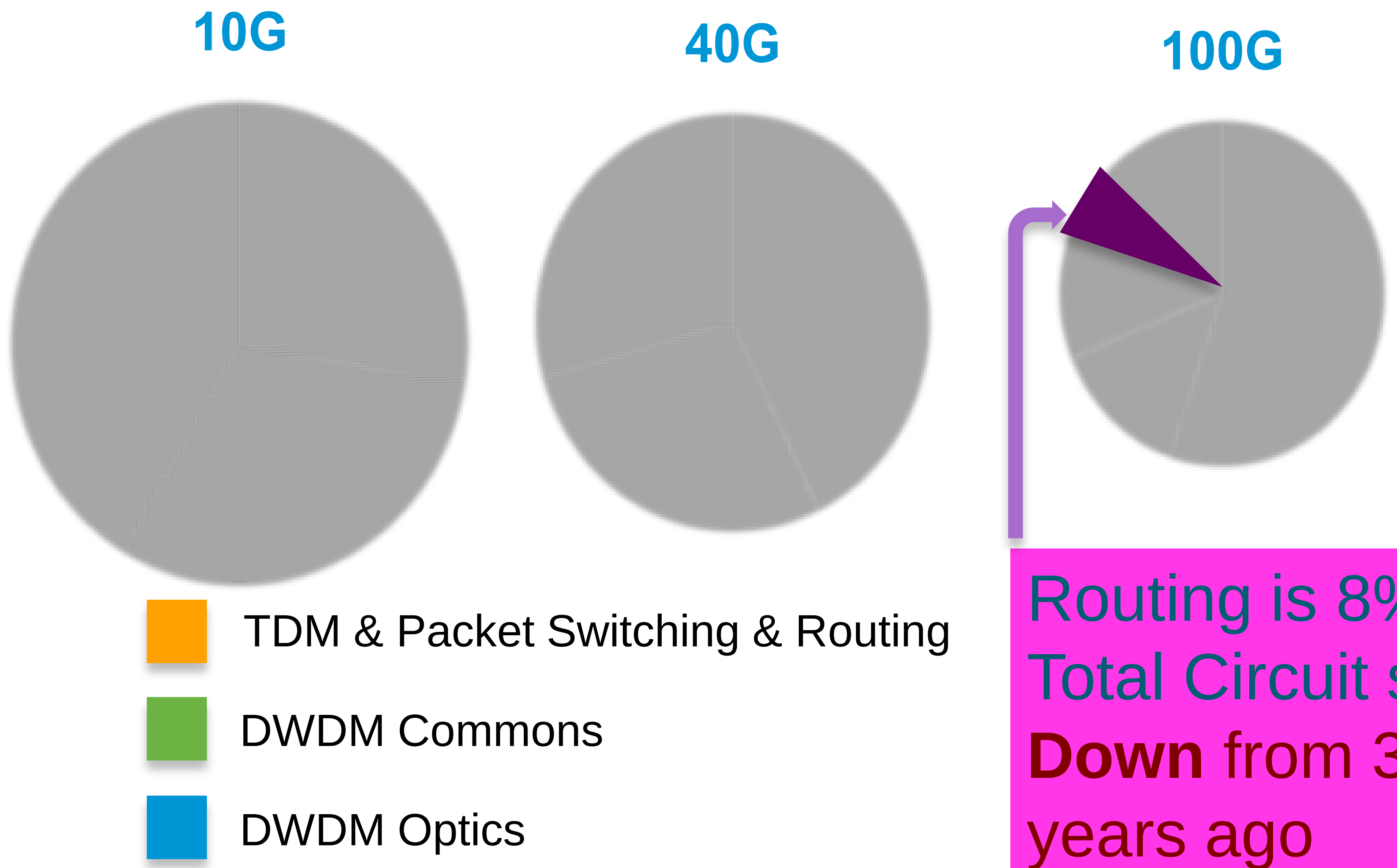
No Longer North and South; now East and West



How Technology Affects Economics

Percent of CAPEX, cost per bit

- The higher data rate means more complexity in optics and higher optical cost
- The ratio of L3 and Optical cost is changing with the data rate



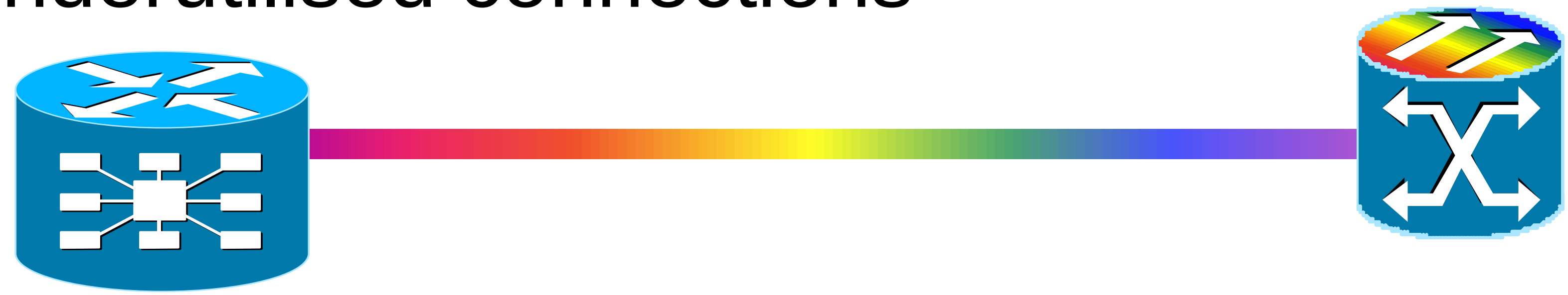
Routing is 8% of Total Circuit spend, **Down** from 35% 7 years ago

IP+Optical Business Drivers

- Increase Service Velocity
- Collapse Layers – reduce devices, space, power & OpEx
- Hybrid IP+TDM capabilities
  – Support legacy services
  – Migrate to single wavelength
- Eliminate interconnect optics cost

IP+Optical Business Drivers, Continued

- Flexibility of L3 and Optical results in the following benefits:
  - Reduce port numbers
  - Optical bypass opportunity
  - Greater flexibility for Layer 3 services
  - Additional network connectivity options, lower CAPEX
  - All network changes driven by software
  - Increase average utilisation per link
  - Release underutilised connections



What does IP+Optical Mean?

Distinct aspects define a true added value IP+Optical solution

- Data Plane integration

- Control Plane Integration
  - Multilayer Control Plane

- Management Plane Integration

Standards Bodies and Organisations

For Your Reference

I E T F

Charter: Evolution of the Internet (IP) Architecture

Active Participants:
- **Service Providers**
- **Vendors**

Charter: Global Telecom Architecture and Standards

Member Organisations:
- **Global Service Providers**
- **PTTs, ILECs, IXCs**
- **Telecom equipment vendors**
- **Governments**

OIF

Charter: Development of Optical Networking Products and Services

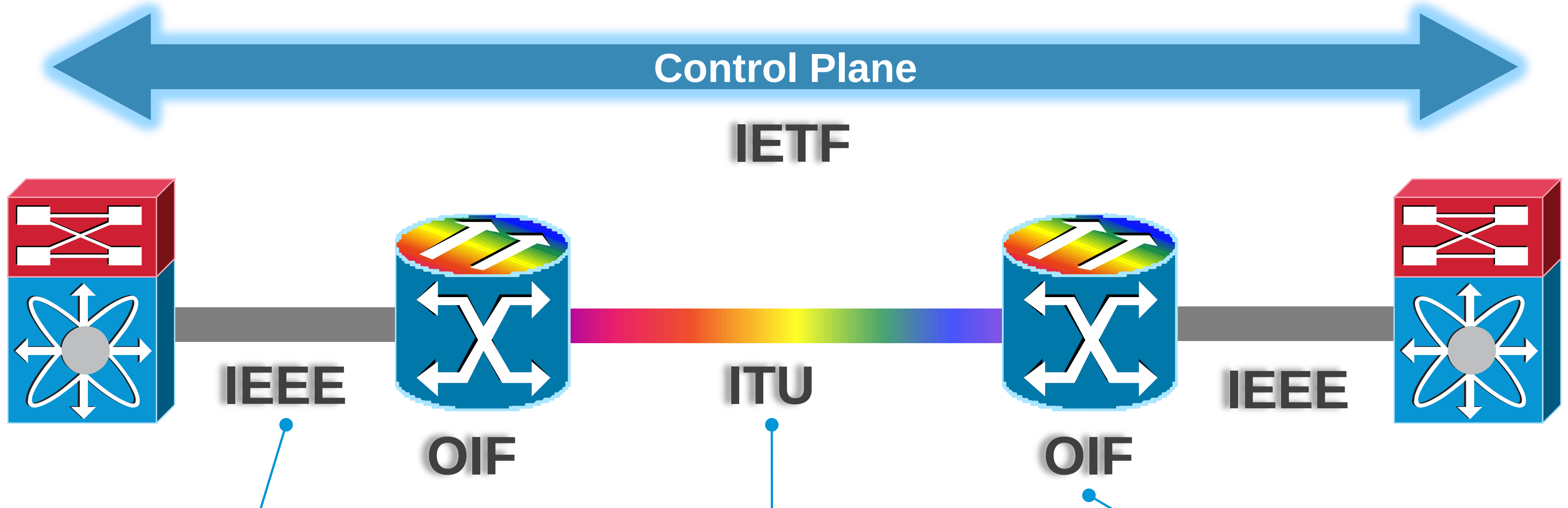
Member Organisations:
- **PTTs, ISPs, ILECs, IXCs**
- **Optical Networking Vendors**

IEEE Advancing Technology for Humanity

Charter (802.3 working group): Define the physical layer and data link layer's media access control (MAC) of wired Ethernet

Member Organisations:
- **Component Vendors**
- **Networking Vendors**

Standards Drive Adoption



Client Interfaces
Layer 2 interoperability

Transport Networks
Layer 1/0 interoperability

Hardware Vendors
Component Interoperability, Commonality

New ROADM Trends to Support Seamless Integration

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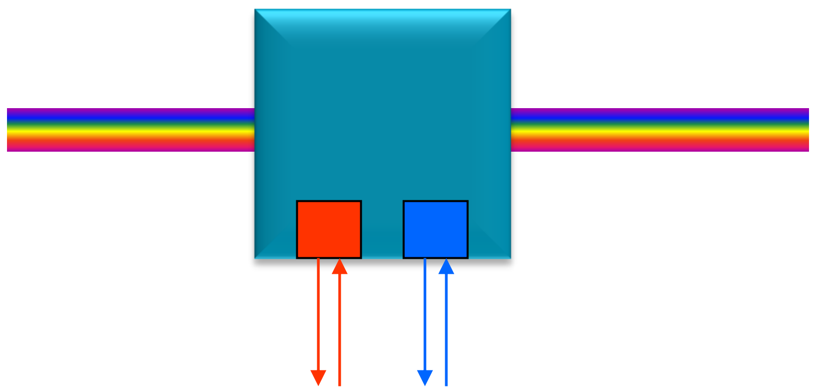
What is a ROADM?

A ROADM is a Wavelength Switch

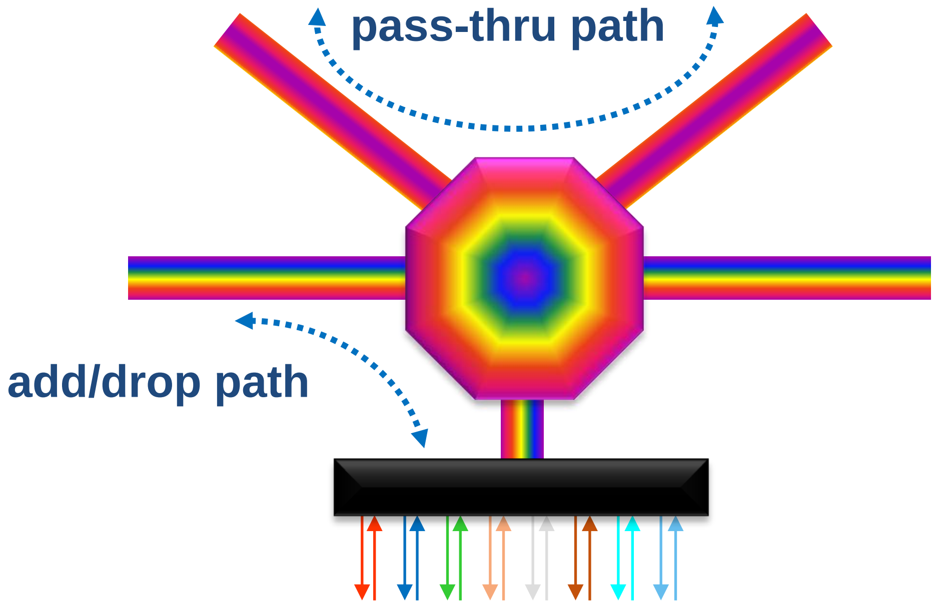
Traditional OADM



A fixed number of channels
A fixed set of channels

Physical Ring Only (2 Degree)

Reconfigurable OADM



Any number of channels (0 to 40/80)
Any set of channels, directional

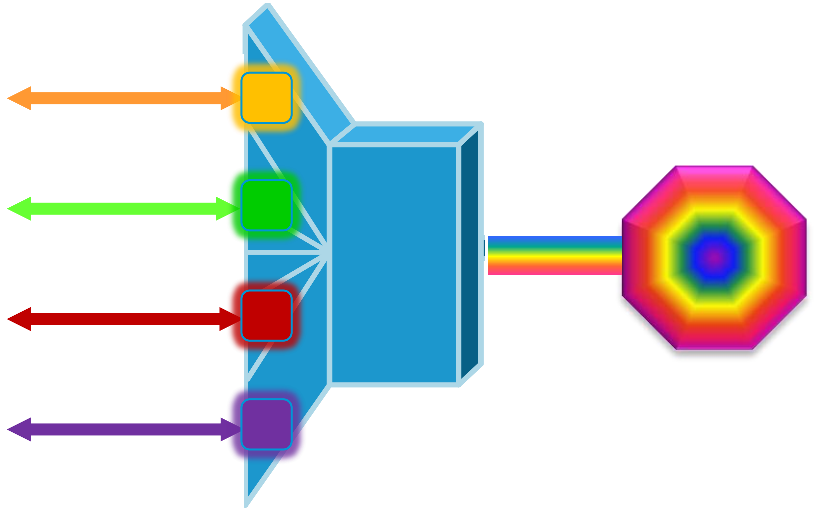
Physical Ring (2D) or Mesh (Multi-Degree)

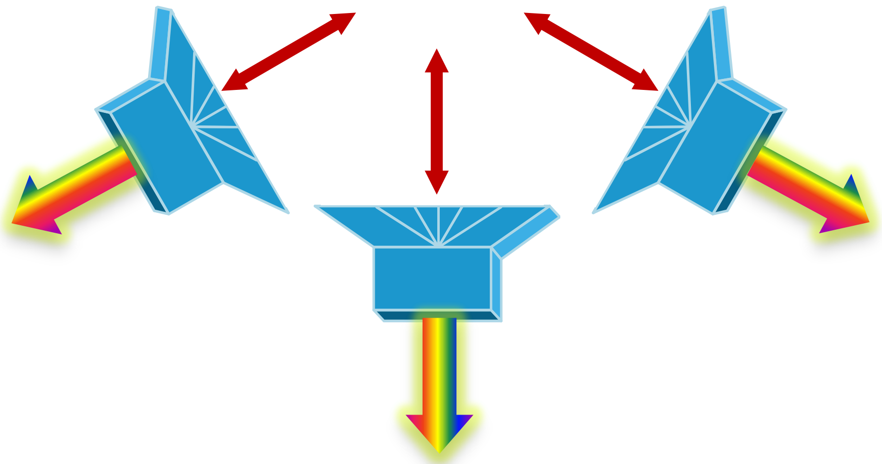
Animated slide

… because ROADM ports were coloured and directional.

Coloured Add/Drop
Fixed port frequency assignment
One unique frequency per port

Directional Add/Drop
Physical add/drop port is tied to a ROADM “degree”



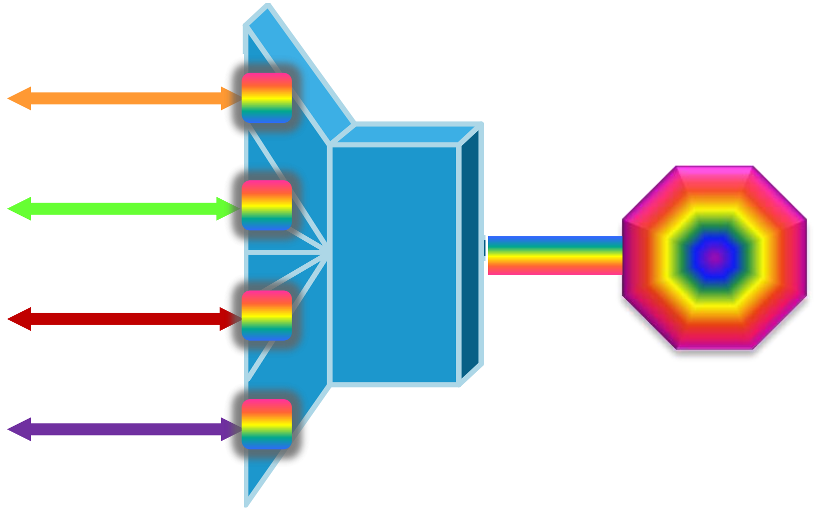


Due to these restrictions, a change in **direction** or **frequency** of an optical circuit required a **physical change** (move interface to different port) at the endpoints.

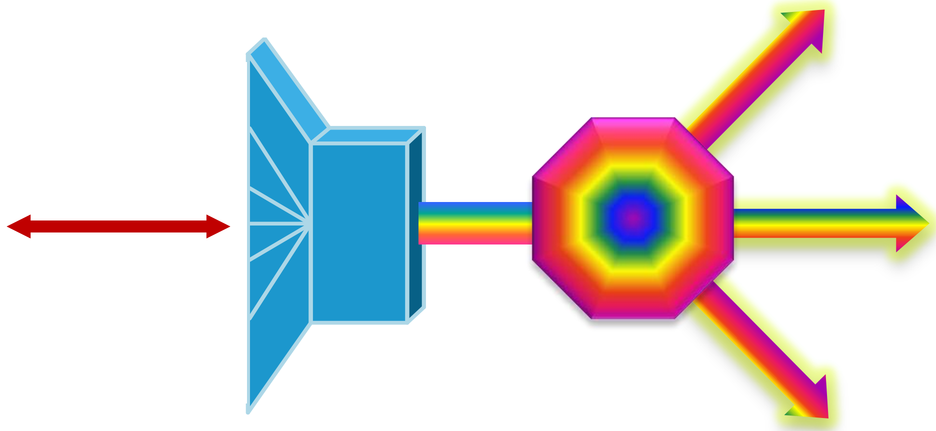
Colourless and Omni-directional Capabilities

Add Touchless flexibility, and hence Programmability, to ROADM networks

Colourless Add/Drop
No port-frequency assignment
Any frequency, any port



Omni-Directional Add/Drop
Add/Drop ports can be routed to/from any ROADM degree



With **Colourless** plus **Omni-Directional**, the frequency and direction of the signal can be changed, without requiring a change of ROADM add/drop port, therefore no truck rolls.

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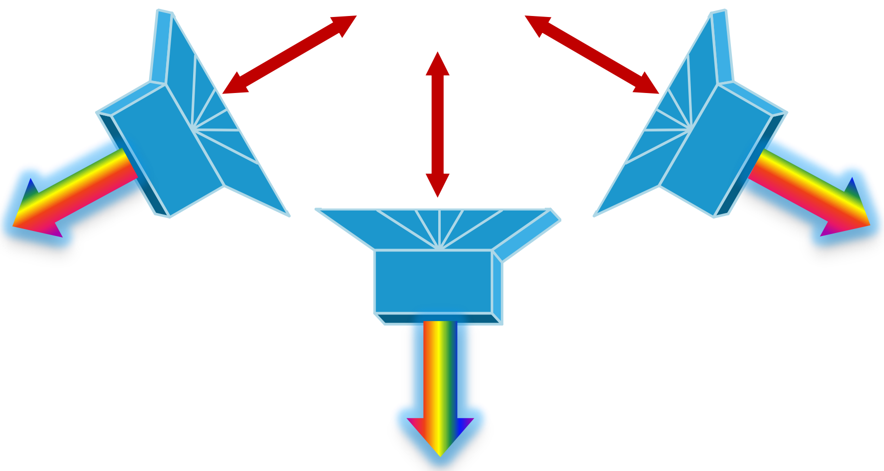
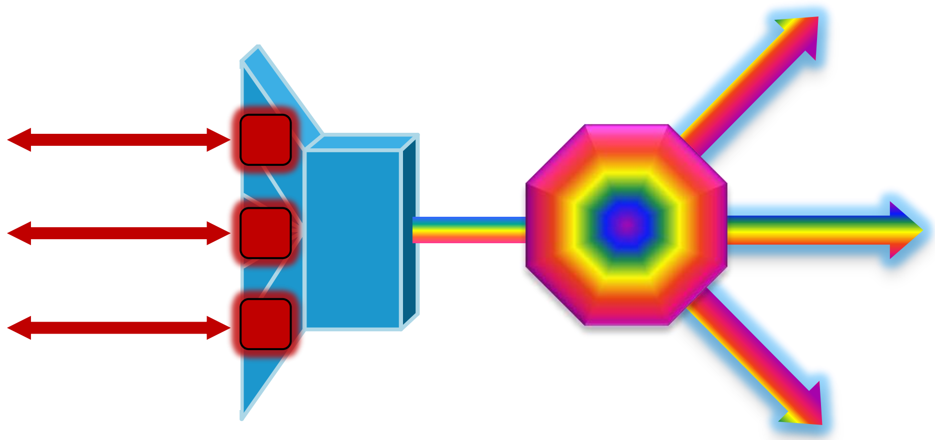
But…Colourless and Omni-directional introduce wavelength contention at the add/drop stage. Need a Contentionless architecture.

Directional Add/Drop ROADMs are by definition Contentionless



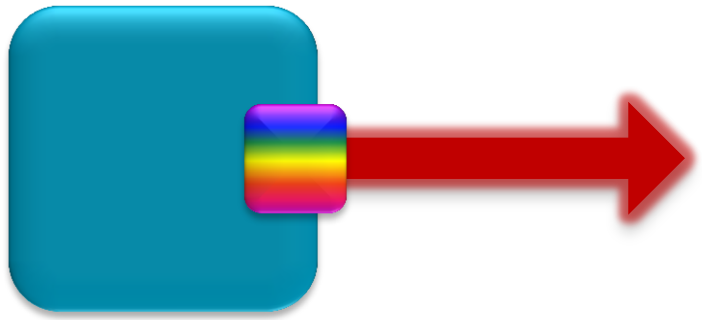
Contentionless allows multiple instances of the same frequency to add/drop from one unit.



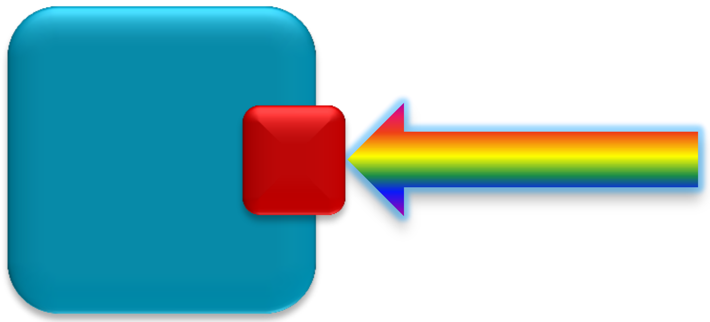
With **Contentionless**, N instances of a given wavelength (where N = the number of line degrees in the ROADM node) can be add/dropped from a single device, eliminating any restrictions on dynamic wavelength provisioning.

Tuneable lasers and coherent receivers are also key enablers of IP+Optical

Transmitter can tune its laser's frequency to any channel in the ITU grid.



Receiver can select any channel from of a composite (unfiltered) signal.



Tuneable lasers work with colourless add/drop to enable touchless changes in the frequency of an optical signal. **Coherent receivers** simplify the construction of colourless and omni-directional ROADM nodes.

Key Takeaways

- Colourless and tunable optics allow changing wavelength with no physical re-cabling
- Allow for any to any switching in the optical domain
- Allow for re-routing in the optical domain
- Omni-directional and tunability
- Use the C-band spectrum to its full capacity

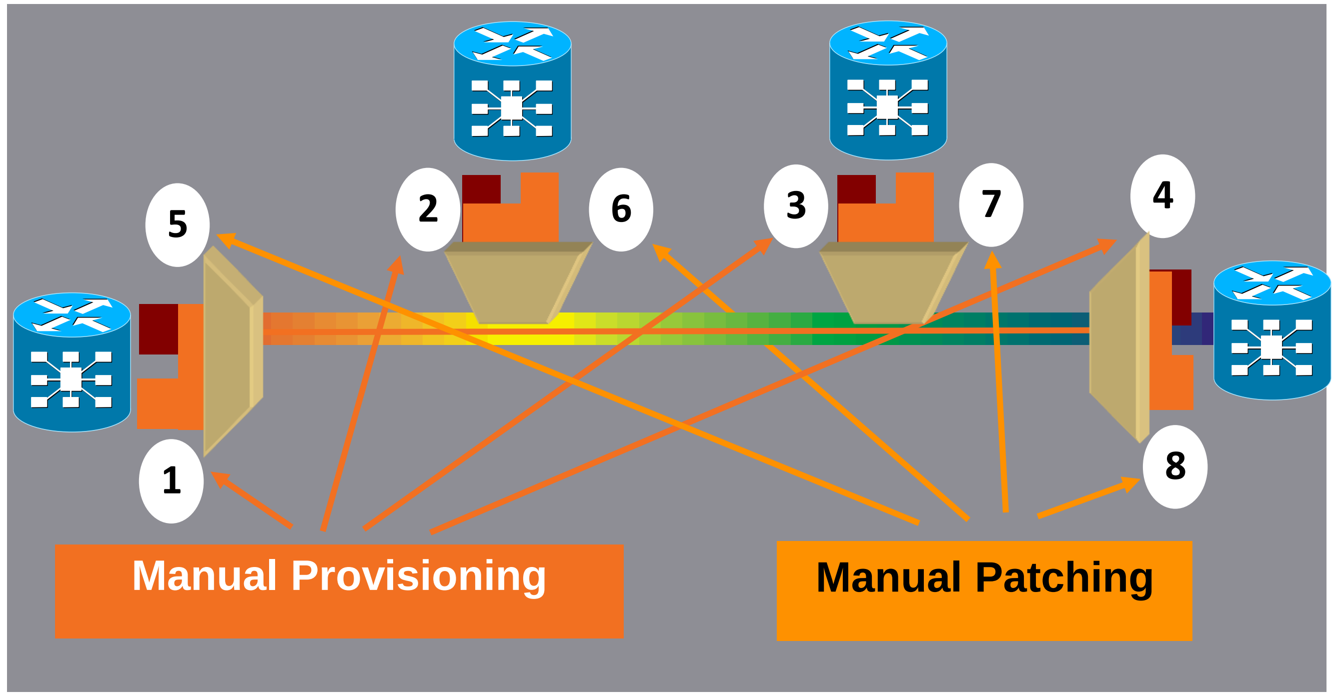
These features open the door for a new agile DWDM control plane

Multilayer Control Planes

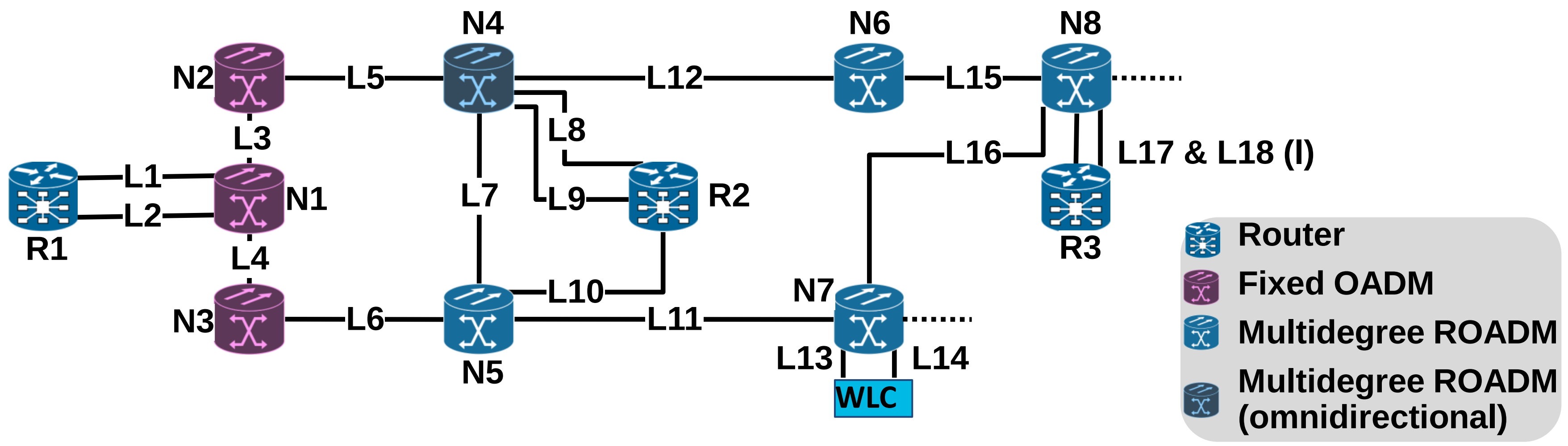
The Optical Layer – Current

Manual Patching

- Manual provisioning of each node
- Manual patching of each node
- High OpEx
- Truck rolls to every node



What Should an Optical Control Plane do?



Elements of an OCP

Resource Discovery	Topology Discovery	Traffic Provisioning	Traffic Restoration	Network Restoration	Network Optimisation

Increasing Complexity →

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Agile Control Plane Requirements

Requirements			
Tunability	Colourless	Omni-Directional	Impairment-aware

Enabling Zero Touch End to End Solution

GMPLS Introduction

- Generalised control plane for different types of network devices
  - Packet-Switch Capable (PSC)
  - Layer-2 Switch Capable (L2SC)
  - Time-Division-Multiplex Capable (TDM)
  - Lambda-Switch Capable (LSC)
  - Fibre-Switch Capable (FSC)
- Two major models: peer (NNI) and overlay (UNI)
- Different label formats depending on network type
  - We focus on LSC here

GMPLS Introduction (Cont’d)

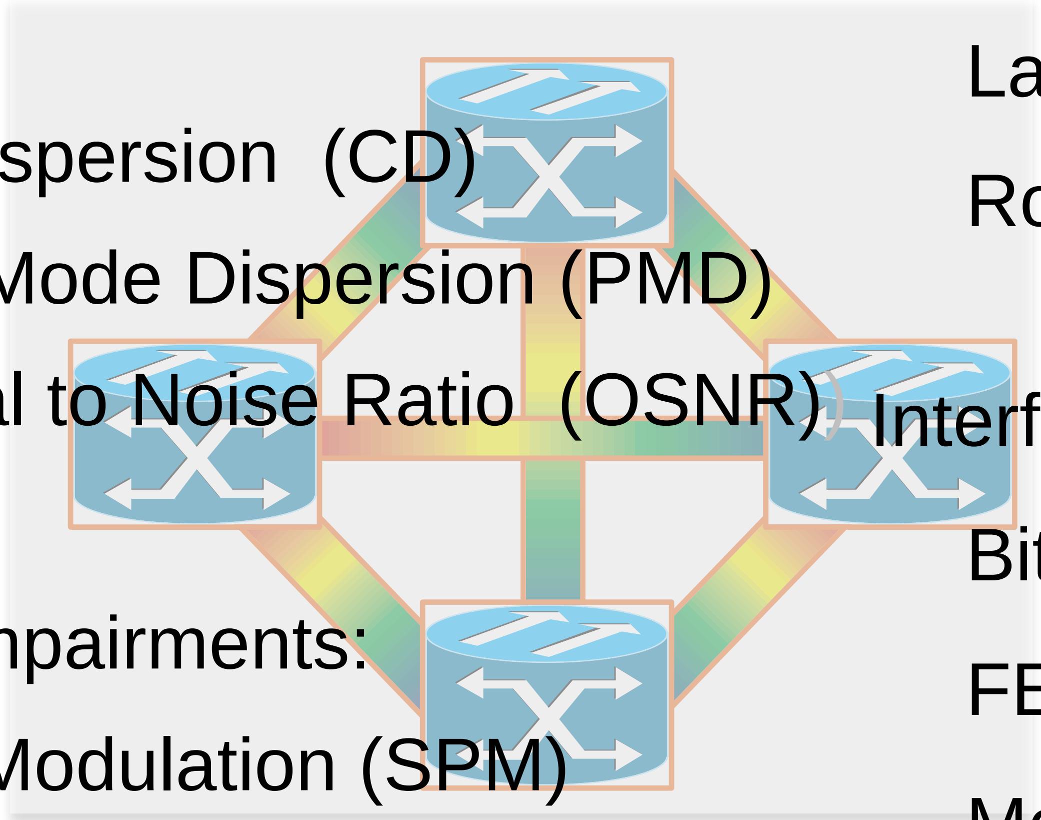
- Based on initial RSVP-TE, OSPF-TE and ISIS-TE extensions
- Strict separation of control and forwarding planes
- Supports bi-directional LSPs
- IP based control plane (no LDP)
- No IP based forwarding plane

What is Wavelength Switched Optical Network (WSON)?

- It is a GMPLS control plane which is “DWDM aware”:
  - LSP are wavelength and,
  - the control plane is aware of optical impairments
- WSON enables lambda setup on the fly
- WSON enables lambda re-routing
- WSON enables a lambda revalidation against a failure reparation

Cisco WSON Parameters – Embedded Optical Layer Intelligence

Foundation for Multi-layer Information Exchange



Linear Impairments

– Power Loss
– Chromatic Dispersion (CD)
– Polarisation Mode Dispersion (PMD)
– Optical Signal to Noise Ratio (OSNR)

Non linear Optical impairments:

– Self-Phase Modulation (SPM)
– Cross-Phase Modulation (XPM)
– Four-Wave Mixing (FWM)

Topology

Lambda assignment

Route choices (C-SPF)

Interface Characteristics

Bit rate

FEC

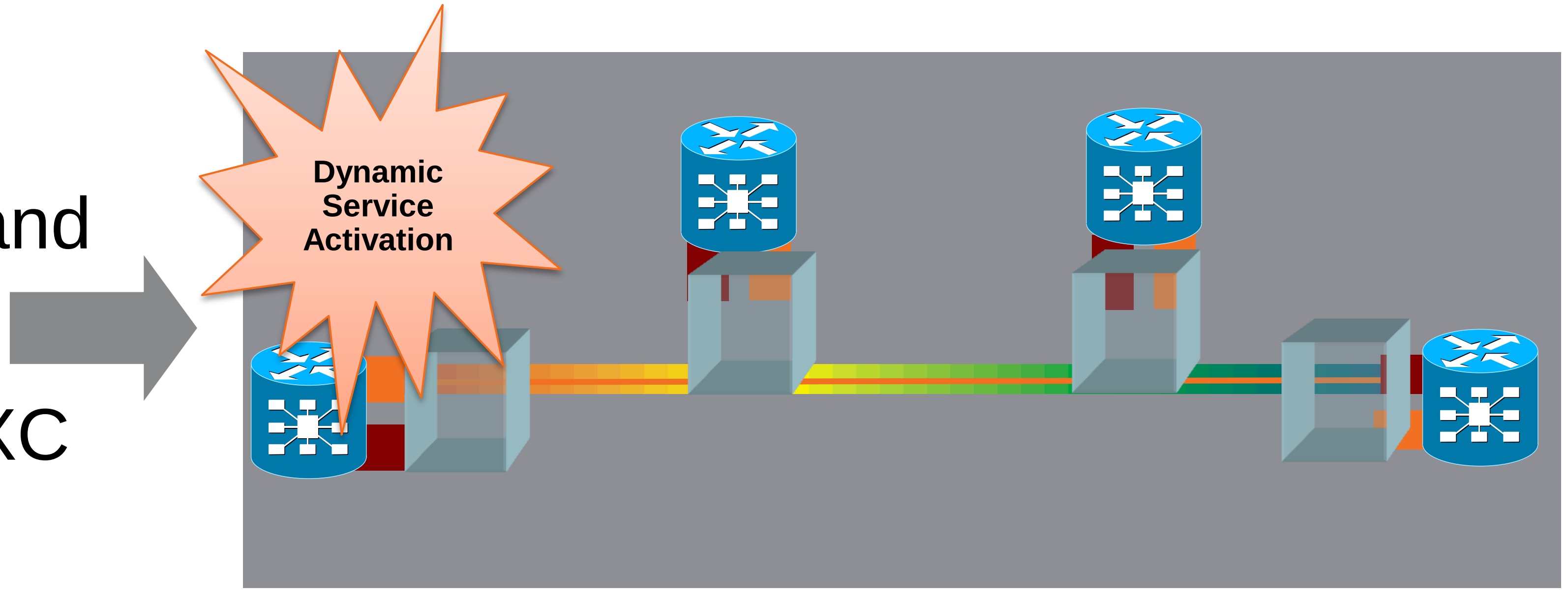
Modulation format

Regeneration Capability

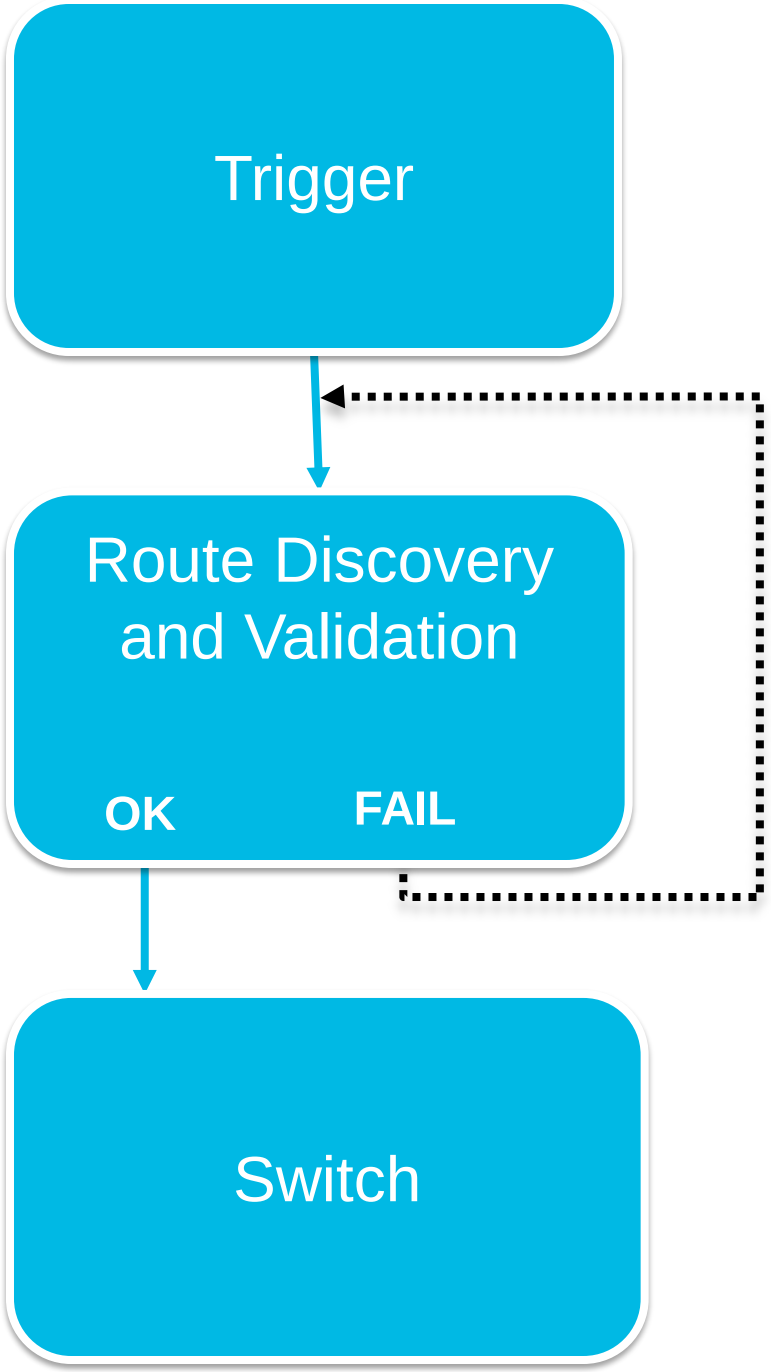
Automating the Optical Layer with WSON

Dynamic Service Activation with Colourless, Omnidirectionality and GMPLS

- Auto provisioning wavelength on demand via GMPLS
- Auto restoration via ROADMs and WXC
- Lower OpEx even further
- No truck rolls



WSON Restoration



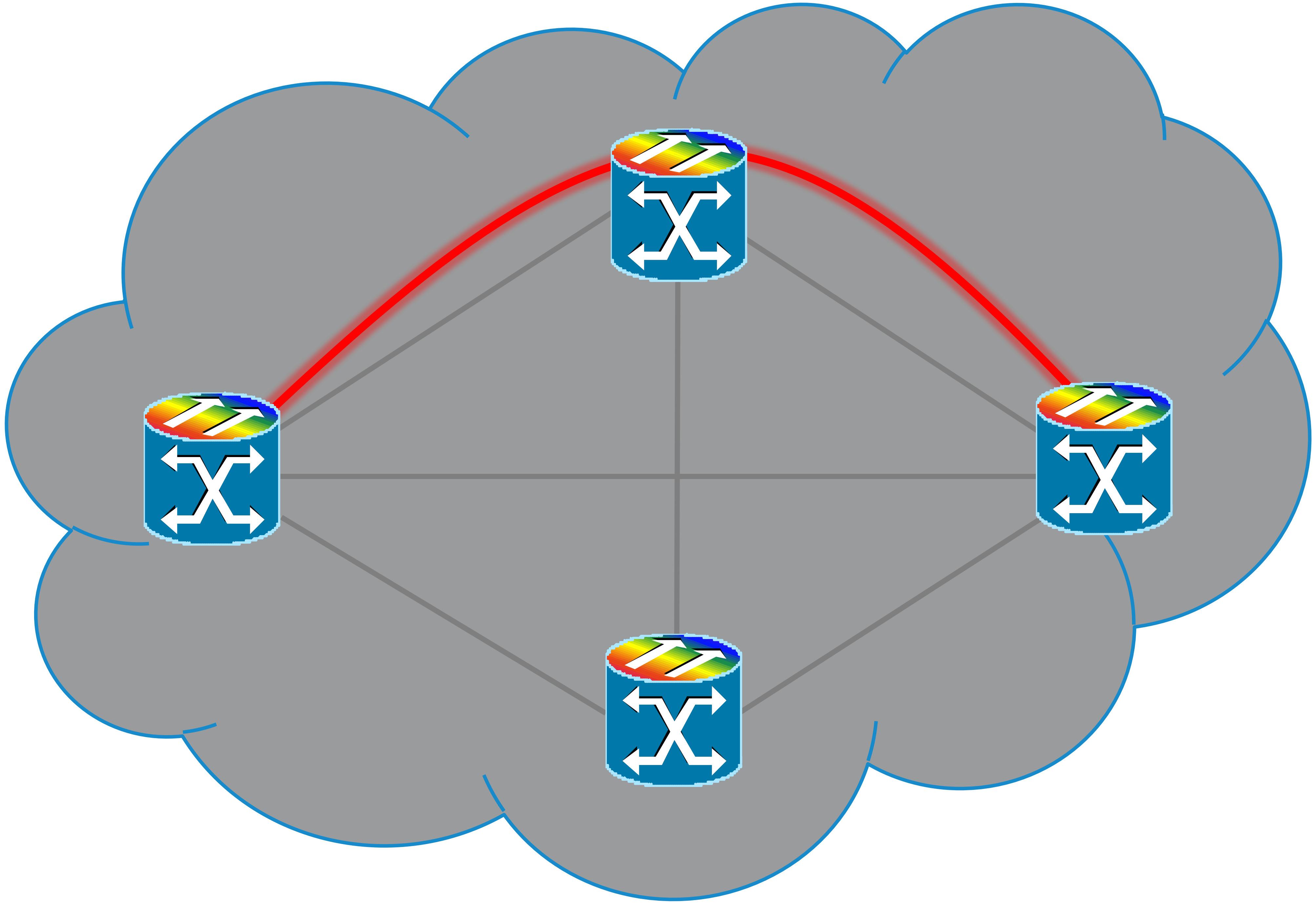
Link Failure
Signal Failure

Constrained OSPF algorithm
First try original wavelength, then others

Re-tune interface wavelength (if necessary)
Provision VOAs and WXC ports

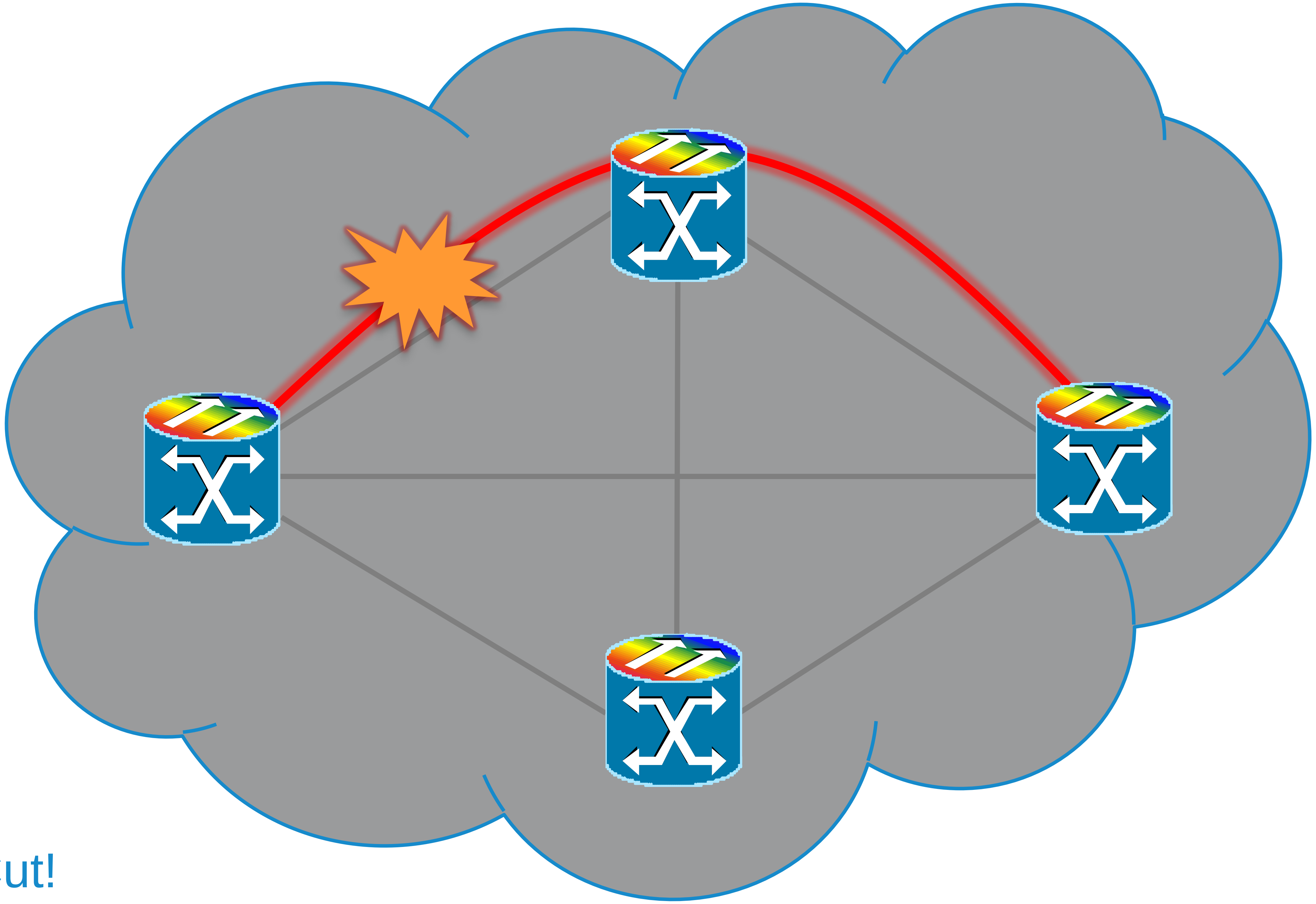
Wavelength Switched Optical Network

Auto Restoration



Wavelength Switched Optical Network

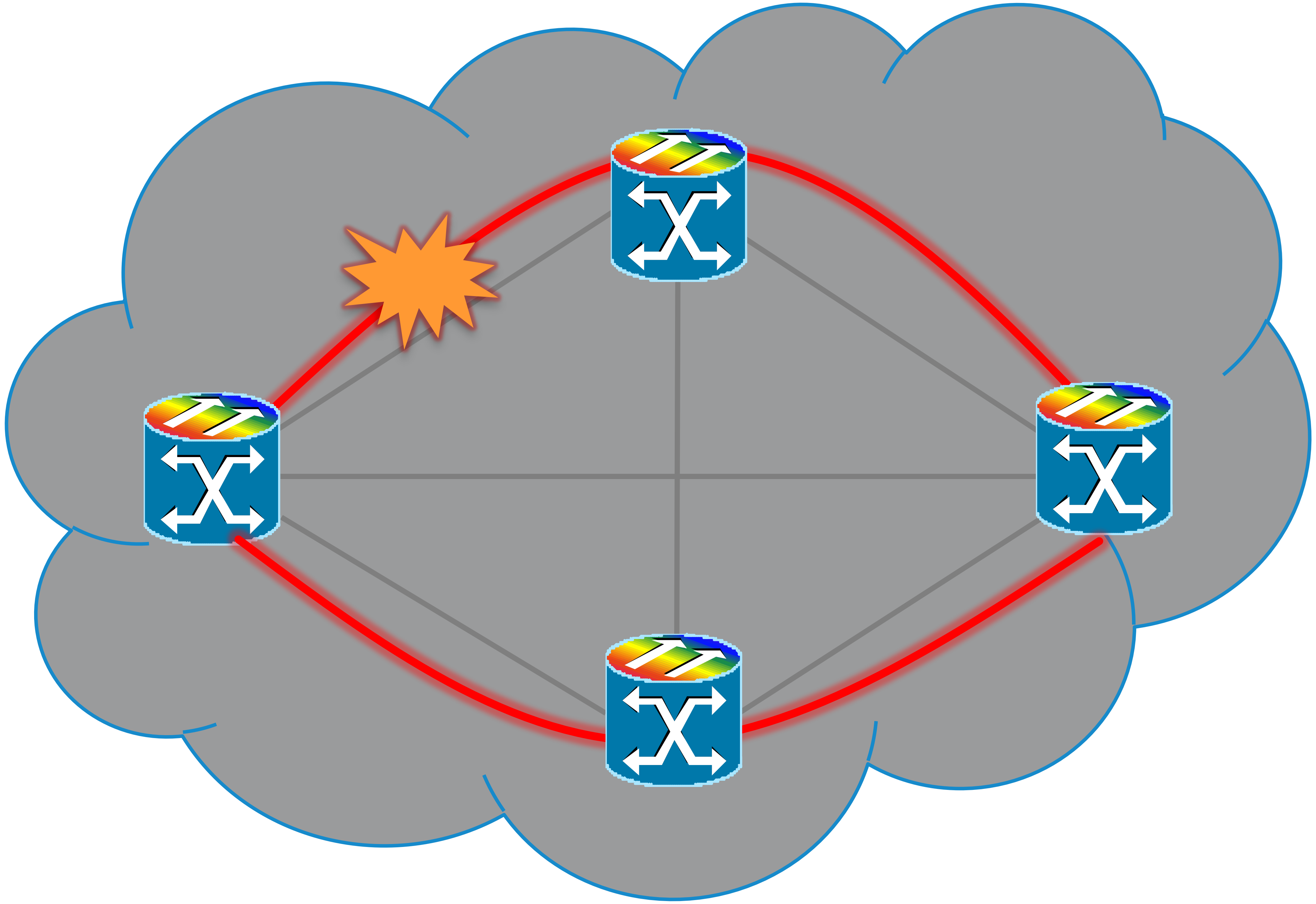
Auto Restoration



Fibre Cut!

Wavelength Switched Optical Network

Auto Restoration



Embedded WSON intelligence locates and verifies a new path

Restoration is Slower than Protection

- If rapid failure detection and recovery is needed it is assumed that existing packet IP/ MPLS mechanisms (e.g., BFD, IP-FRR, TE-FRR,LDP-FRR, mLDP-FRR, fast convergence) will be used for protection and recovery.
- IP+Optical Solutions can use Proactive Protection
- Protected services (Y-cable, PSM, FibreSwitch) should be used for valuable traffic to provide rapid protection at the optical layer.
- Restoration is Best Effort.

What if we Integrate IP Control Plane with WSON?

- Reduce Optical Circuit Turn Up Time
- On Demand Bandwidth Provisioning
- Constrained Circuit Request to Avoid Shared Risk
- Alarm Correlation
- Network Optimisation

Multi Layer Control Plane

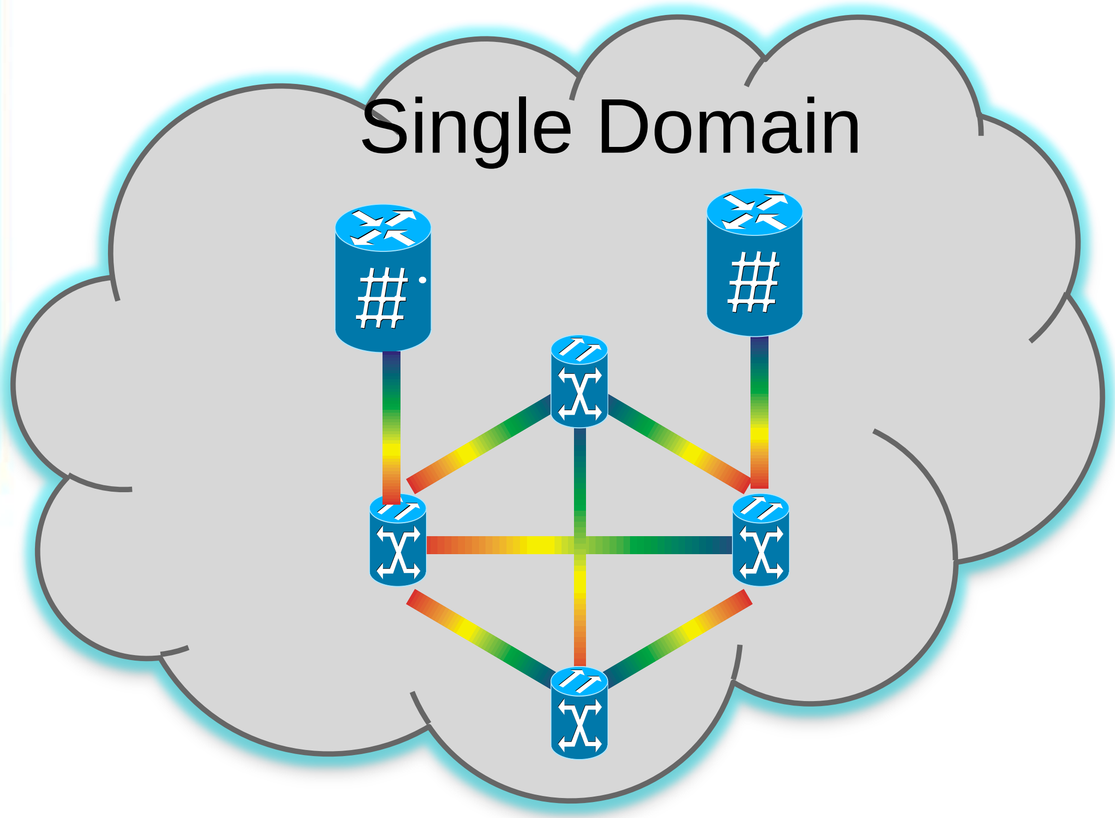
Two key models

Peer Model – Optical NEs and Routing NEs are one from the control plane perspective, same IGP.

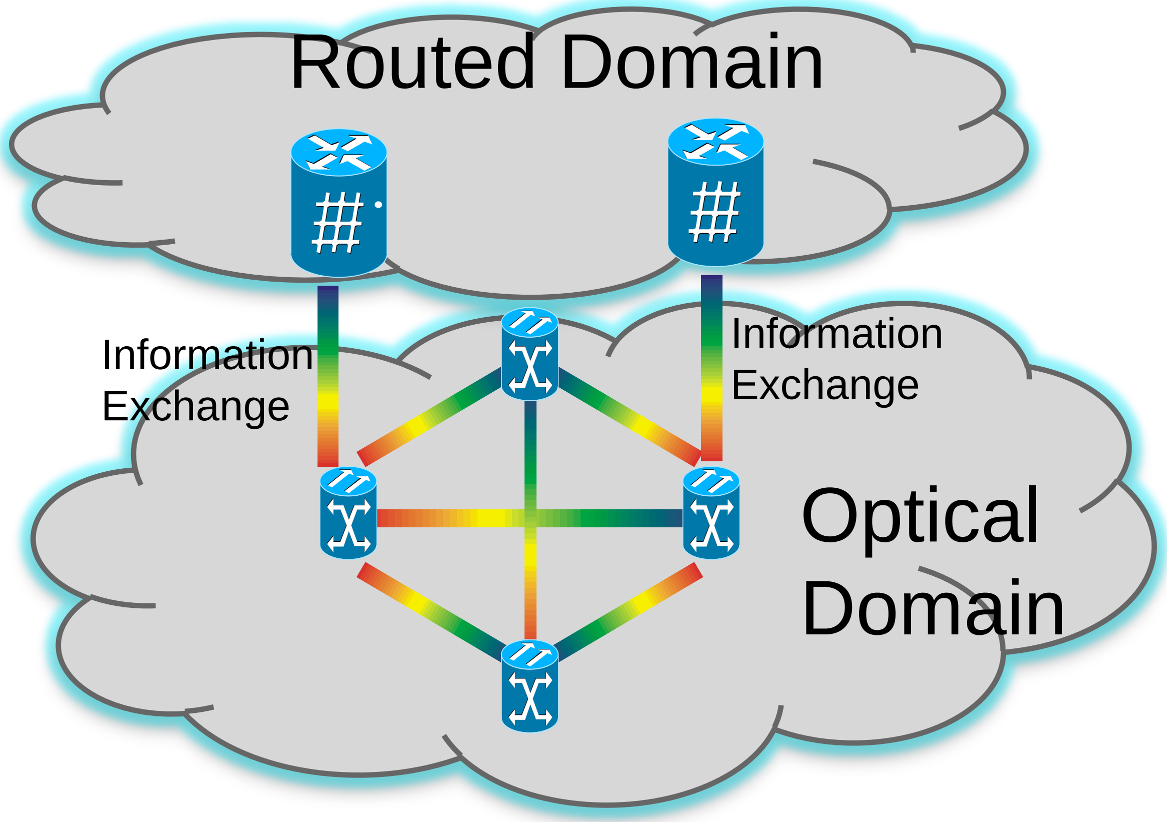
- Does not respect operational boundaries; does not scale

Overlay Model – Having different Control Planes per Layer and signalling between them

- Respects Boundaries and Scales

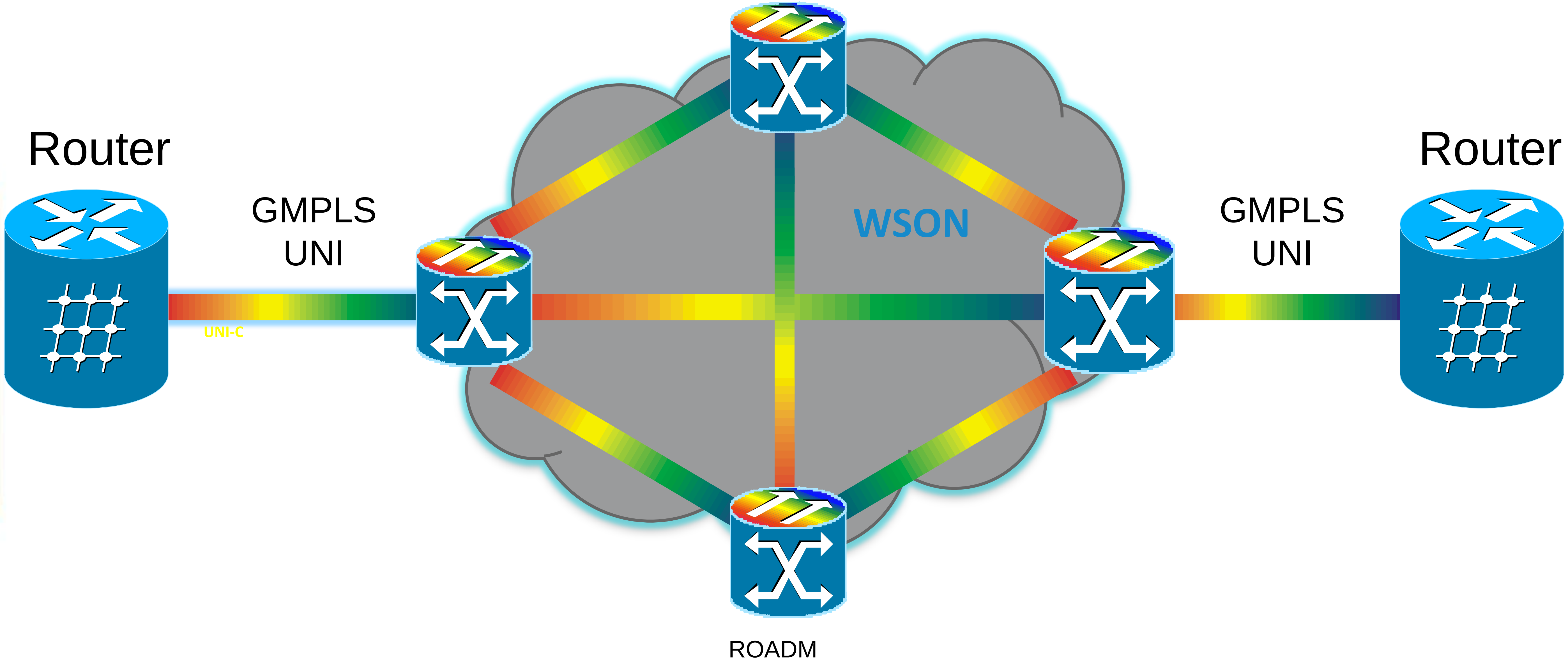


Peer Model



Overlay Model

WSON and IP Control Plane to Communicate - GMPLS UNI



GMPLS – User Network Interface

- User-Network Interface (UNI) to implement an overlay model between two networks – with limited communication between them
- Enables a Cisco router to signal paths dynamically through a DWDM network
- Paths may be signaled with diversity requirements
- Two UNI components
  - Client: UNI-C
  - Network: UNI-N
- Building block for multi-layer routing

* Formerly known as iOverlay

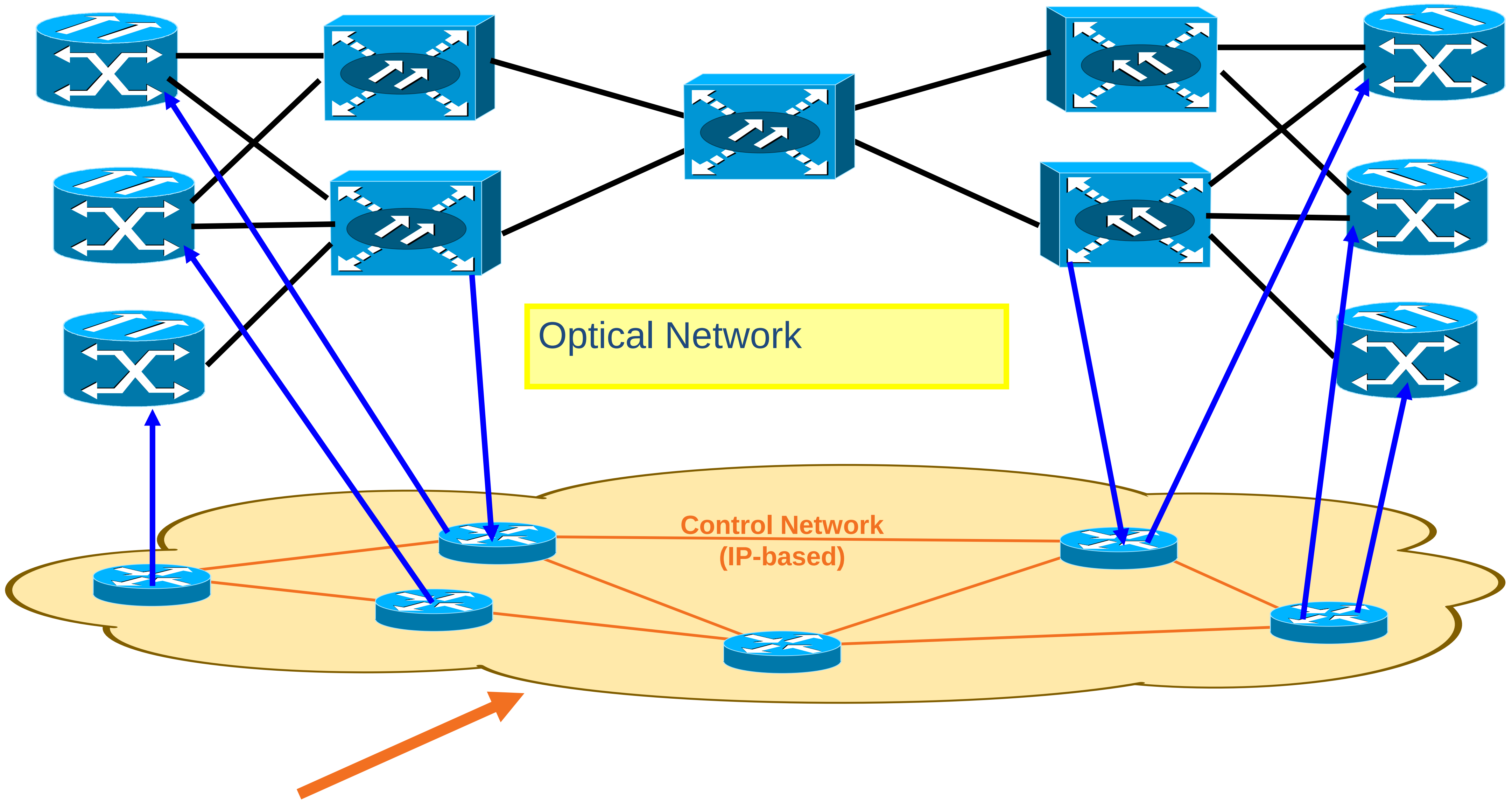
Link Management Protocol (LMP)

- Performs two core functions
  - Control channel management
  - Link property correlation
- Runs over UDP with mechanisms for reliable message transmission
- Includes mechanisms for LMP neighbour discovery
- Most messages exchanged over control channel
- Can also provide link connectivity verification and fault management

RSVP

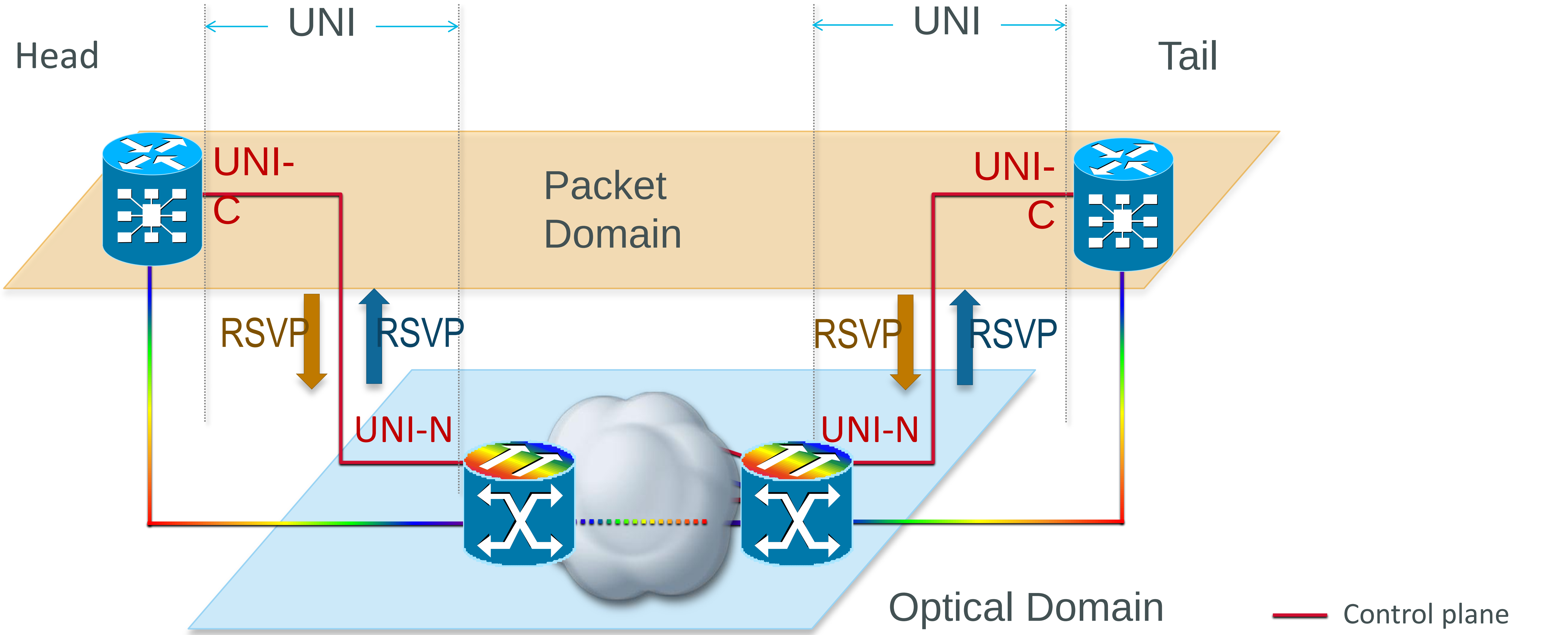
- Client Requests connections from optical network using GMPLS RSVP-TE Extensions
- RSVP signalling is identical to GMPLS extenstions specified in RFC 3473 except where noted in RFC 4208.

GMPLS UNI - IP Control Channel



IP Control Channel (IPCC)

GMPLS UNI – Reference Model (IP+Optical)

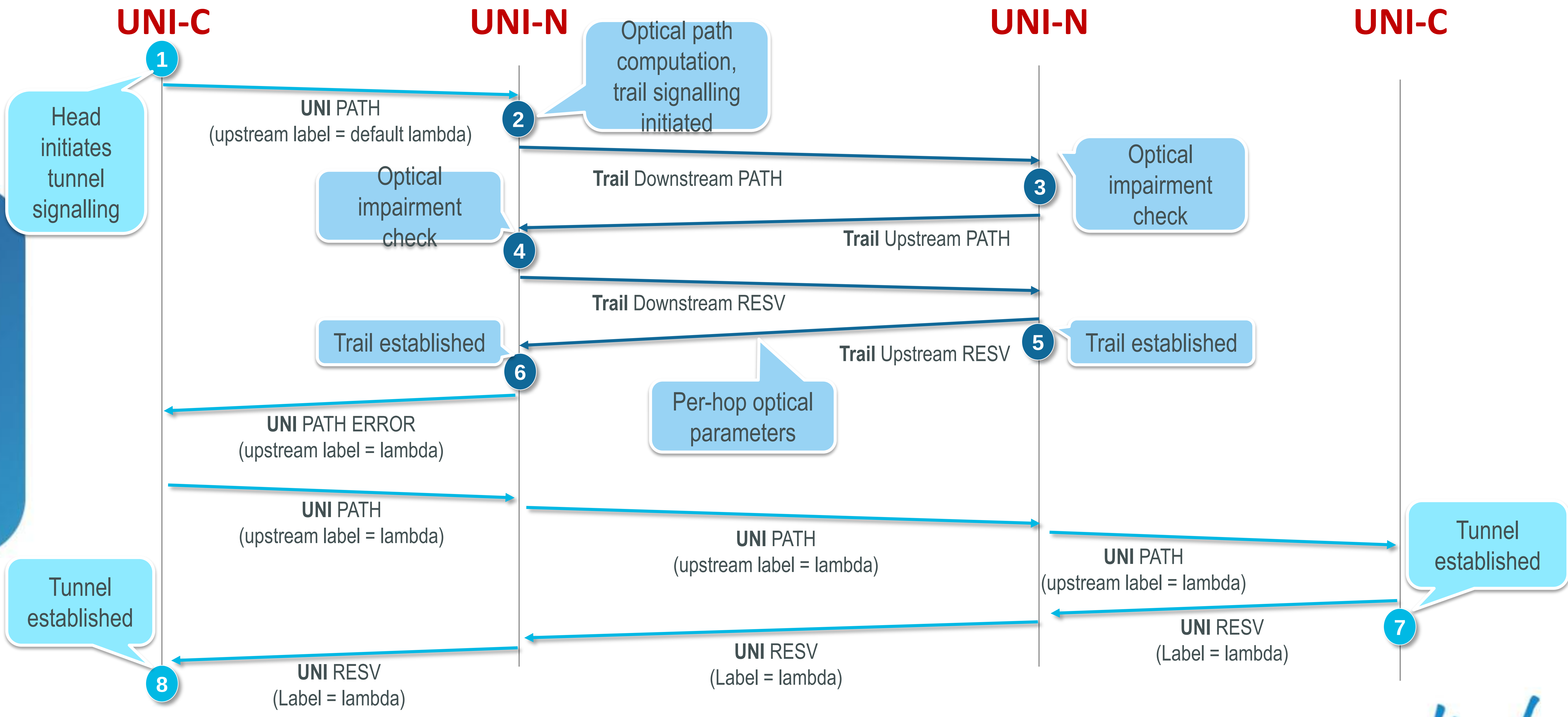


UNI honors administrative boundaries while allowing controlled interaction

Path Computation and Signalling (no ERO)

- UNI-C (Head)
  - Initiates signalling (default lambda)
  - No explicit path (ERO) defined / signaled
  - Signalling initiated towards remote UNI-C (optical loopback or optical link address)
  - Bi-directional path (upstream and downstream labels)
- UNI-N
  - Arrival of PATH message without ERO triggers path computation to destination across optical domain
  - PATH calculations performed at the UNI-N head
  - Establishment of optical path (trail) required for UNI signalling to proceed

Signalling –Path Setup



Generalised Label for Lambda-Switch-Capable (LSC) Label Switching Routers

Grid	Channel Spacing	Identifier	n
3 bits	4 bits	9 bits	16 bits

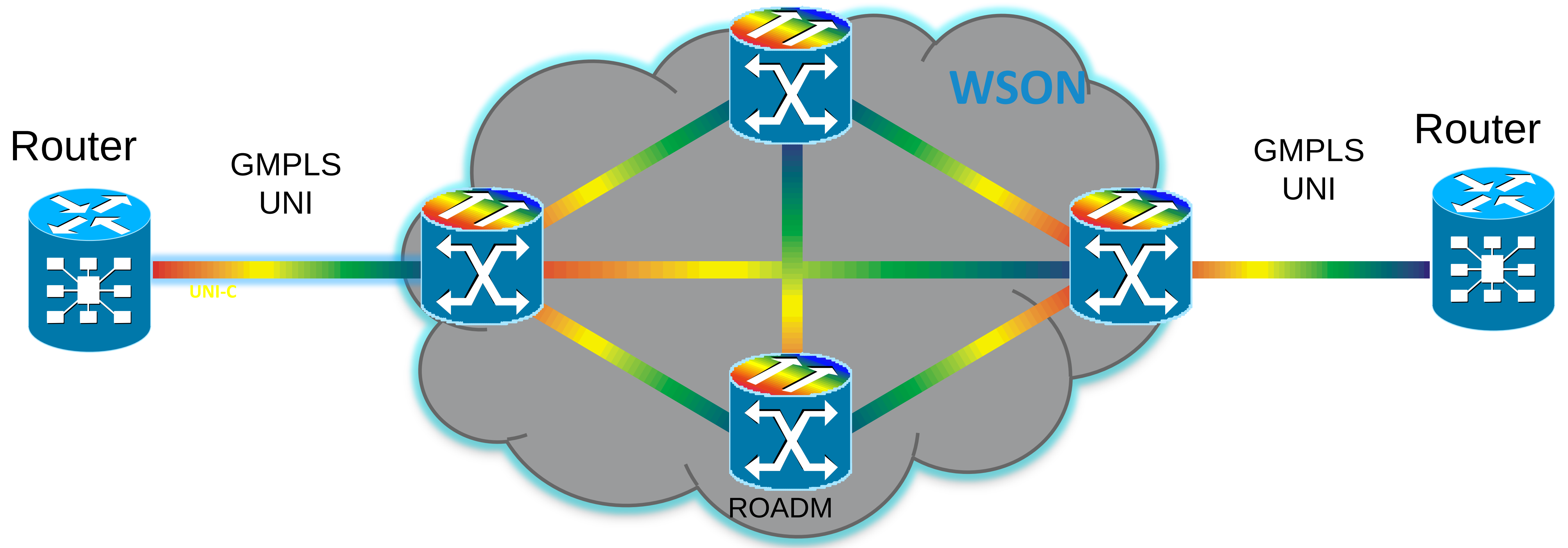
Grid – Optical grid as defined in ITU-T G.694.1
Channel Spacing – Spacing between DWDM channels in GHz
Identifier – Per-node distinguisher between lasers than can transmit same lambda
n – value used to compute frequency (two's complement)

Grid	Value
Reserved	0
ITU-T DWDM	1
ITU-T CWDM	2
Future Use	3 - 7

DWDM Channel Spacing (GHz)	Value
Reserved	0
100	1
50	2
25	3
12.5	4
Future Use	5 - 15

Frequency (THz) = 193.1 THz + n * channel spacing (THz)

GMPLS-UNI Example Setup



Node	L3/Packet ID	Optical Router ID	L3/Packet Link Address	Optical I/F Address
Head UNI-C	1.1.1.1	10.58.46.1	10.0.0.1	100.11.11.11
Ingress UNI-N	n/a	10.58.46.2	n/a	100.12.12.12
Egress UNI-N	n/a	10.58.47.2	n/a	100.19.19.19
Tail UNI-C	2.2.2.2	10.58.47.1	10.0.0.2	100.20.20.20

Sample Base GMPLS UNI Config – Head

LMP Properties

Optical I/F of LMP Neighbour

UNI-C Optical link address

Control Channel

Optical Router ID

```
lmp
 gmpls optical-uni
  controller dwdm0/2/0/0
    neighbor nbr_A
     neighbor link-id ipv4 unicast 100.12.12.12
     neighbor interface-id unnumbered 13
     link-id ipv4 unicast 100.11.11.11
 !
     neighbor nbr_A
         ipcc routed
         router-id ipv4 unicast 10.58.46.2
         !
   router-id ipv4 unicast 10.58.46.1
```

Sample Base GMPLS UNI Config – Head (Cont'd)

RSVP Refresh

GMPLS Tunnel Configuration

```
rsvp
  interface HundredGigE0/2/0/0
      signalling refresh optical interval 3600
      signalling refresh optical missed

mpls traffic-eng
     interface HundredGigE0/2/0/0
        gmpls optical-uni
            controller dwdm0/2/0/0
             tunnel-id 1
                destination ipv4 unicast 100.20.20.20
                path-option 10 no-ero lockdown
```

Sample Base GMPLS UNI Config- Tail

LMP Properties

Control Channel

Optical Router ID

```
lmp
  gmpls optical-uni
      controller dwdm0/3/0/0
        neighbor nbr_A
        neighbor link-id ipv4 unicast
100.19.19.19
        neighbor interface-id unnumbered 13
        link-id ipv4 unicast 100.20.20.20
 !
       neighbor nbr_A
        ipcc routed
        router-id ipv4 unicast 10.58.47.2
!
        router-id ipv4 unicast 10.58.47.1
```

Sample Base GMPLS UNI Config- Tail (Cont'd)

RSVP Refresh

TE Link Properties

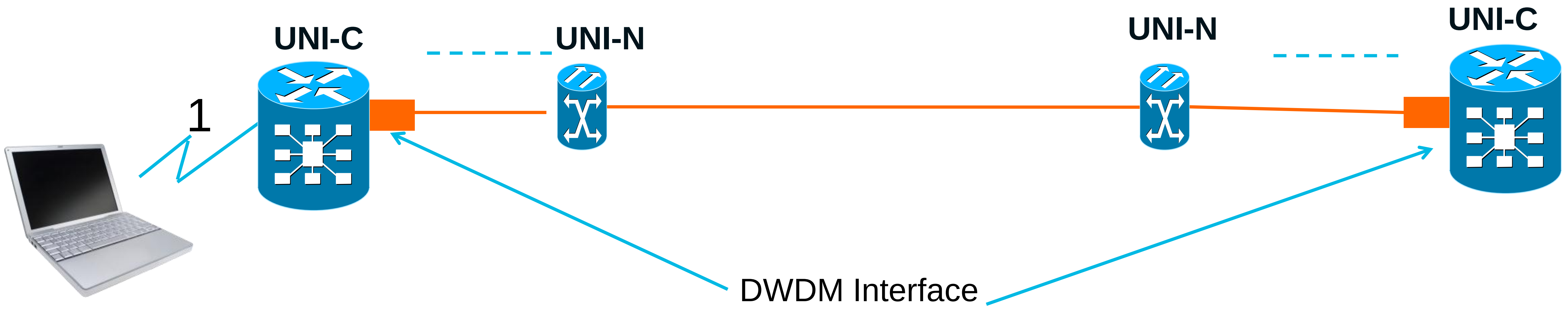
No GMPLS Tunnel configuration

But must tell interface to "listen"

```
rsvp
 interface HundredGigE0/3/0/0
        signalling refresh optical interval 3600
         signalling refresh optical missed 24
!
!
mpls traffic-eng
   interface HundredGigE0/3/0/0
 !
  gmpls optical-uni
        controller dwdm0/3/0/0
```

Provisioning using GMPLS UNI Example

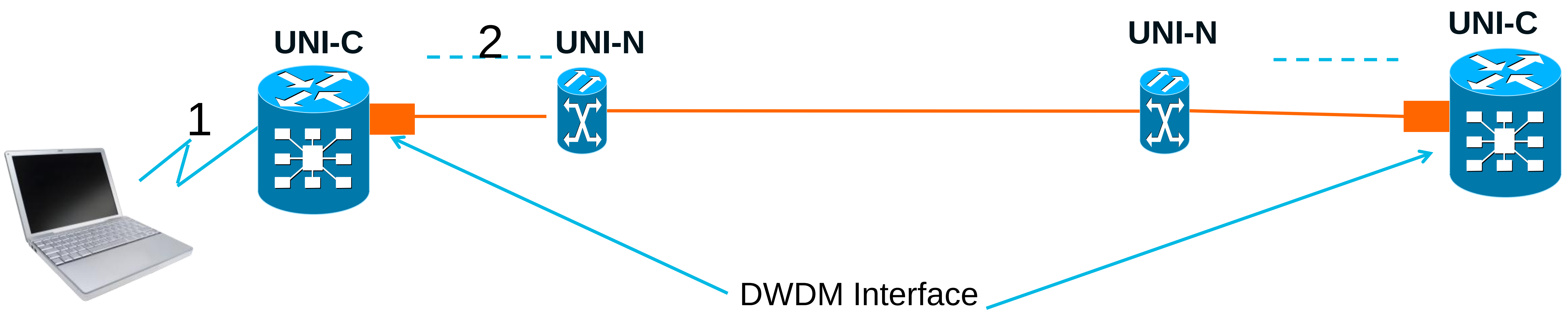
Circuit Request



1. Router requests a circuit between Source and Destination Routers Interfaces

Provisioning using GMPLS UNI Example

Circuit Request



1. Router requests a circuit between Source and Destination Routers Interfaces
2. Using GMPLS UNI I/F Router signals UNI-N system requesting path to destination

Provisioning using GMPLS UNI Example

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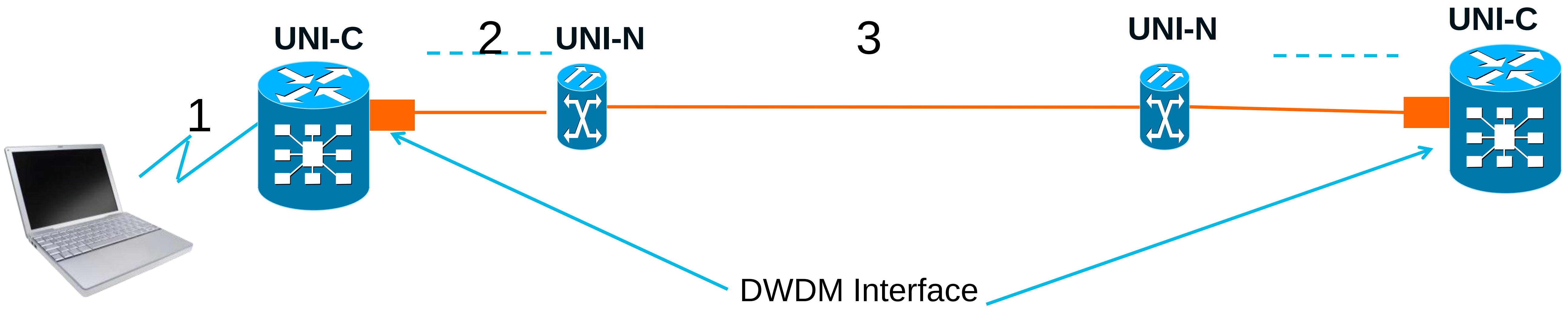

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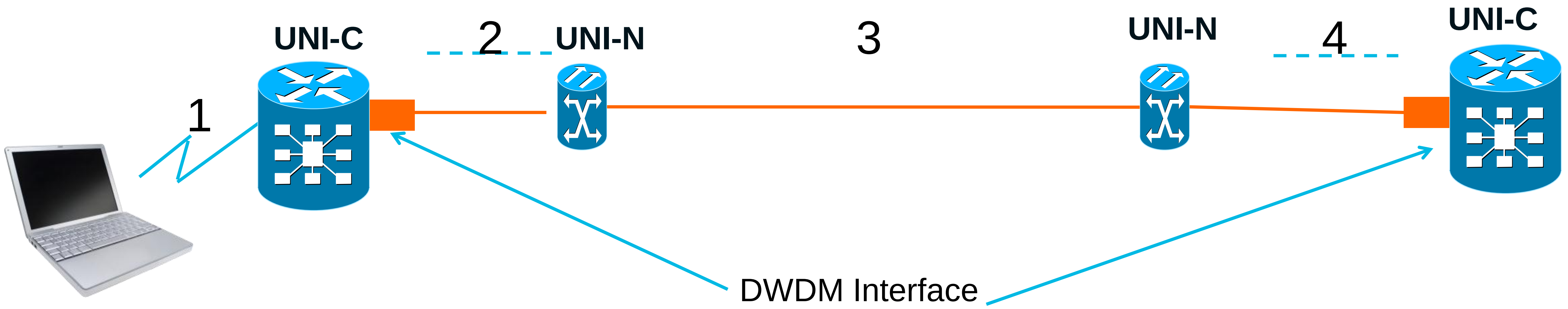
3. UNI-N initiates DWDM CP (WSON) and finds best path based on Diversity contraints

Provisioning using GMPLS UNI Example

Circuit Request



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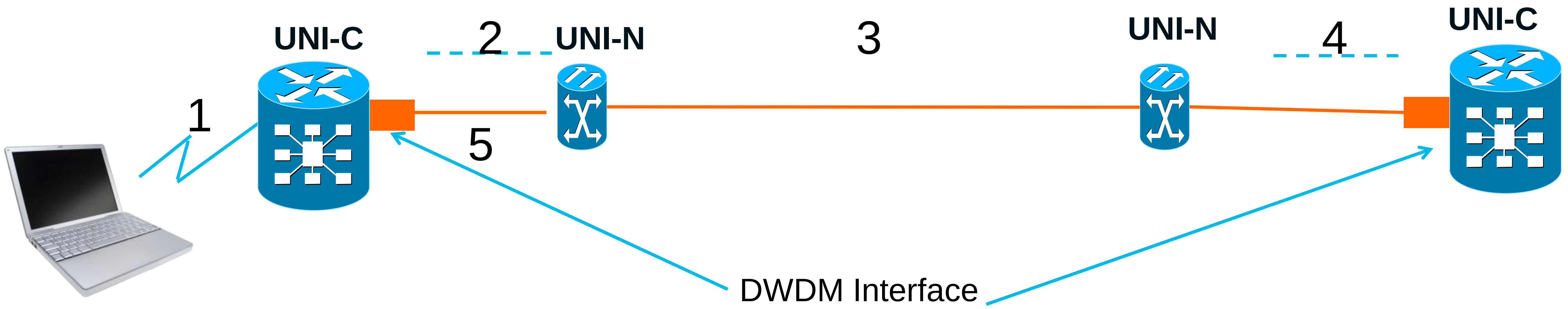
4. Destination UNI-N Node signals Destination router and requests IPoDWDM interface to be set to specific wavelength

Provisioning using GMPLS UNI Example

Circuit Request



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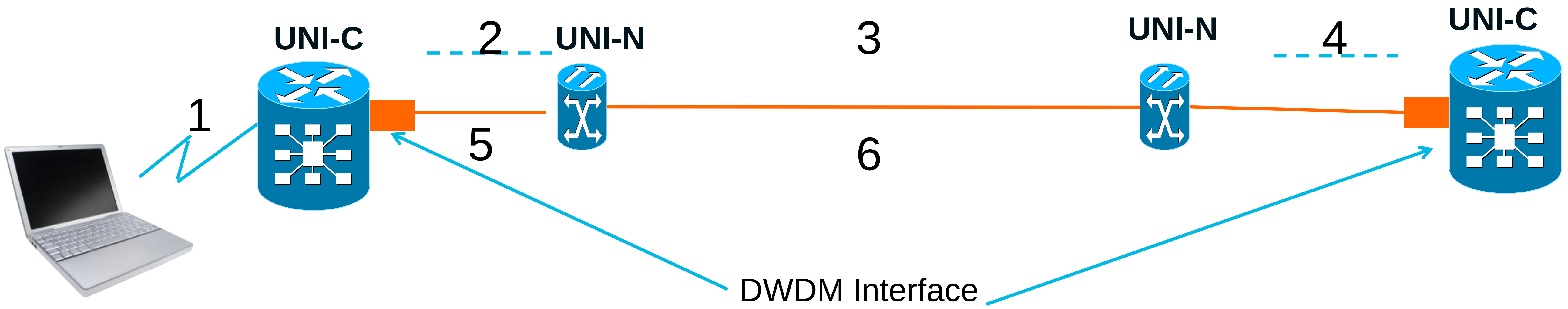
3. UNI-N initiates DWDM CP (WSON) and finds best path based on Diversity constraints
4. Destination UNI-N Node signals Destination router and requests IPoDWDM interface to be set to specific wavelength
5. Head End UNI-N signals Head End router to set IPoDWDM interface to specific wavelength

Provisioning using GMPLS UNI Example

Circuit Request



1. Router requests a circuit between Source and Destination Routers Interfaces
2. Using GMPLS UNI I/F Router signals UNI-N system requesting path to destination
3. UNI-N initiates DWDM CP (WSON) and finds best path based on Diversity constraints
4. Destination UNI-N Node signals Destination router and requests IPoDWDM interface to be set to specific wavelength
5. Head End UNI-N signals Head End router to set IPoDWDM interface to specific wavelength
6. Path is up and interfaces are ALLOCATED

Layer Interaction – Provisioning

Dramatically Increase Circuit Turn-up Velocity

– Yesterday → Months

  L3 team requests circuit of L0 team, with specific criteria

  L0 team verifies available path, matching request criteria

  L0 team verifies performance and resources

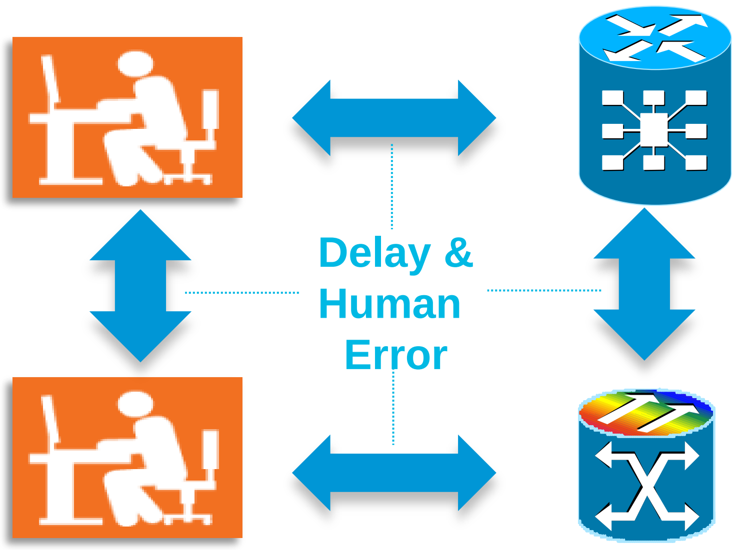
  L0 / L3 teams coordinate circuit turn-up

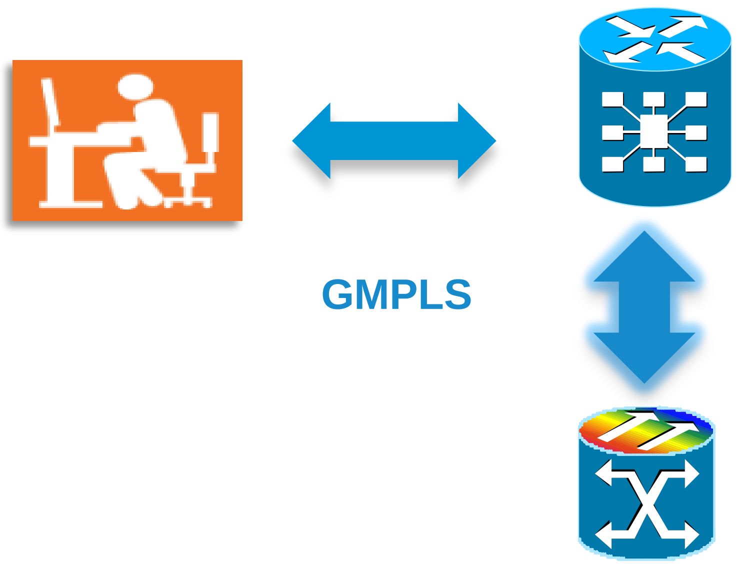
– Today - GMPLS → Minutes

  Client signals circuit request along with criteria

  L0 signals wavelength to use or path error message

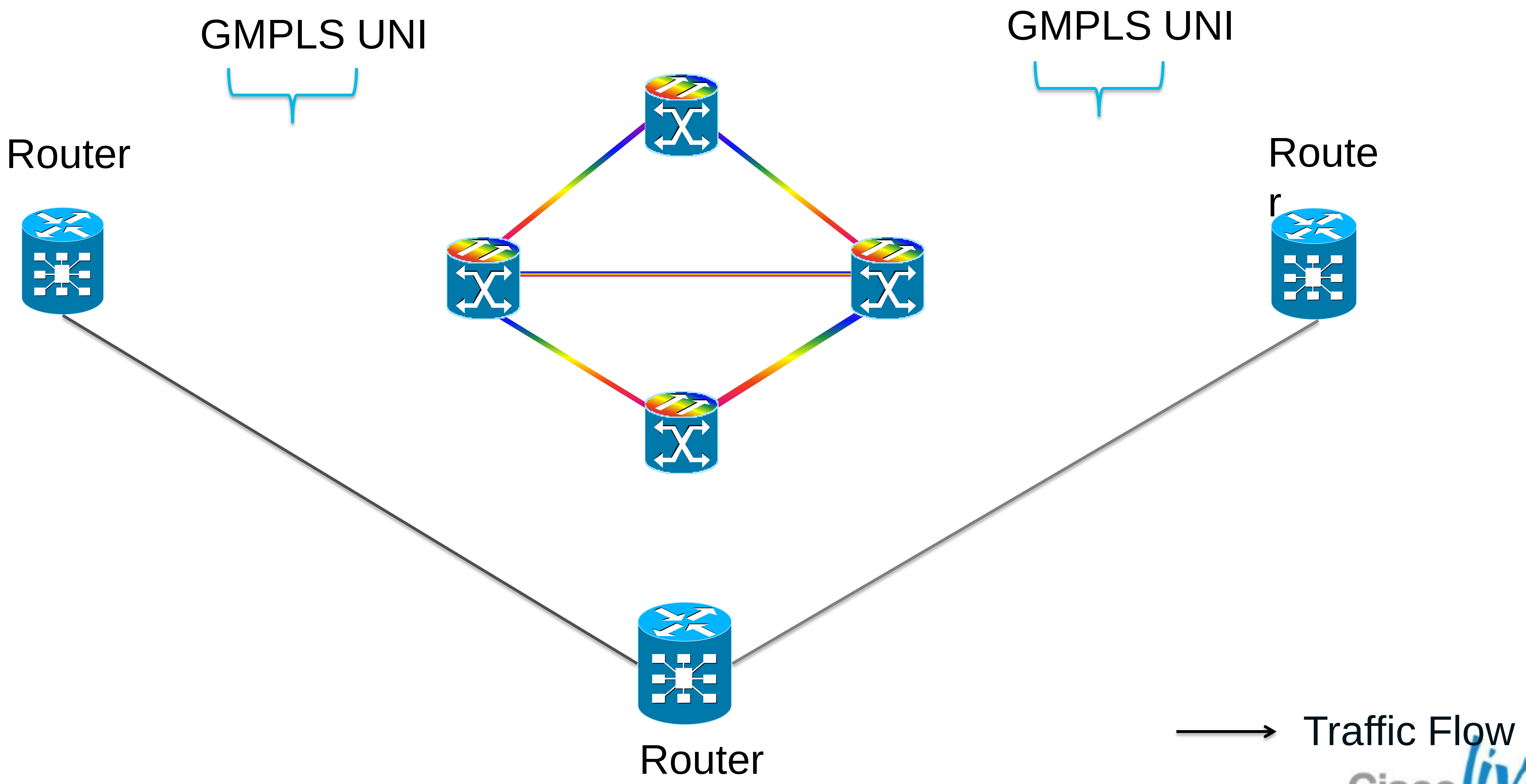
  Circuit is turned up





Putting it Together

WSON, GMPLS UNI and IPoDWDM Proactive Protection



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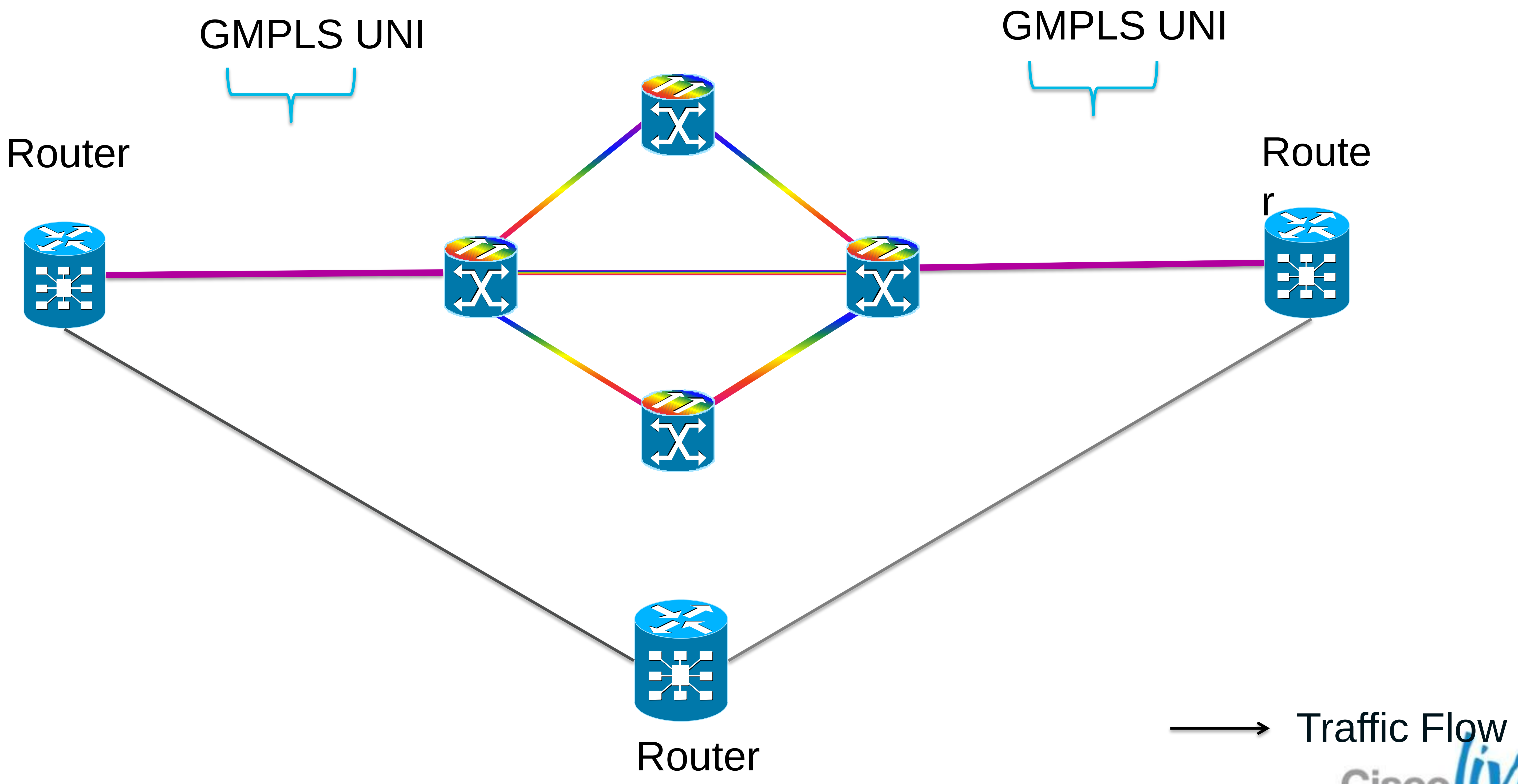
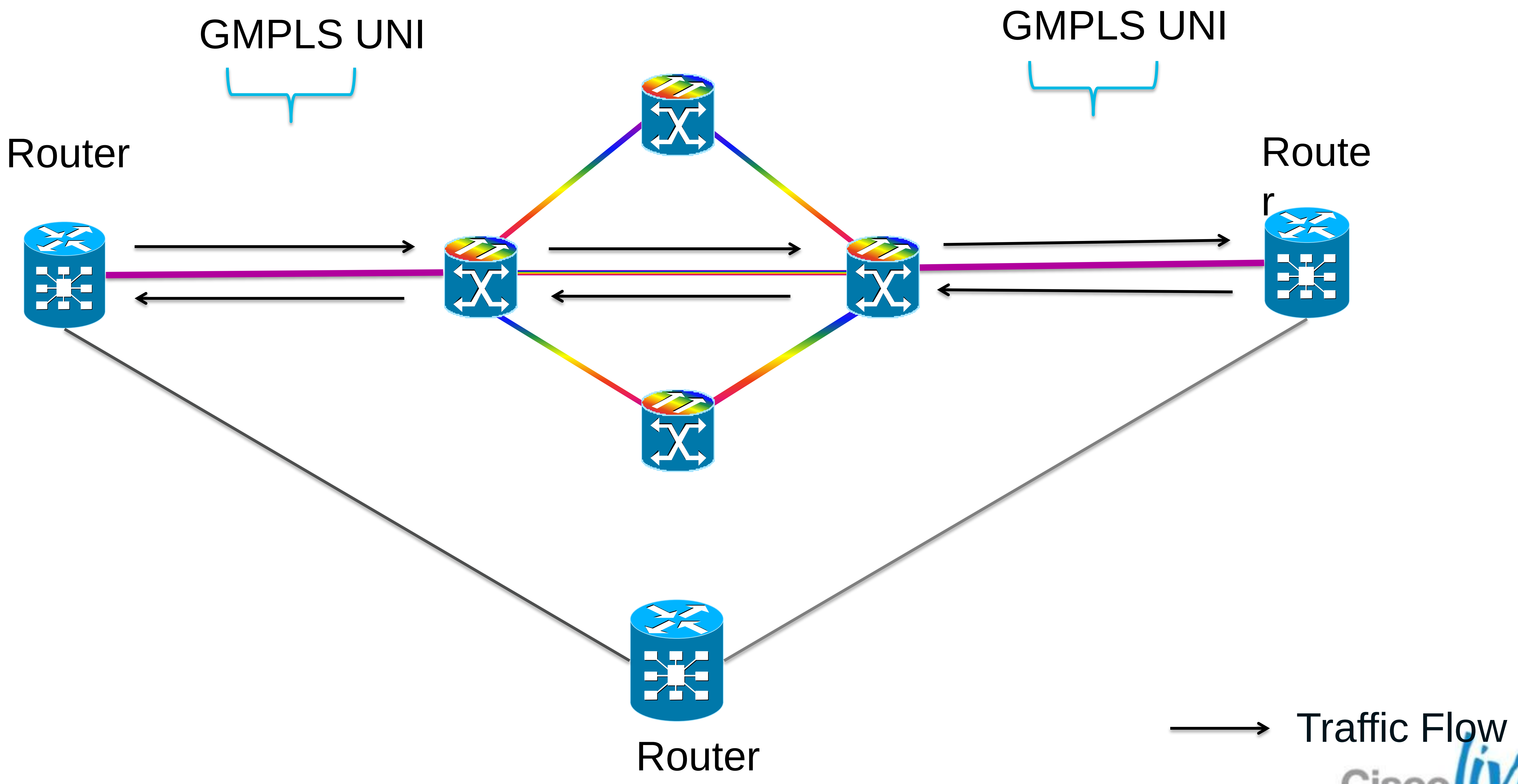


Putting it Together

WSON, GMPLS UNI and IPoDWDM Proactive Protection



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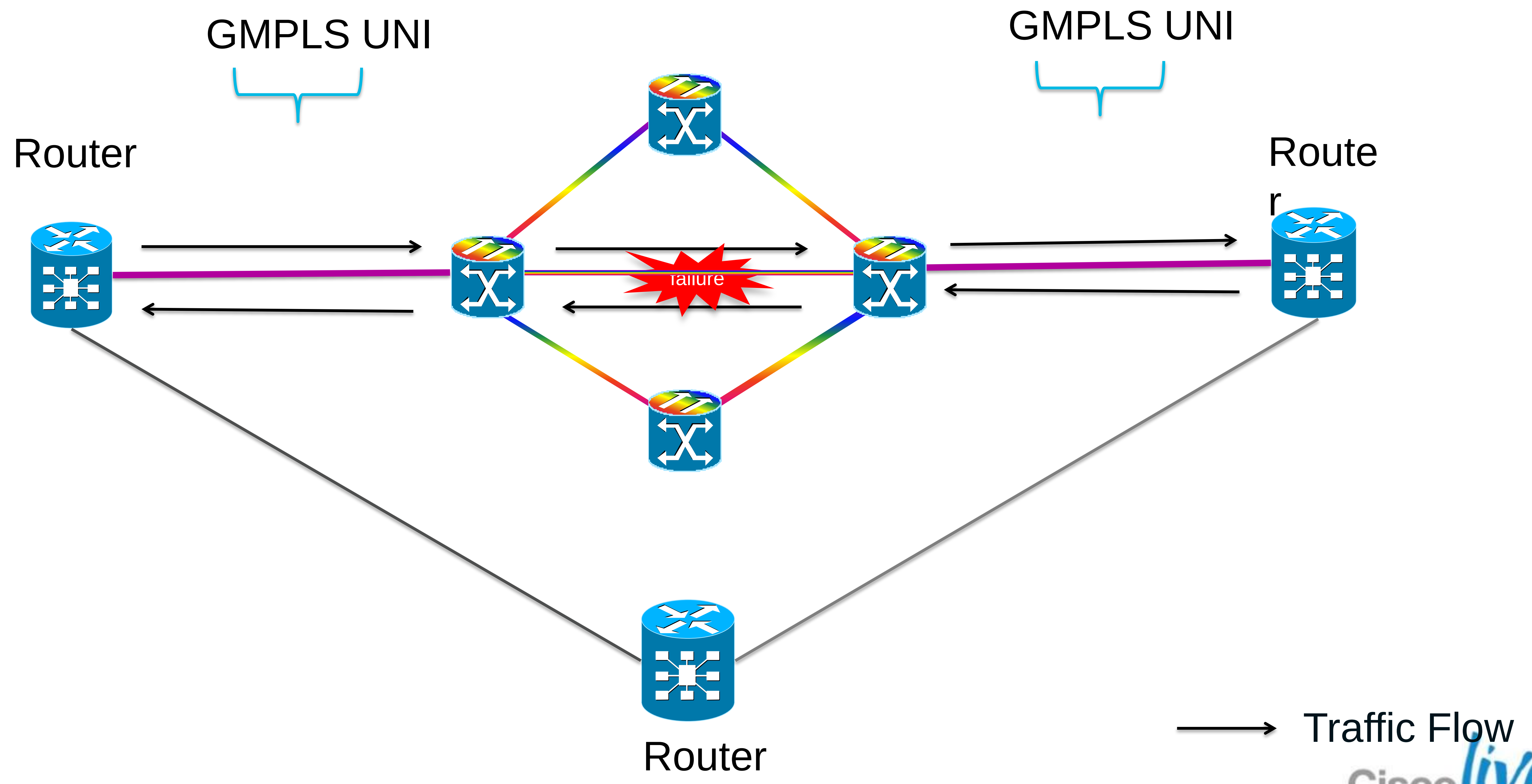
WSON, GMPLS UNI and IPoDWDM Proactive Protection



Putting it Together

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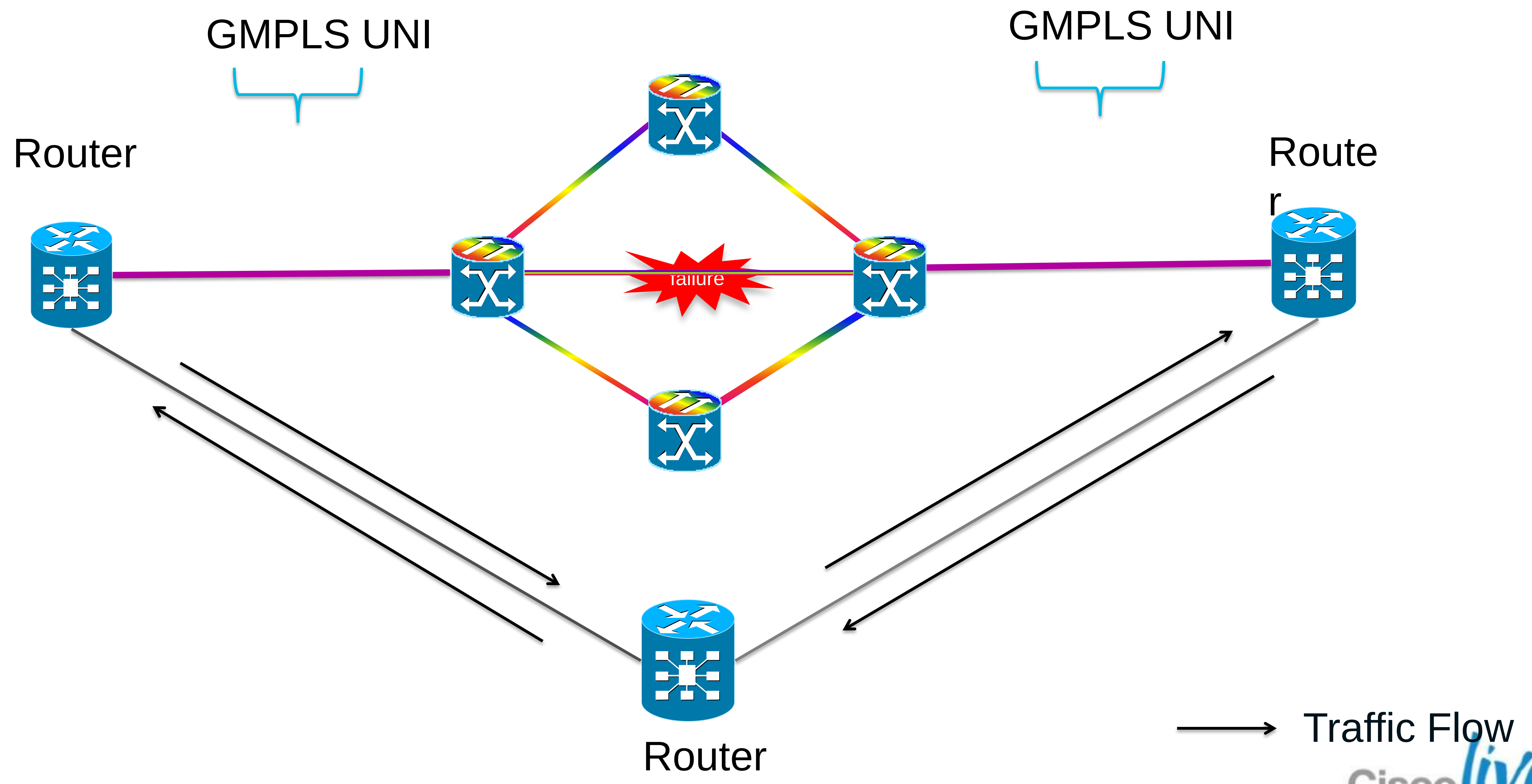
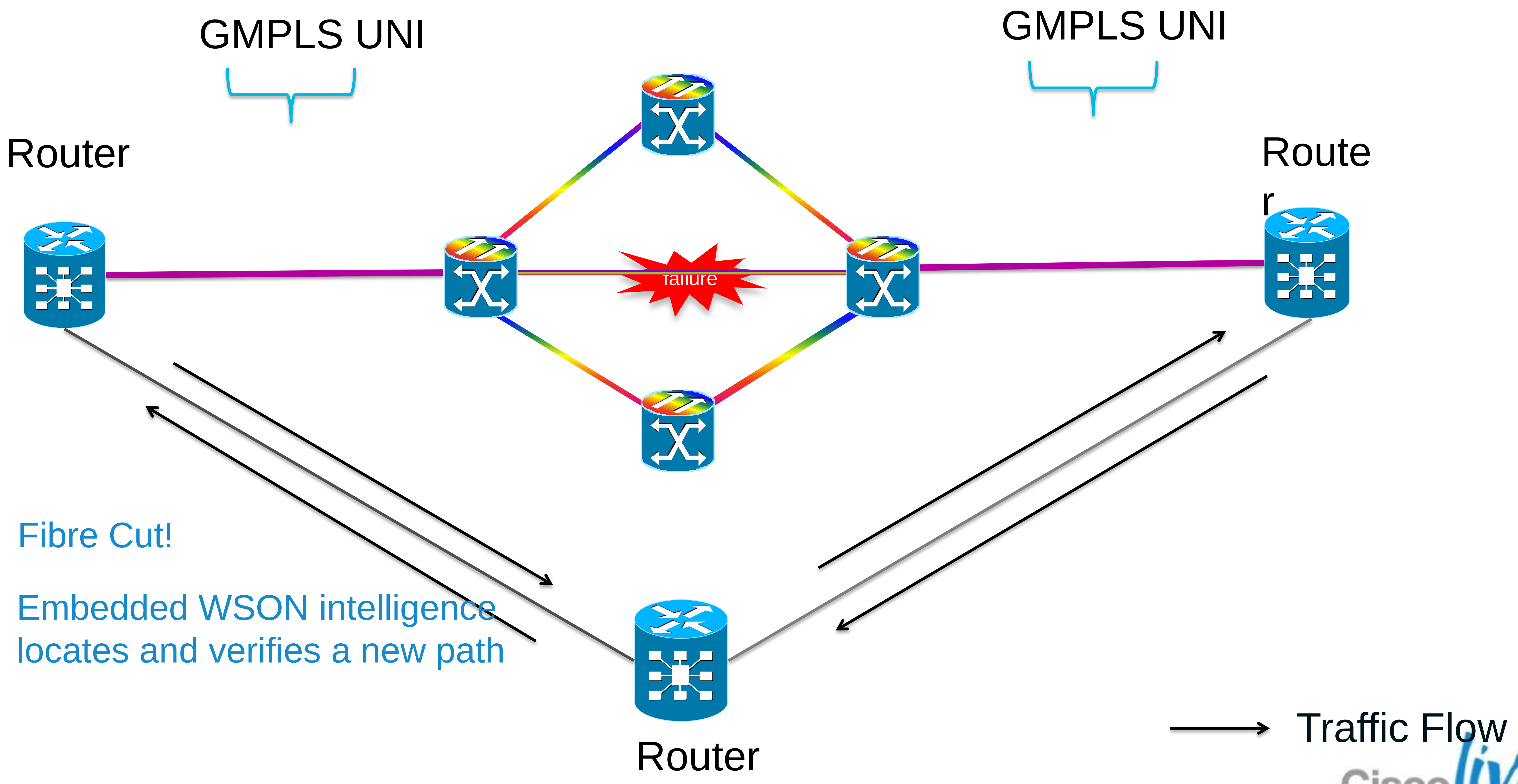


Putting it Together

WSON, GMPLS UNI and IPoDWDM Proactive Protection

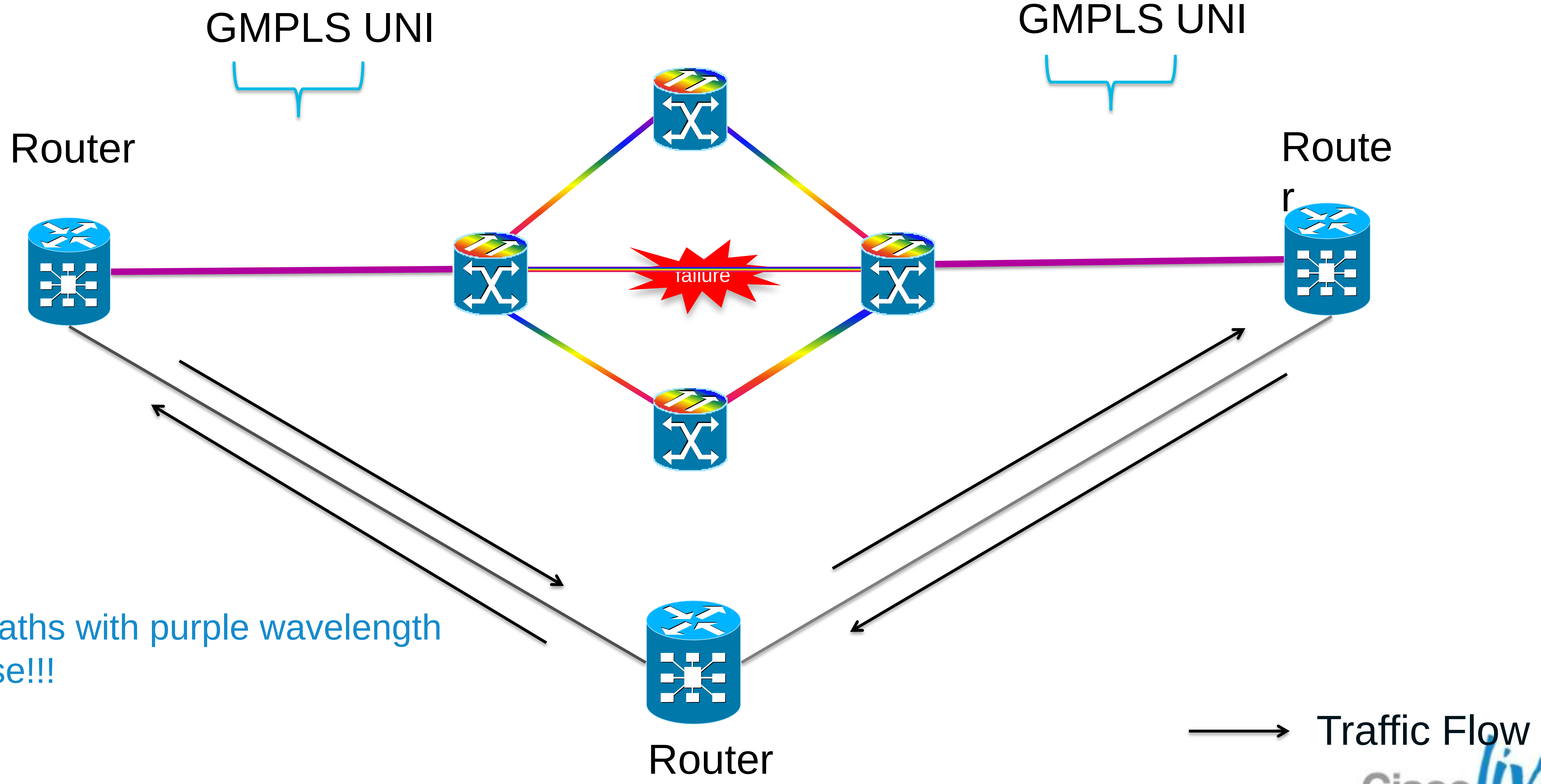


Fibre Cut!

Embedded WSON intelligence locates and verifies a new path

Putting it Together

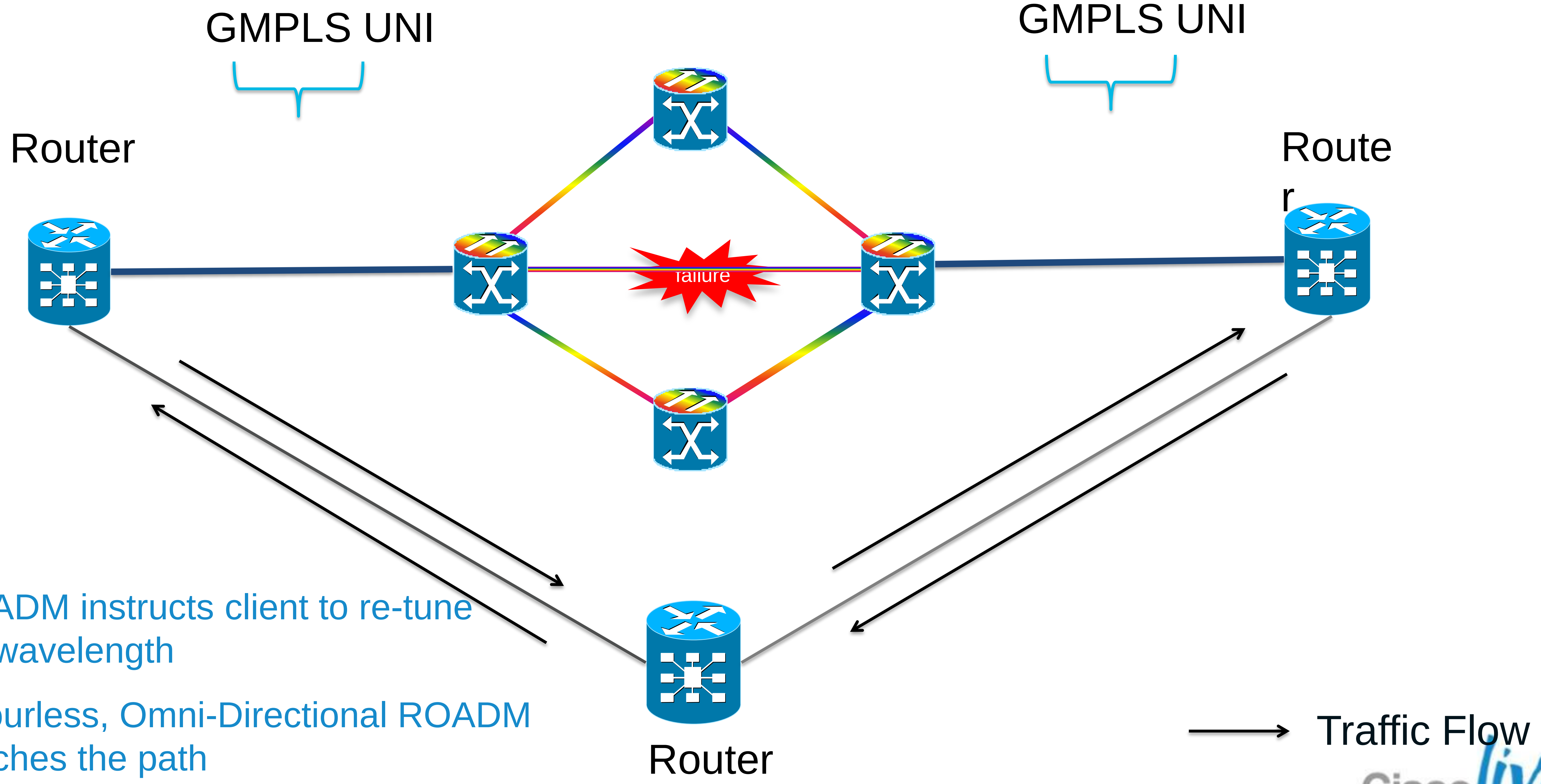
WSON, GMPLS UNI and IPoDWDM Proactive Protection



All paths with purple wavelength
In use!!!

Putting it Together

WSON, GMPLS UNI and IPoDWDM Proactive Protection

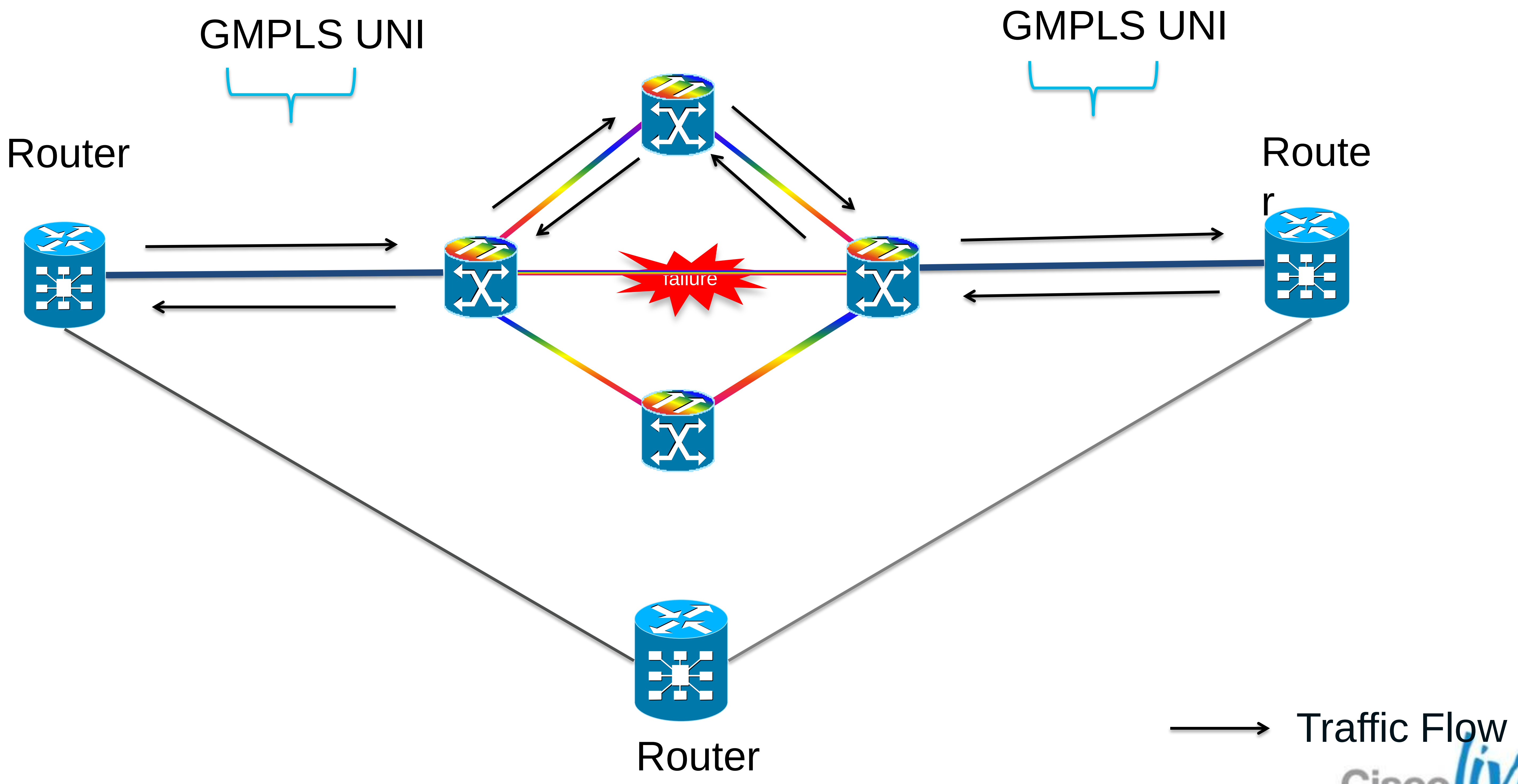


ROADM instructs client to re-tune its wavelength

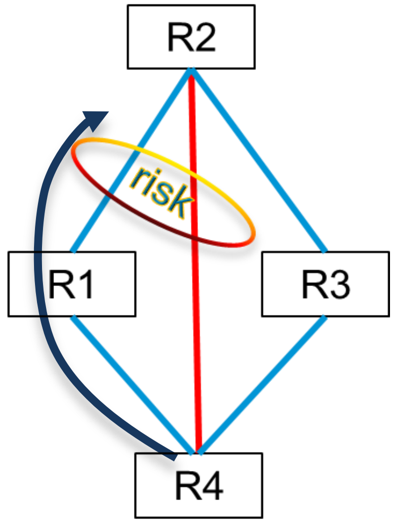
Colourless, Omni-Directional ROADM switches the path

Putting it Together

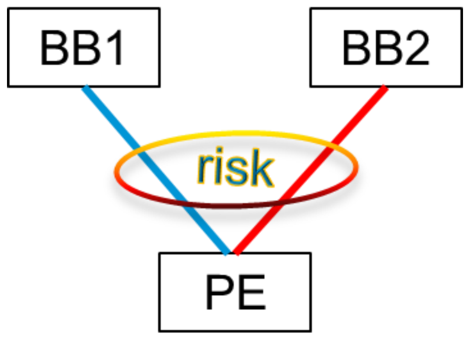
WSON, GMPLS UNI and IPoDWDM Proactive Protection



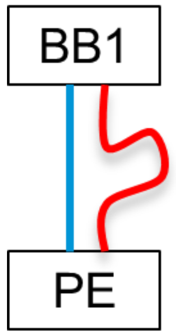
Inefficiencies in Layer 2/3 Network



LFA/TE FRR Fate-Sharing from primary



WAN Disjointness for PoP



Homogenous Latency and Fate sharing Bundle

- Impacts SLA
  - downtime, latency, loss, predictability of service
- Impacts bottom-line
  - SLA penalty, unoptimised capacity, support complexity

Basis for nLight Control Plane

- The solution to these problems are simple
- If the client layer knows basic information from the server layer: SRLG, latency…
- To-date, this information is invisible to the client layer
- We need to allow for information sharing between Client and Server

Multi Layer Control Plane

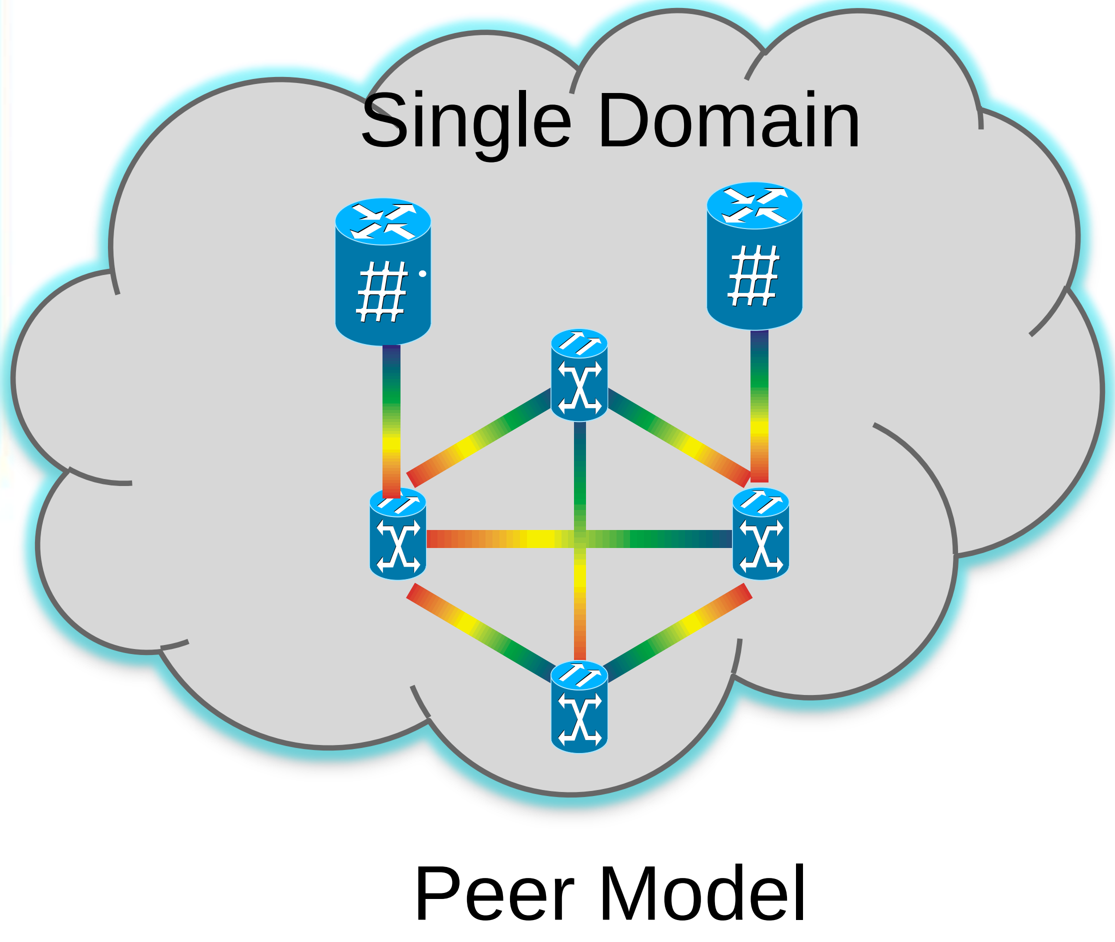
Two key models

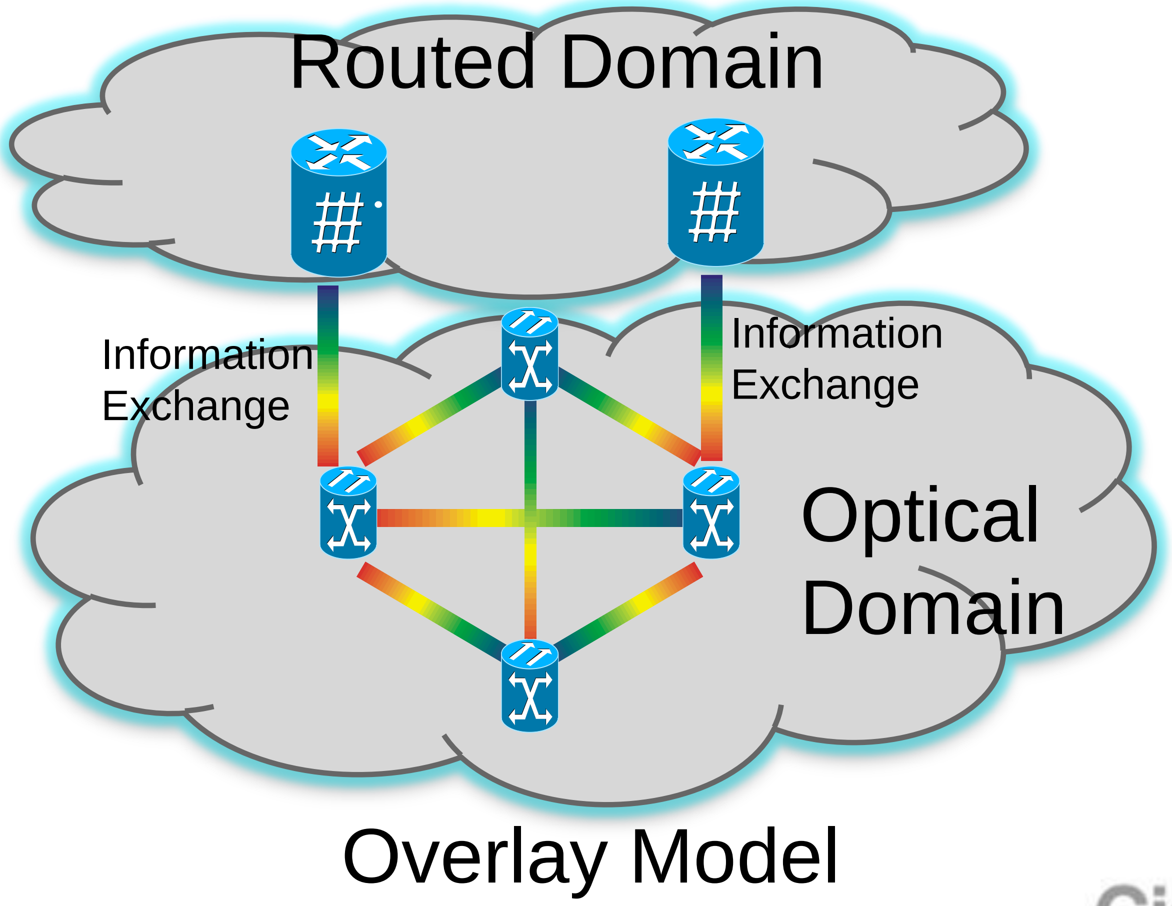
Peer Model – Optical NEs and Routing NEs are one from the control plane perspective, same IGP.

- Does not respect operational boundaries; does not scale

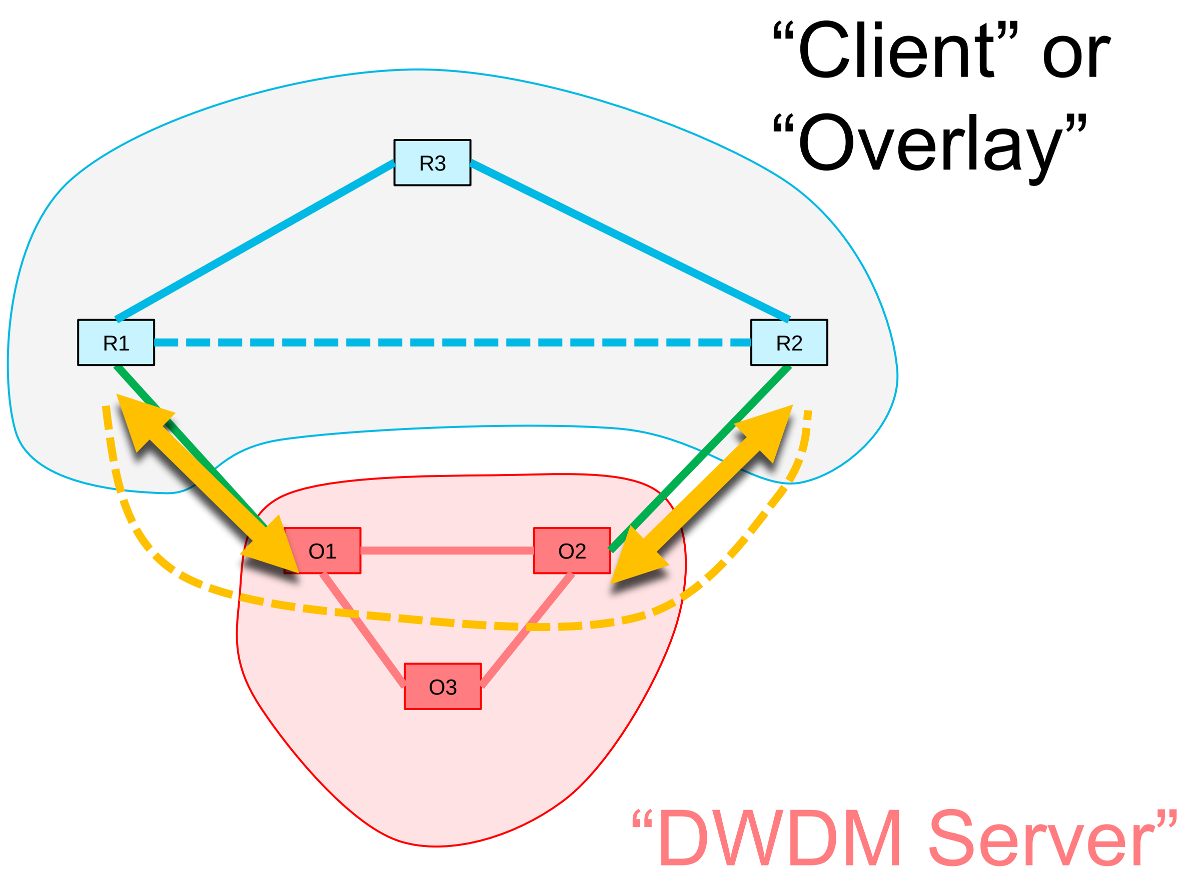
Overlay Model – Having different Control Planes per Layer and signalling between them

- Respects Boundaries and Scales





nLight Architecture



- Overlay client uses service from Server layer (i.e. IP/MPLS)
- Two independent layers decoupled

Benefits of IGP Decoupling

- The IGP's of each layer are de-coupled
  - L3 network runs multi-level ISIS
  - ROADM network runs OSPF
- **Divide et Impera Benefits**
  - Scale
  - Operational expertise
  - Organisational segmentation

Multilayer Control Plane - nLight

- GMPLS UNI extension to include SRLG and Coordinated maintenance functionality
- GMPLS UNI extension to support next generation of Multi-rate/Multi-Modulation/Multicarrier HS Optics
- Automatic Bandwidth service from MPLS CP and WSON CP will be the end goal to deploy a true Multi-Layer Network
- Integration of an L1/L3 awareness in a Network Planner Prime module

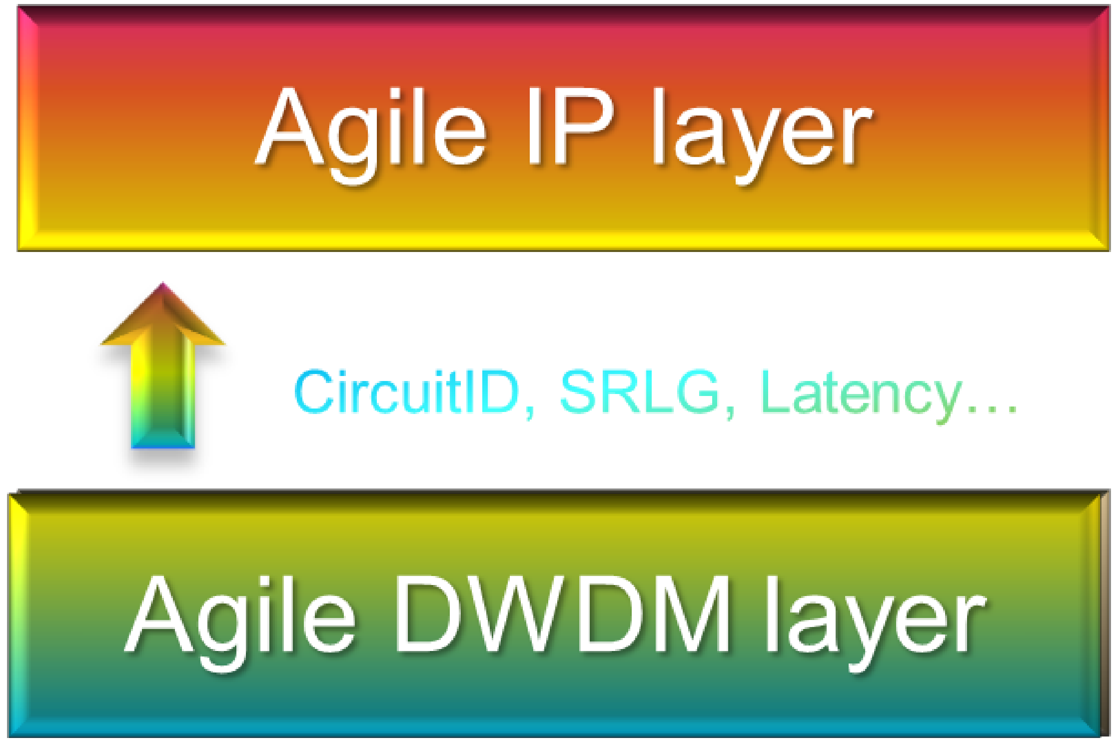
Information Flowing through nLight with GMPLS UNI

- When signalling a circuit, a client **may** request
  - server SRLG's to be excluded or included
  - the path to follow another Circuit-ID
  - the path to be disjoint from another Circuit-ID
  - an optimisation upon shortest latency
  - a bound on latency not to exceed
  - an optimisation upon lowest optical cost
  - optical restoration
  - optical re-optimisation

Information Flowing through nLight GMPLS UNI

- For each circuit it signals, a client **may** be informed of
  - Circuit-ID – unique identifier in server context
  - SRLG's along the circuit
  - Latency through the server network
  - Path through the server network

  Information continuously refreshed
- A client **may** be informed of server topology/resource



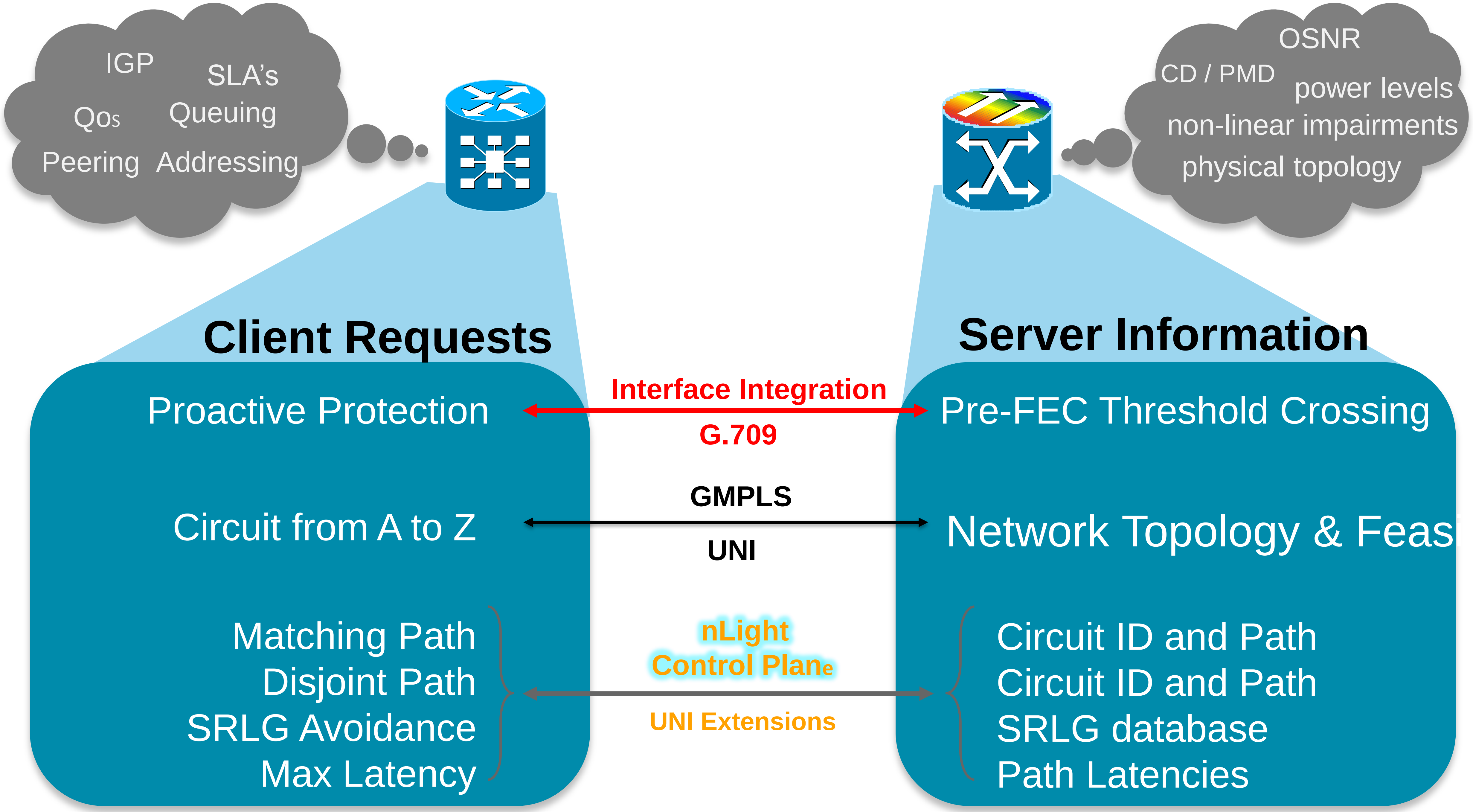
Policy Controlled
by the Server Layer

nLight Resolves the Inefficiencies

- Efficient IP/MPLS FRR
  - thanks to SRLG discovery
- Enforcement of disjointess or same-path requirements
  - thanks to SRLG/Circuit-ID disjointness
- Efficient diagnostics
  - latency discovery
- Efficient operation
  - multi-layer maintenance coordination

Intelligent Information Exchange

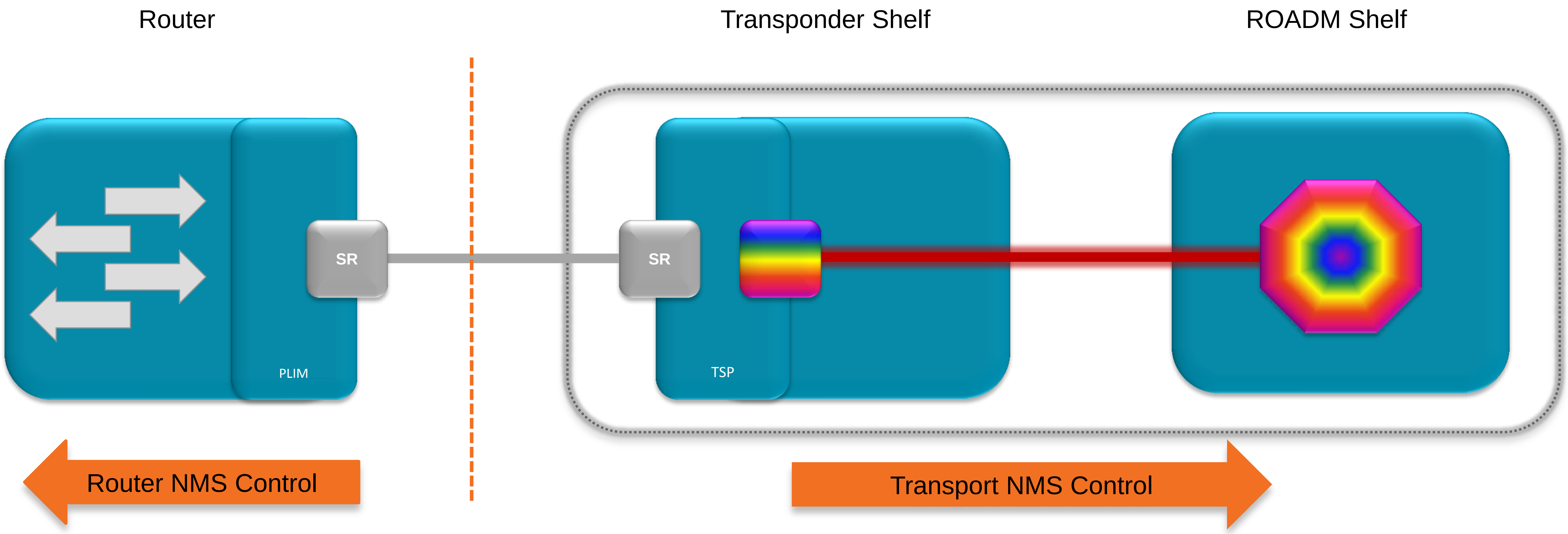
Proactive Protection, GMPLS, Control Plane



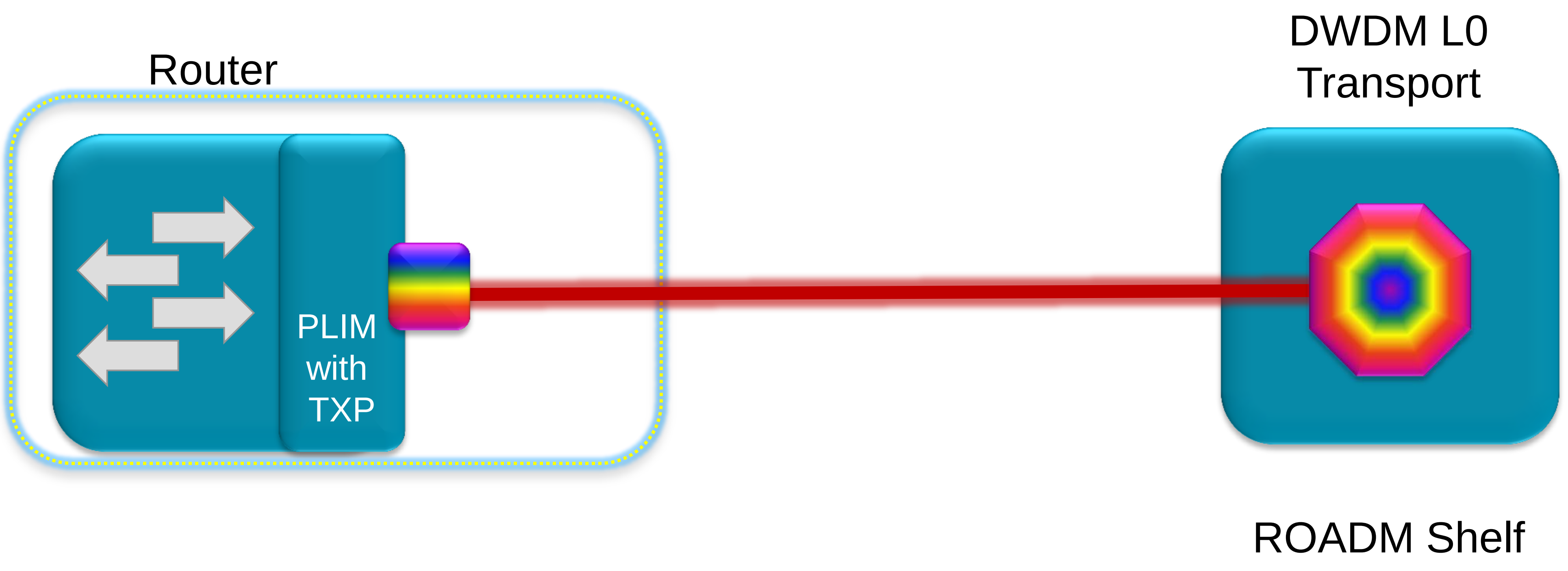
IP+Optical Architectures and Management

The Traditional Approach

- Split Management: Router NE management + Transport NE management
- i.e. WDM Power levels, OTN overhead, and alarms not available on the router
- No topology or performance information sharing between device types



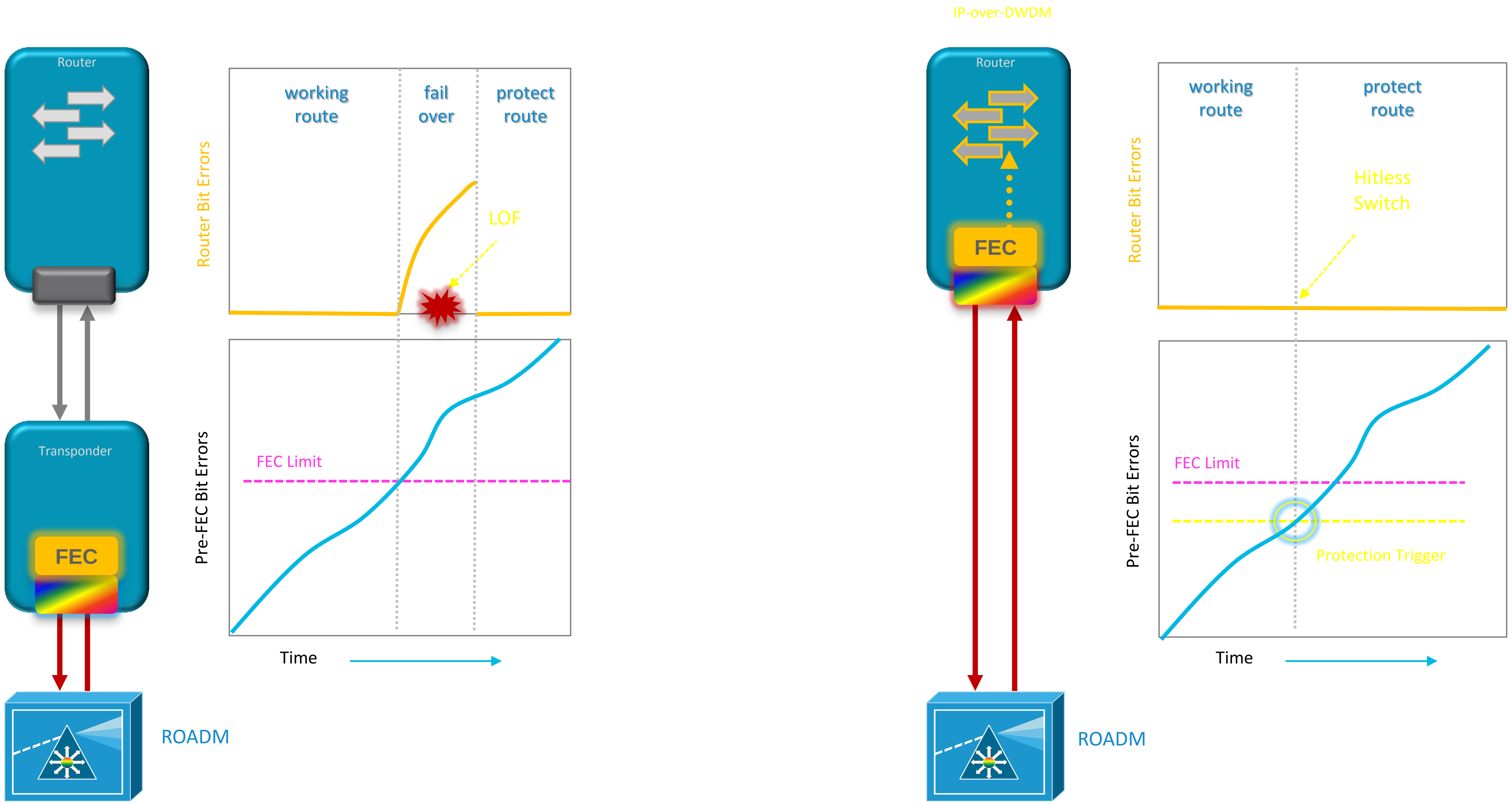
Transponder in Router



- Transponder integrated in the router
- Manage via CLI, SNMP or EMS system of DWDM transport
- Power levels, OTN overhead, PM, and alarms available in real-time on the router

Transponder in Router

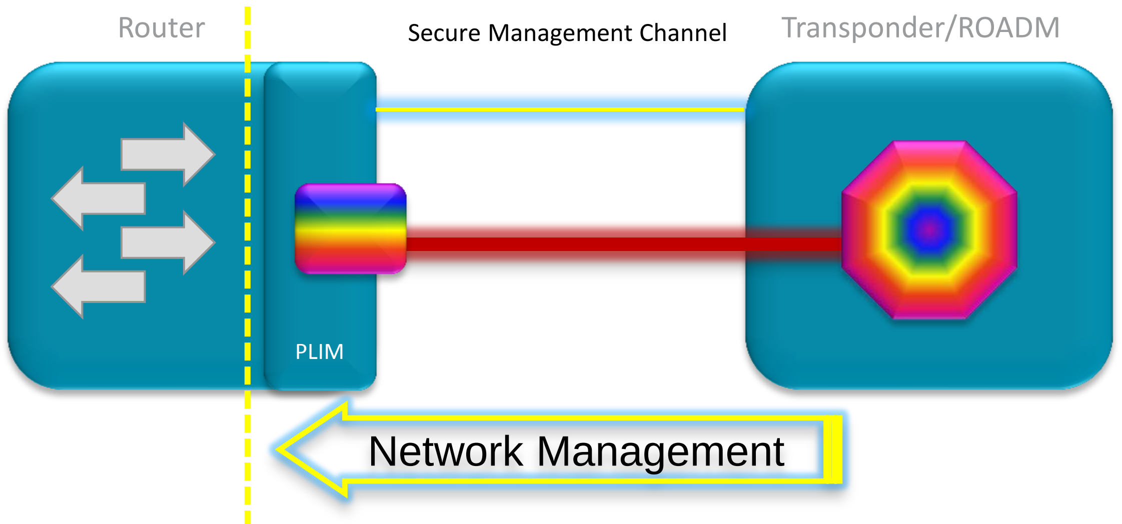
Proactive Protection



Virtual Transponder

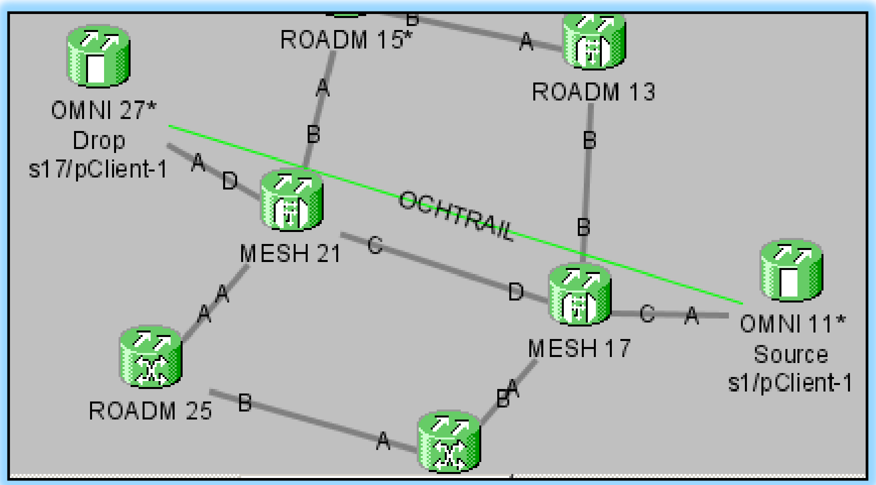
Transponder Virtualised onto the Router Interface

- Retains existing operational model
- Respects boundaries between packet / optical administrative groups



Router Management

- L2/L3 Interface Information
- Routing Protocols
- IP Addressing
- Security

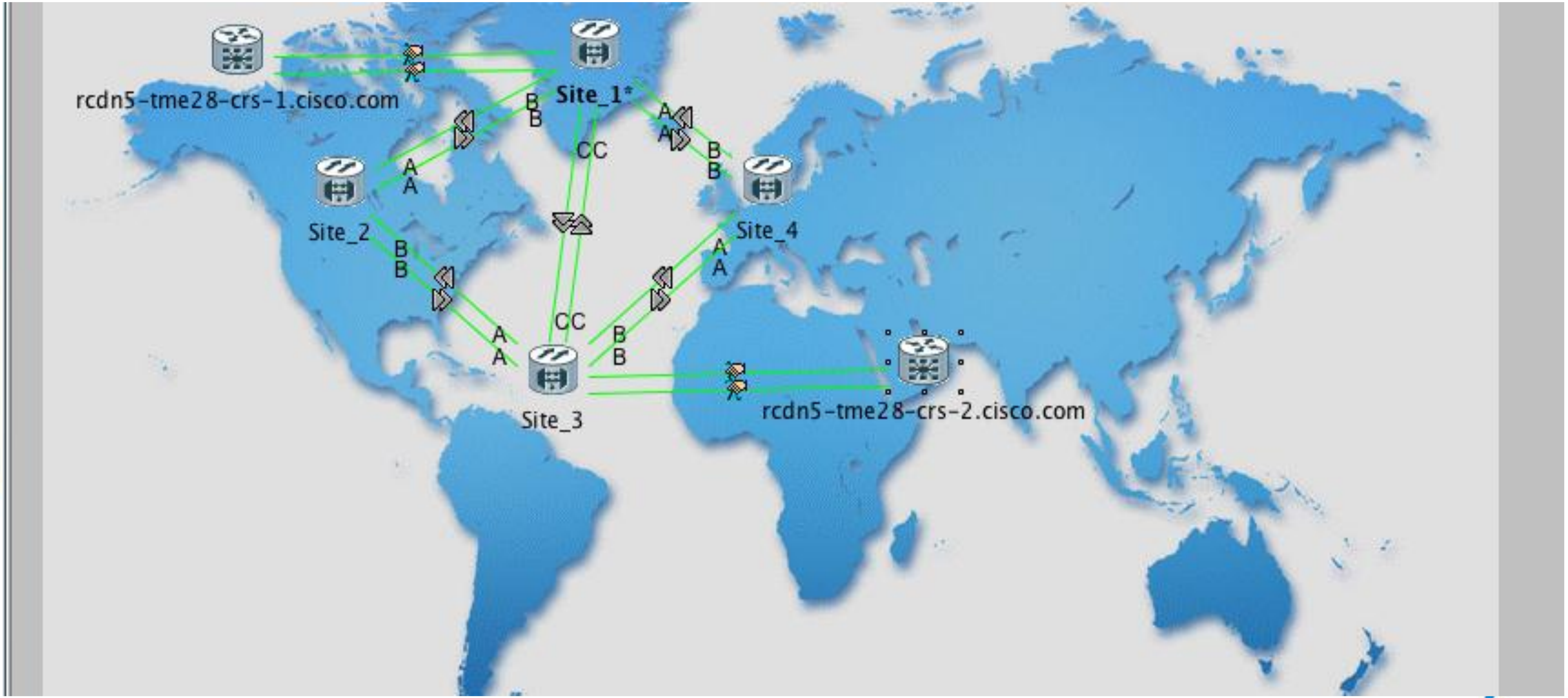


DWDM Management

- L1 Interface Information
- Wavelength Usage
- Power Levels and Thresholds
- Performance Monitoring

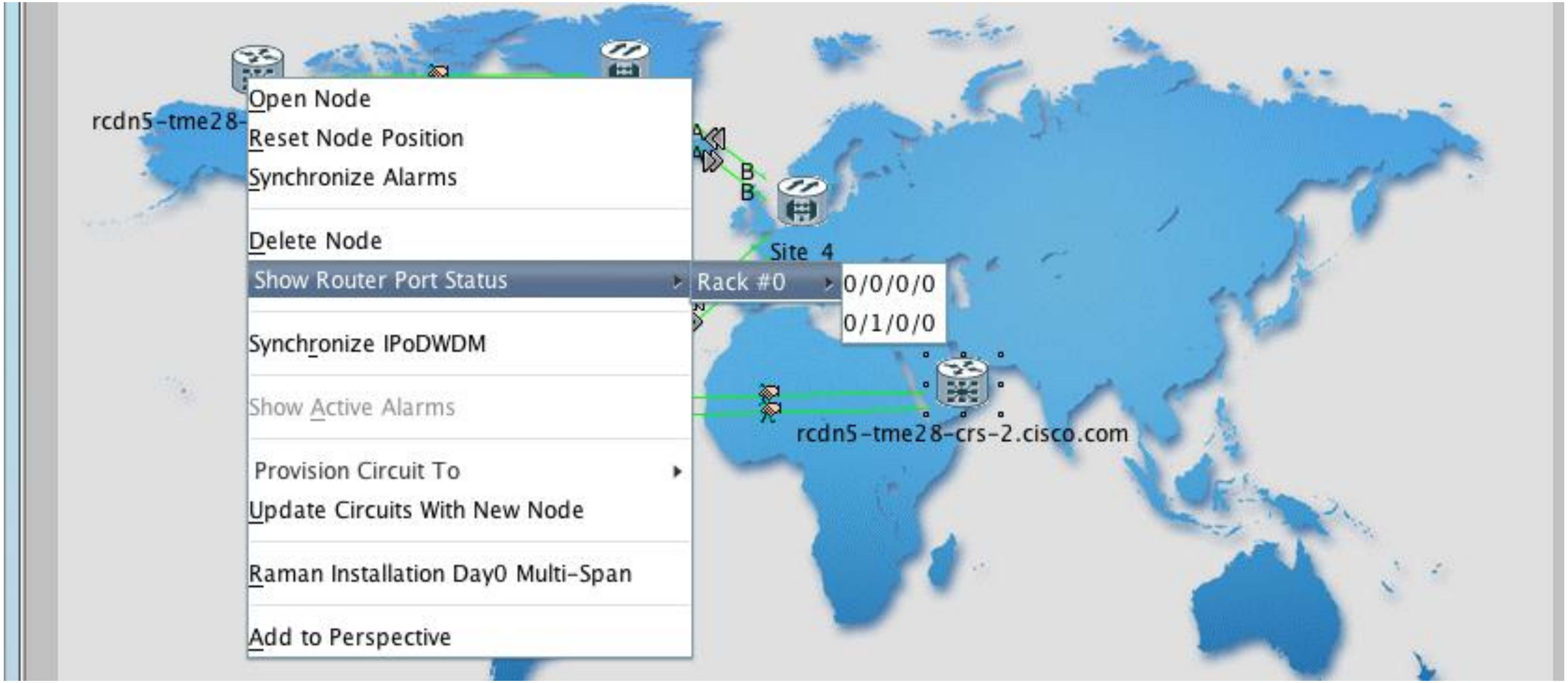
Virtual Transponder

General View



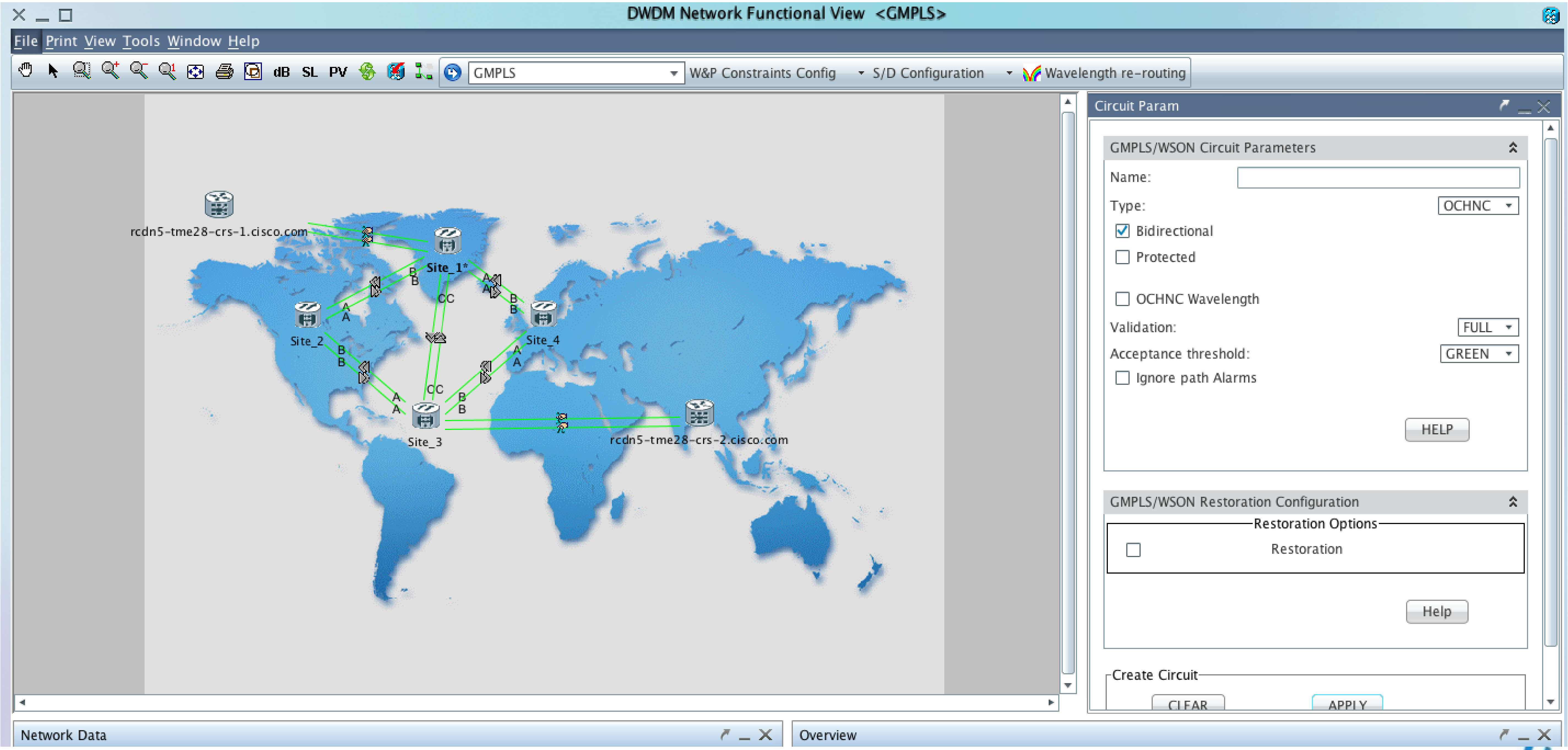
Virtual Transponder

View Router G709 and optical characteristics



Virtual Transponder

Setting up OCHTrail



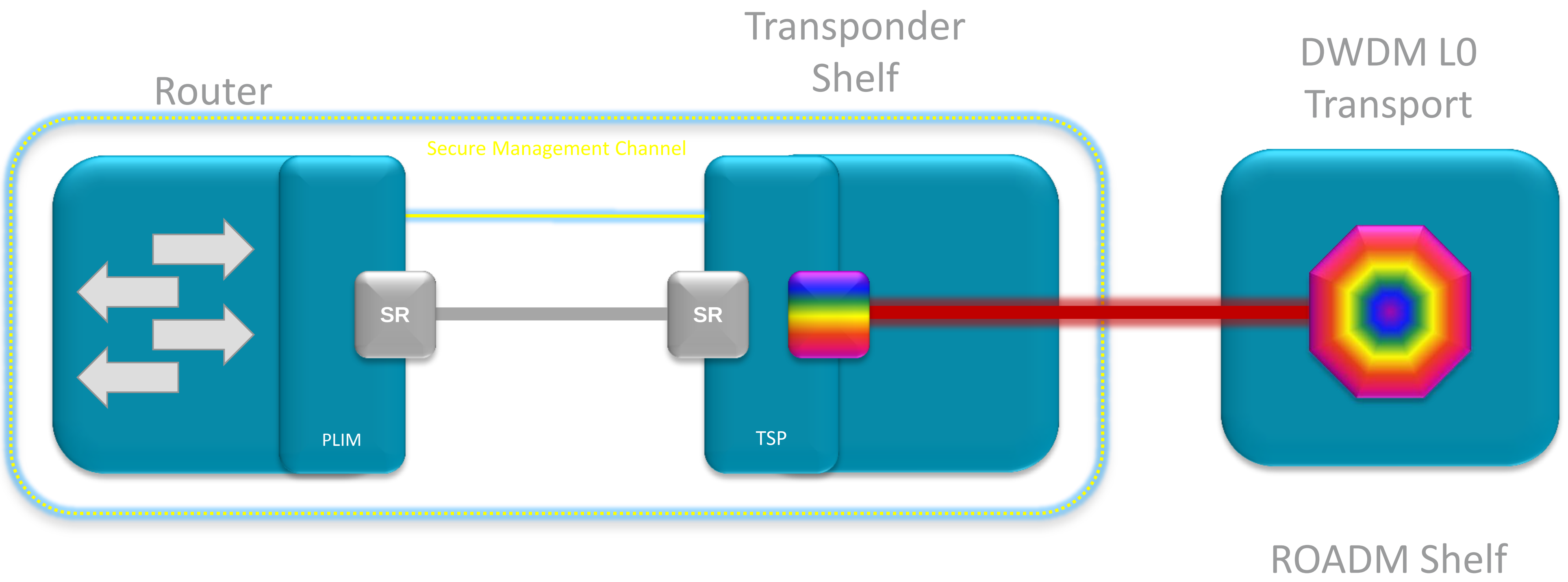
Optical Shelf Concept

Solving the Moore vs. Shannon dilemma

- Realise benefits from combining Optics + Processing…when it makes sense. But for the future…
- Decouple Optics from Processing
  - Space / Size
  - Lifecycle
- Zero Cost interconnect
- Value add functionality (take advantage of OEO)
  - Pack waves efficiently
- Maintain unified management

IP+Optical: Satellite

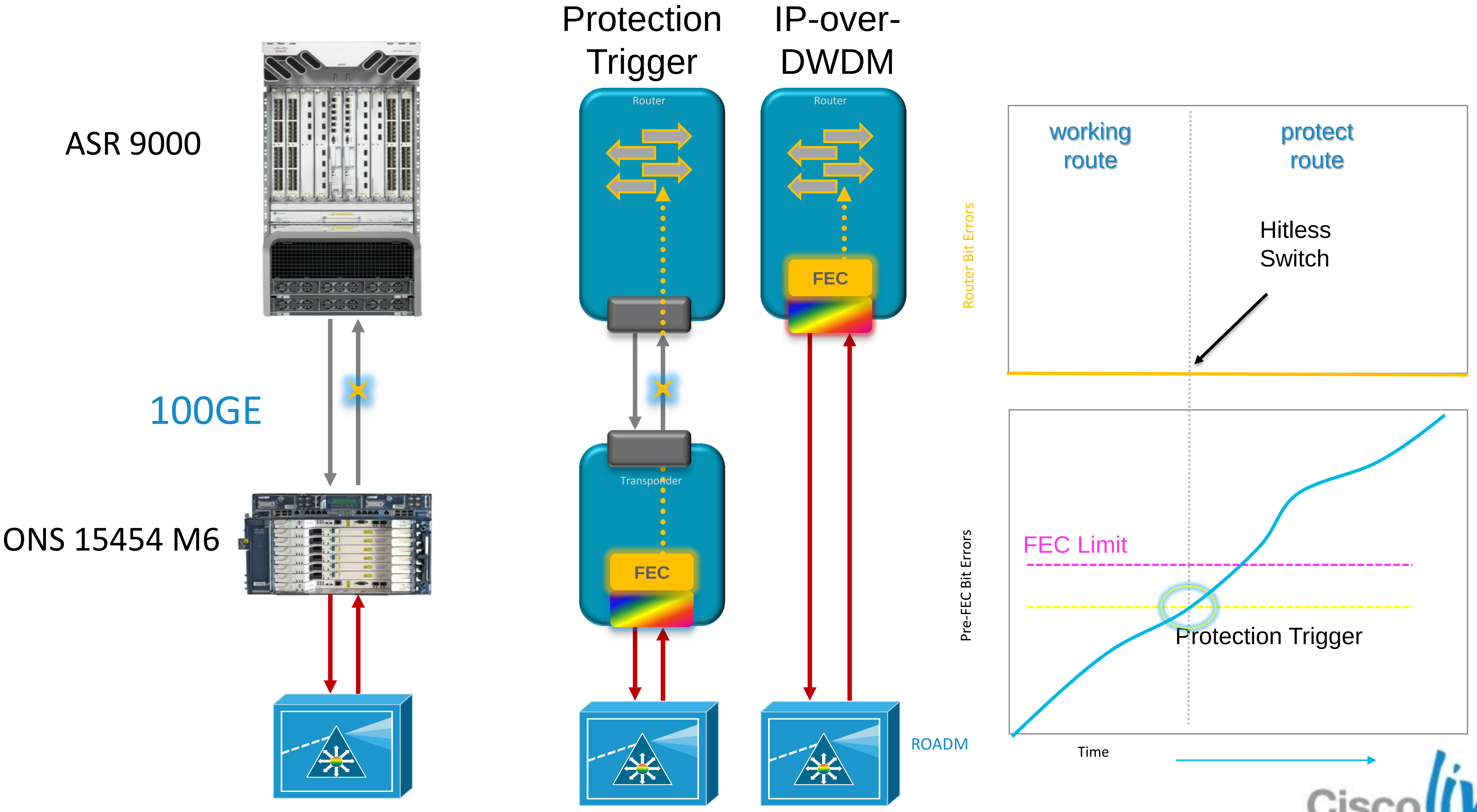
Router Interface Virtualised onto the Transponder



- Transponder becomes an extension of the router
- Power levels, OTN overhead, and alarms available in real-time on the router
- DWDM interface controlled and monitored by router CLI or OTN MIB
- Control Plane Interaction

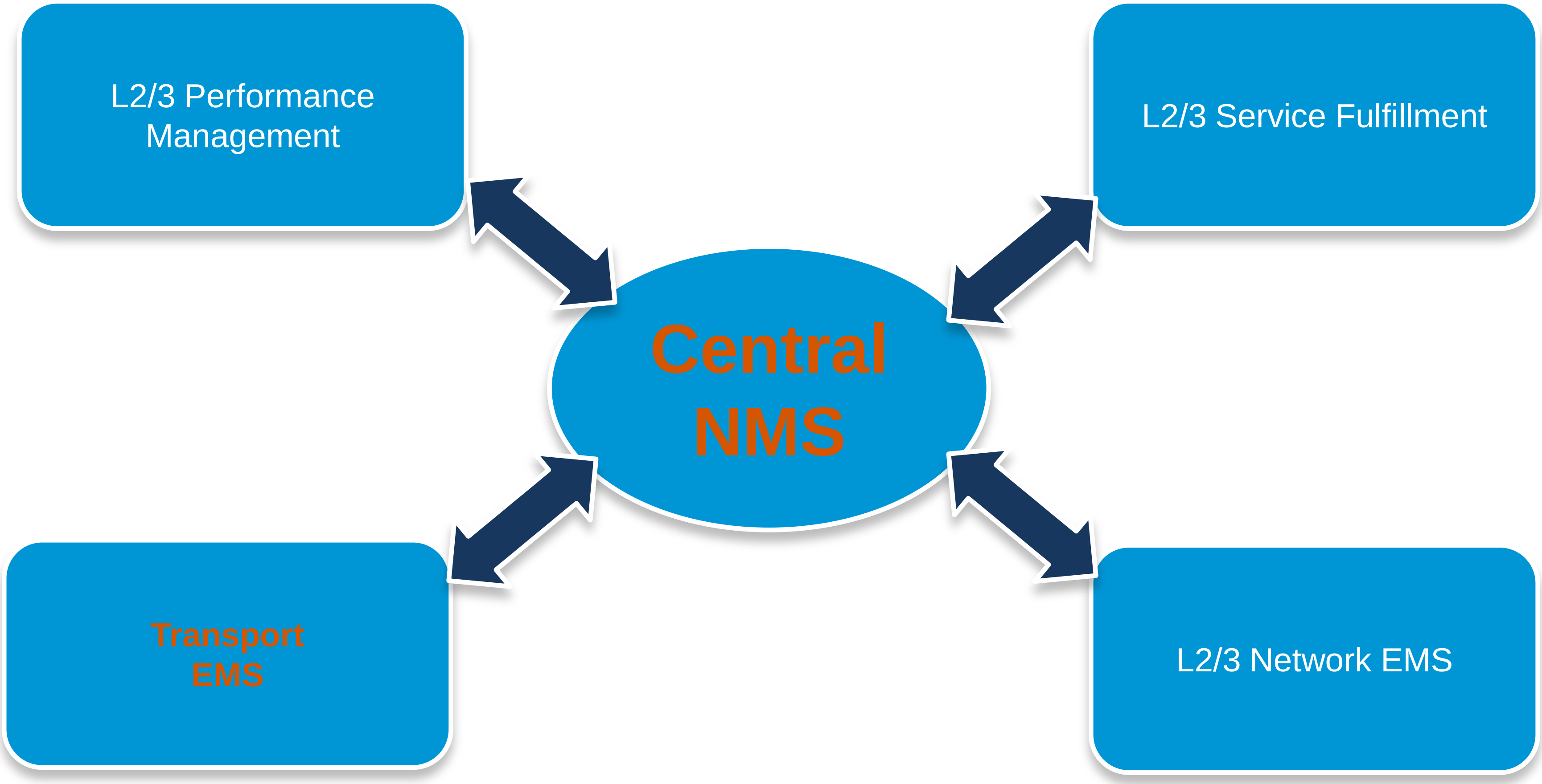
IP+Optical Satellite

Proactive Protection



IP+Optical Network Management

- A modular suite of applications
- A-to-Z management for next-generation packet and transport networks
- Designed for lower Total Cost of Ownership



Crucial to the usability of the NGN, control plane alone is not enough…

Summary

- Packet traffic increasing
- IP+Optical decreases expenses while streamlining services
- New ROADM trends to support optical agile networks enabling multilayer control planes
- Multilayer control planes add network automation and resiliency as well as decrease TCO
- New architectures enable next generation networks

Q & A

Acronyms

For Your Reference

C-SPF	Constrained Shortest Path First
CD	Chromatic Dispersion
CP-DQPSK	Coherent Polarisation-Mux Differential Quadrature Phase Shift Keying
DSP	Digital Signal Processing
DWDM	Dense Wave Division Multiplexing
ELEAF	E-Large Effective Area Fibre
FEC	Forward Error Correction
FRR	Fast Re-Route
FWM	Four Wave Mixing
GMPLS	Generalised Multi Protocol Label Switching
IETF	Internet Engineeing Task Force
ITU	International Telecommunications Union
LFA	Loop Free Alternate
LSP	Labeled Switch Path
NNI	Network-Network Interface
OCP	Optical Control Plane

OIF	Optical Internetworking Forum
OSNR	Optical Signal to Noise Ratio
OTN	Optical Transport Network
PMD	Polarisation Mode Dispersion
QAM	Quadrature Amplitude Modulation
ROADM	Reprogrammable Optical Add/Drop Multiplexer
SLA	Service Level Agreement
SMF	Single Mode Fibre
SRLG	Shared Risk Link Groups
TDM	Time Division Multiplexed
TE	Traffic Engineering
UNI	User-Network Interface
WSON	Wavelength Switched Optical Network
WXC	Wavelength Cross Connect
XPM	Cross Phase Modulation
YoY	Year over Year

Final Thoughts

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