Review of Networking Concepts

Part 1: Switching Networks

• The first few lectures of this course cover basic, but important, concepts of computer networking
Summary of Topics

- Taxonomy of switching networks
- Principles of circuit and packet switching
- Multiplexing techniques: FDM, TDM, statistical multiplexing
- Datagram and VC packet networks
- Packet forwarding in datagram and VC packet networks

Communication Networks

- **Problem**: Connect end systems that want to exchange information
  (Device = telephone, computer, terminals, etc.)

- **Simple Solution**: Connect each pair of end system by a dedicated point-to-point link
  - The simple solution is sufficient if the number of end systems is small
• With a large number of end systems it is not practical to connect each pair

A communication network provides a scalable solution to connect a large number of end systems

• Principles:
  – There are two types of devices: end systems and nodes
  – Each node is connected to at least one node
  – Network nodes carry the information from a source to a destination end system
  – Note: Network nodes do not generate information
Communication Networks

• A generic communication network:

Other names for “end system”: station, **host**, terminal
Other names for “node”: switch, **router**, gateway

Example Networks

• [Evolution of the UUNet Network 1996-2000](#)

• [UVA Backbone Network](#)
Taxonomy of Networks

- Communication networks can be classified based on the way in which the nodes exchange information:

  Communication Network
  - Circuit-Switched Network
    - Frequency Division Multiplexing
  - Packet-Switched Network
    - Time Division Multiplexing
    - Wavelength Division Multiplexing
  - Datagram Network
  - Virtual Circuit Network

Circuit Switching

- In a circuit-switched network, a dedicated communication path ("circuit") is established between two stations through the nodes of the network.

- The dedicated path is called a circuit-switched connection or circuit.

- A circuit occupies a fixed capacity of each link for the entire lifetime of the connection. Capacity unused by the circuit cannot be used by other circuits.

- Data is not delayed at the switches.
Circuit-switched communication involves three phases:

1. Circuit Establishment
2. Data Transfer
3. Circuit Termination

“Busy Signal” if capacity for a circuit not available

Most important circuit-switching networks:

- Telephone networks
- ISDN (Integrated Services Digital Networks)
Implementation of Circuit-Switching

- There are two ways to implement circuits
  - Frequency Division Multiplexing (FDM)
  - Time Division Multiplexing (TDM)
  - Wavelength Division Multiplexing (WDM)

- Example: Voice in (analog) telephone network:
  - Needed bandwidth: 3000 Hz
  - Allocated bandwidth: 4000 Hz
  Therefore, a channel with 64 kHz can carry 16 voice conversations

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Frequency Division Multiplexing (FDM)

- **Approach:** Divide the frequency spectrum into logical channels and assign each information flow one logical channel
Frequency Division Multiplexing (FDM)

- A circuit switch bundles (multiplexes) multiple voice calls on a high-bandwidth link
- **Frequency-Division-Multiplexing (FDM):** Each circuit receives a fixed bandwidth. The frequency of each call is shifted, so that multiple calls do not interfere

Time Division Multiplexing (TDM)

- **Approach:** Multiple signals can be carried on a single transmission medium by interleaving portions of each signal in time
Time Division Multiplexing (TDM)

- Time is divided into frames of fixed length
- Each frame has a fixed number of constant-sized “slots”
- Each circuit obtains one or more “slots” per frame

Circuit Switch

- A circuit switch relays a circuit from an input to an output link
- A switch reassigns frequencies (FDM) or time slot allocation (TDM)
- No queueing or other delays are experienced
Packet Switching

- Data are sent as formatted bit-sequences, so-called packets
- Packets have the following structure:
  - Header and Trailer carry control information

- Each packet is passed through the network from node to node along some path (Forwarding/Routing)
- At each node the entire packet is received, stored briefly, and then forwarded to the next node (Store-and-Forward Networks)
- Packet transmission is never interrupted (no preemption)
- No capacity is allocated for packets

A Packet Switch

![A Packet Switch Diagram]
Statistical Multiplexing

- Packet transmission on a link is referred to as **statistical multiplexing**
  - There is no fixed allocation of packet transmissions
  - Packets are multiplexed as they arrive

Datagram Packet Switching

- The network nodes process each packet independently
  - If Host A sends two packets back-to-back to Host B over a datagram packet network, the network cannot tell that the packets belong together. In fact, the two packets can take different routes
- Packets are called **datagrams**
- Implications of datagram packet switching:
  - A sequence of packets can be received in a different order than it was sent
  - Each packet header must contain the full address of the destination
Virtual-Circuit Packet Switching

- Virtual-circuit packet switching is a hybrid of circuit switching and packet switching

- All data is transmitted as packets
- All packets from one packet stream are sent along a pre-established path (=virtual circuit)

- Guarantees in-sequence delivery of packets
- **However**: Packets from different virtual circuits may be interleaved

Virtual-Circuit Packet Switching

- Communication with virtual circuits (VC) takes place in three phases:
  1. VC Establishment
  2. Data Transfer
  3. VC Disconnect

- Note: Packet headers don’t need to contain the full destination address of the packet
Packet Forwarding and Routing

- There are two parts to the routing problem:
  1. How to pass a packet from an input interface to the output interface of a router (packet forwarding)?
  2. How to calculate routes (routing algorithm)?

- Packet forwarding is done differently in datagram and virtual-circuit packet networks

- Route calculation is similar in datagram and virtual-circuit packet networks

Datagram Packet Switching

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Packet Forwarding of Datagrams

• Recall: In datagram networks, each packet must carry the full destination address
• Each router maintains a routing table which has one row for each possible destination address
• The lookup yields the address of the next hop (next-hop routing)

Routing Table of node v

<table>
<thead>
<tr>
<th>to</th>
<th>via (next hop)</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>n</td>
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</tbody>
</table>

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Packet Forwarding of Datagrams

- When a packet arrives at an incoming link, ...
  1. The router looks up the routing table
  2. The routing table lookup yields the address of the next node (next hop)
  3. The packet is transmitted onto the outgoing link that goes to the next hop

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Forwarding Datagrams

<table>
<thead>
<tr>
<th>To</th>
<th>Next hop</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>E</td>
<td>B</td>
</tr>
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<td>-</td>
</tr>
<tr>
<td>X</td>
<td>B</td>
</tr>
</tbody>
</table>

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Packet Forwarding with Virtual Circuits

- **Recall**: In VC networks, the route is setup in the connection establishment phase
- During the setup, each router assigns a VC number (VC#) to the virtual circuit
- The VC# can be different for each hop
- VC# is written into the packet headers

**Routing Table of node v**

<table>
<thead>
<tr>
<th>from</th>
<th>VC#</th>
<th>to</th>
<th>VC#</th>
</tr>
</thead>
<tbody>
<tr>
<td>w</td>
<td>2</td>
<td>v</td>
<td>3</td>
</tr>
</tbody>
</table>

![Routing Table of node v](image)

Packet Forwarding of Virtual Circuits

- When a packet with VC_{in} in header arrives from router n_{in}, ...
  1. The router looks up the routing table for an entry with (VC_{in}, n_{in})
  2. The routing table lookup yields (VC_{out}, n_{out})
  3. The router updates the VC# of the header to VC_{out} and transmits the packet to n_{out}

**Routing Table of node v**

<table>
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<td>v</td>
<td>3</td>
</tr>
</tbody>
</table>

![Routing Table of node v](image)
Forwarding with VCs

Part 1: VC setup from X to E

<table>
<thead>
<tr>
<th>n_in</th>
<th>V_in</th>
<th>n_out</th>
<th>V_out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n_in</th>
<th>V_in</th>
<th>n_out</th>
<th>V_out</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>5</td>
<td>E</td>
<td>3</td>
</tr>
</tbody>
</table>

Part 2: Forwarding the packet

<table>
<thead>
<tr>
<th>n_in</th>
<th>V_in</th>
<th>n_out</th>
<th>V_out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C</td>
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<tbody>
<tr>
<td>D</td>
<td>5</td>
<td>E</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>V_in</th>
<th>n_out</th>
<th>V_out</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>3</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
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### Comparison

#### Circuit Switching
- Dedicated transmission path
- Continuous transmission
- Path stays fixed for entire connection
- Call setup delay
- Negligible transmission delay
- No queueing delay
- Busy signal overloaded network
- Fixed bandwidth for each circuit
- No overhead after call setup

#### Datagram Packet Switching
- No dedicated transmission path
- Transmission of packets
- Route of each packet is independent
- No setup delay
- Transmission delay for each packet
- Queueing delays at switches
- Delays increase in overloaded networks
- Bandwidth is shared by all packets
- Overhead in each packet

#### VC Packet Switching
- No dedicated transmission path
- Transmission of packets
- Path stays fixed for entire connection
- Call setup delay
- Transmission delay for each packet
- Queueing delays at switches
- Delays increase in overloaded networks
- Bandwidth is shared by all packets
- Overhead in each packet