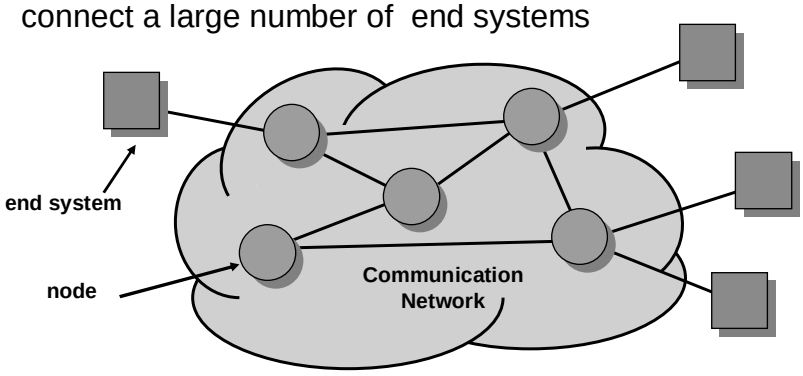
Switching Networks

Communication Networks

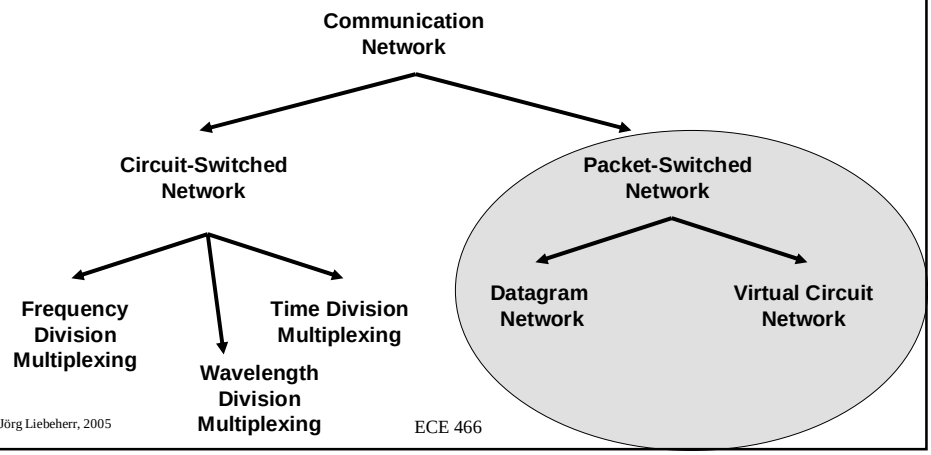
- A **communication network** provides a scalable solution to connect a large number of end systems



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

Taxonomy of Networks

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



Circuit Switching

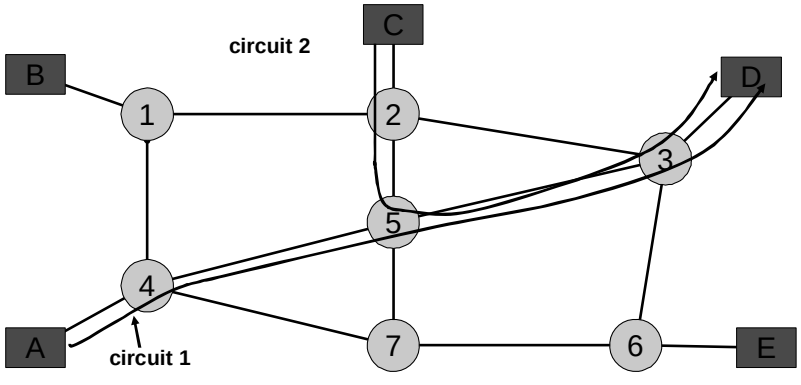
- A dedicated communication path **("circuit")** is established
- Bandwidth on a link is statically allocated
  - Each circuit occupies a fixed capacity
  - Unused capacity cannot be used by other circuit
  - "Busy Signal" if capacity for a circuit not available
- Circuit-switched communication involves three phases:
  1. **Circuit Establishment**
  2. **Data Transfer**
  3. **Circuit Release**
- Circuit-switched multiplexing
  - FDM, WDM
  - TDM
- Data is not formatted ("raw bit stream")

Packet Switching

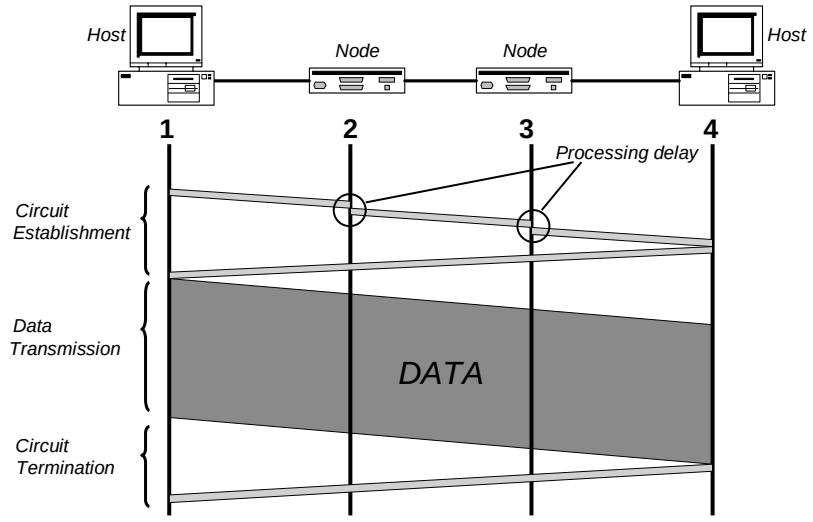
- Data are sent as formatted bit-sequences, so-called packets

- 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
- Multiplexing: Statistical TDM

Circuit Switching



Timing in Circuit Switching

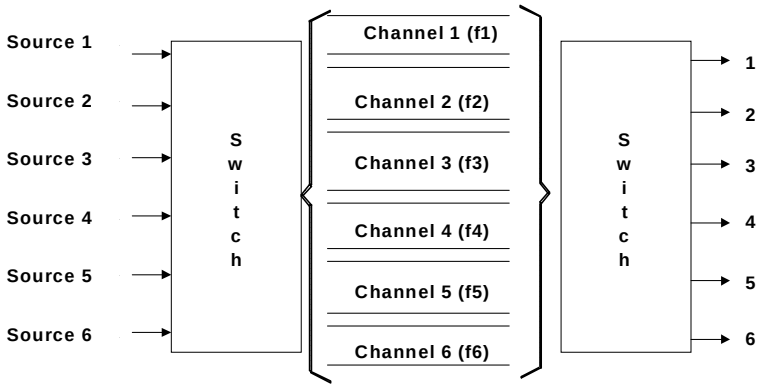


Implementation of Circuit-Switching

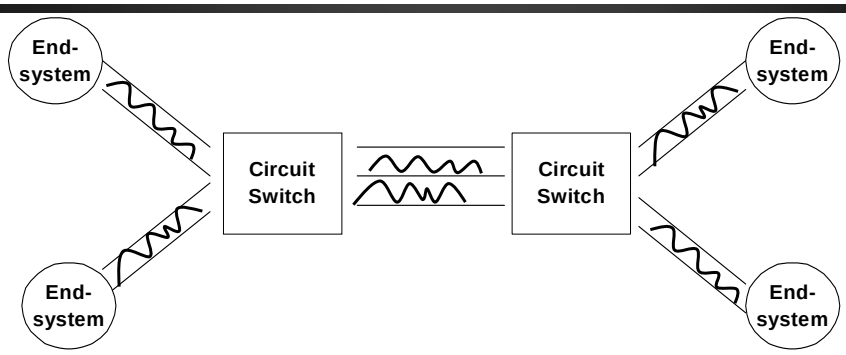
- There are three ways to implement circuits
  - Frequency Division Multiplexing (FDM)
  - Time Division Multiplexing (TDM)
  - Wavelength Division Multiplexing (WDM)

Frequency Division Multiplexing (FDM)

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



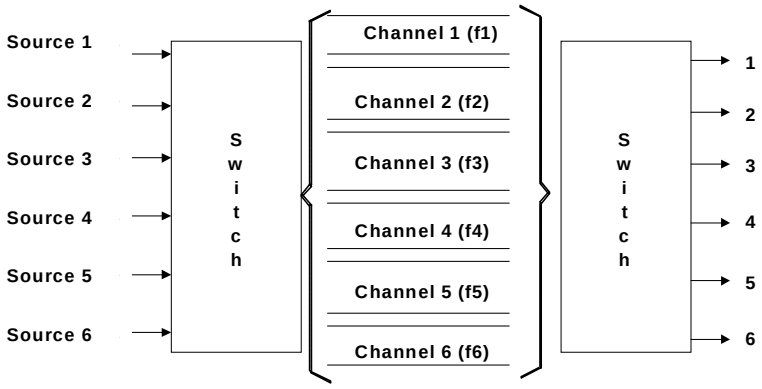
Frequency Division Multiplexing (FDM)



- 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

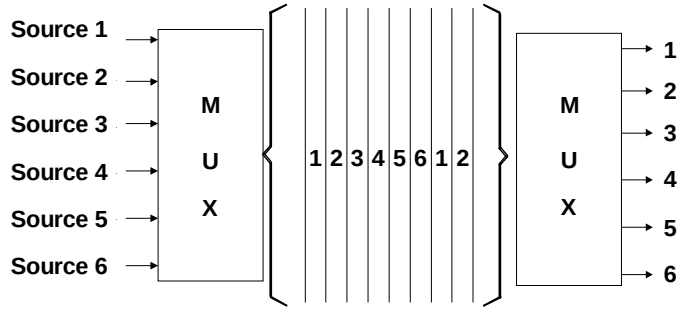
Frequency Division Multiplexing (FDM)

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

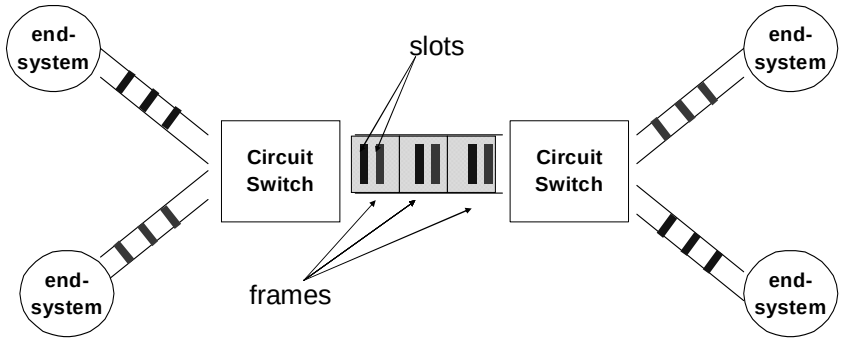


Time Division Multiplexing (TDM)

- **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

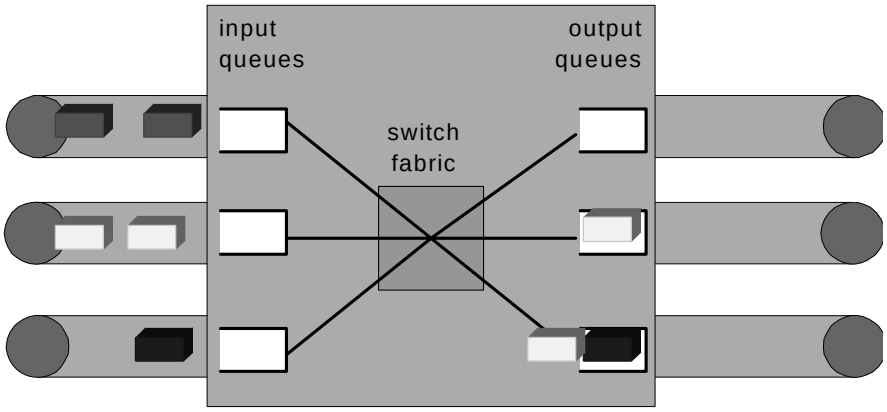
Packet Switching

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

  - Header and Trailer carry control information

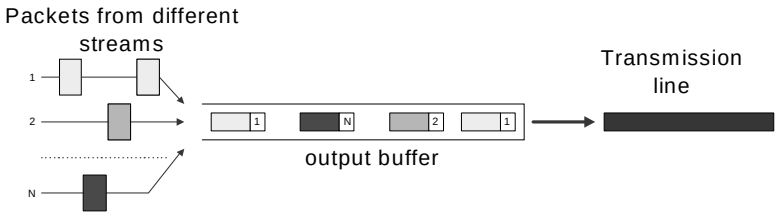
- Each packet is passed through the network from node to node along some path (**Forwarding/Routing**)
- At each node the entire packet is received, stored briefly, and then forwarded to the next node (**Store-and-Forward Networks**)
- Packet transmission is never interrupted (no preemption)
- No capacity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

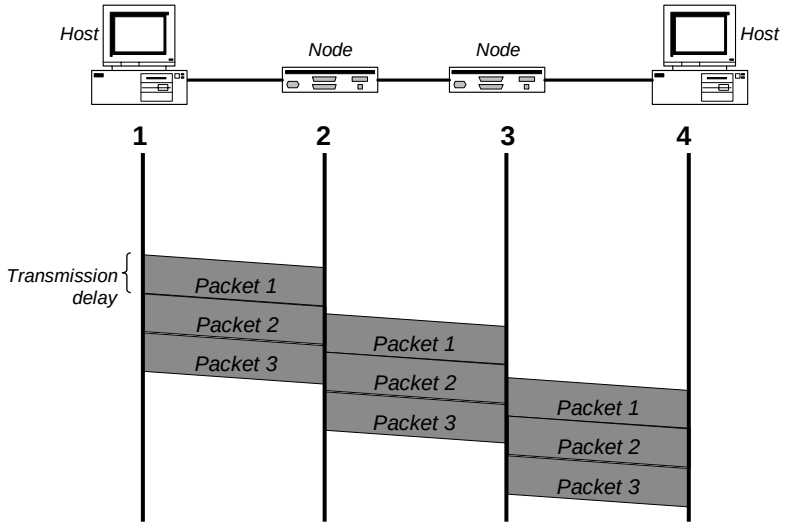
- The network nodes process each packet independently

  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

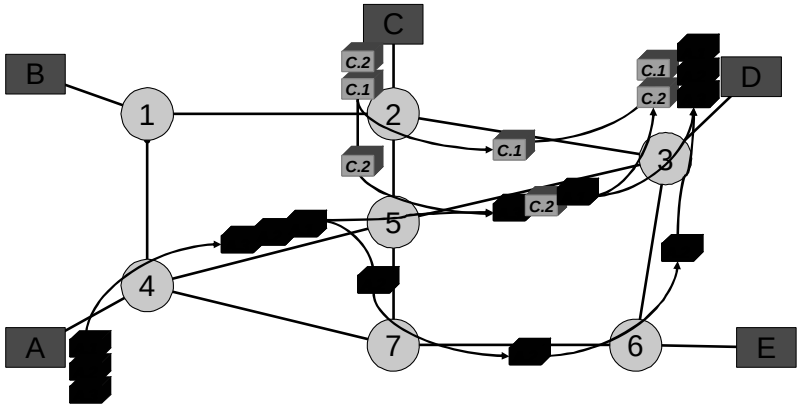
- Packets are called datagrams

- 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

Timing of Datagram Packet Switching



Datagram Packet Switching



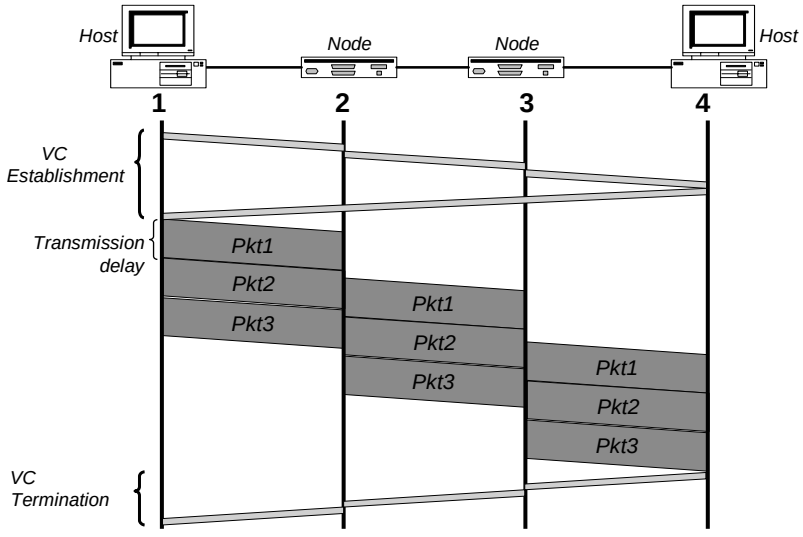
Virtual-Circuit Packet Switching

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

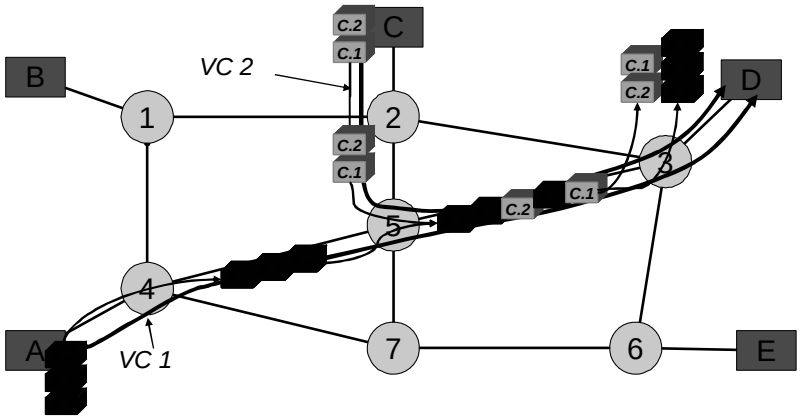
Virtual-Circuit Packet Switching

- Guarantees in-sequence delivery of packets, but packets from different virtual circuits may be interleaved
- Packet headers don't need to contain the full destination address of the packet

Timing of VC Packet Switching



Virtual-Circuit Packet Switching



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**)?

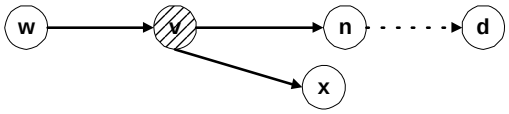
  Crucial Difference:
  - Datagram networks organize their routing table according to destination addresses. All packets with same destination are handled in the same way
  - VC packet networks set up routing table for each virtual circuit during the call-establishment phase. Each switch has a routing table entry for each virtual circuit going through this switch.

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

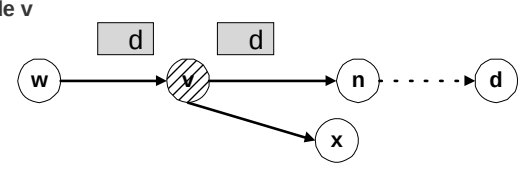


Packet Forwarding of Datagrams

- 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

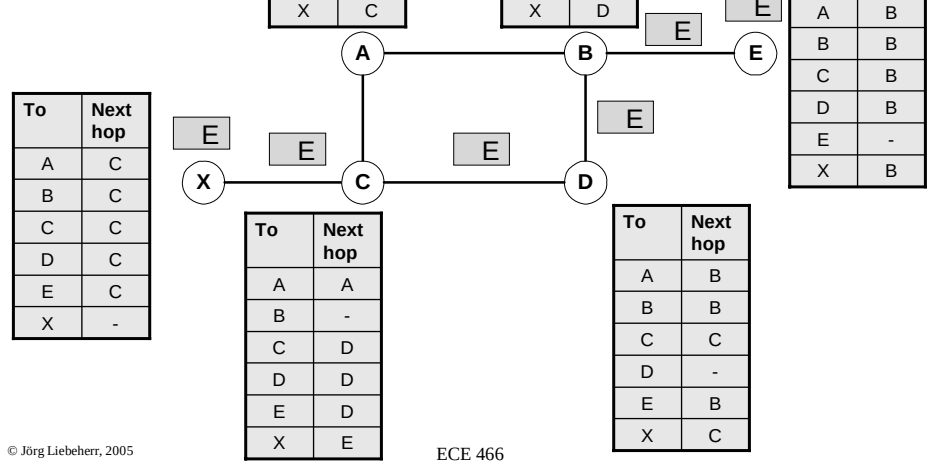
To	Next hop
A	A
B	-
C	D
D	D
E	E
X	D

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

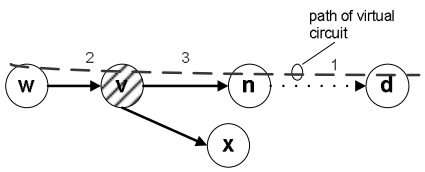


Packet Forwarding with Virtual Circuits

- **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	d	3

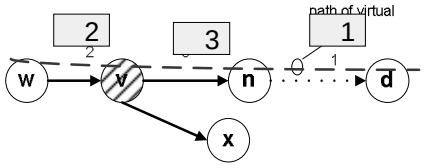


Packet Forwarding of Virtual Circuits

- 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}

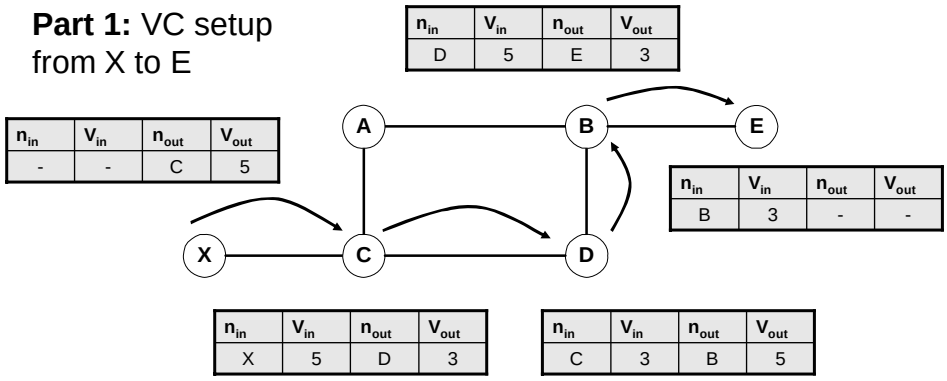
Routing Table of node v

from	VC#	to	VC#
w	2	n	3



Forwarding with VCs

Part 1: VC setup from X to E



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

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

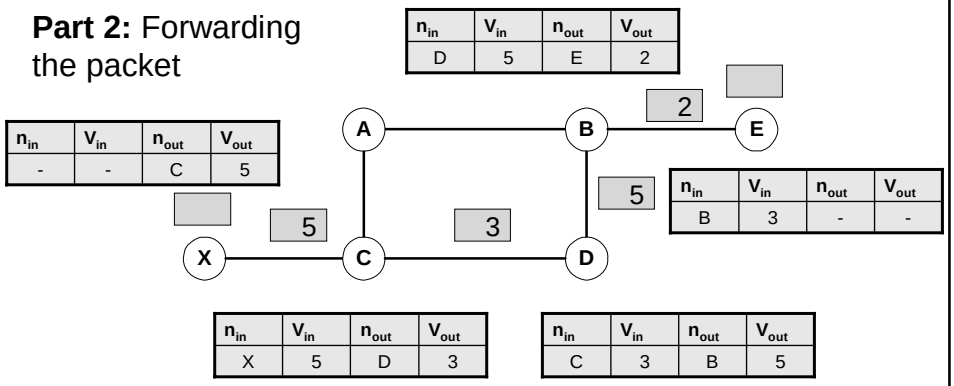
n_{in}	V_{in}	n_{out}	V_{out}
B	3	-	-

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

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

Forwarding with VCs

Part 2: Forwarding the packet



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

Packet Switching Technologies

- Both packet switching technologies are used.
- **Datagram packet switching:**
  - Internet
  - Switched LANs
- **Virtual-circuit packet switching**
  - Asynchronous Transfer Mode (ATM)
  - Multi-protocol label switching (MPLS)