CS 356: Computer Network Architectures

Lecture 13: Border Gateway Protocol and switching hardware

[PD] chapter 4.1.2
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Today

• Border Gateway Protocol (BGP)

• Lab 2
The Internet
All ASes are not equal
Intra-domain vs. inter-domain routing

Each AS runs an Intra-domain routing protocol inside.

BGP: inter-domain
BGP is a policy routing protocol

- BGP helps an AS choose a next-hop AS

- Decision made based on AS policies

- Policies are largely determined by AS relationships
AS relationships

- Very complex economic landscape

- Simplifying a bit:
  - Transit: “I pay you to carry my packets to everywhere” (provider-customer)
  - Peering: “For free, I carry your packets to my customers only.” (peer-peer)

- Technical definition of tier-1 ISP: In the “default-free” zone. No transit.
  - Note that other “tiers” are marketing, but convenient. “Tier 3” may connect to tier-1.

- ASes keep them as secret
Tier 1 ISP
Default free, Has information on every prefix

Tier 2 Regional
Default: provider

Tier 2: Regional/National

Tier 3: Local

Tier 1

ISP

Tier 2

Tier 3 (local)
Who pays whom?

- Transit: Customer pays the provider
  - Who is who? Usually, the one who can “live without” the other. AT&T does not need Duke, but Duke needs some ISP.

- What if both need each other? Free Peering.
  - Instead of sending packets over $$ transit, set up a direct connection and exchange traffic for free!
• Tier 1s must all peer with each other by definition
  – Tier 1s form a full mesh Internet core

• Peering *can* give:
  – Better performance
  – Lower cost

• But negotiating *can* be very tricky!
Business and peering

• Cooperative competition (coopetition)

• Much more desirable to have your peer’s customers
  – Much nicer to get paid for transit

• Peering “tiffs” are relatively common in early days

  31 Jul 2005: Level 3 Notifies Cogent of intent to disconnect.
  16 Aug 2005: Cogent begins massive sales effort and mentions a 15 Sept. expected depeering date.
  31 Aug 2005: Level 3 Notifies Cogent again of intent to disconnect (according to Level 3)
  5 Oct 2005 9:50 UTC: Level 3 disconnects Cogent. Mass hysteria ensues up to, and including policymakers in Washington, D.C.
  7 Oct 2005: Level 3 reconnects Cogent

During the “outage”, Level 3 and Cogent’s singly homed customers could not reach each other. (~ 4% of the Internet’s prefixes were isolated from each other)
Internet exchange point

- https://www.internetexchangemap.com/

- Places where ISPs interconnect and exchange traffic

- https://www.internetexchangemap.com/
London Internet Exchange (LINX)

• Telehouse Docklands, July 2005. Photo by John Arundel.
Inside an Internet Exchange Point


• By Stefan Funke from Frankfurt, Germany - Switch RackUploaded by MainFrame, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=26260389
Terms

- Route: a network prefix plus path attributes
- Customer/provider/peer routes: route advertisements heard from customers/providers/peers
- Transit service: If A advertises a route to B, it implies that A will forward packets coming from B to any destination in the advertised prefix

Diagram:

- Duke 152.3/16
- NC RegNet 152.3/16
- UNC

Links:
- 152.2.3.4 to 152.3.137.179
BGP

Autonomous Systems (ASes)

Route Advertisement

Traffic

Session (over TCP)

BGP peers
Enforcing relationships

• Two mechanisms
  – Route export filters
    • Control what routes you send to neighbors
  – Route import ranking
    • Controls which route you prefer of those you hear.
    • “LOCALPREF” – Local Preference. More later.
Export Policies

- **Provider → Customer**
  - All routes so as to provide transit service
- **Customer → Provider**
  - Only customer routes
  - Why?
    - Only transit for those that pay
- **Peer → Peer**
  - Only customer routes
Import policies

• Same routes heard from providers, customers, and peers, whom to choose?
  – customer > peer > provider
  – Why?
  – Choose the most economic routes!
    • Customer route: charge $$ 😊
    • Peer route: free
    • Provider route: pay $$ 😞
Now the nitty-gritty details!
BGP

• **BGP = Border Gateway Protocol**
  – Currently in version 4, specified in RFC 1771. (~ 60 pages)

• Inter-domain routing protocol for routing between autonomous systems

• Uses TCP to establish a BGP session and to send routing messages over the BGP session

• BGP is a path vector protocol
  – Similar to distance vector routing, but routing messages in BGP contain complete paths

• Network administrators can specify routing policies
BGP policy routing

• BGP’s goal is to find any path (not an optimal one)
  – Since the internals of the AS are never revealed, finding an optimal path is not feasible

• Network administrator sets BGP’s policies to determine the best path to reach a destination network
BGP messages

- OPEN
- UPDATE
  - Announcements
    - Dest  Next-hop  AS Path … other attributes …
    - 128.2.0.0/16  196.7.106.245  2905 701 1239 5050 9
  - Withdrawals
- KEEPALIVE
  - Keepalive timer / hold timer
- Key thing: The Next Hop attribute
Path Vector

• ASPATH Attribute
  – Records what ASes a route goes through
  – Loop avoidance: Immediately discard
  – Shortest path heuristics

• Like distance vector, but fixes the count-to-infinity problem
I can reach d via B,D

I can reach d via A,B,D

I can reach d via C,A,B,D
Two types of BGP sessions

- eBGP session is a BGP session between two routers in different ASes.
- iBGP session is a BGP session between internal routers of an AS.
Route propagation via eBGP and iBGP

- iBGP is organized into a full mesh topology, or iBGP sessions are relayed using a route reflector.
Common BGP path attributes

- **Origin**: indicates how BGP learned about a particular route
  - IGP (internal gateway protocol)
  - EGP (external gateway protocol)
  - Incomplete

- **AS path**:
  - When a route advertisement passes through an autonomous system, the AS number is added to an ordered list of AS numbers that the route advertisement has traversed

- **Next hop**

- **Multi Exit Disc** (MED, multiple exit discriminator):
  - used as a suggestion to an external AS regarding the preferred route into the AS

- **Local pref**: is used to prefer an exit point from the local autonomous system

- **Community**: apply routing decisions to a group of destinations
BGP route selection process

• Input/output engine may filter routes or manipulate their attributes
Best path selection algorithm

1. If next hop is inaccessible, ignore routes

2. Prefer the route with the largest local preference value

3. If local prefs are the same, prefer route with the shortest AS path

4. If AS_path is the same, prefer route with lowest origin (IGP < EGP < incomplete)

5. If origin is the same, prefer the route with lowest MED

6. IF MEDs are the same, prefer eBGP paths to iBGP paths

7. If all the above are the same, prefer the route that can be reached via the closest IGP neighbor

8. If the IGP costs are the same, prefer the router with lowest router id
Joining BGP with IGP Information

Forwarding Table
<table>
<thead>
<tr>
<th>destination</th>
<th>next hop</th>
</tr>
</thead>
<tbody>
<tr>
<td>192.0.2.0/30</td>
<td>10.10.10.10</td>
</tr>
</tbody>
</table>

+ BGP

Forwarding Table
<table>
<thead>
<tr>
<th>destination</th>
<th>next hop</th>
</tr>
</thead>
<tbody>
<tr>
<td>128.112.0.0/16</td>
<td>10.10.10.10</td>
</tr>
<tr>
<td>192.0.2.0/30</td>
<td>10.10.10.10</td>
</tr>
</tbody>
</table>

128.112.0.0/16
Next Hop = 192.0.2.1
Load balancing

- Same route from two providers
- Outbound is “easy” (you have control)
  - Set localpref according to goals
- Inbound is tough (nobody has to listen)
  - AS path prepending
  - MEDs
    - Hot and Cold Potato Routing (picture)
    - Often ignored unless contracts involved
    - Practical use: tier-1 peering with a content provider
Hot-Potato Routing (early exit)
Cold-Potato Routing (MED)
BGP Scalability
Routing table scalability with Classful IP Addresses

- Fast growing routing table size
- Classless inter-domain routing aims to address this issue
CIDR hierarchical address allocation

• IP addresses are hierarchically allocated.
• An ISP obtains an address block from a Regional Internet Registry
• An ISP allocates a subdivision of the address block to an organization
• An organization recursively allocates subdivision of its address block to its networks
• A host in a network obtains an address within the address block assigned to the network
Hierarchical address allocation

- ISP obtains an address block 128.0.0.0/8 \( \rightarrow [128.0.0.0, 128.255.255.255] \)
- ISP allocates 128.195.0.0/16 ([128.195.0.0, 128.195.255.255]) to the university.
- University allocates 128.195.4.0/24 ([128.195.4.0, 128.195.4.255]) to the CS department’s network
- A host on the CS department’s network gets one IP address 128.195.4.150
CIDR allows route aggregation

- ISP1 announces one address prefix 128.0.0.0/8 to ISP2
- ISP2 can use one routing entry to reach all networks connected to ISP1

You can reach 128.0.0.0/8 via ISP1
Multi-homing increases routing table size

You can reach 128.0.0.0/8 and 204.1.0.0/16 via ISP1.

<table>
<thead>
<tr>
<th></th>
<th>ISP1</th>
<th>ISP2</th>
</tr>
</thead>
<tbody>
<tr>
<td>128.0.0.0/8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>204.1.0.0/16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>ISP2</th>
<th>ISP3</th>
</tr>
</thead>
<tbody>
<tr>
<td>204.0.0.0/8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>204.1.0.0/16</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>204.1.0.0/16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Global routing tables continue to grow (1989-now)

Source: https://www.cidr-report.org
BGP Summary

- BGP uses the path vector algorithm
- Its path selection algorithm is complicated
- Policy is mostly determined by economic considerations
Lab2 – Simple Router

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Overview

Your task is to implement a simple router with a static routing table. It will be able to do the following:

– The router will handle raw Ethernet frames;
– It will process the packets just like a real router;
– then forward them to the correct outgoing interface.
Packet Handling Procedure

- In the aspect of Router

```
#include <sr_router.h>

void sr_router() {
    // Packet handling functions
    sr_handlepacket();
    sr_send_packet();
    // ARP, ICMP, IP handlers
}
```
What you need to implement

• sr_arpcache.c       sr_arpcache_sweepreqs(struct sr_instance *sr)
  – The assignment requires you to send an ARP request about once a second until a reply comes back or we have sent five requests. This function is defined in sr_arpcache.c and called every second, and you should add code that iterates through the ARP request queue and re-sends any outstanding ARP requests that haven't been sent in the past second. If an ARP request has been sent 5 times with no response, a destination host unreachable should go back to all the sender of packets that were waiting on a reply to this ARP request.

• sr_router.c        sr_handlepacket(struct sr_instance* sr, …)
  – This method, located in sr_router.c, is called by the router each time a packet is received. The "packet" argument points to the packet buffer which contains the full packet including the ethernet header. The name of the receiving interface is passed into the method as well.
Helper Functions

`arpcache.c`

`sr_arpcache_lookup(struct sr_arpcache *cache, uint32_t ip)`
look for the MAC address in cache based on ip

`sr_arpcache_dump(struct sr_arpcache *cache)`
print the list of current ARP cache

`sr_if.c`

`sr_get_interface(struct sr_instance* sr, const char* name)`
get the property of specific interface by its name

`sr_print_if_list(struct sr_instance* sr)`
print the list of interfaces in current router

`sr_protocol.h`

`header definition`
define the header information
Helper Functions

**sr_rt.c**

- `sr_print_routing_table(struct sr_instance* sr)`
  - print out the content of routing table

- `sr_print_routing_entry(struct sr_rt* entry)`
  - print out the verbose information of a specific routing entry

**sr_utils.c**

- `cksum (const void * _data, int len)`
  - calculate the checksum of a range of packet content

- `print_hdrs(uint8_t * buf, uint32_t length)`
  - print the content of a network packet header
ICMP packet format

- [http://www.networksorcery.com/enp/protocol/icmp.htm](http://www.networksorcery.com/enp/protocol/icmp.htm)

**ICMP header:**

<table>
<thead>
<tr>
<th>Type</th>
<th>Code</th>
<th>ICMP header checksum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Type. 8 bits.  
Specifies the format of the ICMP message.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Echo reply</td>
<td>RFC 792</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Destination unreachable</td>
<td>RFC 792</td>
</tr>
<tr>
<td>4</td>
<td>Source quench</td>
<td>RFC 792</td>
</tr>
<tr>
<td>5</td>
<td>Redirect</td>
<td>RFC 792</td>
</tr>
<tr>
<td>6</td>
<td>Alternate host address</td>
<td>RFC 792</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Echo request</td>
<td>RFC 792</td>
</tr>
<tr>
<td>9</td>
<td>Router advertisement</td>
<td>RFC 1256</td>
</tr>
<tr>
<td>10</td>
<td>Router solicitation</td>
<td>RFC 1256</td>
</tr>
<tr>
<td>11</td>
<td>Time exceeded</td>
<td>RFC 792</td>
</tr>
<tr>
<td>12</td>
<td>Parameter problem</td>
<td>RFC 792</td>
</tr>
<tr>
<td>13</td>
<td>Parameter problem</td>
<td>RFC 792</td>
</tr>
</tbody>
</table>