The Network Layer

TCP/IP

- Application
- Transport
- Network
- Data Link
- Physical

Main Functions

- Routing.
  - Find path (route) between source and destination.
- Forwarding.
  - When data is received, forward it toward the destination based on routing information.
- Who performs these functions?
  - Routers/switches.
How routers operate?

- Store and forward.
  - Switch stores data they receive in memory; next switch examines data, determines which interface to send it, and forwards data on.

- Next-hop forwarding.
  - If data not destined to directly connected host, switch forwards it to the cheapest next hop toward destination.
  - Next hop does not depend on source, not on the path traveled so far.

Routing Table

- Switches need to know where to forward data they receive.
  - Essentially, destination address -> next hop.

- Table containing destination and associated next-hop information.

Air travel analogy:

- At each airport there is a table showing the cheapest next hop to every destination.
- The source does not matter!
- Example: at Denver airport,
  - NY go to Chicago
  - DC go to Chicago
  - Miami go to Houston
  - Houston go to Houston
  - Los Angeles go to Los Angeles
  - San Diego go to Los Angeles
### More Routing Table

- Each router stores information about forwarding in a **routing table**.
  - Initialized at system initialization.
  - Must be updated as network topology changes.
- Routing table contains a list of destination and next hop for each destination.
- Routing table is built by routing protocol.

### Routing and Hierarchical Addresses

- Hierarchical addresses allow routing tables to be smaller and more concise.

At switch 2:

<table>
<thead>
<tr>
<th>Destination</th>
<th>Next hop</th>
<th>Destination</th>
<th>Next Hop</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,1</td>
<td>Interface 1</td>
<td>1, any</td>
<td>Interface 1</td>
</tr>
<tr>
<td>1,3</td>
<td>Interface 1</td>
<td>1, any</td>
<td>Interface 1</td>
</tr>
<tr>
<td>3,6</td>
<td>Interface 4</td>
<td>3, any</td>
<td>Interface 4</td>
</tr>
<tr>
<td>3,8</td>
<td>Interface 4</td>
<td>3, any</td>
<td>Interface 4</td>
</tr>
<tr>
<td>2,5</td>
<td>Interface 5</td>
<td>2, any</td>
<td>Local</td>
</tr>
<tr>
<td>2,6</td>
<td>Interface 6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Network Layer: Implementation and Services

- Circuit switching versus packet switching.

Circuit Switching

- Old telephone technology
- For each connection, physical switches are set in the telephone network to create a **physical “circuit”**
  - That’s the job of the switching office

Circuit Switching - Example

- Switches are set up at the beginning of the connection and maintained throughout the connection
- Network resources **reserved** and **dedicated** from sender to receiver
- Not a very efficient strategy
  - A connection “holds” a physical line even during “silence” periods (when there is nothing to transmit)
Packet Switching

- Sharing by taking turns.
  - Analogy: conveyor belt in a warehouse.
  - Items are picked from the storage room and placed on the conveyor belt every time a customer makes an order.
  - Different customers may request a different number of items.
  - Different users' items may be interspersed on the conveyor belt (they are "multiplexed").

- Networks use a similar idea
  - **Packet Switching**
    - Packetize data to transfer.
    - Multiplex it onto the wire.
    - Packets from different connections share the same link.

Packet Switching Example

Packet Switching (cont’d)

- Each packet is composed by the **payload** (the data we want to transmit) and a **header**.
  - The header contains information useful for network layer functions.
  - Contains:
    - Source (sender’s) address
    - Destination (recipient’s) address
    - Packet size
    - Sequence number
    - Error checking information

- The header introduces **overhead**, that is, additional bits to be sent.
  - Therefore, it is not wise to have packets that are too small.
    - What happens if the payload is just 1 bit?

- **Addresses**
  - Each computer attached to a network is assigned a unique **number** (called **address**).
  - A packet contains the address of the sender and the receiver.
Packet Switching (cont’d)

• In general, packets need not be of the same size
  – Maximum transmission unit (MTU)
  – No minimum size
    • But, header size is fixed (e.g., 20 bytes for TCP/IP).
• Original data chopped up into packets.
  – The application (e.g., email) does not know that the data to be transmitted is packetized.
  – When packets are received, they are put together before the application accesses the data.

Packet Switching (cont’d)

• What kind of delay should we expect?
  – Time-division multiplexing: constant delay.
  – Packet switching multiplexing: variable delay (it depends on the traffic on the line).
    • Conveyor belt example: if there are many customers before you, you may have to wait more.

Circuit Switching vs Packet Switching

Circuit switching
• Must set up a connection (initial delay)
• Connection is reliable
• Resources are dedicated
  – Therefore they are used inefficiently!

Packet switching
• Very small set-up delay
• Efficient shared use of resources
• Possible congestion and consequent packet dropping