CS 352
Internet Technology
Fall 2025

Badri Nath

Course Details on Canvas

Dept. of Computer Science
Rutgers University

About me

- PhD from UMASS, Amherst
- Research in distributed systems, databases, wireless
- Now scaling systems for AI applications
- Industry experience
- Involved in startups : 1) wireless space
- 2) AI for document understanding
- 3) NOW- designing AI pipelines for finance forecasting

Course Management

- Professor: Badri Nath
  - http://www.cs.rutgers.edu/~badri
  - badri@cs.rutgers.edu
  - Office hours: Monday 1 PM-3 PM (room 320 CORE) or by appt
  - Class: Monday,Thursday 8:30 to 9:50 AM
  - In person: TIL 254
  - Text book: Computer Networks- Kurose and Ross (7th,edition)- can use 8th or 9th edition
- TAs

1. Section 1
2. Section 2
3. Section 3

- Course info
  - **All class notes will be on canvas**

The world has changed

- **ChatGPT Statistics 2025: Mind boggling**
- 190.6 million people use ChatGPT daily.
- ChatGPT has 800 million weekly active users as of 2025.
- ChatGPT gets 5.72 billion monthly visits.
- Over 1 billion daily queries are processed on ChatGPT.
- All this in two+ years
- How? AI + network (Internet) access
-

Predictions

- Programming as a cognitive skill will have no value
  - Cursor, copilot, claude-code
- Driving on your own will be expensive
  - Driverless cars, waymo
- More manual labor outsourced to robots
  - Robotic kitchen, robotic delivery
- Personalized dynamic content creation
  - 5 minute movie (AI generated) to your liking- in realtime

What should you focus?

- Build systems
- Design large scale systems
- Sam Altman says

What is a Network?

- Way to connect 2 or more entities with an Interconnection or link to carry some items
- Interconnection may happen over any medium

1. Entities?.....
2. Link? …….
3. Carry?.....

1. Entities?.....
2. Link? …….
3. Carry?.....

1. Entities?.....
2. Link? …….
3. Carry?.....

What are some design attributes for these networks?

- Road network
  - …
  - …
- Airplane network
  - …
  - …
- Social network
  - …
  - …
- In this class we will learn about design attributes of computer networks and in particular the Internet

What is a Computer Network?

- Carrier of information (bits) between 2 or more computing entities
- Interconnection or links can be any medium capable of communicating information:
  - copper wire
  - Lasers (optic fiber)
  - Microwave
  - Cable (coax), satellite link
  - Wireless link (cellular, 802.11, bluetooth)
- Examples: Cable, Ethernet, 802.11(WIFI), cellular, satellite

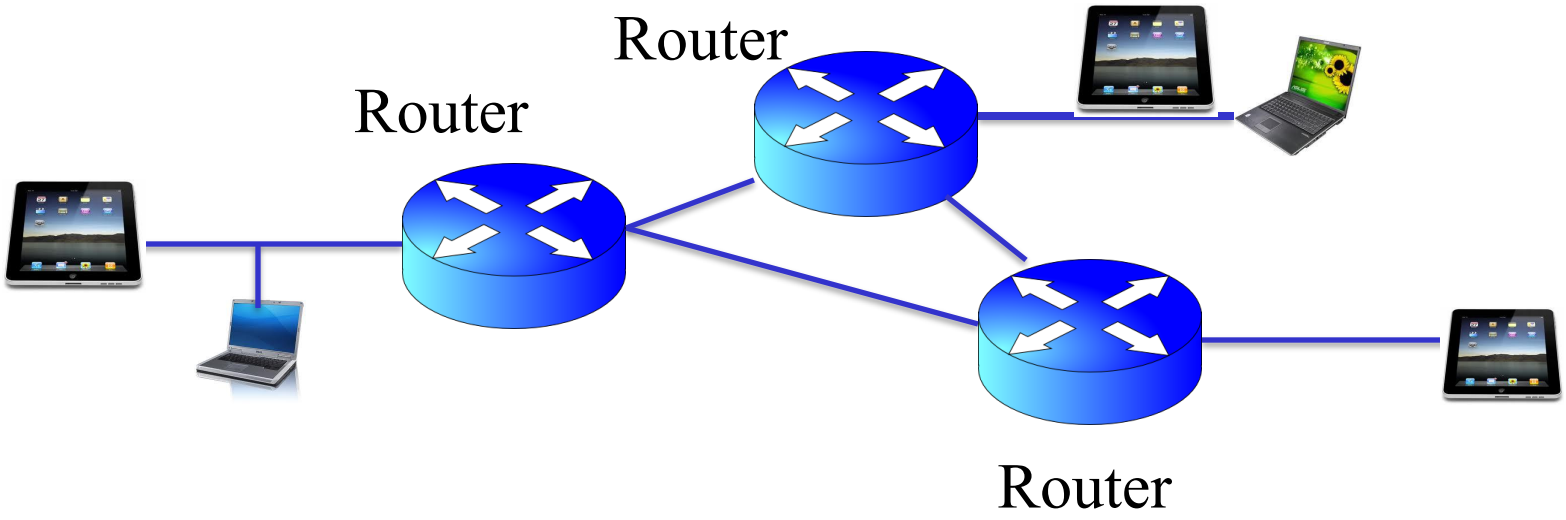
A single link network

- Send bits of data in packets or frames
- Need to worry about errors, how to convert bits into signals and vice versa

A single link multiple access network

- Send bits of data in packets or frames
- Need to worry about errors, how to convert bits into signals and vice versa
- In addition, how to differentiate among many receivers
- Every host as a link layer address– MAC address
- Packets or frames will have destination address
- Can't have every computer in the world on the same link!

A network



- Connect multiple links via routers
- Need to figure out how to route data packets from one host to another host

Why Networks?

- Availability of Resources
  - Resources become available regardless of the user's physical location
- Load balancing
  - Jobs processed on least loaded machine
  - High Reliability
  - Alternative source of supply (multiple copies)
- Human-to-Human Communication
  - e.g., Messaging, Posts(blogs,images, videos),Telephone (Voice-over IP)

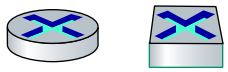
What is Internet Technology?

- What is an internet?
  - Network of networks
- What is *the* Internet?
  - A global internet based on the IP protocol
  - Network to network – adopt a common language
- To what does "Internet technology" refer?
  - Architecture, protocols and services (applications)
  - In this course, we focus on architecture and protocols (specs for message exchange between entities)

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)

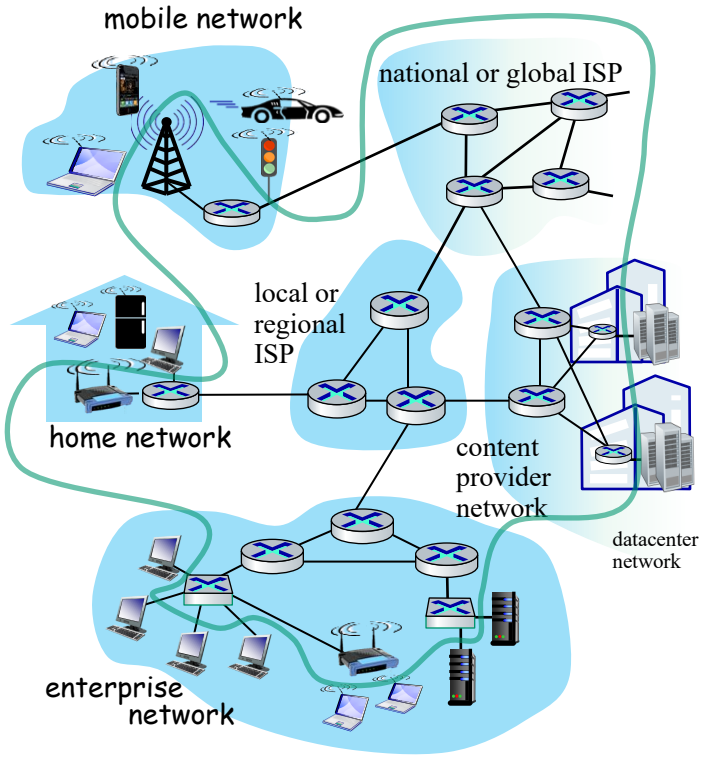
- *routers, switches*

Communication links

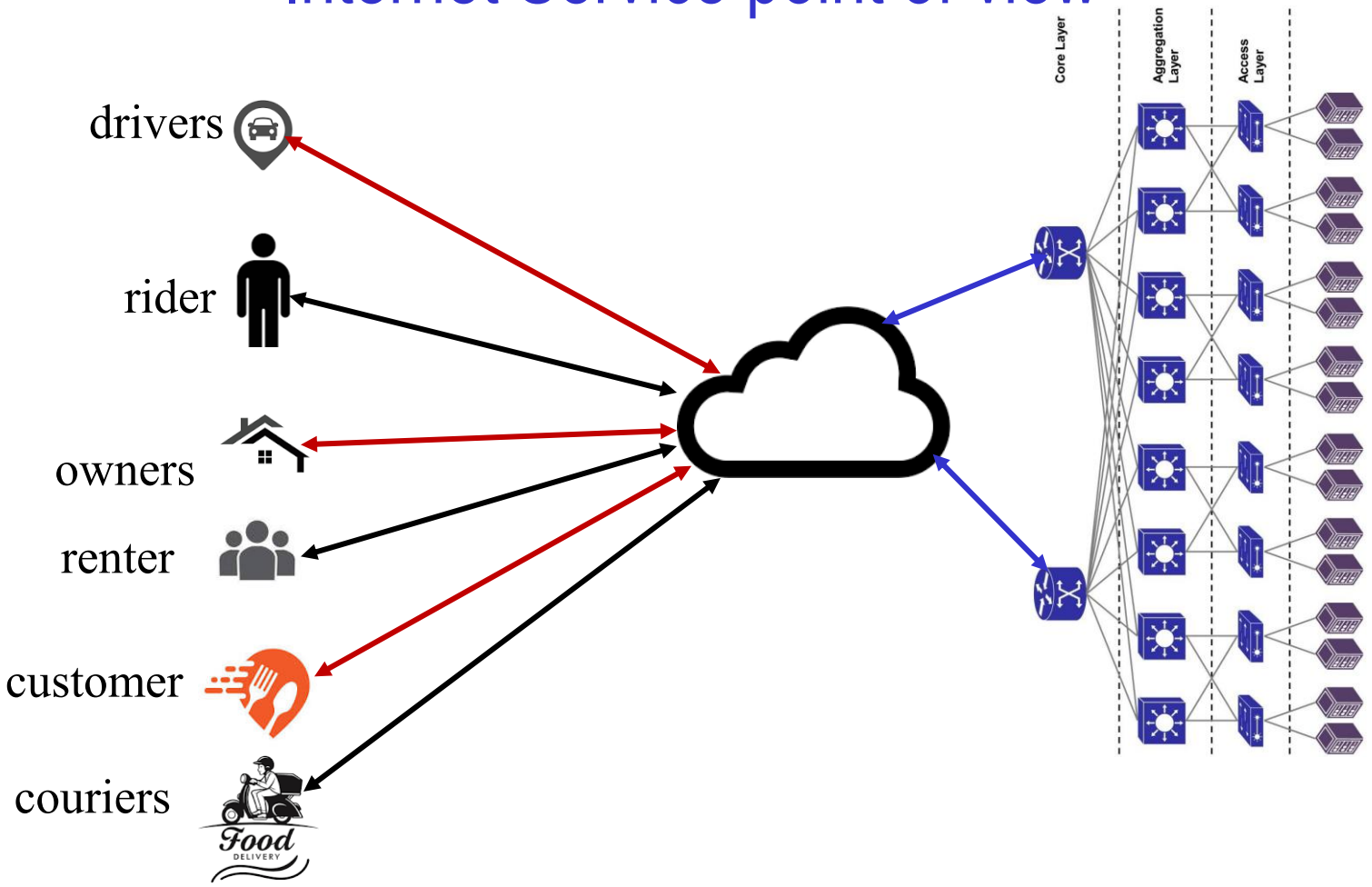
- fiber, copper, radio, satellite
- transmission rate: *bandwidth*

Networks

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



Internet Service point of view



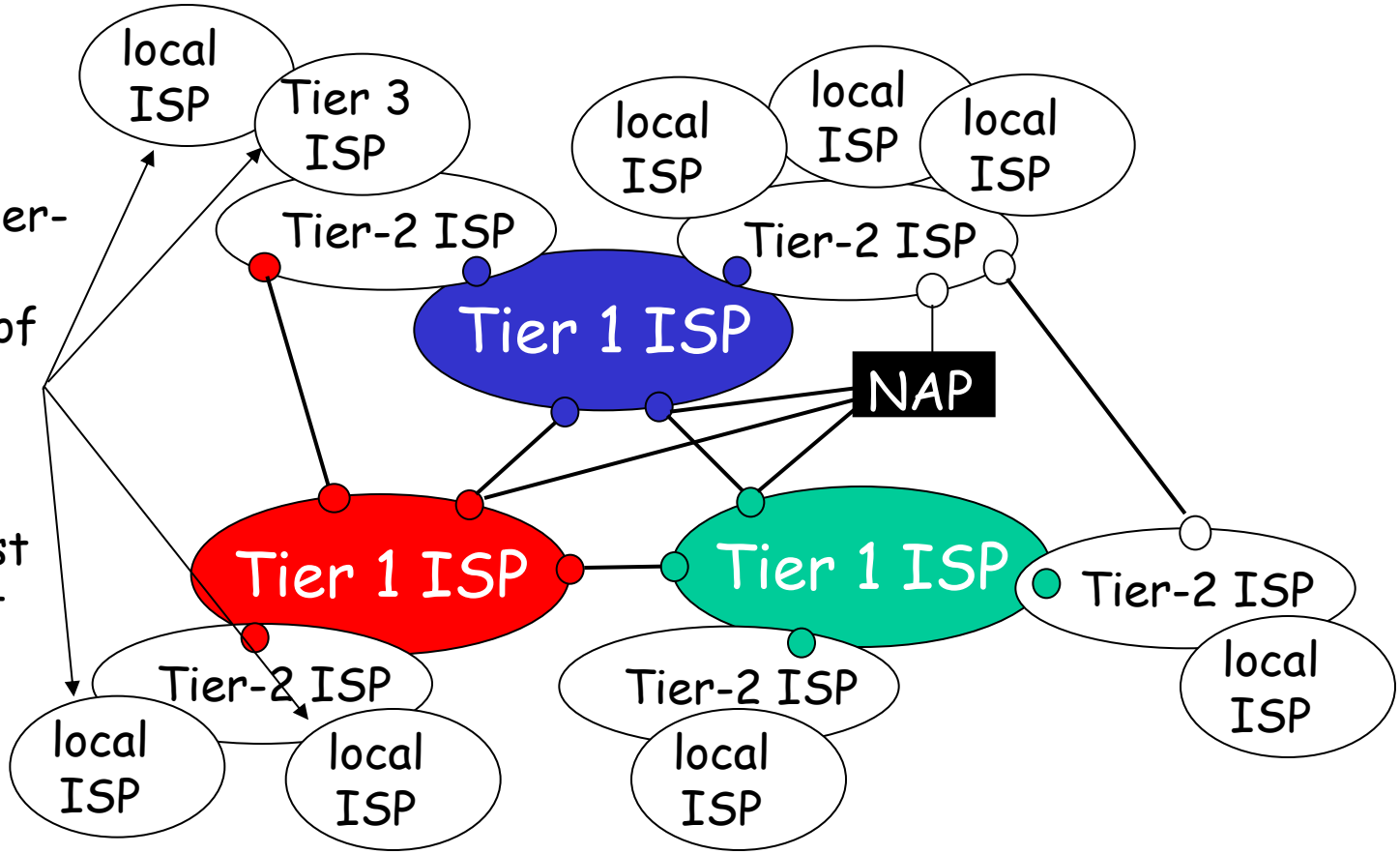
Learn how to build systems

Internet stakeholders

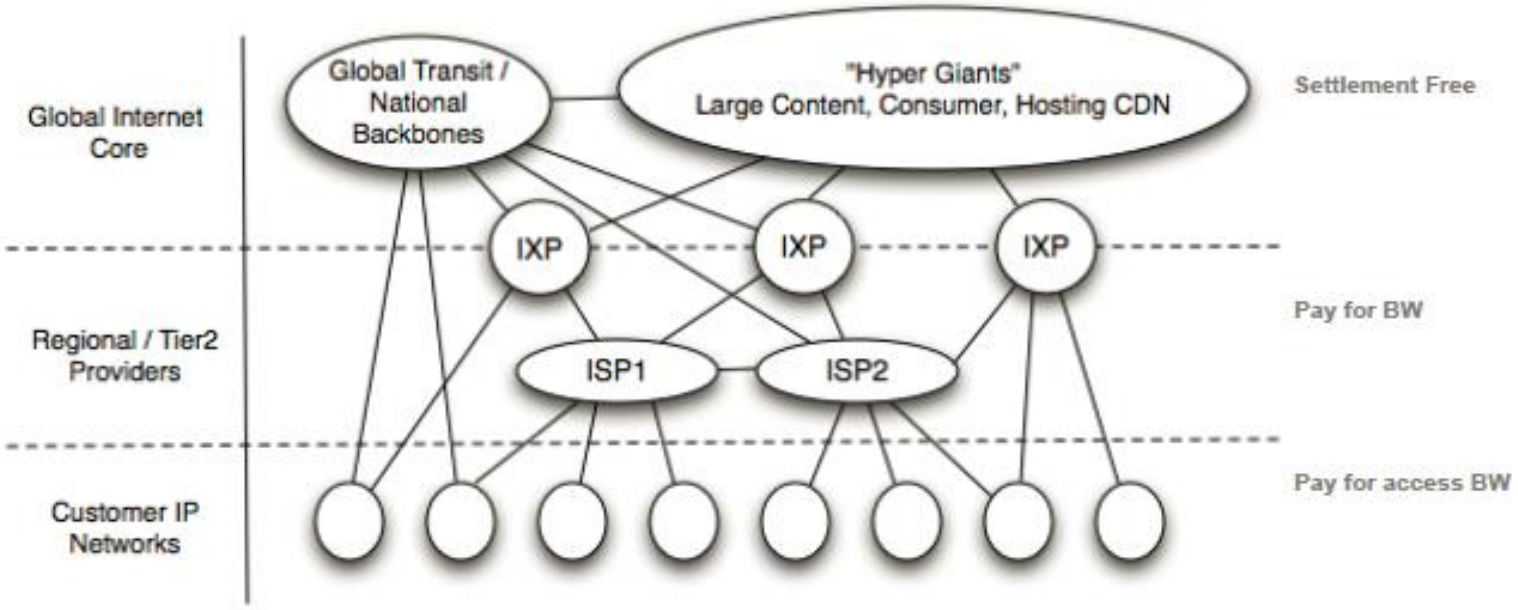
- ISPs- Internet Service Providers
  - Local ISPs- Tier 3 (cablevision)
  - Regional ISPs – Tier2 (internap)
  - Global ISPs (verizon, Sprint, ATT, level 3, century link, Deutsche Telekom, NTT) provide access to entire internet; connect ISP to other ISPs
- Peering ISPs
  - Have a mutual relationship about forwarding traffic of each others customers (no $ involved)
- Transit ISPs
  - Provides access to all reachable customers ($$ involved)

Core Networks: ISP Tiers

Local and tier-3 ISPs are *customers* of higher tier ISPs connecting them to rest of Internet



ISPs connected via Exchanges



- Internet Exchange Point, Flatter Internet
- Business models among, content provider, transit providers, and customers
- Net Neutrality

Internet Inter-domain traffic By Labovitz et.al, SIGCOMM 2010

Evolution of Internet Applications

2010-now

Tik Tok

UBER

1992	1996	2000	2004	2008
ftp web	chat Games IM Yahoo!	news Blog Search amazon	Music itunes Games search Google	Wikipedia Craiglist Youtube

NETFLIX

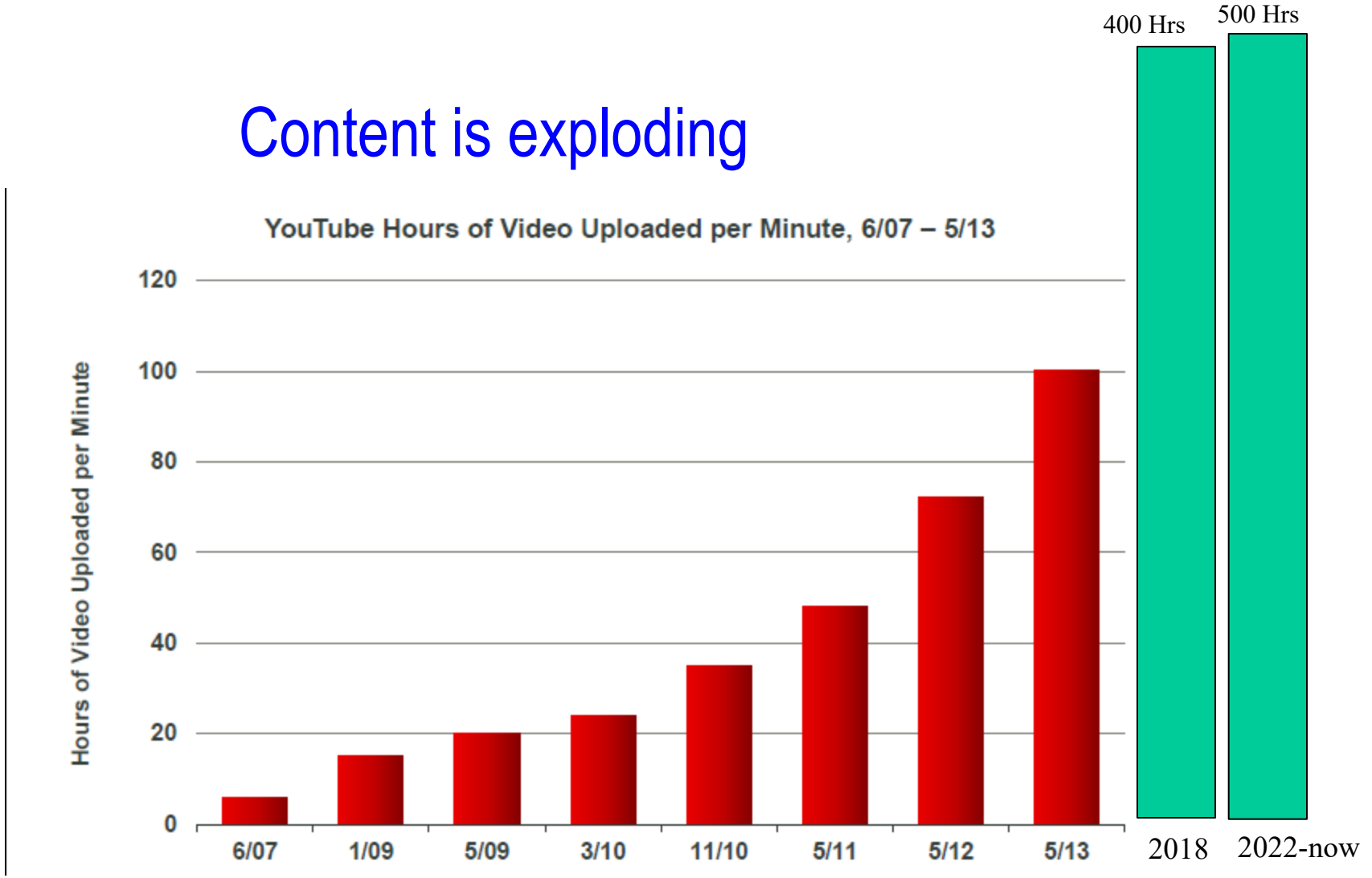
airbnb

Spotify

Web evolution

- Web 1.0
  - Read-only web
  - Content ➔ Users
  - Yahoo, google, daily targum
- Web 2.0
  - Read-write web
  - Content ➔Users and Users ➔ Content
  - Blog, wikipedia, facebook, twitter, youtube
- Web 3.0
  - Contextual web
  - Personalized, location dependent
  - Craiglist on your phone changes as you drive around!!
  - Apps on your phone- payment venmo paypal
- Web 4.0
  - Inanimate objects or devices connected as first class objects
  - -- refrigerator, car, garage door, …. Thermostat
- Now.. Generative web chat GPT (LLMs), Dall-E. Synthetic Content generation
- What is real? What is virtual?

Content is exploding



HD quality video: 2G to 4G / hour

Source: Mary Meeker Internet trends Presentation

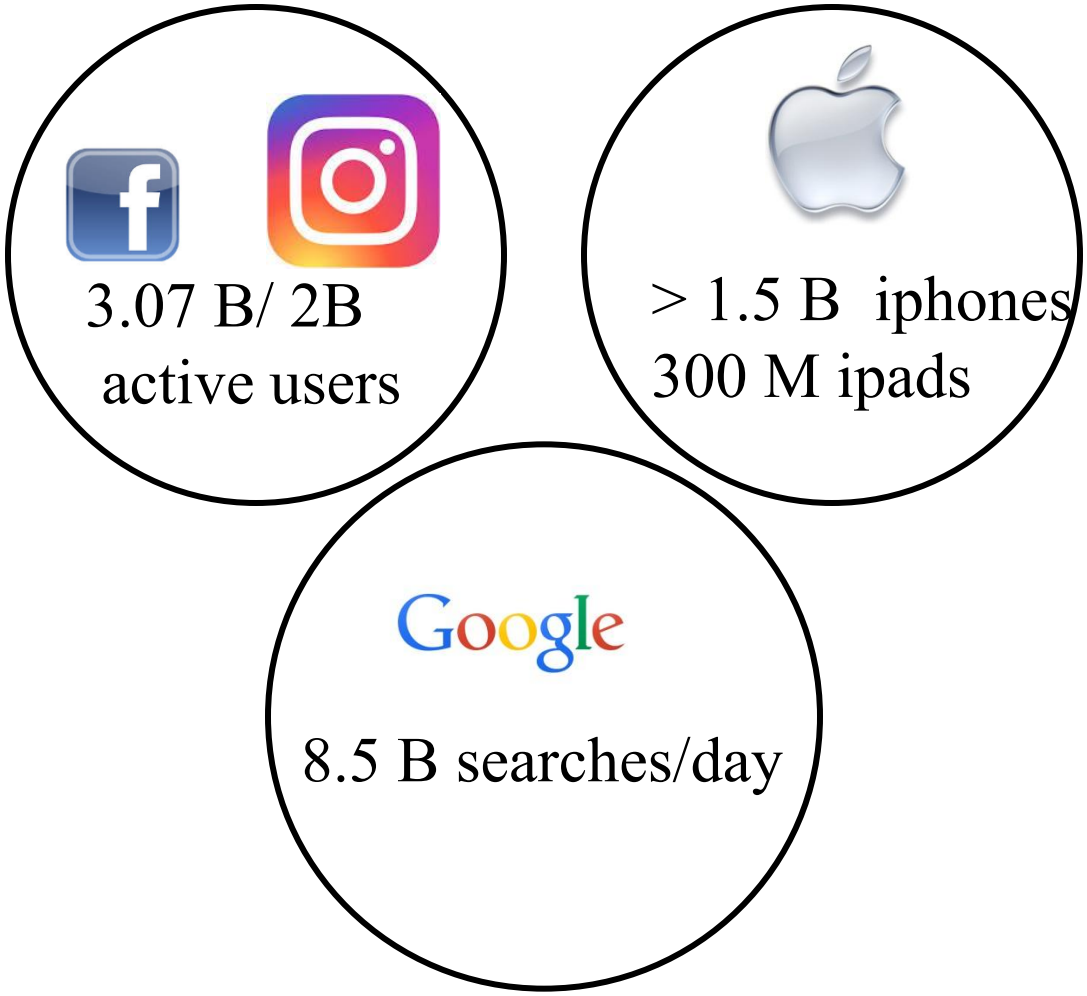
Just dancing and listening to video, tweets, selfies, share

Source: Mary Meeker Internet trends Presentation

Transforming entire economy

- Mobile payment
  - Venmo, block, stripe, paypal
- Shared resource platforms
  - Uber, Airbnb
- Generative AI
  - Coding, report writing

Scale of Web apps (Billions)



Impact of the Net on People

- Access to remote information
  - HW assignments from canvas
  - Stock quotes from financial web site
  - News, wikipedia, google
- Person to person and group communication
  - email, zoom, whatsapp, blogs,fb(meta), twitter, podcasts, instagram, snapchat
- Interactive entertainment
  - youtube (video clips), netflix (movies), tiktok (shorts), spotify (music), meta (reels)
- Online commerce
  - Amazon, Priceline, Ebay
- Cloud services
  - AWS, GCP and Azure (own vs rent)

Impact of the Net on Society

- The good
  - Access to information (i-commerce), e-commerce, incredible productivity tool, remote surgery, health care
- The bad
  - gossip, too much information, chat room, net addicts, privacy
- The ugly
  - Fraud, pornography, phishing, threatening e-mail (bullying)
- But, it is just a mirror of society

Types of Networks in an Internet

- Local area networks
  - Privately owned, within building
  - High speed, broadcast, Ethernet, WIFI, blue tooth
    - 2 to 100 Mbps to 10s of Gbps (10^9)
- Wide area networks
  - Spans a large area
  - Point-to-point, high speed fiber or trunk lines
    - Long delays but very high speed links
    - Several Gbps

Types of Networks *(cont'd)*

- Wireless networks
  - Hosts connected by infrared or radio links
  - Local area and wide area
  - Satellite networks

Historical perspective

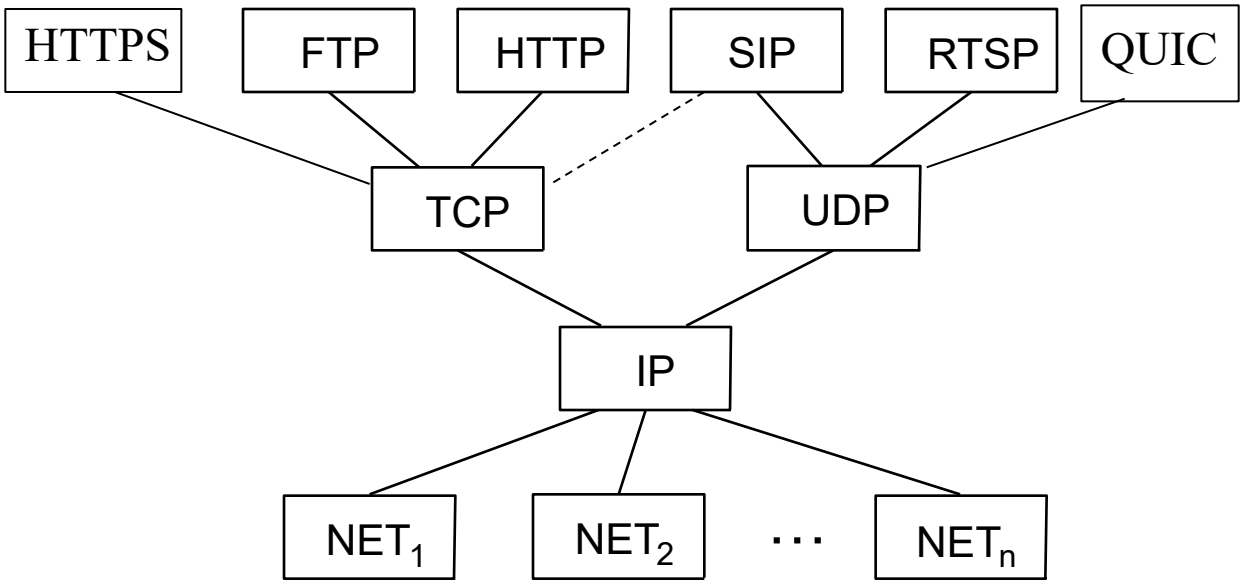
- Late 1960's: ARPAnet (4 nodes)
- Early 1970's: Aloha net, ethernet, multiple access problem
- Mid-to-late 1970's: TCP/IP, 4.2BSD
- 1980's to early 1990's: early internet growth, e-mail & file transfer dominant, NSFNET
- Mid 1990s: NSFnet handed over to commercial service providers, WWW explodes
- Late 90s, business models using the internet; dot-com boom and bust
- Early to mid 2000s, WEB 2.0(read-write), Facebook, google, wikipedia
- Now &Future: WEB 3.0 (personalization), WEB 4.0 (answer generation) Embedded networks, Robotics, robotic kitchen, networked devices, media convergence.

Protocols

- Building blocks of a network architecture
- Each protocol object has two different interfaces
  - *service interface*: operations on this protocol
  - *peer-to-peer interface*: messages exchanged with peer
- Term "protocol" refers to both the specification and implementation of the module

Internet Architecture

- Defined by Internet Engineering Task Force (IETF)
- Hourglass Design
- Anything over IP, IP over anything



Why Layering?

- Network communication is very complex
  - **So much diversity and range**
- Testing and maintenance is simplified
- Easy to replace a single layer with a different version

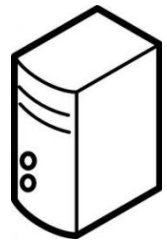
functionality at each layer

https | Application | Encryption, Authentication

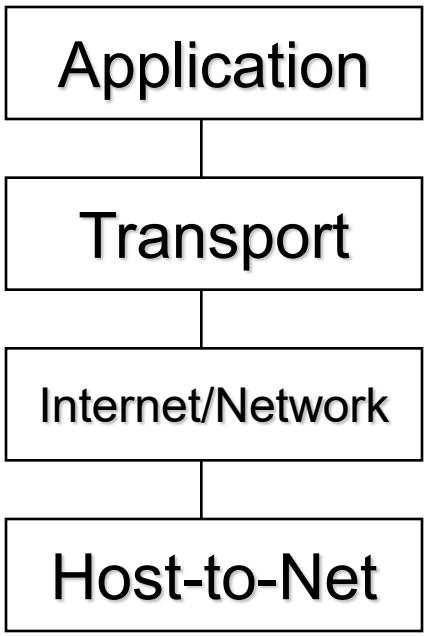
Port# | Transport | E-2-E

IP Address | Network | Routing

MAC Address | Link | Access



TCP/IP Layering Architecture



- A simplified model
- The network layer
  - Hosts drop packets into this layer, layer routes towards destination- only promise- try my best
- The transport layer
  - reliable byte-oriented stream

Host-to-Network layer: a) Physical Layer

- Functions:
  - Transmission of a raw bit stream
  - Forms the physical interface between devices
- Issues:
  - Which modulation technique (bits to pulse)?
  - How long will a bit last?
  - Bit-serial or parallel transmission?
  - Half- or Full-duplex transmission?
  - How many pins does the network connector have?
  - How is a connection set up or torn down?

Host-to-network layer
b) Data Link Layer

- Functions:
  - Provides reliable transfer of information between two adjacent nodes
  - Creates frames, or packets, from bits and vice versa
  - Provides frame-level error control
  - Provides flow control
- In summary, the data link layer provides the network layer with what appears to be an error-free link for packets

Network Layer

- Functions:
  - Where is the host located?
  - Which host? Name?
  - Responsible for routing decisions
    - Dynamic routing
    - Fixed routing

Transport Layer

- Functions:
  - Hide the details of the network from the session layer
    - Example: If we want replace a point-to-point link with a satellite link, this change should not affect the behavior of the upper layers
  - Provides reliable end-to-end communication
- Functions:
  - Perform end-to-end flow control
  - Perform packet retransmission when packets are lost by the network

Application Layer

- Application layer protocols are application-dependent
- Provides session support and presentation support
  - Session state, encryption, encoding
- Implements communication between two applications of the same type
- Examples:
  - FTP
  - HTTP
  - SMTP (email)
  - XMPP Extensible messaging and presence protocol
  - SIP Session Inititation Protocol

Course Goals

- Understand the basic principles of computer networks
- Understand the Internet and its protocols
- Understand the key design principles used to build the Internet

Course Work

- Written Home Works (8%)
  - **Around 5 to 7**
- 2 Mid-terms (15% each- total 30%)
- Final exam (30%) Tuesday, **December 15**, **8-11 AM**
- Project (32%)
  - **Project 1 (8%)**
  - **Project 2 (8%) Projects groups of 2**
  - **Project 3 (8%)**
  - **Project 4 (8%)**

Programming assignments

- four projects
  - Can work in groups of 2
- Both program and write-up required
- Background needed to get started:
  - C or Python (211, 214 level)
    - Comfortable using data structures(stacks, trees, vector)
  - Unix (login, handin, permissions, gcc, ilab machines) , canvas

Academic integrity

- No cheating on projects and exams
  - Run code similarity detectors on the projects & code review
  - Scrutinize exams for copying
- Department academic integrity policy
  - http://www.cs.rutgers.edu/policies/academicintegrity/
  - Acknowledge your awareness of this policy to continue to access department computing facilities

Some Definitions

- Network: **Collection of interconnected machines**
- Host: **Machine running user application**
- Subnet: **Subset of the network, responsible for carrying messages between hosts**
- Channel: **Logical line of communication**
- Topology: **Network configuration**
- Router: **Process packets and routes packets towards the destination**
- Protocol: **Rules of communication**

1. How Do Computers Communicate?

- With 1's and 0's
  - Computers only deal with 1's and 0's
  - So do networks
- How do we transmit 1's and 0's in a network?

Physical Transmission

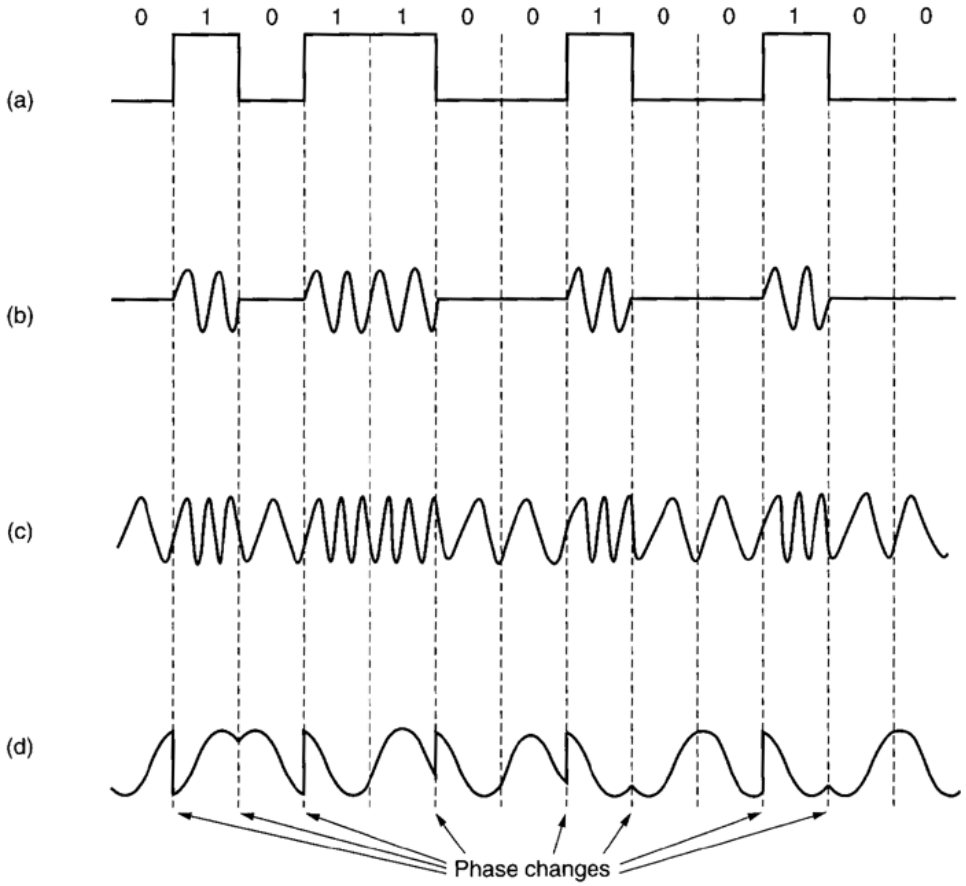


Fig. 2-18. (a) A binary signal. (b) Amplitude modulation. (c) Frequency modulation. (d) Phase modulation.

Switching Schemes

(1) Circuit Switching

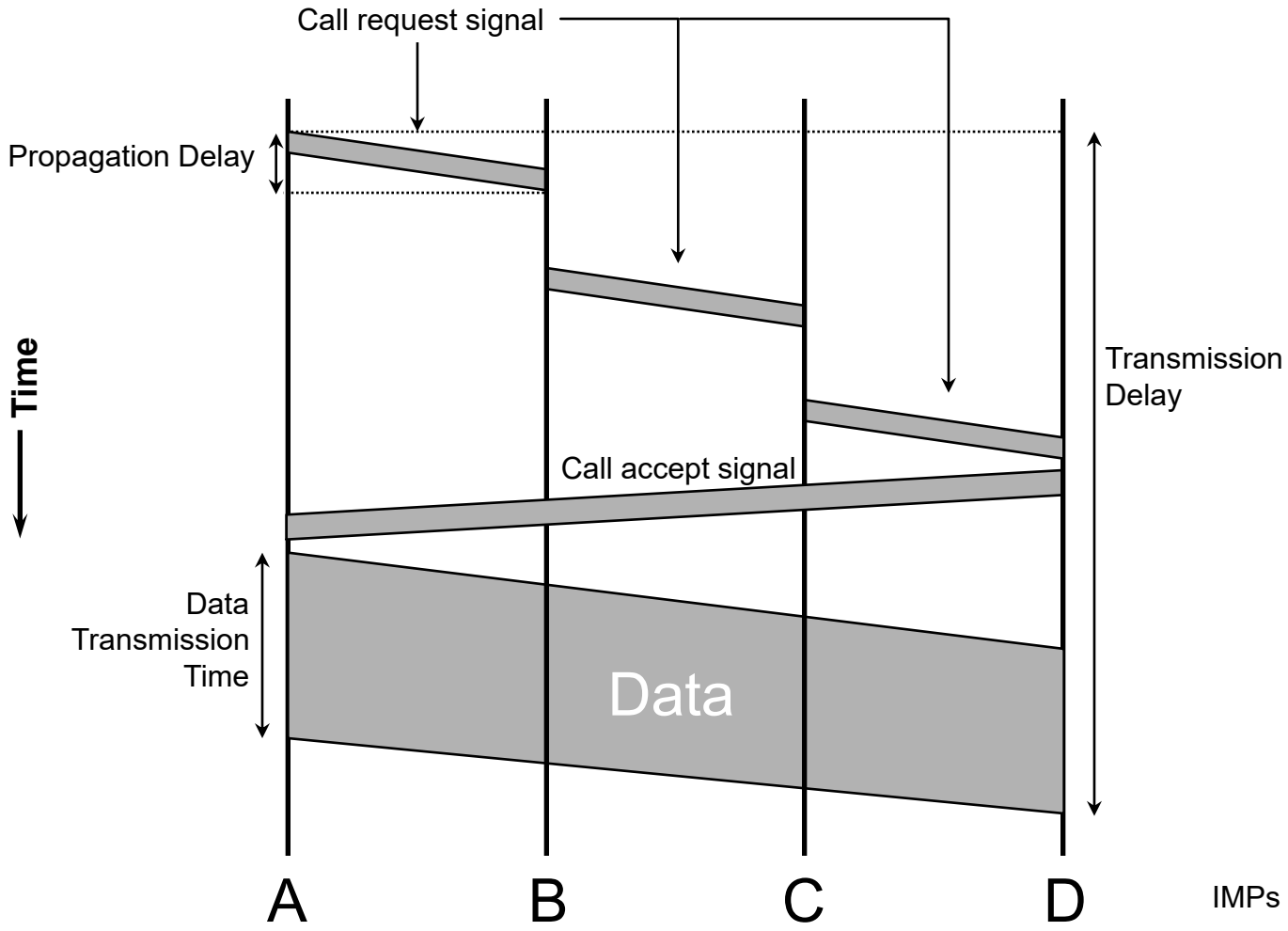
(2) Message Switching (Store-and-Forward)

(3) Packet Switching (Store-and-Forward)

Circuit Switching

- Provides service by setting up the total path of connected lines from the origin to the destination
- Example: Telephone network

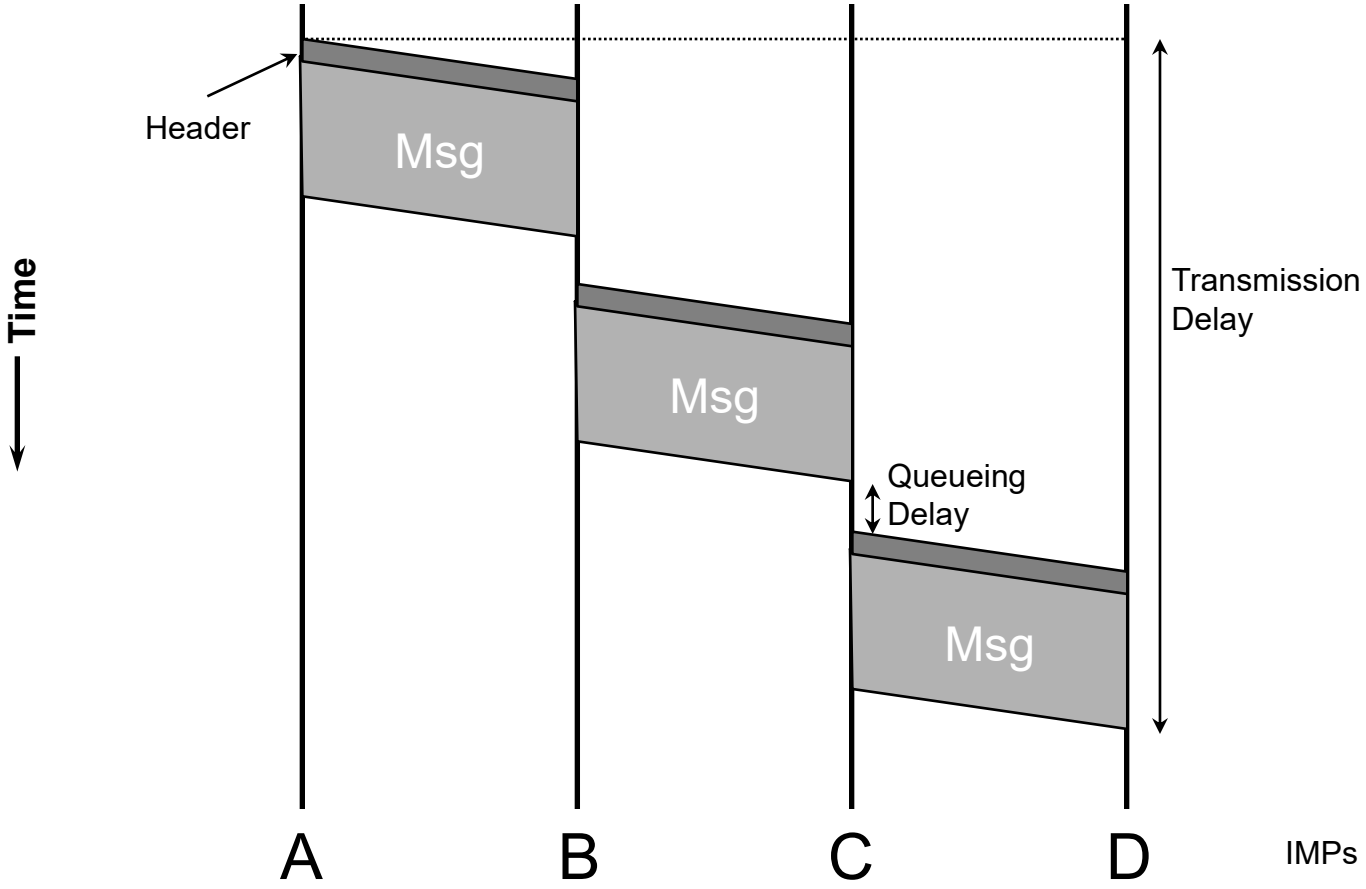
Circuit Switching (cont'd)



Message Switching

- Each message is addressed to a destination
- When the entire message is received at a router, the next step in its journey is selected; if this selected channel is busy, the message waits in a queue until the channel becomes free
- Thus, the message "hops" from node to node through a network while allocating only one channel at a time
- Analogy: Postal service

Message Switching (cont'd)



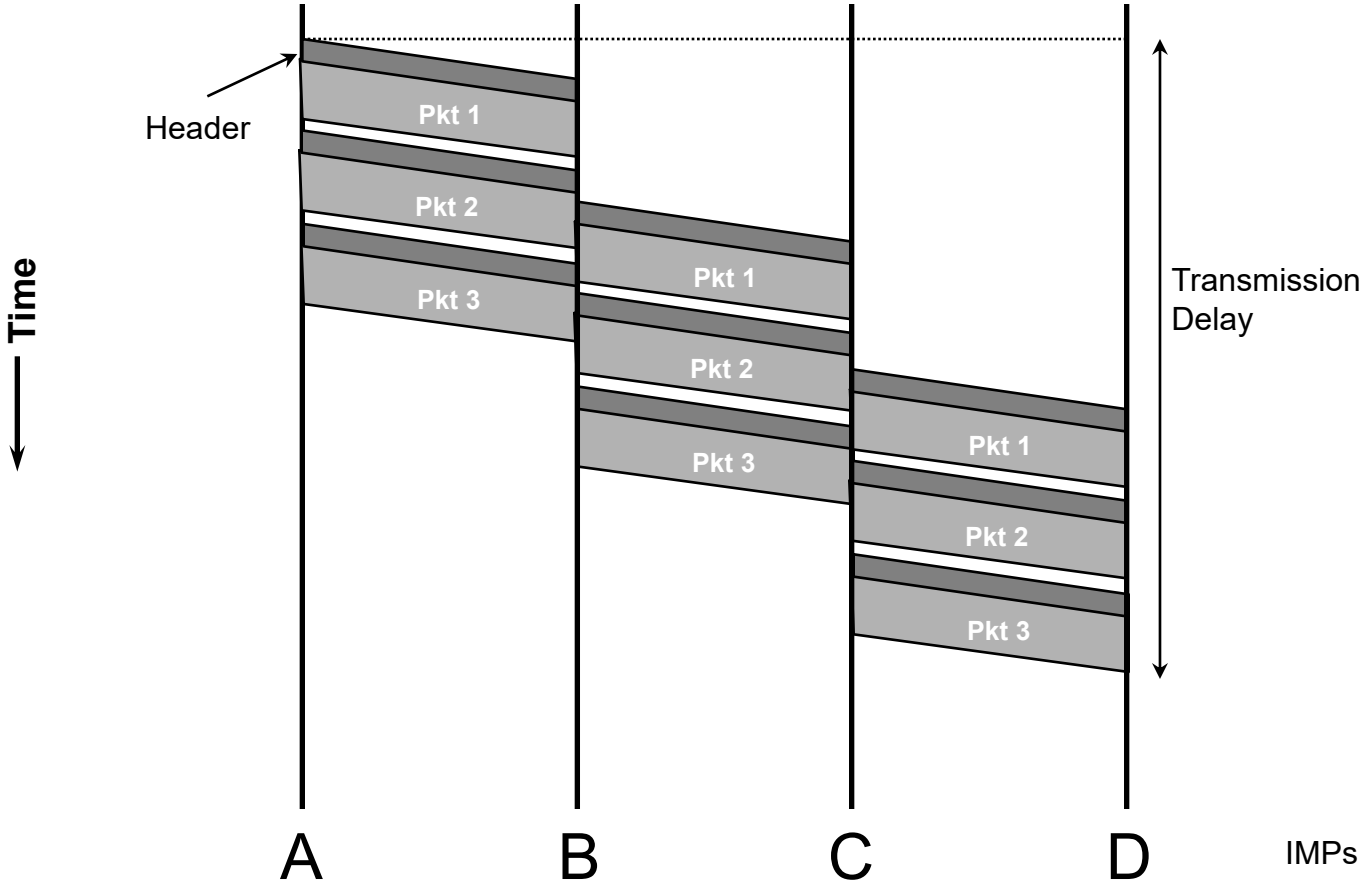
Packet Switching

- Messages are split into smaller pieces called **packets**
- These packets are numbered and addressed and sent through the network one at a time
- Pipelining

Conveyor belt

- Time for the first box = time to travel the length of the belt
  - **Propagation delay**
- Time for successive boxes (1/rate at which boxes are put on the belt)
- Transmission time = number of boxes /rate
- For packets the units are bits/sec, Bytes/sec or packets/sec
- Total transfer time= Transmission time + Propagation delay

Packet Switching (cont'd)



Comparisons

(1) **Header Overhead**

Circuit < Message < Packet

(2) **Transmission Delay**

Short Bursty Messages:

Packet < Message < Circuit

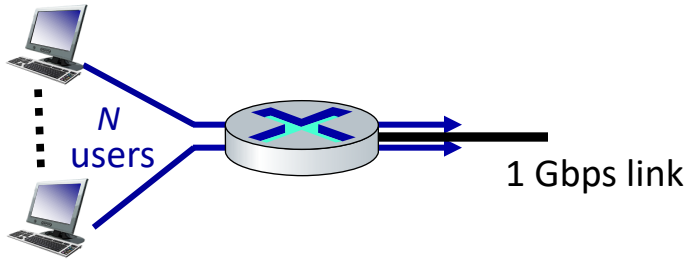
Long Continuous Messages:

Circuit < Message < Packet

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:* with 35 users, probability > 10 active at same time is less than .0004 *

Q: how did we get value 0.0004?

A: HW problem (for those with course in probability only)

Packet switching versus circuit switching

Is packet switching a "slam dunk winner"?

- great for "bursty" data – sometimes has data to send, but at other times not
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: packet delay and loss due to buffer overflow
  - protocols needed for reliable data transfer, congestion control
- *Q:* How to provide circuit-like behavior with packet-switching?
  - "It's complicated." We'll study various techniques that try to make packet switching as "circuit-like" as possible.

Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet switching)?

Measuring a Network's Performance

A Brief Introduction

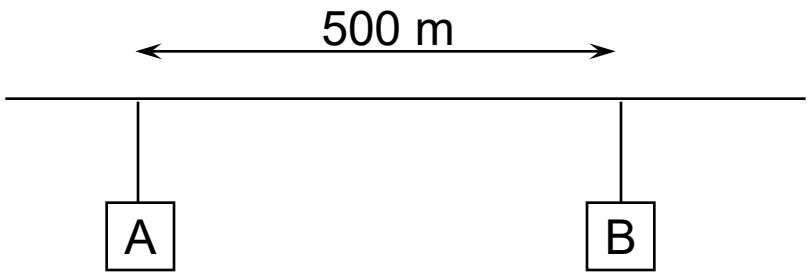
Some Definitions

- **Packet length**: size of a packet (units = bits or bytes)
- **Channel speed or bandwidth**: How fast the channel can transmit bits (units = bits/second or Bytes/second or packets/second)
- **Packet transmission time**: amount of time to transmit an entire packet (units = seconds)
- **Propagation delay**: Delay imposed by the properties of the link. Depends on the link's distance (units = seconds)
- Total transfer time =propagation delay + packet transmission time

Digression: Units

- **Bits** are the units used to describe an amount of data in a network
  - 1 kilobit (Kbit) = 1×10^3 bits = 1,000 bits
  - 1 megabit (Mbit) = 1×10^6 bits = 1,000,000 bits
  - 1 gigabit (Gbit) = 1×10^9 bits = 1,000,000,000 bits
- **Seconds** are the units used to measure time
  - 1 millisecond (msec) = 1×10^{-3} seconds = 0.001 seconds
  - 1 microsecond (μsec) = 1×10^{-6} seconds = 0.000001 seconds
  - 1 nanosecond (nsec) = 1×10^{-9} seconds = 0.000000001 seconds
- **Bits per second** are the units used to measure channel capacity/bandwidth and throughput
  - bit per second (bps)
  - kilobits per second (Kbps)
  - megabits per second (Mbps)
- Bytes (8 bits a byte) Mega bytes, Giga bytes, Tera bytes, Peta Bytes, Exa bytes

Example



packet length = 1500 bytes
channel capacity = 10 Mbps
propagation delay factor = 5 μsec/km

1. How long does it take a single bit to travel on the link from A to B?
2. How long does it take A to transmit an entire packet onto the link?

Propagation Delay

1. How long does it take a single bit to travel on the link from A to B of length 500 m with a prop. delay factor = 5 **μsec**/km ?

Another way to ask this question:

If it takes a signal 5 μsec to travel 1 kilometer, then how long does it take a signal to travel 500 meters?

$$\frac{5\ \mu\text{sec}}{1000\ \text{m}} = \frac{t}{500\ \text{m}}$$

Solving for t…

$t = 2.5\ \mu\text{sec}$

Packet Transmission Time

2. How long does it take A to transmit an entire packet onto the link?

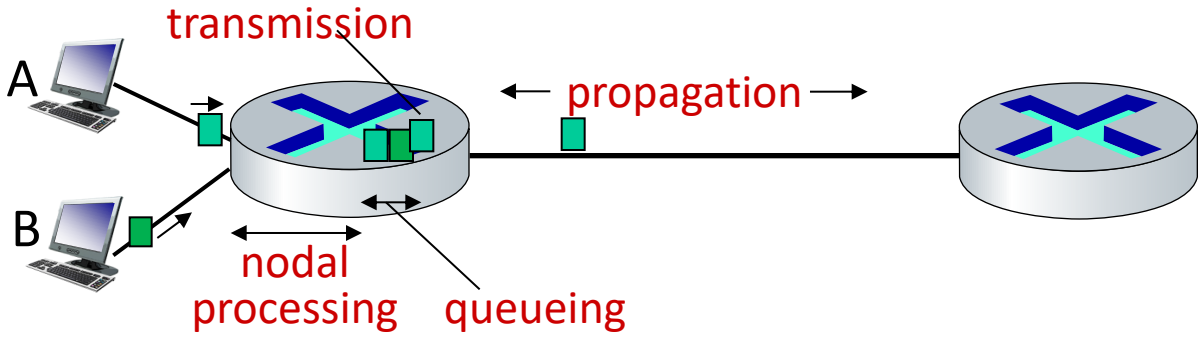
Relevant information: packet length = 1500 bytes
channel speed = 10 Mbps

Another way to ask this question:
If the link can transmit 10 million bits in a second, how many seconds does it take to transmit 1500 bytes (8x1500 bits)?

$$\frac{10 \text{ Mbits}}{1 \text{ sec}} = \frac{1500 \times 8 \text{ bits}}{t}$$

Solving for t…
t = 0.0012 sec (or 1.2 msec)

Packet delay: four sources



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

d_{trans}: transmission delay:

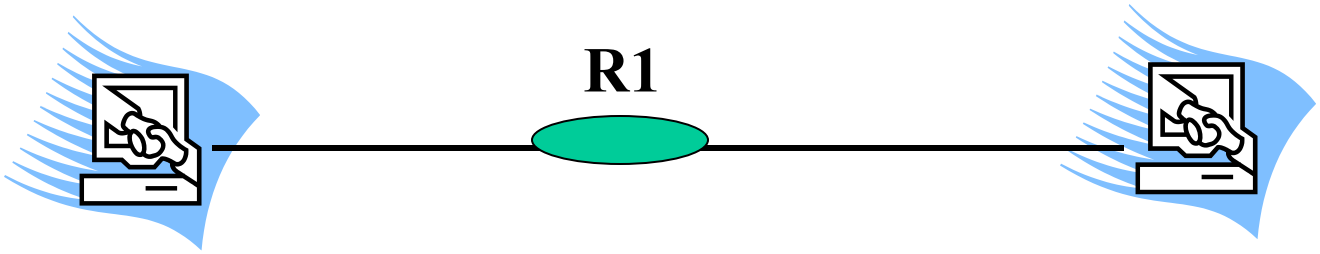
- L: packet length (bits)
- R: link *transmission rate (bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay:

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

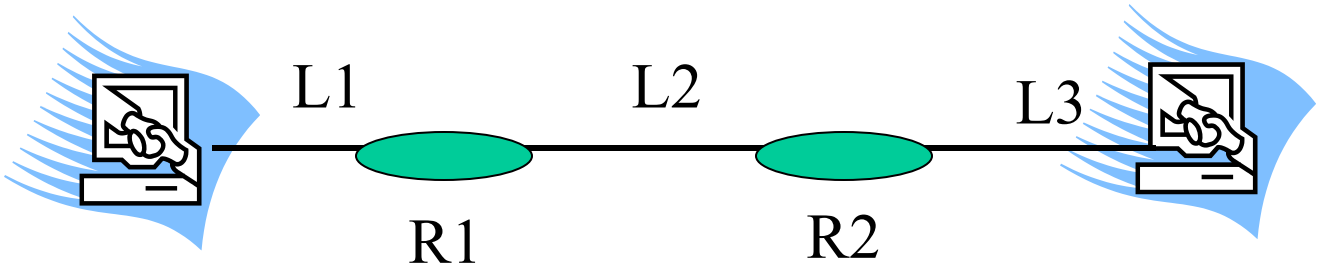
d_{trans} and d_{prop} *very* different

Message switching vs Packet switching



- Link speed is 1000 Bytes/sec. (ignore prop delay)
- Packet size is 100 Bytes, file size is 1000 Bytes
- Find total time to transfer the entire file under the two switching techniques
  - Msg switching
  - Packet switching

Message switching vs Packet switching



- Link speed is 1000 Bytes per second . (ignore prop delay, ignore header overhead)
- Packet size is 100 Bytes, file size is 1000 Bytes
- Find total time to transfer the entire file under the two switching techniques