Routing Basics

Campus Network Design & Operations Workshop

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Routing Concepts

- Routers
- Routing
- Forwarding
- Some definitions
- Routing Protocols
What is a Router?

- A router is a layer 3 device
- Used for interconnecting networks at layer 3
- A router generally has at least two interfaces
  - With VLANs a router can have only one physical interface (known as “router on a stick”)
- A router looks at the destination address in the IP packet, and decides how to forward it
The Forwarding Table

• Each router/host has a *forwarding table*, indicating the path or the next hop for a given destination host or a network.
• The router/host tries to match the destination address of a packet against entries in the forwarding table.
• If there is a match, the router forwards it to the corresponding gateway router or directly to the destination host.
• Default route is taken if no other entry matches the destination address.
The Forwarding Table

<table>
<thead>
<tr>
<th>Destination</th>
<th>Next-Hop</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.40.0.0/16</td>
<td>192.248.40.60</td>
<td>Ethernet0</td>
</tr>
<tr>
<td>192.248.0.140/30</td>
<td>Directly connected</td>
<td>Serial1</td>
</tr>
<tr>
<td>192.248.40.0/26</td>
<td>Directly connected</td>
<td>Ethernet0</td>
</tr>
<tr>
<td>192.248.0.0/17</td>
<td>192.248.0.141</td>
<td>Serial1</td>
</tr>
<tr>
<td>203.94.73.202/32</td>
<td>192.248.40.3</td>
<td>Ethernet0</td>
</tr>
<tr>
<td>203.115.6.132/30</td>
<td>Directly connected</td>
<td>Serial0</td>
</tr>
<tr>
<td>Default</td>
<td>203.115.6.133</td>
<td>Serial0</td>
</tr>
</tbody>
</table>

Typical forwarding table on a simple edge router
IP Routing – finding the path

• Forwarding table entry (the path) is created by the administrator (static) or received from a routing protocol (dynamic)
• More than one routing protocol may run on a router
  – Each routing protocol builds its own routing table (Local RIB)
• Several alternative paths may exist
  – Best path selected for the router’s Global routing table (RIB)
• Decisions are updated periodically or as topology changes (event driven)
• Decisions are based on:
  – Topology, policies and metrics (hop count, filtering, delay, bandwidth, etc.)
IP route lookup

• Based on destination IP address
• “longest match” routing
  – More specific prefix preferred over less specific prefix
  – **Example:** packet with destination of 172.16.1.1 is sent to the router announcing 172.16.1.0/24 rather than the router announcing 172.16.0.0/16.
IP route lookup

• Based on destination IP address

<table>
<thead>
<tr>
<th>Destination</th>
<th>NextHop</th>
</tr>
</thead>
<tbody>
<tr>
<td>172.16.0.0/16</td>
<td>R3</td>
</tr>
<tr>
<td>172.16.1.0/24</td>
<td>R4</td>
</tr>
<tr>
<td>172.18.0.0/16</td>
<td>R5</td>
</tr>
<tr>
<td>172.19.0.0/16</td>
<td>R6</td>
</tr>
<tr>
<td>……</td>
<td></td>
</tr>
</tbody>
</table>
IP route lookup: Longest match routing

- Based on destination IP address

Packet: Destination IP address: 172.16.1.1

R2's IP routing table:
- 172.16.0.0/16 → R3
- 172.16.1.0/24 → R4
- 172.18.0.0/16 → R5
- 172.19.0.0/16 → R6
- ......

172.16.0.0/16 announced from here
172.16.1.0/24 announced from here

Match!
IP route lookup:
Longest match routing

• Based on destination IP address

Packet: Destination IP address: 172.16.1.1

R2’s IP routing table

172.16.0.0/16 ➞ R3
172.16.1.0/24 ➞ R4
172.18.0.0/16 ➞ R5
172.19.0.0/16 ➞ R6
......

172.16.1.1 exists inside 172.16.1.0/24

172.16.0.0/16 announced from here

172.16.1.0/24 announced from here

Match as well!
IP route lookup: Longest match routing

- Based on destination IP address

Packet: Destination IP address: 172.16.1.1

R2’s IP routing table:
- 172.16.0.0/16 → R3
- 172.16.1.0/24 → R4
- 172.18.0.0/16 → R5
- 172.19.0.0/16 → R6
- .......

172.16.0.0/16 announced from here

172.16.1.0/24 announced from here

172.16.1.0/24

Does not match!
IP route lookup:
Longest match routing

- Based on destination IP address
IP route lookup: Longest match routing

• Based on destination IP address

Packet: Destination IP address: 172.16.1.1

R2’s IP routing table:
- 172.16.0.0/16 → R3
- 172.16.1.0/24 → R4
- 172.18.0.0/16 → R5
- 172.19.0.0/16 → R6
- ……

Longest match, 24 bit prefix

172.16.0.0/16 announced from here

172.16.1.0/24 announced from here
Routing versus Forwarding

• Routing = building maps and giving directions

• Forwarding = moving packets between interfaces according to the “directions”
IP Forwarding

• Router decides which interface a packet is sent to
• Forwarding table populated by routing process
• Forwarding decisions:
  – destination address
  – class of service (fair queuing, precedence, others)
  – local requirements (packet filtering)
• Forwarding is usually aided by special hardware
Routing Tables Feed the Forwarding Table

- BGP 4 Routing Table
- IS-IS - Local RIB
- OSPF - Local RIB
- Static Routes
- Connected Routes

Forwarding Information Base (FIB)
Routing Information Base (RIB)
The FIB

• FIB is the Forwarding Table
  – It contains destinations, the interfaces and the next-hops to get to those destinations
  – It is built from the router’s Global RIB
  – Used by the router to figure out where to send the packet
  – Cisco IOS: `show ip cef`
The Global RIB

• The Global RIB is the Routing Table
  – Built from the routing tables/RIBs of the routing protocols and static routes on the router
    • Routing protocol priority varies per vendor – see addendum
  – It contains all the known destinations and the next-hops used to get to those destinations
  – One destination can have lots of possible next-hops – only the best next-hop goes into the Global RIB
  – The Global RIB is used to build the FIB
  – Cisco IOS: `show ip route`
Explicit versus Default Routing

• Default: Pointing all destinations to another device
  − Simple, cheap (CPU, memory, bandwidth)
  − No overhead
  − Low granularity (metric games)
• Explicit: Every known destination (default free zone)
  − Complex, expensive (CPU, memory, bandwidth)
  − High overhead
  − High granularity (every destination known)
• Hybrid: Default plus some destinations
  − Minimise overhead
  − Provide useful granularity
  − Requires some filtering knowledge
Egress Traffic

• How packets leave your network
• Egress traffic depends on:
  – Route availability (what others send you)
  – Route acceptance (what you accept from others)
  – Policy and tuning (what you do with routes from others)
  – Peering and transit agreements
Ingress Traffic

• How packets enter your network
• Ingress traffic depends on:
  – What information you send and to whom
  – Based on your addressing and ASes
  – Based on others’ policy (what they accept from you and what they do with it)
Autonomous System (AS)

- Collection of networks with same routing policy
- Single routing protocol
- Usually under single ownership, trust and administrative control
Definition of terms

• Neighbors
  – AS’s which directly exchange routing information
  – Routers which exchange routing information

• Announce
  – send routing information to a neighbor

• Accept
  – receive and use routing information sent by a neighbor

• Originate
  – insert routing information into external announcements (usually as a result of the IGP)

• Peers
  – routers in neighboring AS’s or within one AS which exchange routing and policy information
Routing flow and Packet flow

For networks in AS1 and AS2 to communicate:
- AS1 must announce to AS2
- AS2 must accept from AS1
- AS2 must announce to AS1
- AS1 must accept from AS2
Routing flow and Traffic flow

- Traffic flow is always in the opposite direction of the flow of Routing information
  - Filtering outgoing routing information inhibits traffic flow inbound
  - Filtering inbound routing information inhibits traffic flow outbound
Routing Protocols

We now know what routing means…
…but what do the routers get up to?
And why are we doing this anyway?
1: How Does Routing Work?

• Internet is made up of the RENs and ISPs who connect to each other’s networks
• How does an ISP in Kenya tell an ISP in Japan what end-users it has?
• And how does that ISP send data packets to the customers of the ISP in Japan, and get responses back
  - After all, as on a local ethernet, two-way packet flow is needed for communication between two devices
2: How Does Routing Work?

• ISP in Kenya could buy a direct connection to the ISP in Japan
  – But this doesn’t scale – thousands of ISPs, would need thousands of connections, and cost would be astronomical

• Instead, ISP in Kenya tells its neighboring ISPs what end-users it has
  – And the neighboring ISPs pass this information on to their neighbors, and so on
  – This process repeats until the information reaches the ISP in Japan
3: How Does Routing Work?

• This process is called “Routing”
• The mechanisms used are called “Routing Protocols”
• Routing and Routing Protocols ensures that
  – The Internet can scale
  – Thousands of ISPs can provide connectivity to each other
  – We have the Internet we see today
4: How Does Routing Work?

- ISP in Kenya doesn’t actually tell its neighboring ISPs the names of the end-users
  - (network equipment does not understand names)
- Instead, the ISP will have received an IP address block as a member of the Regional Internet Registry serving Kenya
  - The end-users will have received address space from this address block as part of their “Internet service”
  - And the ISP announces this address block to its neighboring ISPs – this is called announcing a “route”
Routing Protocols

• Routers use “routing protocols” to exchange routing information with each other
  − IGP is used to refer to the process running on routers inside a network
  − EGP is used to refer to the process running between routers bordering directly connected networks
What Is an IGP?

• **Interior Gateway Protocol**
• Within an Autonomous System
• Carries information about internal infrastructure prefixes
• Two widely used IGPs:
  - OSPF (Open Shortest Path First)
  - IS-IS (Intermediate System to Intermediate System)
Why Does Internet Need an IGP?

• Backbone scaling in RENs and ISPs
  − Hierarchy
  − Limiting scope of failure
  − Only used for Operator’s infrastructure addresses, not end user addresses or anything else
  − Design goal is to minimise number of prefixes in IGP to aid scalability and rapid convergence

• Scalable internal routing for end user networks
What Is an EGP?

• **Exterior Gateway Protocol**
• Used to convey routing information between Autonomous Systems
• De-coupled from the IGP
• The only EGP is Border Gateway Protocol (BGP)
Why Does Internet need an EGP?

• Scaling to large network
  – Hierarchy
  – Limit scope of failure
• Define Administrative Boundary
• Policy
  – Control reachability of prefixes
  – Merge separate organisations
  – Connect multiple IGPs
• Application: RENs, ISPs, Multihomed end-users
Interior versus Exterior Routing Protocols

• Interior
  - Automatic neighbor discovery
  - Generally trust your IGP routers
  - Prefixes go to all IGP routers

• Exterior
  - Specifically configured peers
  - Connecting with outside networks
  - Set administrative boundaries
Hierarchy of Routing Protocols

- BGP and OSPF/IS-IS
- Other ISPs
- End Users
- IXP
- NREN/ISP
- REN
- Local Internet
- Static/BGP
- Campus
- BGP
- BGP
Questions?
# FYI: Default Administrative Distances

<table>
<thead>
<tr>
<th>Route Source</th>
<th>Cisco</th>
<th>Juniper</th>
<th>Huawei</th>
<th>Dell</th>
<th>Nokia</th>
<th>Mikrotik</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connected Interface</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Static Route</td>
<td>1</td>
<td>5</td>
<td>60</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>EIGRP Summary Route</td>
<td>5</td>
<td>N/A</td>
<td>?</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>External BGP</td>
<td>20</td>
<td>170</td>
<td>255</td>
<td>20</td>
<td>170</td>
<td>20</td>
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<tr>
<td>Internal EIGRP Route</td>
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<td>?</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>IGRP</td>
<td>100</td>
<td>N/A</td>
<td>?</td>
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<td>N/A</td>
</tr>
<tr>
<td>OSPF</td>
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<td>10</td>
<td>10</td>
<td>110</td>
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<td>110</td>
</tr>
<tr>
<td>IS-IS</td>
<td>115</td>
<td>18</td>
<td>15</td>
<td>115</td>
<td>18</td>
<td>N/A</td>
</tr>
<tr>
<td>RIP</td>
<td>120</td>
<td>100</td>
<td>100</td>
<td>120</td>
<td>100</td>
<td>120</td>
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<tr>
<td>EGP</td>
<td>140</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>External EIGRP</td>
<td>170</td>
<td>N/A</td>
<td>?</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Internal BGP</td>
<td>200</td>
<td>170</td>
<td>255</td>
<td>200</td>
<td>130</td>
<td>200</td>
</tr>
<tr>
<td>Unknown</td>
<td>255</td>
<td>255</td>
<td>?</td>
<td>255</td>
<td>?</td>
<td></td>
</tr>
</tbody>
</table>