Tutorial: MPLS Applications Overview

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Disclaimer

- **The views presented are of the author and do not necessarily represent Juniper Networks.**

Topics

- Traffic engineering
- Fast reroute
- VPNs
- Pseudo-wires
- Protocol comparison

Topics

- **Traffic engineering**
- **Fast reroute**
- **VPNs**
- **Pseudo-wires**
- **Protocol comparison**

Traffic engineering (TE)

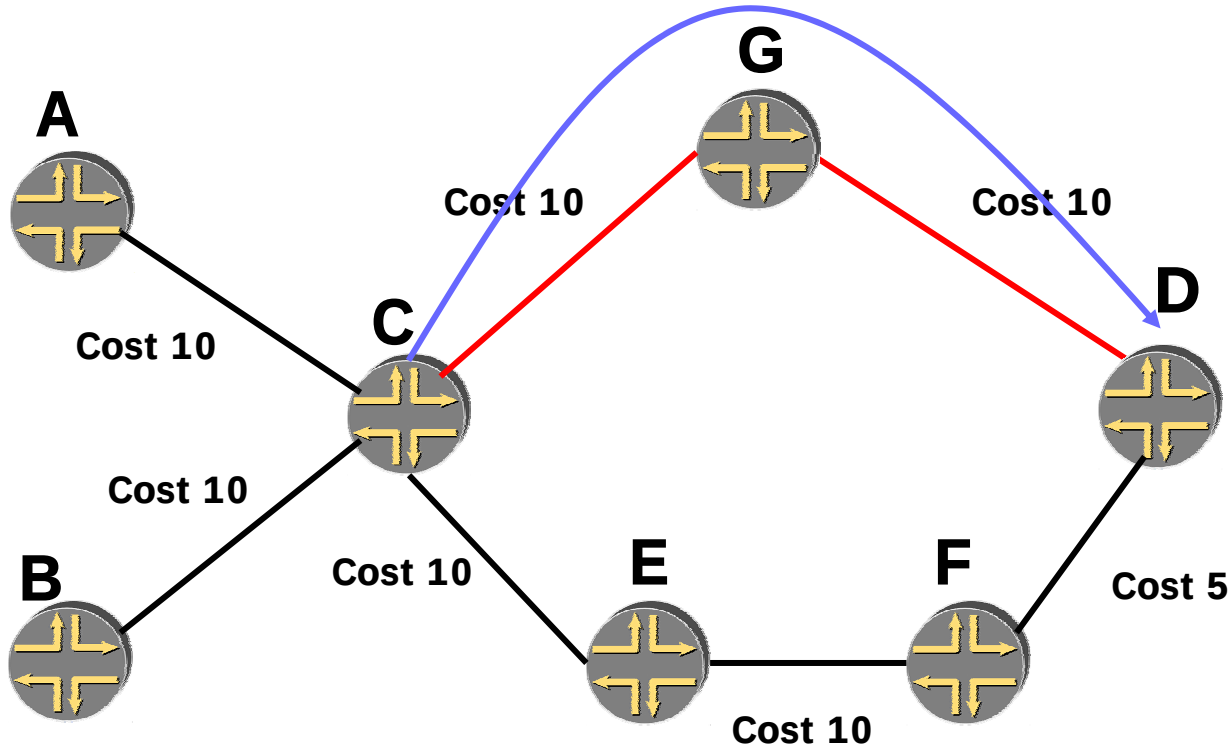
- **Avoid a situation in which some parts of the network are congested while others are underutilized.**
- **Goal: most efficient use of available resources, especially bandwidth.**

TE using IP routing

- Routing determines the paths taken by traffic, thus controls how much traffic traverses each link.
- IP routing characteristics:

1. Forwarding based on the destination address.
2. Routing changes can be made via manipulation of protocol metrics.

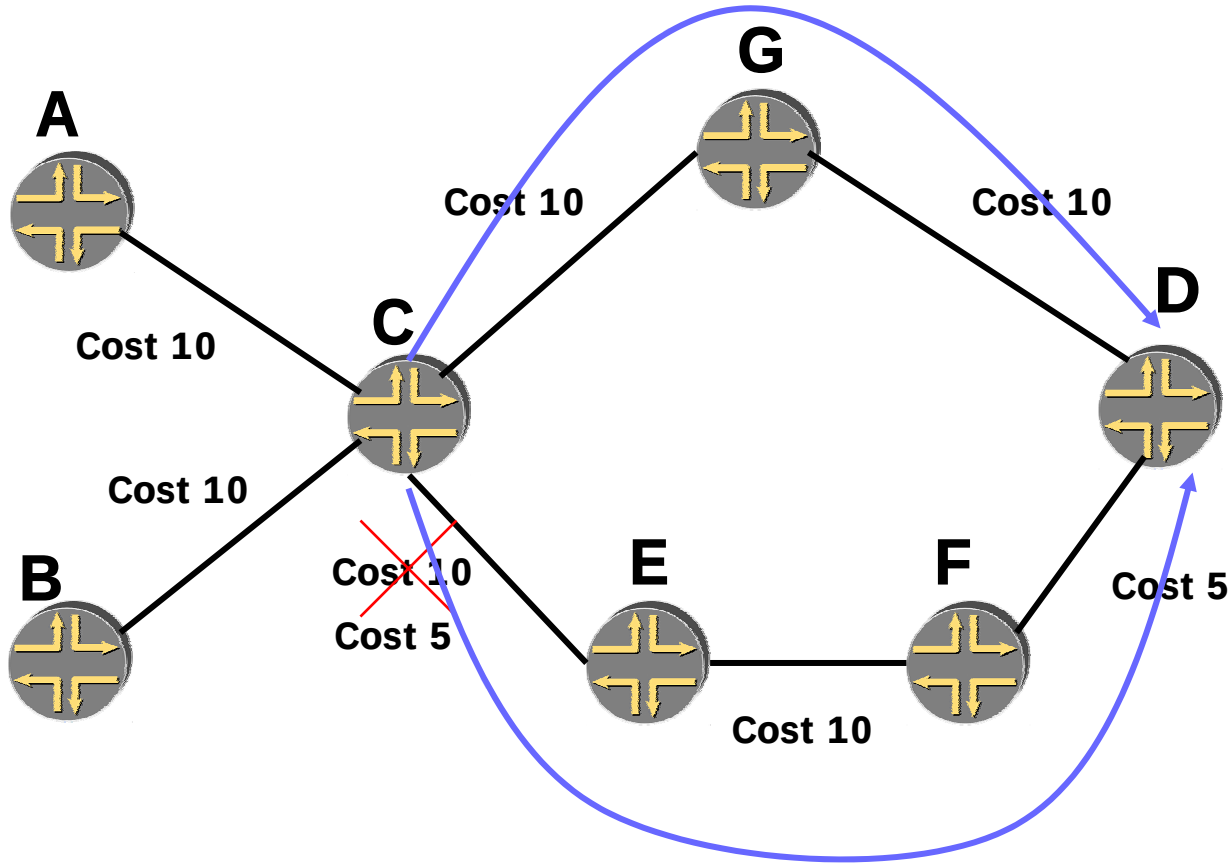
An example –
The fish topology – shortest path



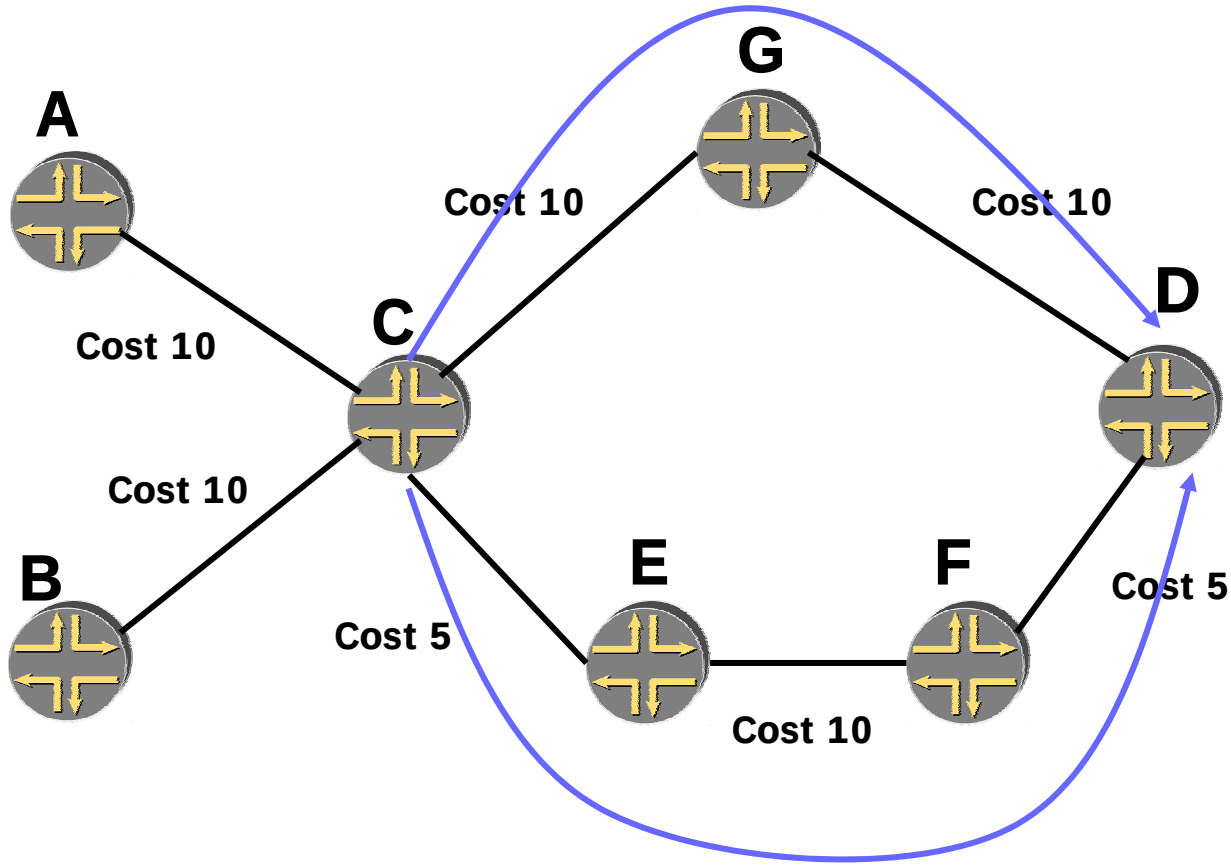
All links are 150Mbps.

A and B are each sending 100Mbps

The fish topology – equal cost

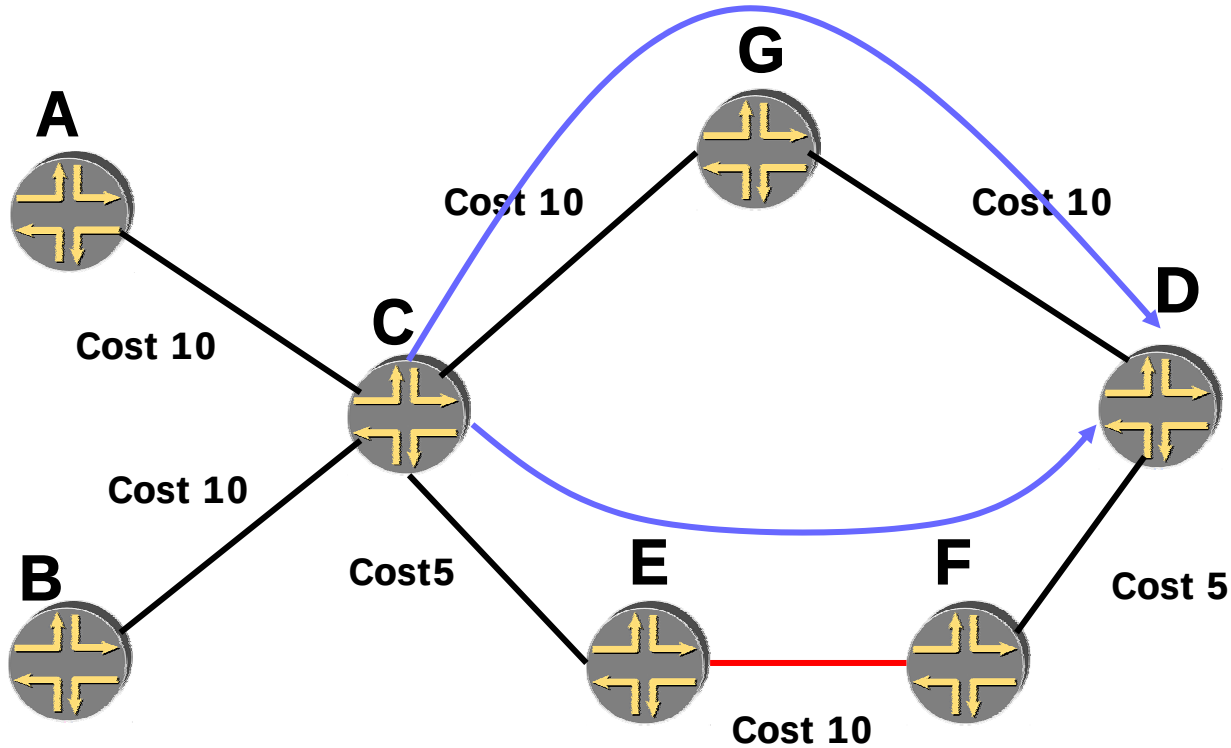


The fish topology – controlling forwarding



Traffic from A should take the shorter path.

The fish topology – bandwidth constraints



All links are 150Mbps, except E-F which is 50Mbs

A is sending 120Mbs, B is sending 40Mbs

The problems

- **Need path that is optimal with regard to some metric and also needs to take into account other constraints = > constraint-based routing.**

Constraint-based routing

1. **Requires path calculation at the beginning of the path (source of the path).**

2. **When the path is determined by the source, can’t use destination-based forwarding to forward traffic along that path.**

Traffic engineering with constraint-based routing

- **Path calculation and setup:**
  1. **Information distribution**
  2. **Path selection**
  3. **Path signaling**
- **Forwarding**

Path calculation

- **CSPF – constrained SPF**
- **Like conventional SPF, computes shortest path (with regard to some administrative metric).**
- **But takes into account only paths that satisfy one or more user-defined constraints (e.g. available bandwidth)**

Path calculation (cont)

- Requires extensions to the IGPs to carry additional information (available bw).
- Can be done online or offline.
- Explained in detail at the previous nanog.

Path signaling and forwarding

- **Useful properties of MPLS for this context:**

1. **Can establish paths based on explicit routes using RSVP (the ERO object).**

2. **Forwarding is based on a label rather than on a destination address.**

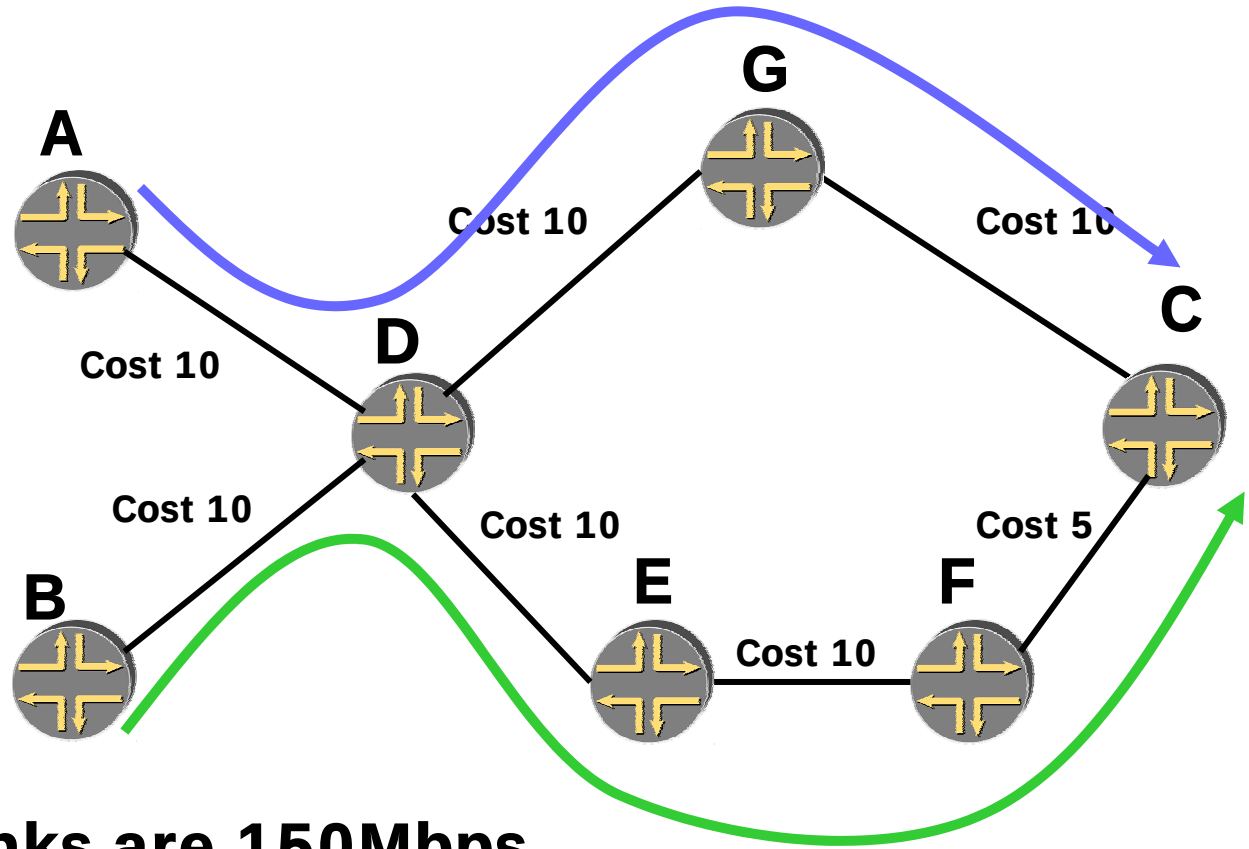
Traffic engineering with MPLS

- Information distribution => IGP extensions
- Path selection => CSPF
- Path signaling => RSVP
- Forwarding => MPLS

The result:

Paths that are optimal with regards to both routing protocol metrics and comply to given constraints.

The fish topology revisited (1)

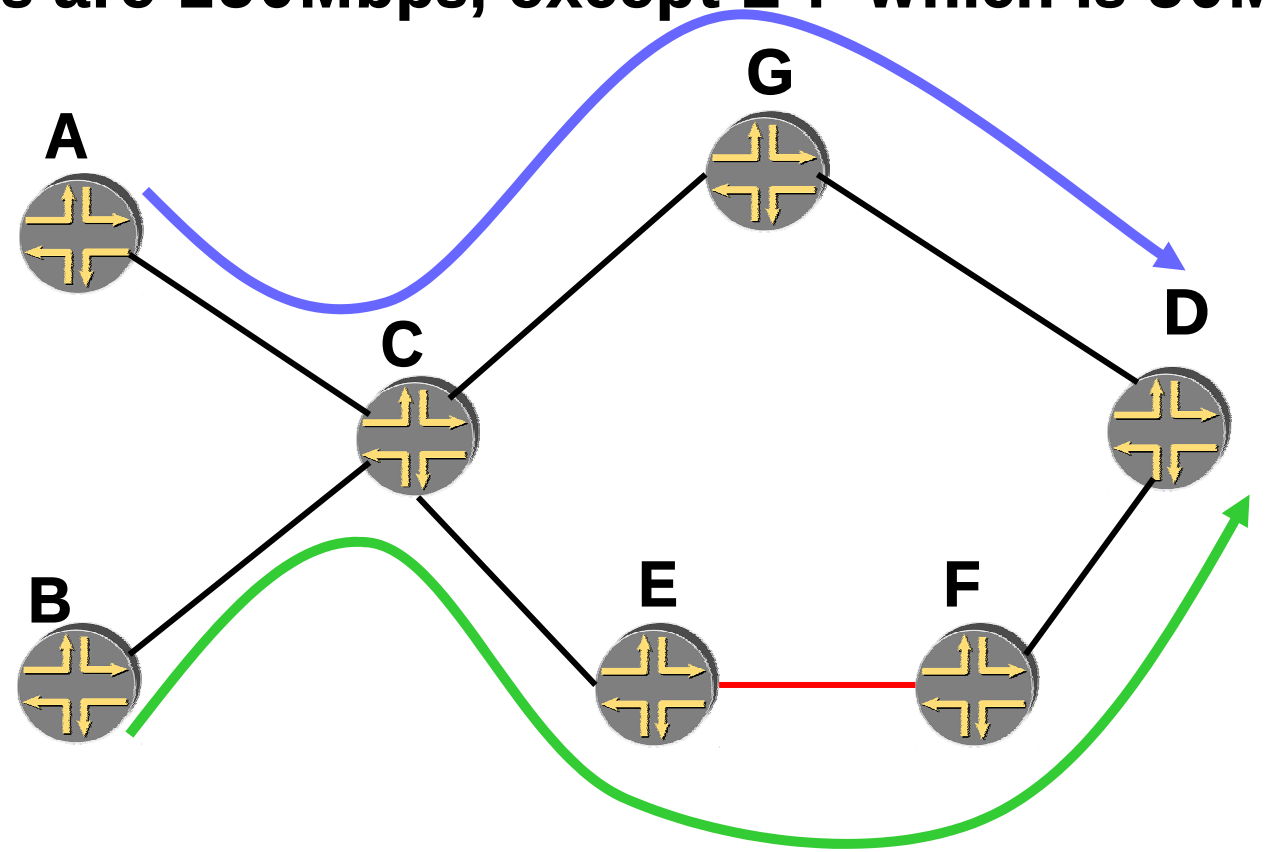


All links are 150Mbps.

A and B are each sending 100Mbps

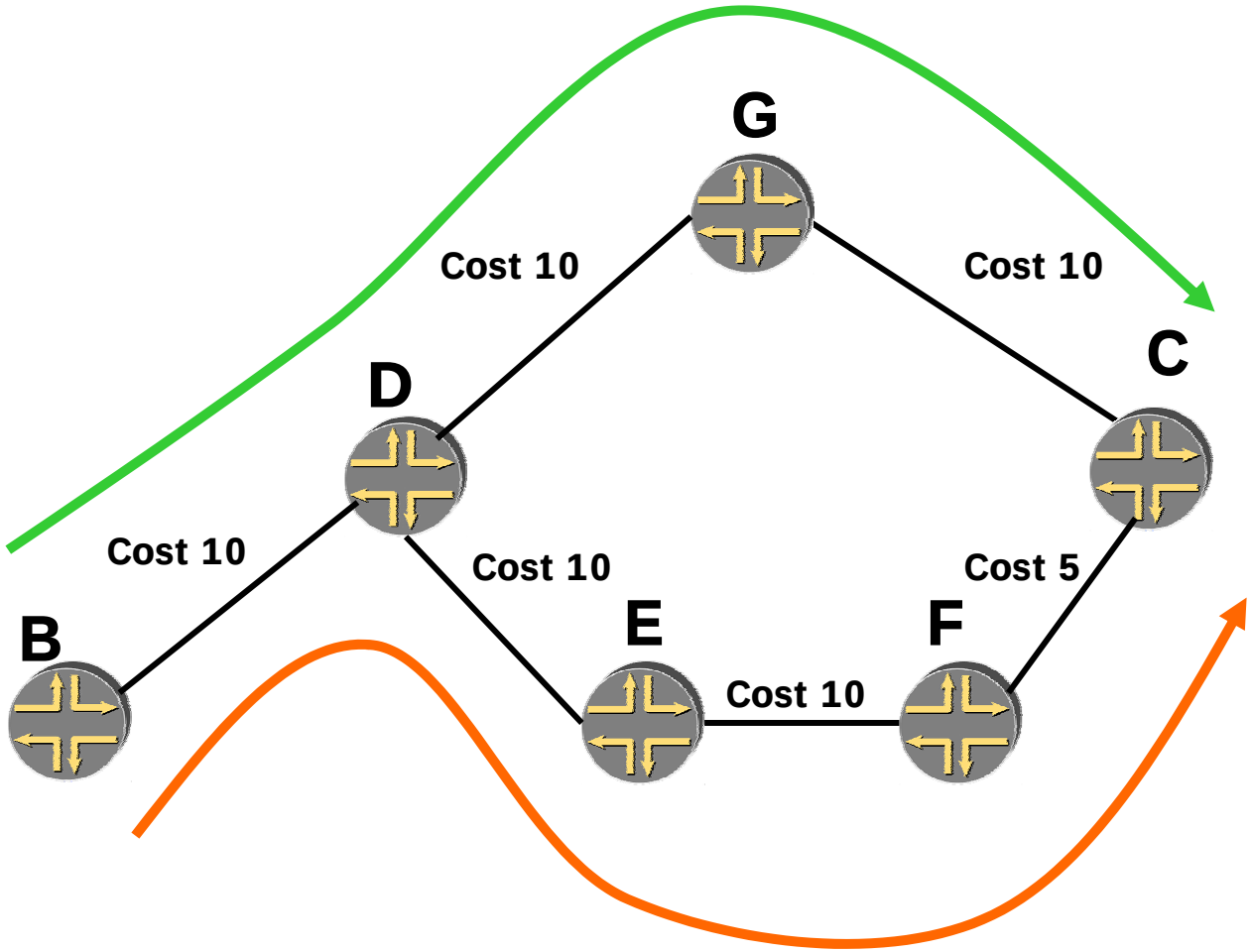
The fish topology revisited (2)

All links are 150Mbps, except E-F which is 50Mbs



A is sending 120Mbs, B is sending 40Mbs

The fish topology revisited (3)



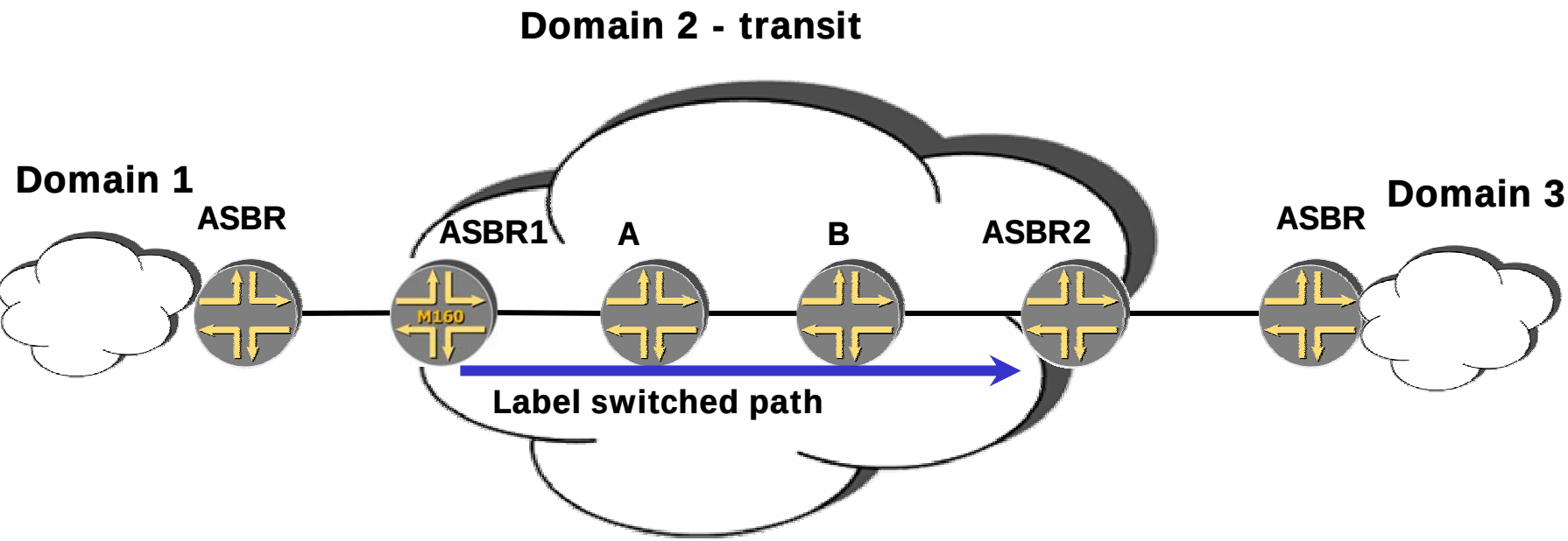
Split the traffic from B.

Traffic engineering BGP destinations

- **When an LSP is available to the BGP nexthop of a particular route, can use the LSP to forward the traffic to that route.**

Traffic engineering BGP destinations (cont)

- **LSP between ASBRs. All transit traffic will use this LSP.**



Traffic engineering BGP destinations (cont)

- Control the path that transit traffic takes inside the domain.
- Forwarding is done based on MPLS labels. The routers in the middle of the network don’t need to have knowledge of the destinations.
- It is possible to have a BGP-free core.

What about load sharing?

- **Create several tunnels to the same destination.**
- **Load balance the BGP traffic across these tunnels.**

Traffic engineering IGP destinations

- **Advantage: allows mixing paths determined by constraint-based routing with paths determined by IP routing -> can apply traffic engineering to only a portion of the network.**

- **Attractive scaling property.**

Traffic engineering IGP destinations

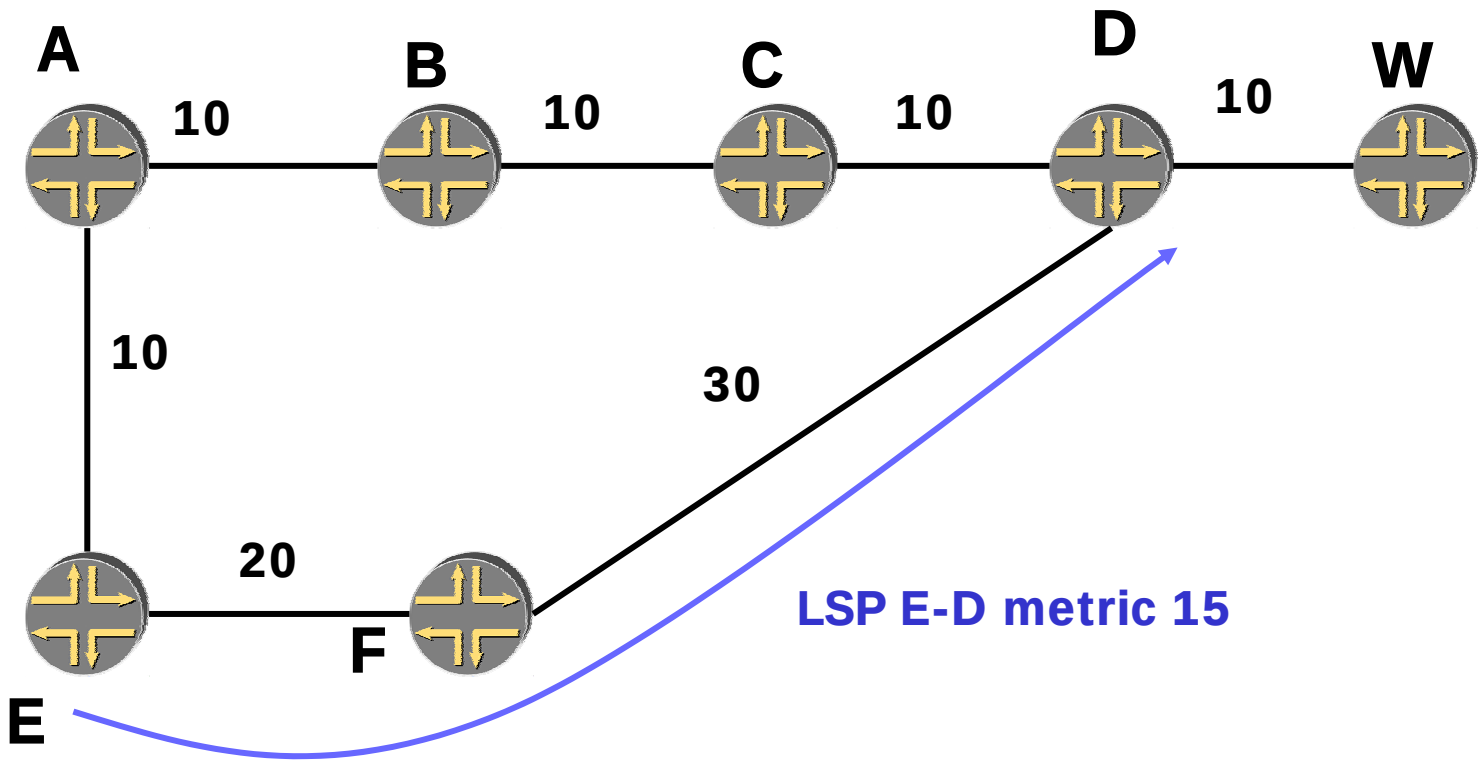
- **Two concepts:**

1. **Allow IGP on the LSP head-end to use the LSP in the SPF computation. (other routers in the network will not know about the existence of this LSP).**
2. **Advertise the LSP in the link-state advertisements, so that other routers can also take it into account in their computations.**

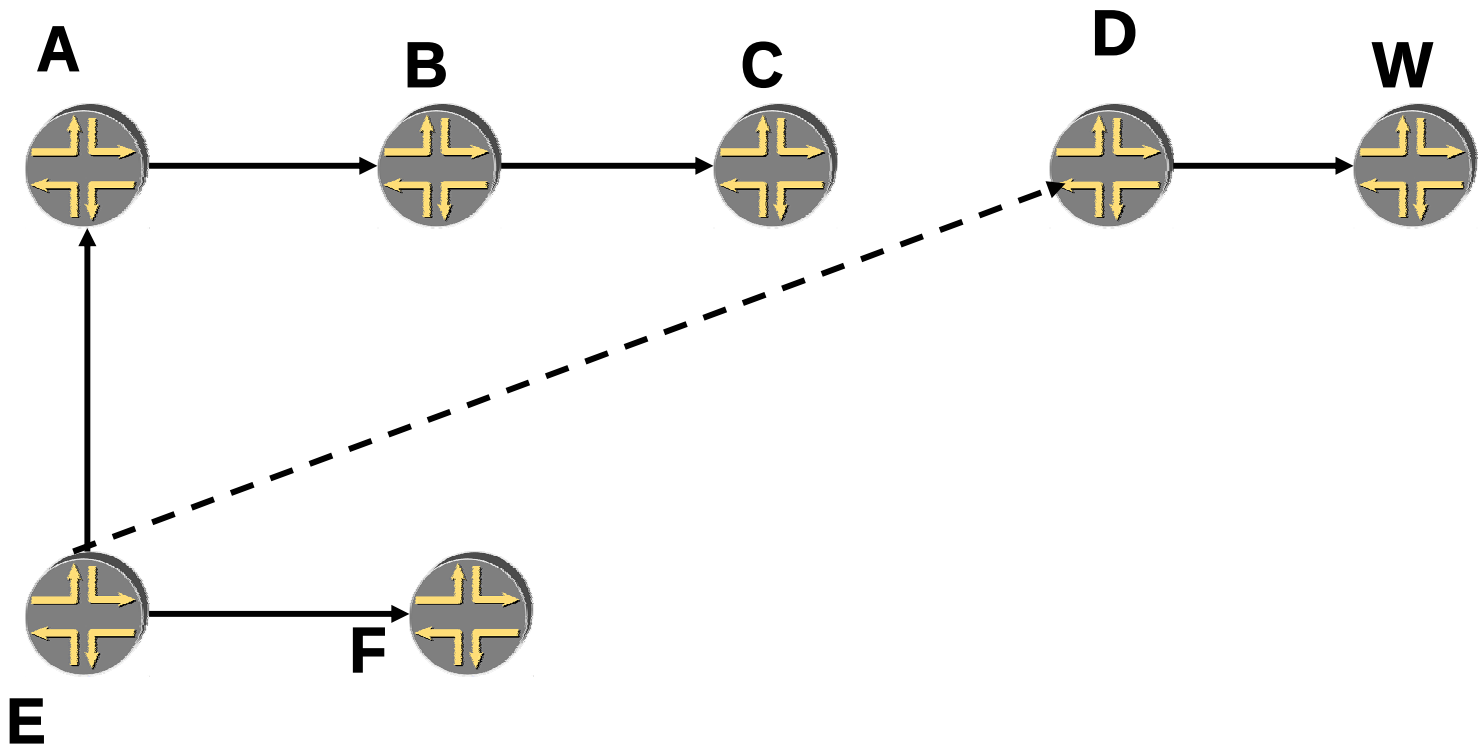
Allow SPF at the head-end to use the LSP

- **The idea: modify SPF to take advantage of this LSP.**
- **The shortest path to the LSP endpoint and to destinations behind it will be through the LSP.**

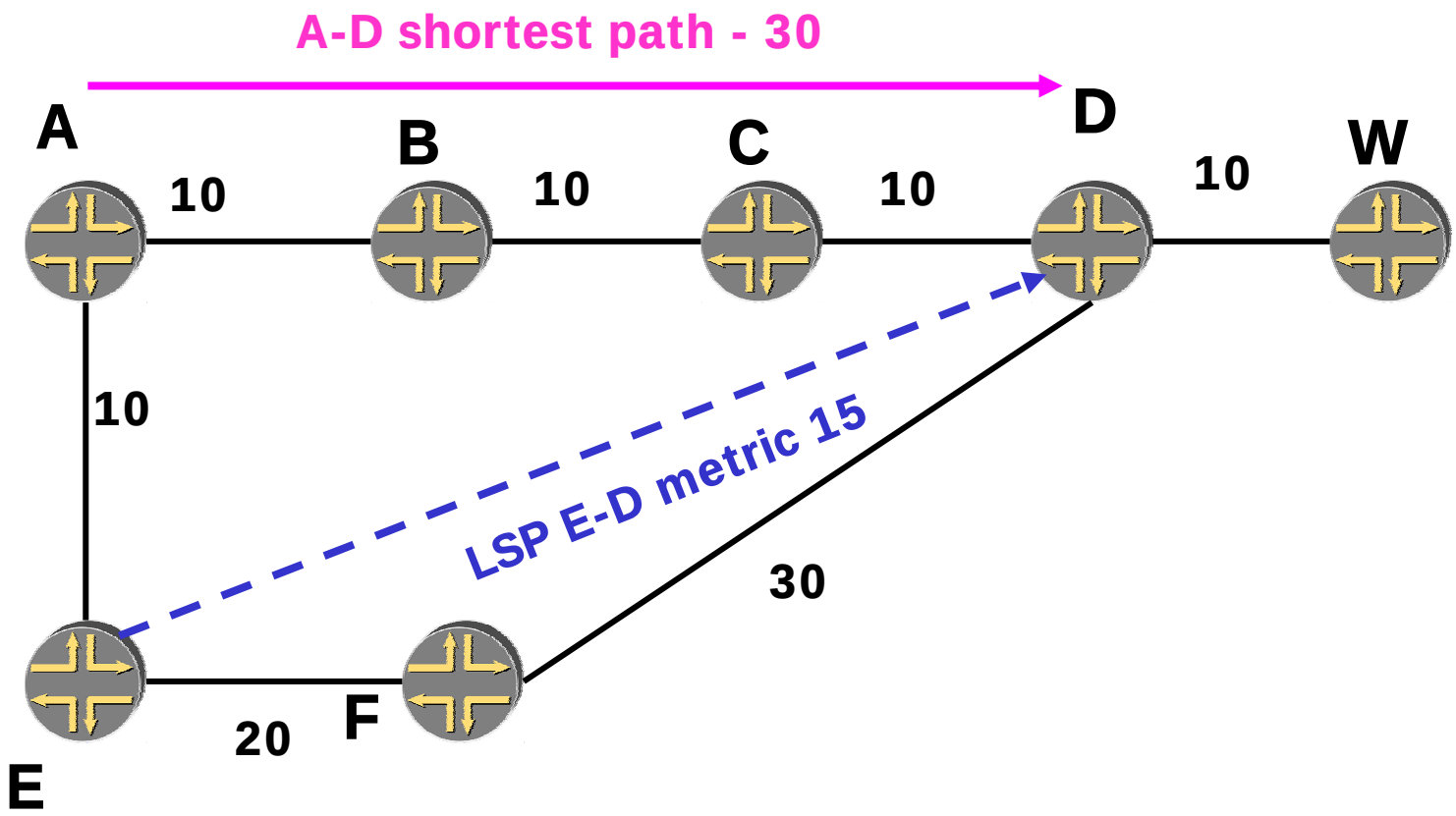
Allow the head-end to use the LSP - example



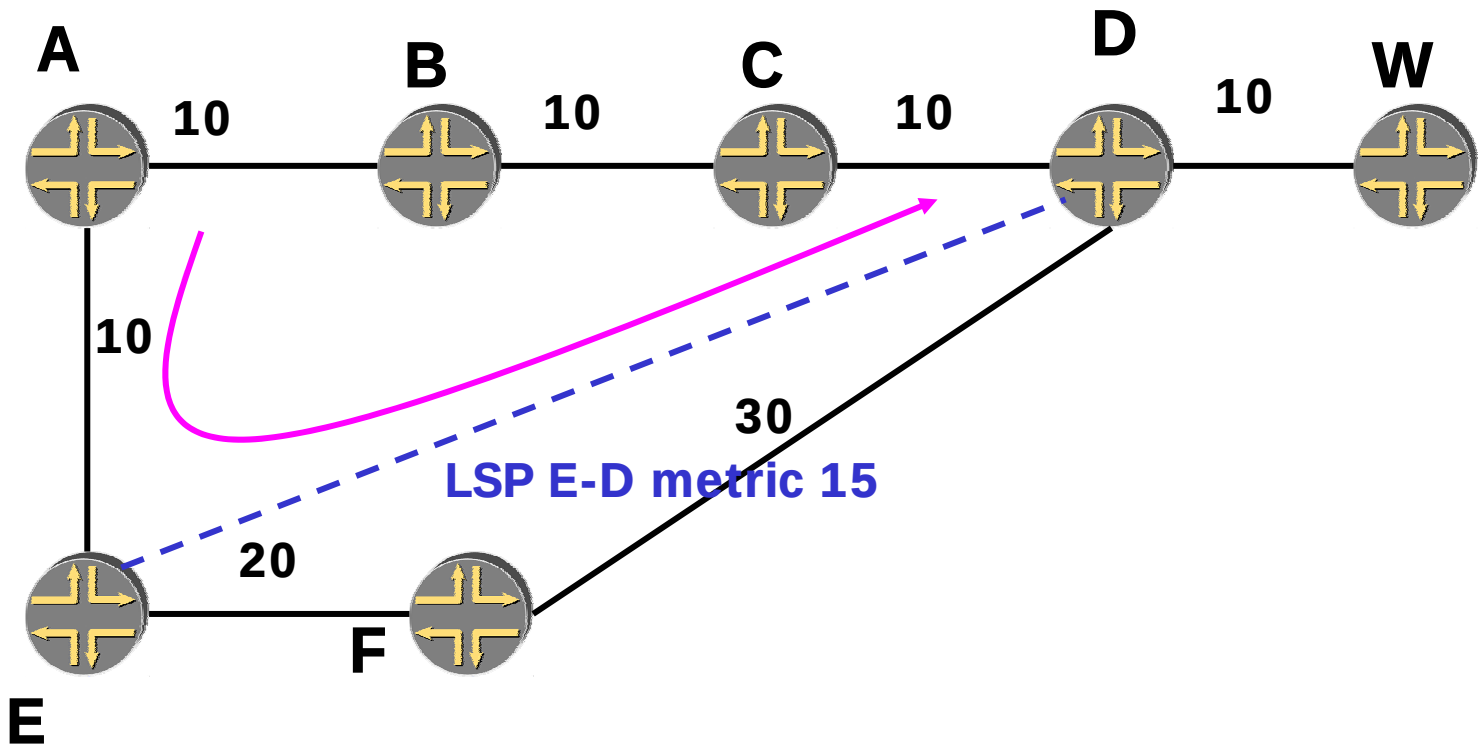
Allow the head-end to use the LSP – example SPF tree from E



Advertising LSPs in the IGP –why is it needed?



Advertising LSPs in the IGP - example



A-D shortest path 25

Advertising LSPs in the IGP

- Advertise the LSP as a unidirectional, point-to-point link in the link-state database.
- All routes can compute paths using the LSP.

Summary 1: Applications of MPLS to traffic engineering

- Load share traffic across paths with unequal cost.
- Enable definition of flexible forwarding policies.
- Route primary paths away from known bottlenecks or points of congestion.
- Control the path of traffic to destinations outside the domain.
- Mix routing determined by MPLS constraint-based routing with routing determined by plain IP. Thus no need for a full-mesh of LSPs everywhere.

Other features useful for traffic engineering

- LSP priorities
- Automatic bandwidth adjustment
- Path protection

LSP priority and preemption

- **The idea: some LSPs are more important than others, and can “kick out” the less important ones, when resource contention occurs.**
- **This happens during computation and setup, not at forwarding time.**

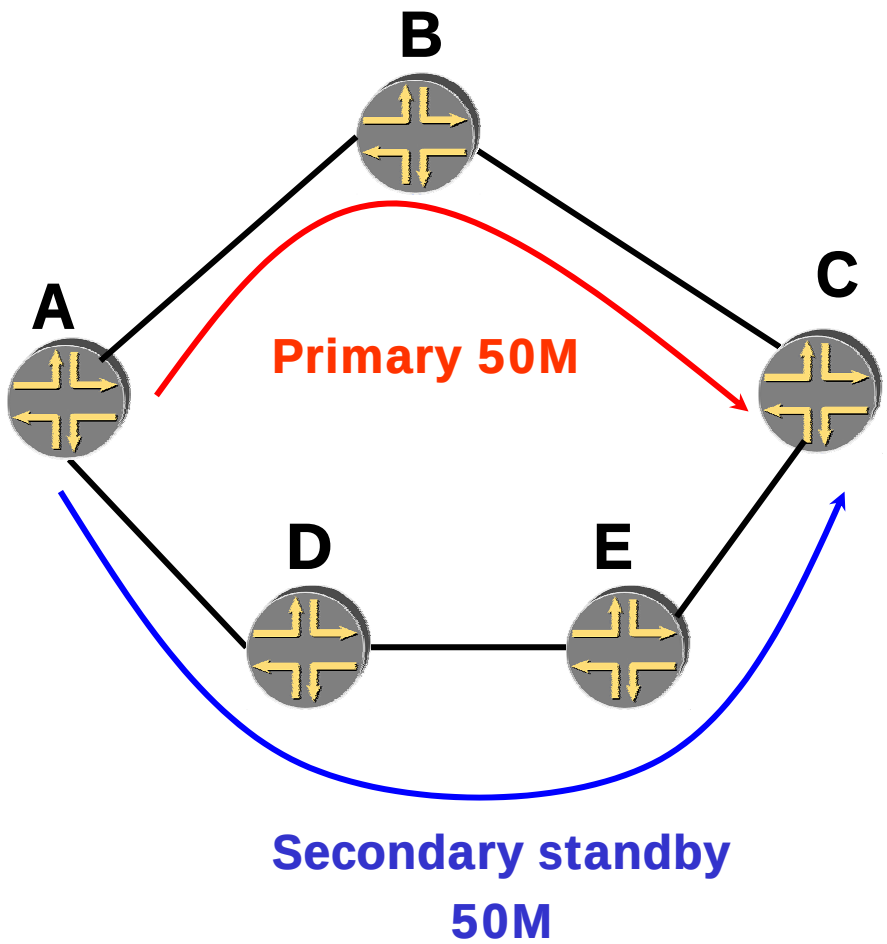
Auto-bandwidth

- The idea – monitor the traffic rate on an LSP, and resize the bandwidth on the LSP to match with the traffic rates going down the tunnel.
- May result in an LSP rerouting.
- The traffic flowing down the LSP will not be affected.
- Turned on at the head end of the LSP.

Path protection

- The idea – protect an LSP by having an additional (secondary standby) LSP set up in parallel to it.
- The secondary standby is signaled ahead of time, from the head end. Can be made to avoid crossing the same links/nodes as the protected LSP.
- The secondary standby is used only in case of failure, but is up and ready all the time.

Path protection



Path protection (cont)

- **Advantage:**
  1. **Gives precise control over where the traffic reroutes in case of failure.**
  2. **The secondary standby is taking a diverse path.**

Path protection (cont)

- **Disadvantages:**
  1. **Reserves resources for the backup, but most of the time they are not used.**
  2. **Builds one secondary standby for each protected path.**
  3. **Takes effect when the head end finds out about the failure.**

Summary 2: More applications of MPLS to traffic engineering

- Provide a mechanism to prioritize LSPs in the case of resource contention
- Automatic bandwidth adjustment
- Provide precise control over how a path is rerouted in case of a single or multiple failures

Topics

- Traffic engineering
- Fast reroute
- VPNs
- Pseudo-wires
- Protocol comparison

Fast reroute

- **Goal – reduce packet loss during routing transients.**
- **Two factors:**
  1. **The time it takes to detect the failure (e.g. the time it takes to detect a link-down event – rely on link-layer mechanisms).**
  2. **The time it takes to distribute the information about the failure and recompute forwarding tables.**

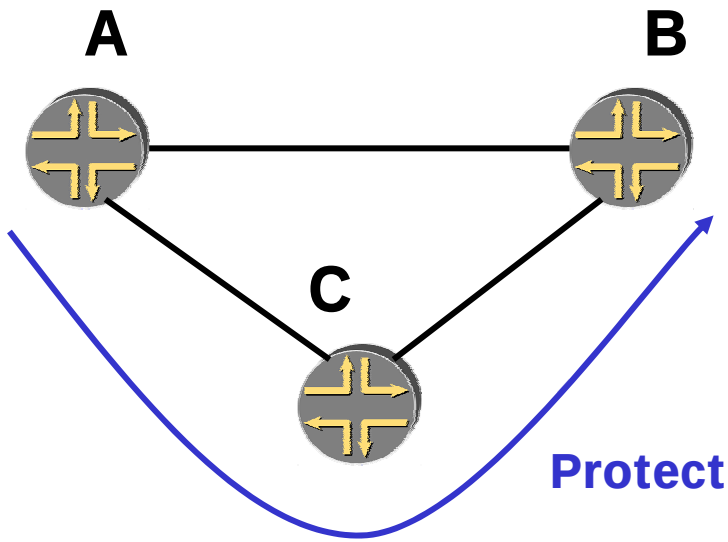
Fast reroute with IP?

- IP routing protocols are distributed in nature, and require that all routers converge to a consistent view of the routing information.
- In a large network, may have convergence in the order of a few seconds.
- A link failure can cause congestion in one part of the network, while leaving other parts free of congestion.

Fast reroute – the idea

- **The idea: reroute the traffic around the failure along an alternative path.**
- **Goal: reduce (not eliminate!) packet loss.**
- **Local protection – link protection, node protection. Will only discuss link protection.**

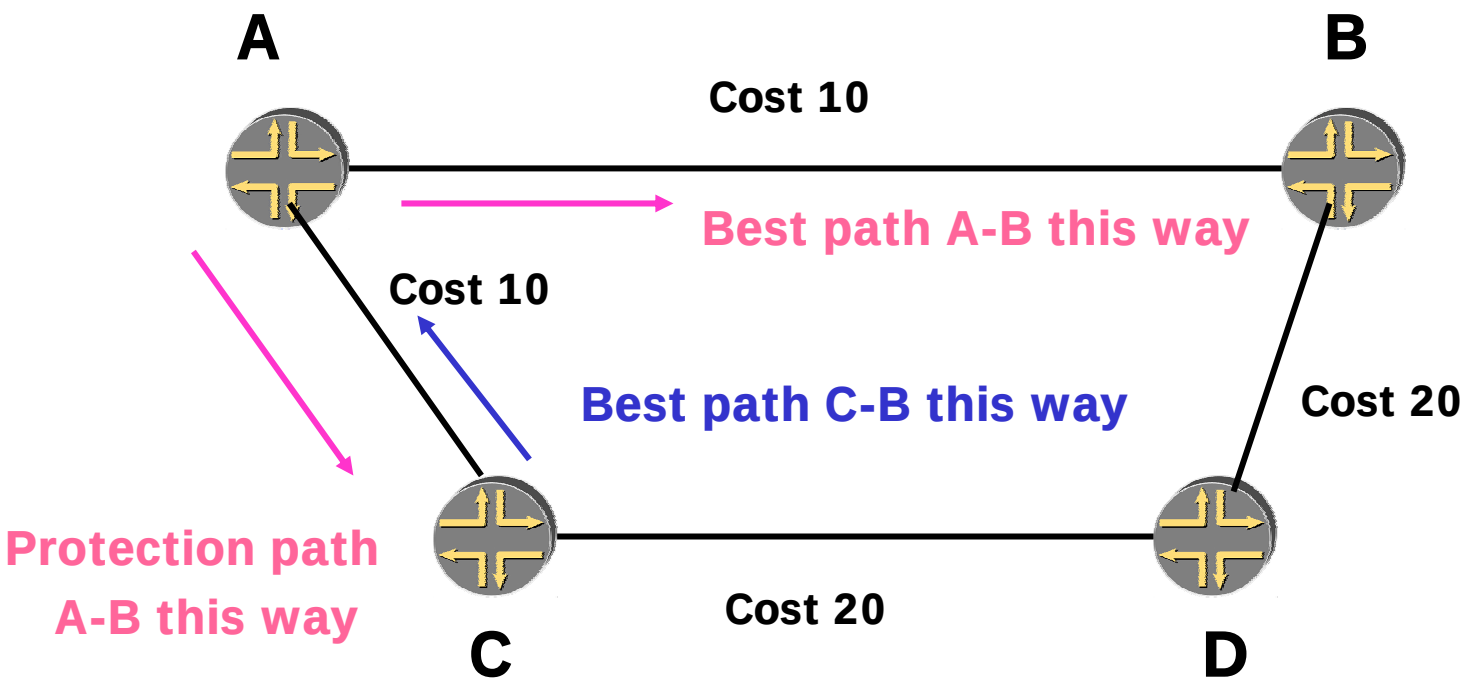
Fast reroute – the idea



Will still have traffic loss:

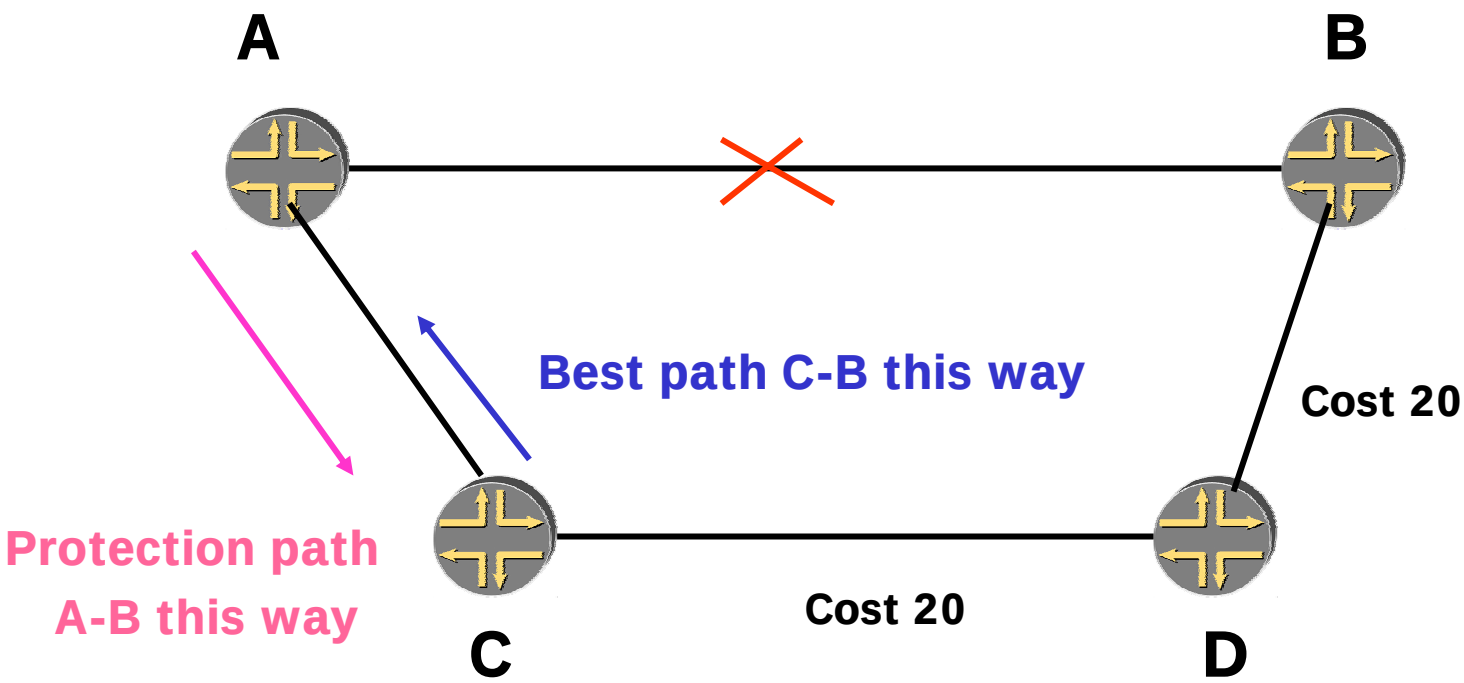
the failure needs to be detected, the traffic needs to be switched to the alternate path.

Fast reroute with IP ?



Goal – protect against failure of the link A-B

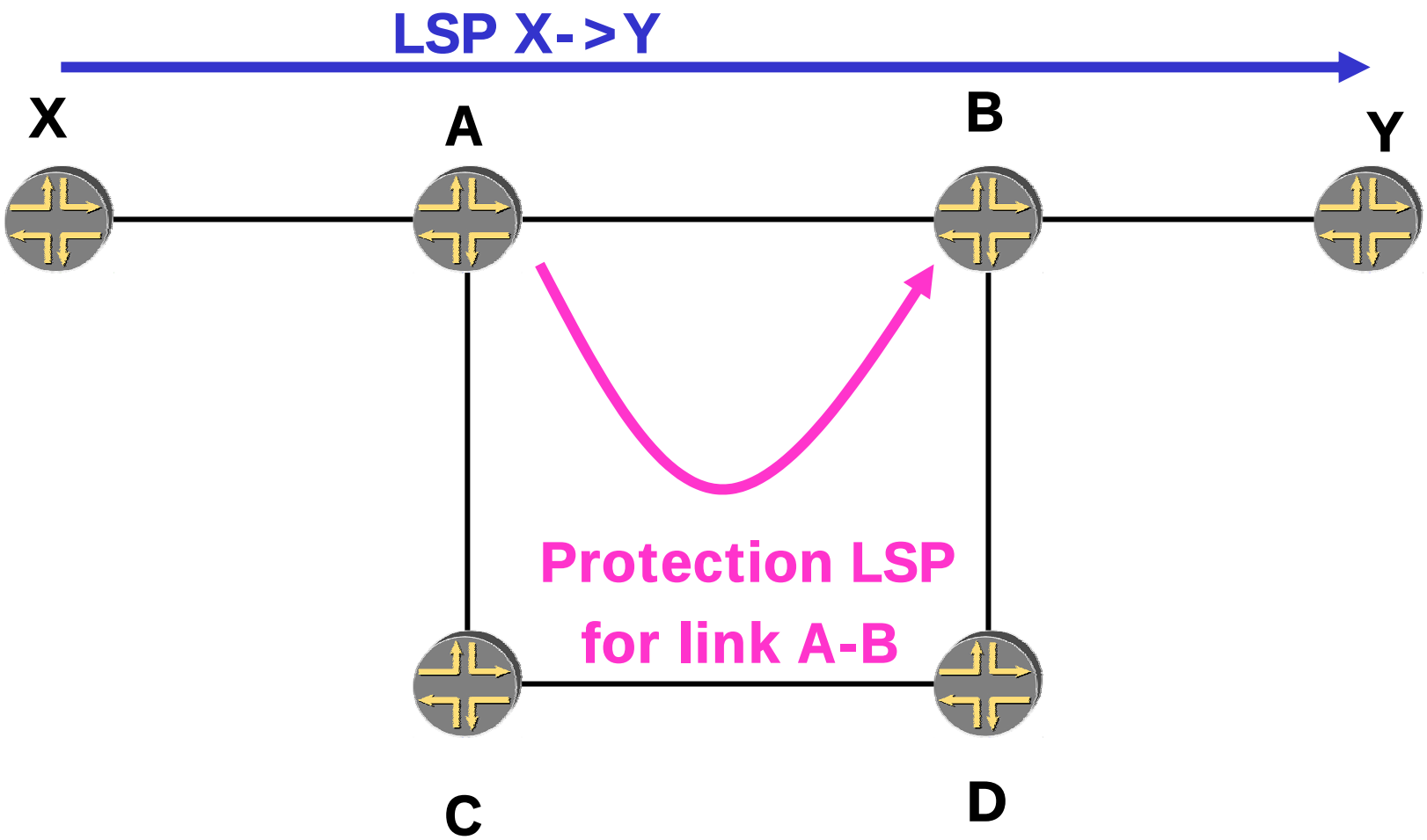
Fast reroute with IP ?(cont)



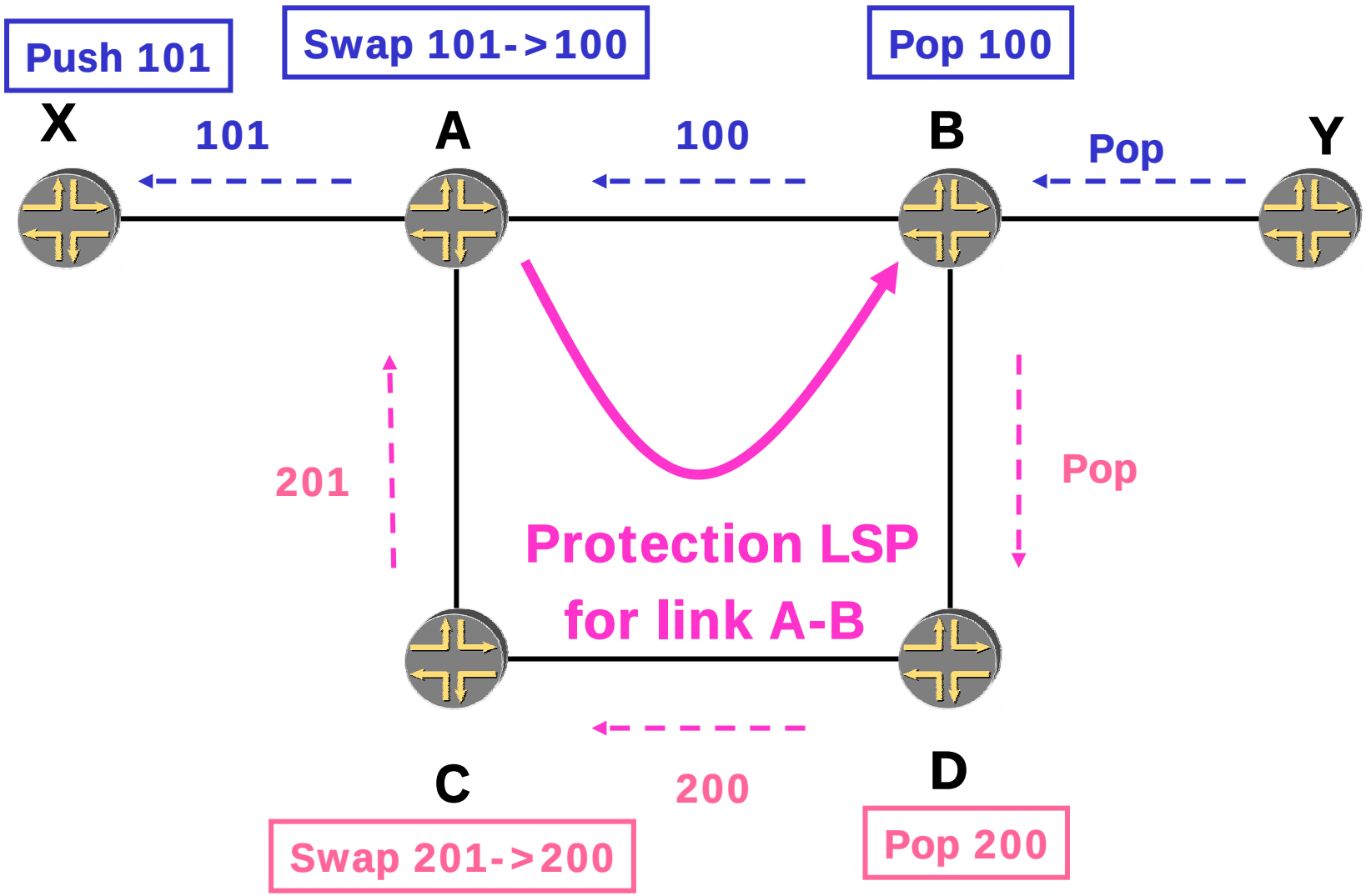
Fast reroute with MPLS

- **The problem: hop-by-hop, destination-based routing.**
- **The idea: construct a “protection” LSP around a point of failure. Nest the LSPs that traverse the point of failure onto the protection LSP.**

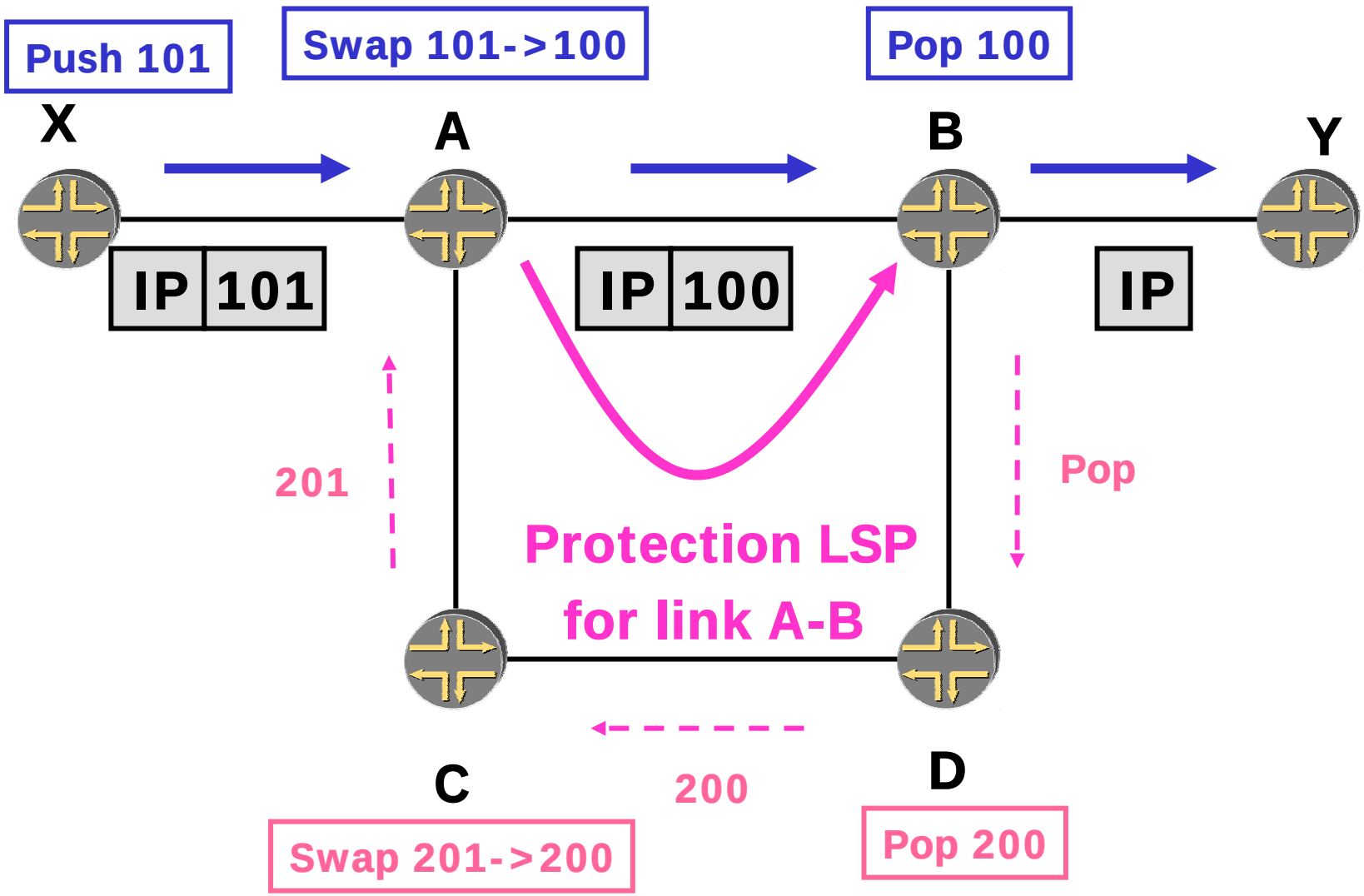
Fast reroute with MPLS (cont)



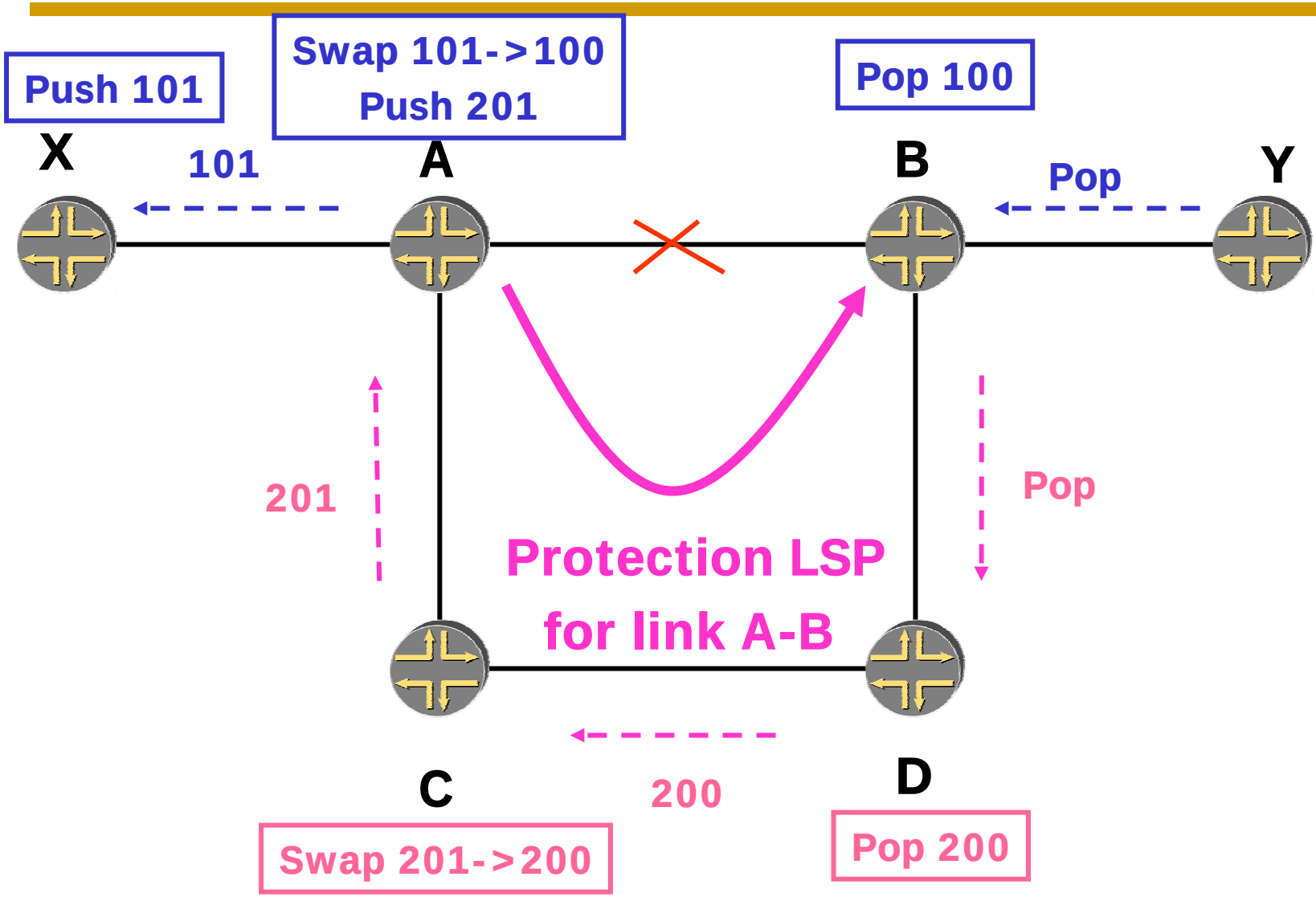
Fast reroute with MPLS (cont)



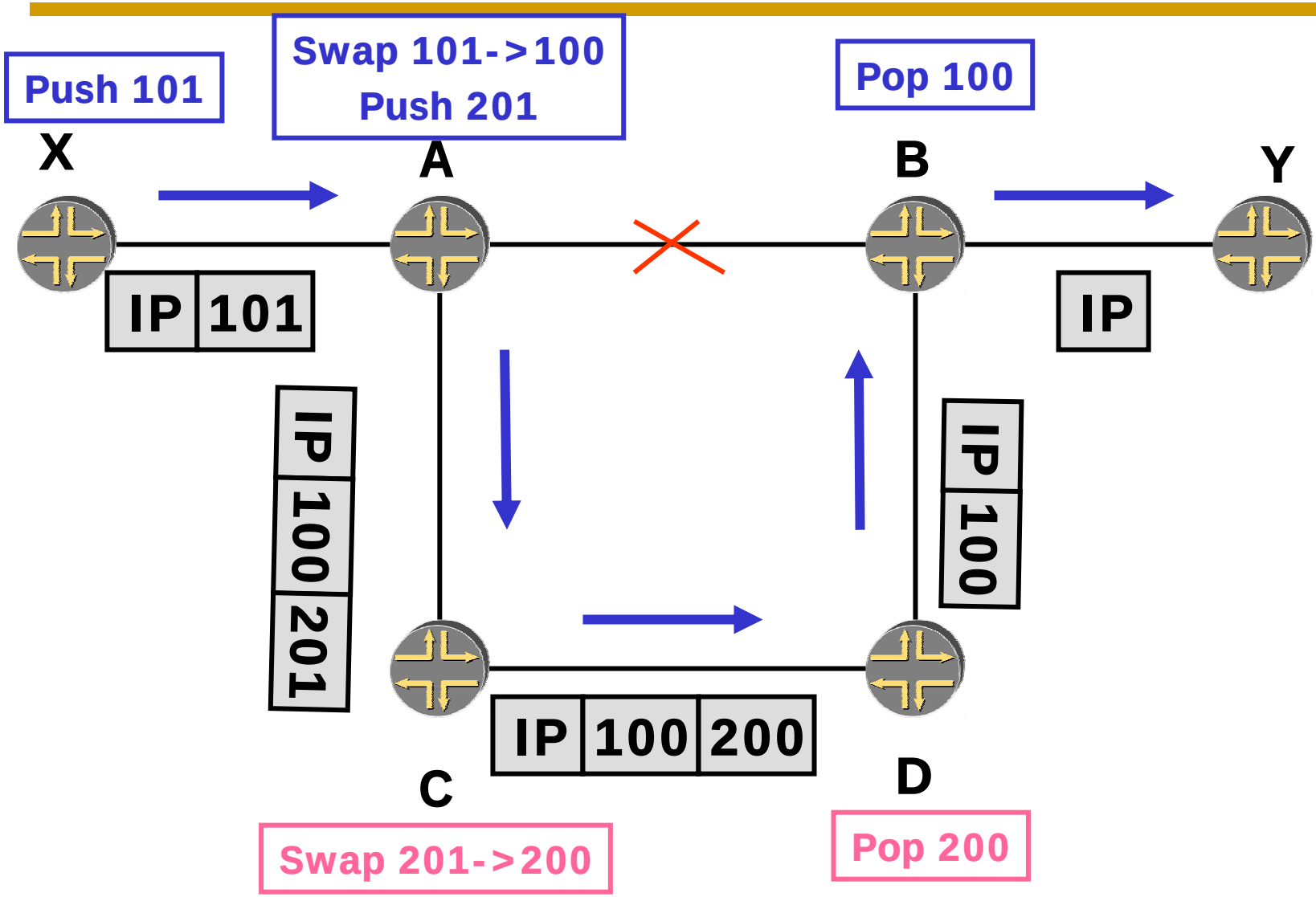
Fast reroute with MPLS (cont)



Fast reroute with MPLS (cont)



Fast reroute with MPLS (cont)



Link protection

- The protection LSP is set up ahead of time.
- Traffic loss still occurs, for the period of time until A detects the link-down event and switches the traffic to the protection LSP.
- The intention is to use the protection LSP for a short time until a new path will be recomputed.

Link protection

- **The protection LSP protects a _link_.**
- **The protection LSP is signaled around the protected link, from the node upstream of the link to the node downstream of the link, ahead of time.**
- **Traffic from one LSP or from many LSPs can be carried over it. Different scaling properties.**

Fast reroute - summary

- Traffic loss is a function of the link failure detection time instead of being a function of the head-end rerouting.
- The protection LSP is intended for short-time use after the failure.
- One can choose to protect just a few of the critical resources.

Topics

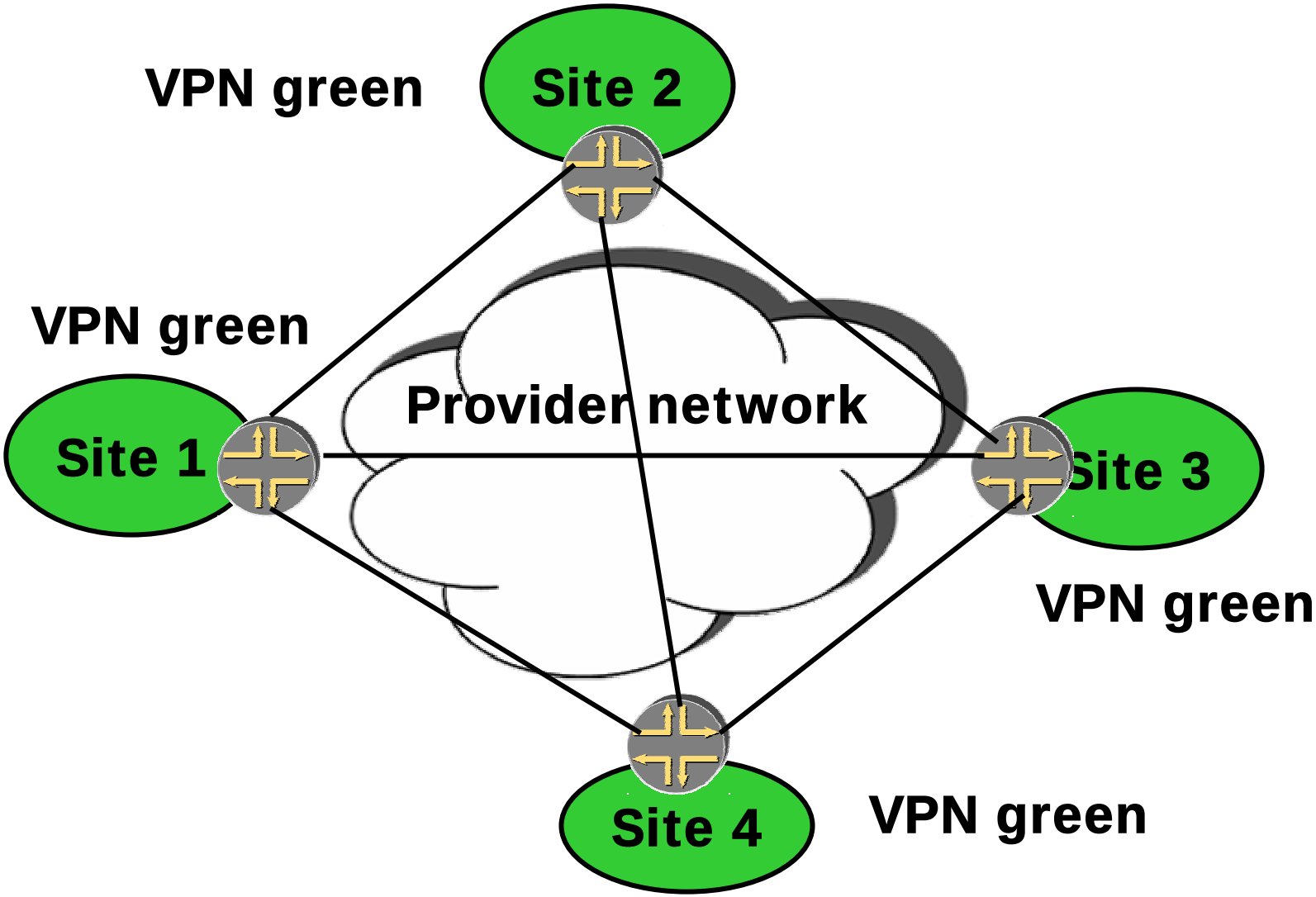
- Traffic engineering
- Fast reroute
- VPNs
- Pseudo-wires
- Protocol comparison

VPNs

- **Virtual Private Networks – provide a private network over a shared infrastructure.**

- **Interconnect geographically separate sites, with the same privacy and guarantees as a private network.**

VPNs


VPN green
Site 2
VPN green
Provider network
Site 1
Site 3
VPN green
Site 4
VPN green

The Overlay Model for VPNs

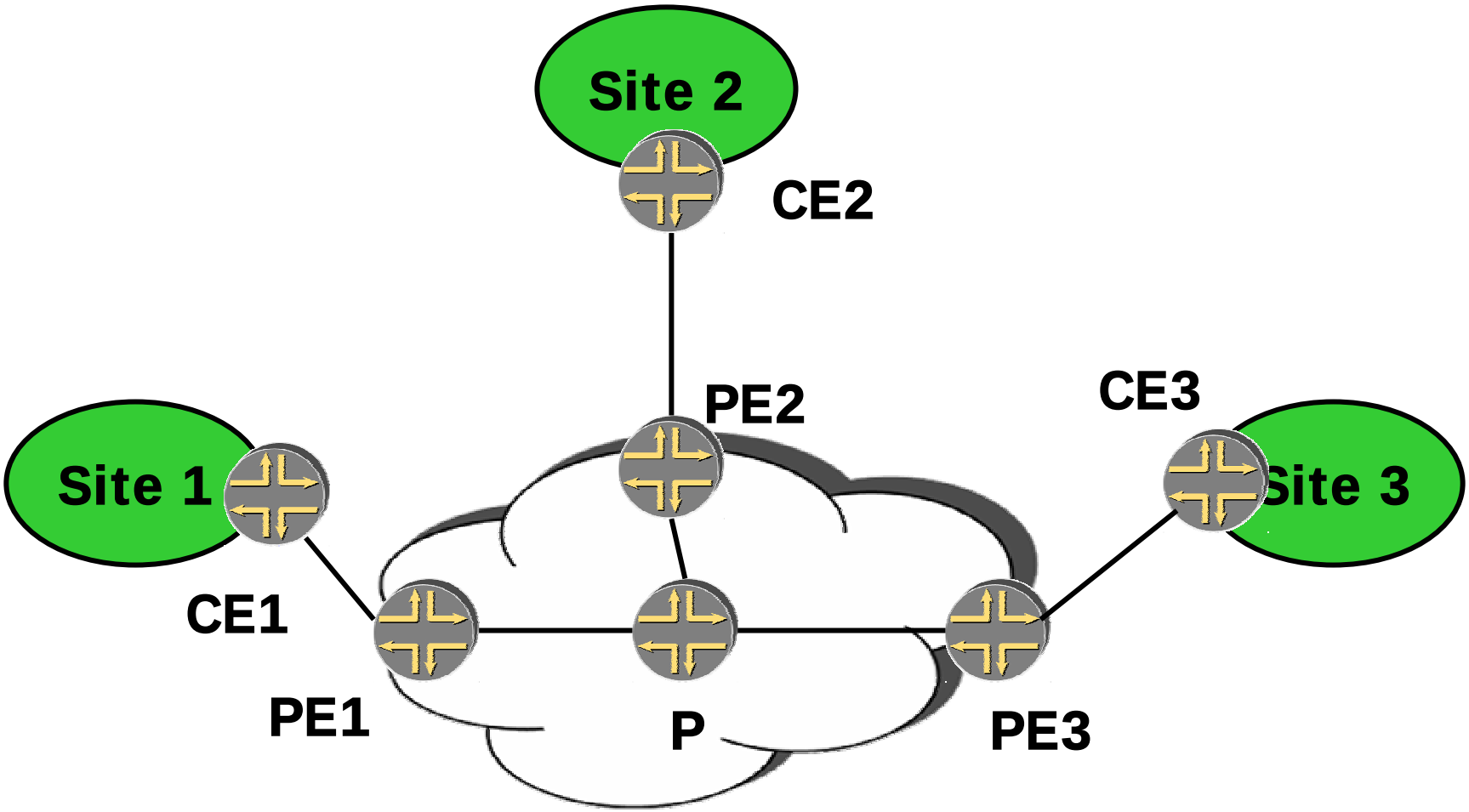
- Sites are connected with p2p links – leased lines, FR circuits, ATM circuits, GRE, IPsec.
- Customer routers peer with customer routers.
- The provider needs to design and operate "virtual backbones" for all the customers – scaling issue.
- Problem with VPNs that have a large number of sites.
- Adding a new site requires configuring all the existing sites.

BGP-MPLS VPNs

- **Goal: solve the scaling issues. Support thousands of VPNs, support VPNs with hundreds of sites per VPN, support overlapping address space.**

- **Peer model – customer routers peer with provider routers.**

Terminology



Properties of the model

- CE router peers with a PE router, but not with other CE routers.
- Adding/deleting a new site requires configuring the PE router connected to the site.
- A PE router only needs to maintain routes for the VPNs whose sites are directly connected.

BGP-MPLS VPNs - areas

- Separation of forwarding
- Distribution of routing information
- New address type
- Forwarding with MPLS

Operation – separation of forwarding

- **Goal: control connectivity by segregating the forwarding information.**
- **PE router connected to CEs from several VPNs.**
- **With a single forwarding table, it is possible to forward packets from one VPN to another.**

Multiple forwarding tables

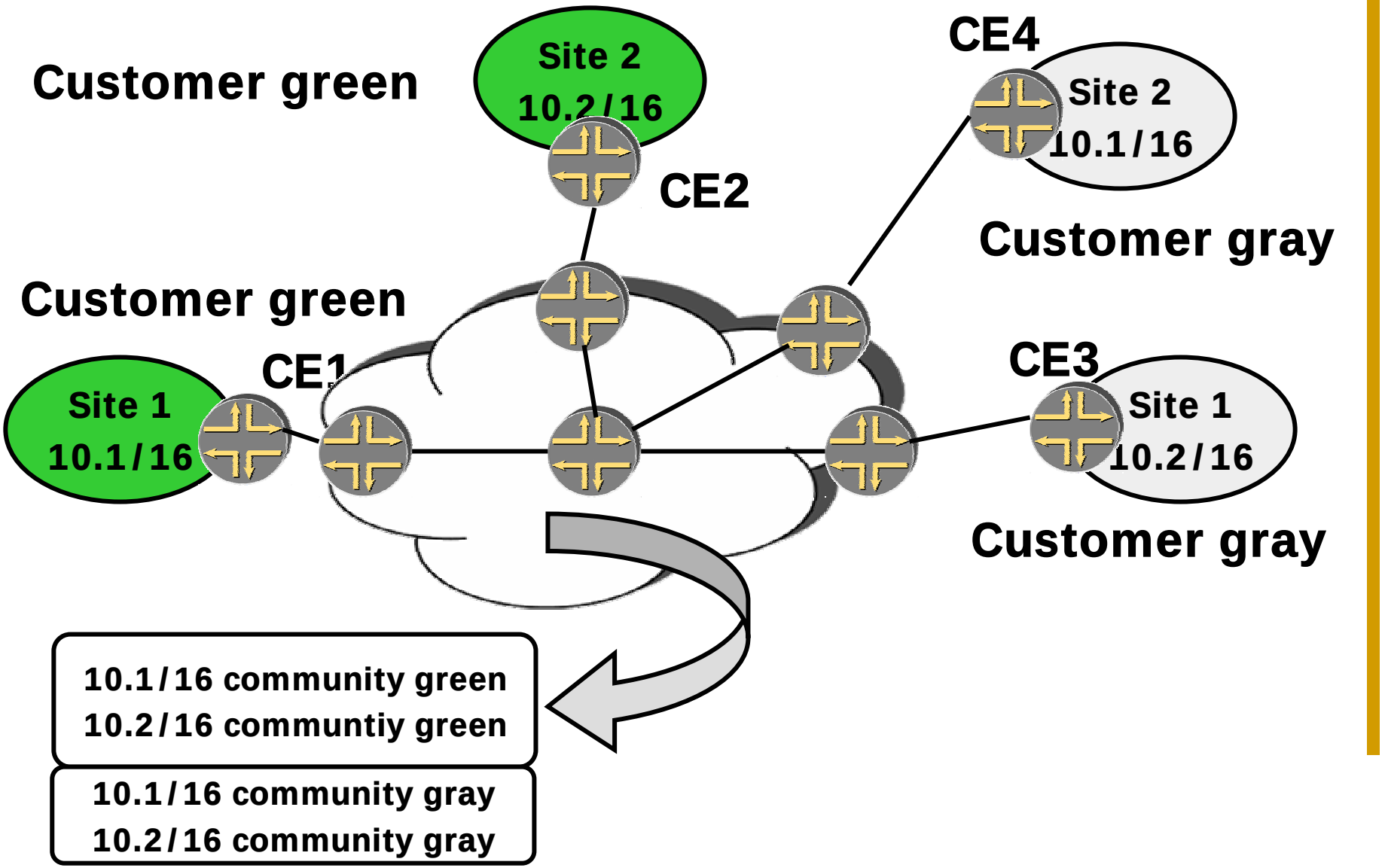
- **Multiple forwarding tables – each table associated with a site.**
- **Packets from the customer are identified based on the incoming port, which identifies the forwarding table.**
- **Contents: routes received from the CE, and routes received from remote PEs with constrained routing.**

Operation - Distribution of routing information

- **The idea:**

1. **CE advertises routes to the local PE via some routing protocol.**
2. **The local PE marks these routes with a particular (extended) community and advertises them in BGP.**
3. **The routes are distributed to all remote PE by BGP.**
4. **Remote PE receives BGP routes, filters them based on the community and advertises them to the CE.**

Example


Customer green
Site 2
10.2/16
CE2
CE4
Site 2
10.1/16
Customer gray
Customer green
CE1
Site 1
10.1/16
CE3
Site 1
10.2/16
Customer gray
10.1/16 community green
10.2/16 communtiy green
10.1/16 community gray
10.2/16 community gray

The model so far (1)

- **The addresses used in the VPNs need to be unique in the provider's network.**
- **The P routers carry all VPN routes.**

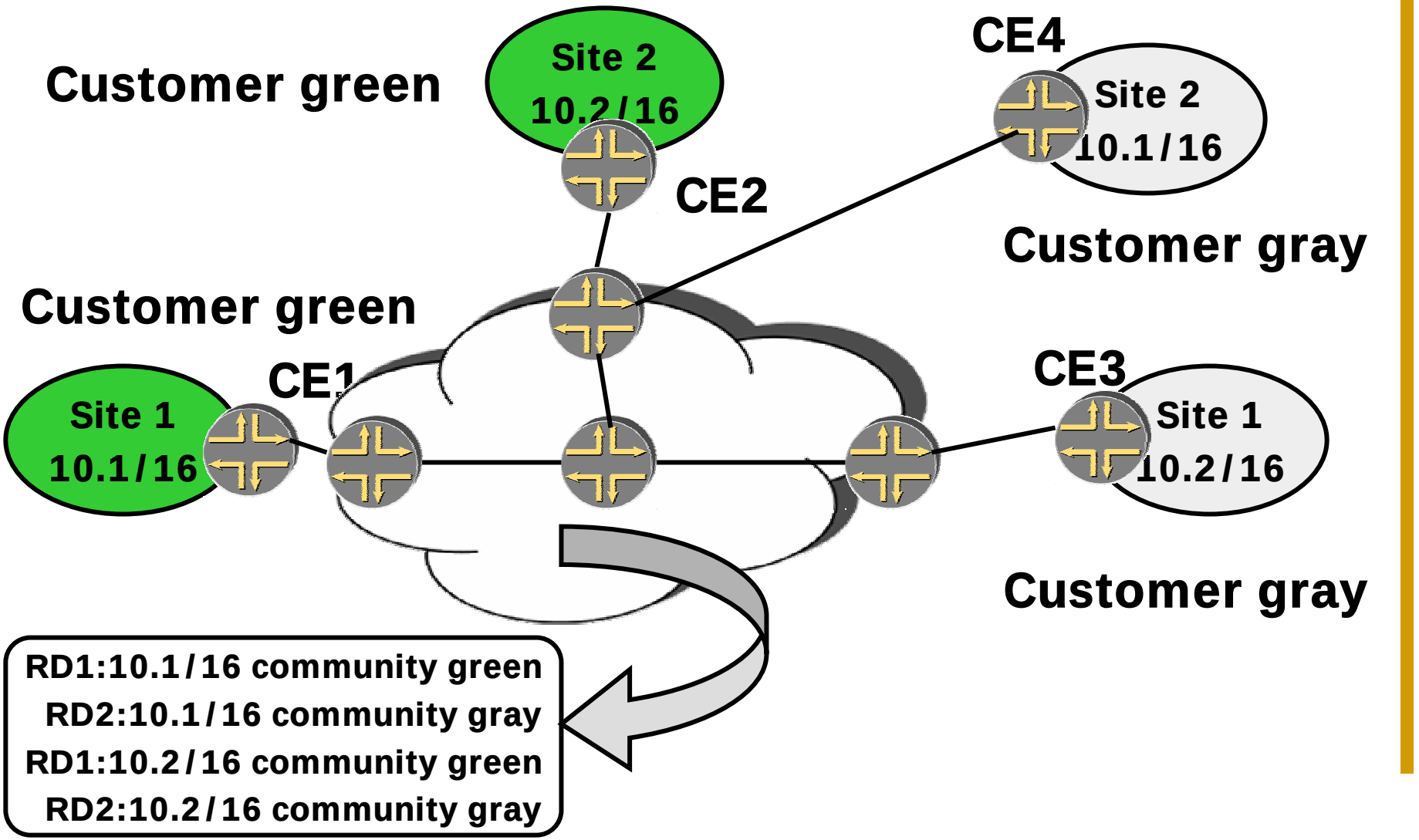
Operation: overlapping address space and VPN-IP addresses

- **Goal: turn non-unique addresses into unique addresses.**
- **Constructed by concatenating an IP address and an 8 byte unique identifier called the route distinguisher.**
- **Route Distinguisher – Type (2) AS (2) Assigned Number (4) – doesn't have to be the same for all routes in the VPN.**

VPN-IP addresses (cont)

- Advertised in a special address family by BGP.
- Used only in the provider's network.
- Used only in the control plane.
- The translation from IP addresses to VPN-IP addresses happens on the PE.
- Not used for route filtering (we use communities for that).

Example using VPN-IP addresses



The model so far (2)

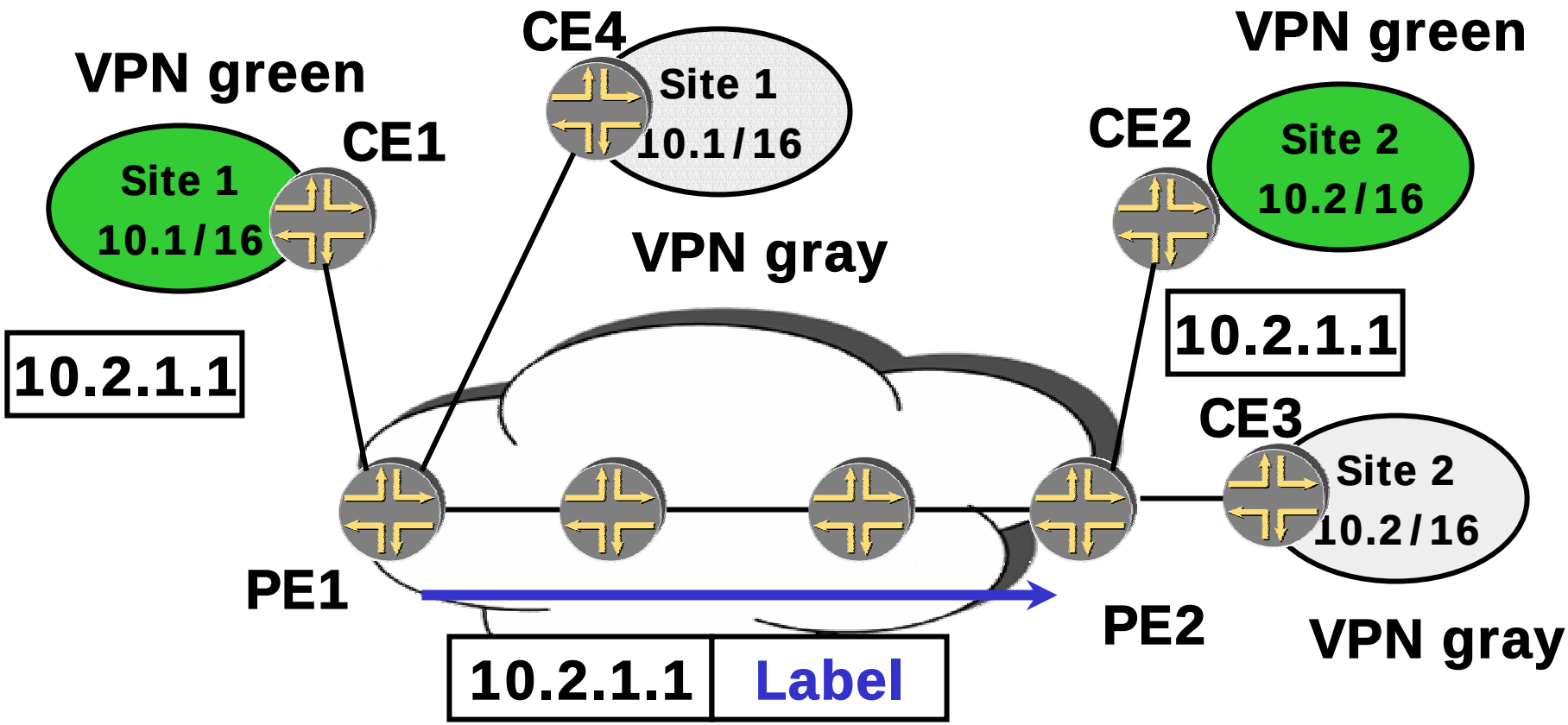
- Can use overlapping address space.
- How to forward based on VPN-IP addresses?
- The P routers still carry all the VPN routes.

MPLS-VPNs

- VPN-IP addresses are used by the routing protocols, but do not appear in headers of IP packets.

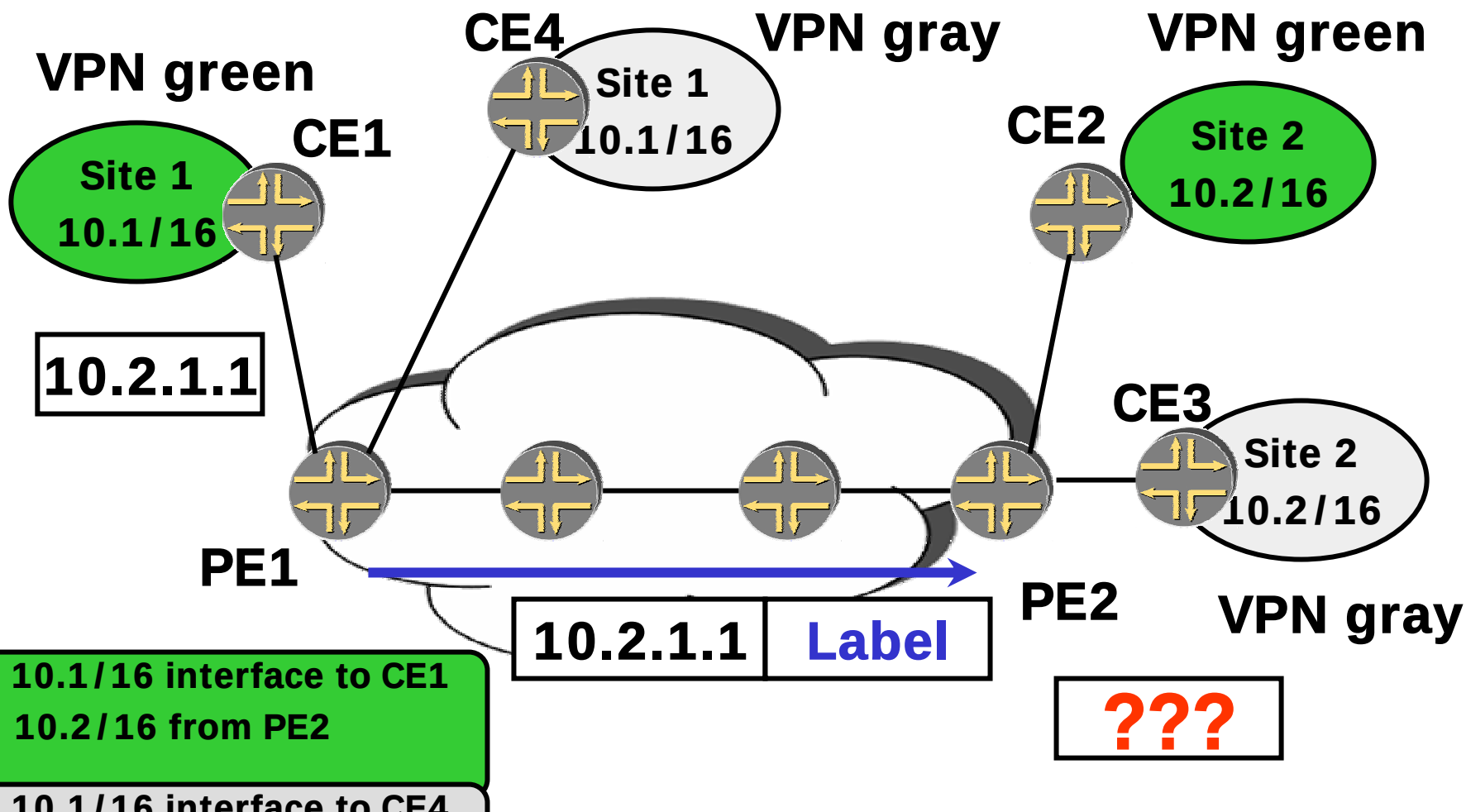
- Need a way to forward traffic along routes to VPN-IP addresses. MPLS decouples forwarding from the destination information.

Forwarding traffic - so far (1)



10.1/16 interface to CE1
10.2/16 from PE2

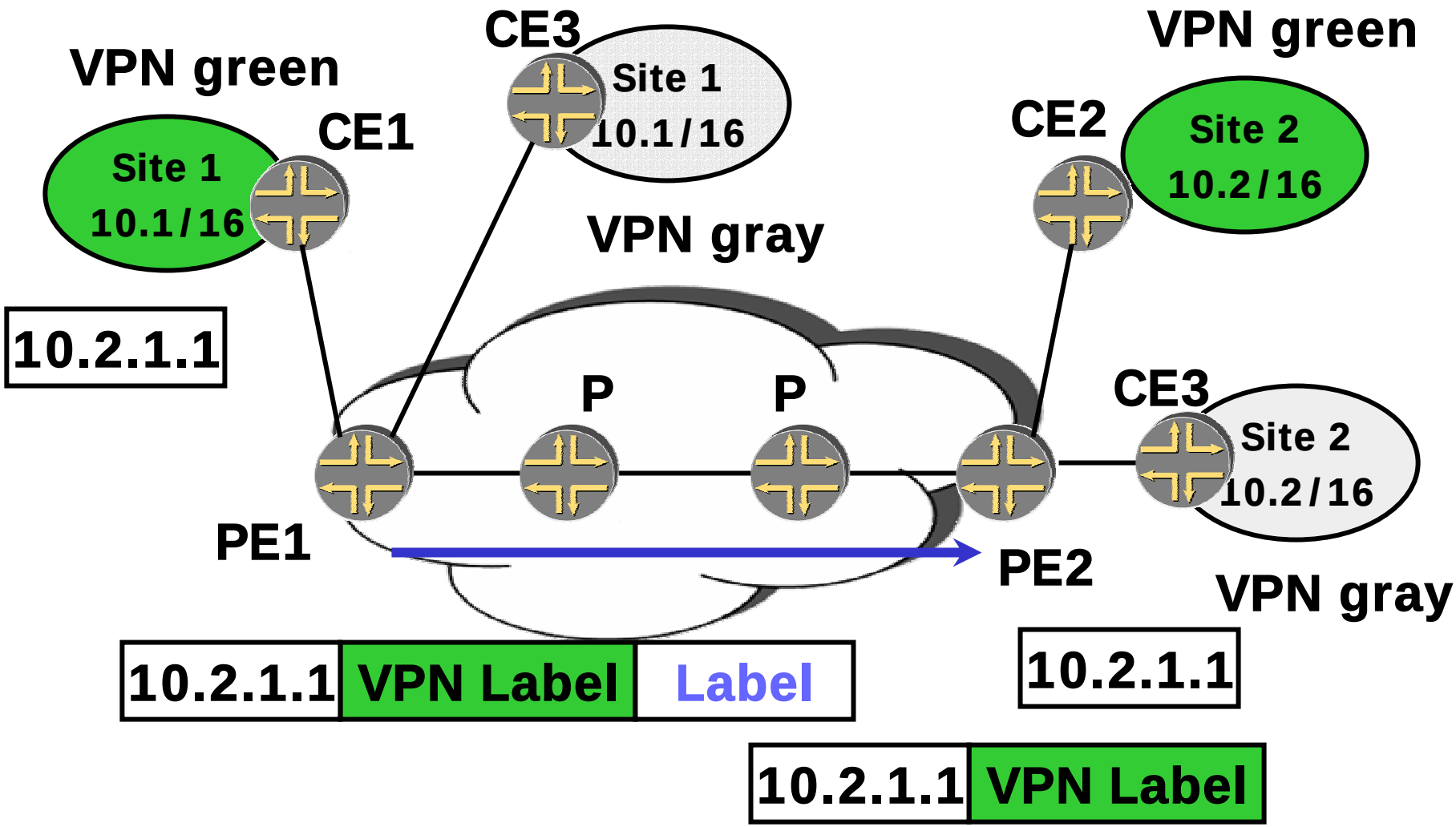
Forwarding traffic - so far (2)



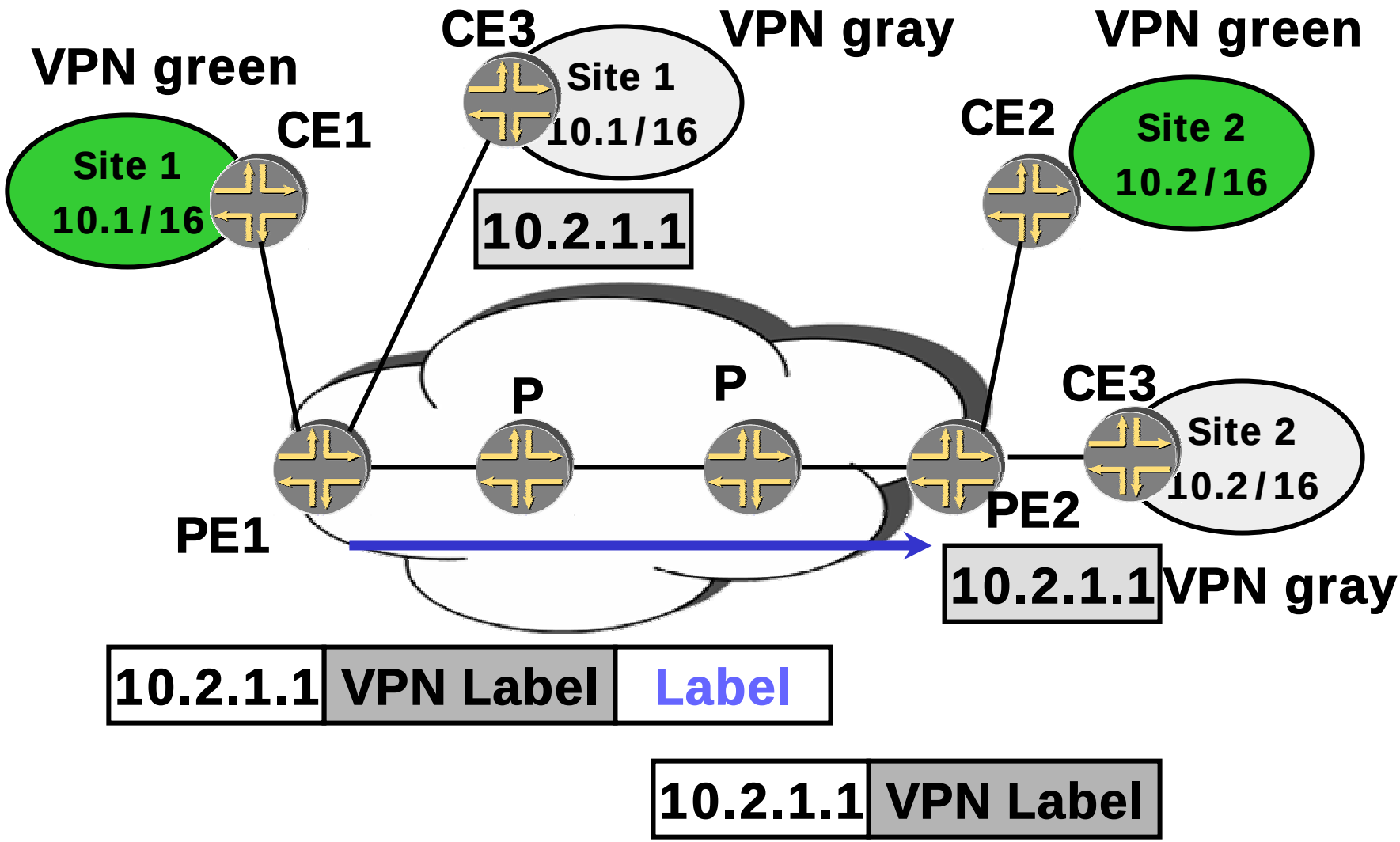
VPN labels

- The idea: Use a label to identify the VPN.
- The VPN label is distributed by BGP, along with the VPN-IP address.
- Traffic will carry two labels, the VPN label and the LSP label.
- The remote PE makes the forwarding decision based on the VPN label.

Forwarding traffic - revisited



Forwarding traffic - revisited



Summary

- P routers don’t need to maintain VPN routes at all. Only need to maintain routes to other P and PE routers.
- PE routers maintain VPN routes, but only for VPNs that have sites attached to them.
- VPNs can have overlapping address spaces.

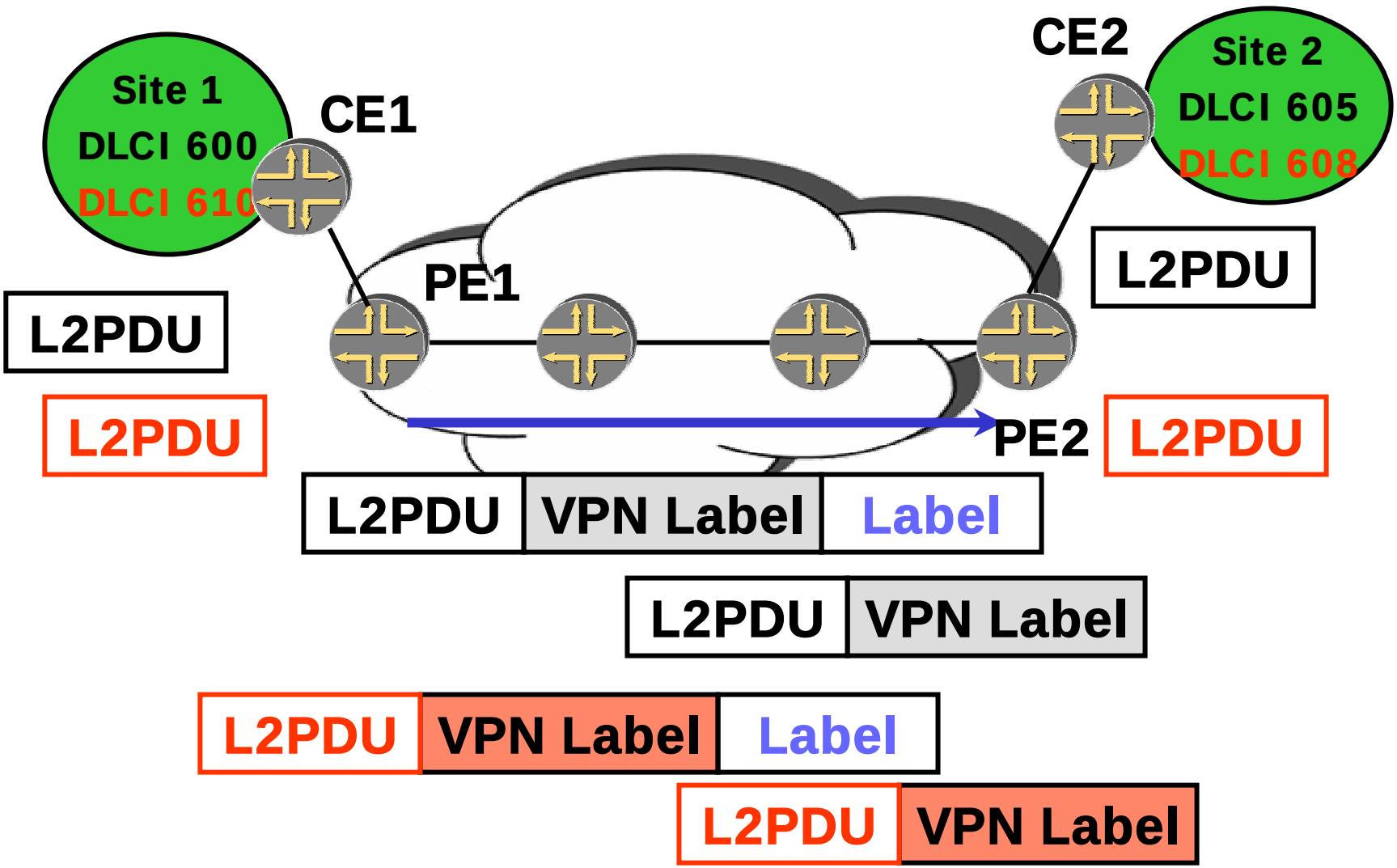
Topics

- Traffic engineering
- Fast reroute
- VPNs
- Pseudo-wires
- Protocol comparison

Pseudo wire

- The idea: emulate a point to point layer 2 connection over an MPLS network. Carry PDUs of layer 2 protocols over MPLS.
- Extend the same model from L3VPN. Similarly, use an additional label to improve scalability.
- In L3VPNs, the CEs advertise IP addresses. Here, they advertise “L2 information”.

The idea


Site 1
DLCI 600
DLCI 610
CE1
PE1
CE2
Site 2
DLCI 605
DLCI 608
L2PDU
L2PDU
L2PDU
PE2
L2PDU
L2PDU
VPN Label
Label
L2PDU
VPN Label
L2PDU
VPN Label
Label
L2PDU
VPN Label

Applications to L2

- **Need one label per circuit.**
- **The label can be advertised with BGP or with special extensions to LDP.**

Topics

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LDP and RSVP

- Why are we talking about them ?
- Overview of the protocols
- Comparison and applicability

Protocol LDP – Label Distribution

- Not a routing protocol, relies on other routing protocols for forwarding decisions, loop prevention, etc.
- Label distribution initiated from the endpoint.
- There is no concept of the head-end requesting the establishment of an LSP to an endpoint.
- Labels exchanged between LDP neighbors

LDP – (continued)

- The created LSPs follow the IP shortest path.
- TCP based (reliable), incremental updates.
- Allows creation of multiple paths for the same prefix (load balancing)
- Useful when need to establish a large number of LSPs. Easy to set up.

RSVP – TE

- Extension of the Resource Reservation Protocol for label distribution and traffic engineering.
- Soft state, requires periodic refreshes.
- Creates point to point tunnels, initiated from the head end. Labels distributed only along this path.

RSVP – TE (cont)

- Supports explicit paths. Can set up LSPs along paths computed with CSPF, so can take into account bandwidth allocations.
- Supports fast restoration in case of failures.

Comparison

- **Ease of configuration – both initially, and when making incremental additions.**
- **State maintenance**
- **Tracking the IGP state to determine forwarding state**

LDP & RSVP applicability

	LDP	RSVP
Label distribution	Yes	Yes
Traffic engineering	No	Yes
Traffic protection	No	Yes
VPN	Yes	Yes

More ...

- RSVP soft preemption
- Diffserv-TE
- Node protection
- Graceful restart
- LSP ping
- VPNs
- MPLS management – mibs
- Inter-AS RSVP tunnels
- VPLS

Thank you!

Please send comments to ina@juniper.net