Lecture 2: Internet Structure

COMP 332, Spring 2023
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Acknowledgements: materials adapted from Computer Networking: A Top Down Approach 7th edition: ©1996-2016, J.F Kurose and K.W. Ross, All Rights Reserved as well as from slides by Abraham Matta at Boston University and some material from Computer Networks by Tannenbaum and Wetherall.

Today

1. Announcements
   - Homework 1 posted, due Tuesday, Feb. 7 by 11:59p
   - Help sessions: Sun/Mon/Tues, 7-9p in Exley 638. Also virtually

2. Building a network
   - Protocols
   - Layering
   - Key services

3. Internet organization
   - Edge
     - How you connect to Internet
   - Core
     - How your packets get to their destination
     - Circuit-switching vs. packet-switching:

Building a Network

PROTOCOLS

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Many, many things happening in a network

Networks are complex,
with many pieces

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

Questions:

How can we possible organize and manage a network?

Some approaches: standards, protocols, and layering

Standards

If computers comply to same standards

- can interoperate even if computers are of different types or connected to different types of networks

Standards organizations

- Europe
  - ITU-T (formerly CCITT), e.g. publications X.25, V.24, etc.
    - X-series define how to connect a host to PSDN (Data)
    - V-series define how to connect a host to PSTN (Telephone)
    - I-series define how to connect a host to ISDN (Integrated)
  - ISO, developed OSI architecture
- US: IETF, EIA, IEEE, ANSI, NIST, …
  - IETF RFCs define Internet standards for non-proprietary protocols
  - IEEE 802 define standards for links, e.g. Ethernet, WiFi

How do devices decide what to send and when?

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

Human protocols

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

Network protocols

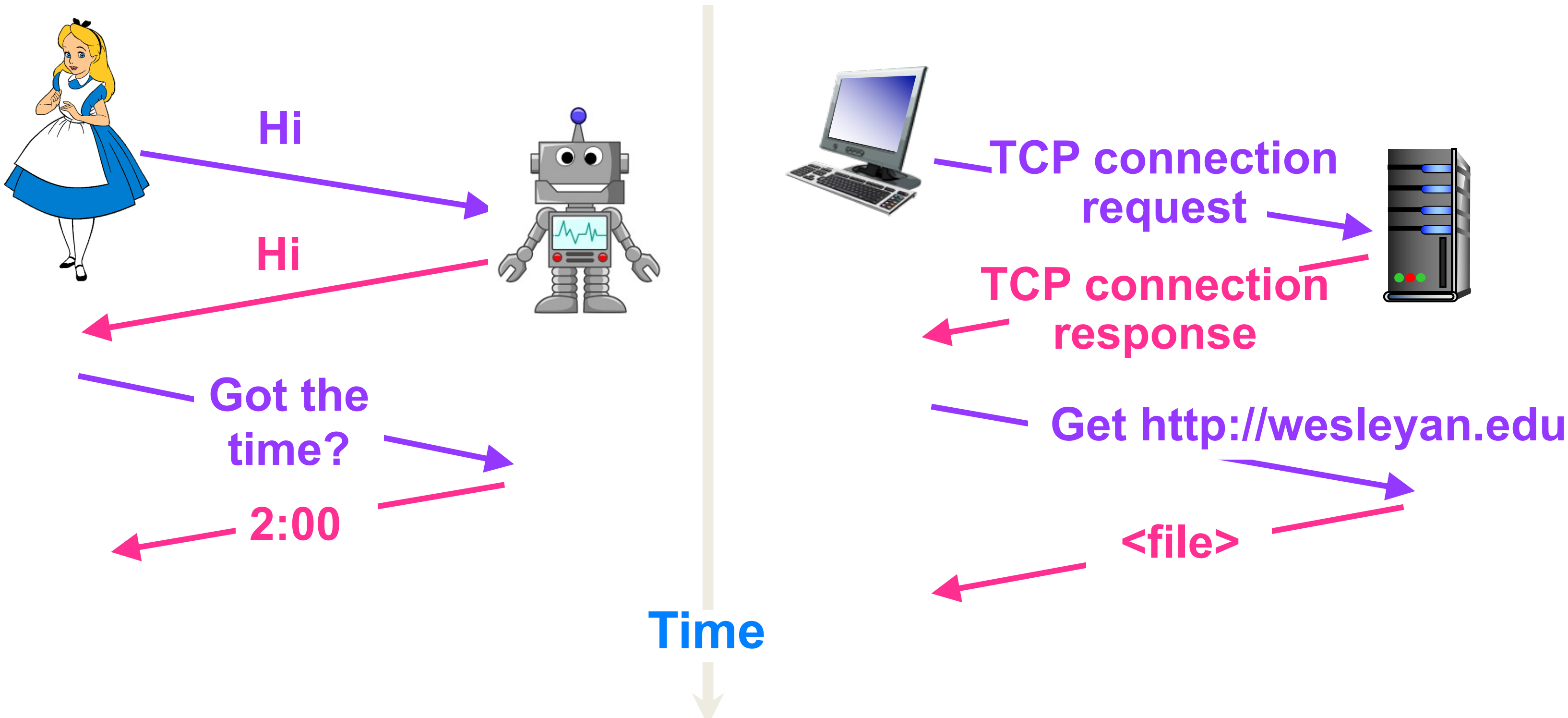
- machines rather than humans
- all communication activity in Internet governed by protocols

… specific messages sent

… actions taken when messages received, or other events

Protocol example

A human protocol and a computer network protocol:



Q: other human protocols?

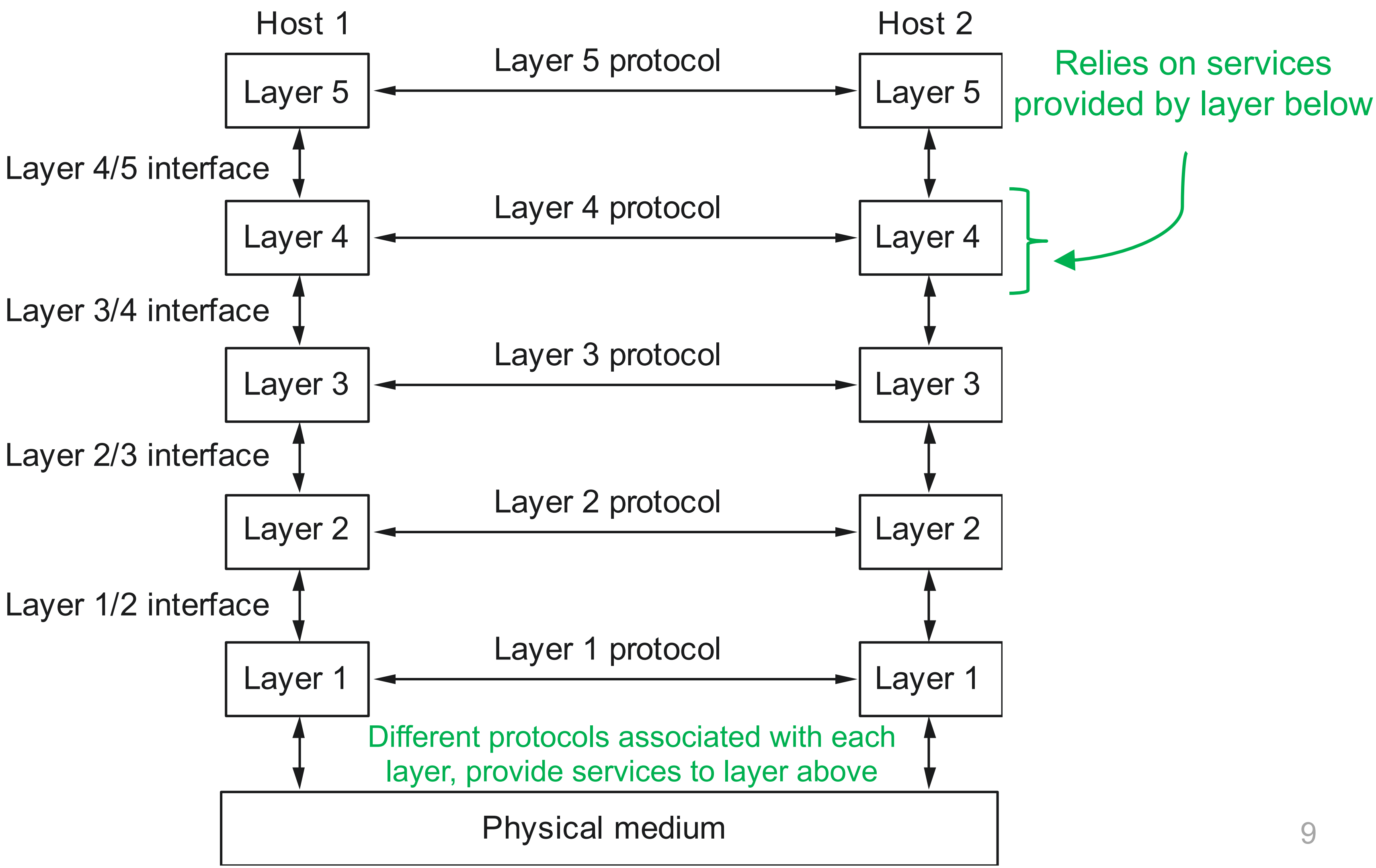
Many protocols used on Internet: TCP, IP, TLS, HTTP, …

Building a Network

LAYERING

Layered network architecture

Each layer of stack has certain protocols associated with it.
Different protocols provide different services



Why layering?

Pros

- identifies and captures how parts of system relate
- information hiding
  - hide info in one part of system from another
  - higher layer shielded from how lower layer implemented
- modularity
  - easy to change implementation of service provided by layer
  - as long as layer still provides same services to higher layer, higher layers can stay unchanged

Cons

- duplicate functionality
  - higher layer may duplicate functionality in lower layer
  - e.g., error checking; link by link, end to end
- one layer may need info from another layer
- no cross-layer optimization

7-Layer ISO/OSI Model

application: user interface

presentation:

allow applications to interpret meaning of data

e.g., encryption, compression, machine-specific conventions

session: synchronization, check-pointing, recovery of data exchange

Internet protocol stack is "missing" these layers. These services, if needed, must be implemented in application. Needed?

transport: multiplexing/demultiplexing, fragmentation/reassembly, end-to-end flow, congestion and error control

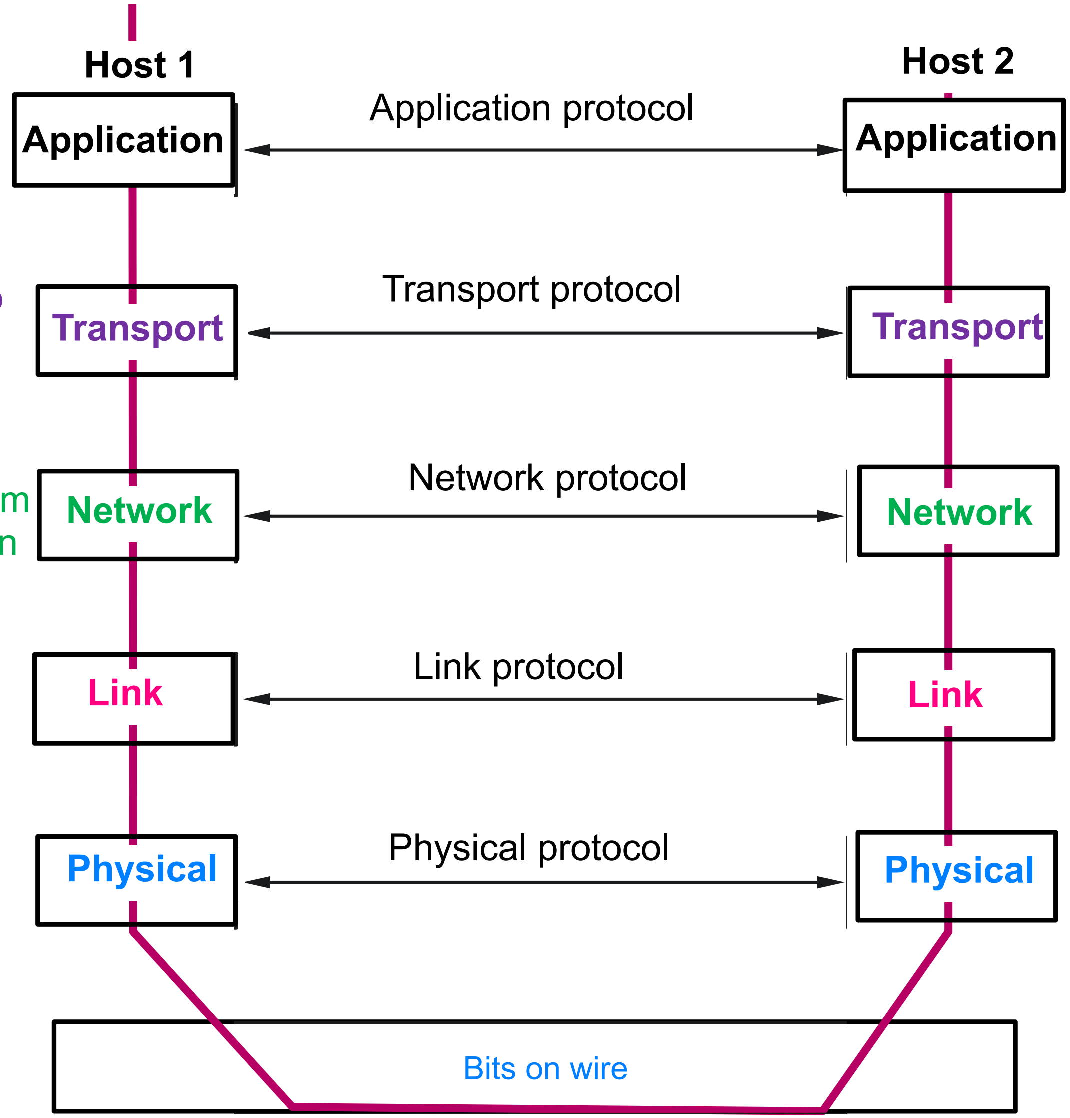
network: addressing and routing

data link: link flow and error control

physical: physical and electrical interfaces (normally 100% hardware)

5-layer Internet protocol stack

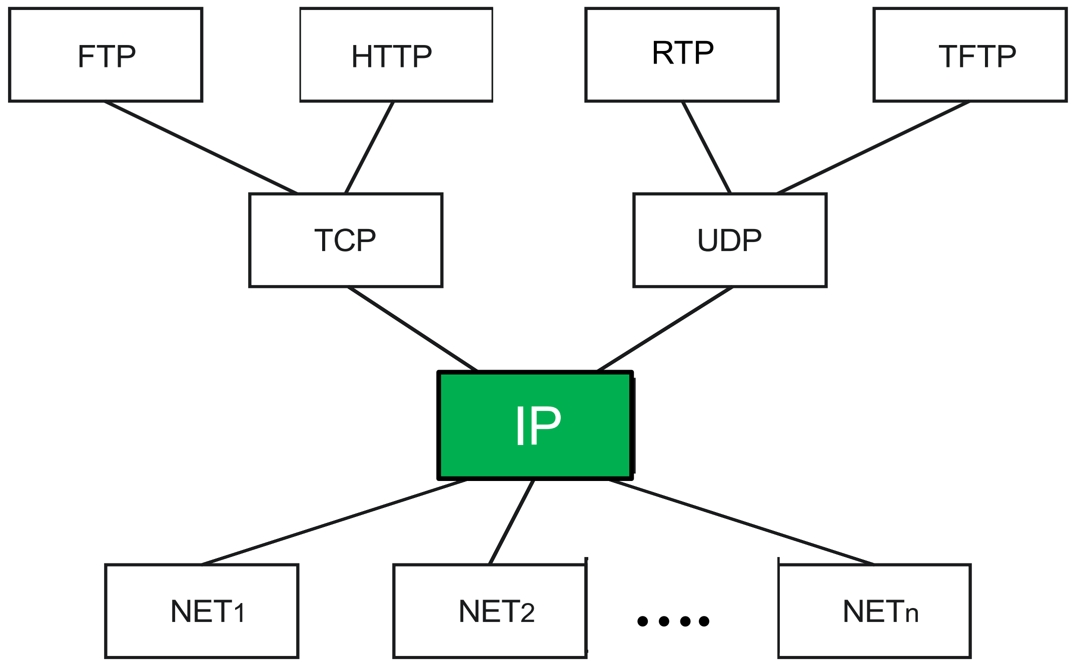
Mail service example	Service provided
Person reads letter	Support network applications
Letter delivered to person in house	Deliver msgs to app endpoints, flow control, reliability
Letter conveyed between sending house and receiving house	Route segments from source to destination host (indirect)
Letter conveyed from house to mailbox/P.O or from one P.O directly to another P.O.	Move pkt over link from one host to next host (direct)
The actual carrying of the letter across a "link"	Move individual bits in frame from one host to next



5-layer Internet protocol stack

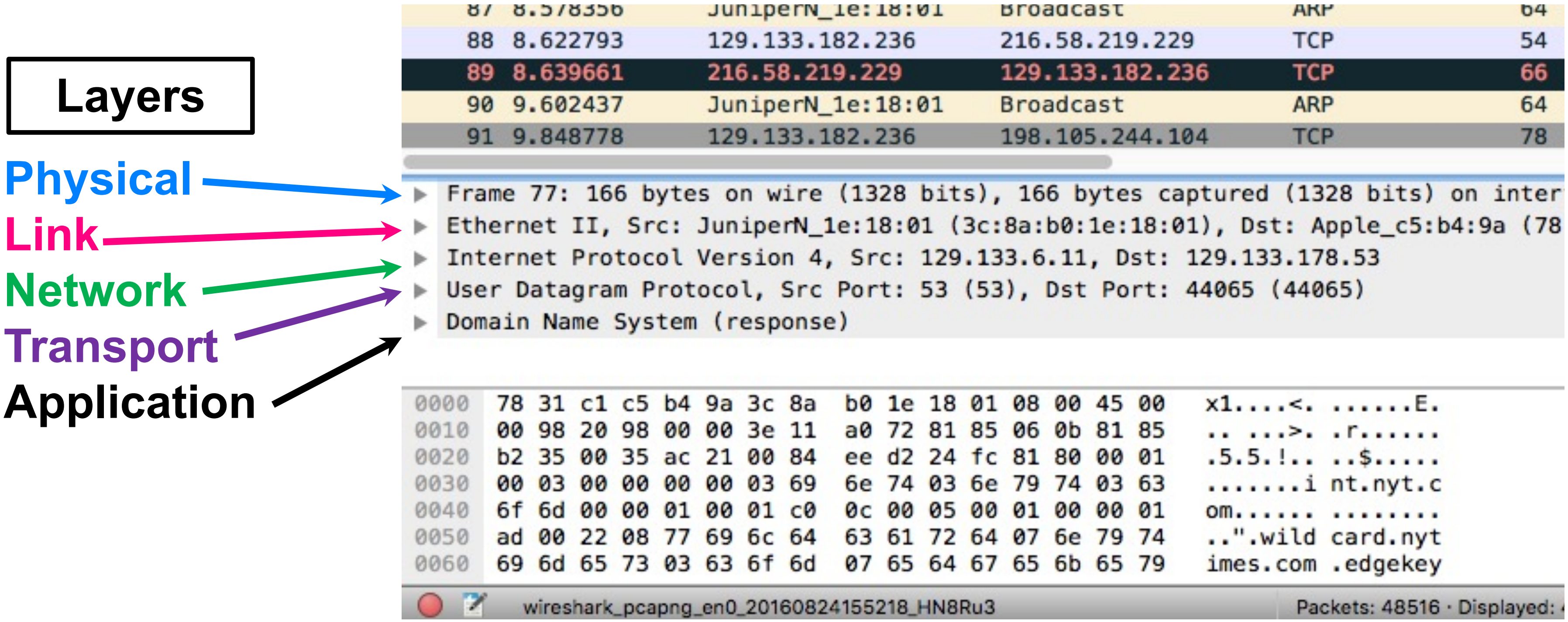
	Layer	Service provided to upper layer	Protocols	Unit of information
5	Application	• Support network applications	FTP, DNS, SMTP, HTTP	**Message** 1 message may be split into multiple segments
4	**Transport**	• Deliver messages to app endpoints • Flow control • Reliability	TCP (reliable) UDP (best-effort)	**Segment** (TCP) **Datagram** (UDP) 1 segment may be split into multiple packets
3	**Network**	• Route segments from source to destination host	IP (best-effort) Routing protocols	**Packet** (TCP) **Datagram** (UDP)
2	**Link**	• Move packet over link from one host to next host	Ethernet, 802.11	**Frame** MTU is 1500 bytes
1	**Physical**	• Move individual bits in frame from one host to next • "bits on wire"	Ethernet phy 802.11 phy Bluetooth phy DSL	**Bit**

Protocol graph for Internet



IP is called narrow waist of Internet:
Allows interconnectivity of many different kinds of networks as long as they use IP

Looking at protocol stack in Wireshark



We'll talk in depth about Wireshark and how to use next week

Building a Network

KEY SERVICES

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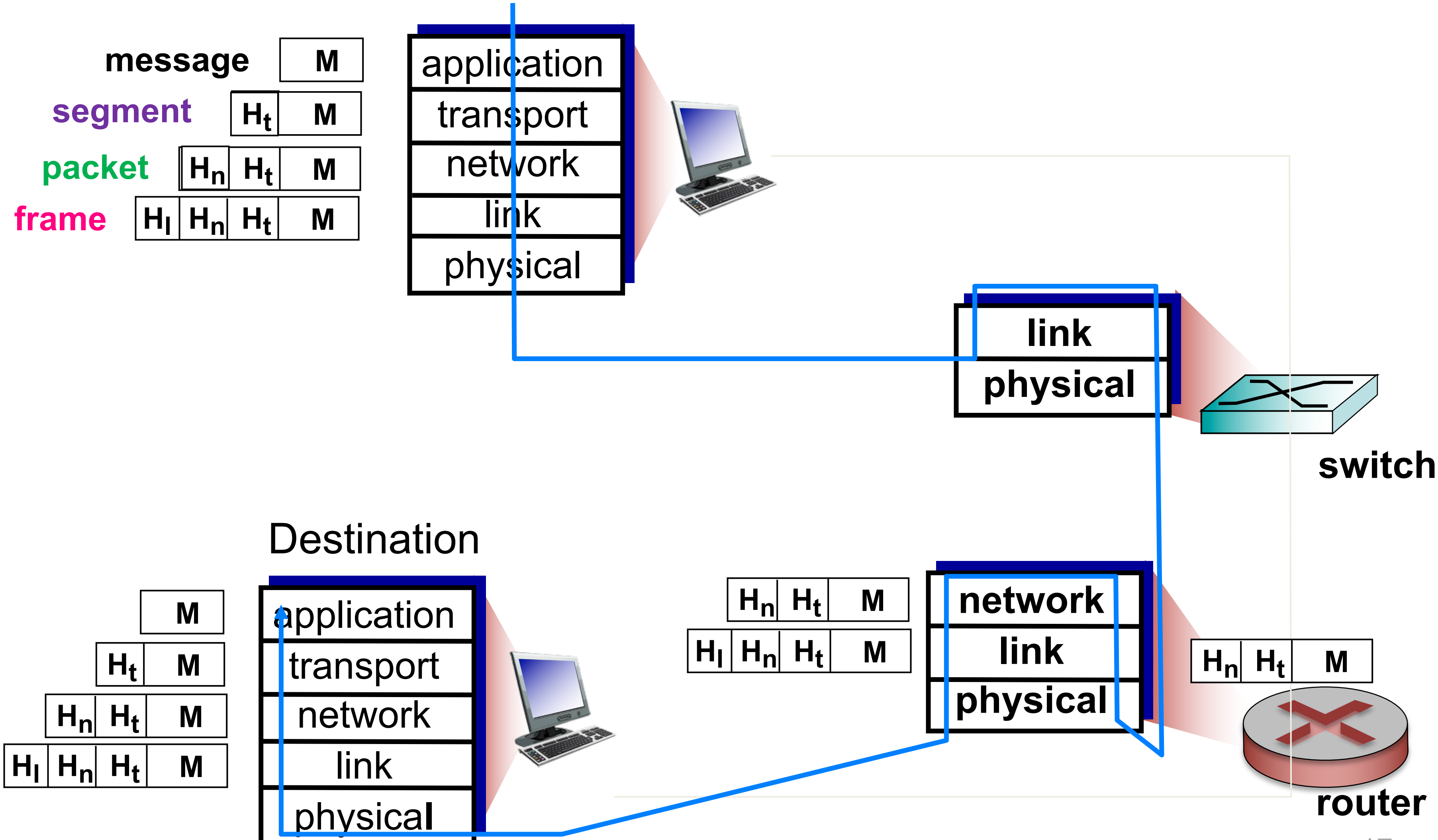
Encapsulation/Decapsulation

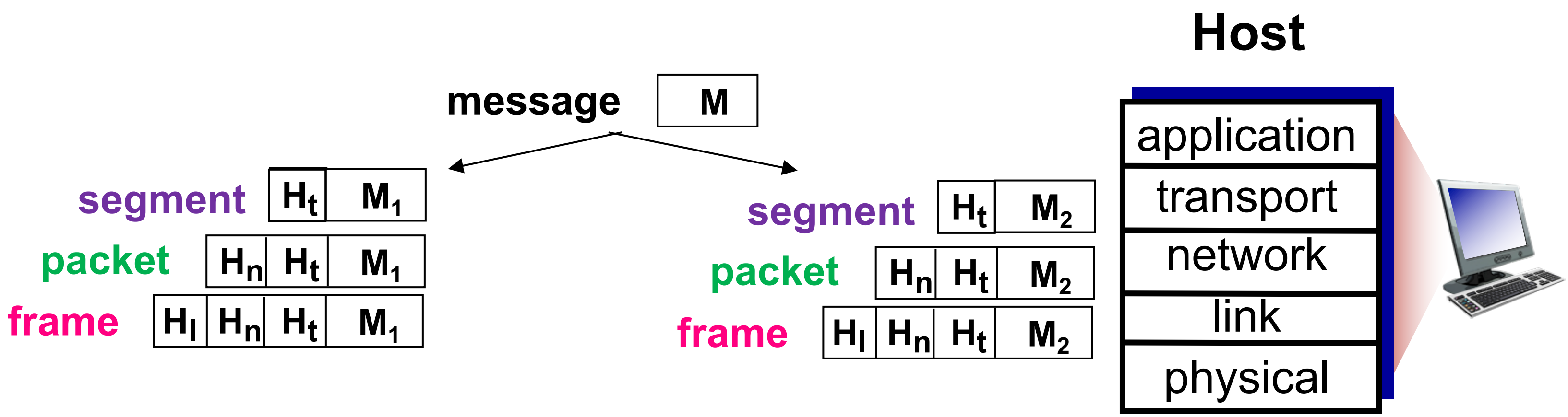
Headers must be added/removed from data unit at each layer



Fragmentation/Assembly

If data unit too large for layer below, must fragment/assemble

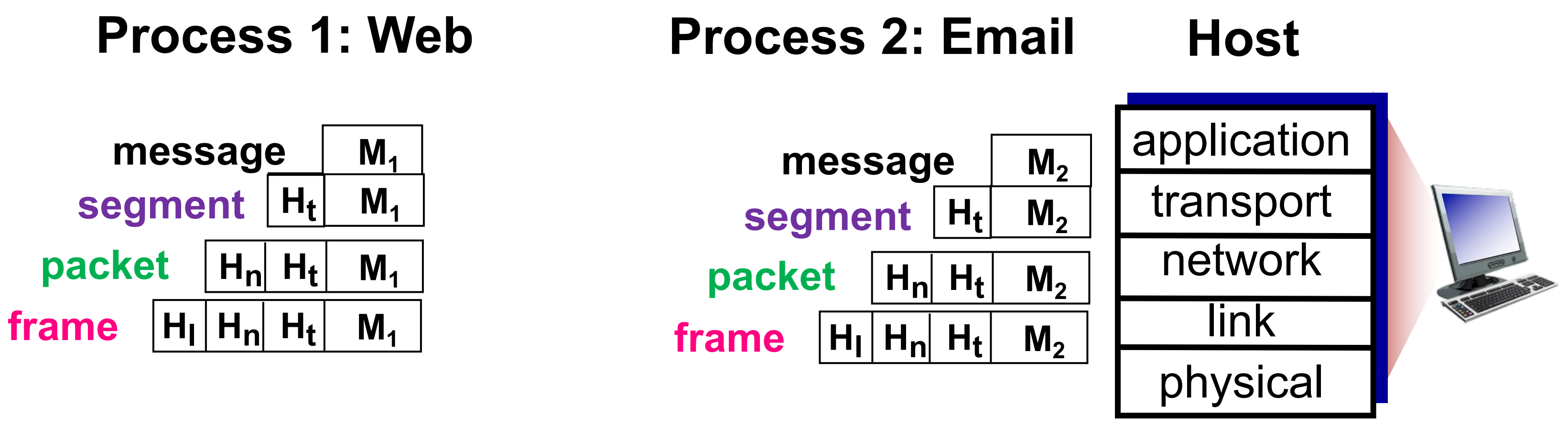
Why fragment? Max size of Ethernet frame is specified to be 1522 bytes



Need additional book-keeping to keep track of which **segments** belong to which **message**

Multiplexing/Demultiplexing

Many processes sending network traffic simultaneously on host, many hosts sharing network



Need additional book-keeping to keep track of which **segments** belong to which **process** on host

Internet Organization

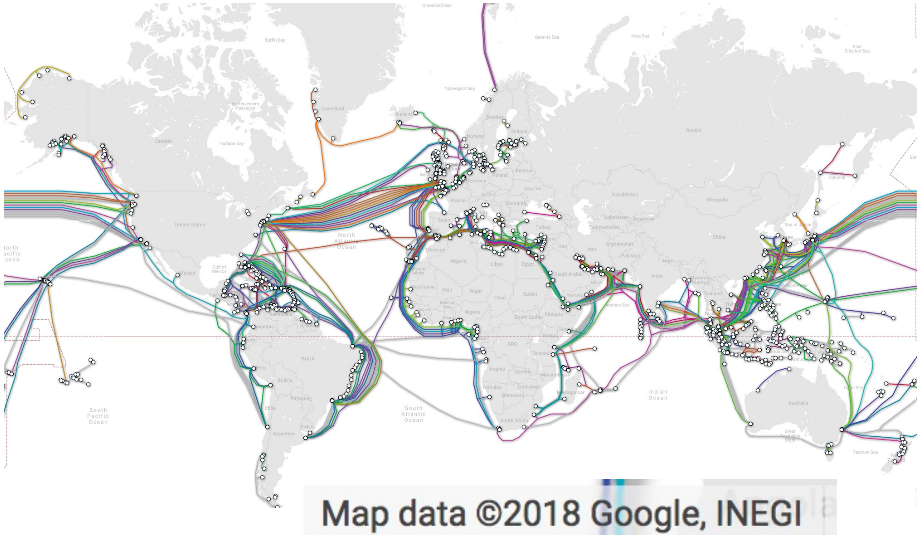
OVERVIEW

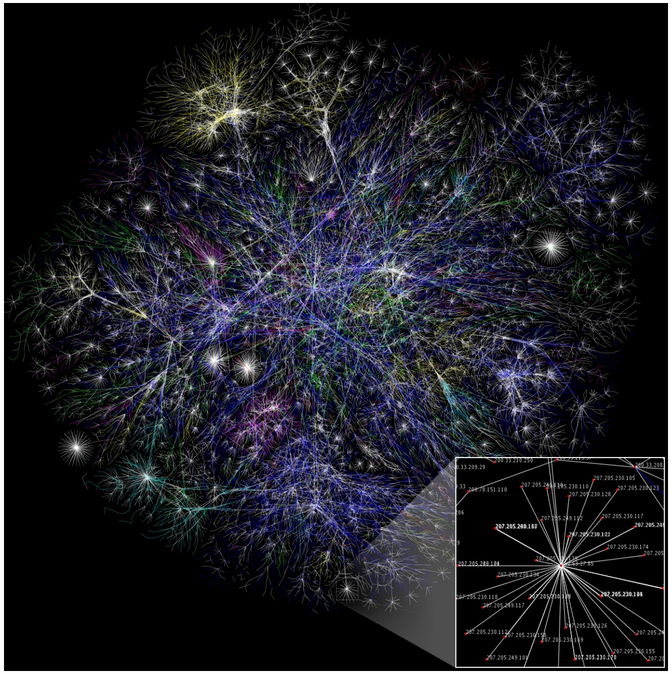
The story of the Internet

Not so long ago, a new kind of communication network was needed ...

… one that could withstand a nuclear war

… and in 1969 the Internet was born





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The Internet has been constantly evolving

…over the past 45+ years

Early Internet design decisions

- have far-reaching consequences today
- impact security, privacy, scalability, quality of service

To understand impact today

- we need to first understand Internet structure

How is the Internet organized?

Billions of connected hosts

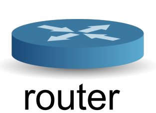
- run network applications

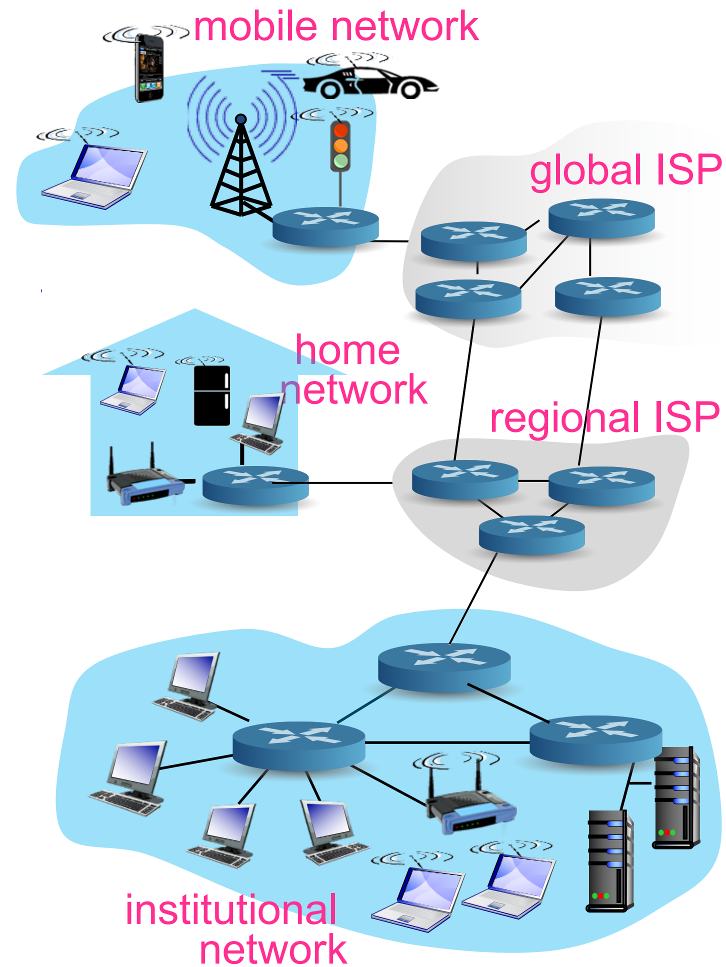
Communication links

- carry info between apps on hosts
- fiber, copper, radio, satellite
- transmission rate: data per second

Routers (like post offices)

- forward packets (like letters)





ISP: Internet Service Provider

Digging deeper

Network edge

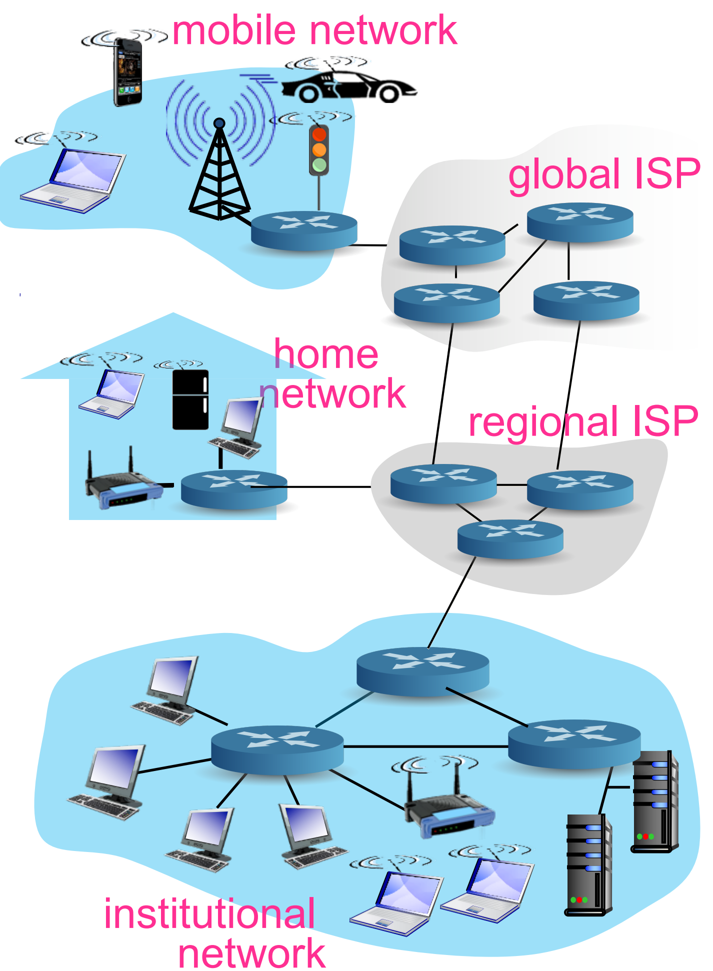
- hosts: clients and servers
- servers often in data centers

Network core

- interconnected routers
- network of networks

Internet is network of networks:
i.e., internetwork

Every device must implement IP
(Internet Protocol) and have IP address



ISP: Internet Service Provider

Internet provides services

Services to applications

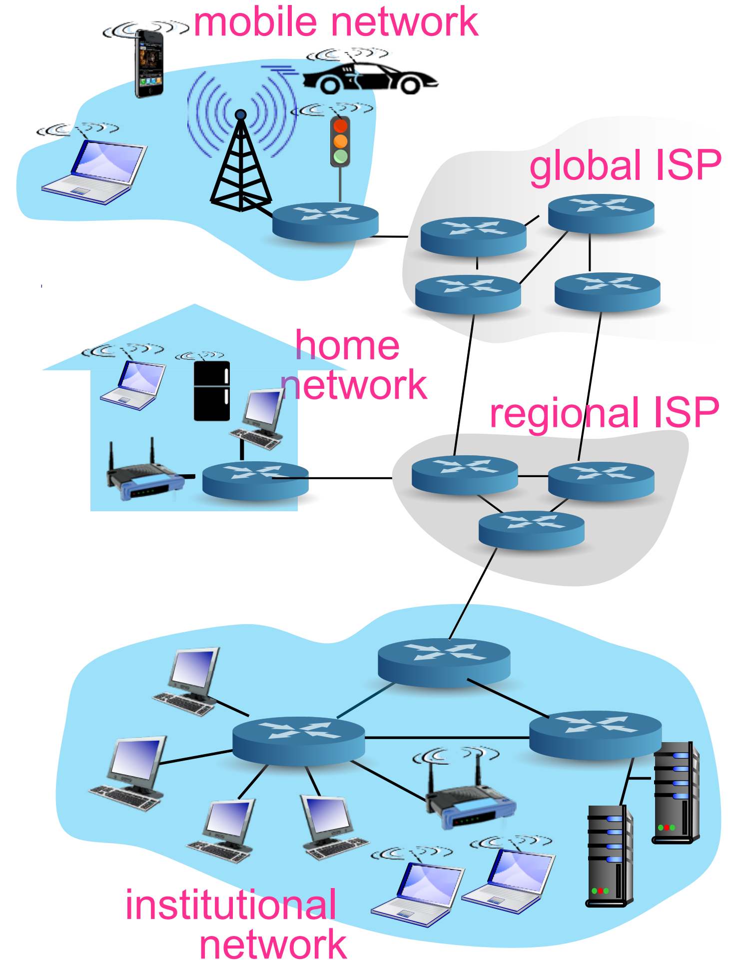
- e.g., web, VoIP, email, games, ecommerce, social networks

Programming interface to apps

- **hooks**
  - for sending and receiving app programs to connect to Internet
- **service options**
  - analogous to postal service

Protocols

- control message sending, receiving



ISP: Internet Service Provider

Where to place functionality in Internet?

Option 1

- inside network (switches/routers)

Option 2

- at edges (hosts)

Illustrates end-end principle

- some functionality can only be correctly implemented at end-hosts
  - e.g., file transfer
    - should each link check or end hosts check for loss/errors?
    - what if a link on path fails?

Internet Organization

EDGE

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How do you connect to Internet?

Hosts connect to edge router

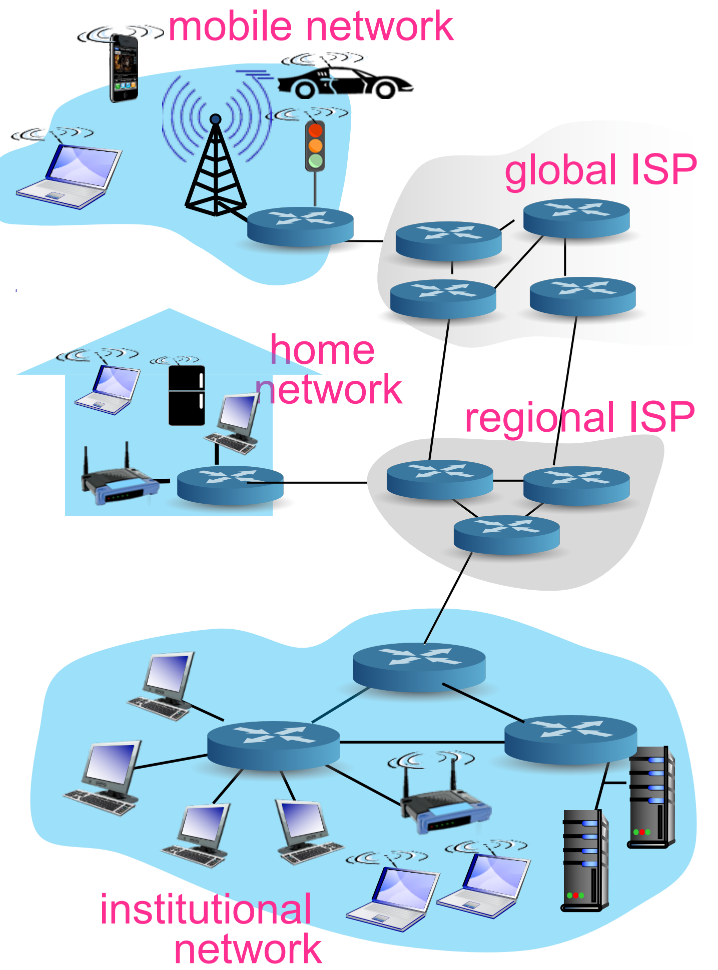
- access network/ISP

Access networks

- **residential**
  - DSL (telephone), cable,
- **institutional**
  - school, company
- **mobile**

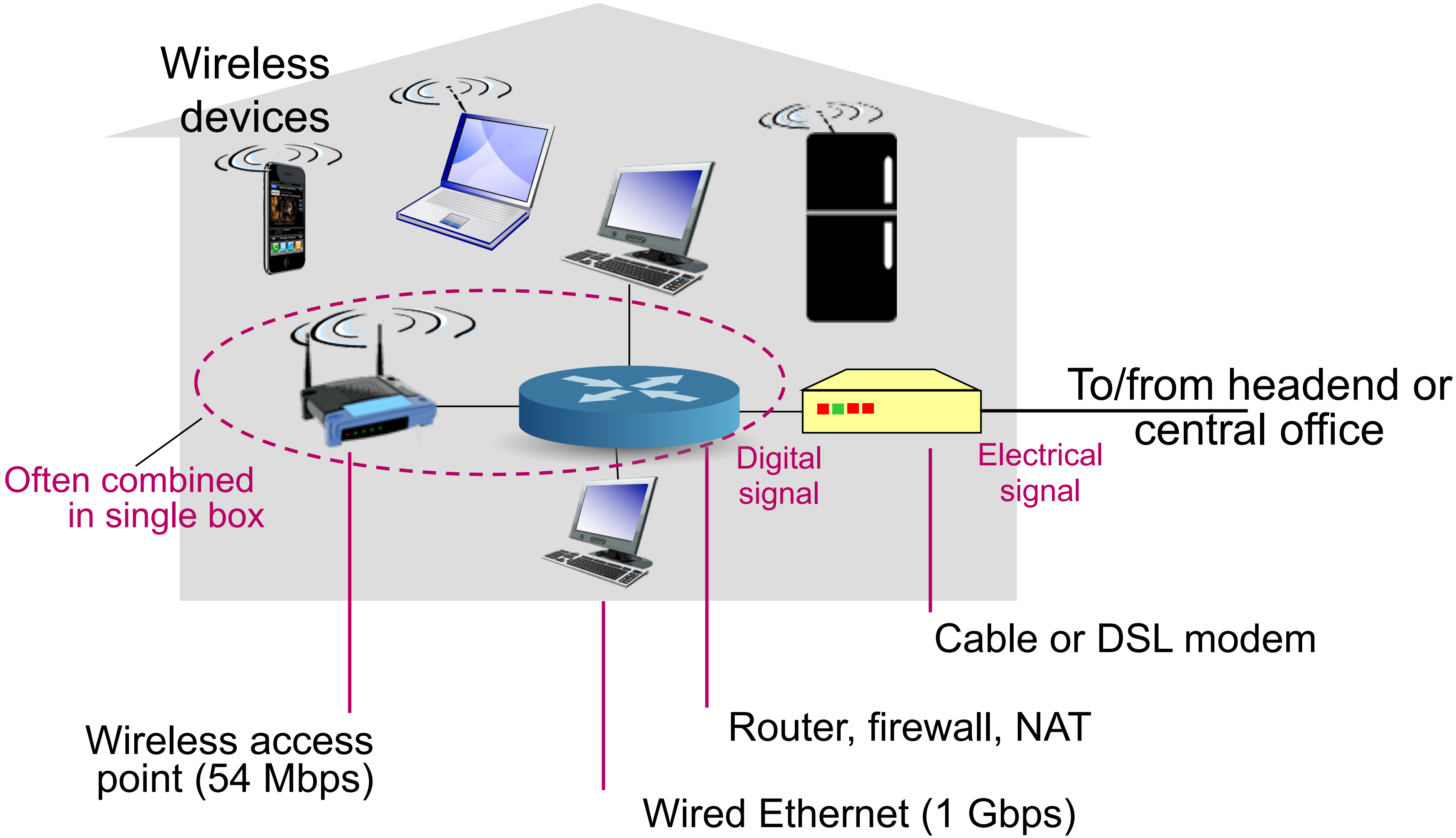
Issues

- bandwidth (bps) of access network?
- shared or dedicated?



ISP: Internet Service Provider

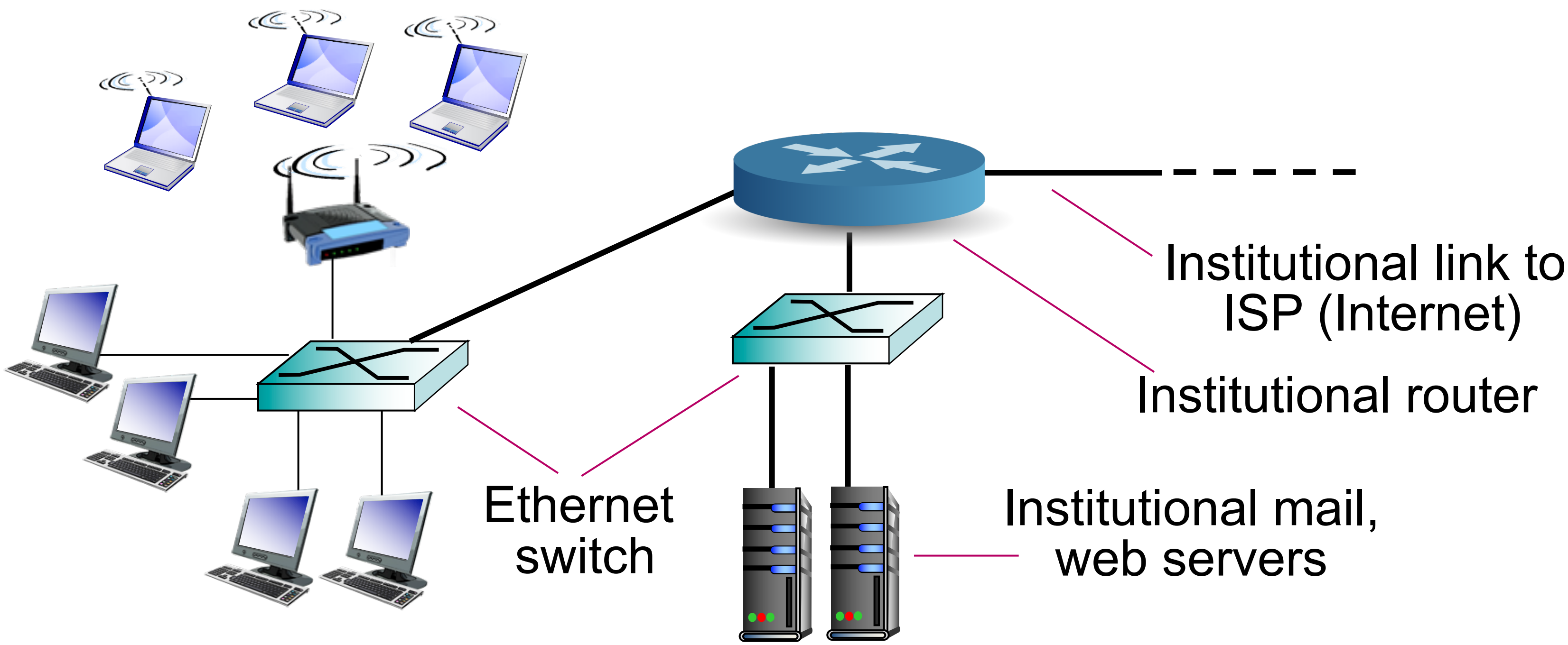
Home access network



Enterprise access network (Ethernet)

Typically used in companies, universities, etc.

- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch



Wireless access network

Shared wireless access network

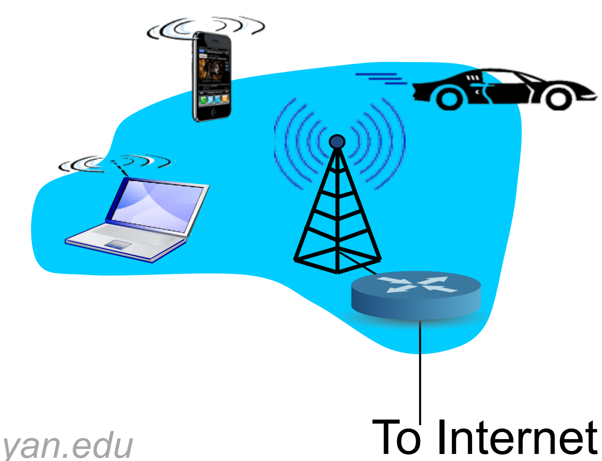
- connects end system to router via base station (aka "access point")

Wireless LANs

- within building (100 ft.)
- 802.11b/g/n (WiFi):
  - 11, 54, 450 Mbps

Wide-area wireless access

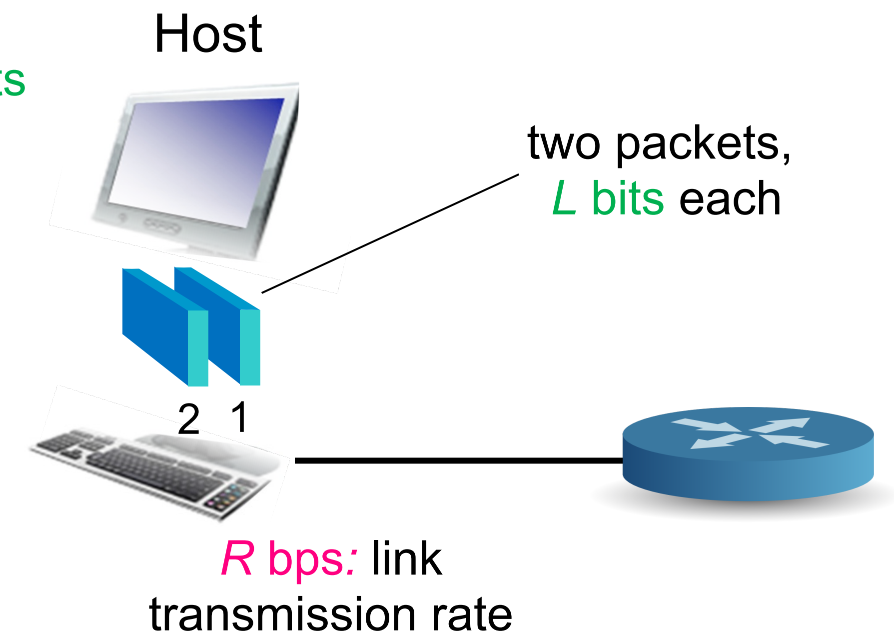
- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE



Host sends packets into access network

1. Given application message
   - breaks into packets
     - smaller chunks of length *L* bits

2. Transmit packets into access network
   - at transmission rate *R*
     - aka link capacity
     - aka link bandwidth



Transmission delay	=	Time to transmit *L*-bit packet into link	=	$\frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$