NETWORKERS 2004

DEPLOYING MPLS TRAFFIC ENGINEERING

SESSION RST-2603

Some Assumptions

- You understand basic IP routing
- You understand MPLS concepts and operation
- You understand how a link-state protocol works
- Some knowledge of QoS is useful
- You will still be awake at the end of this

A Blatant Plug

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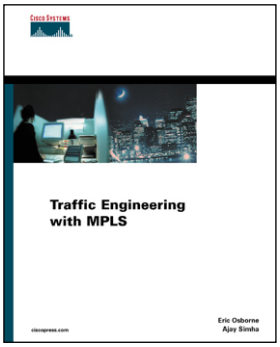
- **Traffic Engineering with MPLS**

  ISBN: 1-58705-031-5

- **Now available in Portuguese and Chinese!**



Agenda

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- **Traffic Engineering Overview**
- **Traffic Engineering Theory**
- **Configuration**
- **Protection**
- **Diffserv Traffic Engineering (DS-TE)**
- **Design and Scalability**
- **MPLS-VPN, Multicast and TE**
- **Summary**

TRAFFIC ENGINEERING OVERVIEW

Network vs. Traffic Engineering

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- **Network engineering**
  - **Build your network to carry your predicted traffic**
- **Traffic engineering**
  - **Manipulate your traffic to fit your network**
- **Traffic patterns are impossible to accurately predict**
- **Symmetric bandwidths/topologies, asymmetric load**
- **TE can be done with IGP costs, ATM/FR, or MPLS**

Motivation for Traffic Engineering

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- **Increase efficiency of bandwidth resources**
  - **Prevent over-utilized (congested) links whilst other links are under-utilized**
- **Ensure the most desirable/appropriate path for some/all traffic**
  - **Override the shortest path selected by the IGP**
- **Replace ATM/FR cores**
  - **PVC-like traffic placement without IGP full mesh and associated O(N^2) flooding**
- **The ultimate goal is COST SAVING**
  - **Service development also progressing**

The "Fish" Problem (Shortest Path)

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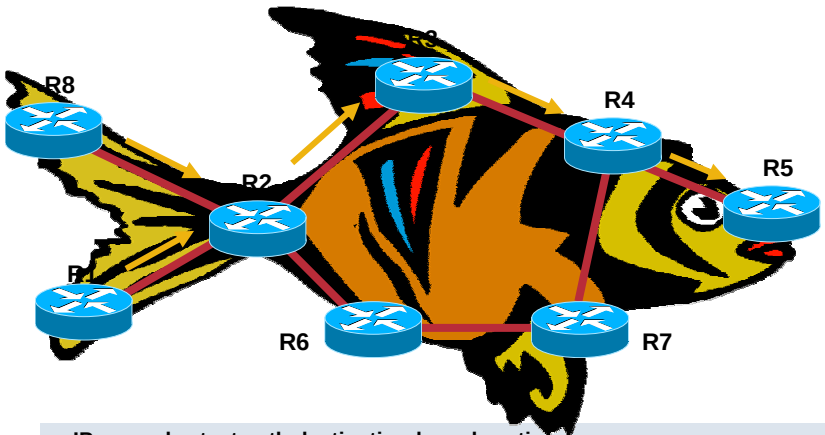
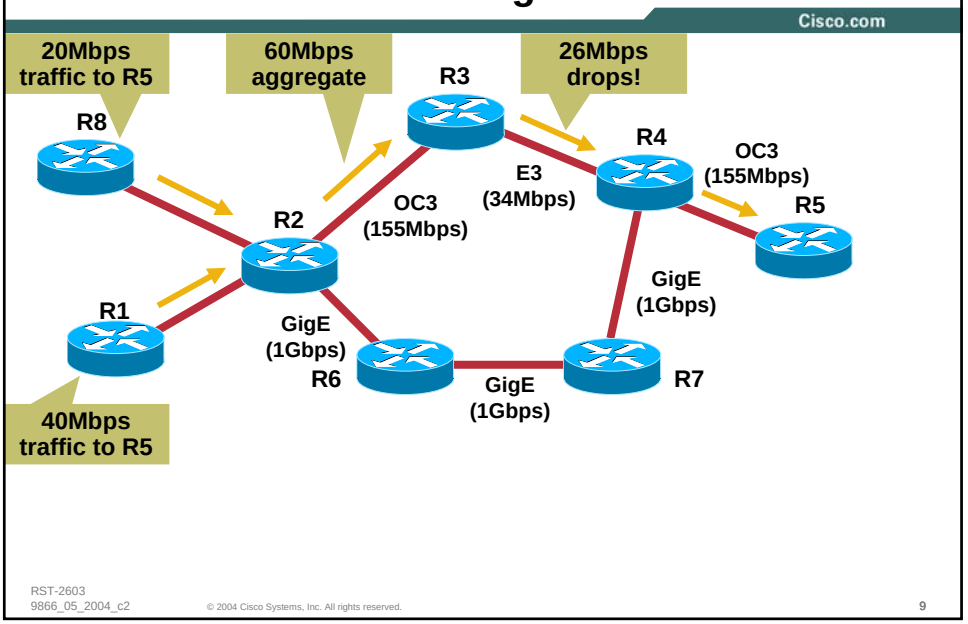


- **IP uses shortest path destination-based routing**
- **Shortest path may not be the only path**
- **Alternate paths may be under-utilized**
- **Whilst the shortest path is over-utilized**

Shortest Path and Congestion



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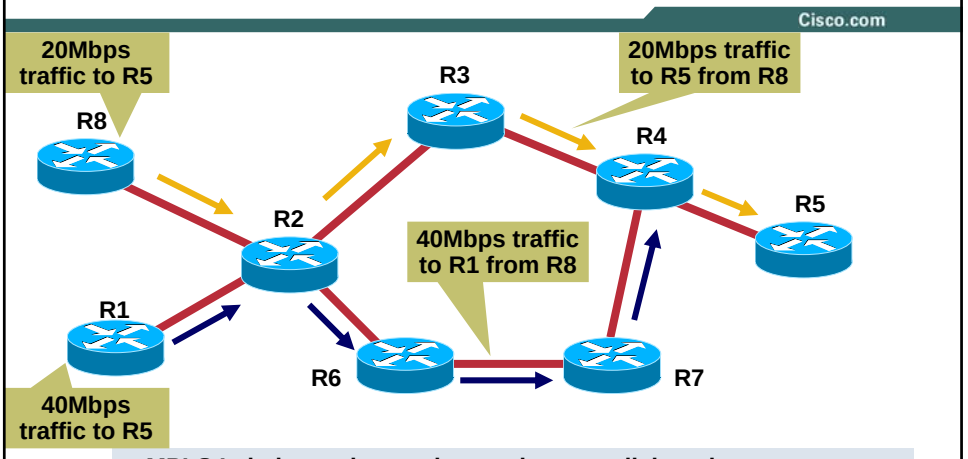
The TE Solution



- MPLS Labels can be used to engineer explicit paths
- Tunnels are UNI-DIRECTIONAL

Normal path: R8 → R2 → R3 → R4 → R5

Tunnel path: R1 → R2 → R6 → R7 → R4

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Terminology

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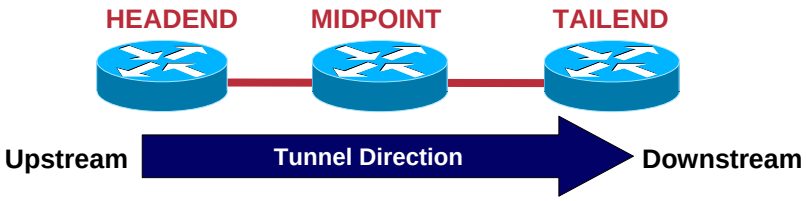
- **Constrained-Based Shortest Path First (CSPF)**
  - **MPLS-TE uses CSPF to create a shortest path based on a series of constraints:**
    - **Bandwidth**
    - **Affinity/link attributes**
    - **…or an explicitly configured path**
- **Tunnels are UNI-DIRECTIONAL!**



TRAFFIC ENGINEERING THEORY

Traffic Engineering Components

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- Information distribution
- Path selection/calculation
- Path setup
- Trunk admission control
- Forwarding traffic on to tunnel
- Path maintenance

Information Distribution

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- Need to flood TE information (Resource Attributes) across the network
  - Available bandwidth per priority level, a few other things
- IGP extensions flood this information
  - OSPF uses Type 10 (area-local) Opaque LSAs
  - ISIS uses new TLVs
- Basic IGP: {self, neighbors, cost to neighbors}
- TE extensions: {self, neighbors, cost to neighbors, available bandwidth to neighbors}
- TE bandwidth is a control-plane number only

Path Calculation

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- Once available bandwidth information and attributes are flooded, router may calculate a path from head to tail
  - Path may be explicitly configured by operator
- TE Headend does a “Constrained SPF” (CSPF) calculation to find the best path
- CSPF is just like regular IGP SPF, except
  - Takes required bandwidth and attributes into account
- Looks for best path from a head to a single tail (unlike OSPF)
- Minimal impact on CPU utilization using CSPF
- Path can also be explicitly configured

Path Setup

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- Once the path is calculated, it must be signaled across the network
  - Reserve any bandwidth to avoid “double booking” from other TE reservations
  - Priority can be used to pre-empt low priority existing tunnels
- RSVP used to set up TE LSP
  - PATH messages (from head to tail) carries LABEL_REQUEST
  - RESV messages (from tail to head) carries LABEL
- When RESV reaches headend, tunnel interface = UP
- RSVP messages exist for LSP teardown and error sig

Trunk Admission Control

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- **On receipt of PATH message**
  - **Router will check there is bandwidth available to honour the reservation**
  - **If bandwidth available then RSVP accepted**
- **On receipt of a RESV message**
  - **Router actually reserves the bandwidth for the TE LSP**
  - **If pre-emption is required lower priority LSP are torn down**
- **OSPF/ISIS updates are triggered**

Path Setup Example

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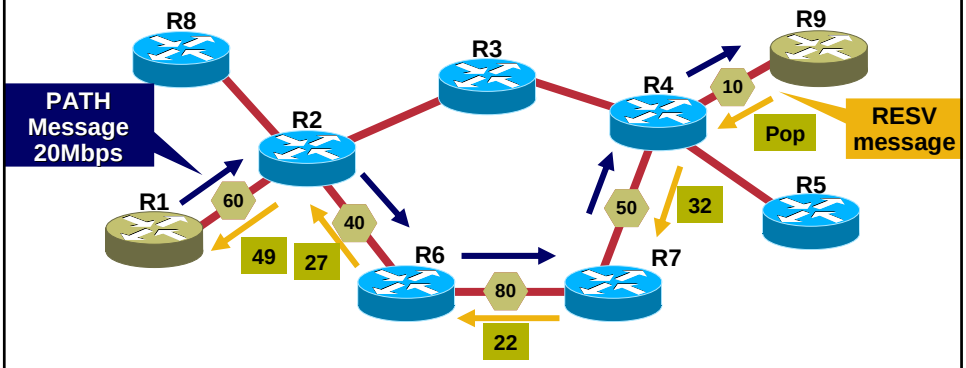

RSVP PATH: R1 → R2 → R6 → R7 → R4 → R9
RSVP RESV: Returns labels and reserves bandwidth on each link
80 Bandwidth available
49 Returned label via RESV message

Forwarding Traffic to a Tunnel

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- Static routing
- Policy routing
  - Global table only—not from VRF at present
- Autoroute
- Forwarding Adjacency

Static, autoroute, and forwarding adjacency get you unequal-cost load-balancing

Autoroute

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- Used to include TE LSP in SPF calculations
- IGP adjacency is NOT run over the tunnel!
- Tunnel is treated as a directly connected link to the tail
  - When tunnel tail is seen in PATH list during IGP SPF, replace outgoing physical interface with tunnel interface
  - Inherit tunnel to all downstream neighbors of said tail

Autoroute Topology (OSPF and ISIS)

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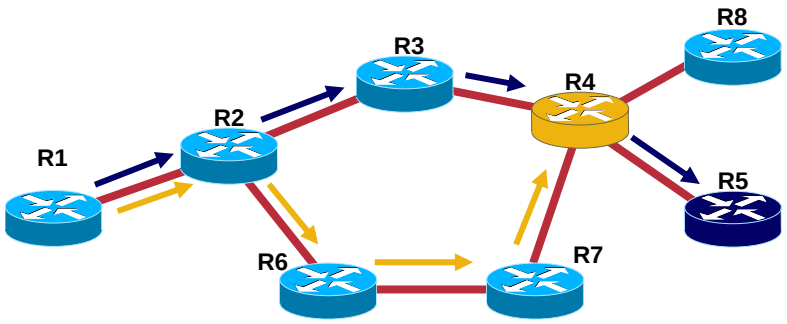

Tunnel1: R1 ➔R2 ➔ R3 ➔ R4 ➔ R5
Tunnel2: R1 ➔R6 ➔ R7 ➔ R4

Autoroute Topology (OSPF and ISIS)

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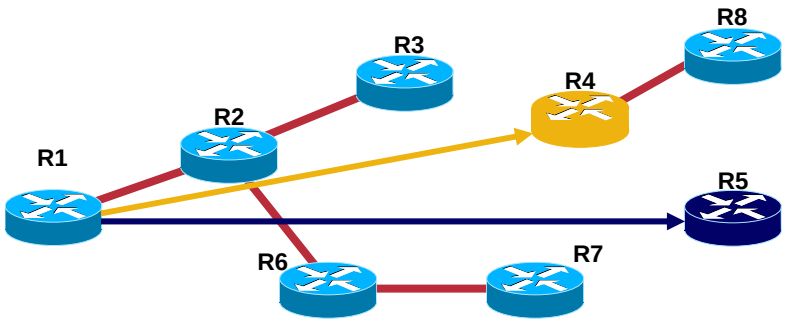

From R1 router perspective:
Next hop to R4 and R8 is Tunnel1
Next hop to R5 is Tunnel2
All nodes behind tunnel routed via tunnel

Forwarding Adjacency

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- Autoroute does not advertise the LSP into the IGP
- There may be a requirement to advertise the existence of TE tunnels to upstream routers
  - Like an ATM/FR PVC—attract traffic to a router regardless of the cost of the underlying physical network cost
- Useful as a drop-in replacement for ATM/FR (and during migration)
- Can get suboptimal forwarding (NOT loops) if you're not careful

Forwarding Adjacency

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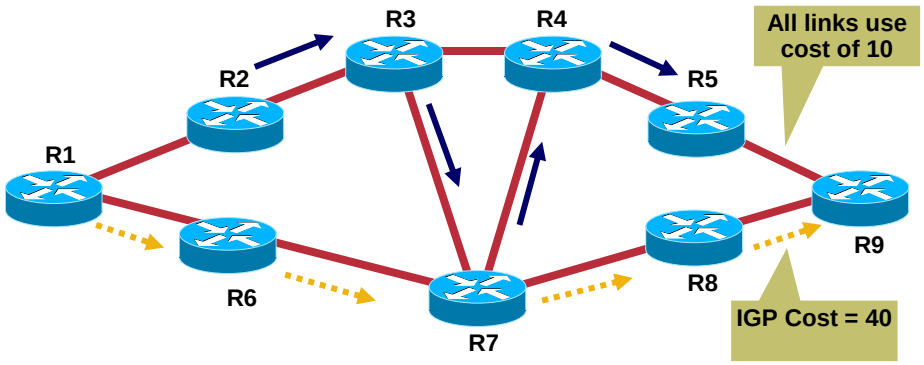

Tunnel: R2 → R3 → R7 → R4 → R5
R1 shortest path to R9 via IGP
Tunnel at R2 is never used as R1 can't see it

Advertise TE Links into IGP

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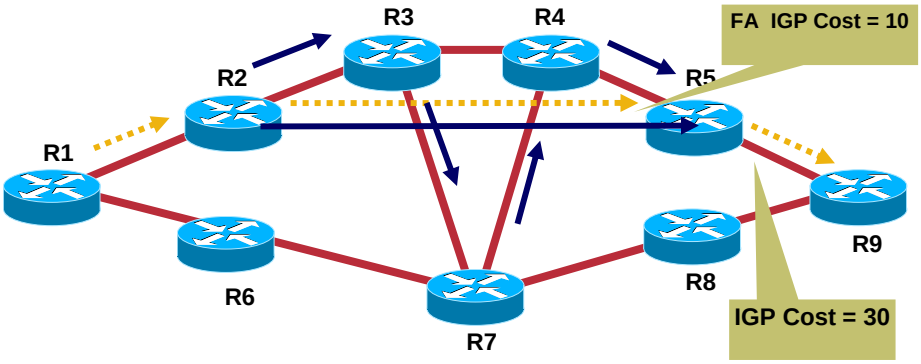

Tunnel: R2 ➔R3 ➔ R4 ➔ R5
R1 shortest path to R9

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Load Balancing Across FA

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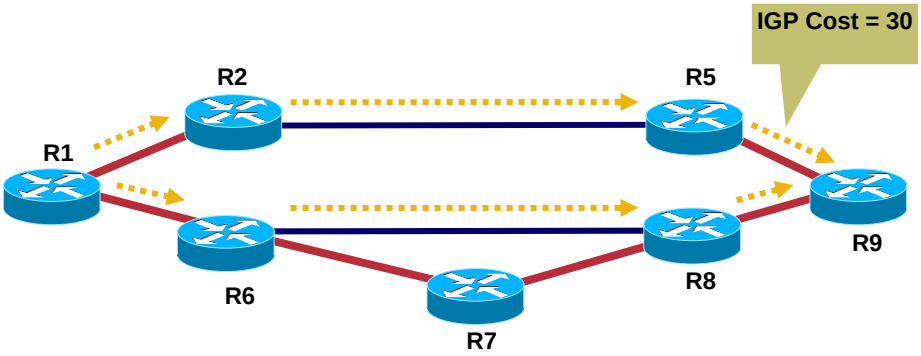

Tunnel: R2 ➔R3 ➔ R4 ➔ R5
R1 shortest path to R9

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Unequal Cost Load Balancing

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- IP routing has equal-cost load balancing, but not unequal cost*
- Unequal cost load balancing difficult to do while guaranteeing a loop-free topology
- Since MPLS doesn't forward based on IP header, permanent routing loops don't happen
- 16 hash buckets for next-hop, shared in rough proportion to configured tunnel bandwidth or load-share value

*EIGRP Has 'Variance', but That's Not as Flexible

Unequal Cost: Example 1

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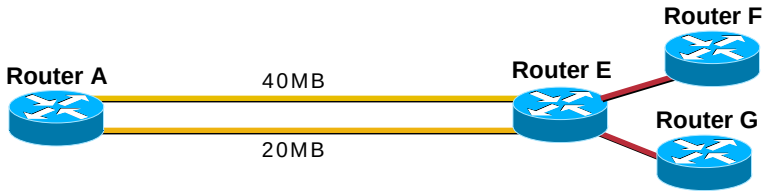


```
gsr1#show ip route 192.168.1.8
Routing entry for 192.168.1.8/32
  Known via "isis", distance 115, metric 83, type level-2
  Redistributing via isis
  Last update from 192.168.1.8 on Tunnel0, 00:00:21 ago
  Routing Descriptor Blocks:
  * 192.168.1.8, from 192.168.1.8, via Tunnel0
      Route metric is 83, traffic share count is 2
    192.168.1.8, from 192.168.1.8, via Tunnel1
      Route metric is 83, traffic share count is 1
```

Unequal Cost: Example 1

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```
gsr1#sh ip cef 192.168.1.8 internal
……
Load distribution: 0 1 0 1 0 1 0 1 0 1 0 0 0 0 0 0 (refcount 1)
  Hash  OK  Interface                 Address         Packets  Tags imposed
  1     Y   Tunnel0                   point2point           0    {23}
  2     Y   Tunnel1                   point2point           0    {34}
……
```

Note That the Load Distribution Is 11:5—Very Close to 2:1, but Not Quite!

Unequal Cost: Example 2

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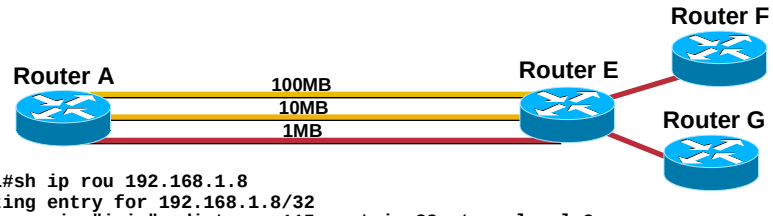


```
gsr1#sh ip rou 192.168.1.8
Routing entry for 192.168.1.8/32
  Known via "isis", distance 115, metric 83, type level-2
  Redistributing via isis
  Last update from 192.168.1.8 on Tunnel2, 00:00:08 ago
  Routing Descriptor Blocks:
  * 192.168.1.8, from 192.168.1.8, via Tunnel0
      Route metric is 83, traffic share count is 100
    192.168.1.8, from 192.168.1.8, via Tunnel1
      Route metric is 83, traffic share count is 10
    192.168.1.8, from 192.168.1.8, via Tunnel2
      Route metric is 83, traffic share count is 1
```

Q: How Does 100:10:1 Fit Into a 16-Deep Hash?

Unequal Cost: Example 2

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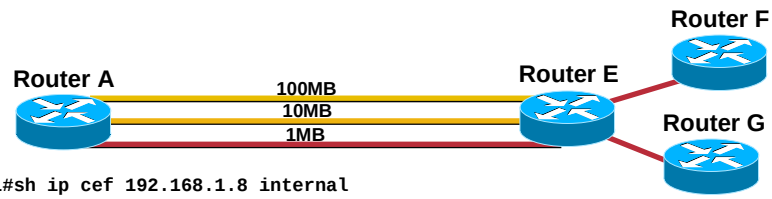


```
gsr1#sh ip cef 192.168.1.8 internal
……
 Load distribution: 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 (refcount 1)

  Hash  OK  Interface                 Address         Packets  Tags imposed
  1     Y   Tunnel0                   point2point           0    {36}
  2     Y   Tunnel1                   point2point           0    {37}
……
```

A: Any Way It Wants to! 15:1, 14:2, 13:2:1, it depends on the order the tunnels come up

Deployment Guideline: Don't use tunnel metrics that don't reduce to 16 buckets!

Path Maintenance

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- **Steady-state information load is low**
  - Especially with refresh reduction (RFC2961)
- **Path re-optimization**
  - Process where some traffic trunks are rerouted to new paths so as to improve the overall efficiency in bandwidth utilization
  - For example, traffic may be moved to secondary path during failure; when primary path is restored traffic moved back
- **Path restoration**
  - Comprised of two techniques; local protection (link and node) and path protection
  - Discussed later in protection section

CONFIGURATION

Prerequisite Configuration (Global)

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```
ip cef [distributed]
mpls traffic-eng tunnels
```

Information Distribution

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- **OSPF**

```
mpls traffic-eng tunnels
mpls traffic-eng router-id loopback0
mpls traffic-eng area ospf-area
```

- **ISIS**

```
mpls traffic-eng tunnels
mpls traffic-eng router-id loopback0
mpls traffic-eng level-x
metric-style wide
```


Information Distribution

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- **On each physical interface**

```
interface pos0/0
  mpls traffic-eng tunnels
  ip rsvp bandwidth Kbps (Optional)
  mpls traffic-eng attribute-flags attributes (Opt)
```

Build a Tunnel Interface (Headend)

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```
interface Tunnel0
  ip unnumbered loopback0
  tunnel destination RID-of-tail
  tunnel mode mpls traffic-eng
  tunnel mpls traffic-eng bandwidth  10
```


Tunnel Attributes

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```
interface Tunnel0
  tunnel mpls traffic-eng bandwidth Kbps
  tunnel mpls traffic-eng priority pri [hold-pri]
  tunnel mpls traffic-eng affinity properties [mask]
  tunnel mpls traffic-eng autoroute announce
```

Path Calculation

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- Dynamic path calculation

```
int Tunnel0
   tunnel mpls traffic-eng path-option # dynamic
```

- Explicit path calculation

```
int Tunnel0
  tunnel mpls traffic path-opt # explicit name foo

ip explicit-path name foo
   next-address 1.2.3.4 [loose]
   next-address 1.2.3.8 [loose]
```


Multiple Path Calculations

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- A tunnel interface can have several path options, to be tried successively

```
tunnel mpls traffic-eng path-option 10 explicit name foo
tunnel mpls traffic-eng path-option 20 explicit name bar
tunnel mpls traffic-eng path-option 30 dynamic
```

- Path-options can each have their own bandwidth

```
tunnel mpls traffic-eng path-option 10 explicit name foo
     bandwidth 100
tunnel mpls traffic-eng path-option 20 explicit name bar
     bandwidth 50
tunnel mpls traffic-eng path-option 30 dynamic
     bandwidth 0
```

LSP Attributes

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Configure on Tunnel:

```
tunnel mpls traffic-eng path-
  option 10 dynamic attributes
  foo
```

Attribute list 'foo' is defined at:

```
mpls traffic-eng lsp
  attributes foo
 bandwidth 25
 priority 2 2
```

- Attribute list options

```
affinity
auto-bw
bandwidth
lockdown
priority
protection
record-route
```


Static and Policy Routing Down a Tunnel

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- **Static routing**

```
ip route prefix mask Tunnel0
```

- **Policy routing (Global Table)**

```
access-list 101 permit tcp any any eq www

interface Serial0
  ip policy route-map foo

route-map foo
  match ip address 101
  set interface Tunnel0
```

Autoroute and Forwarding Adjacency

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```
interface Tunnel0
  tunnel mpls traffic-eng autoroute announce
                          OR
  tunnel mpls traffic-eng forwarding-adjacency
  isis metric x level-y (ISIS)
  ip ospf cost ospf-cost (OSPF)
```


Summary Configuration (1/2)

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```
ip cef (distributed}
mpls traffic-eng tunnels
interface Tunnel0
  tunnel mode mpls traffic-eng
  ip unnumbered Loopback0
  tunnel destination RID-of-tail
  tunnel mpls traffic-eng autoroute announce
  tunnel mpls traffic-eng path-option 10 dynamic
```

Summary Configuration (2/2)

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```
! Configure in IGP
mpls traffic-eng tunnels
mpls traffic-eng router-id Loopback0
mpls traffic-eng area ospf-area (OSPF)
mpls traffic-eng level-x (ISIS)
metric-style wide
!
! On Physical interface
interface POS0/0
  mpls traffic-eng tunnels
  ip rsvp bandwidth Kbps
```


You Want SHOW Commands?

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```
show mpls traffic-eng link-management admission-cont
show mpls traffic-eng link-management advertisements
show mpls traffic-eng link-management bandwidth-alloc
show mpls traffic-eng link-management igp-neighbors
show mpls traffic-eng link-management interfaces
show mpls traffic-eng link-management summary
show mpls traffic-eng forwarding-adjacency
show mpls traffic tunnel backup
show mpls traffic-eng fast-reroute database
show mpls traffic-eng tunnels
show mpls traffic-eng tunnels summary
show mpls traffic-eng what's-for-dinner
```

PROTECTION

Protection

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- Mechanism to minimize packet loss during a failure
- Pre-provisioned protection tunnels that carry traffic when a protected link or node goes down
- MPLS TE protection also known as FAST REROUTE (FRR)
- FRR protects against LINK FAILURE
  - For example, Fibre cut, Carrier Loss, ADM failure
- FRR protects against NODE FAILURE
  - For example, power failure, hardware crash, maintenance
- Real Soon Now: protection against CONDUIT FAILURE (SRLG)
  - Conduit may carry multiple fibres, don't want to protect C1:F1 with C1:F2

Categories of Fast Reroute Protection

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- **Local protection**
  - **Link protection**
  - **Node protection**
  - **Protect a piece of the network (node or link)**
  - **1:N scalability**
  - **Fast failure recovery due to local repair**
- **Path protection**
  - **Real soon now**
  - **Protects individual tunnels**
  - **1:1 scalability**

Link Protection

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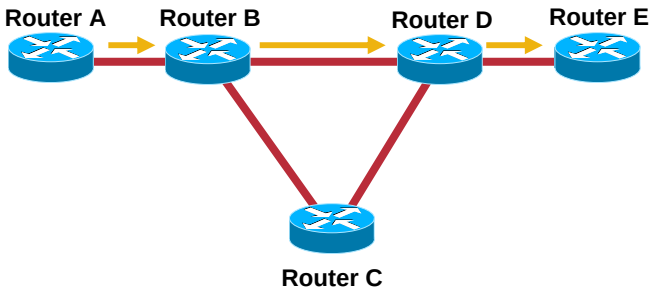
- **TE Tunnel A → B → D → E**



Link Protection

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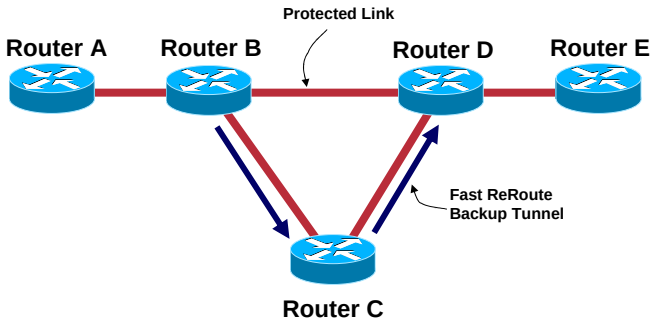
- B has a pre-provisioned backup tunnel to the other end of the protected link (Router D) B ➔ C ➔ D
- FRR relies on the fact that D is using global label space



Link Protection

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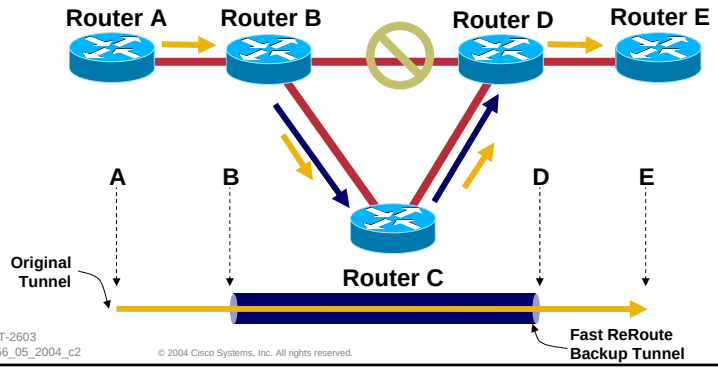
- When B ➔ D link fails, A ➔ E tunnel is encapsulated in B ➔ D tunnel
- Backup tunnel is used until A can re-compute tunnel path as A ➔ B ➔ C ➔ D ➔ E (~5-15 seconds or so)



Link Protection Example

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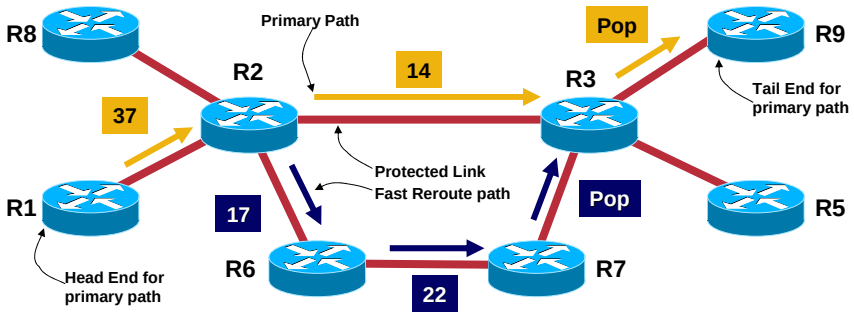

Primary path: R1 ➔ R2 ➔ R3 ➔ R9

Fast Reroute path: R2 ➔ R6 ➔ R7 ➔ R3

Normal TE Operation

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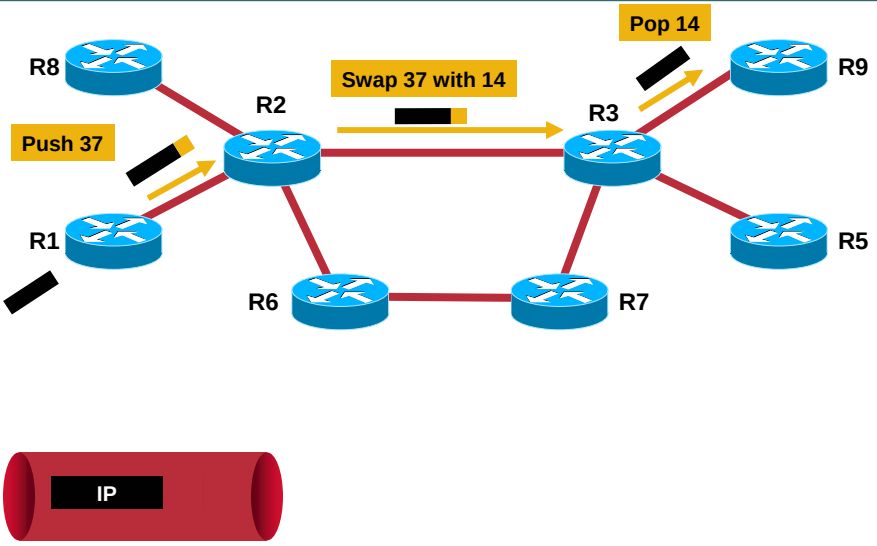

Fast Reroute Link Failure

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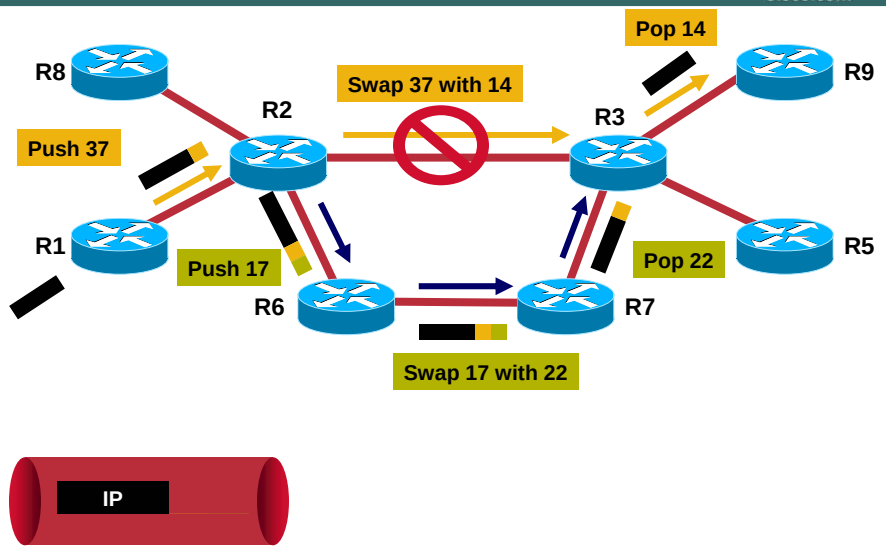

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Link Protection Configuration

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```
interface Tunnel0
 tunnel destination Router D
 … explicit-path R2-R3-R4
 no tunnel mpls traffic-eng autoroute announce
```


```
interface POS0/0
 mpls traffic-eng backup-path Tunnel0
```


```
interface Tunnel0
 tunnel destination Router E
 .. etc ...
 tunnel mpls traffic-eng fast-reroute
```

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Node Protection

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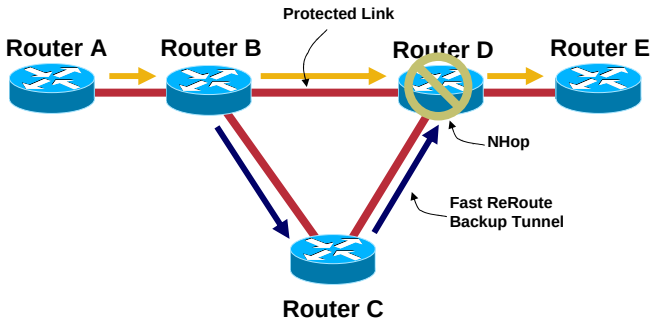
- What if Router D failed?
- Link protection would not help as the backup tunnel terminates on Router D (which is the NHop of the protected link)



Node Protection

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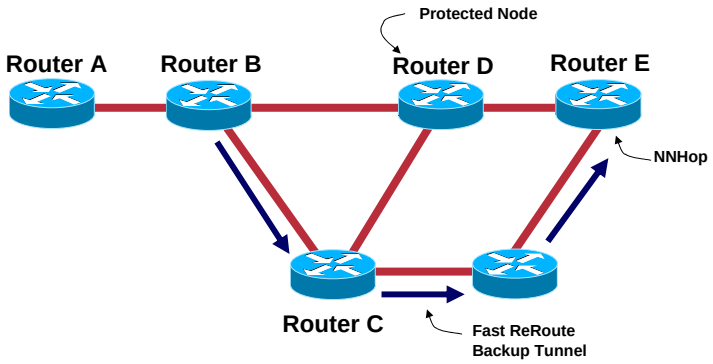
- SOLUTION: NODE PROTECTION (If network topology allows)
- Protect tunnel to the next hop PAST the protected link (NNhop)



Node Protection

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- Node protection still has the same convergence properties as link protection
- Deciding where to place your backup tunnels is a much harder problem to solve on a large-scale
- For small-scale protection, link may be better
- Auto-tunnel and auto-mesh can help with this
- Configuration is identical to link protection, except where you terminate the backup tunnel (NNHop vs. NHop)

Link and Node Protection Times

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- Link and Node protection are very similar
- Protection times are commonly linear to number of protected items
- One nationwide provider gets ~35ms of loss
- New code on GSR E3 linecards gets a prefix-independent 2ms-4ms loss

Path Protection

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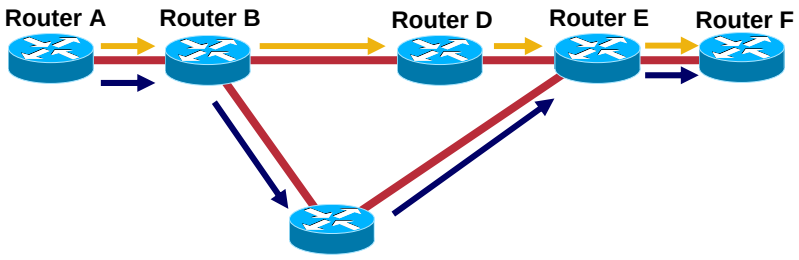
- **Path protection: Multiple tunnels from TE head to tail, across diverse paths**



Path Protection

Cisco.com

- **Least scalable, most resource-consuming, slowest convergence of all 3 protection schemes**
- **With no protection, worst-case packet loss is 3x path delay**
- **With path protection, worst-case packet loss is 1x path delay**
- **With link or node protection, packet loss is easily engineered to be subsecond (<100ms, <50ms, 4ms, all possible)**
- **Path protection is useful in a few places:**
  - **Geographically constrained regions (e.g. Japan)**
  - **Only a few protected LSPs (one-off per-circuit AToM protection)**

QoS/MPLS/MPLS-TE

No Need for TE or DiffServ

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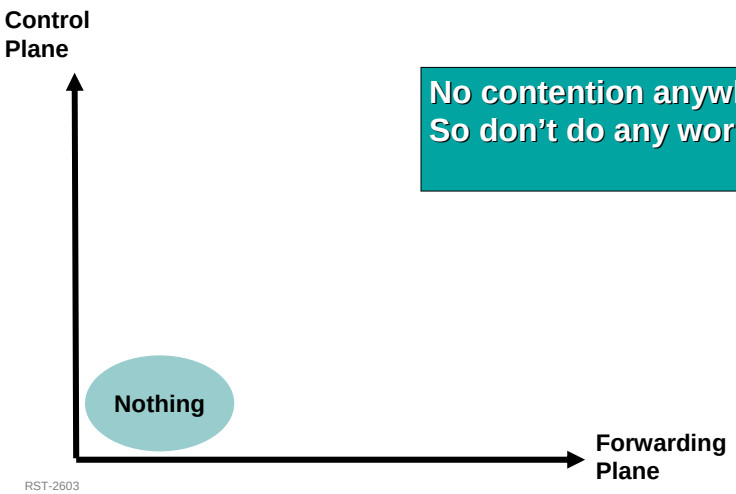

Need DiffServ, Don't Need TE

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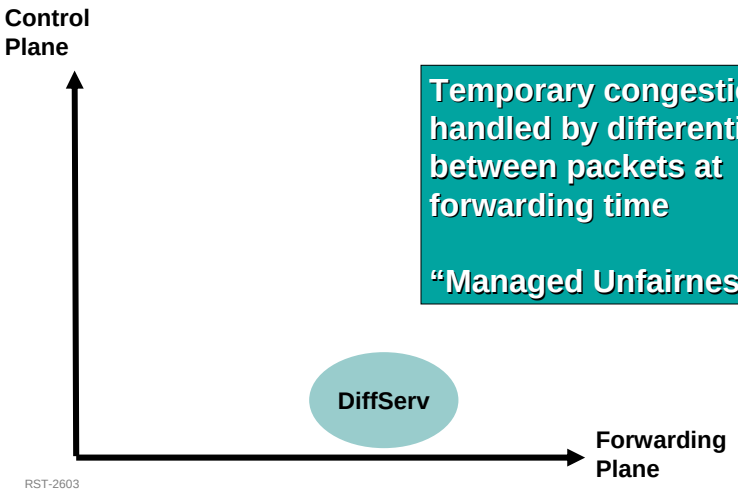

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More Efficient Use of IP Bandwidth, but No Contention

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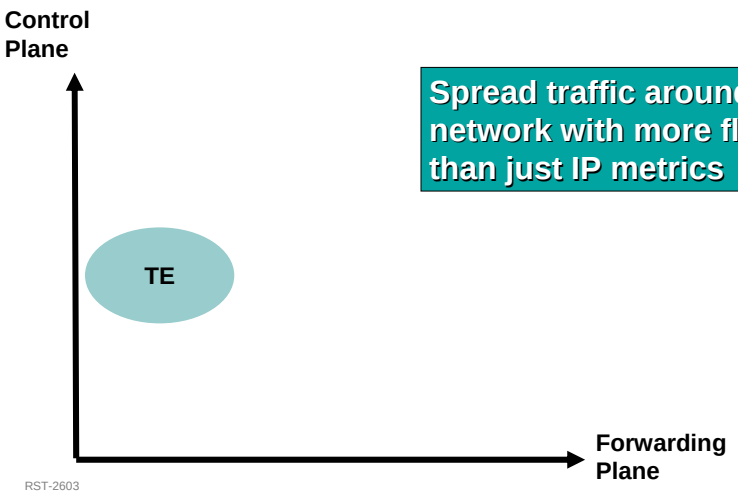

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Bandwidth Optimization and Congestion Management in Parallel

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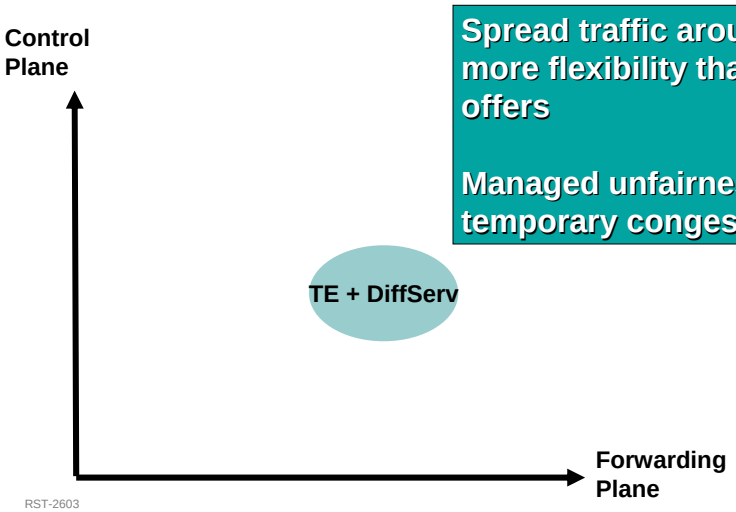
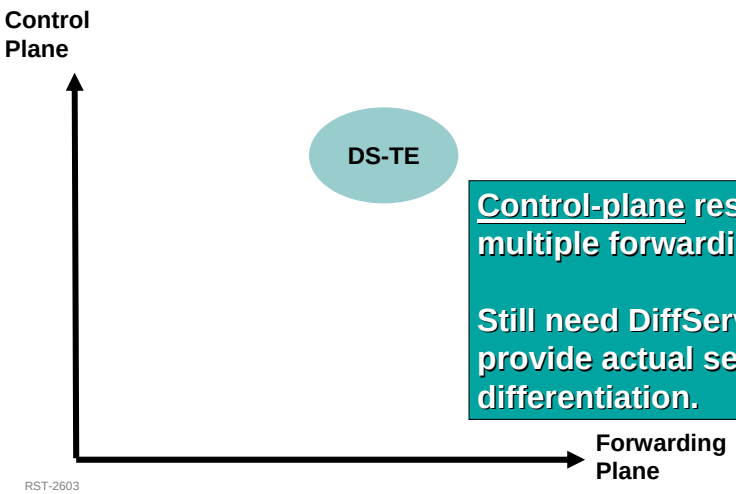


Reserve Per-Class Bandwidth, Sort Of

Cisco.com



Minimize Packet Loss at Any Point

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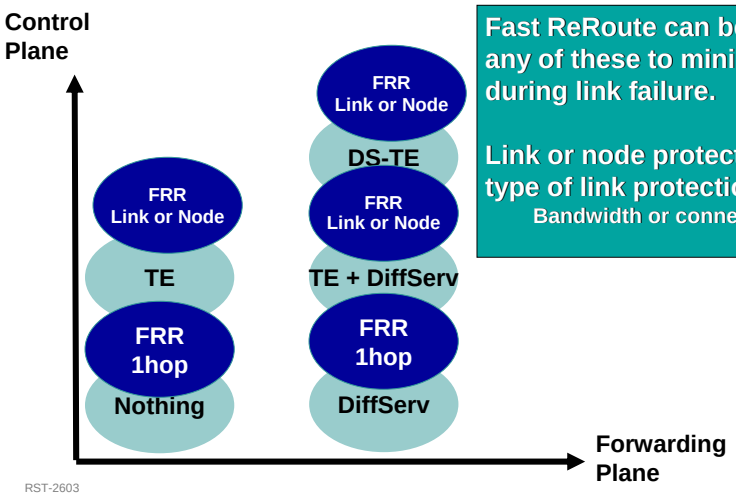

Fast ReRoute can be combined with any of these to minimize packet loss during link failure.

Link or node protection (1hop is a type of link protection)

Bandwidth or connectivity protection.

DiffServ-Aware TE

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- Regular TE allows for one reservable bandwidth amount per link
- Regular (FIFO) queuing allows for one queue per link
- DiffServ queuing (e.g. LLQ) allows for more than one queue per link
- DS-TE allows for more than one reservable bandwidth amount per link
- Basic idea: connect PHB class bandwidth to DS-TE bandwidth sub-pool
- Still a control-plane reservation only

DESIGN AND SCALABILITY

Design Approach and Scalability

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Two Methods to Deploy MPLS-TE

- **Tactical**
  - **As needed to clear up congestion**
  - **You only have tunnels when there is a problem (and you must remember to remove them**
- **Strategic**
  - **Mesh of TE tunnels between a level of routers**
  - **Typically P to P but can be PE to PE in smaller networks**
  - **N(N-1) LSPs (one in each direction)**

Design Spectrum

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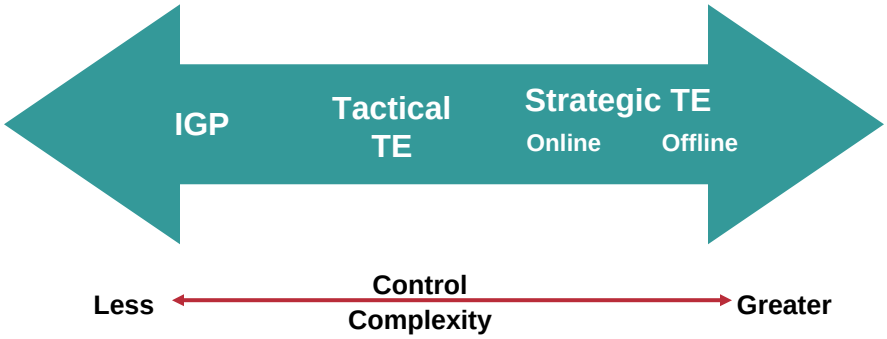

Tactical: Large ISP Case Study

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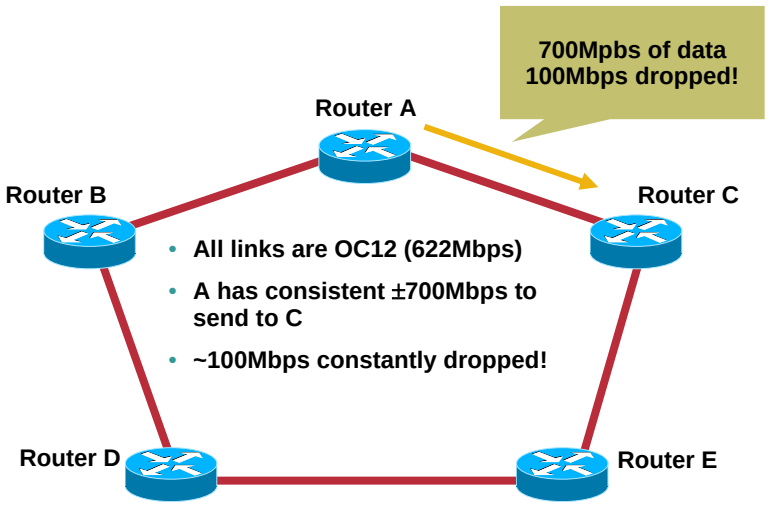

- All links are OC12 (622Mbps)
- A has consistent ±700Mbps to send to C
- ~100Mbps constantly dropped!

Multiple TE and Unequal Cost Load Balancing

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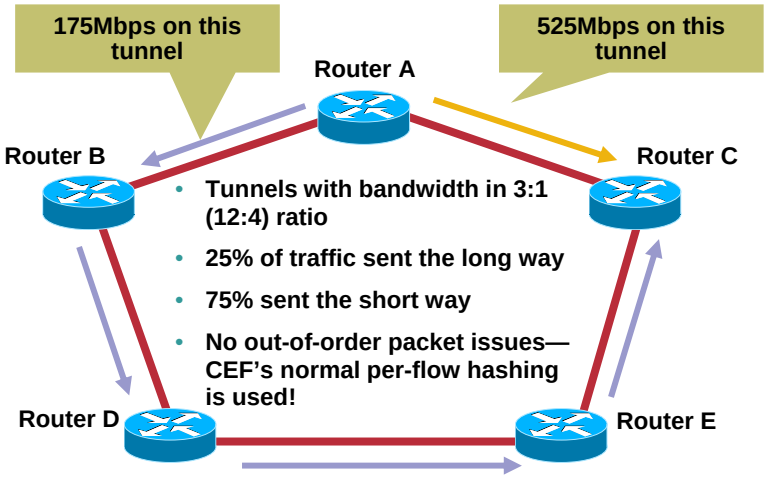

Tactical

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- As needed—Easy, quick, but hard to track over time
- Easy to forget why a tunnel is in place
- Inter-node BW requirements may change, tunnels may be working around issues that no longer exist

Strategic

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- Full mesh of TE tunnels between routers
- Initially deploy tunnels with 0 bandwidth
- Monitor tunnel interface statistics
  - ~Bandwidth used between router pairs
    - TE tunnels have interface MIBs
    - Make sure that Σtunnel <= Σnetwork BW
- As tunnel bandwidth is changed, tunnels will find the best path across the network

Strategic: Physical Topology

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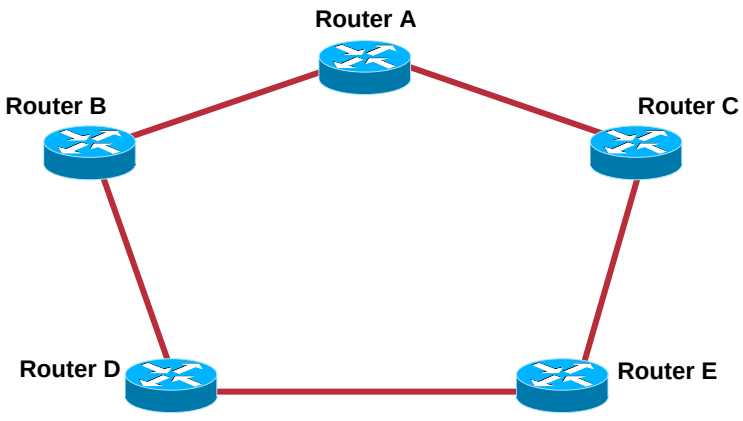

Strategic: Logical Topology

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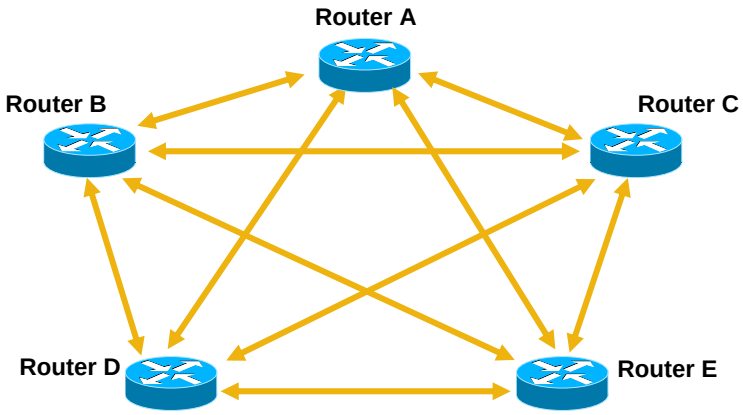
- Total of 20 tunnels in this network
- Each link is actually 2 unidirectional tunnels



Strategic

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- N routers, N*(N-1) tunnels
- Routing protocols do not run over a TE tunnel
  - Unlike an ATM/FR full mesh!
- Tunnels are unidirectional
  - This is a good thing
  - Can have different bandwidth reservations in two different directions

Scalability

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Code	Number of Headend Tunnels	Number of Mid-Points	Number of Tails
12.0ST	600	10,000	5,000

- In late 2000/early 2001, we said, “how many tunnels come up in 5 minutes?”
- Answer as above
- With latest code, above converges in 2-3 minutes
- Haven’t need to formalize larger-number testing
  - Largest customer we know of has a network about ¼ this size
- Bottom line: MPLS-TE scalability is not the gating factor in scaling your network

Protection Scalability

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- N is number of nodes in the TE cloud (10-150)
- D is backbone degree of connectivity (4-6 avg, max 12-16)
- Primary full mesh: O(N^2)
- Link protection: additional O(N*D) tunnels
- Node protection: additional O(N*D^2) tunnels
- Path protection: additional O(N^2) tunnels

Scalability

Cisco.com

http://www.cisco.com/univercd/cc/td/doc/product/software/ios120/120newft/120limit/120st/120st14/scalable.htm

- **Search CCO for "Scalability Enhancements for MPLS Traffic Engineering"**

MPLS VPN, MULTICAST, AND TE

TE and MPLS VPNs

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- **MPLS VPNs**
  - **VPN label is carried across network by IGP label**
- **MPLS TE label can serve as the IGP label**
  - **TE tunnels must connect PE-PE…**
- **Otherwise enable LDP/TDP on tunnel interface**
  - **Using Targeted LDP session**

MPLS VPN over PE-PE TE Tunnel

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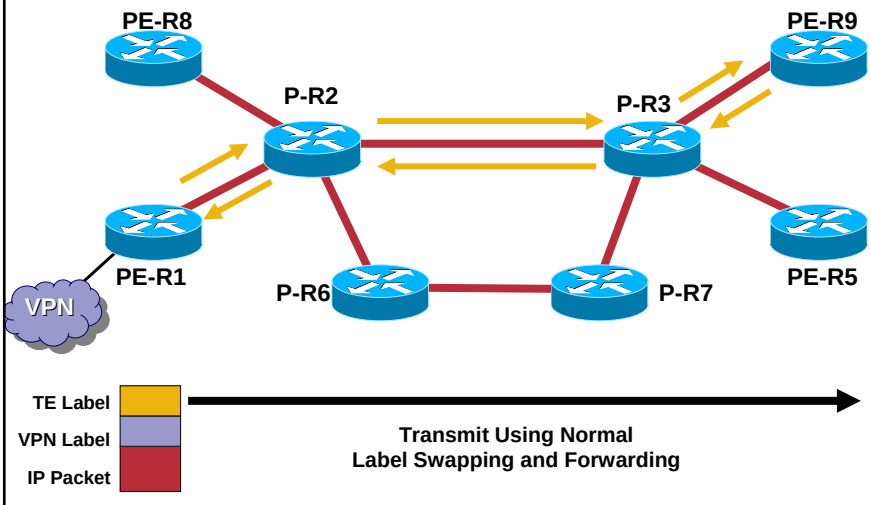

MPLS VPN over P-P TE Tunnel

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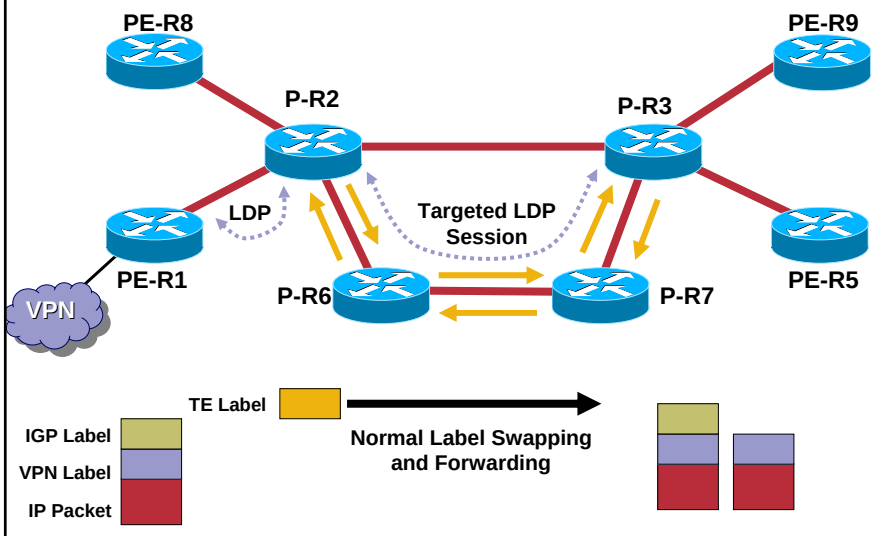

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TE and Multicast

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- Multicast requires RPF
- Multicast packets should arrive on interface that is shortest path to source
- Autoroute causes IGP to point to TE tunnel
- As packets don't exit tunnel interface, multicast breaks!
- Cisco IOS has a command to fix it (under IGP config)…

```
mpls traffic-eng multicast intact
```

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SUMMARY

MPLS TE

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- Helps optimize network utilisation (strategic)
- Assists in handling unexpected congestion (tactical)
- Provides fast reroute for link and node failures
- TE is only part of a method of guaranteeing bandwidth
  - It is a control plane mechanism only
  - Must be used with traditional QoS mechanisms

Complete Your Online Session Evaluation!

Cisco.com

WHAT: Complete an online session evaluation and your name will be entered into a daily drawing

WHY: Win fabulous prizes! Give us your feedback!

WHERE: Go to the Internet stations located throughout the Convention Center

HOW: Winners will be posted on the onsite Networkers Website; four winners per day