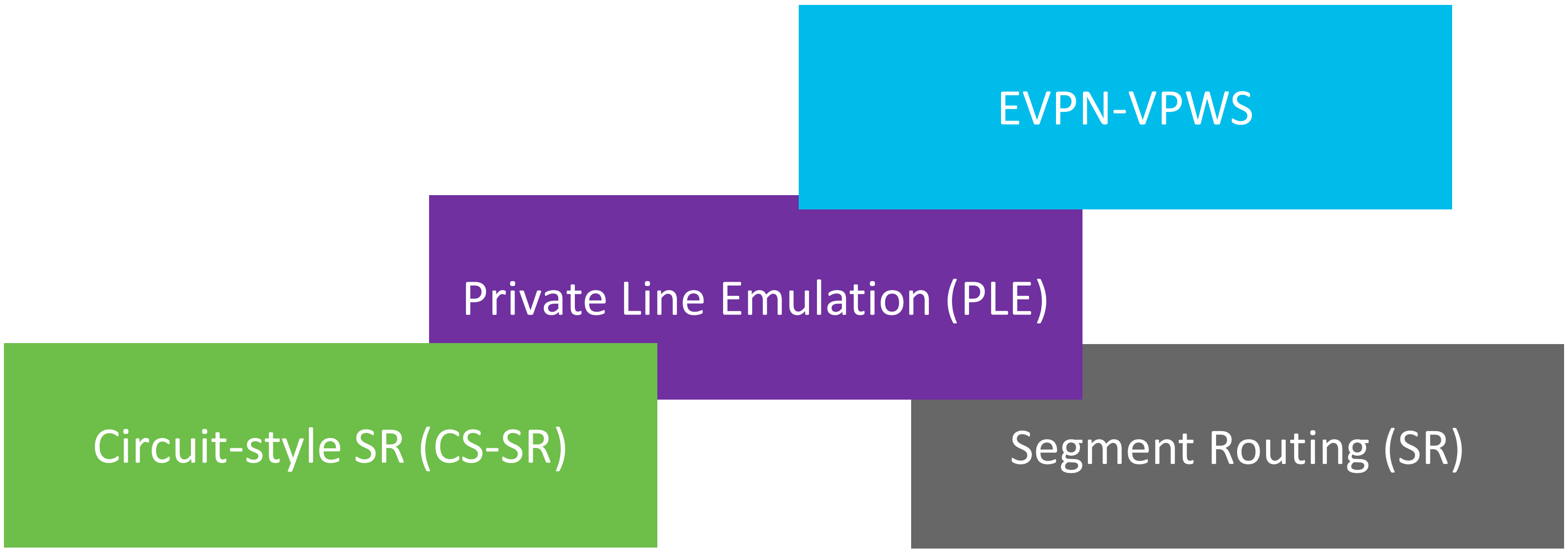
What is Private Line Emulation (PLE) and Why should you Care?

Cisco Knowledge Network - November 22nd 2022

Christian Schmutzer, Distinguished Engineer

Today we are solving a puzzle together ☺



VPWS … Virtual Private Wire Service
EVPN … Ethernet Virtual Private Network

Agenda

- Market landscape & motivation
- Line > circuit > pseudowire
- Private line emulation
- Circuit-style segment routing
- Key take aways

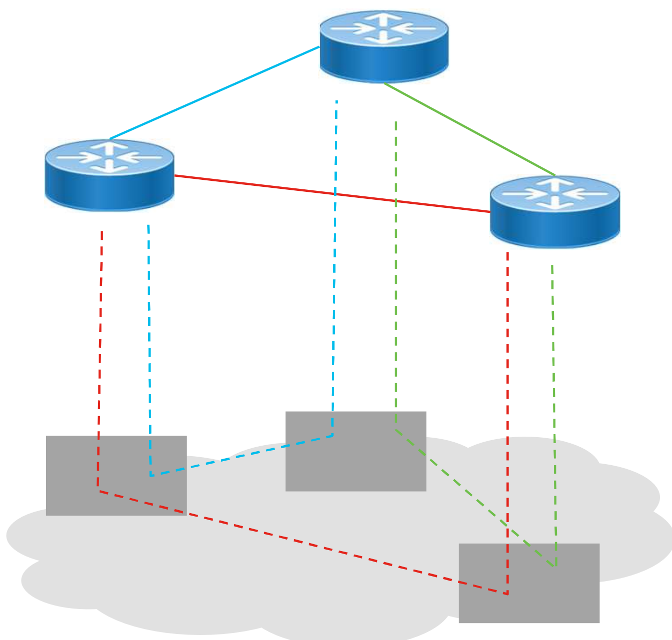
Market Landscape & Motivation

Wavelength / private line services

- High capacity
  - >10Gbps per service
- Committed / dedicated resources from A to Z
- Organisational boundaries
  - Different organisations inside a service provider
  - Whole sale connectivity between service providers
  - Enterprise services

Typical use cases

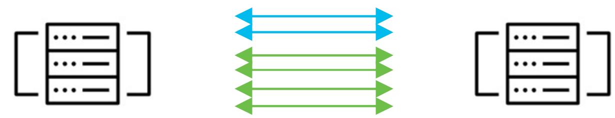
Dedicated WAN pipes



Customer

Transport provider

Data center interconnect



Data centre A

Data centre B

"Cloud connect"

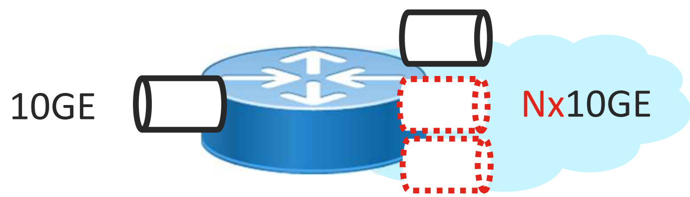
Enterprise private cloud

Public cloud

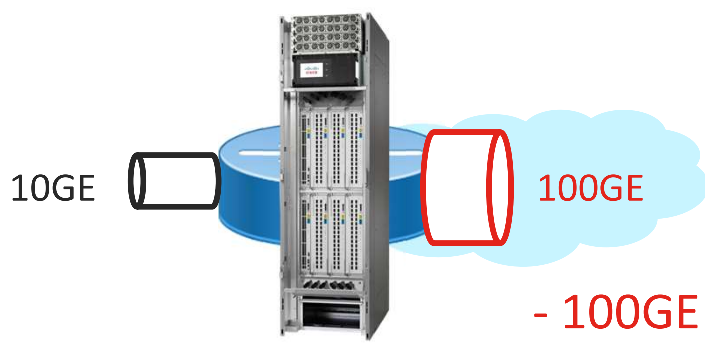
AWS, Azure, GCP, …

The uplink interface capacity challenge

In the past



Link bundle / ECMP !? (5-tuple hashing, …)



- 100GE expensive
- limited router choice

Traffic engineering

- Traffic is routed across congested “shortest” (ECMP) path
  - How can I divert traffic to longer / different paths?
- Introduce RSVP-TE?
  - Full vs partial-on-demand mesh
  - Manual vs auto-bandwidth
- IGP metric optimization?

Deploying TDM to overcome the challenges

Trans-/Muxponder point2point

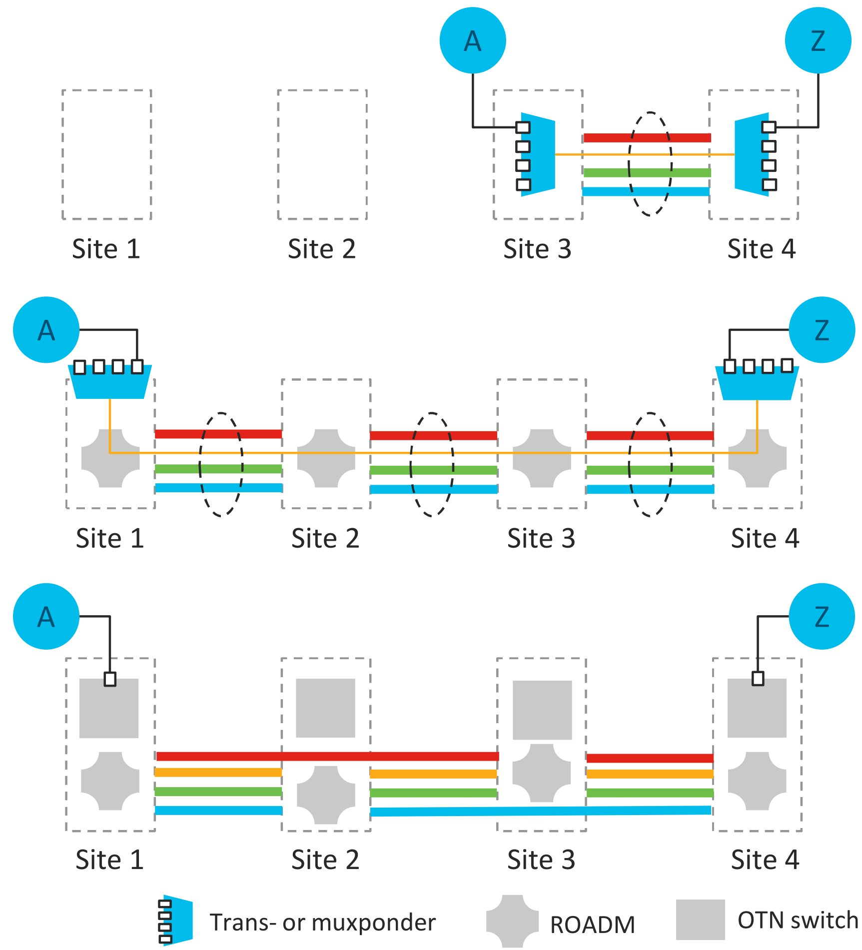
- Simple and cost effect for close-by locations

Trans-/Muxponder across ROADMs

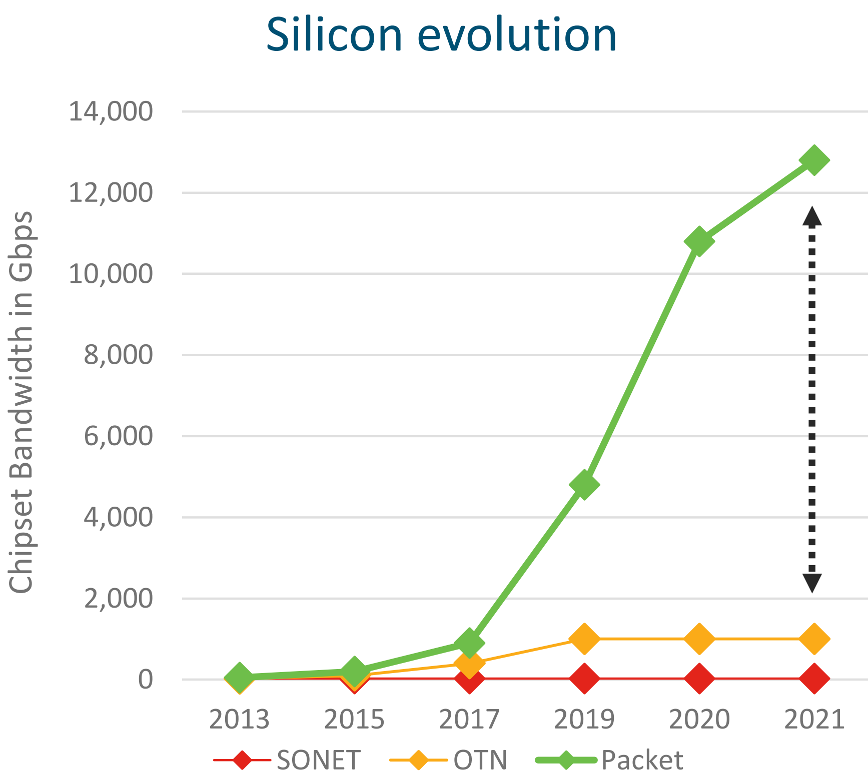
- Allows for greater geographic reach
- Likely bad wavelength utilization (especially for 10GE)
- Low spectral efficiency due to 100G/200G wavelength end-to-end

Electrical switching (OTN)

- Greater base network cost
- Ideal wavelength utilization
- Optimum spectral efficiency using wavelengths at highest possible rate (100-1.2Tbps)



Routers are no longer small nor expensive!



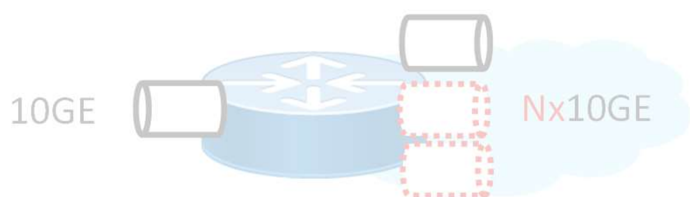
Cisco NCS540
- 800Gbps
- Mix of 10,25,40,50,100 and 400GE

Cisco8201
- 12.8Tbps
- Mix of 10,25,40,100 and 400GE

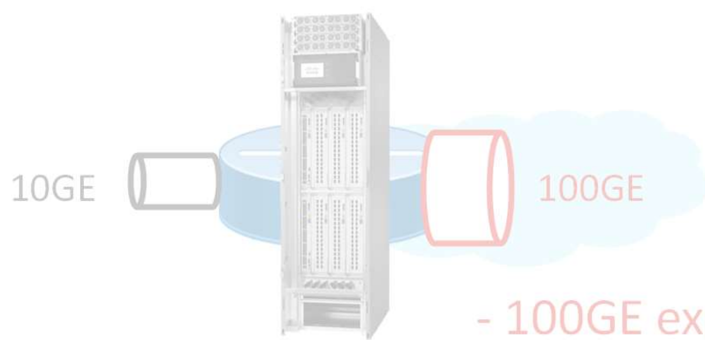
Cisco8812
- 172.8Tbps
- Mix of 10,40,100 and 400GE

No more uplink interface capacity challenge

In the past

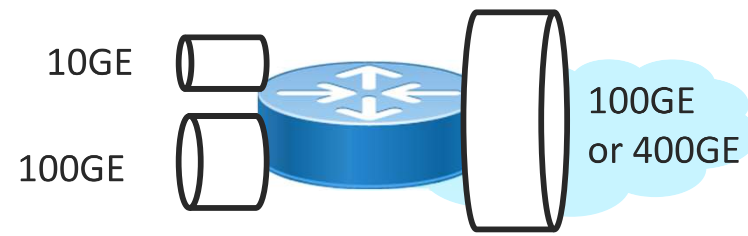


Link bundle / ECMP !?



- 100GE expensive
- limited router choice

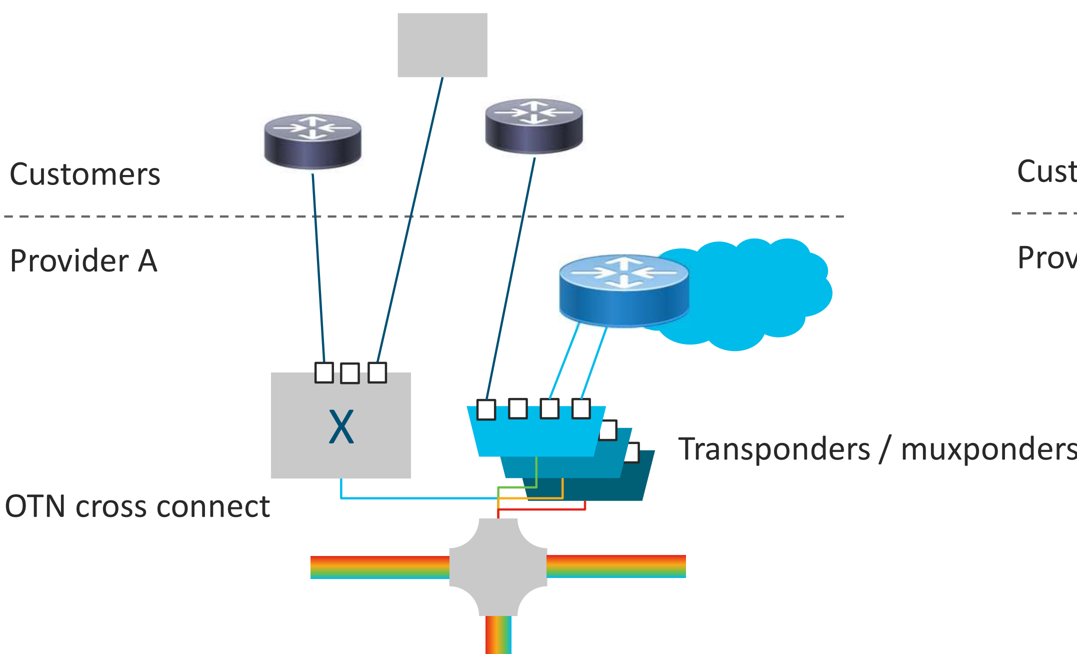
Today



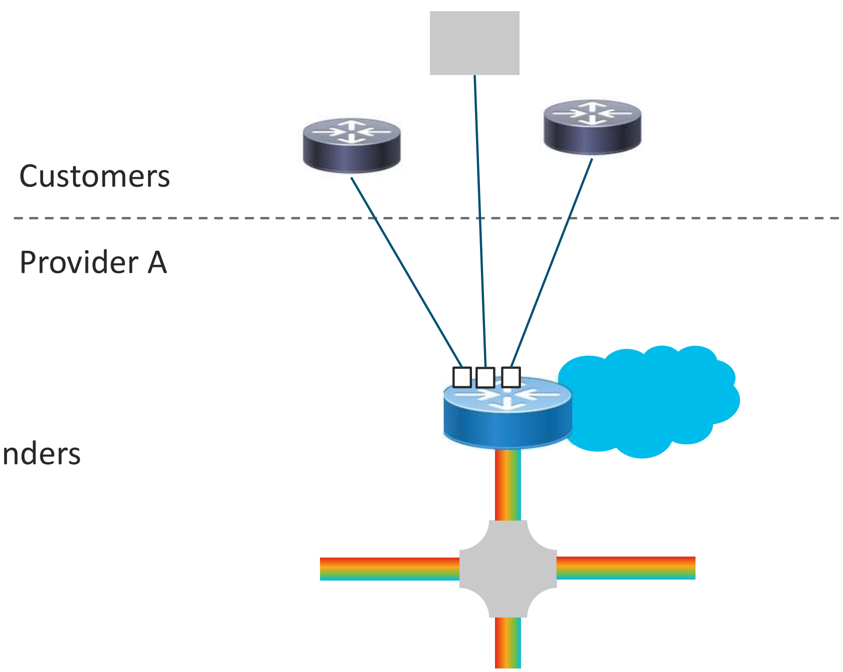
- Very cost effective 400GE
- Flexible router choice

Do things differently

Why this?

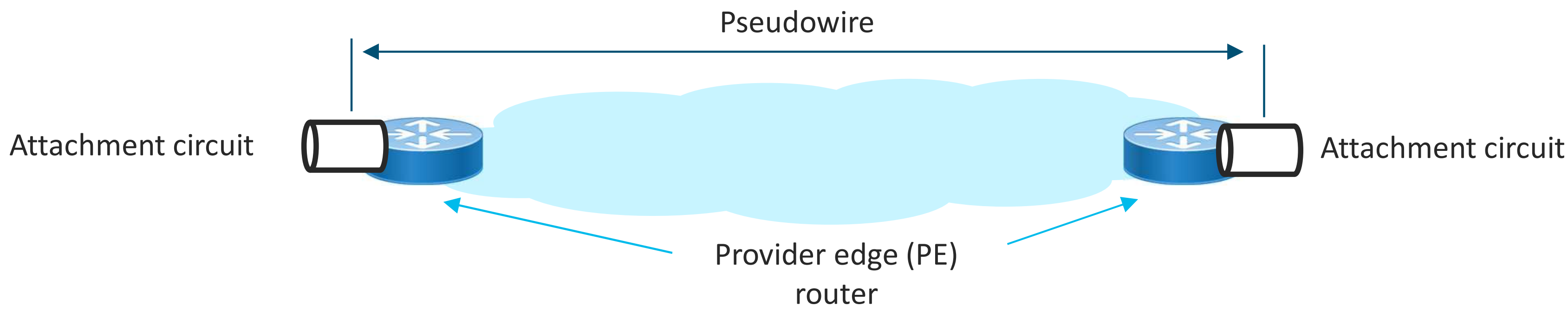


... if you can do this !



Line > Circuit > Pseudowire

Virtual Private Wire Service (Pseudowire)



- Emulation of a “Telecommunications service”
- Initially defined by IETF PWE3 working group via RFC 3985
  - T-LDP for pseudowire signaling
  - Frame Relay, ATM, Ethernet and TDM
- Modernized by IETF BESS working group via RFC 8214
  - MP-BGP for pseudowire signaling → EVPN-VPWS

Some remaining challenges

- Someone is asking me for a non-ethernet connection
  - SONET/SDH (clear channel)
  - Fibre Channel
- Challenges with control protocols and Ethernet Private Lines (EPL)
  - aka ”L2CP transparency”
- Synchronization (i.e. per client SyncE)
- “MTU bloat”
  - Customers asking >9216 byte MTU size
  - Core (MPLS NNI) MTU > service MTU !

Control protocols – a never ending story?

- MACSEC uses EAPOL (IEEE 802.1X-2010) for key exchange
  - EtherType 0x888e and destination MAC 01-80-C2-00-00-03
- MEF 45.1 is only "recommending" to pass those frames for ethernet private lines (EPLs)

Protocol Type	Protocol Identifier	L2CP Destination Address	L2CP Action
STP[3]/RSTP[4]/MSTP[4]	LLC Address: 0x42	01-80-C2-00-00-00	Pass
E-LMI[15]	EtherType: 0x88EE	01-80-C2-00-00-07	Pass[6]
LLDP[1]	EtherType: 0x88CC	01-80-C2-00-00-0E	Pass
PTP Peer Delay[8]	EtherType: 0x88F7	01-80-C2-00-00-0E	Pass
GARP[4]/MRP[4] Reserved Address	any	01-80-C2-00-00-20 through 01-80-C2-00-00-2F	Pass

Table 9 – EPL Option 2 L2CP Processing Requirements

Protocol Type	Protocol Identifier	L2CP Destination Address	L2CP Action
PAUSE[7]	Etherype: 0x8808 Subtype: 0x0001	01-80-C2-00-00-01	Discard
LACP/LAMP[2]	EtherType: 0x8809 Subtypes: 0x01, 0x02	01-80-C2-00-00-02	Pass
Link OAM[7]	EtherType: 0x8809 Subtype: 0x03	01-80-C2-00-00-02	Pass
Port Authentication[6]	EtherType: 0x888E	01-80-C2-00-00-03	Pass
ESMC[11]	EtherType: 0x8809 Subtype: 0x0A	01-80-C2-00-00-02	Pass[7]

Table 10 – EPL Option 2 L2CP Processing Recommendations

Private Line Emulation (PLE)

Private Line Emulation (PLE)

Technology Introduction

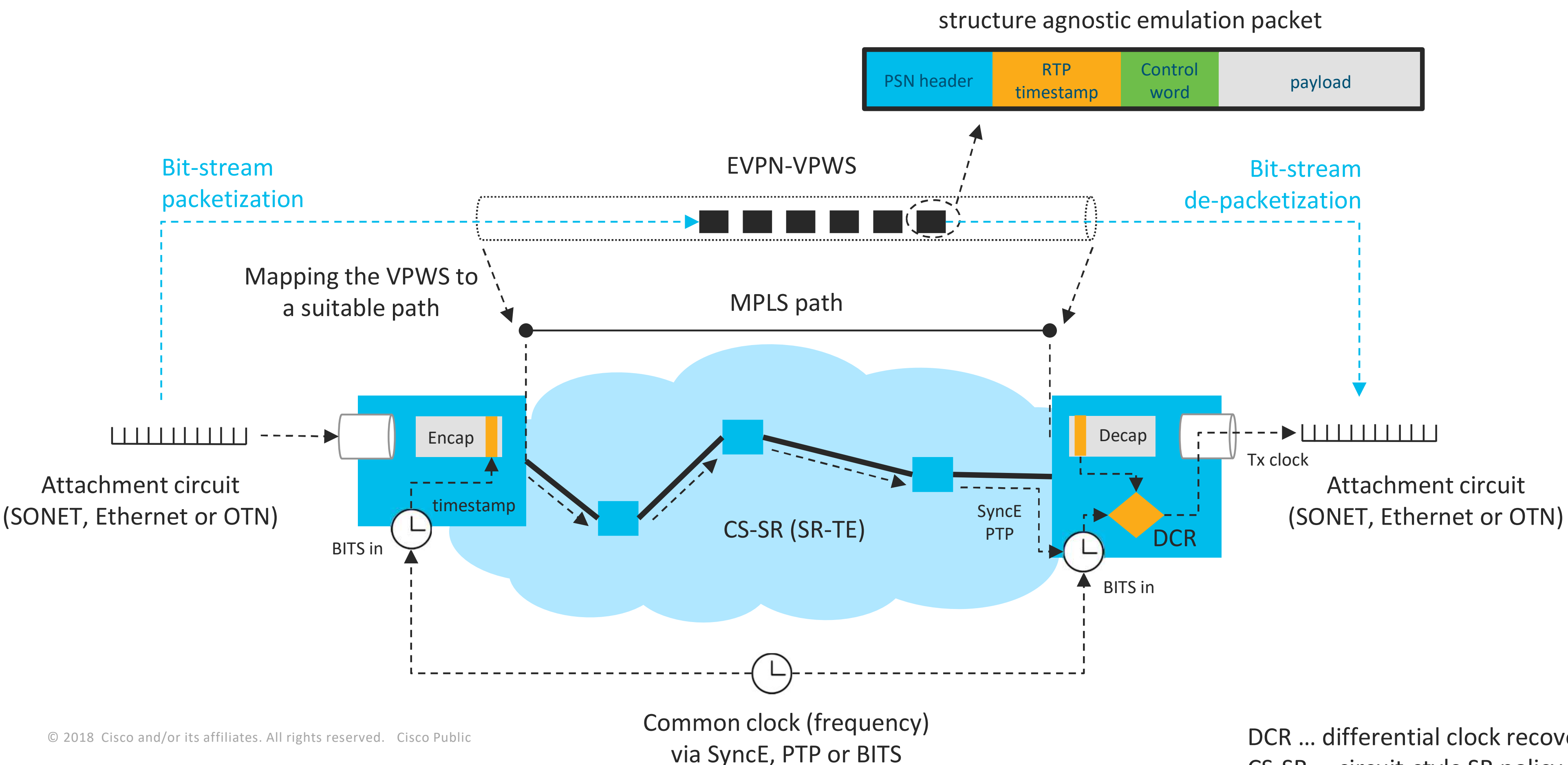
What is Private Line Emulation (PLE)?

Bit-transparency
&
Non-ethernet protocol

+

Point-to-point L2VPN
service over IP/MPLS

Private Line Emulation (aka PLE)



DCR … differential clock recovery
CS-SR … circuit-style SR policy

PLE MPA Overview

- Supported client types
  - 1GE, 10GE
  - OC48/STM16, OC192/STM64
  - Fibre channel (1, 2, 4, 8 ,10 ,16 and 32G)
  - OTU2, OTU2e
- Any mix of client types supported
- Supported in the following NCS5500/5700 series routes

NC55-OIP-02

NCS-55A2

NCS-57C3

PLE payload types

Suppored today (using NC55-OIP-02=)

	SONET/SDH	OTN	Ethernet	Fibre Channel
1Gbps		ODU0	1GE	FC100
	OC48/STM16	ODU1		FC200
				FC400
				FC800
	OC192/STM64	ODU2/ODU2e	10GE	
				FC1600
				FC3200
100Gbps		ODU4	100GE	

PLE MPA Feature Details

- Dejitter buffer to compensate +-400usec PDV
- Configurable PLE payload size
  - Default = 1024 bytes
  - 128-1472 bytes, increments of 64 bytes
- Comprehensive Performance monitoring
  - Client ingress
  - Client egress
  - PLE pseudowire (lost/dropped freames, packet loss state, dejitter buffer overrun/underun)
- Facility and terminal loopback
- PRBS based service activation testing

PLE transmission supervision

- Trail supervision functions are implemented via
  - PLE control word
  - BGP PLE signalling attribute
- Some examples
  - Client signal failure is communicated via L bit set
  - No path AIS equivalent as it is implicit from pseudowire packet being detected
  - Trail backward failure indication is done by R bit set
  - Connectvity validation is performed via Endpoint-ID TLV during BGP signalling
- Standardization at IETF under way to ensure interopability

PLE control word [1)]

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 0 0|L|R|RSV|FRG|   LEN     |       Sequence number         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

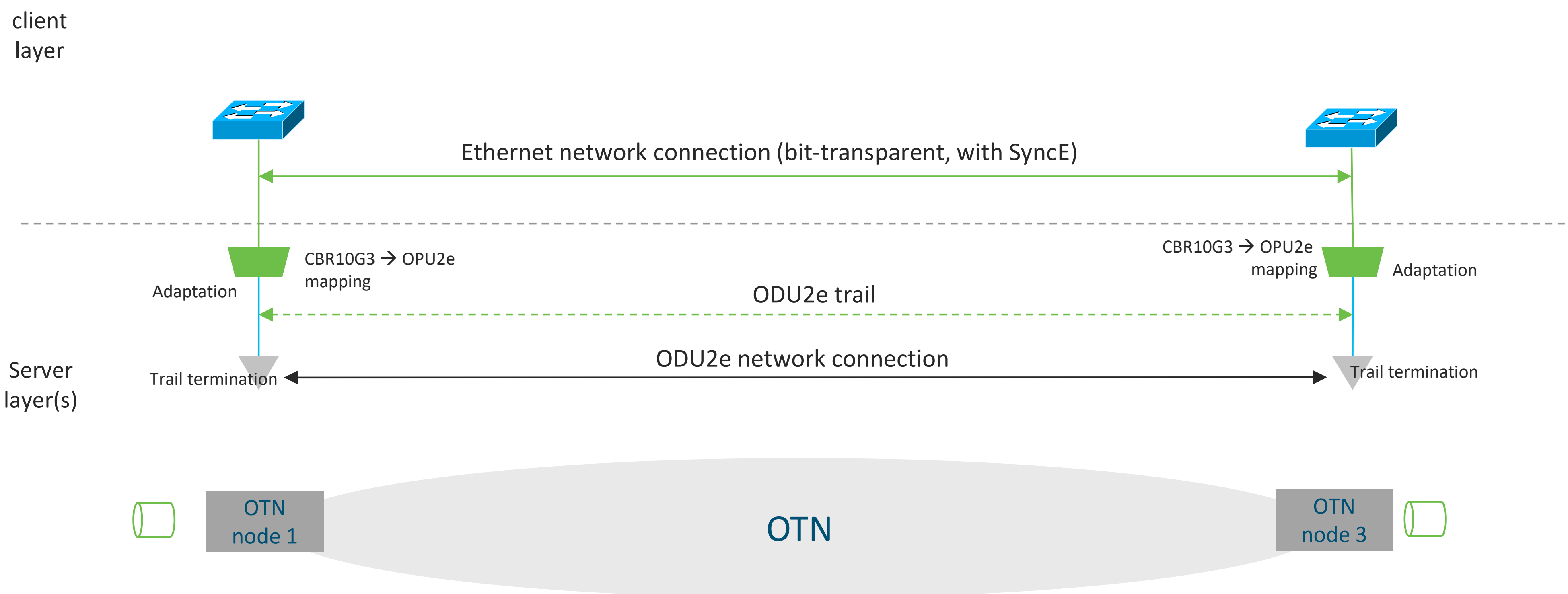
BGP PLE attribute [2)]

TLV Type	Name	Length	Mandatory
1	PW Type TLV	3	Y
2	PLE/CEP/TDM Bit-rate TLV	5	Y
3	PLE/CEP Options TLV	3	Y 1*
4	TDM Options TLV	13	Y 2*
5	PLE/CEP/TDM Payload Bytes TLV	3	N
6	Endpoint-ID TLV	0..80	N

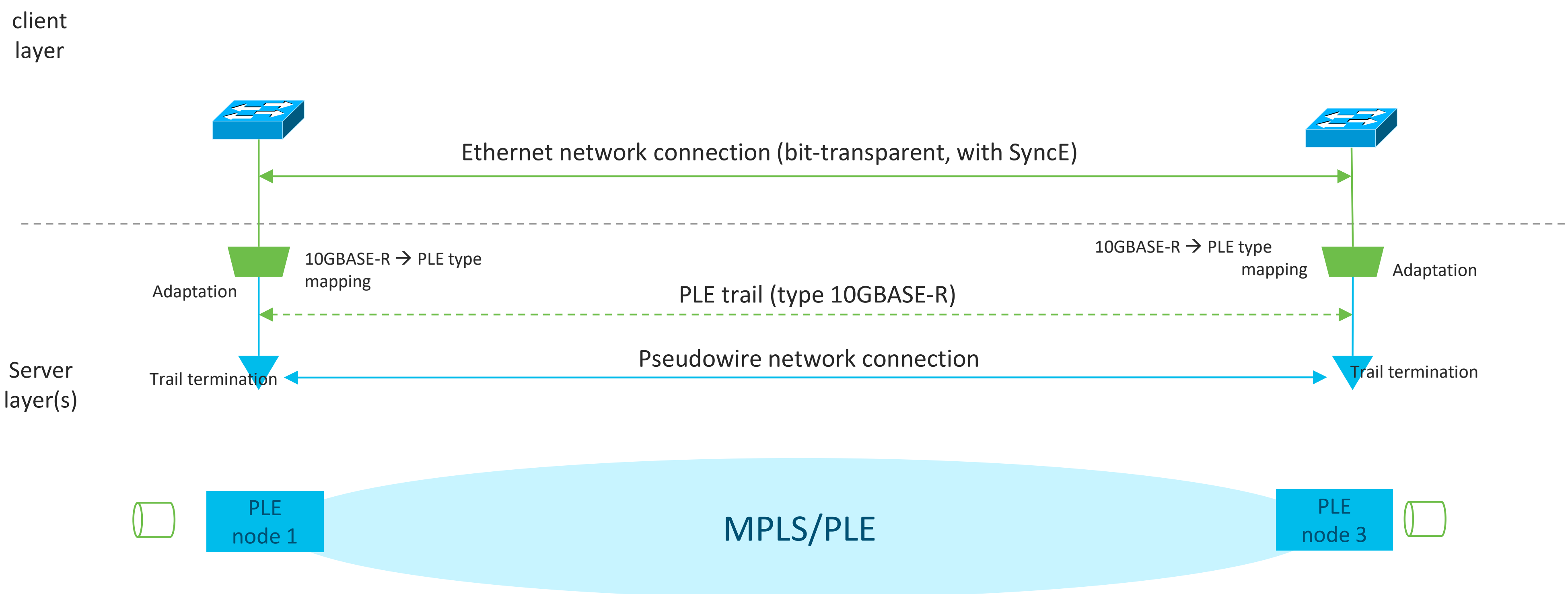
1* PLE/CEP only, 2* TDM only

https://datatracker.ietf.org/doc/draft-schmutzer-pals-ple
https://datatracker.ietf.org/doc/html/draft-schmutzer-bess-ple-vpws-signalling

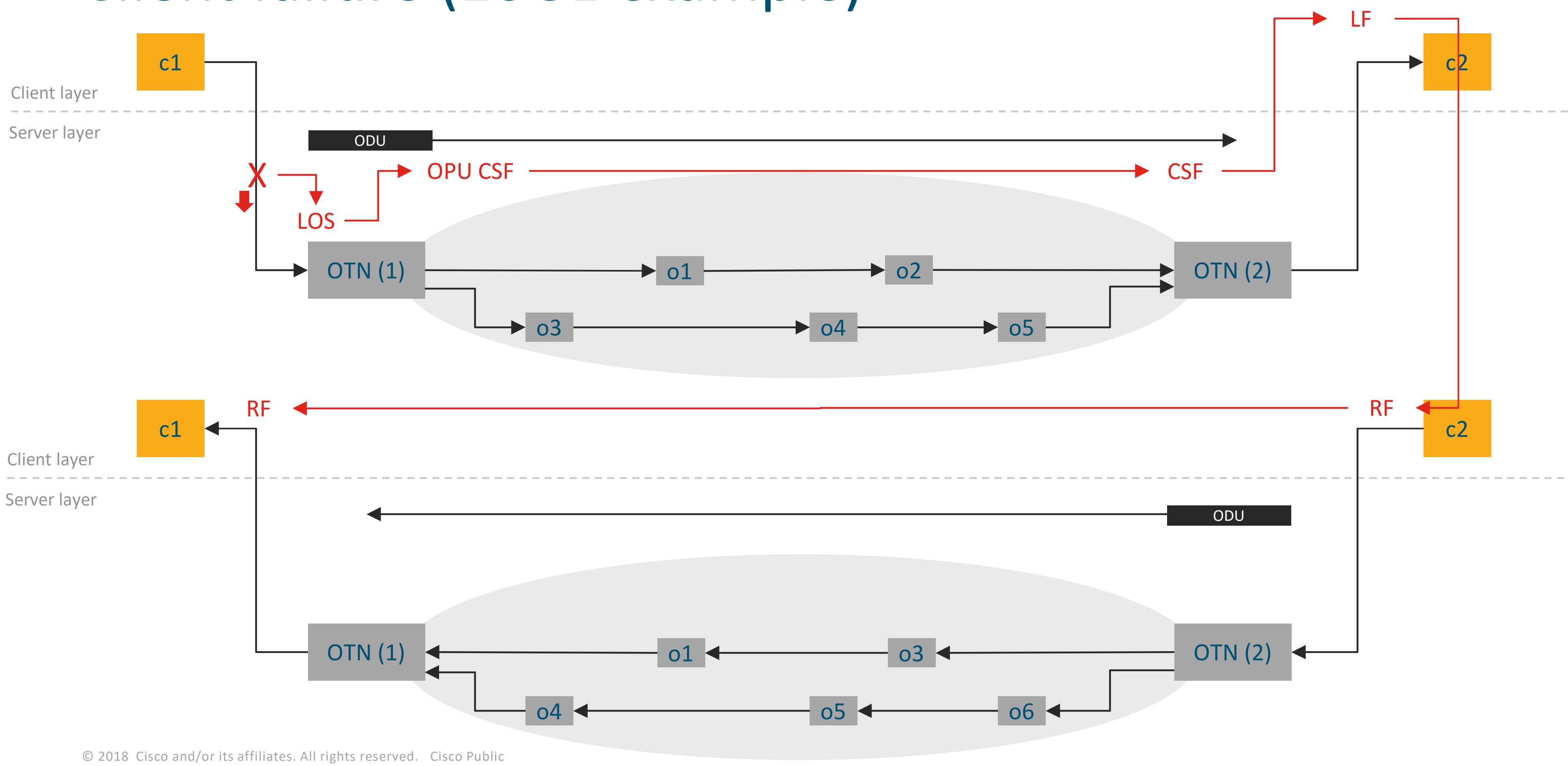
Current mode of operation = OTN



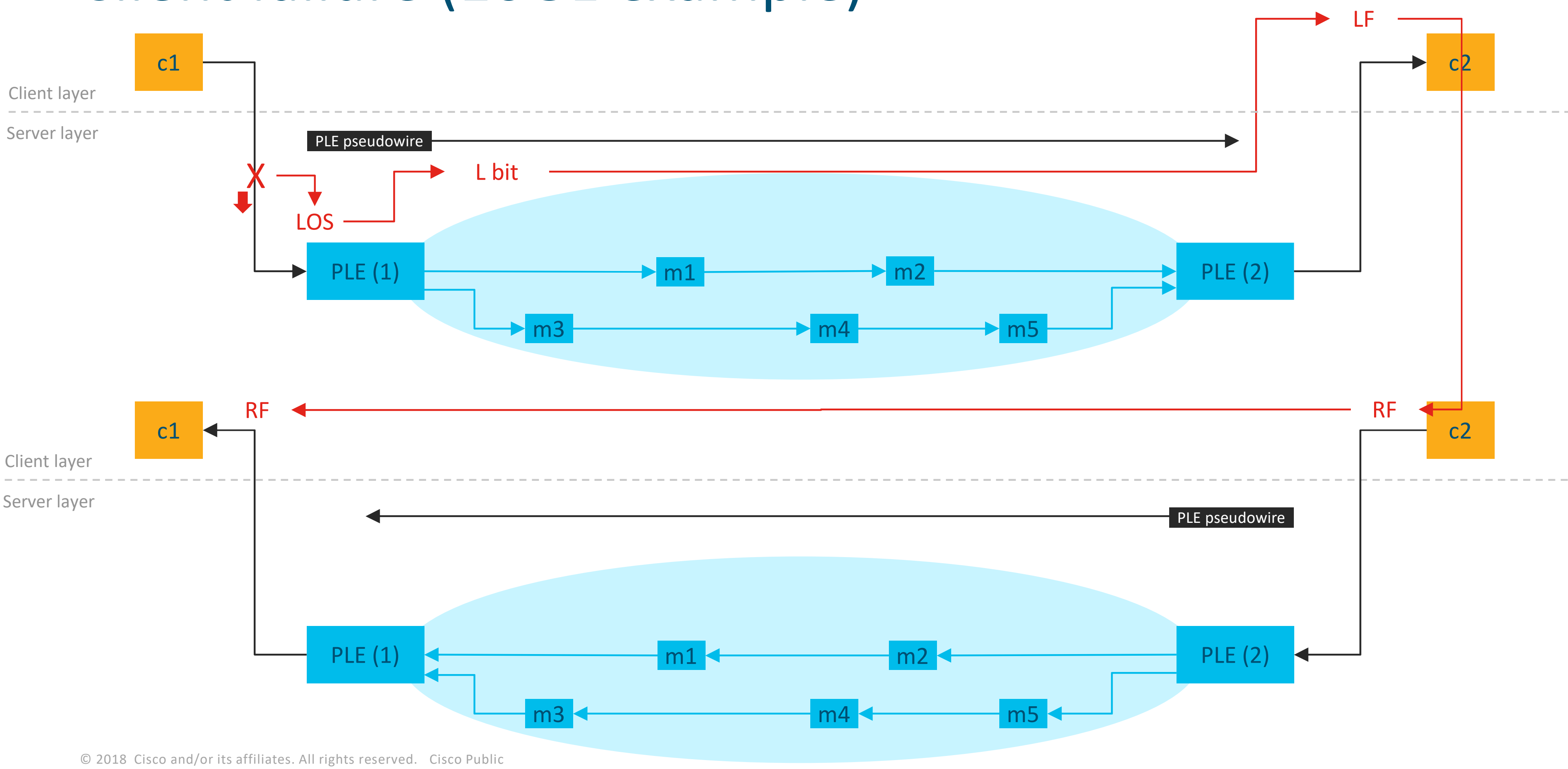
Future mode of operation = PLE



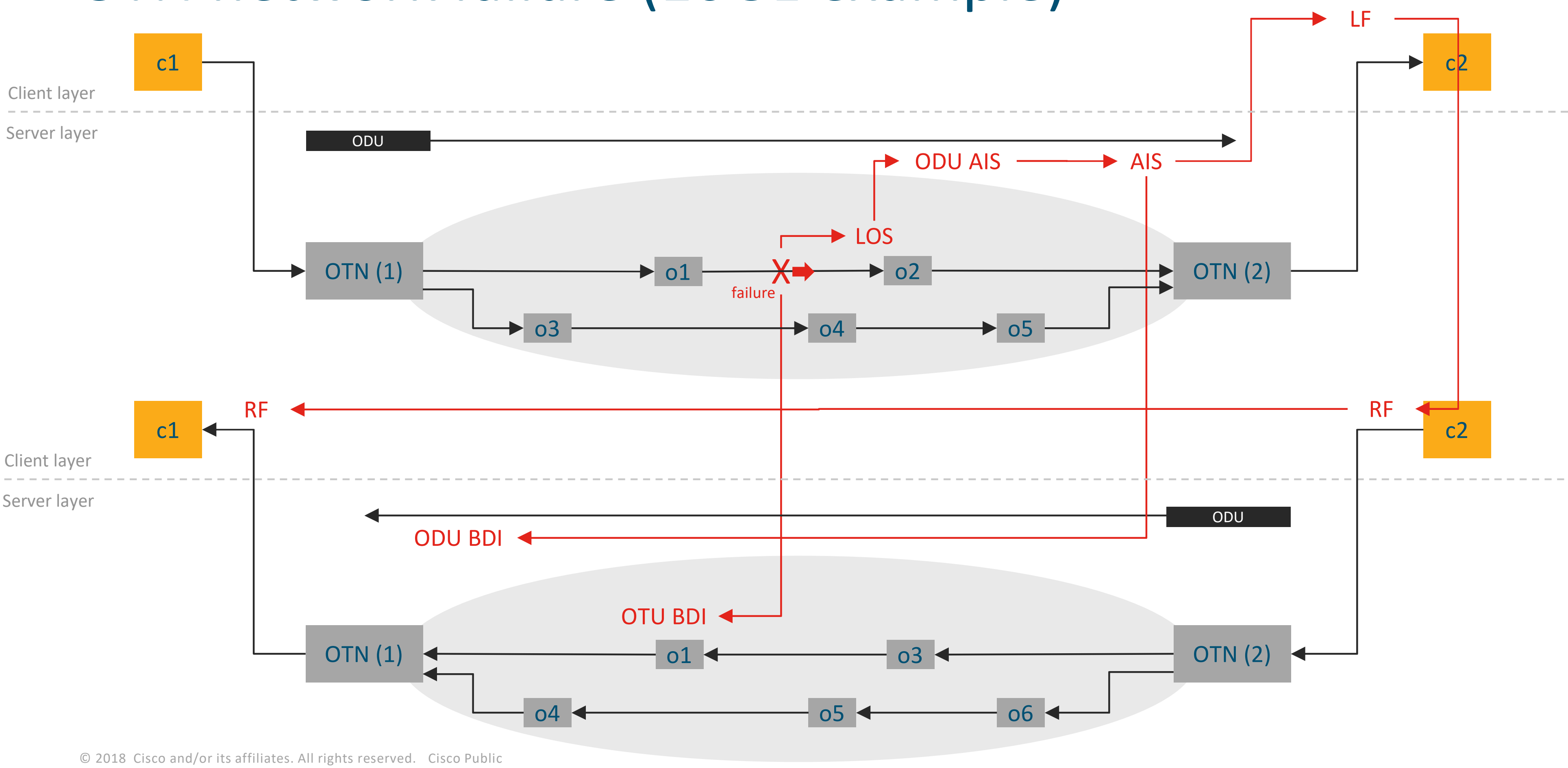
Client failure (10GE example)



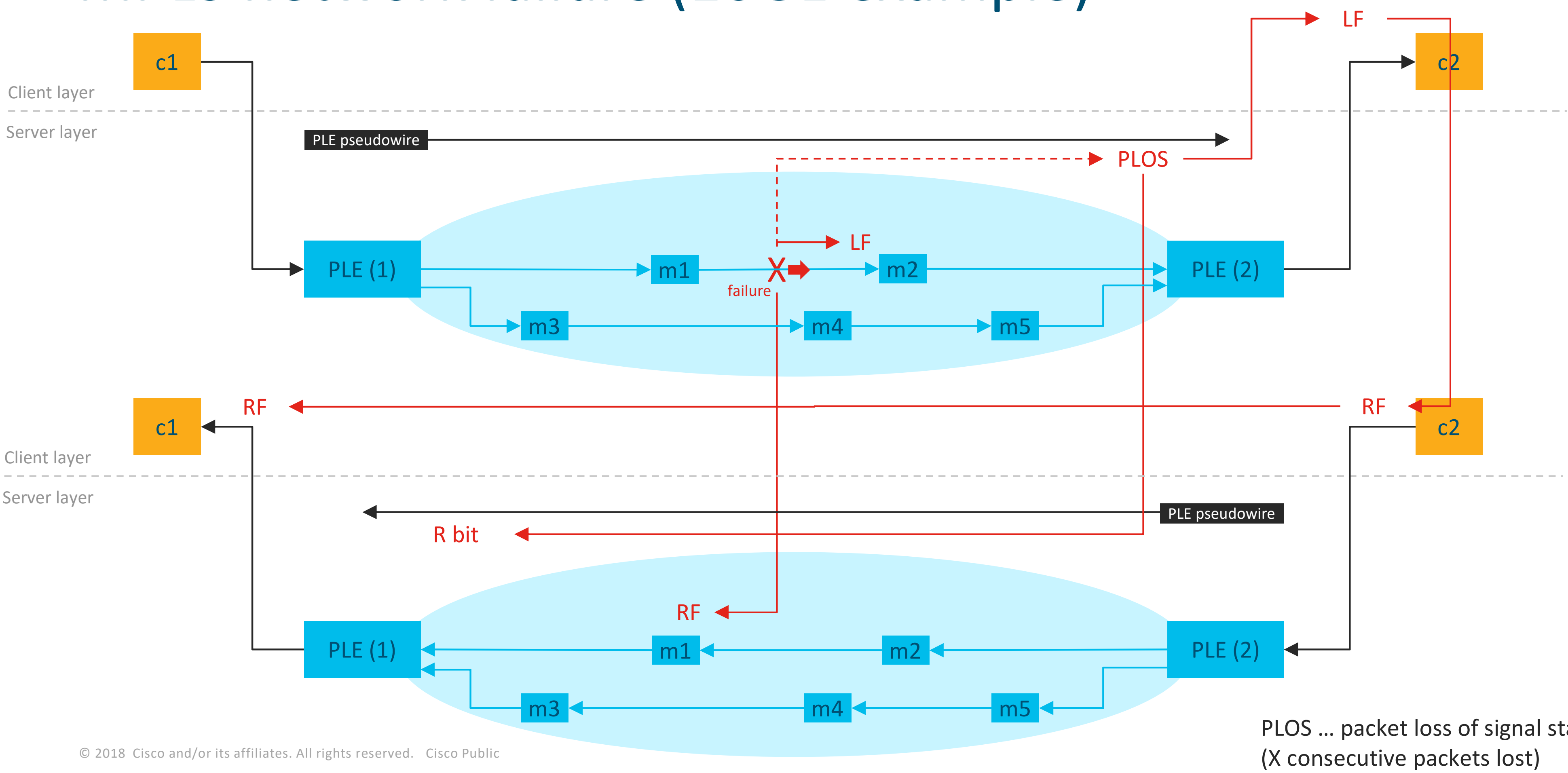
Client failure (10GE example)



OTN network failure (10GE example)



MPLS network failure (10GE example)



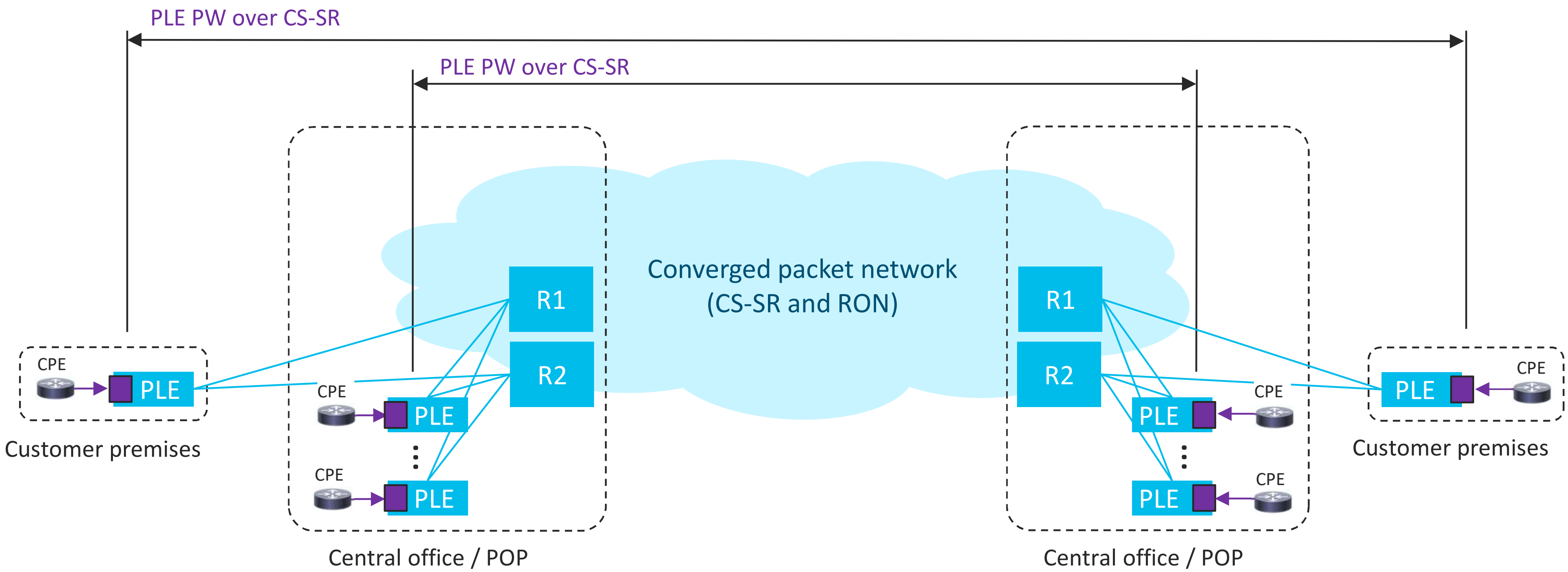
PLOS … packet loss of signal state
(X consecutive packets lost)

Private Line Emulation (PLE)

Topology Considerations

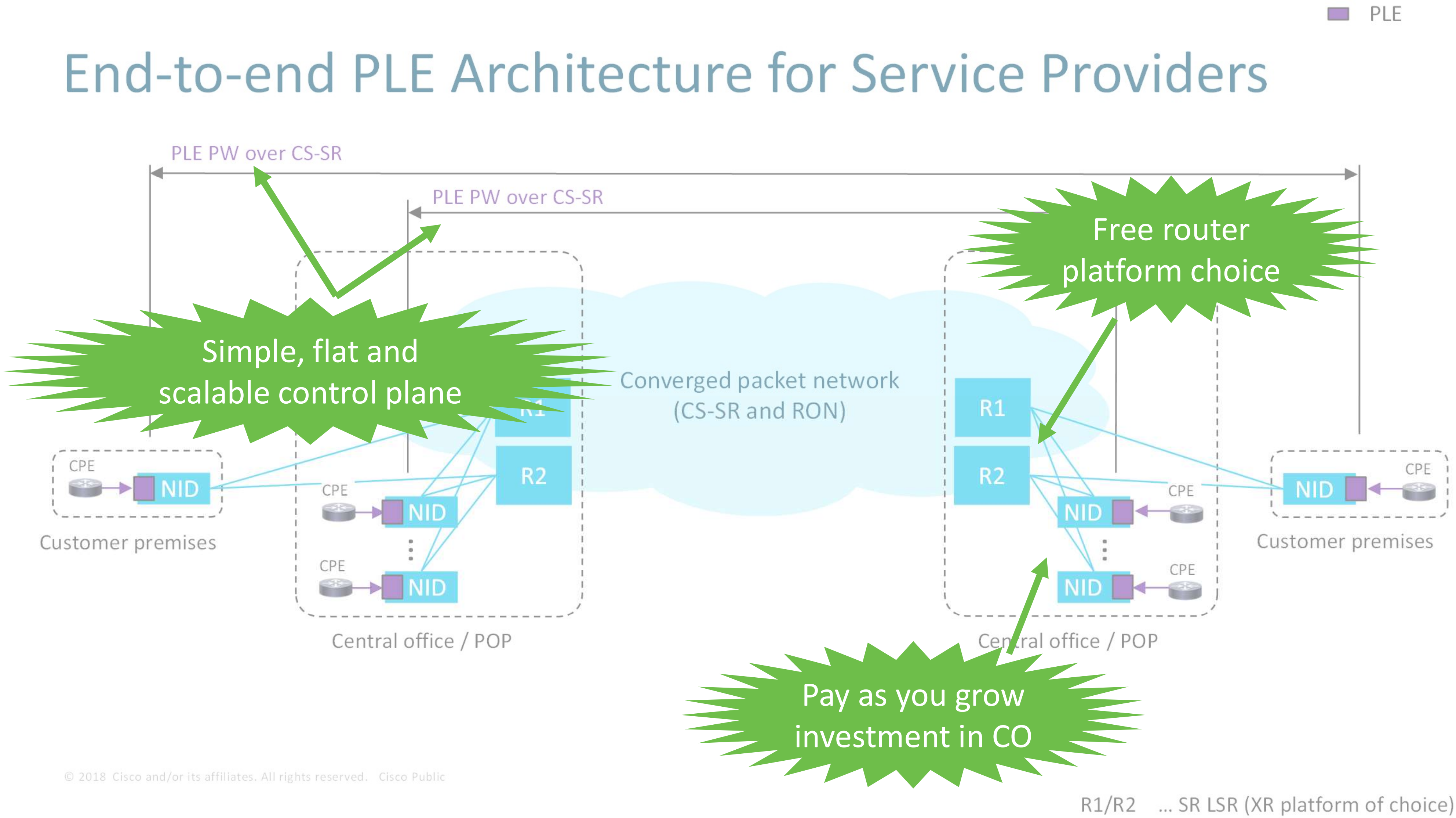
PLE port

End-to-end PLE Architecture for Service Providers

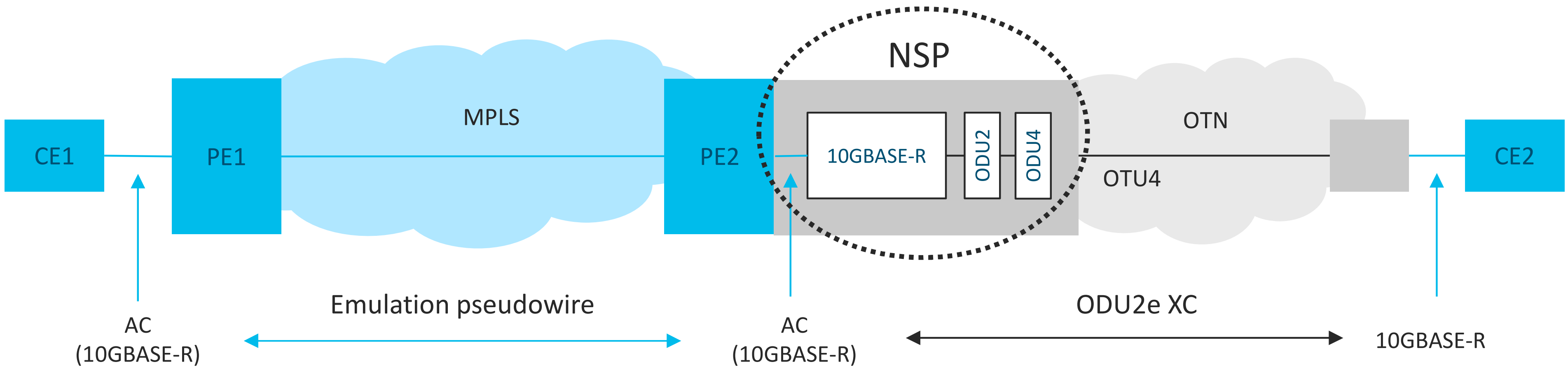


R1/R2 ... SR LSR (XR platform of choice)

End-to-end PLE Architecture for Service Providers



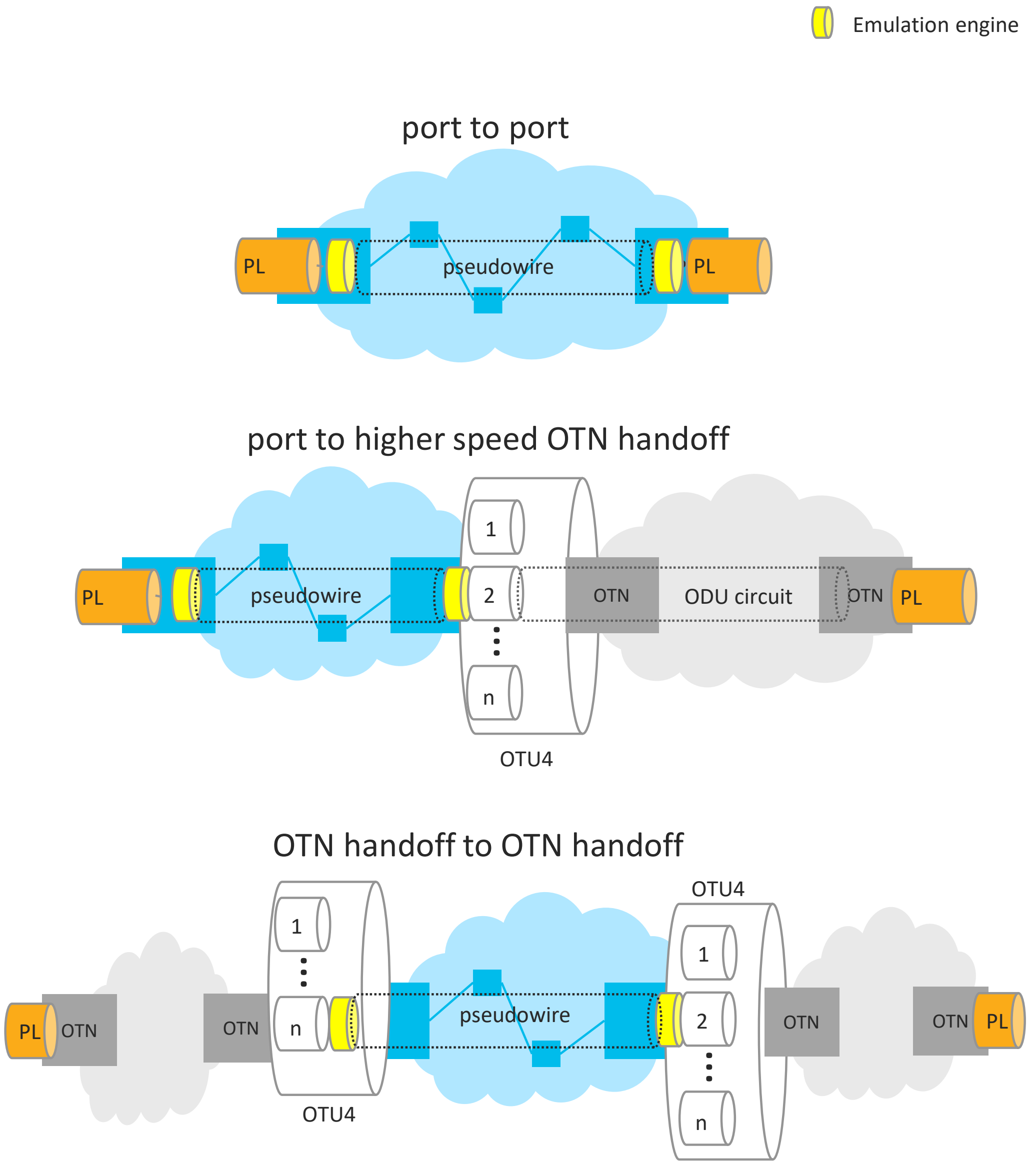
Emulation is independent of the physical Interface



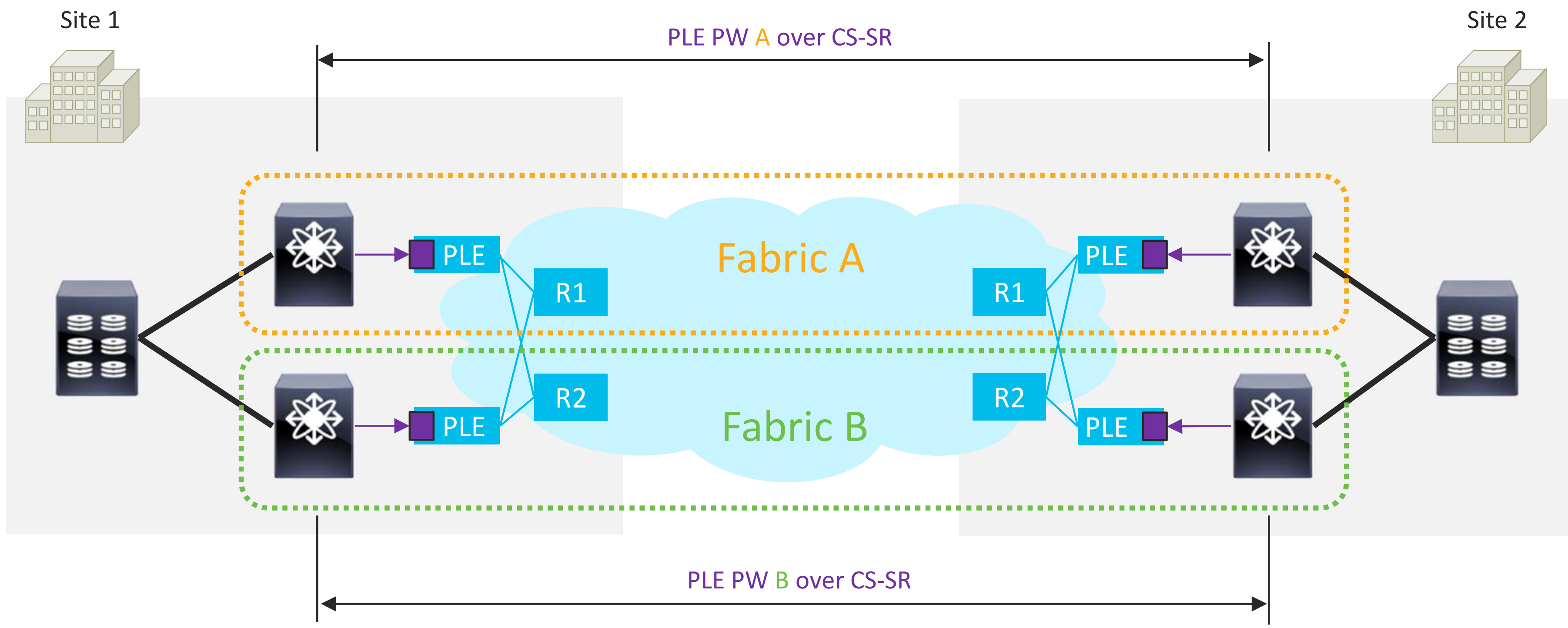
- Similar to SAToP (RFC 4553) the structure agnostic attachment circuit is independent from the physical port type
- It can either be a physical ethernet port or ODU2e mapped “logical” 10GE port inside a 100Gbps OTU4 interface extracted by the native service processing (NSP) function

PLE use cases

- Both endpoints in the PLE domain
  - simple client to client PLE PWs
  - port based
- One endpoint in an OTN domain
  - Channnelized OTN interface
  - OTN / PLE gateway (interworking) function
  - ODU termination and native PLE transport
- Both endpoints in OTN domains
  - Channnelized OTN interface
  - Transparent ODU transport



Applying PLE to Storage Area Networks

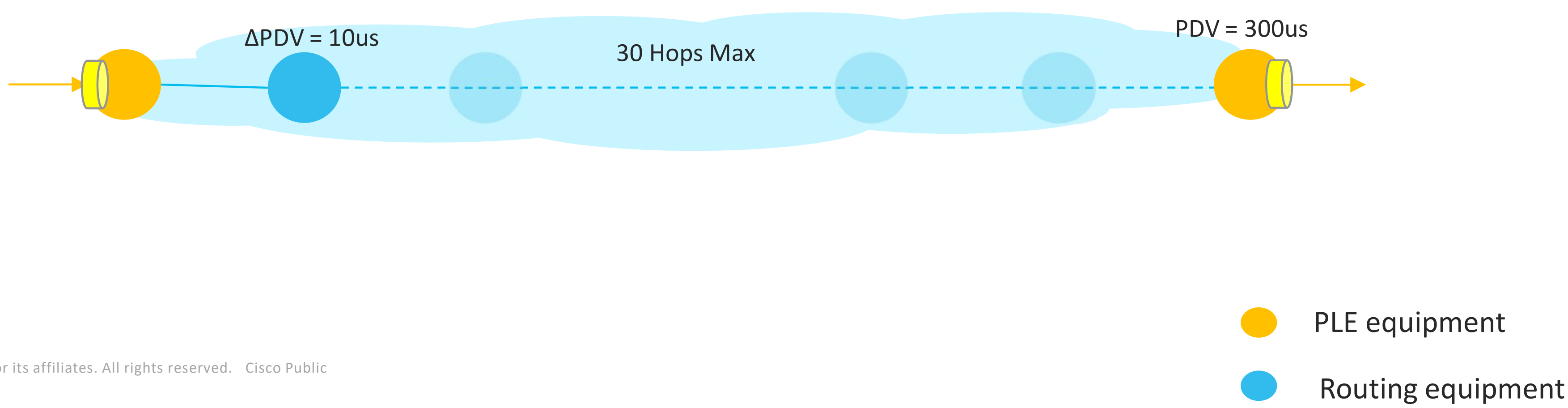


Private Line Emulation (PLE)

Packet Transport Requirements

Managing packet delay variation (PDV)

- Single node jitter expected below 10us for unsubscribed priority queue
- A de-jitter buffer 800us allows for a network diameter of up to 30 hops (+/-300us)
- Operating a single de-jitter buffer to perform far-end skew compensation does lead to optimized end2end path latency

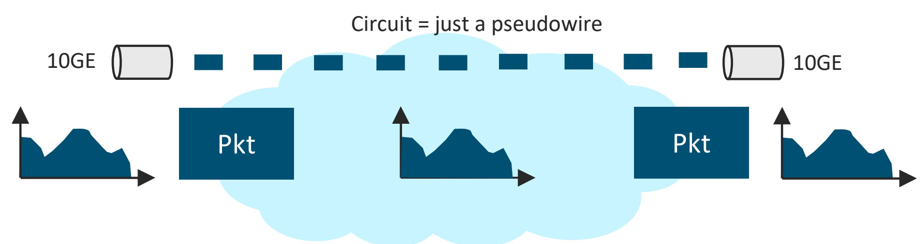


Achieving low PDV

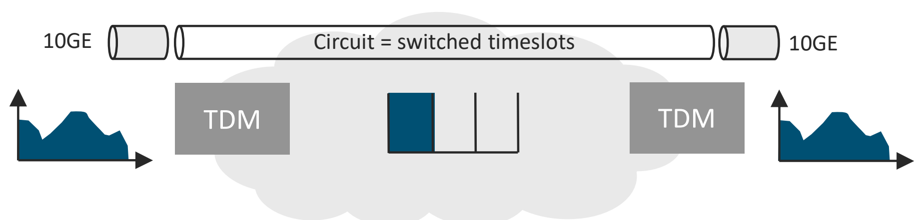
- Packet networks are no longer ”slow” or introduce high latency thanks to hardware-based packet forwarding
- The only reason for increased latency can be congestion (packets have to be stored in a buffer until a link is ready to send them)
- Implementing strict bandwidth accounting (RSVP-TE or central PCE) allows to design a packet network with a utilization <100% on every link which avoids packets being buffered
- Implementing QoS with PLE traffic mapped to a strict priority queue to cover temporary congestion scenarios
- This ensures overall transfer delay of a packet node to be in ~10 usec range (similar to or even less than OTN switches!)

Emulation driving need for bandwidth commitment

- Native packet transport
  - Bandwidth only consumed when customer is sending data
  - Allows for multiple traffic classes and forwarding behaviors

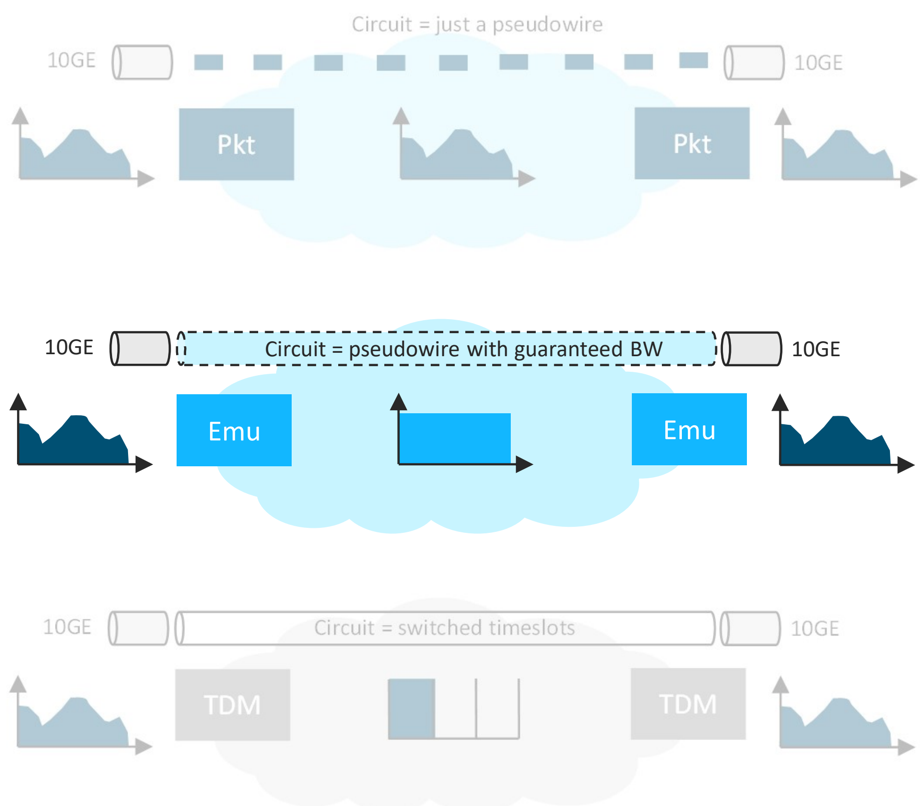


- TDM transport
  - Static timeslot allocation



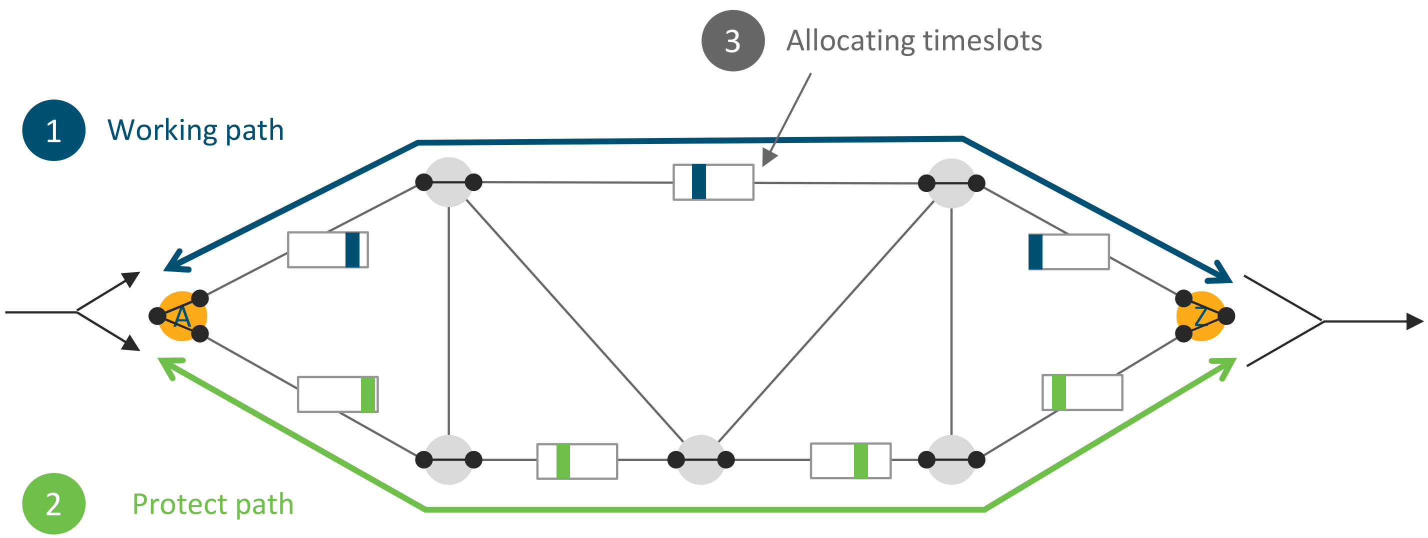
Emulation driving need for bandwidth commitment

- Native packet transport
  - Bandwidth only consumed when customer is sending data
  - Allows for multiple traffic classes and forwarding behaviors
- Emulation
  - Bit transparency
  - Constant network load
- TDM transport
  - Static timeslot allocation

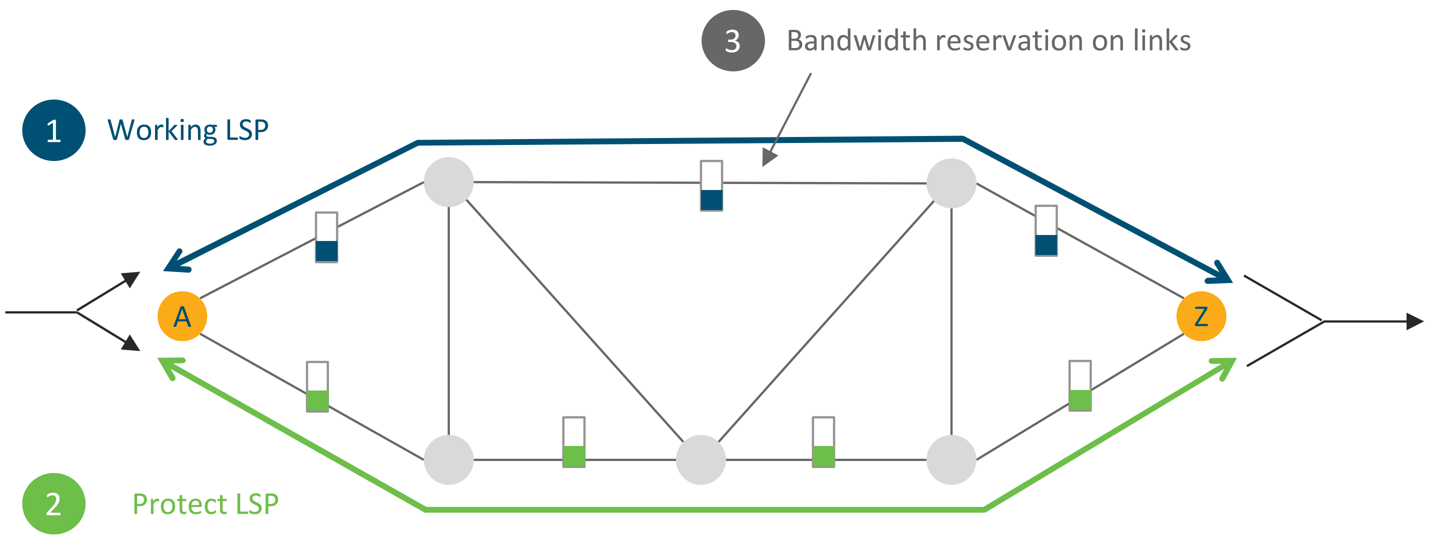


Circuit-Style Segment Routing (CS-SR)

TDM = Timeslots & series of cross connects

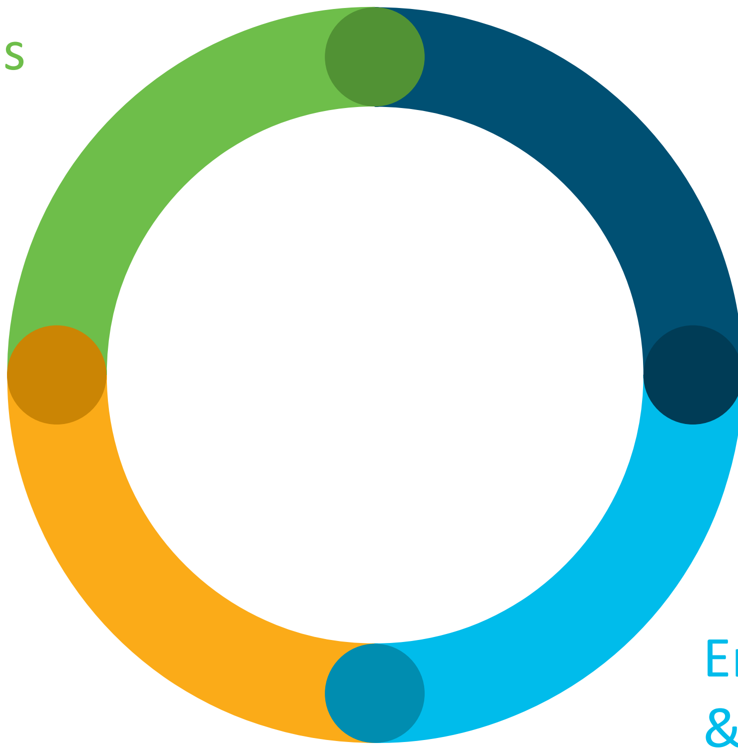


Path protected, co-routed, bi-directional LSPs



Circuit-Style Segment Routing (CS-SR)

Traffic engineered paths
- bidirectional
- co-routed
- persistent

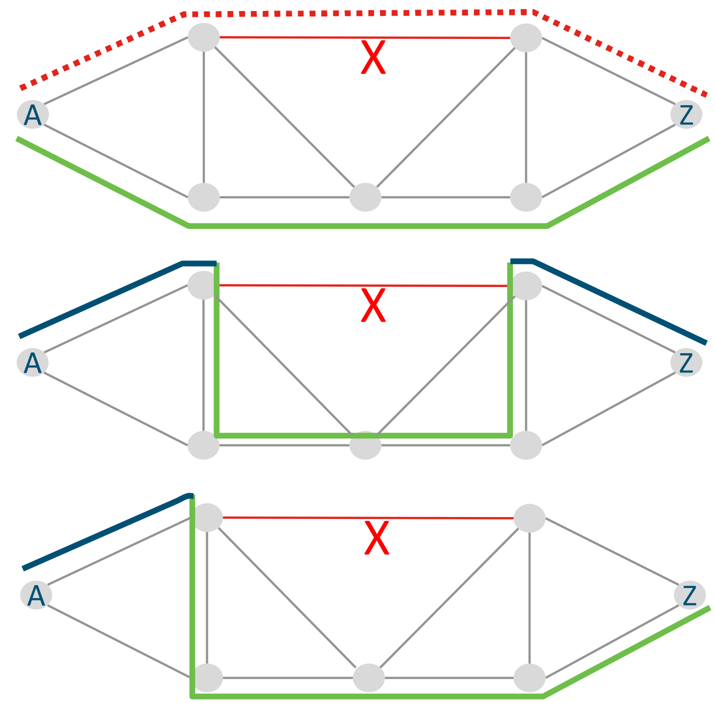


Strict bandwidth commitment

Path OAM

End-to-end path protection & restoration

Why do Protection Schemes matter?



Path Protection

pre-allocated bandwidth end2end

MPLS-TE FRR

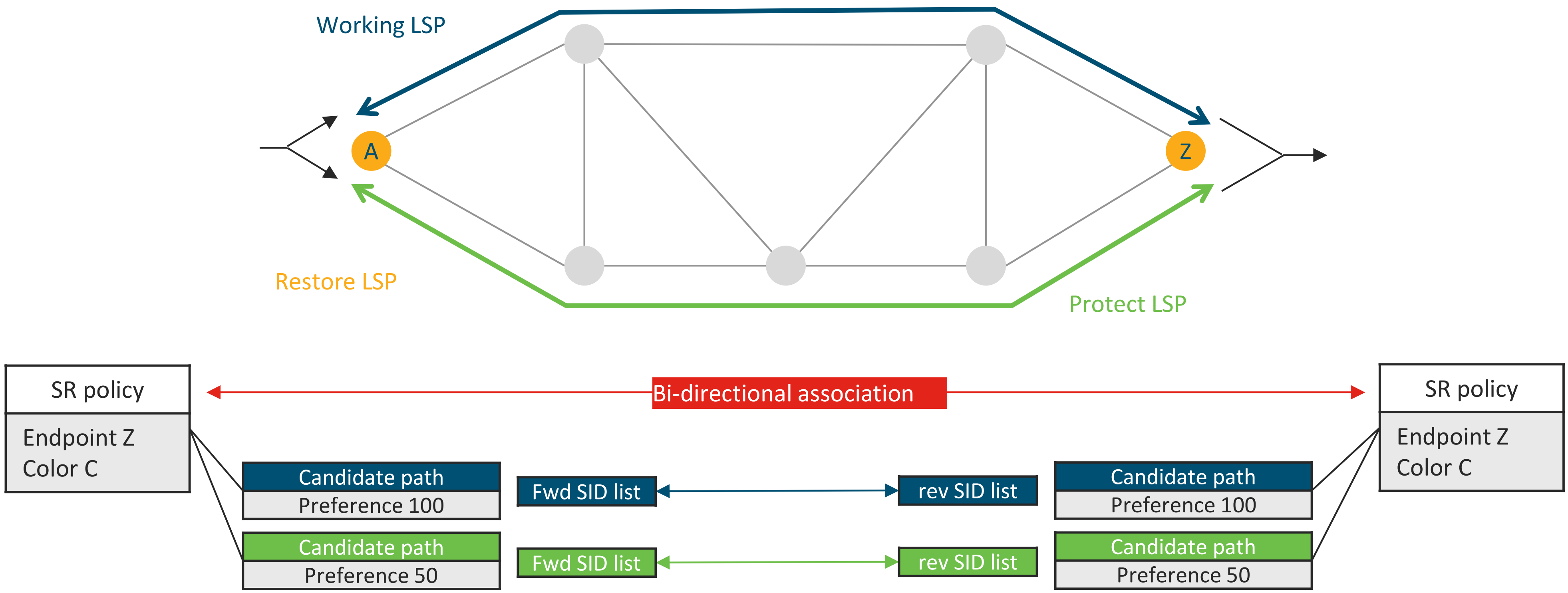
Local bypass protection, without bandwidth allocated

Loop Free Alternate (LFA)

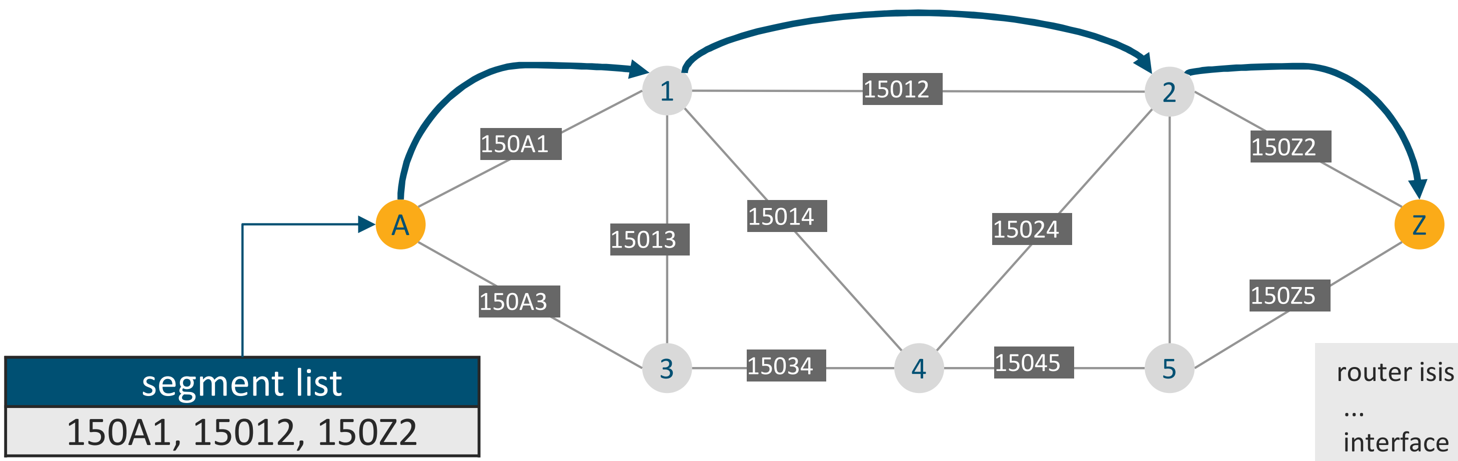
Post convergence path, without bandwidth allocated

Each scheme does require different capacity planning strategy !

Path protected, co-routed, bi-directional SR Policy



Deterministic and persistent SR Paths

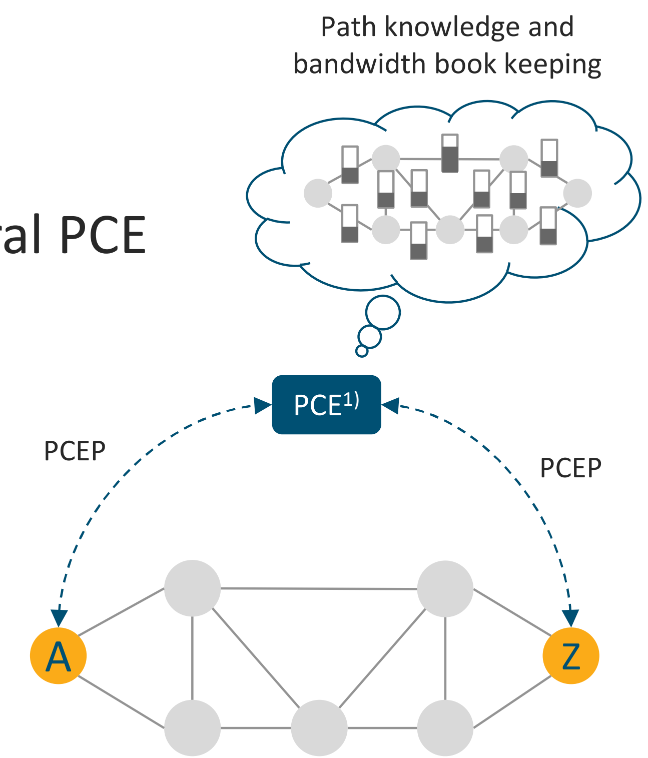



```
router isis core
 ...
 interface HundredGigE0/0/2/0
  ...
  address-family ipv4 unicast
  ...
   adjacency-sid absolute 15012
```

- Strict list of adjacency SIDs → no ECMP
- Manual adjacency SIDs → persistent across node reloads
- Unprotected adjacency SIDs → no traffic rerouting due to TI-LFA

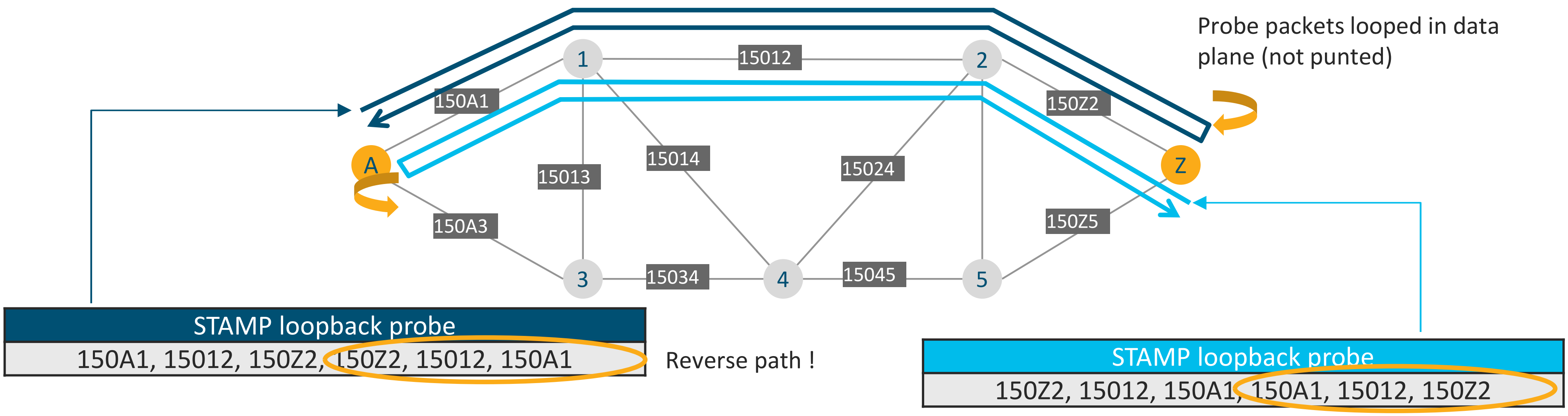
PCC-initated CS-SR policy creation

- A SR policy is configured on both endpoints
- Each endpoint requests a path via PCEP from a central PCE
  - Common bi-directional association
  - Required bandwidth
  - Path constraints
- The central PCE maintains a real time view of
  - The network topology (BGP-LS)
  - All path/bandwidth requests (PCEP)



1) Cisco Crosswork Optimization Engine (COE)

Candidate Path Connectivity Verification (Liveness)

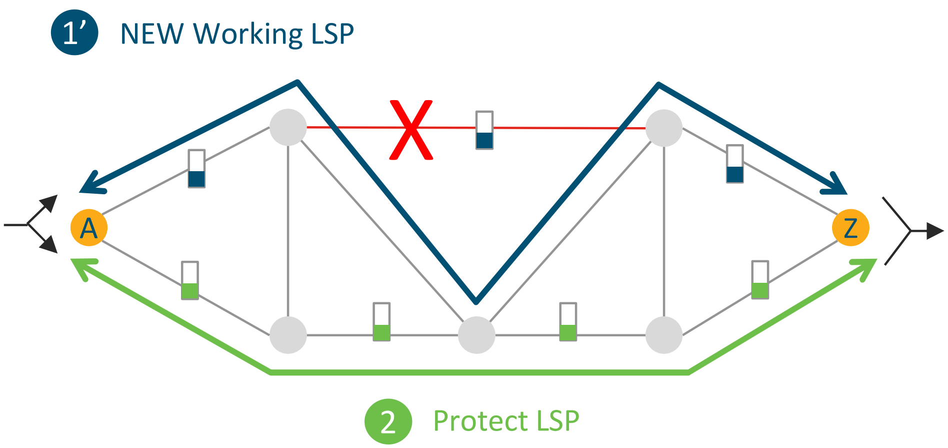


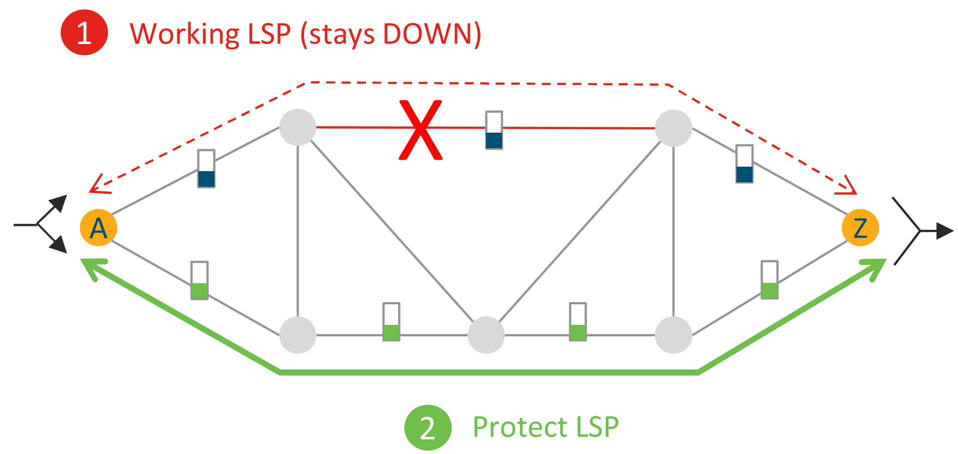
- Simple TWAMP enabling liveness and performance measurement (loss and delay)
- Candidate path is up as soon as single probe packet was received
- Candidate path is declared down when N consecutive probe packets are lost
- Due to loopback mode, also unidirectional failures are detected by both endpoints

Persistency

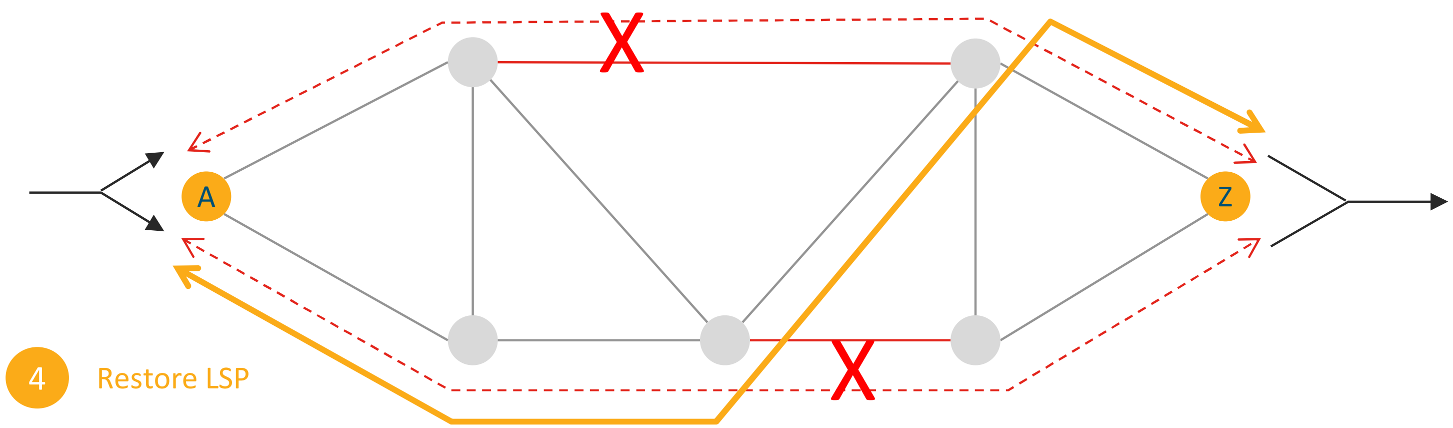
Classic TE behavior

Transport expectation

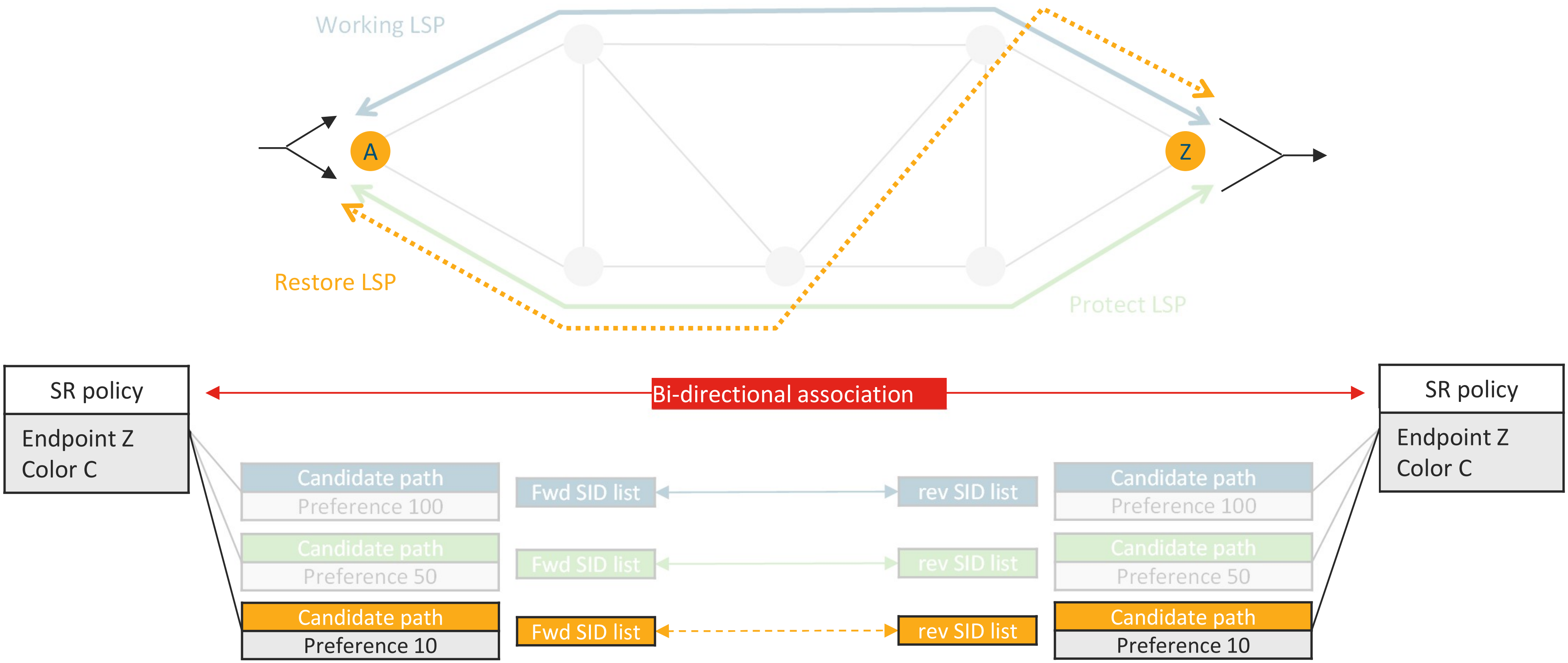




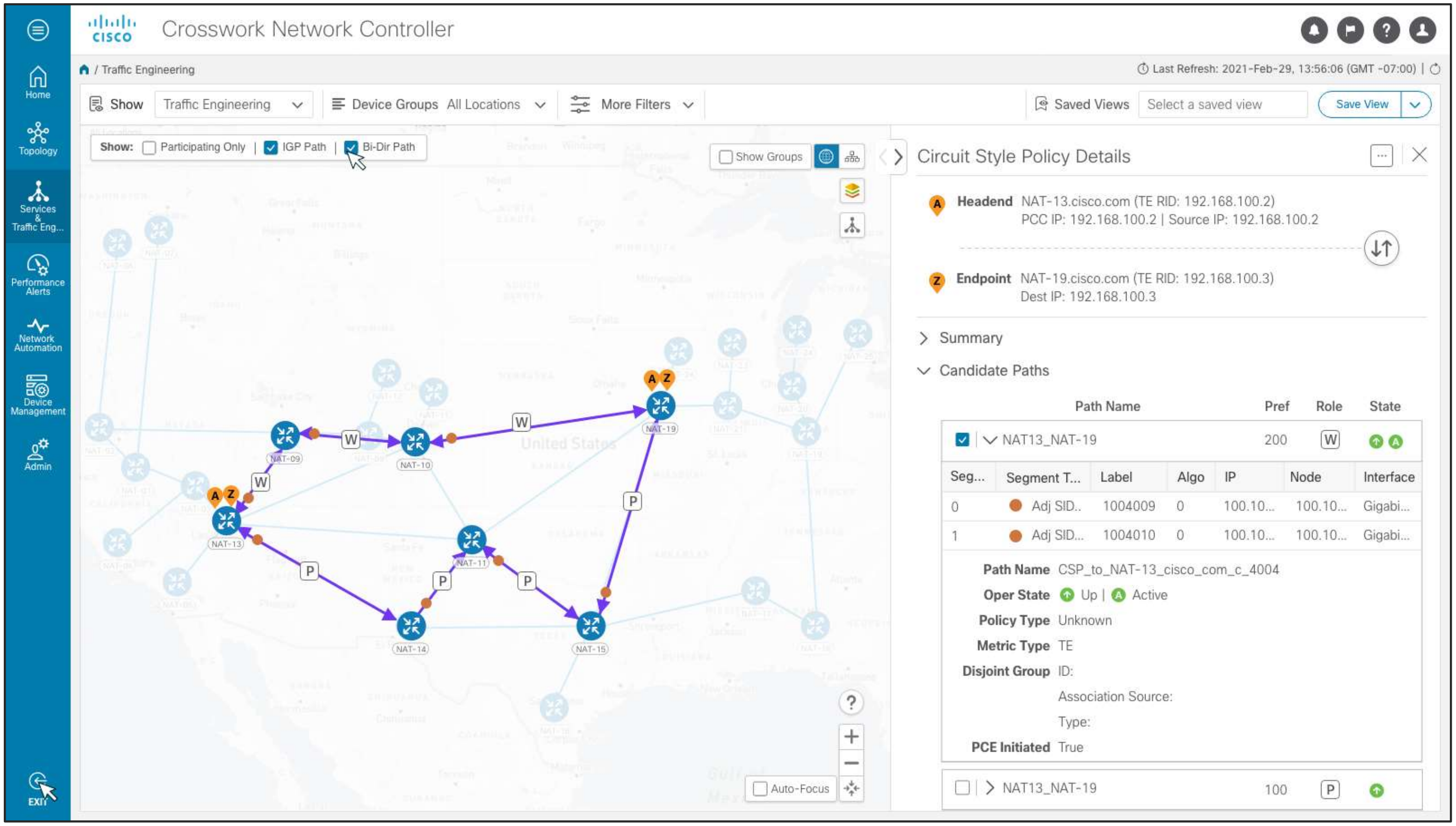
Restoration to handle double-failures



Path protected, co-routed, bi-directional SR policy



Path Visualization and Maintenance via Cisco COE



Key Take Aways

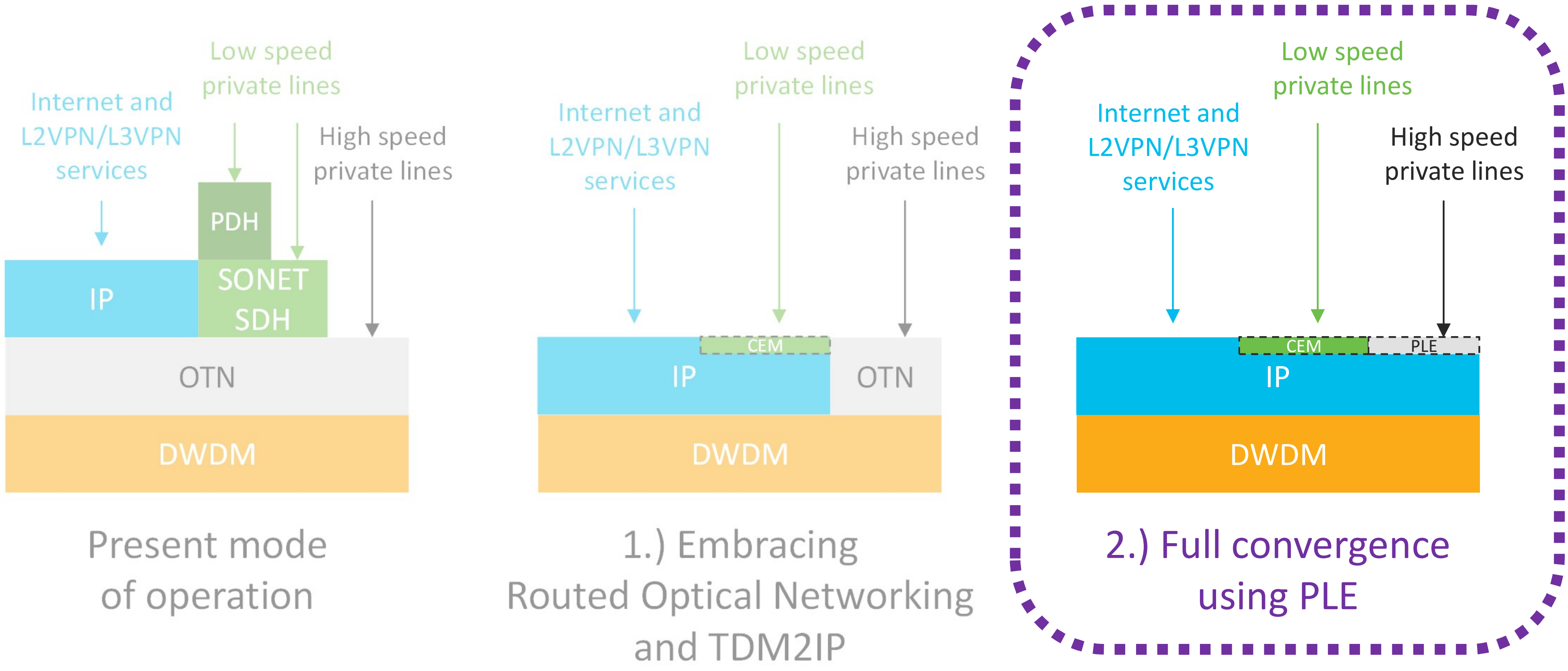
Putting it all together

	Private line	"Dedicated" E-line	Switched E-line
Service overlay	**PLE** • Bit transparent • Multi-protocol (TDM, FibreChannel)	**EVPN-VPWS** • Ethernet only • No special hardware required	
Underlay transport	**Circuit-style SR (CS-SR)** • bi-directional path with bandwidth guarantees • End-to-end path protection and restoration		**SR** • Scale & simplicity
	connection-oriented		connection-less

Both PLE and CS-SR are “open”

- PLE data plane
  - https://datatracker.ietf.org/doc/html/draft-schmutzer-pals-ple
  - 4th revision introduced how to carry 200GE and 400GE
- Circuit-style SR policies
  - Two drafts
    - https://datatracker.ietf.org/doc/html/draft-schmutzer-spring-cs-sr-policy
    - https://datatracker.ietf.org/doc/html/draft-sidor-pce-circuit-style-pcep-extensions
  - Presentation of both drafts at IETF113 and IETF114 triggered great interest and lead to support from multiple vendors and customers

Converging all Services onto a single IP Infrastructure



For more Information

- Please visit our Routed Optical Networking page
  - https://www.cisco.com/c/en/us/solutions/service-provider/routed-optical-networking/index.html
- You will find
  - The PLE solution brief
  - The PLE MPA datasheet
  - A PLE introduction video
- … and a lot more!

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