Review of Networking Concepts

Part 1: Switching Networks

- The first few lectures of this course cover basic, but important, concepts of computer networking

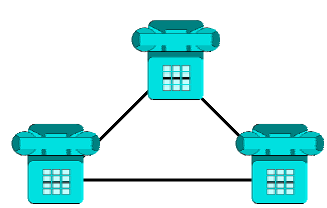
Summary of Topics

- 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

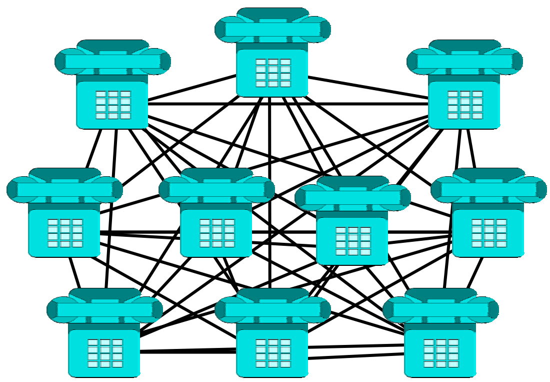
- **Problem**: Connect end systems that want to exchange information
  (Device = telephone, computer, terminals, etc.)

- **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



Communication Networks

- With a large number of end systems it is not practical to connect each pair



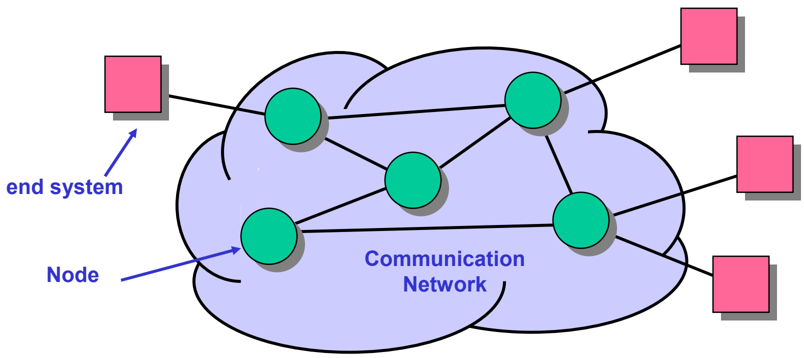
Communication Networks

- 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

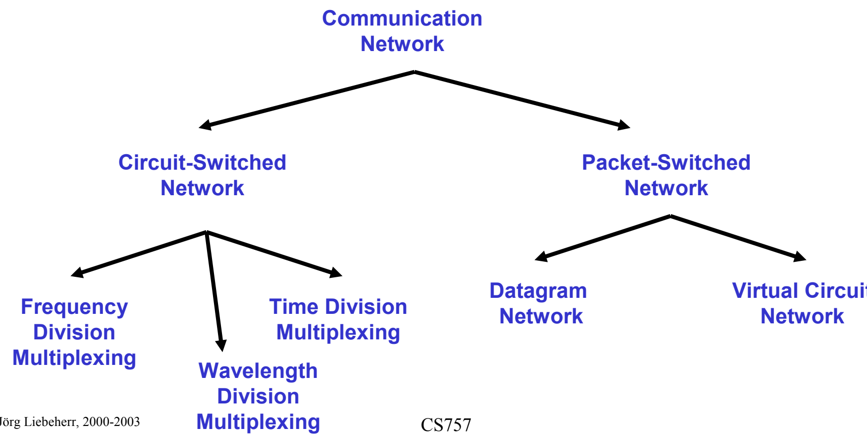
Example Networks

- Evolution of the UUNet Network 1996-2000
- UVA Backbone Network

Source: National Science Foundation

Taxonomy of Networks

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



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

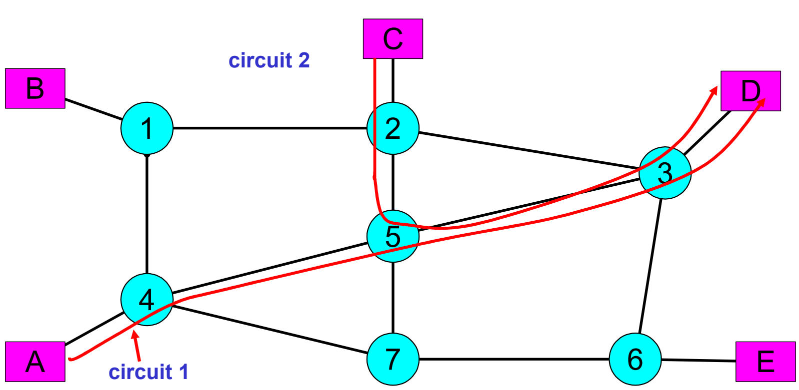
- Data is not delayed at the switches

Circuit Switching

- 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)

Circuit Switching



Implementation of Circuit-Switching

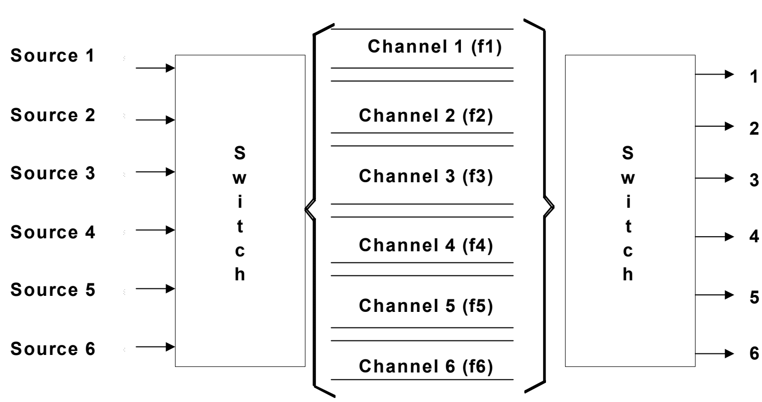
- There are two ways to implement circuits
  - Frequency Division Multiplexing (FDM)
  - Time Division Multiplexing (TDM)
  - Wavelength Division Multiplexing (WDM)

- Example: Voice in (analog) telephone network:
  - Needed bandwidth: 3000 Hz
  - Allocated bandwidth: 4000 Hz

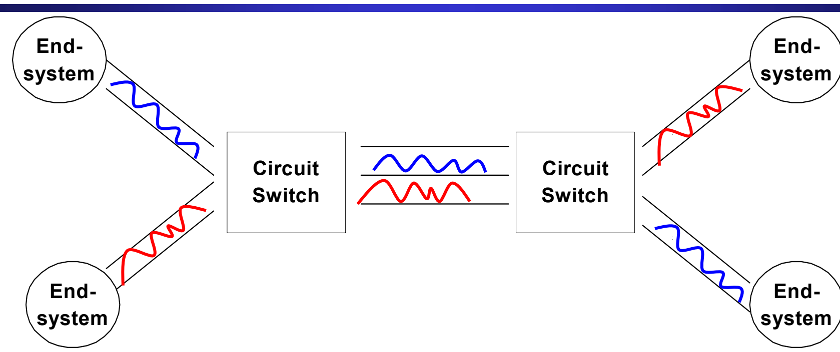
  Therefore, a channel with 64 kHz can carry 16 voice conversations

Frequency Division Multiplexing (FDM)

- **Approach:** Divide the frequency spectrum into logical channels and assign each information flow one logical channel



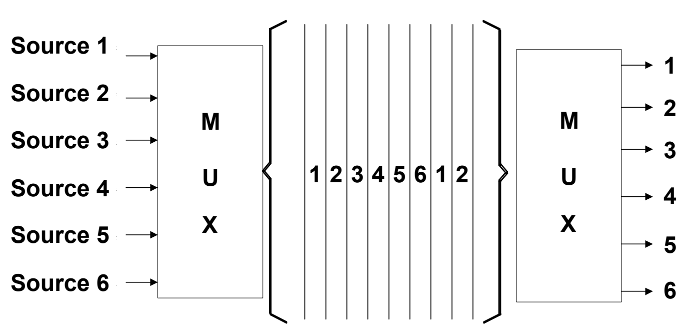
Frequency Division Multiplexing (FDM)



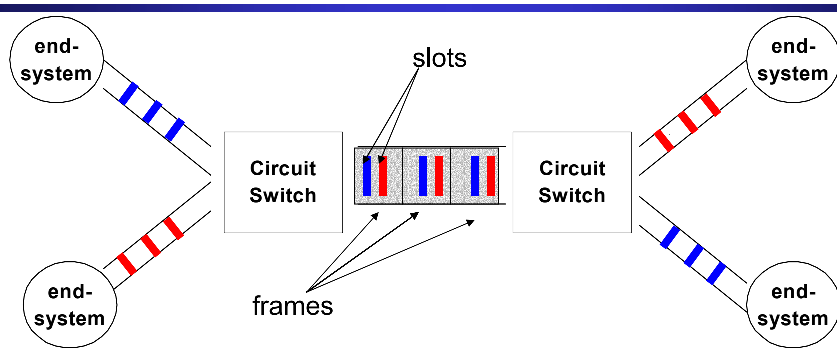
- A circuit switch bundles (multiplexes) multiple voice calls on a high-bandwidth link
- **Frequency-Division-Multiplexing (FDM):** Each circuit receives a fixed bandwidth. The frequency of each call is shifted, so that multiple calls do not interfere

Time Division Multiplexing (TDM)

- **Approach:** Multiple signals can be carried on a single transmission medium by interleaving portions of each signal in time

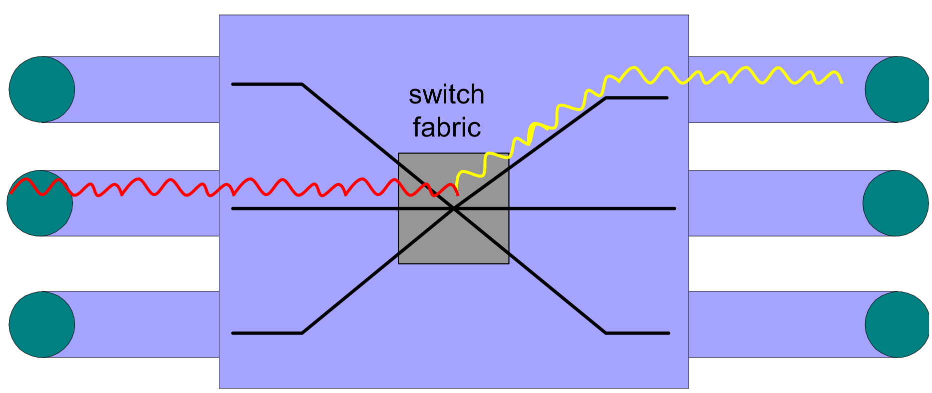


Time Division Multiplexing (TDM)



- 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

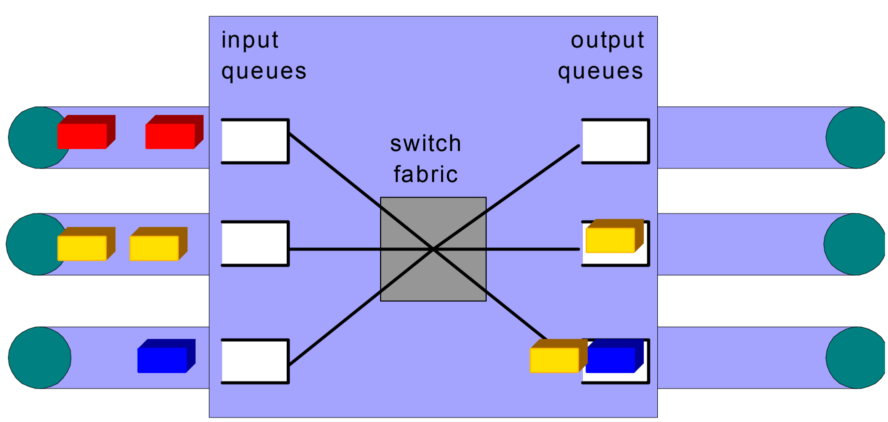
Packet Switching

- Data are sent as formatted bit-sequences, so-called packets
- Packets have the following structure:

  - Header and Trailer carry control information

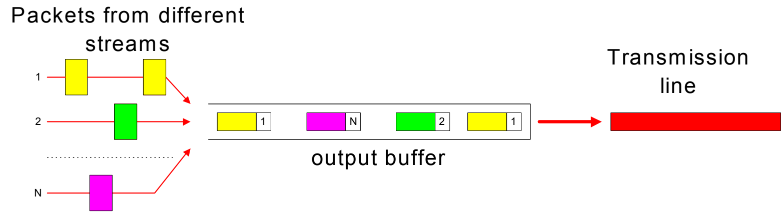
- Each packet is passed through the network from node to node along some path (**Forwarding/Routing**)
- At each node the entire packet is received, stored briefly, and then forwarded to the next node (**Store-and-Forward Networks**)
- Packet transmission is never interrupted (no preemption)
- No capacity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

A Packet Switch



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

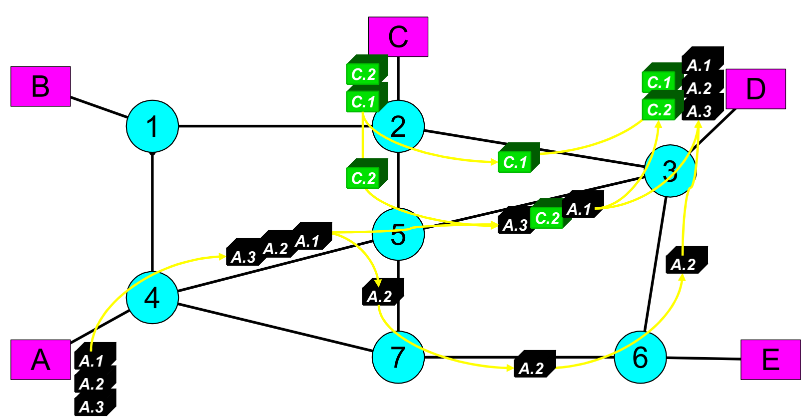
Packet Forwarding and Routing

- 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**)?

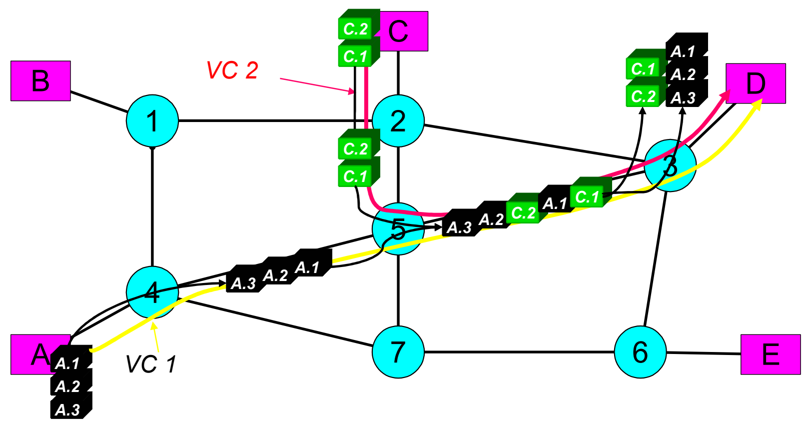
- Packet forwarding is done differently in datagram and virtual-circuit packet networks

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

Datagram Packet Switching



Virtual-Circuit Packet Switching

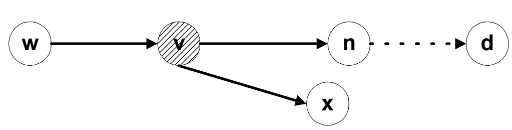


Packet Forwarding of Datagrams

- 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

to	via (next hop)
d	n

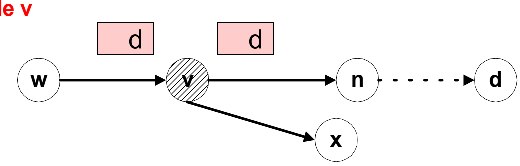


Packet Forwarding of Datagrams

- 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

Routing Table of node v

to	via (next hop)
d	n

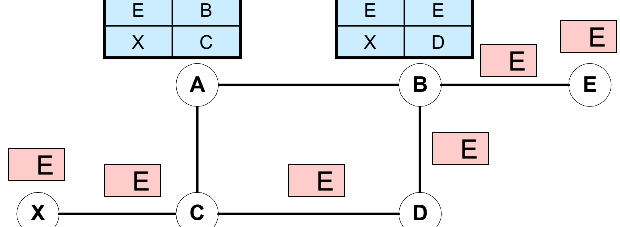


Forwarding Datagrams

To	Next hop
A	-
B	B
C	C
D	C
E	B
X	C

To	Next hop
A	A
B	-
C	D
D	D
E	E
X	D

To	Next hop
A	B
B	B
C	B
D	B
E	-
X	B



To	Next hop
A	C
B	C
C	C
D	C
E	C
X	-

To	Next hop
A	A
B	-
C	D
D	D
E	D
X	E

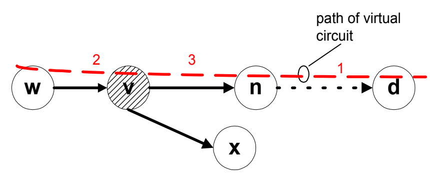
To	Next hop
A	B
B	B
C	C
D	-
E	B
X	C

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

from	VC#	to	VC#
w	2	v	3

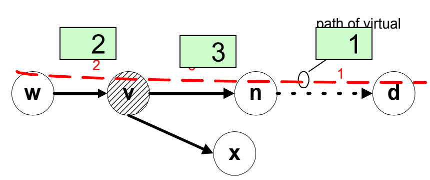


Packet Forwarding of Virtual Circuits

- 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}

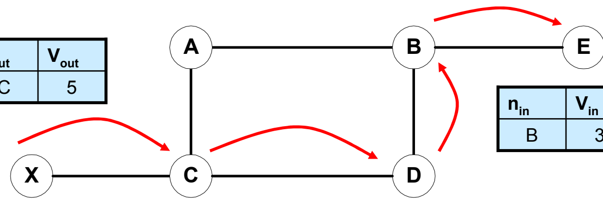
Routing Table of node v

from	VC#	to	VC#
w	2	v	3



Forwarding with VCs

Part 1: VC setup from X to E



n_{in}	V_{in}	n_{out}	V_{out}
-	-	C	5

n_{in}	V_{in}	n_{out}	V_{out}
X	5	D	3

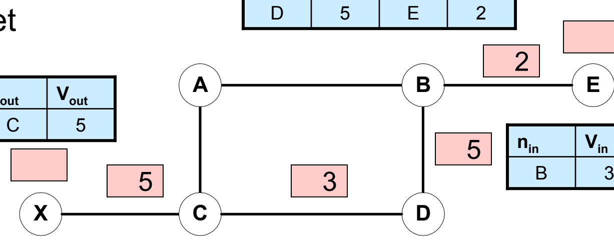
n_{in}	V_{in}	n_{out}	V_{out}
C	3	B	5

n_{in}	V_{in}	n_{out}	V_{out}
D	5	E	3

n_{in}	V_{in}	n_{out}	V_{out}
B	3	-	-

Forwarding with VCs

Part 2: Forwarding the packet



n_{in}	V_{in}	n_{out}	V_{out}
-	-	C	5

n_{in}	V_{in}	n_{out}	V_{out}
X	5	D	3

n_{in}	V_{in}	n_{out}	V_{out}
C	3	B	5

n_{in}	V_{in}	n_{out}	V_{out}
D	5	E	2

n_{in}	V_{in}	n_{out}	V_{out}
B	3	-	-

Comparison

Circuit Switching	Datagram Packet Switching	VC Packet Switching
Dedicated transmission path	No dedicated transmission path	No dedicated transmission path
Continuous transmission	Transmission of packets	Transmission of packets
Path stays fixed for entire connection	Route of each packet is independent	Path stays fixed for entire connection
Call setup delay	No setup delay	Call setup delay
Negligible transmission delay	Transmission delay for each packet	Transmission delay for each packet
No queueing delay	Queueing delays at switches	Queueing delays at switches
Busy signal overloaded network	Delays increase in overloaded networks	Delays increase in overloaded networks
Fixed bandwidth for each circuit	Bandwidth is shared by all packets	Bandwidth is shared by all packets
No overhead after call setup	Overhead in each packet	Overhead in each packet