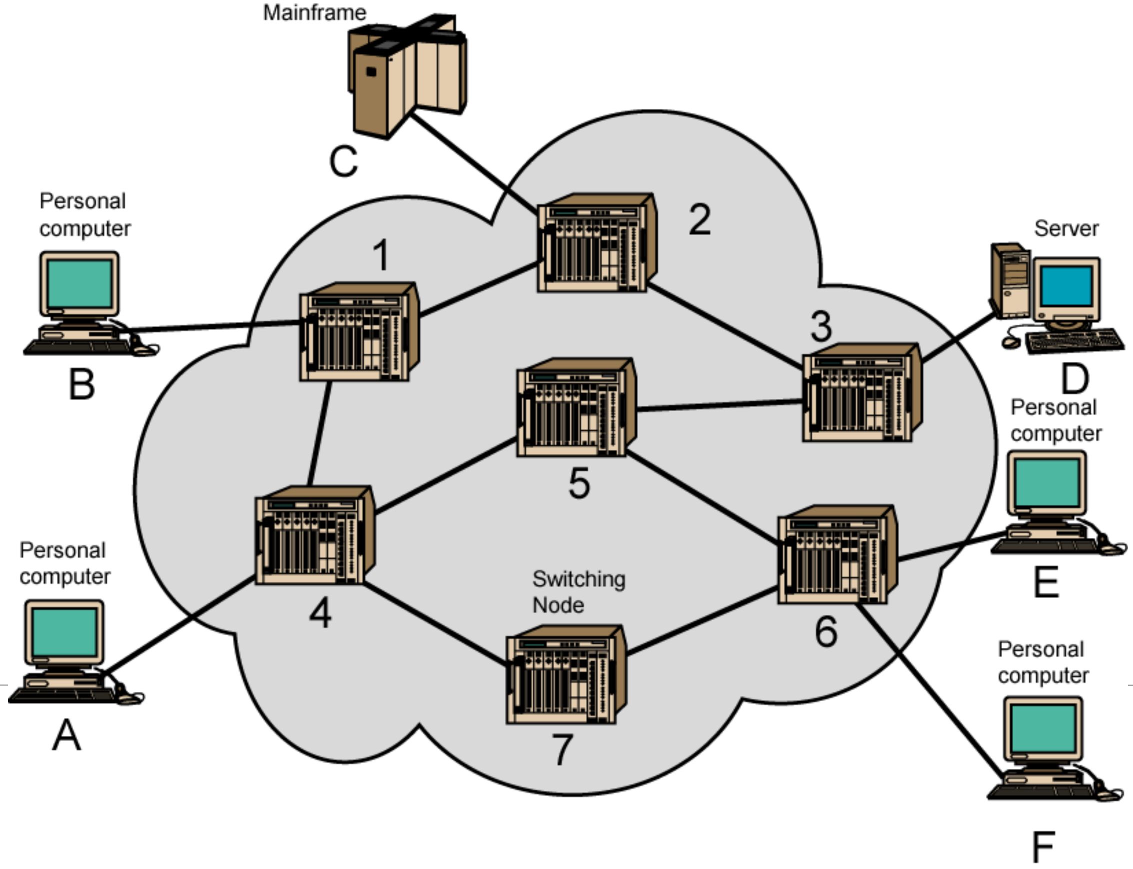
Computer Networks I

Circuit Switching and Packet Switching

Amitangshu Pal
Computer Science and Engineering
IIT Kanpur

Simple Switched Network

- We will learn two types of switching
  - Circuit Switching
  - Packet Switching
    - Datagram Packet switching
    - Virtual Circuit Packet switching

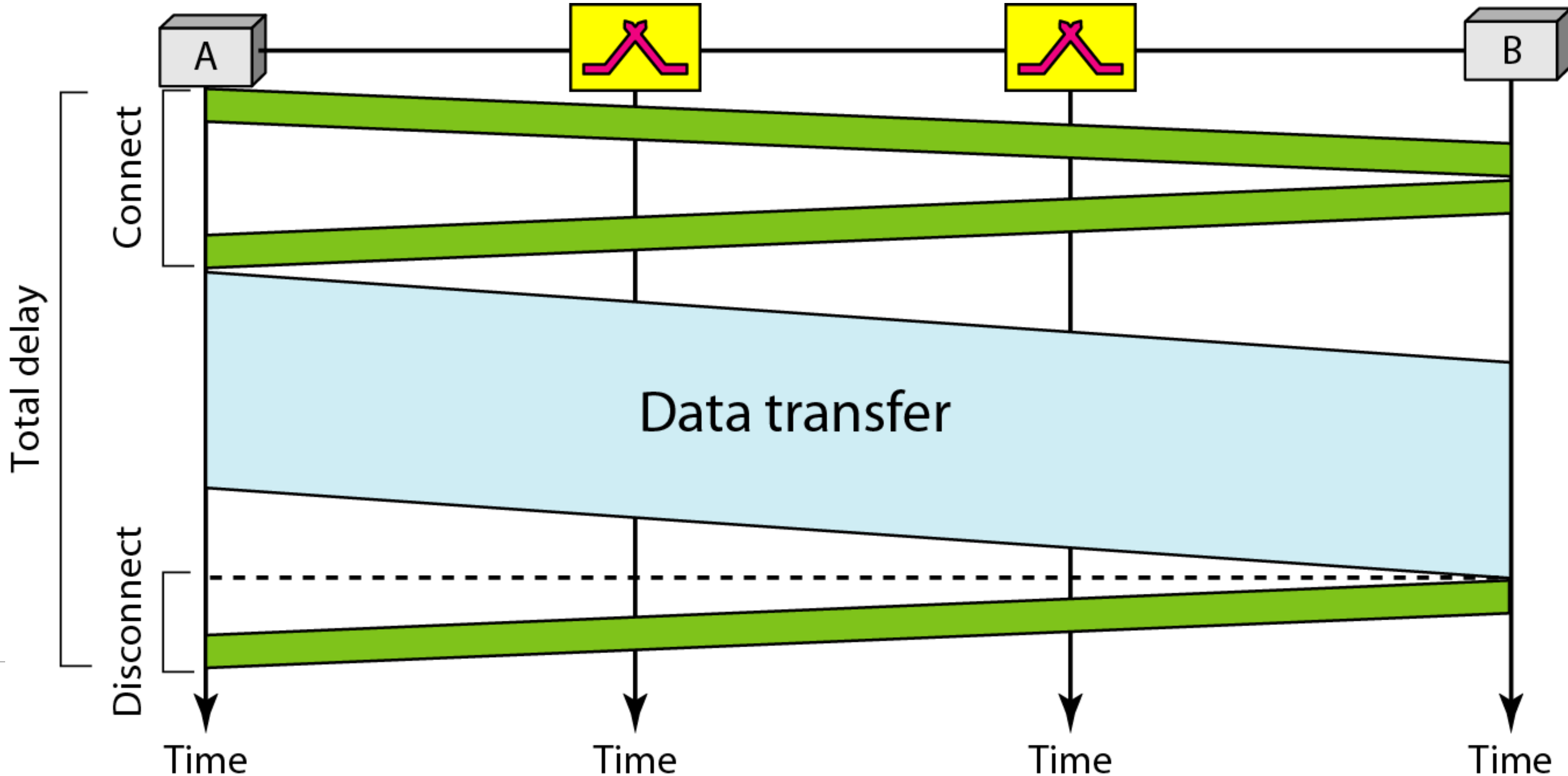


Circuit Switching

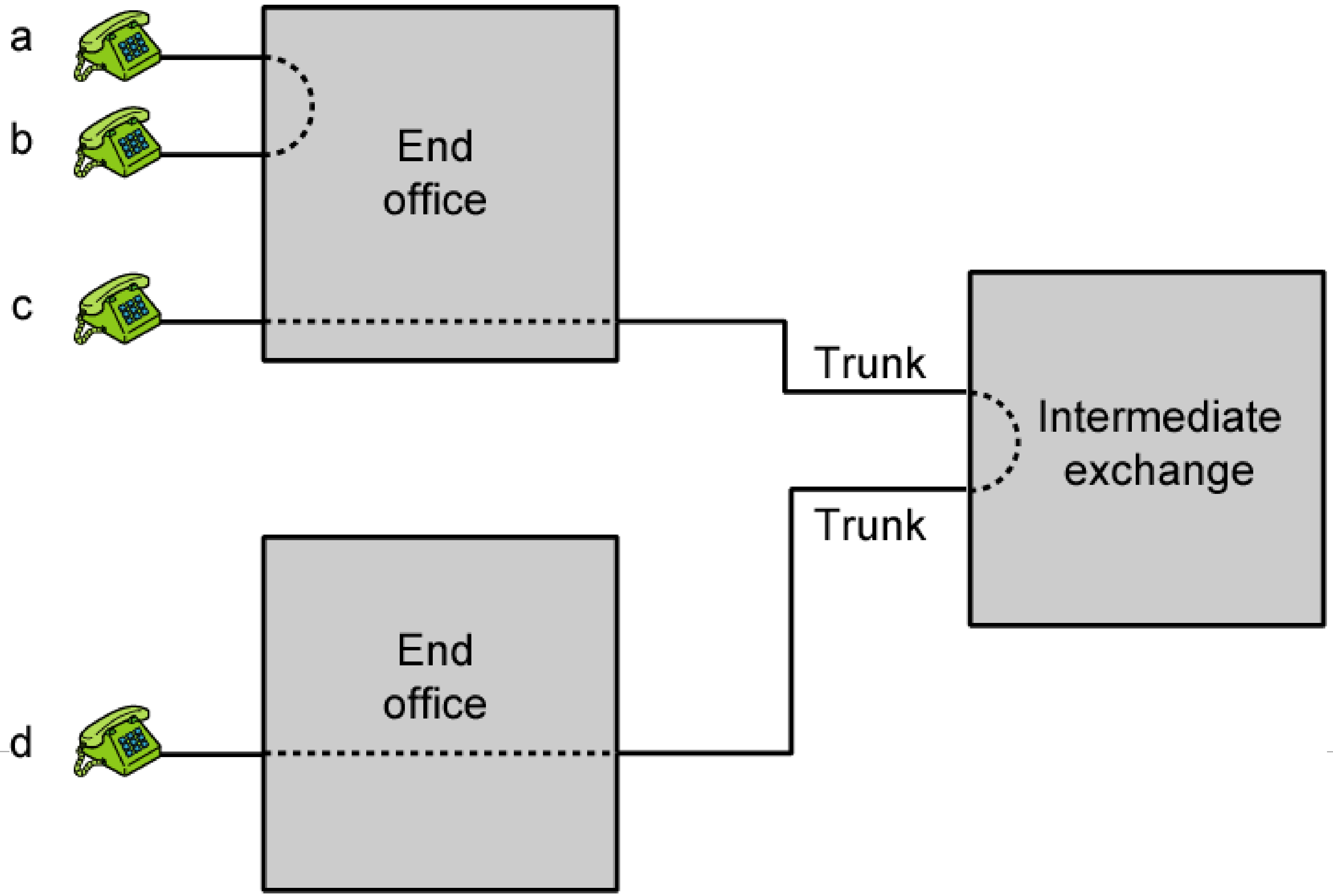
Circuit Switching

- ❑Dedicated communication path between two stations
- ❑Three phases
    - Circuit establish
    - Data transfer
    - Circuit disconnect
- ❑Must have switching capacity and channel capacity to establish connection
- ❑Must have intelligence to work out routing

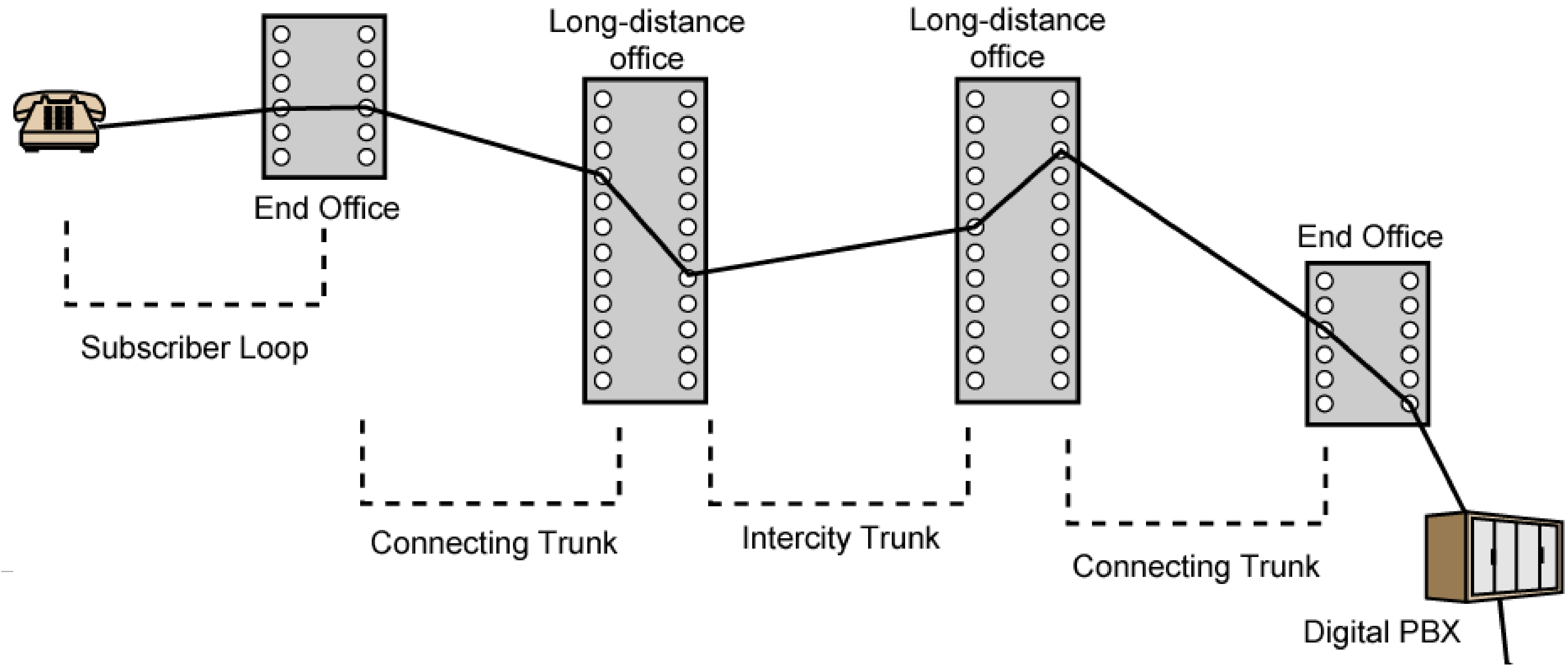
Circuit Switching



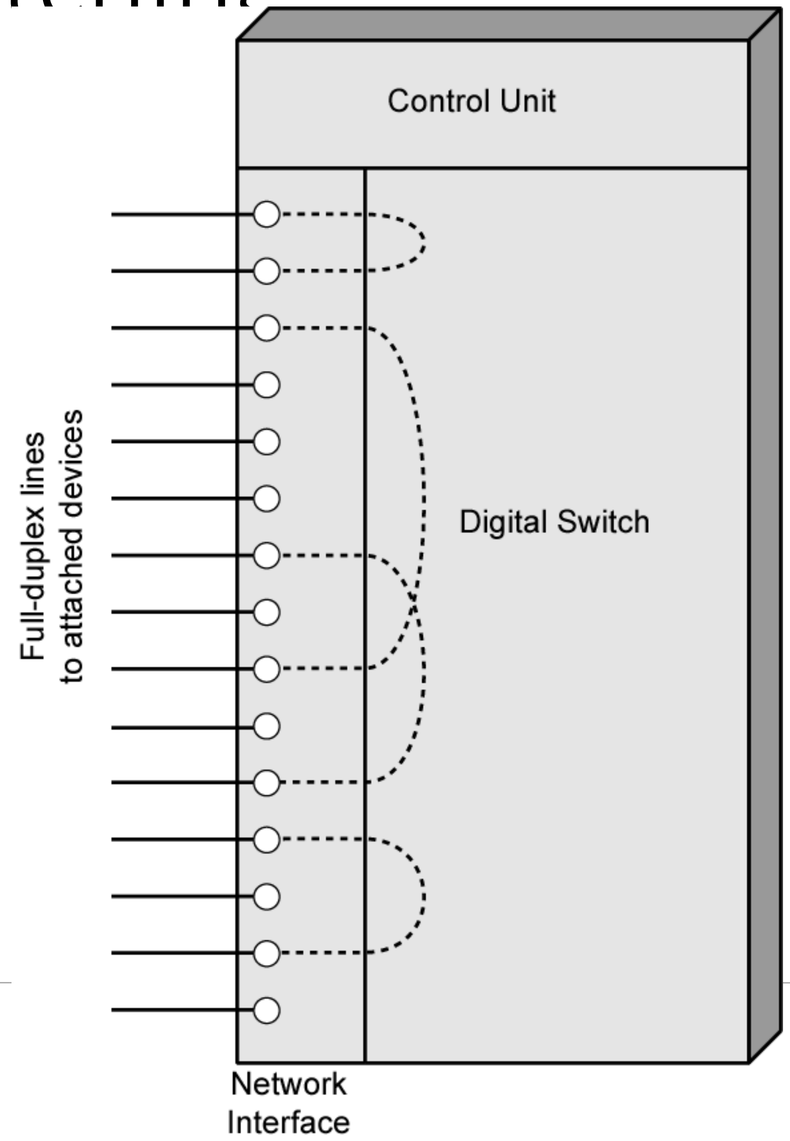
Circuit Switching



Circuit Switching



Circuit Switching



Circuit Switching

- ❑Inefficiency
  - Channel capacity is dedicated for the whole duration of a connection
  - If no data, capacity is wasted
- ❑Delay
  - Long initial delay: circuit establishment takes time
  - Low data delay: after the circuit establishment, information is transmitted at a fixed data rate with no delay other than the propagation delay. The delay at each node is negligible.
- ❑Developed for voice traffic (public telephone network) but can also applied to data traffic.
  - For voice connections, the resulting circuit will enjoy a high percentage of utilization because most of the time one party or the other is talking.
  - But how about data connections?

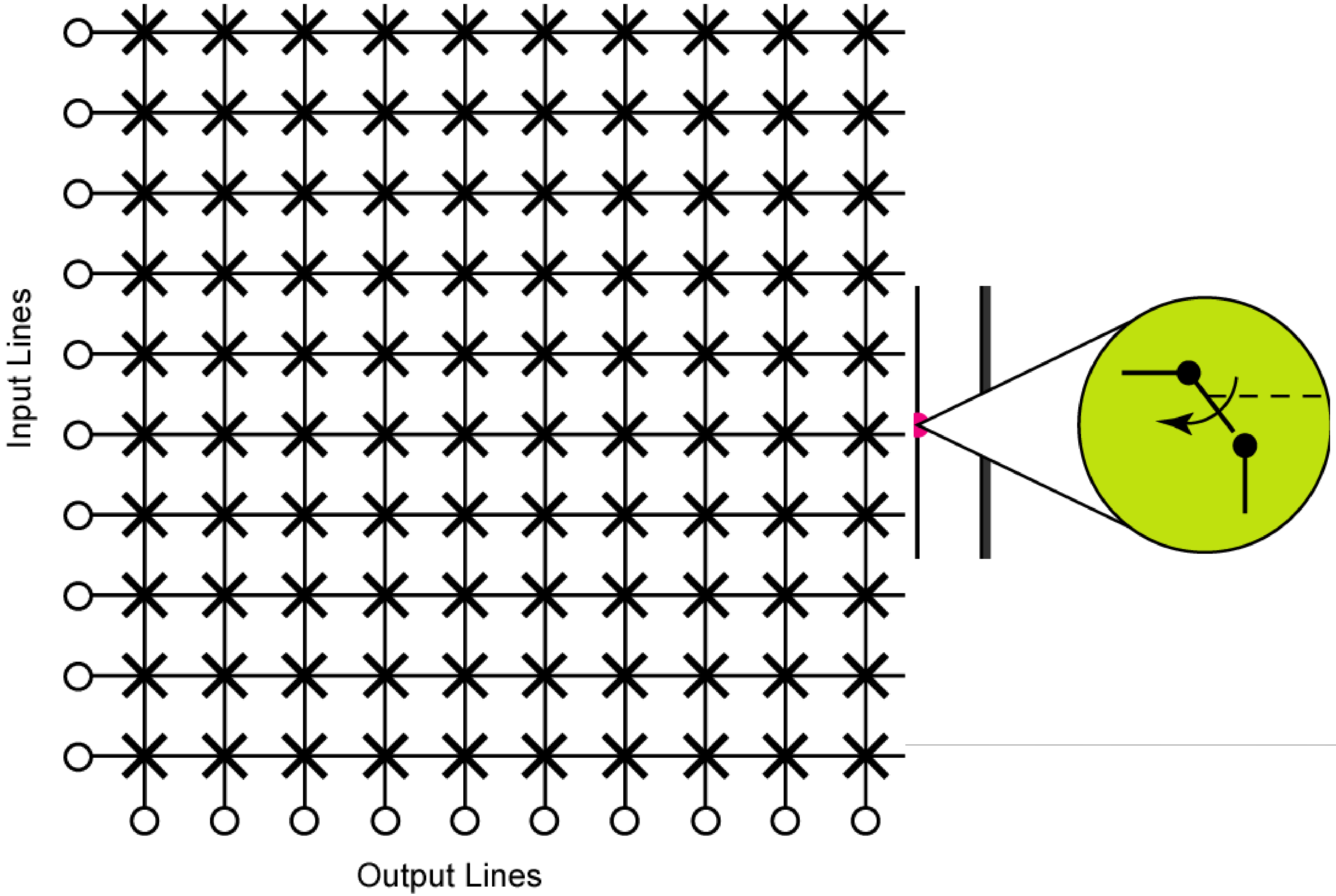
Switches: Blocking and Non-Blocking

- Blocking
  - A network is unable to connect stations because all paths are in use
  - Used on voice systems
    - Short duration calls
- Non-blocking
  - Permits all stations to connect (in pairs) at once
  - Used for some data connections

Switches: Crossbar

- Developed for analog environment
- Separate physical paths
- Crossbar switch
  - Number of crosspoints grows as square of number of stations
  - Loss of crosspoint prevents connection
  - Inefficient use of crosspoints
    - All stations connected, only a few crosspoints in use
  - Non-blocking

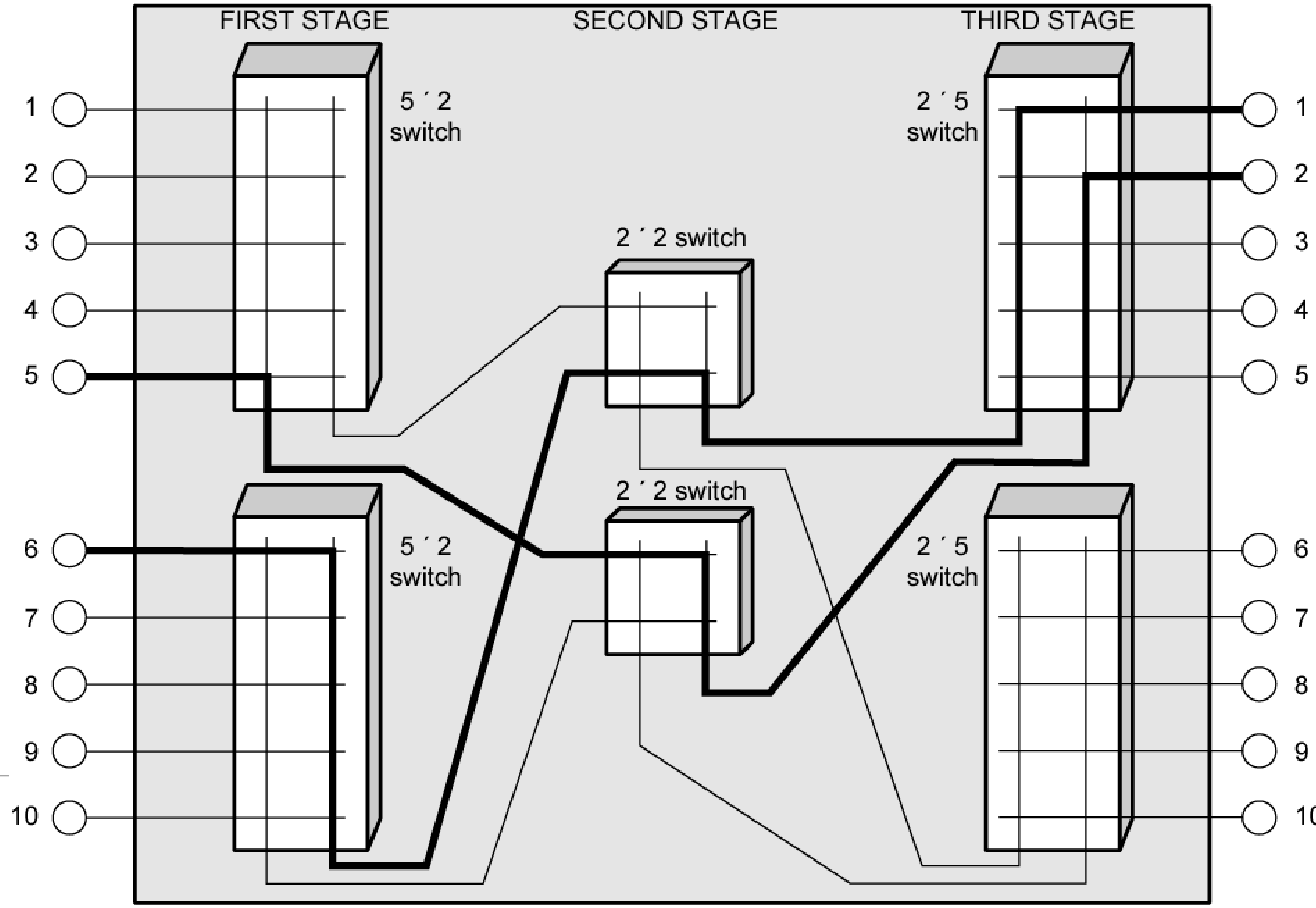
Switches: Crossbar



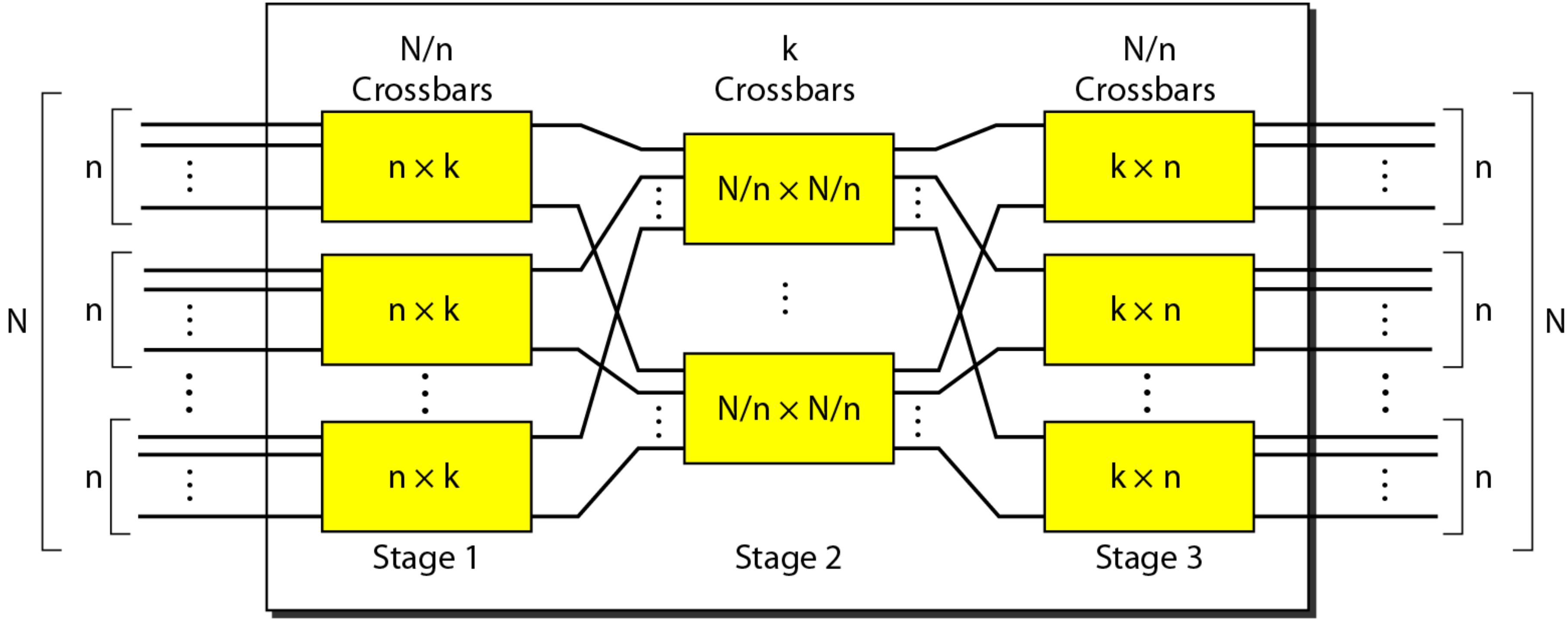
Switches: Multistage Switch

- Reduced number of crosspoints
- More than one path through network
  - Increased reliability
- More complex control
- May be blocking

Switches: Multistage Switch



Switches: Multistage Switch



In a three-stage switch, the total number of crosspoints is

$2kN + k(N/n)^2$

which is much smaller than the number of crosspoints in a single-stage switch (N^2).

Switches: Example

- *Design a three-stage, 200 × 200 switch ($N = 200$) with $k = 4$ and $n = 20$.*

- *Solution:*

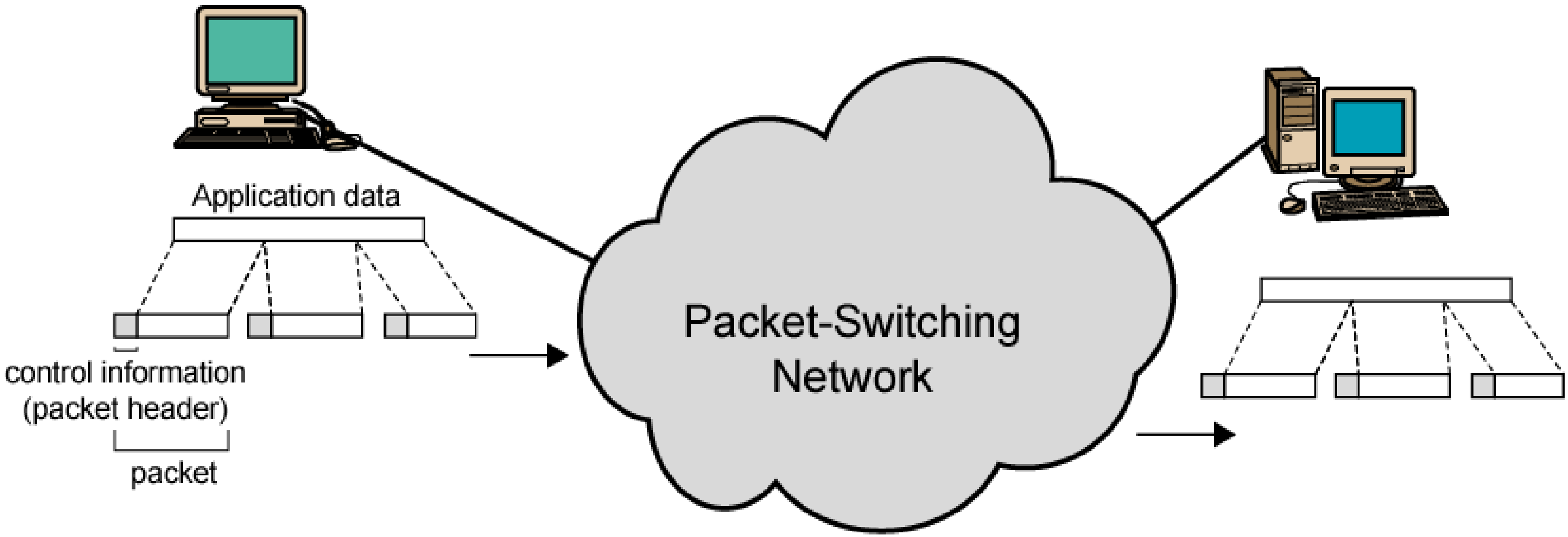
In the first stage we have N/n or 10 crossbars, each of size 20 × 4. In the second stage, we have 4 crossbars, each of size 10 × 10. In the third stage, we have 10 crossbars, each of size 4 × 20. The total number of crosspoints is $2kN + k(N/n)^2$, or 2000 crosspoints. This is 5 percent of the number of crosspoints in a single-stage switch (200 × 200 = 40,000).

Packet Switching

Packet Switching

- Data transmitted in small packets
  - 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

Packet Switching



Packet Switching

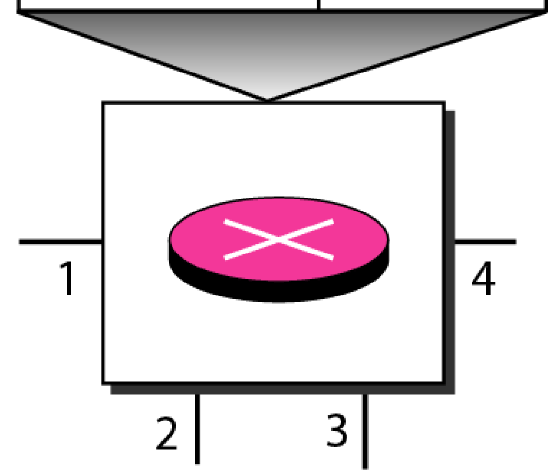
- Line efficiency
  - Single node to node link can be shared by many packets over time
  - Packets queued and transmitted as fast as possible
- Data rate conversion
  - Each station connects to the local node at its own speed
  - Nodes buffer data if required to equalize rates
- Packets are accepted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

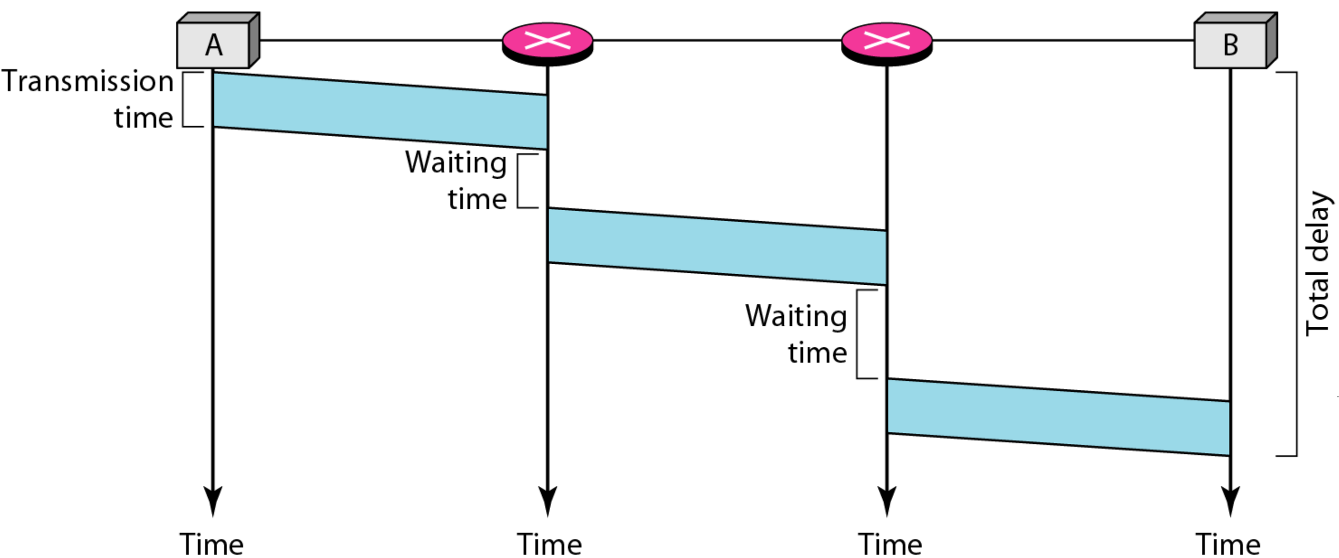
- Two types:
  - Datagram packet switching
  - Virtual circuit packet switching

Datagram Packet Switching

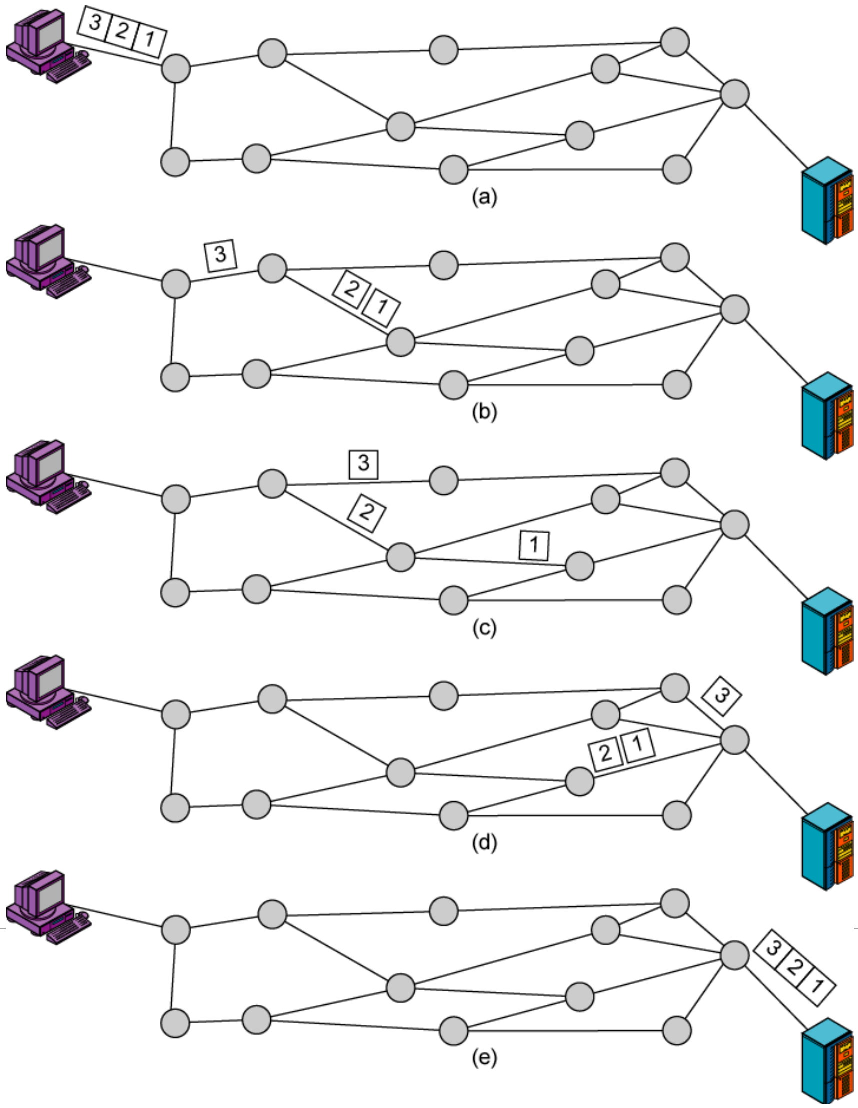
- Each packet treated independently
- Packets can take any practical route
- Packets may arrive out of order
- Packets may go missing
- Up to receiver to re-order packets and recover from missing packets

Destination address	Output port
1232	1
4150	2
⋮	⋮
9130	3





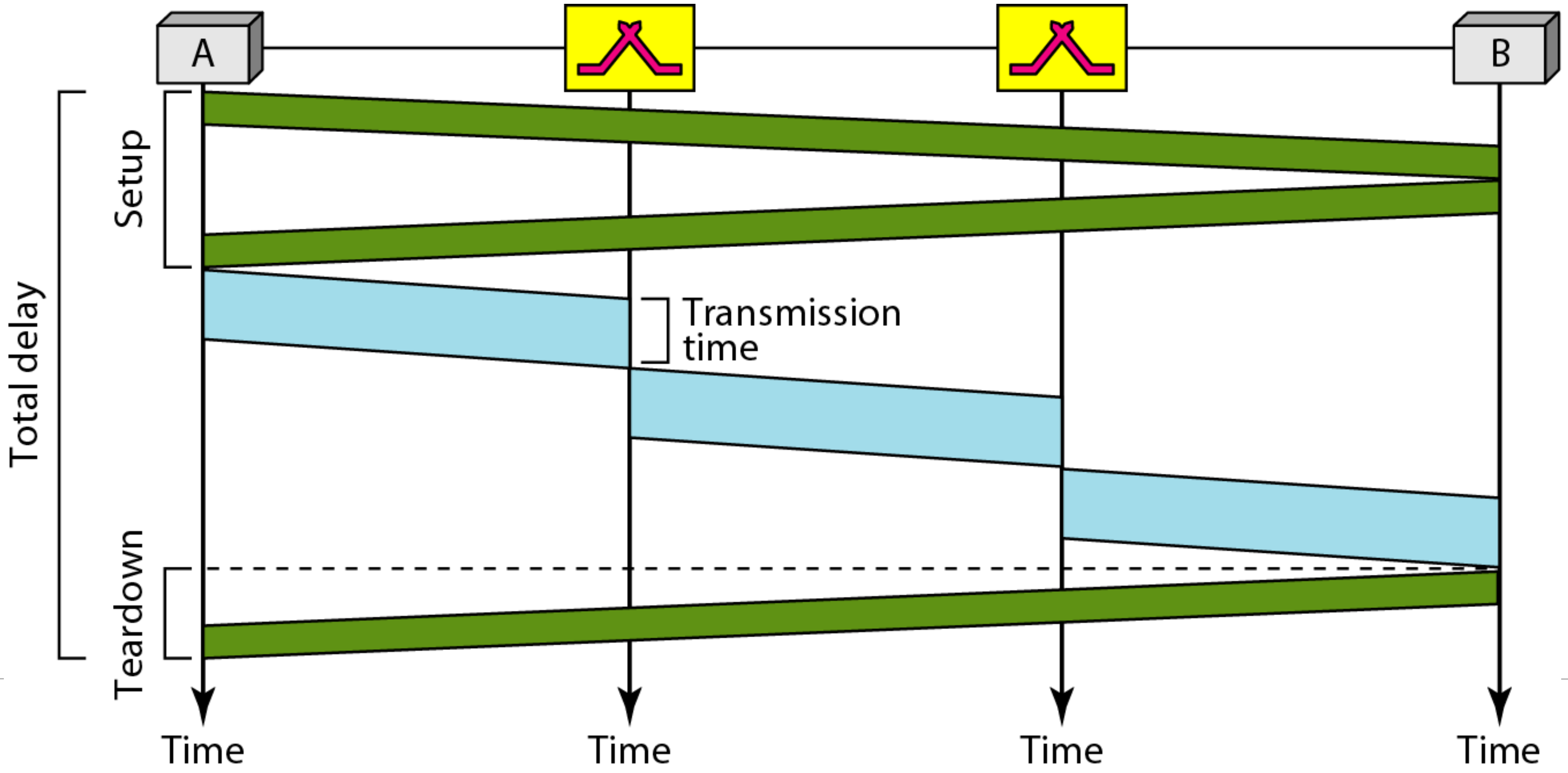
Datagram Packet Switching



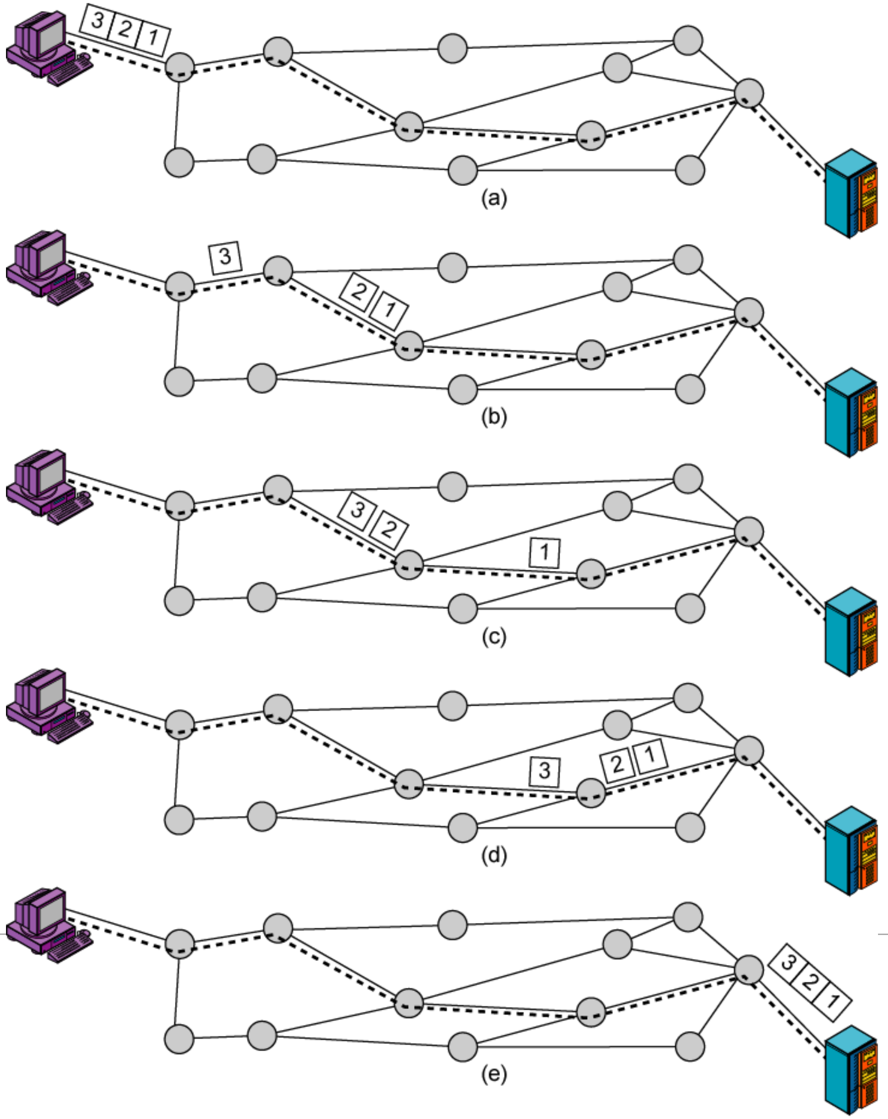
Virtual Circuit Packet Switching

- 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

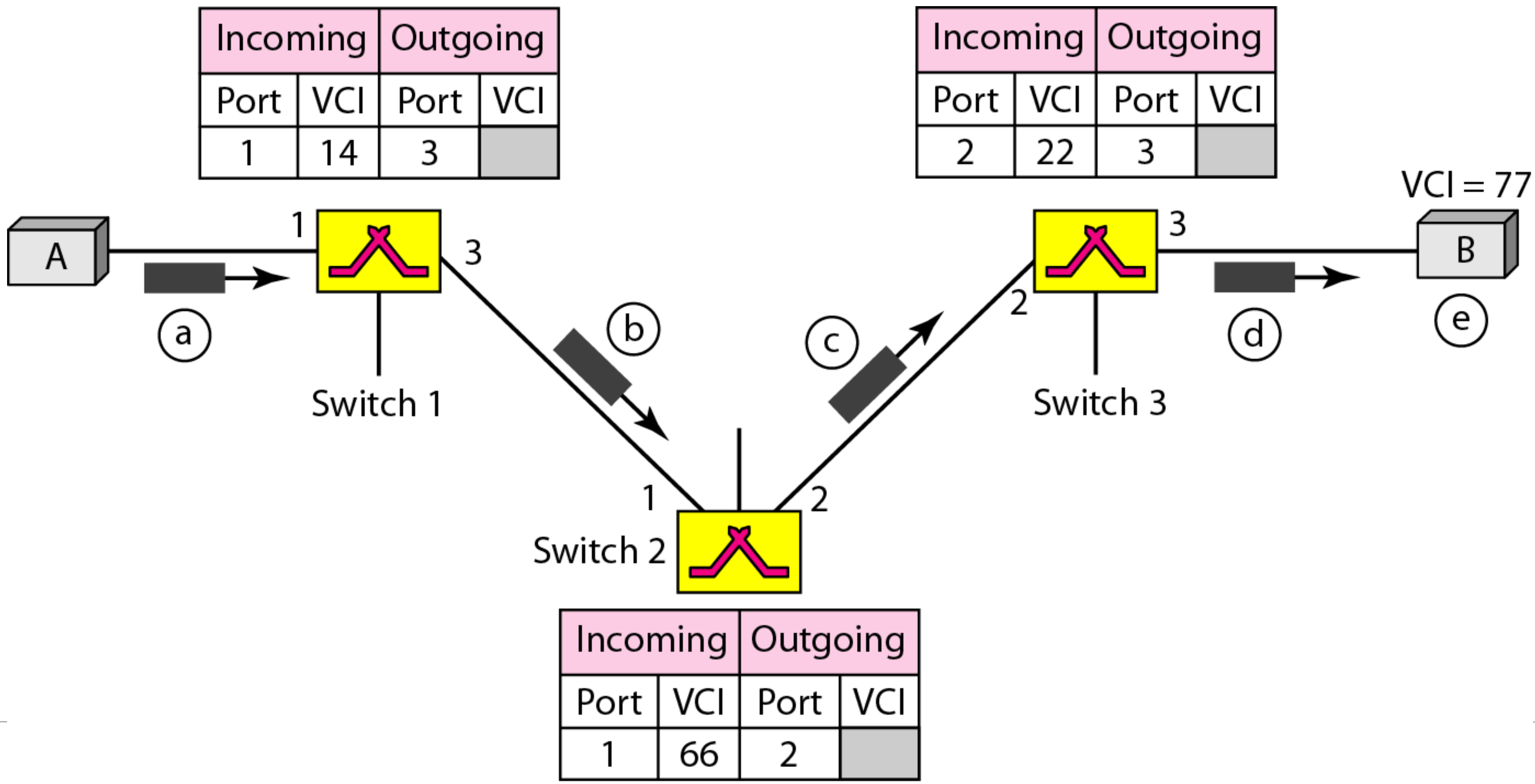
Virtual Circuit Packet Switching



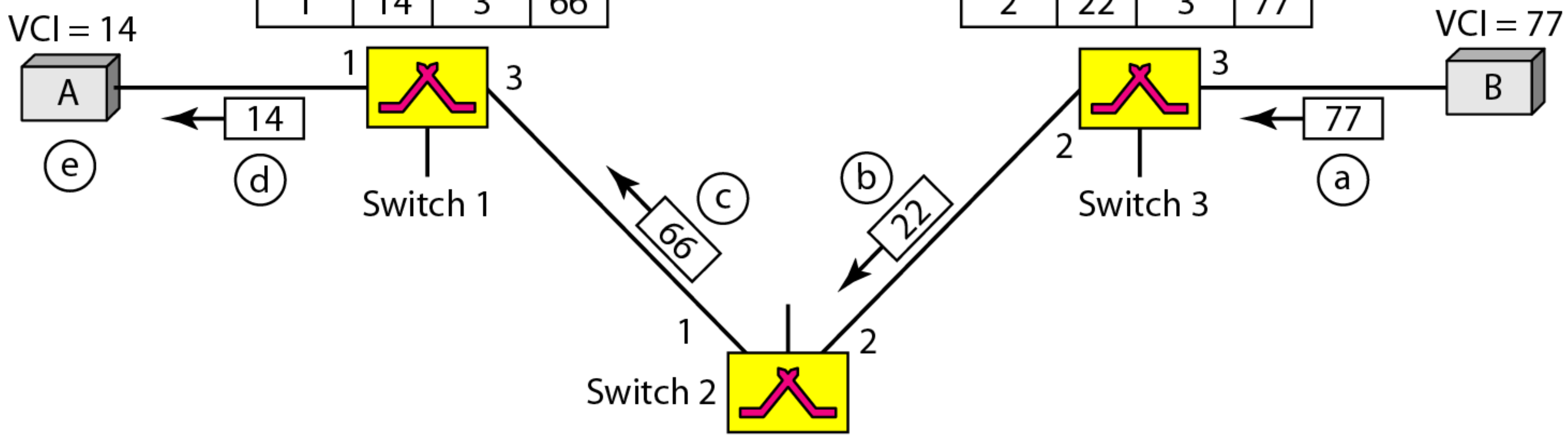
Virtual Circuit Packet Switching



Virtual Circuit Packet Switching: Setup Reqst



Virtual Circuit Packet Switching: Setup Ack



Switch 1:

Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	66

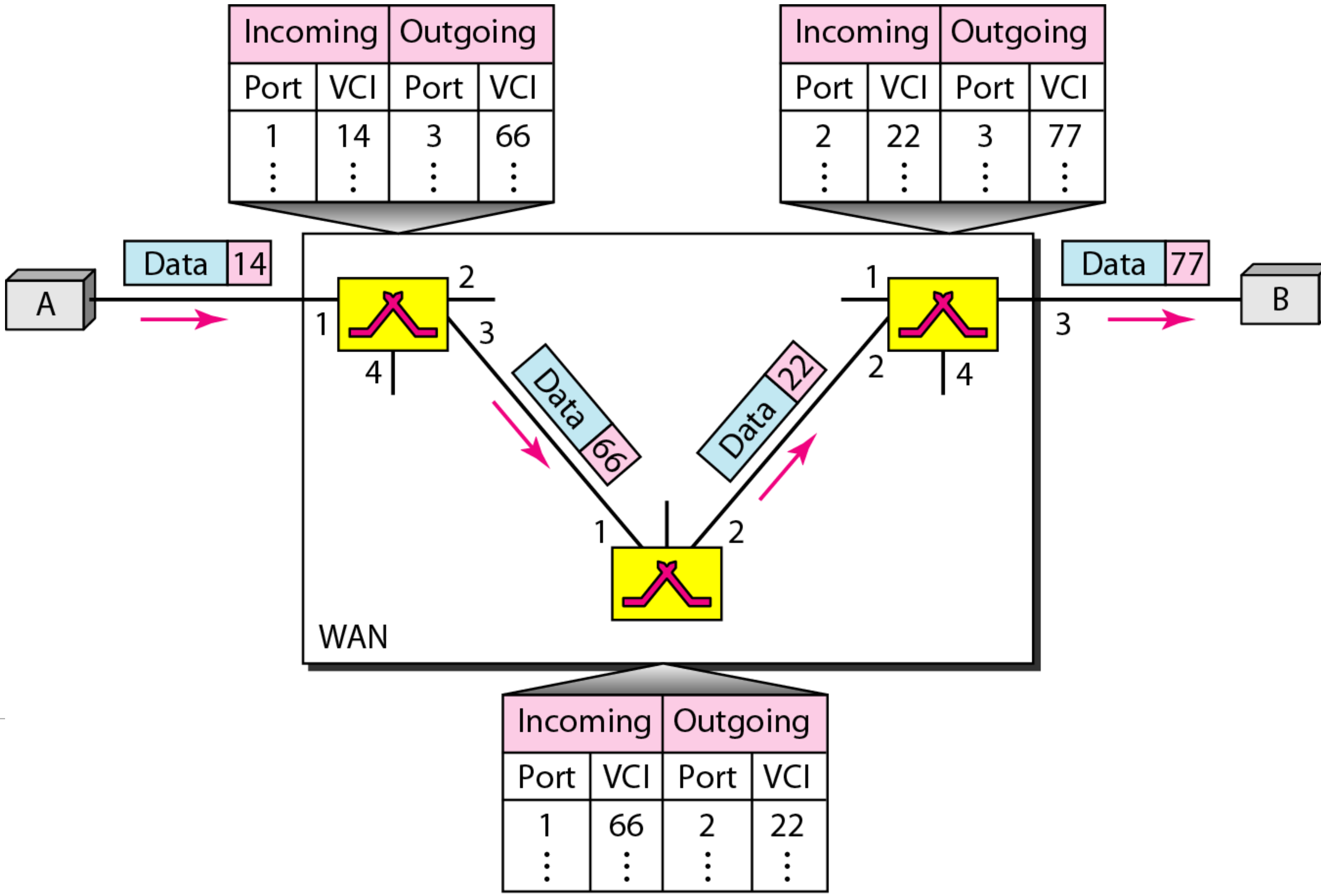
Switch 3:

Incoming		Outgoing	
Port	VCI	Port	VCI
2	22	3	77

Switch 2:

Incoming		Outgoing	
Port	VCI	Port	VCI
1	66	2	22

Virtual Circuit Packet Switching: Data Trans



Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	66
⋮	⋮	⋮	⋮

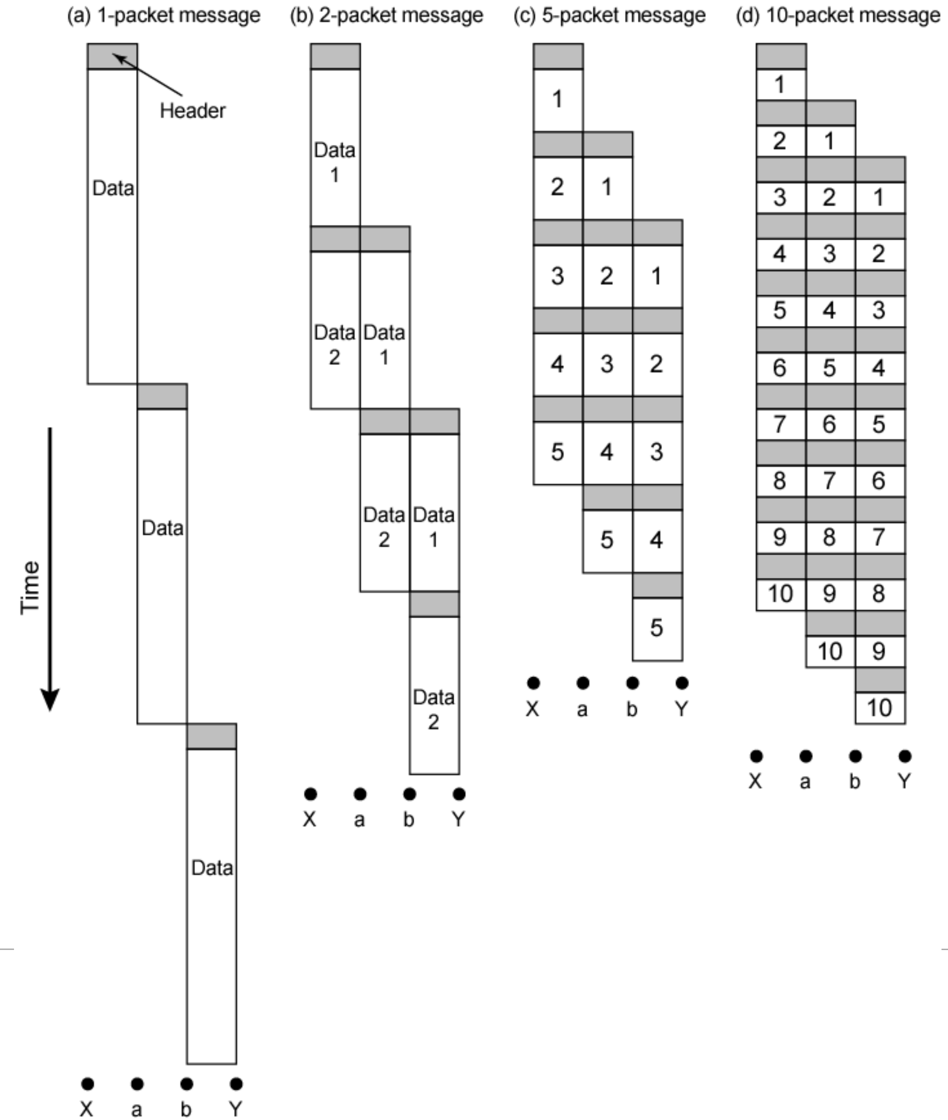
Incoming		Outgoing	
Port	VCI	Port	VCI
2	22	3	77
⋮	⋮	⋮	⋮

Incoming		Outgoing	
Port	VCI	Port	VCI
1	66	2	22
⋮	⋮	⋮	⋮

Datagram vs Virtual Packet Switching

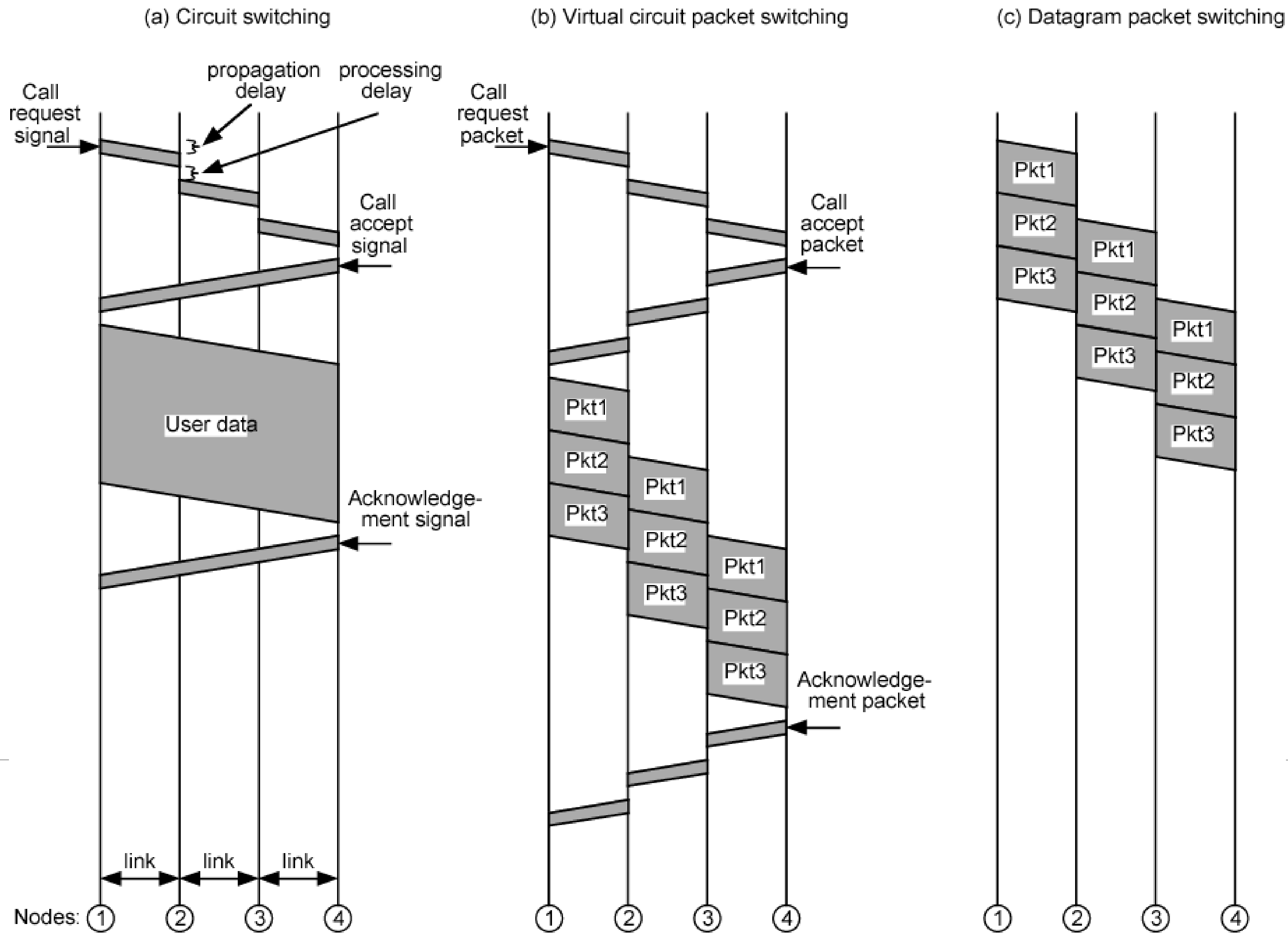
- Virtual circuits
  - Network can provide sequencing and error control
  - Packets are forwarded more quickly
    - No routing decisions to make
  - Less reliable
    - Loss of a node looses all circuits through that node
- Datagram
  - No call setup phase
    - Better if few packets
  - More flexible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

Packet Size



(a) 1-packet message
(b) 2-packet message
(c) 5-packet message
(d) 10-packet message
Header
Data
Data 1
Data 2
Time
X
a
b
Y

Event Timing



Comparison

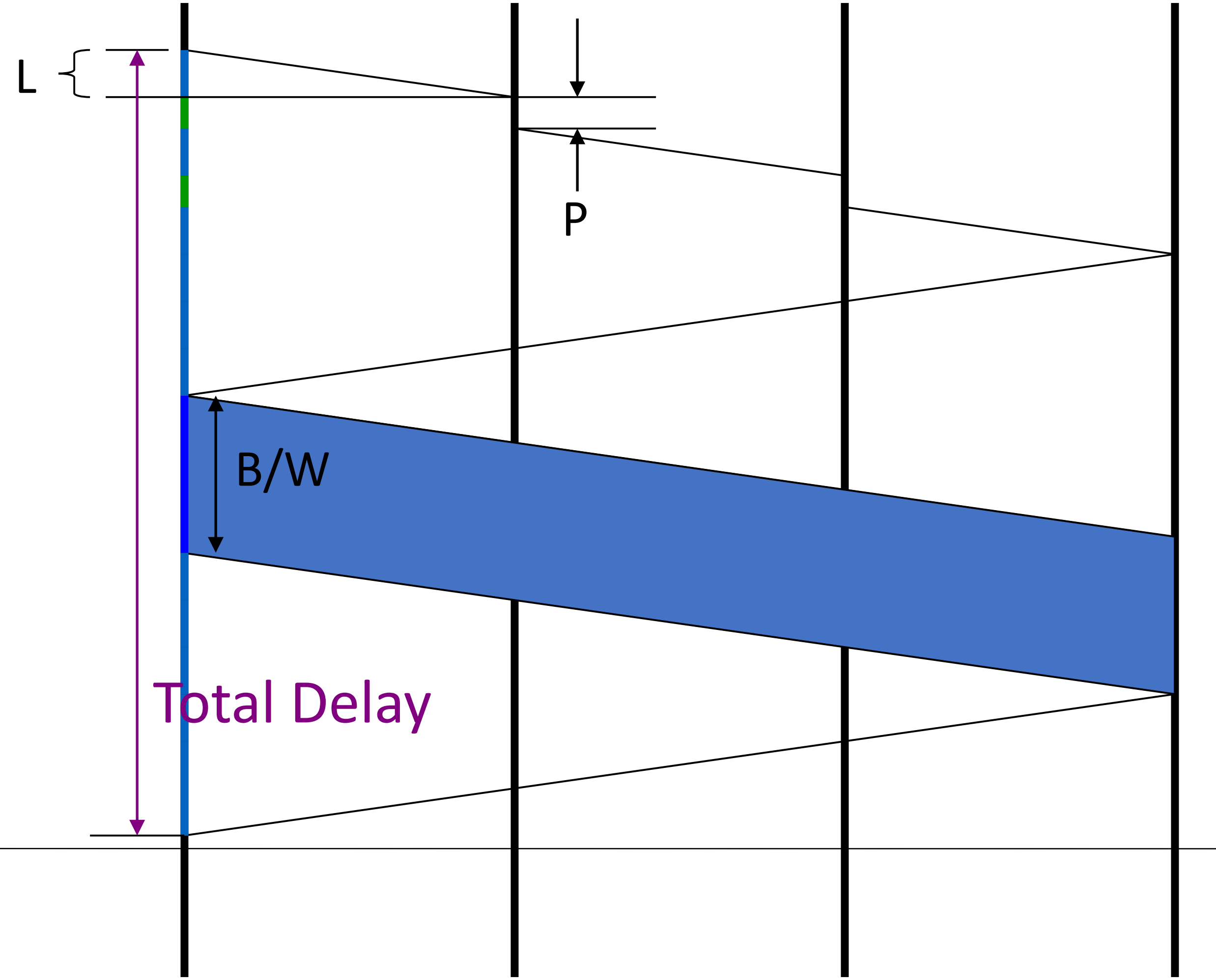
Circuit Switching	Datagram Packet Switching	Virtual Circuit Packet Switching
Dedicated transmission path	No dedicated path	No dedicated path
Continuous transmission of data	Transmission of packets	Transmission of packets
Fast enough for interactive	Fast enough for interactive	Fast enough for interactive
Messages are not stored	Packets may be stored until delivered	Packets stored until delivered
The path is established for entire conversation	Route established for each packet	Route established for entire conversation
Call setup delay; negligible transmission delay	Packet transmission delay	Call setup delay; packet transmission delay
Busy signal if called party busy	Sender may be notified if packet not delivered	Sender notified of connection denial
Overload may block call setup; no delay for established calls	Overload increases packet delay	Overload may block call setup; increases packet delay
Electromechanical or computerized switching nodes	Small switching nodes	Small switching nodes
User responsible for message loss protection	Network may be responsible for individual packets	Network may be responsible for packet sequences
Usually no speed or code conversion	Speed and code conversion	Speed and code conversion
Fixed bandwidth	Dynamic use of bandwidth	Dynamic use of bandwidth
No overhead bits after call setup	Overhead bits in each packet	Overhead bits in each packet

Timing in Circuit Switching

Assume:

- Number of hops = M
- Per-hop processing delay = P
- Link propagation delay = L
- Transmission speed = W bit/s
- Message size = B bits

Total Delay = total propagation
+ total transmission
+ total processing
= 4ML + B/W + (M-1)P



Timing in Datagram Packet Switching

Assume:

Number of hops = M

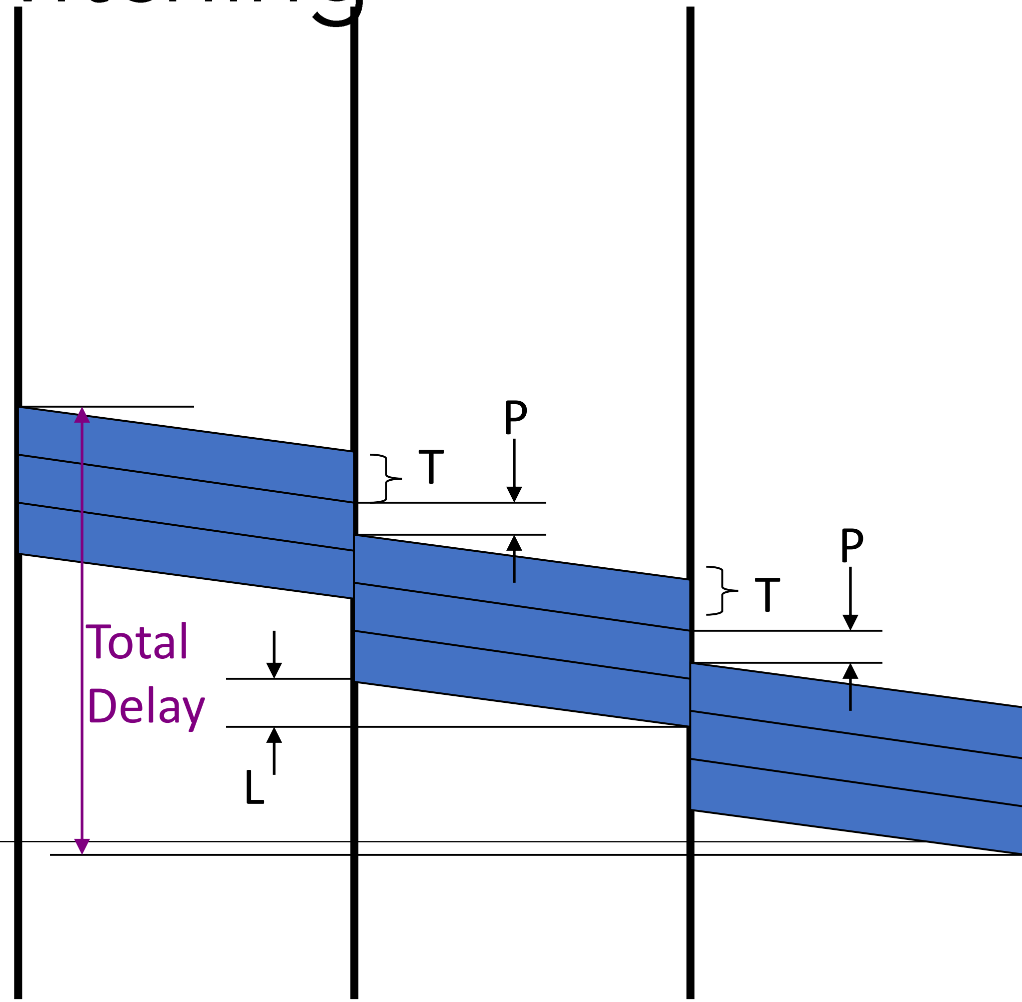
Per-hop processing delay = P

Link propagation delay = L

Packet transmission delay = T

Message size = N packets

Total Delay = total propagation
+ total transmission
+ total store&forward
+ total processing
= ML + NT + (M-1)T + (M-1)P



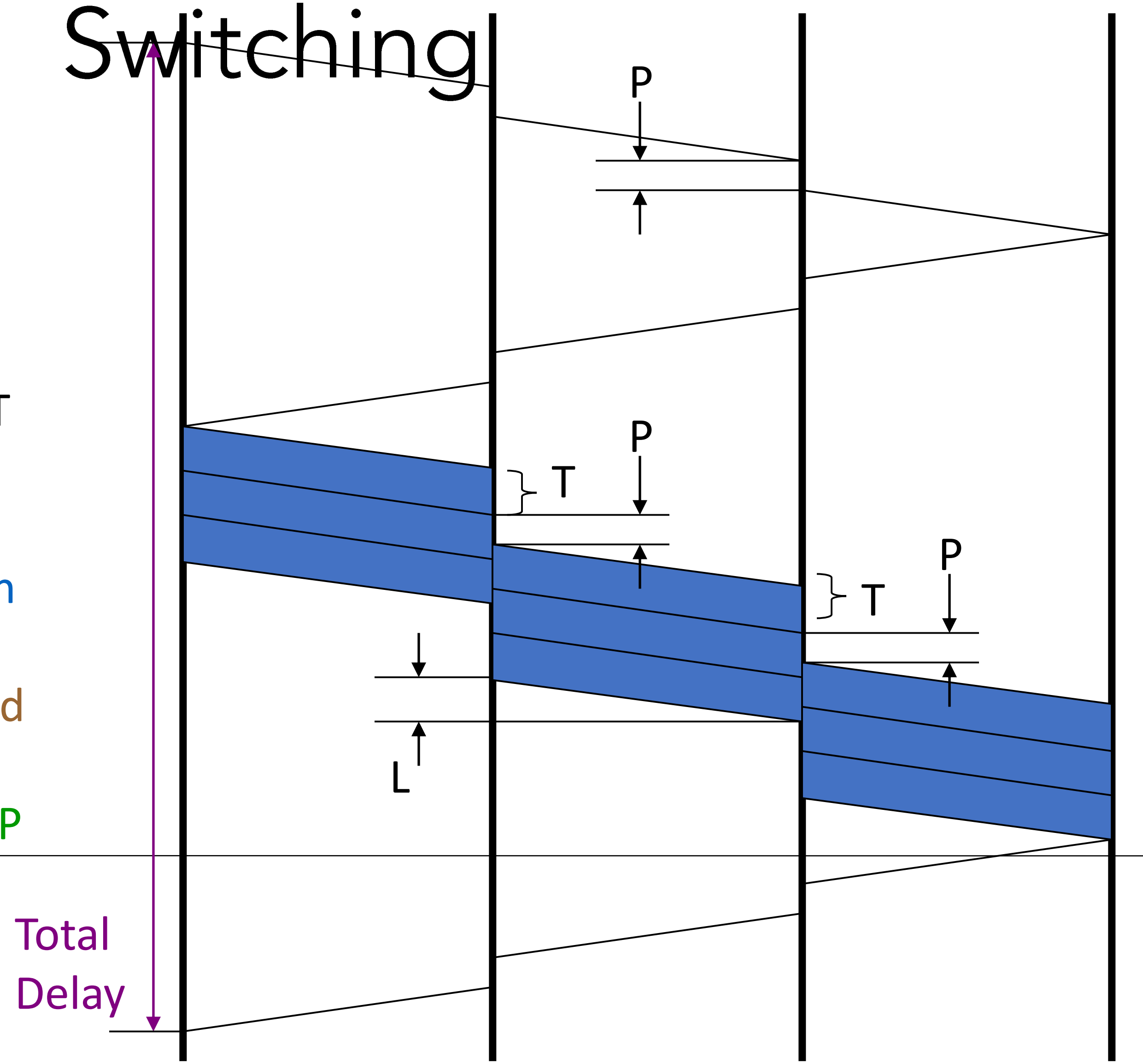
Timing in Virt. Circ. Packet Switching

Assume:

- Number of hops = M
- Per-hop processing delay = P
- Link propagation delay = L
- Packet transmission delay = T
- Message size = N packets

Total Delay = total propagation
+ total transmission
+ total store&forward
+ total processing

$= 4ML + NT + (M-1)T + 4(M-1)P$



Remark

- We are often interested only in the delay elapsed from the time the first bit was sent to the time the last bit was received (i.e., we exclude the time involved in acknowledging connection termination). If this is the case, the delay will be given as follows:
  - Circuit Switching:

  Delay = 3ML + B/W + (M-1)P

  - Datagram packet switching:

  Delay = ML + NT + (M-1)T + (M-1)P (same as before)

  - Virtual circuit packet switching:

  Delay = 3ML + NT + (M-1)T + 3(M-1)P

Solved Exercises

Q1: It's 1989. Alice and Bob are 4 hops apart on a datagram packet-switched network where each link is 100 mile long. Per-hop processing delay is 5μs. Packets are 1500 bytes long. All links have a transmission speed of 56kbit/s (original speed of Internet backbone links in the 80s). The speed of light in the wire is approximately 125,000 miles/s. If Bob sends a 10-packet message to Alice, how long will it take Alice to receive the message up to the last bit (measured from the time Bob starts sending)?

- Answer: We know the following:
  - Number of hops M=4,
  - Number of packets N=10,
  - Per-hop processing delay P=5μs=0.000005s,
  - Link propagation delay L = distance/speed of light = 100/125,000 = 0.0008s,
  - Packet size = 1500 bytes = 1500*8=12,000 bits,
  - Packet transmission delay T = packet size/transmission speed = 12,000/56000 =0.214s.

  Delay = ML + NT + (M-1)T + (M-1)P =0.0032 + 2.14 + 0.642 + 0.000015 = 2.785s.
- Note that the total delay is dominated by the transmission delay which depends on link speed. A link with a higher transmission speed can reduce the delay dramatically.

Solved Exercises

Q2: Alice and Bob 12 years later. All is the same, except that link transmission speed now is 1Gbit/s. How long will it take Alice to receive the message up to the last bit (measured from the time Bob starts sending)?

- Answer: As before, we know the following:
  - Number of hops M=4,
  - Number of packets N=10,
  - Per-hop processing delay P=5μs,
  - Link propagation delay L = distance/speed of light = 100/125,000 = 800μs,
  - Packet size = 1500 bytes = 1500*8=12,000 bits,
  - Packet transmission delay T = packet size/transmission speed = 12,000/10^9 =12μs.

  Delay = ML + NT + (M-1)T + (M-1)P =3200 + 120 + 36 + 15 = 3371μs = 3.371ms.
- Note that the total delay is now dominated by the **propagation delay** which cannot be improved because it is constrained by the speed of light. Hence, it is unlikely that future technologies will significantly reduce the delay of Bob’s message at this point (unless we break the speed of light)!

Solved Exercises

Q3: Repeat Q1 and Q2, assuming that the network uses circuit switching instead of datagram packet switching. Bob's message is the same length as before.

- Answer: Year 1989:
  - Number of hops $M=4$,
  - Message size $B = 10 * 1500 * 8 = 120{,}000$ bits (it is not packetized)
  - Link transmission speed $W = 56$kbit/s,
  - Per-hop processing delay $P=0.000005$s,
  - Link propagation delay L = distance/speed of light = $100/125{,}000 = 0.0008$s,

  Delay = $3ML + B/W + (M-1)P = 0.0096 + 2.14 + 0.000015 = 2.1496$s
- Note that the delay improved over the case of datagram packet switching for the same link speed. Why?
- Year 2001: Let link transmission speed be W = 1Gbit/s

  Delay = $3ML + B/W + (M-1)P = 9600 + 120 + 15 = 9735\mu s = 9.735$ms
- Note that the delay is worse than in the case of datagram packet switching. Why?

Observations

- With the advances in transmission speed total delays are dominated by propagation delays which are bound by the speed of light.
- Circuit switching adds an extra roundtrip over datagram packet switching, but eliminates store and forward delays. We have two cases:
  - When links are slow, the bottleneck is transmission speed on the link. Eliminating the need to store-and-forward helps a lot. The extra roundtrip adds only negligible delay. Hence, using circuit switching results in a net reduction in delay.
  - When links are fast, the bottleneck is propagation delay. Adding a roundtrip hurts a lot. Eliminating the need for store-and-forward saves a negligible amount of time. Hence, using circuit switching results in a net increase in delay.

THANK YOU

QUESTIONS???