Announcements

- Fourth quiz on Monday, March 1st.
- Third HTML discussion session today by Kiran (before class).
- Summary posted on the Web page.
- FINAL HTML discussion session by Debasree on Thu 3-4pm in BE 109.
- Quiz review session on Friday by Kiran in BE 354I from 4:45-5:45.
  - Practice quiz.
- In order to schedule a second review session, we will wait to hear from you first.

 Networks and IP addressing

- IP address:
  - **Network** part + **Host** part
- Network:
  - Any host can physically be reached by any other host **without intervening router**
  - All hosts in the same network have the same network number

Routing Table (revisited)

<table>
<thead>
<tr>
<th>Dest. Net</th>
<th>next router</th>
<th>Nhops</th>
</tr>
</thead>
<tbody>
<tr>
<td>223.1.1</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>223.1.2</td>
<td>223.1.1.4</td>
<td>1</td>
</tr>
<tr>
<td>223.1.3</td>
<td>223.1.1.4</td>
<td>1</td>
</tr>
</tbody>
</table>

network consisting of 3 IP networks (for IP addresses starting with 223 (class C), first 24 bits are network address).
**Routing Example 1**

Datagram from A to B:
- look up net. address of B
- find B is on same net. as A
- link layer will send datagram directly to B inside link-layer frame
  - B and A are directly connected

**Routing Example 2**

Datagram from A to E:
- look up network address of E
- E on different network
  - A, E not directly attached
  - routing table: next hop router to E is 223.1.1.4
  - link layer sends datagram to router 223.1.1.4 inside link-layer frame
  - datagram arrives at 223.1.1.4
  - continued.....

**Routing Example 2 (cont’d)**

Arriving at 223.1.4, destined for 223.1.2.2
- look up network address of E
  - E on same network as router’s interface 223.1.2.9
  - router, E directly attached
  - link layer sends datagram to 223.1.2.2 inside link-layer frame
    via interface 223.1.2.9
  - datagram arrives at 223.1.2.2!!! (hooray!)

**Internetwork Routing**

- Internetworks are collections on networks.
- The Internet interconnects autonomous systems (ASs).
- Hierarchical structure.
Internetwork Routing

- 2-level hierarchy:
  - Routing within each network: interior gateway protocol.
  - Routing between networks: exterior gateway protocol.
- Within each network, different routing algorithms can be used.
- Each network is autonomously managed and independent of others: autonomous system (AS).

Internetwork Routing (cont’d)

- Typically, packet starts in its LAN. Gateway receives it (broadcast on LAN to “unknown” destination).
- Gateway sends packet to gateway on the destination network using its routing table.

The Internetworking Layer

- The Internet as a collection on networks or autonomous systems (ASs).
- Hierarchical structure.

The Internet Protocol: IP

- Glues Internet together.
- Common network-layer protocol spoken by all Internet participating networks.
- Best effort datagram service:
  - No reliability guarantees.
  - No ordering guarantees.
**IP (cont’d)**

- **IP** is responsible for datagram routing.
- **Important**: each datagram is routed independently!
  - Two different datagrams from the same source to the same destination can take different routes!
  - Why?
  - Implications?

**IP (cont’d)**

- **IP** provides a **best effort** delivery mechanism
  - Does not guarantee to prevent duplicate datagrams, delayed and out-of-order delivery, corruption of data or datagram loss
- **Reliable delivery** is provided by the **transport layer**, not the **network layer (IP)**
- Network layer (IP) can **detect** and **report** errors without actually **fixing** them

**Datagrams**

- Transport layer breaks data streams into datagrams which are transmitted over Internet, possibly being fragmented.
- When all datagram fragments arrive at destination, reassembled by network layer and delivered to transport layer at destination host.

**IP Datagram Format**

- **IP** datagram consists of header and data (or payload).
- **Header**:
  - 20-byte fixed (mandatory) part.
  - Variable length optional part.
**IP Versions**

  - Current, predominant version.
  - 32-bit long addresses.
  - Longer addresses (16-byte long).

**Encapsulation Revisited**

- Each datagram is **encapsulated** within a data link layer frame
  - The whole datagram is placed in the **data area** of the frame.
  - The data link layer addresses for source and destination included in the frame header.
Encapsulation Across Multiple Hops

- Each router in the path from source to destination:
  - **Decapsulates** datagram from incoming frame.
  - **Forwards** datagram - determines next hop.
  - **Encapsulates** datagram in outgoing frame.

Maximum Transfer Unit

- Each data link layer technology specifies the maximum size of a frame.
  - Called the Maximum Transfer Unit (MTU).
    - Ethernet: 1,500 bytes.
    - Token Ring: 2048 or 4096 bytes.
- What happens when large packet wants to travel through network with smaller MTU?
  - Maximum payloads (data portion of datagram) range from 48 bytes (ATM cells) to 64Kbytes (IP packets).

MTU (cont’d)

- A possible solution:
  - The sender may limit the size of the datagrams to the MTU of the network
  - What if there are other networks in the path to destination with smaller MTU?
Fragmentation

- Another solution (used by IP): fragmentation.
- Gateways break packets into fragments to fit the network’s MTU; each sent as separate datagram.
- Gateway on the other side have to reassemble fragments into original datagram.

Keeping Track of Fragments

- Fragments must be numbered so that original data stream can be reconstructed.
- Define elementary fragment size that can pass through every network.
- When packet fragmented, all pieces equal to elementary fragment size, except last one (may be smaller).
- Datagram may contain several fragments.

Fragmentation - Example