Interdomain routing with BGP4
Part 5/5

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November 2004
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 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 $O(\text{months})$

- **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)

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

ISP: 193.190.0.0/16
- Towards 193.190.10.11
- Towards 193.190.30.13

Site1, alpha.com
10.0.1.0/24
- WAN interface: 193.190.20.12
- LAN interface: 10.0.1.1
- IP Tunnels
  - Towards 193.190.10.11
  - Towards 193.190.30.13

Site2, alpha.com
10.0.2.0/24
- WAN interface: 193.190.10.11
- LAN interface: 10.0.2.1
- IP Tunnels
  - Towards 193.190.20.12
  - Towards 193.190.30.13

Site3, alpha.com
10.0.4.0/24
- WAN interface: 193.190.30.13
- LAN interface: 10.0.4.1
- IP Tunnels
  - Towards 193.190.10.11
  - Towards 193.190.20.12

Backbone routers only use this address block.

BGP/2004.5.9
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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
**GRE Tunnel**

- **Principle**
  - Tunnel is used to carry network layer packets

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### GRE Tunnel Header

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<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
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<td>Ver</td>
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<td>IHL</td>
<td>Internet Header Length field</td>
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<tr>
<td>DS</td>
<td>Destination Protocol field</td>
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<tr>
<td>Total length</td>
<td>Total length of the packet</td>
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<td>Fragment Offset field</td>
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<td>Time to Live field</td>
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<tr>
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<td>Checksum field</td>
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<tr>
<td>Source IP address</td>
<td></td>
</tr>
<tr>
<td>Destination IP address</td>
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</tr>
<tr>
<td>C</td>
<td>GRE Flag field</td>
</tr>
<tr>
<td>Reserved</td>
<td>Reserved field</td>
</tr>
<tr>
<td>Ver</td>
<td>Protocol Type field</td>
</tr>
<tr>
<td>Protocol Type</td>
<td>Protocol Type field</td>
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<tr>
<td>Checksum (option)</td>
<td>Checksum (option)</td>
</tr>
<tr>
<td>Reserved</td>
<td>Reserved field</td>
</tr>
</tbody>
</table>

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- **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**

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

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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
    - \( n \times (n-1)/2 \) 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
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
- 10.0.4.0/24, use label L1
- 10.0.1.0/24, use label L2

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

LAN interface: 10.0.1.0/24
- 10.0.4.0/24, use label L4
- 10.0.2.0/24, use label L5

LAN interface: 10.0.1.1
- 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
Outline

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  • The VPN problem
  • Provider-provisionned BGP/MPLS VPNs
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
Provider-provisionned MPLS VPN (2)

- Principle of the solution

- Transmission of one packet in **beta.be**, site1 to site2
- Transmission of one packet in **alpha.com**, site1 to 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

- **ISP backbone**:
  - 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
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
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

- Site 1, alpha.com
  - 10.0.1.0/24

- Site 2, alpha.com
  - 10.0.2.0/24

- Site 3, alpha.com
  - 10.0.4.0/24

- Site 1, beta.be
  - 10.0.4.0/24

- Site 2, beta.be
  - 10.0.2.0/24

- Site 3, alpha.com
  - 10.0.4.0/24

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

**Site 1**, alpha.com: 10.0.1.0/24

**Site 2**, beta.be: 10.0.2.0/24

**Site 3**, alpha.com: 10.0.4.0/24

- **ISP backbone**
- **CE**
- **PE1**
- **PE2**
- **PE3**
- **Pa**
- **Pb**

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

**Example**

- **Site 1, alpha.com**
  - 10.0.1.0/24

- **Site 2, beta.be**
  - 10.0.2.0/24

- **Site 3, alpha.com**
  - 10.0.4.0/24

PE3's routing tables:
- **beta.be**
  - 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

BGP/2004.5.24

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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.
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
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**
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
MP-BGP and the VPN-IPv4 addresses

- Example
- per-VPN route distinguisher
MP-BGP and the VPN-IPv4 addresses (2)

- Example
  - per-site route distinguisher

```
| PE2  | 2.2.2.2 | AS20 |
| PE4  | 4.4.4.4 |      |
| PE5  | 5.5.5.5 |      |
| P    |         |      |

- UPDATE sent by PE4
- NextHop: 4.4.4.4
- VPN-IPv4 address
  - RD: 4.4.4.4:10
  - Prefix: 10.0.0.0/8
- Route Target (Ext.Com)
  - Magenta

- UPDATE sent by PE5
- NextHop: 5.5.5.5
- VPN-IPv4 address
  - RD: 5.5.5.5:123
  - Prefix: 12.0.0.0/8
- Route Target (Ext.Com)
  - Magenta
```

VPN-A
- 10/8
  - CEA1
  - 2.2.2.2
  - RD: 4.4.4.4:10
  - Prefix: 10.0.0.0/8
  - Route Target (Ext.Com)
  - Magenta

VPN-B
- 10/8
  - CEB2
  - 4.4.4.4

VPN-A
- 11/8
  - CEA2

VPN-B
- 12/8
  - CEB3

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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
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 target for Hub
  - one route target for all spoke sites

```
Hub, beta.be 10.0.2.0/24

Spoke2, beta.be 10.0.3.0/24

Spoke1, beta.be 10.0.4.0/24

Spoke3, beta.be 10.0.1.0/24
```
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
Distribution of labels (2)

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

---

- **Site 1, alpha.com**
  - 10.0.1.0/24

- **Spoke 1, beta.be**
  - 10.0.4.0/24

- **Spoke 2, beta.be**
  - 10.0.3.0/24

- **Hub, beta.be**
  - 10.0.2.0/24

- **Site 3, alpha.com**
  - 10.0.4.0/24

---

**PE1**
Redistributes through iBGP the following routes and labels
- VPN alpha rt: alpha, next-hop = PE1, label = L11
- VPN beta rt: beta_hub, next-hop = PE1, label = L17

**PE2**

**PE3**
Redistributes through iBGP
- VPN beta rt: beta_soke, next-hop = PE3, label = L1
- VPN alpha rt: alpha, next-hop = PE3, label = L9
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
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
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
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 encapsulate the packets?

Normal IP packet → Encapsulated packet → Normal IP packet

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<tr>
<th>Ver</th>
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<th>ToS</th>
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<td>Prot.MPLS</td>
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PE1 IP address

PE3 IP address

MPLS Label

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<td>Checksum</td>
</tr>
</tbody>
</table>

Source IP address

Destination IP address

Payload
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: 10.0.4.0/24 L9

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 establishing 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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