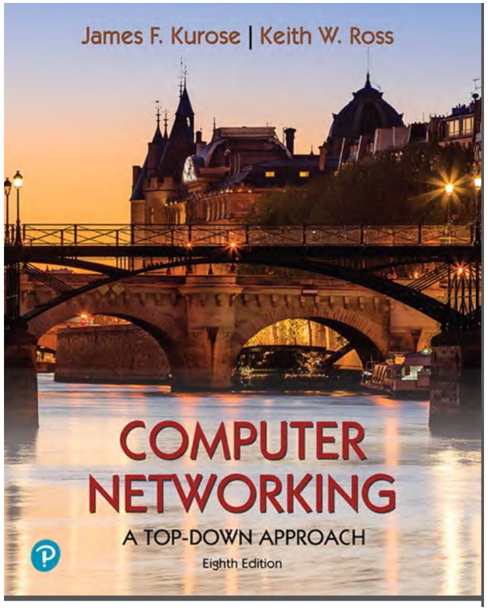
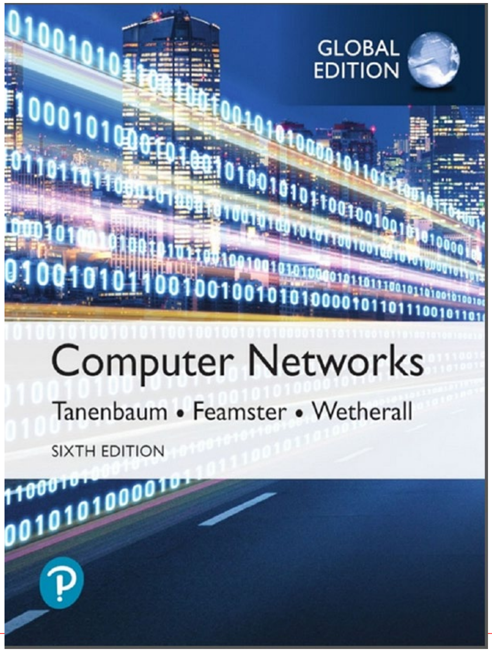
EE 444 Introduction to Computer Networks

Text Books

James F. Kurose, Keith W. Ross, Computer Networking, 8/e, 2021.



Andrew Tanenbaum, Nick Feamster, David Wetherall, Computer Networks, 6/e, 2021.



Required

- **Prerequisite(s):**

An introductory course on Probability Theory (EE230).

- **Background Requirement(s):**
- EE441 is strongly recommended. Possible other skills: Python, C/C++, Matlab.

Course Objective (Why should you take this course?)

- Basic computer networking technologies
- Layered approach/ Modular design/ Interfaces
- Concepts of network performance
- Performances of some classical networking architectures

Course Outline (Tentative)

- Introduction to Computer Networking
- Basic Queuing Theory
- Application Layer
- Transport Layer
- Network Layer and Routing
- Data Link Layer
- Medium Access Control Sublayer
- Further subjects (we will decide what to talk about based on the time left at the end of the semester)

Grading

- 4 Short Exams: 50% (Equal Weight)
- Final exam: 35%
- Programming assignments: 15%
- 5% bonus for attendance >=80%.

Homework

- HTTP
  - Usage of HTTP protocol and high-level web communication
  - Web scraping (python library: beautifulsoup4)
- Socket Programming:
  - Communication between two instances using TCP/UDP sockets
  - Python & Matlab
- Wireshark
  - Analysis of internet packets using a specialized program

Introduction to Computer Networking

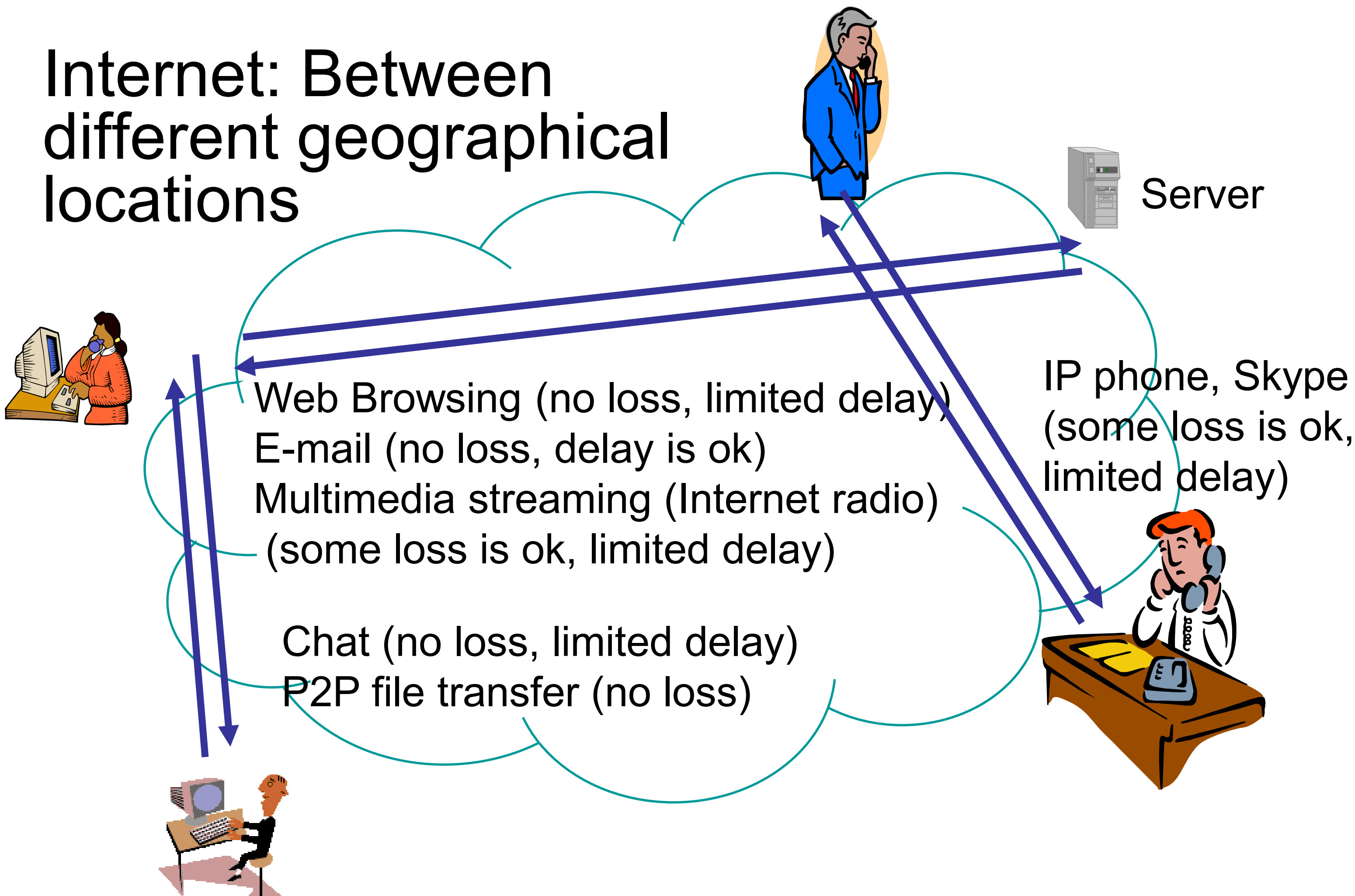
Course Overview

Why do we need computer networking?

- We want to exchange information between/among remote locations (not at the same physical location).
- Run applications with different needs

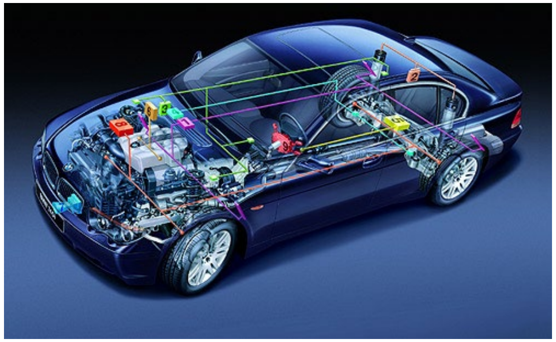
Exchanging information

- Internet: Between different geographical locations



Exchanging information

- Embedded environments: Between different system components (micro controllers, sensors)



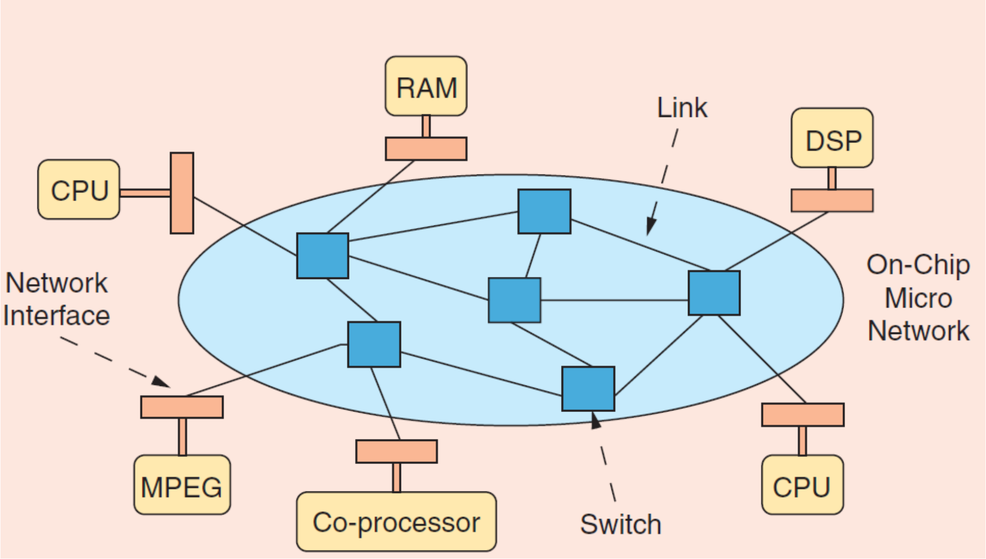
In vehicle networking
for X-by-wire applications
Example Application: break by wire

Factory floor networking
for manufacturing systems

Real-time, limited delay, no loss

Exchanging information

- Network on Chip (NoC): Between different intellectual property blocks on chip



Exchanging information

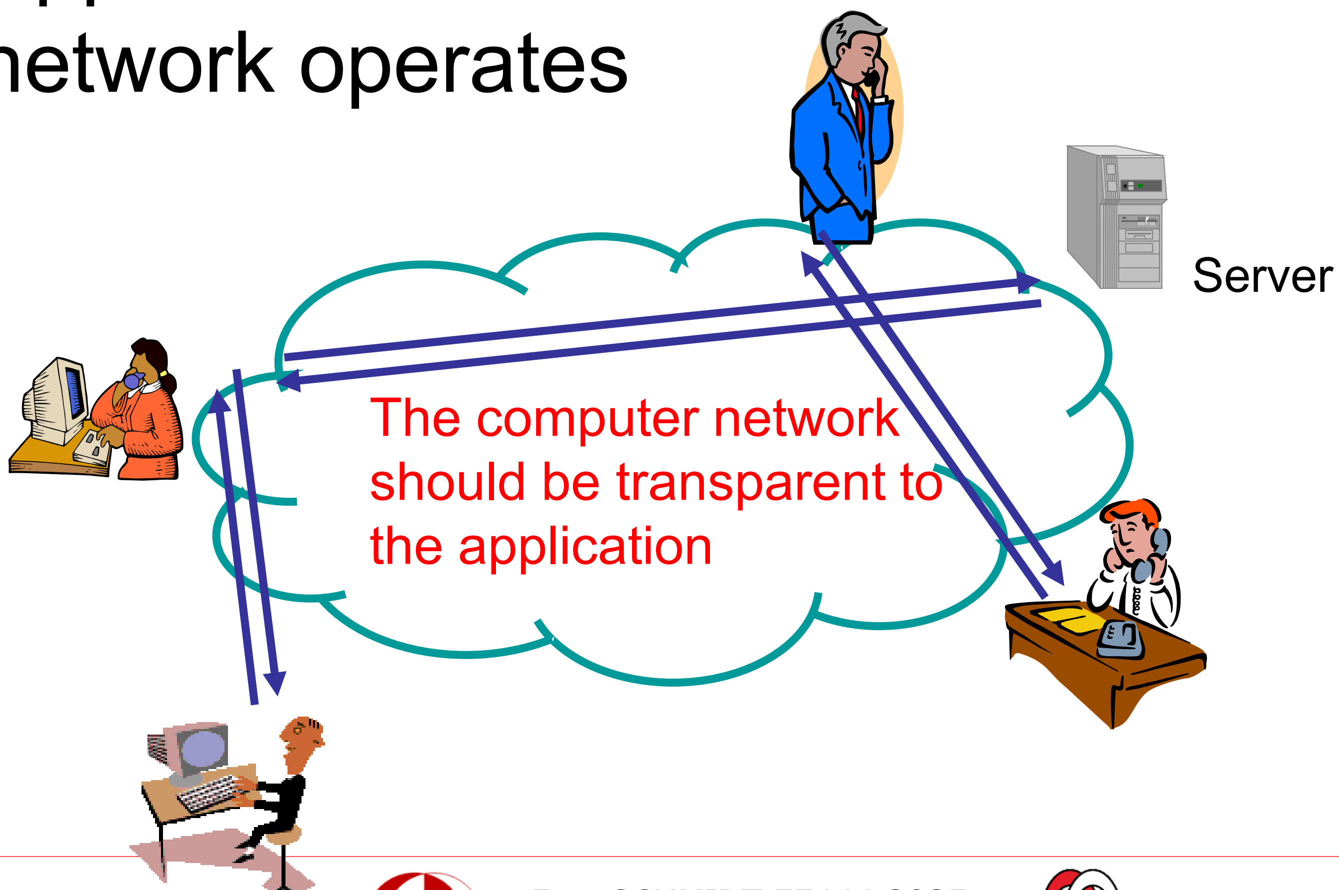
- Different applications with different requirements
- Different distances:
  - Internet, Embedded Systems, Network on Chip
- Different physical media:
  - Copper wire, optical fiber, wireless
- Different technologies:
  - Gigabit Ethernet, 3G/4G/5G Wireless, SONET-SDH
- Different speeds
  - Kbps, Mbps, Gbps

Speed of data transfer

Technology	Speed	Physical Medium	Application
Regular telephone service (POTS)	Up to 56 Kbps	twisted pair	Home and small business access
3G Wireless	21 Mbps downstream 5.8 Mbps upstream	RF in space (wireless)	Simultaneous access to different services (voice, video etc), Web surfing, instant messaging
4G (LTE Advanced)	Peak download 1Gbps Peak upload 500Mbps	RF in space (wireless)	Simultaneous access to different services (voice, video etc), Web surfing, instant messaging
Fast Ethernet	100 Mbps	100BASE-T (twisted pair); 100BASE-T (twisted pair); 100BASE-T (optical fiber)	Most popular business local area network (LAN) Workstations with 10 Mbps Ethernet cards can plug into a Fast Ethernet LAN
Gigabit Ethernet	1 Gbps	Optical fiber (and "copper" up to 100 meters)	Workstations/networks with 10/100 Mbps Ethernet plug into Gigabit Ethernet switches
OC-192	10 Gbps	Optical fiber	Backbone
OC-768	40 Gbps	Optical fiber	Backbone

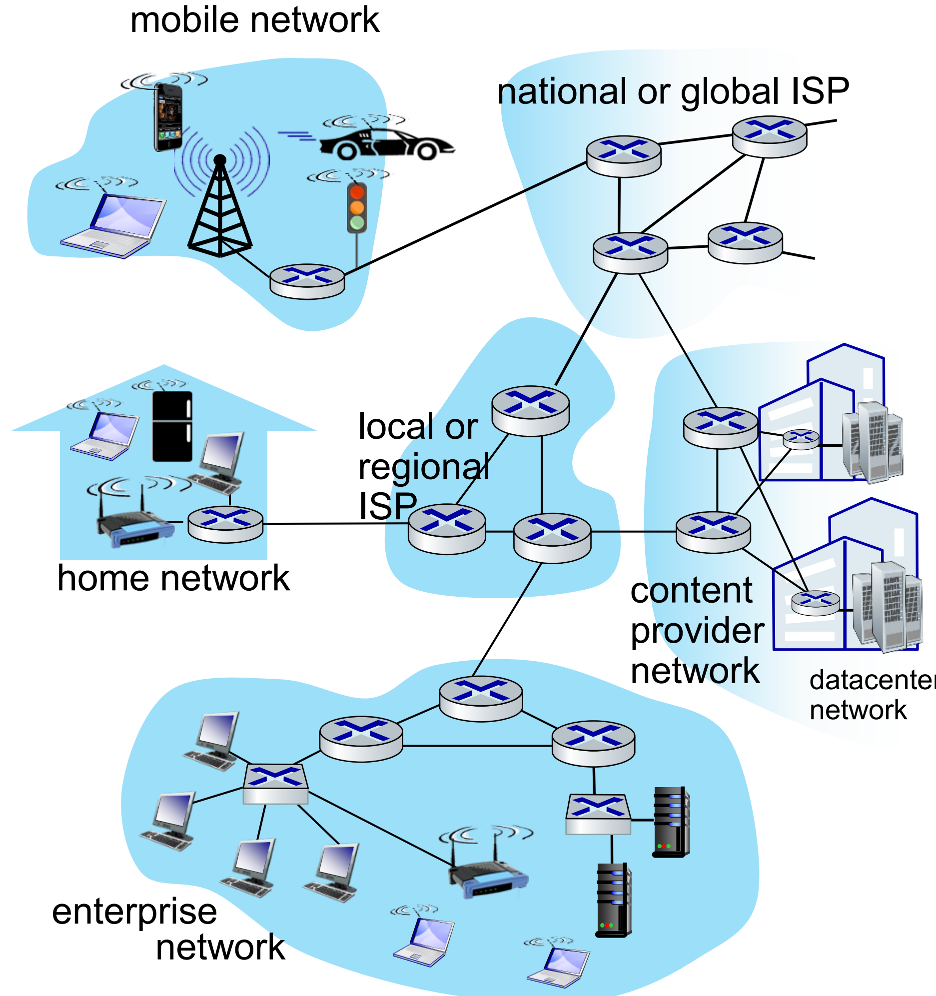
Basic Philosophy

- Applications do not need to know how the network operates



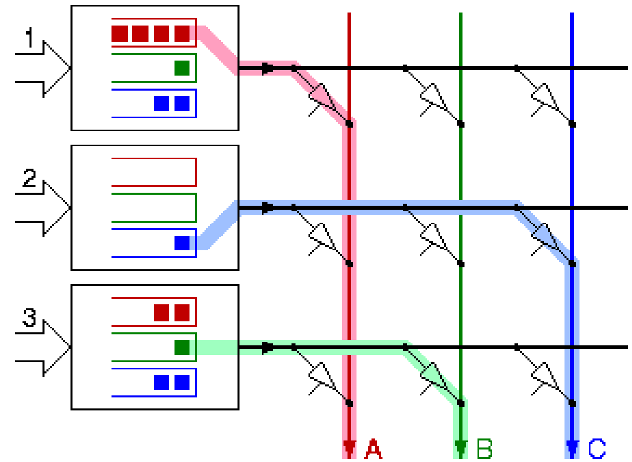
What's the Internet?

- millions of connected computing devices: *hosts = end systems*
  - running *network apps*
- *protocols:* rules of communication
- *routers:* special network devices
  - On demand connection
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate = *bandwidth*

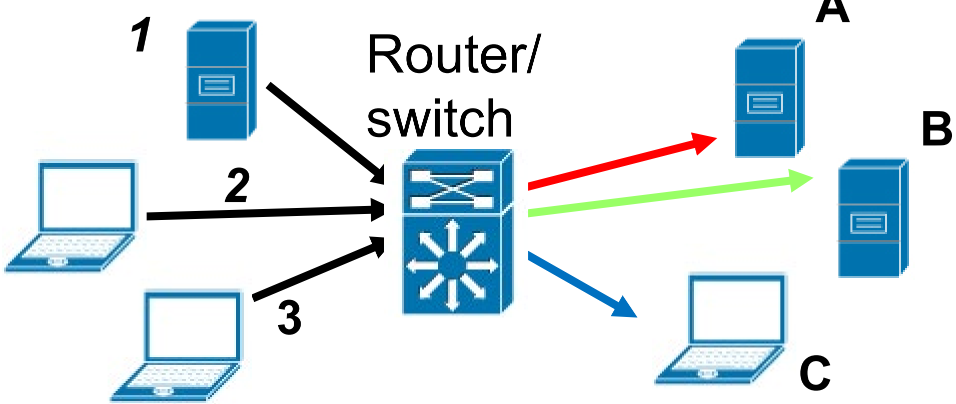


Switching: Switches and routers

- On demand N to N I/O connection:
  - Switch fabric: Special interconnection hardware in the switch/router
  - Switches packets from inputs to outputs



Inside: Crossbar switch fabric



What are the hosts?

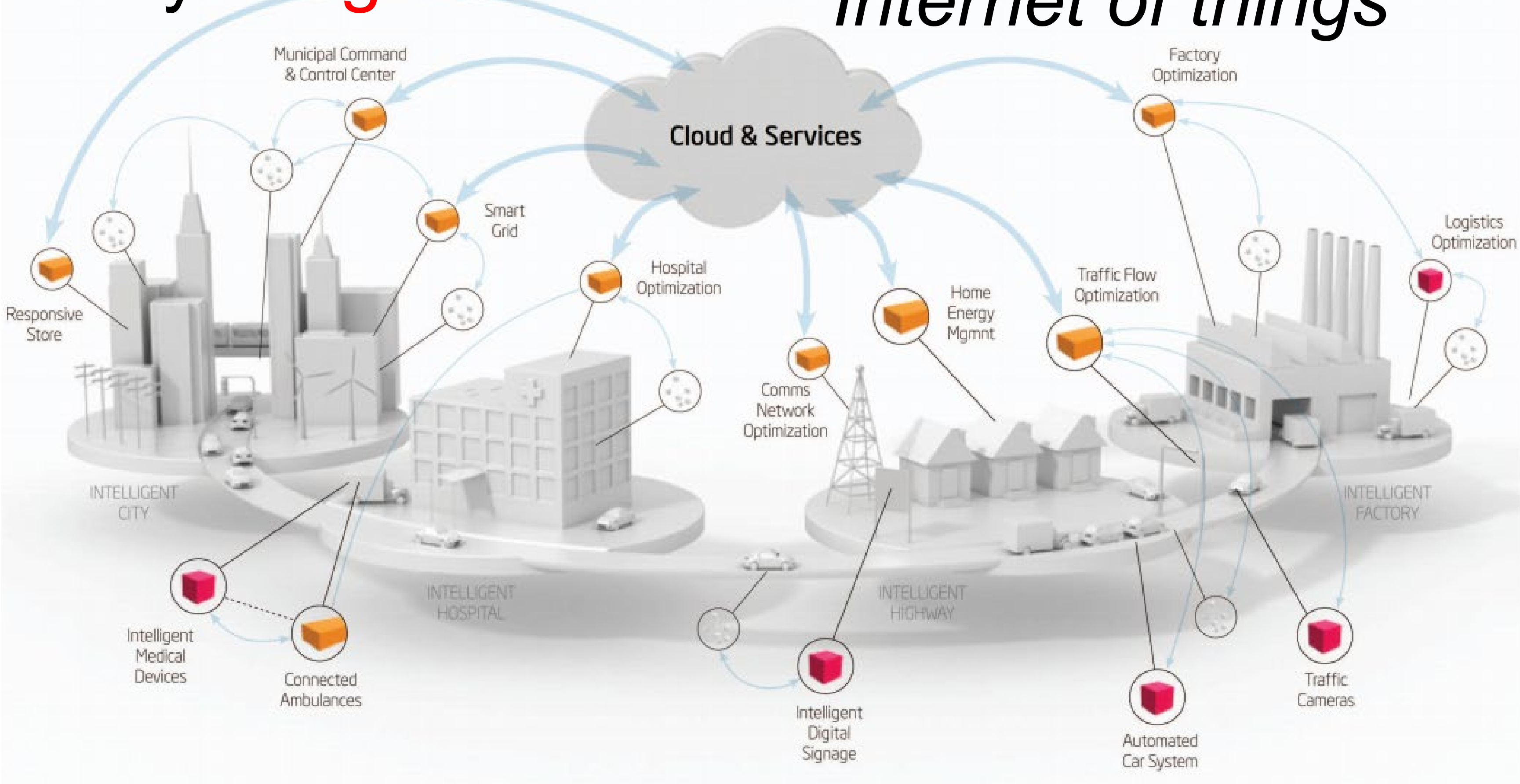
- Desktop or portable computers, smart phones
- Cars

Tesla's Full Self-Driving (FSD) Beta:
Tesla's FSD Beta operates by collecting vast amounts of data from its fleet of vehicles. This data is transmitted to Tesla's cloud servers, where it's processed to improve the neural networks that power the FSD system. The refined algorithms are then sent back to individual vehicles through over-the-air updates, enabling continuous improvement in autonomous driving capabilities.

What are the hosts?

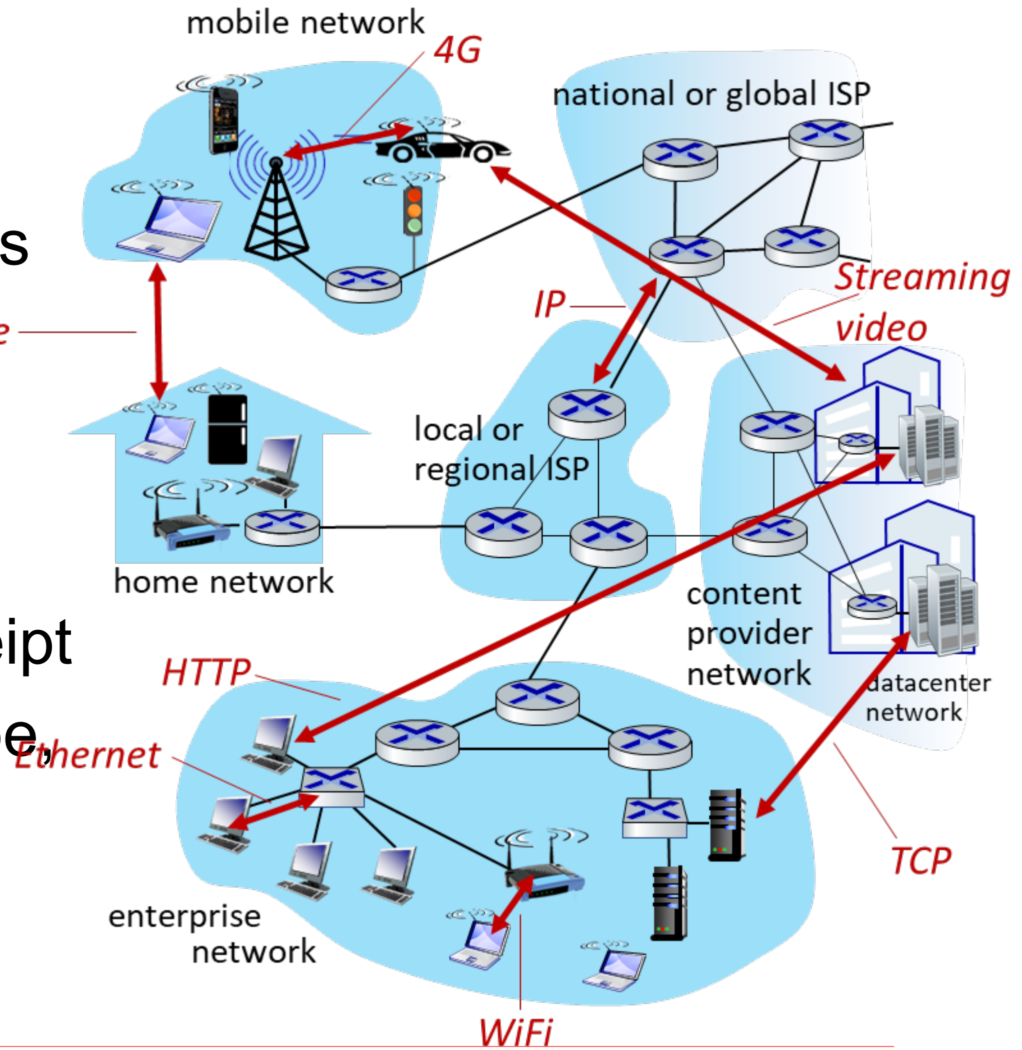
- Any thing!

"Internet of things"

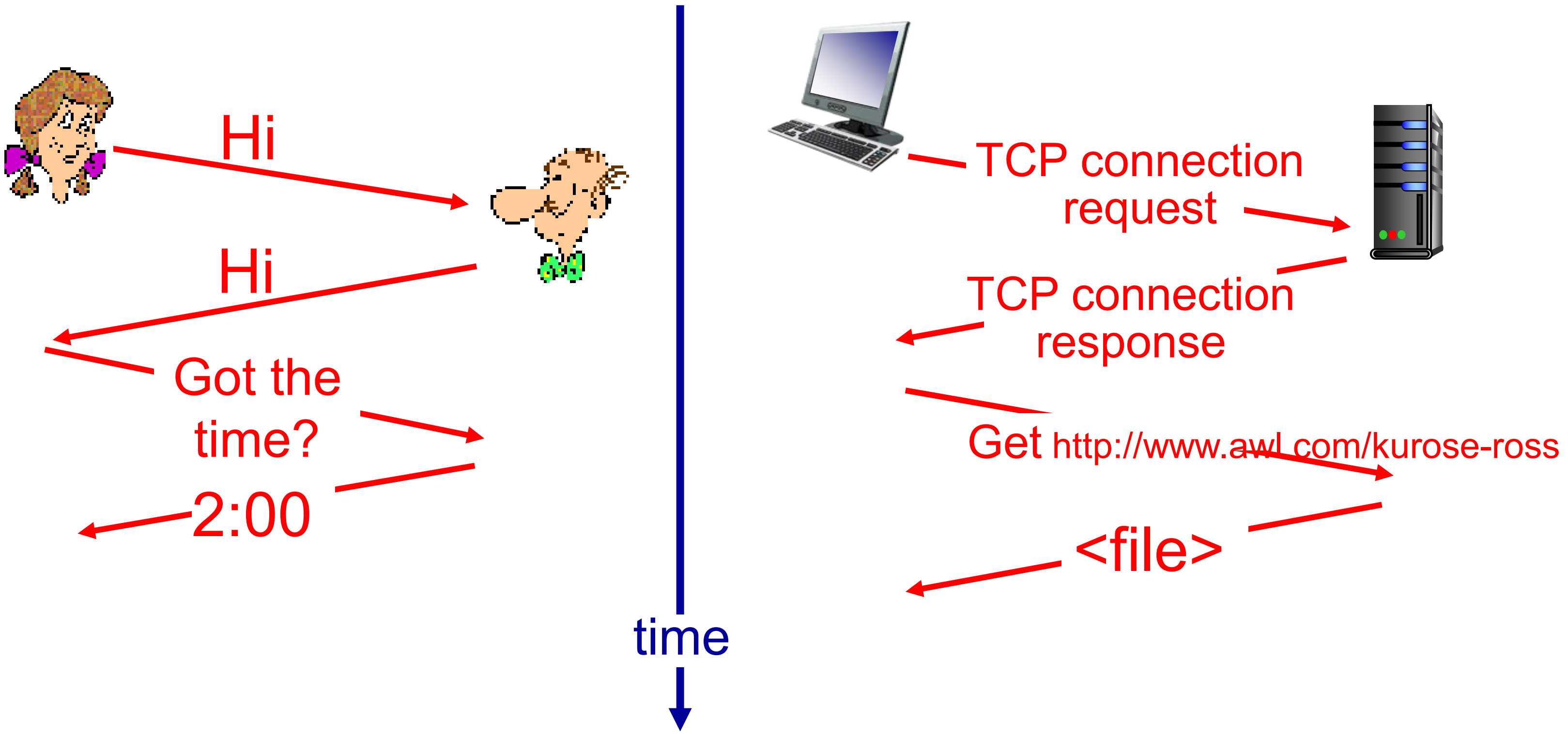


What's the Internet: Protocols

- Communications between computers require very specific unambiguous rules
- *protocols* define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt
- e.g., TCP, IP, HTTP, Skype, Ethernet



A human protocol and a computer network protocol



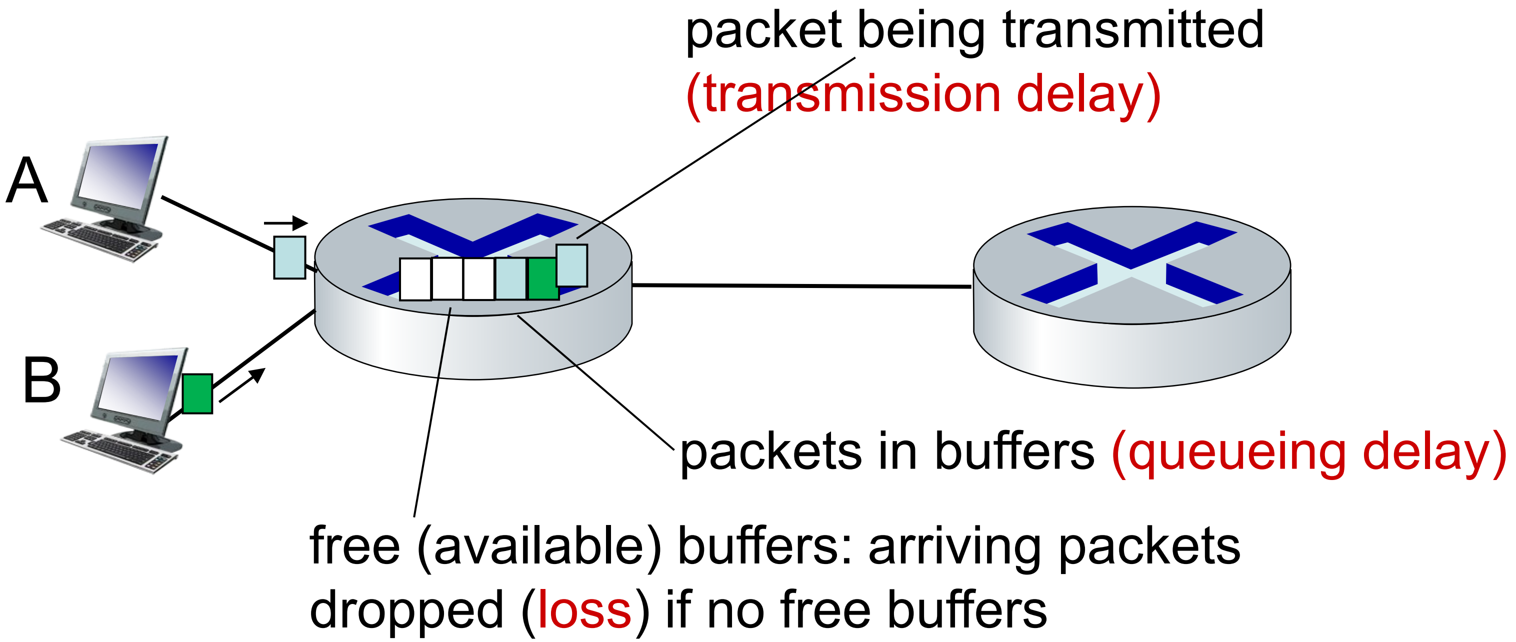
Network Performance Criteria

- Bounded delay
- Small delay variation (jitter)
- Small packet-loss probability
- Maximum Throughput~100%
- Service differentiation among classes of traffic
- Example: For high class traffic packet loss ratio$<10^{-10}$

How do loss and delay occur?

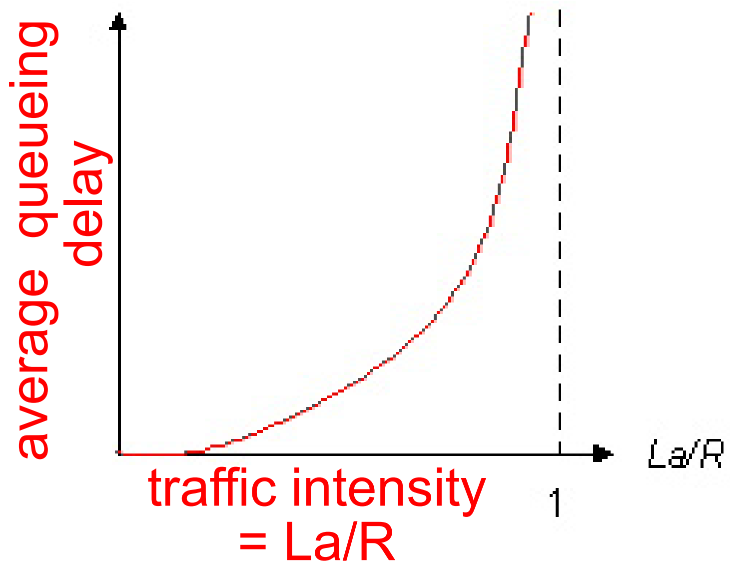
packets *queue* in router buffers

- packet arrival rate to link *temporarily* exceeds output link capacity
- packets queue, wait for turn



Queueing delay

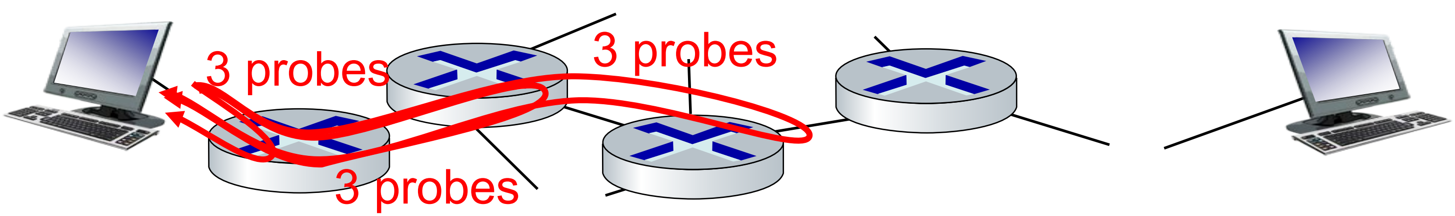
- R: link bandwidth (bps)
- L: packet length (bits)
- a: average packet arrival rate



- La/R ~ 0: avg. queueing delay small
- La/R -> 1: avg. queueing delay large
- La/R > 1: more “work” arriving
- than can be serviced, average delay infinite!

"Real" Internet delays and routes

- What do "real" Internet delay & loss look like?
- **<u>Traceroute</u>** <u>program:</u> provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender measures time interval between transmission and reply.



“Real” Internet delays and routes

tracert www.ece.cmu.edu

Three ROUNDTRIP delay measurements

Tracing route to www.ece.cmu.edu [128.2.131.66]over a maximum of 30 hops:

1	4 ms	9 ms	4 ms	eeatm.eee.metu.edu.tr [144.122.166.1]
2	1 ms	1 ms	1 ms	rt1.metu.edu.tr [144.122.2.1]
3	40 ms	44 ms	29 ms	144.122.1.21
4	12 ms	3 ms	3 ms	193.140.85.137
5	10 ms	12 ms	11 ms	193.140.0.150
6	31 ms	32 ms	32 ms	ulakbim.mx1.bud.hu.geant.net [62.40.125.129]
7	46 ms	46 ms	46 ms	62.40.98.47
8	136 ms	136 ms	140 ms	internet2-gw.mx1.fra.de.geant.net [62.40.125.18]
9	142 ms	142 ms	142 ms	internet2-re-wash.3rox.net [192.88.115.82]
10	146 ms	146 ms	146 ms	pod-i-nh.cmu.3rox.net [147.73.16.121]
11	147 ms	148 ms	147 ms	CORE0-POD-I-DCNS.GW.CMU.NET [128.2.0.193]
12	143 ms	143 ms	143 ms	POD-A-CORE0.GW.CMU.NET [128.2.0.154]
13	144 ms	145 ms	144 ms	ECE-RTR-POD-A-CYH.GW.CMU.NET [128.2.35.210]
14	146 ms	146 ms	147 ms	WWW.ECE.CMU.EDU [128.2.131.66]

Trace complete.

Network Organization

Networks are complex, with many "pieces":

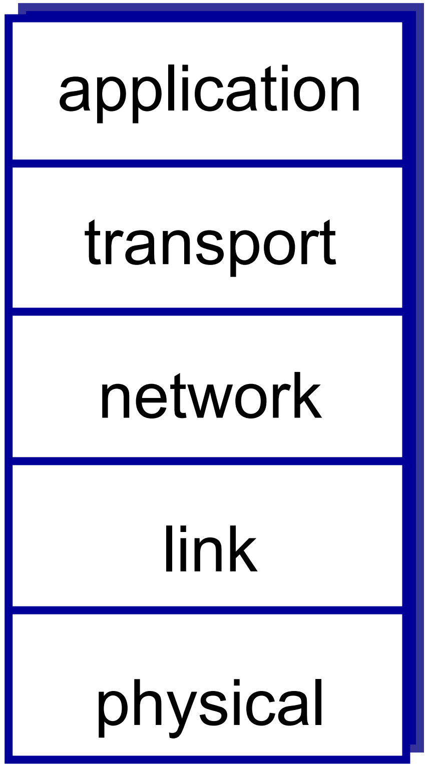
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

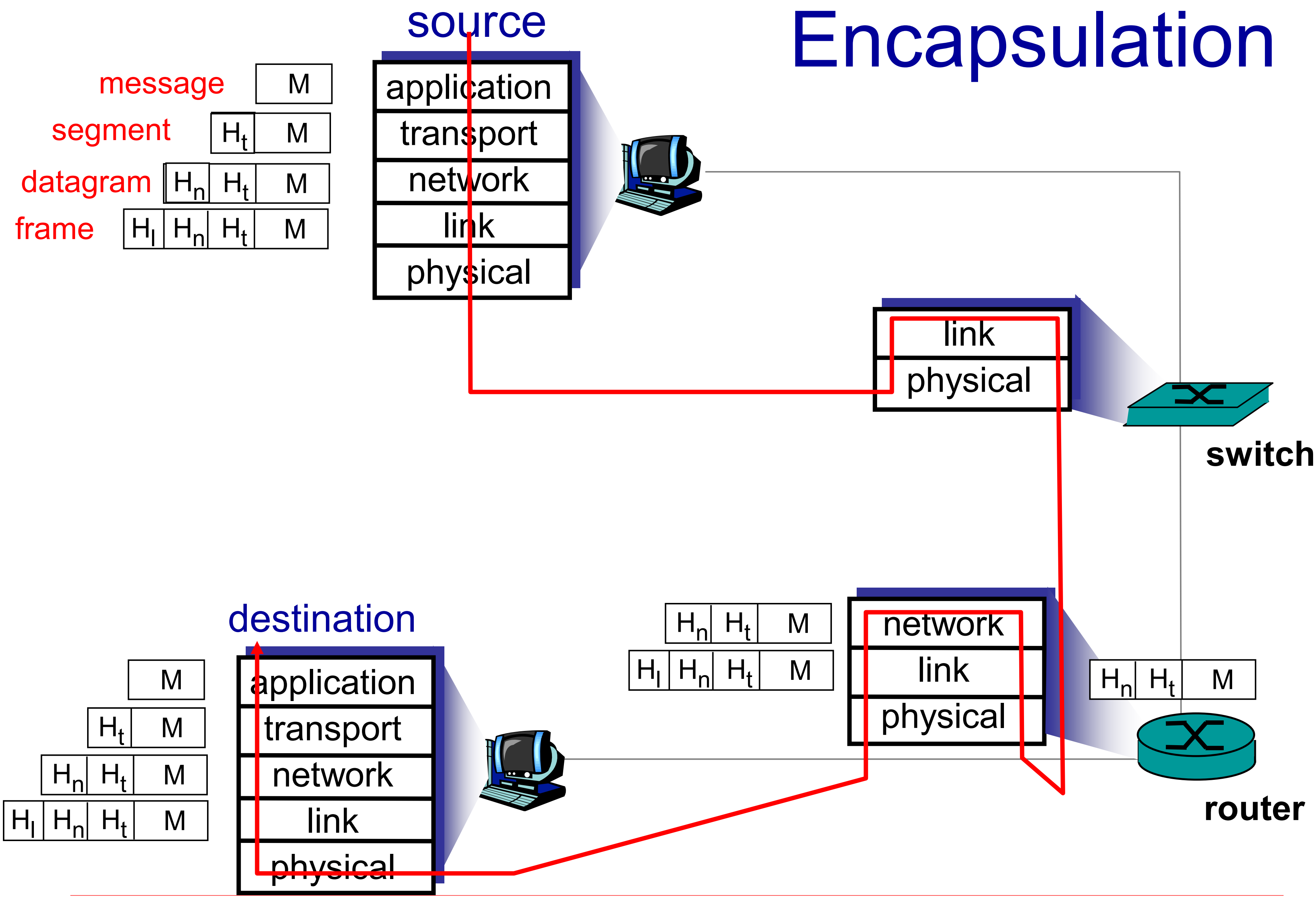
Is there any hope of *organizing* structure of network?

Solution: Internet protocol stack

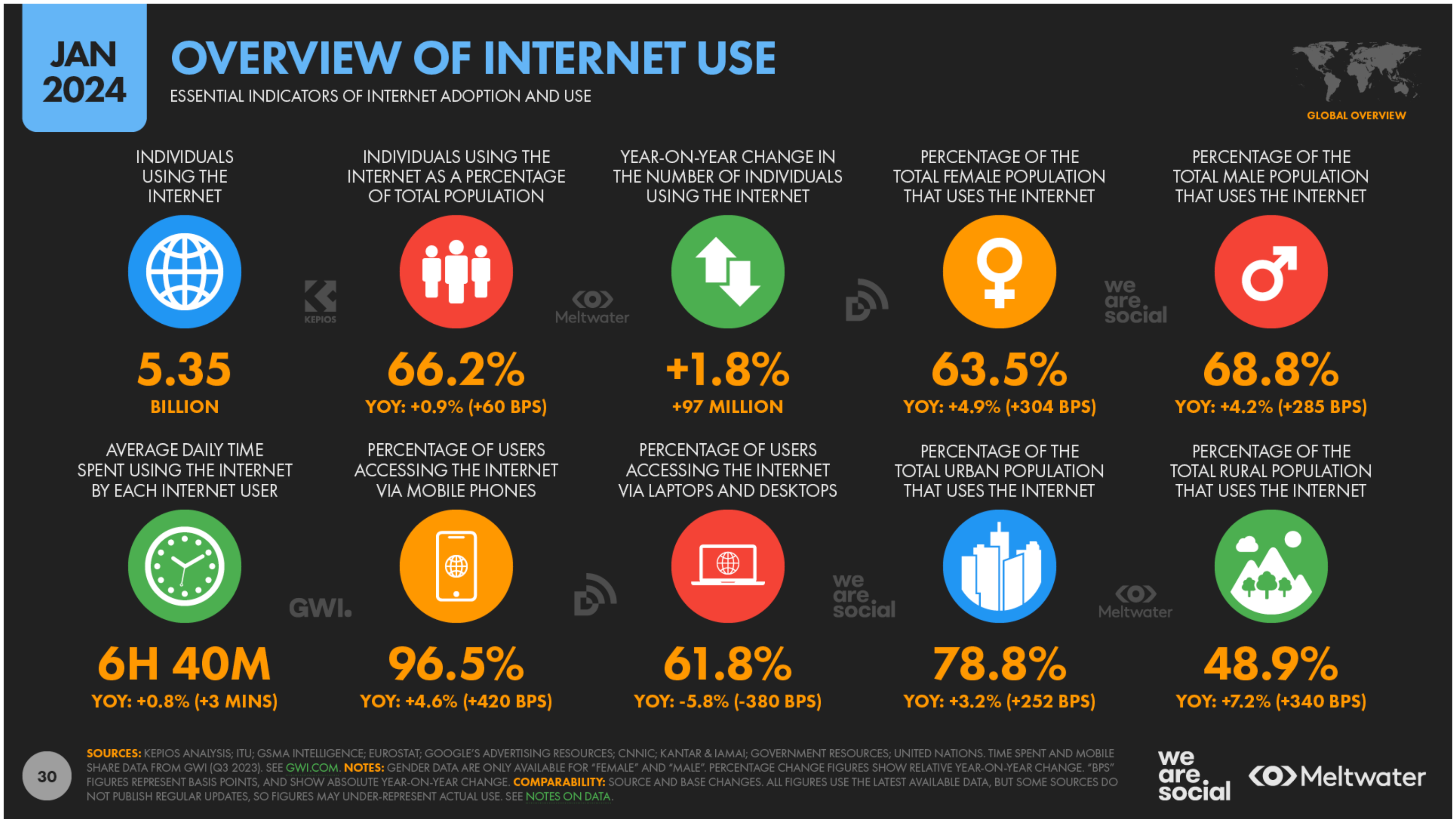
- application: supporting network applications
  - FTP, SMTP, HTTP
- transport: process-process data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- physical: bits “on the wire”



Encapsulation

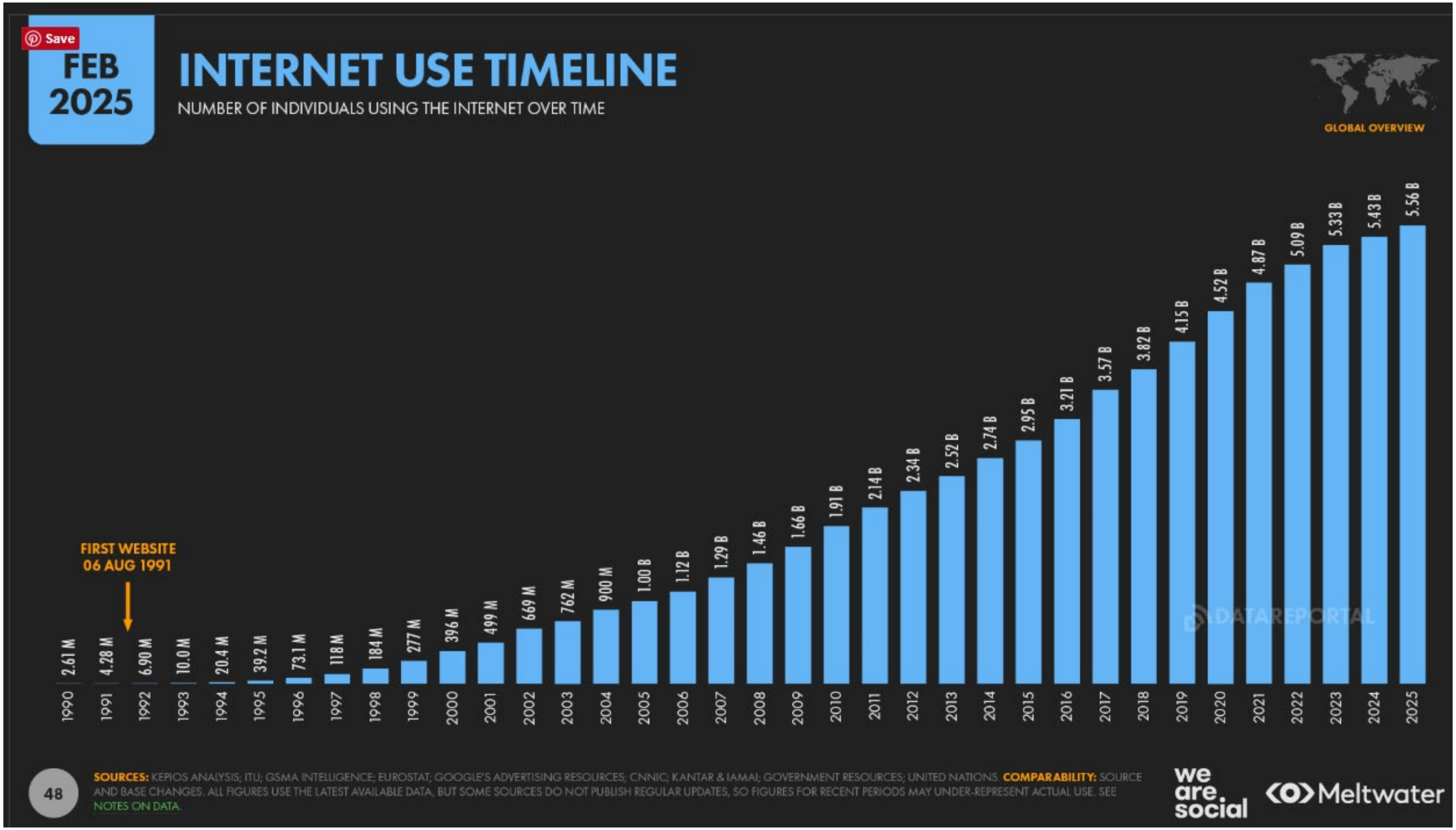


Current Internet

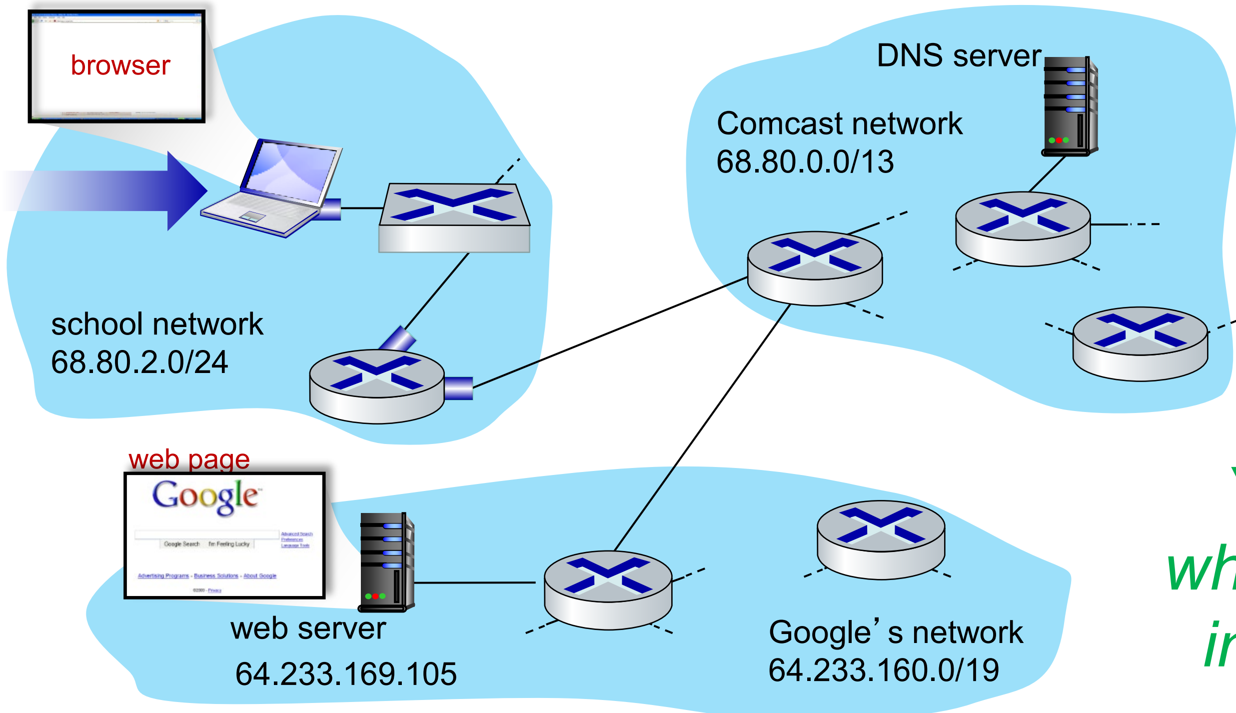


https://datareportal.com/reports/digital-2024-deep-dive-the-state-of-internet-adoption

Current Internet



At end of the course



scenario:

- arriving mobile client attaches to network …
- requests web page: www.google.com

You know what happens in all detail!! !

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Spring 2025