Chapter 7
Routing Protocols
Nonroutable Protocols

- In the early days of networking, networks were small collections of computers linked together
  - For the purposes of sharing information and expensive peripherals
- Early networks were sometimes configured as peer-to-peer networks
  - Computers communicate with and provide services to their “peers”
  - All communication occurs on the same network segment
Nonroutable Protocols (continued)

Figure 7-1 Early network model using coaxial cable
Nonroutable Protocols (continued)

• Several **nonroutable protocols** exist in today’s networking world
• NetBEUI (NetBIOS Enhanced User Interface)
  – The most common nonroutable protocol
  – Ships with all Microsoft Windows operating systems
• NetBEUI cannot scale into large internetworks
  – Cannot hold Network layer information in its network header
Routed Protocols

- **Routed protocols**
  - Have packet headers that can contain Network layer addresses
  - Developed to support networks consisting of multiple networks or subnetworks

- Protocols that can carry Network layer information
  - Transmission Control Protocol/Internet Protocol (TCP/IP)
  - Internetwork Packet Exchange/Sequenced Packet Exchange (IPX/SPX)
Figure 7-2  Common internetwork
Routed Protocols (continued)

• For routed protocols to work on a network
  – Every device must be configured with a unique IP or IPX address (**logical address**)
Figure 7-3  Common internetwork with IP addresses
Routing Protocols

- **Routing protocols**
  - Protocols used by routers to make path determination choices and to share those choices with other routers

- **Hop count**
  - The number of routers a packet must pass through to reach a particular network

- **Metric**
  - A value used to define the suitability of a particular route
  - Routers use metrics to determine which routes are better than other routes
Routing Protocols (continued)

<table>
<thead>
<tr>
<th>Network</th>
<th>Path</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network 2</td>
<td>Available via RouterB</td>
<td>Directly connected</td>
</tr>
<tr>
<td>Network 3</td>
<td>Available via RouterA</td>
<td>1 hop</td>
</tr>
<tr>
<td>Network 4</td>
<td>Available via RouterC</td>
<td>2 hops</td>
</tr>
</tbody>
</table>

**Table 7-1**  Conceptual routing table
Routing Protocols (continued)

• **Autonomous system (AS)**
  – Uses Interior Gateway Protocols as routing protocols
  – A group of routers under the control of a single administration

• **Interior Gateway Protocols (IGPs)** are
  – Routing protocols used within an AS

• **Exterior Gateway Protocols (EGPs)**
  – Routing protocols used to route information between multiple autonomous systems
Routing Protocols (continued)

Figure 7-4  Big Tin Inc.’s AS
Routing Protocols (continued)

- **Examples of IGPs**
  - Routing Information Protocol (RIP)
  - Interior Gateway Routing Protocol (IGRP)
  - Enhanced Interior Gateway Routing Protocol (EIGRP)
  - Open Shortest Path First (OSPF)
- **Example of EGP**
  - Border Gateway Protocol (BGP)
Two Types of IGPs

• **Distance-vector routing protocols**
  – Broadcast their entire routing table to each neighbor router at predetermined intervals
  – The actual interval depends on the distance-vector routing protocol in use
    • Varies between 30 and 90 seconds
  – Sometimes referred to as **routing by rumor**
  – Suffer from slow time to **convergence**
    • A state where all routers on the internetwork share a common view of the internetwork routes
Two Types of IGPs (continued)

RouterB's route table

RouterB sends its entire route table to RouterA when the update interval is reached.

RouterA's route table

RouterA incorporates any updates and changes and, when its update interval is reached, forwards its entire table to RouterC. RouterC sends its route table back to RouterA as soon as its update interval is reached.

Figure 7-5  Distance-vector routing protocol process
Two Types of IGPs (continued)

**Time 1:** RouterB loses connectivity to the Ethernet network available via F0/0.

**Time 2:** RouterB reaches its update interval and sends to RouterA a route table that marks the network on F0/0 as unavailable.

**Time 3:** RouterA incorporates the changes it receives from RouterB and, once its update interval is reached, propagates those changes to RouterC.

**Figure 7-6** Distance-vector convergence example
Two Types of IGPs (continued)

- Distance-vector routing protocols (continued)
  - **Routing loops**
    - Often referred to as count-to-infinity problems
    - Loops, without preventive measures, will cause packets to bounce around the internetwork infinitely
  - **Defining a maximum**
    - One of the easiest ways to limit count-to-infinity problems
  - **Split horizon and split horizon with poison reverse**
    - Two other common ways to prevent routing loops when using distance-vector routing protocols
Figure 7-7  Distance-vector convergence problems
Two Types of IGPs (continued)

- Distance-vector routing protocols (continued)
  - **Hold-down timer**
    - Another common technique used to stop routing loops
    - Allow a router to place a route in a state where it will not accept any changes to that route

- **Link-state routing protocols**
  - Use **link-state advertisements (LSAs)** to inform neighbor routers on the internetwork
  - LSAs contain only the local links for the advertised router
Two Types of IGPs (continued)

• Link-state routing protocols (continued)
  – **Shortest Path First (SPF) algorithm**
    • Uses the link information to compute the routes
    • Router CPU resources are used instead of bandwidth
  – **Link-state packets (LSPs)**
    • Packets used to send out LSAs
    • Allow every router in the internetwork to share a common view of the **topology** of the internetwork
  – A link-state routing protocol **floods**, or multicasts, LSPs to the network
  – Later updates will be **triggered updates**
Time 1: RouterB at startup floods the network with link-state packets and informs RouterA and RouterC of its link-state packets. Convergence time is drastically reduced, as compared to distance-vector routing protocols.

Figure 7-8  Link-state advertisements
Two Types of IGPs (continued)

• Link-state routing protocols (continued)
  – Routers using link-state protocols must be configured with more memory and processing power
    • Than those using distance-vector routing protocols
  – Link-state routing protocols such as OSPF are much more complicated to configure on the routers
Two Types of IGPs (continued)

<table>
<thead>
<tr>
<th>Distance-Vector</th>
<th>Link-State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periodically broadcasts entire routing table to</td>
<td>Multicasts links to all routers in the AS on startup; all other routing</td>
</tr>
<tr>
<td>neighbor routers</td>
<td>table updates contain only updated routes; updates occur when a network</td>
</tr>
<tr>
<td></td>
<td>topology change occurs</td>
</tr>
<tr>
<td>Slow to converge</td>
<td>Fast to converge due to link-state advertisements</td>
</tr>
<tr>
<td>Prone to routing loops because of routing-by-rumor</td>
<td>Less prone to routing loops because all other routers share a common view</td>
</tr>
<tr>
<td>nature</td>
<td>of the network</td>
</tr>
<tr>
<td>Easy to configure and administer</td>
<td>Harder to configure; requires greater memory and processing power on each</td>
</tr>
<tr>
<td></td>
<td>router</td>
</tr>
<tr>
<td>Consumes relatively more bandwidth</td>
<td>Consumes relatively less bandwidth</td>
</tr>
</tbody>
</table>

**Table 7-2**  Major characteristics of distance-vector and link-state routing protocols
Routing Information Protocol

- Routing Information Protocol (RIP)
  - The easiest Interior Gateway Protocol to configure is RIPv1
  - A distance-vector routing protocol that broadcasts entire routing tables to neighbors every 30 seconds
  - RIP uses hop count as its sole metric
- RIP has a maximum hop count of 15
  - As a result, RIP does not work in large internetworks
- RIP is capable of load balancing
- RIP is susceptible to all the problems normally associated with distance-vector routing protocols
Enabling RIP Routing

**Figure 7-9** Sample IP network
Enabling RIP Routing (continued)

• To start configuring RIP, you must:
  – Enter privileged mode first
  – Enter global configuration mode on your router
• Enable RIP with the `router rip` command
Enabling RIP Routing (continued)

You enter the `enable` command to enter privileged mode. The `routername#` prompt notifies you that you are in privileged mode.

RouterB con0 is now available

Press RETURN to get started.

User Access Verification

Password:
RouterB>en
Password:
RouterB#config t
Enter configuration commands, one per line. End with CNTL/Z.
RouterB(config)#

`config t` is a shortened form of the `configure terminal` command. It places you in global configuration mode.

This is the global configuration mode prompt. It is at this prompt that you will enable RIP.

Figure 7-10  Global configuration mode
Enabling RIP Routing (continued)

Password:
RouterB>en
Password:
RouterB#config t
Enter configuration commands, one per line. End with CNTL/Z.
RouterB(config)#router rip
RouterB(config-router)#network 172.22.0.0
RouterB(config-router)#^Z
RouterB#
%SYS-5-CONFIG_I: Configured from console by console
RouterB#

The **router rip** command enables RIP routing on the router
The **network** [network #] command is used to specify the major networks RIP will advertise

**Figure 7-11** Configuring RIP
Configuring RIP Routing for Each Major Network

- **network command**
  - Turns on RIP routing for a network
  - An individual `network` command must be issued for each separate network directly connected to the router
- **show ip route command**
  - Displays a router’s routing table
- **Administrative distance**
  - A value used to determine the reliability of the information regarding a particular route
  - Administrative distances range from 0–255
### Configuring RIP Routing for Each Major Network (continued)

The `show ip route` command will work in privileged or user mode.

This entry shows the administrative distance and hop count of the destination network. Network 172.22.5.0 has an administrative distance of 120 and is 2 hops away. All routes learned via RIP will have administrative distances of 120.

<table>
<thead>
<tr>
<th>Codes:</th>
<th>C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP, D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area, E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP, i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default, U - per-user static route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gateway of last resort is not set</td>
<td></td>
</tr>
<tr>
<td>The R signifies that the route was learned via RIP.</td>
<td></td>
</tr>
</tbody>
</table>

| 172.22.0.0/16 is subnetted, 4 subnets                                                                                                           |
|---|---------------------------------------------------------------------------------------------------------------------------------------------------|
| C  | 172.22.2.0 is directly connected, FastEthernet0/0                                                                                               |
| C  | 172.22.3.0 is directly connected, Serial0/1                                                                                                   |
| R  | 172.22.4.0 [120/1] via 172.22.3.1, 00:00:15, Serial0/1                                                                                         |
| R  | 172.22.5.0 [120/2] via 172.22.3.1, 00:00:15, Serial0/1                                                                                         |

**Figure 7-12** Output from the `show ip route` command
Configuring RIP Routing for Each Major Network (continued)

<table>
<thead>
<tr>
<th>Route Learned via:</th>
<th>Administrative Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directly connected network</td>
<td>0</td>
</tr>
<tr>
<td>Static route</td>
<td>1</td>
</tr>
<tr>
<td>EIGRP</td>
<td>90</td>
</tr>
<tr>
<td>IGRP</td>
<td>100</td>
</tr>
<tr>
<td>OSPF</td>
<td>110</td>
</tr>
<tr>
<td>RIP</td>
<td>120</td>
</tr>
<tr>
<td>Unknown</td>
<td>255</td>
</tr>
</tbody>
</table>

*Table 7-3  Administrative distances*
Show ip protocol and debug ip rip Commands

- Commands used to monitor RIP
- A route is considered invalid if six consecutive update intervals pass without an update from that route
- **Flush interval**
  - The time at which a route will be totally removed from the routing table if no updates are received
- **debug ip rip command**
  - Displays real-time rip updates being sent and received and places very high processing demands on your router, which could affect network performance
Show ip protocol and debug ip rip Commands (continued)

RouterB> **show ip protocol**
Routing Protocol is "rip"
- Sending updates every 30 seconds, next due in 6 seconds
- Invalid after 180 seconds, hold down 180, flushed after 240
- Outgoing update filter list for all interfaces is not set
- Incoming update filter list for all interfaces is not set
- Redistributing: rip
  Default version control: send version 1, receive any version
<table>
<thead>
<tr>
<th>Interface</th>
<th>Send</th>
<th>Recv</th>
<th>Key-chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>FastEthernet0/0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Serial0/1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Routing for Networks:
- 172.22.0.0
Routing Information Sources:
<table>
<thead>
<tr>
<th>Gateway</th>
<th>Distance</th>
<th>Last Update</th>
</tr>
</thead>
<tbody>
<tr>
<td>172.22.3.1</td>
<td>120</td>
<td>00:00:27</td>
</tr>
</tbody>
</table>
Distance: (default is 120)

Figure 7-13  Output from the show ip protocol command
RouterB>en
Password:
RouterB#debug ip rip
RIP protocol debugging is on
RouterB#
RIP: received v1 update from 172.22.3.1 on Serial0/1
  172.22.4.0 in 1 hops
  172.22.5.0 in 2 hops
RouterB#
RIP: sending v1 update to 255.255.255.255 via FastEthernet0/0
  subnet 172.22.3.0, metric 1
  subnet 172.22.4.0, metric 2
  subnet 172.22.5.0, metric 3
RIP: sending v1 update to 255.255.255.255 via Serial0/1 (172.22.3.2)
  subnet 172.22.2.0, metric 1
RIP: ignored v1 update from bad source 172.22.5.1 on FastEthernet0/0
RIP: received v1 update from 172.22.3.1 on Serial0/1
  172.22.4.0 in 1 hops
  172.22.5.0 in 2 hops
RouterB#
RIP: sending v1 update to 255.255.255.255 via FastEthernet0/0
  subnet 172.22.3.0, metric 1
  subnet 172.22.4.0, metric 2
  subnet 172.22.5.0, metric 3
RIP: sending v1 update to 255.255.255.255 via Serial0/1 (172.22.3.2)
  subnet 172.22.2.0, metric 1
RIP: ignored v1 update from bad source 172.22.5.1 on FastEthernet0/0
RouterB#no debug ip rip
RIP protocol debugging is off
RouterB#

Figure 7-14  Output from the debug ip rip command
Show ip protocol and debug ip rip Commands (continued)

The route to subnet 172.22.5.0 is in hold-down and marked as possibly down

RouterB#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route

Gateway of last resort is not set

    172.22.0.0/16 is subnetted, 4 subnets
C    172.22.2.0 is directly connected, FastEthernet0/0
C    172.22.3.0 is directly connected, Serial0/1
R    172.22.4.0 [120/1] via 172.22.3.1, 00:00:19, Serial0/1
R    172.22.5.0/24 is possibly down, routing via 172.22.3.1, Serial0/1

Figure 7-15  Output from the show ip route command
Show ip protocol **and** debug ip rip Commands (continued)

The route to subnet 172.22.5.0 has been removed from the route table

```
RouterB#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route
Gateway of last resort is not set

    172.22.0.0/16 is subnetted, 3 subnets
    C   172.22.2.0 is directly connected, FastEthernet0/0
    C   172.22.3.0 is directly connected, Serial0/1
    R   172.22.4.0 [120/1] via 172.22.3.1, 00:00:10, Serial0/1

RouterB#
```

**Figure 7-16** New output from the show ip route command
Show ip protocol and debug ip rip Commands (continued)

Figure 7-17  RIP problems caused by hop count reliance
Interior Gateway Routing Protocol

- IGRP is a proprietary distance-vector routing protocol
  - Created by Cisco to solve some of the problems associated with RIP
- A larger hop-count metric allows IGRP to be used on larger networks
  - IGRP supports a hop count of 255, although 100 is the default if hop count is configured to be used as a metric
- The `metric maximum-hops` command allows you to set the maximum hop count for IGRP
Interior Gateway Routing Protocol (continued)

- The default metrics for IGRP are bandwidth and delay only
- Metrics that can be configured for IGRP
  - Hops: number of routers between source and destination networks
  - Load: the load on a link in the path
  - Bandwidth: the speed of the link (default)
  - Reliability: measures reliability with a scale of 0 to 255
  - Delay: the delay on the medium (default)
  - MTU: the size of the datagram
Static Routing

• Some networks are so small that using a routing protocol creates:
  – Unnecessary traffic
  – An inefficient use of router processor resources

• **Stub routers**
  – Routers with only one route out
  – Stub routers are usually the last router in a chain

• **Stub networks**
  – Networks with one route to the Internet

• **Static routes** are configured by a network administrator using the `ip route` command
Adding Static Routes

<table>
<thead>
<tr>
<th>Network</th>
<th>Subnet Mask</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>172.32.4.0</td>
<td>255.255.255.0</td>
<td>172.32.4.1</td>
</tr>
<tr>
<td>172.32.3.0</td>
<td>255.255.255.0</td>
<td>172.32.3.1</td>
</tr>
<tr>
<td>172.32.2.0</td>
<td>255.255.255.0</td>
<td>172.32.2.2</td>
</tr>
<tr>
<td>172.32.1.0</td>
<td>255.255.255.0</td>
<td>172.32.2.1</td>
</tr>
</tbody>
</table>

**Figure 7-18**  Routing table for RouterC
Adding Static Routes (continued)

- **Syntax for the `ip route` command:**
  
  `ip route [destination network address] [destination network mask] [ip address next hop interface] [administrative distance]`

- **Examples:**
  
  `ip route 172.32.3.0 255.255.255.0 172.32.2.2`
  
  `ip route 172.32.4.0 255.255.255.0 172.32.2.2`
Adding Static Routes (continued)

- Changing administrative distance
  - The `ip route` command allows you to configure an administrative distance
  - Unless you add an administrative distance value to the end of your `ip route` command
  - The administrative distance will be 1

- Configuring a default route
  - All packets that are not defined specifically in your routing table will go to the specified interface for the default route
Adding Static Routes (continued)

• Configuring a default route (continued)
  – A **default route** is a type of static route that the administrator configures
  – You can use the `ip default-network` command or the `ip route 0.0.0.0 0.0.0.0` command to configure a default route
  – Default routes are sometimes called **quad zero routes**
  – A default route is used only if no other route to a network exists in the routing table
Adding Static Routes (continued)

**Figure 7-19** Default route example