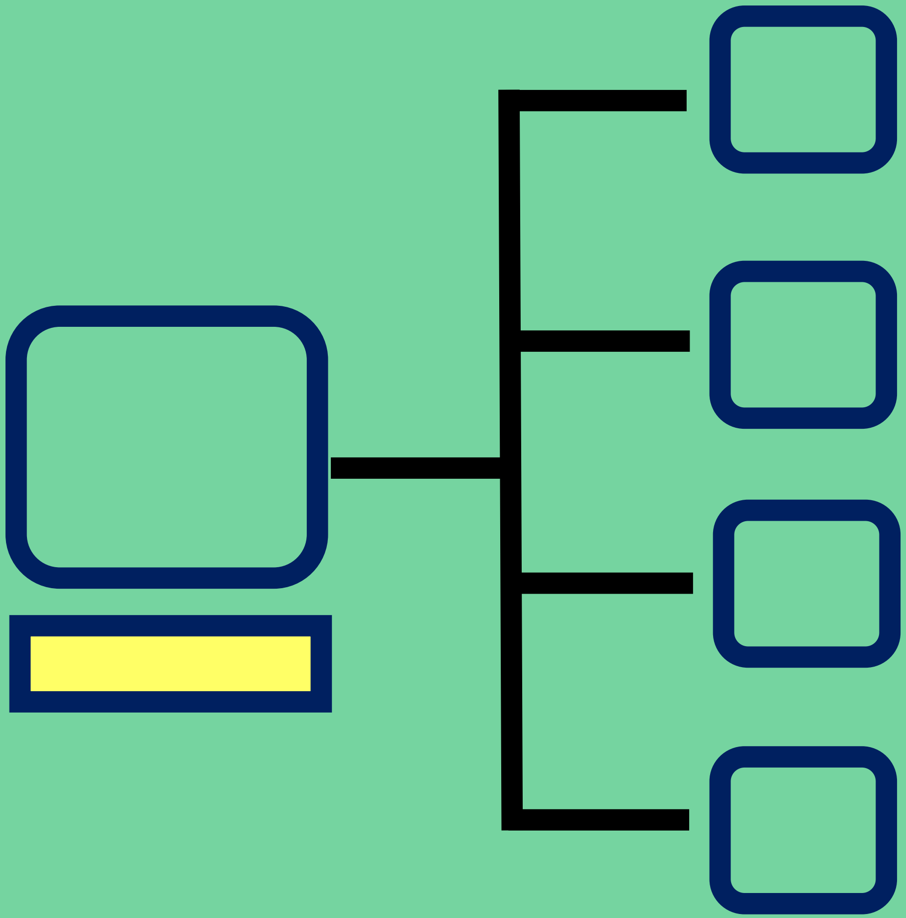
COMP2211: Networks and Systems



Lecture 2

Core Concepts of Computer Networks

Re-cap

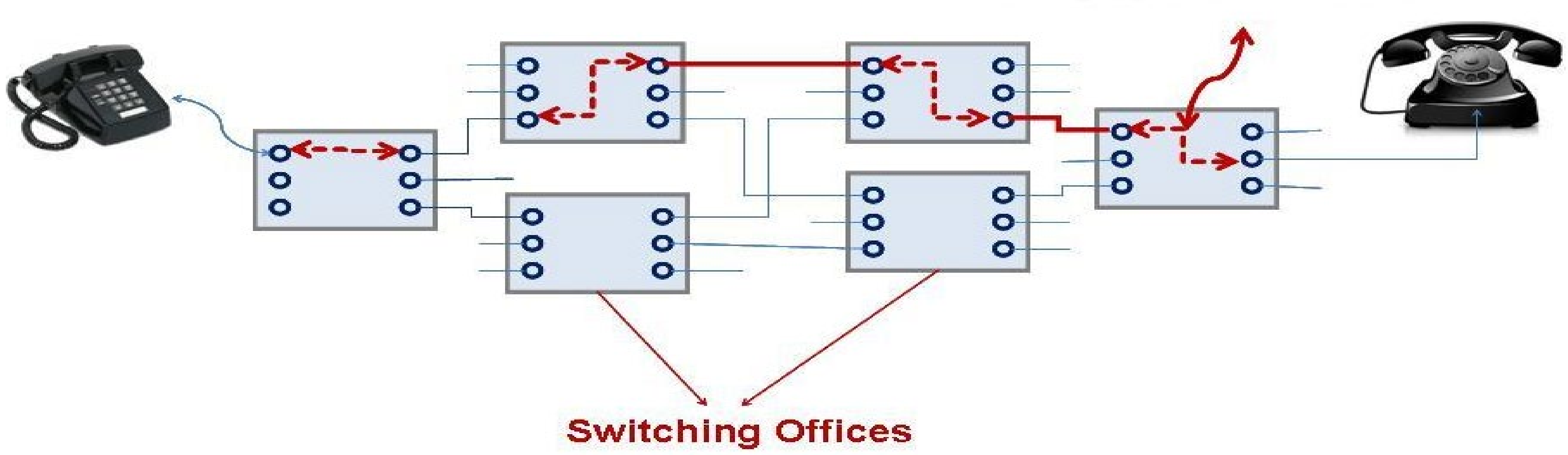
- Network hardware components
- Physical media for data communications
- Network protocols
- Different access networks
- Network security

Today's Outline

- Packet switching vs. circuit switching
- OSI reference model
- Routing and forwarding
- Delay and loss in networks

Circuit Switching

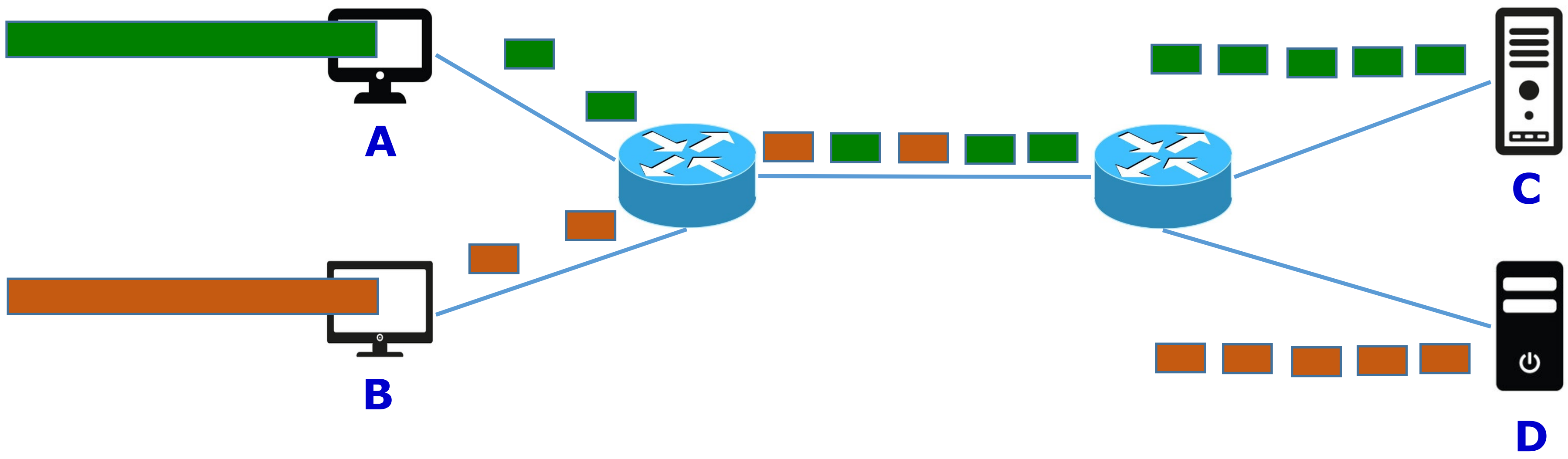
Two network nodes establish a dedicated communication channel (called circuit) before the nodes may communicate.



- Users remain connected to and enjoy the full bandwidth of the channel until the session terminated.
- Commonly used in traditional telephone networks.

Packet Switching

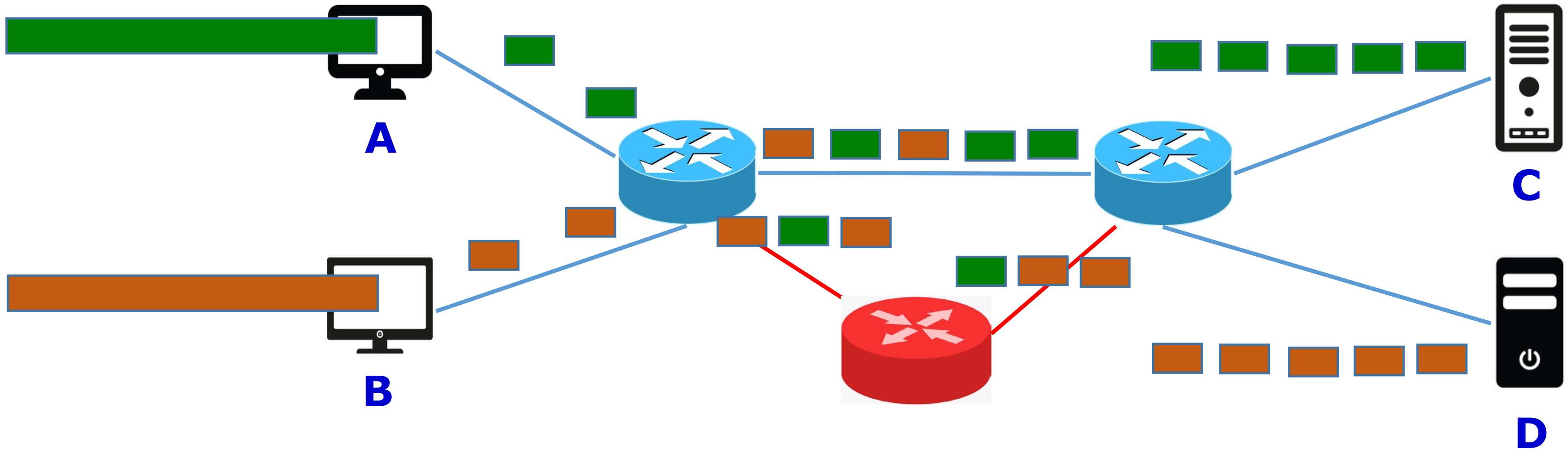
Two network nodes do not establish a dedicated communication channel. Transmission links are shared by multiple users.



- End devices break application data into small pieces for transmissions.
- Use transmission links more efficiently.

Packet Switching (cont.)

Two network nodes do not establish a dedicated communication channel. Transmission links are shared by multiple users.



- End devices break application data into small pieces for transmissions.
- Use transmission links more efficiently.
- Different pieces may take different paths to reach the destinations.

OSI Reference Model

Open Systems Interconnection model (OSI model)

Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data-link Layer
Physical Layer

- Each layer provides some functionality to the upper layers and relies on lower layers
- Upper layers are more concerned with user services and applications
- Lower layers are more concerned with hardware and the actual transmission of data

OSI Reference Model (cont.)

Application Layer	Emails, web browser, file transfer, Skype…
Presentation Layer	translate data formats, data encryption/decryption
Session Layer	establish/terminate a session, synch communicating nodes
Transport Layer	support communications between diverse applications across diverse networks
Network Layer	determine the best path through the network
Data-link Layer	define frames, detect and manage collisions, error detection
Physical Layer	manage physical medium and signal transmissions

Not the actual network. Only a representation of a network operation.

OSI Reference Model (cont.)

- Advantages of a layered model

  - Preventing technology or capability changes in one layer from affecting other layers above or below

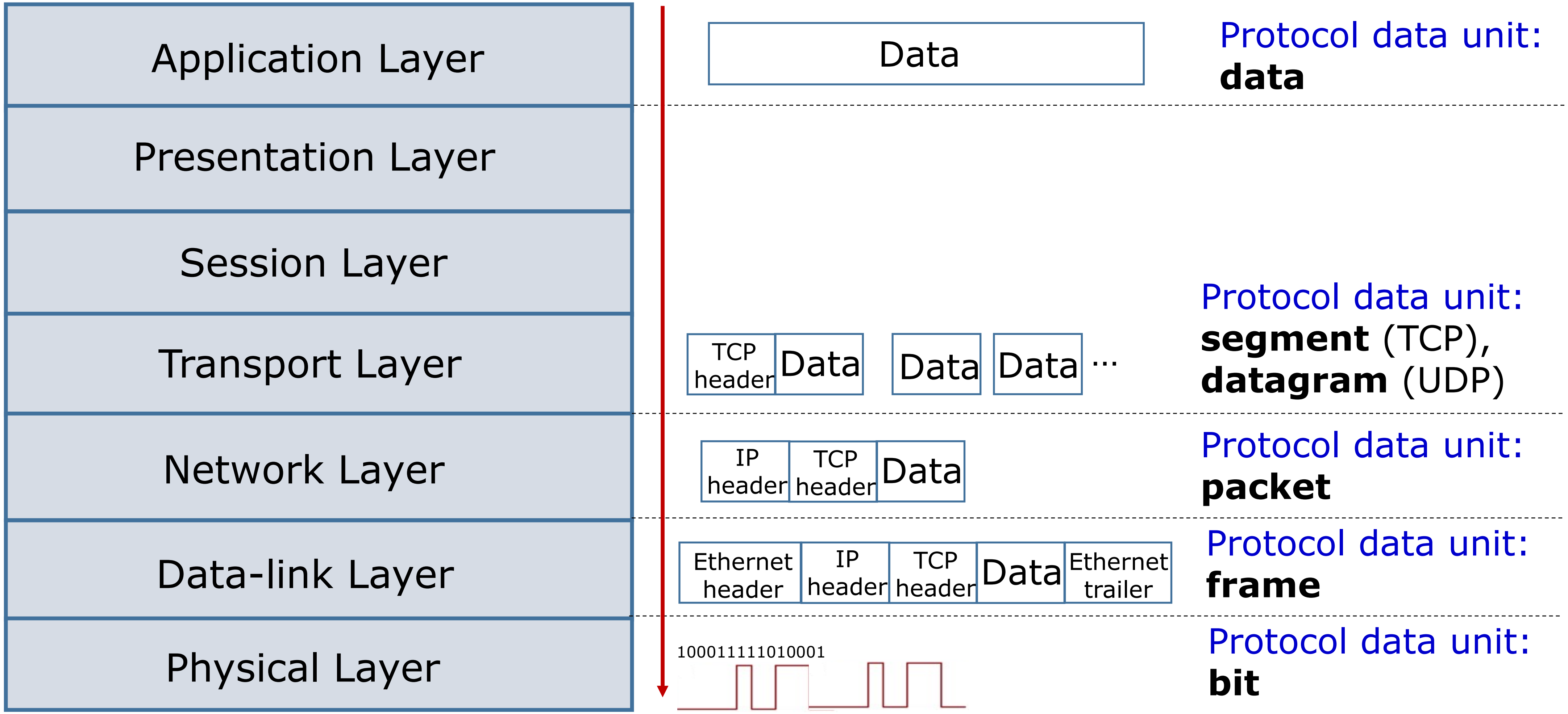
  - Providing a common language to describe networking functions and capabilities

  - Assisting in protocol design

    Protocols at different layers work together to form a protocol suite, e.g., HTTP/TCP/IP

Protocol Encapsulation

Sender side



Protocol De-Encapsulation

Receiver side

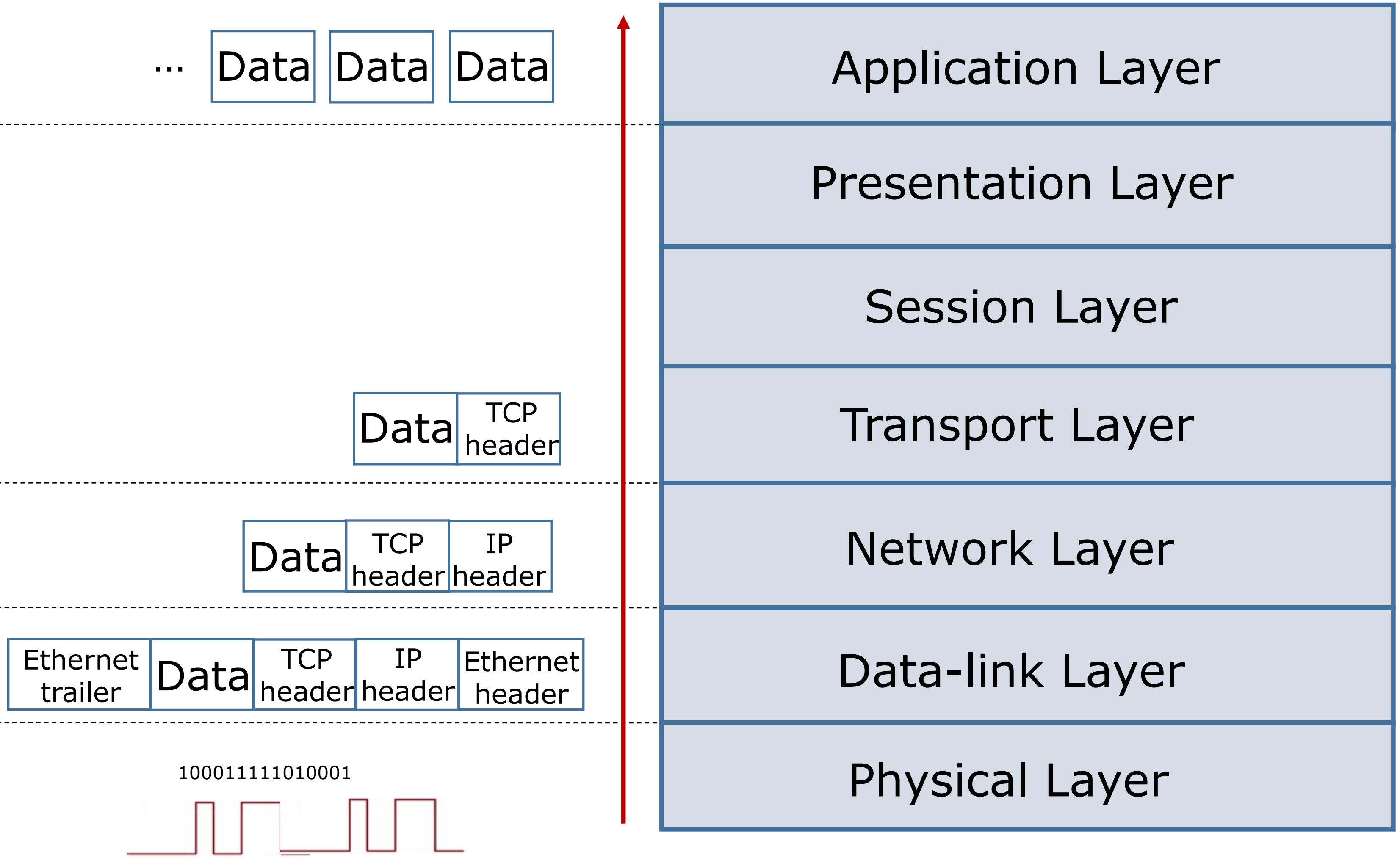
Protocol data unit:
data

Protocol data unit:
segment (TCP),
datagram (UDP)

Protocol data unit:
packet

Protocol data unit:
frame

Protocol data unit:
bit



TCP/IP Model

OSI Model		TCP/IP Model
Application Layer	Http, DNS, DHCP, FTP	Application Layer
Presentation Layer		
Session Layer		
Transport Layer	TCP, UDP	Transport Layer
Network Layer	IPv4, IPv6	Network Layer
Data-link Layer	PPP, Frame relay, Ethernet	Network Access
Physical Layer		

Network Structure

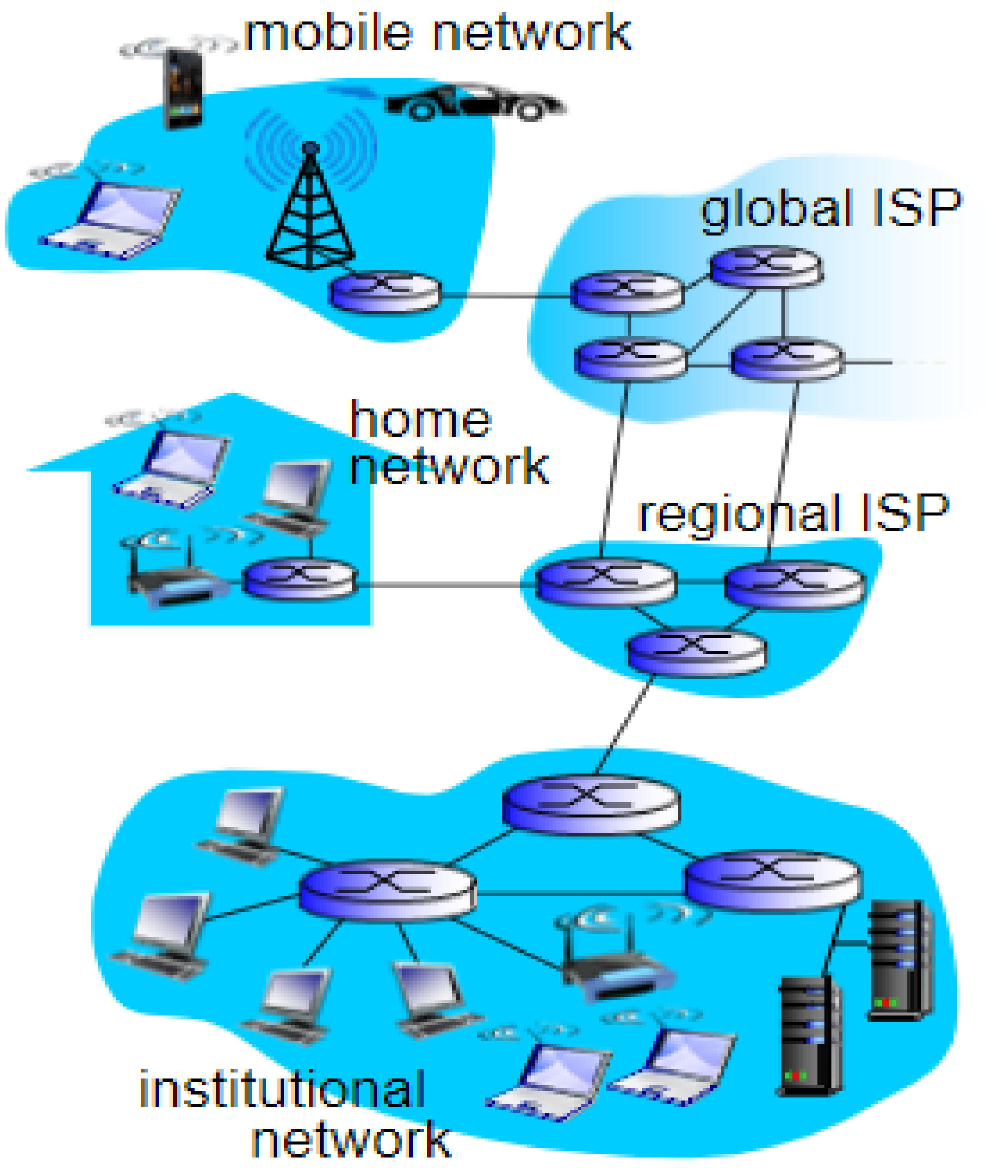
Network edge

- End devices/hosts: clients, servers
- Client: various traditional and modern smart user devices
- Server: often in data centres

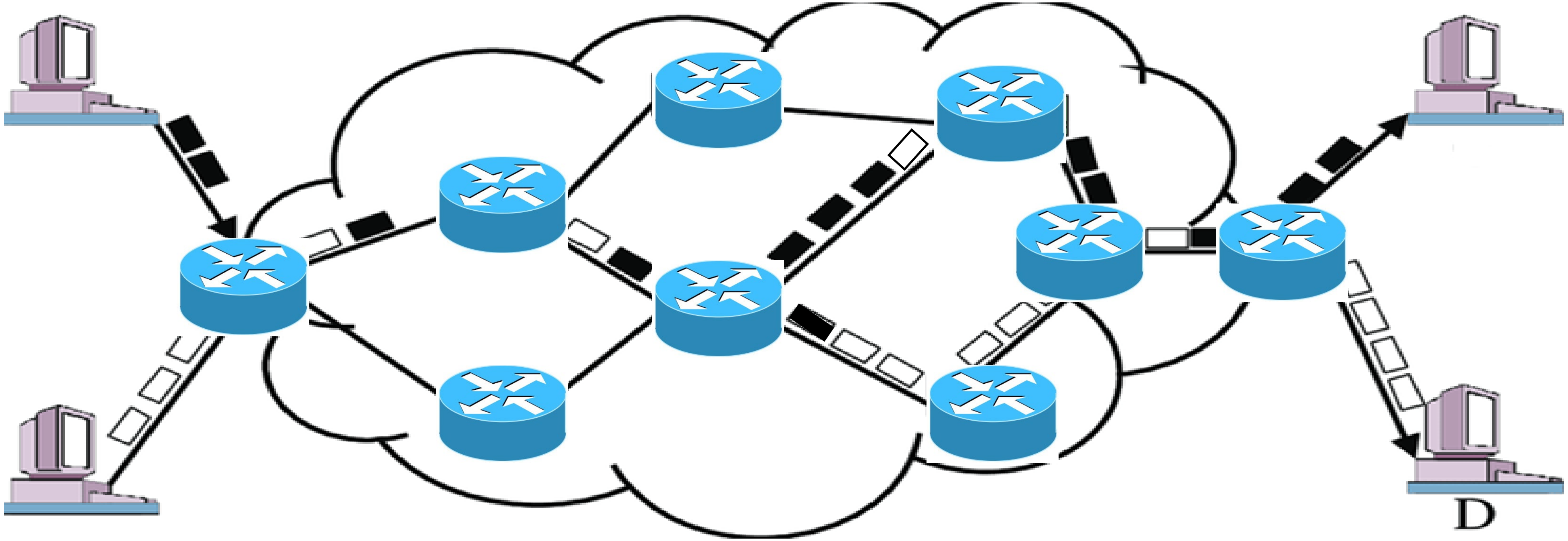
Network core

- Mesh of interconnected routers
- Packets travel from one router to the next, across links on path from source to destination

Data are broken into small pieces at network edges. Packet switching enables multiple network edges to share the network core.



Routing And Forwarding



Routing: routers determine the next hop on which to send a piece of data.

Forwarding: intermediary network devices move a piece of data from one interface to another interface

Routing And Forwarding (cont.)

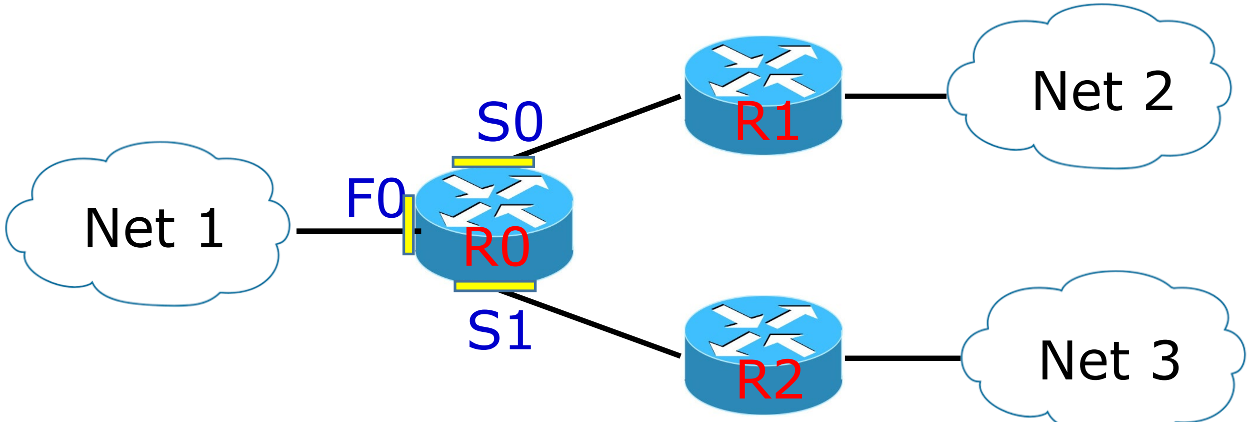
Data Routing: routers determine the next hop (router) on which to send a piece of data.

How to determine a next hop?

- Routing algorithms select the best paths for packets to reach the destinations
  - Different ways to determine the best paths: delays, error rates, energy consumption, and many more.
- Routers record the next hops & associated interfaces in their routing tables.

Routing table in R0

Network	Next hop	Interface
Net 1	Itself	F0
Net 2	R1	S0
Net 3	R2	S1

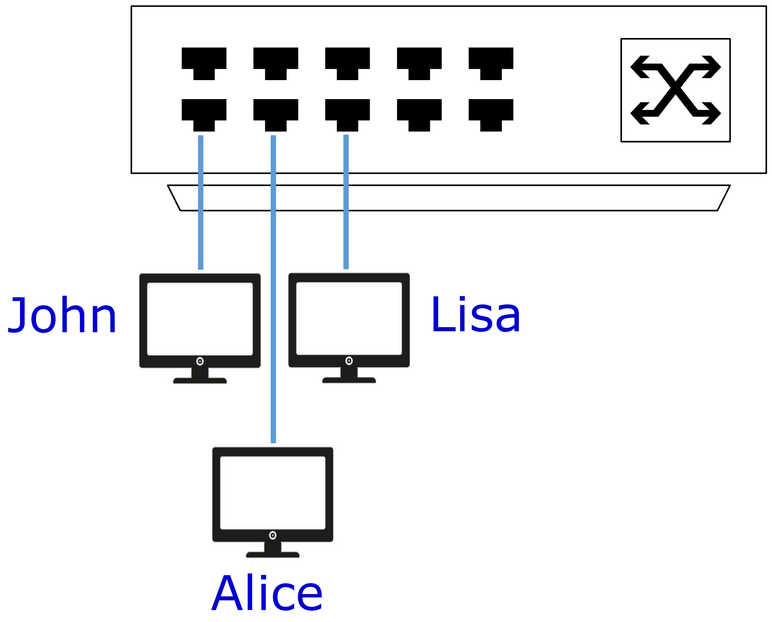


You may manually configure routing tables for small networks.

Routing & Forwarding (cont.)

Data Forwarding: intermediary network devices move a piece of data from one interface to another interface.

Switches:



Switching table

MAC address	Port number
John's MAC address	Port 1
Alice's MAC address	Port 2
Lisa's MAC address	Port 3
…	…

Switch operations

Form switching tables:
- based on source MAC addresses

Forward a frame:
- check the destination MAC address of the frame

. if not on its switching table, broadcast excluding the source port;

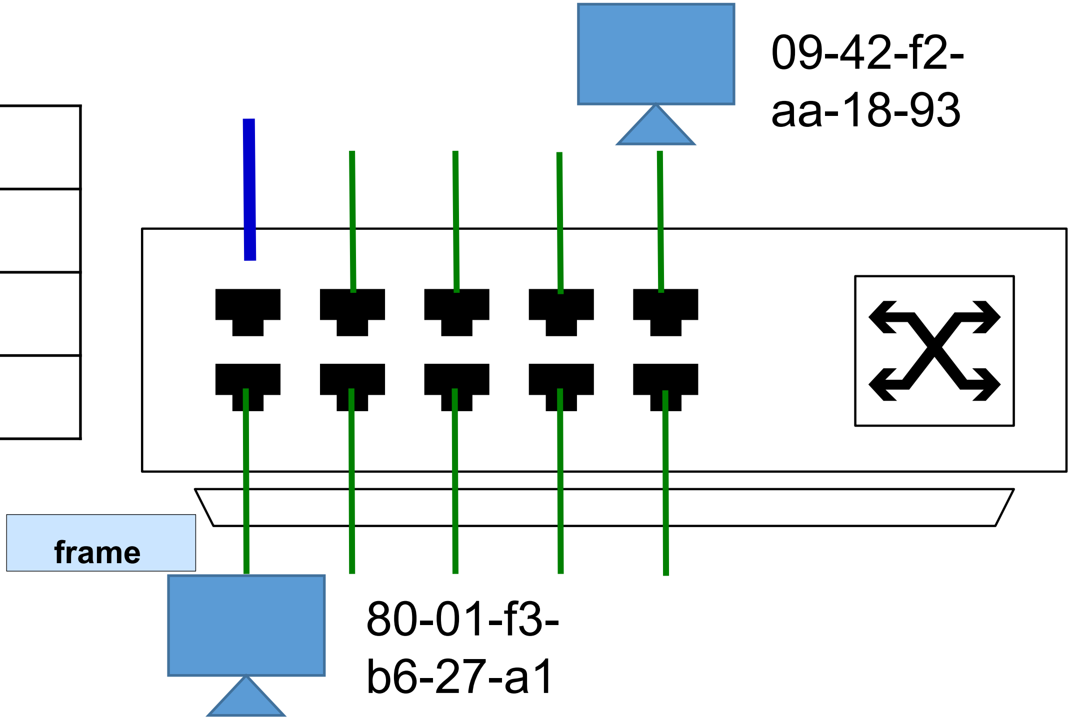
. if on its switching table, unicast to the destination port.

How Does A Switch Work?

80-01-f3-b6-27-a1 wants to send a frame to 09-42-f2-aa-18-93

Switching Table

MAC	Port
80-01-f3-b6-27-a1	**1**



Source: 80-01-f3-b6-27-a1
Destination: 09-42-f2-aa-18-93

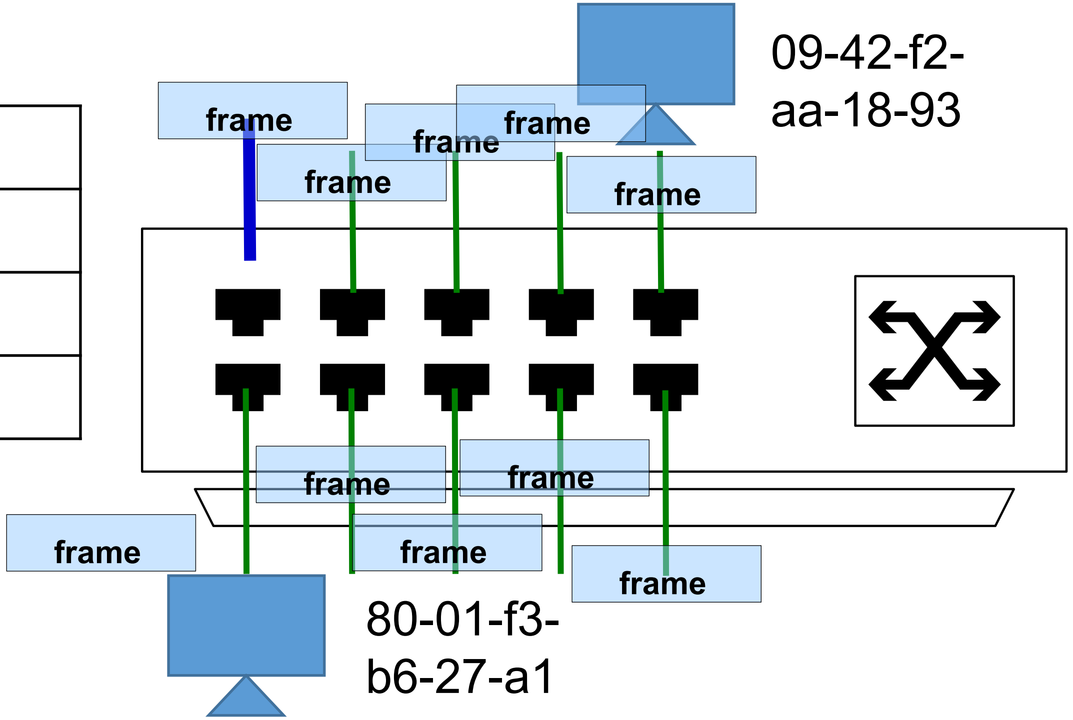
The Switch checks if the source address is in the table (already seen). If not, add the source address and the port.

How Does A Switch Work? (cont.)

80-01-f3-b6-27-a1 wants to send a frame to 09-42-f2-aa-18-93

Switching Table

MAC	Port
80-01-f3-b6-27-a1	1



Source: 80-01-f3-b6-27-a1
Destination: 09-42-f2-aa-18-93

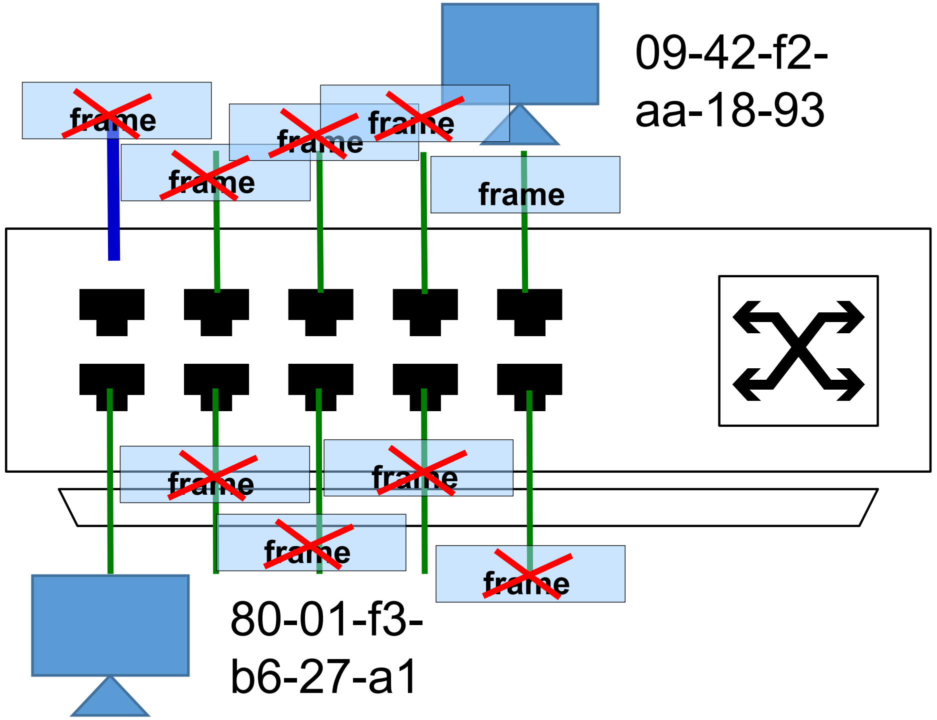
Then inspect the destination address.
Is there a port associated with the address in the table? If not, forward to all the ports (but not the input port)

How Does A Switch Work? (cont.)

80-01-f3-b6-27-a1 wants to send a frame to 09-42-f2-aa-18-93

Switching Table

MAC	Port
80-01-f3-b6-27-a1	1



Source: 80-01-f3-b6-27-a1
Destination: 09-42-f2-aa-18-93

However, only the real destination will process the packet.

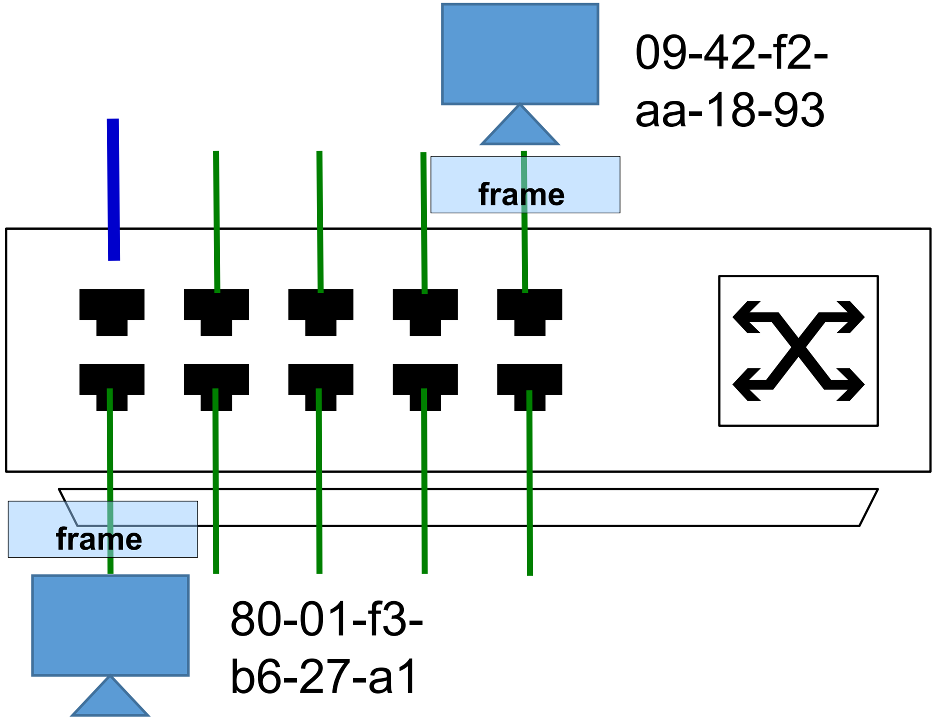
This means that all the other nodes will discard the packet except for the node with MAC address 09-42-f2-aa-18-93

How Does A Switch Work? (cont.)

09-42-f2-aa-18-93 wants to send a frame to 80-01-f3-b6-27-a1

Switching Table

MAC	Port
80-01-f3-b6-27-a1	**1**
09-42-f2-aa-18-93	**8**



Source: 09-42-f2-aa-18-93
Destination: 80-01-f3-b6-27-a1

1. Check the source address which is not in the table. Update the table.
2. Check the destination address which is on the table. Forward the frame to port 1 only.

Routing & Forwarding (cont.)

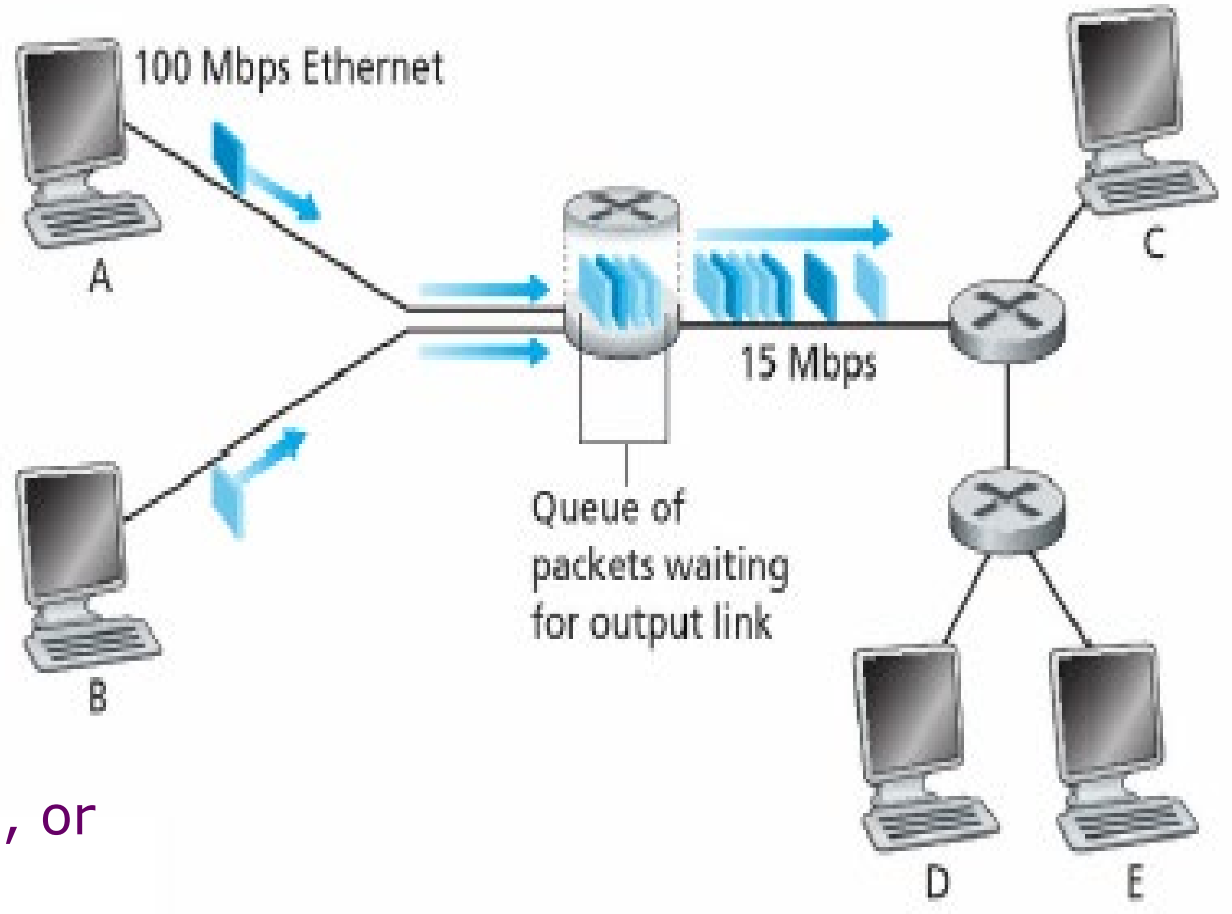
Store and Forward: a telecommunications technique in which an intermediary device keeps information and sends it at a later time to the destination or to another intermediary device.

- Nodal processing delay
  - Time spent on
    - Checking bit errors
    - Determining output link
  - Intermediary devices generate such delays
- Queuing delay
  - Happen at routers

Queuing Delay and Loss

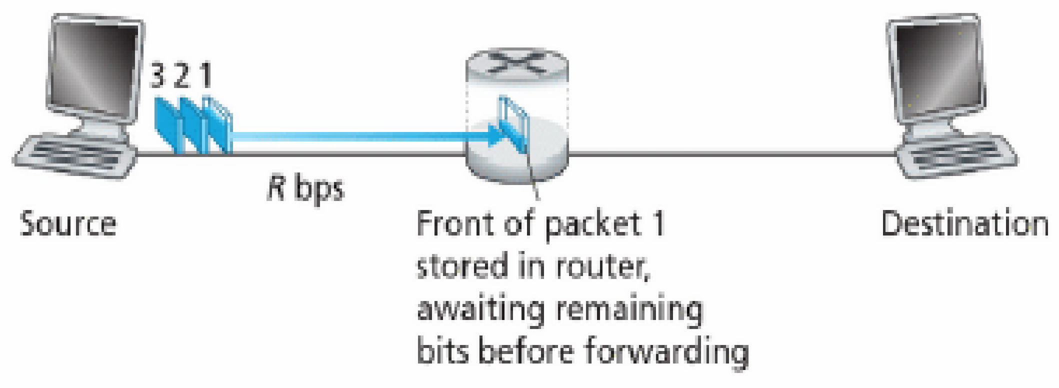
For a router, if the data input rate (in bit/s) exceeds the data output rate for a period of time:

- Packets will queue, wait to be transmitted on link.
- If queue (buffer/memory) fills up, Packets can be dropped (lost).
- Lost packet may be retransmitted by previous node, by source (end devices), or not at all.



Transmission Delay

Transmission delay (or store-and-forward delay) is the amount of time required to push all the bits in a piece of data onto the wire.



Entire data piece must arrive at router before it can be transmitted on next link.

- The data transmission rate of a link is the bandwidth of this link
- bps = bit/s

How long will be the delay of an L-bit packet?

- Take $\frac{L}{R}$ seconds to transmit (push out) an L-bit packet into link at R bps.
- This is called the transmission delay of this L-bit packet.
- End-to-end delay: $2\frac{L}{R}$.

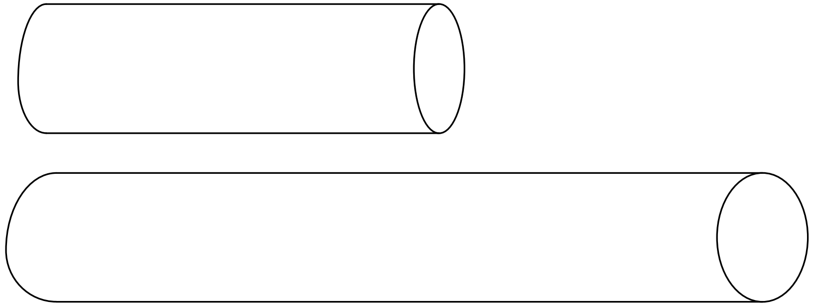
(assuming zero nodal process delay, queuing delay, propagation delay)

Propagation Delay

- Defines the time required to travel through the medium
  - Unit: *second* or *s*

Pipe analogy:

Short pipe -> Short Latency/Delay
Long pipe -> Long Latency/Delay



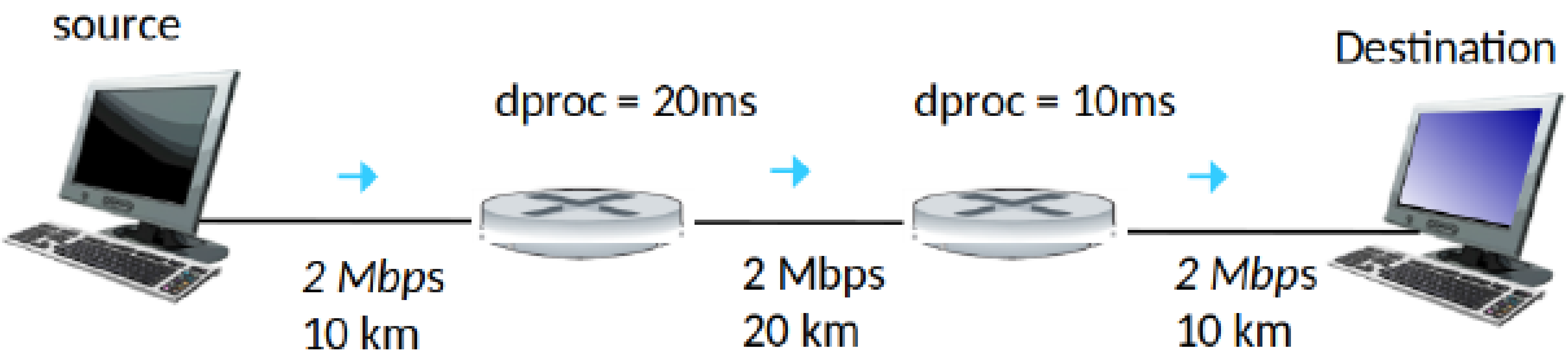
Four Sources of A Packet Delay

A packet delay d_P is formulised by

$$d_P = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{proc}: nodal processing delay	- Check bit errors - Determine output link - Typically < *msec*
d_{queue}: queueing delay	- Time waiting for transmission - Depends on congestion level of router
d_{trans}: transmission delay	- L: packet length (*bits*) - R: link bandwidth (*bps*, *bit/s*) - d_{trans}= L / R
d_{prop}: propagation delay	- *d*: length of physical link - *s*: propagation speed (~*2x10⁸ meters/sec*) - d_{prop}= d / s

A Practical Example



How long does it take a packet of 1Mb to travel from source to destination?

Assume that the propagation speed in all segments is 2 km/s.

What Do “real” Internet Delay & Loss Look Like?

- Traceroute program: provides delay measurement from source to router along end-end Internet path towards destination.

- For all *i*:
  - Sends three packets to router *i* on path towards destination
  - Router *i* will return packets to sender
  - Sender calculates time intervals between transmissions and replies

What do "real" Internet delay & loss look like?

traceroute: gaia.cs.umass.edu to www.eurecom.fr

3 delay measurements from
gaia.cs.umass.edu to cs-gw.cs.umass.edu

```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

trans-oceanic link

* means no response (probe lost, router not replying)

- * Do some traceroutes from exotic countries at www.traceroute.org

Summary

- Circuit switching vs. packet switching
- OSI reference model, data encapsulation/de-encapsulation
- Delay and loss

Next Lecture:

- Application layer