CS2105

An *Awesome* Introduction to Computer Networks

Lecture 1: Introduction

NUS National University of Singapore
Department of Computer Science
School of Computing

Course Instructors

Dr. Zhou Lifeng

Senior Lecturer

Office: COM2 #02-56

Email: zhoulifeng@nus.edu.sg

Dr. Leong Wai Kay

Lecturer

Office: COM2 #02-11

Email: waikay@comp.nus.edu.sg

What is CS2105 About?

- Discussion of fundamental **concepts** and **principles** behind computer networking
  - Using the Internet as a case study
- Introduction to networking tools and networked application programming
  - Programming with Python, Java, or C++

What you will NOT learn in CS2105

- How to configure hardware, e.g. router
  - This is covered in CS3103 Computer Networks Practice - perform hands-on experiments in subnetting, DHCP, DNS, RIP, OSPF, TCP handshaking and congestion mechanism
- Mobile and wireless networks
  - This is covered in CS4222 Wireless Networking

Textbook

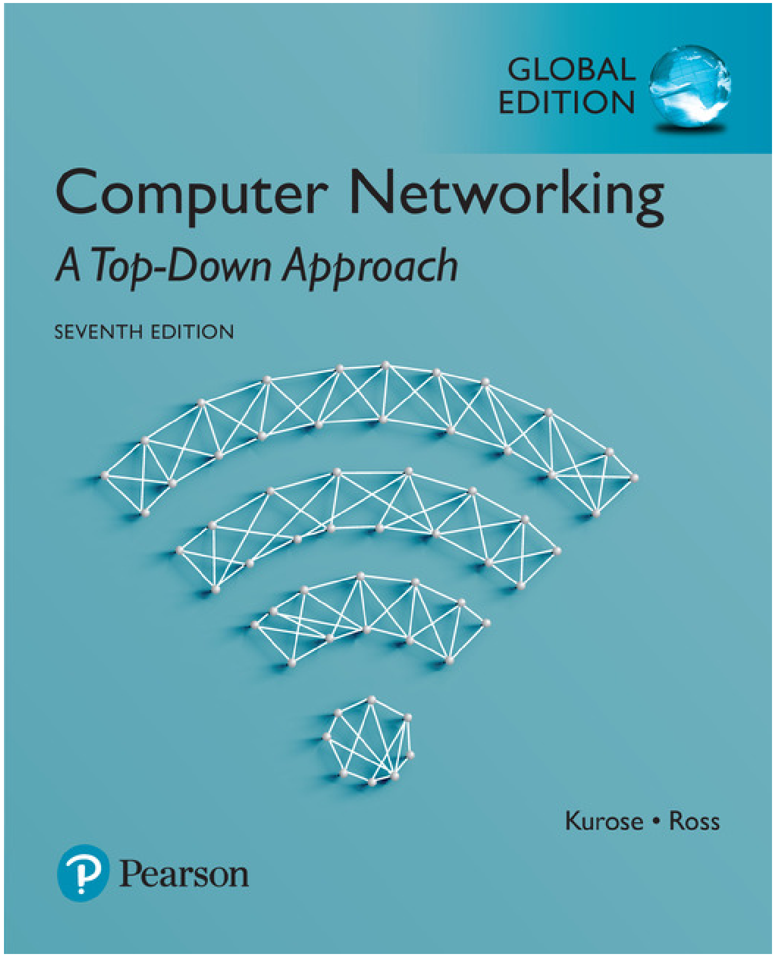
Computer Networking: A Top-Down Approach: Global Edition, 7/E

Authors : Kurose

Ross

Publisher : Pearson

ISBN : 9781292153599



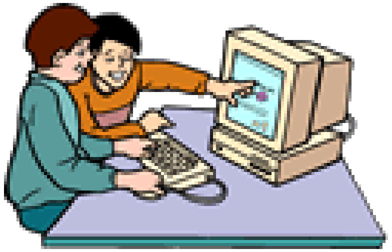
Acknowledgement:
Most of the lecture slides are adopted from slides of this textbook.

Available at **NUS Campus bookstore**

Contact Hours

- Lectures
  - Every Monday 2 - 4pm @ ICube Auditorium
  - 2 hours per session
  - week 8 lecture reserved for midterm test
- Tutorials
  - Start from week 3.
  - 1 hour per session
  - No tutorial in week 8 ☺
- Consultation
  - Email me or Wai Kay to make arrangement

Assessments



- CA (50%)
  - Tutorial attendance/participation - 5%
  - Individual programming assignments - 25%
  - Mid-term test (week 8 lecture time: Mon, 7 Oct 2019, 2:10 - 3:30pm) - 20%
- Final Exam (50%)
  - Mon, 2 Dec 2019, 5 - 7pm

Notes and Tips

- Why CS2105 can be **easy**
  - You use and interact with the Internet constantly
  - Many of the concepts are intuitive and based on very practical design considerations
  - There are very few equations!

- Why CS2105 can be **tough**
  - Many concepts are covered
  - Programming!

Lecture 1: Introduction

After this class, you are expected to:

- understand the basic terms, including host, packet, protocol, throughput, store-and-forward, and autonomous system.
- know about the logical (five protocol layers) and physical (a network of ASes) architecture of the Internet.
- understand the different components of end-to-end delay and their relations to bandwidth, packet size, distance, propagation speed, and queue size.

Lecture 1: Roadmap

1.1 What is the Internet?

1.2 Network Edge

1.3 Network Core

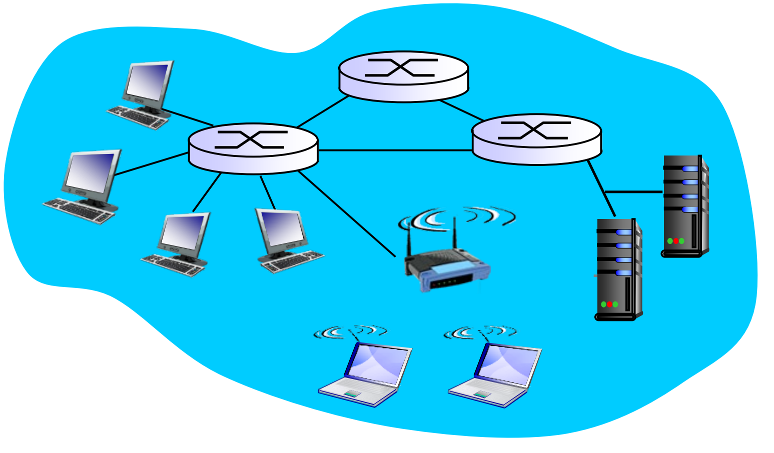
1.4 Delay, Loss and Throughput in Networks

1.5 Protocol Layers and Service Models

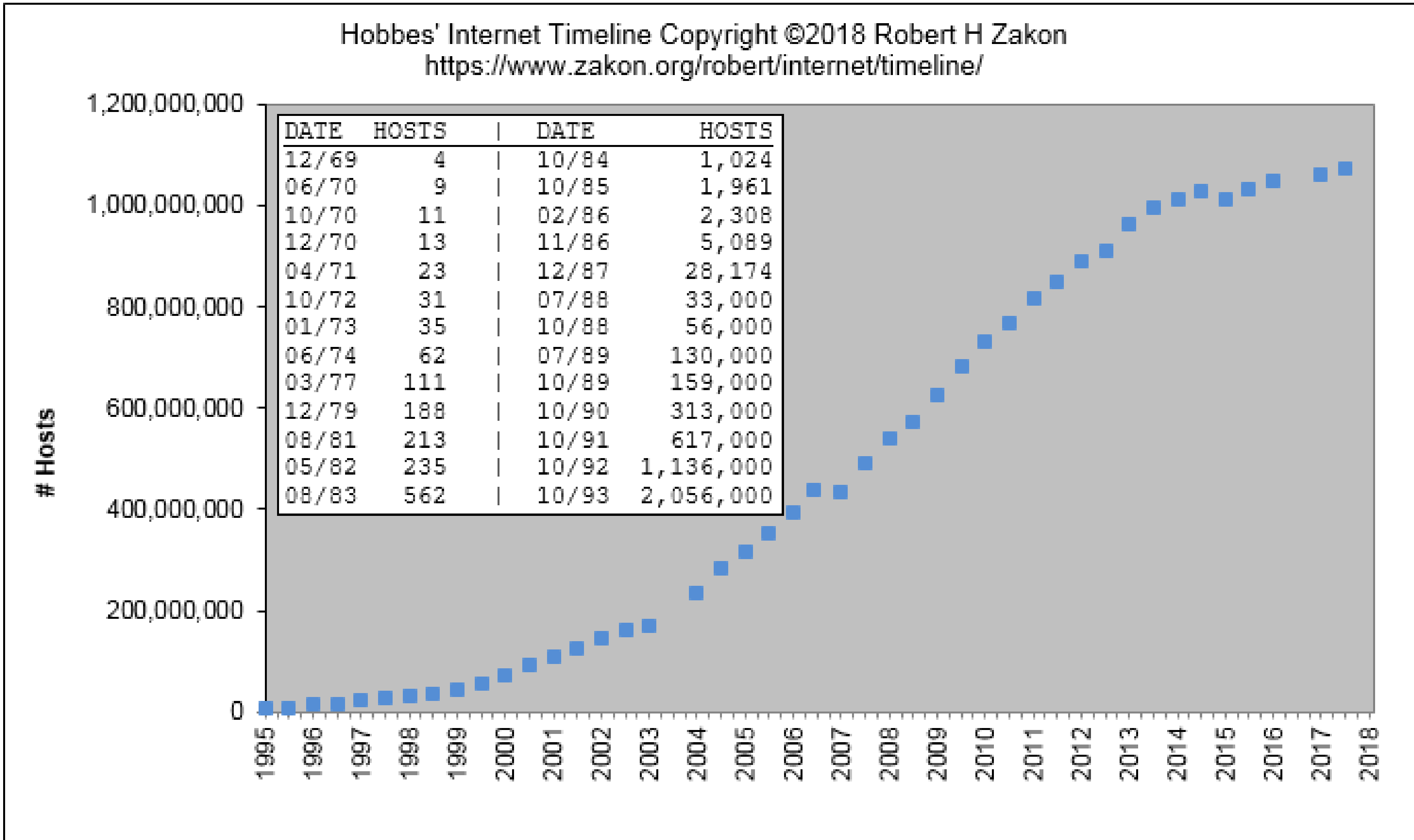
Kurose Textbook, Chapter 1
(Some slides are taken from the book)

Internet: "nuts and bolts" View

- The Internet is a network of connected computing devices (e.g. PC, server, laptop, smartphone)
  - such devices are known as *hosts* or *end systems*.
  - they run network applications (e.g. WhatsApp, browser).
  - they communicate over links.



Growth of Internet Hosts



DATE	HOSTS	DATE	HOSTS
12/69	4	10/84	1,024
06/70	9	10/85	1,961
10/70	11	02/86	2,308
12/70	13	11/86	5,089
04/71	23	12/87	28,174
10/72	31	07/88	33,000
01/73	35	10/88	56,000
06/74	62	07/89	130,000
03/77	111	10/89	159,000
12/79	188	10/90	313,000
08/81	213	10/91	617,000
05/82	235	10/92	1,136,000
08/83	562	10/93	2,056,000

“Fun” Internet-connected Devices

IP picture frame
http://www.ceiva.com/

Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

Internet
refrigerator

Slingbox: watch,
control cable TV remotely

sensorized,
bed
mattress

Internet phones

Lecture 1: Roadmap

1.1 What is the Internet?

1.2 Network Edge

- hosts, access networks, links

1.3 Network Core

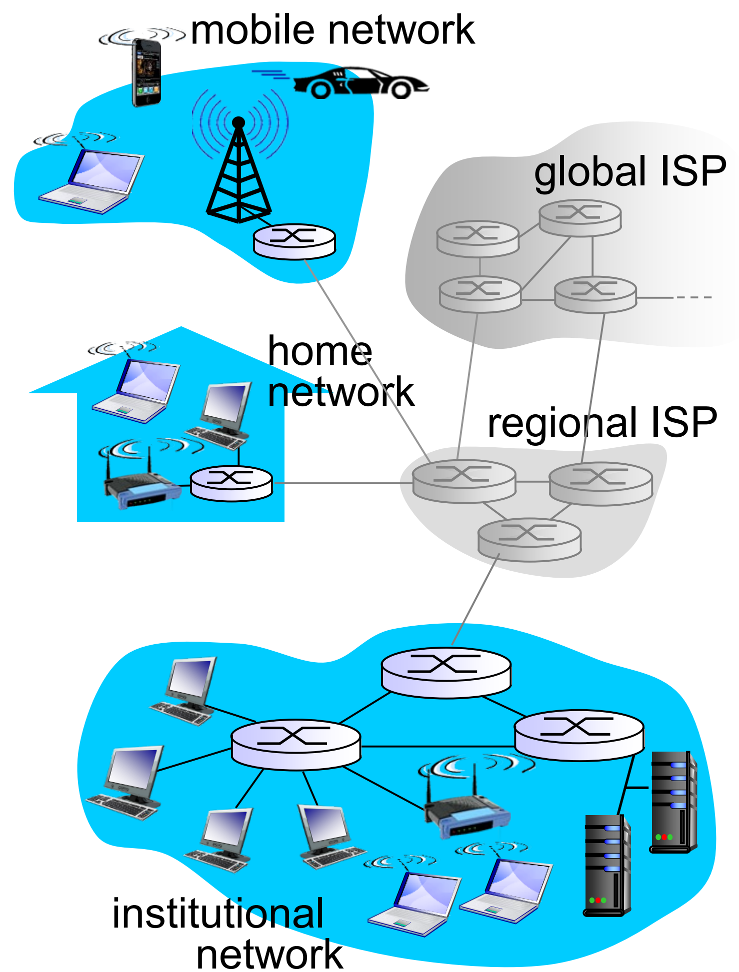
- packet switching, circuit switching, network structure

1.4 Delay, Loss and Throughput in Networks

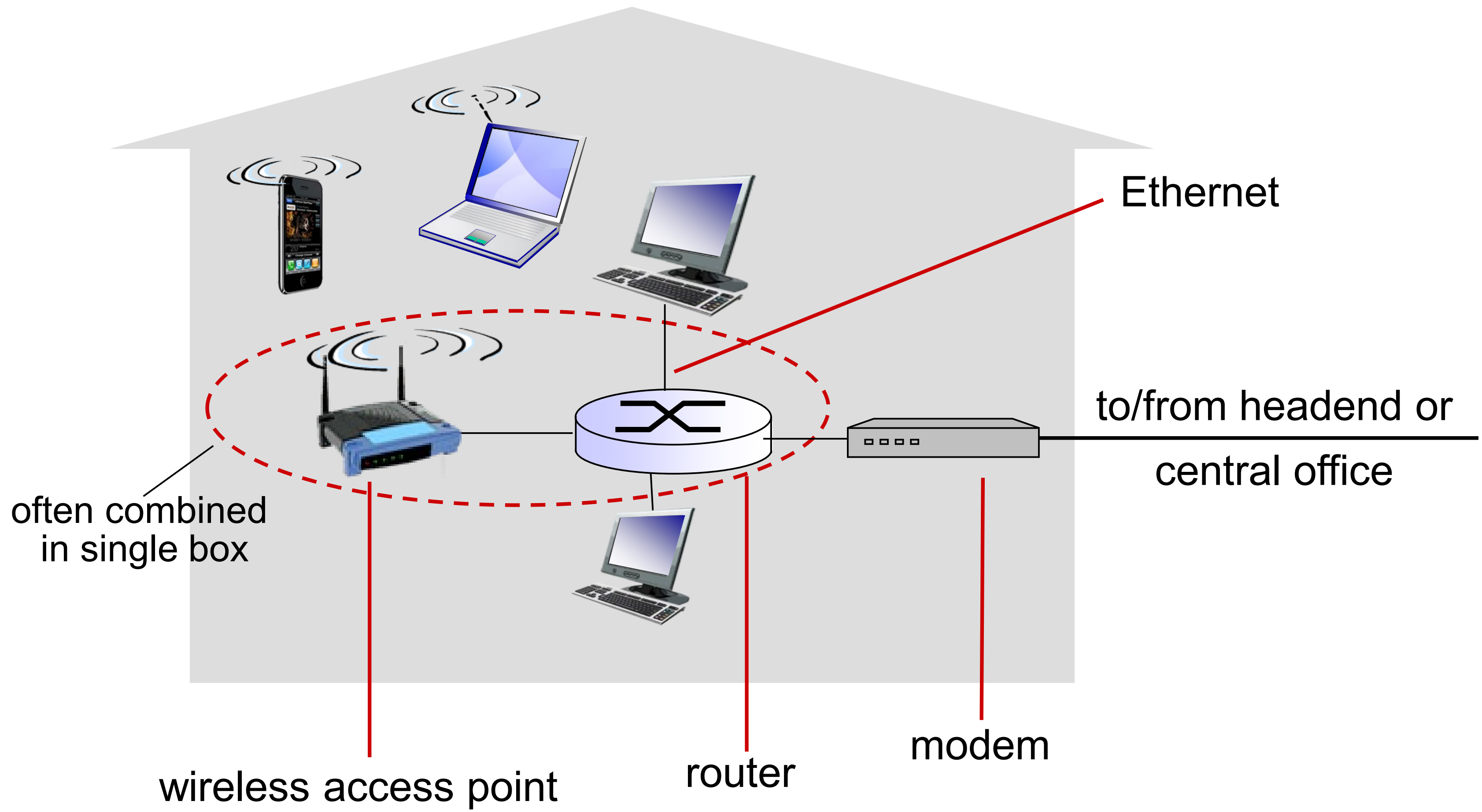
1.5 Protocol Layers and Service Models

Access Networks

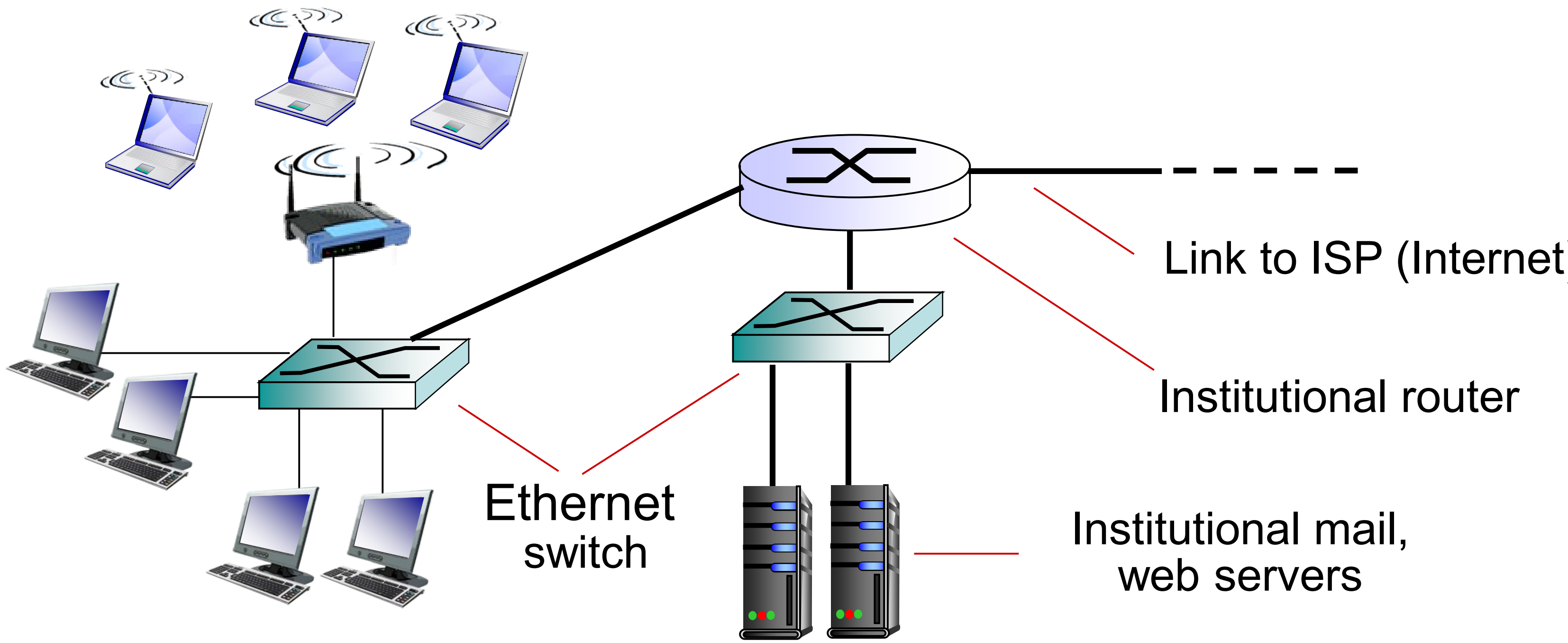
- Hosts access the Internet through *access network*.
  - Residential access networks
  - Institutional access networks (school, company)
  - Mobile access networks



Home Networks



Enterprise Access Networks (Ethernet)



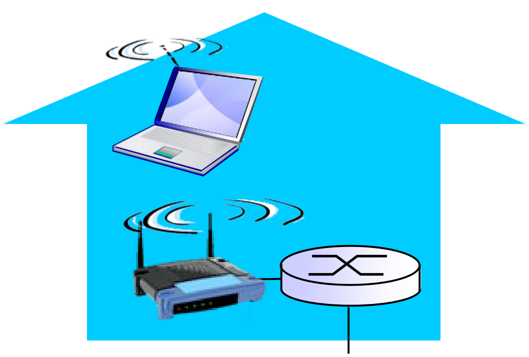
- Typically used in companies, universities, etc.
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- Today, hosts typically connect to Ethernet switch

Wireless Access Networks

- Wireless access network connects hosts to router
  - via base station aka "access point"

Wireless LANs:

- within building (100 ft)
- 802.11b/g/n/ac (Wi-Fi)



to Internet

Wide-area wireless access

- 3G, 4G
- provided by telco (cellular) operator, 10's km

to Internet

Physical Media

- Hosts connect to the access network over different physical media.
  - Guided media:
    - signals propagate in solid media

Twisted pair cable

Coaxial cable

Fiber optic cable

  - Unguided media:
    - signals propagate freely, e.g., radio

Lecture 1: Roadmap

1.1 What is the Internet?

1.2 Network Edge

- hosts, access networks, links

1.3 Network Core

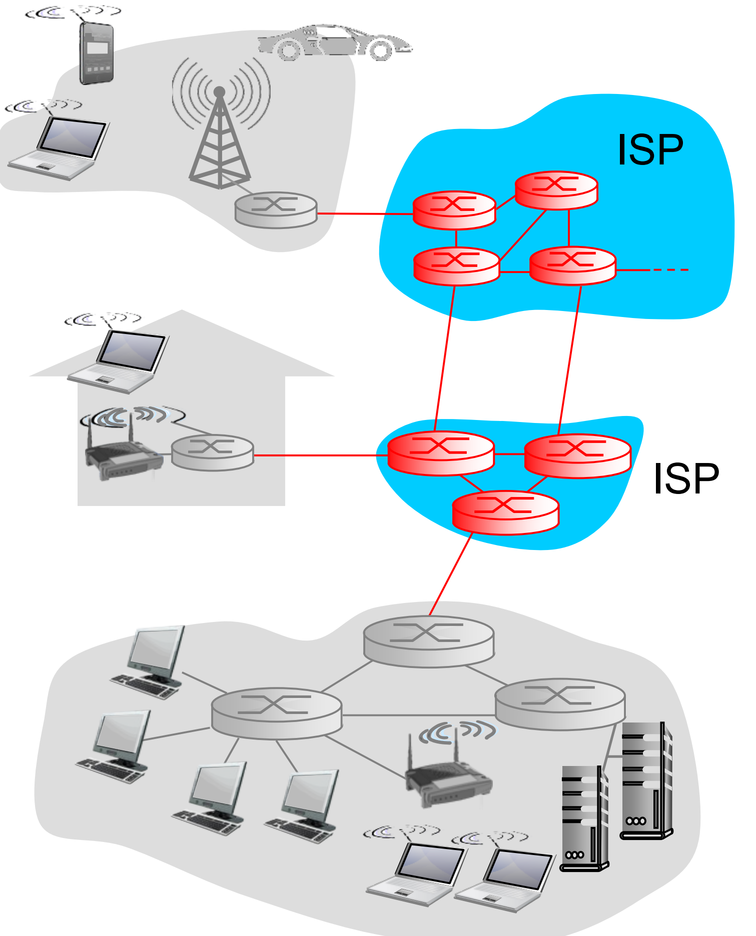
- packet switching, circuit switching, network structure

1.4 Delay, Loss and Throughput in Networks

1.5 Protocol Layers and Service Models

The Network Core

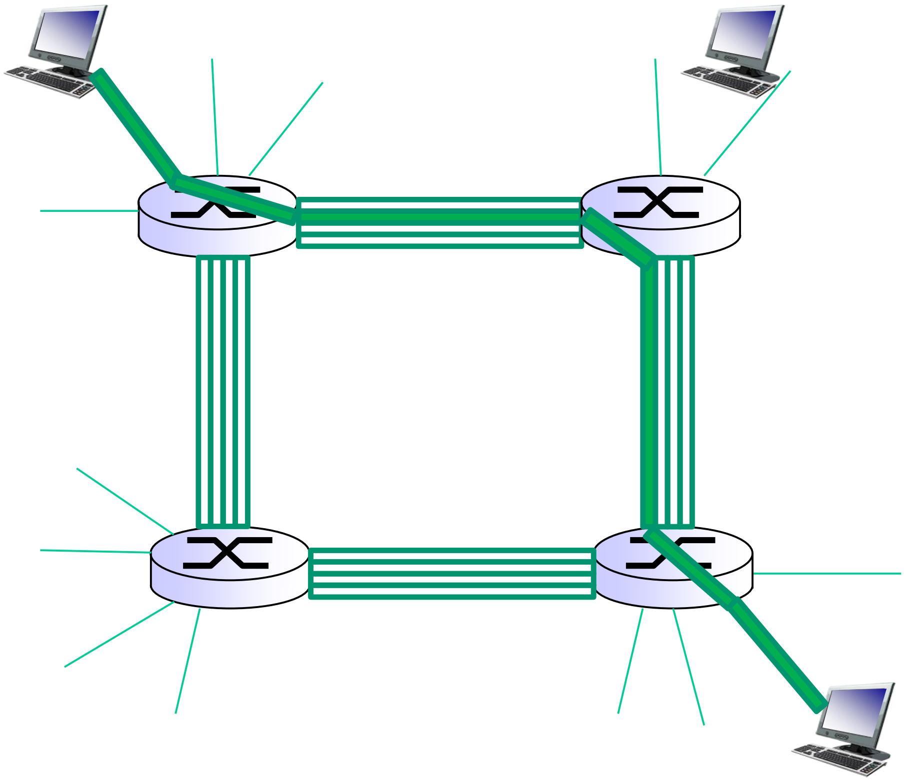
- A mesh of interconnected routers
- The fundamental question: how is data transmitted through net?
  - Circuit switching: dedicated circuit per call
  - Packet switching: data sent thru net in discrete “chunks”



Circuit Switching

End-end resources allocated to and reserved for “call” between source & dest:

- call setup required
- circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- commonly used in traditional telephone networks
- divide link bandwidth into “pieces”
  - frequency division
  - time division

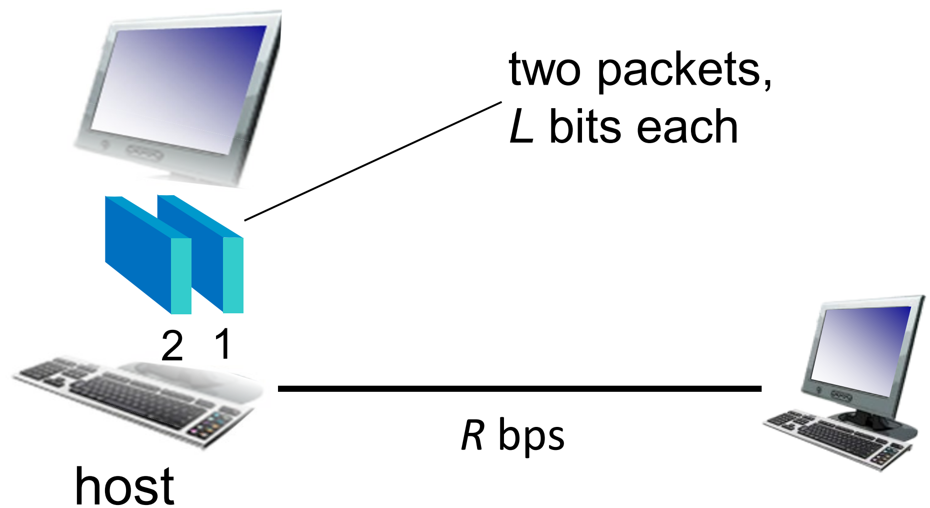


In above diagram, each link has four circuits. A “call” gets 2nd circuit in top link and 1st circuit in right link.

Packet Switching

Host sending function:

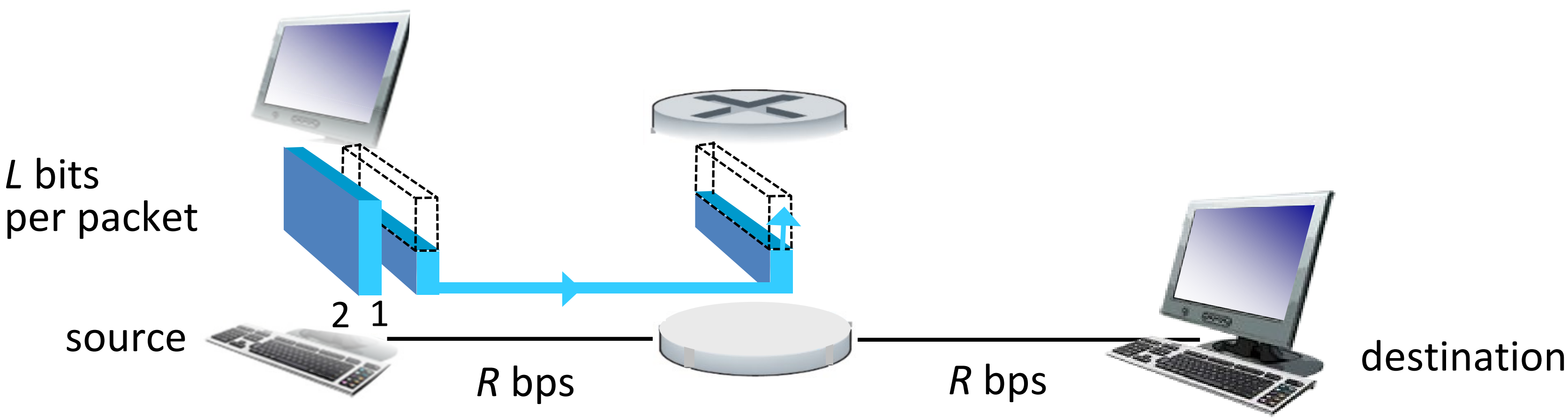
- breaks application message into smaller chunks, known as *packets*, of length *L* bits
- transmits packets onto the link at *transmission rate R*
  - link transmission rate is aka *link capacity* or *link bandwidth*



$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Packet-switching: store-and-forward

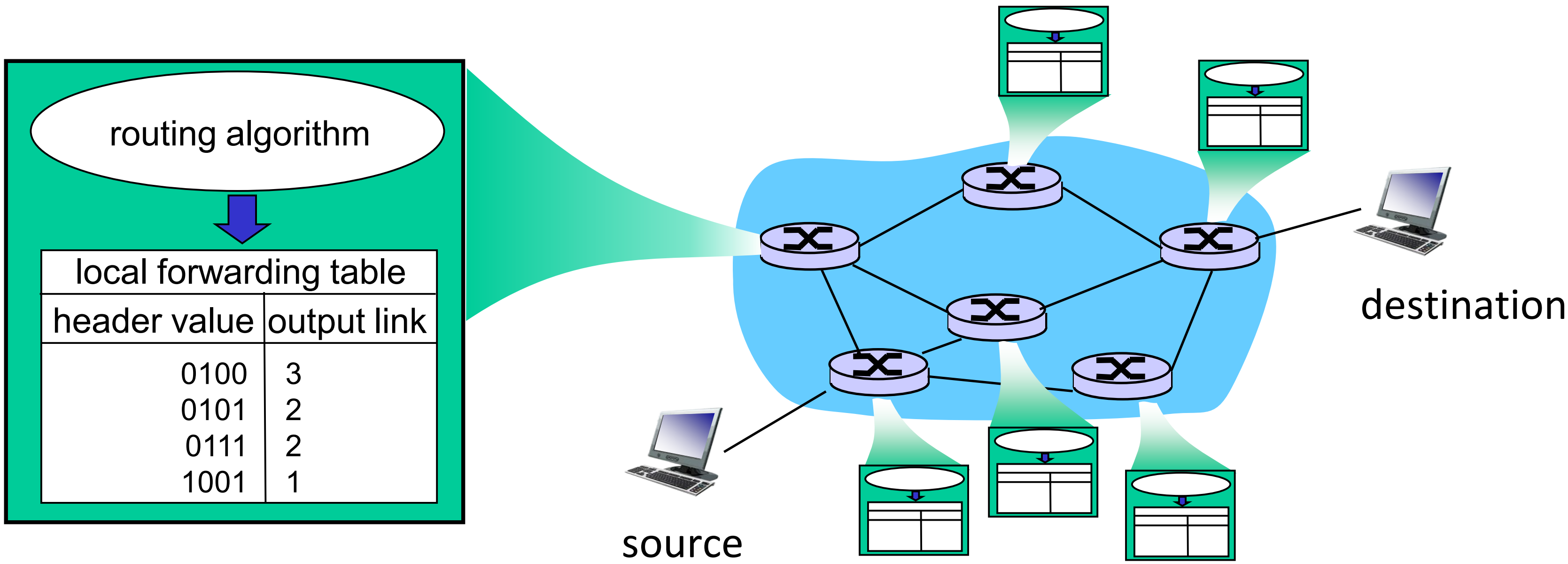
- Packets are passed from one router to the next, across links on path from source to destination.
- *Store and forward:* entire packet must arrive at a router before it can be transmitted on the next link.



End-to-end delay = 2*L/R (assuming no other delay)

Routing and Addressing

- Routers determine source-destination route taken by packets.
  - Routing algorithms
- Addressing: each packet needs to carry source and destination information



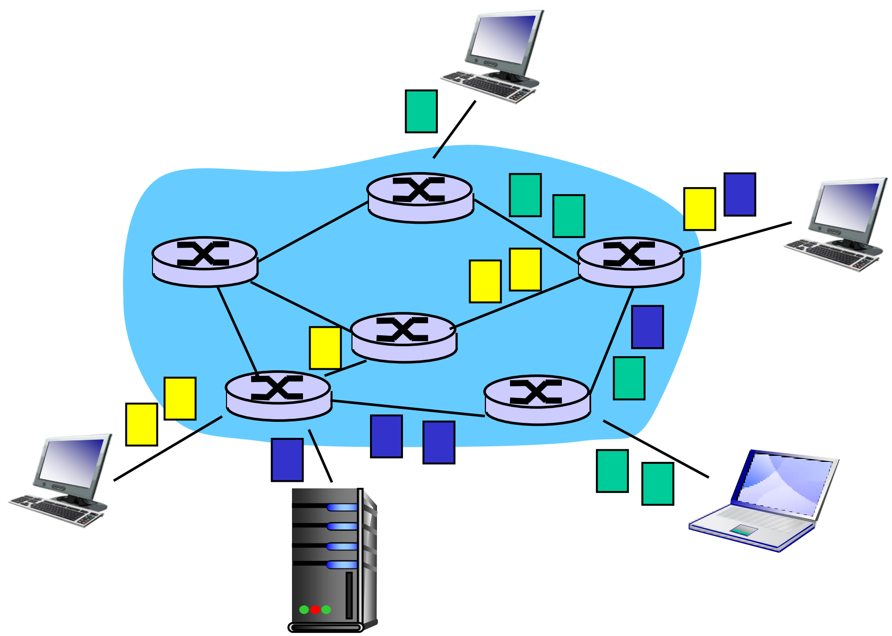
Packet Switching

- The Internet is a packet switching network
- User A, B … 's packets *share* network resources
- Resources are used on demand
- Excessive congestion is possible

Bandwidth division into "pieces"

Dedicated allocation

Resource reservation

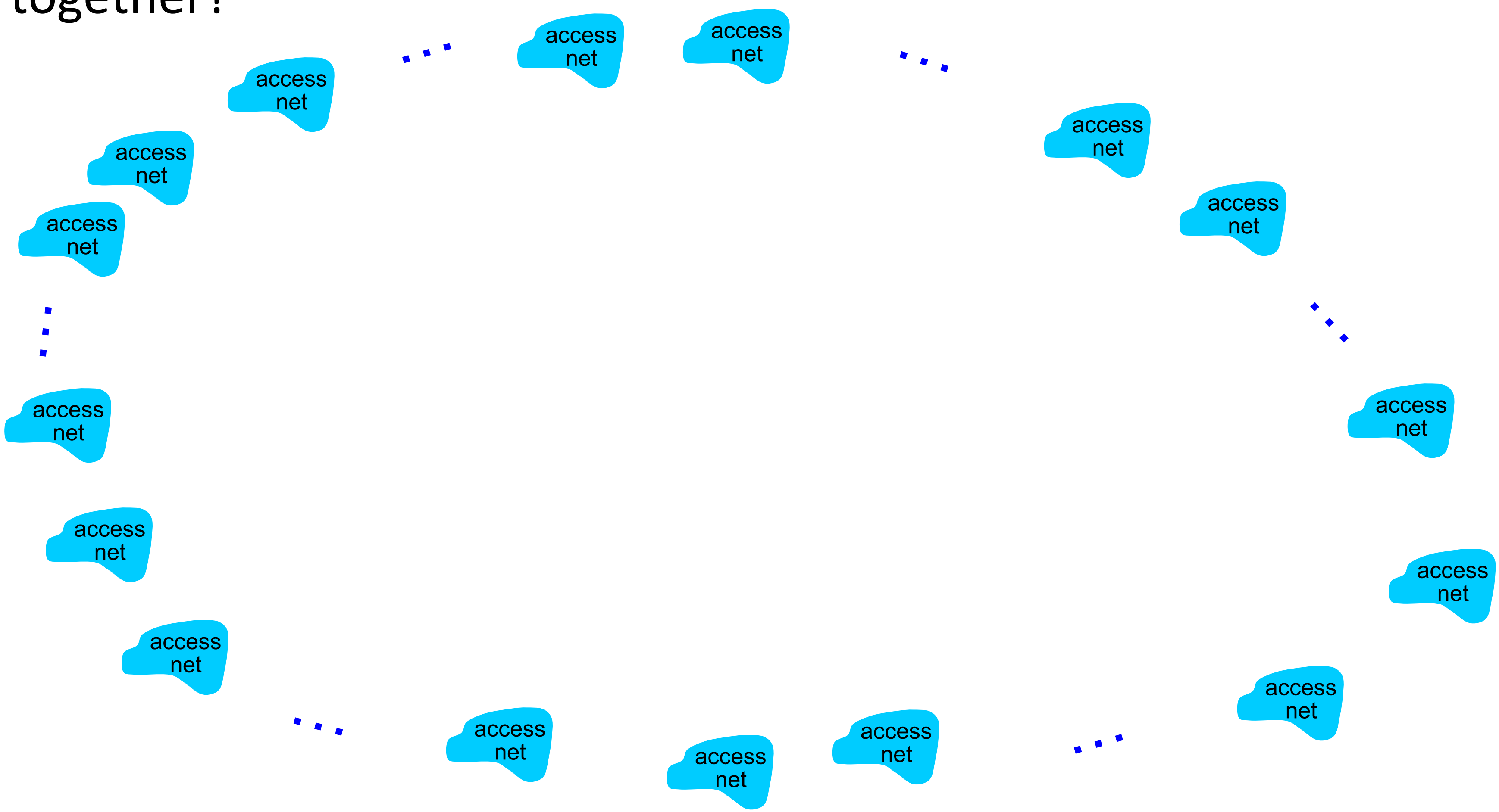


Internet Structure: Network of Networks

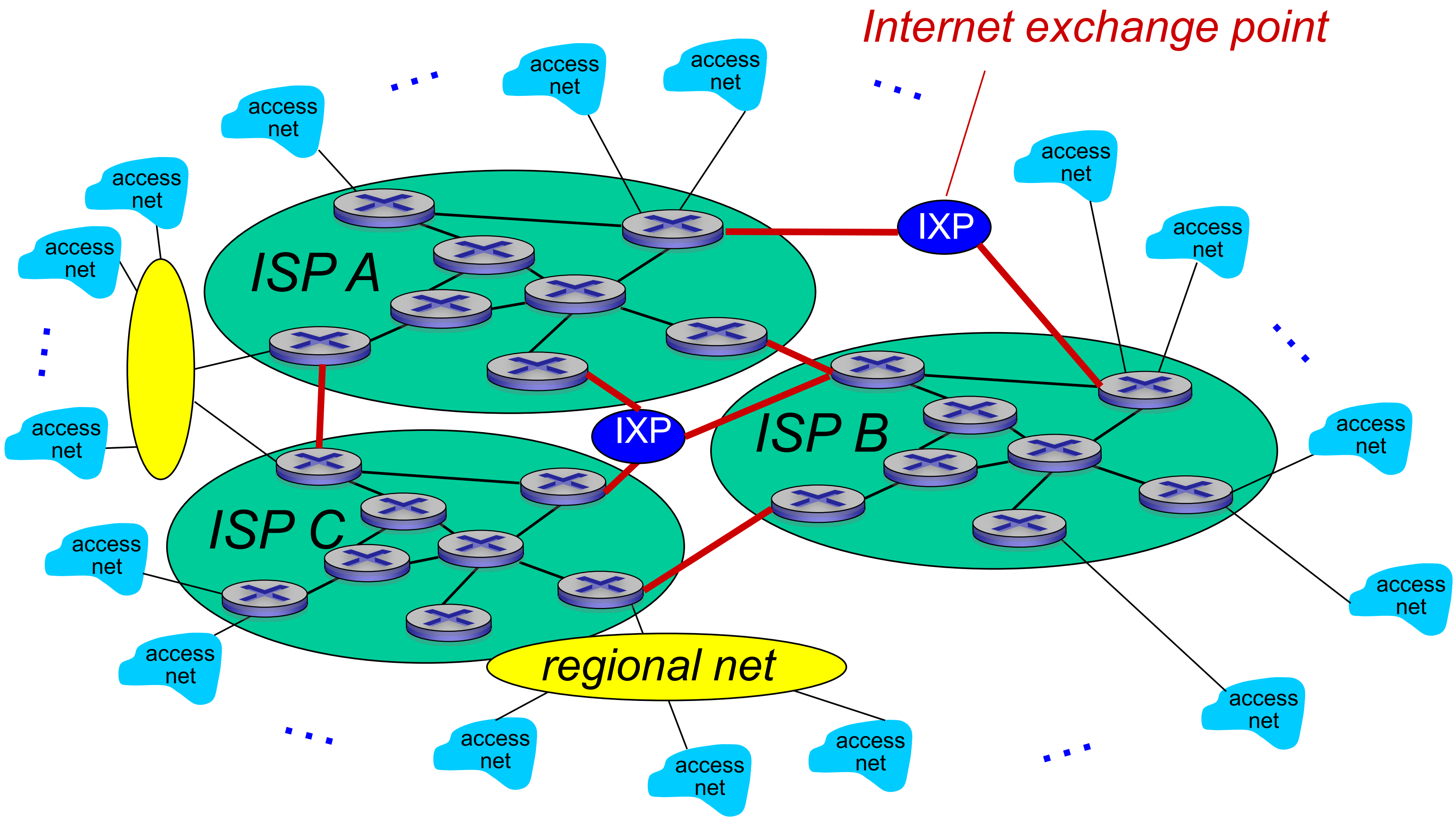
- Hosts connect to Internet via access ISPs (Internet Service Providers)
  - Residential, company and university ISPs
- Access ISPs in turn must be interconnected.
- Resulting network of networks is very complex
  - Evolution was driven by economics and national policies
- Therefore, the Internet is a “network-of-networks”, organized into autonomous systems (AS), each is owned by an organization.

Internet Structure: Network of Networks

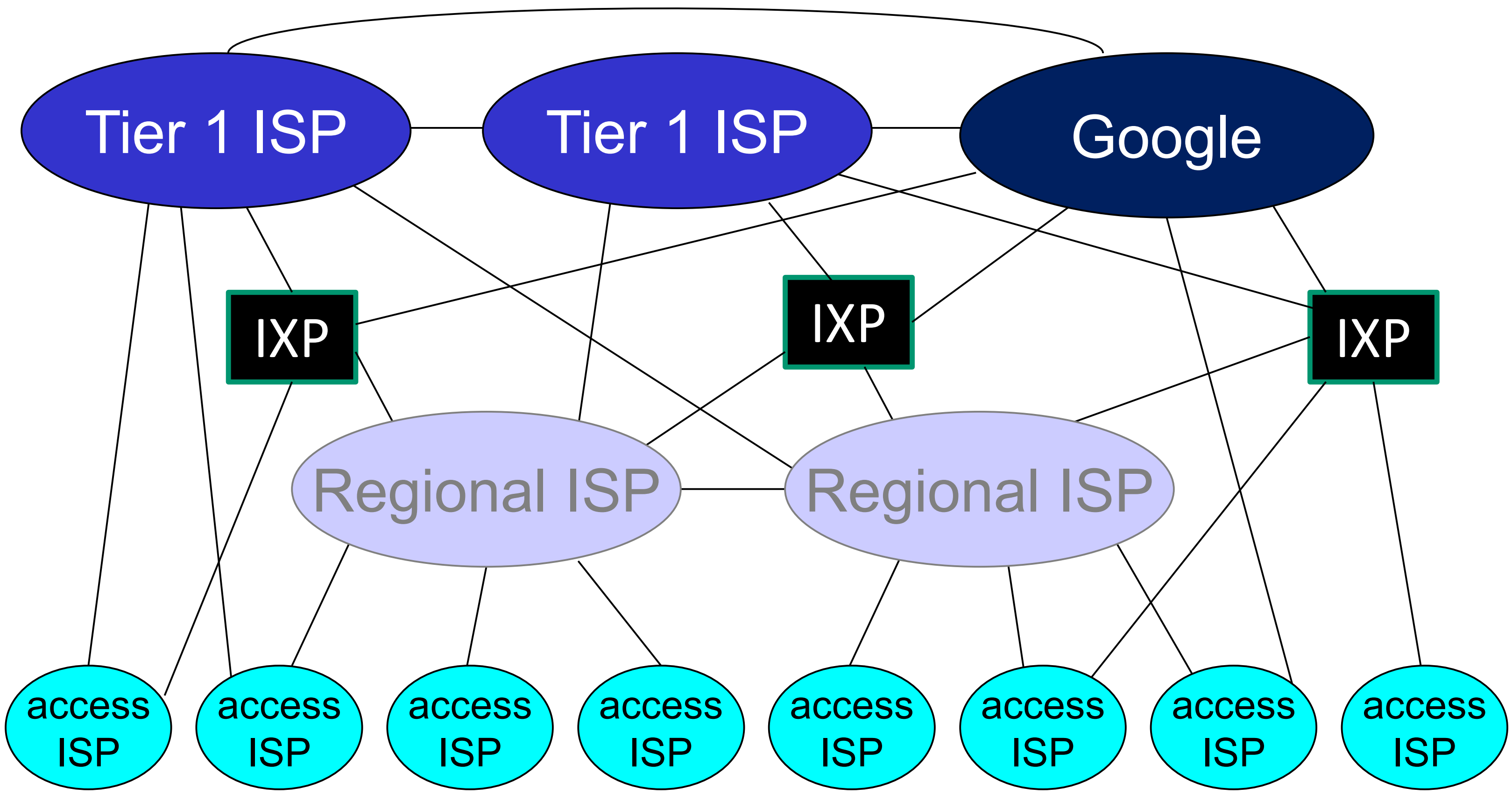
Question: given *millions* of access nets, how to connect them together?



Internet Structure: Network of Networks



Internet Structure: Network of Networks



Who Runs the Internet?

- IP address & Internet Naming administered by Network Information Centre (NIC)
  - Refer to: www.sgnic.net.sg; www.apnic.org
- The Internet Society (ISOC) - Provides leadership in Internet related standards, education, and policy around the world.
- The Internet Architecture Board (IAB) - Authority to issue and update technical standards regarding Internet protocols.
- Internet Engineering Task Force (IETF) - Protocol engineering, development and standardization arm of the IAB.
  - Internet standards are published as RFCs (Request For Comments)
    - Refer to: www.ietf.org; for RFCs: http://www.ietf.org/rfc.html

Lecture 1: Roadmap

1.1 What is the Internet?

1.2 Network Edge

- hosts, access networks, links

1.3 Network Core

- packet switching, circuit switching, network structure

1.4 Delay, Loss and Throughput in Networks

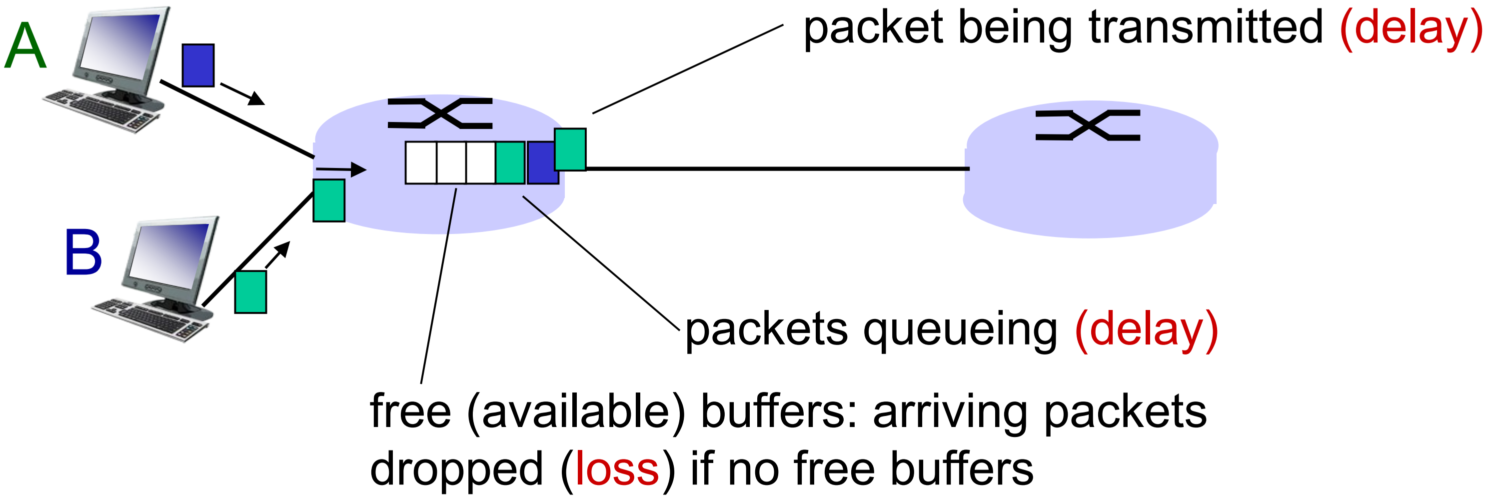
1.5 Protocol Layers and Service Models

Recall: Packet Switching Network

- To send a packet in a packet switching network,
  1. Sender transmit a packet onto the link as a sequence of bits.
  2. Bits are propagated to the next node (e.g. a router) on the link.
  3. Router stores, processes and forwards the packet to the next link.
  4. Steps 2 & 3 repeat till the packet arrives at the receiver.

How do Delay and Loss Occur?

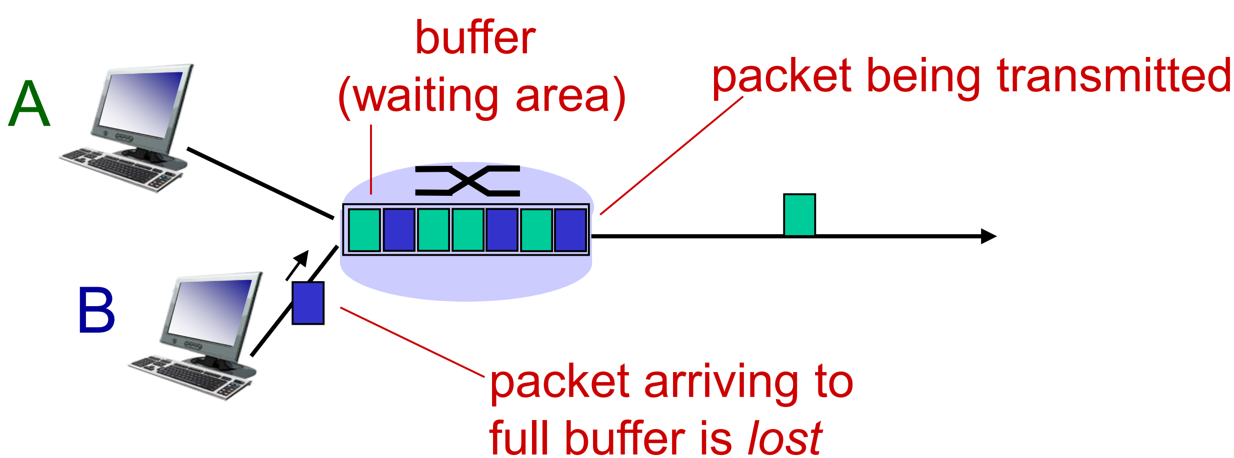
- Packets *queue* in router buffers
  - wait for turn to be sent out one by one



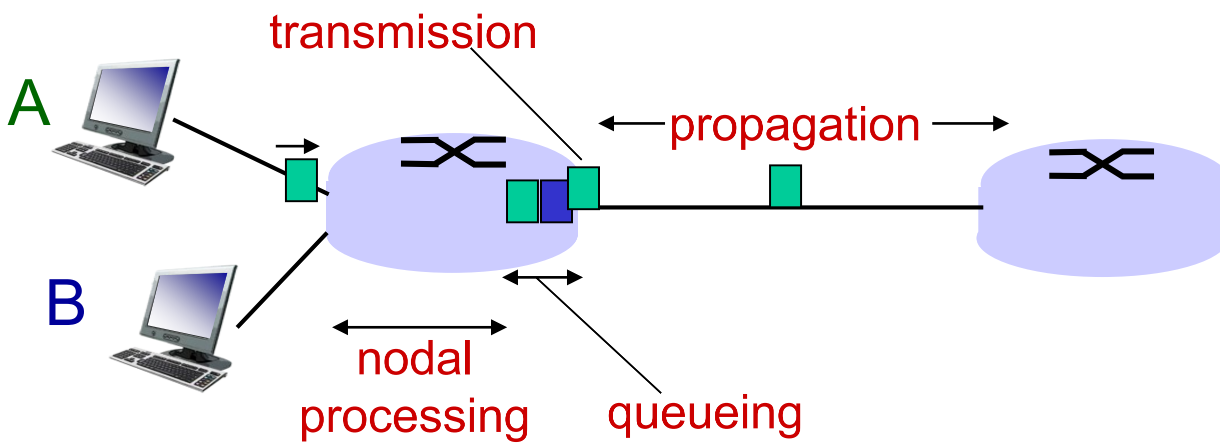
Q: What if packet arrival rate exceeds departure rate?

Packet Loss

- Queue (aka buffer) of a router has finite capacity.
- Packet arriving to full queue will be dropped (aka lost).
- Lost packet may be retransmitted by previous node, by source host, or not at all.



Four Sources of Packet Delay



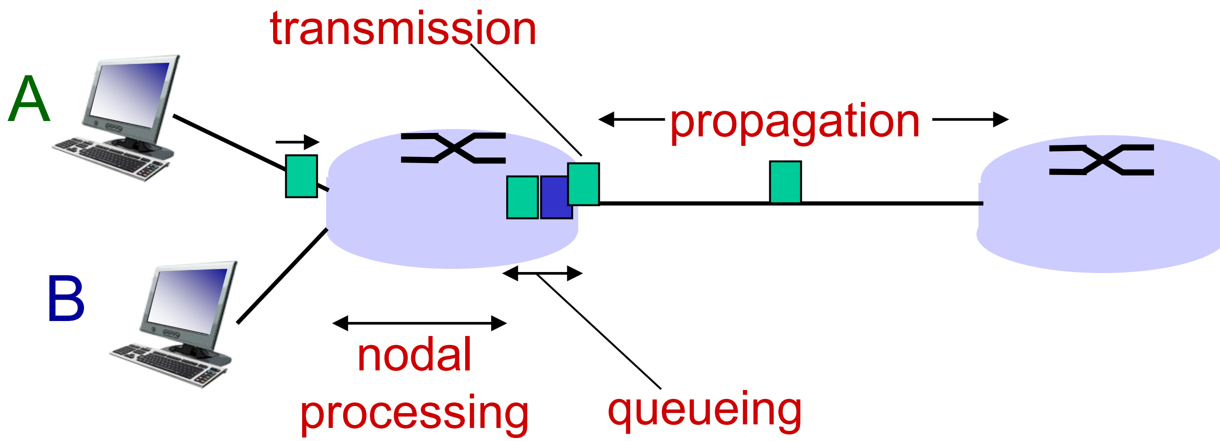
d_{proc}: nodal processing

- check bit errors
- determine output link
- typically < msec

d_{queue}: queuing delay

- time waiting in the queue for transmission
- depends on congestion level of router

Four Sources of Packet Delay



d_{trans}: transmission delay

- *L*: packet length (bits)
- *R*: link *bandwidth (bps)*
- $d_{trans} = L/R$

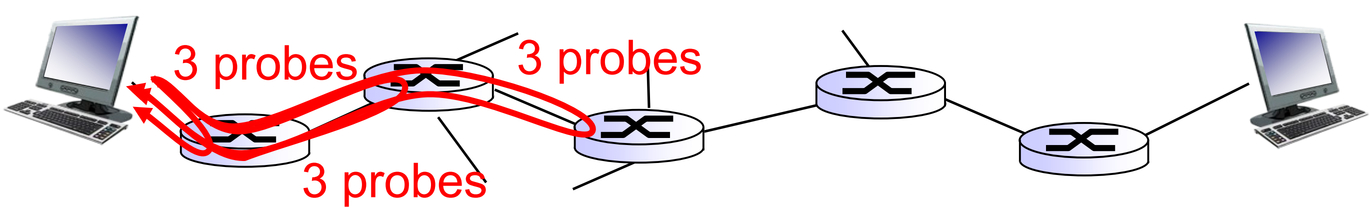
d_{prop}: propagation delay

- *d*: length of physical link
- s: propagation speed in medium (~2×10^8 m/sec)
- $d_{prop} = d/s$

End-to-end Packet Delay

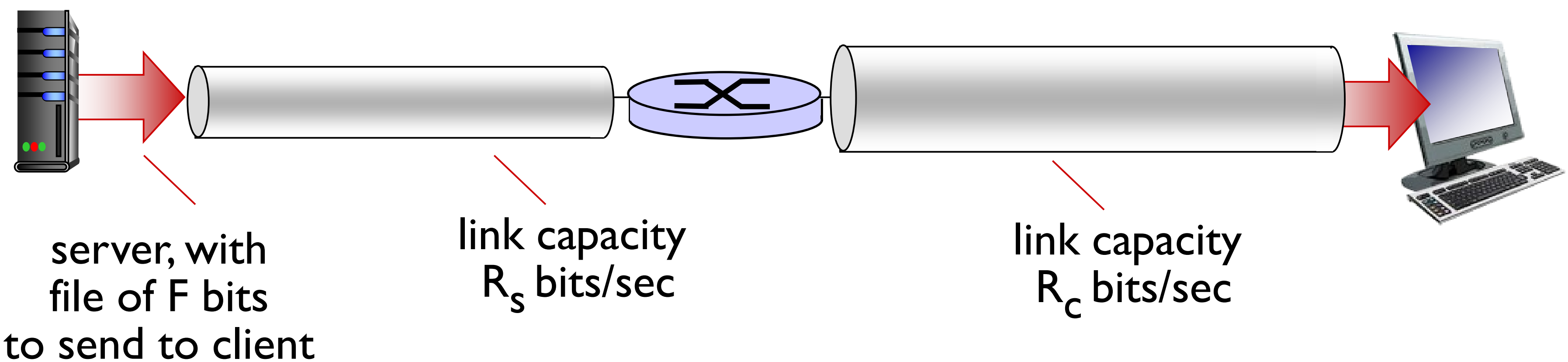
- End-to-end packet delay is the time taken for a packet to travel from source to destination. It consists of:
  - transmission delay
  - propagation delay
  - processing delay
  - queueing delay

traceroute program displays the route (path) from source to destination and measures the delay from source to each router along the end-end Internet path.



Throughput

- Throughput: how many bits can be transmitted per unit time.
  - Throughput is measured for end-to-end communication.
  - Link capacity (bandwidth) is meant for a specific link.



Metric Units

- 1 byte = 8 bits

Exp.	Explicit	Prefix	Exp.	Explicit	Prefix
10^{-3}	0.001	milli	10^{3}	1,000	Kilo
10^{-6}	0.000001	micro	10^{6}	1,000,000	Mega
10^{-9}	0.000000001	nano	10^{9}	1,000,000,000	Giga
10^{-12}	0.000000000001	pico	10^{12}	1,000,000,000,000	Tera
10^{-15}	0.000000000000001	femto	10^{15}	1,000,000,000,000,000	Peta
10^{-18}	0.000000000000000001	atto	10^{18}	1,000,000,000,000,000,000	Exa
10^{-21}	0.000000000000000000001	zepto	10^{21}	1,000,000,000,000,000,000,000	Zetta
10^{-24}	0.000000000000000000000001	yocto	10^{24}	1,000,000,000,000,000,000,000,000	Yotta

The principal metric prefixes

Lecture 1: Roadmap

1.1 What is the Internet?

1.2 Network Edge

- hosts, access networks, links

1.3 Network Core

- packet switching, circuit switching, network structure

1.4 Delay, Loss and Throughput in Networks

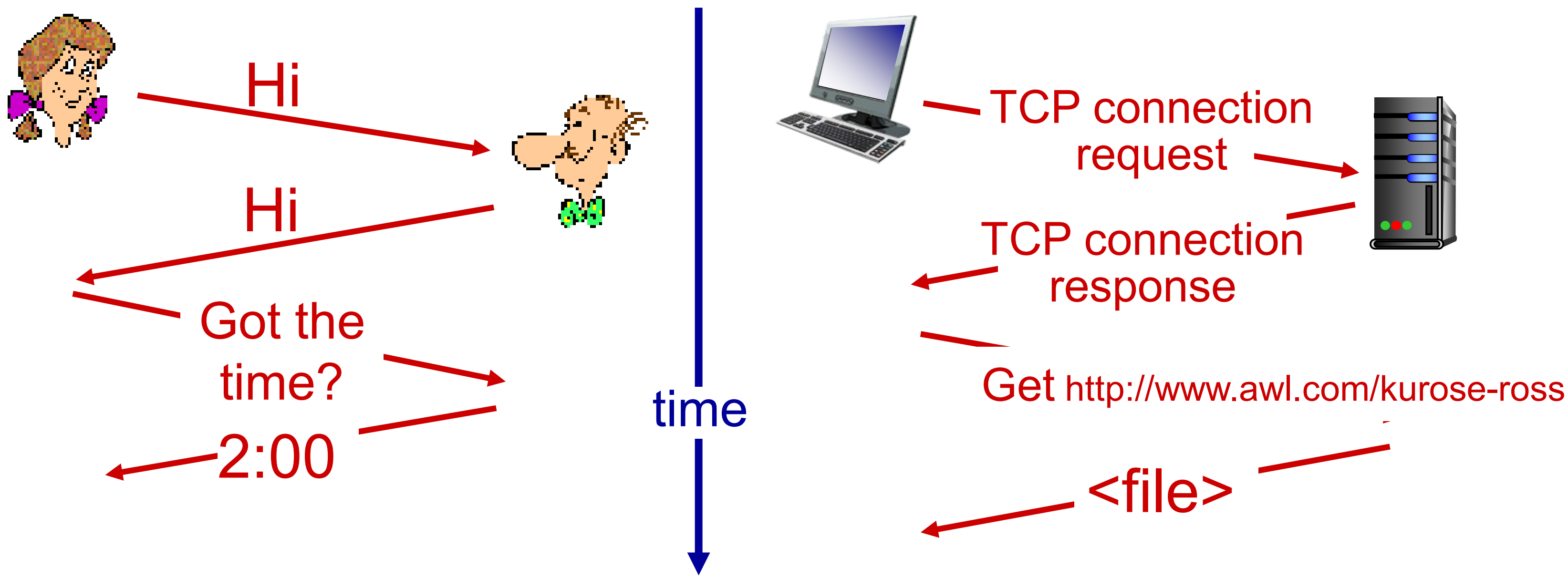
1.5 Protocol Layers and Service Models

Internet: a Service View

- The Internet supports various kinds of network applications:
  - Web, VoIP, email, games, e-commerce, social nets, …
- Network applications exchange messages and communicate among peers according to protocols.

What's a Protocol?

a human protocol and a computer network protocol:



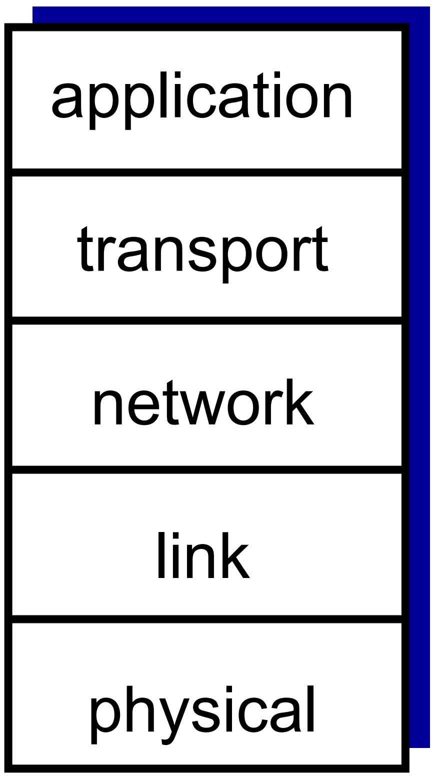
Protocols define format and order of messages exchanged and the actions taken after messages are sent or received.

Protocol "Layers"

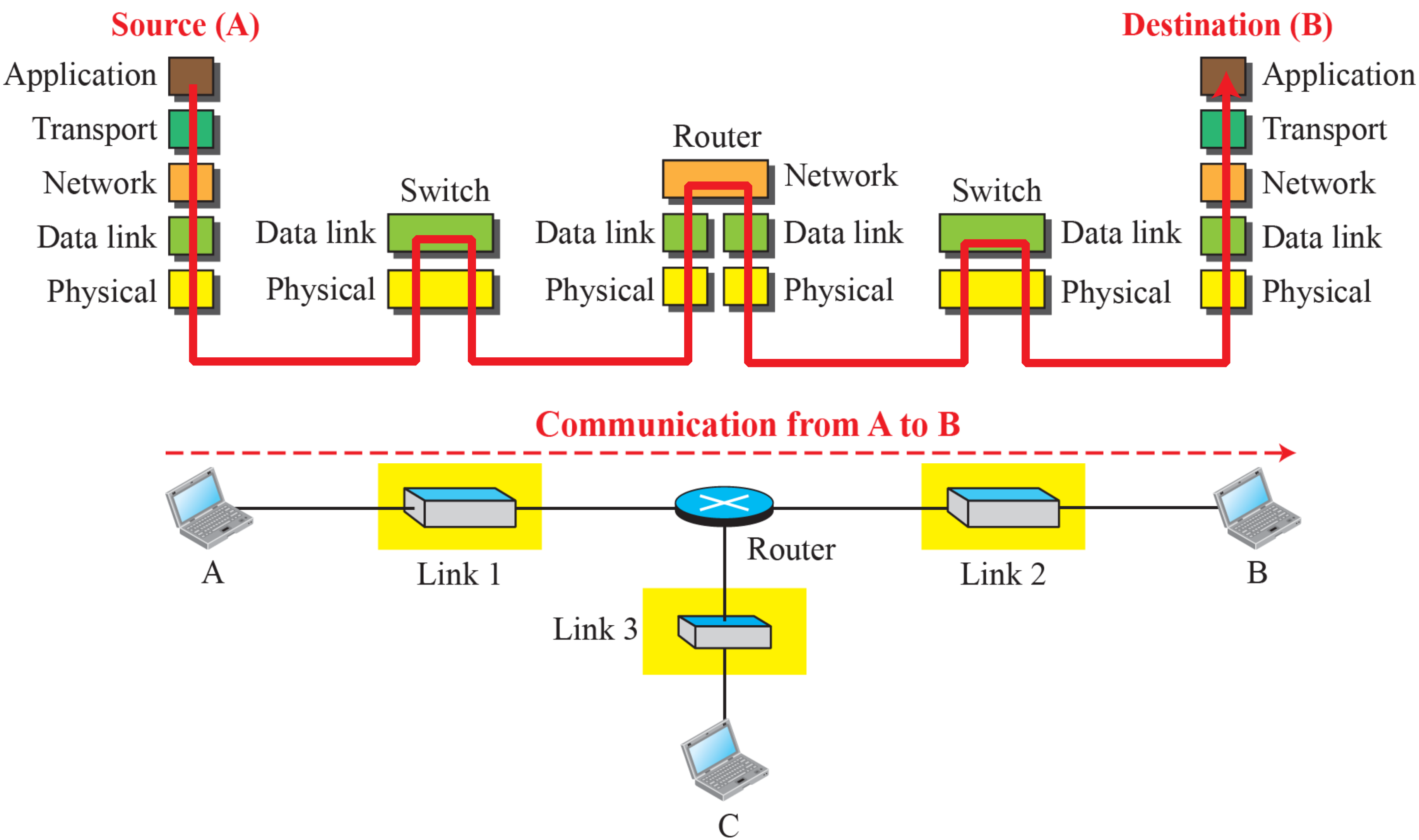
- Protocols in the Internet are logically organized into "layers" according to their purposes.
  - Each layer provides a service
  - Simple interfaces between layers
  - Hide details from each other
- Layering is a common CS trick to deal with large and complex systems.
  - Explicit structure allows identification, relationship of complex system's pieces
  - Modularization eases maintenance, updating of system
    - E.g. change of implementation of one layer's service is transparent to rest of system

Internet Protocol Stack

- *application:* supporting network applications
  - FTP, SMTP, HTTP
- *transport:* process-to-process data transfer
  - TCP, UDP
- *network:* routing of datagrams from source to destination
  - IP, routing protocols
- *link:* data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi), PPP
- *physical:* bits “on the wire”

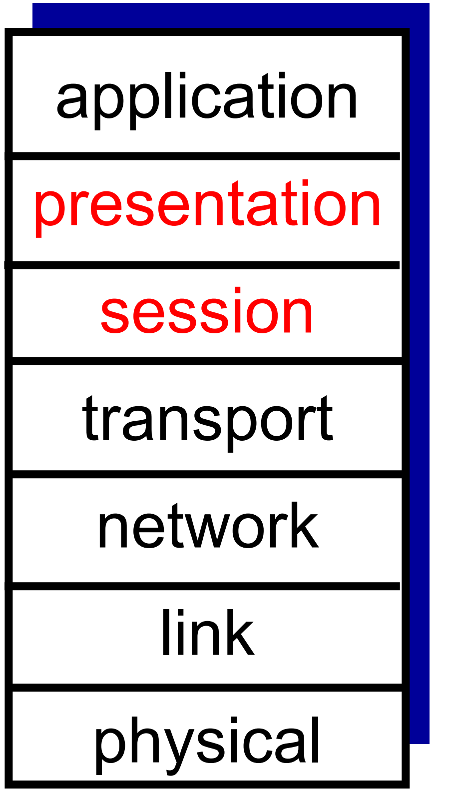


Example


Source (A)
Destination (B)
Application
Transport
Network
Data link
Physical
Switch
Data link
Physical
Router
Network
Data link
Physical
Data link
Physical
Switch
Data link
Physical
Application
Transport
Network
Data link
Physical
Communication from A to B
A
Link 1
Router
Link 2
B
Link 3
C

ISO/OSI reference model (FYI)

- Theoretical model – not in use
- Two additional layers not present in Internet Protocol Stack
  - *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
  - *session:* synchronization, checkpointing, recovery of data exchange



Lecture 1: Summary

covered a "ton" of material!

- Internet overview
- Network edge, core, access network
  - packet-switching versus circuit-switching
  - Internet structure
- Performance: loss, delay, throughput
- What's a protocol?
- Layering, service models

you now have:

- Context, overview, "feel" of networking
- More depth, detail *to follow!*