CS2105 Introduction to Computer Networks

Lecture 1

Introduction

13 Aug 2018

Learning Outcomes

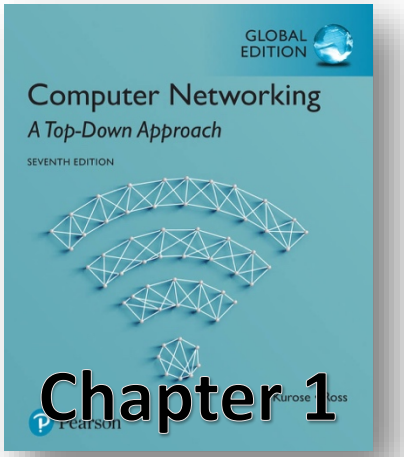
At the end of this class, you should:

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

Pre-Lecture Quiz

https://goo.gl/oyZ2ey

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

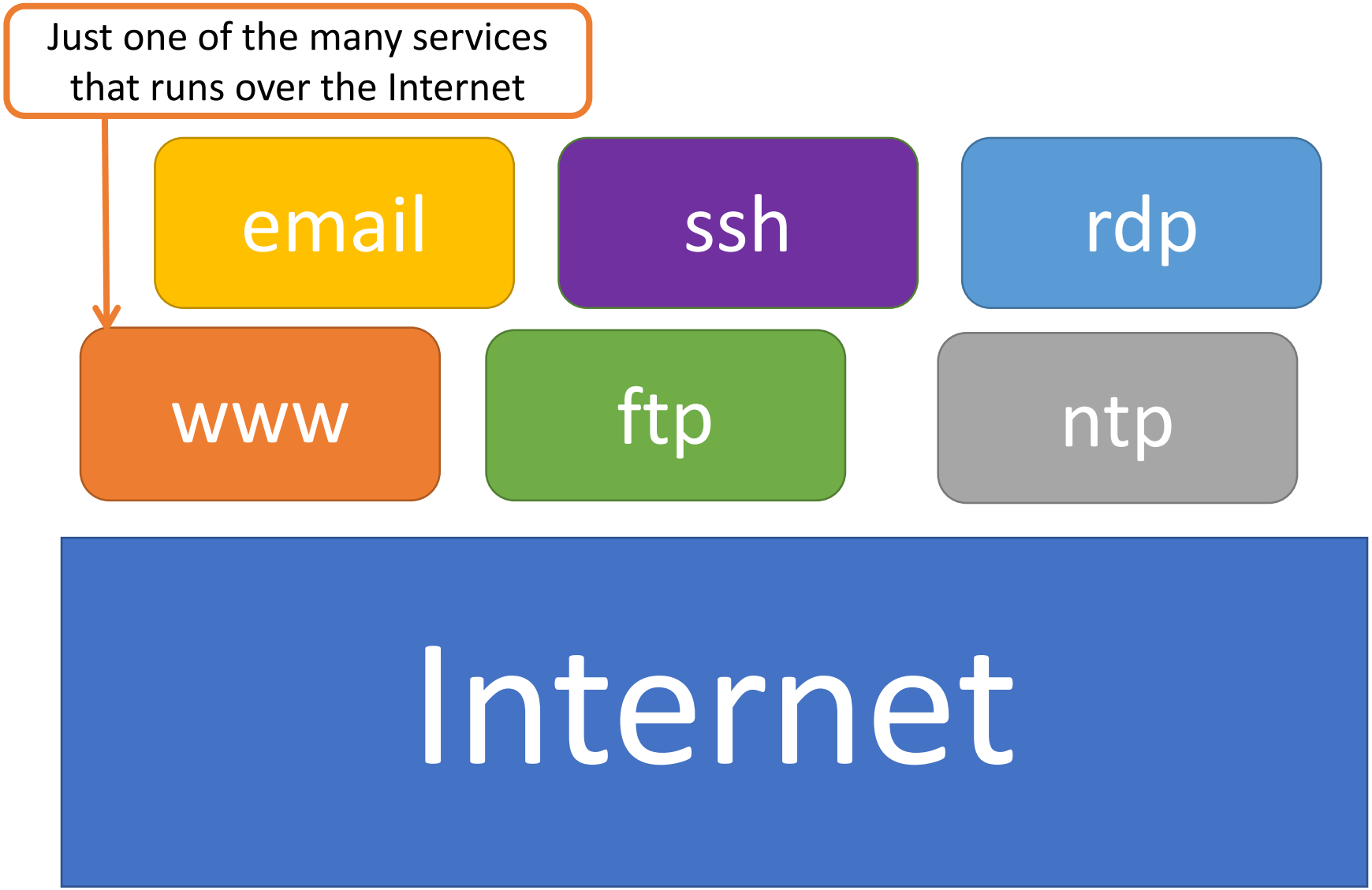
1.5 Protocol Layers and Service Models

Why the Internet?

- US Department of Defense
  - Maintain communication during a nuclear war
  - Reliable redundancy
- APRANET
  - One of many early networks

- Why the Internet?
- What is the Internet?

Internet ≠ World Wide Web

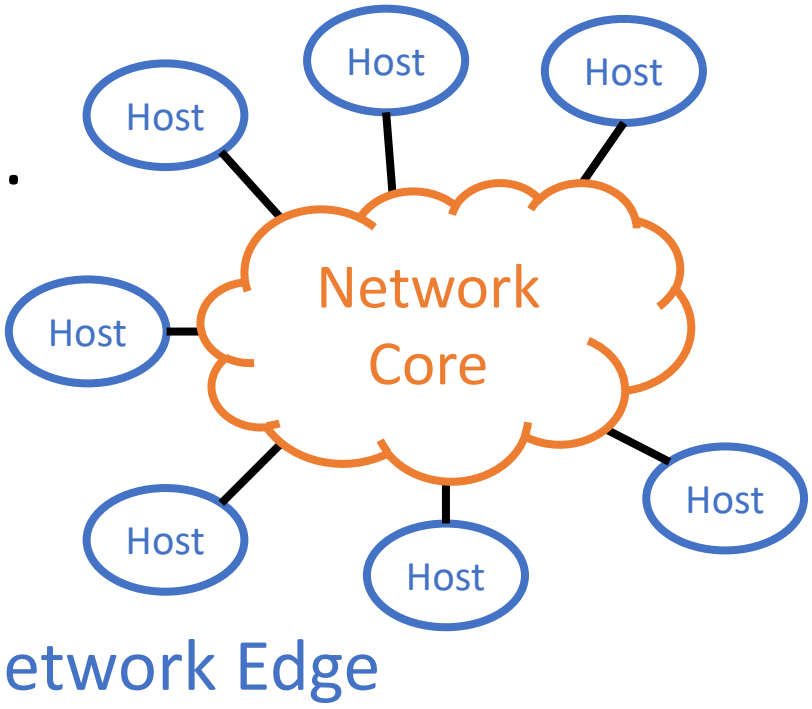

Just one of the many services that runs over the Internet
email
ssh
rdp
www
ftp
ntp
Internet


alamy stock photo
ERP014
www.alamy.com

The Internet is a network of connected computing devices

In other words

- It is infrastructure that connects hosts/end systems together
  - Allows hosts to communicate with each other
- Network edge
  - End hosts, servers, etc.
- Network core
  - ISPs, Routers, etc.



- Why the Internet?
- What is the Internet?
- How the Internet is organised?

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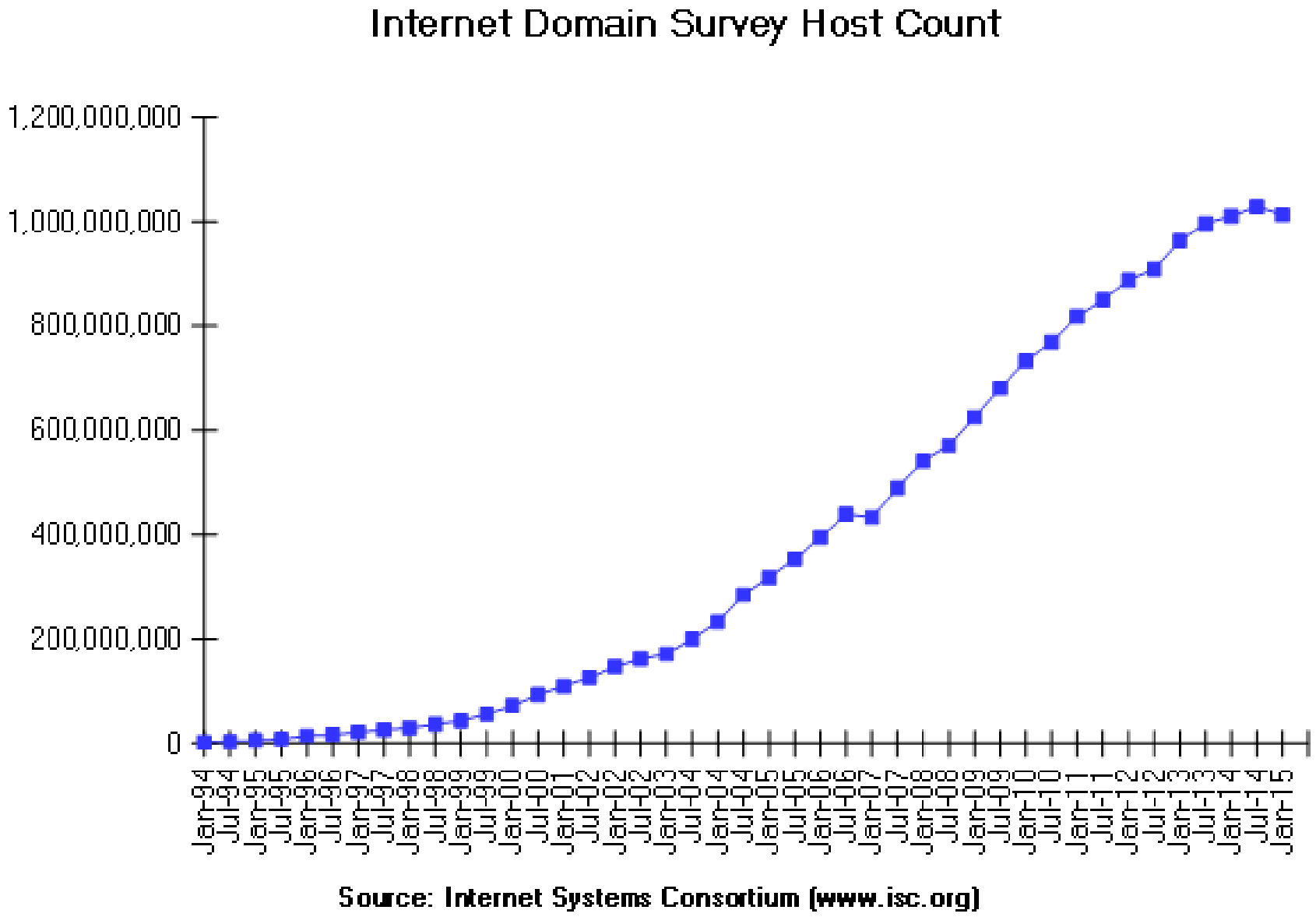
Hosts/End Systems


Internet Domain Survey Host Count
1,200,000,000
1,000,000,000
800,000,000
600,000,000
400,000,000
200,000,000
0
Jan-94
Jul-94
Jan-95
Jul-95
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Jan-15
Source: Internet Systems Consortium (www.isc.org)

Hosts run network applications

Examples

- Web: browsers ↔ web servers
- WoW: clients ↔ game servers
- VoIP: IP phones ↔ PBX servers
- BitTorrent: peers ↔ trackers
- BitCoin: miners ↔ exchange

Applications
communicate using
protocols

Protocols define the:

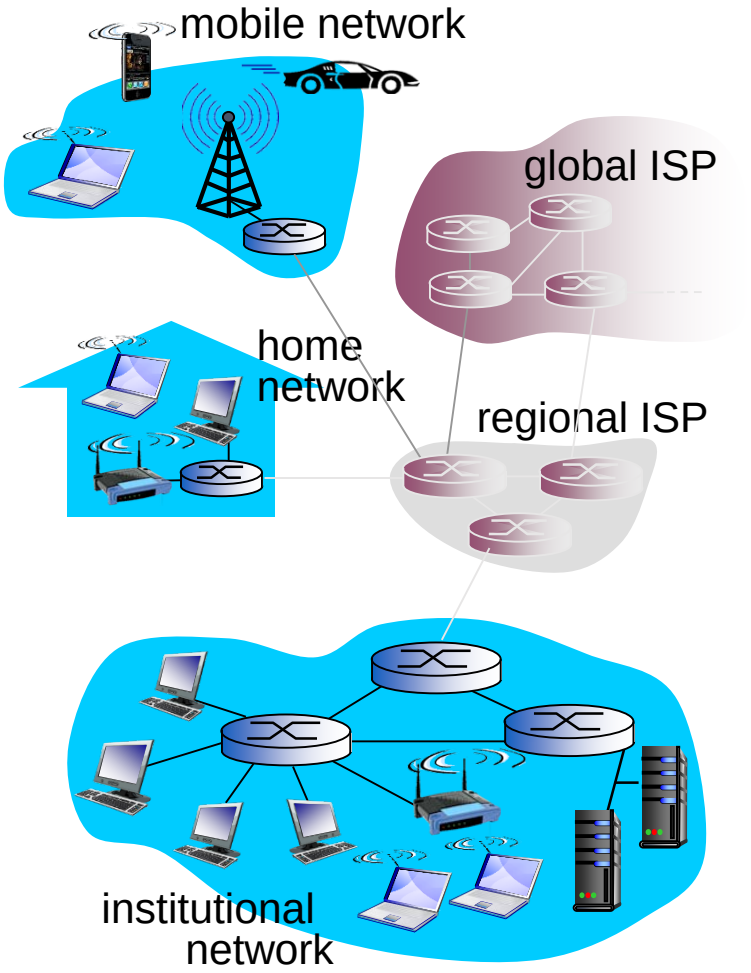
1. format and order of messages exchanged among network entities, and
2. actions taken upon receiving or sending the messages

Some Examples

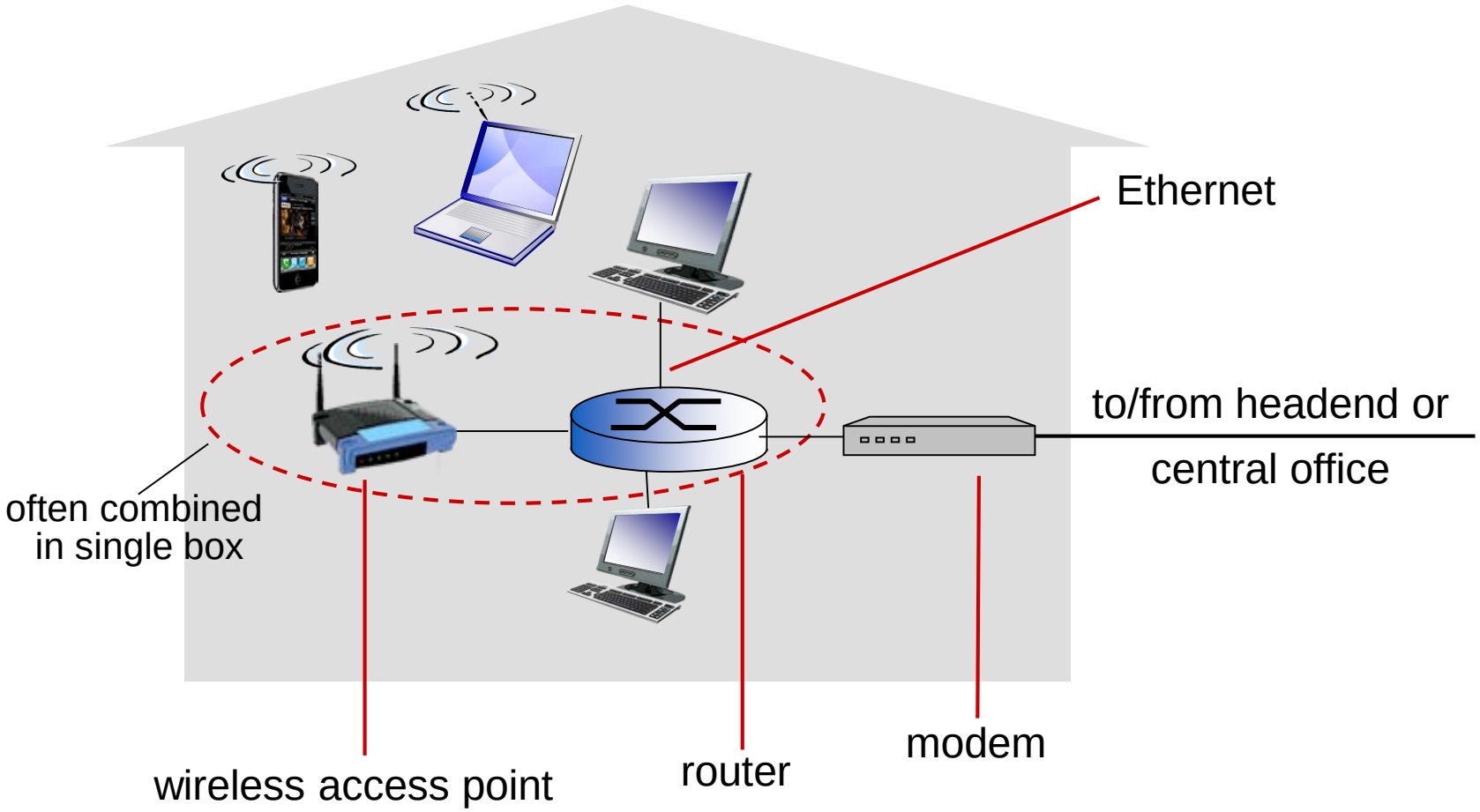
HTTP, FTP, SMTP, TCP, RTP

Access Networks

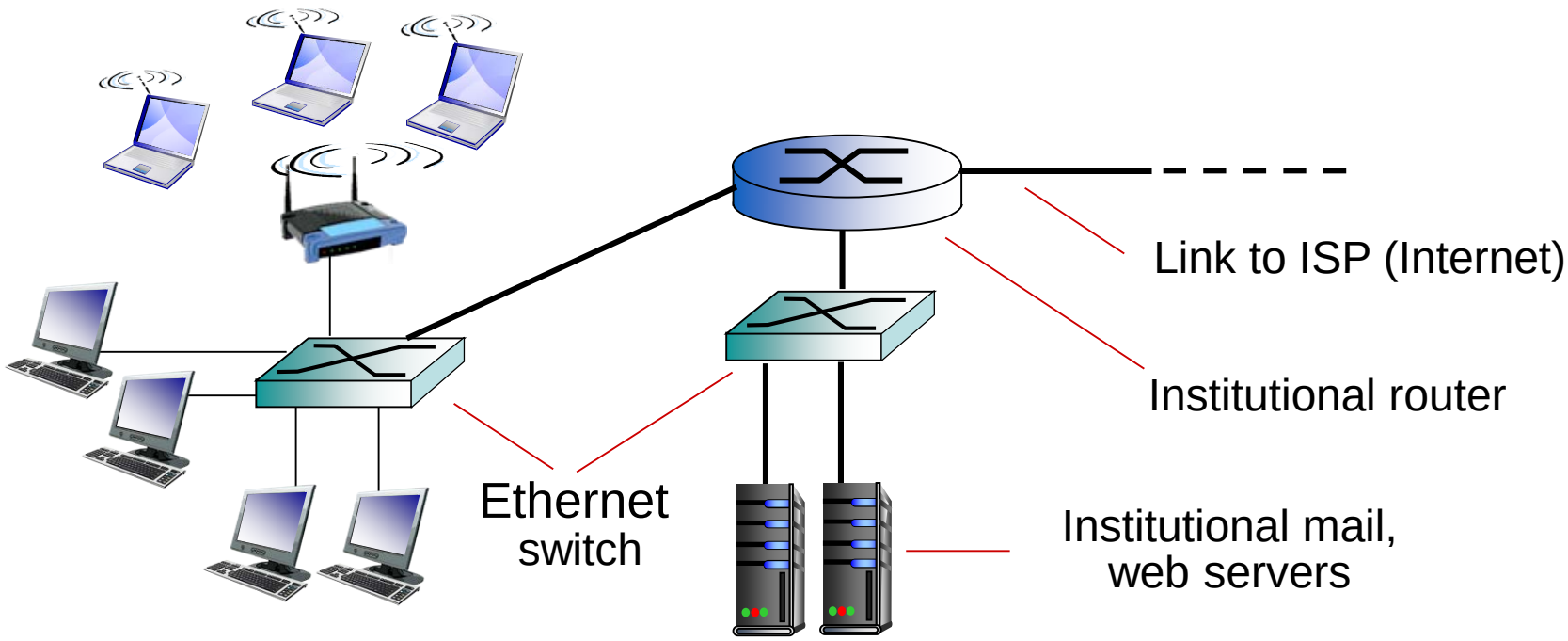
- Hosts access the Internet through *access network*.
  - Residential access networks
  - Institutional access networks (school, company)
  - Mobile access networks



Home Networks



Enterprise Access Networks

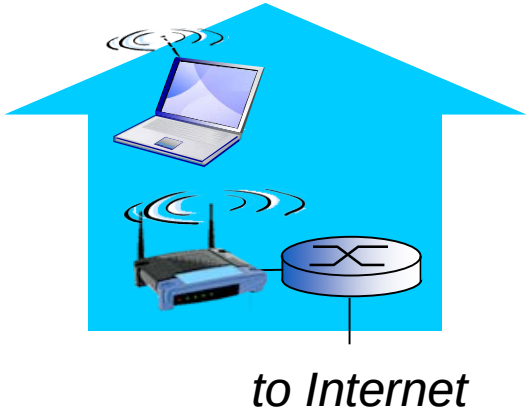


- Typically used in companies, universities, etc.
  - 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
  - Today, hosts typically connect to Ethernet switch

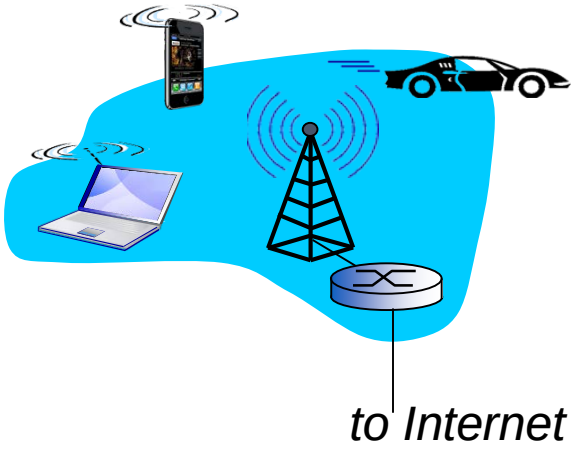
Wireless Access Networks

- 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)



- Wide-area wireless access
  - 3G, 4G
  - provided by telco (cellular) operator, 10’s km



Physical Media

- Hosts connect to the access network over different physical media (cable).
  - Guided media:
    - signals propagate in solid media, e.g. fiber
  - Unguided media:
    - signals propagate freely, e.g., Wi-Fi, cellular

Unshielded twisted pair

Coaxial cable

Fiber optics

Radio waves

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1.2 Network Edge

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1.3 Network Core

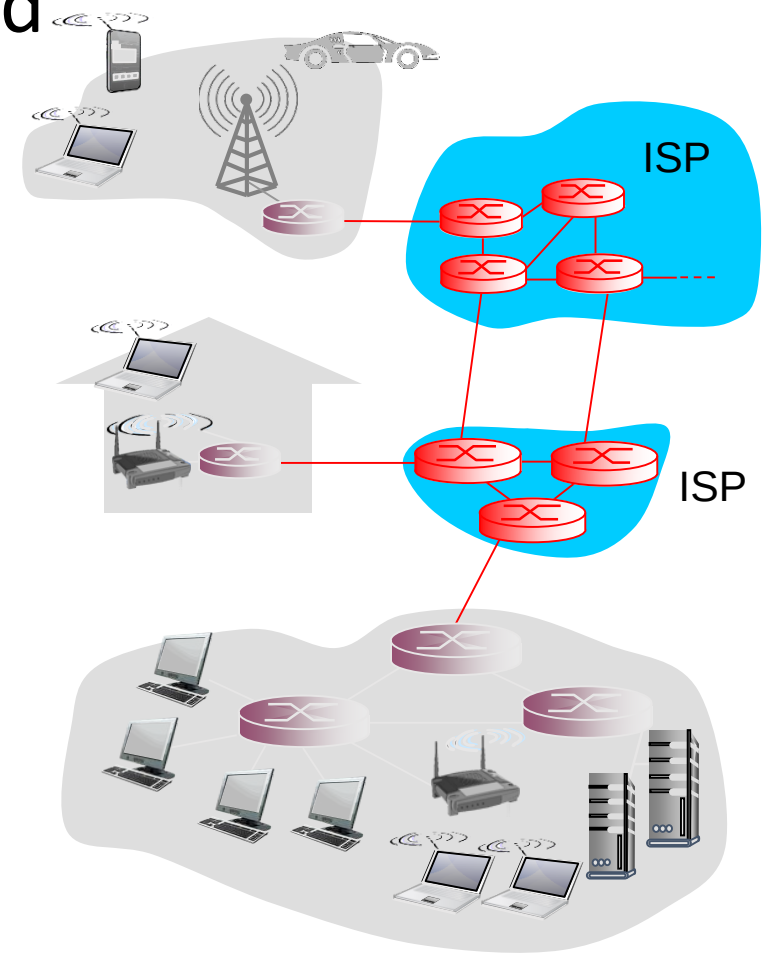
- packet switching, circuit switching, network structure

1.4 Delay, Loss and Throughput in Networks

1.5 Protocol Layers and Service Models

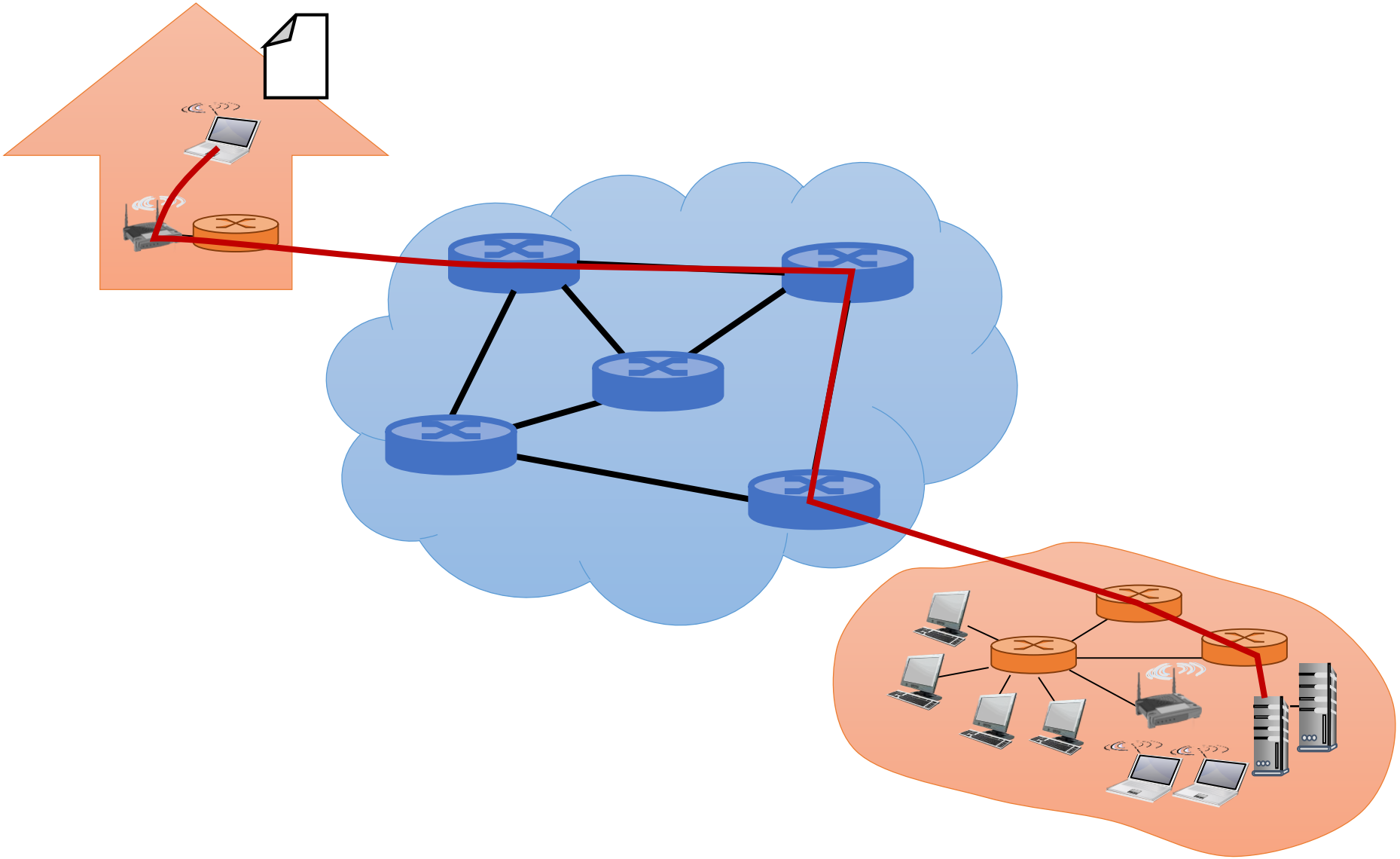
The Network Core

- A mesh of interconnected routers
- The fundamental question: how is data transmitted through the network?
  1. Circuit switching
  2. Packet switching



Circuit Switching

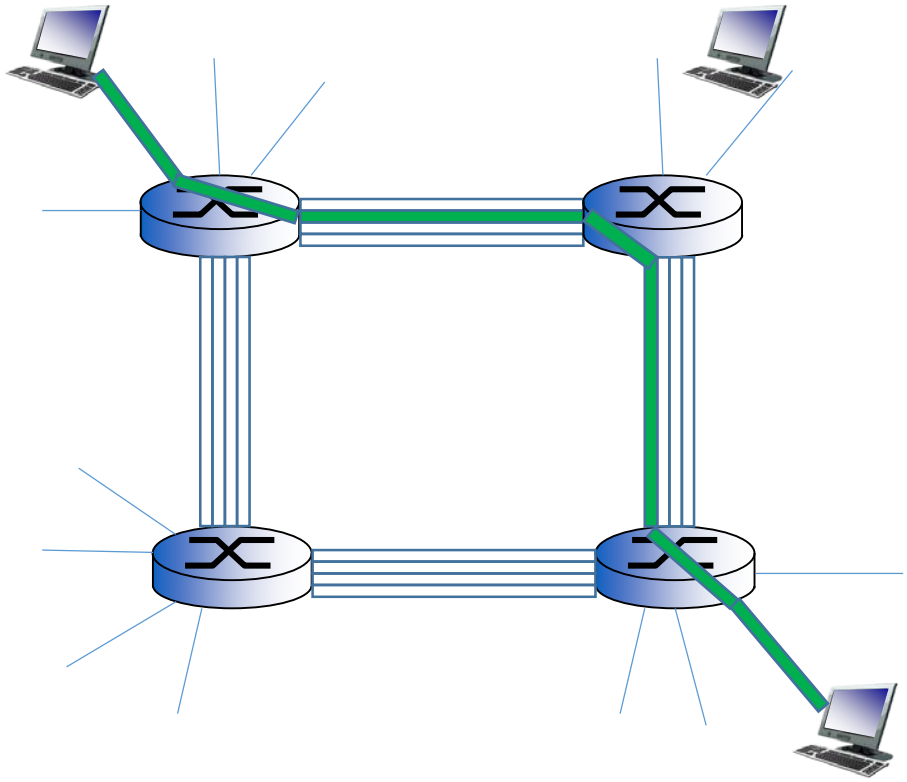
Circuit Switching



Circuit Switching

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

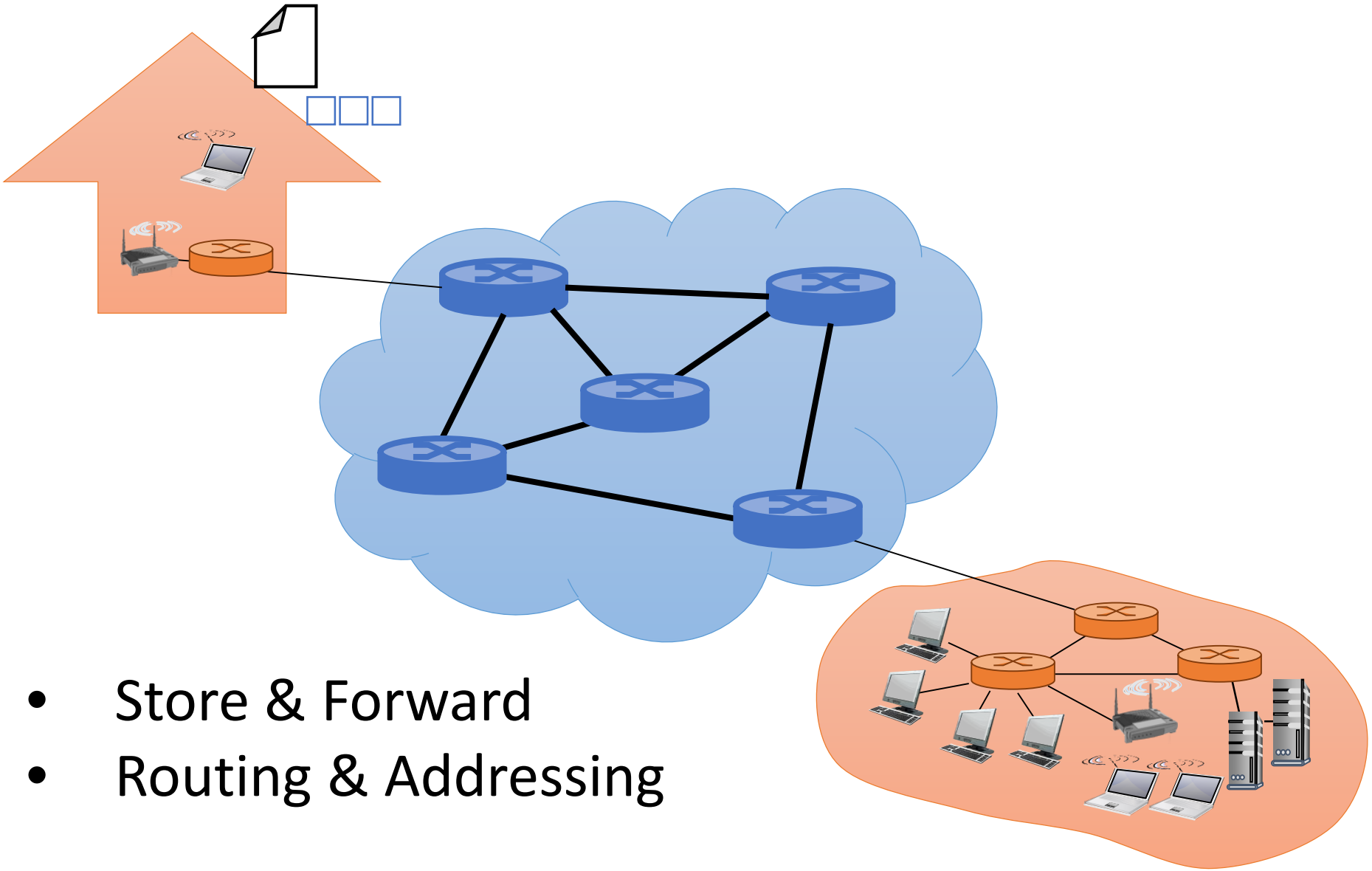
- call setup required
- circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- commonly used in traditional telephone networks
- divide link bandwidth into "pieces"
  - frequency division
  - time division



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

Packet Switching

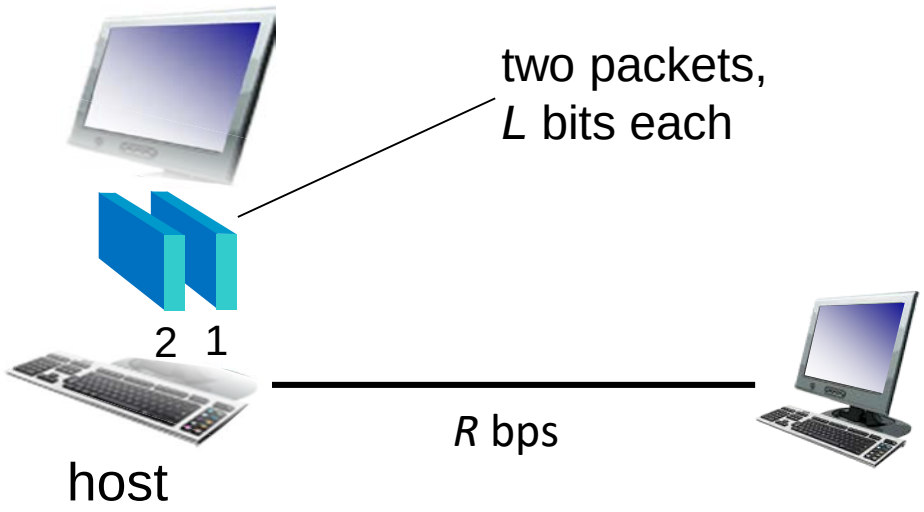
Packet Switching



- Store & Forward
- Routing & Addressing

Packet Switching

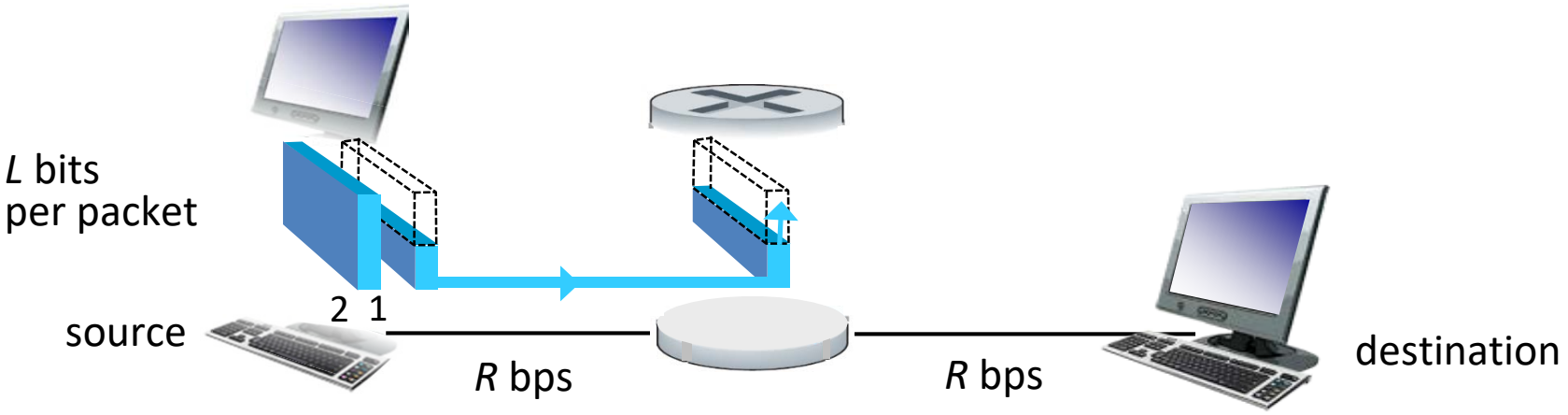
- Host sending function:
  - breaks application message into smaller chunks, known as packets, of length L bits
  - transmits packets onto the link at transmission rate R
    - link transmission rate is aka link capacity or link bandwidth



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

Packet-switching: store-and-forward

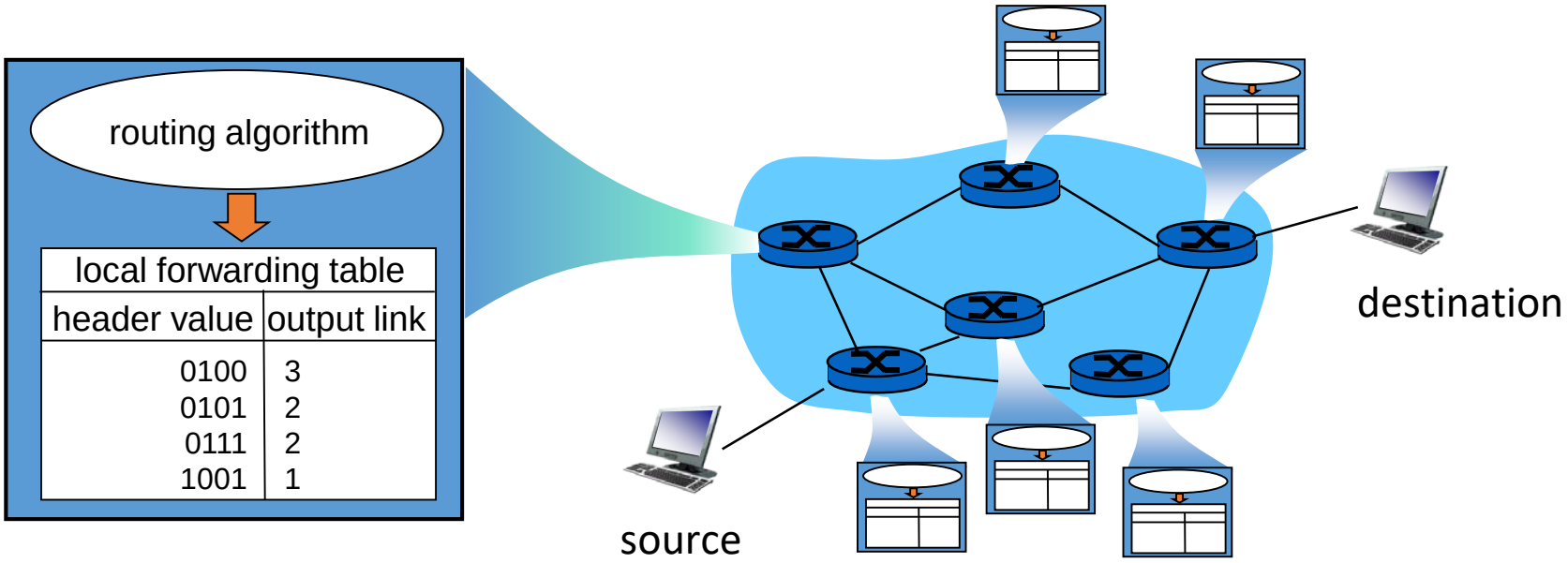
- Packets are passed from one router to the next, across links on path from source to destination.
- *Store and forward:* entire packet must arrive at a router before it can be transmitted on the next link.



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



Which is more efficient?

Circuit Switching

- Setup/teardown required
- Resources are reserved
- Service is guaranteed

Packet Switching

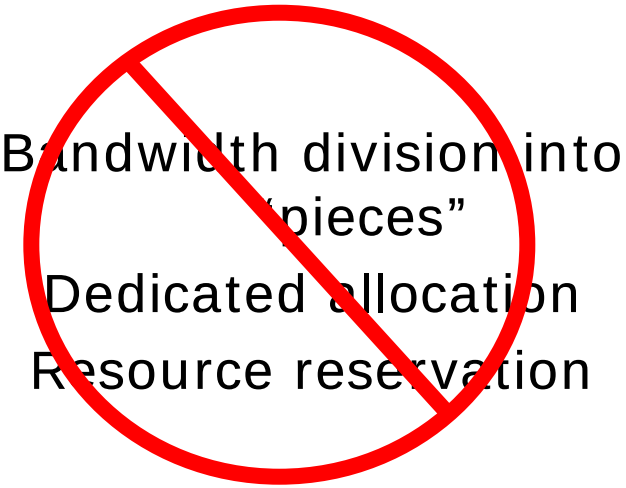
- No setup/teardown required
- Resources shared on demand
- Best effort service

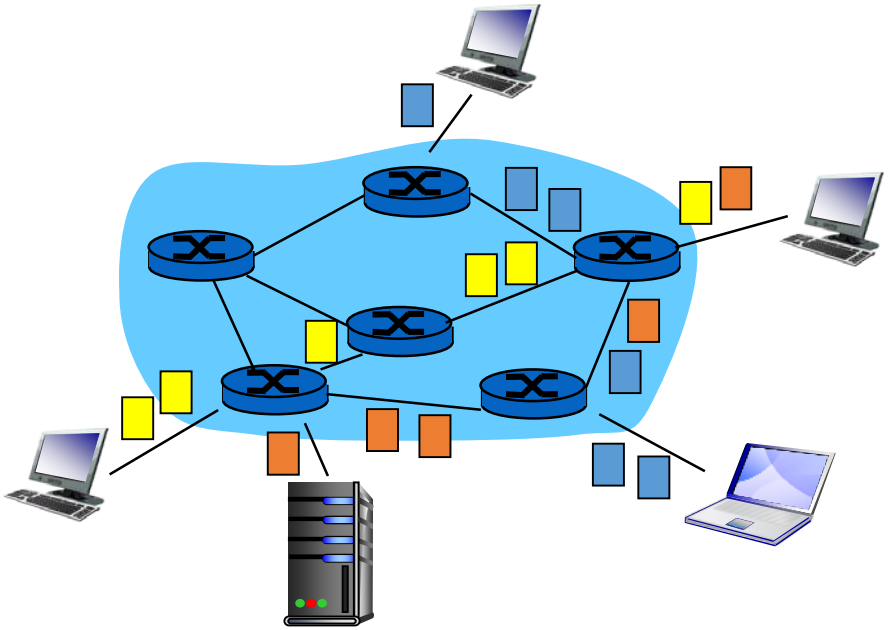
What does the Internet use?

The Internet is a packet switching network

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





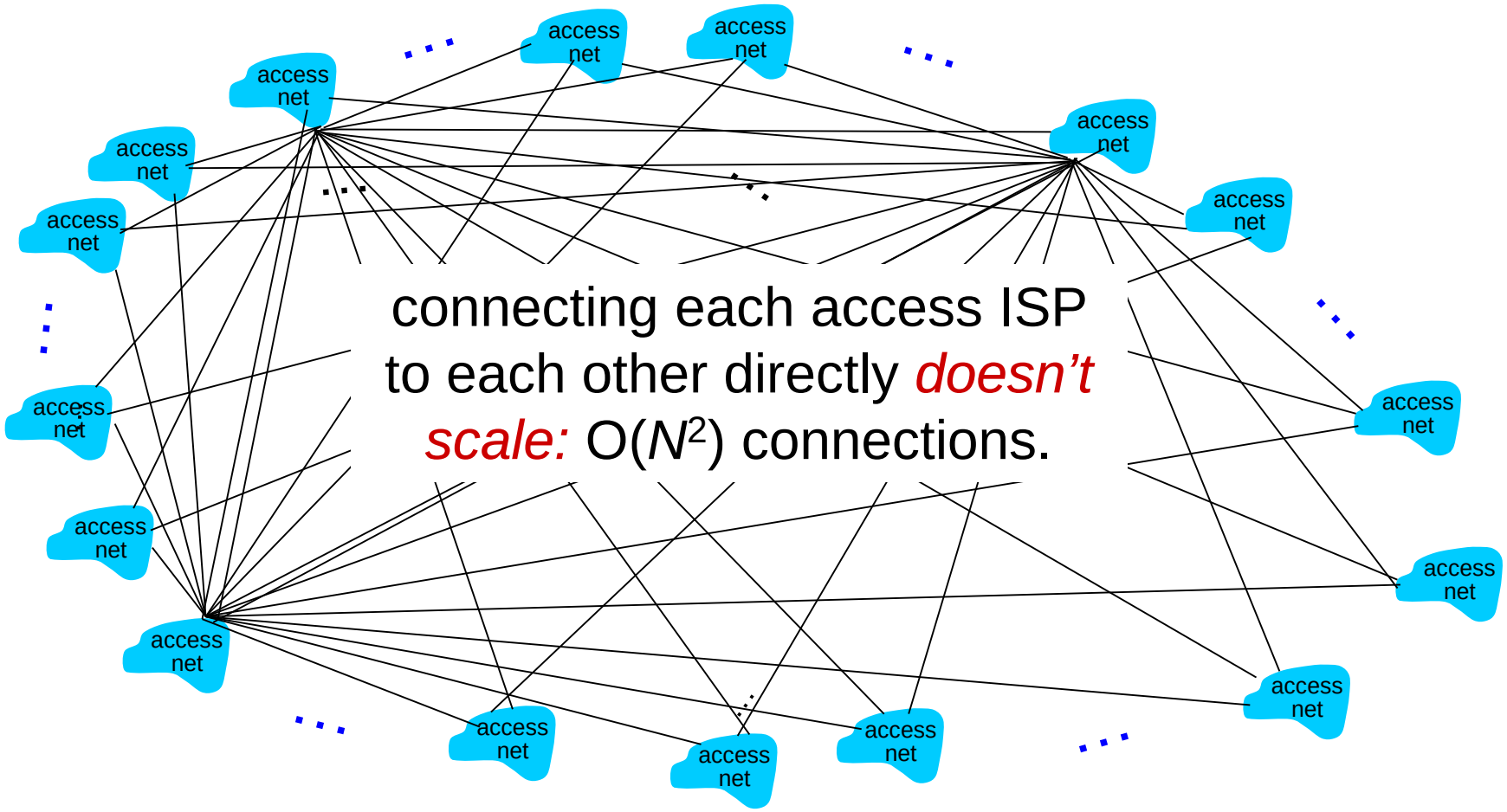
- Who owns the Internet?
- Who owns the core?
- How do you access the Internet?

Internet Service Providers

“Tier 3”

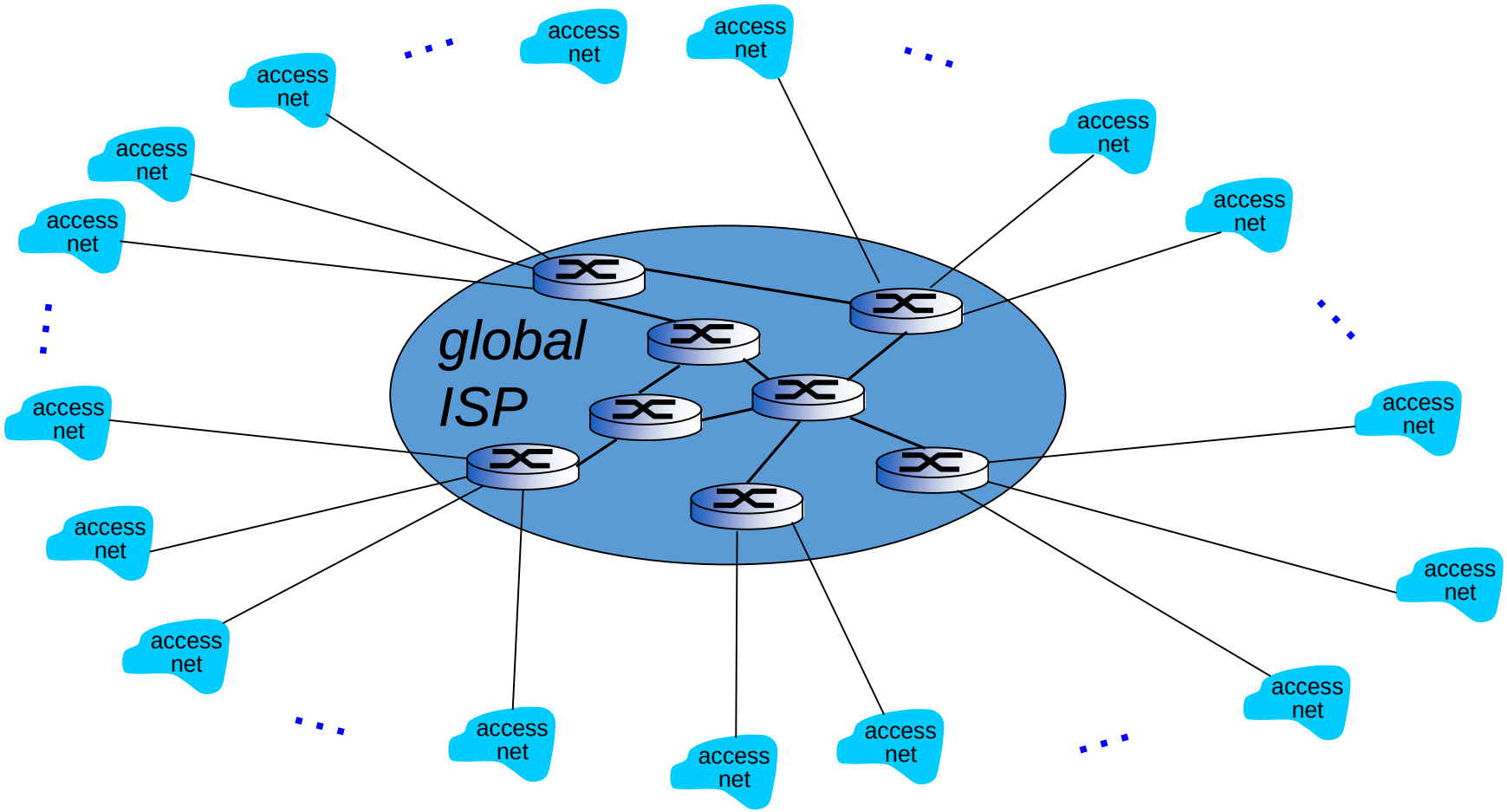
Connecting the Internet

- How should access ISPs connect to each other?



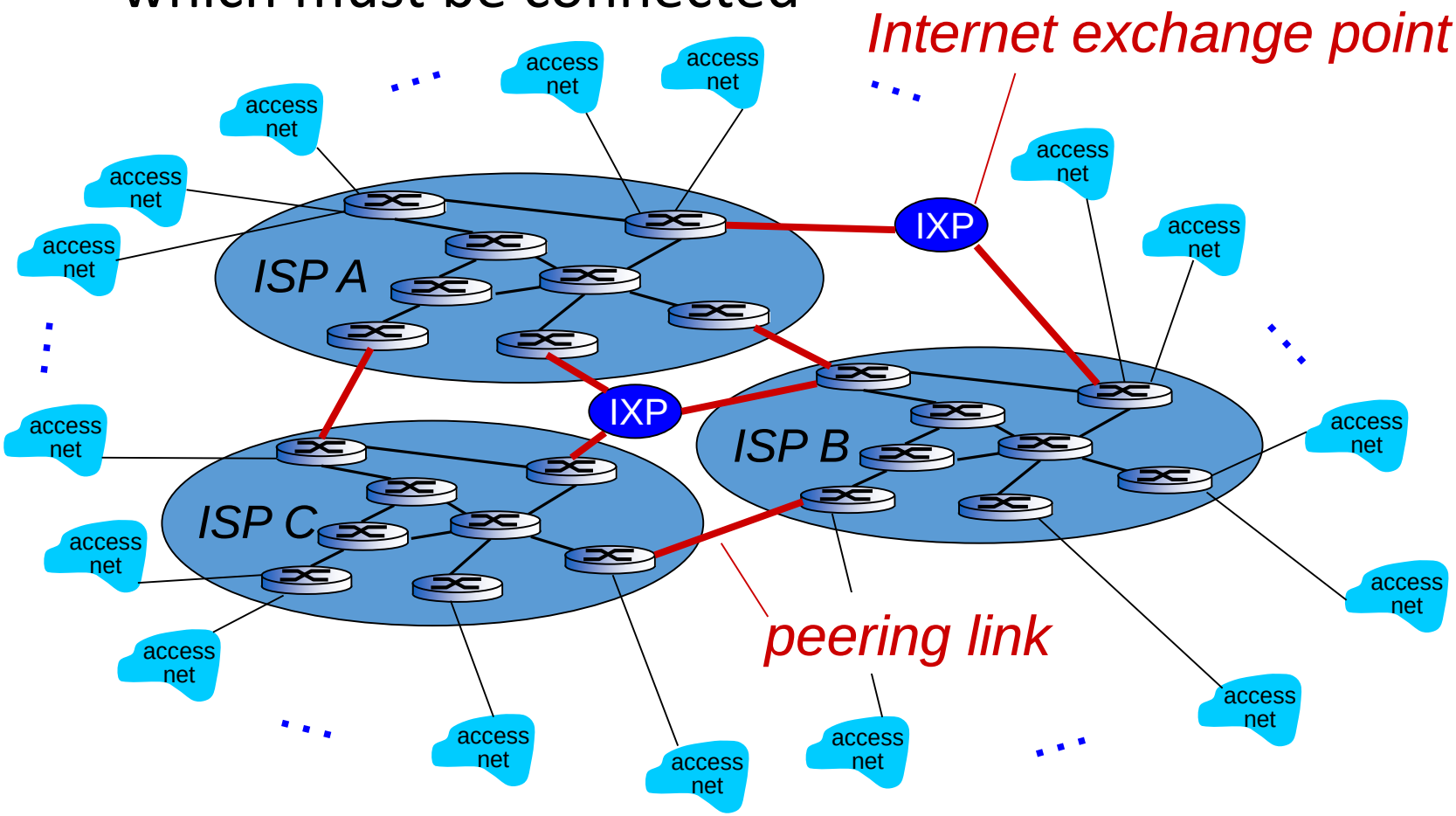
Connecting the Internet

- Connect each access ISP to a Global ISP



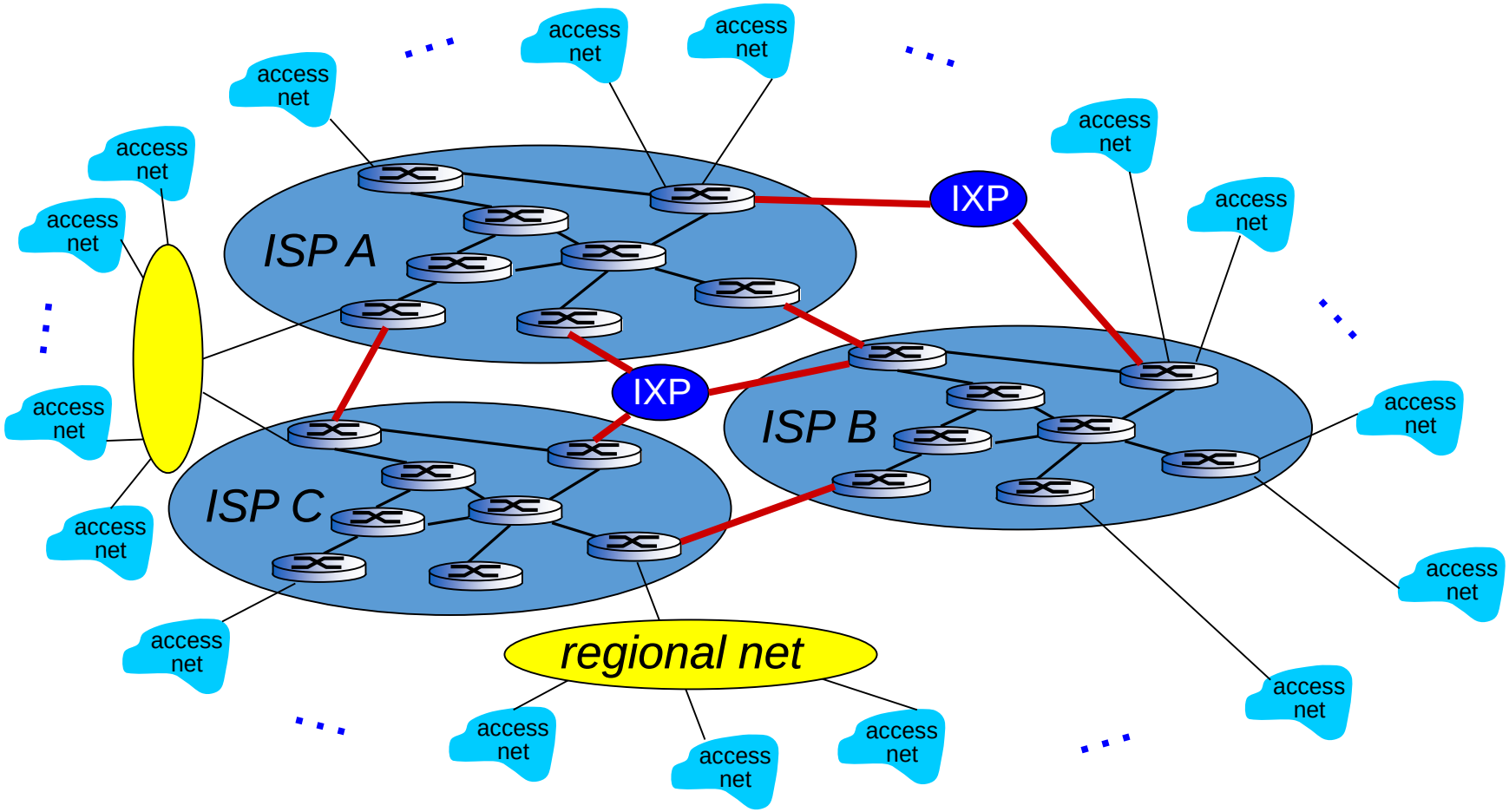
Connecting the Internet

- If one Global ISP is a viable business, there will be competitors
  - which must be connected



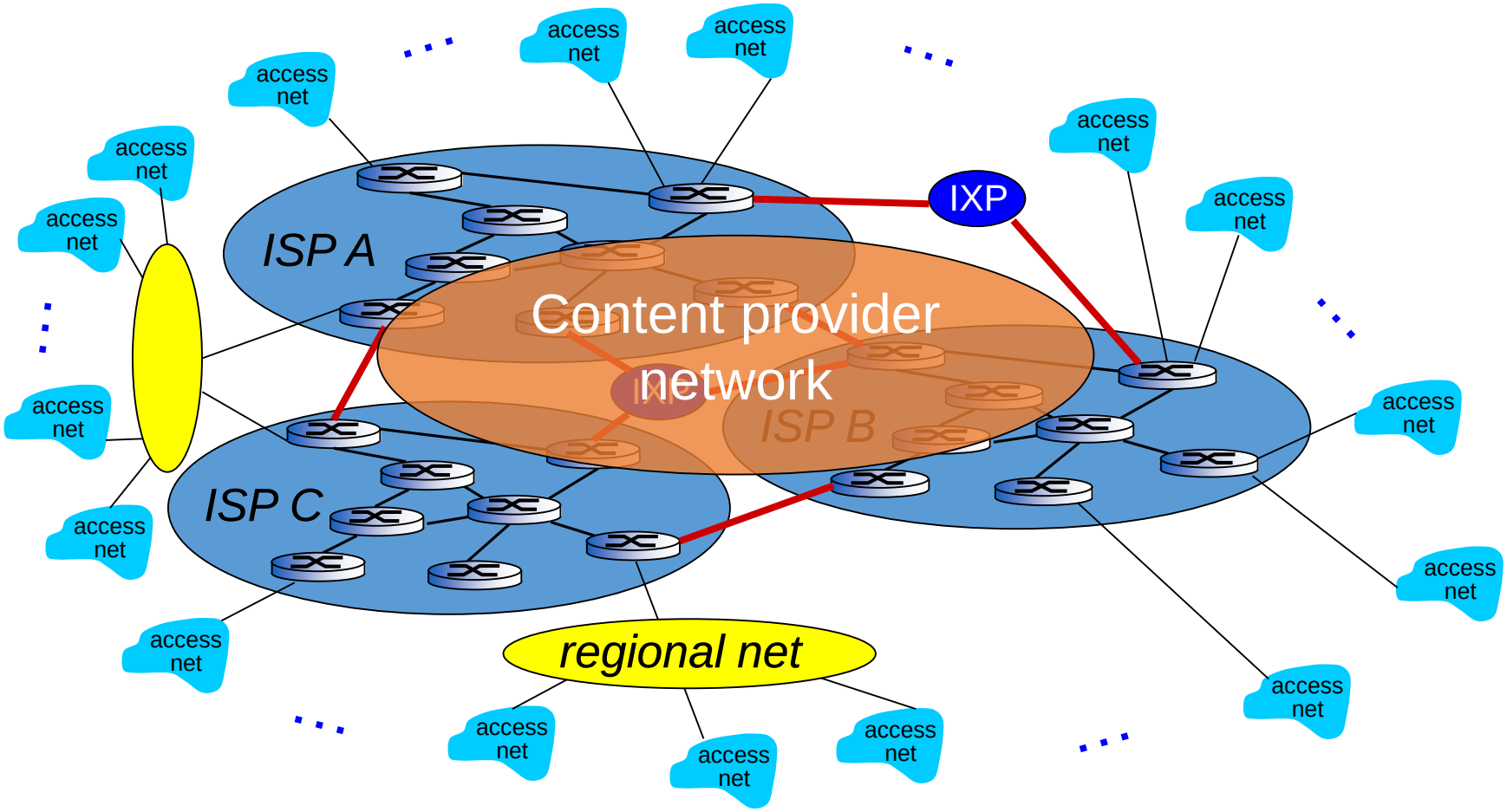
Connecting the Internet

- Regional networks may arise as middlemen to connect access net to ISPs



Connecting the Internet

- Content providers like Google or Akamai might even run their own network
  - to bring services content closer to users



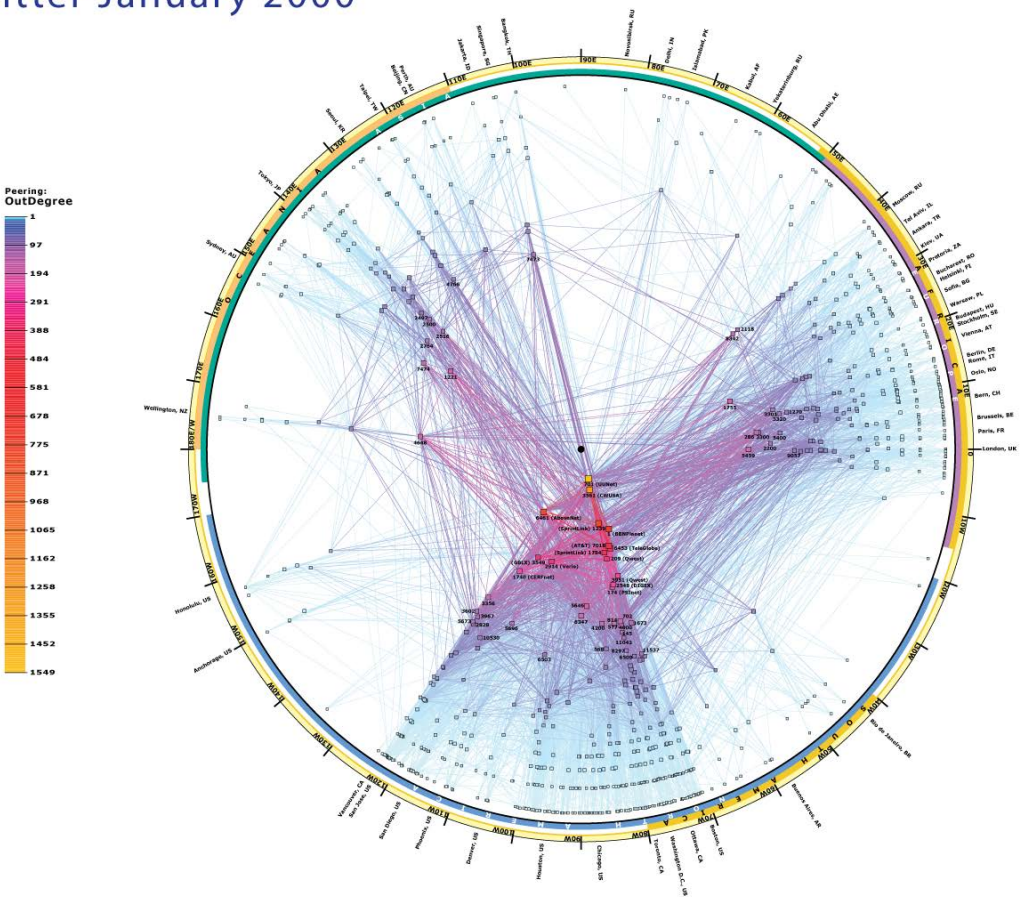
The Internet is a network of networks

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.

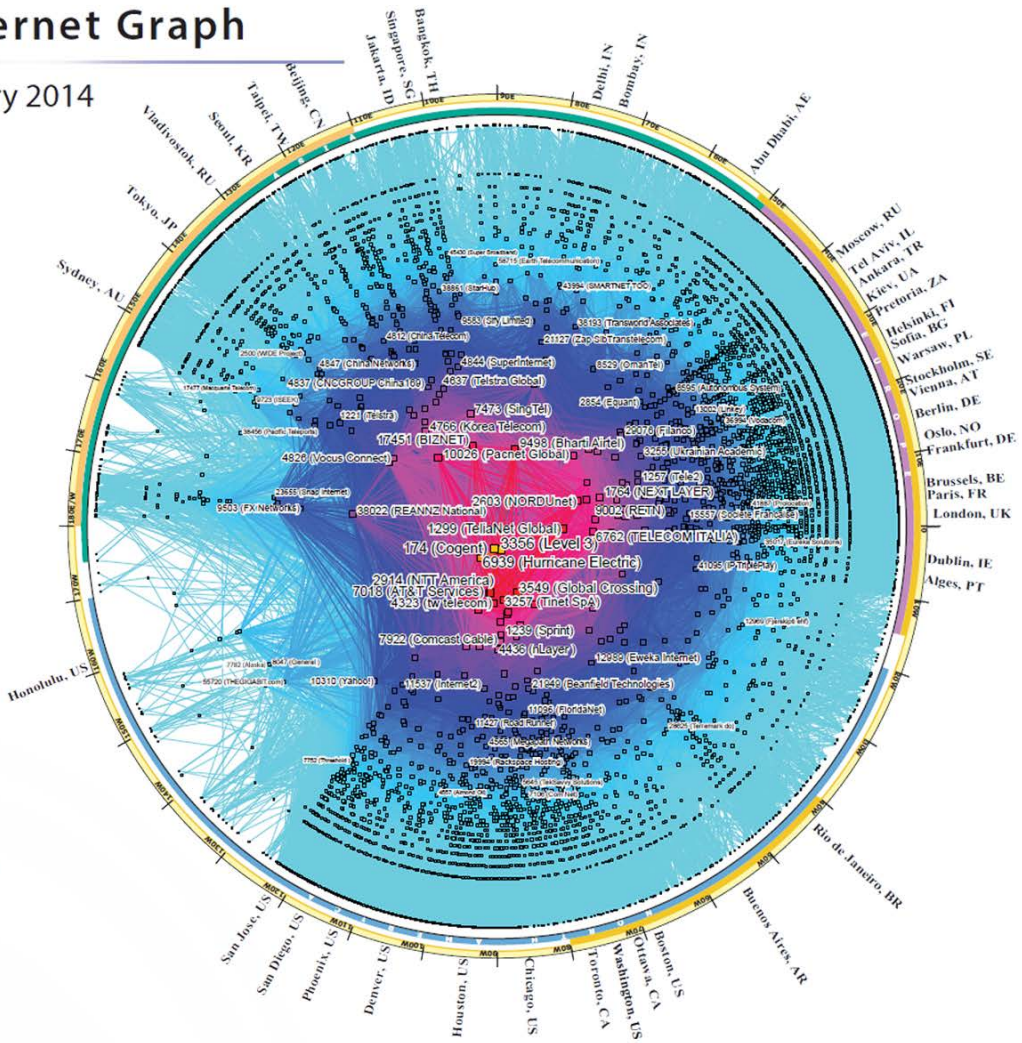
CAIDA's IPv4 AS Core
AS-level INTERNET GRAPH

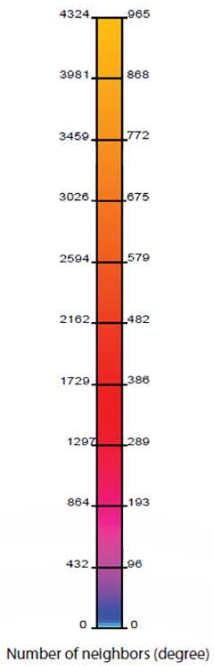
Skitter January 2000



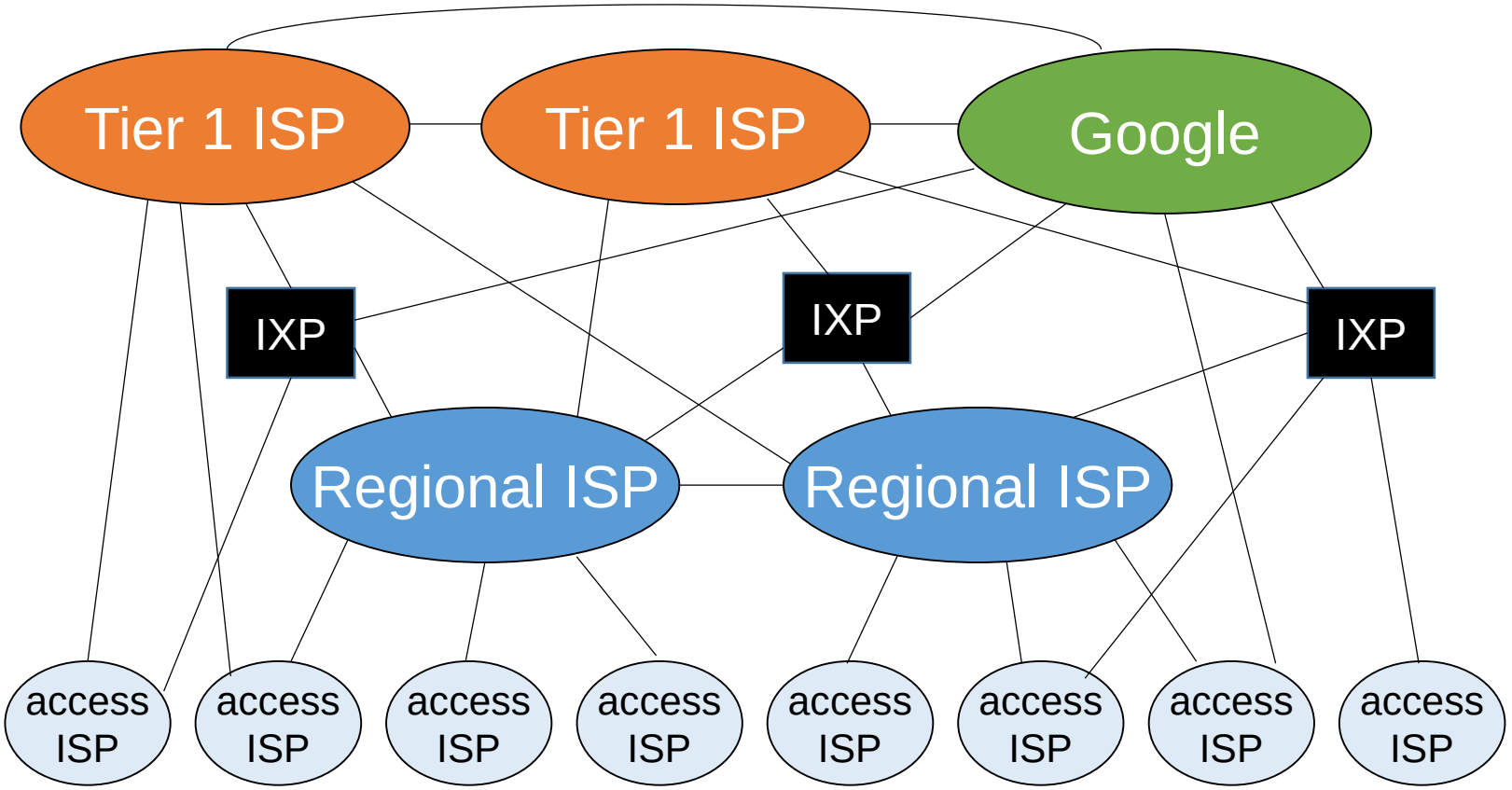
CAIDA's IPv4 AS Core
AS-level Internet Graph

Archipelago January 2014





Internet structure



- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

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

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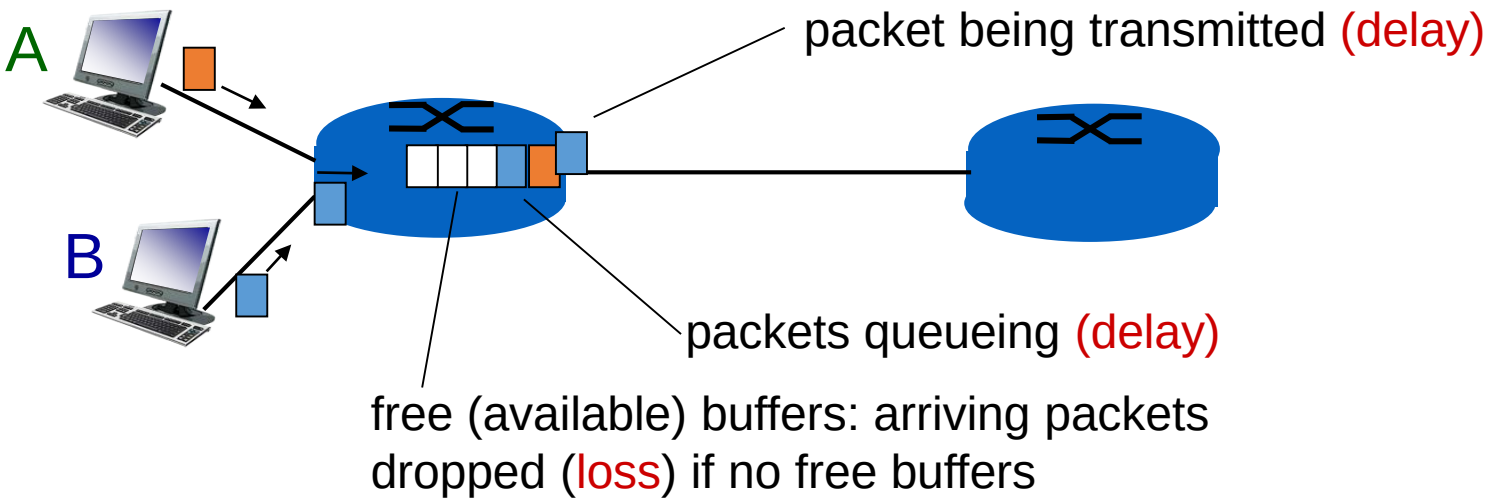
Recall: Packet Switching Network

To send a packet in a packet switching network,

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

How does loss occur?

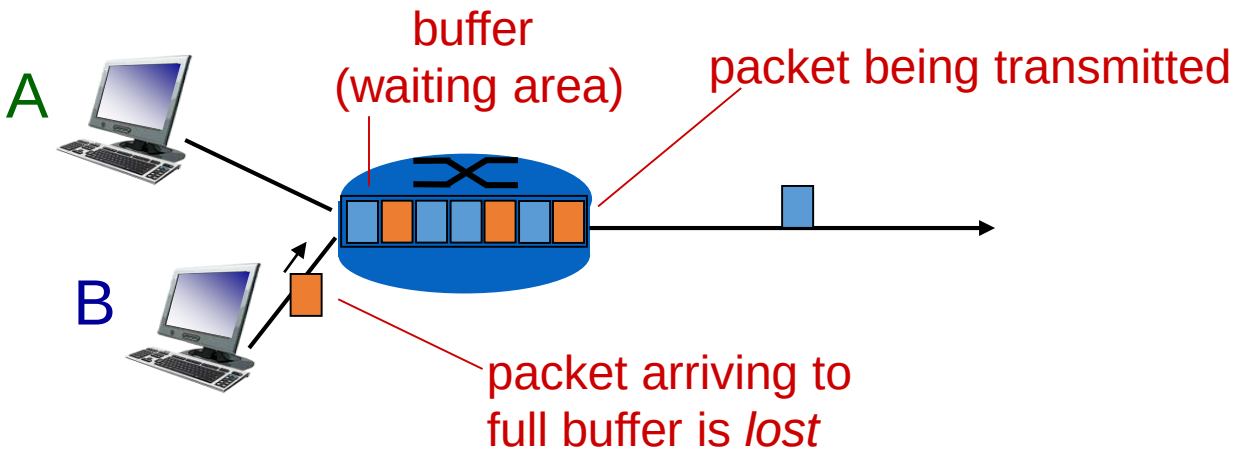
- Packets queue in router buffers
  - wait for turn to be sent out one by one



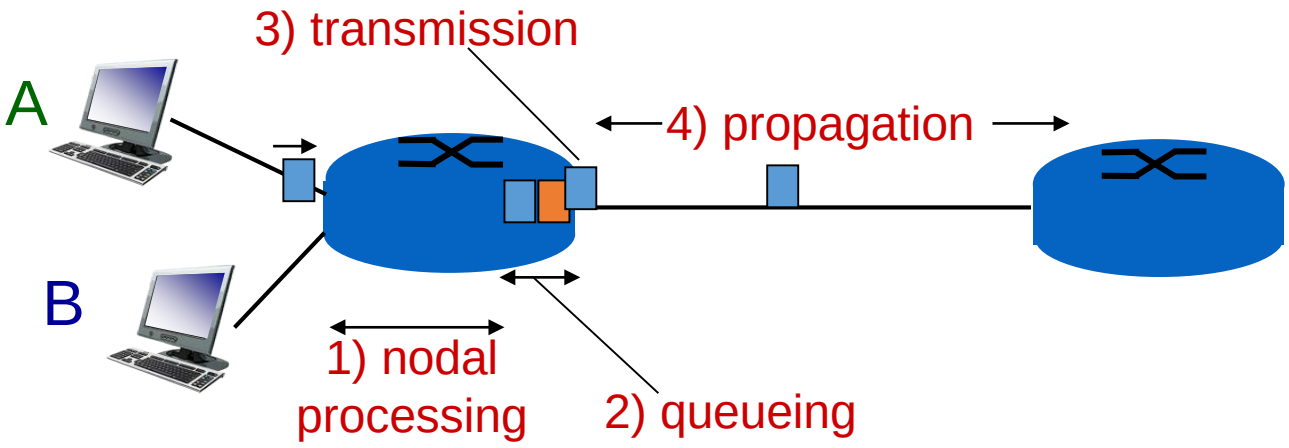
Q: What if packet arrival rate exceeds departure rate?

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



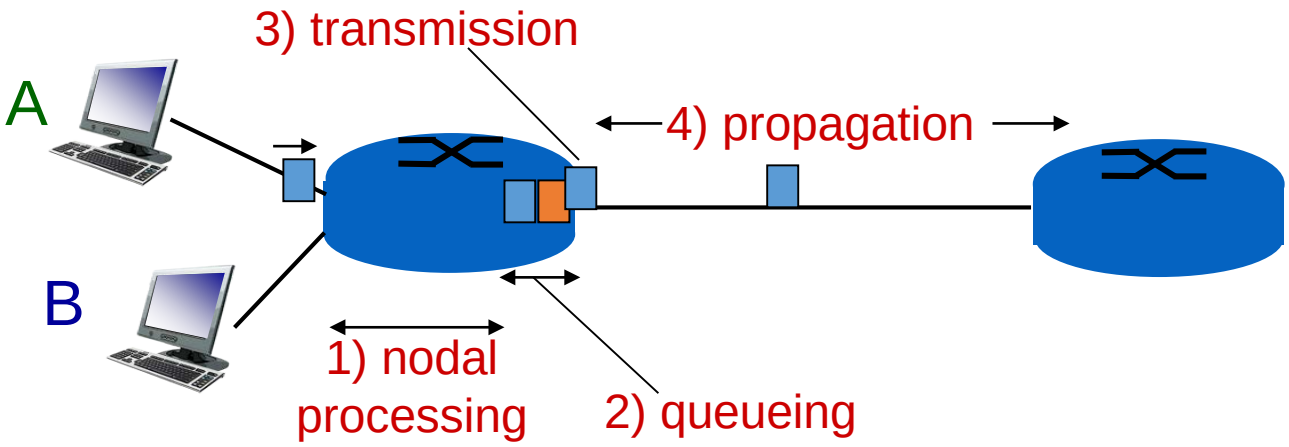
d_{proc}: processing delay

- 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

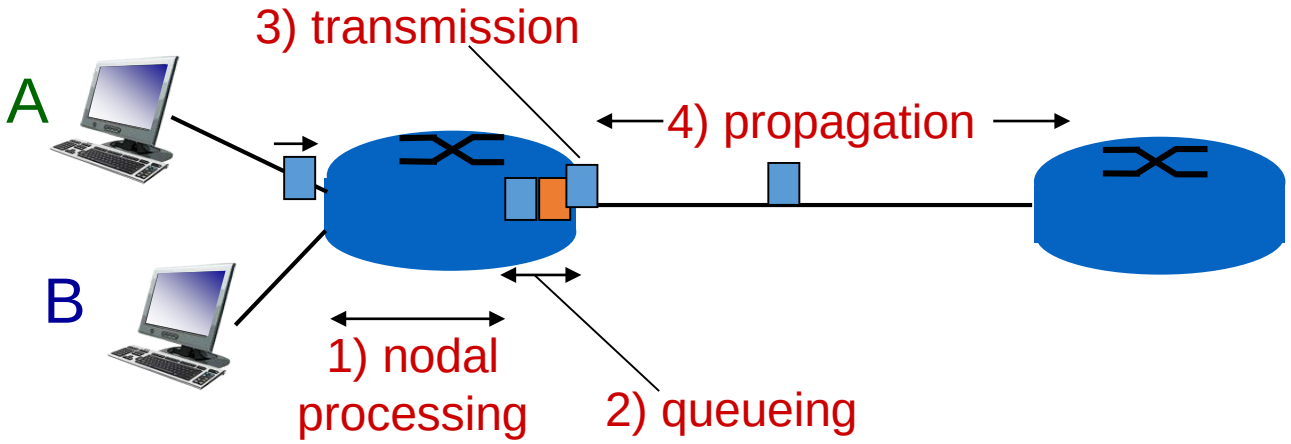
- *L*: packet length (bits)
- *R*: link *bandwidth (bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay

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

d_{trans} and d_{prop} *very* different

Four Sources of Packet Delay

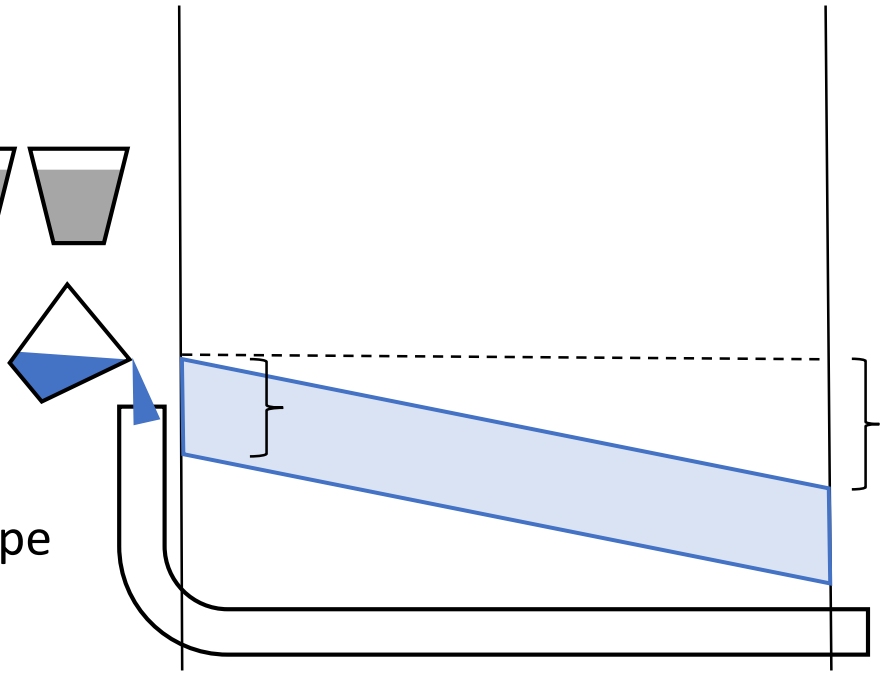


1) Processing: Check bucket

2) Queueing: Wait for turn

3) Transmission: Time taken to pour into pipe

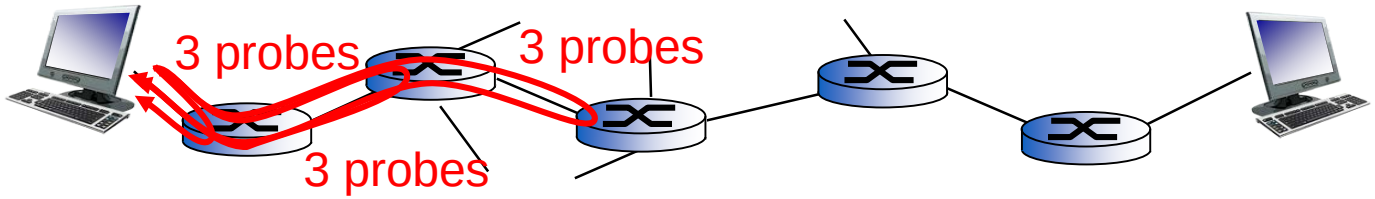
4) Propagation: Time taken to travel across pipe



End-to-end Packet Delay

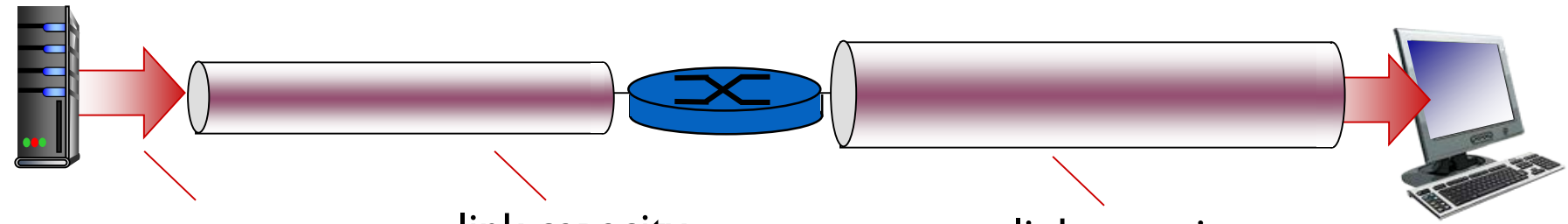
- End-to-end packet delay is the time taken for a packet to travel from source to destination. It consists of:
  - transmission delay
  - propagation delay
  - processing delay
  - queueing delay

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

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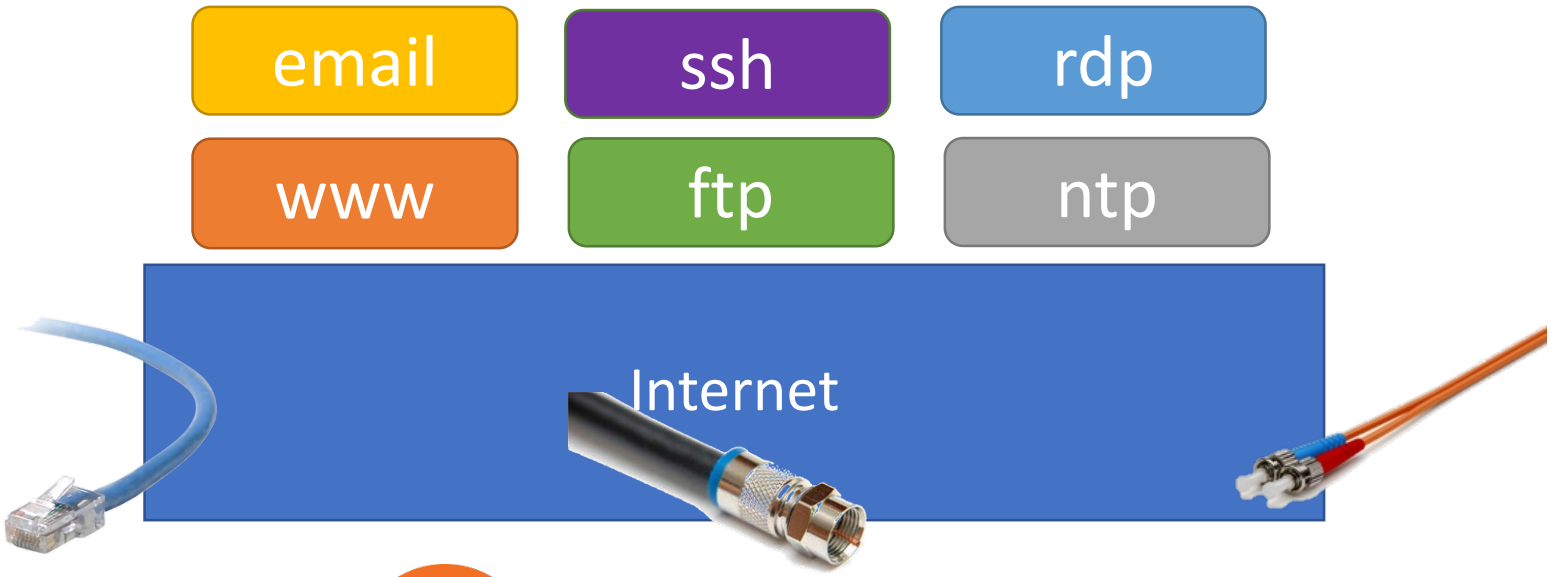
Internet: A Service View



m1

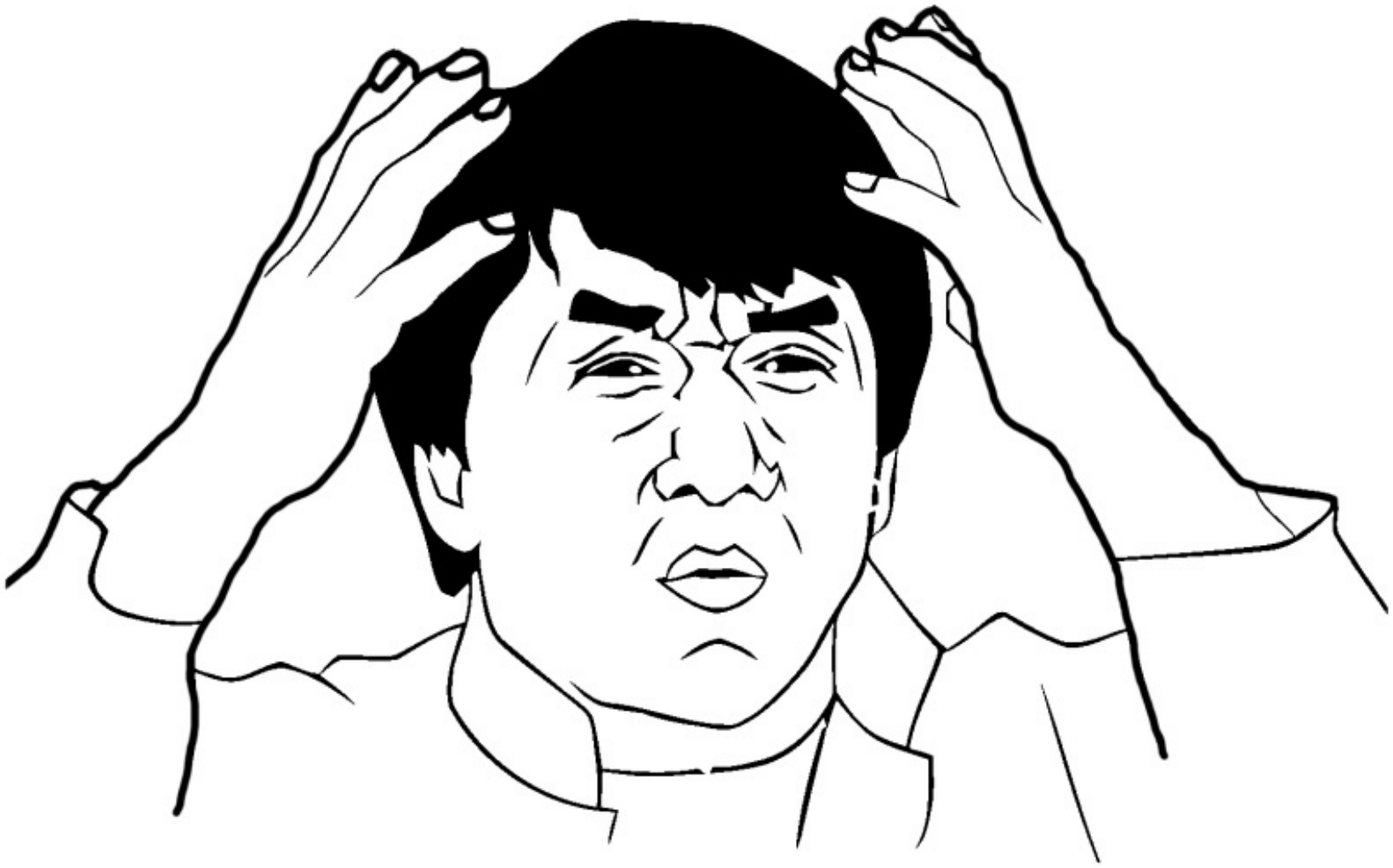
MyRepublic

StarHub

SingTel

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.

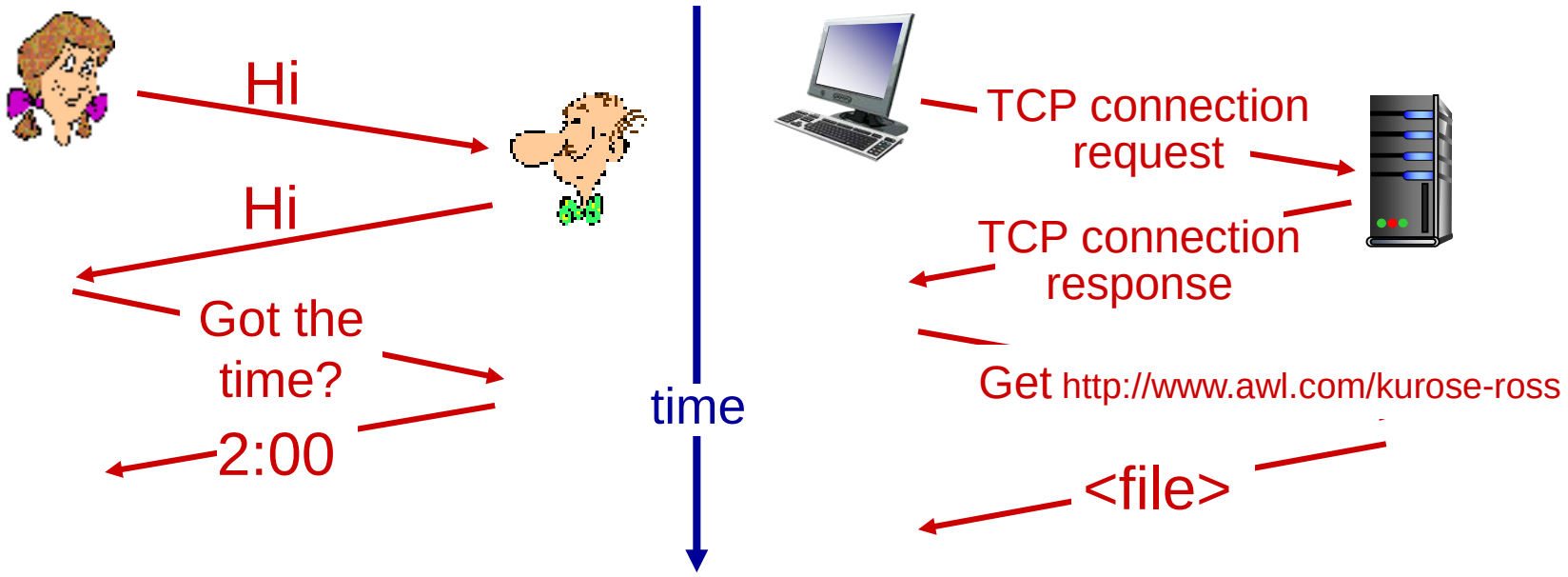


Layering

A common CS trick to deal with large and complex systems

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


中国邮政
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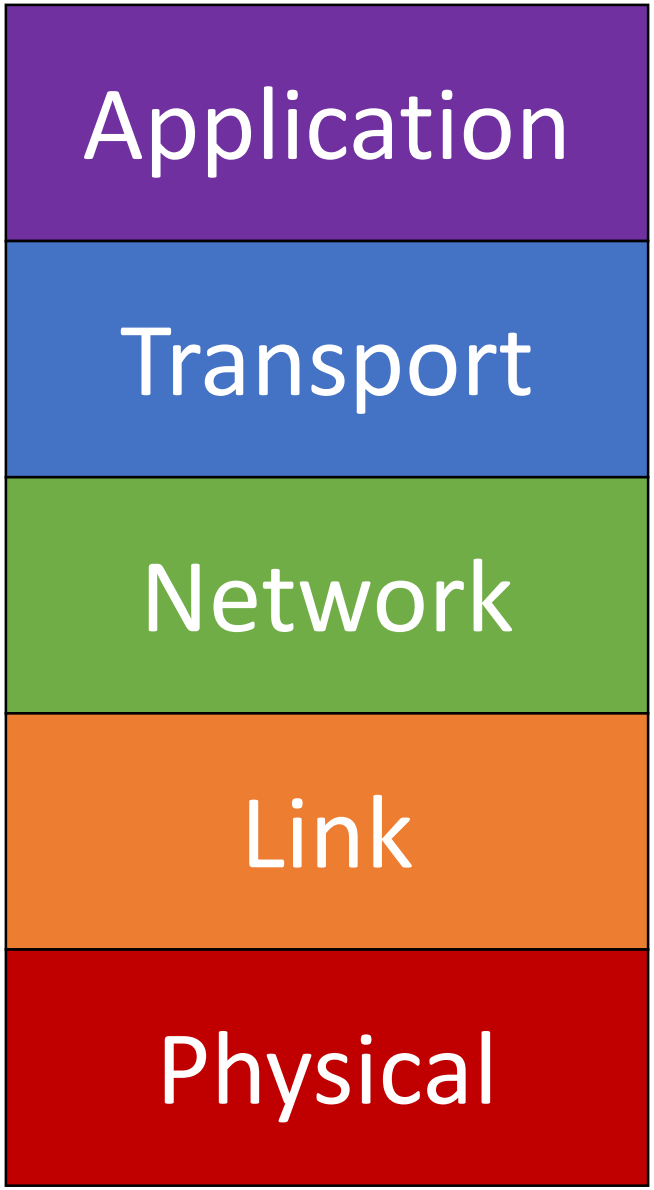
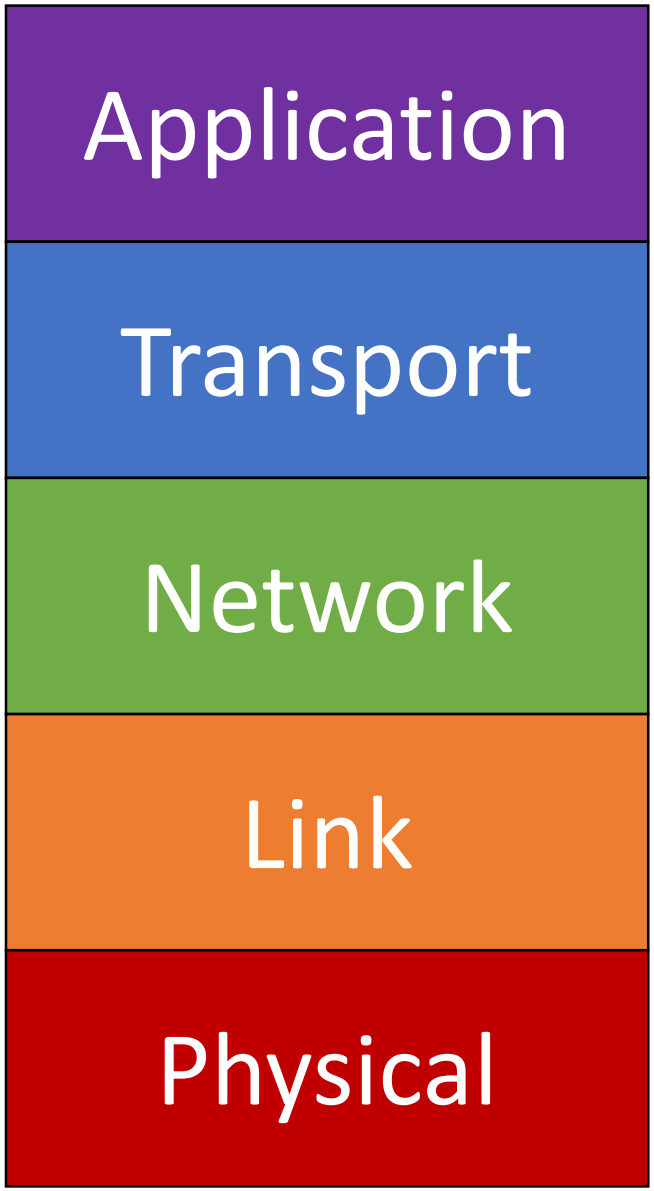

Application
Transport
Network
Link
Physical



Applications treat the Internet as a black box

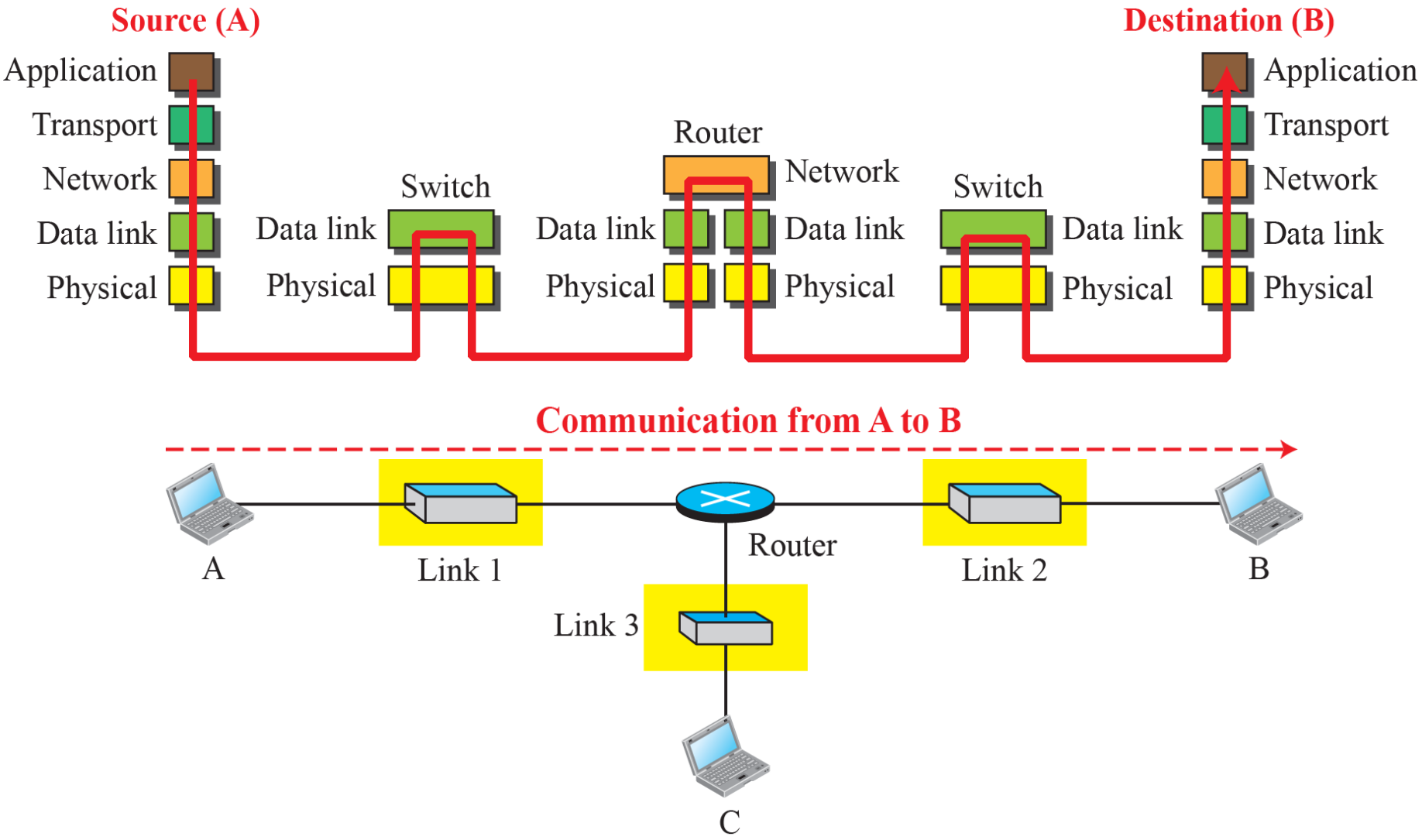
process-to-process data transfer

routing of datagrams from host to host

data transfer between neighbouring network elements

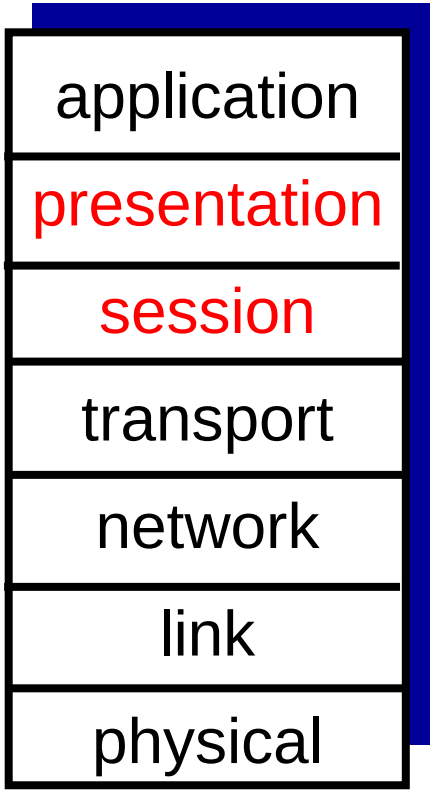
bits on the wire/air

Example


Source (A)
Destination (B)
Application
Transport
Network
Data link
Physical
Switch
Router
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

- Internet overview
- Network edge, core, access network
  - packet-switching vs 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!

Next Week

Application Layer