Announcements

- Quiz 3 grades are out.
- Quiz 3 stats:
  - Total points: 60
  - Maximum score: 60
  - Minimum: 34
  - Average: 52.85 (88%).
- HTML discussions:
  - Kiran had one today.
  - Debasree will have one tomorrow

Internetworking

- Interconnection of 2 or more networks forming an internetwork, or internet.
  - LANs, MANs, and WANs.
- Different networks mean different protocols.
  - TCP/IP, IBM’s SNA, DEC’s DECnet, ATM, Novell and AppleTalk.
**Example Internetwork**

- **802.3 LAN**
- **802.5 LAN**
- **LAN-WAN-LAN**
- **X.25 WAN**
- **LAN-WAN**
- **LAN-LAN**
- **SNA WAN**

Gateway: device connecting 2 or more different networks.

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**Repeater (cont’d)**

- **Maximum-size Ethernet segment**

Figure 11.2 A repeater is connecting two Ethernets. The repeater connects directly to the cable.

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**Gateways**

- **Repeaters/hubs**: operate at physical layer (bits); amplify/regenerate signal.
- **Bridges**: operate at the data link layer.
- **Routers**: operate at network layer.
- **Gateways**: interconnect (different) networks.

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**Bridges**

- A **bridge** is a hardware device used to extend a LAN.
- A bridge forwards complete, correct frames (packets) from one segment to another.
- Pairs of computers on the extended LAN can communicate with each other
  - They do not know whether a bridge separates them.
Gateways

- A **gateway** is a hardware component that interconnects networks.
- A gateway has interfaces on multiple networks.

![Gateway Diagram]

Gateways (cont’d)

- Networks can use different technologies.
- Gateway forwards packets between networks
  - Uses packet address to decide which network to send it to.
- Transforms packets as necessary to meet protocols for each network.
- An internetwork is composed of arbitrarily many networks interconnected by gateways.

![Internetwork Diagram]

Gateways (cont’d)

- Note that gateways can have more than two interfaces!

![Gateway Diagram]

How do networks differ?

- Service offered: datagram versus virtual circuit.
- Protocols: Ethernet, token ring, etc.
- Addressing: flat (802) versus hierarchical (IP).
- Maximum transmission unit.
- Etc…
**Internetworking**

- Internetworking software builds a single, seamless **virtual network** out of multiple physical networks
  - Universal addressing scheme.
  - Universal networking.
- All details of physical networks are hidden from users and application programs.

**TCP/IP**

- **TCP/IP** is the most widely used internetworking protocol suite
  - Initially funded through ARPA.
  - Picked up by NSF.
  - Used in the Internet.
- Other internetworking protocols exist but are less used
  - Example: AppleTalk, X.25, etc.

**Host and Routers**

- A **host computer** (or just host) is any system attached to an (inter)network that runs applications
  - May be a supercomputer or a toaster!
- TCP/IP allows any pair of hosts on an internetwork to communicate directly
- Differently from routers, hosts typically have only one interface and don’t forward packets
**Universal Addressing**

- One key aspect of internetworks is **unique addresses**.
- Sending host puts destination internetworking address in the packet.
- Destination addresses can be interpreted by any intermediate router/gateway.
- Router/gateway examines address and forwards packet on to the destination.

**IP Addresses**

- Each machine on the Internet has a unique **IP address**.
- The IP address is different from the “physical” /“MAC” address.
  - The “physical address” is the address of a computer (actually, of a NIC) in the LAN.
    - It is only known within the LAN.
  - The IP address is a universal address.
  - When a packet arrives in a LAN, there needs to be a conversion from IP to MAC address (local “address resolution”).

**IP Addresses (cont’d)**

- An IP address is represented by a binary number with 32 bits.
  - Meaning that there are around 4 billion addresses.
  - Often IP addresses are represented in “dotted decimal”, such as 128.114.144.4.
    - Each group of numbers can go from 0 to 255.

**IP Address Organization**

- Each IP address is divided into a **prefix** and a **suffix**
  - **Prefix** identifies **network** to which computers are attached.
  - **Suffix** identifies computers within that network.
**Network and Host Numbers**

- Every network in a TCP/IP internet is assigned a unique **network number**.
- Each host on a specific network is assigned a **host address** that is unique within that network.
- Host’s IP address is the combination of the network number (prefix) and host address (suffix).
- Assignment of network numbers must be coordinated globally; assignment of host addresses can be managed locally.

**IP Address Format**

- IP address are 32 bits long.
- There are different **classes of addresses**, corresponding to different subdivisions of the 32 bits into prefix and suffix.
  - Some address classes have **large prefix, small suffix**.
    - Many such networks, few hosts per network.
  - Other address classes have **small prefix, large suffix**.
    - Few such networks, many hosts per network.

**IP Address Format (cont’d)**

- How can we recognize to which class an IP address belongs to?
  - Look at the first 4 bits!

<table>
<thead>
<tr>
<th>bits</th>
<th>0 1 2 3 4</th>
<th>8 16 24 31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>[0] prefix</td>
<td>suffix</td>
</tr>
<tr>
<td>Class B</td>
<td>[10] prefix</td>
<td>suffix</td>
</tr>
<tr>
<td>Class C</td>
<td>[110] prefix</td>
<td>suffix</td>
</tr>
<tr>
<td>Class D</td>
<td>[1110] multicast address</td>
<td></td>
</tr>
<tr>
<td>Class E</td>
<td>[1111] reserved for future use</td>
<td></td>
</tr>
</tbody>
</table>

**IP Address Format (cont’d)**

- Class A, B and C are **primary classes**.
  - Used for ordinary addressing.
- Class D is used for **multicast**, which is a limited form of **broadcast**.
  - Internet hosts join a **multicast group**.
  - Packets are delivered to all members of the group.
  - Routers manage delivery of single packets from source to all members of multicast group.
- Class E is reserved.
IP Addresses (cont’d)

- Another way to determine the address class is by looking at the first group of numbers in the dotted decimal notation.

<table>
<thead>
<tr>
<th>Class</th>
<th>Range of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 through 127</td>
</tr>
<tr>
<td>B</td>
<td>128 through 191</td>
</tr>
<tr>
<td>C</td>
<td>192 through 223</td>
</tr>
<tr>
<td>D</td>
<td>224 through 239</td>
</tr>
<tr>
<td>E</td>
<td>240 through 255</td>
</tr>
</tbody>
</table>

Networks and Hosts in Each Class

<table>
<thead>
<tr>
<th>Class</th>
<th>Bits In Prefix</th>
<th>Maximum Number of Networks</th>
<th>Bits In Suffix</th>
<th>Maximum Number Of Hosts Per Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>7</td>
<td>128</td>
<td>24</td>
<td>16777216</td>
</tr>
<tr>
<td>B</td>
<td>14</td>
<td>16384</td>
<td>16</td>
<td>65536</td>
</tr>
<tr>
<td>C</td>
<td>21</td>
<td>2097152</td>
<td>8</td>
<td>256</td>
</tr>
</tbody>
</table>

Understanding IP Addresses

- Remember: the first 3 digits determine the class of the address.
- Depending on the class of an address, we can find out its prefix and its suffix.
  - If Class A: ppp.sss.sss.sss (with 0 ≤ ppp ≤ 127)
  - If Class B: ppp.ppp.sss.sss (with 128 ≤ ppp ≤ 191)
  - If Class C: ppp.ppp.ppp.sss (with 192 ≤ ppp ≤ 223)
- Examples:
  - 10.0.0.37 (class A)
  - 128.10.0.1 (class B)
  - 192.5.48.3 (class C)

Example: A Private Internet
**IP addresses: how to get one?**

- The **network IP numbers** are assigned by the **Network Information Center**
- How does **host** get its IP address in the network? Two possibilities:
  - 1: Hard-coded by system administrator in a file inside the host
  - 2: **DHCP**: “Dynamic Host Configuration Protocol”
    - Dynamically get address: “plug-and-play”

**DHCP**

- DHCP allows a computer to join a new network and automatically obtain an IP address. The network administrator establishes a pool of addresses for DHCP to assign.
- When a computer boots, it broadcasts a **DHCP request** to which a server sends a **DHCP reply**
- DHCP allows non-mobile computers that run **server software** to be assigned a **permanent address** (won't change when the computer reboots)
  - The permanent address actually needs to be re-negotiated after a certain period of time