Routing Terminology

Forwarding
– Refers to datagram transfer
– Uses routing table
– Performed by host or router

Routing
– Refers to propagation of routing information
– Inserts / changes values in routing table
– Performed by routers

Routing and Forwarding

Routing Algorithm Classification

Global or decentralized info

Global:
• All routers have complete topology, link cost info
• “Link state” algorithms

Decentralized:
• Router knows physically-connected neighbors, link costs to neighbors
• Compute and exchange info with neighbors
• “Distance vector” algorithms

Static or dynamic

Static:
• Routes change slowly over time

Dynamic:
• Routes may change quickly
• Periodic updates in response to link cost changes

Two Forms of Internet Routing

Static routing
– Forwarding table initialized when system boots
– No further changes

Dynamic routing
– Forwarding table is initialized when system boots
– Routing software learns routes and updates table
– Continuous changes are possible

Static Routing

Used by most Internet hosts
Typical routing table has entries for:
Local network → direct delivery
Default → nearest router
Dynamic Routing

- Used by IP routers
- Requires special software
- Each router communicates with its neighbors by passing routing information
- Uses a route propagation protocol

Routing in the Internet

A route propagation protocol allows one router to exchange routing information with another
- But this cannot scale to the entire Internet
  - Billions of destinations, can’t store it all in routing tables!
  - Routing info exchange would swamp links!

Autonomous Systems

An autonomous system is a region of the Internet (networks and routers) that is administered by a single authority
Examples:
  - UUNet (Verizon) backbone network
  - Regional Internet Service Providers
  - Big universities
Each AS chooses a routing protocol

Routing in the Internet

Routers and networks in the Internet are divided into regions
- Autonomous systems (AS)
  - Routers in same AS run same routing protocol
    - "Intra-AS" routing protocol
Gateway router
  - At "edge" of its own AS
  - Has link to router in another AS
  - Summarizes AS routing info and passes it to other AS

Intra-AS Routing

Interior Gateway Protocols (IGPs)
- Used by routers within an autonomous system
- Destinations lie within same AS
Example protocols
- RIP (old but simple)
- OSPF (better)
Inter-AS Routing

Exterior Gateway Protocols (EGPs)
- Used between autonomous systems
- Destinations lie throughout Internet

Example protocols
- EGP
- BGP (more recent)

Why Different Intra- and Inter-AS Routing?

Policy:
- Inter-AS: admin wants control over how its traffic routed, who routes through its net.
- Intra-AS: single admin, so no policy decisions needed

Scale:
- Hierarchical routing saves table size, reduced update traffic

Performance:
- Intra-AS: can focus on performance
- Inter-AS: policy may dominate over performance

Distance Vector Routing

All nodes start by building a local view of what nodes are 1 hop away.
Every node sends its vector to its directly connected neighbors.

F tells A that it can reach G at cost 1. A knows it can reach F at cost 1, so it updated its own vector to indicate that it can reach G at cost 2. Higher cost routes to G will be ignored, finding a lower cost route will replace the route currently in the vector.

After a few iterations of these exchanges, the routing table converges to a consistent state.

Periodic updates: Every t seconds, send local info to your neighbors. This informs other nodes that you are running.

Triggered updates: Every time you learn new info from a neighbor that makes you to update your local vector, send the recomputed vector to all your neighbors.

IGP / EGP Use

RIP (Routing Information Protocol)

Included in BSD-UNIX distribution in 1982
- Distance vector algorithm
  - distance metric: # hops (max = 15 hops), each link has cost 1
  - DVs exchanged with neighbors every 30 sec via UDP

From router A to destination subnets:

<table>
<thead>
<tr>
<th>subnet</th>
<th>hops</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>1</td>
</tr>
<tr>
<td>v</td>
<td>2</td>
</tr>
<tr>
<td>w</td>
<td>2</td>
</tr>
<tr>
<td>x</td>
<td>3</td>
</tr>
<tr>
<td>y</td>
<td>3</td>
</tr>
<tr>
<td>z</td>
<td>2</td>
</tr>
</tbody>
</table>

RIP Example

Routing table in router D

<table>
<thead>
<tr>
<th>destination subnet</th>
<th>next router</th>
<th># 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>x</td>
<td>--</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
RIP Example

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<tbody>
<tr>
<td>w</td>
<td>x</td>
<td>1</td>
</tr>
<tr>
<td>z</td>
<td>y</td>
<td>2</td>
</tr>
<tr>
<td>z</td>
<td>B</td>
<td>5</td>
</tr>
<tr>
<td>x</td>
<td>--</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Routing table in router D

OSPF (Open Shortest Path First)

Open Shortest Path First Protocol (OSPF)
- Routing within an autonomous system (IGP)
- More powerful but more complex than RIP
- Can scale to handle a much larger number of routers than other IGPs
- Uses Link State Algorithm

OSPF (Open Shortest Path First)

OSPF Areas and Efficiency
- Allows subdivision of AS into areas
- Link-status information propagated within area
- Routes summarized before being propagated to another area
- Reduces overhead (less broadcast traffic)

Link State Routing
- Each node knows the distance to its neighbors
- The distance information (link state) is broadcast to all nodes in the network
- Each node calculates its routing table independently
  - Route calculations based on Dijkstra’s shortest-path first algorithm

OSPF AS Organized in a 2-level Hierarchy

Border Gateway Protocol (BGP-4)

Currently the EGP of choice for the Internet
- Provides routing between autonomous systems
- Gives path of autonomous systems for each destination
- Uses reliable transport (TCP)
- Distance vector algorithm

BGP Tracing: http://www.routeviews.org/
Graph Abstraction

Graph: $G = (N,E)$

$N =$ set of routers = { u, v, w, x, y, z }

$E =$ set of links = { (u, v), (u, x), (v, x), (v, w), (x, w), (x, y), (w, y), (w, z), (y, z) }

Graph abstraction is useful in other contexts, such as P2P, where $N$ is set of peers and $E$ is set of TCP connections.

Graph Abstraction: Costs

$c(x, x') =$ cost of link $(x, x')$

e.g., $c(w, z) = 5$

Cost could always be 1, or inversely related to bandwidth, or inversely related to congestion

Cost of path $(x_1, x_2, x_3, ..., x_p) = c(x_1, x_2) + c(x_2, x_3) + ... + c(x_{p-1}, x_p)$

Question: What’s the least-cost path between $u$ and $z$?

Routing algorithm: Finds the least-cost path.