Hierarchical Routing

- Problem with maintaining one routing table
  - ???
- Administrative autonomy
  - Autonomous System (AS)
    - routers in same AS run same routing protocol - "intra-AS" routing protocol (intra-domain routing)
    - routers in different AS can run different intra-AS routing protocol – "inter-AS" routing (inter-domain routing)

Intra-AS and Inter-AS Routing

Gateways:
- perform inter-AS routing amongst themselves
- perform intra-AS routing with other routers in their AS

Diagram:

- network layer
- link layer
- physical layer

inter-AS, intra-AS routing in gateway A.c
Intra-AS and Inter-AS Routing

Routing in the Internet

The Global Internet consists of Autonomous Systems (AS) interconnected with each other:
- **Stub AS**: small corporation
- **Multihomed AS**: large corporation (no transit)
- **Transit AS**: provider (ISP)

Two-level routing:
- **Intra-AS**: administrator is responsible for choice
- **Inter-AS**: unique standard

Intra-AS Routing

Also known as Interior Gateway Protocols (IGP)

Most common IGPs:
- **RIP**: Routing Information Protocol (distance vector) – RIP v2
- **OSPF**: Open Shortest Path First (link state) – OSPF v2
RIP (Routing Information Protocol)

- Distance vector algorithm
- Included in BSD-UNIX Distribution in 1982
  - Originated from Xerox Network System (XNS)
- Distance metric: # of hops (max = 15 hops)
  - Use # of hops as the link cost
- Distance vectors: exchanged every 30 sec via Response Message (also called advertisement), is actually the routing table
- Each advertisement: route to up to 25 destination nets

RIP (Routing Information Protocol)

<table>
<thead>
<tr>
<th>Destination Network</th>
<th>Next Router</th>
<th>Num. of hops to dest</th>
</tr>
</thead>
<tbody>
<tr>
<td>w</td>
<td>A</td>
<td>2</td>
</tr>
<tr>
<td>y</td>
<td>B</td>
<td>2</td>
</tr>
<tr>
<td>z</td>
<td>B</td>
<td>7</td>
</tr>
<tr>
<td>x</td>
<td>--</td>
<td>1</td>
</tr>
</tbody>
</table>

Routing table in D

RIP: Link Failure and Recovery

If no advertisement heard after 180 sec ->
neighbor/link declared dead
- routes via neighbor invalidated
- new advertisements sent to neighbors
- neighbors in turn send out new advertisements (if tables changed)
- link failure info quickly propagates to entire net
RIP Table Example

Router: giroflee.eurocom.fr

<table>
<thead>
<tr>
<th>Destination</th>
<th>Gateway</th>
<th>Flags</th>
<th>Ref</th>
<th>Use</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>127.0.0.1</td>
<td>127.0.0.1</td>
<td>UH</td>
<td>0</td>
<td>26492</td>
<td>lo0</td>
</tr>
<tr>
<td>192.168.2.</td>
<td>192.168.2.5</td>
<td>U</td>
<td>2</td>
<td>13</td>
<td>fa0</td>
</tr>
<tr>
<td>193.55.114.</td>
<td>193.55.114.6</td>
<td>U</td>
<td>3</td>
<td>58503</td>
<td>le0</td>
</tr>
<tr>
<td>224.0.0.0</td>
<td>193.55.114.4</td>
<td>U</td>
<td>3</td>
<td>0</td>
<td>le0</td>
</tr>
<tr>
<td>default</td>
<td>193.55.114.129</td>
<td>UG</td>
<td>0</td>
<td>143454</td>
<td></td>
</tr>
</tbody>
</table>

Three attached class C networks (LANs)
Router only knows routes to attached LANs
Default router used to "go up"
Route multicast address: 224.0.0.0
Loopback interface (for debugging)

OSPF (Open Shortest Path First)

- "open": publicly available
- Uses Link State algorithm
  - LS packet dissemination
  - Topology map at each node
  - Route computation using Dijkstra's algorithm
- Advertisements disseminated to entire AS (via flooding)
- Run on top of IP and send out through raw socket

OSPF "Advanced" Features (not in RIP)

- **Security:** all OSPF messages authenticated (to prevent malicious intrusion) – over IP
- **Multiple same-cost paths** allowed (only one path in RIP) – traffic load balancing
- **Hierarchical OSPF** in large domains (RIP doesn't support hierarchical routing.)
Hierarchical OSPF

Two-level hierarchy: local area, backbone
- Link-state advertisements only within area
- Each node has detailed area topology, only know direction (shortest path) to nets in other areas
- **Area border routers**: "summarize" distances to nets in own area, advertise to other Area Border routers
- **Backbone routers**: run OSPF routing limited to backbone
- **Boundary routers**: connect to other AS's

3-Phase Routing Database Synchronization Procedure

- **Hello Phase** – each router establishes neighbor relationship by saying "I am here"
- **DB Exchange Phase**: each router tells its neighbors about his knowledge on the "partial maps"
- **Flooding Phase**: each router will flood the new information it receives on the "partial maps" from others

*The process will cease after DB is synchronized*
**Inter-AS Routing**

BGP (Border Gateway Protocol): the de facto standard, the current version is 4, known as BGP4

Path Vector protocol:
- similar to Distance Vector protocol
- each Border Gateway broadcasts to neighbors (peers) entire path (i.e., sequence of ASs) to destination
- E.g., Gateway X may send its path to dest. Z:

\[
\text{Path (X,Z)} = X, Y_1, Y_2, Y_3, ..., Z
\]