# William Stallings
# Data and Computer Communications

## Chapter 10

## Packet Switching

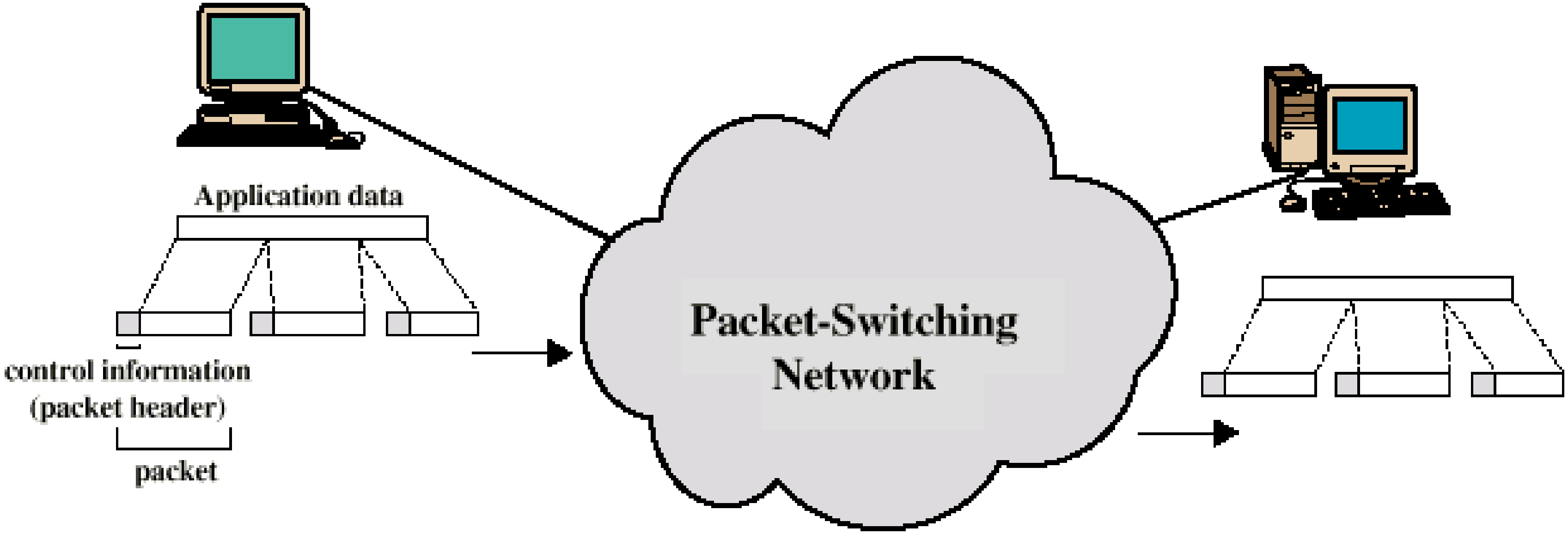
# Principles

- Circuit switching designed for voice
  - Resources dedicated to a particular call
  - Much of the time a data connection is idle
  - Data rate is fixed
    - Both ends must operate at the same rate

# Basic Operation

- Data transmitted in small packets
  - Typically 1000 octets
  - Longer messages split into series of packets
  - Each packet contains a portion of user data plus some control info
- Control info
  - Routing (addressing) info
- Packets are received, stored briefly (buffered) and past on to the next node
  - Store and forward

# Use of Packets



# Advantages

- Line efficiency
  - Single node to node link can be shared by many packets over time
  - Packets queued and transmitted as fast as possible
- Data rate conversion
  - Each station connects to the local node at its own speed
  - Nodes buffer data if required to equalize rates
- Packets are accepted even when network is busy
  - Delivery may slow down
- Priorities can be used

# Switching Technique

- Station breaks long message into packets
- Packets sent one at a time to the network
- Packets handled in two ways
    - Datagram
    - Virtual circuit

# Datagram

- Each packet treated independently
- Packets can take any practical route
- Packets may arrive out of order
- Packets may go missing
- Up to receiver to re-order packets and recover from missing packets

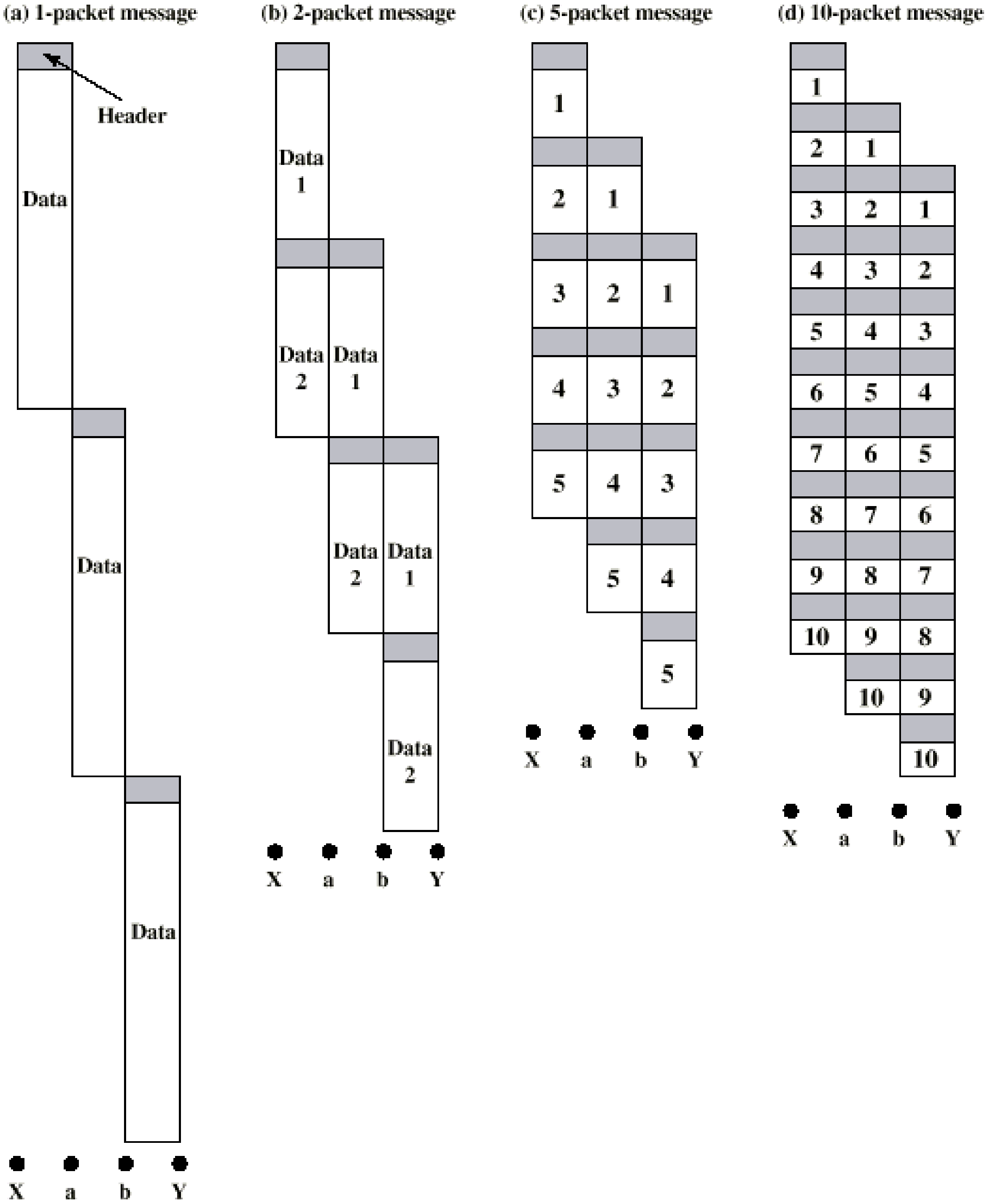
# Virtual Circuit

- Preplanned route established before any packets sent
- Call request and call accept packets establish connection (handshake)
- Each packet contains a virtual circuit identifier instead of destination address
- No routing decisions required for each packet
- Clear request to drop circuit
- Not a dedicated path

# Virtual Circuits v Datagram

- Virtual circuits
  - Network can provide sequencing and error control
  - Packets are forwarded more quickly
    - No routing decisions to make
  - Less reliable
    - Loss of a node looses all circuits through that node
- Datagram
  - No call setup phase
    - Better if few packets
  - More flexible
    - Routing can be used to avoid congested parts of the network

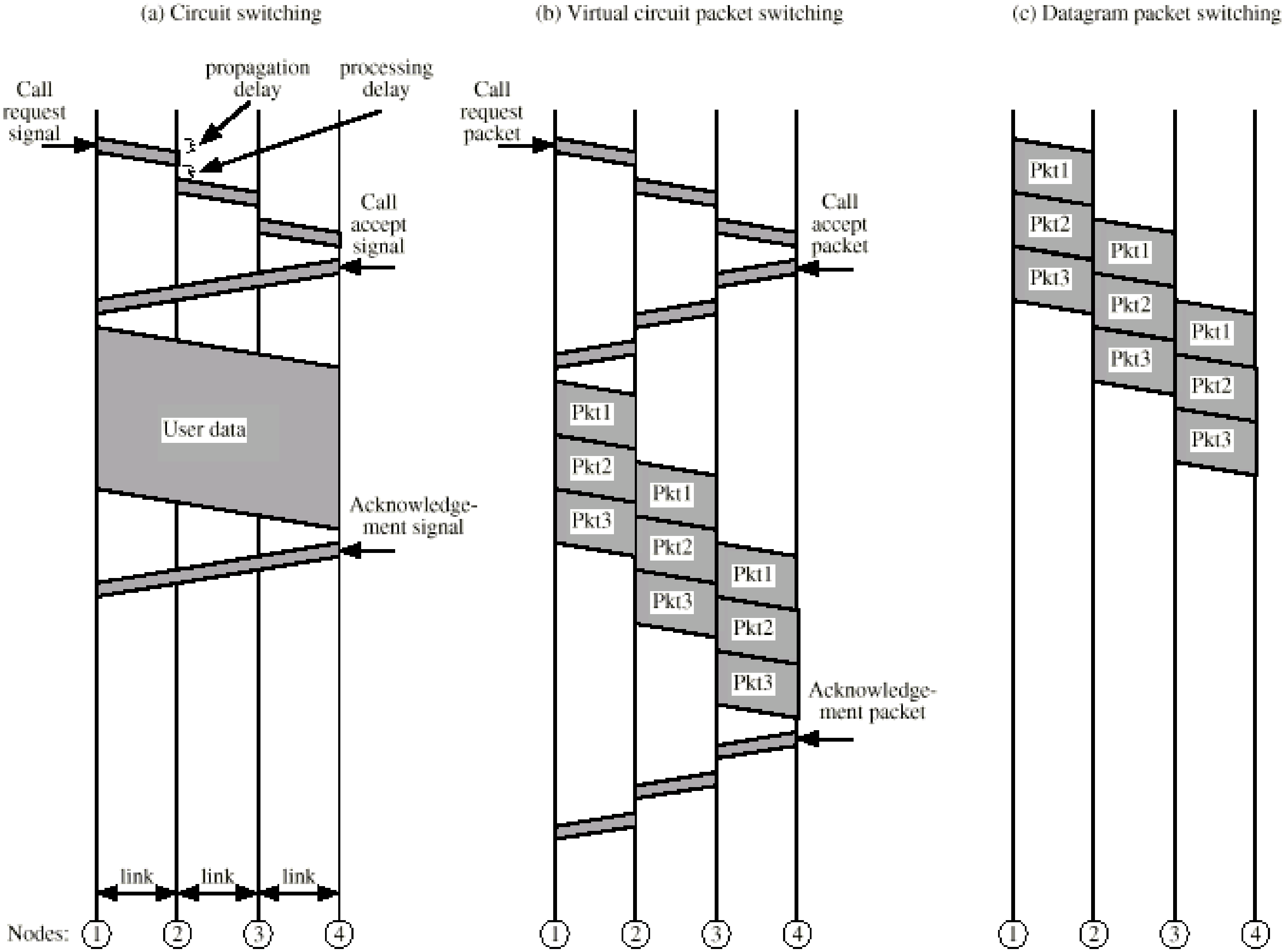
# Packet Size


(a) 1-packet message
Header
Data
Data
Data
X
a
b
Y
(b) 2-packet message
Data 1
Data 2
Data 1
Data 2
Data 1
Data 2
X
a
b
Y
(c) 5-packet message
1
2
1
3
2
1
4
3
2
5
4
3
5
4
5
X
a
b
Y
(d) 10-packet message
1
2
1
3
2
1
4
3
2
5
4
3
6
5
4
7
6
5
8
7
6
9
8
7
10
9
8
10
9
10
X
a
b
Y

# Circuit v Packet Switching

- Performance
  - Propagation delay
  - Transmission time
  - Node delay

# Event Timing



# External and Internal Operation

- Packet switching - datagrams or virtual circuits
- Interface between station and network node
  - Connection oriented
    - Station requests logical connection (virtual circuit)
    - All packets identified as belonging to that connection & sequentially numbered
    - Network delivers packets in sequence
    - External virtual circuit service
    - e.g. X.25
    - Different from internal virtual circuit operation
  - Connectionless
    - Packets handled independently
    - External datagram service
    - Different from internal datagram operation

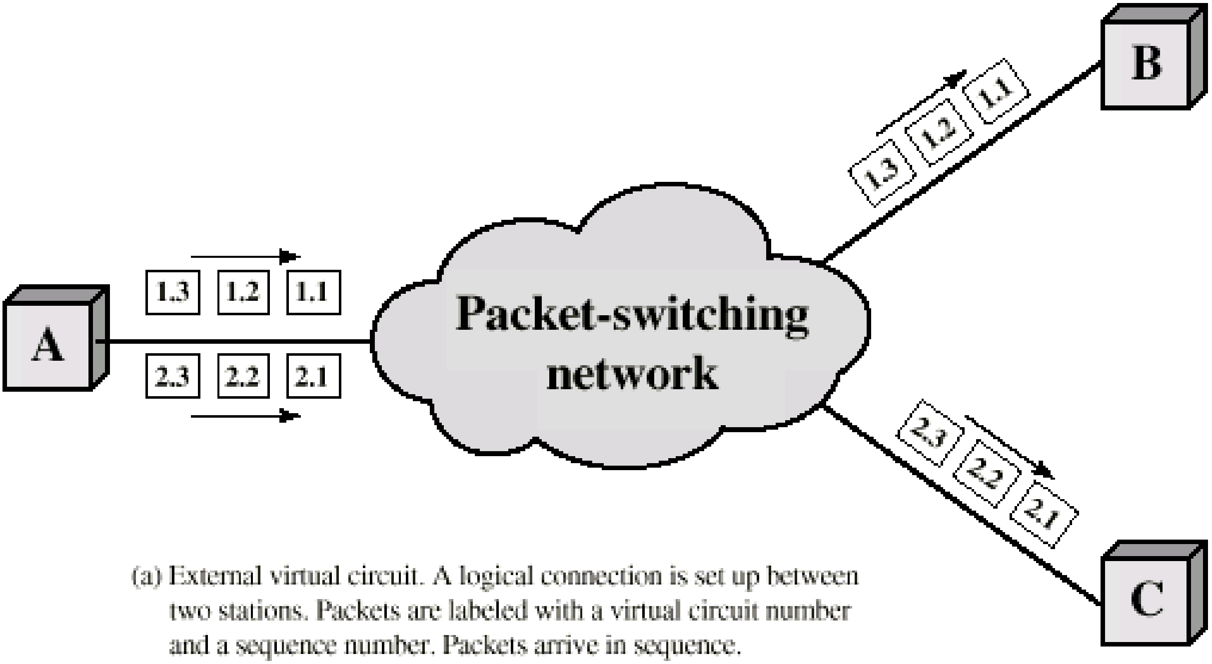
# Combinations (1)

- External virtual circuit, internal virtual circuit
  - Dedicated route through network
- External virtual circuit, internal datagram
  - Network handles each packet separately
  - Different packets for the same external virtual circuit may take different internal routes
  - Network buffers at destination node for re-ordering

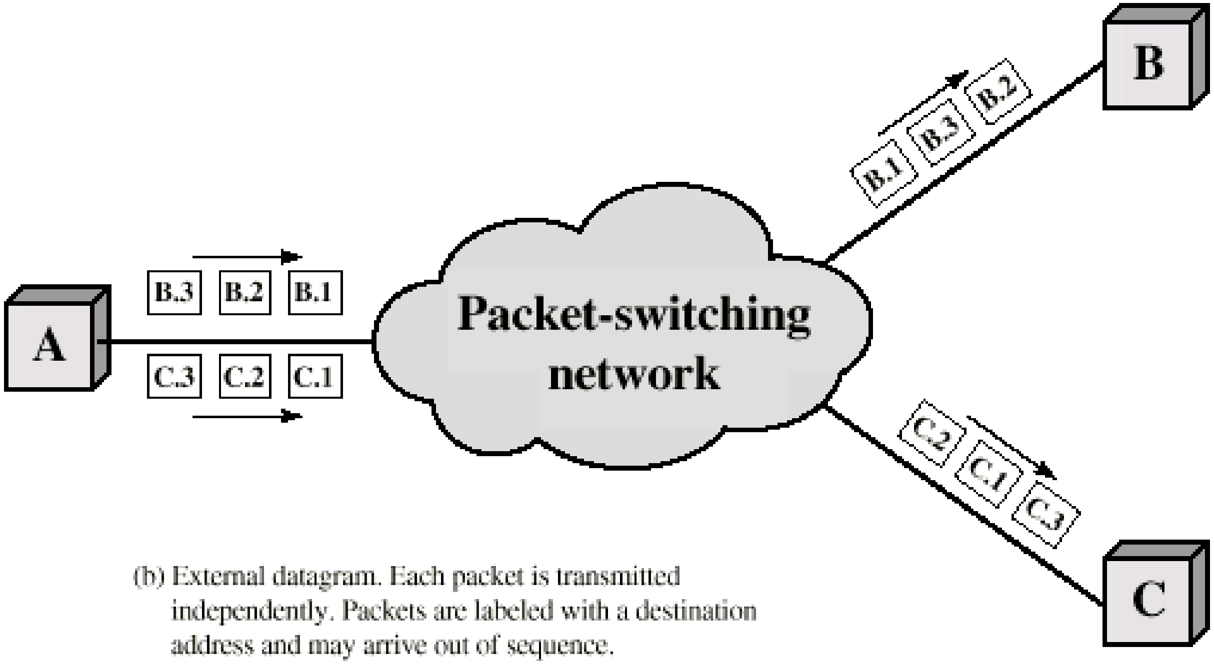
# Combinations (2)

- External datagram, internal datagram
  - Packets treated independently by both network and user
- External datagram, internal virtual circuit
  - External user does not see any connections
  - External user sends one packet at a time
  - Network sets up logical connections

# External Virtual Circuit and Datagram Operation

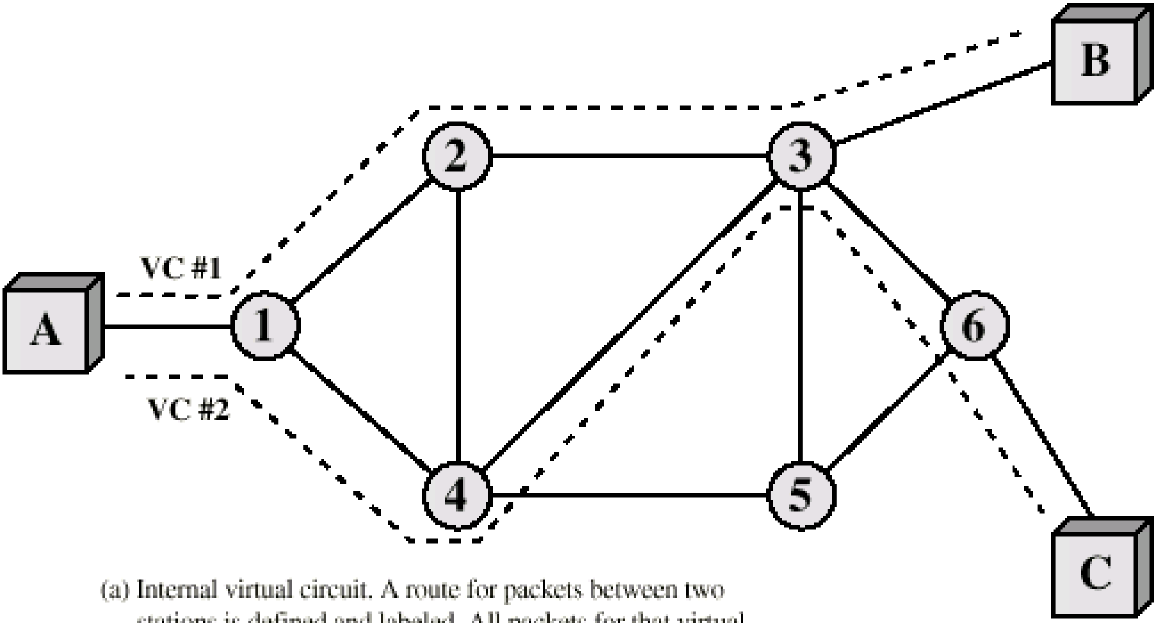


(a) External virtual circuit. A logical connection is set up between two stations. Packets are labeled with a virtual circuit number and a sequence number. Packets arrive in sequence.

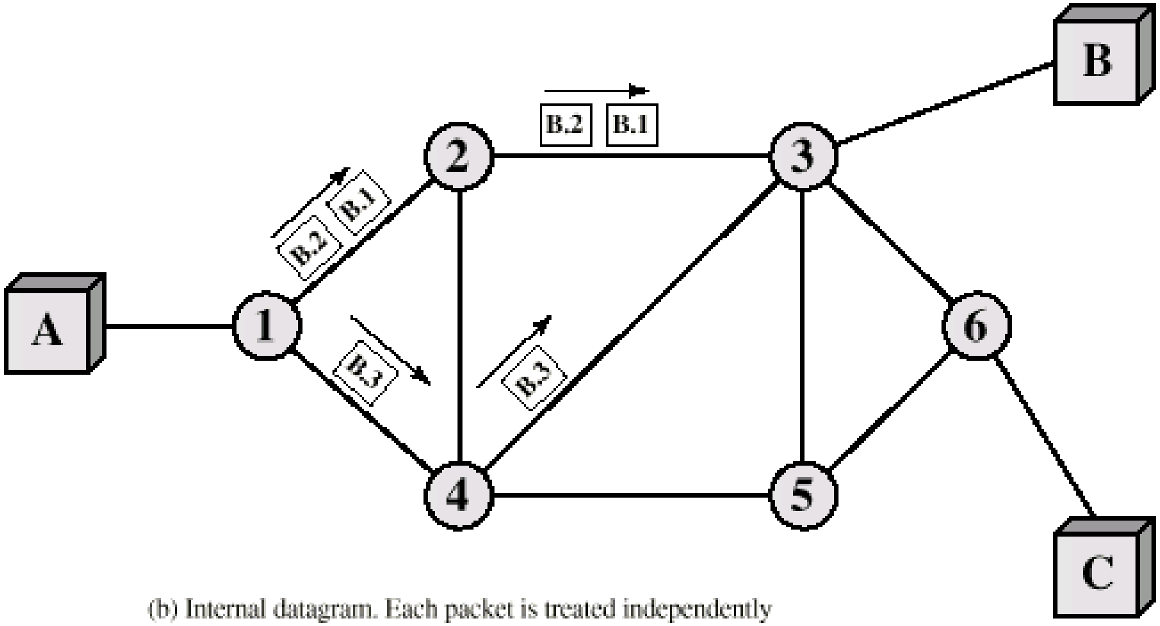


(b) External datagram. Each packet is transmitted independently. Packets are labeled with a destination address and may arrive out of sequence.

# Internal Virtual Circuit and Datagram Operation



(a) Internal virtual circuit. A route for packets between two stations is defined and labeled. All packets for that virtual circuit follow the same route and arrive in the same sequence.



(b) Internal datagram. Each packet is treated independently by the network. Packets are labeled with a destination address and may arrive at the destination node out of sequence.

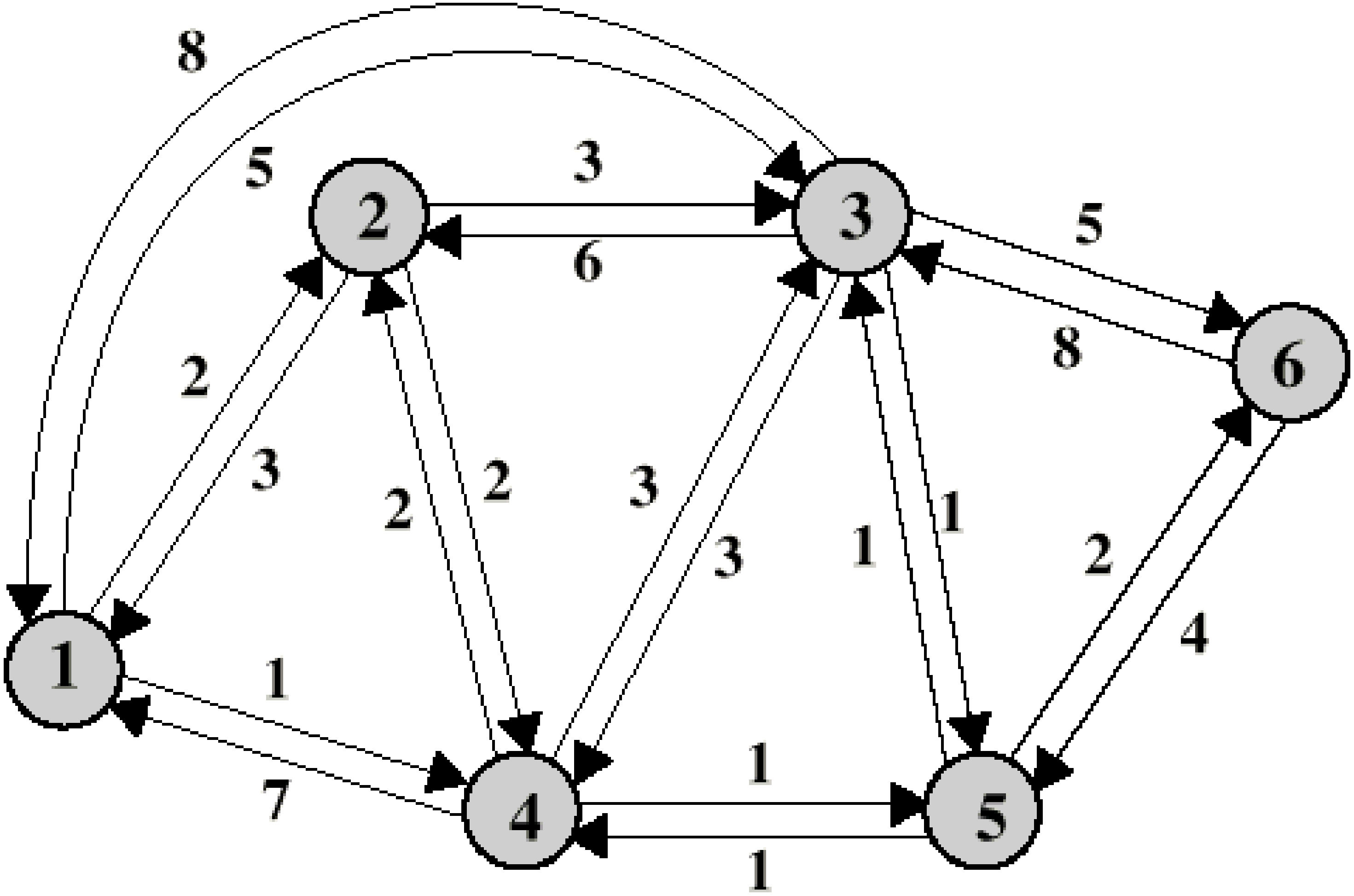
# Routing

- Complex, crucial aspect of packet switched networks
- Characteristics required
  - Correctness
  - Simplicity
  - Robustness
  - Stability
  - Fairness
  - Optimality
  - Efficiency

# Performance Criteria

- Used for selection of route
- Minimum hop
- Least cost
  - See Stallings appendix 10A for routing algorithms

# Costing of Routes



# Decision Time and Place

- Time
  - Packet or virtual circuit basis
- Place
  - Distributed
    - Made by each node
  - Centralized
  - Source

# Network Information Source and Update Timing

- Routing decisions usually based on knowledge of network (not always)
- Distributed routing
  - Nodes use local knowledge
  - May collect info from adjacent nodes
  - May collect info from all nodes on a potential route
- Central routing
  - Collect info from all nodes
- Update timing
  - When is network info held by nodes updated
  - Fixed - never updated
  - Adaptive - regular updates

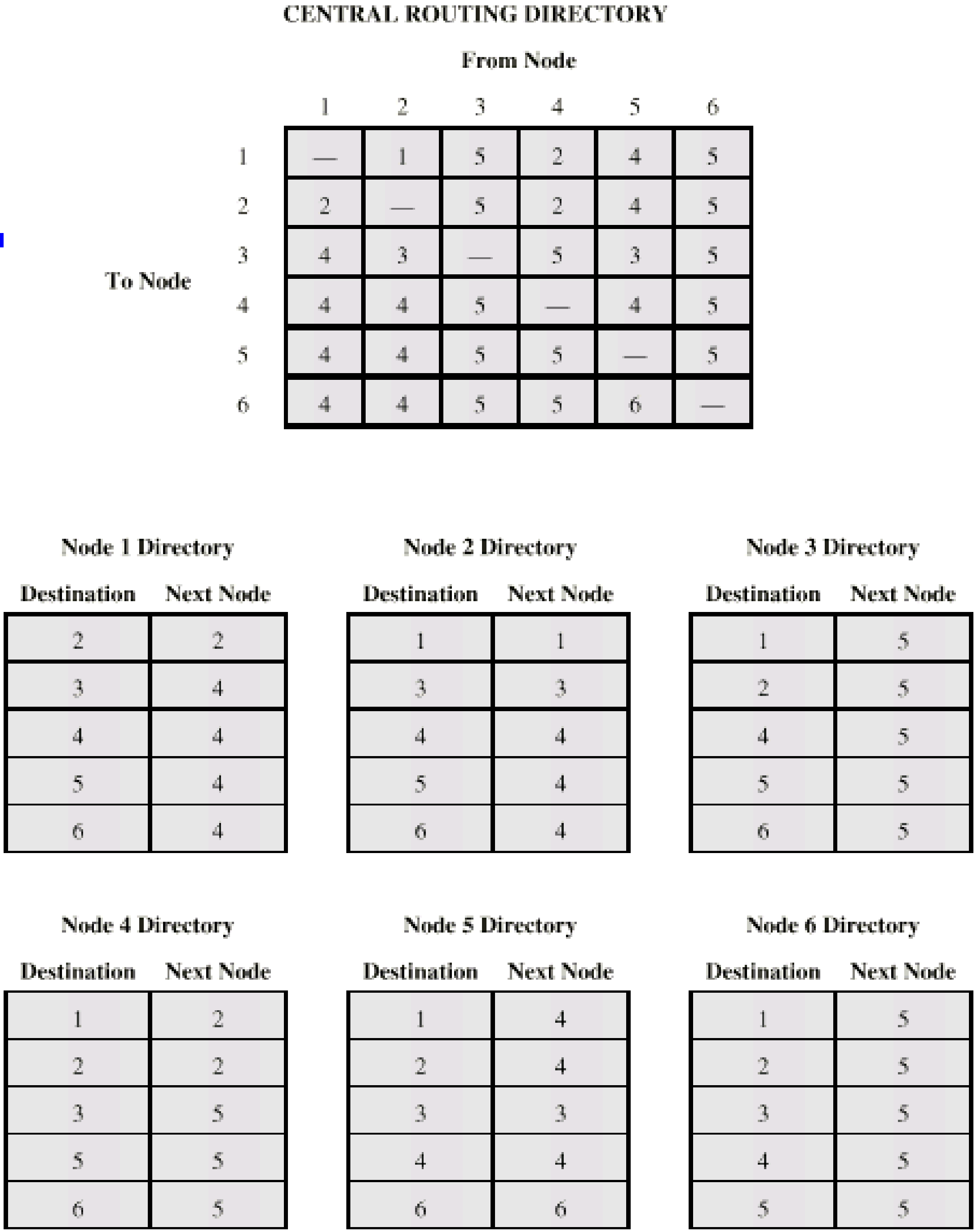
# Routing Strategies

- Fixed
- Flooding
- Random
- Adaptive

# Fixed Routing

- Single permanent route for each source to destination pair
- Determine routes using a least cost algorithm (appendix 10A)
- Route fixed, at least until a change in network topology

# Fixed Routing Tables



CENTRAL ROUTING DIRECTORY

From Node

| To Node | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | — | 1 | 5 | 2 | 4 | 5 |
| 2 | 2 | — | 5 | 2 | 4 | 5 |
| 3 | 4 | 3 | — | 5 | 3 | 5 |
| 4 | 4 | 4 | 5 | — | 4 | 5 |
| 5 | 4 | 4 | 5 | 5 | — | 5 |
| 6 | 4 | 4 | 5 | 5 | 6 | — |

Node 1 Directory

| Destination | Next Node |
|---|---|
| 2 | 2 |
| 3 | 4 |
| 4 | 4 |
| 5 | 4 |
| 6 | 4 |

Node 2 Directory

| Destination | Next Node |
|---|---|
| 1 | 1 |
| 3 | 3 |
| 4 | 4 |
| 5 | 4 |
| 6 | 4 |

Node 3 Directory

| Destination | Next Node |
|---|---|
| 1 | 5 |
| 2 | 5 |
| 4 | 5 |
| 5 | 5 |
| 6 | 5 |

Node 4 Directory

| Destination | Next Node |
|---|---|
| 1 | 2 |
| 2 | 2 |
| 3 | 5 |
| 5 | 5 |
| 6 | 5 |

Node 5 Directory

| Destination | Next Node |
|---|---|
| 1 | 4 |
| 2 | 4 |
| 3 | 3 |
| 4 | 4 |
| 6 | 6 |

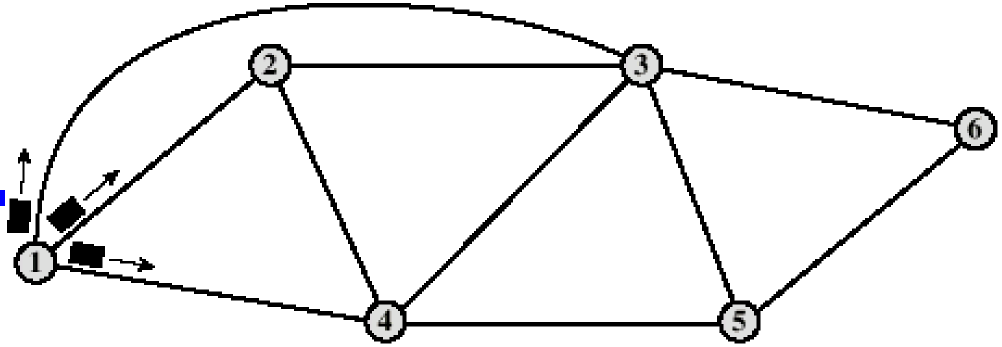
Node 6 Directory

| Destination | Next Node |
|---|---|
| 1 | 5 |
| 2 | 5 |
| 3 | 5 |
| 4 | 5 |
| 5 | 5 |

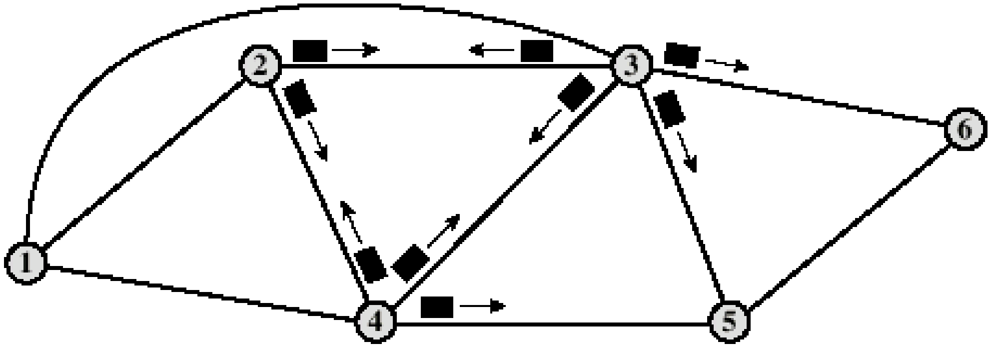
# Flooding

- No network info required
- Packet sent by node to every neighbor
- Incoming packets retransmitted on every link except incoming link
- Eventually a number of copies will arrive at destination
- Each packet is uniquely numbered so duplicates can be discarded
- Nodes can remember packets already forwarded to keep network load in bounds
- Can include a hop count in packets

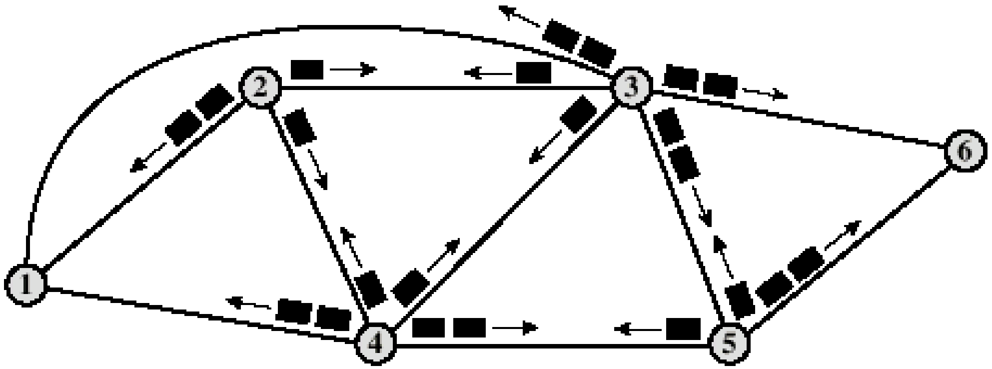
# Flooding Example



(a) First hop



(b) Second hop



(c) Third hop

# Properties of Flooding

- All possible routes are tried
  - Very robust
- At least one packet will have taken minimum hop count route
  - Can be used to set up virtual circuit
- All nodes are visited
  - Useful to distribute information (e.g. routing)

# Random Routing

- Node selects one outgoing path for retransmission of incoming packet
- Selection can be random or round robin
- Can select outgoing path based on probability calculation
- No network info needed
- Route is typically not least cost nor minimum hop

# Adaptive Routing

- Used by almost all packet switching networks
- Routing decisions change as conditions on the network change
    - Failure
    - Congestion
- Requires info about network
- Decisions more complex
- Tradeoff between quality of network info and overhead
- Reacting too quickly can cause oscillation
- Too slowly to be relevant

# Adaptive Routing - Advantages

- Improved performance
- Aid congestion control (See chapter 12)
- Complex system
    - May not realize theoretical benefits

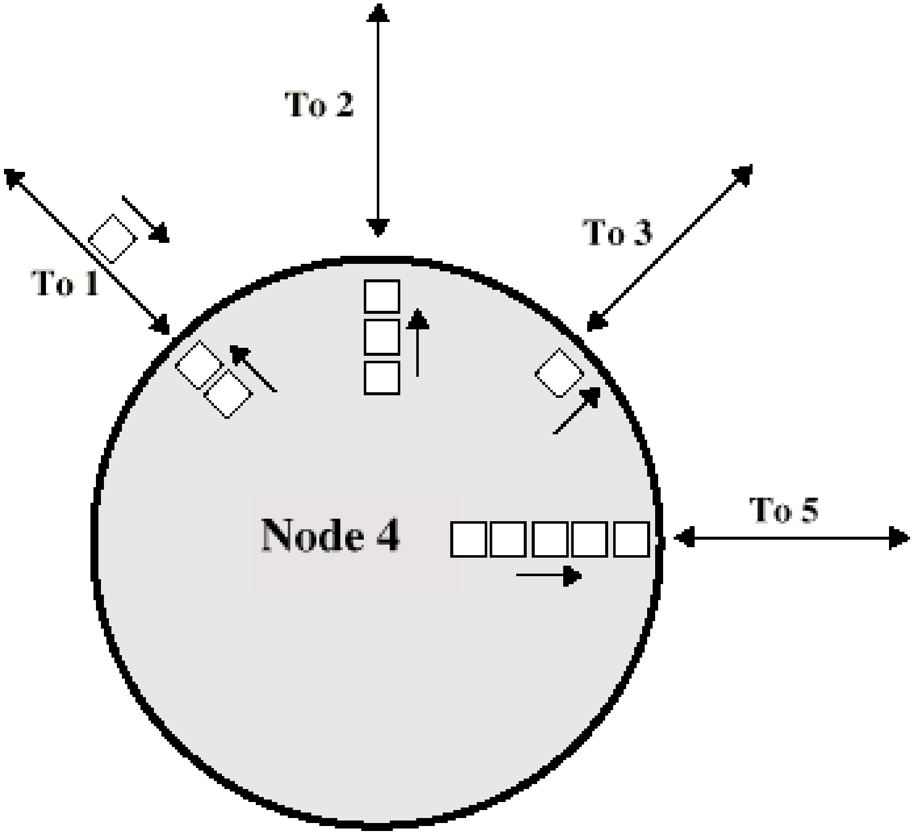
# Classification

- Based on information sources
    - Local (isolated)
        - Route to outgoing link with shortest queue
        - Can include bias for each destination
        - Rarely used - do not make use of easily available info
    - Adjacent nodes
    - All nodes

# Isolated Adaptive Routing

Node 4's Bias
Table for
Destination 6

| Next Node | Bias |
|---|---|
| 1 | 9 |
| 2 | 6 |
| 3 | 3 |
| 5 | 0 |



# ARPANET Routing Strategies(1)

- First Generation
  - 1969
  - Distributed adaptive
  - Estimated delay as performance criterion
  - Bellman-Ford algorithm (appendix 10a)
  - Node exchanges delay vector with neighbors
  - Update routing table based on incoming info
  - Doesn't consider line speed, just queue length
  - Queue length not a good measurement of delay
  - Responds slowly to congestion

# ARPANET Routing Strategies(2)

- Second Generation
  - 1979
  - Uses delay as performance criterion
  - Delay measured directly
  - Uses Dijkstra’s algorithm (appendix 10a)
  - Good under light and medium loads
  - Under heavy loads, little correlation between reported delays and those experienced

# ARPANET Routing Strategies(3)

- Third Generation
  - 1987
  - Link cost calculations changed
  - Measure average delay over last 10 seconds
  - Normalize based on current value and previous results

# X.25

- 1976
- Interface between host and packet switched network
- Almost universal on packet switched networks and packet switching in ISDN
- Defines three layers
  - Physical
  - Link
  - Packet

# X.25 - Physical

- Interface between attached station and link to node
- Data terminal equipment DTE (user equipment)
- Data circuit terminating equipment DCE (node)
- Uses physical layer specification X.21
- Reliable transfer across physical link
- Sequence of frames

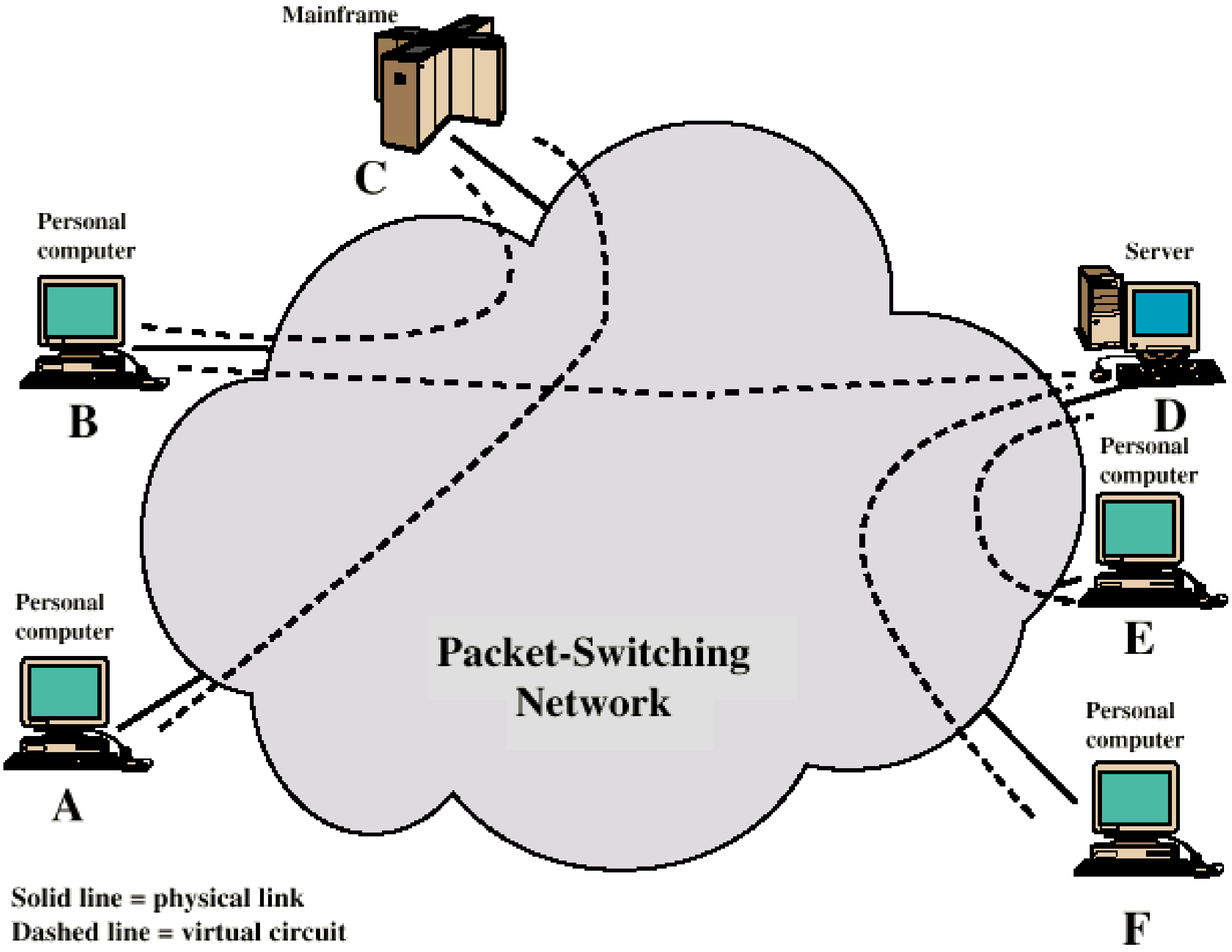
# X.25 - Link

- Link Access Protocol Balanced (LAPB)
  - Subset of HDLC
  - see chapter 7

# X.25 - Packet

- External virtual circuits
- Logical connections (virtual circuits) between subscribers

# X.25 Use of Virtual Circuits

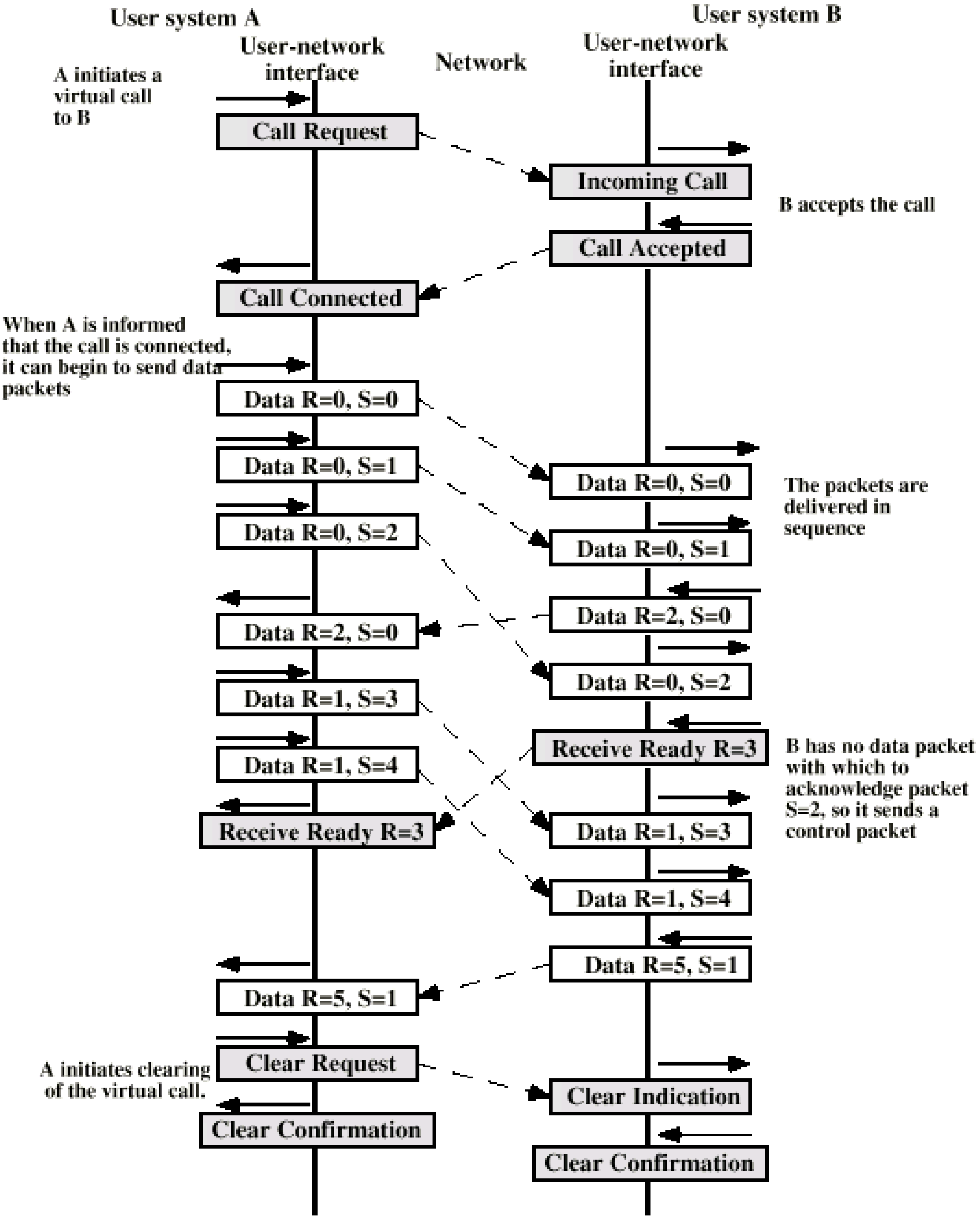


Solid line = physical link
Dashed line = virtual circuit

# Virtual Circuit Service

- Virtual Call
  - Dynamically established
- Permanent virtual circuit
  - Fixed network assigned virtual circuit

# Virtual Call



User system A

User-network interface

Network

User system B

User-network interface

A initiates a virtual call to B

Call Request

Incoming Call

B accepts the call

Call Accepted

Call Connected

When A is informed that the call is connected, it can begin to send data packets

Data R=0, S=0

Data R=0, S=1

Data R=0, S=2

Data R=0, S=0

Data R=0, S=1

The packets are delivered in sequence

Data R=2, S=0

Data R=2, S=0

Data R=0, S=2

Data R=1, S=3

Data R=1, S=4

Receive Ready R=3

B has no data packet with which to acknowledge packet S=2, so it sends a control packet

Receive Ready R=3

Data R=1, S=3

Data R=1, S=4

Data R=5, S=1

Data R=5, S=1

Clear Request

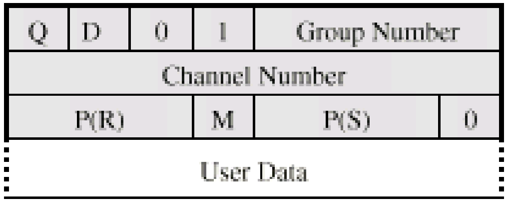
A initiates clearing of the virtual call.

Clear Indication

Clear Confirmation

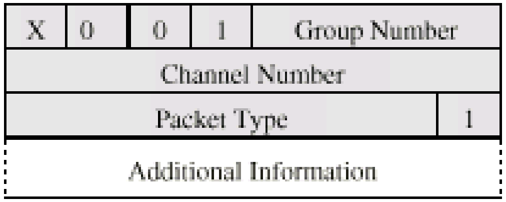
Clear Confirmation

# Packet Format



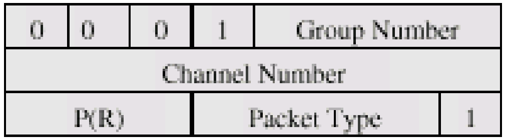
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Q | D | 0 | 1 | Group Number | | | |
| Channel Number | | | | | | | |
| P(R) | | | M | P(S) | | | 0 |
| User Data | | | | | | | |

(a) Data packet with 3-bit sequence numbers



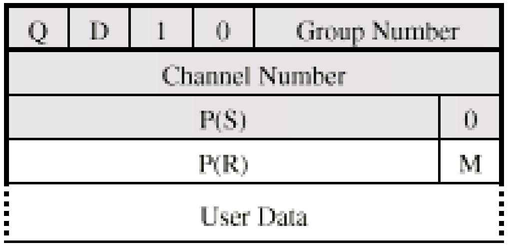
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| X | 0 | 0 | 1 | Group Number | | | |
| Channel Number | | | | | | | |
| Packet Type | | | | | | | 1 |
| Additional Information | | | | | | | |

(b) Control packet for virtual calls with 3-bit sequence numbers



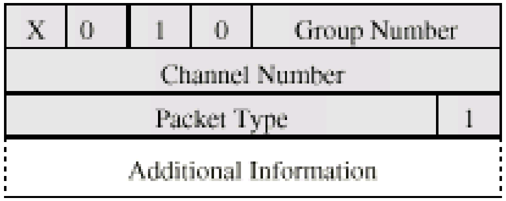
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 1 | Group Number | | | |
| Channel Number | | | | | | | |
| P(R) | | | Packet Type | | | | 1 |

(c) RR, RNR, and REJ packets with 3-bit sequence numbers



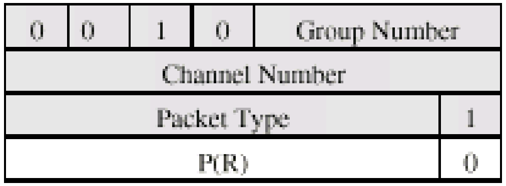
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Q | D | 1 | 0 | Group Number | | | |
| Channel Number | | | | | | | |
| P(S) | | | | | | | 0 |
| P(R) | | | | | | | M |
| User Data | | | | | | | |

(d) Data packet with 7-bit sequence numbers



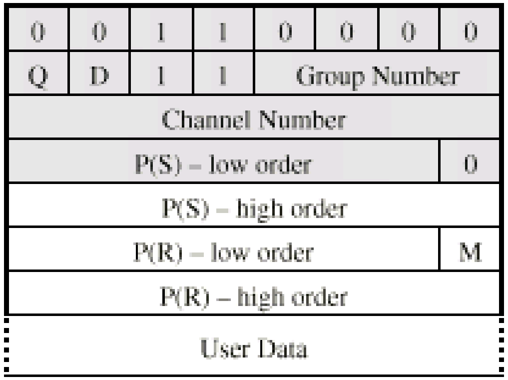
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| X | 0 | 1 | 0 | Group Number | | | |
| Channel Number | | | | | | | |
| Packet Type | | | | | | | 1 |
| Additional Information | | | | | | | |

(e) Control packet for virtual calls with 7-bit sequence numbers



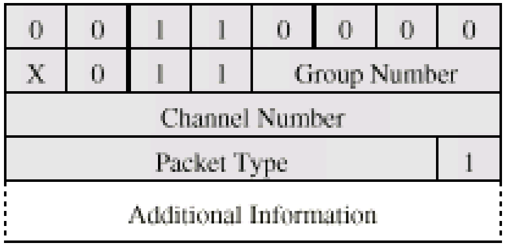
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 0 | Group Number | | | |
| Channel Number | | | | | | | |
| Packet Type | | | | | | | 1 |
| P(R) | | | | | | | 0 |

(f) RR, RNR, and REJ packets with 7-bit sequence numbers



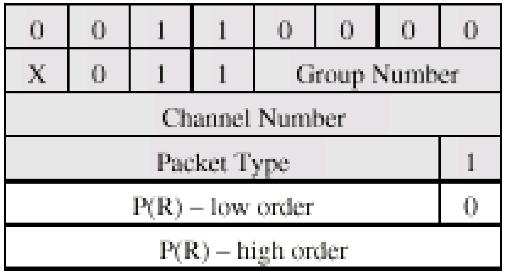
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Q | D | 1 | 1 | Group Number | | | |
| Channel Number | | | | | | | |
| P(S) – low order | | | | | | | 0 |
| P(S) – high order | | | | | | | |
| P(R) – low order | | | | | | | M |
| P(R) – high order | | | | | | | |
| User Data | | | | | | | |

(g) Data packet with 15-bit sequence numbers



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| X | 0 | 1 | 1 | Group Number | | | |
| Channel Number | | | | | | | |
| Packet Type | | | | | | | 1 |
| Additional Information | | | | | | | |

(h) Control packet for virtual calls with 15-bit sequence numbers



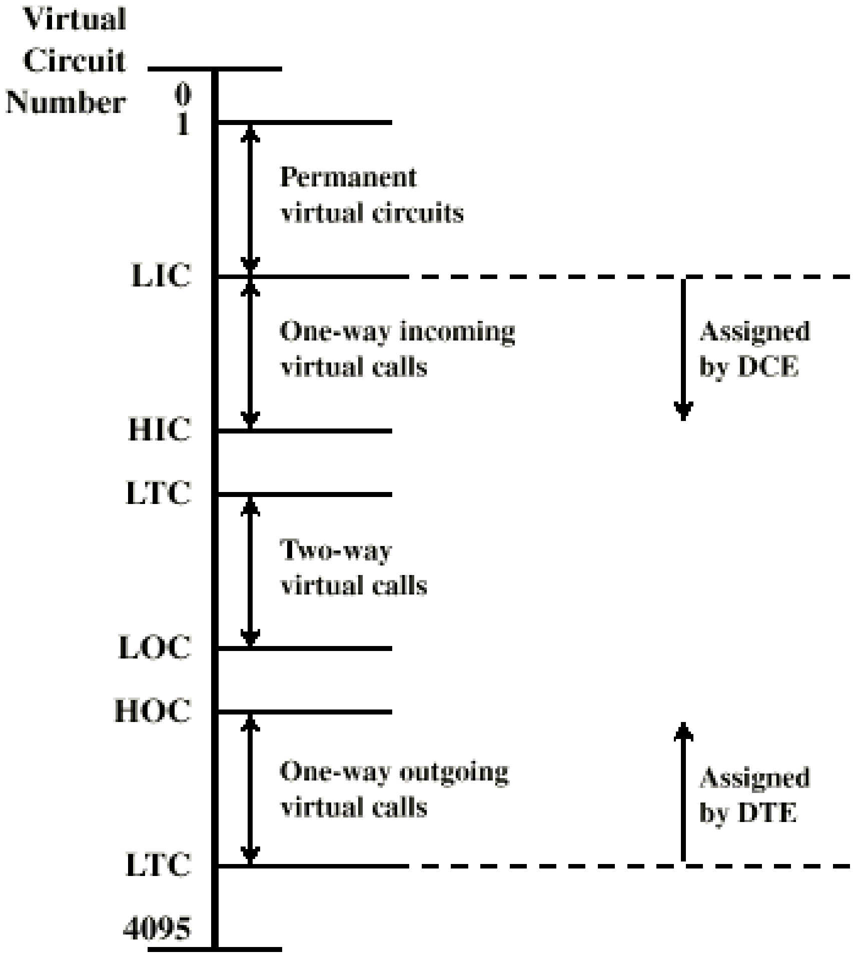
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| X | 0 | 1 | 1 | Group Number | | | |
| Channel Number | | | | | | | |
| Packet Type | | | | | | | 1 |
| P(R) – low order | | | | | | | 0 |
| P(R) – high order | | | | | | | |

(i) RR, RNR, and REJ packets with 15-bit sequence numbers

# Multiplexing

- DTE can establish 4095 simultaneous virtual circuits with other DTEs over a single DTC-DCE link
- Packets contain 12 bit virtual circuit number

# Virtual Circuit Numbering



LIC = Lowest incoming channel
HIC = Highest incoming channel
LTC = Lowest two-way channel

HTC = Highest two-way channel
LOC = Lowest outgoing channel
HOC = Highest outgoing channel

Virtual circuit number = logical group number and logical channel number

# Flow and Error Control

- HDLS (Chapter 7)

# Packet Sequences

- Complete packet sequences
- Allows longer blocks of data across network with smaller packet size without loss of block integrity
- A packets
    - M bit 1, D bit 0
- B packets
    - The rest
- Zero or more A followed by B

# Reset and Restart

- Reset
  - Reinitialize virtual circuit
  - Sequence numbers set to zero
  - Packets in transit lost
  - Up to higher level protocol to recover lost packets
  - Triggered by loss of packet, sequence number error, congestion, loss of network internal virtual circuit
- Restart
  - Equivalent to a clear request on all virtual circuits
  - E.g. temporary loss of network access

# Required Reading

- Stalling Chapter 10
- X.25 info from ITU-T web site
- Routing information from Comer