Interdomain routing with BGP4
Part 5/5

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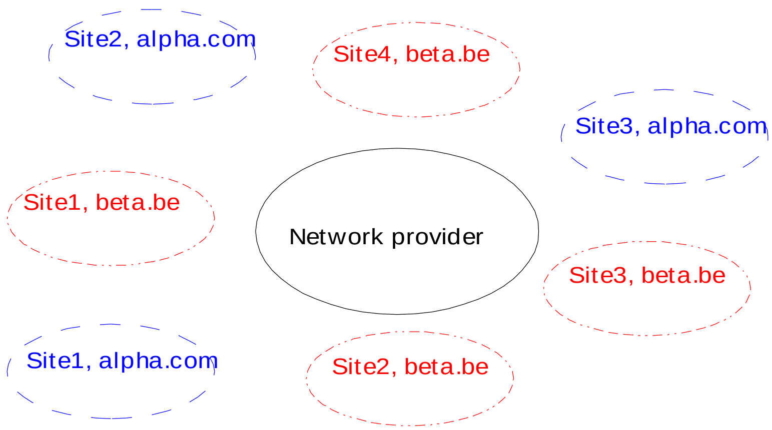
Outline

- Organization of the global Internet
- BGP basics
- BGP in large networks
- Interdomain traffic engineering with BGP
- BGP-based Virtual Private Networks
  - The VPN problem
  - Provider-provisionned BGP/ MPLS VPNs

The BGP-based VPNs were initially proposed in :
E. Rosen, Y. Rekhter, BGP/MPLS VPNs, RFC2547, March 1999

They are now being developped without two IETF working groups :
http://www.ietf.org/html.charters/l2vpn-charter.html focusses on the provision of layer-2 VPNs
http://www.ietf.org/html.charters/l3vpn-charter.html focusses on the provision of layer-3 VPNs. We mainly discuss the layer-3 VPNs in this tutorial

The VPN problem

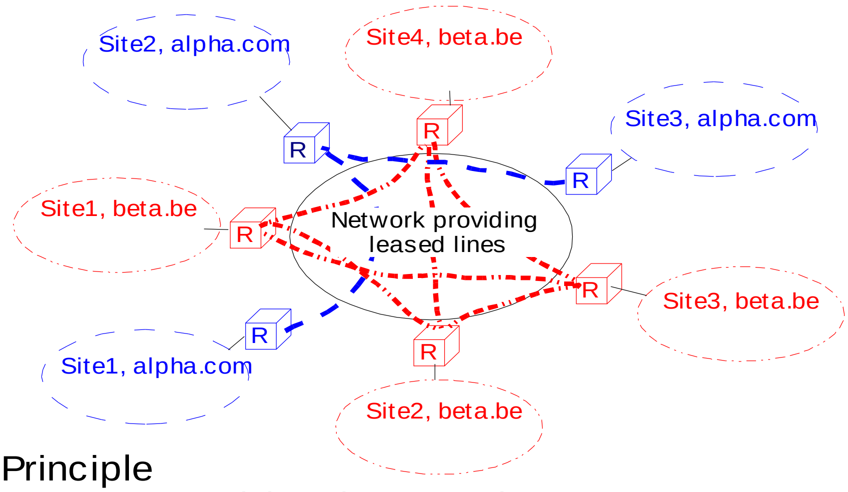


- How to efficiently create
  - one network containing the sites from alpha.com
  - one network containing the sites from beta.be

What should be the goal of a good VPN ?

- A good VPN service should
  - Support multiple corporate customers
    - in this case, the traffic from these customers should be isolated
    - some security features should be supported to ensure that packets from public Internet can be introduced inside VPN
  - provide QoS guarantees for corporate customers
    - typical solution is to reuse the classical mechanisms
  - be easy to utilize and manage
    - from the customer viewpoint
    - from the service provider viewpoint

The classical solution

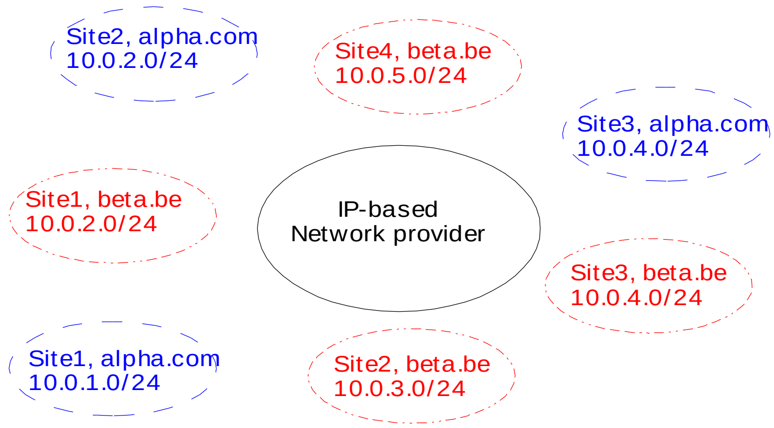


- Principle
  - Create leased lines between sites
    - full mesh (beta.be), hub and spoke (alpha.com) topologies

Evaluation of the classical solution

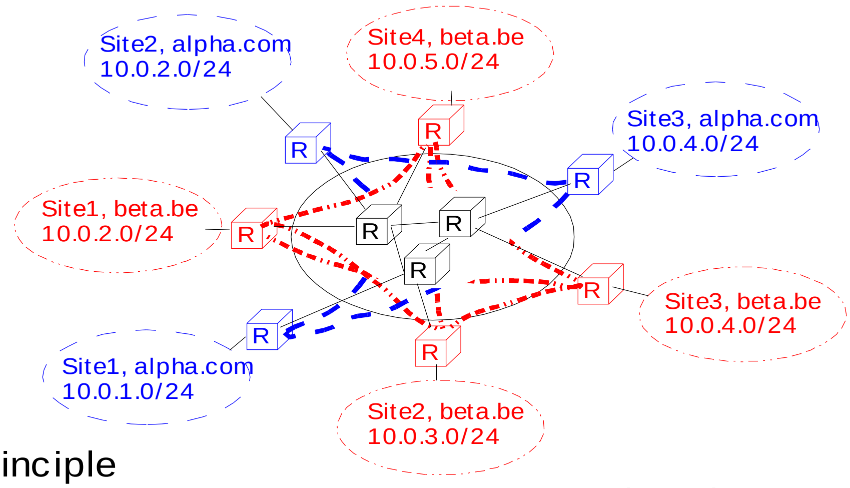
- Advantage
  - the quality of the service provided by the service provider is usually very good
- Drawbacks
  - the number of leased lines can be high
    - n*(n-1)/2 leased lines in total for full mesh
    - For a VPN with n sites, each router needs n-1 interfaces to obtain a full mesh
  - Flexibility
    - addition of a VPN may require several new lines
    - installation of leased line may require O(months)
  - Cost can be high
    - no statistical multiplexing on provider's backbone
    - link costs even if no traffic is exchanged

The IP-VPN problem



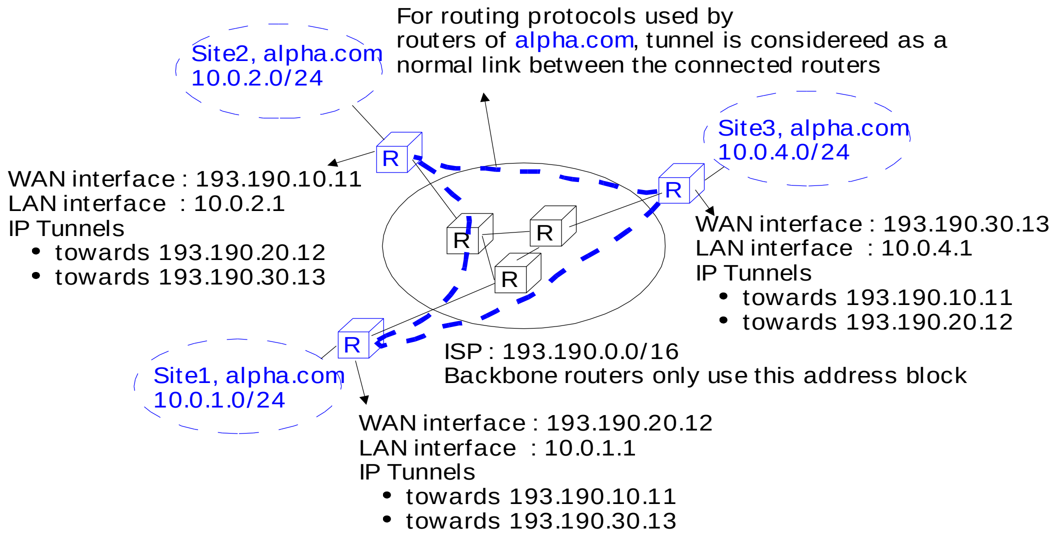
- How to efficiently create
  - one network containing the sites from alpha.com
  - one network containing the sites from beta.be
- When only IP packets are exchanged

A customer-provisionned IP VPN



- Principle
  - create IP tunnels from customer routers through ISP
  - drawback : configuration burden on customer routers

A customer-provisionned IP-VPN (2)



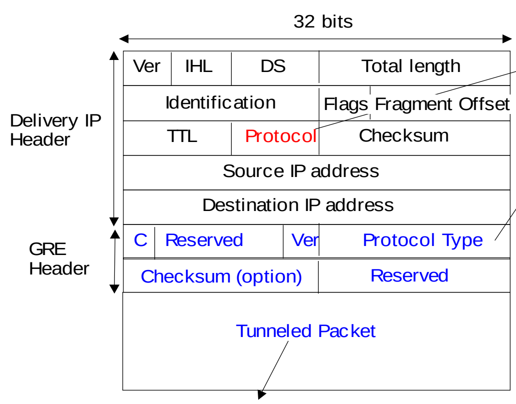
IP Tunnels

- Many IP tunneling protocols exist
  - IP in IP tunneling
    - can be used to carry IP packets inside IP packets
  - Generic Routing Encapsulation
    - can be used to carry network layer packets inside IP packets
  - Point-to-point tunneling protocol
    - can be used to carry PPP frames through TCP/IP network
  - Layer 2 Tunneling protocol
    - can be used to carry PPP frames through TCP/IP network
  - IPSec
    - security (authentication/confidentiality) extensions to IP also include tunneling capabilities

A discussion of the various tunnels that could be used to build VPNs may be found in :
R. Callon, M. Suzuki (Eds), A Framework for Layer 3 Provider Provisioned Virtual Private Networks, Internet draft, <draft-ietf-l3vpn-framework-00.txt>, work in progress, March 2003

GRE Tunnel

- Principle
  - Tunnel is used to carry network layer packets



IP Protocol
Value 47 is reserved to indicate that IP packet carries GRE-encapsulated packet

Protocol Type
Indicates the type of network layer packet carried by tunnel
same values as Ethernet type field (0x800 for IP packet)

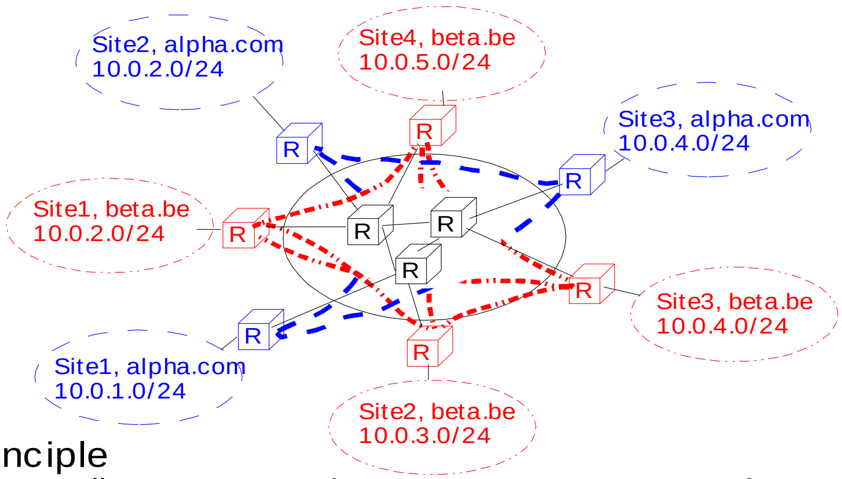
Tunneled packet may be optionally protected by Checksum in GRE header

Can contain any network layer packet understood by destination system that can be placed inside Ethernet frame

Evaluation of the simple IP solution

- Advantage
  - Flexibility
    - a single physical interface on each router
  - Cost
    - VPN site can multiplex traffic to different sites on this link
- Drawbacks
  - the number of tunnels can be high
    - n*(n-1)/2 tunnels in total for full mesh
    - For a VPN with n sites, each router needs n-1 tunnels to obtain a full mesh
  - Flexibility
    - addition of a VPN require adding new tunnels
  - Security
    - depends on tunneling mechanism used
      - weak with GRE, better with Ipsec

A simple MPLS-based solution



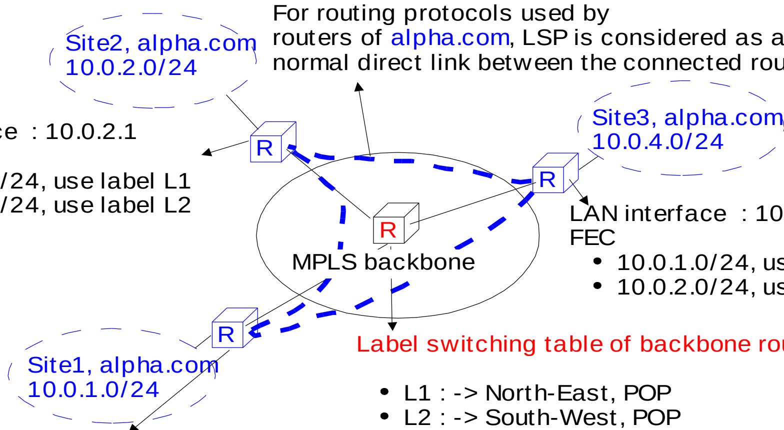
- Principle
  - Manually create LSPs between customer routers from VPN sites through MPLS backbone

This simple MPLS-based solution is similar in principle to the solution used to support VPN with technologies based on the label switching paradigm like

- ATM : Asynchronous Transfer Mode
- Frame Relay

A simple MPLS-based solution (2)

For routing protocols used by routers of alpha.com, LSP is considered as a normal direct link between the connected routers



LAN interface : 10.0.2.1
FEC
- 10.0.4.0/24, use label L1
- 10.0.1.0/24, use label L2

LAN interface : 10.0.4.1
FEC
- 10.0.1.0/24, use label L6
- 10.0.2.0/24, use label L3

LAN interface : 10.0.1.1
FEC
- 10.0.4.0/24, use label L4
- 10.0.2.0/24, use label L5

Label switching table of backbone router

- L1 : -> North-East, POP
- L2 : -> South-West, POP
- L3 : -> North-West, POP
- L4 : -> North-East, POP
- L5 : -> North-West, POP
- L6 : -> South-West, POP

Evaluation of the simple MPLS solution

- Advantages
  - a single physical line per VPN site
  - QoS can be provided on a per-LSP basis
  - Flexibility
    - bandwidth of each LSP can be easily updated
  - Cost
    - statistical multiplexing is possible on MPLS backbone
- Drawbacks
  - MPLS support
    - routers of the VPN sites must support MPLS
    - backbone routers must support MPLS
  - configuration burden
    - backbone routers must be configured for each new LSP
    - customer routers must be configured for each new site

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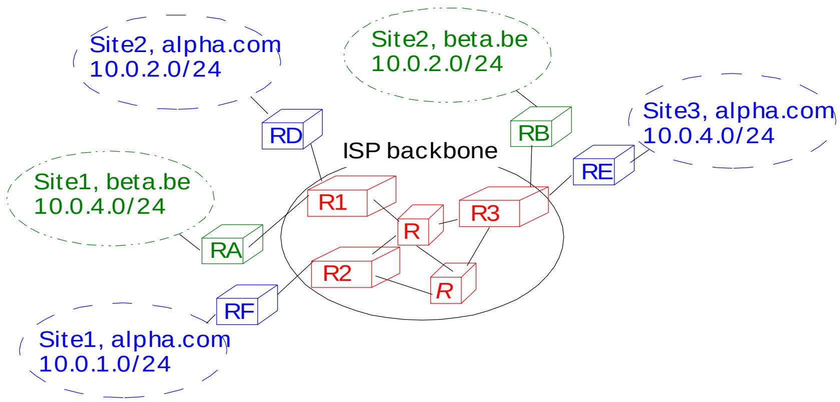
Provider-provisionned MPLS VPN

- Objective
  - Find a solution that is as automatic as possible
    - for the service provider
    - for the customers of the VPN service
  - Addition of a new site to an existing VPN
    - only the new customer router should need to be configured on the VPN
    - only a single router from the service provider should need to be configured on the provider's backbone

The provider-provisionned MPLS VPNs are defined in
RFC2547 BGP/MPLS VPNs. E. Rosen, Y. Rekhter. March 1999.

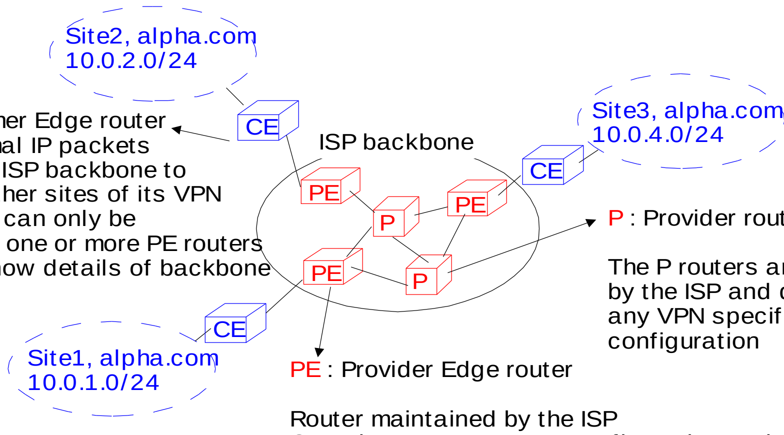
Provider-provisionned MPLS VPN (2)

- Principle of the solution



  - transmission of one packet in beta.be, site1to site2
  - transmission of one packet in alpha.com, site1to site3

Provider-based MPLS solution (3)



CE : Customer Edge router
Sends normal IP packets through the ISP backbone to reach the other sites of its VPN
A CE router can only be attached to one or more PE routers
Does not know details of backbone

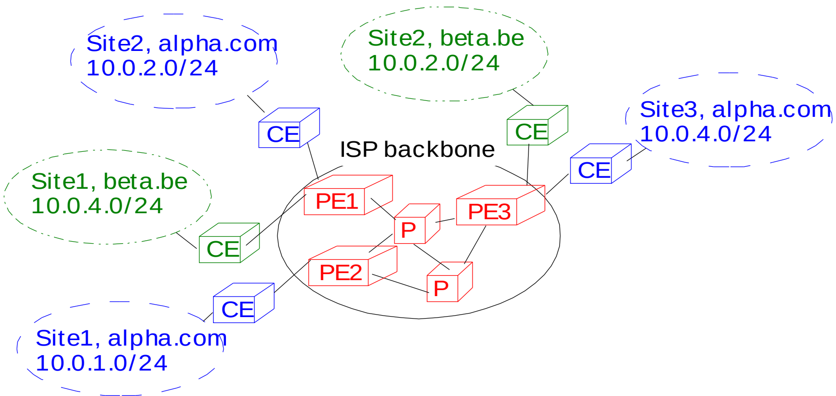
P : Provider router

The P routers are managed by the ISP and do not carry any VPN specific configuration

PE : Provider Edge router

Router maintained by the ISP
Contains some per-VPN configuration and ensures that the IP packets sent by a particular VPN site are delivered to the PE router attached to the destination VPN site

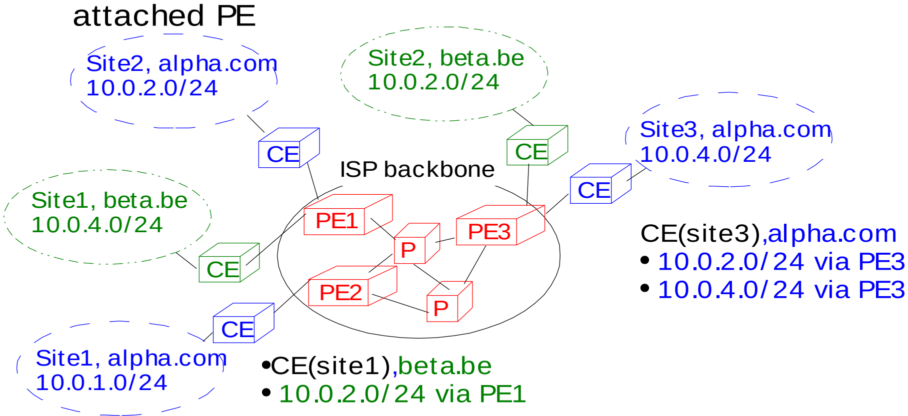
Problems to solve



- How to forward the packets from one CE router to the appropriate CE router of the same VPN ?
  - Need routing tables on CE, PE and P routers
  - How to efficiently distribute these routing tables ?

Routing tables on the CE routers

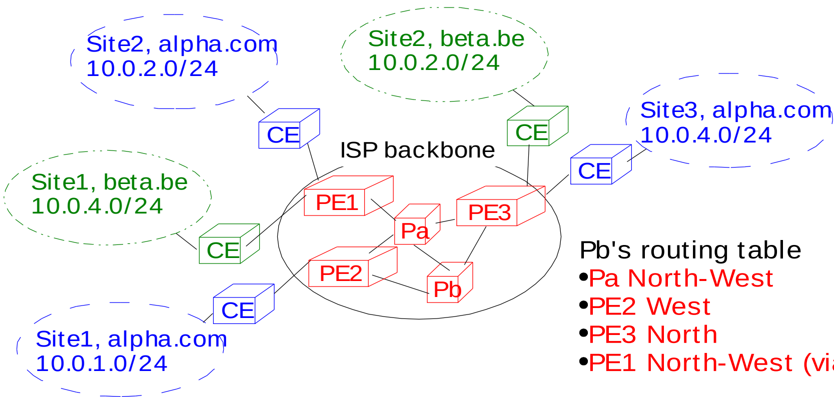
- Principle
  - Each CE router contains one routing table with the routes belonging to its VPN
    - CE does not know anything about ISP besides its attached PE



See
Eric C. Rosen, Yakov Rekhter, BGP/MPLS IP VPNs, Internet draft, draft-ietf-l3vpn-rfc2547bis-03.txt, October 2004, work in progress

Routing tables on the P routers

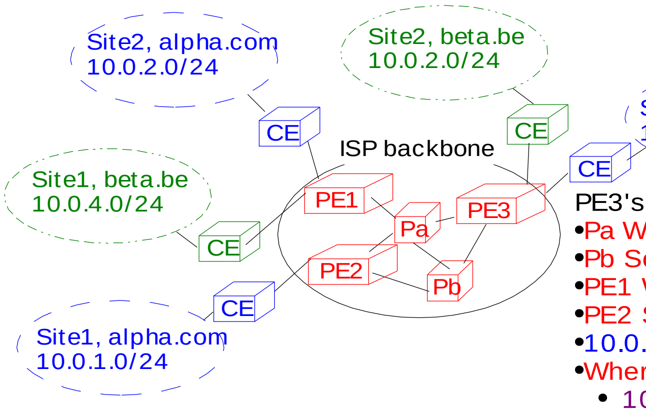
- Principle
  - P routers only know how to reach the routers in their backbone
    - P routers do not know anything about VPNs



Pb's routing table
- Pa North-West
- PE2 West
- PE3 North
- PE1 North-West (via Pa)

Routing tables on the PE routers

- Problem
  - Corporate networks often use RFC1918 addresses
  - Two different VPNs may use same IP subnets

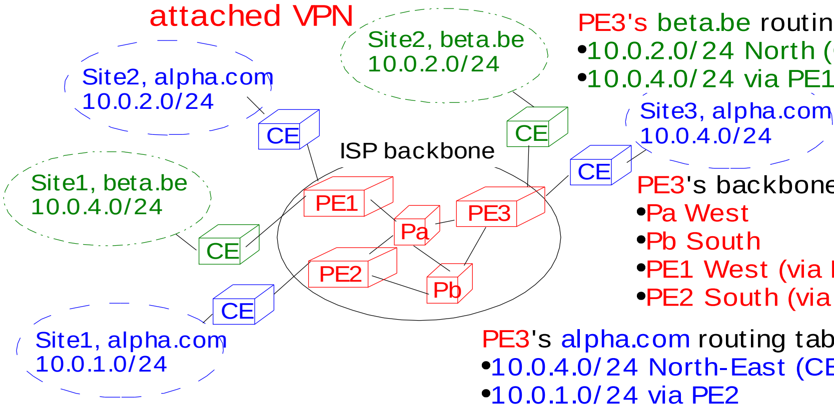


PE3's possible routing table

- Pa West
- Pb South
- PE1 West (via Pa)
- PE2 South (via Pb)
- 10.0.1.0 West (via PE2)
- Where are
  - 10.0.2.0/24 ???
  - 10.0.4.0/24

Routing tables on PE routers (2)

- Principle
  - Each PE router maintains several routing tables
    - standard routing table
    - one VPN Routing and Forwarding table (VRF) per attached VPN



PE3's beta.be routing table
- 10.0.2.0/24 North (CE)
- 10.0.4.0/24 via PE1

PE3's backbone routing table
- Pa West
- Pb South
- PE1 West (via Pa)
- PE2 South (via Pb)

PE3's alpha.com routing table
- 10.0.4.0/24 North-East (CE)
- 10.0.1.0/24 via PE2
- 10.0.2.0/24 via PE1

The VRF contains all the routes belonging to a given VPN. This VRF is used to forward the packets that are received inside the corresponding VPN. For example, when considering PE3, it will use the beta.be VRF to forward a packet received on its North interface while it will use the alpha.com VRF to forward a packet received on its Nort-East interface.

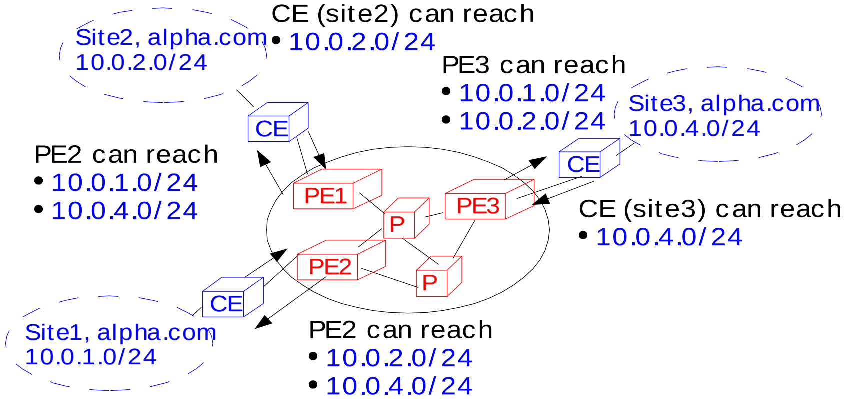
Distribution of the routing tables

- Routing problem
  - How can we correctly distribute the routing information to the CE, PE and P routers ?
    - A CE router must advertise its local routes to its attached PE and must receive the remote routes (or a default route) from this router
    - A PE router must receive two types of routing information
      - per VPN routing information for the routes reachable through attached CE routers and through remote PE routers
        - For scalability reasons, a PE router should only know the routing information about the VPNs that it directly supports
      - ISP routing information to be able to reach other PE routers
    - A P router must maintain routing information for the ISP
      - For scalability reasons, a P router should not know any VPN specific information

Distribution of routing information(2)

- Route distribution between CE and PE
  - static routes
    - both PE and CE are configured with static routes
    - suitable for small VPN sites with a single link
  - RIP
    - RIP is used by the CE to announce the routes reachable on its local network
    - RIP is used by the PE to announce the routes of the same VPN learned from the other PE routers
    - useful for medium VPN sites with multiple links
  - Other routing protocols
    - OSPF
      - This is a special OSPF instance between PE and CE, not the OSPF that is used inside the ISP backbone
    - eBGP
      - CE router uses eBGP session to advertise routes to PE

Distribution of routing information(3)

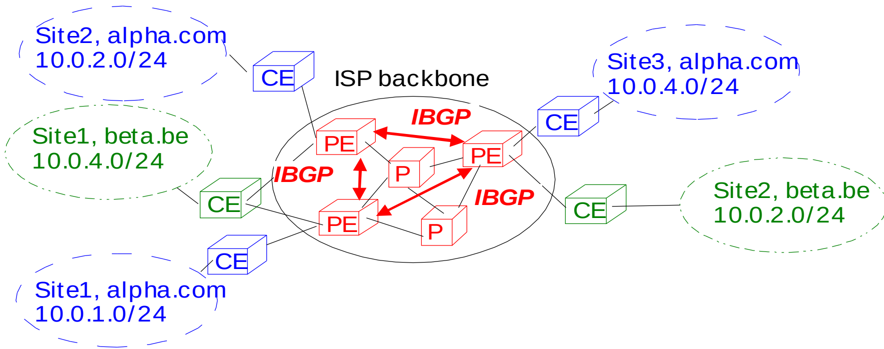


- In the backbone, all P and PE routers know ISP backbone topology by using the normal IGP

In this example, the routes between the CE and the PE routers can be exchanged by using any of the protocols discussed in the previous slide.

Distribution of routing information (4)

- Distribution of per VPN routes between PEs

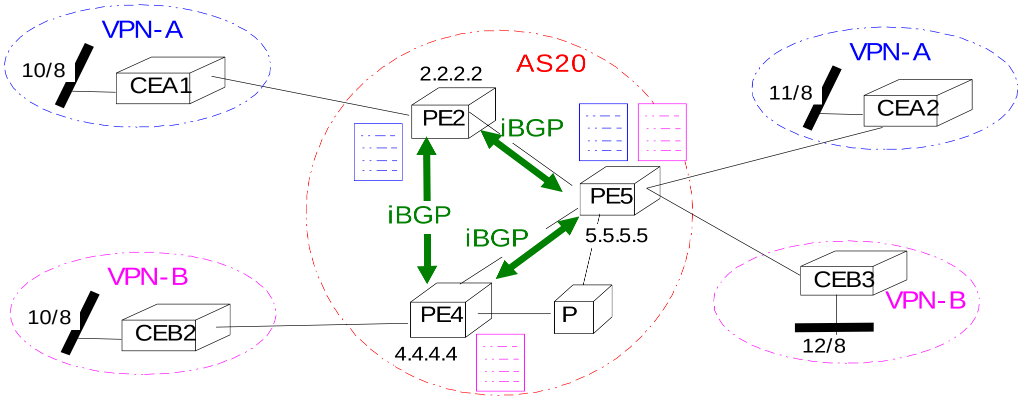


- Principle
  - iBGP full mesh between PE routers
    - P routers do not need to run iBGP since they do not maintain per-VPN routes
  - iBGP sessions are used to redistribute the routes learned from CE routers to distant PE routers

If the ISP network is large, the iBGP full-mesh can be replaced by the classical iBGP scaling techniques that are Route Reflectors and Confederations. In the case of Route Reflectors, a PE would typically be client of two Route Reflectors and the Route Reflectors would be fully meshed. The iBGP sessions used for normal Internet routing and for VPNs can be the same or different. In some ISPs, a different iBGP distribution is used for the VPNs.

The distribution of the VPN routes by the PE routers

- Two problems must be solved
  - How to distribute the A and B routes for 10/8 ?
  - How to ensure that PE4 only receives B routes ?



MP-BGP and the VPN-IPv4 addresses

- MP-BGP
  - an extension to BGP that allows a BGP router to advertise non-IPv4 routes
    - IPv6
    - IP multicast
    - VPN-IPv4
- The VPN-IPv4 address family
  - a method used by PE routers to encode IP v4 VPN addresses before advertising them with MP-BGP
    - a VPN-IPv4 address contains
      - an 8 bytes route distinguisher
      - an IPv4 prefix
    - BGP considers VPN-IPv4 addresses as *opaque bitstring*
    - two types of route distinguishers
      - `AS:value`
      - `IPaddress:value`

MP-BGP is defined in
Tony Bates, Ravi Chandra , Dave Katz,Yakov Rekhter Multiprotocol Extensions for BGP-4, Internet draft, draft-ietf-idr-rfc2858bis-06.txt, 2004, work in progress

Controlling the distribution of VPN routes

- How to ensure that VPN-IPv4 routes only reach the PE routers attached to those VPNs ?
  - associate one or more route targets to each VRF
  - a route associated with RT x must be distributed to all PE routers that have a VRF with RT=x
  - RT is encoded as an BGP extended community
    - `ASnumber:value`
    - `IPv4address:value`
  - Control of the distribution
    - PE router knows the RT supported by each of its peers and only advertises the appropriate VPN-IPv4 routes
    - or PE router advertises all its VPN-IPv4 routes and peers filter the received routes based on the attached RT

The BGP Extended Community attribute is defined in :

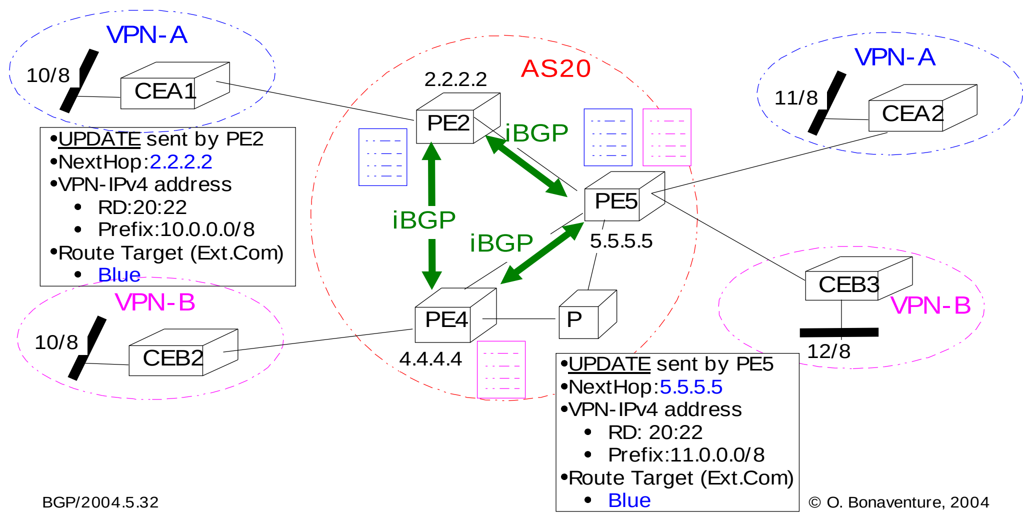
Sangli, Tappan and Rekhter, "BGP Extended Communities Attribute", Internet draft, draft-ietf-idr-bgp-ext-communities-06.txt, work in progress, Aug. 2003

Compared to the classical communities, the main advantage of the extended communities is their size. The classical communities are 32-bits wide, and a block of 2^{16} values is allocated to each AS (ASX:1 to ASX:65535). If the communities were used to support VPNs, an AS could only define 2^{16} route target values. With extended communities, each AS can define 2^{32} different route target values.

The cooperative route filtering mechanism that can be used by PE router to advertise to their peers the routes that they wish to receive is defined in :
Chen, Rekhter, "Cooperative Route Filtering Capability for BGP-4", Internet draft, draft-ietf-idr-route-filter-09.txt, work in progress, August 2003

MP-BGP and the VPN-IPv4 addresses

- Example
  - per-VPN route distinguisher



An additional element of the RFC2457 architecture that does not appear in the slides is that each PE router defines, for each VPN attached to the router:
• an import policy to specifiy, which routes received via BGP or the PE-CE protocol can be installed in the VRF
• an export policy to specify which routes installed in the VRF need to be advertised by using the PE-CE protocol or BGP

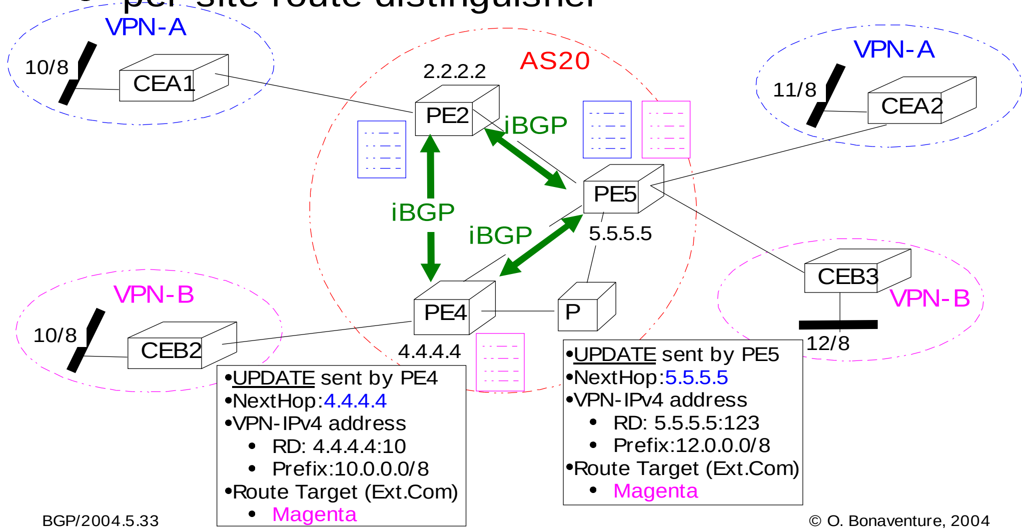
Of course, those policies will depend on the route distinguishers and the route targets being used.

In this example, the following import filters and import policies will be used
•PE5 imports the iBGP advertisements with extended communities blue and magenta since it has a CE route of VPNA and VPNB attached
- The routes with RD 20:222 that are received by PE5 are placed in its VPN-A VRF

•PE4 does not import the BGP advertisements that carry the Blue extended community since no CE router of VPNA is attached to PE4

MP-BGP and the VPN-IPv4 addresses (2)

- Example
  - per-site route distinguisher



In this example, the following import filters and import policies will be used

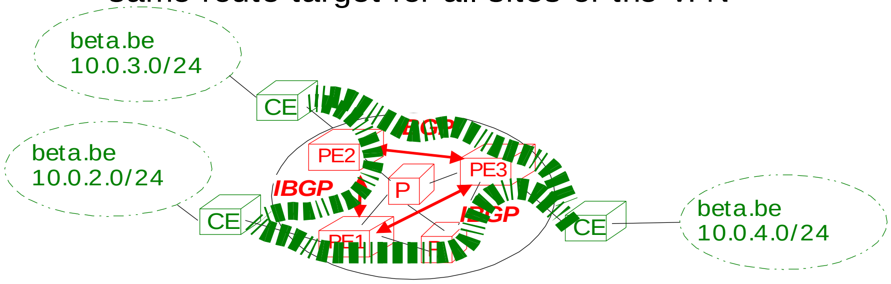
•PE5 imports the iBGP advertisements with extended communities blue and magenta since it has a CE route of VPNA and VPNB attached

- The routes with RD 4.4.4.4:10 that are received by PE5 are placed in its VPN-B VRF

•PE2 does not import the BGP advertisements that carry the Magenta extended community since no CE router of VPNB is attached to PE2

Types of VPN connectivity

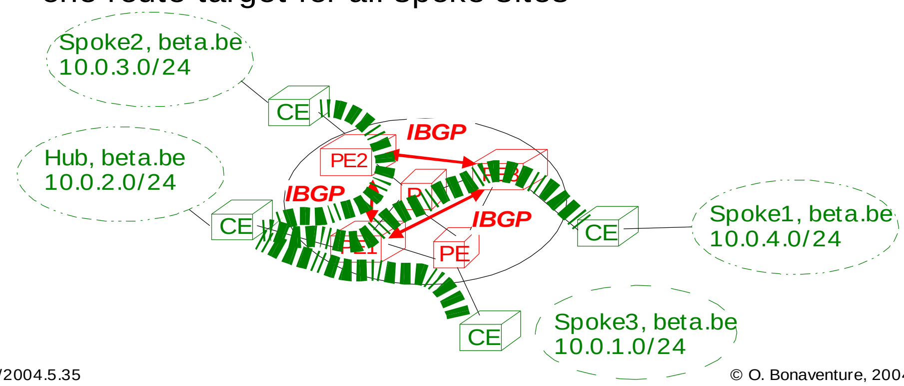
- Utilization of the BGP extended community attribute
  - depends on the type of inter-sites connectivity within each supported VPN
- Full mesh connectivity
  - all sites are equal
  - same route target for all sites of the VPN



In the figure above, the dotted lines show the packet flows between the CE routers of the beta.be VPN

Types of VPN connectivity (2)

- Hub & spoke connectivity
  - two types of sites
    - large (hub) site sends to all
    - small (spoke) sites use hub as relay site to reach others
  - one route targetfor Hub
  - one route target for all spoke sites



In this example, Hub, beta.be is used as a transit router for all packets exchanged between any sites of the VPN.

For a discussion of the characteristics of deployed VPNs, see :
Satish Raghunath, K.K. Ramakrishnan, Shivkumar Kalyanaraman, Chris Chase, "Measurement Based Characterization and Provisioning of IP VPNs," , Internet Measurements Conference, 2004

Types of VPN connectivity (3)

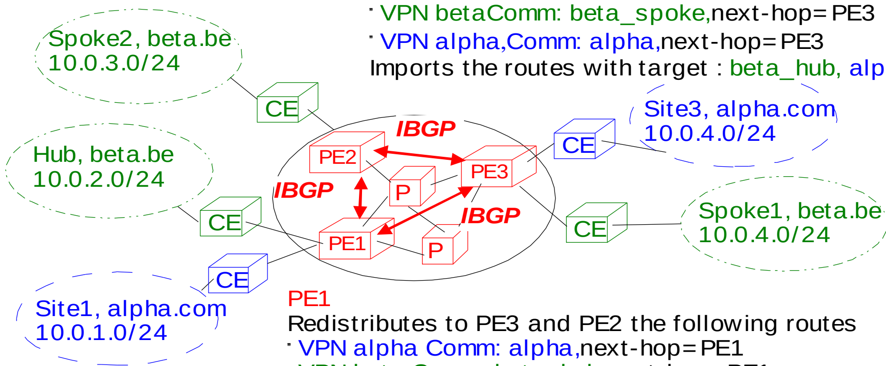
PE2

- Redistributes : VPN beta Comm: beta_spoke,next-hop=PE2
- Imports routes with target : beta_hub

PE3

- Redistributes
- VPN betaComm: beta_spoke,next-hop=PE3
- VPN alpha,Comm: alpha,next-hop=PE3

Imports the routes with target : beta_hub, alpha



PE1

Redistributes to PE3 and PE2 the following routes

- VPN alpha Comm: alpha,next-hop=PE1
- VPN beta Comm: beta_hub,next-hop=PE1

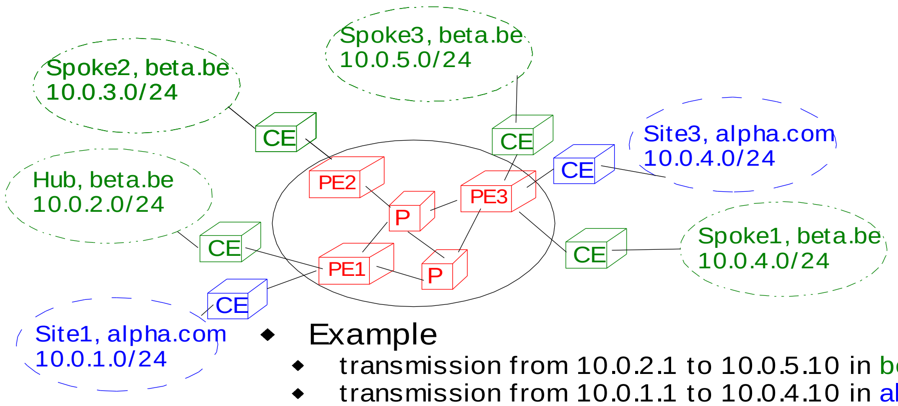
Imports the routes with target

- alpha, beta_spoke

Solving the forwarding problem

- How to forward the packets from each VPN through the provider's backbone ?
  - sending pure IP packets is not possible
    - P routers cannot know VPN-specific routes
    - different VPNs use the same RFC1918 addresses
- Principle of the solution
  - CE routers send normal IP packets
    - CE routers remain as simple as possible
  - PE routers maintain several routing tables
    - one routing table per VPN attached to PE router
    - one routing table for the ISP backbone
  - PE encapsulate VPN packets
    - Common solution is to encapsulate with MPLS
    - Some ISPs are using GRE, L2TP or IPSec

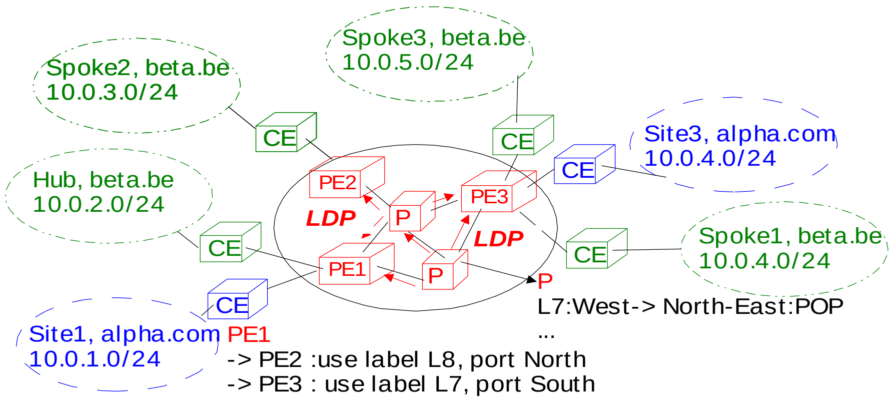
Solving the forwarding problem with MPLS



- Example
  - transmission from 10.0.2.1 to 10.0.5.10 in beta.be
  - transmission from 10.0.1.1 to 10.0.4.10 in alpha.com

- Principle of the solution : two levels of label
  - one level of label is used to reach the next-hop PE
  - one level of label is used to indicate the VRF to be used (and thus the outgoing CE) in the egress PE

Distribution of labels

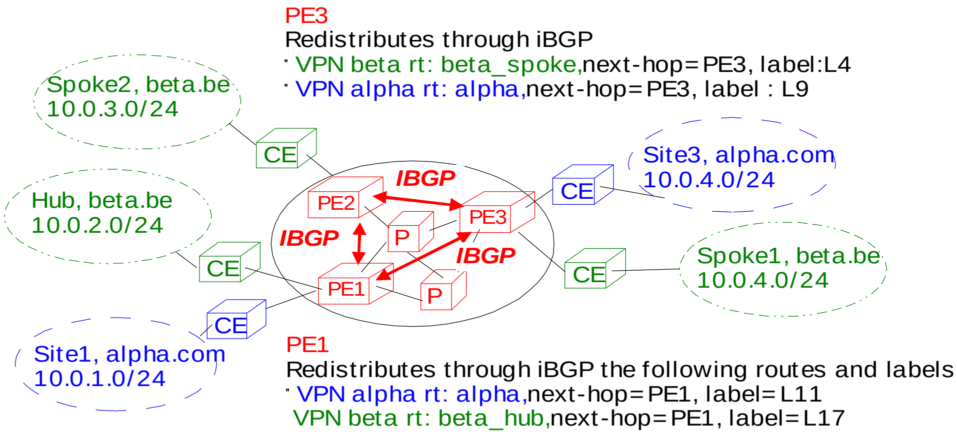


- Inside ISP backbone, use LDP to distribute labels between P and PE routers
  - each PE knows the label to use to reach any PE router
  - number of labels in P router depends on the number of PE, and not on the number of VPN sites

LDP is the common way to distribute the labels to reach the PE routers in the backbone. However, the PE-PE MPLS LSPs could also be traffic engineered tunnels established with RSVP-TE.

Usually, the PE-PE MPLS LSP will be configured with penultimate label popping, i.e. the penultimate router will POP the top label of the packet when sending the encapsulated packet to the final PE router.

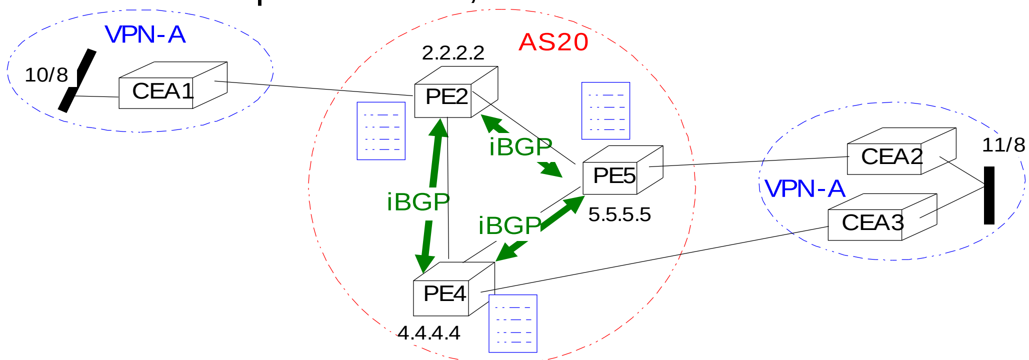
Distribution of labels (2)



- Principle
  - use iBGP to distribute VPN labels between PE routers

Packet flow in RFC2457 VPNs

- With per-VPN RD, how does PE2 reach 11/8 ?

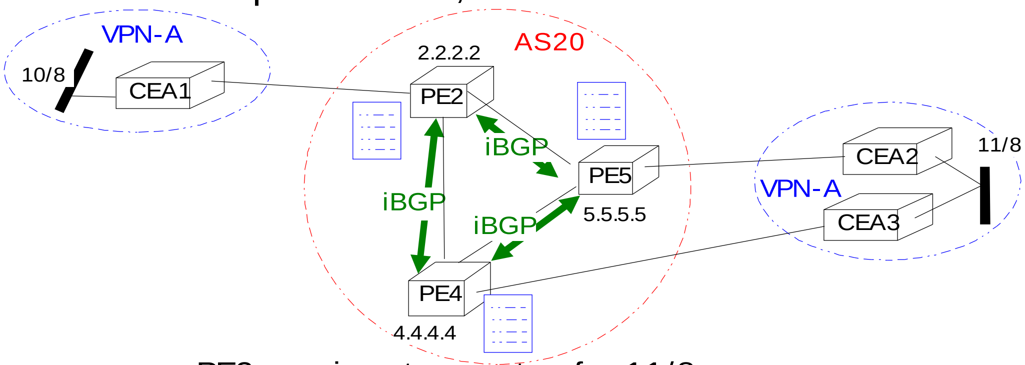


- PE2 receives two routes for 20:10:11/8
  - 20:10:11/8 from PE4 with nexthop = 4.4.4.4 (PE4)
  - 20:10:11/8 from PE5 with nexthop = 5.5.5.5 (PE5)
- PE2 selects the best route with its BGP decision process and installs it inside its VPN-A VRF
  - PE2 may use two LSPs to reach 11/8 via PE4 and PE5

In this example, we assume that the route target used by PE5 is 20:10 (20 because the AS number of the ISP and 10 is the number allocated by the ISP for VPN-A, assuming per-VPN route targets)

Packet flow in RFC2457 VPNs (2)

- With per-site RD, how does PE2 reach 11/8 ?

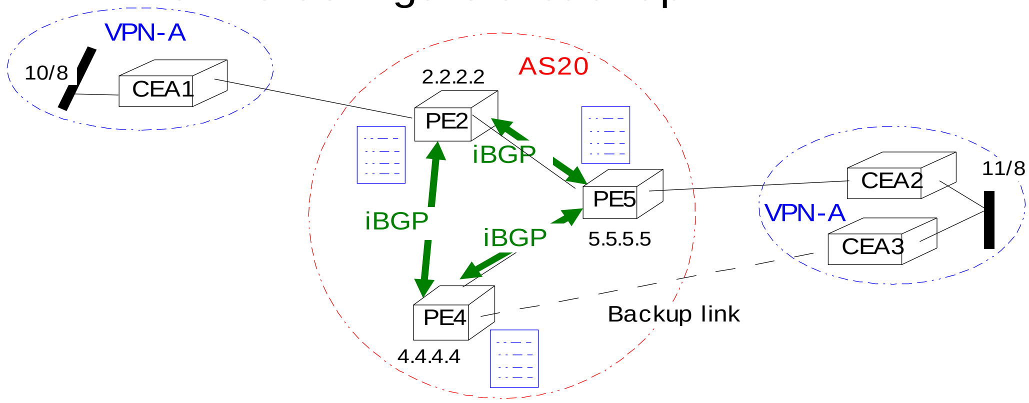


- PE2 receives two routes for 11/8
  - 4.4.4.4:123:11/8 from PE4 with nexthop = 4.4.4.4 (PE4)
  - 5.5.5.5:456:11/8 from PE5 with nexthop = 5.5.5.5 (PE5)
- BGP does not help PE2 to select which route is the best, the selection is done when installing in VPN-A VRF
  - PE2 may use two LSPs to reach 11/8 via PE4 and PE5

In this example, 123 and 456 are locally unique numbers managed by PE4 and PE5.

Backup links with RFC2457 VPNs

- How to configure a backup link ?



  - PE4 adds localpref=50 to route learned from CEA3
  - PE4 and all routers will prefer the route via PE5/CEA2
  - Failure of link CEA2-PE5 will force PE5 to withdraw its VPN route towards 11/8 and the route via PE4 will be used

In this scenario, the convergence time in case of failure will depend on several factors :
- the time to detect the failure of the PE5-CEA2 link

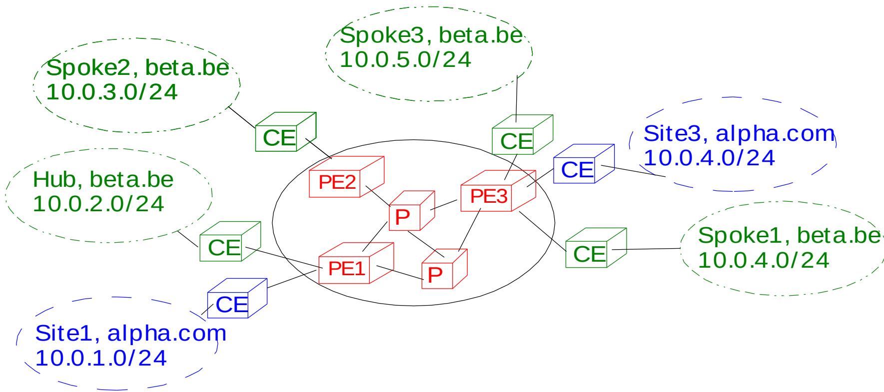
  the best solution is clearly to detect the failure at layer1 or layer2. If the PE-CE protocol is used to detect the failure, then it may elapse several tens of seconds before the failure is actually detect and PE5 withdraws its VPN-IPv4 route

The type of route distinguishers used by PE4 and PE5 may influence the convergence time in large networks.

If PE4 and PE5 use the same route distinguishers for the routes learned from respectively CEA3 and CEA2, then when PE4 learns the RD:11/8 via iBGP, it will withdraw its own RD:11/8 route. When link PE5-CEA2 fails, PE4 will need to advertise its own route to all PE routers in the blue VPN. The propagation of this advertisement may take some time.

If PE4 and PE5 use different route distinguishers, e.g. 4.4.4.4:20 and 5.5.5.5:21, then both VPN-IPv4 routes will be received by all PE routers attached to CE routers in VPN-A. When installing the routes in their VRF, all PE routers will prefer the route with the 5.5.5.5:21 RD since it has the highest localpref value. However, all PE routers will always know both routes. Thus, if the route with RD=5.5.5.5:21 is withdrawn, then each PE router can quickly switch to the route with RD=4.4.4.4:20 provided, of course, that there is already a LSP between this PE router and PE4.

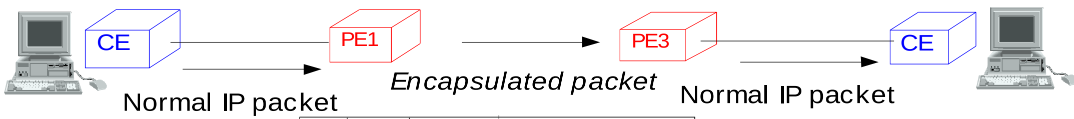
Solving the forwarding problem with tunnels



- Principle of the solution : Tunnel+MPLS
  - one tunnel is used to reach the next-hop PE
  - one MPLS label is used to indicate the VRF to be used (and thus the outgoing CE) in the egress PE

Solving the forwarding problem with tunnels (2)

- How to the encapsulate the packets ?



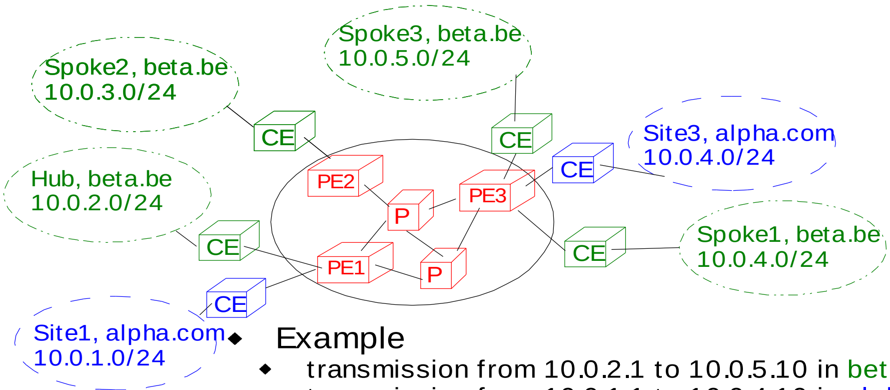
Ver	IHL	ToS	Total length
Identification		Flags	Fragment Offset
TTL	Prot.MPLS	Checksum	
PE1 IP address			
PE3 IP address			
MPLS Label			TTL
Ver	IHL	ToS	Total length
Identification		Flags	Fragment Offset
TTL	Protocol	Checksum	
Source IP address			
Destination IP address			
Payload			

It is also possible to use GRE tunnels to reach the egress PE instead of using MPLS-over-IP tunnel.

The MPLS-over-IP tunnel is described in :
Tom Worster, Yakov Rekhter, Eric C. Rosen, editor, Encapsulating MPLS in IP or Generic Routing Encapsulation (GRE), Internet draft, draft-ietf-mpls-in-ip-or-gre-08.txt, 2004, Work in progress

Solving the forwarding problem with tunnels (3)

PE3
Redistributes via iBGP
- VPN beta rt: beta_spoke,next-hop=PE3, 10.0.5.0/24:label:L4
- VPN beta rt: beta_spoke,next-hop=PE3, 10.0.4.0/24:label:L5
- VPN alpha rt: alpha,next-hop=PE3, label : 10.0.4.0/24L9



- Example
  - transmission from 10.0.2.1 to 10.0.5.10 in beta.be
  - transmission from 10.0.1.1 to 10.0.4.10 in alpha.com

Comparison of VPN solutions

- Provider-provisionned BGP/MPLS VPNs
  - Easy to configure for customer and provider
  - Provider can provide special QoS to VPN
  - But customer routes are distributed inside the provider's network by iBGP
    - provider may need to carry a large number of routes if clients use /32, /30 or /28 subnets
      - some ISPs report BGP/MPLS VPN tables larger than the BGP tables of backbone Internet routers
    - stability and convergence time of routing in the customer network depends on provider's iBGP
      - BGP has a rather slow convergence
      - Customer does not entirely controls routing in its VPN

Comparison of VPN solutions (2)

- Customer-provisionned VPNs
  - Providers are not involved in the provisionning of the VPN
    - no per-VPN routing tables to maintain and distribute
    - no revenue for value-added service
  - Customer builds VPN by establising tunnels
    - it may be difficult to automate the tunnel establishment
    - a large number of tunnels may be required
  - Customer has full control over routing in the VPN
    - Routing protocol can be tuned for fast convergence, load balancing or whatever
      - no direct interactions between ISP's routing and VPN routing
    - Customer must be able to configure routers correctly

Thank you

Questions and comments can be sent to

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