Announcements

• HW1 is graded
  – Pick up after class
  – Mean = 81
Recap

• Spanning tree algorithms
  – Finds routing information for bridges
  – Doesn’t scale to Internet size networks

• Internet Protocol (IPv4)
  – Packet format
  – Packet fragmentation
Today

- IP Addressing
- Subnetting
- DNS (Domain Name System)
IP addresses

- Hierarchical, not flat as in Ethernet

- Written as four decimal numbers separated by dots: 158.130.14.2
## Network Classes

<table>
<thead>
<tr>
<th>Class</th>
<th># of nets</th>
<th># of hosts per net</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>126</td>
<td>~16 million</td>
</tr>
<tr>
<td>B</td>
<td>8192</td>
<td>65534</td>
</tr>
<tr>
<td>C</td>
<td>~2 million</td>
<td>254</td>
</tr>
</tbody>
</table>
IP Datagram Delivery

• Every IP packet (datagram) contains the destination IP address
• The network part of the address uniquely identifies a single network that is part of the larger Internet.
• All hosts and routers that share the same network part of their address are connected to the same physical network.
• Routers can exchange packets on any network they’re attached to.
IP Forwarding algorithm

- If (Network # dest == Network # interface) then deliver to destination over interface
- else if (Network # dest in forwarding table) deliver packet to NextHop router
- else deliver packet to default router

- Forwarding tables
  - Contain (Network #, NextHop) pairs
  - Additional information
  - Built by routing protocol
Question:

• How does the hierarchical address scheme improve scalability?
ARP - Address Resolution Protocol

- **Problem:**
  - Need mapping between IP and link layer addresses.

- **Solution: ARP**
  - Every host maintains IP–Link layer mapping table (cache)
  - Timeout associated with cached info (15 min.)

- **Sender**
  - Broadcasts “Who is IP addr X?”
  - Broadcast message includes sender’s IP & Link Layer address

- **Receivers**
  - Any host with sender in cache “refreshes” time-out
  - Host with IP address X replies “IP X is Link Layer Y”
  - Target host adds sender (if not already in cache)
ICMP: Internet Control Message Protocol

• Collection of error & control messages
• Sent back to the source when Router or Host cannot process packet correctly
• Error Examples:
  – Destination host unreachable
  – Reassembly process failed
  – TTL reached 0
  – IP Header Checksum failed
• Control Example:
  – Redirect – tells source about a better route
Scaling Problems

• Not enough network numbers.
  – Class C network with 2 nodes wastes 253 IP addresses
  – Class B network with ~300 nodes wastes 64,000 IP addresses
  – Only $2^{14} \sim 16,500$ class B networks

• Routing information too cumbersome.
  – More networks means larger routing tables
Subnetting

- Idea: One IP network number allocated to several physical networks.
  - The multiple physical networks are called *subnets*
  - Should be close together (why?)
  - Useful when a large company (or university!) has many physical networks.
Subnet Numbers

• Solution: Subnetting
  – All nodes are configured with subnet mask
  – Allows definition of a subnet number
    • All hosts on a physical subnetwork share the same subnet number

Subnet Mask (255.255.255.0)

| 11111111111111111111111111111111 | 00000000 |

Subnetted Address:
Example of Subnetting

Subnet mask: 255.255.255.128
Subnet #: 128.96.34.0

128.96.34.1

128.96.34.130

Subnet mask: 255.255.255.128
Subnet #: 128.96.34.128

128.96.34.129

Subnet mask: 255.255.255.0
Subnet #: 128.96.33.0

128.96.33.1

128.96.33.14
Subnets, continued

- Mask is bitwise-ANDed with address
- This is done at routers
- Router tables in this model:
  - <Subnet #, Subnet Mask, NextHop>
- Subnetting allows a set of physical networks to look like a single logical network from elsewhere
Forwarding Algorithm

D = destination IP address
for each forwarding table entry
(SubnetNumber, SubnetMask, NextHop)
  D1 = SubnetMask & D
  if D1 = SubnetNumber
    if NextHop is an interface
      deliver datagram directly to destination
    else
      deliver datagram to NextHop (router)
Domain Name System

- System for mapping mnemonic names for computers into IP addresses.
  
  \[ \text{zeta.cis.upenn.edu} \rightarrow 158.130.12.244 \]

- Domain Hierarchy
- Name Servers
- Name Resolution
Domain Name Hierarchy

edu  com  gov  mil  org  net

cornell … upenn  cisco…yahoo  nasa … nsf  arpa … navy  …
cis  seas  wharton …
Hierarchy of Name Servers

- Root Name Server
- Cornell Name Server
- Upenn Name Server
  - CIS Name Server
  - SEAS Name Server
  - Wharton Name Server
Records on Name Servers

- <Name, Value, Type, Class>
- Types
  - A Host to address mappings
  - NS Name server address mappings
  - CNAME Aliases
  - MX Mail server mappings
- Class IN for IP addresses
Name resolution

Client

198.168.0.100

Local Name server

198.168.0.1

198.168.0.100

Root Name server

zeta.cis.upenn.edu

128.196.128.233

zeta.cis.upenn.edu

Upenn Name server

zeta.cis.upenn.edu

198.168.0.1

zeta.cis.upenn.edu

CIS Name server

198.168.0.100