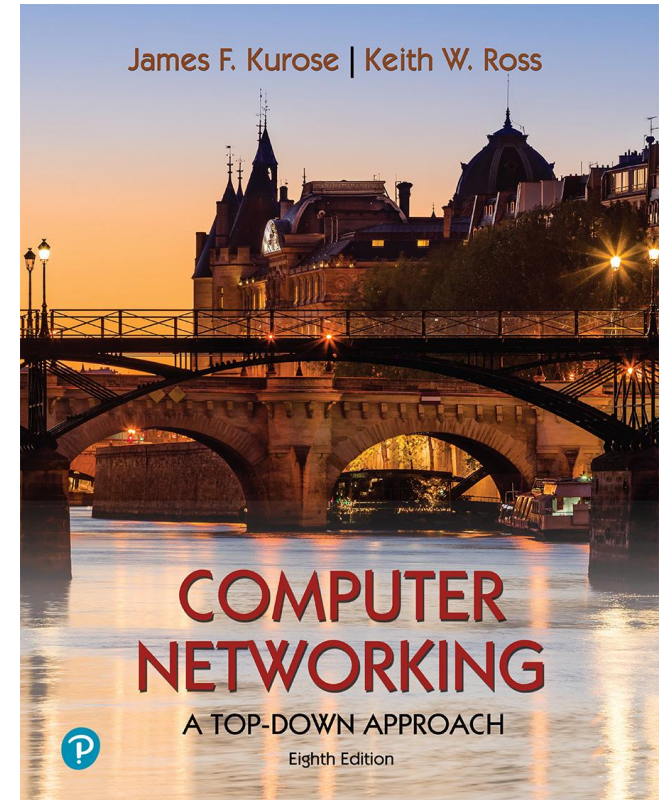# Chapter 1
Introduction

Chuming Qiao/Yaxiong Xie

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University at Buffalo, SUNY

Adapted from the slides of the book's authors

Computer Networking: A Top-Down Approach

8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Chapter 1: introduction

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
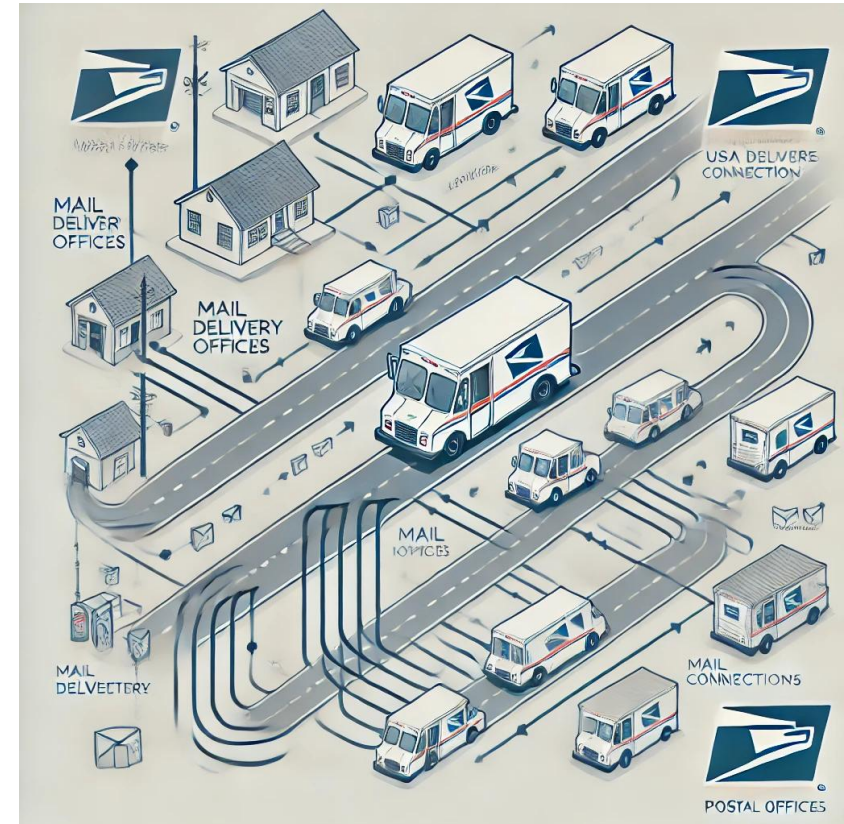- Security

What's Internet? An analogy: USPS

USPS system

USPS network

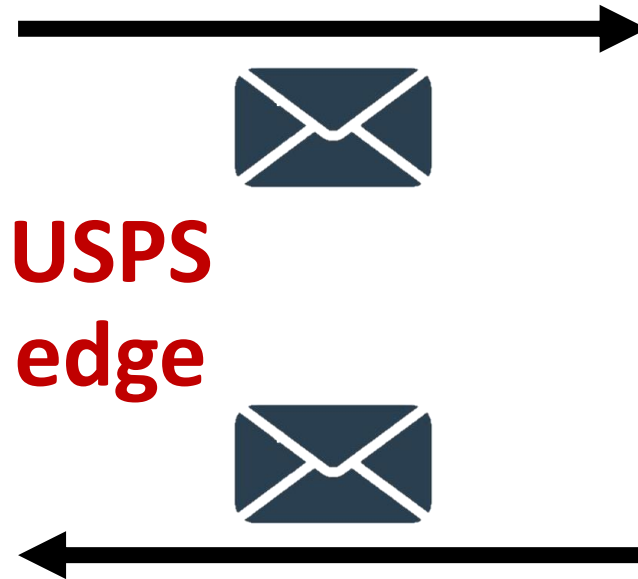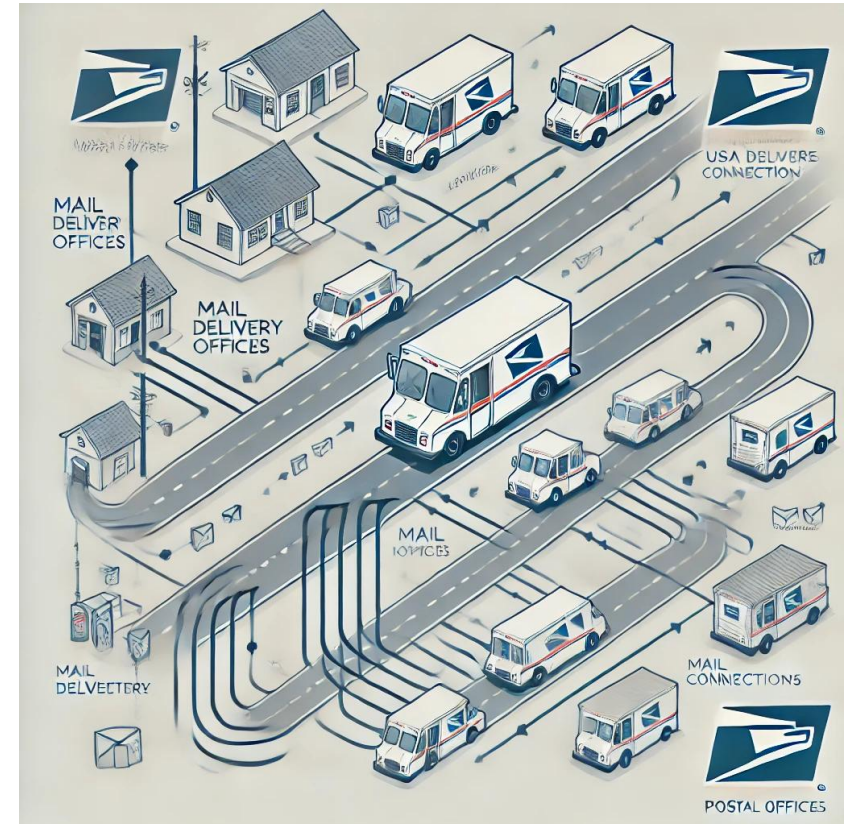# What's Internet? An analogy: USPS

USPS system

USPS network

What's Internet? An analogy: USPS

USPS system

USPS edge

USPS core network

What's Internet?

Internet System

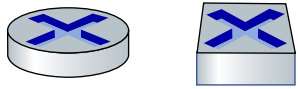**Packets**

Internet edge

Packets

Internet core network

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)
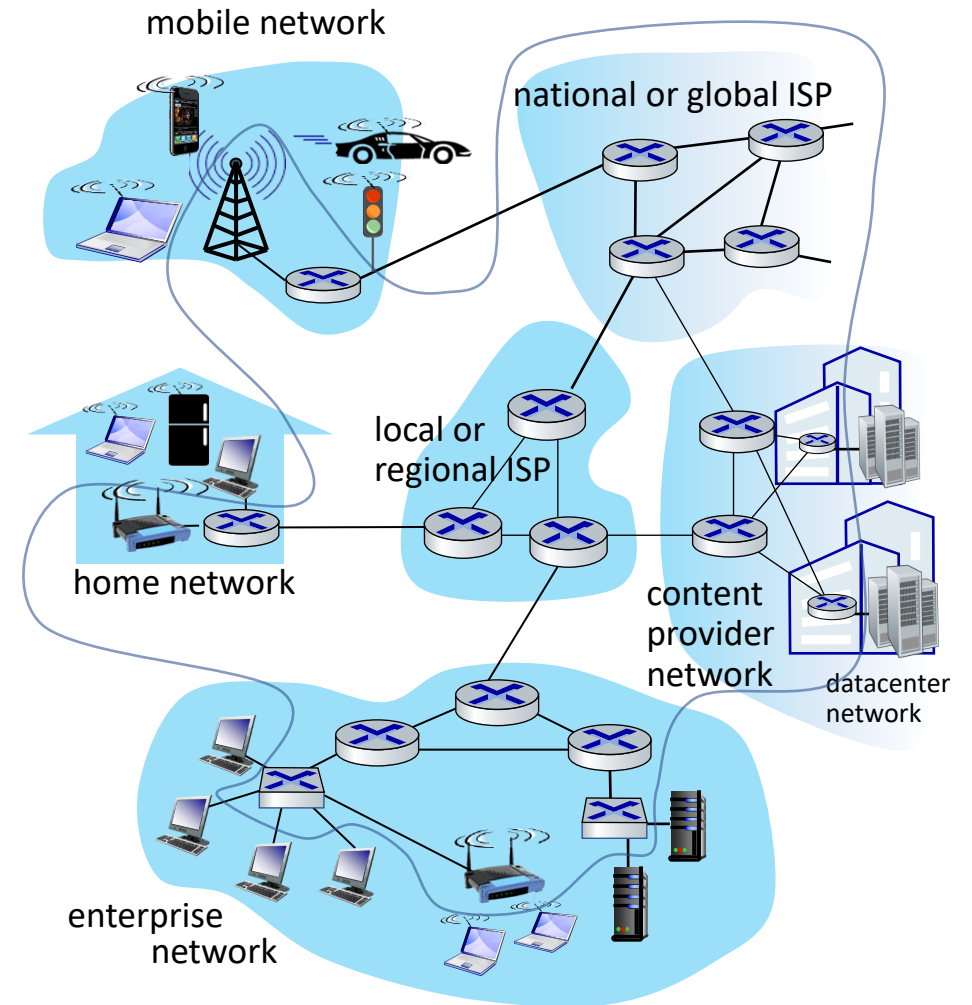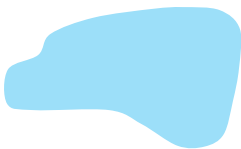
- *routers, switches*

Communication links

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

Networks

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

mobile network

national or global ISP

local or regional ISP

home network

content provider network

datacenter network

enterprise network

What's the Internet: "nuts and bolts" view -continued

- *Software: protocols* control sending, receiving of msgs
  - e.g., HTTP (web), SMTP (for email server),
  - Wifi /BT (802.x) for wireless devices,
  - Ethernet (for local area networks),
  - TCP/UDP (for hosts on the internet)
  - IP (for the routers in the core networks)

- Internet standards define these protocols
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force

Introduction

What's a protocol?

Human protocols:

- "what's the time?"
- "I have a question"
- introductions

Rules for:

… specific messages sent

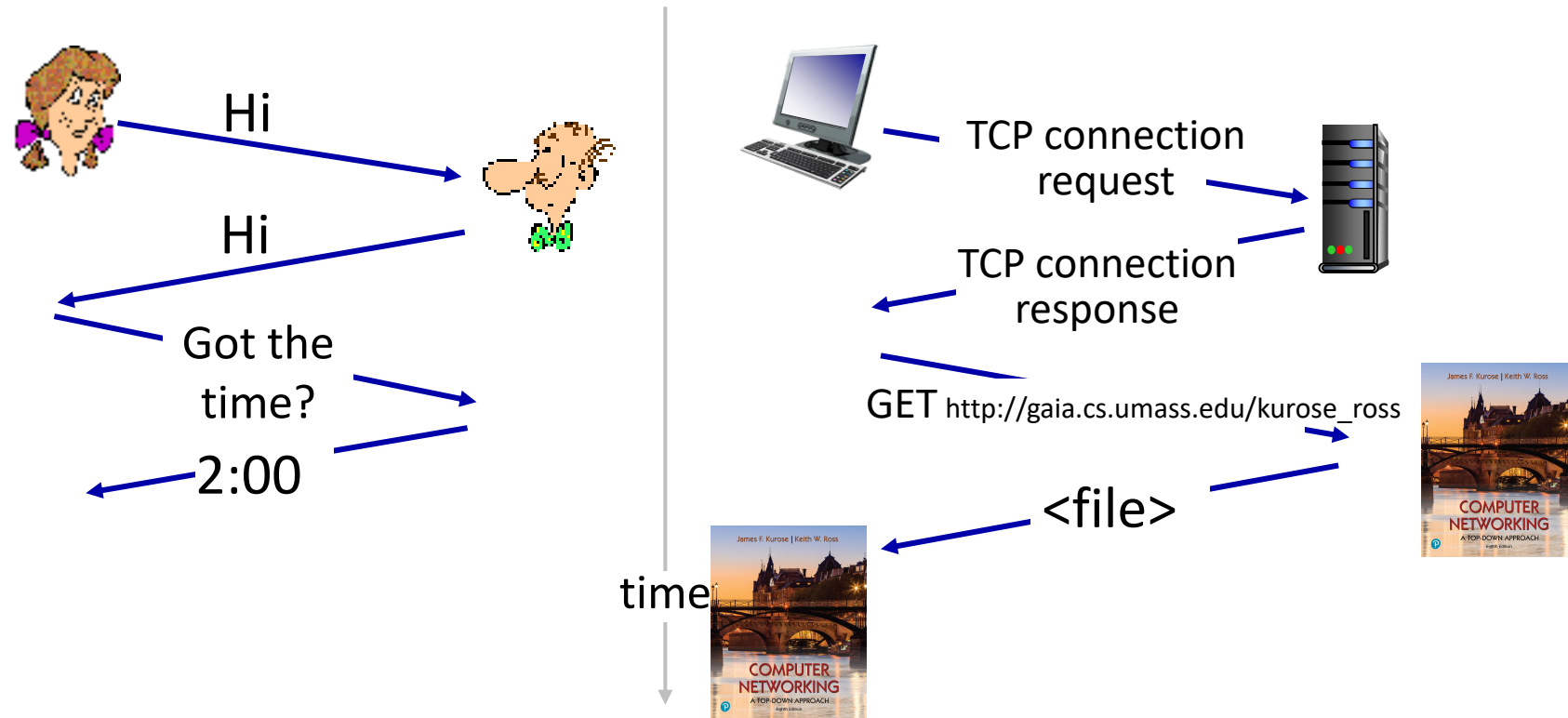… specific actions taken when message received, or other events

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
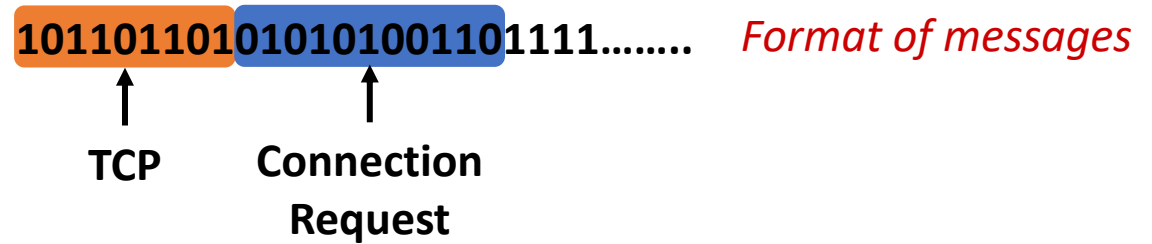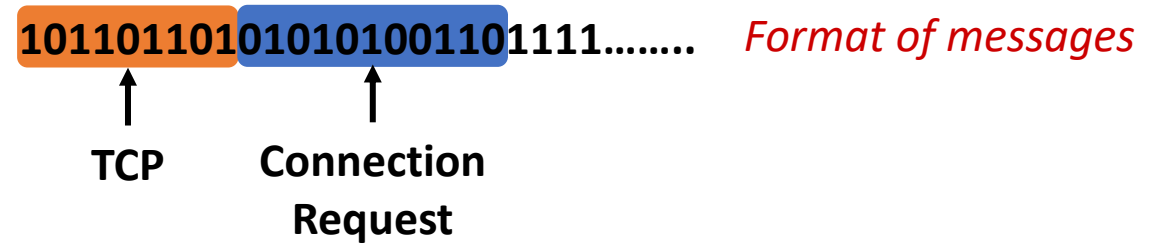
What's a protocol?

A human protocol and a computer network protocol:

What's a protocol?

A human protocol and a computer network protocol:

TCP connection request

1011011010101010010011011111........ *Format of messages*

TCP

Connection Request

What's a protocol?

A human protocol and a computer network protocol:

TCP connection request

TCP connection response

GET http://gaia.cs.umass.edu/kurose_ross

<file>

10110110101010101001101111........

Format of messages

TCP

Connection Request
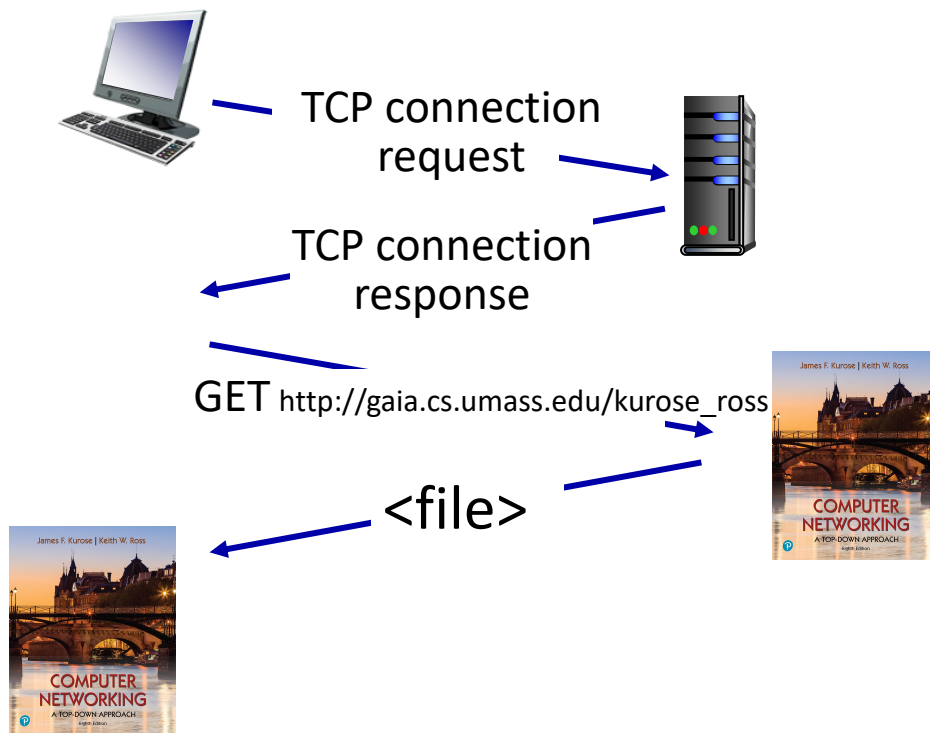
Order of messages

What's a protocol?

A human protocol and a computer network protocol:

TCP connection request

TCP connection response
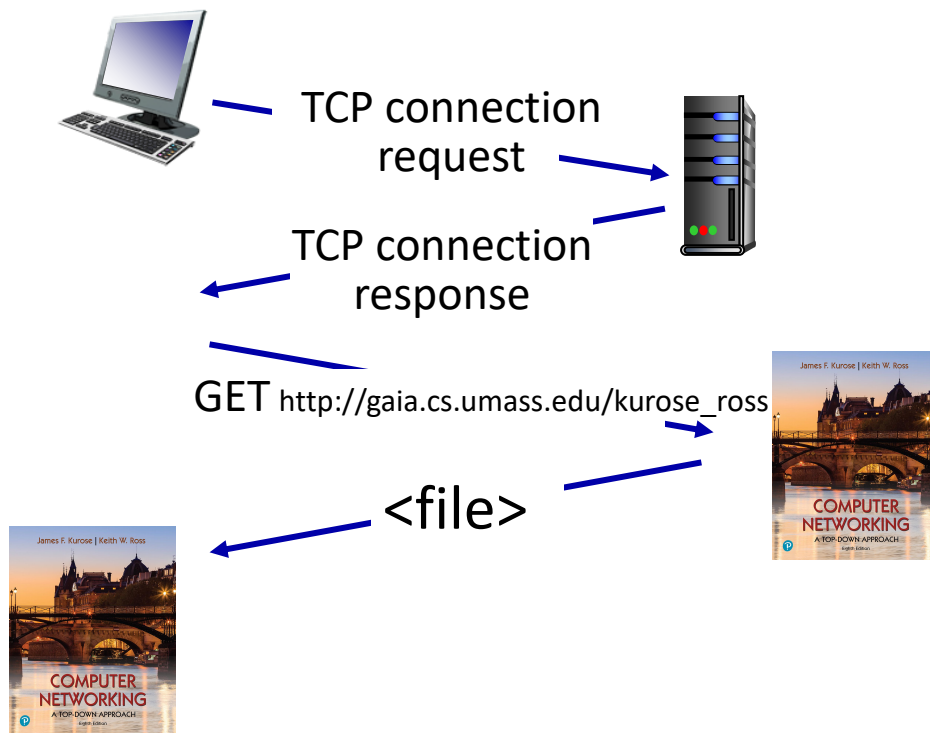
GET http://gaia.cs.umass.edu/kurose_ross

<file>

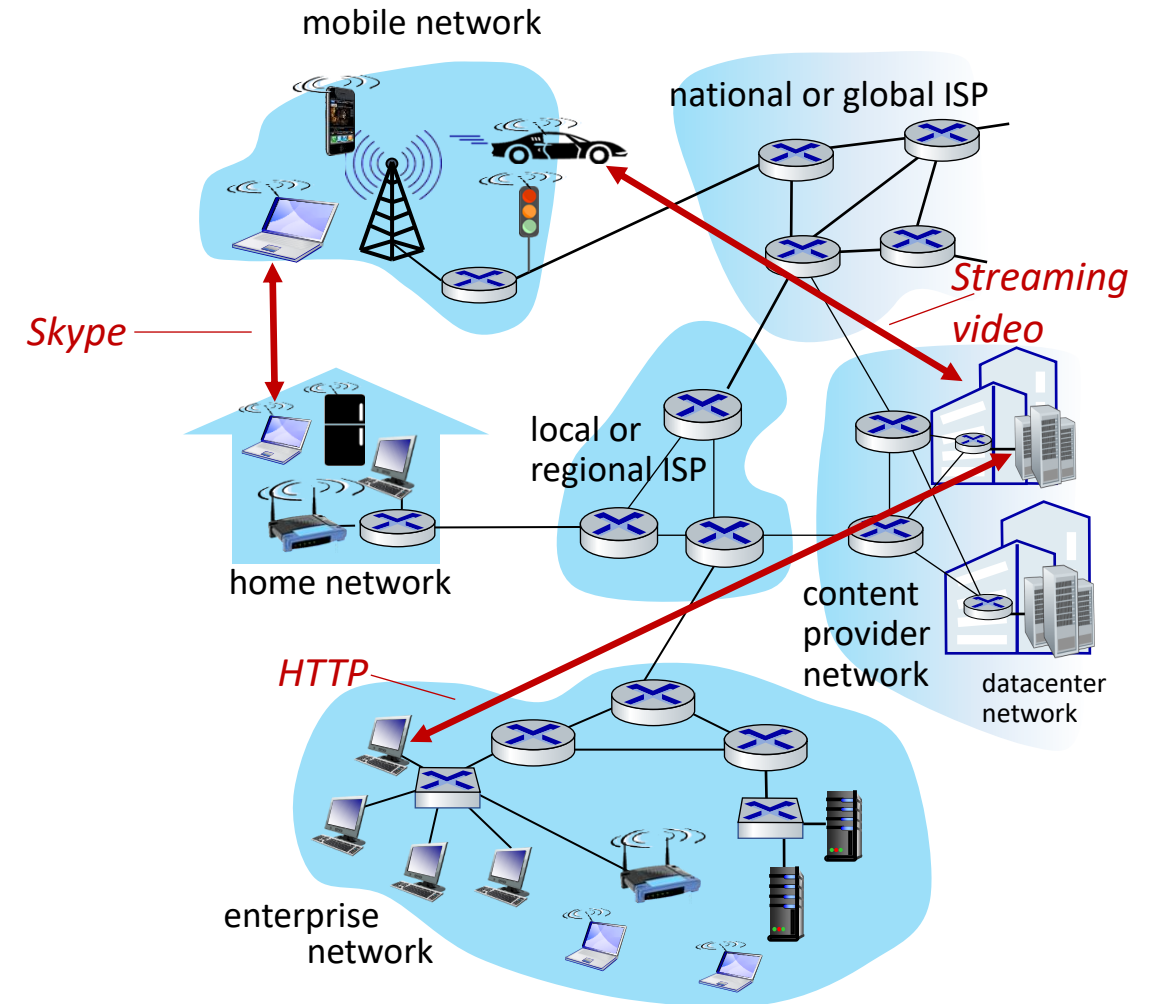**1011011010**0101010011011111........   *Format of messages*

TCP   Connection Request
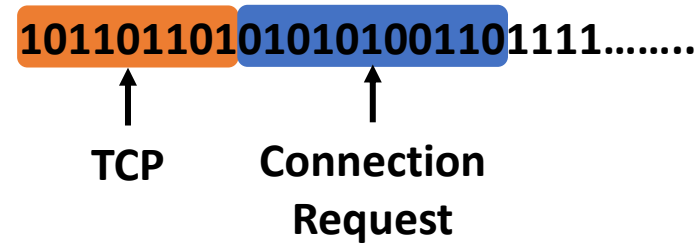
Order of messages

Actions actions taken on message transmission, receipt

The Internet: a "services" view

- *As an Infrastructure that provides services to applications:*
  - Web, streaming video, multimedia teleconferencing, social media,…
  - provided by hardware and software (*protocols*)
- provides *programming interface* to distributed applications:
  - "hooks" allowing sending/receiving apps to "connect" to, use Internet transport service
  - provides service options, analogous to postal service

mobile network

national or global ISP

Skype

Streaming video

local or regional ISP

home network

content provider network
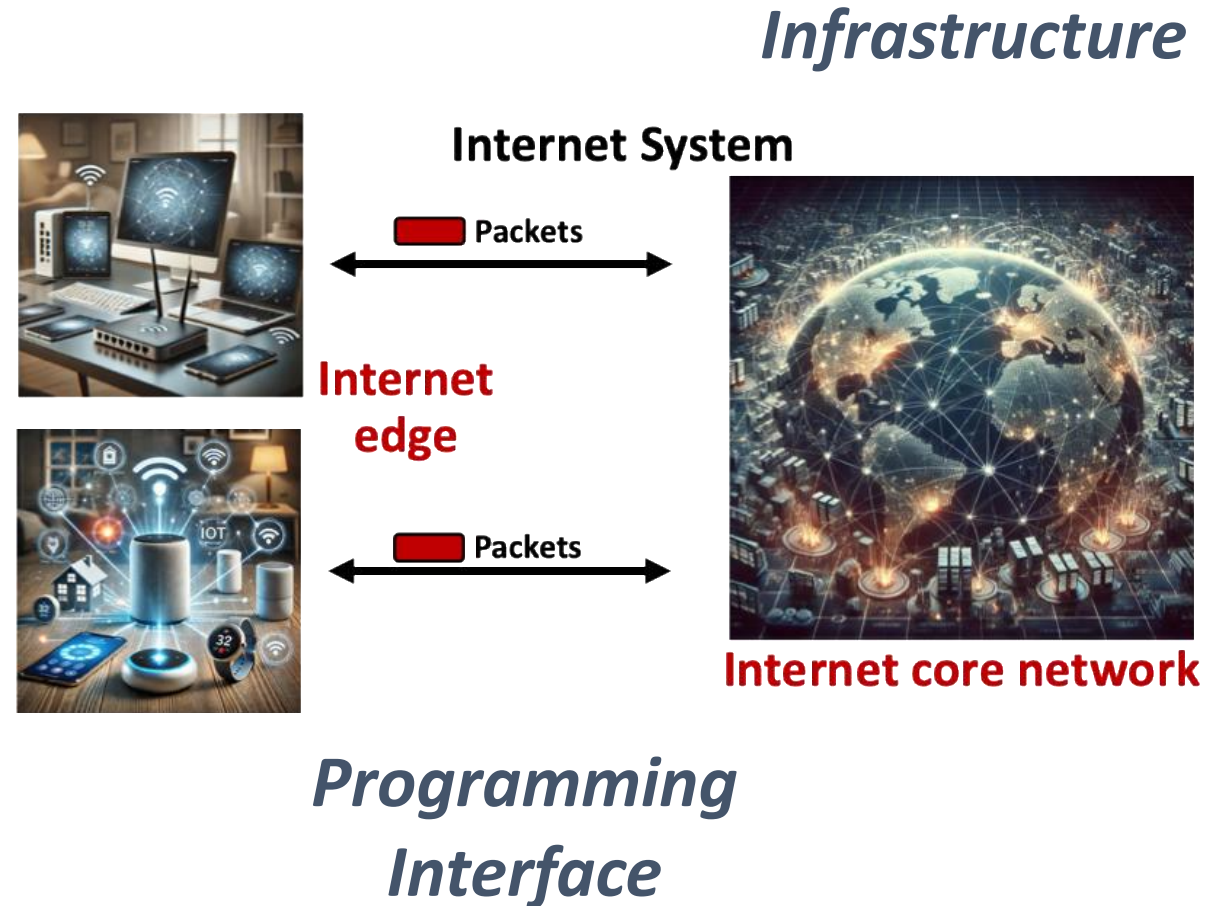
datacenter network

HTTP

enterprise network

The Internet: a "services" view

- *As an Infrastructure* that provides services to applications:
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Infrastructure

Internet System

Packets

Internet edge

Internet core network

Packets

Programming Interface

What's the Internet: a service view

- **services provided by protocols**
  - running on hosts and routers.

- **two types of services provided to apps:**
  - Connectionless (UDP)
    - faster/quicker delivery (no need to set up any connection)
    - less reliable, no orderly packets delivered
    - Suitable for real-time streaming
  - Connection-oriented (TCP)
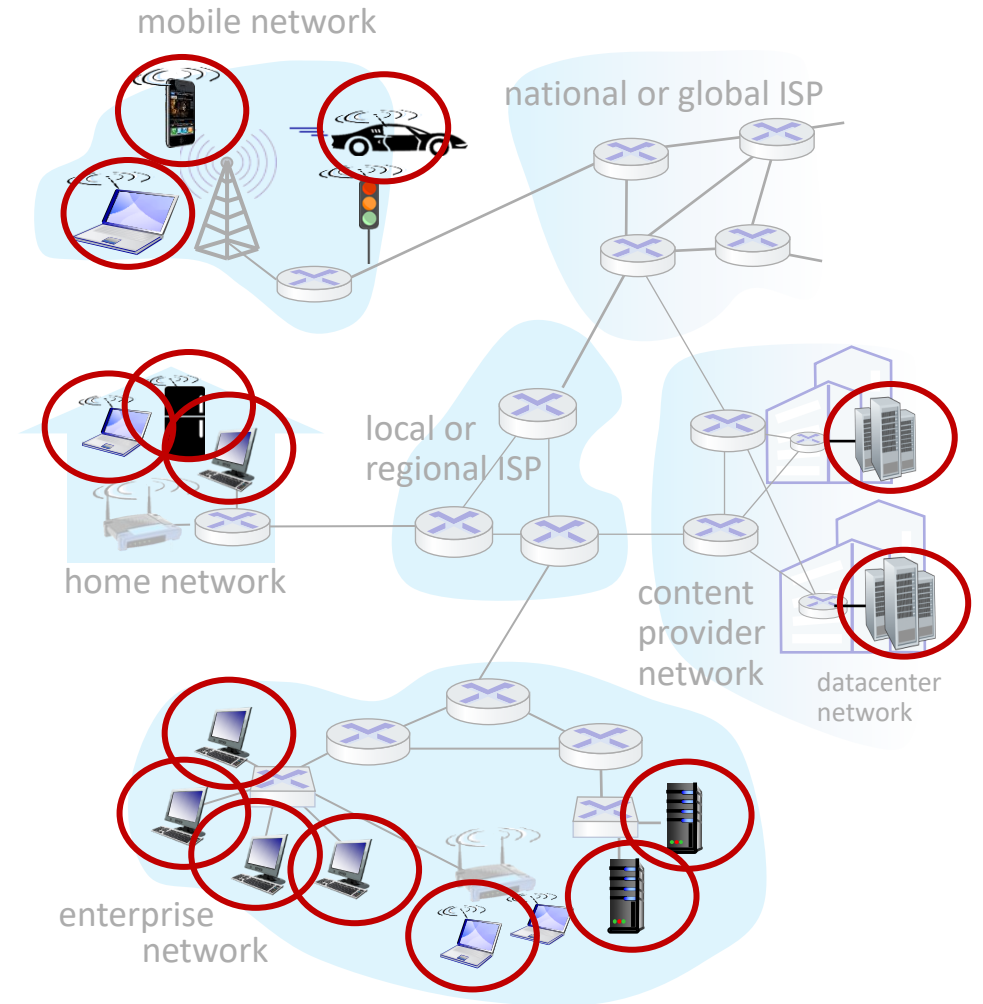   - Suitable for file/email transfers

Chapter 1: 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
- Security
- Protocol layers, service models
- History

A closer look at Internet structure

Network edge:

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

mobile network

national or global ISP

local or regional ISP

home network

content provider network

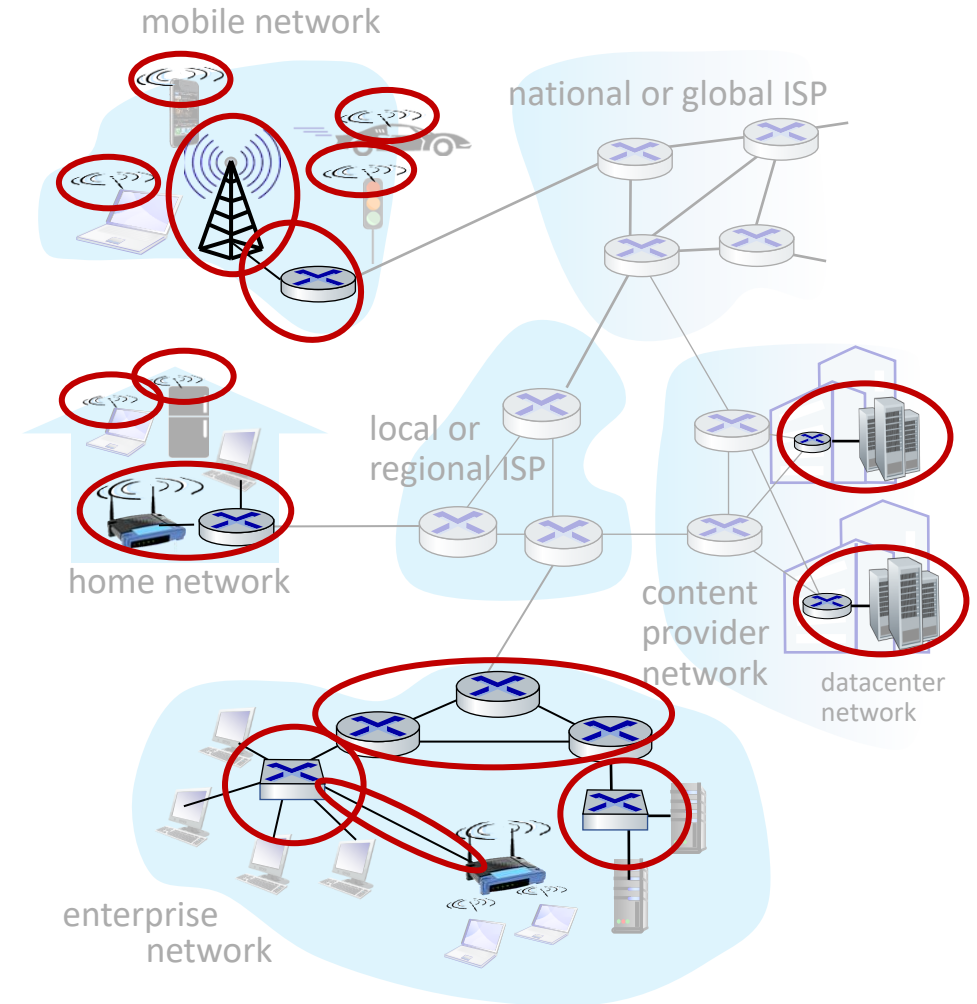datacenter network

enterprise network

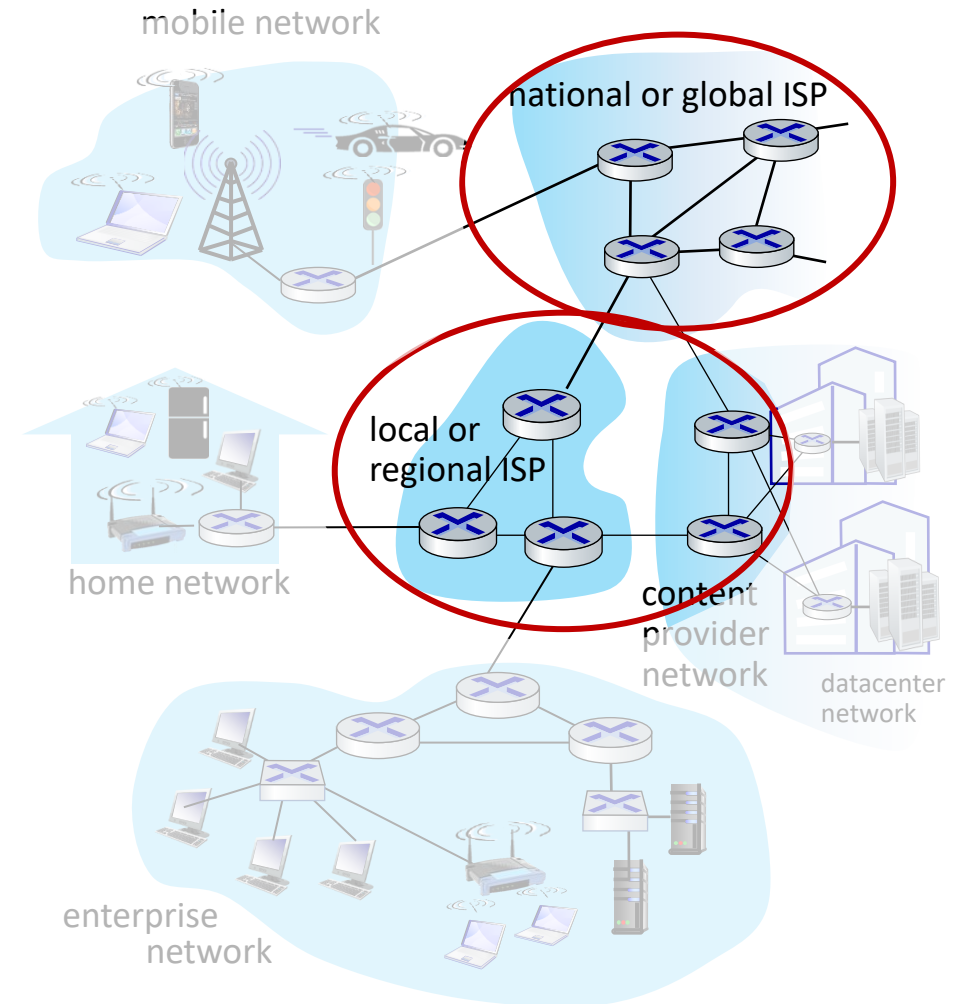# A closer look at Internet structure

Network edge:

- hosts: clients and servers

- servers often in data centers

Access networks, physical media:

- wired, wireless communication links

mobile network

national or global ISP

local or regional ISP

home network

content provider network

datacenter network

enterprise network

A closer look at Internet structure

Network edge:

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

Access networks, physical media:

- wired, wireless communication links

Network core:

- interconnected routers
- network of networks

mobile network

national or global ISP

local or regional ISP

home network

content provider network

datacenter network
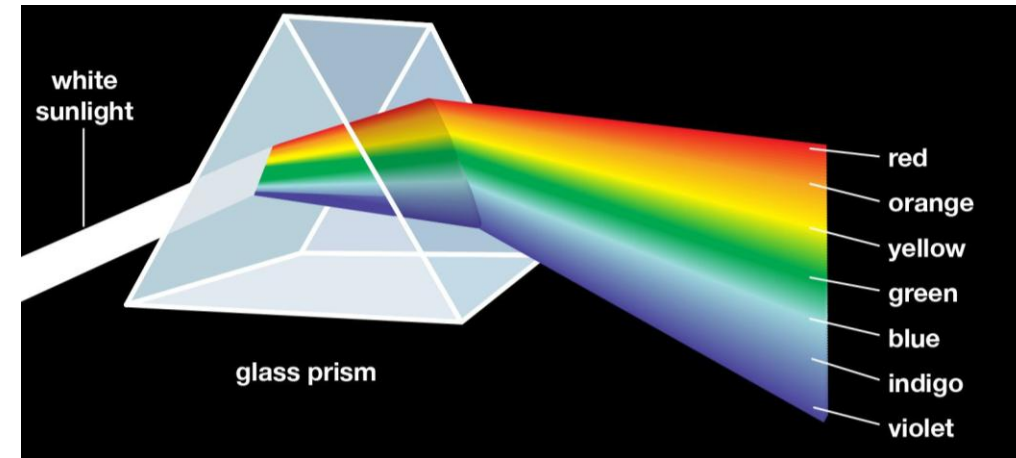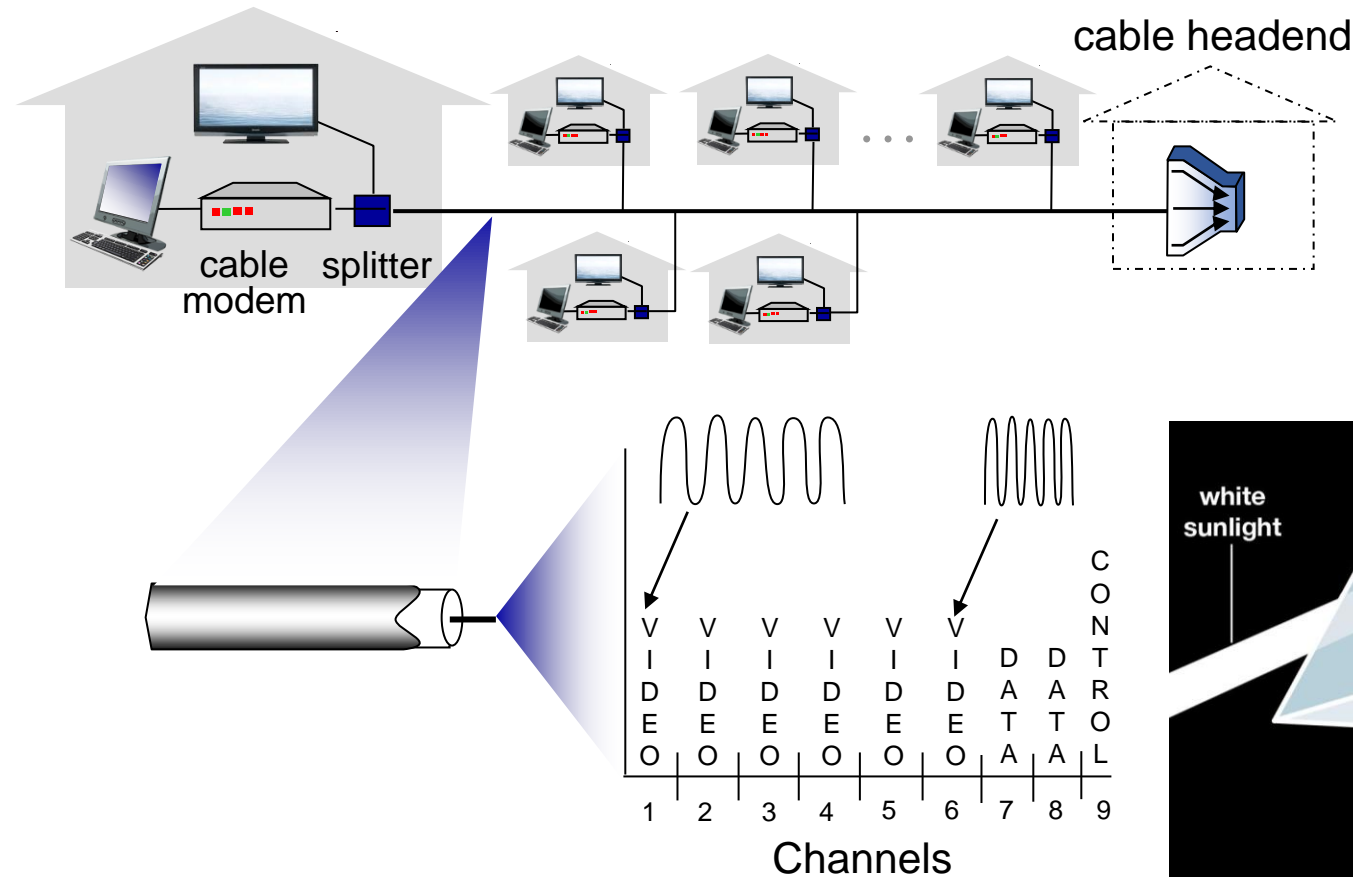
enterprise network

Access networks and physical media

Q: How to connect end systems to edge router?

▪ residential access nets

▪ institutional access networks (school, company)

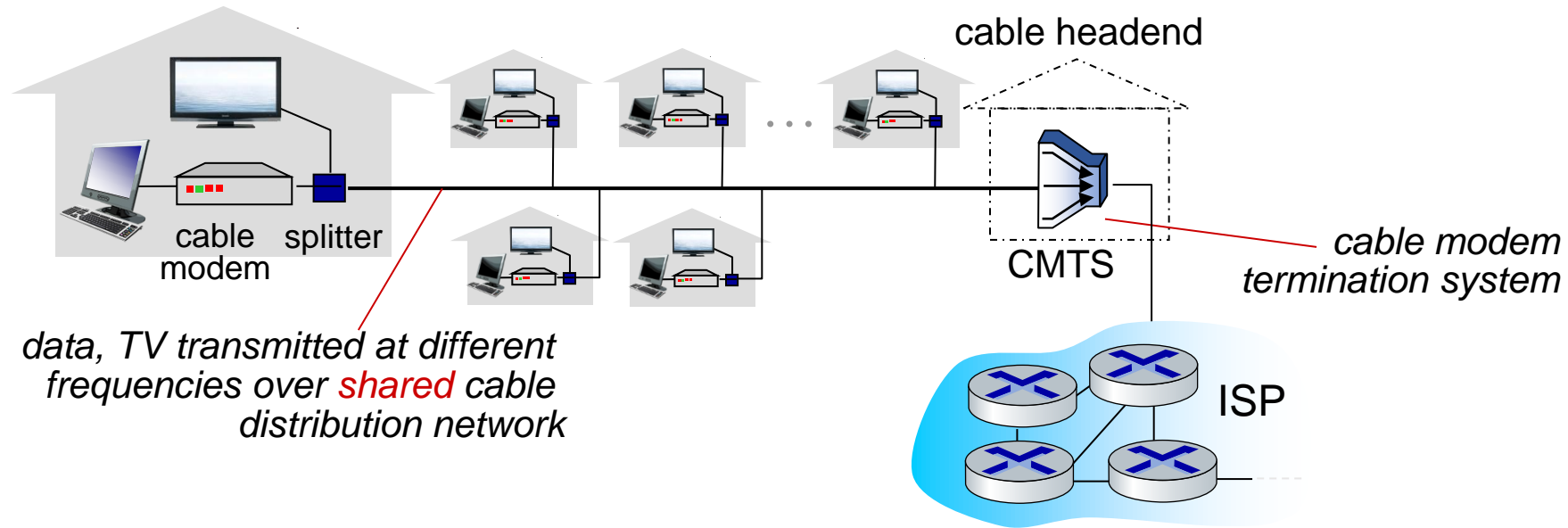▪ mobile access networks (WiFi, 4G/5G)
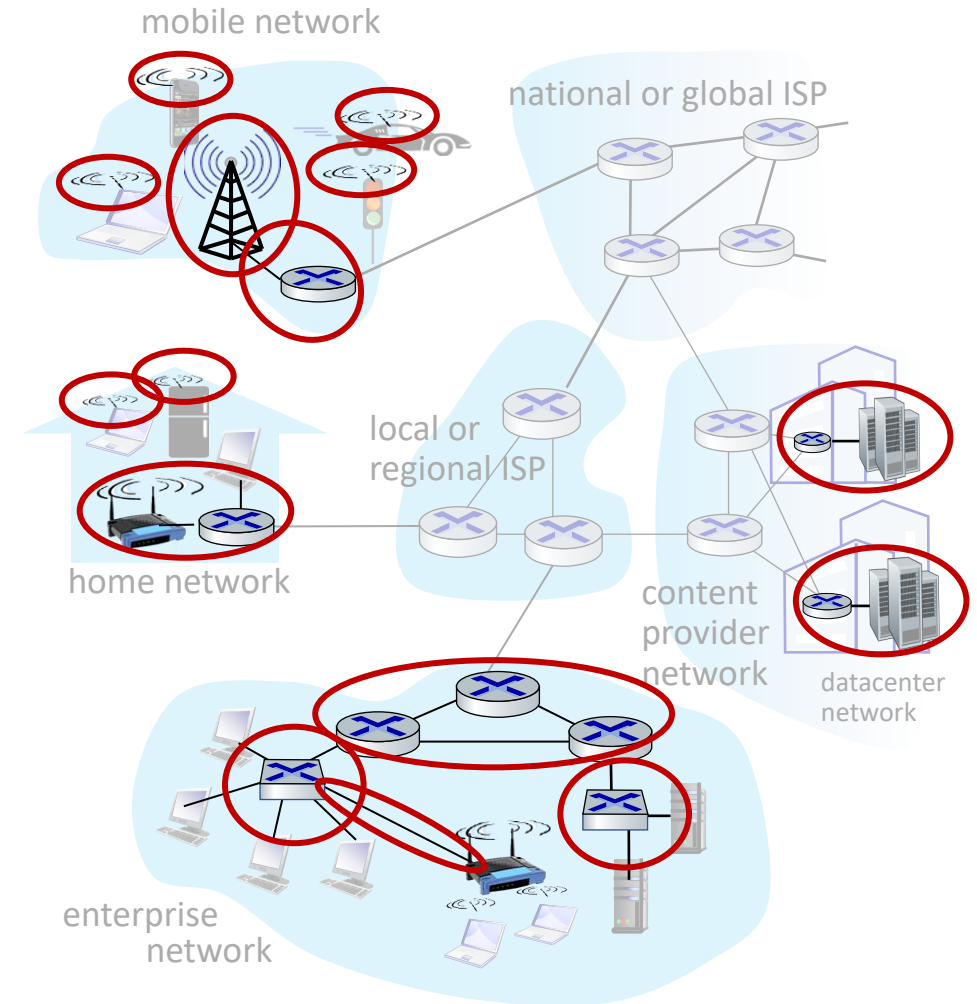
Access networks: cable-based access

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

Access networks: cable-based access

data, TV transmitted at different frequencies over *shared* cable distribution network

- **HFC: hybrid fiber coax**
  - asymmetric: up to 40 Mbps – 1.2 Gbps downstream transmission rate, 30-100 Mbps upstream transmission rate
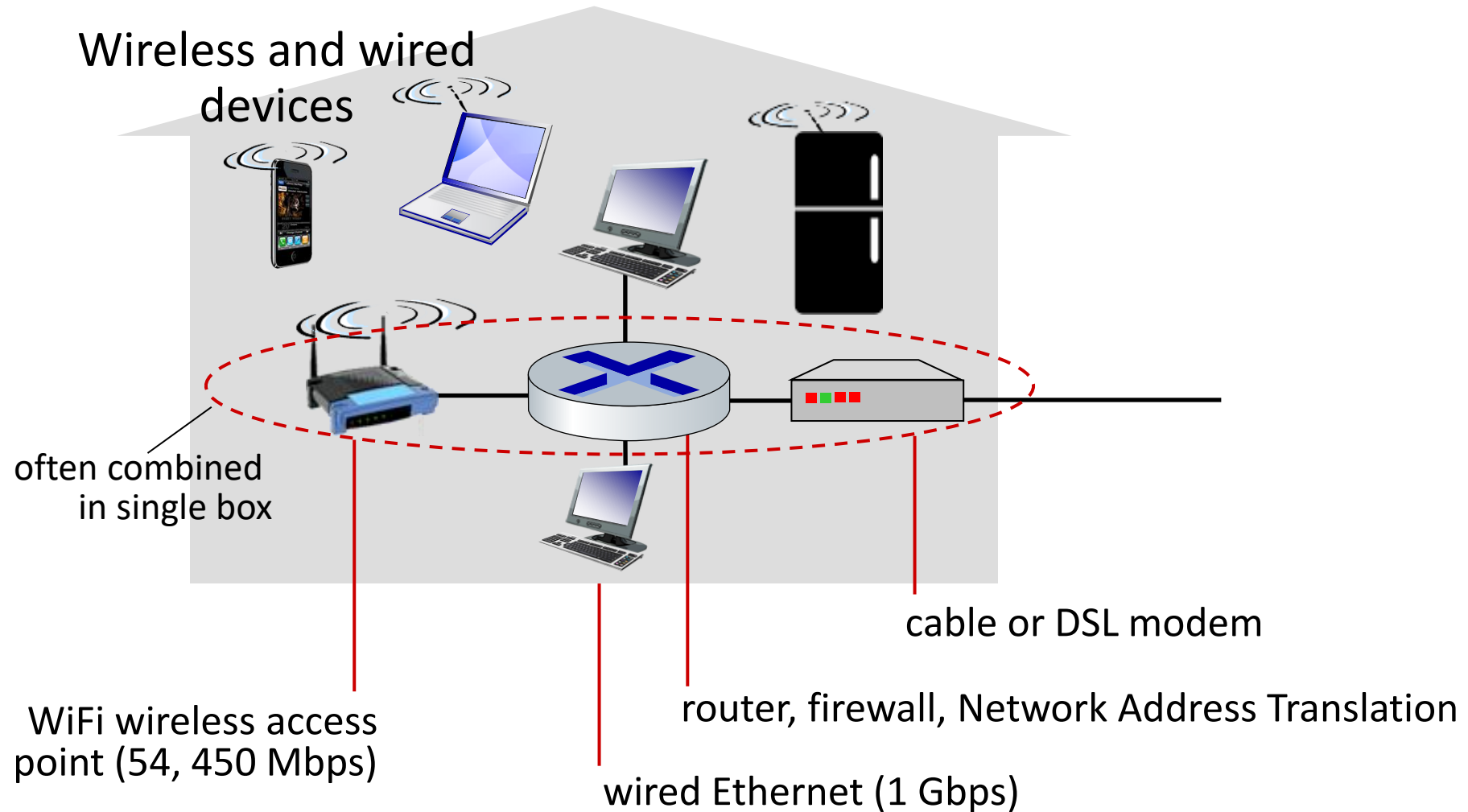- **network** of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable headend

Access networks: digital subscriber line (DSL)

voice, data transmitted
at different frequencies over
dedicated line to central office

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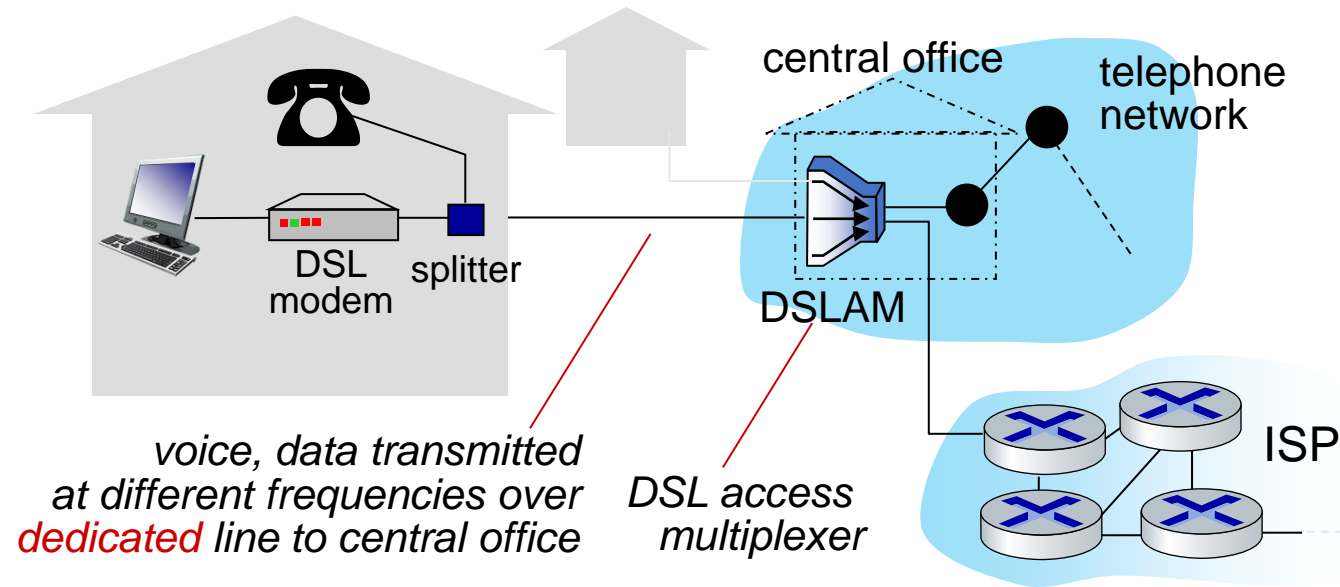
- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- 24-52 Mbps dedicated downstream transmission rate
- 3.5-16 Mbps dedicated upstream transmission rate
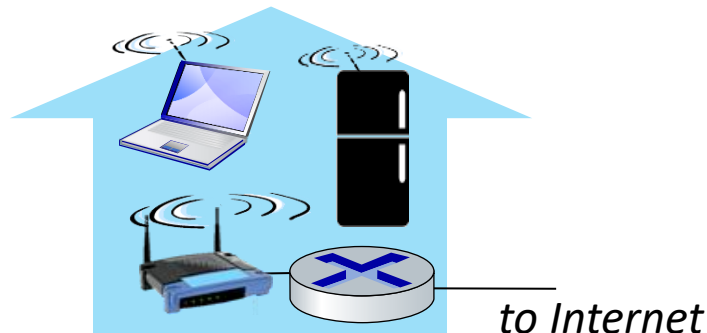
Access networks: home networks

Wireless and wired devices

often combined in single box

WiFi wireless access point (54, 450 Mbps)

wired Ethernet (1 Gbps)

router, firewall, Network Address Translation

cable or DSL modem

Wireless access networks

Shared *wireless* access network connects end system to router
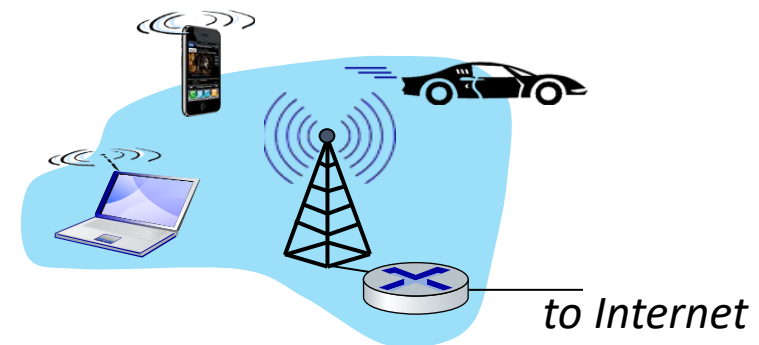
- via base station aka "access point"

Wireless local area networks (WLANs)

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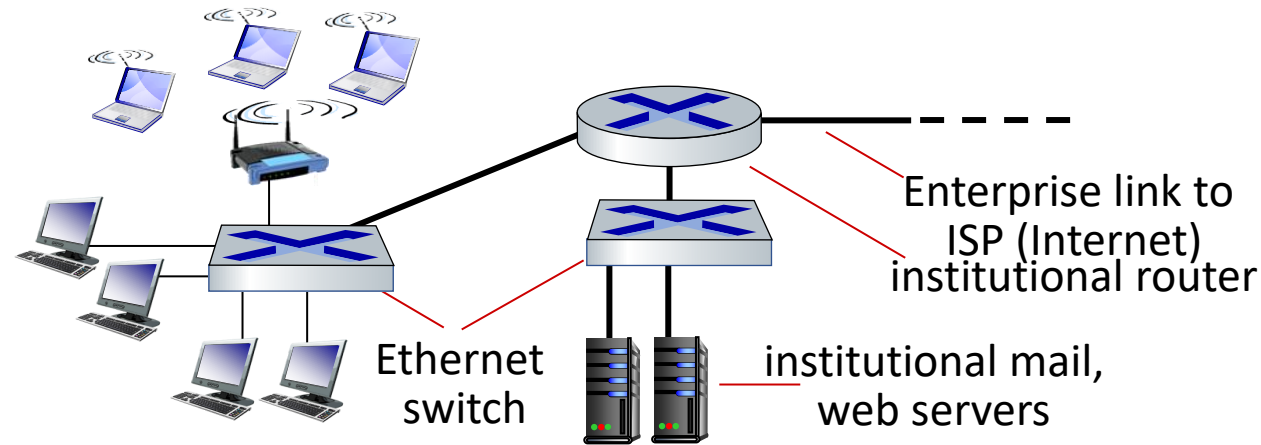- 802.11b/g/n (WiFi): 11, 54, 450 Mbps transmission rate

to Internet

Wide-area cellular access networks

- provided by mobile, cellular network operator (10's km)
- 10's Mbps
- 4G cellular networks (5G coming)

to Internet

Access networks: enterprise networks

Enterprise link to
ISP (Internet)
institutional router

Ethernet
switch

institutional mail,
web servers

- companies, universities, etc.
- mix of wired, wireless link technologies, connecting a mix of switches and routers (we'll cover differences shortly)
  - Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps
  - WiFi: wireless access points at 11, 54, 450 Mbps

Access networks: data center networks

- high-bandwidth links (10s to 100s Gbps) connect hundreds to thousands of servers together, and to Internet

Courtesy: Massachusetts Green High Performance Computing Center (mghpcc.org)
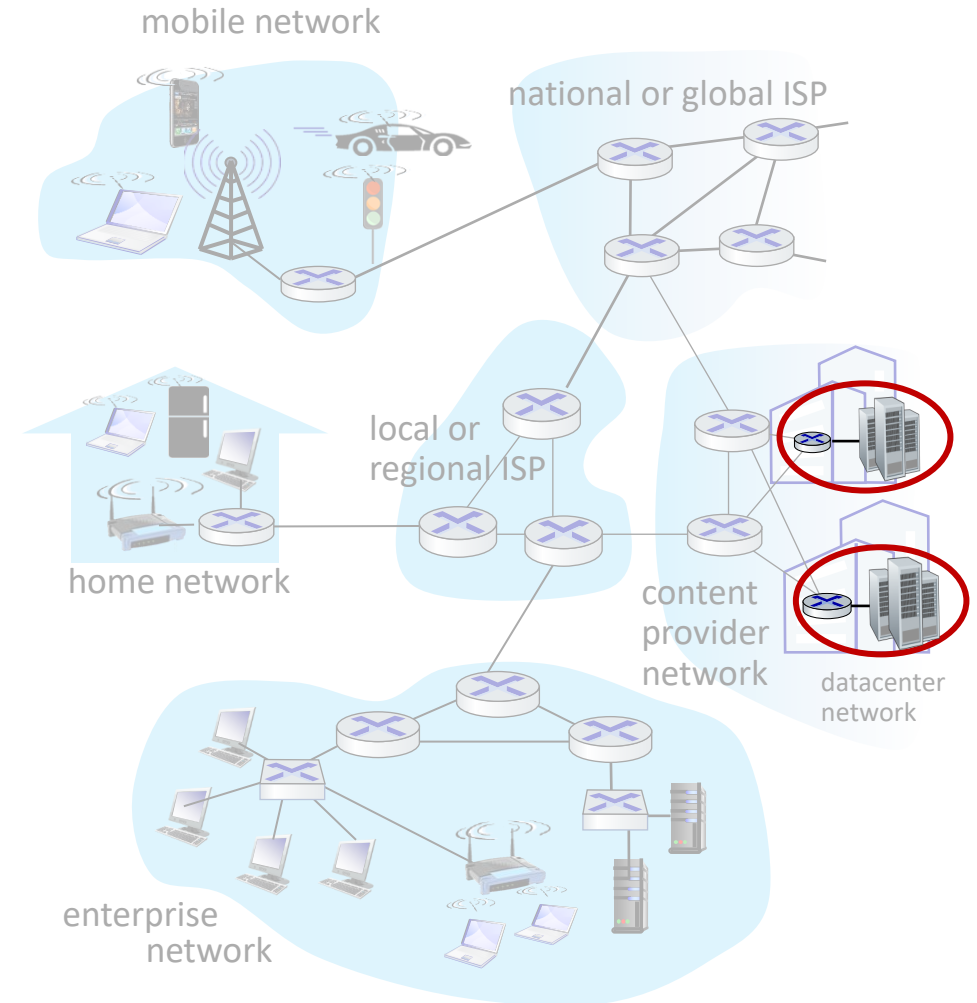
Host: sends *packets* of data

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*

App Data

10110110101010101001101111........Bits

Packet 1   **Packet 2**
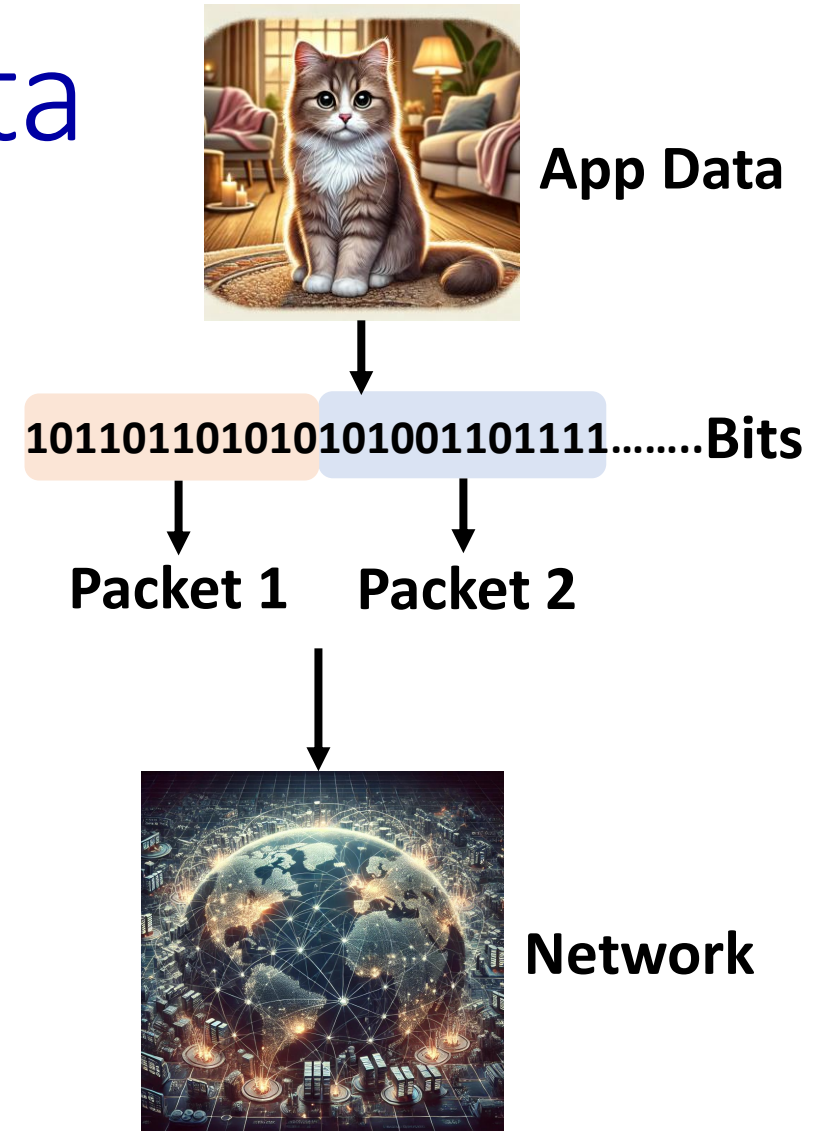
Network

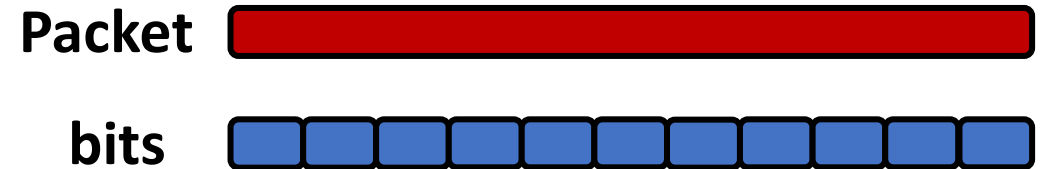# Host: sends *packets* of data
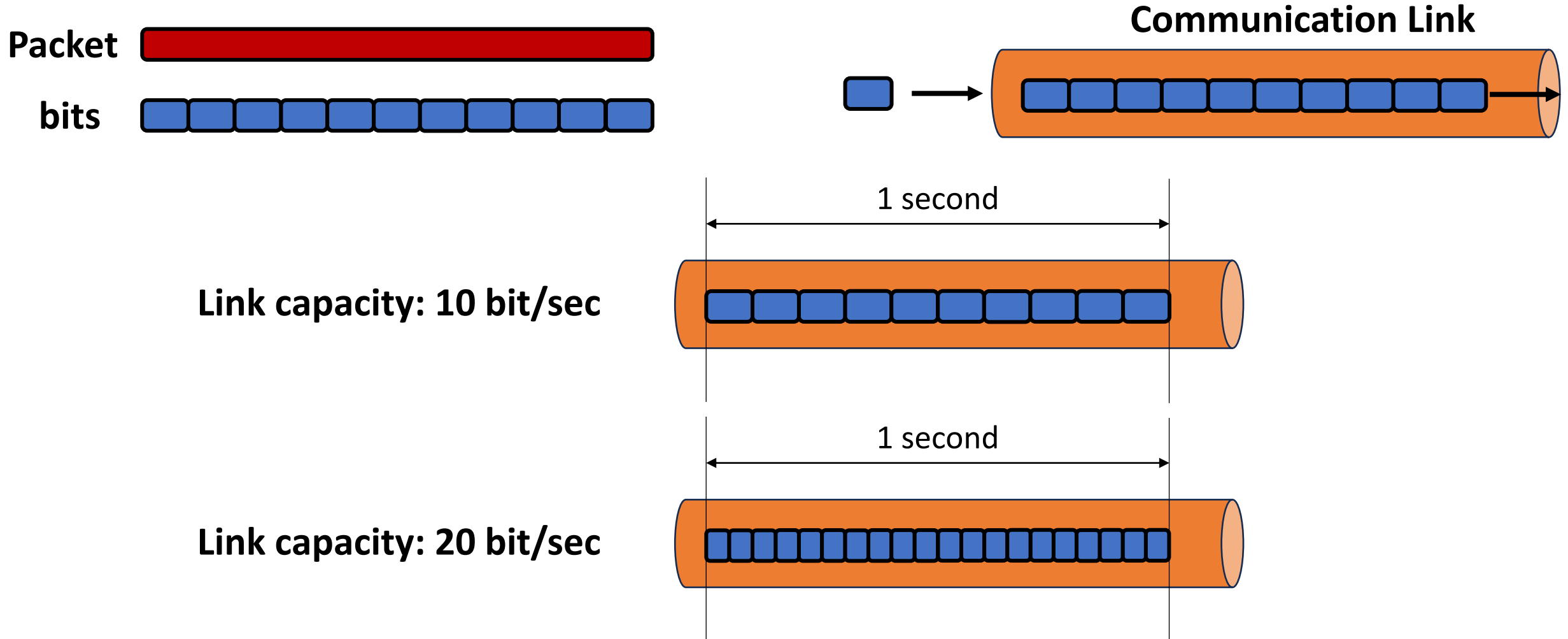
host sending function:

- 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*

Packet

bits

Communication Link
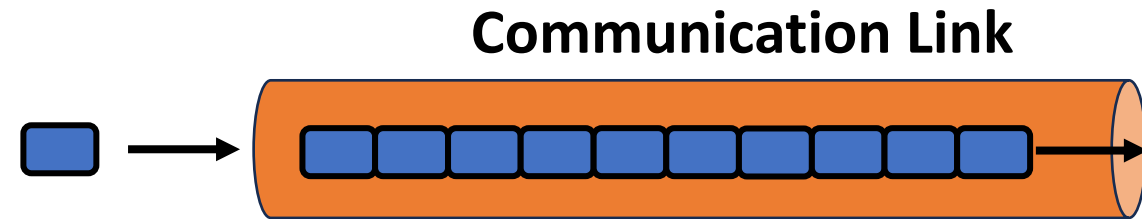
What's the transmission rate R, link capacity or link bandwidth?

Host: sends *packets* of data

Link *transmission rate R, aka Link Capacity, aka link bandwidth*

Packet

bits

Communication Link

1 second

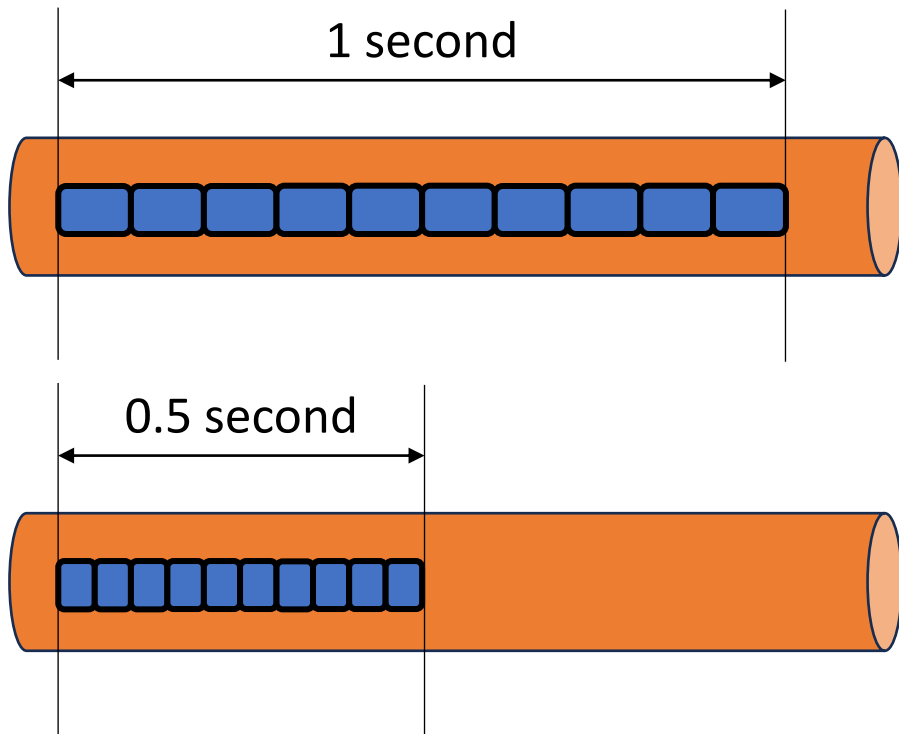**Link capacity: 10 bit/sec**

1 second

Link capacity: 20 bit/sec

Host: sends *packets* of data

Link *transmission rate R, aka Link Capacity, aka link bandwidth*

Packet transmission delay

- How long it takes for transmitting all the bits into the network or communication link

1 second

A packet with 10 bits

10 bits

0.5 second

$$\begin{array}{ccc} \text{packet} \\ \text{transmission} \\ \text{delay} \end{array} = \begin{array}{c} \text{time needed to} \\ \text{transmit } L\text{-bit} \\ \text{packet into link} \end{array} = \dfrac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Communication Links: physical media

- **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
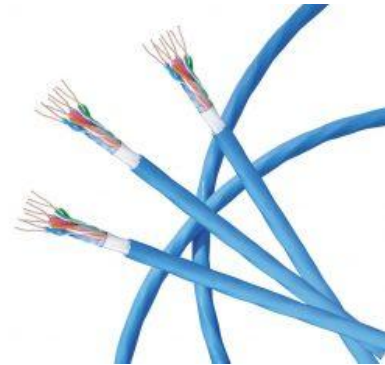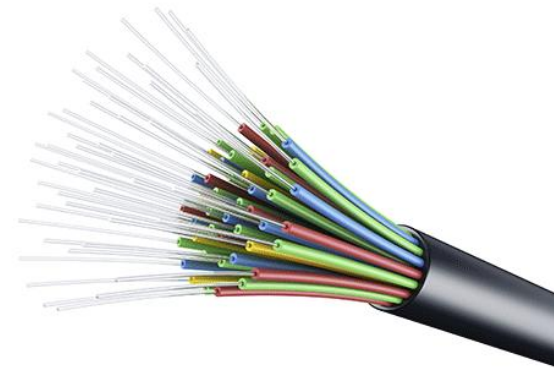
Communication Links: physical media

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 wireless spectrum

- no physical "wire"

- broadcast, "half-duplex" (sender to receiver)

- propagation environment effects:
  - reflection
  - obstruction by objects
 - Interference/noise

Links: physical media

Wireless radio

- signal carried in various "bands" in wireless spectrum
- no physical "wire"
- broadcast, "half-duplex" (sender to receiver)
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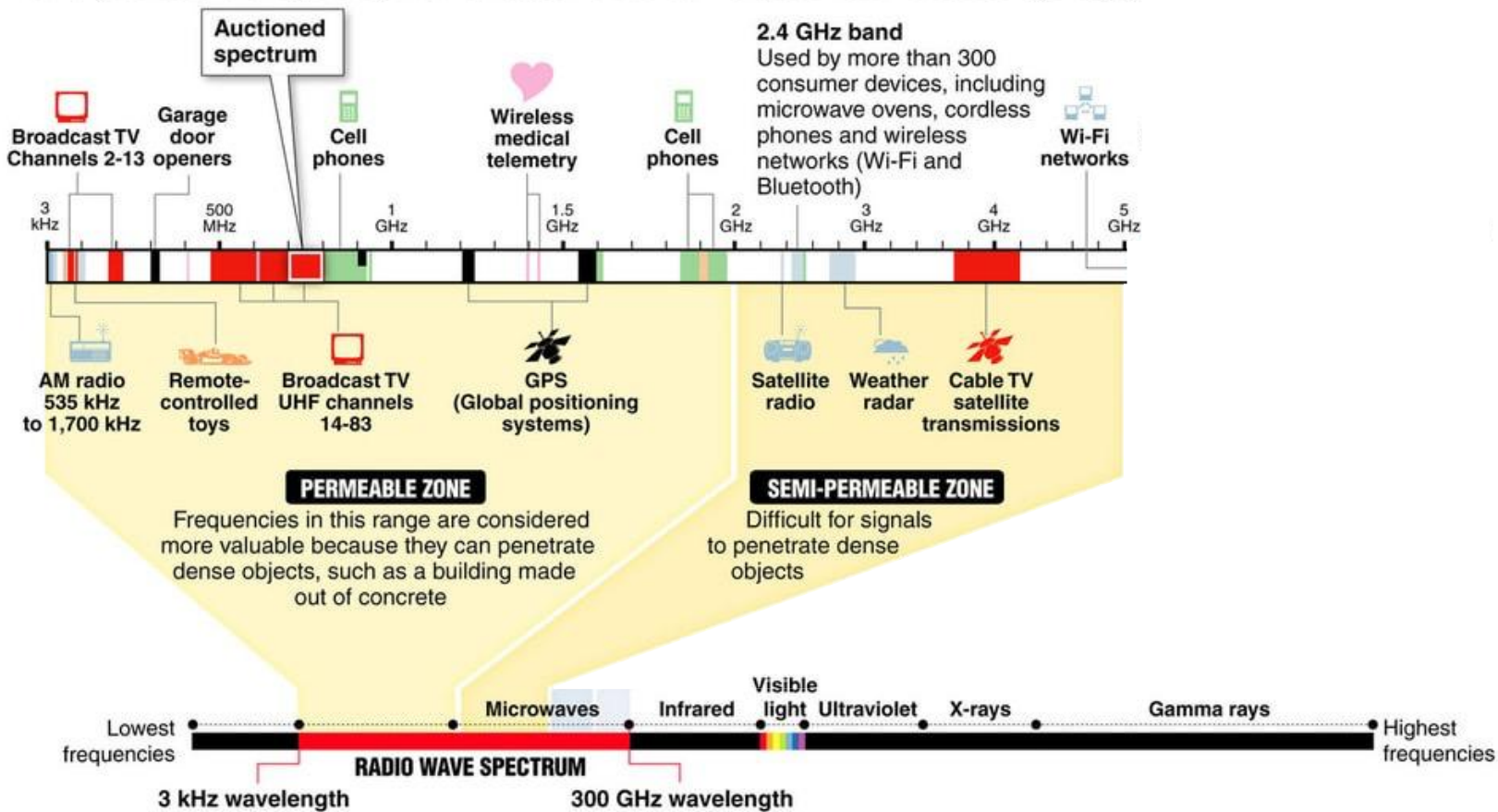 - obstruction by objects
  - Interference/noise

Radio link types:

- Wireless LAN (WiFi)
  - 10-100's Mbps; 10's of meters
- wide-area (e.g., 4G cellular)
  - 10's Mbps over ~10 Km
- Bluetooth: cable replacement
  - short distances, limited rates
- satellite
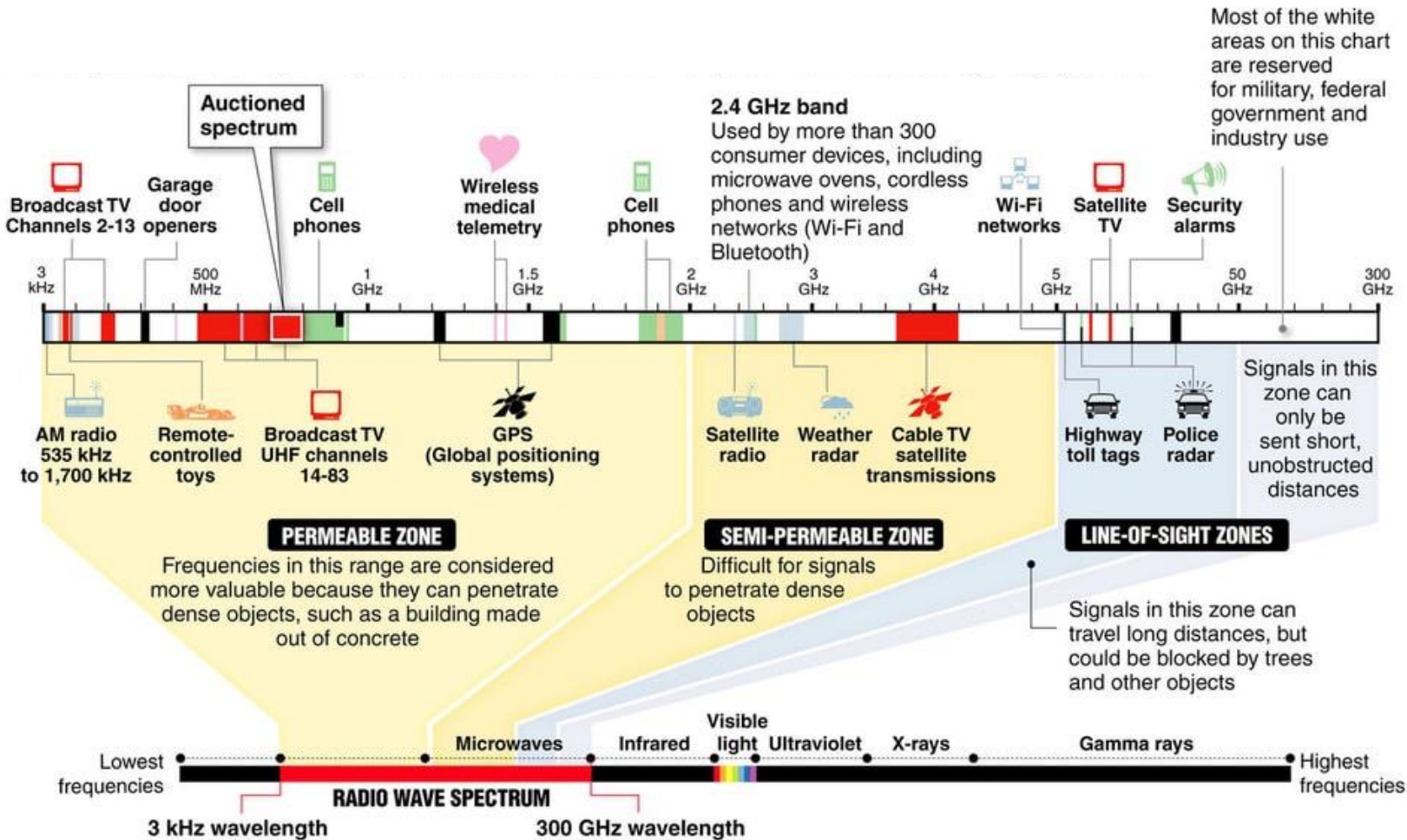 - up to 45 Mbps per channel
  - 270 msec end-end delay

Wireless Spectrum
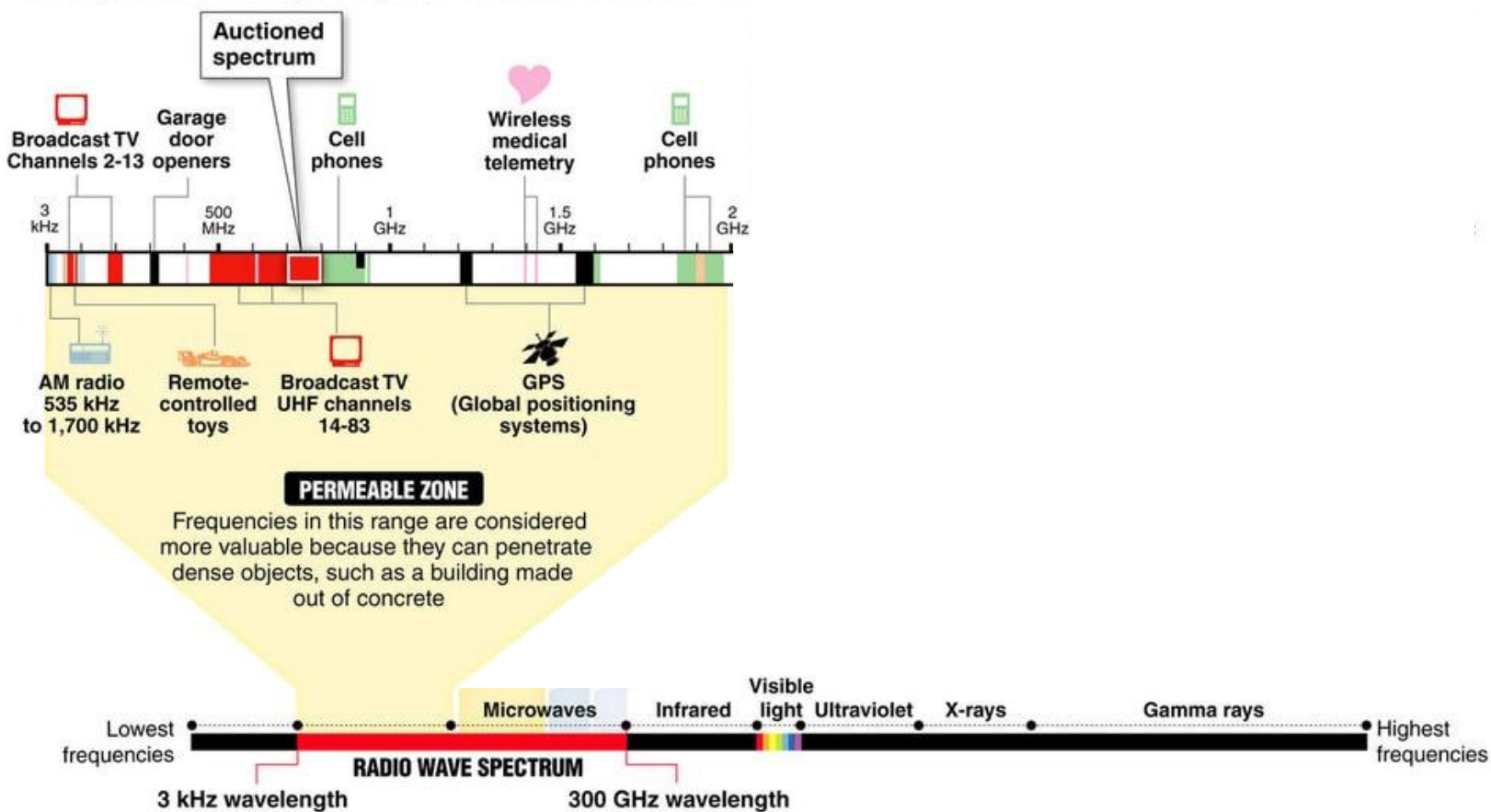
Wireless Spectrum

Wireless Spectrum

Wireless Spectrum

Verizon and AT&T dominate spectrum auction, spending combined $69 billion

Top two carriers buy licenses nationwide, outspending T-Mobile and US Cellular.

JON BRODKIN - 2/25/2021, 11:14 AM

Verizon and AT&T dominated the US government's latest spectrum auction, spending a combined $68.9 billion on licenses in the upper 3GHz band.

Verizon's winning bids totaled $45.45 billion, while AT&T's came in at $23.41 billion. T-Mobile was third with $9.34 billion as the three biggest wireless carriers accounted for the vast majority of the $81.17 billion in winning bids, the Federal Communications Commission said in results released yesterday. US Cellular, a regional carrier, was a distant fourth in spending, at $1.28 billion, but came in third, ahead of T-Mobile, in the number of licenses won.