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Deploying MPLS Traffic Engineering

Session RST-2062

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Agenda

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- **Prerequisites**
- **Background**
- **Theory**
- **Practice**
- **Fast ReRoute**
- **Tunnel Builder and Tunnel Builder Pro**
- **Design and Scaling**
- **New and Exciting Things**

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Prerequisites

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- **Must understand basic IP routing**
- **Should understand MPLS basics**
- **Should understand how a link-state protocol works**
- **QoS knowledge is helpful**

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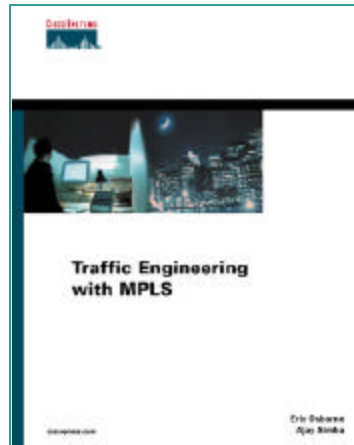
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A Blatant Plug

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- **Traffic Engineering with MPLS**
ISBN: 1-58705-031-5



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Background—Why Have MPLS-TE?

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- IP networks route based only on destination (route)
- ATM/FR networks switch based on both source and destination (PVC, etc)
- Some very large IP networks were built on ATM or FR to take advantage of src/dst routing
- Overlay networks inherently hinder scaling (see “The Fish Problem”)
- MPLS-TE lets you do src/dst routing while removing the major scaling limitation of overlay networks
- MPLS-TE has since evolved to do things other than bandwidth optimization

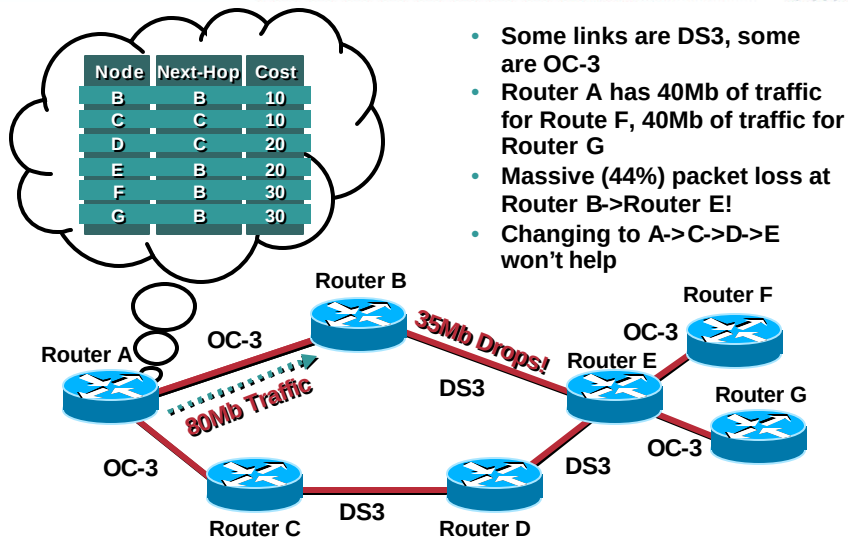
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The Fish Problem

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- Some links are DS3, some are OC-3
- Router A has 40Mb of traffic for Route F, 40Mb of traffic for Router G
- Massive (44%) packet loss at Router B->Router E!
- Changing to A->C->D->E won't help

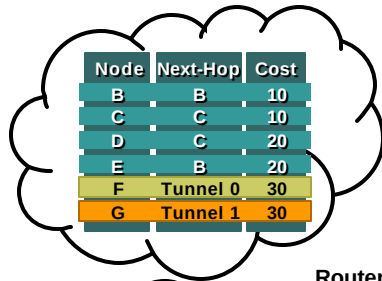
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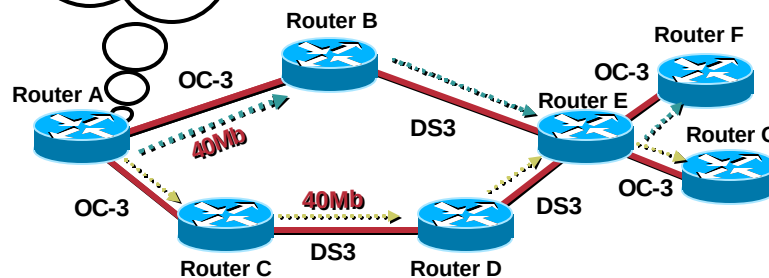
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What MPLS-TE Addresses

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- Router A sees all links
- Router A computes paths on properties other than just shortest cost
- Like a L2 PVC, but **no IGP adjacency** over the 'PVC'!



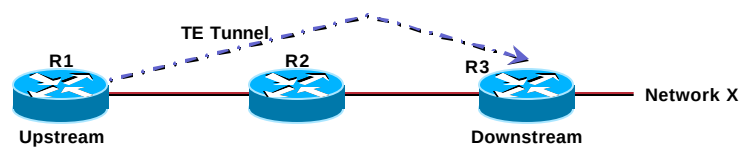
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A Terminology Slide—Head, Tail, LSP, etc.

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- Head-End is a router on which a TE tunnel is configured (R1)
- Tail-End is the router on which TE tunnel terminates (R3)
- Mid-point is a router thru which the TE tunnel passes (R2)
- LSP is the Label Switched Path taken by the TE tunnel, here R1-R2-R3
- Downstream router is a router closer to the tunnel tail
- Upstream router is farther from the tunnel tail (so R2 is upstream to R3's downstream, R1 is upstream from R2's downstream)

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Theory

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- Information Distribution
- Path Calculation
- Path Setup
- Routing Traffic Down A Tunnel

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Information Distribution

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- TE LSPs can (optionally) reserve bandwidth across the network
- Reserving bandwidth is one of the ways to find more optimal paths to a destination
- This is a **control-plane reservation only**
- Need to flood available bandwidth information across the network
- IGP extensions flood this information
 - OSPF uses Type 10 (area-local) Opaque LSAs
 - ISIS uses new TLVs
 - Some other information flooded, not important now

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Path Calculation

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- Once available bandwidth information is flooded, router may calculate a path from head to tail
 - Path may already be preconfigured on the router, will talk about that later
- TE Headend does a “Constrained SPF” (CSPF) calculation to find the best path
- CSPF is just like regular IGP SPF, except
 - Takes required bandwidth into account
 - Looks for best path from a head to a single tail, not to all devices
- N tunnel tails, N CSPFs
- In practice, there has been zero impact from CSPF CPU utilization on even the largest networks

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Path Setup

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- Once the path is calculated, need to signal it across the network
- Why? Two reasons:
 1. Reserve any bandwidth, so that other LSPs can't overload the path
 2. Establish an LSP for loop-free forwarding along an arbitrary path

Like ATM VC/FR DLCI

See "The Fish Problem," later

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Path Setup

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- PATH messages = from head to tail
(think "call setup") carries LABEL_REQUEST
- RESV messages = from tail to head
(think "call ACK") carries LABEL
- Other RSVP message types exist for LSP teardown and error signaling

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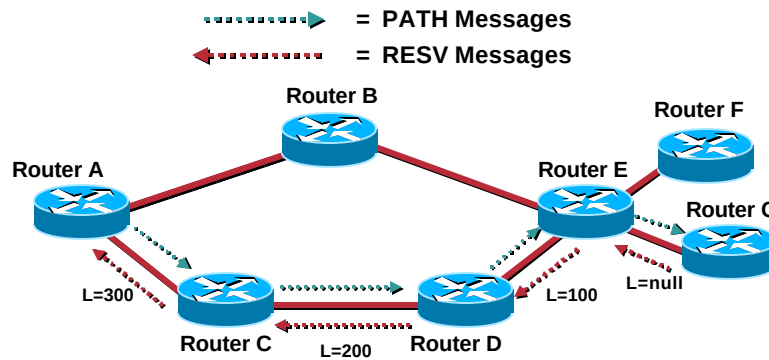
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Path Setup

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- PATH message: “Can I have 40Mb along this path?”
- RESV message: “Yes, and here’s the label to use”
- LFIB is set up along each hop



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Path Setup

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- Once RESV reaches headend, tunnel interface comes up
- Errors along the way are handled appropriately (tunnel does not come up, message gives point of failure and reason for failure)

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Path Setup

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- **Fundamental points here:**

You can use MPLS-TE to forward traffic down a path other than that determined by your IGP cost

You can determine these arbitrary paths per tunnel headend

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Routing Traffic Down a Tunnel

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- **Once RESV reaches headend, tunnel interface comes up**
- **How to get traffic down the tunnel?**
 1. **Autoroute**
 2. **Forwarding adjacency**
 3. **Static routes**
 4. **Policy routing**

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Autoroute

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- Tunnel is treated as a directly connected link to the tail
- IGP adjacency is **NOT** run over the tunnel!
Unlike an ATM/FR VC
- Autoroute limited to single area/level only

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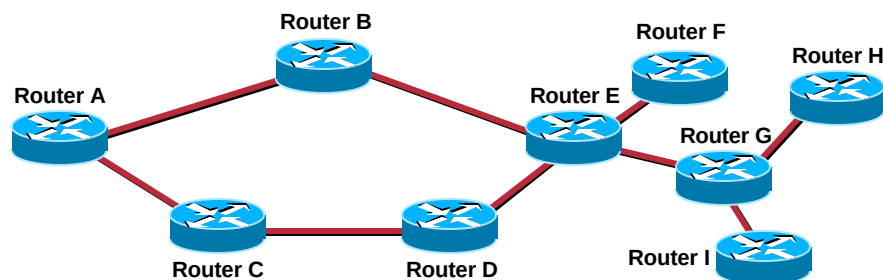
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Autoroute

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This Is the Physical Topology



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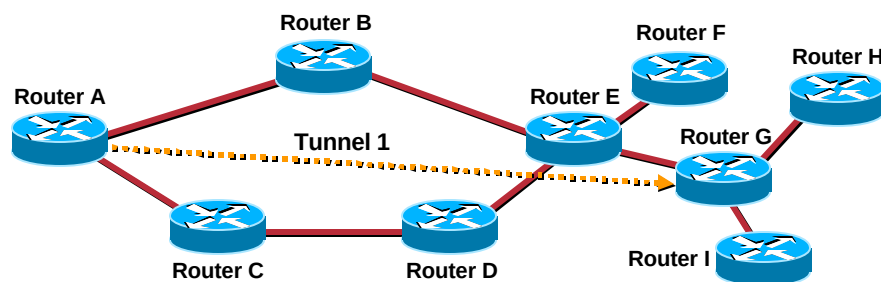
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Autoroute

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- This is Router A's logical topology
- By default, other routers don't see the tunnel!



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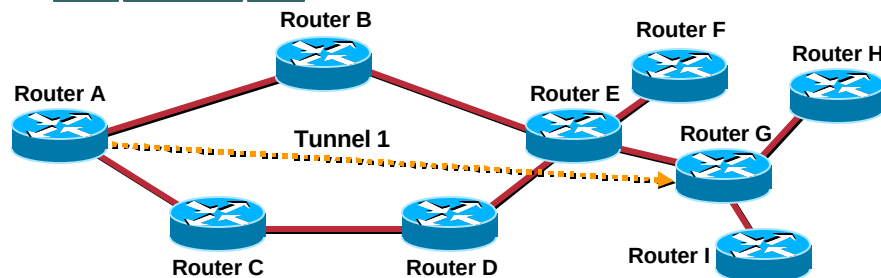
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Autoroute

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Node	Next-Hop	Cost
B	B	10
C	C	10
D	C	20
E	B	20
F	B	30
G	Tunnel 1	30
H	Tunnel 1	40
I	Tunnel 1	40

- Router A's routing table, built via auto-route
- Everything "behind" the tunnel is routed via the tunnel



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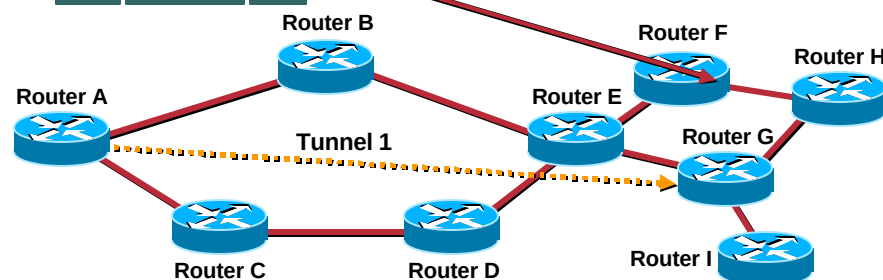
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Autoroute

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Node	Next-Hop	Cost
B	B	10
C	C	10
D	C	20
E	B	20
F	B	30
G	Tunnel 1	30
H	Tunnel 1 & B	40
I	Tunnel 1	40

- If there was a link from F to H, Router A would have 2 paths to H (A->G->H and A->B->E->F->H)
- Nothing else changes



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Forwarding Adjacency

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- With autoroute, the LSP is not advertised into the IGP
- This is the right behavior if you're adding TE to an IP network, but maybe not if you're migrating from ATM/FR to TE
- Sometimes advertising the LSP into the IGP as a link is necessary to preserve the routing outside the ATM/FR cloud

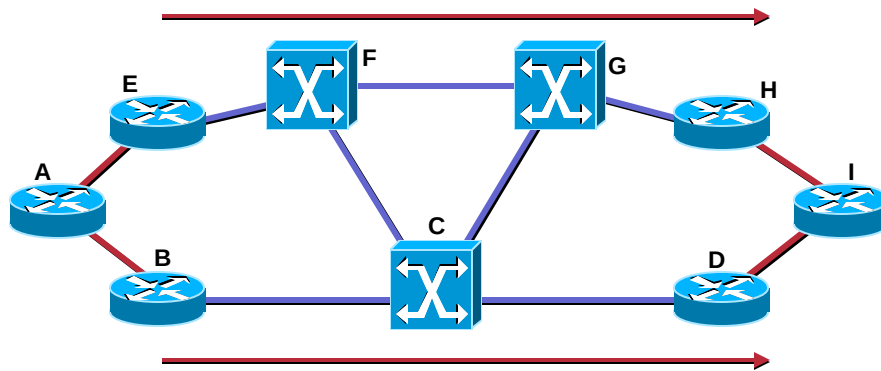
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ATM Model

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- Cost of ATM links (blue) is unknown to routers
- A sees two links in IGP—E->H and B->D
- A can load-share between B and E

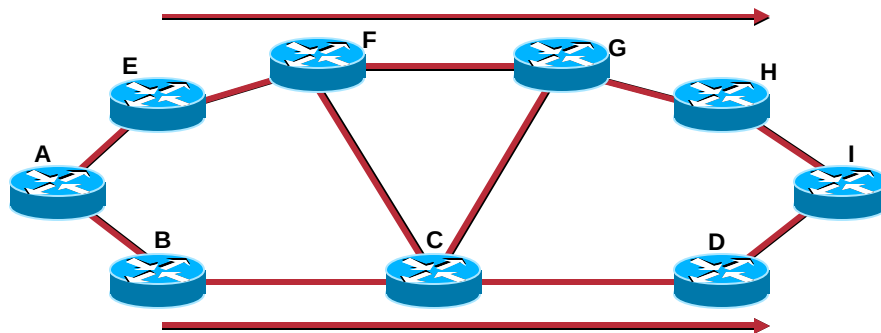
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Before FA

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- All links have cost of 10
- A's shortest path to I is A->B->C->D->I
- A doesn't see TE tunnels on {E,B}, alternate path never gets used!
- Changing link costs is undesirable, can have strange adverse effects

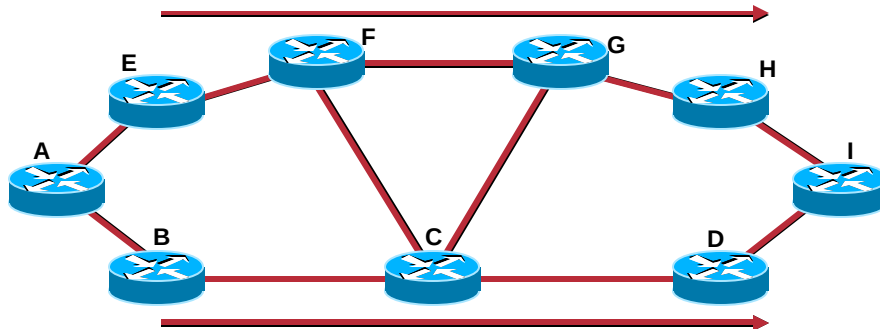
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FA Advertises TE Tunnels in the IGP

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- With forwarding-adjacency, A can see the TE tunnels as links
- A can then send traffic across both paths
- This is desirable in some topologies (looks just like ATM did, same methodologies can be applied)

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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

*EIGRP has "variance," but that's not as flexible

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Unequal Cost Load Balancing

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- Since MPLS doesn't forward based on IP header, permanent routing loops do not happen
- 16 hash buckets for next-hop, shared in **rough** proportion to configured tunnel bandwidth or load-share value

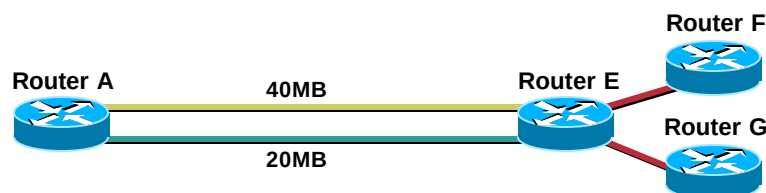
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Unequal Cost: Example 1

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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
```

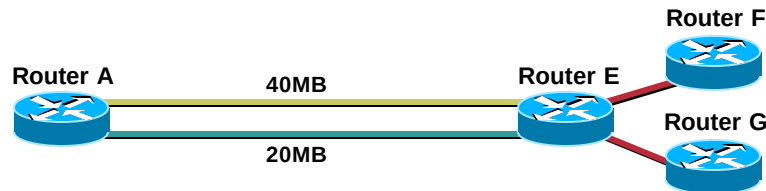
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Unequal Cost: Example 1

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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!**

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Practice

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- Prerequisites (global config)
`ip cef {distributed}`
`mpls traffic-eng tunnels`

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Practice

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- Build a tunnel interface (headend)
`interface Tunnel0`
`tunnel mode mpls traffic-eng`
`ip unnumbered loopback0`
`tunnel destination <RID of tail>`

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Information Distribution

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OSPF

```
mpls traffic-eng tunnels
mpls traffic-eng router-id loopback0
mpls traffic-eng area <x>
```

ISIS

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

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Information Distribution

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On Each Physical Interface

```
mpls traffic-eng tunnels
(optional) ip rsvp bandwidth {x}
```

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Path Calculation

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EITHER

```
int Tunnel0
```

```
  tunnel mpls traffic-eng path-option  
    <num> dynamic
```

OR

```
int Tunnel0
```

```
  tunnel mpls traffic-eng path-option  
    <num> explicit name foo
```

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Path Calculation

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Global Config:

```
ip explicit-path name foo
```

```
  next-address 1.2.3.4 {loose}
```

```
  next-address 1.2.3.8 {loose}
```

(etc)

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Path Calculation

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Can Tell the Tunnel How BW to Reserve

```
int Tunnel0
```

```
    tunnel mpls traffic-eng bandwidth <x>
```

- X is in Kbps

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Path Calculation

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- 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
```

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Path Setup

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- Nothing to configure to explicitly enable path setup
- `mpls traffic-eng tunnels` (from before) implicitly enables RSVP on the physical i/f

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Routing Traffic Down a Tunnel

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Autoroute:

```
tunnel mpls traffic-eng autoroute announce
```

Forwarding adjacency:

```
tunnel mpls traffic-eng forwarding-adjacency
```

Then

```
isis metric <x> level-<y>
```

Or

```
ip ospf cost <x>
```

On Tunnel Interface

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Static Routes

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```
ip route <prefix> <mask> Tunnel0
...duh...
```

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Policy Routing

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```
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
```

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Summary Config (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
```

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Summary Config (2/2)

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```
(in IGP)  
mpls traffic-eng tunnels  
mpls traffic-eng router-id Loopback0  
OSPF mpls traffic-eng area <x>  
ISIS mpls traffic-eng level-<x>  
      metric-style wide  
  
(physical interface)  
interface POS0/0  
  mpls traffic-eng tunnels  
  ip rsvp bandwidth <kbps>
```

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Nerd knobs

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- You betcha!
- Dozens or more
- Headend knobs, midpoint knobs, RSVP knobs, autoroute knobs, pcalc knobs, IGP knobs, etc.
- “Cisco Systems: We got the gun, you got the foot”
- Some of the more useful ones:
 1. To advertise implicit-null from Tail-end
`mpls traffic-eng signalling advertise implicit-null`
 2. To interpret explicit-null at PHP (hidden command)
`mpls traffic-eng signalling interpret explicit-null`
 3. To automatically consider any new links as they come up
`mpls traffic-eng reoptimize events link-up`

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Fast ReRoute

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- Fundamental point from earlier: “you can use MPLS-TE to forward traffic down a path other than that determined by your IGP cost”
- FRR builds a path to be used in case of a failure in the network
- Minimize packet loss by avoiding transient routing loops

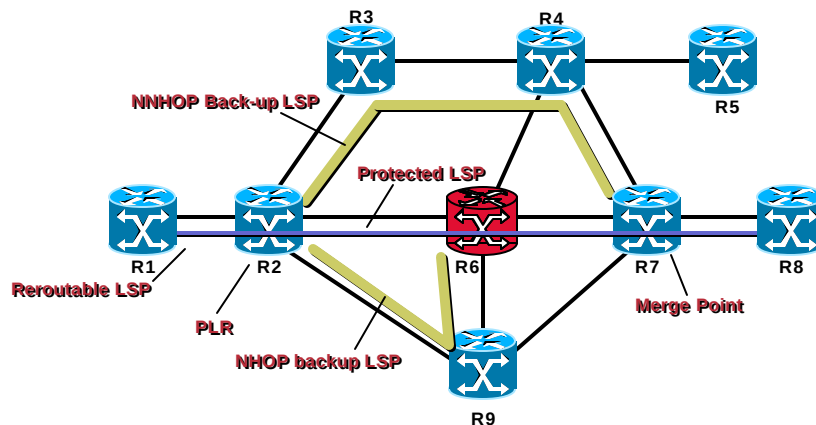
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Terminology

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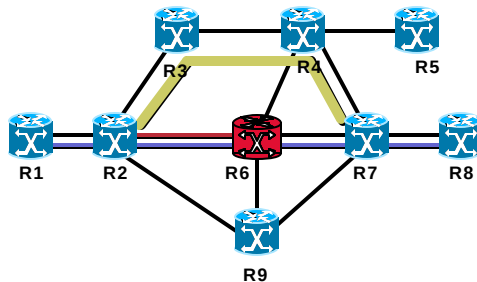
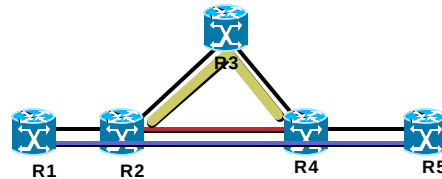
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Fast ReRoute

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MPLS Fast Reroute Local Repair

- **Link protection:**
the backup tunnel tail-head (MP) is one hop away from the PLR



- **Node protection:**
the backup tunnel tail-end (MP) is two hops away from the PLR

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IP Failure Recovery

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For IP to Recover From a Failure, Several Things Need to Happen:

Thing	Time
Link Failure Detection	usec–msec
Failure Propagation+SPF	• hundreds of msec with aggressive tuning (400ms for 500 pfx) • sec (5-10) with defaults
Local forwarding rewrite	<100ms
TOTAL:	~500ms–10sec

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FRR Failure Recovery

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Since FRR is a Local Decision, No Propagation Needs to Take Place

Thing	Time
Link Failure Detection	usec–msec
Failure Propagation+SPF	0
Local forwarding rewrite	<100ms
TOTAL:	<100ms (often <50ms, <10ms with properly greased skateboard)

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Caveats

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- As always, your mileage may vary; one slide does not do IP or FRR justice
- Local failure recovery is always faster than distributed failure recovery
- What meets your needs? What makes more sense for your network? Etc...

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FRR Procedures

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1. Pre-establish backup paths
2. Failure happens, protected traffic is switched onto backup paths
3. After local repair, tunnel headends are signaled to recover if they want; no time pressure here, failure is being protected against
4. Protection is in place for hopefully ~10-30+ seconds; during that time, **data gets through**

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FRR Configuration

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- 1) Configure protection tunnel on R2

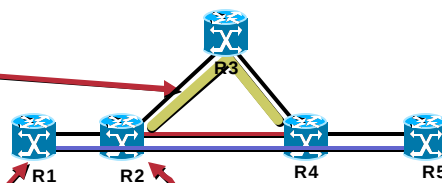
```
interface Tunnel0
.. dest R4
.. explicit-path R2-R3-R4
.. NO autoroute!!!
```

- 2) Protect an interface

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

- 3) Headend requests protection

```
interface Tunnel0
.. dest R4
.. etc ...
tunnel mpls traffic-eng fast-reroute
```



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FRR Nerd Knobs?

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- You betcha!
- Bandwidth protection vs. connectivity protection is the big one
- Don't want to reserve bandwidth on the protection tunnel, this is wasteful
- Either use TBCPro (see later) or backup bandwidth on the **protection tunnel** (yellow tunnel in previous slide)
tunnel mpls traffic-eng backup-bw <kbps>
- Allows backup to be a little smart about where it protects primary tunnels
- Only really useful if protecting 1 interface with >1 tunnels
- Offline calculation can be much smarter, but there's operational tradeoffs

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Agenda

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- Prerequisites
- Background
- Theory
- Practice
- Fast ReRoute
- **Tunnel Builder and Tunnel Builder Pro**
- Design and Scaling
- New and Exciting Things

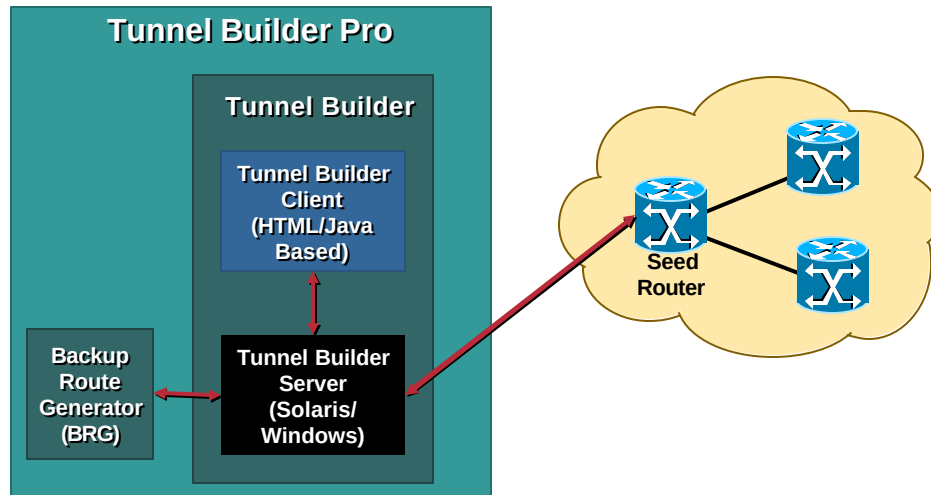
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Cisco MPLS Tunnel Builder Pro

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Tunnel Builder and Tunnel Builder Pro

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- **Tunnel Builder:** a GUI to help manage the creation, placement, and measurement of TE tunnels
- **Tunnel Builder Pro:** TB + software to calculate placement for FR protection tunnels
- Both TB and TBPro currently shipping
- The slides in this section focus on TBPro and backup calculation

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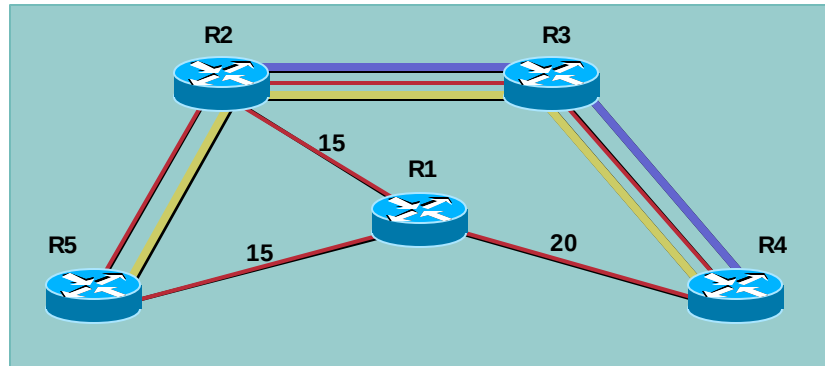
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Backup Bandwidth Sharing at Work

Cisco.com



- Objective: Protect Router, R1—Orange and Blue Tunnels
- Naïve approach—each tunnel needs capacity 15 Mbps
- Shared approach—allocate 20Mbps on Links, R2 -> R3 -> R4; 15 Mbps on R5 -> R2

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TB Pro Versus Constrained Shortest Path First (CSPF)

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Node Protection, Comparative Results

Network 1 Backbone—152 Router Protection Scenarios

Algorithm	Protected	Proved Impossible	No Solution Found
CSPF-Based	54	12	86
TB Pro	134	17	1

Network 2 Backbone—100 Router Protection Scenarios

Algorithm	Protected	Proved Impossible	No Solution Found
CSPF-Based	28	0	72
TB Pro	98	2	0

TB Pro Running on a Intel PIII @ 1Ghz with 1G RAM for Approximately 20 Minutes

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Design and Scaling

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- Designing with primary tunnels
- Designing with backup tunnels

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Designing with Primary Tunnels

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- **Full mesh (strategic TE)**
 - Mesh of TE tunnels between a level of routers
 - Typically $P \leftrightarrow P$, can be $PE \leftrightarrow PE$ in smaller networks
 - $O(N^2)$ LSPs
- **As-needed (tactical TE)**
 - Put a tunnel in place to work around temporary congestion due to unforeseen shift in traffic demand
 - Need to keep an eye on your tunnels

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Strategic TE (Full Mesh)

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- **Supported scalability numbers:**
 - 600 tunnel headends per node
 - 10,000 midpoints per node
- **Largest numbers deployed today:**
 - 100 routers full mesh = ~10,000 tunnels in the network
 - As many as 2,000-3,000 at certain midpoints
 - Plenty of room to grow!

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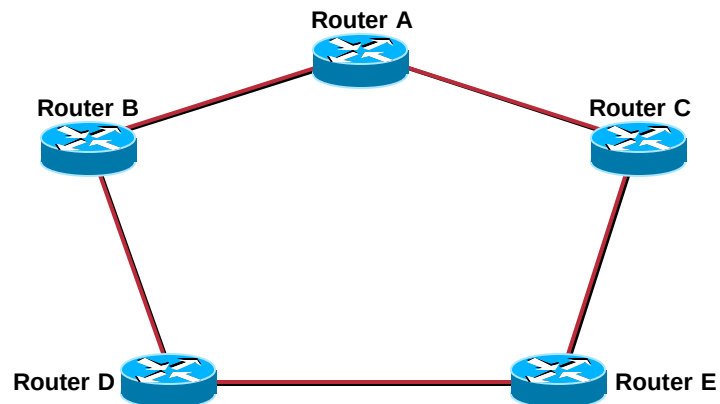
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Strategic

Cisco.com

- Physical topology is:



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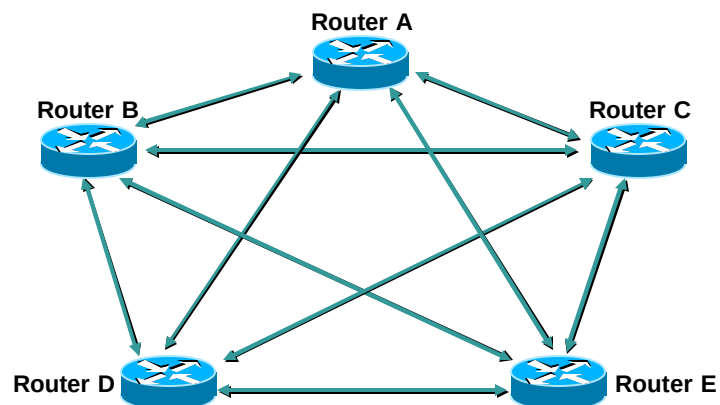
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Strategic

Cisco.com

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



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Strategic

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- Things to remember with full mesh

N routers, $N*(N-1)$ tunnels

Routing protocols not run over TE tunnels—
unlike an ATM/FR full mesh!

Tunnels are **unidirectional**—this is a
good thing

...Can have different bandwidth reservations
in two different directions

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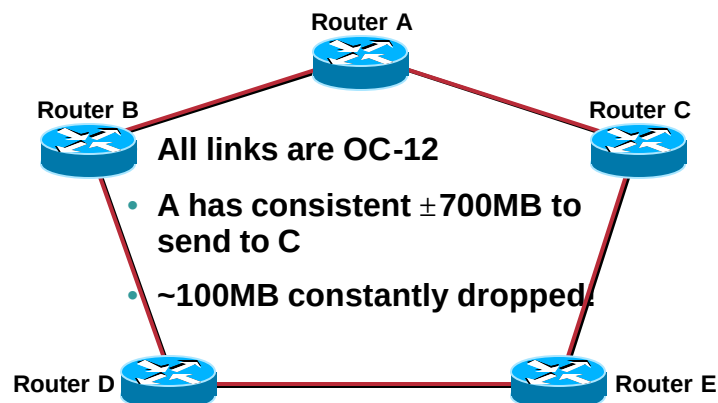
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Tactical

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Case Study: A Large US ISP



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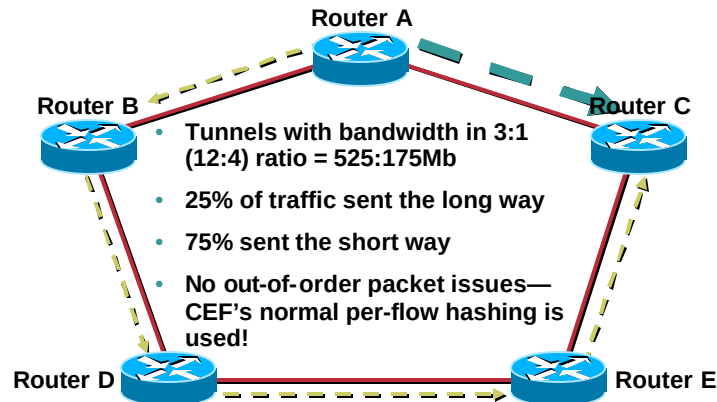
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Tactical

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- **Solution: Multiple tunnels, unequal cost load sharing!**



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Strategic vs. Tactical

Cisco.com

- Both methods are in use today and have been for some years now
- Strategic means you always have tunnels, and it means you have a lot of tunnels
Consistent mode of operation,
lots of interfaces to manage
- Tactical means you only have tunnels when you have problems
...which means removing tunnels that are no longer necessary
- Which one you pick is up to you, both methods are valid

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Designing with Backup Tunnels

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- **Connectivity protection**

Router calculates the path for its backup tunnel

Assume that any found path can carry any link's traffic during failure

Don't signal bandwidth for the backup tunnel!

Use DiffServ to solve any contention due to congestion while FRR is in use

- **Bandwidth protection**

Offline tool calculates paths for protection LSPs

Assurance that bandwidth is available during failure

More complex to maintain, may require additional network bandwidth

Allows you to **always** meet SLAs during failure

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Reasonable Combinations

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Primary Backup \	None	Tactical	Strategic
None	IP	TE to work around congestion	Bandwidth optimization (online or offline)
Connectivity Protection	1hop online	1hop online + sporadic tactical	Bandwidth optimization (online or offline) + online backup
Bandwidth Protection	1hop offline	1hop online + sporadic tactical	Bandwidth optimization (online or offline) + offline backup

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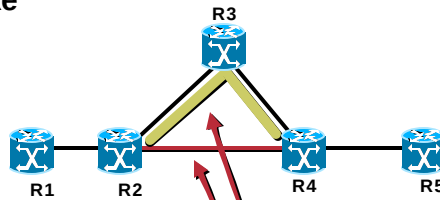
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1hop FRR

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- Useful if you want to take advantage of FRR but don't need primary bandwidth optimization
- All primary tunnels go between two directly connected nodes (tunnels are 1 hop long)
- Backup tunnel protects only that primary
- Currently in production in a few large IP (VPN, VoIP) networks



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New and Exciting Things

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- Tunnel selection
- Refresh reduction and reliable messaging
- MD5 and SHA-1 for RSVP
- LSP Attributes
- AutoTunnel
- Inter-AS TE
- Hierarchical TE Tunnels

DISCLAIMER: All dates are estimates, I do not make any schedule decisions, a shipping date is only final once the code has already shipped, etc, etc, etc.

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Tunnel Selection

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- On an AToM PE, an easy way to push a specific AToM circuit down a specific TE tunnel
- 12.0(25)S, shipping now:

```
pseudowire-class T41
encapsulation mpls
preferred-path interface Tunnel41 disable-fallback
```

```
interface gigabitethernet3/0.2
encapsulation dot1Q 204
xconnect 1.0.0.4 4 pw-class T41
```

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Refresh Reduction and Reliable Messaging

Cisco.com

- Shipped in 12.0(24)S
- RFC2961

```
(config)# ip rsvp signalling  
refresh reduction
```

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MD5 and SHA-1 for RSVP

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- Scheduled to ship in 12.0(26)S
- ETA July/August
- RFC2747, RFC3097

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LSP Attributes

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- Scheduled to ship in 12.0(26)S
- ETA July/August
- LSP Attributes is really two things:
 - 1) Bandwidth override on path option
 - 2) LSP Attribute Lists

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Bandwidth Override on Path Option

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- Can specify a bandwidth on a path-option that overrides the tunnel BW:

```
tunnel mpls traffic-eng bandwidth 1000
tunnel mpls traffic-eng path-option 1
explicit name path1
tunnel mpls traffic-eng path-option 2
explicit name path2 bandwidth 500
tunnel mpls traffic-eng path-option 3
dynamic bandwidth 0
```

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LSP Attribute Lists

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- Control full set of LSP attributes per path, not per tunnel
- More complex, more powerful
- Also scheduled to ship in 12.0(26)S

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LSP Attribute Lists

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(global config)

```
mpls traffic-eng lsp attributes bar
```

```
affinity 7 7
```

```
bandwidth 1000
```

```
priority 1 1
```

interface Tunnel0

```
tunnel mpls traffic-eng path-option 10 explicit  
name foo attributes bar
```

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AutoTunnel

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- **Scheduled to ship in 12.0(26)S**
ETA July/August
- **Obviates need to configure NHop and NNHop backup tunnels**
- **Further enhancements on the radar (mesh groups)**

mpls traffic-eng auto-tunnel backup

- **That's it! No configuring backup or 1-hop primary tunnels!**
- **Tradeoff between convenience and flexibility**

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Inter-AS TE

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draft -vasseur -inter -as -te

- **On the radar**
- **Used to build a TE LSP across multiple ASes**

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Hierarchical TE Tunnels

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- a la draft-ietf-mpls-lsp-hierarchy
- On the radar

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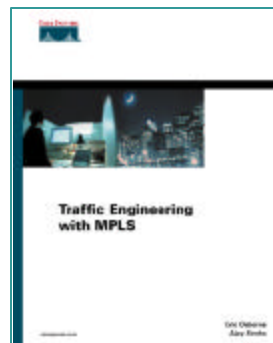
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Recommended Reading

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Traffic Engineering with MPLS

ISBN: 1587050315



Available on-site at the Cisco Company Store

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