Chapter 1: Introduction

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CECS 474 Computer Network Interoperability

Dept. of Computer Engineering & Computer Science, California State University Long Beach

Week 2 _ Tuesday

Chapter 1: introduction

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Chapter goal:

- Get "feel," "big picture," introduction to terminology
  - more depth, detail *later* in course

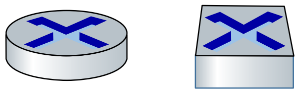
Overview/roadmap:

- What *is* the Internet? What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Protocol layers, service models
- Security
- History

The Internet: a "nuts and bolts" view

Billions of connected computing *devices*:

- *hosts = end systems*
- running *network apps* at Internet's "edge"



Packet switches: forward packets (chunks of data)

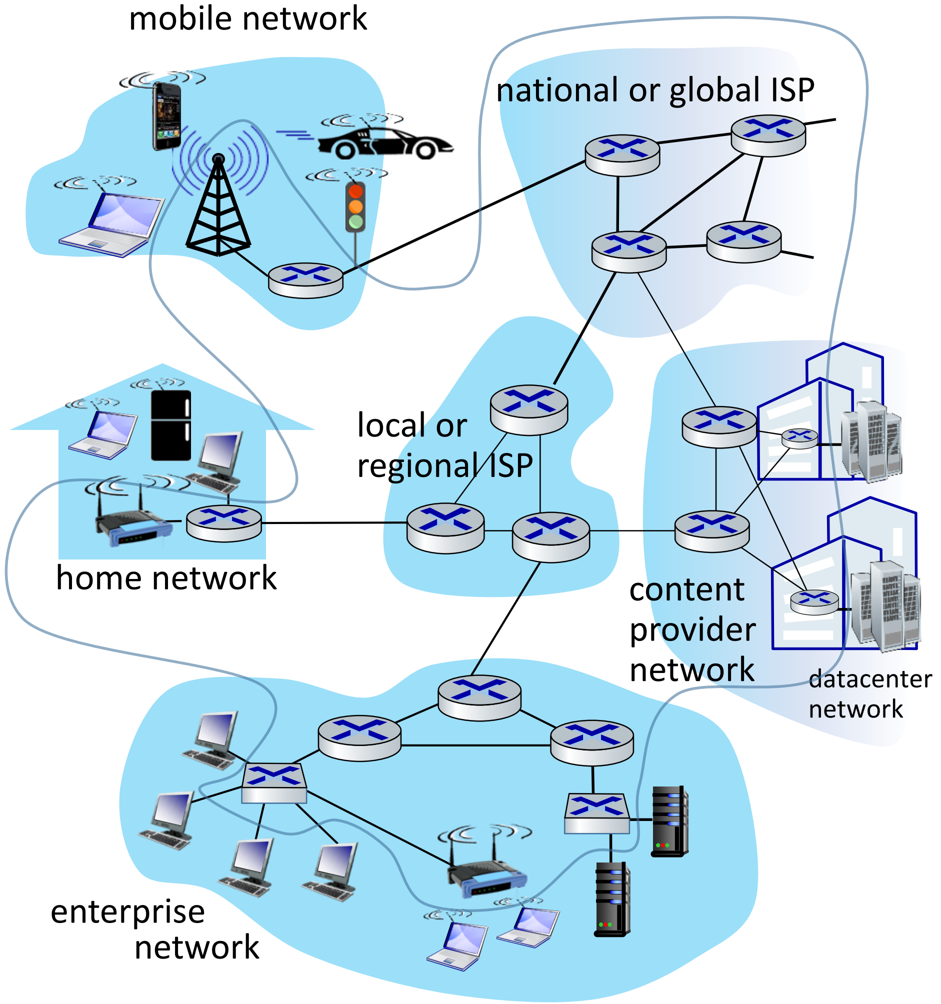
- *routers, switches*

Communication links

- fiber, copper, radio, satellite
- transmission rate: *bandwidth*

Networks

- collection of devices, routers, links: managed by an organization



“Fun” Internet-connected devices


Amazon Echo


IP picture frame


Internet refrigerator


Pacemaker & Monitor

bikes



Remote control cable TV

Security Camera


AR devices


cars


Internet phones

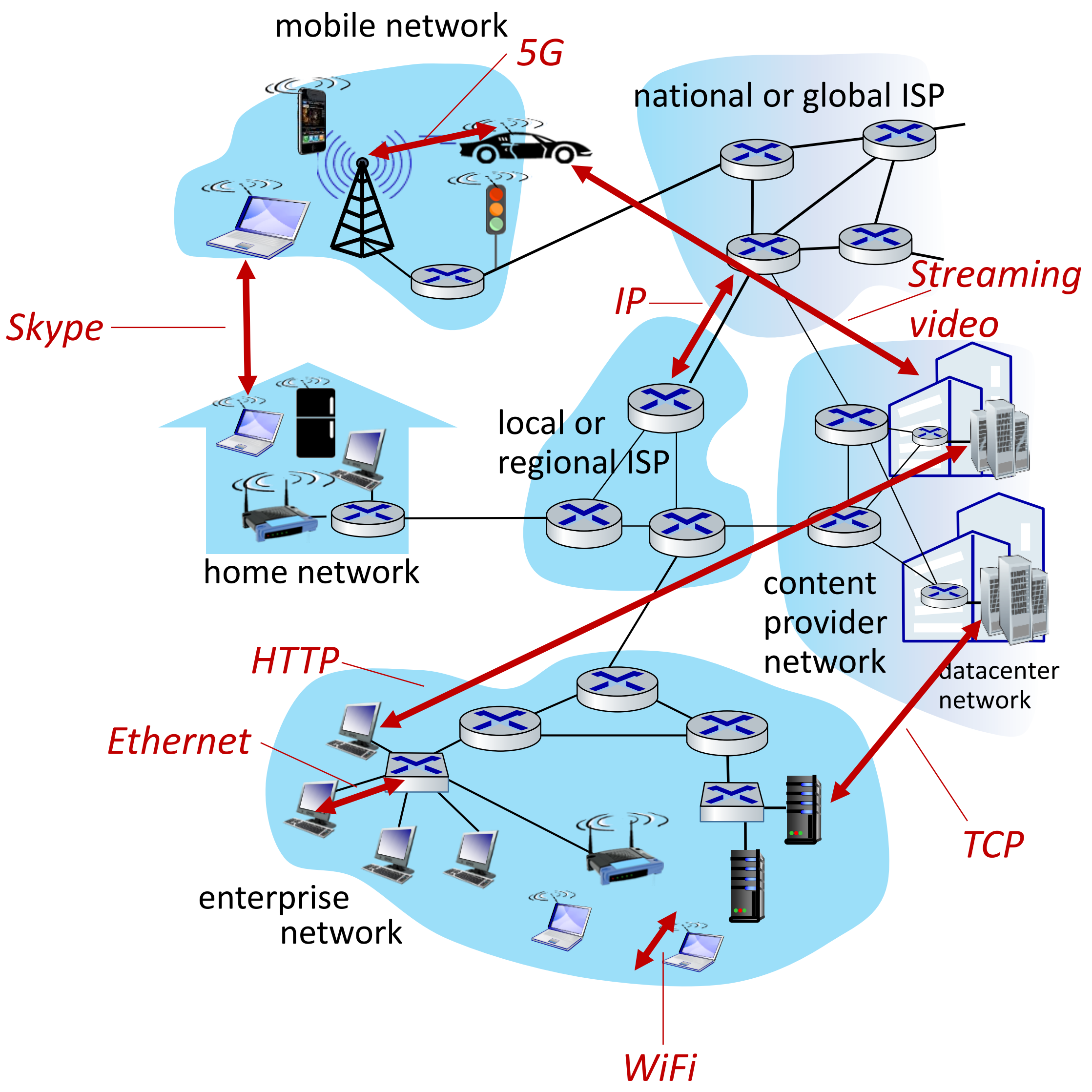

Gaming devices


Fitbit


scooters

The Internet: a "services" view

- *Internet: "network of networks"*
  - Interconnected ISPs
- *protocols* are *everywhere*
  - control sending, receiving of messages
  - e.g., HTTP (Web), streaming video, Skype, TCP, IP, WiFi, 5G, Ethernet
- *Internet standards*
  - IETF: Internet Engineering Task Force (developed by)
  - RFCs: Request for Comments



What’s a protocol?

Human protocols:

- “what’s the time?”
- “I have a question”
- introductions

Rules for:

… specific messages sent

… specific actions taken when message received, or other events

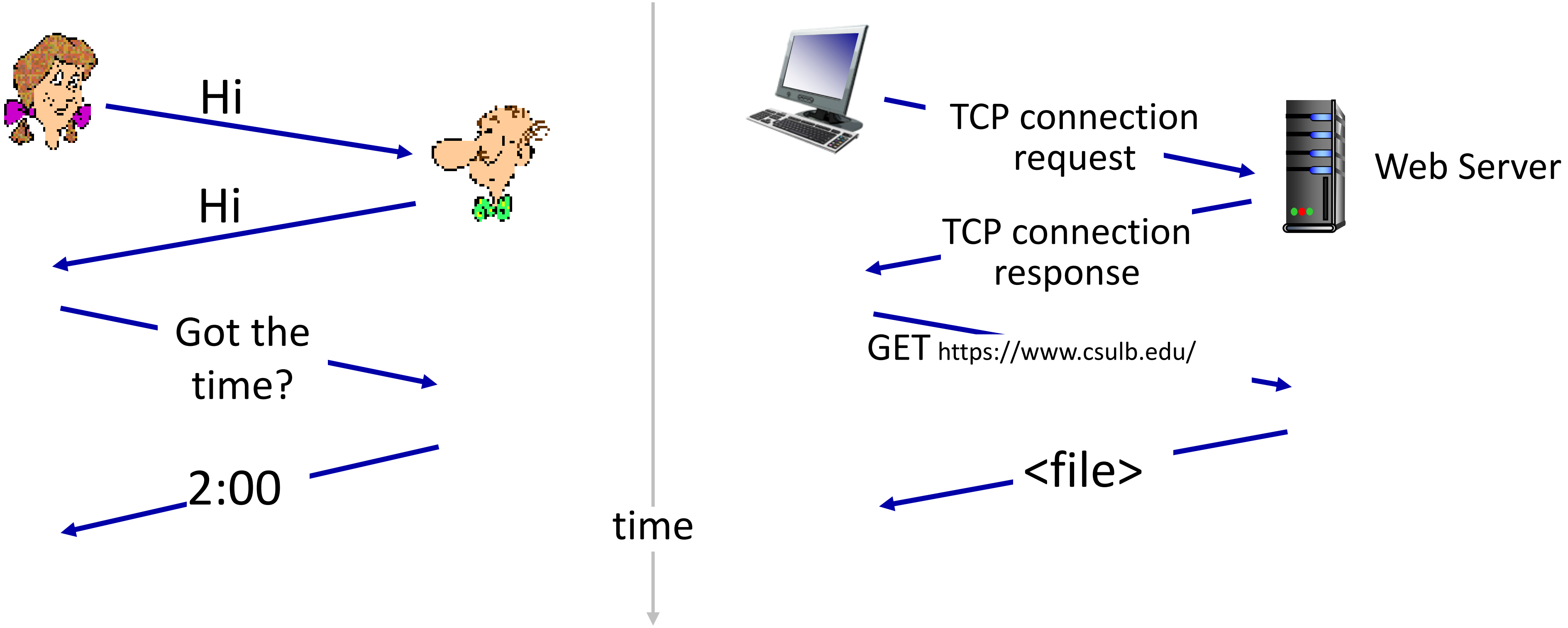
Network protocols:

- computers (devices) rather than humans
- all communication activity in Internet governed by protocols

Protocols define the format, order of messages sent and received among network entities, and actions taken on message transmission, receipt

What’s a protocol?

A human protocol and a computer network protocol:



Chapter 1: roadmap

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- What *is* the Internet?
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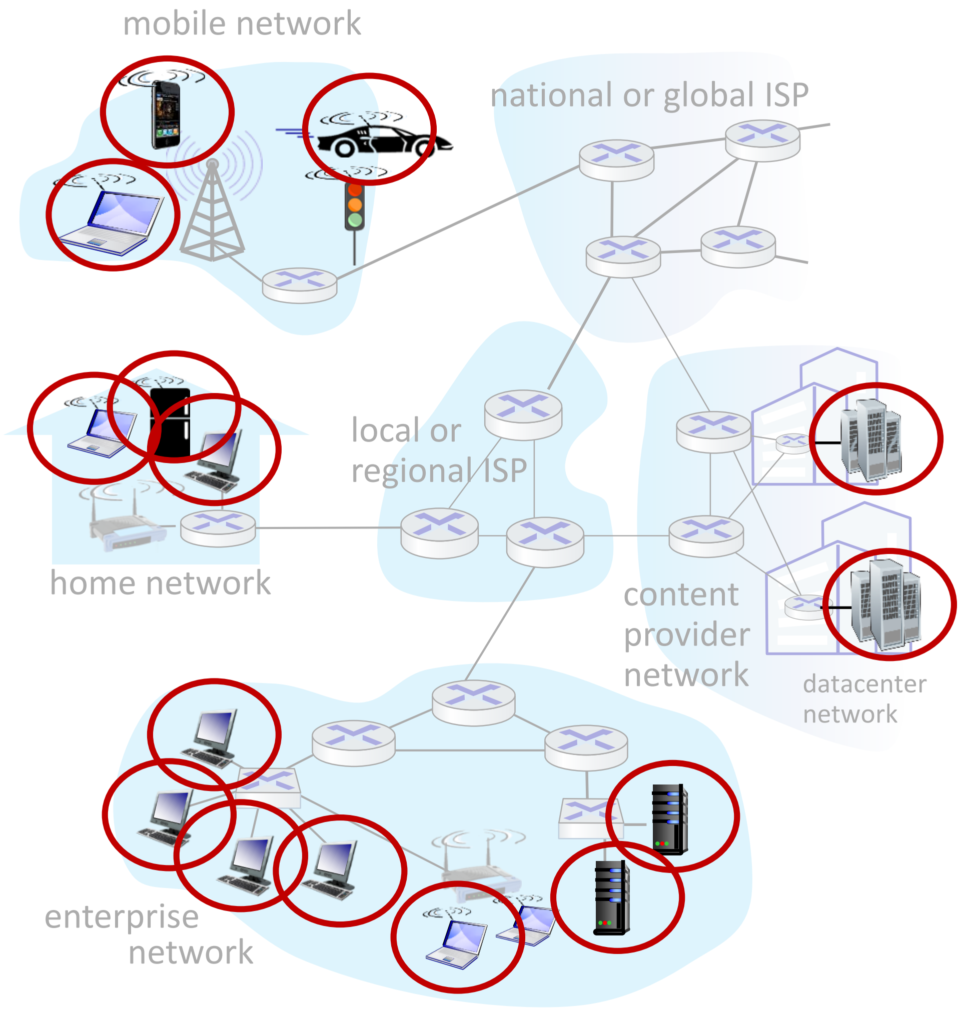
A closer look at Internet structure

Network edge:

- end systems
- hosts: clients and servers
- servers often in data centers



A closer look at Internet structure

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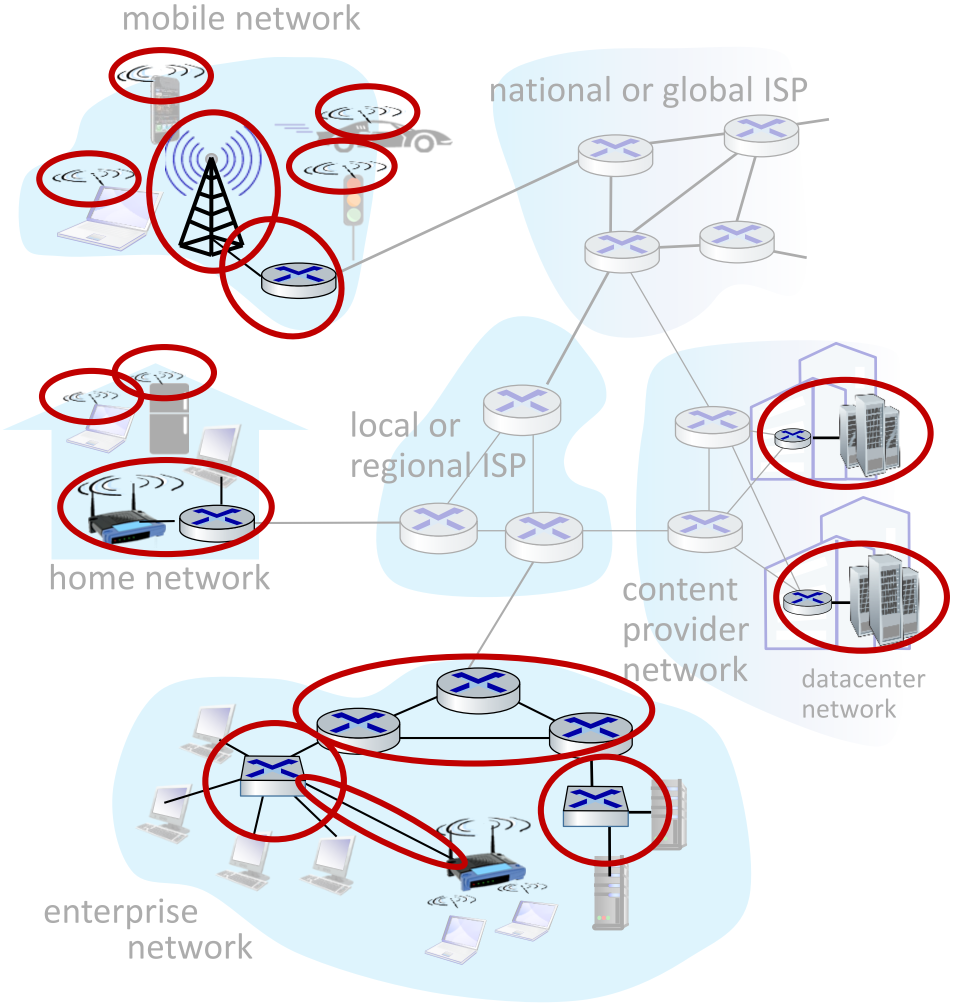
Network edge:

- end systems
- hosts: clients and servers
- servers often in data centers

Access networks, physical media:

- wired, wireless communication links



A closer look at Internet structure

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Network edge:
- end systems
- hosts: clients and servers
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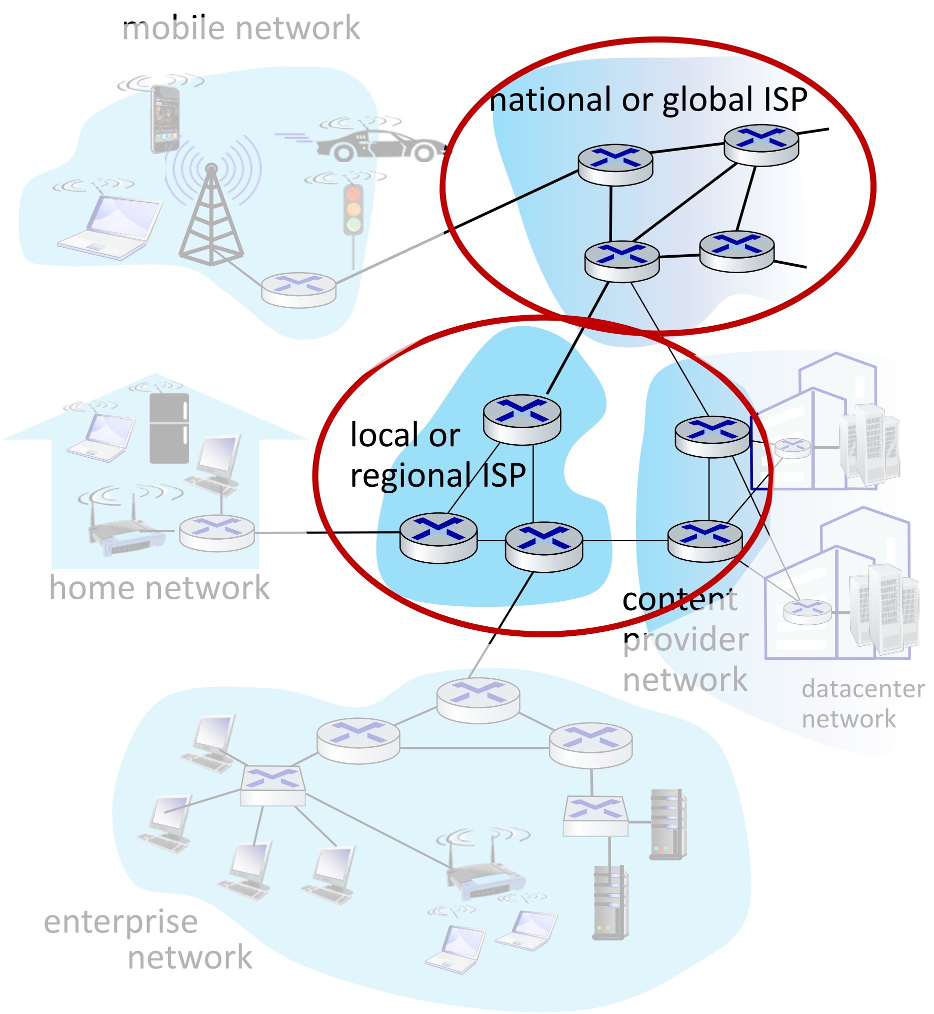
Access networks, physical media:
- wired, wireless communication links

Network core:
- interconnected routers
- network of networks



Access networks and physical media

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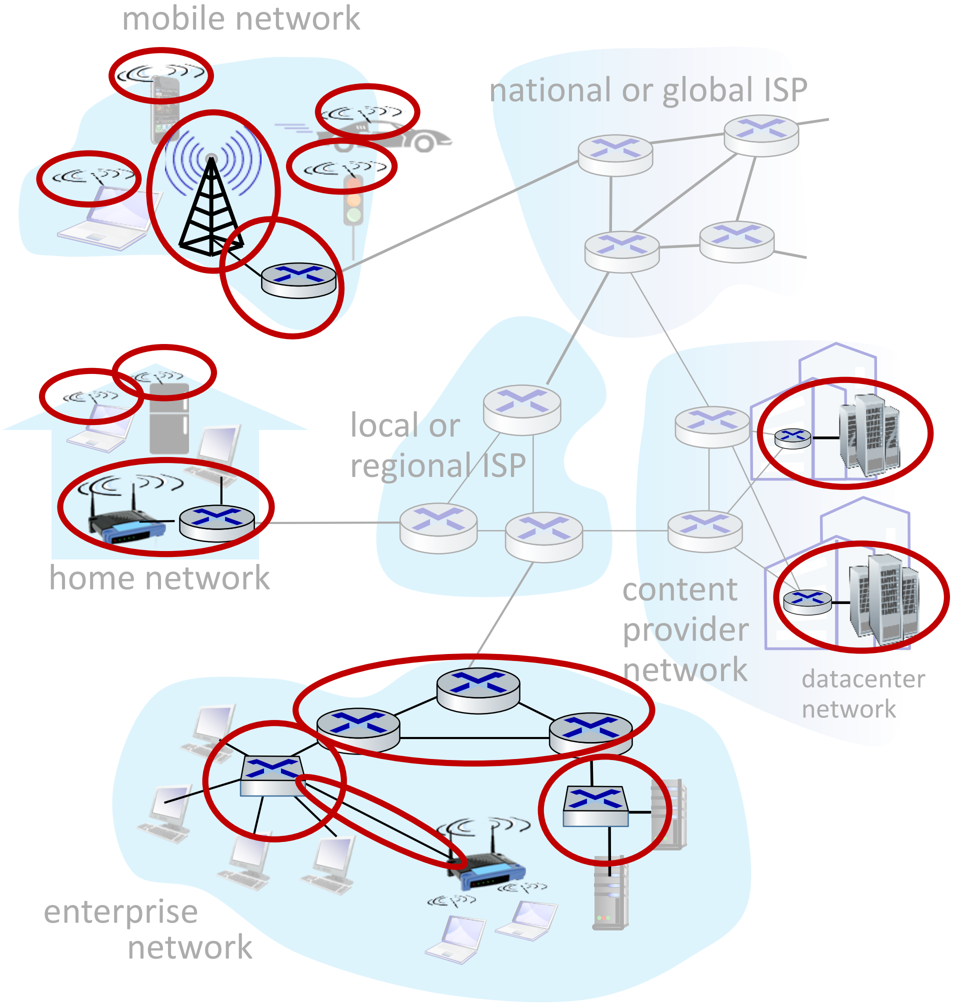
Q: How to connect end systems to edge router?

- residential access nets
- institutional access networks (school, company)
- mobile access networks (WiFi, 4G/5G)



Access network classification?
(based on the physical media)

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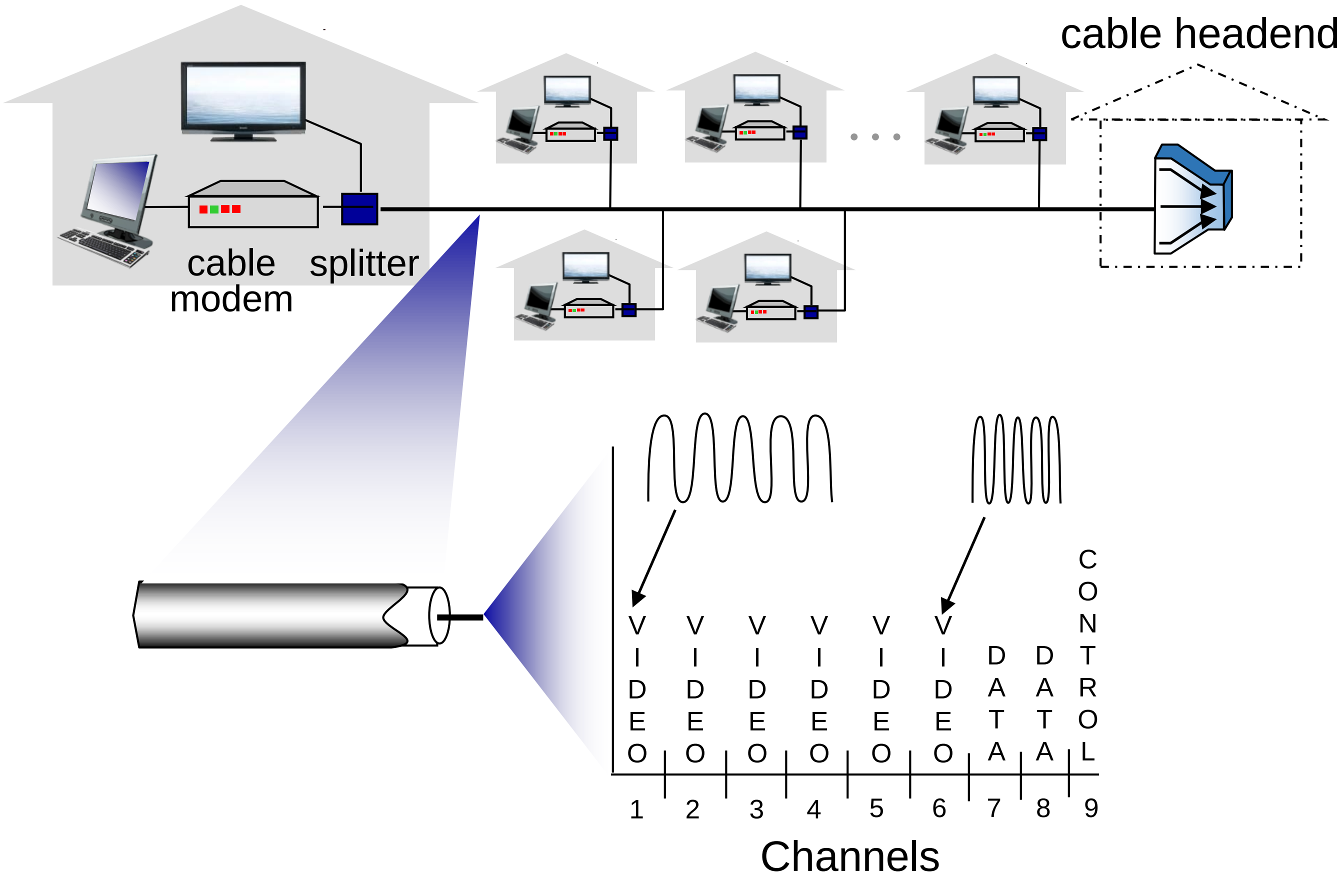
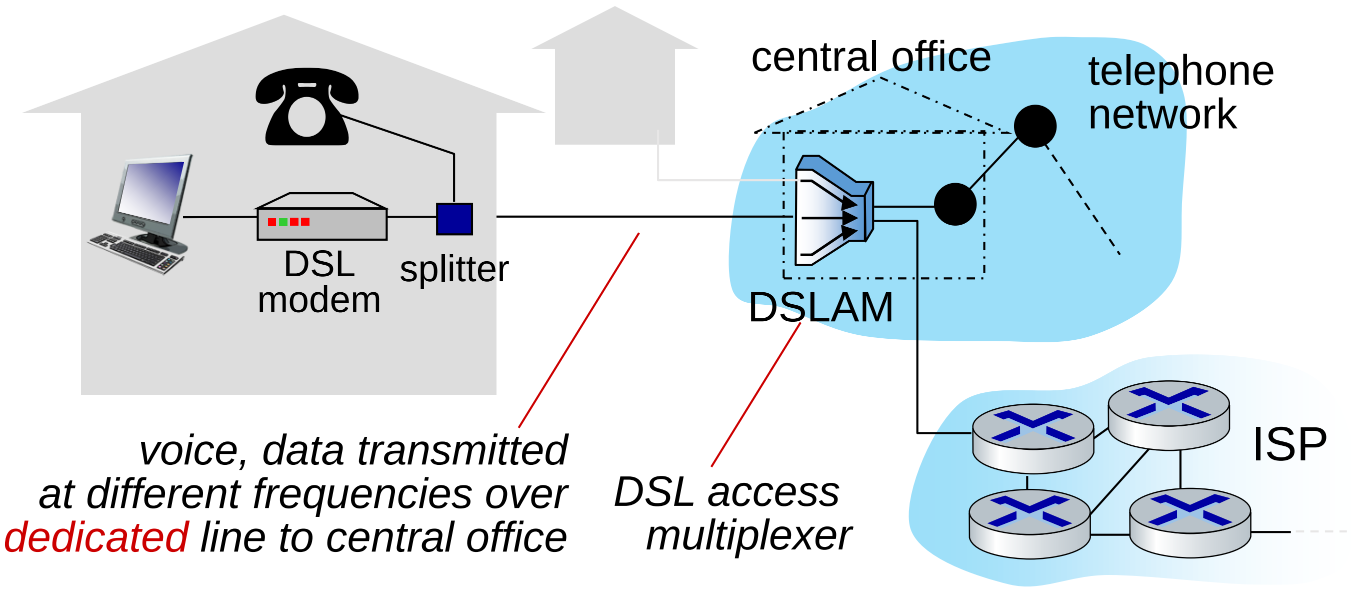
Access networks: cable-based access



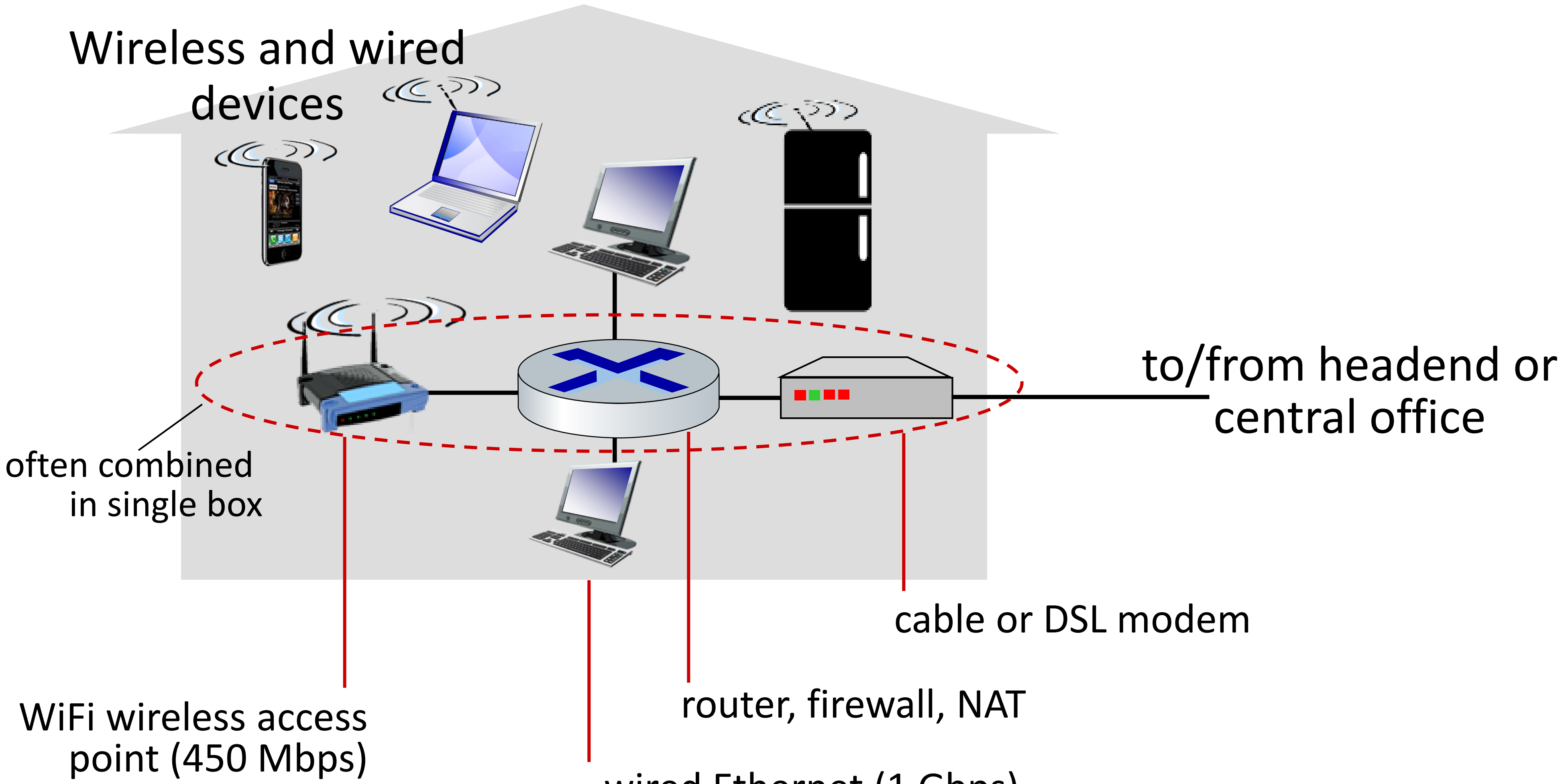
frequency division multiplexing (FDM): different channels transmitted in different frequency bands

Access networks: digital subscriber line (DSL)



- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- 24-52 Mbps dedicated downstream transmission rate
- 3.5-16 Mbps dedicated upstream transmission rate

Access networks: home networks



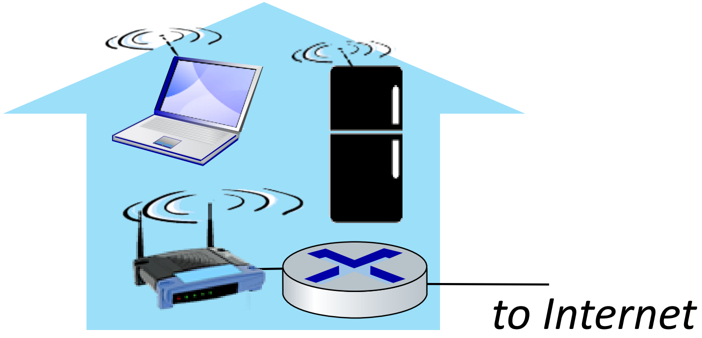
Wireless access networks

Shared *wireless* access network connects end system to router

- via base station aka "access point"

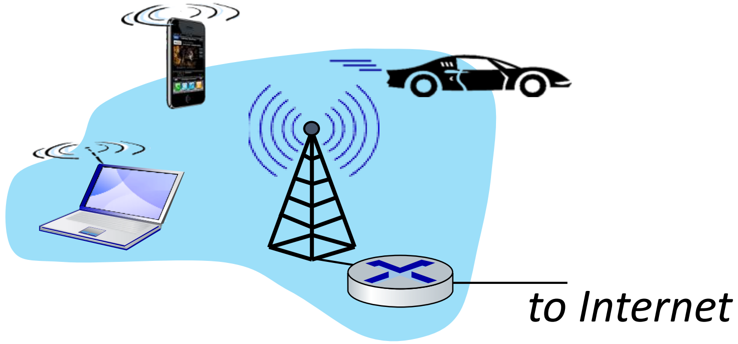
Wireless local area networks (WLANs)

- typically within or around building (~100 ft)
- 802.11b/g/n (WiFi): 11, 54, 450 Mbps transmission rate



Wide-area cellular access networks

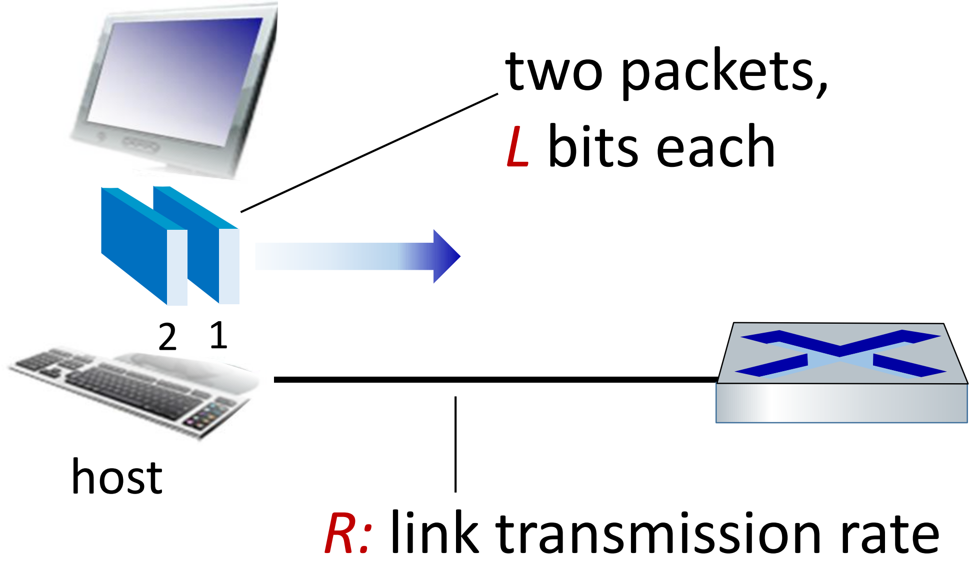
- provided by mobile, cellular network operator (10's km)
- 10's Mbps
- 5G cellular networks (6G coming)



Host: sends *packets* of data

Host sending function:

- takes application message
- breaks into smaller chunks, known as *packets*, of length *L* bits
- transmits packet into access network at *transmission rate R*
  - link transmission rate, aka link *capacity, aka link bandwidth*



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

Links: physical media

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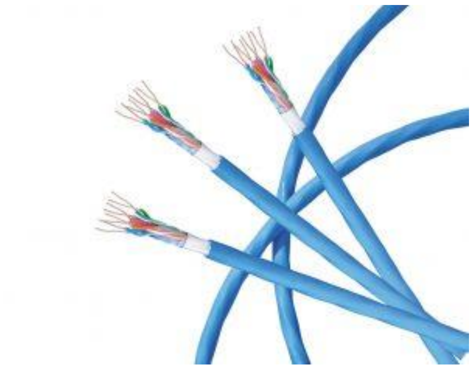
- bit: propagates between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver
- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio

Twisted pair (TP)

- two insulated copper wires
  - Category 5: 100 Mbps, 1 Gbps Ethernet
  - Category 6: 10Gbps Ethernet



Links: physical media

Coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple frequency channels on cable
  - 100’s Mbps per channel

Fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (10’s-100’s Gbps)
- low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise

Links: physical media

Wireless radio

- signal carried in various "bands" in electromagnetic spectrum
- no physical "wire"
- broadcast, multicast, "half-duplex" (sender to receiver)
- propagation environment effects:
  - reflection
  - obstruction by objects
  - Interference/noise

Radio link types:

- Wireless LAN (WiFi)
  - 10-100's Mbps; 10's of meters
- wide-area (e.g., 5G cellular)
  - 10's Mbps over ~10 Km
- Bluetooth: cable replacement
  - short distances, limited rates
- terrestrial microwave
  - point-to-point; 45 Mbps channels
- satellite
  - up to 45 Mbps per channel
  - 270 msec end-end delay

Chapter 1: roadmap

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The network core

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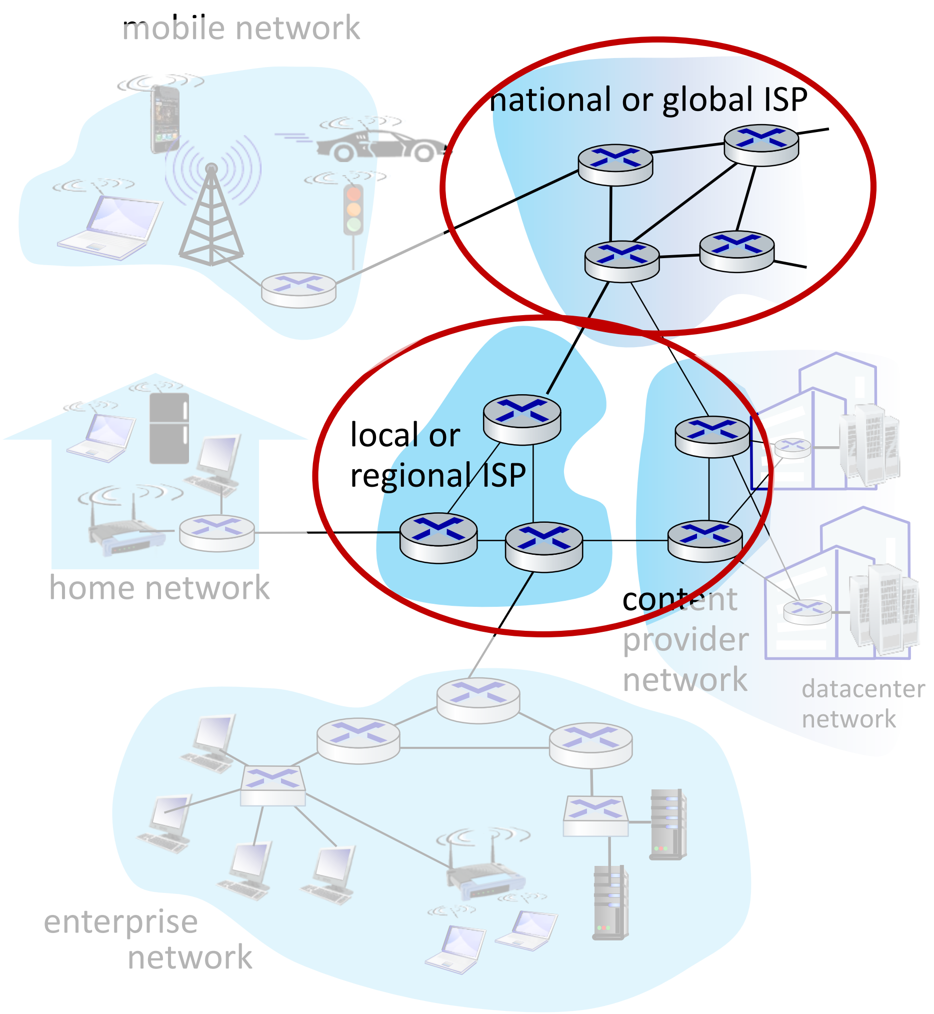
- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into *packets*
  - network forwards packets from one router to the next, across links on path from source to destination
- circuit-switching: dedicated circuit per call, a path is reserved



Two key network-core functions

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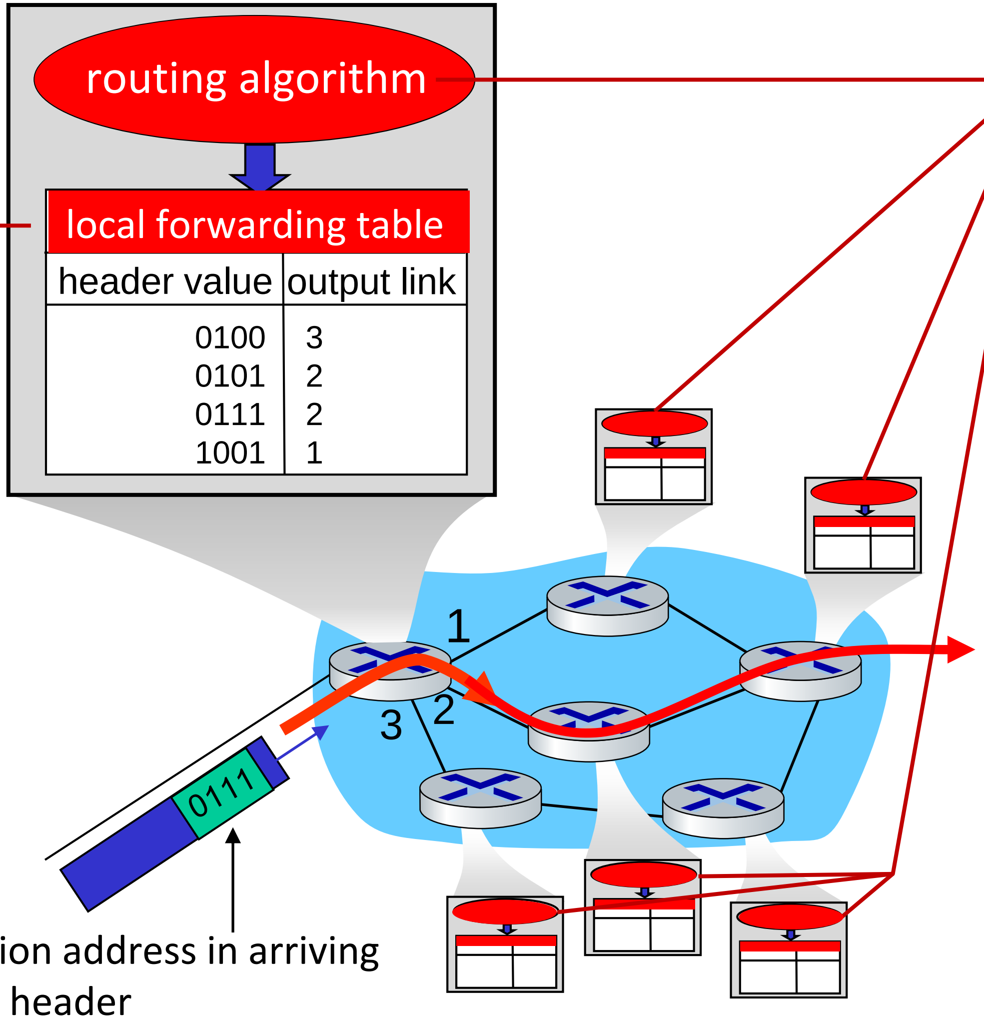
Forwarding:
- aka "switching"
- *local* action: move arriving packets from router's input link to appropriate router output link



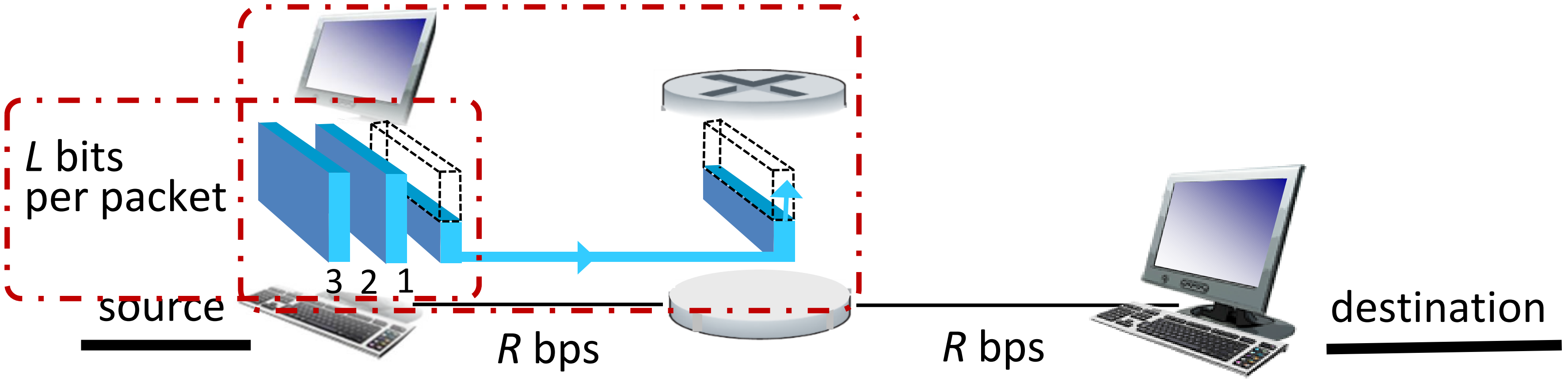
Routing:
- *global* action: determine source-destination paths taken by packets
- routing algorithms

Week 3 _ Tuesday


45 h
3,053 miles
48 h
3,309 miles
routing
United States
San Jose
Northampton
Seattle
Portland
San Francisco
Los Angeles
San Diego
Las Vegas
Phoenix
Tucson
El Paso
Dallas
Austin
Houston
San Antonio
New Orleans
Kansas City
Minneapolis
Chicago
Detroit
Toronto
Ottawa
Montreal
Quebec City
Indianapolis
Nashville
Atlanta
Charlotte
Jacksonville
Orlando
Tampa
New York
Philadelphia
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
COLORADO
ARIZONA
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
IOWA
OKLAHOMA
TEXAS
ARKANSAS
LOUISIANA
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
TENNESSEE
KENTUCKY
ILLINOIS
INDIANA
OHIO
WISCONSIN
MICHIGAN
PENNSYLVANIA
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
MARYLAND
DE
NJ
CT
RI
VERMONT
NEW HAMPSHIRE
MAINE
BAJA CALIFORNIA
SONORA
CHIHUAHUA
COAHUILA
Victoria


forwarding
forwarding
45 h
3,053 miles
48 h
3,309 miles
San Jose
Northampton
United States
Sacramento
Cleveland

Packet-switching: store-and-forward



- *store and forward: entire* packet must arrive at router before it can be transmitted on next link
- packet transmission delay: takes L/R seconds to transmit (push out) L-bit packet into link at R bps

One-hop numerical example:

- L = 10 Kbits
- R = 100 Mbps
- one-hop transmission delay = 0.1 msec

Packet-switching: queueing

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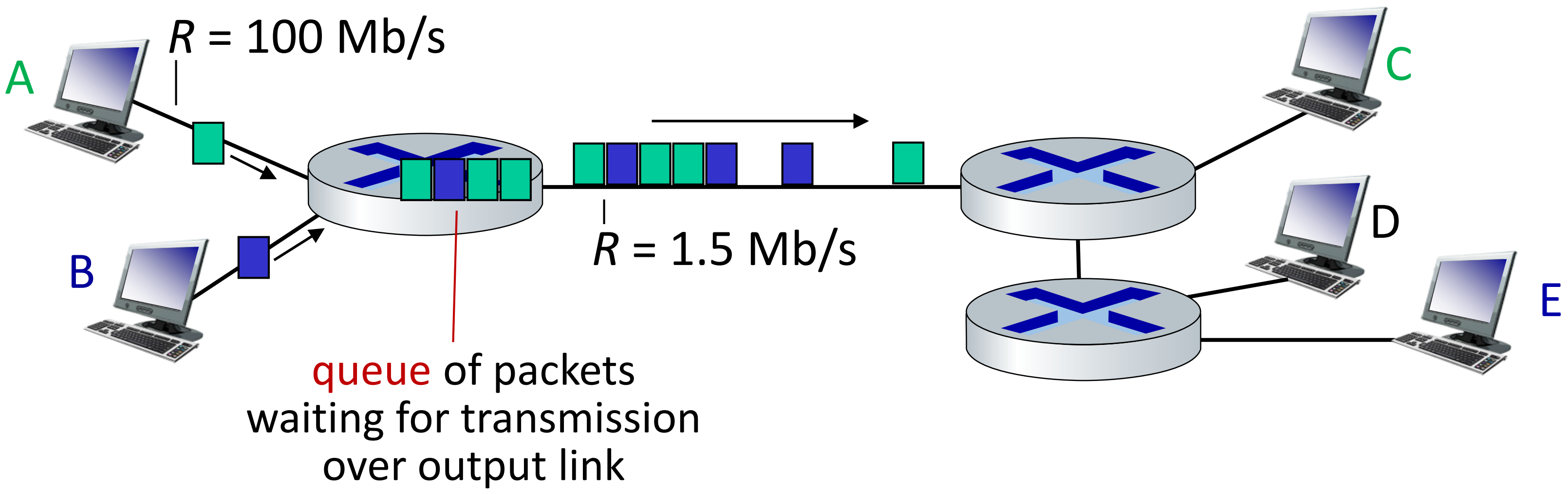
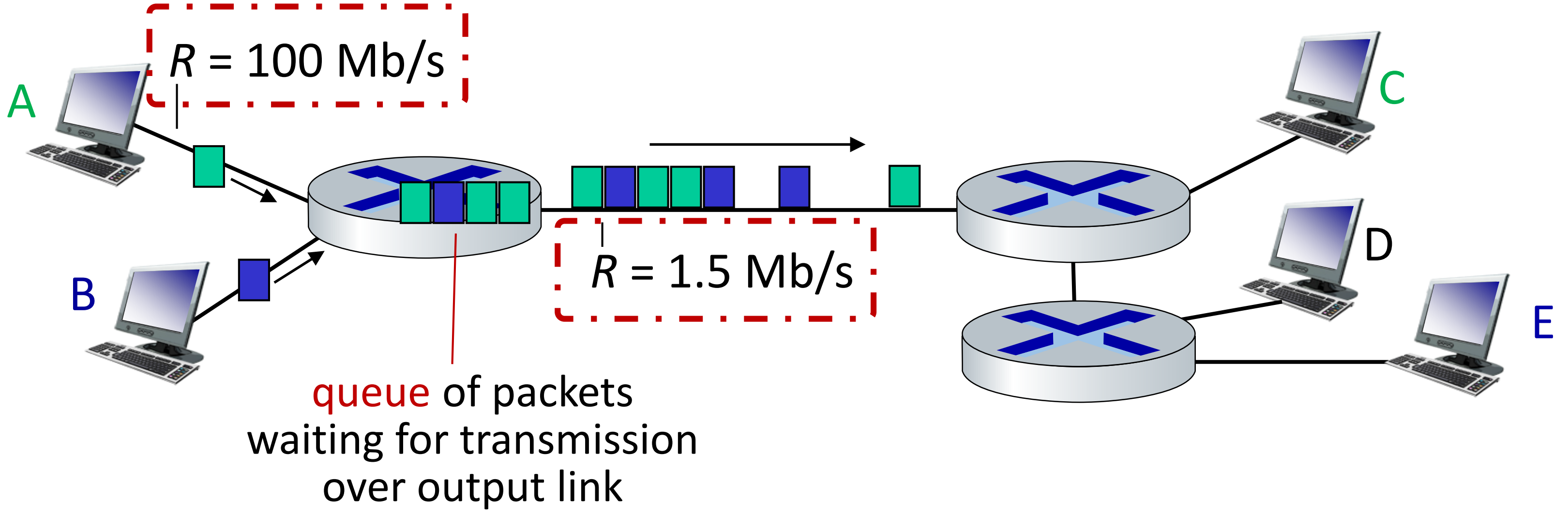


Queueing occurs when work arrives faster than it can be serviced:

Packet-switching: queueing



Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) in router fills up

Alternative to packet switching: circuit switching

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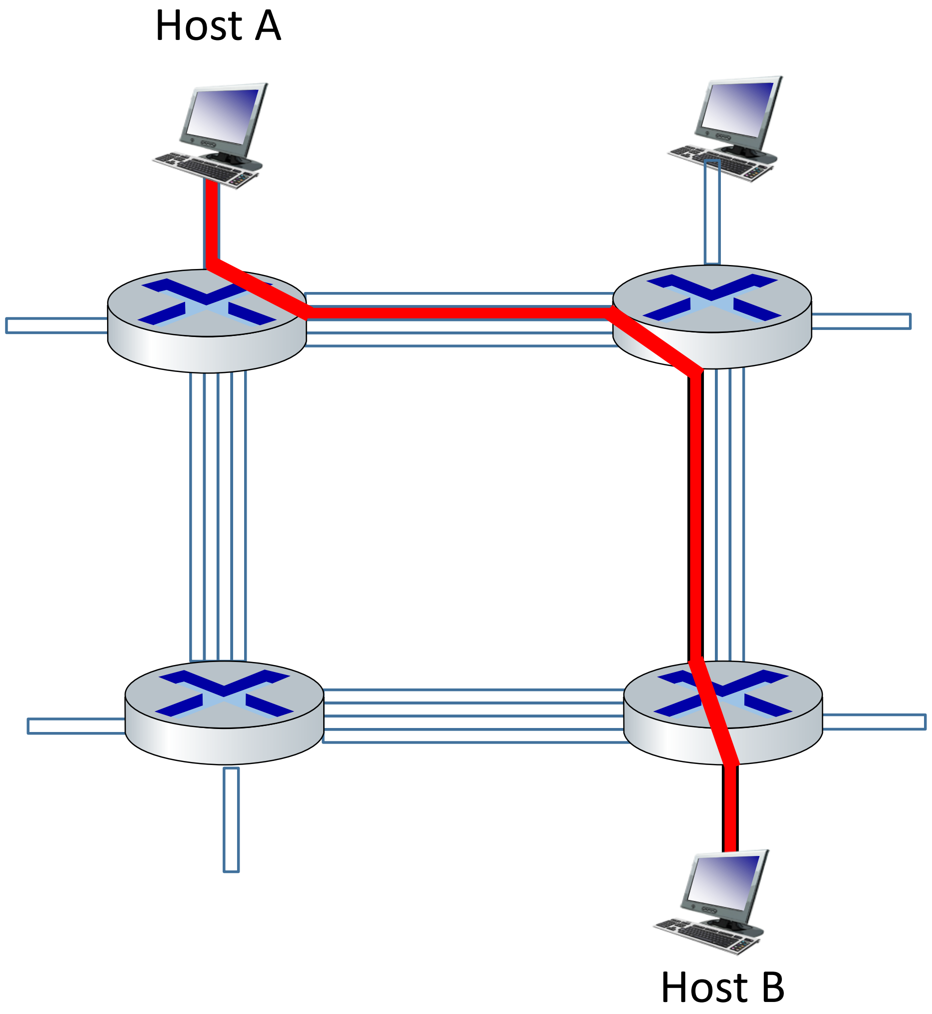
- end-end resources allocated to, reserved for "call" between source and destination
- in diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call (no sharing)
- commonly used in traditional telephone networks



Circuit switching: FDM and TDM

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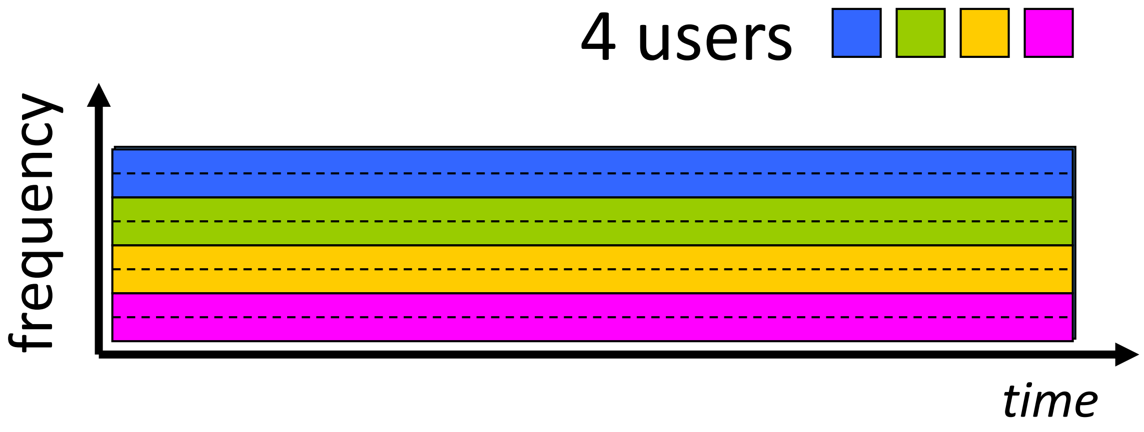
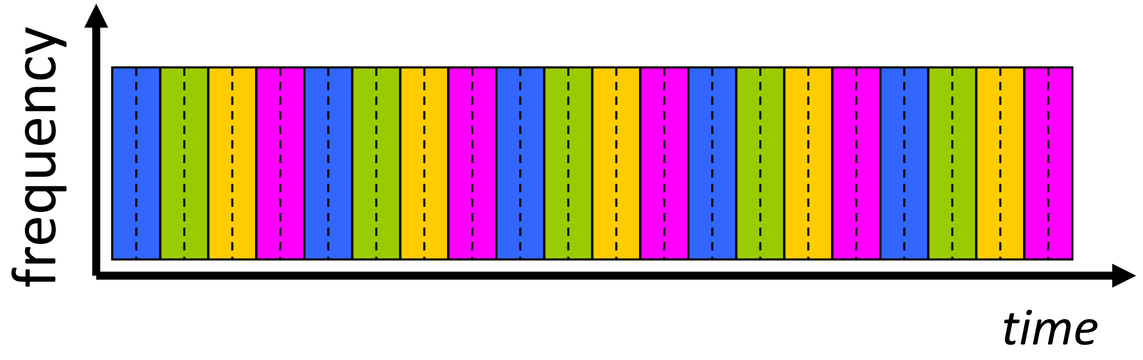
Frequency Division Multiplexing (FDM)

- optical, electromagnetic frequencies divided into (narrow) frequency bands
- each call allocated its own band, can transmit at max rate of that narrow band



Time Division Multiplexing (TDM)

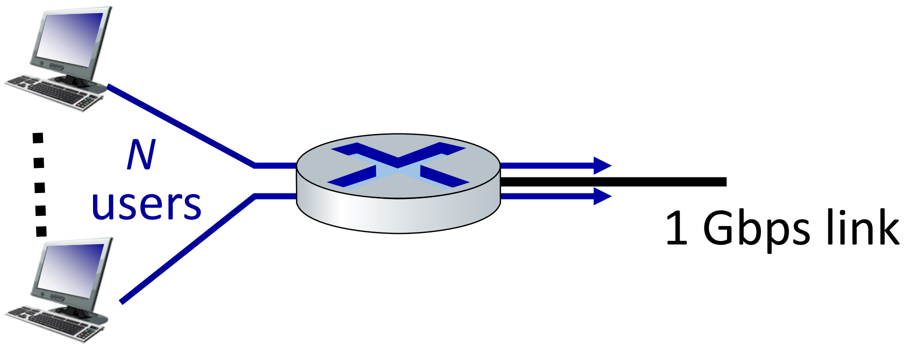
- time divided into slots
- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band (only) during its time slot(s)



Packet switching versus circuit switching

example:

- 1 Gb/s link
- each user:
  - 100 Mb/s when "active"
  - active 10% of time



Q: how many users can use this network under circuit-switching and packet switching?

- *circuit-switching:* 10 users
- *packet switching:* at least 10 users

Packet switching versus circuit switching

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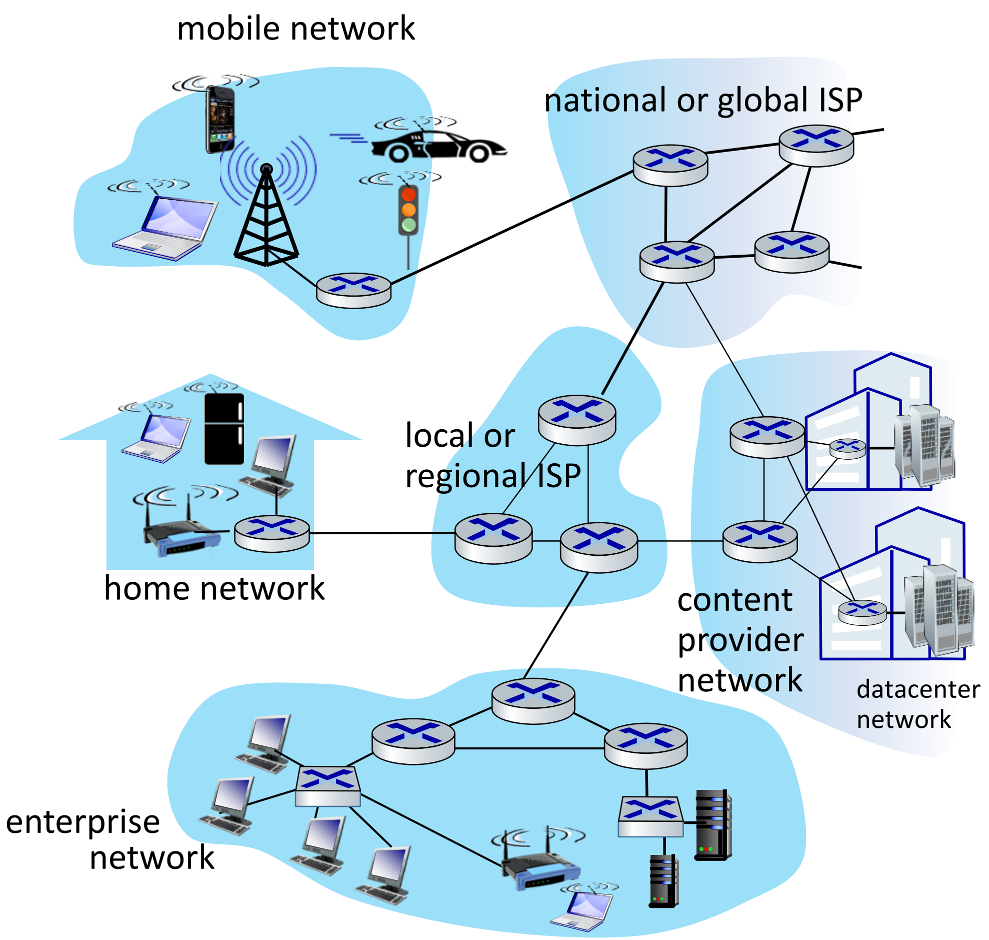
Item	Circuit switching	Packet switching
Dedicated path	Yes*	No
Bandwidth available	Fixed	Dynamic*
Potentially wasted	Yes	No*
Store-and-forward trans.	No	Yes*
Call setup	Yes*	Not needed
When can congestion occur	At setup time*	On every packet
Charging	Per minute	Per packet*
Each packet follows the same route	Yes*	No

Internet structure: a "network of networks"

- hosts connect to Internet via access Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
  - so that *any* two hosts *(anywhere!)* can send packets to each other
- resulting network of networks is very complex
  - evolution driven by economics, national policies



Let's take a stepwise approach to describe current Internet structure

Internet structure: a “network of networks”

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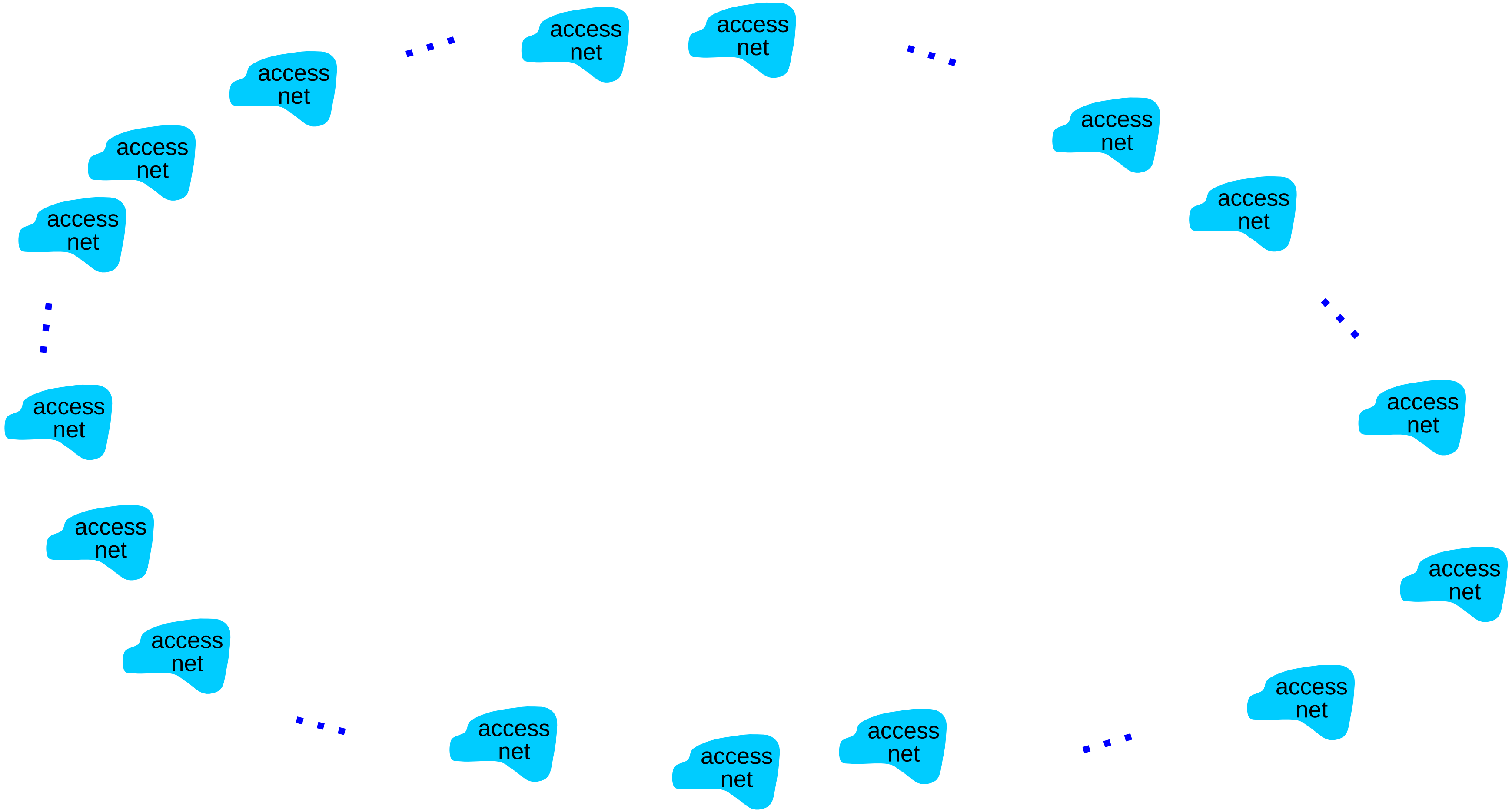
Question: given *millions* of access ISPs, how to connect them together?



Internet structure: a "network of networks"

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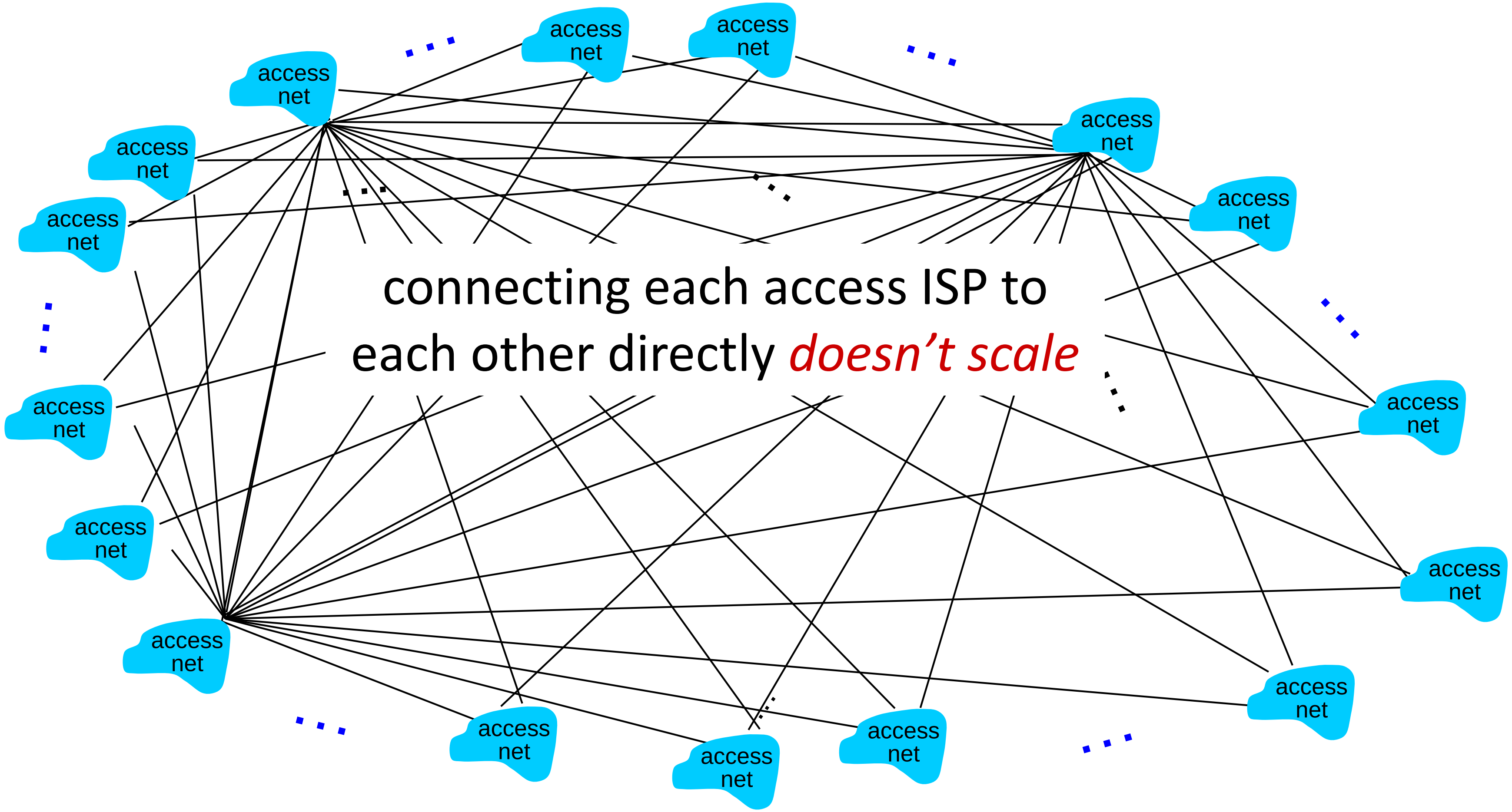

Internet structure: a "network of networks"

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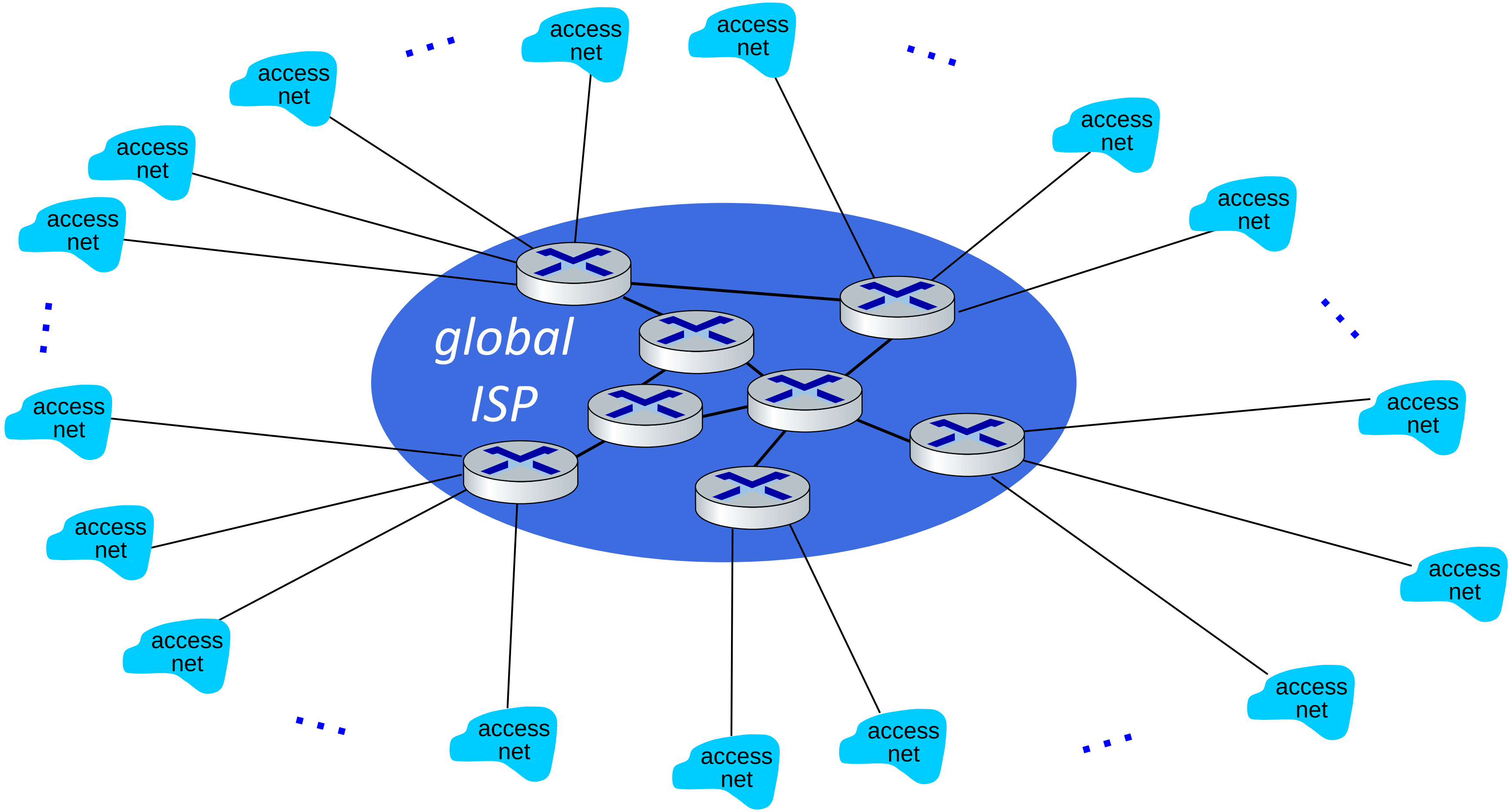
Option: connect each access ISP to one global transit ISP?
Customer and provider ISPs have economic agreement.



Internet structure: a “network of networks”

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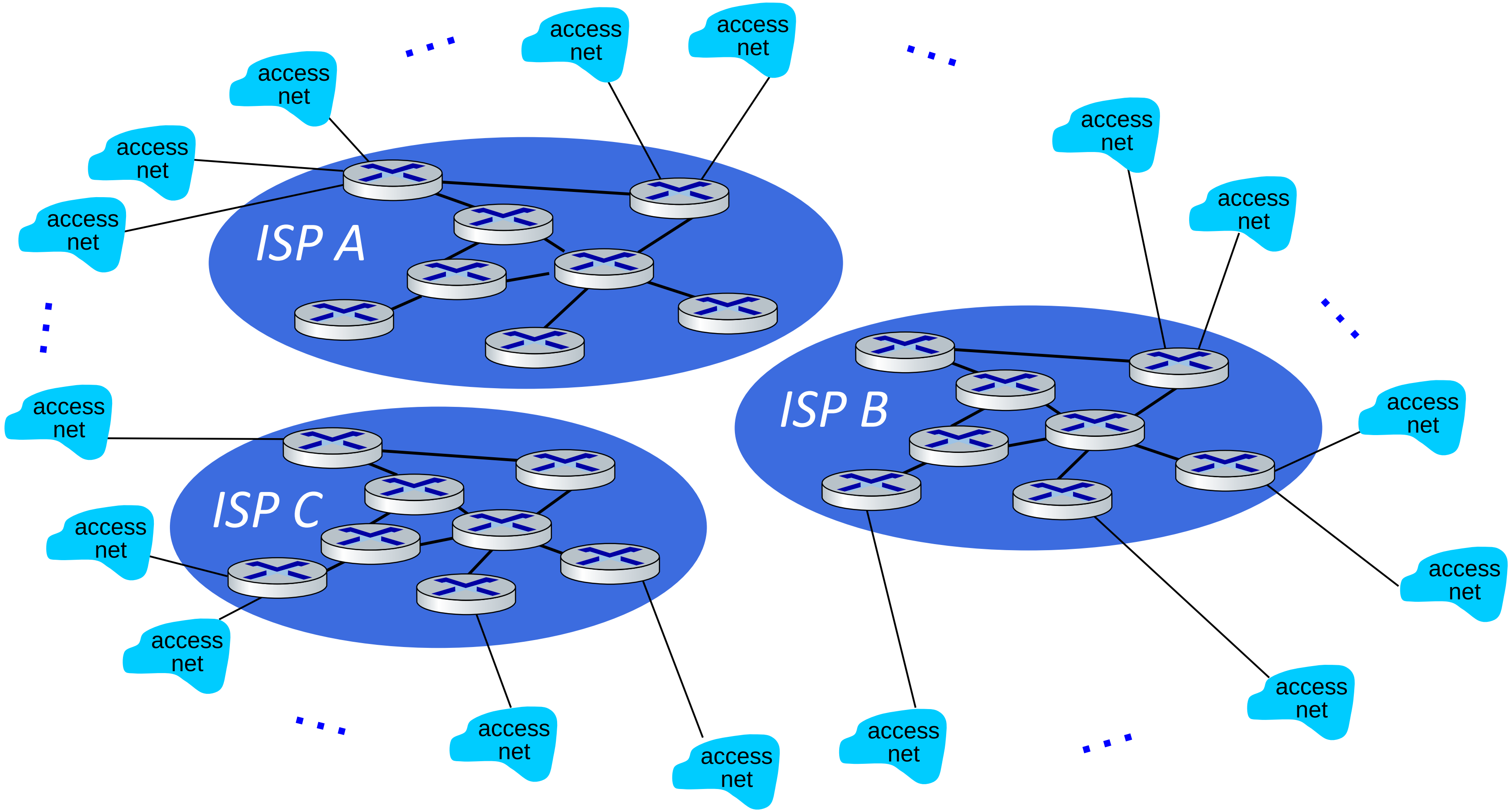
But if one global ISP is viable business, there will be competitors ….



Internet structure: a "network of networks"

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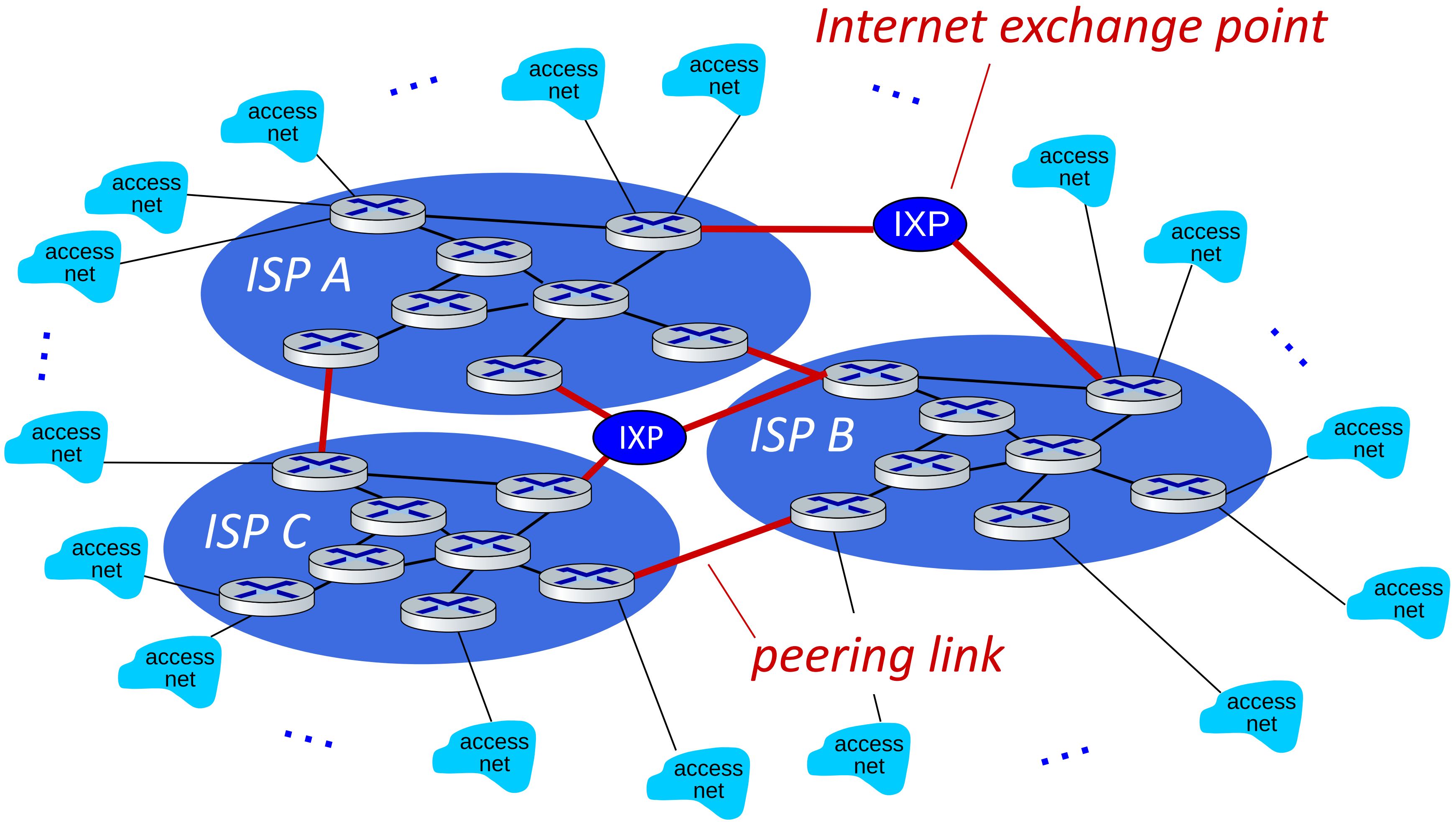
But if one global ISP is viable business, there will be competitors …. who will want to be connected



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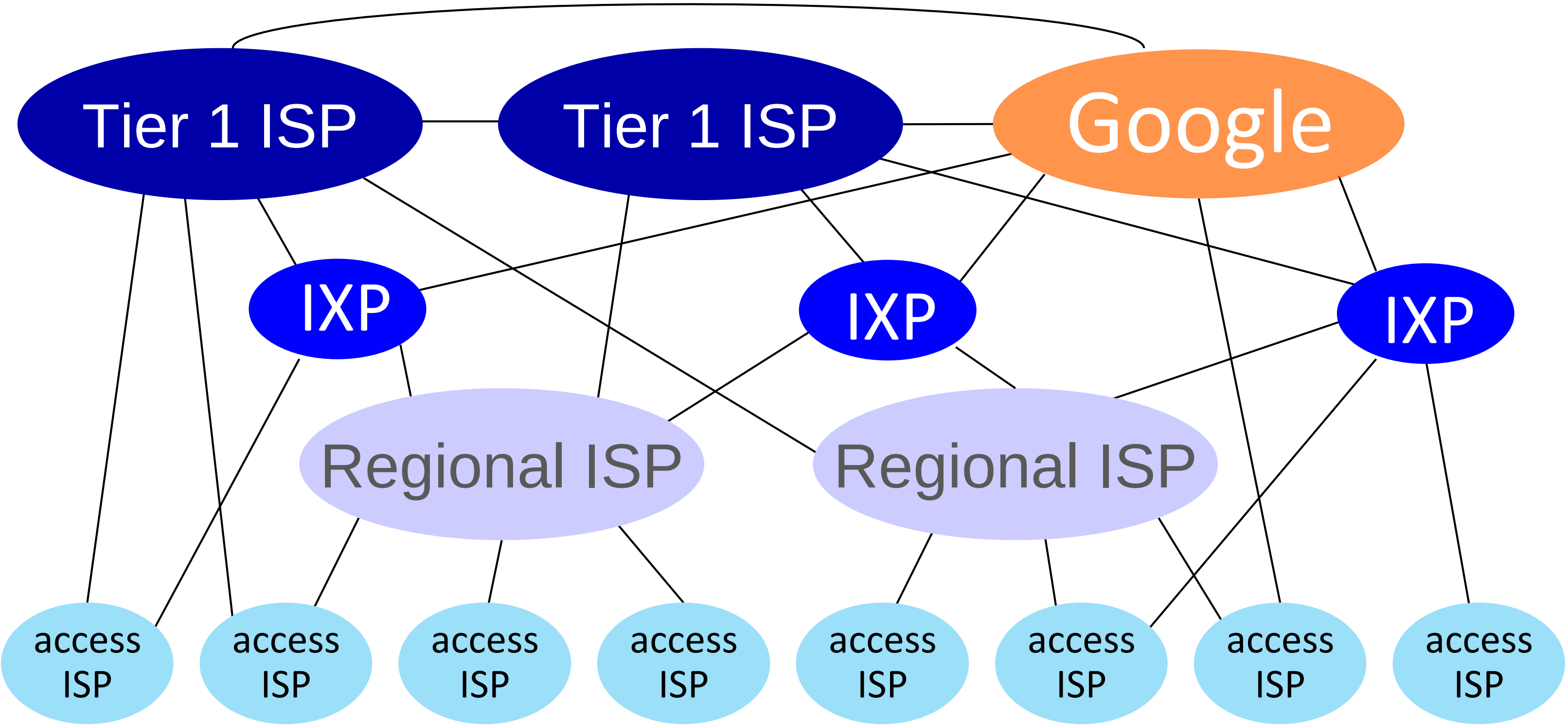
Internet structure: a "network of networks"



At "center": small # of well-connected large networks

- "tier-1" commercial ISPs, national & international coverage
- content provider networks (e.g., Google, Facebook): private network connects its data centers to Internet, often bypassing tier-1, regional ISPs

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How do packet delay and loss occur?

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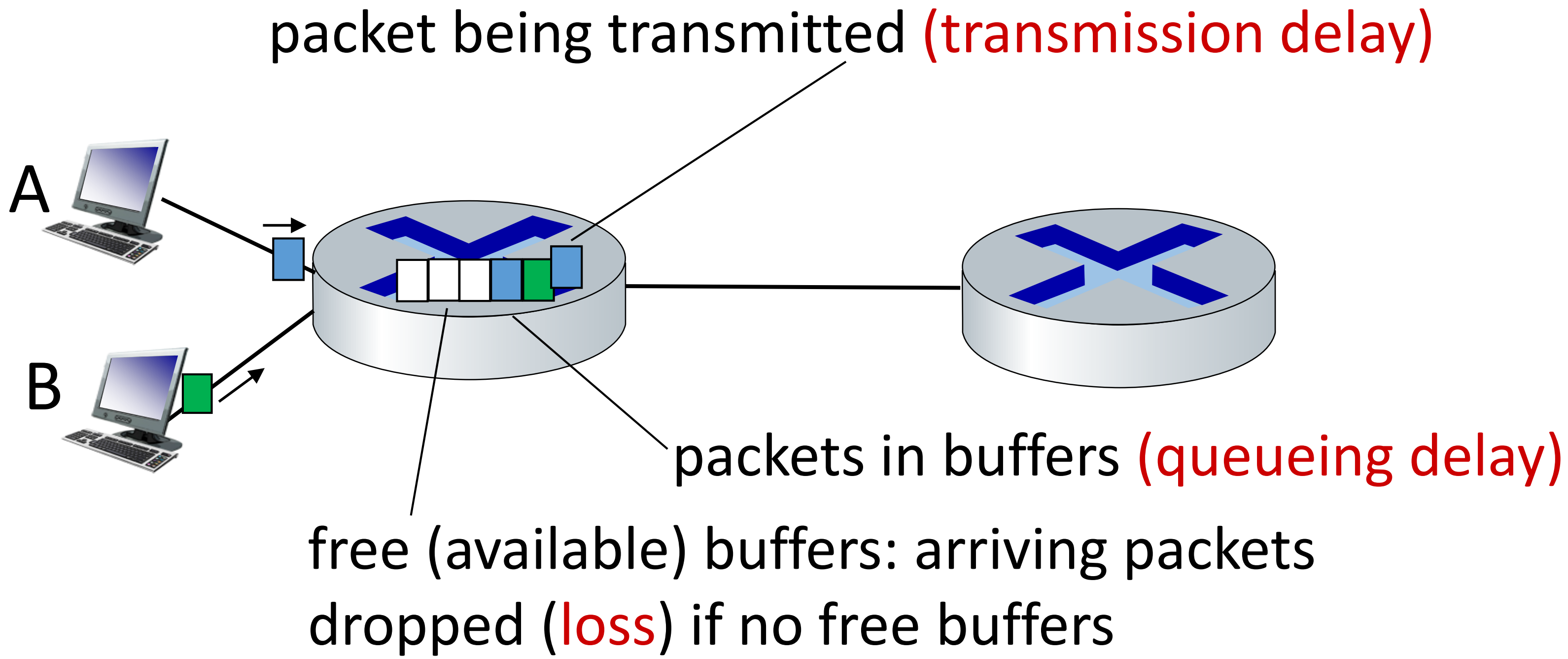
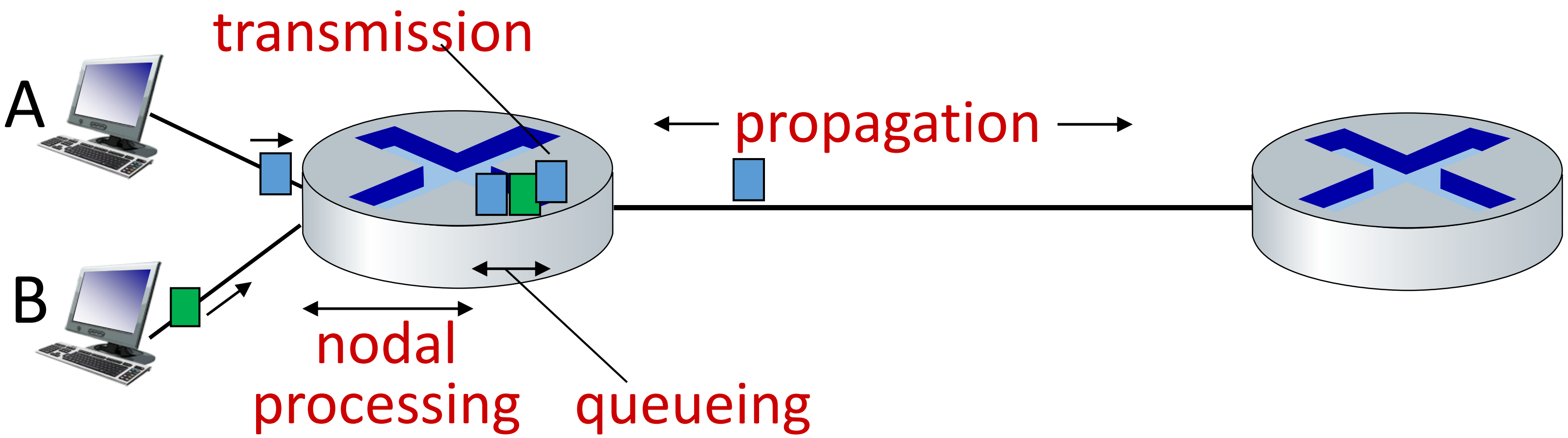
- packets *queue* in router buffers, waiting for turn for transmission
  - queue length grows when arrival rate to link (temporarily) exceeds output link capacity
- packet *loss* occurs when memory to hold queued packets fills up



Packet delay: four sources

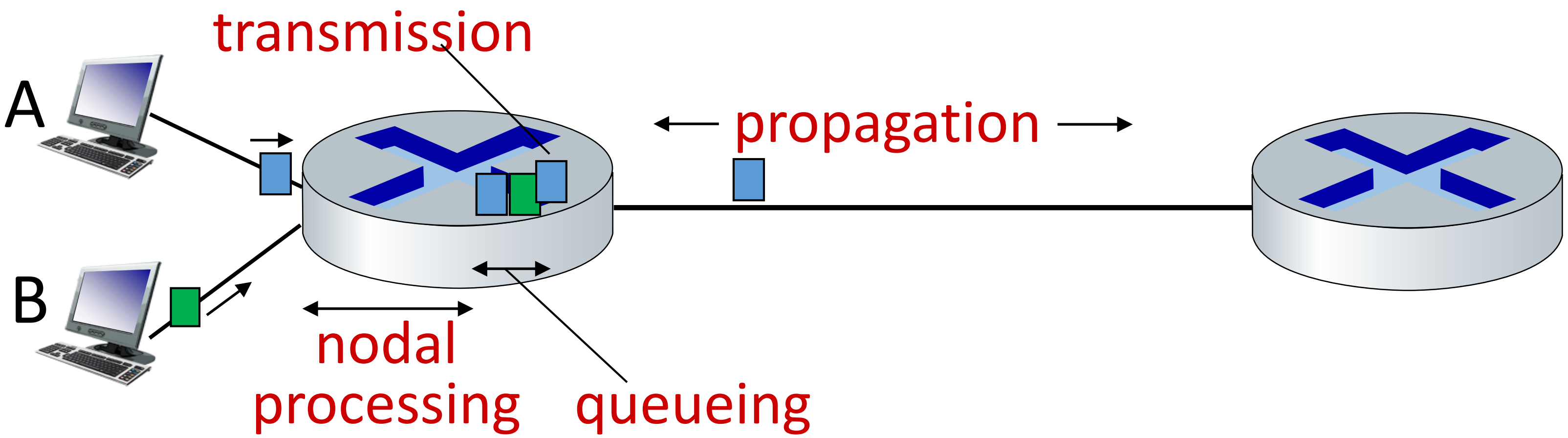


$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{proc}: nodal processing
- check bit errors
- determine output link
- typically < microsecs

d_{queue}: queueing delay
- time waiting at output link for transmission
- depends on congestion level of router

Packet delay: four sources



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

d_{trans}: transmission delay:

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

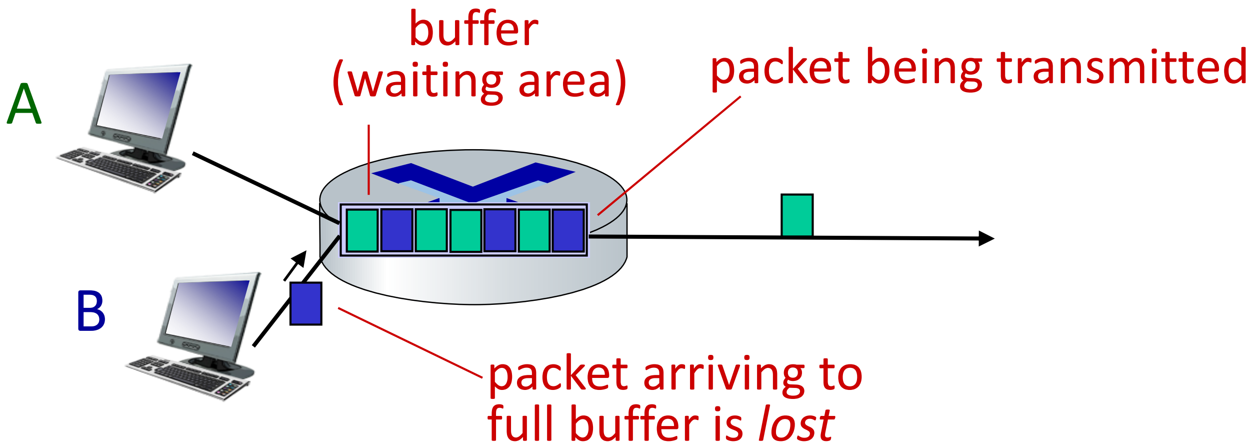
d_{prop}: propagation delay:

- d: length of physical link
- s: propagation speed (~2x10^8 m/sec)
- $d_{prop} = d/s$

d_{trans} and d_{prop}
very different

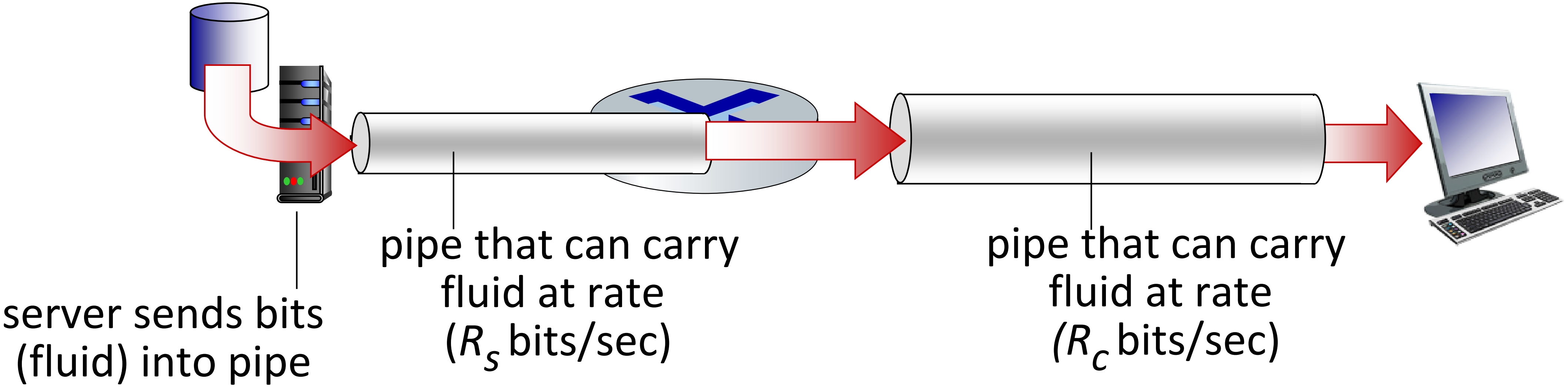
Packet loss

- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



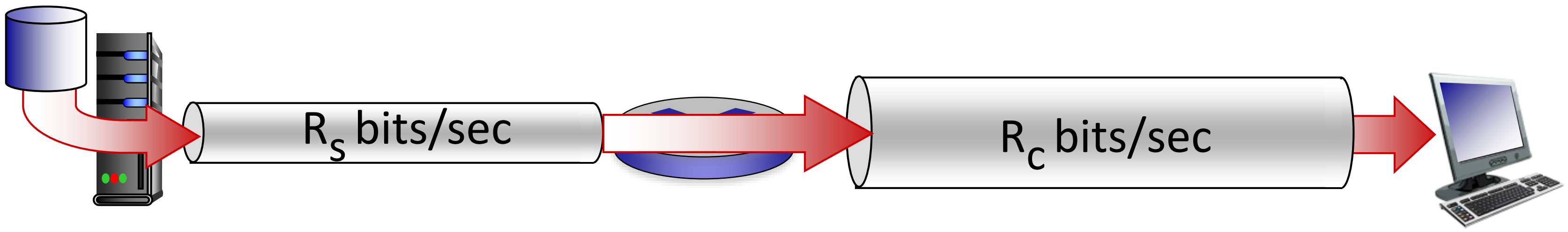
Throughput

- *throughput:* rate (bits/time unit) at which bits are being sent from sender to receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time

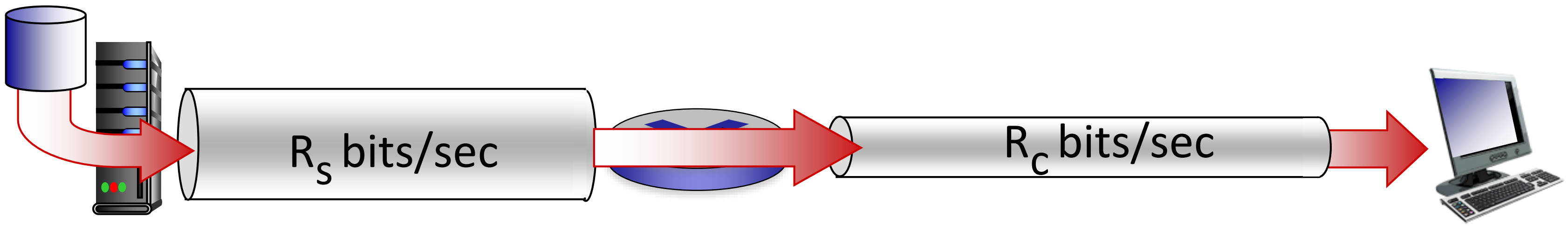


Throughput

$R_s < R_c$ What is average end-end throughput?



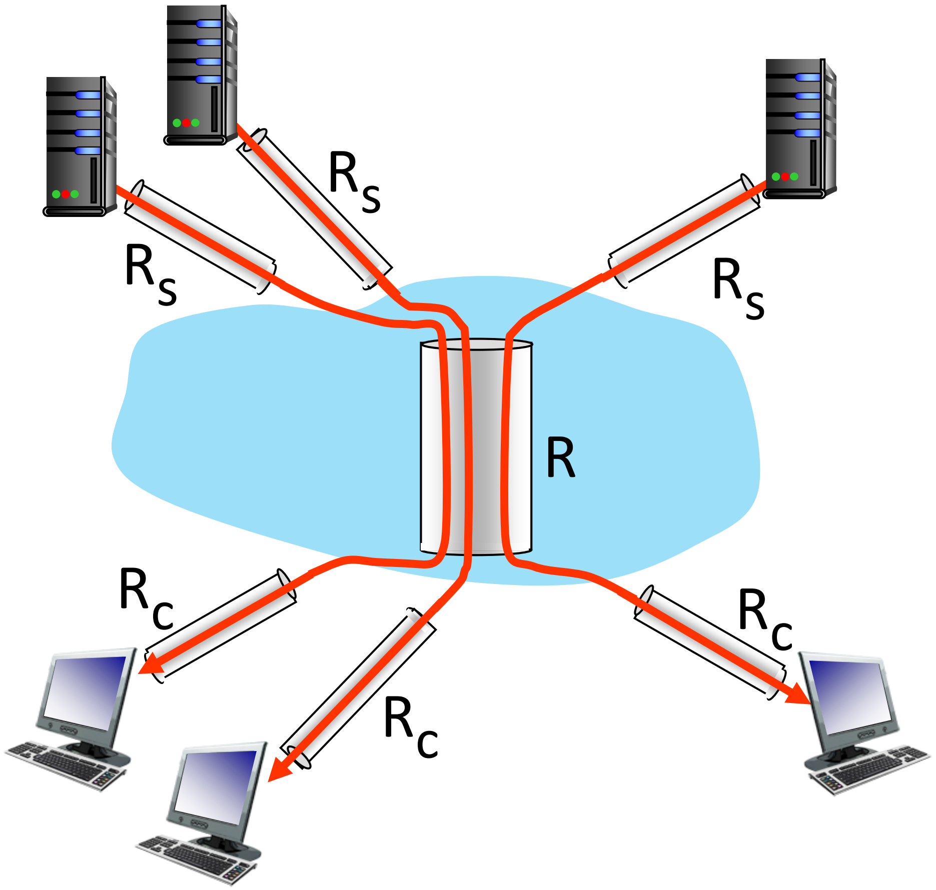
$R_s > R_c$ What is average end-end throughput?



bottleneck link

link on end-end path that constrains end-end throughput

Throughput: network scenario



10 connections (fairly) share backbone bottleneck link *R* bits/sec

- per-connection end-end throughput: $min(R_c,R_s,R/10)$
- in practice: R_c or R_s is often bottleneck

Chapter 1: roadmap

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- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- **Security**
- Protocol layers, service models
- History

Network security

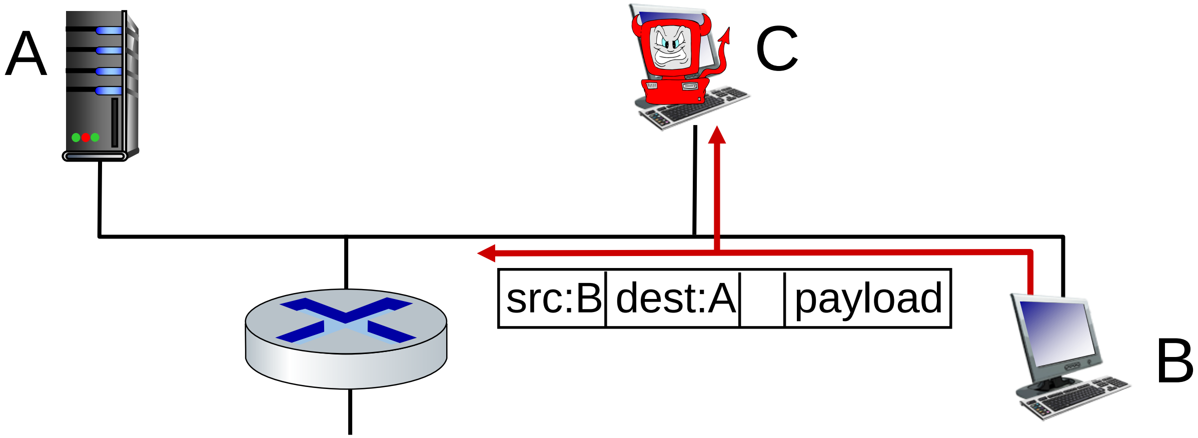
- Internet not originally designed with (much) security in mind
  - *original vision:* “a group of mutually trusting users attached to a transparent network” ☺
  - Internet protocol designers playing “catch-up”
  - security considerations in all layers!
- We now need to think about:
  - how bad guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks

Week 4 _ Tuesday

Bad guys: packet interception

packet "sniffing":

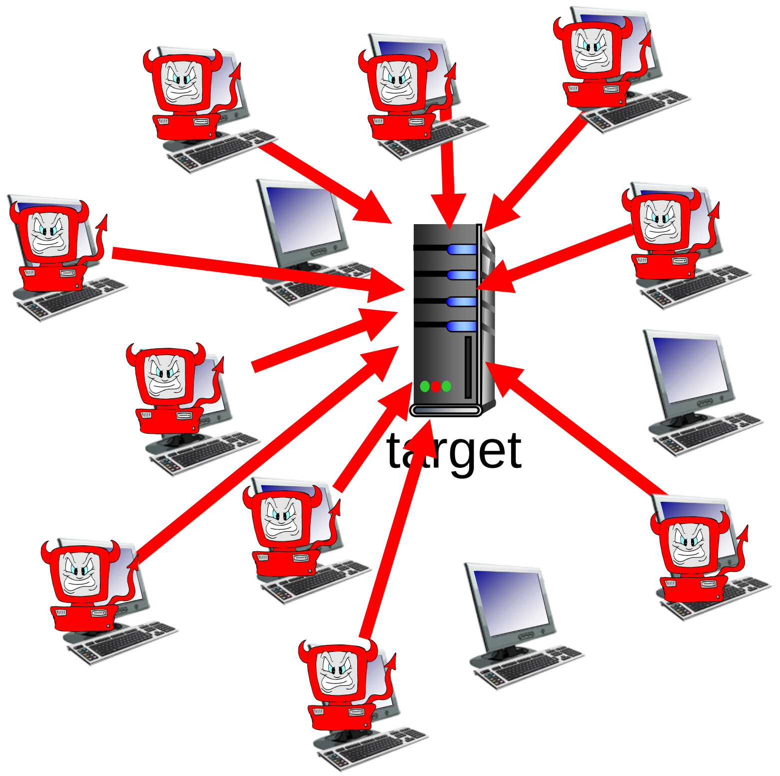
- broadcast media (shared Ethernet, wireless)
- Packet sniffer (C) reads/records all packets (e.g., including passwords!) passing by its interface



Bad guys: denial of service

Denial of Service (DoS): attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts



Lines of defense:

- authentication: proving you are who you say you are
  - cellular networks provides hardware identity via SIM card; no such hardware assist in traditional Internet
- confidentiality: via encryption
- integrity checks: digital signatures prevent/detect tampering
- access restrictions: password-protected VPNs
- firewalls: specialized “middleboxes” in access and core networks:
  - off-by-default: filter incoming packets to restrict senders, receivers, applications
  - detecting/reacting to DOS attacks

More information, please read the chapter 8 of the recommend textbook (computer networking)

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Protocol "layers" and reference models

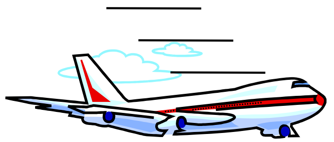
Networks are complex, with many "pieces":

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question: is there any hope of *organizing* structure of network?

- and/or our *discussion* of networks?

Example: organization of air travel



end-to-end transfer of person plus baggage

ticket (purchase)
baggage (check)
gates (load)
runway takeoff
airplane routing

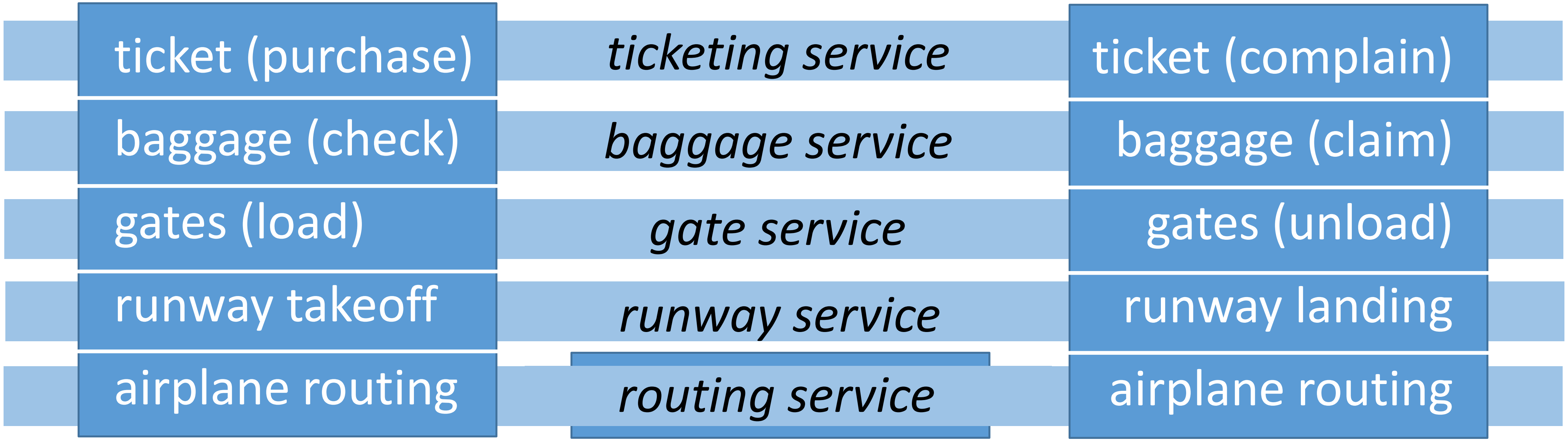
ticket (complain)
baggage (claim)
gates (unload)
runway landing
airplane routing

airplane routing

How would you *define/discuss* the *system* of airline travel?

- a series of steps, involving many services

Example: organization of air travel

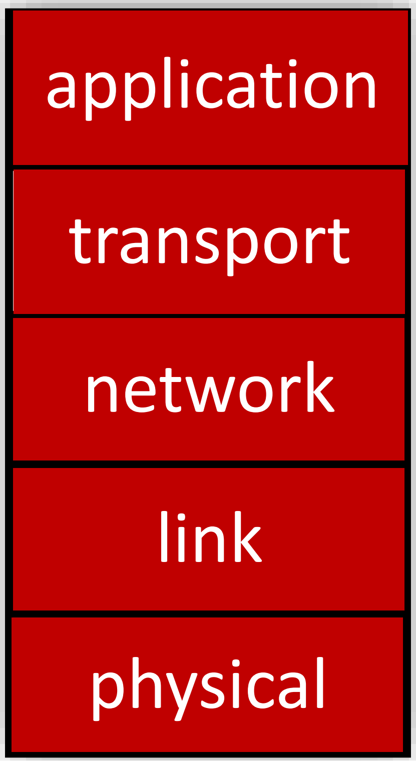


layers: each layer implements a service

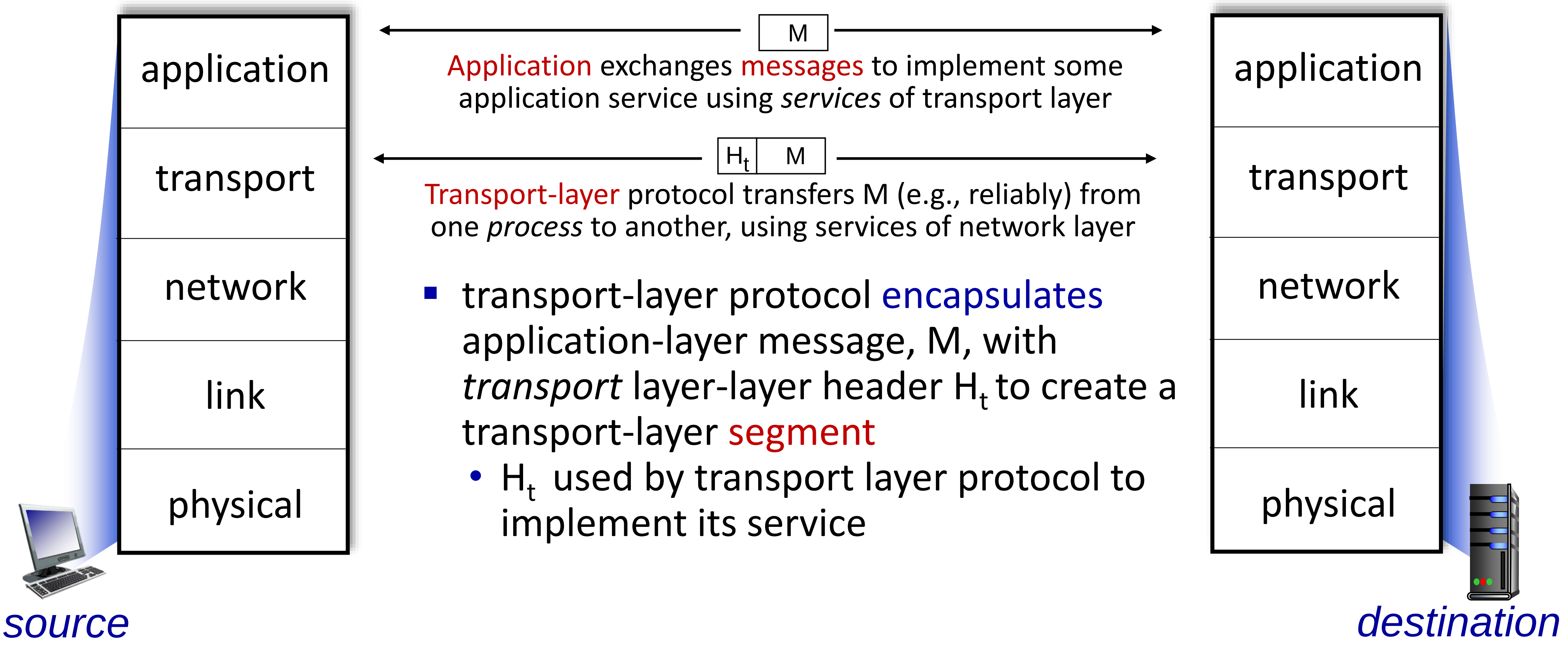
- via its own internal-layer actions
- relying on services provided by layer below

Layered Internet protocol stack

- *application:* supporting network applications
  - HTTP, SMTP……
- *transport:* process-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) …..
- *physical:* bits "on the wire"

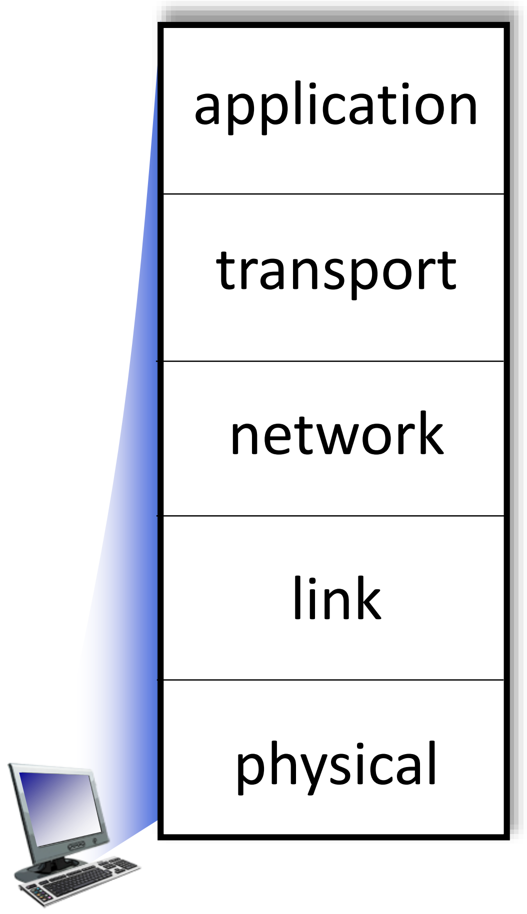


Services, Layering and Encapsulation



- transport-layer protocol encapsulates application-layer message, M, with *transport* layer-layer header H_t to create a transport-layer segment
  - H_t used by transport layer protocol to implement its service

Services, Layering and Encapsulation



source

M

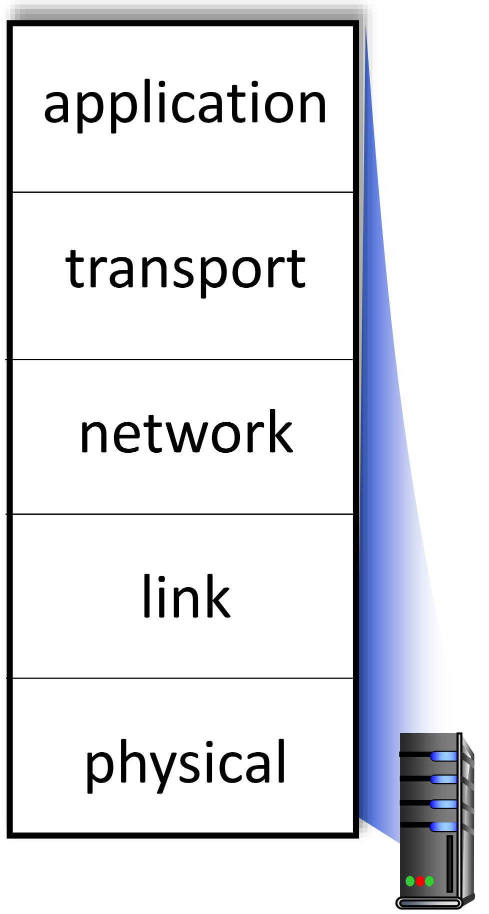
H_t M

Transport-layer protocol transfers M (e.g., reliably) from one *process* to another, using services of network layer

H_n H_t M

Network-layer protocol transfers transport-layer segment [H_t | M] from one *host* to another, using link layer services

- network-layer protocol encapsulates transport-layer segment [H_t | M] with network layer header H_n to create a network-layer datagram
  - H_n used by network layer protocol to implement its service



destination

Services, Layering and Encapsulation

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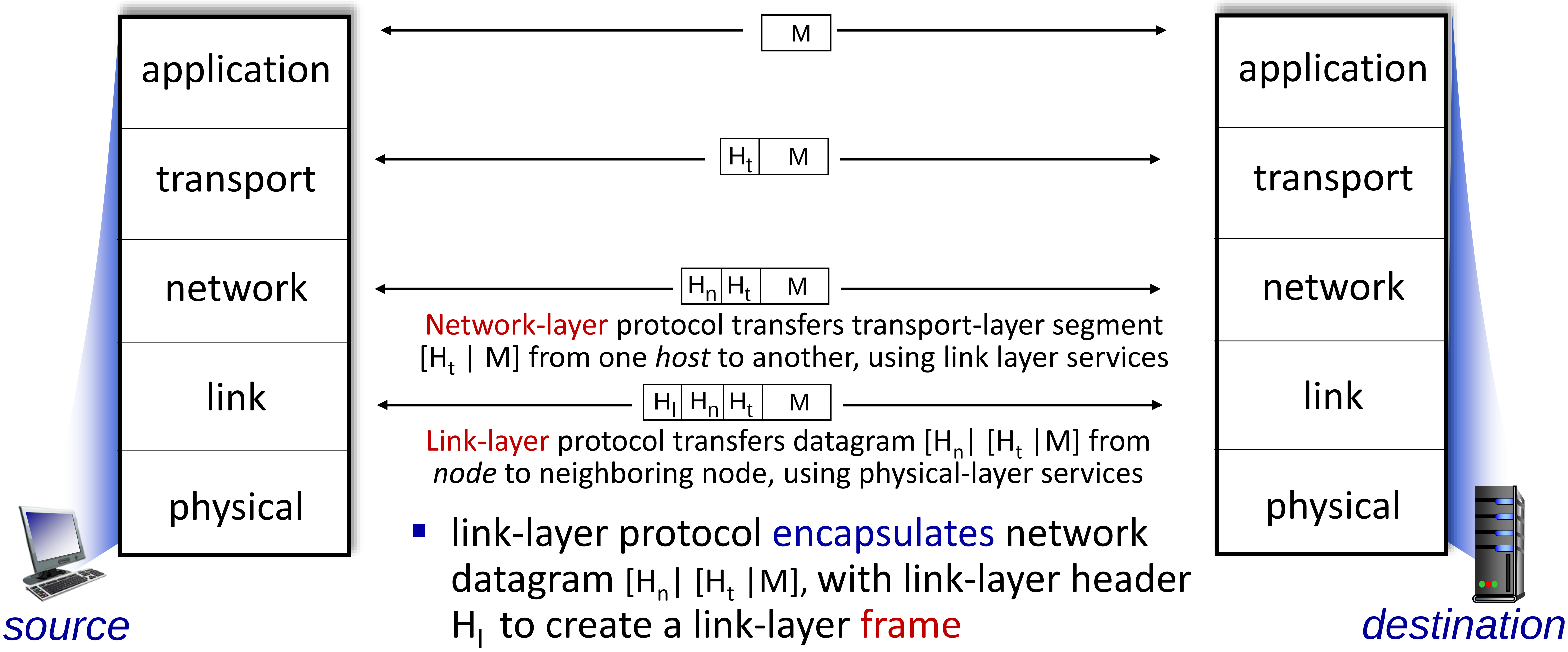
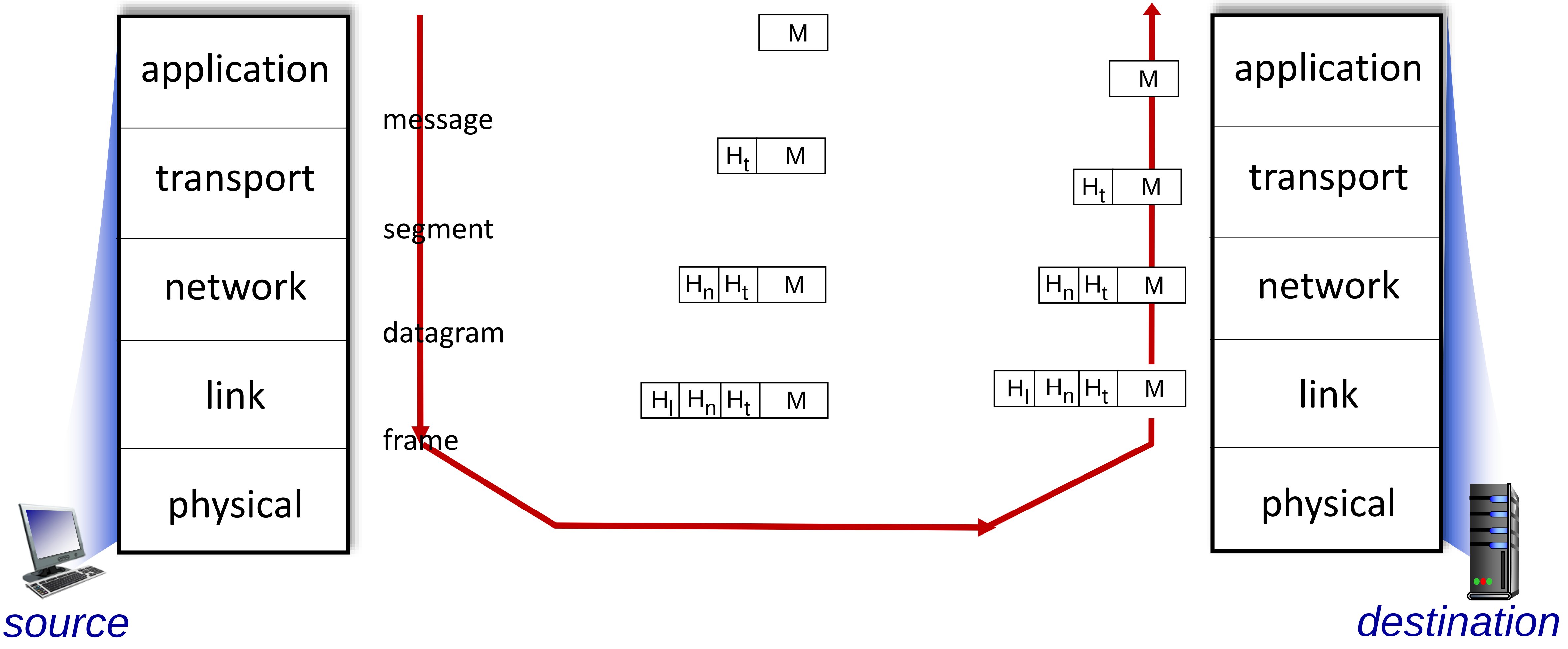


- link-layer protocol encapsulates network datagram [H_n| [H_t |M], with link-layer header H_l to create a link-layer frame

Services, Layering and Encapsulation



Encapsulation: an end-end view

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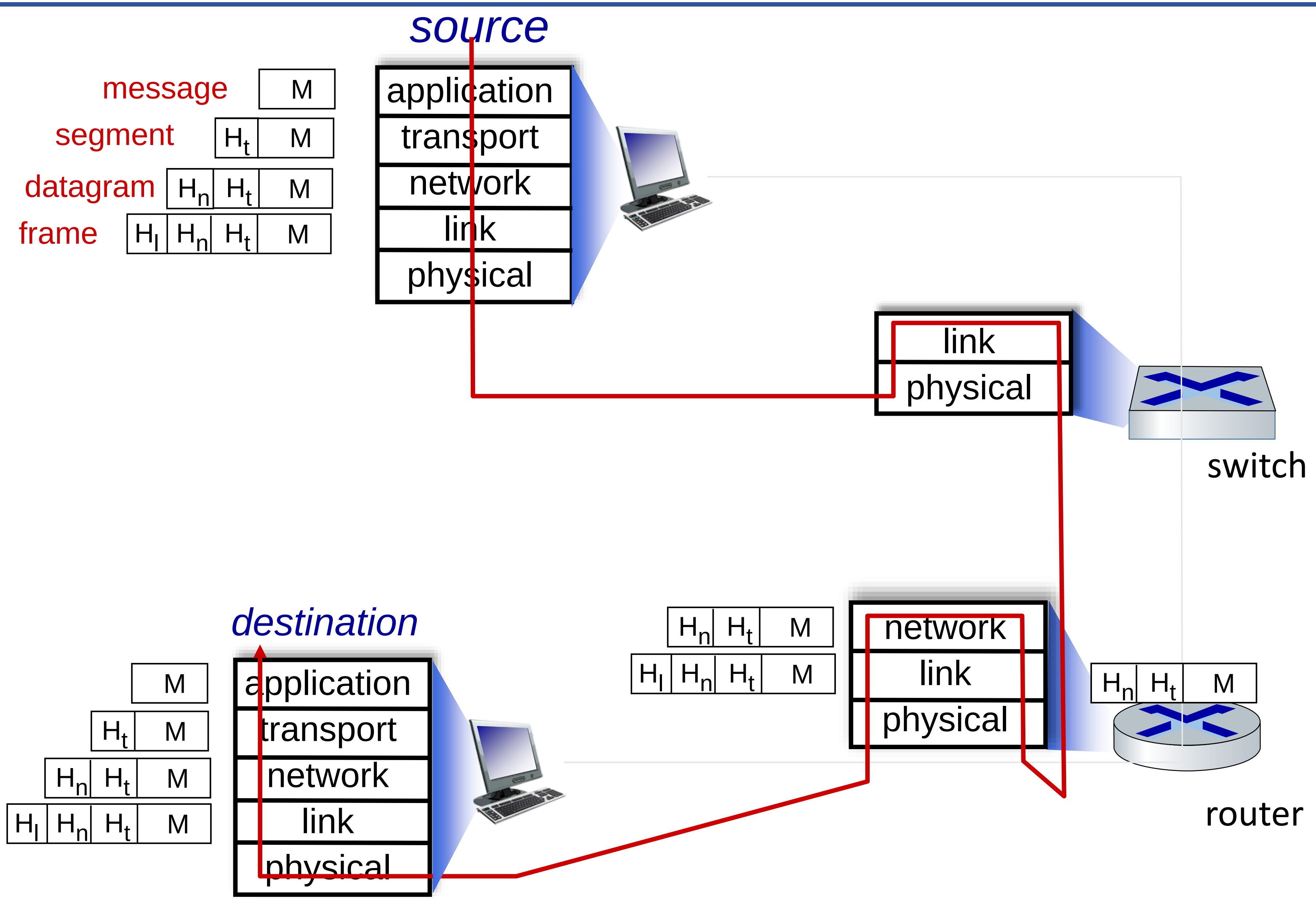

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Internet history

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1972:
  - ARPAnet has 15 nodes
  - ARPAnet public demo
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program

Internet history

1972-1980: Internetworking, new and proprietary networks

- 1970: ALOHAnet satellite network in Hawaii
- 1979: ARPAnet has 200 nodes

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1988: TCP congestion control

Internet history

1990, 2000s: commercialization, the Web, new applications

- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - late 1990s: commercialization of the Web

2005-present: scale, SDN, mobility, cloud

- 2008: software-defined networking (SDN)
- increasing ubiquity of high-speed wireless access: 4G/5G, WiFi

The End