TOMORROW starts here.

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Deploying MPLS Traffic Engineering

BRKMPL-2100

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Agenda

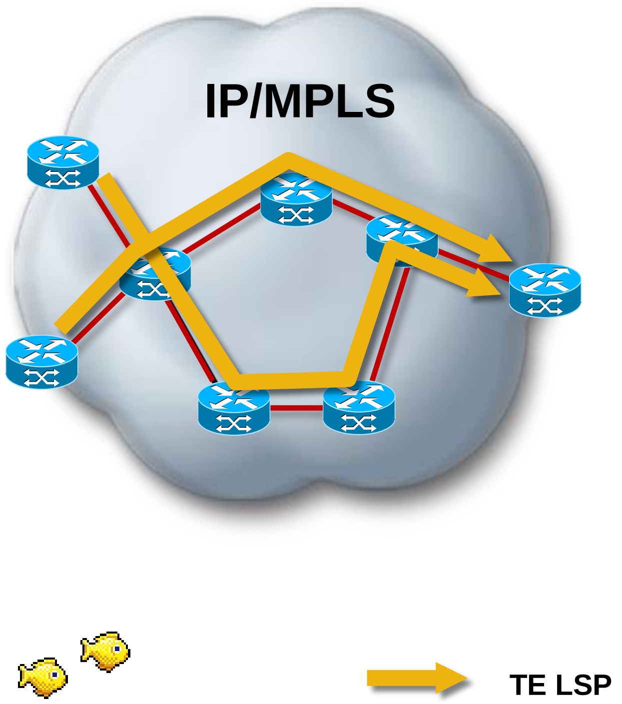
- Technology Overview
- TE and QoS
- Traffic Protection
- Bandwidth optimization
- Centralized Tunnel Creation and Control
- General Deployment Considerations



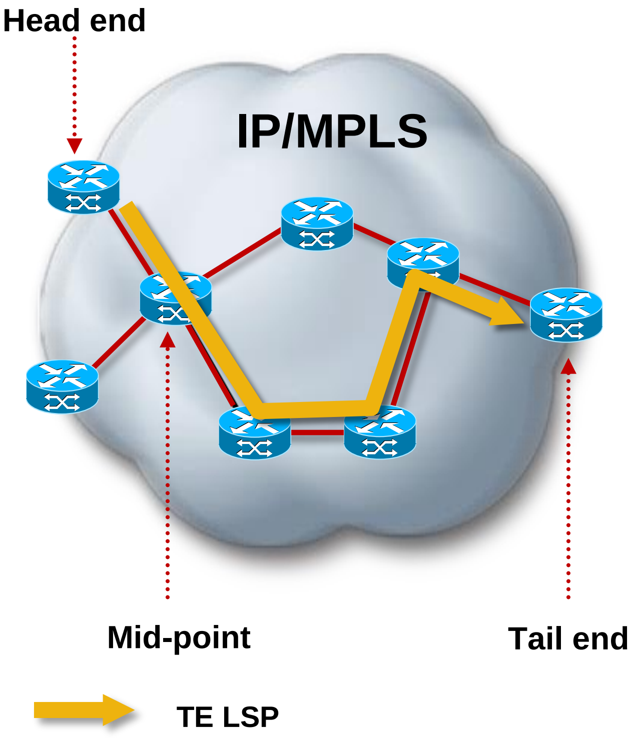

Technology Overview

MPLS TE Overview

- Introduces explicit routing
- Supports constraint-based routing
- Supports admission control
- Provides protection capabilities
- Uses RSVP-TE to establish LSPs
- Uses ISIS / OSPF extensions to advertise link attributes



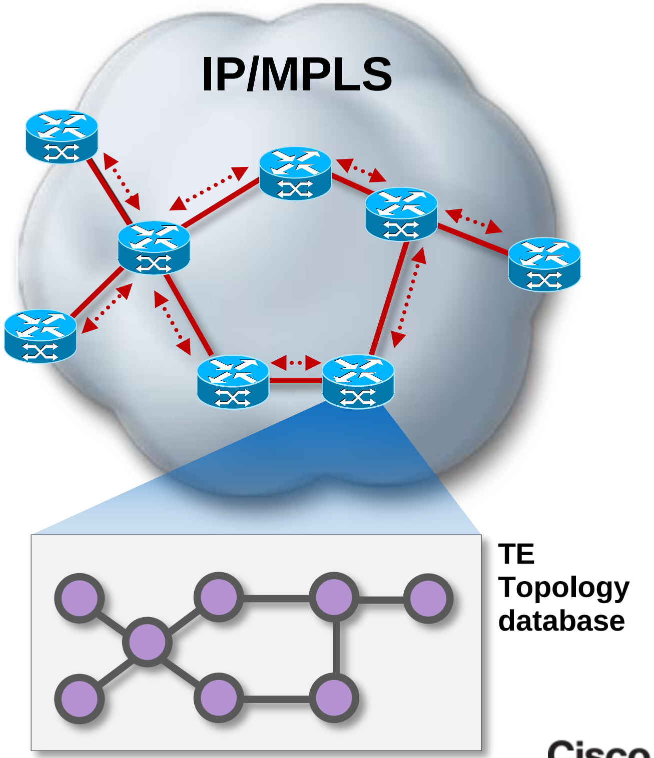
How MPLS TE Works



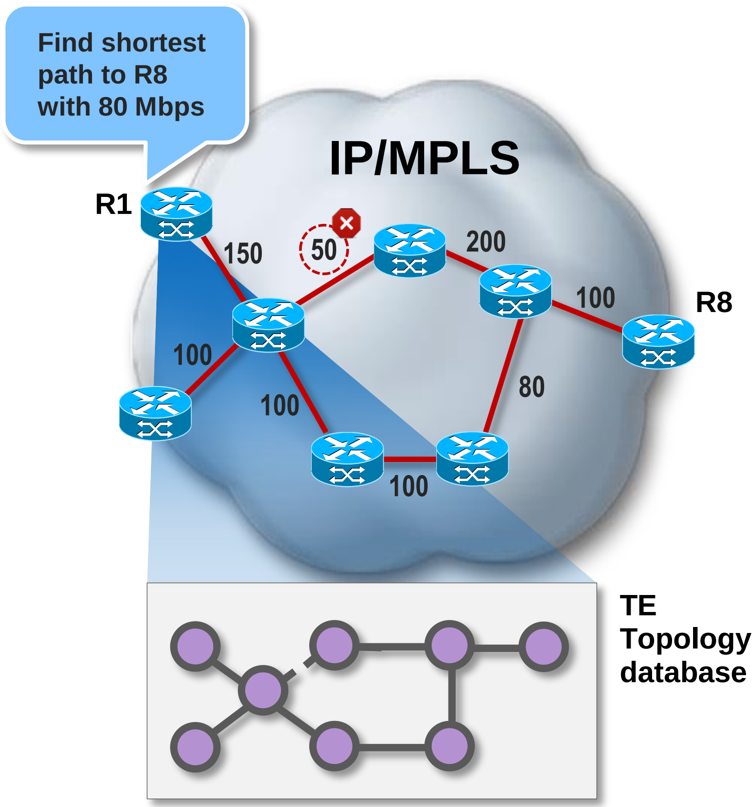
- Link information Distribution*
  - ISIS-TE
  - OSPF-TE
- Path Calculation (CSPF)*
- Path Setup (RSVP-TE)
- Forwarding Traffic down Tunnel
  - Auto-route (announce / destinations)
  - Static route
  - PBR
  - PBTS / CBTS
  - Forwarding Adjacency
  - Pseudowire Tunnel select

Link Information Distribution

- Additional link characteristics
  - Interface address
  - Neighbor address
  - Physical bandwidth
  - Maximum reservable bandwidth
  - Unreserved bandwidth (at eight priorities)
  - TE metric
  - Administrative group (attribute flags)
- IS-IS or OSPF flood link information
- All TE nodes build a TE topology database
- Not required if using off-line path computation



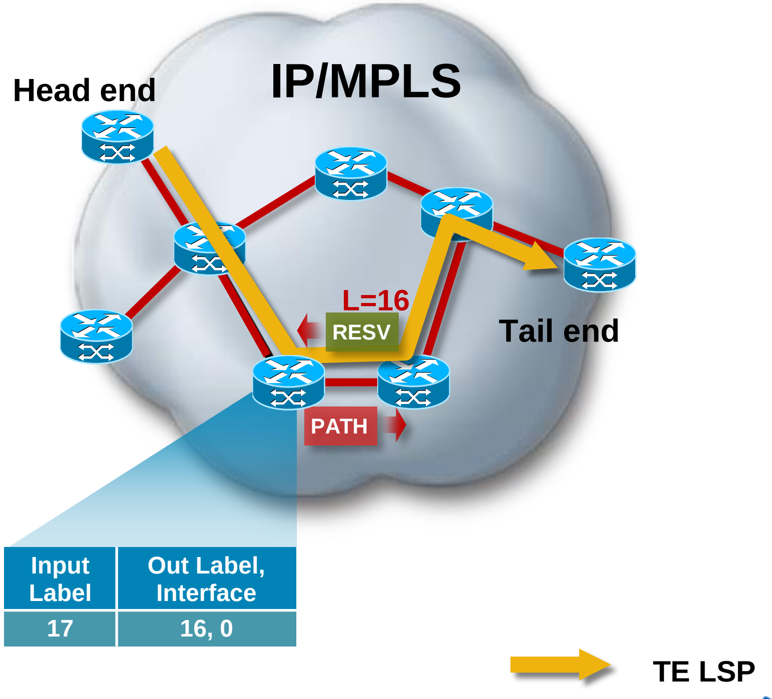
Path Calculation



- TE nodes can perform constraint-based routing
- Tunnel head end generally responsible for path calculation
- Constraints and topology database used as input to path computation
- Shortest-path-first algorithm ignores links not meeting constraints
- Tunnel can be signaled once a path is found
- Not required if using offline path computation

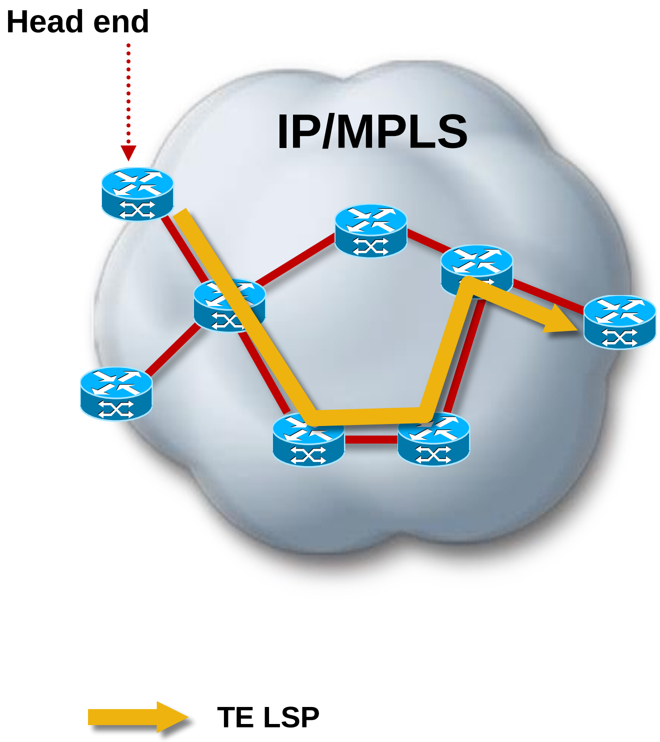
TE LSP Signaling

- Tunnel signaled with TE extensions to RSVP
- Soft state maintained with downstream PATH messages
- Soft state maintained with upstream RESV messages
- New RSVP objects
  - LABEL_REQUEST (PATH)
  - LABEL (RESV)
  - EXPLICIT_ROUTE
  - RECORD_ROUTE (PATH/RESV)
  - SESSION_ATTRIBUTE (PATH)
- LFIB populated using RSVP labels allocated by RESV messages



Input Label	Out Label, Interface
17	16, 0

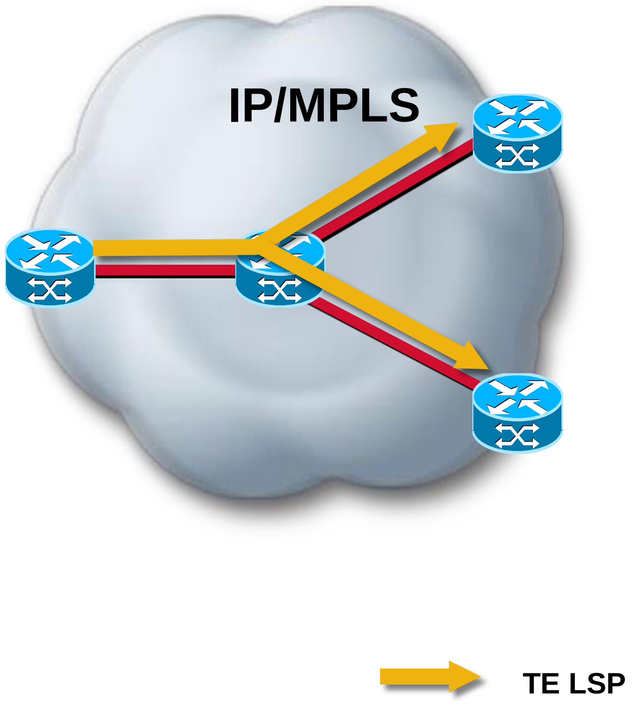
Traffic Selection



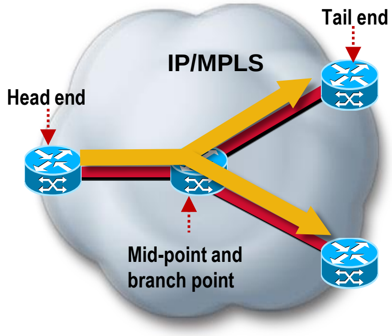
- Traffic enters tunnel at head end
- Multiple traffic selection options
  - Auto-route (announce / destination)
  - Static routes
  - Policy Based Routing
  - Forward Adjacency
  - Pseudowire Tunnel Selection
  - Policy / Class Based Tunnel Selection
- Tunnel path computation independent of routing decision injecting traffic into tunnel

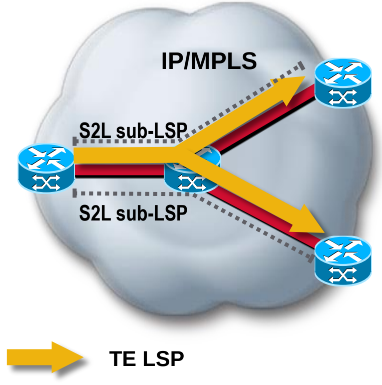
Point-to-Multipoint (P2MP)TE LSP

- Unidirectional
- Explicitly routed
- One head end, but one or more tail ends (destinations)
- Same characteristics (constraints, protection, etc.) for all destinations



P2MP TE LSP Terminology

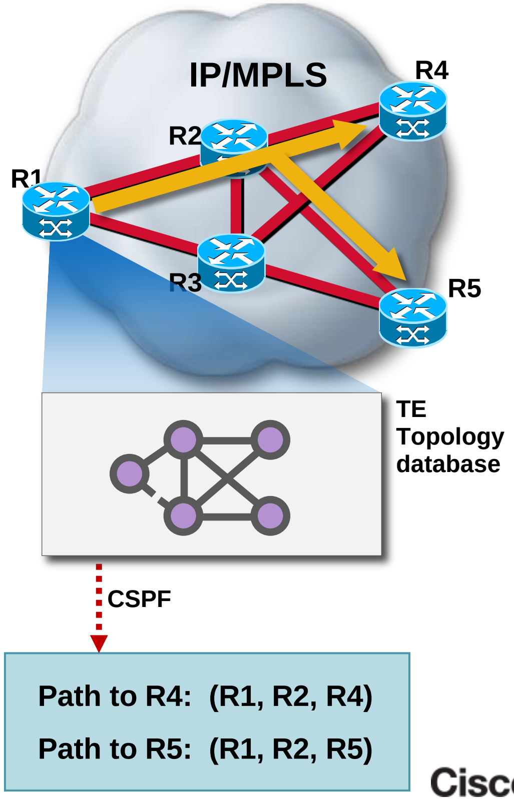




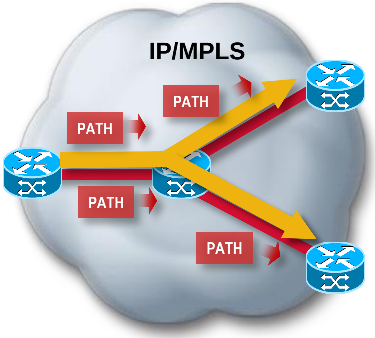
- Head-end/Source: Node where LSP signaling is initiated
- Mid-point: Transit node where LSP signaling is processed (not a head-end, not a tail-end)
- Tail-end/Leaf/destination: node where LSP signaling ends
- Branch point: Node where packet replication is performed
- Source-to-leaf (S2L) sub-LSP: P2MP TE LSP segment that runs from source to one leaf

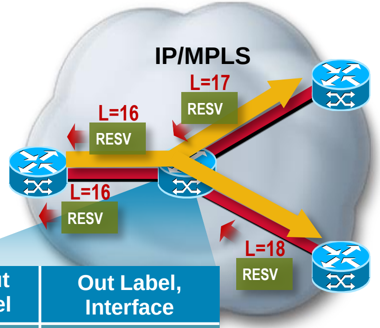
P2MP TE LSP Path Computation

- Constrained Shortest Path First (CSPF) used to compute an adequate tree
- CSPF executed per destination
- TE topology database and tunnel constraints used as input for path computation
- Path constraints may include loose, included, excluded hops
- Same constraints for all destinations (bandwidth, affinities, priorities, etc.)
- Path computation yields explicit path to each destination
- No changes to OSPF/IS-IS TE extensions
- Static paths possible with offline path computation



P2MP TE LSP Signaling





Input Label	Out Label, Interface
16	17, 0 18, 1

- Source sends unique PATH message per destination
- LFIB populated using RSVP labels allocated by RESV messages
- Multicast state built by reusing sub-LSP labels at branch points

Configuring P2MP Tunnel at Head End (Cisco IOS)

```
mpls traffic-eng destination list name P2MP-LIST-DST1
 ip 172.16.255.1 path-option 10 explicit name PATH1
 ip 172.16.255.2 path-option 10 dynamic
 ip 172.16.255.3 path-option 10 dynamic
 ip 172.16.255.4 path-option 10 dynamic
!
interface Tunnel1
 description FROM-ROUTER-TO-LIST-DST1
 ip unnumbered Loopback0
 tunnel mode mpls traffic-eng point-to-multipoint
 tunnel destination list mpls traffic-eng name P2MP-LIST-DST1
 tunnel mpls traffic-eng priority 7 7
 tunnel mpls traffic-eng bandwidth 1000
!
```

Destination list with one path-option per destination

P2MP TE Tunnel

Destination list

Signaled bandwidth and setup / hold priorities

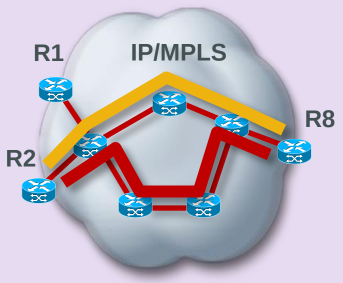
Configuring P2MP Tunnel at Head End (Cisco IOS XR)

```
interface tunnel-mte1
 ipv4 unnumbered Loopback0
 destination 172.16.255.129
  path-option 10 explicit name PATH1
  path-option 20 dynamic
 !
 destination 172.16.255.130
  path-option 10 dynamic
 !
 priority 0 0
 signalled-bandwidth 100000
!
```

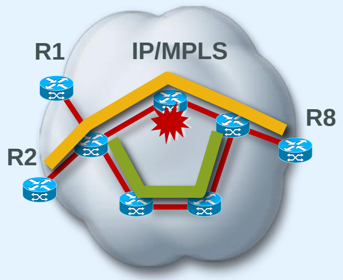
- MPLS TE P2MP tunnel
- Destination with path-option list
- Destination with single path-option
- Signaled bandwidth and setup / hold priorities

MPLS TE Use Cases

Point-to-Point SLA

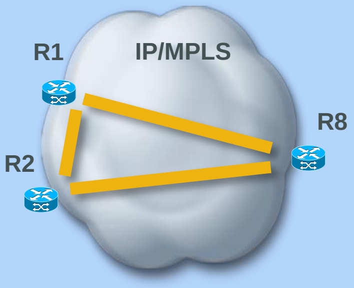


Protection

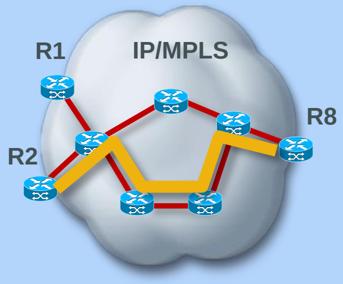


Bandwidth Optimization

Strategic / Planned

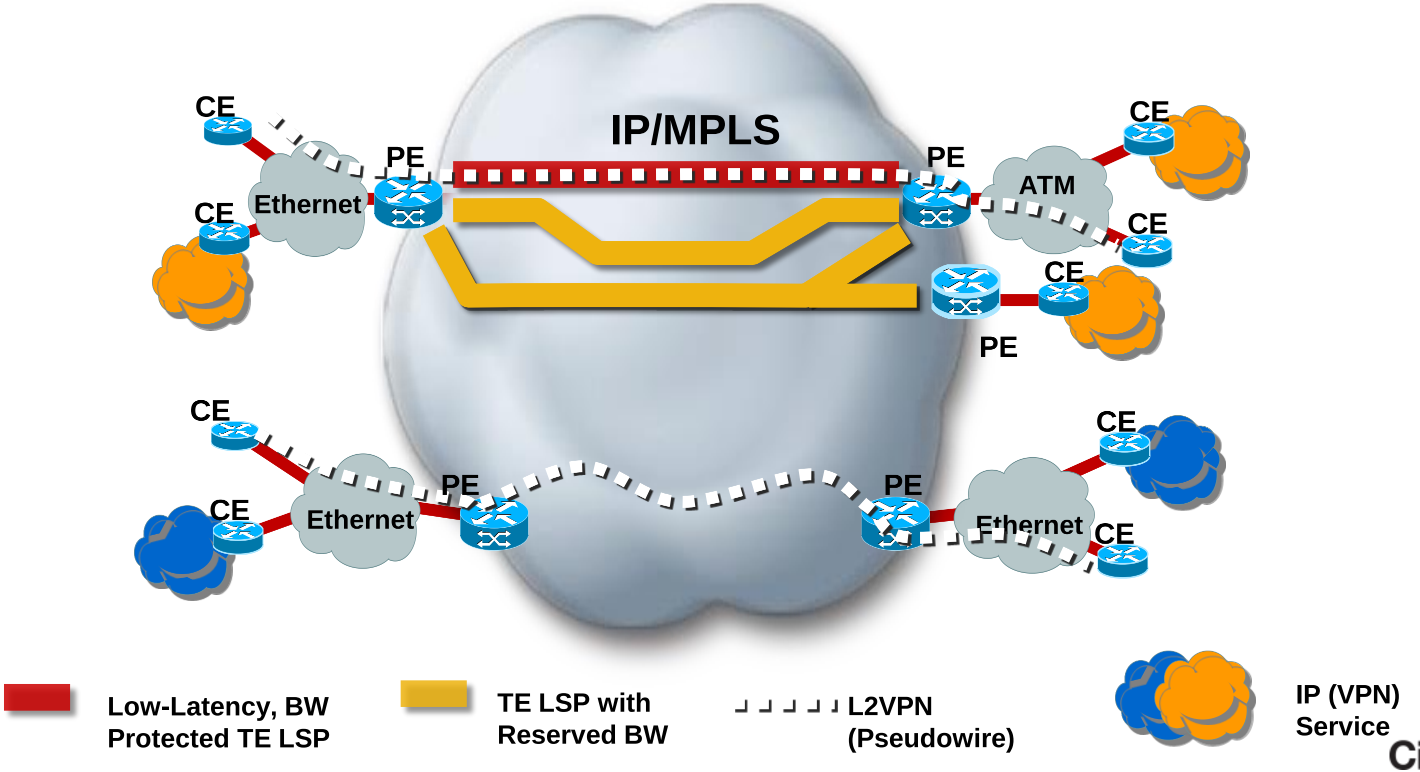


Tactical / Reactive



MPLS TE Integration with Network Services

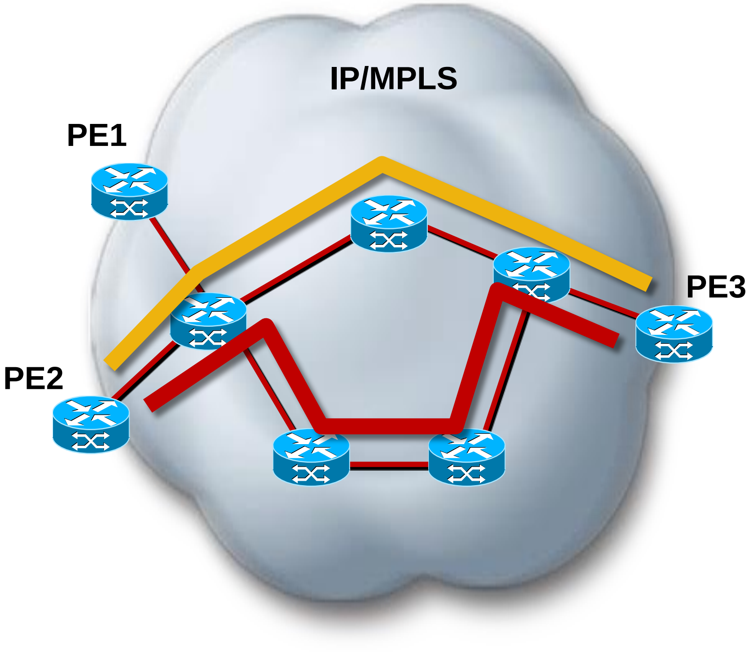
A TE LSP provides transport for different network services






TE and QoS

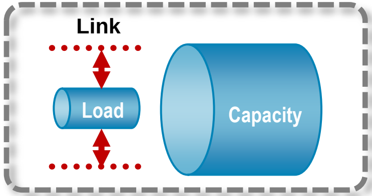
Motivations



- Point-to-point SLAs
- Admission control
- Integration with DiffServ architecture
- Increased routing control to improve network performance

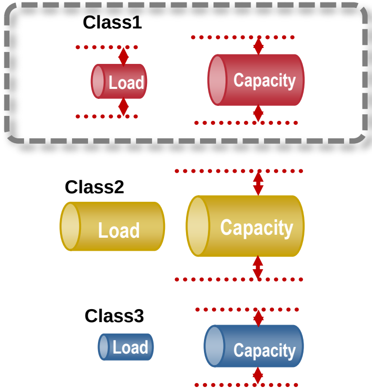
MPLS TE and DiffServ Deployment Models

MPLS TE and no DiffServ



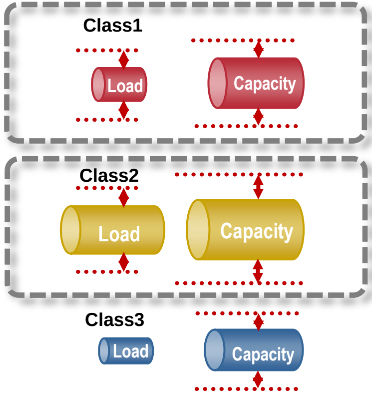
- A solution when:
  - No differentiation required
  - Optimization required
- Limit link load to actual link capacity
- No notion of traffic classes

MPLS TE and DiffServ



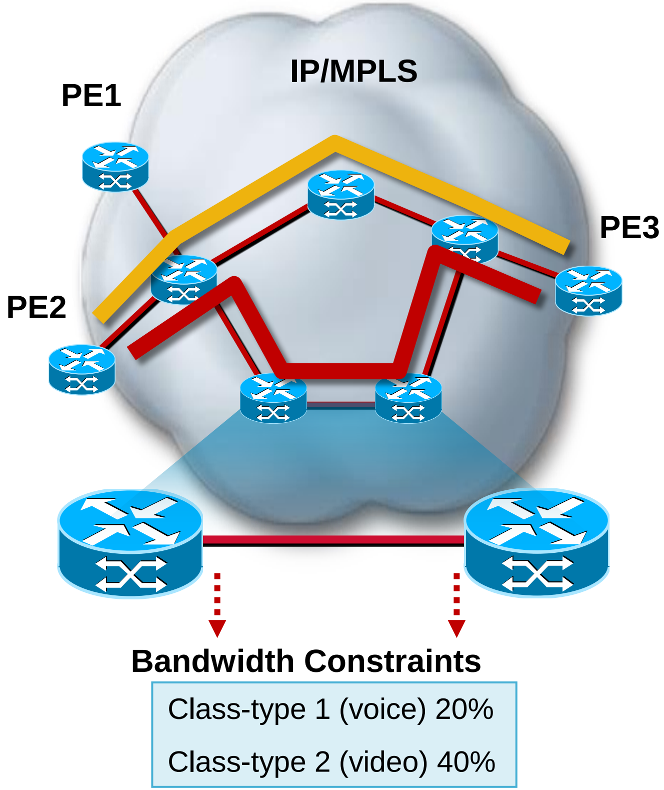
- A solution when:
  - Differentiation required
  - Optimization required
- Limit class capacity to expected class load
- Limit class load to actual class capacity for one class

DiffServ-Aware TE and DiffServ



- A solution when:
  - Strong differentiation required
  - Fine optimization required
- Limit class capacity to expected class load
- Limit class load to actual class capacity for at least two classes

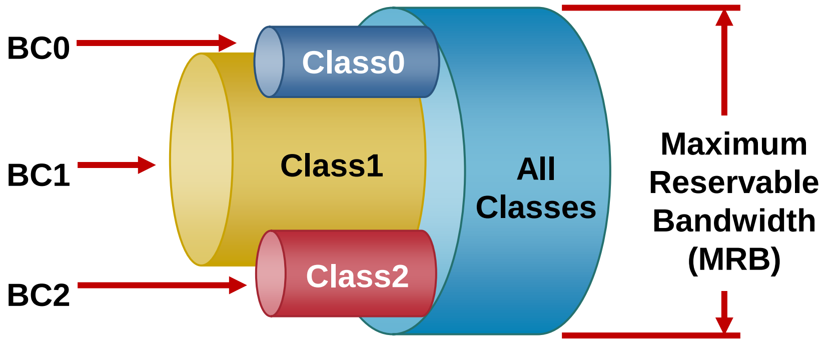
DiffServ-Aware Traffic Engineering



- Enables per-class traffic engineering
- IS-IS or OSPF flood link information (as usual)
- Per-class unreserved bandwidth on each link
- New RSVP object (CLASSTYPE)
- Nodes manages link bandwidth using a bandwidth constraint model
- Two models defined
  - Maximum Allocation Model (MAM)
  - Russian Doll Model (RDM)
- Unique class definition and constraint model throughout network
- Two classes (class-types) in current implementations

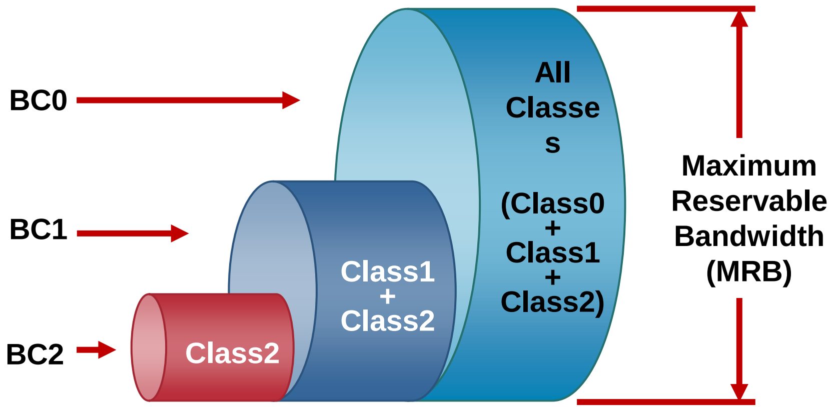
Maximum Allocation Model (MAM)

- BW pool applies to one class
- Sum of BW pools may exceed MRB
- Sum of total reserved BW may not exceed MRB
- Current implementation supports BC0 and BC1



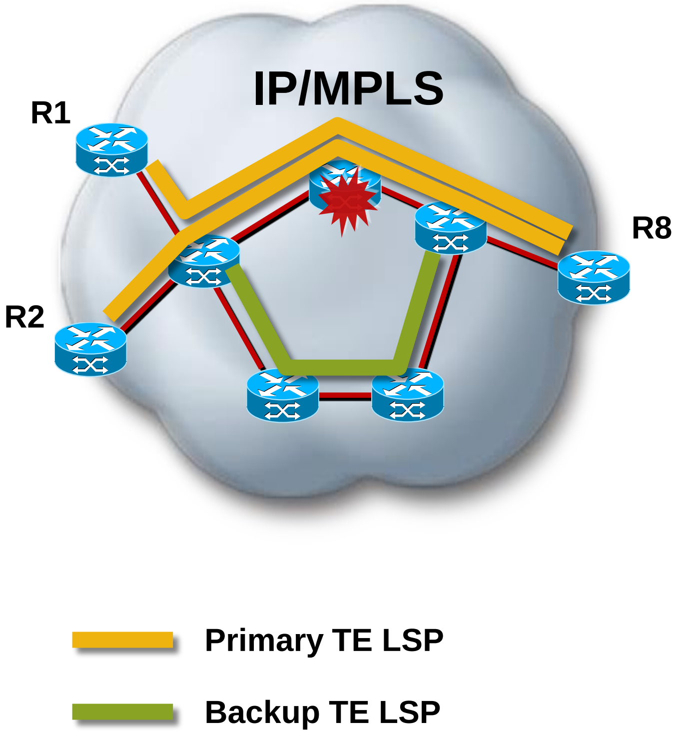
Russian Dolls Model (RDM)

- BW pool applies to one or more classes
- Global BW pool (BC0) equals MRB
- BC0..BCn used for computing unreserved BW for class n
- Current implementation supports BC0 and BC1



Traffic Protection

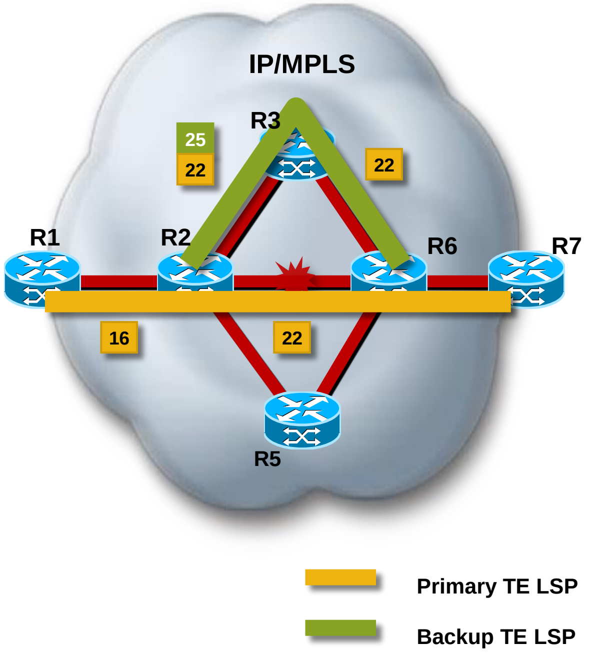
Traffic Protection Using MPLS TE Fast Re-Route (FRR)



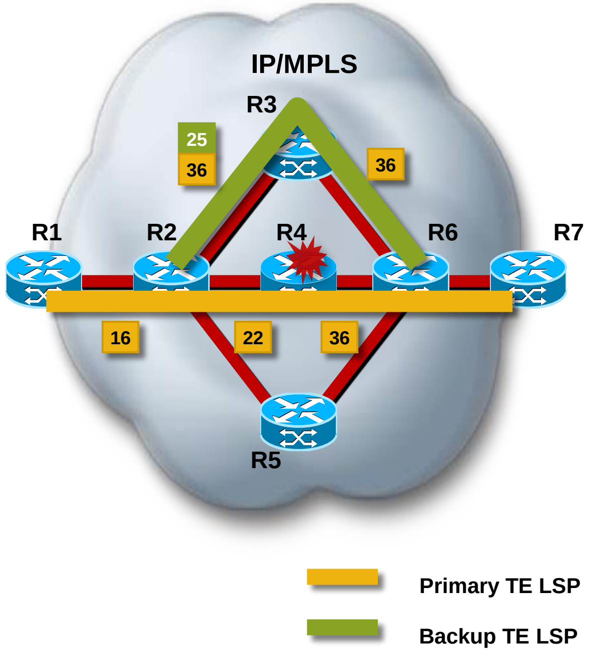
- Sub-second recovery against node/link failures
- Scalable 1:N protection
- Greater protection granularity
- Cost-effective alternative to 1:1 protection
- Bandwidth protection
- Topology independent

FRR Link Protection Operation

- Requires pre-signalled next-hop (NHOP) backup tunnel
- Point of Local Repair (PLR) swaps label and pushes backup label
- Backup terminates on Merge Point (MP) where traffic re-joins primary
- Restoration time expected under ~50 ms



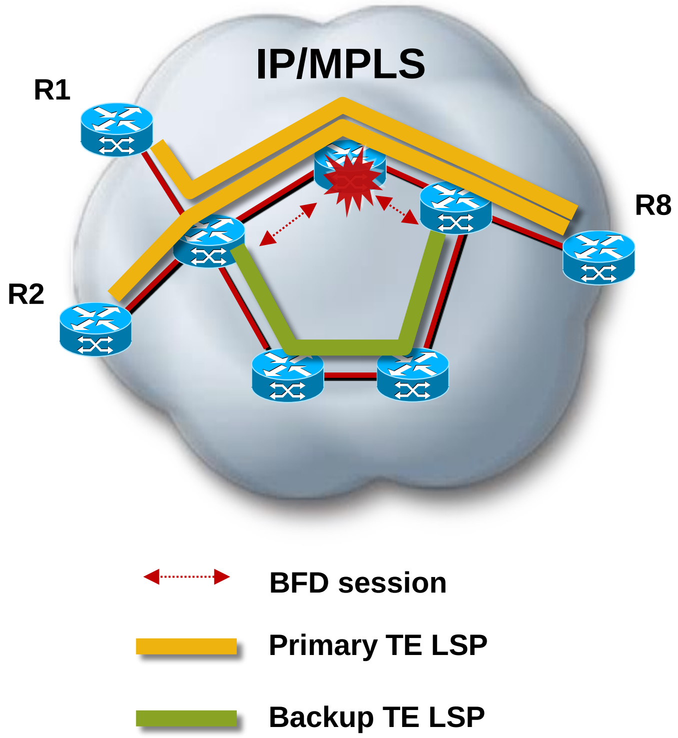
FRR Node Protection Operation



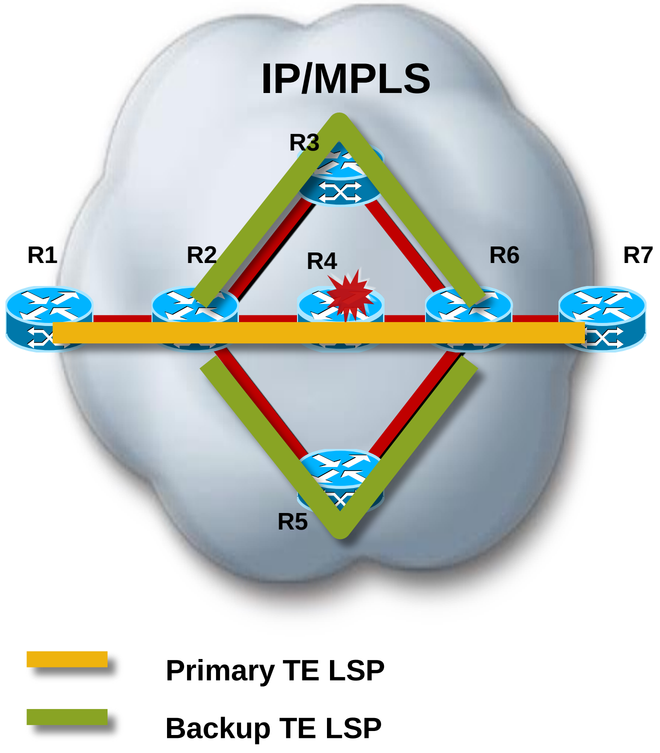
- Requires pre-signalled next-next-hop (NNHOP) backup tunnel
- Point of Local Repair (PLR) swaps next-hop label and pushes backup label
- Backup terminates on Merge Point (MP) where traffic re-joins primary
- Restoration time depends on failure detection time

Bidirectional Forwarding Detection Trigger for FRR

- FRR relies on quick PLR failure detection
- Some failures may not produce loss of signal or alarms on a link
- BFD provides light-weight neighbor connectivity failure detection
- Preferred over RSVP Hellos



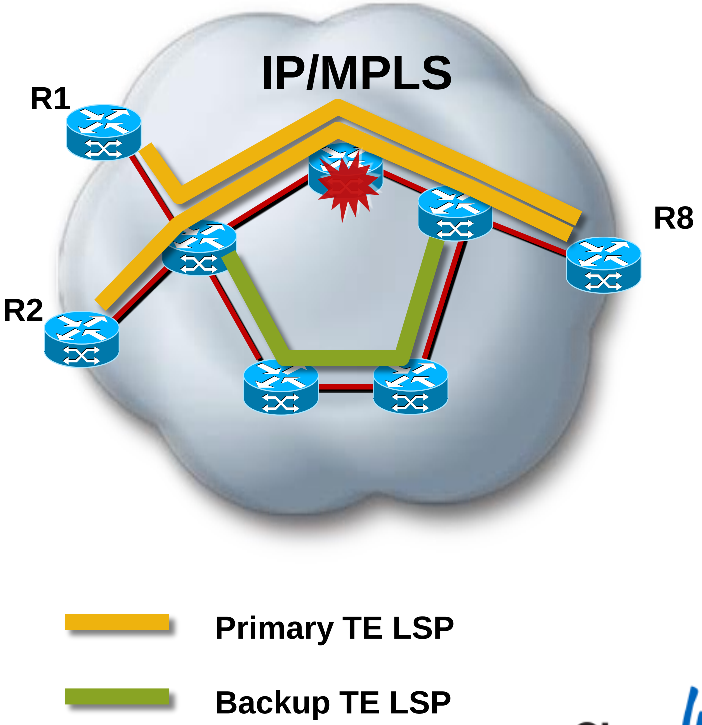
Bandwidth Protection



- Backup tunnel with associated bandwidth capacity
- Backup tunnel may or may not actually signal bandwidth
- PLR will decide best backup to protect primary
  - nhop/nnhop
  - backup-bw
  - class-type
  - node-protection flag

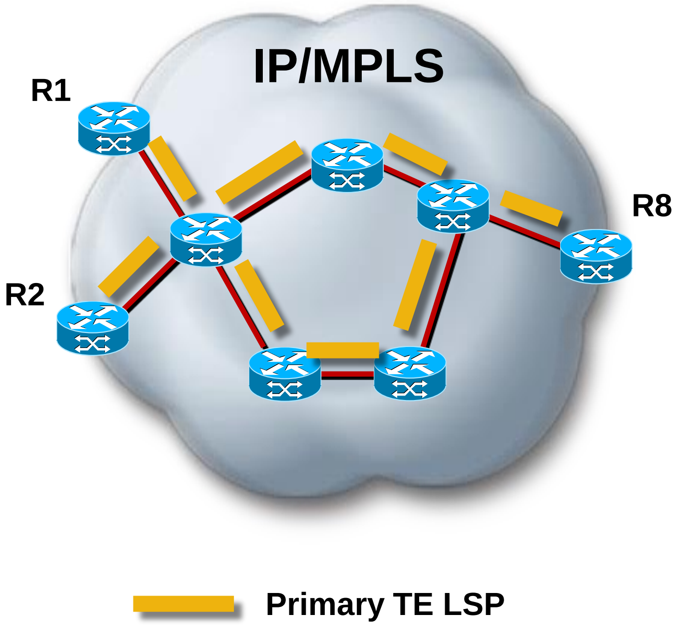
AutoTunnel: Primary Tunnels
What's the Problem?

- FRR can protect TE Traffic
- No protection mechanism for IP or LDP traffic
- How to leverage FRR for all traffic?
- What if protection desired without traffic engineering?



AutoTunnel: Primary Tunnels
What's the Solution?

Forward all traffic through a one-hop protected primary TE tunnel



- Create protected one-hop tunnels on all TE links

Priority	7/7
Bandwidth	0
Affinity	0x0/0xFFFF
Auto-BW	OFF
Auto-Route	ON
Fast-Reroute	ON
Forwarding-Adj	OFF
Load-Sharing	OFF

- Tunnel interfaces not shown on router configuration
- Configure desired backup tunnels (manually or automatically)

Configuring AutoTunnel Primary Tunnels (Cisco IOS)

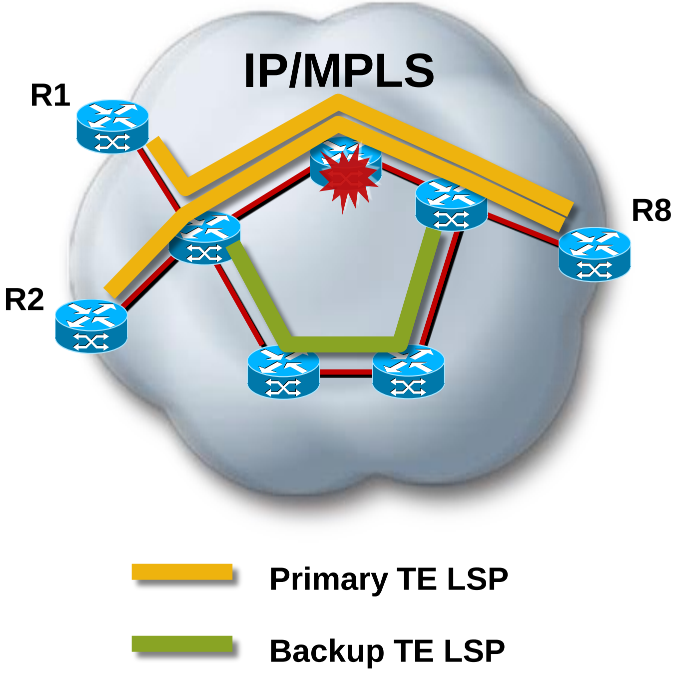
```
mpls traffic-eng tunnels
mpls traffic-eng auto-tunnel primary onehop
mpls traffic-eng auto-tunnel primary tunnel-num min 900 max 999
!
```

Enable auto-tunnel primary

Range for primary tunnel interfaces

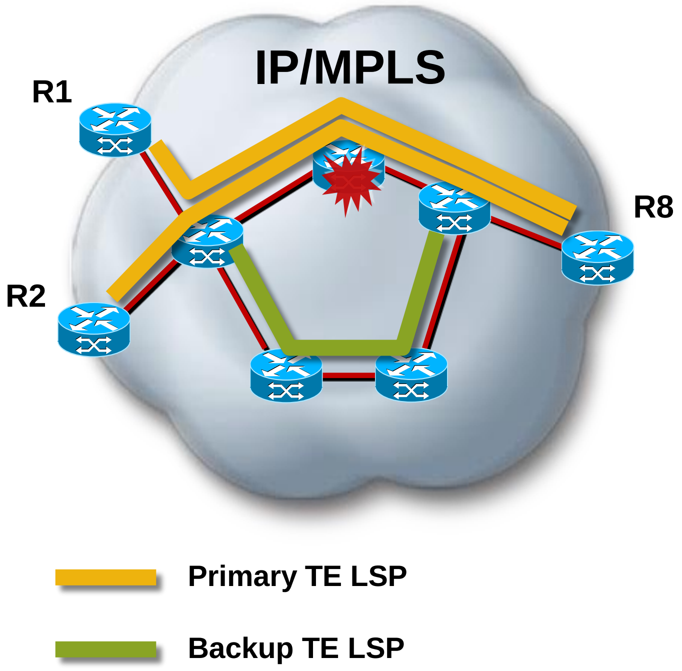
AutoTunnel: Backup Tunnels
What's the Problem?

- MPLS FRR requires backup tunnels to be preconfigured
- Automation of backup tunnels is desirable



AutoTunnel: Backup Tunnels
What's the Solution?

Create backup tunnels automatically as needed



- Detect if a primary tunnel requires protection and is not protected
- Verify that a backup tunnel doesn't already exist
- Compute a backup path to NHOP and NNHOP excluding the protected facility
- Optionally, consider shared risk link groups during backup path computation
- Signal backup tunnels

Configuring AutoTunnel Backup Tunnels (Cisco IOS)

```
mpls traffic-eng tunnels
mpls traffic-eng auto-tunnel backup nhop-only
mpls traffic-eng auto-tunnel backup tunnel-num min 1900 max 1999
mpls traffic-eng auto-tunnel backup srlg exclude preferred
!
```

Enable auto-tunnel backup (NHOP tunnels only)

Range for backup tunnel interfaces

Preferably consider SRLGs

Configuring AutoTunnel Backup Tunnels (Cisco IOS XR)

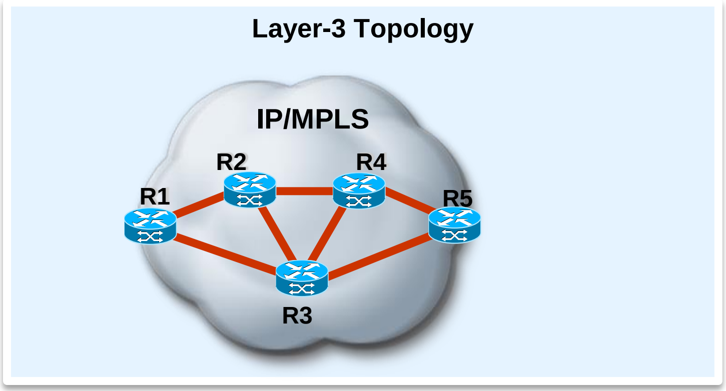
```
ipv4 unnumbered mpls traffic-eng Loopback 0
!
mpls traffic-eng
 interface GigabitEthernet0/0/0/0
  auto-tunnel backup
   exclude srlg preferred
   nhop-only
  !
 !
 auto-tunnel backup
  tunnel-id min min 1900 max 1999
 !
!
```

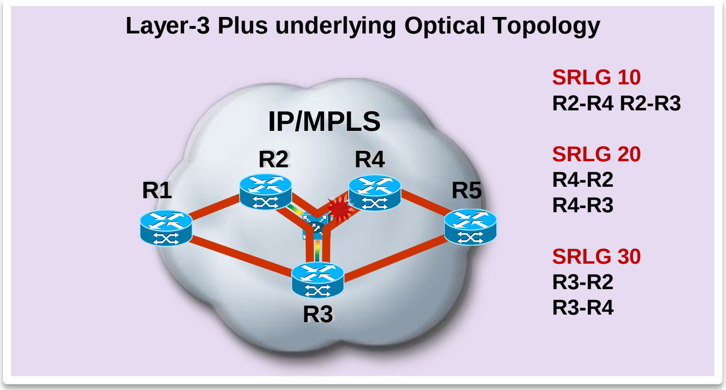
Source interface for backup tunnels

Protect interface with dynamically created (next-hop only) backup tunnels. Preferably consider SRLGs.

Range for backup tunnel interfaces

Shared Risk Link Group (SRLG)

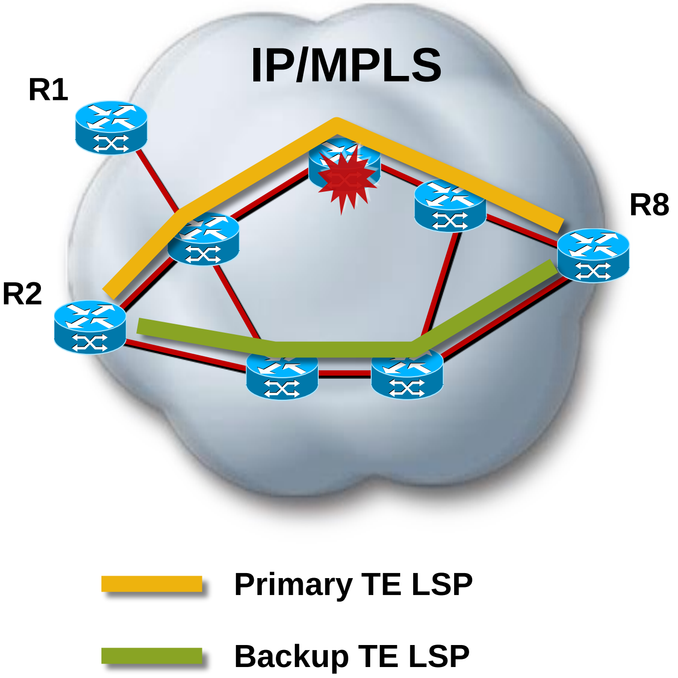




- Some links may share same physical resource (e.g. fiber, conduit)
- AutoTunnel Backup can force or prefer exclusion of SRLG to guarantee diversely routed backup tunnels
- IS-IS and OSPF flood SRLG membership as an additional link attribute

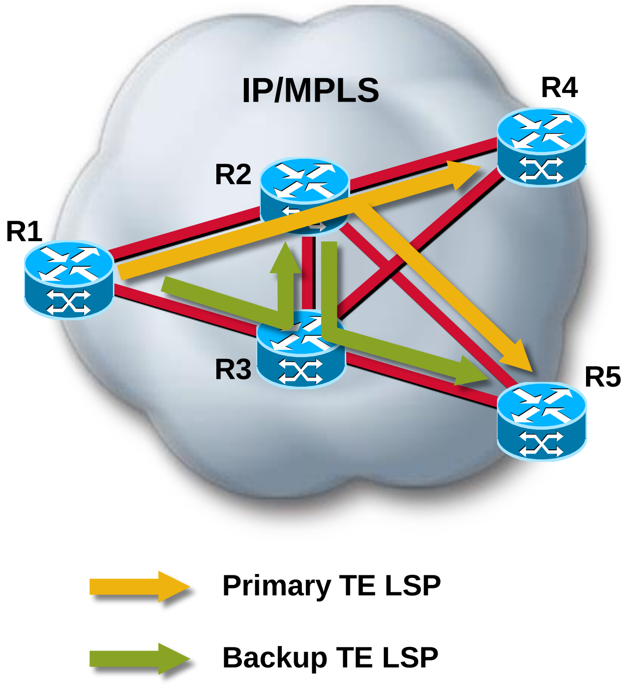
What About Path Protection?

- Primary and standby share head and tail, but expected to be diversely routed
- Generally higher restoration times compared to local protection
- Doubles number of TE LSPs (1:1 protection)
- May be an acceptable solution for restricted topologies (e.g. rings)
- Cisco IOS
  - Separate path option sequences for primary and standby
  - Explicit paths only
  - No path diversity
- Cisco IOS XR
  - Single or separate path-option sequence for primary and standby
  - Explicit and dynamic paths
  - Automatic path diversity (node-link, node, link) when using single path-option sequence
  - BFD may be used for end-to-end fault detection

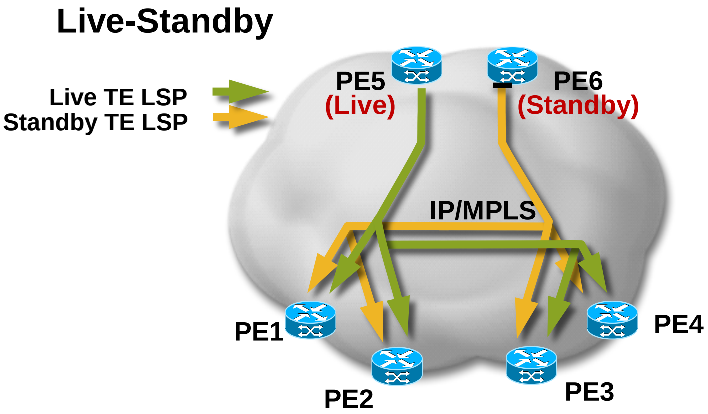


P2MP TE LSP Traffic Protection

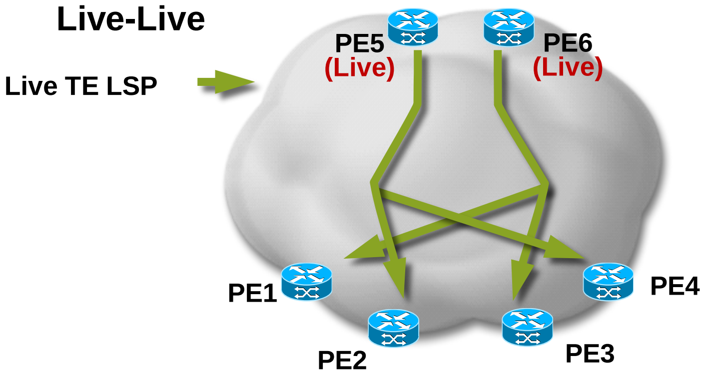
- No new protocol extensions to support FRR
- Protection requirement applies to all destinations
- P2P LSP as backup tunnel for a sub-LSP
- No changes to label stacking procedure
- Only link protection supported
- Head-end protection requires path redundancy (live-standby / live-live)



Head End Resiliency Models for P2MP TE



- Redundant TE LSPs with different ingress PEs
- LSPs may or may not be disjoint
- Link failures generally protected via FRR
- Several bandwidth options for Standby TE LSP
  - Same bandwidth reservation as Live path
  - No bandwidth reservation
  - Adaptive bandwidth reservation (auto-bandwidth)



- Redundant P2MP LSPs with different ingress and egress PEs
- LSPs are generally disjoint
- Receiver or near-receiver stream selection and switchover
- FRR generally not a requirement
- Same bandwidth reservation on both TE LSPs




Bandwidth optimization

Strategic / Planned Bandwidth Optimization

Traffic Matrix

	R1	R2	R3	R4	R5	R6
R1	4	7	1	5	4	5
R2	2	2	4	7	2	3
R3	1	2	9	5	5	5
R4	9	1	4	1	3	1
R5	3	7	9	2	7	7
R6	6	3	5	4	9	12

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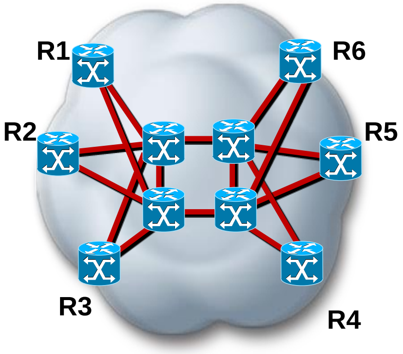
Physical Topology



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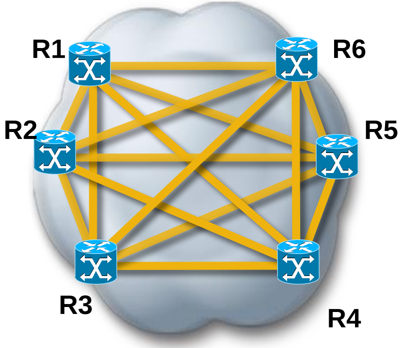
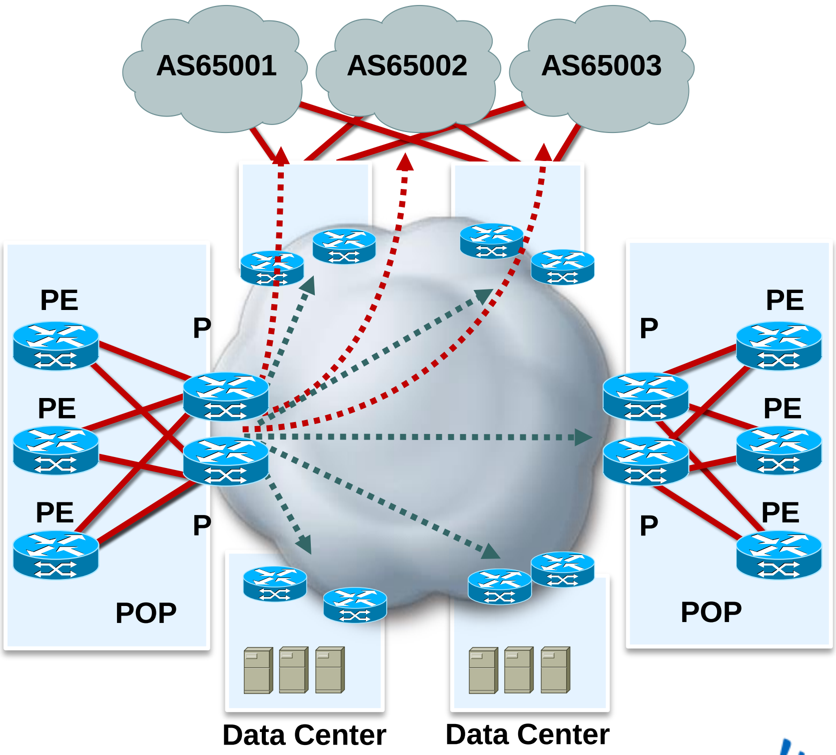
Tunnel mesh to satisfy traffic matrix



- Tries to optimize underlying physical topology based on traffic matrix
- Key goal is to avoid link over/under utilization
- On-line (CSPF) or off-line path computation
- May result in a significant number of tunnels
- Should not increase your routing adjacencies

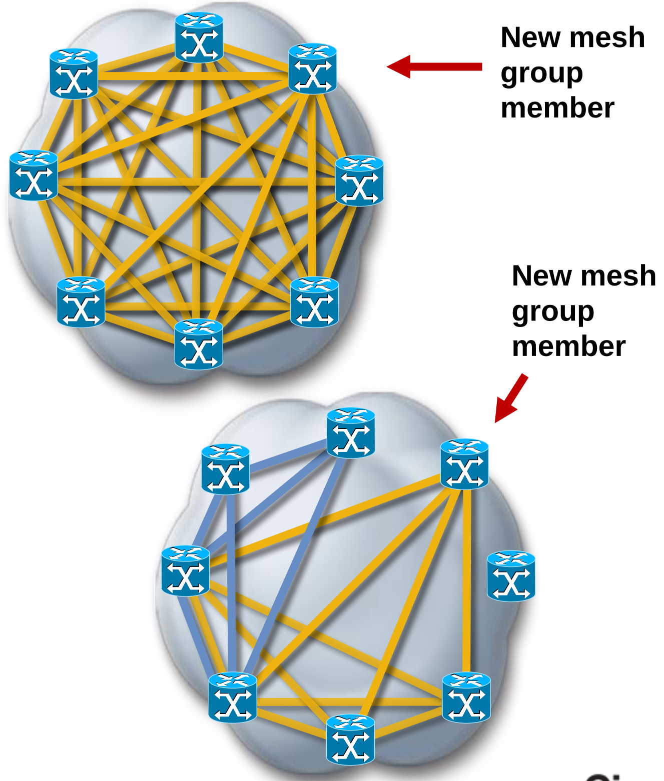
Traffic Matrix Measurement

- Interface counters on unconstrained tunnels
- Interface MIB
- MPLS LSR MIB
- NetFlow
  - NetFlow BGP Next Hop
  - MPLS-Aware NetFlow
  - Egress/Output NetFlow
- BGP policy accounting
  - Communities
  - AS path
  - IP prefix

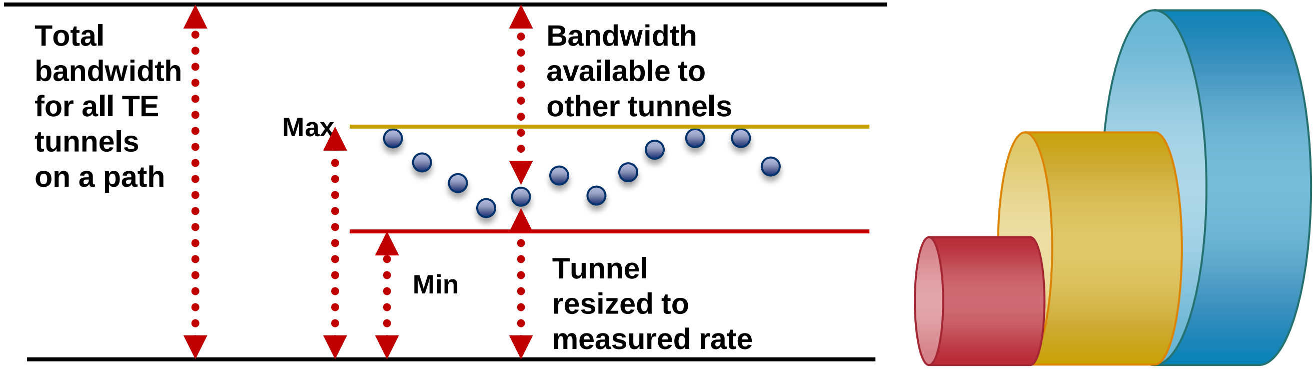


AutoTunnel Mesh

- Mesh group: LSRs to mesh automatically
- Membership identified by
  - Matching TE Router ID against ACL (Cisco IOS and IOS XR)
  - IGP mesh-group advertisement (Cisco IOS)
- Each member automatically creates tunnel upon detection of a member
- Tunnels instantiated from template
- Individual tunnels not displayed in router configuration



Auto Bandwidth



- Dynamically adjust bandwidth reservation based on measured traffic
- Optional minimum and maximum limits
- Sampling and resizing timers
- Tunnel resized to largest sample since last adjustment
- Actual resizing can be subject to adjustment threshold and overflow/underflow detection

Configuring AutoTunnel Mesh (Cisco IOS)

```
mpls traffic-eng tunnels
mpls traffic-eng auto-tunnel mesh
!
interface Auto-Template1
 ip unnumbered Loopback0
 tunnel destination mesh-group 10
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng path-option 10 dynamic
 tunnel mpls traffic-eng auto-bw frequency 3600
!
router ospf 16
 log-adjacency-changes
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
 mpls traffic-eng mesh-group 10 Loopback0 area 0
 passive-interface Loopback0
 network 172.16.0.0 0.0.255.255 area 0
!
```

- Enable Auto-tunnel Mesh
- Tunnel template
- Template instanciated for each member of mesh group 10
- Dynamic (CSPF) path and dynamic bandwidth adjustment for all mesh tunnels
- Advertise mesh group 10 membership in area 0

Configuring AutoTunnel Mesh (Cisco IOS XR)

```
ipv4 unnumbered mpls traffic-eng Loopback 0
!
mpls traffic-eng
 auto-tunnel mesh
  group 10
   attribute-set 10
   destination-list DST-RID-ACL
  !
  tunnel-id min 1000 max 2000
 !
 attribute-set auto-mesh 10
  autoroute announce
  path-selection metric te
 !
!
```

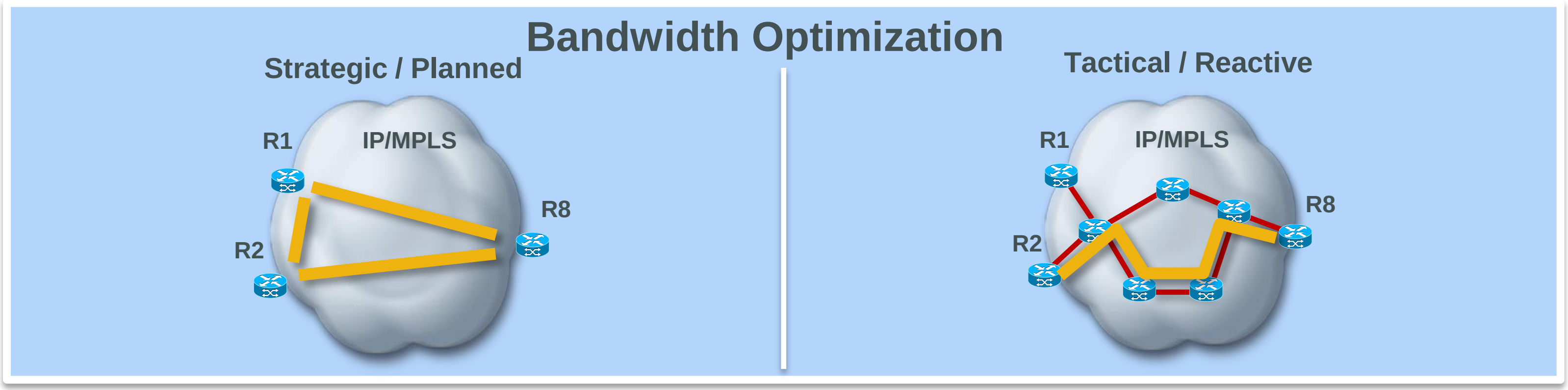
Source interface for backup tunnels

Mesh group 10 identified by ACL DST-RID-ACL

Range for mesh tunnel interfaces

Attribute set for tunnels in mesh group 10

Tactical / Reactive Bandwidth Optimization

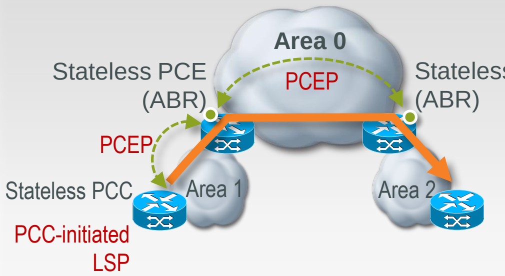


- Selective deployment of tunnels when highly-utilized links are identified
- Generally, deployed until next upgrade cycle alleviates congested links

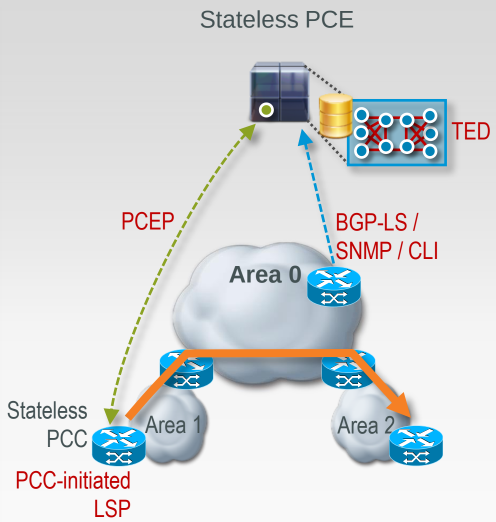
Centralized Tunnel Creation and Control

Cisco PCE Models (Cisco IOS XR)

Inter-Area MPLS TE

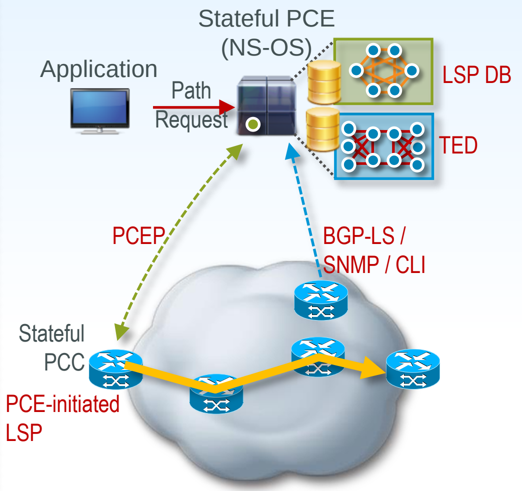


- ABRs act as stateless PCEs
- ABRs implement backward recursive PCE-Based Computation
- Introduced in IOS XR 3.5.2
- IOS XR 5.1.1 introduces PCEP RFC-compliance



- Out-of-network, stateless PCE server
- PCC initiates LSPs
- Introduced in IOS XR 3.5.2
- IOS XR 5.1.1 introduces PCEP RFC-compliance

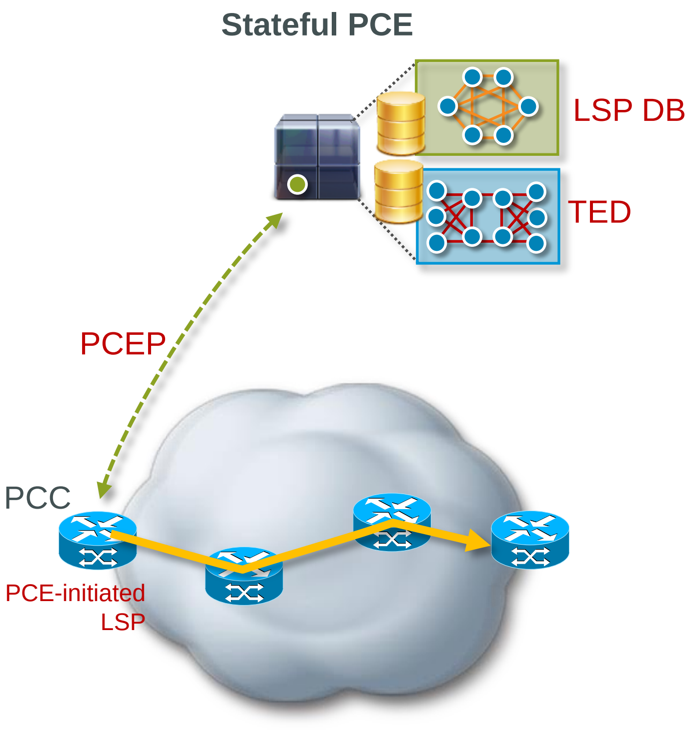
SDNWAN Orchestration



- Out-of-network, stateful PCE server
- PCE always initiates LSPs
- Introduced in IOS XR 5.1.1

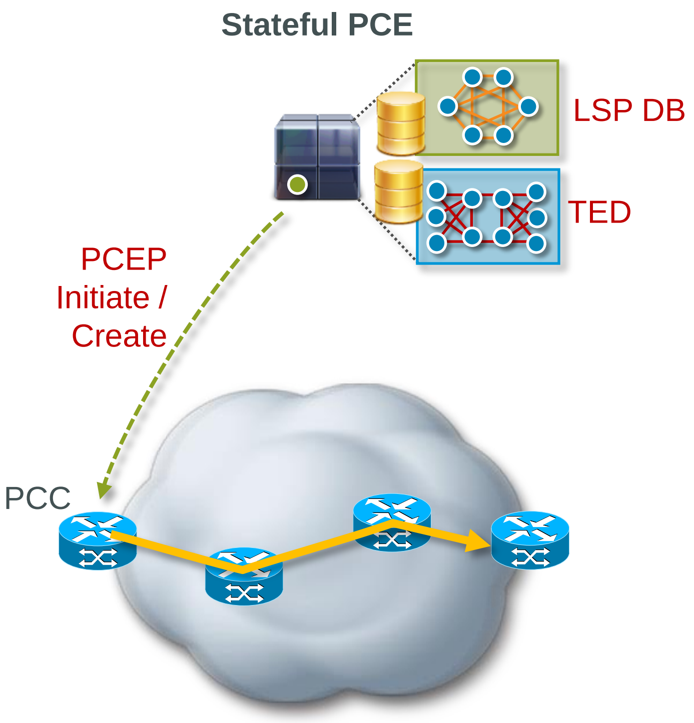
Active Stateful PCE

- Introduces PCEP extensions for
  - LSP state synchronization between PCCs and PCEs
  - PCC delegation of LSP control to PCE
- Active stateful PCE
  - PCC maintains state synchronization with PCE
  - PCC may delegate LSP control to PCE
- PCC always owns LSP state
- Cisco WAN orchestration solution relies on an active stateful PCE that initiates LSP setup



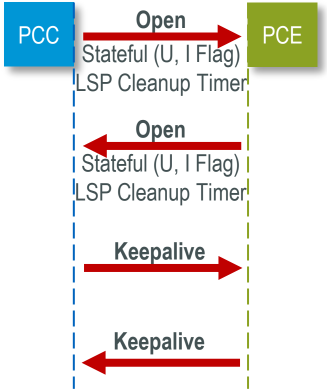
PCE-Initiated Tunnels in Cisco IOS XR

- Treated as dynamically created tunnels (auto-tunnel)
- Tunnel number allocated from user defined range
- Router does NOT verify or compute path that PCE provides (treated as verbatim path)
- Router does not attempt local LSP re-optimization
- PCE responsible for LSP re-optimization
- PCE sends an PCEP Update when a better path exists
- Tunnels may be inter-area
- Only PCE-initiated LSPs can be delegated



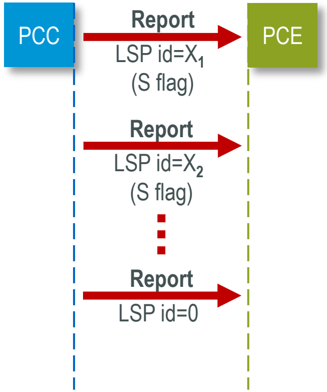
PCE-Initiated LSP

Session Establishment



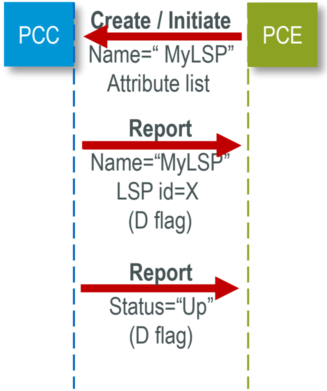
- PCE / PCC advertise stateful capability
- Session support LSP updates (U flag)
- Session supports LSP creation/initiation (I flag)
- Cleanup timer for PCE LSPs
- Session established when both peers receive keepalive

State Synchronization



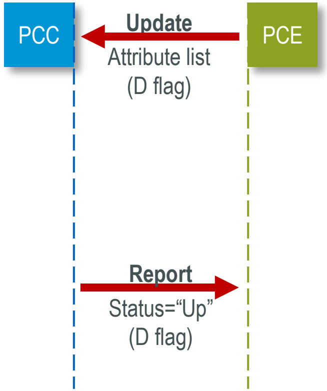
- Full synchronization of LSP state after session established
- PCC reports all PCE-initiated LSPs to synchronize (S flag) state with PCE
- PCC uses LSP id 0 to indicate end of synchronization

LSP Creation / Initiation



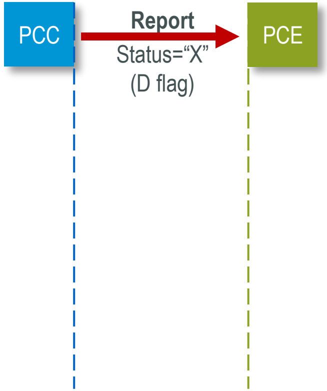
- PCE request LSP creation / initiation with attribute list
- PCC attempts LSP setup and reports back LSP id and state
- PCC automatically delegates LSP control (D flag) to PCE
- PCC may not revoke delegation
- PCE may return delegation

LSP Update



- PCE updates LSP state and/or attributes
- Report with status='Up' sent to all stateful PCEs

LSP Reporting



- PCC reports LSP state as part of
  - Initial state synchronization
  - Control delegation
  - Control revoking
  - Deletion
  - Signaling error
  - State change
- Sent to all stateful PCEs

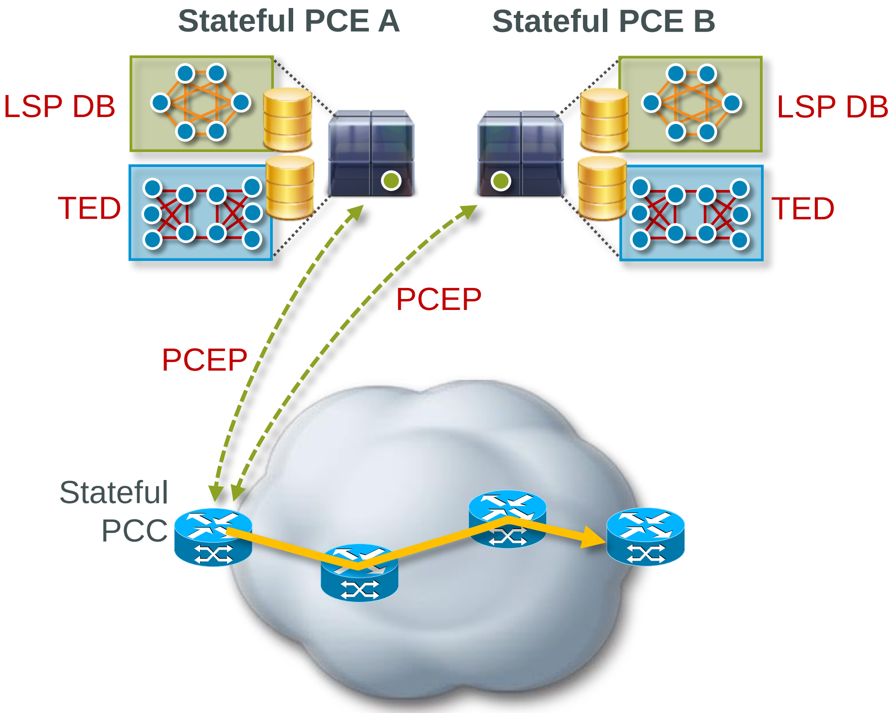
Configuration for PCE-Initiated Tunnels (Cisco IOS XR)

```
ipv4 unnumbered mpls traffic-eng Loopback0
!
mpls traffic-eng
 pce
  peer ipv4 172.16.255.3
  stateful-client
   capabilities instantiation
   capabilities update
  !
 !
 auto-tunnel pcc
  tunnel-id min 1000 max 5000
 !
!
```

- **ipv4 unnumbered mpls traffic-eng Loopback0**: Source interface for tunnels
- **peer ipv4 172.16.255.3**: PCE server
- **capabilities instantiation / capabilities update**: Allow PCE-initiated LSP
- **auto-tunnel pcc / tunnel-id min 1000 max 5000**: Range of tunnel-te interfaces for PCE initiated LSPs

PCE-Initiated LSP (Multiple PCEs)

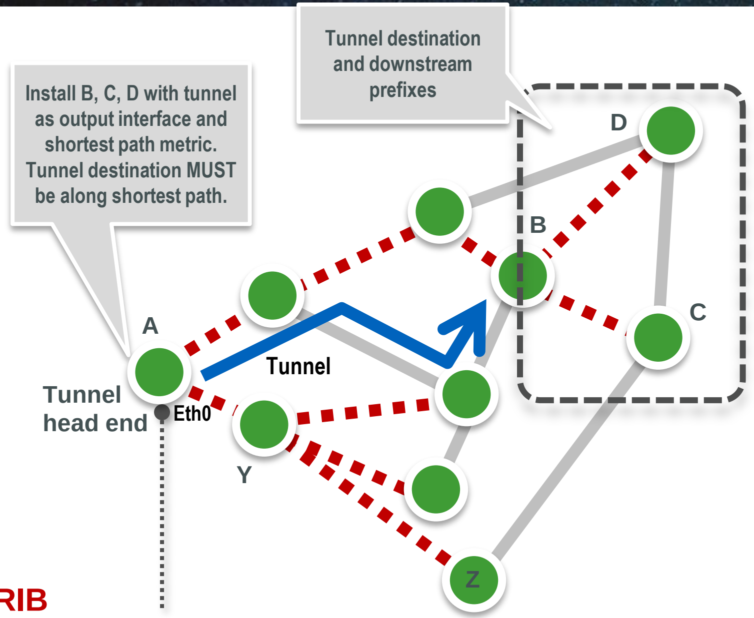
- PCC synchronizes LSP state over all open stateful PCEP sessions
- When a PCE creates / initiates an LSP
  - PCC will report LSP state to all stateful PCEs
  - PCC will only delegate LSP to originating PCE
- LSP may be re-delegated if originating PCE disconnects or renounces delegation
- LSPs may be re-delegated to a stateful PCE sending a matching LSP creation / initiation before LSP cleanup timeout



Traffic Steering into PCE-Initiated Tunnels

- Two approaches
  - Autoroute announce
  - Policy-based tunnel selection (forwarding class id)
- PCE can specify autoroute announce and forwarding class id during LSP creation / instantiation or update
- Attributes encoded as vendor specific TLVs (same approach used to specify load-share)

Autoroute Announce



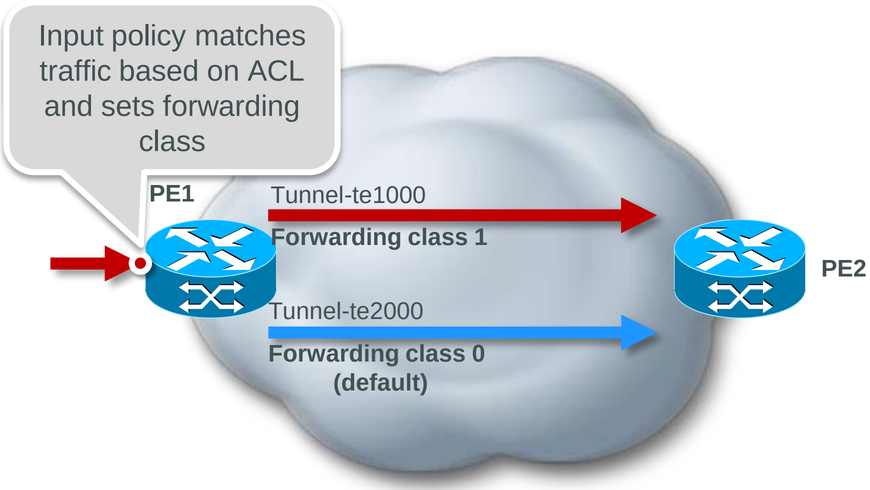
RIB

Prefix	Next Hop	Metric	Out Interface
B	B	30	Tunnel
C	B	40	Tunnel
D	B	40	Tunnel
Z	Y	20	Ethernet0
:	:	:	:

- Prefixes installed in RIB with tunnel as output interface if tunnel destination along shortest path
- Operates on prefixes at tunnel destination and downstream
- Prefixes installed with IGP shortest path metric
- Supported for IS-IS and OSPF

Policy Based Tunnel Selection

- Local mechanism at head-end
- PBR policy sets forwarding class for incoming traffic
- Traffic switched to tunnel with matching forwarding class
- Seven forwarding classes supported (1-7)
- One forwarding class reserved as default (0)





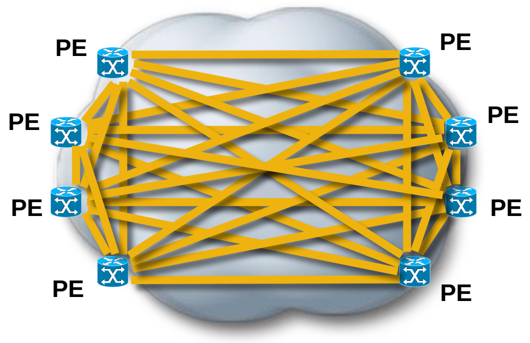

General Deployment Considerations

Should RSVP-TE and LDP be Used Simultaneously?

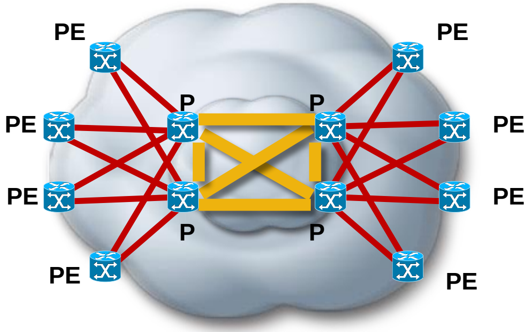
- Guarantees forwarding of VPN traffic if a TE LSP fails
- May be required if full mesh of TE LSPs not in use
- Increased complexity

How Far should Tunnels Span?

56 TE LSP

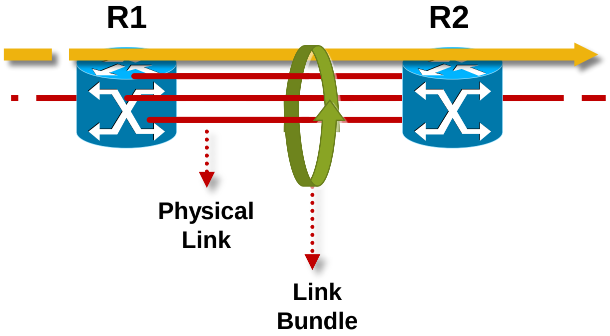


12 TE LSP



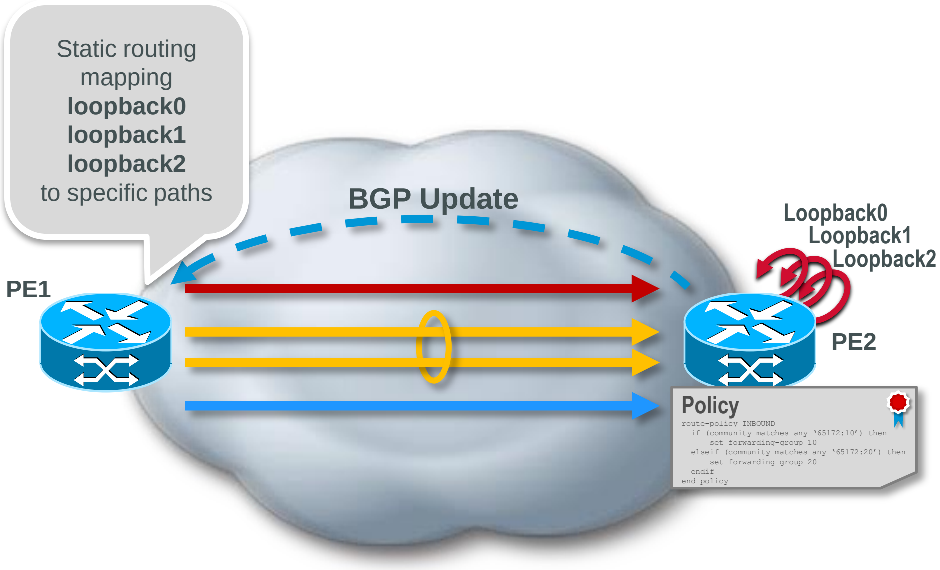
- PE-to-PE Tunnels
  - More granular control on traffic forwarding
  - Larger number of TE LSPs
- P-to-P Tunnels
  - Requires IP tunnels or LDP over TE tunnels to carry VPN traffic (deeper label stack)
  - Fewer TE LSPs
  - May be extended with PE-P tunnels

MPLS TE on Link Bundles



- Different platforms support different link bundles
  - Ethernet
  - POS
  - Multilink PPP
- Bundles appear as single link in topology database
- Same rules for link state flooding
- LSP preemption if bundle bandwidth becomes insufficient
- Configurable minimum number of links to maintain bundle active
- Bundle failure can act as trigger for FRR

Per-Service Tunnel Selection



- Services (L2VPN / L3VPN) generally receive a path automatically
  - Recursive resolution of BGP next hops
  - Recursive resolution of LDP peers
- L2VPN provides granular per-tunnel control using pseudowire tunnel selection
- When using BGP (L2VPN, L3VPN, IP):
  - On tail end, add loopback at destination for each service that needs separate forwarding
  - On tail end, add policy to modify next-hop on BGP updates
  - On head end, add static route to force BGP next hops down specific paths

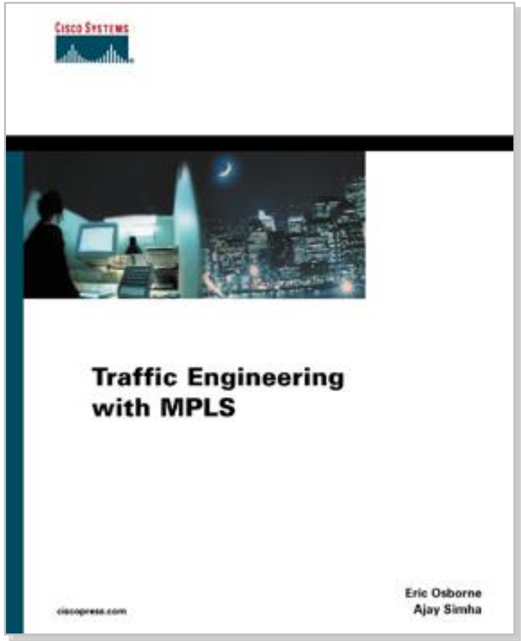


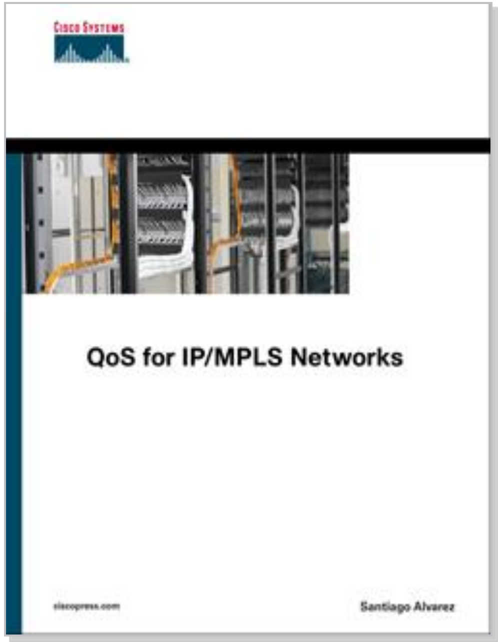

Summary

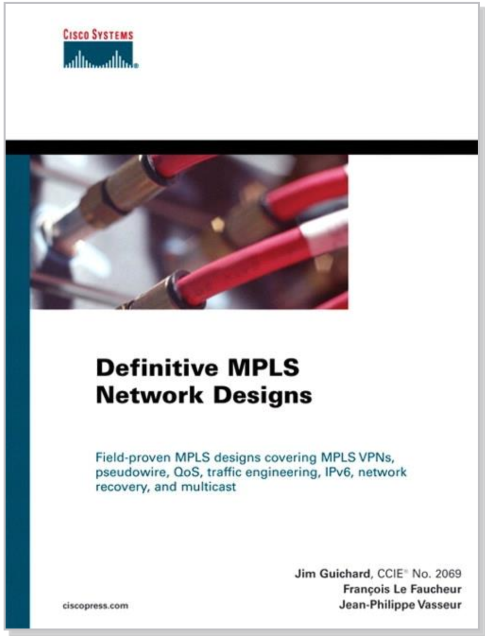
Summary

- Technology Overview
  - Explicit and constrained-based routing
  - TE protocol extensions (OSPF, ISIS and RSVP)
  - P2P and P2MP TE LSP
- TE and QoS
  - DS-TE (MAM, RDM)
  - PBTS / CBTS
- Traffic Protection
  - Link/node protection (auto-tunnel)
  - Bandwidth protection
  - Path protection
- Bandwidth optimization
  - Strategic / planned (full mesh, auto-tunnel)
  - Tactical / reactive
- Centralized Tunnel Creation and Control
  - Centralized SDN model
  - PCE-initiated tunnels
- General Deployment Considerations
  - MPLS TE and LDP
  - PE-to-PE vs. P-to-P tunnels
  - TE over Bundles
  - Per-Service Tunnel Selection

Recommended Reading







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Backup

Configuring MPLS TE and Link Information Distribution Using IS-IS (Cisco IOS)

```
mpls traffic-eng tunnels
!
interface TenGigabitEthernet0/1/0
 ip address 172.16.0.0 255.255.255.254
 ip router isis
 mpls traffic-eng tunnels
 mpls traffic-eng attribute-flags 0xF
 mpls traffic-eng administrative-weight 20
 ip rsvp bandwidth 100000
!
router isis
 net 49.0001.1720.1625.5001.00
 is-type level-2-only
 metric-style wide
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng level-2
 passive-interface Loopback0
!
```

Enable MPLS TE on this node

Enable MPLS TE on this interface, specify attribute flags (colors), TE metric and maximum reservable bandwidth

Enable wide metric format and TE extensions (TE Id, router level)

Configuring MPLS TE and Link Information Distribution Using OSPF (Cisco IOS XR)

```
router ospf DEFAULT
 area 0
  mpls traffic-eng
  interface Loopback0
   passive
  !
  interface TenGigE0/0/0/0
  !
 mpls traffic-eng router-id Loopback0
!
rsvp
 interface TenGigE0/0/0/0
  bandwidth 100000
 !
!
mpls traffic-eng
 interface TenGigE0/0/0/0
  admin-weight 5
  attribute-flags 0x8
 !
!
```

Enable MPLS TE extensions on this area

MPLS TE router id

Configuration mode for RSVP global and interface (e.g. maximum reservable bandwidth) commands

Configuration mode for MPLS TE global and interface (e.g. TE metric, attribute flags) commands

Configuring MPLS TE and Link Information Distribution Using IS-IS (Cisco NX-OS)

```
feature isis
feature mpls traffic-eng

interface Ethernet1/1
  mpls traffic-eng tunnels
  mpls traffic-eng administrative-weight 20
  mpls traffic-eng attribute-flags 0xf
  mpls traffic-eng bandwidth 10000000
  no switchport
  ip address 172.16.0.14/31
  ip router isis DEFAULT
  no shutdown

router isis DEFAULT
  mpls traffic-eng level-2
  mpls traffic-eng router-id loopback0
  net 49.0001.1720.1625.5202.00
  is-type level-2
```

Enable MPLS TE on this device

Enable MPLS TE on this interface, specify attribute flags (colors), TE metric and maximum reservable bandwidth

Enable TE extensions (TE Id, router level)

Configuring Tunnel at Head End (Cisco IOS)

```
interface Tunnel1
 description FROM-ROUTER-TO-DST1
 ip unnumbered Loopback0
 tunnel destination 172.16.255.3
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng priority 5 5
 tunnel mpls traffic-eng bandwidth  10000
 tunnel mpls traffic-eng affinity 0x0 mask 0xF
 tunnel mpls traffic-eng path-option 5 explicit name PATH1
 tunnel mpls traffic-eng path-option 10 dynamic
 !
ip explicit-path name PATH1 enable
 next-address 172.16.0.1
 next-address 172.16.8.0
 !
```

Tunnel destination and TE type

Signaled bandwidth and priority

Consider links with 0x0/0xF as attribute flags (colors)

Tunnel path options (explicit, otherwise, dynamic)

Explicit path definition

Configuring Tunnel at Head End (Cisco IOS XR)

```
explicit-path name PATH1
 index 1 next-address ipv4 unicast 172.16.0.4
 index 2 next-address ipv4 unicast 172.16.0.7
 index 3 next-address ipv4 unicast 172.16.4.2
!
interface tunnel-te1
 description FROM-ROUTER-TO-DST1
 ipv4 unnumbered Loopback0
 priority 5 5
 signalled-bandwidth 100000
 destination 172.16.255.2
 path-option 10 explicit name PATH1
 path-option 20 dynamic
 affinity f mask f
!
```

- Explicit path definition
- MPLS TE point-to-point tunnel
- Signaled bandwidth and priority
- Tunnel destination
- Tunnel path options (explicit, otherwise, dynamic)
- Consider links with 0xF/0xF as attribute flags (colors)

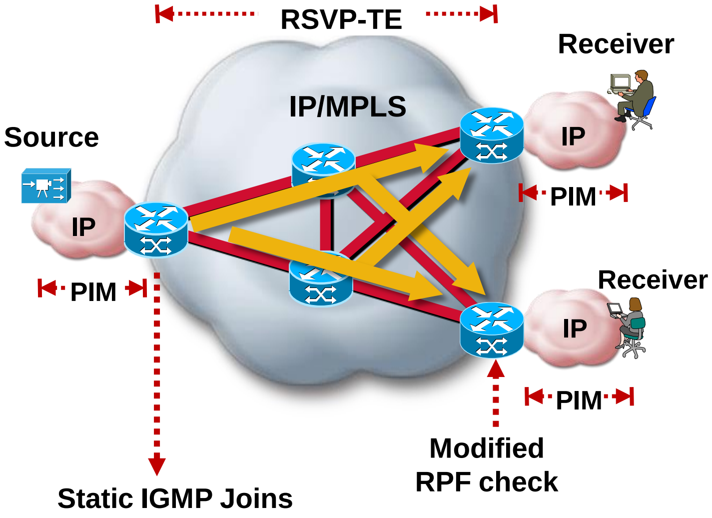
Configuring Tunnel at Head End (Cisco NX-OS)

```
mpls traffic-eng
  explicit-path name PATH1
    index 10 next-address 172.16.0.15
    index 20 next-address 172.16.0.13

interface tunnel-te1
  description FROM-ROUTER-TO-DST1
  ip unnumbered loopback0
  no shutdown
  destination 172.16.255.5
  affinity 0xf mask 0xf
  bandwidth 10000
  path-option 10 explicit name PATH1
  path-option 20 dynamic
  priority 5 5
```

- Explicit path definition
- MPLS TE point-to-point tunnel
- Tunnel destination
- Consider links with 0xF/0xF as attribute flags (colors)
- Signaled bandwidth
- Tunnel path options (explicit, otherwise, dynamic)
- Signaled priority

P2MP TE LSP Traffic Selection
IP Multicast



P2MP Tunnel	Multicast Group
Tunnel1	(192.168.5.1, 232.0.0.1) (192.168.5.1, 232.0.0.2)
Tunnel2	(192.168.5.1, 232.0.0.3)

- One or more IP multicast groups mapped to a Tunnel
- Groups mapped via static IGMP join
- PIM outside of MPLS network
- Modified egress RPF check against TE LSP and tunnel head end (source address)
- Egress node may abstract TE LSP as a virtual interface (LSPVIF) for RPF purposes

Statically Mapping Multicast Groups to a P2MP Tunnel (Cisco IOS)

```
mpls traffic-eng destination list name P2MP-LIST-DST1
 ip 172.16.255.1 path-option 10 explicit name PATH1
 ip 172.16.255.2 path-option 10 dynamic
 ip 172.16.255.3 path-option 10 dynamic
 ip 172.16.255.4 path-option 10 dynamic
!
interface Tunnel1
 description FROM-ROUTER-TO-LIST-DST1
 ip unnumbered Loopback0
 ip pim passive
 ip igmp static-group 232.0.0.1 source 192.168.5.1
 ip igmp static-group 232.0.0.2 source 192.168.5.1
 tunnel mode mpls traffic-eng point-to-multipoint
 tunnel destination list mpls traffic-eng name P2MP-LIST-DST1
 tunnel mpls traffic-eng priority 7 7
 tunnel mpls traffic-eng bandwidth 1000
!
```

Destination list with one path-option per destination

Multipcast groups mapped to tunnel

P2MP TE Tunnel

Destination list

Signaled bandwidth and setup / hold priorities

Configuring RPF Check at P2MP Tunnel Tail End (Cisco IOS)

```
ip multicast mpls traffic-eng
ip mroute 192.168.5.1 255.255.255.255 172.16.255.5
!
```

Enable IPv4 multicast over P2MP TE LSP

Tunnel source (172.16.255.5) as next-hop for IP Multicast source (192.168.5.1) RPF check

Statically Mapping Multicast Groups to a P2MP Tunnel (Cisco IOS XR)

```
interface tunnel-mte1
 ipv4 unnumbered Loopback0
 destination 172.16.255.129
  path-option 10 explicit name PATH1
  path-option 20 dynamic
 !
 destination 172.16.255.130
  path-option 10 dynamic
 !
 priority 0 0
 signalled-bandwidth 100000
!
node-capability label-switched-multicast
multicast-routing
 address-family ipv4
  interface tunnel-mte1
   enable
  !
  interface all enable
 !
!
router igmp
 vrf default
  interface tunnel-mte1
   static-group 232.0.0.1 192.168.5.1
   static-group 232.0.0.2 192.168.5.1
  !
 !
!
```

- MPLS TE P2MP tunnel
- Destination with path-option list
- Destination with single path-option
- Signaled bandwidth and setup / hold priorities
- Enable MPLS multicast
- Enable multicast forwarding over tunnel-mte1
- Multicast groups mapped to tunnel-mte1

Configuring RPF Check at P2MP Tunnel Tail End (Cisco IOS XR)

```
multicast-routing
 address-family ipv4
  core-tree-protocol rsvp-te
  static-rpf 192.168.5.1 32 mpls 172.16.255.3
  interface all enable
 !
!
```

Enable IPv4/v6 multicast over P2MP TE LSP

Tunnel source (172.16.255.3) as next-hop for IP Multicast source (192.168.5.1) RPF check

Configuring MPLS TE and Link Information Distribution Using OSPF (Cisco IOS)

```
mpls traffic-eng tunnels
!
interface TenGigabitEthernet0/1/0
 ip address 172.16.0.0 255.255.255.254
 mpls traffic-eng tunnels
 mpls traffic-eng attribute-flags 0xF
 mpls traffic-eng administrative-weight 20
 ip rsvp bandwidth 100000
!
router ospf 100
 log-adjacency-changes
 passive-interface Loopback0
 network 172.16.0.0 0.0.255.255 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
```

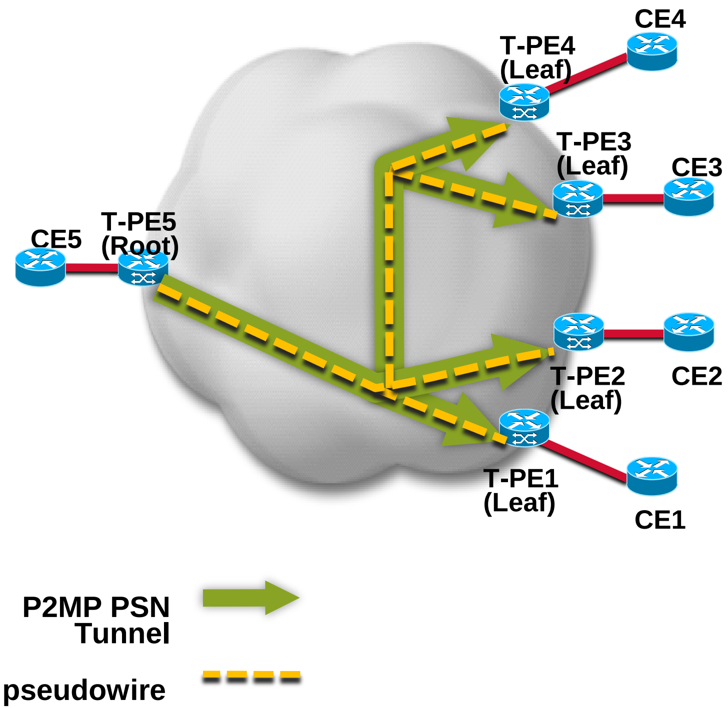
- Enable MPLS TE on this node (mpls traffic-eng tunnels)
- Enable MPLS TE on this interface (mpls traffic-eng tunnels)
- Attribute flags (mpls traffic-eng attribute-flags 0xF)
- TE metric (mpls traffic-eng administrative-weight 20)
- Maximum reservable bandwidth (ip rsvp bandwidth 100000)
- Enable TE extensions (TE router id and area) (mpls traffic-eng router-id Loopback0, mpls traffic-eng area 0)

Configuring MPLS TE and Link Information Distribution Using IS-IS (Cisco IOS XR)

```
router isis DEFAULT
 is-type level-2-only
 net 49.0001.1720.1625.5129.00
 address-family ipv4 unicast
  metric-style wide
  mpls traffic-eng level 2
  mpls traffic-eng router-id Loopback0
 !
 interface Loopback0
  passive
  address-family ipv4 unicast
  !
 !
 interface TenGigE0/0/0/0
  address-family ipv4 unicast
  !
 !
!
rsvp
 interface TenGigE0/0/0/0
  bandwidth 100000
 !
!
mpls traffic-eng
 interface TenGigE0/0/0/0
  admin-weight 5
  attribute-flags 0x8
 !
!
```

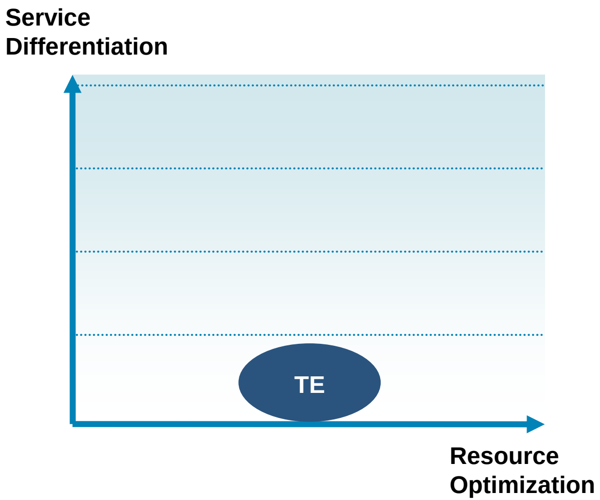
- Enable wide metric format and TE extensions (TE Id, router level)
- Configuration mode for RSVP global and interface commands
- Maximum reservable bandwidth
- Configuration mode for MPLS TE global and interface commands
- TE metric
- Attribute flags

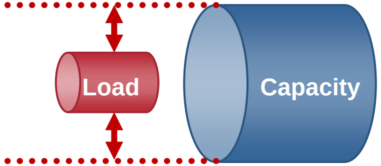
P2MP TE LSP Traffic Selection
Static P2MP Pseudowires



- Provides a layer-2 multicast service with segmentation
- Multicast forwarding plane from root to leaves (all traffic types: multicast, broadcast, unicast)
- Unicast forwarding plane from leaves to root
- Initial implementation supporting only static pseudowire
- Label bindings defined statically on root and leaves
- No control plane (targeted LDP)
- No context-specific label space on leaves

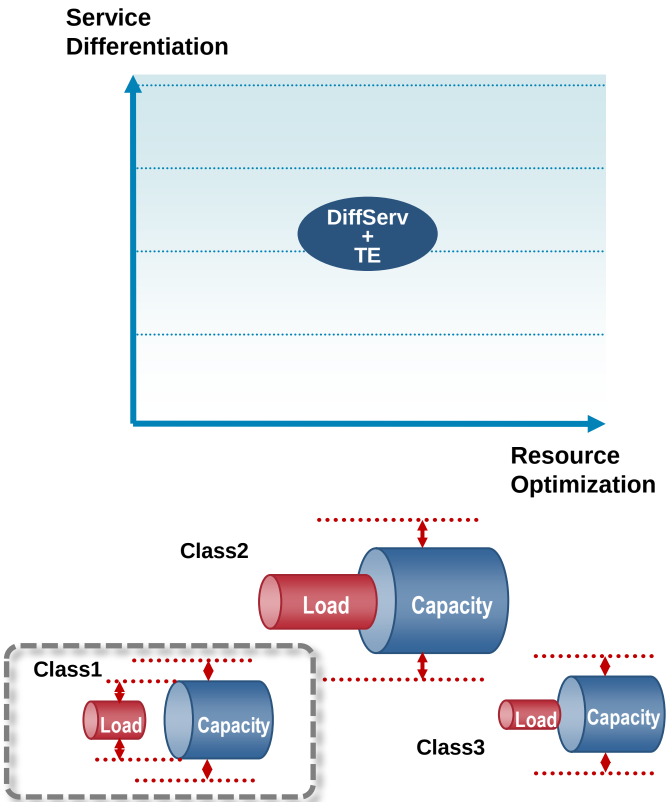
Network with MPLS TE





- A solution when:
  - No differentiation required
  - Optimization required
- Full mesh or selective deployment to avoid over-subscription
- Increased network utilization
- Adjust link load to actual link capacity
- No notion of traffic classes

Network with MPLS DiffServ and MPLS TE



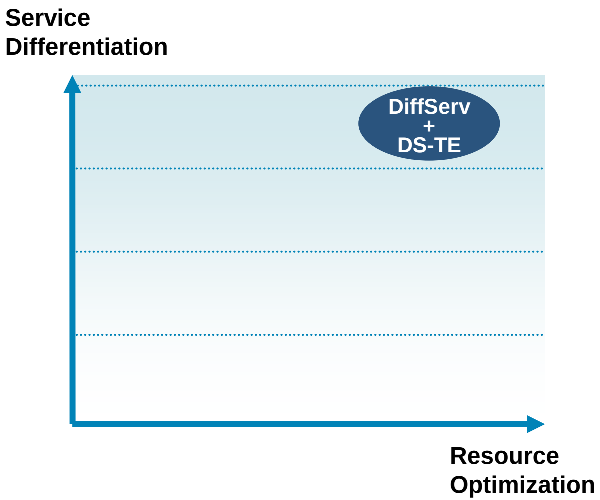
- A solution when:

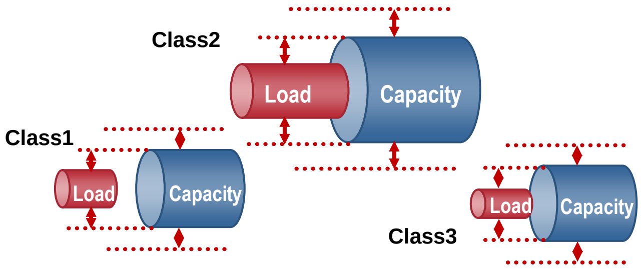
  Differentiation required

  Optimization required

- Adjust class capacity to expected class load
- Adjust class load to actual class capacity for one class
- Alternatively, adjust link load to actual link capacity

Network with MPLS DiffServ and MPLS DS-TE





- A solution when:
  - Strong differentiation required
  - Fine optimization required
- Control both load and capacity per class
- Adjust class capacity to expected class load
- Adjust class load to actual class capacity

Pre-standard DS-TE Implementation

- Only supports Russian Dolls Model (RDM) for bandwidth constraints
- No changes to RSVP-TE specs to signal desired pool (leverages ADSPEC object in PATH messages)
  - Sub-pool TE LSPs signaled as guaranteed service
  - Global pool TE LSPs signaled as controlled-load service
- Modified OSPF-TE and ISIS-TE advertisements to include two pools at 8 priority levels each (16 entries per link total)
- Available on IOS and IOS XR

What Is New in IETF DS-TE Implementation?

- Supports both RDM and MAM (Maximum Allocation Model) for bandwidth constraints
- New CLASSTYPE object in RSVP-TE to signal desired class-type (unused by “class-type 0” for backward compatibility with non-DS-TE)
- Minor Changes to OSPF-TE and ISIS-TE bandwidth advertisements
  - Same “unreserved bandwidth” sub-TLV (8 entries) as non-DS-TE interpreted according to local definition of TE-Class (class-type/preemption priority)
  - New BC sub-TLV
- Operates in migration or IETF mode in Cisco IOS
- Developed simultaneously for IOS and IOS XR

TE-Class Definition Examples

TE-Class definition MUST be consistent throughout the network

Default TE-Class definition

	Priority 0	Priority 1	Priority 2	Priority 3	Priority 4	Priority 5	Priority 6	Priority 7
CT0 (Global)	TE-Class4							TE-Class0
CT1 (Sub)	TE-Class5							TE-Class1

TE-Class definition compatible with non-DS-TE

	Priority 0	Priority 1	Priority 2	Priority 3	Priority 4	Priority 5	Priority 6	Priority 7
CT0 (Global)	TE-Class0	TE-Class1	TE-Class2	TE-Class3	TE-Class4	TE-Class5	TE-Class5	TE-Class7
CT1 (Sub)								

User-defined TE-Classes with no preemption between class-types

	Priority 0	Priority 1	Priority 2	Priority 3	Priority 4	Priority 5	Priority 6	Priority 7
CT0 (Global)					TE-Class4	TE-Class5	TE-Class6	TE-Class7
CT1 (Sub)	TE-Class0	TE-Class1	TE-Class2	TE-Class3				

User-defined TE-Classes with preemption between/within class-types

	Priority 0	Priority 1	Priority 2	Priority 3	Priority 4	Priority 5	Priority 6	Priority 7
CT0 (Global)		TE-Class1		TE-Class3		TE-Class5		TE-Class7
CT1 (Sub)	TE-Class0		TE-Class2		TE-Class4		TE-Class6	

MAM vs. RDM

MAM	RDM
One BC per CT	One or more CTs per BC
Sum of all BCs may exceed maximum reservable bandwidth	BC0 always equals to maximum reservable bandwidth
Preemption not required to provide bandwidth guarantees per CT	Preemption required to provide bandwidth guarantees per CT
Bandwidth efficiency and protection against QoS degradation are mutually exclusive	Provides bandwidth efficiency and protection against QoS degradation simultaneously

Configuring DS-TE Classes and Bandwidth Constraints (Cisco IOS)

RDM

```
mpls traffic-eng tunnels
mpls traffic-eng ds-te mode ietf
mpls traffic-eng ds-te te-classes
 te-class 0 class-type 1 priority 0
 te-class 1 class-type 1 priority 1
 te-class 2 class-type 1 priority 2
 te-class 3 class-type 1 priority 3
 te-class 4 class-type 0 priority 4
 te-class 5 class-type 0 priority 5
 te-class 6 class-type 0 priority 6
 te-class 7 class-type 0 priority 7
!
interface TenGigabitEthernet0/1/0
 ip address 172.16.0.0 255.255.255.254
 mpls traffic-eng tunnels
 ip rsvp bandwidth rdm bc0 155000 bc1 55000
!
```

Enable IETF DS-TE

Explicit TE-Class definition

RDM bandwidth constraints

MAM

```
mpls traffic-eng tunnels
mpls traffic-eng ds-te mode ietf
mpl traffic-eng ds-te bc-model mam
!
interface TenGigabitEthernet0/1/0
 ip address 172.16.0.0 255.255.255.254
 mpls traffic-eng tunnels
 ip rsvp bandwidth mam max-reservable-bw 155000 bc0 100000 bc1 55000
!
```

Enable IETF DS-TE and use default TE-Class definition

Enable MAM

MAM bandwidth constraints

Configuring DS-TE Tunnel (Cisco IOS)

```
interface Tunnel1
 description FROM-ROUTER-TO-DST1-CT0
 ip unnumbered Loopback0
 no ip directed-broadcast
 tunnel destination 172.16.255.3
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng priority 5 5
 tunnel mpls traffic-eng bandwidth 100000 class-type 0
 tunnel mpls traffic-eng path-option 10 dynamic
!
interface Tunnel2
 description FROM-ROUTER-TO-DST1-CT1
 ip unnumbered Loopback0
 no ip directed-broadcast
 tunnel destination 172.16.255.3
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng priority 0 0
 tunnel mpls traffic-eng bandwidth 50000 class-type 1
 tunnel mpls traffic-eng path-option 10 dynamic
!
```

Signal Tunnel1 with CT0 (priority and CT must match valid TE-Class)

Signal Tunnel2 with CT1 (priority and CT must match valid TE-Class)

Configuring DS-TE Classes and Bandwidth Constraints (Cisco IOS XR)

RDM

```
rsvp
 interface TenGigE0/0/0/0
  bandwidth rdm bc0 155000 bc1 55000
 !
!
mpls traffic-eng
 interface TenGigE0/0/0/0
 !
 ds-te mode ietf
 ds-te te-classes
  te-class 0 class-type 1 priority 0
  te-class 1 class-type 1 priority 1
  te-class 2 class-type 1 priority 2
  te-class 3 class-type 1 priority 3
  te-class 4 class-type 0 priority 4
  te-class 5 class-type 0 priority 5
  te-class 6 class-type 0 priority 6
  te-class 7 class-type 0 priority 7
 !
!
```

- RDM bandwidth constraints
- Enable IETF DS-TE
- Explicit TE-Class definition

MAM

```
rsvp
 interface TenGigE0/0/0/0
  bandwidth mam max-reservable-bw 155000 bc0 100000 bc1 55000
 !
!
mpls traffic-eng
 interface TenGigE0/0/0/0
 !
 ds-te mode ietf
 ds-te bc-model mam
!
```

- MAM bandwidth constraints
- Enable IETF DS-TE and use default TE-Class definition
- Enable MAM

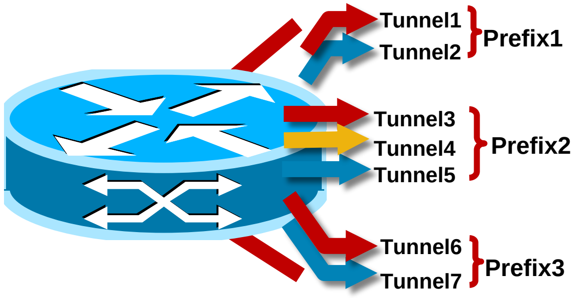
Configuring DS-TE Tunnels (Cisco IOS XR)

```
interface tunnel-te1
 description FROM-ROUTER-TO-DST1-CT0
 ipv4 unnumbered Loopback0
 priority 5 5
 signalled-bandwidth 100000 class-type 0
 destination 172.16.255.2
 path-option 10 dynamic
!
interface tunnel-te2
 description FROM-ROUTER-TO-DST1-CT1
 ipv4 unnumbered Loopback0
 priority 0 0
 signalled-bandwidth 50000 class-type 1
 destination 172.16.255.2
 path-option 10 dynamic
!
```

Signal tunnel-te1 with CT0 (priority and CT must match valid TE-Class)

Signal tunnel-te2 with CT1 (priority and CT must match valid TE-Class)

Policy-based Tunnel Selection: PBTS



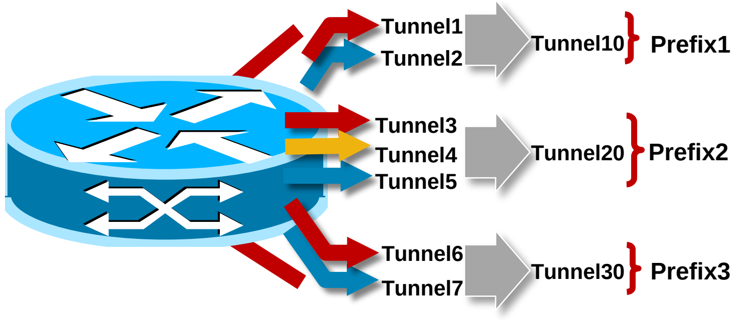
FIB

Prefix1, exp 5	tunnel-te1
Prefix1, *	tunnel-te2
Prefix2, exp 5	tunnel-te3
Prefix2, exp 2	tunnel-te4
Prefix2, *	tunnel-te5
Prefix3, exp 5	tunnel-te6
Prefix3, *	tunnel-te7

- EXP-based selection between multiple tunnels to same destination
- Local mechanism at head-end
- Tunnels configured via `policy-class` or `forwarding-class` with EXP values to carry
- No IGP extensions
- Supports VRF traffic, IP-to-MPLS and MPLS-to-MPLS switching

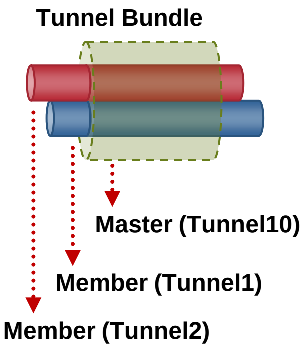
Class-Based Tunnel Selection: CBTS

- EXP-based selection between multiple tunnels to same destination
- Local mechanism at head-end (no IGP extensions)
- Tunnel master bundles tunnel members
- Tunnel selection configured on tunnel master (auto-route, etc.)
- Bundle members configured with EXP values to carry
- Bundle members may be configured as default
- Supports VRF traffic, IP-to-MPLS and MPLS-to-MPLS switching paths



FIB

Prefix1	Tunnel10
Prefix2	Tunnel20
Prefix3	Tunnel30



Configuring CBTS (Cisco IOS)

```
interface Tunnel1
 ip unnumbered Loopback0
 tunnel destination 172.16.255.2
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng bandwidth 50000 class-type 1
 tunnel mpls traffic-eng path-option 10 dynamic
 tunnel mpls traffic-eng exp 5
!
interface Tunnel2
 ip unnumbered Loopback0
 tunnel destination 172.16.255.2
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng bandwidth 100000 class-type 0
 tunnel mpls traffic-eng path-option 10 dynamic
 tunnel mpls traffic-eng exp default
!
interface Tunnel10
 ip unnumbered Loopback0
 tunnel destination 172.16.255.2
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng exp-bundle master
 tunnel mpls traffic-eng exp-bundle member Tunnel1
 tunnel mpls traffic-eng exp-bundle member Tunnel2
!
ip route 192.168.0.0 255.255.255.0 Tunnel10
!
```

Tunnel1 will carry packets with MPLS EXP 5

Tunnel2 will carry packets with MPLS EXP other than 5

Tunnel10 defined as bundle master with Tunnel2 and Tunnel1 as members

CBTS performed on prefix 192.168.0.0/24 using Tunnel10

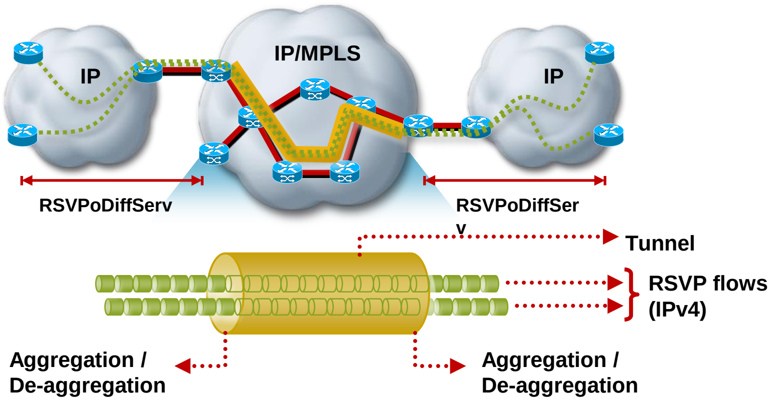
Configuring PBTS (Cisco IOS XR)

```
interface tunnel-te1
 ipv4 unnumbered Loopback0
 autoroute announce
 signalled-bandwidth 10000
 destination 172.16.255.2
 policy-class 5
 path-option 10 explicit name PATH1
 path-option 20 dynamic
!
interface tunnel-te2
 ipv4 unnumbered Loopback0
 autoroute announce
 signalled-bandwidth 50000
 destination 172.16.255.2
 path-option 10 explicit name PATH2
 path-option 20 dynamic
!
```

tunnel-te1 will carry packets with MPLS EXP 5

tunnel-te2 will carry packets with MPLS EXP other than 5 (default tunnel)

Tunnel-based Admission Control



- Tunnel aggregates RSVP (IPv4) flows
- No per-flow state in forwarding plane (only DiffServ)
- No per-flow state in control plane within MPLS TE network
- RSVP enhancements enable end-to-end admission control solution (Receiver Proxy, Sender Notification, Fast Local Repair)

Configuring Tunnel-based Admission Control (Cisco IOS)

```
interface Tunnel1
 ip unnumbered Loopback0
 tunnel destination 172.16.255.2
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng priority 7 7
 tunnel mpls traffic-eng bandwidth 100000
 tunnel mpls traffic-eng path-option 10 dynamic
 ip rsvp policy local default
  maximum senders 200
  maximum bandwidth single 1000
  forward all
 ip rsvp bandwidth 100000
!
interface GigabitEthernet3/3/0
 ip address 192.168.0.1 255.255.255.254
 service-policy output OUT-POLICY
 ip rsvp bandwidth percent 10
 ip rsvp listener outbound reply
 ip rsvp data-packet classification none
 ip rsvp resource-provider none
!
ip rsvp qos
!
```

- Signaled bandwidth
- RSVP local policy (200 flows max, 1Mbps per flow max)
- Maximum reservable bandwidth
- Interface QoS policy (DiffServ)
- Maximum reservable bandwidth
- Act as RSVP receiver proxy on this interface
- No RSVP flow classification
- No RSVP flow queuing
- Enable per-flow RSVP

Configuring FRR (Cisco IOS)

Primary Tunnel

```
interface Tunnel1
 description FROM-ROUTER-TO-DST1-FRR
 ip unnumbered Loopback0
 tunnel destination 172.16.255.2
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng bandwidth  20000
 tunnel mpls traffic-eng path-option 10 dynamic
 tunnel mpls traffic-eng fast-reroute
!
```

Indicate the desire for local protection during signaling

Backup Tunnel

```
interface Tunnel1
 description NNHOP-BACKUP
 ip unnumbered Loopback0
 tunnel destination 172.16.255.2
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng path-option 10 explicit name PATH1
!
interface TenGigabitEthernet1/0/0
 ip address 172.16.192.5 255.255.255.254
 mpls traffic-eng tunnels
 mpls traffic-eng backup-path Tunnel1
 ip rsvp bandwidth
!
```

Explicitly routed backup to 172.16.255.2 with zero bandwidth

Use Tunnel1 as backup for protected LSPs through TenGigabitEthernet1/0/0

Configuring FRR (Cisco IOS XR)

Primary Tunnel

```
interface tunnel-te1
 description FROM-ROUTER-TO-DST1-FRR
 ipv4 unnumbered Loopback0
 signalled-bandwidth 30000
 destination 172.16.255.2
 fast-reroute
 path-option 10 dynamic
!
```

Indicate the desire for local protection during signaling

Backup Tunnel

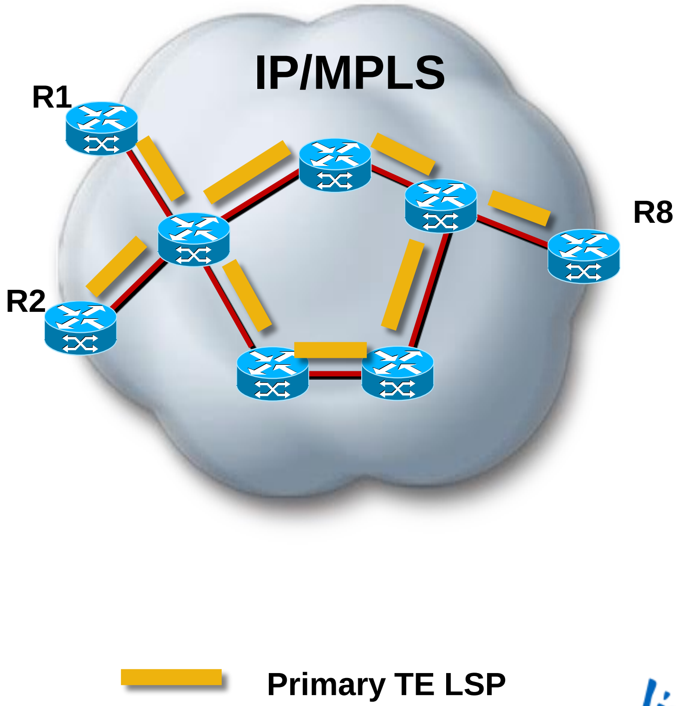
```
interface tunnel-te1
 description NHOP-BACKUP
 ipv4 unnumbered Loopback0
 destination 172.16.255.130
 path-option 10 explicit name PATH1
!
mpls traffic-eng
 interface TenGigE0/0/0/0
  backup-path tunnel-te 1
 !
!
```

Explicitly routed backup to 172.16.255.130 with zero bandwidth

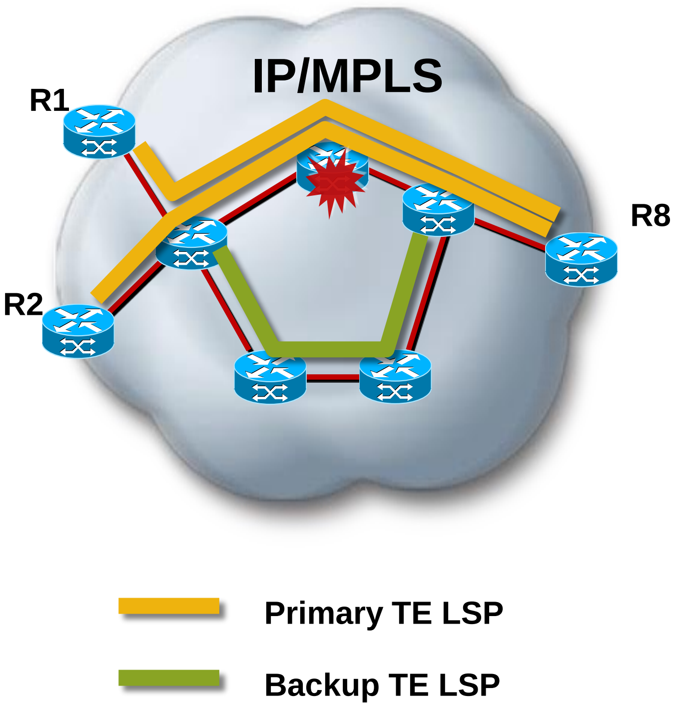
Use tunnel-te1 as backup for protected LSPs through TenGigE0/0/0/0

AutoTunnel: Primary Tunnels
Why One-Hop Tunnels?

- CSPF and SPF yield same results (absence of tunnel constraints)
- Auto-route forwards all traffic through one-hop tunnel
- Traffic logically mapped to tunnel but no label imposed (imp-null)
- traffic is forwarded as if no tunnel was in place



AutoTunnel: Backup Tunnels What's the Solution? (Cont.)



- Backup tunnels are preconfigured

Priority	7/7
Bandwidth	0
Affinity	0x0/0xFFFF
Auto-BW	OFF
Auto-Route	OFF
Fast-Reroute	OFF
Forwarding-Adj	OFF
Load-Sharing	OFF

- Backup tunnel interfaces and paths not shown on router configuration

Configuring SRLG (Cisco IOS)

```
mpls traffic-eng tunnels
mpls traffic-eng auto-tunnel backup nhop-only
mpls traffic-eng auto-tunnel backup srlg exclude force
!
interface TenGigabitEthernet0/1/0
 ip address 172.16.0.0 255.255.255.254
 mpls traffic-eng tunnels
 mpls traffic-eng srlg 15
 mpls traffic-eng srlg 25
 ip rsvp bandwidth
!
interface TenGigabitEthernet1/0/0
 ip address 172.16.0.2 255.255.255.254
 mpls traffic-eng tunnels
 mpls traffic-eng srlg 25
 ip rsvp bandwidth
!
```

Force SRLG exclusion during backup path computation

Interface member of SRLG 15 and 25

Interface member of SRLG 25

Configuring Path Protection (Cisco IOS)

```
interface Tunnel1
 ip unnumbered Loopback0
 tunnel mode mpls traffic-eng
 tunnel destination 172.16.255.2
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng path-option 10 explicit name PATH1
 tunnel mpls traffic-eng path-option 20 explicit name PATH2
 tunnel mpls traffic-eng path-option protect 10 explicit name PPATH1
 tunnel mpls traffic-eng path-option protect 20 explicit name PPATH2
!
```

Standby path to be used for PATH1

Standby path to be used for PATH2

Configuring Enhanced Path Protection (Cisco IOS)

```
mpls traffic-eng path-option list name PATH-LST
 path-option 10 explicit name PE1-P3-P4-PE2
 path-option 20 explicit name PE1-P5-P6-PE2
 path-option 30 explicit name PE1-P7-P8-PE2
!
interface Tunnel1
 ip unnumbered Loopback0
 tunnel mode mpls traffic-eng
 tunnel destination 172.16.255.2
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng path-option 10 explicit name PE1-P1-P2-PE2
 tunnel mpls traffic-eng path-option protect 10 list name PATH-LST
!
```

List of standby paths

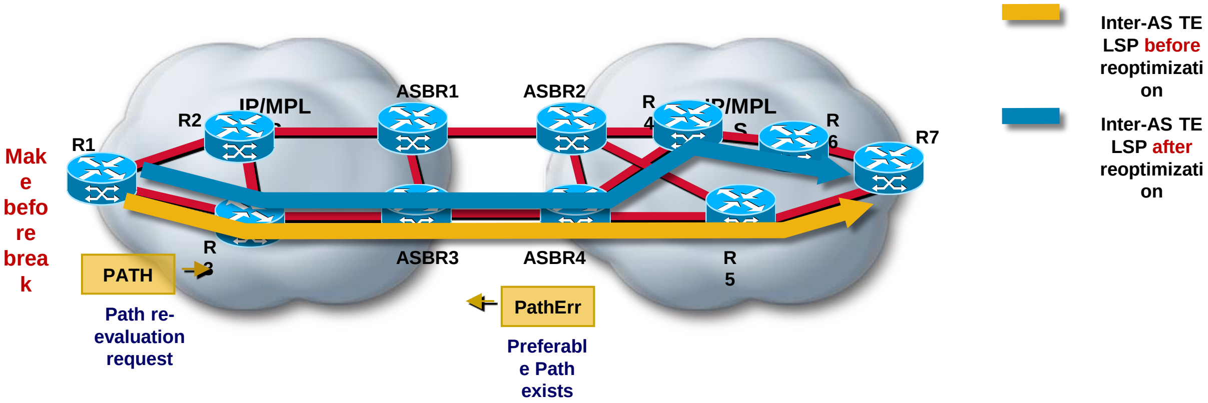
Use path list to protect primary path

Configuring Path Protection (Cisco IOS XR)

```
interface tunnel-te1
 description FROM-ROUTER-TO-DST1
 ipv4 unnumbered Loopback0
 signalled-bandwidth 100000
 destination 172.16.255.2
 affinity f mask f
 path-protection
 path-option 10 explicit name PATH1
 path-option 20 explicit name PATH2
 path-option 30 dynamic
!
```

Signal an acceptable (node-link, node, link diverse) standby TE LSP based on path-option sequence

Inter-Domain TE – TE LSP Reoptimization



- Reoptimization can be timer/event/admin triggered
- Head end sets ‘path re-evaluation request’ flag (SESSION_ATTRIBUTE)
- Head end receives PathErr message notification from boundary router if a preferable path exists
- Make-before-break TE LSP setup can be initiated after PathErr notification

Configuring Inter-Area Tunnels (Cisco IOS)

```
mpls traffic-eng tunnels
!
interface Tunnel1
 ip unnumbered Loopback0
 no ip directed-broadcast
 tunnel destination 172.16.255.7
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng path-option 10 explicit name LOOSE-PATH
!
ip route 172.16.255.7 255.255.255.255 Tunnel1
!
ip explicit-path name LOOSE-PATH enable
 next-address loose 172.16.255.3
 next-address loose 172.16.255.5
!
```

Loose-hop path

Static route mapping IP traffic to Tunnel1

List of ABRs as loose hops

Configuring Inter-Area Tunnels with Autoroute Destinations (Cisco IOS)

```
interface Tunnel1
 ip unnumbered Loopback0
 tunnel mode mpls traffic-eng
 tunnel destination 172.16.255.7
 tunnel mpls traffic-eng autoroute destination
 tunnel mpls traffic-eng path-option 10 explicit name LOOSE-PATH
!
ip explicit-path name LOOSE-PATH enable
 next-address loose 172.16.255.3
 next-address loose 172.16.255.5
!
```

- `tunnel mpls traffic-eng autoroute destination`: Create static route to tunnel destination (172.16.255.7)
- `tunnel mpls traffic-eng path-option 10 explicit name LOOSE-PATH`: Loose-hop path
- `next-address loose` entries: List of **ABRs** as loose hops

Configuring Inter-Area Tunnels (Cisco IOS XR)

```
explicit-path name LOOSE-PATH
 index 1 next-address loose ipv4 unicast 172.16.255.129
 index 2 next-address loose ipv4 unicast 172.16.255.131
!
interface tunnel-te1
 description FROM-ROUTER-TO-DST3
 ipv4 unnumbered Loopback0
 destination 172.16.255.2
 path-option 10 explicit name LOOSE-PATH
!
router static
 address-family ipv4 unicast
  172.16.255.2/32 tunnel-te1
 !
```

List of ABRs as loose hops

Loose-hop path

Static route mapping IP traffic to tunnel-te1

Configuring Inter-AS Tunnels (Cisco IOS)

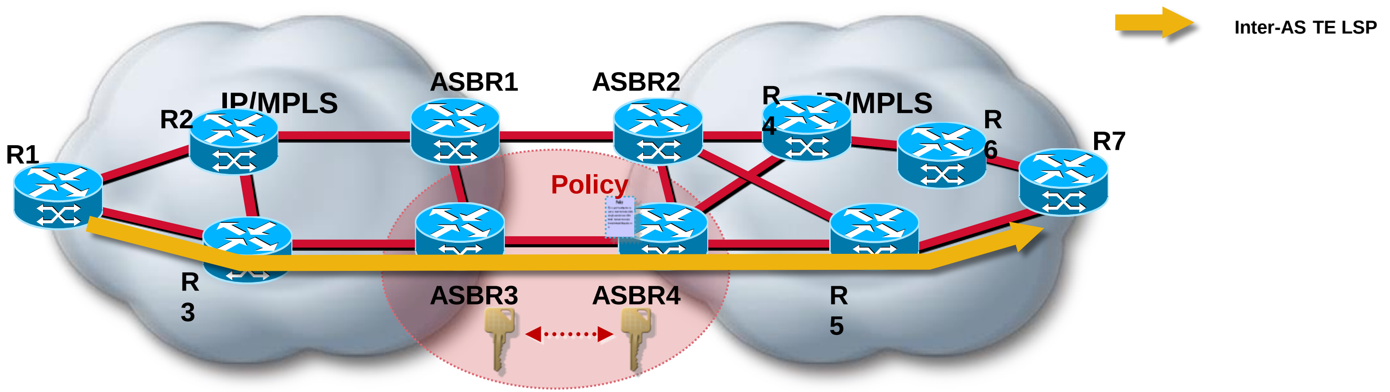
```
mpls traffic-eng tunnels
!
interface Tunnel1
 ip unnumbered Loopback0
 no ip directed-broadcast
 tunnel destination 172.31.255.5
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng priority 7 7
 tunnel mpls traffic-eng bandwidth  1000
 tunnel mpls traffic-eng path-option 10 explicit name LOOSE-PATH
!
ip route 172.31.255.5 255.255.255.255 Tunnel1
!
ip explicit-path name LOOSE-PATH enable
 next-address loose 172.24.255.1
 next-address loose 172.31.255.1
!
```

Loose-hop path

Static route mapping IP traffic to Tunnel1

List of ASBRs as loose hops

Inter-Domain TE – Authentication and Policy Control



- Authentication and policy control desirable for Inter-AS deployments
- ASBR may perform RSVP authentication (MD5/SHA-1)
- ASBR may enforce a local policy for Inter-AS TE LSPs (e.g. limit bandwidth, message types, protection, etc.)

Configuring Inter-AS TE at ASBR (Cisco IOS)

```
mpls traffic-eng tunnels
!
key chain A-ASBR1-key
 key 1
  key-string 7 151E0E18092F222A
!
interface Serial1/0
 ip address 192.168.0.1 255.255.255.252
 mpls traffic-eng tunnels
 mpls traffic-eng passive-interface nbr-te-id 172.16.255.4 nbr-igp-id ospf
172.16.255.4
 ip rsvp bandwidth
 ip rsvp authentication key-chain A-ASBR1-key
 ip rsvp authentication type sha-1
 ip rsvp authentication
!
router bgp 65024
 no synchronization
 bgp log-neighbor-changes
 neighbor 172.24.255.3 remote-as 65024
 neighbor 172.24.255.3 update-source Loopback0
 neighbor 192.168.0.2 remote-as 65016
 no auto-summary
!
ip rsvp policy local origin-as 65016
 no fast-reroute
 maximum bandwidth single 10000
 forward all
!
```

- Authentication key
- Add ASBR link to TE topology database
- Enable RSVP authentication
- Process signaling from AS 65016 if FRR not requested and 10M or less

Distributed Path Computation with Backward Recursive PCE-based Computation (BRPC)

- Head-end sends request to a path computation element (PCE)
- PCE recursively computes virtual shortest path tree (SPT) to destination
- Head-end receives reply with virtual SPT if a path exists
- Head-end uses topology database and virtual SPT to compute end-to-end path
- Head-end can discover PCEs dynamically or have them configured statically

Configuring MPLS TE and LDP Simultaneously (Cisco IOS)

```
mpls label protocol ldp
mpls traffic-eng tunnels
!
interface TenGigabitEthernet0/1/0
 ip address 172.16.0.0 255.255.255.254
 mpls traffic-eng tunnels
 mpls ip
 ip rsvp bandwidth  155000
!
```

- Enable LDP
- Enable MPLS TE
- Enable MPLS TE on interface
- Enable MPLS forwarding for IP (LDP)

Configuring MPLS TE and LDP Simultaneously (Cisco IOS XR)

```
rsvp
 interface TenGigE0/0/0/0
  bandwidth 155000
 !
!
mpls traffic-eng
 interface TenGigE0/0/0/0
 !
!
mpls ldp
 interface TenGigE0/0/0/0
 !
!
```

Configuration mode for RSVP global and interface commands

Configuration mode for MPLS TE global and interface commands

Configuration mode for LDP global and interface commands

Configuring LDP Over a TE Tunnel (Cisco IOS)

```
mpls label protocol ldp
mpls traffic-eng tunnels
!
interface Tunnel1
 ip unnumbered Loopback0
 mpls ip
 tunnel destination 172.16.255.3
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng path-option 10 dynamic
!
```

Enable LDP

Enable MPLS forwarding for IP (LDP) on Tunnel1

Configuring LDP Over a TE Tunnel (Cisco IOS XR)

```
interface tunnel-te1
 ipv4 unnumbered Loopback0
 priority 0 0
 signalled-bandwidth 80000
 autoroute announce
 destination 172.16.255.130
 path-option 10 dynamic
!
rsvp
 interface TenGigE0/0/0/1
  bandwidth 155000
 !
!
mpls traffic-eng
 interface TenGigE0/0/0/1
 !
!
mpls ldp
 interface TenGigE0/0/0/0
 !
 interface tunnel-te1
 !
!
```

Enable LDP

Enable LDP on tunnel-te1

MPLS TE on Ethernet Bundle (Cisco IOS)

```
interface Port-channel1
 ip address 172.16.0.0 255.255.255.254
 mpls traffic-eng tunnels
 mpls traffic-eng attribute-flags 0xF
 mpls traffic-eng administrative-weight 20
 ip rsvp bandwidth percent 100
!
interface GigabitEthernet2/0/0
 no ip address
 channel-protocol lacp
 channel-group 1 mode active
!
interface GigabitEthernet2/0/1
 no ip address
 channel-protocol lacp
 channel-group 1 mode active
!
```

- mpls traffic-eng tunnels — Enable MPLS TE on this interface
- mpls traffic-eng attribute-flags 0xF — Attribute flags
- mpls traffic-eng administrative-weight 20 — TE metric
- ip rsvp bandwidth percent 100 — Maximum reservable bandwidth (100% of total bundle bandwidth)
- channel-protocol lacp — LACP as channel protocol
- channel-group 1 mode active — Associate with Port-channel1 and enable LACP (non-passive)
- channel-protocol lacp — LACP as channel protocol
- channel-group 1 mode active — Associate with Port-channel1 and enable LACP (non-passive)

MPLS TE on Ethernet Bundle (Cisco IOS XR)

```
interface Bundle-Ether1
 ipv4 address 172.16.0.1 255.255.255.254
!
interface GigabitEthernet0/1/0/0
 bundle id 1 mode active
 negotiation auto
!
interface GigabitEthernet0/1/0/1
 bundle id 1 mode active
 negotiation auto
!
router ospf 172
 area 0
  mpls traffic-eng
  interface Bundle-Ether1
   network point-to-point
  !
  interface Loopback0
   passive enable
  !
!
 mpls traffic-eng router-id Loopback0
!
rsvp
 interface Bundle-Ether1
  bandwidth 2000000
 !
!
mpls traffic-eng
 interface Bundle-Ether1
 !
!
```

Interface for bundle id 1

Associate with bundle id 1 (Bundle-Ether1) and enable LACP (non-passive)

Associate with bundle id 1 (Bundle-Ether1) and enable LACP (non-passive)

Enable OSPF on bundle

Maximum reservable bandwidth on bundle

Enable MPLS TE on bundle

Per-VRF Tunnel Selection (Cisco IOS)

```
ip vrf RED
 rd 65172:2
 route-target export 65172:2
 route-target import 65172:2
 bgp next-hop Loopback1
!
interface Loopback0
 ip address 172.16.255.1 255.255.255.255
!
interface Loopback1
 ip address 172.16.255.101 255.255.255.255
!
interface Tunnel1
 description FROM-ROUTER-VRF-TO-DST1
 ip unnumbered Loopback0
 tunnel destination 172.16.255.2
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng path-option 10 dynamic
!
ip route 172.16.255.102 255.255.255.255 Tunnel1
!
```

Loopback1 advertised as next hop for VRF RED

Remote next hop mapped to Tunnel1

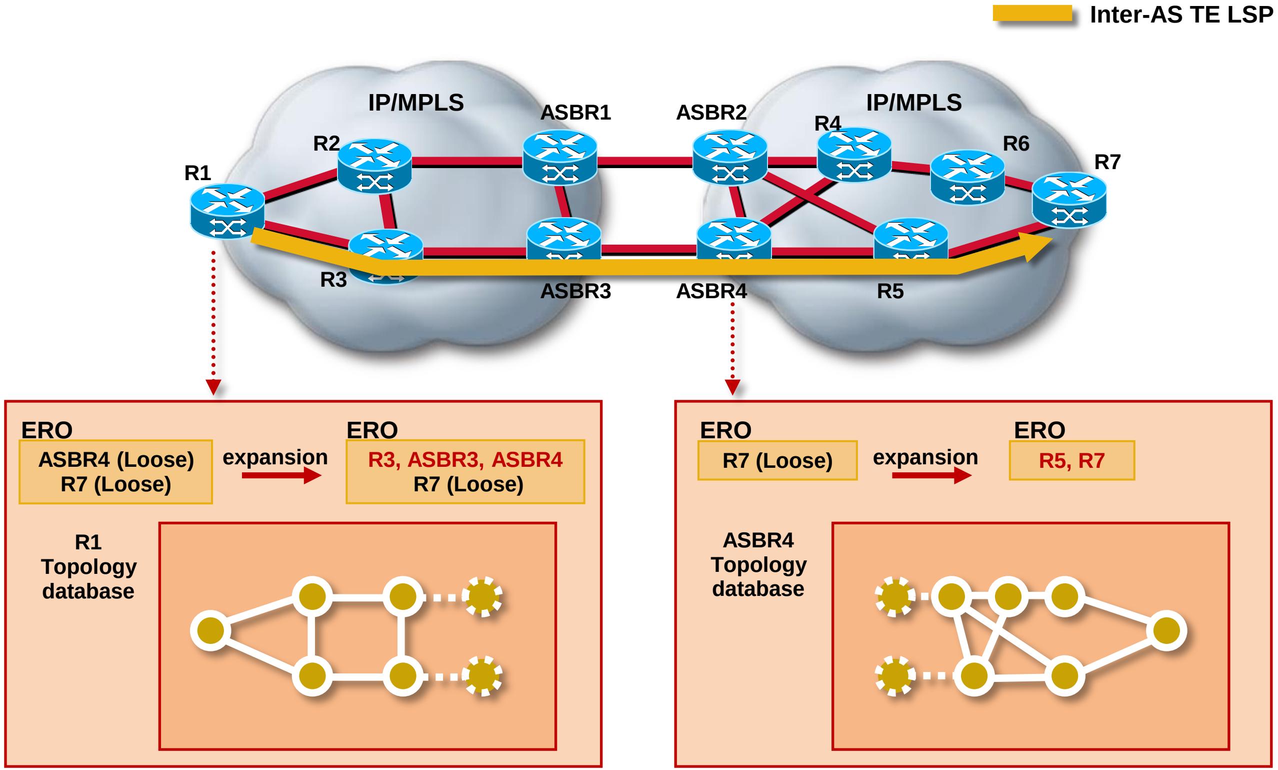



Inter-Domain Traffic Engineering

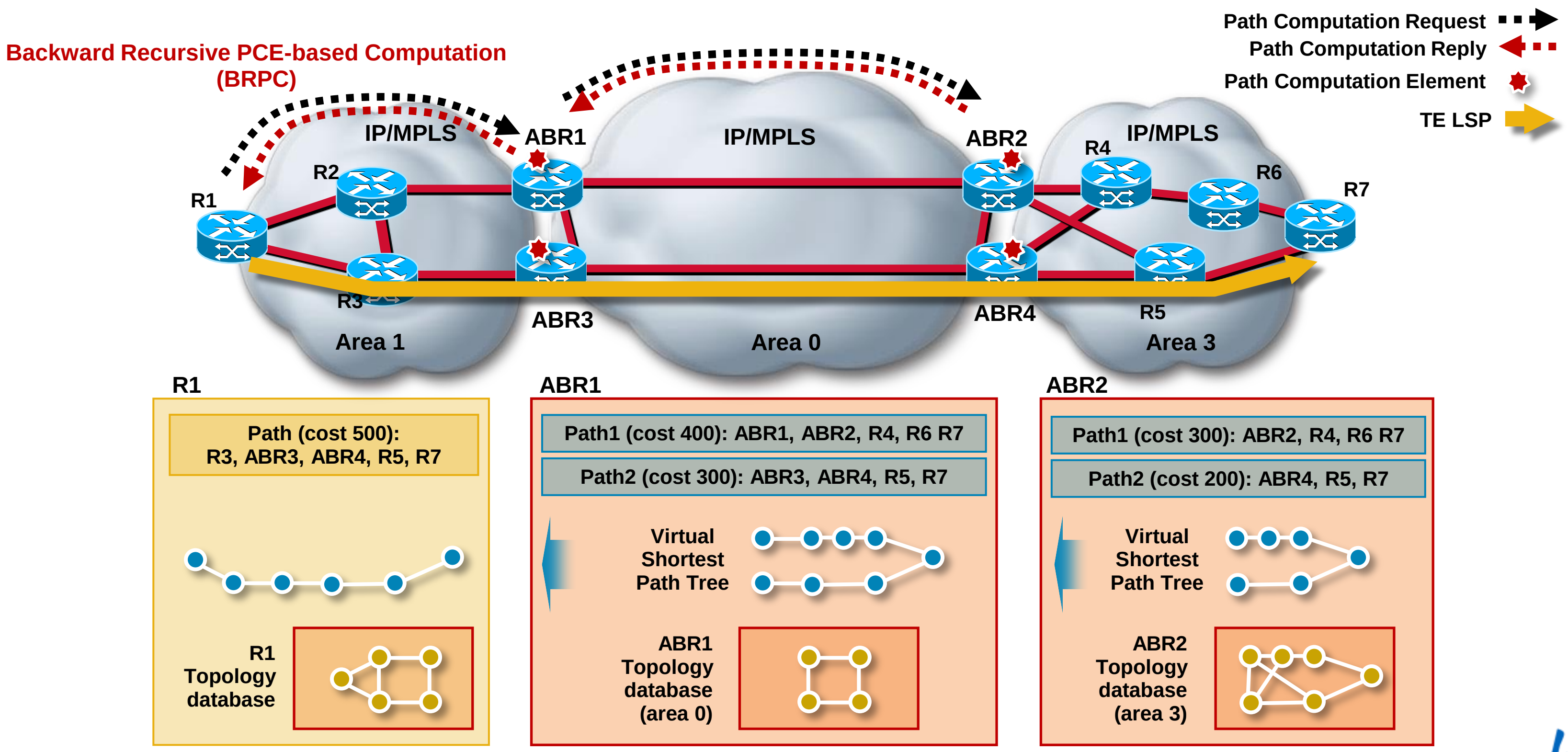
Inter-Domain Traffic Engineering: Introduction

- Domain defined as an IGP area or autonomous system
- Head end lacks complete network topology to perform path computation in both cases
- Two path computation approaches
  - Per-domain (ERO loose-hop expansion)
  - Distributed (Path Computation Element)

Per-Domain Path Computation Using ERO Loose-hop Expansion



Distributed Path Computation using Path Computation Element



Configuring PCE (Cisco IOS XR)

Headend

```
interface tunnel-te1
 description FROM-ROUTER-TO-DST2
 ipv4 unnumbered Loopback0
 destination 172.16.255.1
 path-option 10 dynamic pce
!
router static
 address-family ipv4 unicast
  172.16.255.1/32 tunnel-te1
 !
!
```

Use discovered PCEs for path computation

Static route mapping IP traffic to tunnel-te1

PCE

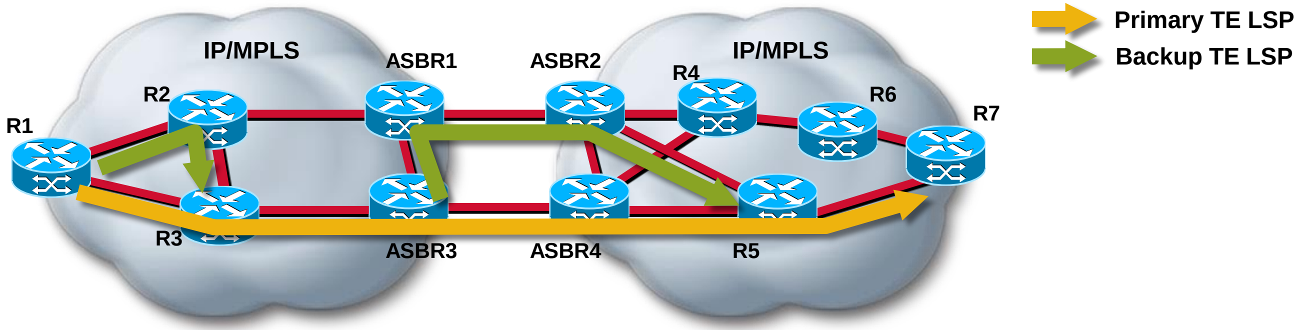
```
mpls traffic-eng
 pce deadtimer 30
 pce address ipv4 172.16.255.129
 pce keepalive 10
!
```

Declare peer down if no keepalive in 30s

Advertise PCE capability with address 172.16.255.129

Send per keepalive every 10s

Inter-Domain TE – Fast Re-route



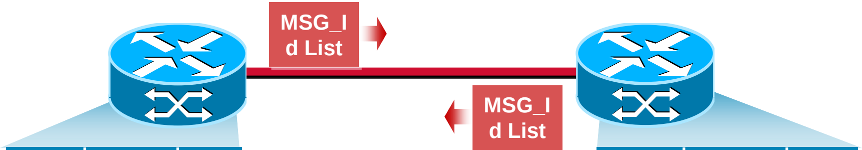
- Same configuration as single domain scenario
- Support for node-id sub-object required to implement ABR/ASBR node protection
- Node-id helps point of local repair (PLR) detect a merge point (MP)

Inter-Domain TE
Take into Account before Implementing

- Semantics of link attributes across domain boundaries
- Semantics of TE-Classes across domain boundaries for DS-TE
- Auto-route destinations creates a static route to tunnel destination and facilitates traffic selection
- Auto-route announce not applicable for traffic selection

Scaling Signaling (Refresh Reduction)

SRefresh Message



	MSG_Id	Path State
LSP1	22	…
LSP2	62	…
:	:	…
LSPn	94	…

	MSG_Id	Resv State
LSP1	43	…
LSP2	37	…
:	:	…
LSPn	29	…

- RSVP soft state needs to be refreshed periodically
- Refresh reduction extensions use message Identifier associated with Path/Resv state
- Summary Refresh (SRefresh) message refreshes state using a message_id list
- SRefresh only replaces refresh Path/Resv messages

Configuring Refresh Reduction (Cisco IOS)

```
mpls traffic-eng tunnels
!
interface TenGigabitEthernet0/1/0
 ip address 172.16.0.0 255.255.255.254
 mpls traffic-eng tunnels
 ip rsvp bandwidth 100000
!
router ospf 100
 log-adjacency-changes
 passive-interface Loopback0
 network 172.16.0.0 0.0.255.255 area 0
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
!
ip rsvp signalling refresh reduction
!
```

Enable refresh reduction

*** Enabled by default in Cisco IOS XR**

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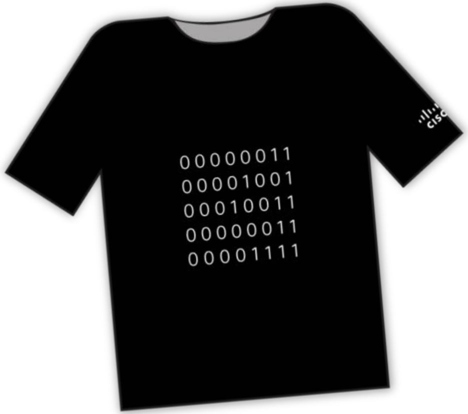

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