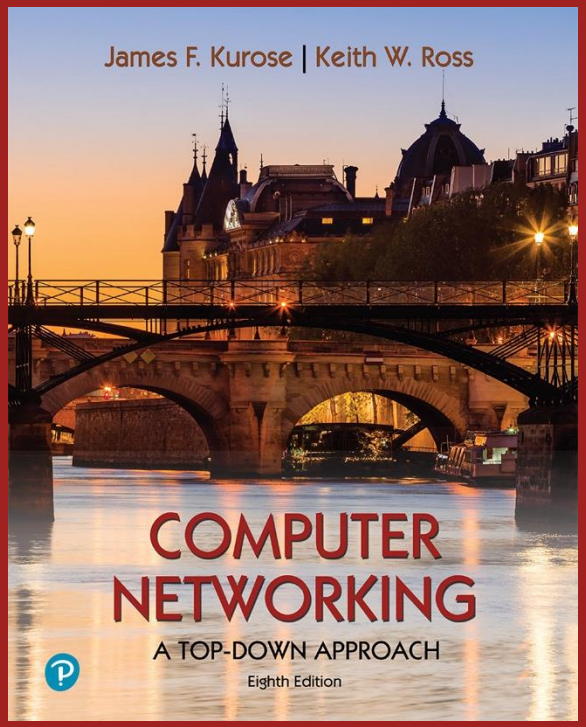


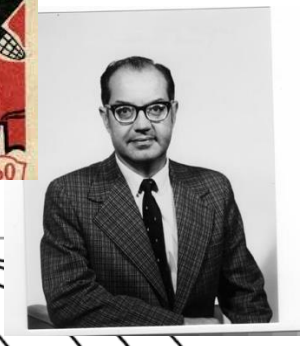
Chapter 1
Computer Networks and the Internet

Computer Networking
A Top-Down Approach
8th Edition, 2020
Pearson,
James F. Kurose, Keith W. Ross

A bit of history

designing a network to survive a nuclear attack

Paul Baran

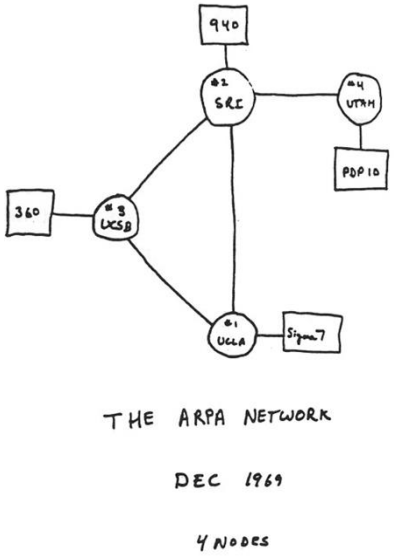


1st network
Interconnecting
2 computers

Leonard Kleinrock

First message on the Internet was …

US government
ARPANET project



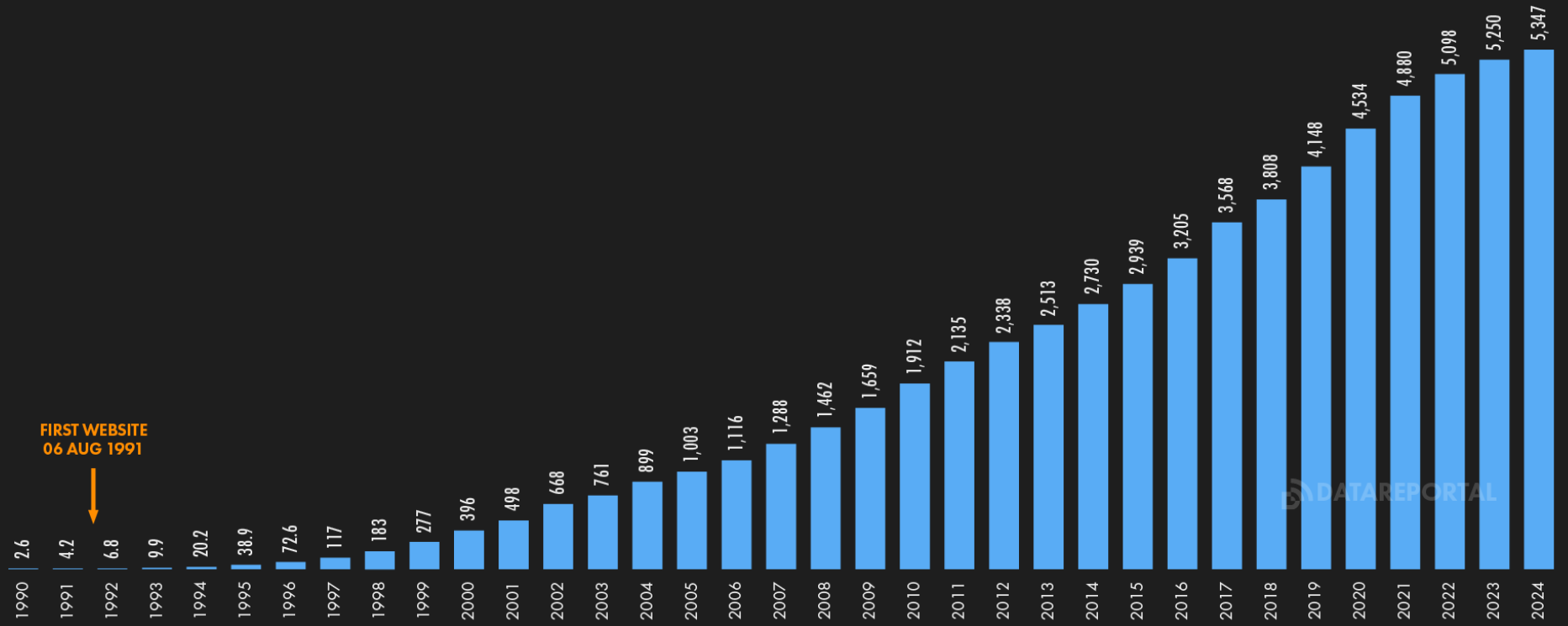
1964 — 1966 — 1969

JAN 2024

INTERNET USE TIMELINE

NUMBER OF INDIVIDUALS USING THE INTERNET OVER TIME (IN MILLIONS)

GLOBAL OVERVIEW



SOURCES: KEPIOS ANALYSIS; ITU; GSMA INTELLIGENCE; EUROSTAT; GOOGLE'S ADVERTISING RESOURCES; CNNIC; KANTAR & IAMAI; GOVERNMENT RESOURCES; UNITED NATIONS. **COMPARABILITY:** SOURCE AND BASE CHANGES. ALL FIGURES USE THE LATEST AVAILABLE DATA, BUT SOME SOURCES DO NOT PUBLISH REGULAR UPDATES, SO FIGURES FOR RECENT PERIODS MAY UNDER-REPRESENT ACTUAL USE. SEE NOTES ON DATA.

we are social Meltwater

JAN 2024

OVERVIEW OF INTERNET USE

ESSENTIAL INDICATORS OF INTERNET ADOPTION AND USE

INDIVIDUALS USING THE INTERNET

5.35
BILLION

INDIVIDUALS USING THE INTERNET AS A PERCENTAGE OF TOTAL POPULATION

66.2%
YOY: +0.9% (+60 BPS)

YEAR-ON-YEAR CHANGE IN THE NUMBER OF INDIVIDUALS USING THE INTERNET

+1.8%
+97 MILLION

PERCENTAGE OF THE TOTAL FEMALE POPULATION THAT USES THE INTERNET

63.5%
YOY: +4.9% (+304 BPS)

PERCENTAGE OF THE TOTAL MALE POPULATION THAT USES THE INTERNET

68.8%
YOY: +4.2% (+285 BPS)

AVERAGE DAILY TIME SPENT USING THE INTERNET BY EACH INTERNET USER

6H 40M
YOY: +0.8% (+3 MINS)

PERCENTAGE OF USERS ACCESSING THE INTERNET VIA MOBILE PHONES

96.5%
YOY: +4.6% (+420 BPS)

PERCENTAGE OF USERS ACCESSING THE INTERNET VIA LAPTOPS AND DESKTOPS

61.8%
YOY: -5.8% (-380 BPS)

PERCENTAGE OF THE TOTAL URBAN POPULATION THAT USES THE INTERNET

78.8%
YOY: +3.2% (+252 BPS)

PERCENTAGE OF THE TOTAL RURAL POPULATION THAT USES THE INTERNET

48.9%
YOY: +7.2% (+340 BPS)

SOURCES: KEPIOS ANALYSIS; ITU; GSMA INTELLIGENCE; EUROSTAT; GOOGLE'S ADVERTISING RESOURCES; CNNIC; KANTAR & IAMAI; GOVERNMENT RESOURCES; UNITED NATIONS. TIME SPENT AND MOBILE SHARE DATA FROM GWI (Q3 2023). SEE GWI.COM. **NOTES:** GENDER DATA ARE ONLY AVAILABLE FOR "FEMALE" AND "MALE". PERCENTAGE CHANGE FIGURES SHOW RELATIVE YEAR-ON-YEAR CHANGE. "BPS" FIGURES REPRESENT BASIS POINTS, AND SHOW ABSOLUTE YEAR-ON-YEAR CHANGE. **COMPARABILITY:** SOURCE AND BASE CHANGES. ALL FIGURES USE THE LATEST AVAILABLE DATA, BUT SOME SOURCES DO NOT PUBLISH REGULAR UPDATES, SO FIGURES MAY UNDER-REPRESENT ACTUAL USE. SEE NOTES ON DATA.

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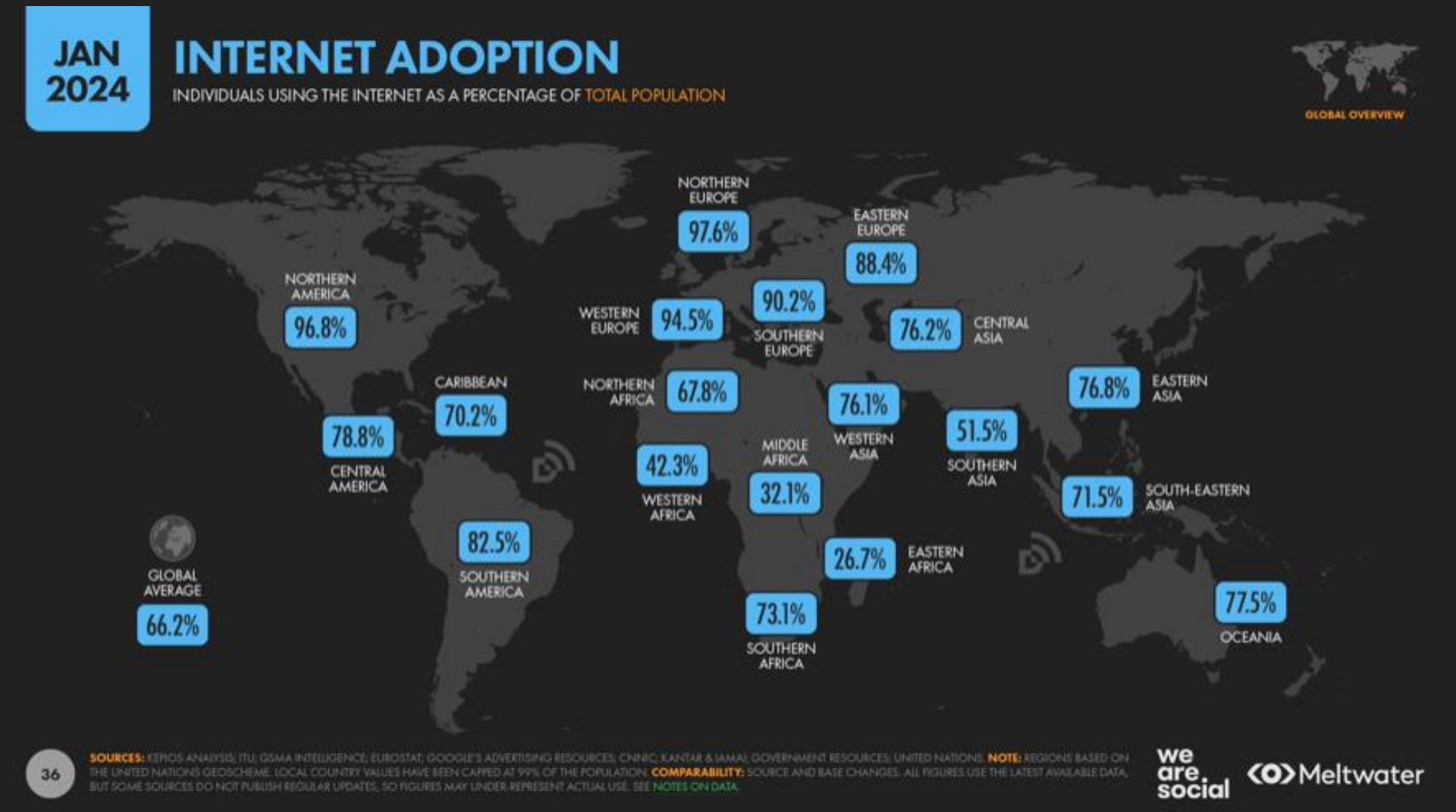

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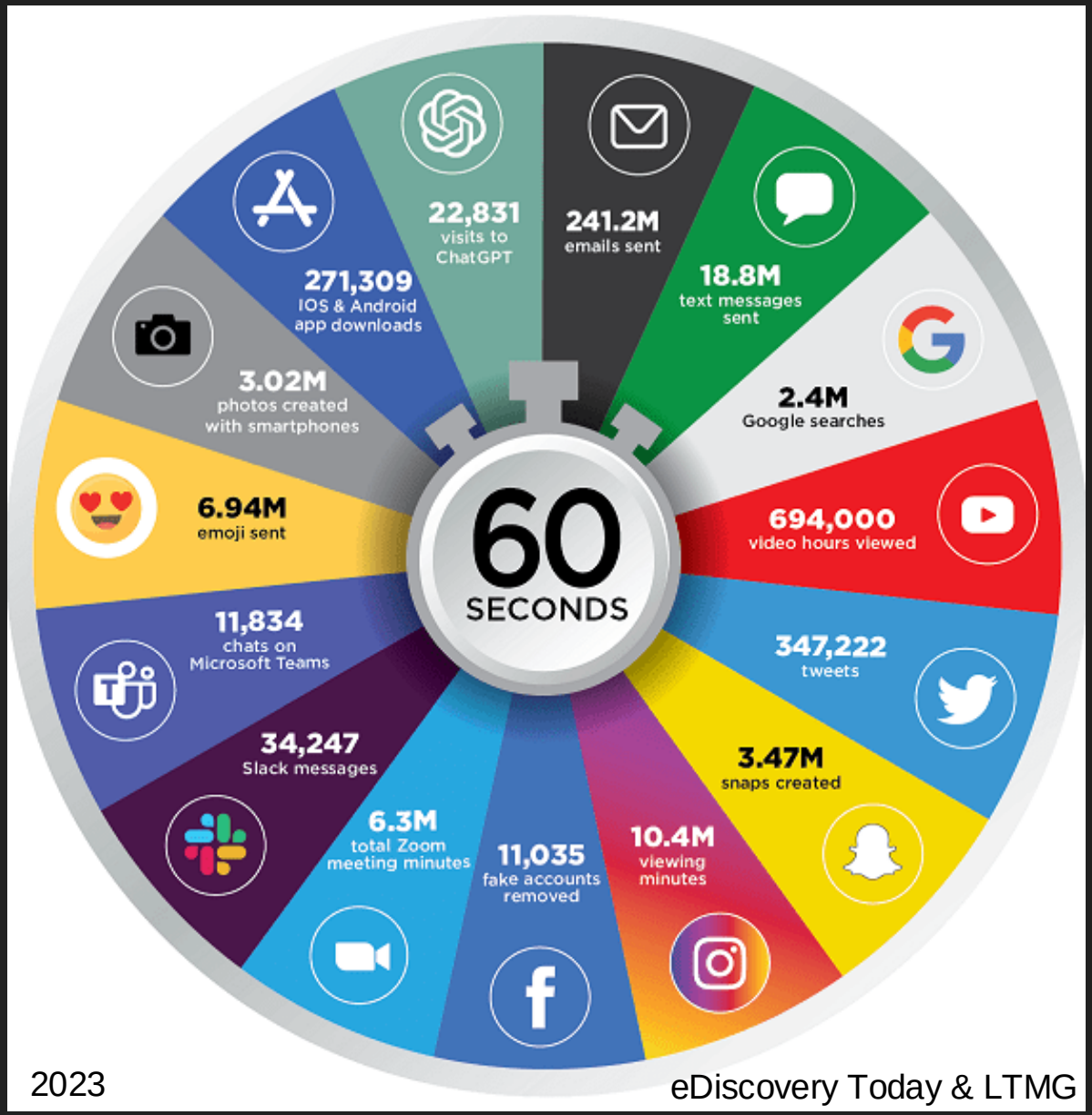
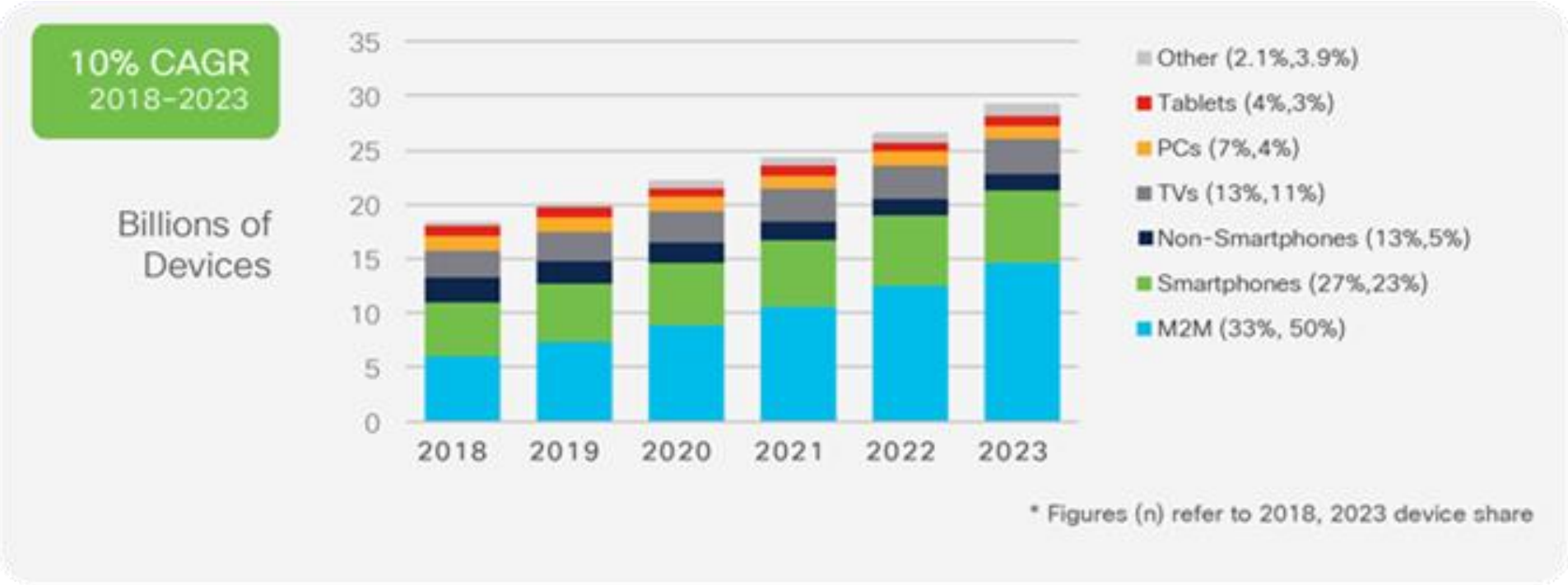
What are Internet Services are used in 1 minute?



2023

eDiscovery Today & LTMG

Which devices connect to the Internet?



Cisco Annual Internet Report 2018-2023

Internet-connected devices

Internet refrigerator

Amazon Echo

IP picture frame

Pacemaker & Monitor

Tweet-a-watt: monitor energy use

bikes

Web-enabled toaster + weather forecaster

cars

Security Camera

Slingbox: remote control cable TV

AR devices

scooters

Internet phones

Gaming devices

sensorized, bed mattress

Fitbit

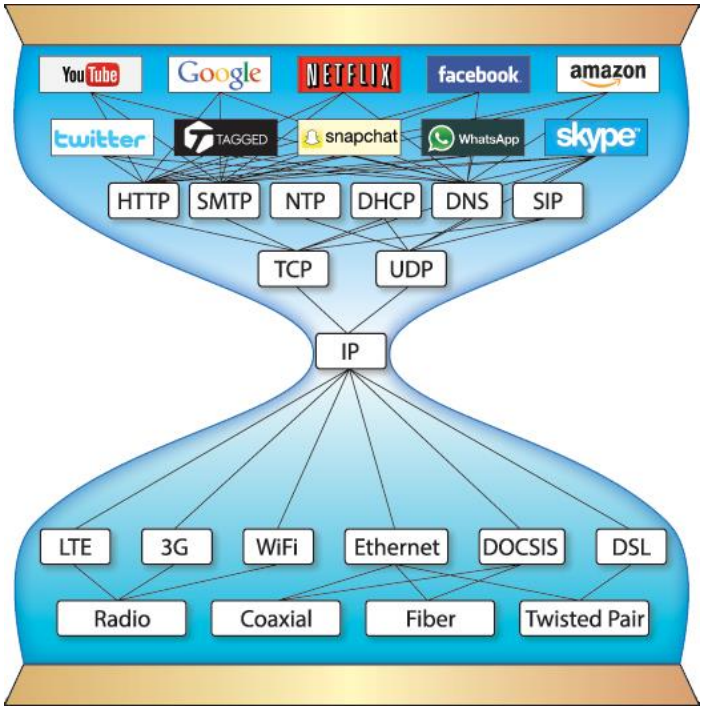
The Internet is transforming everything

- The ways we do business
  - E-commerce, advertising, cloud computing, ...
- The way we have relationships
  - E-mail, IM, Facebook friends, virtual worlds
- How we think about law
  - National boundaries, Wikileaks
- The way we govern
  - E-voting and E-government and fake news
  - Censorship and wiretapping
- The way we fight
  - Cyber-attacks, including nation-state attacks

Chapter 1: Introduction

Our goal:

- Learn how the Internet works
- Learn how to use the Internet
- Learn the underlying principles and > 80 % of technologies used today
  - TCP+UDP, IP, Ethernet
- Not about mobile communications
  ➔ *Mobile And Broadband Access Networks*



Chapter 1 outline

1.1 what is the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

[**1.4** delay, loss, throughput in networks]

1.5 protocol layers, service models

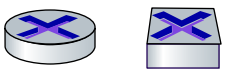
[**1.6** networks under attack: security]

[**1.7** 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)

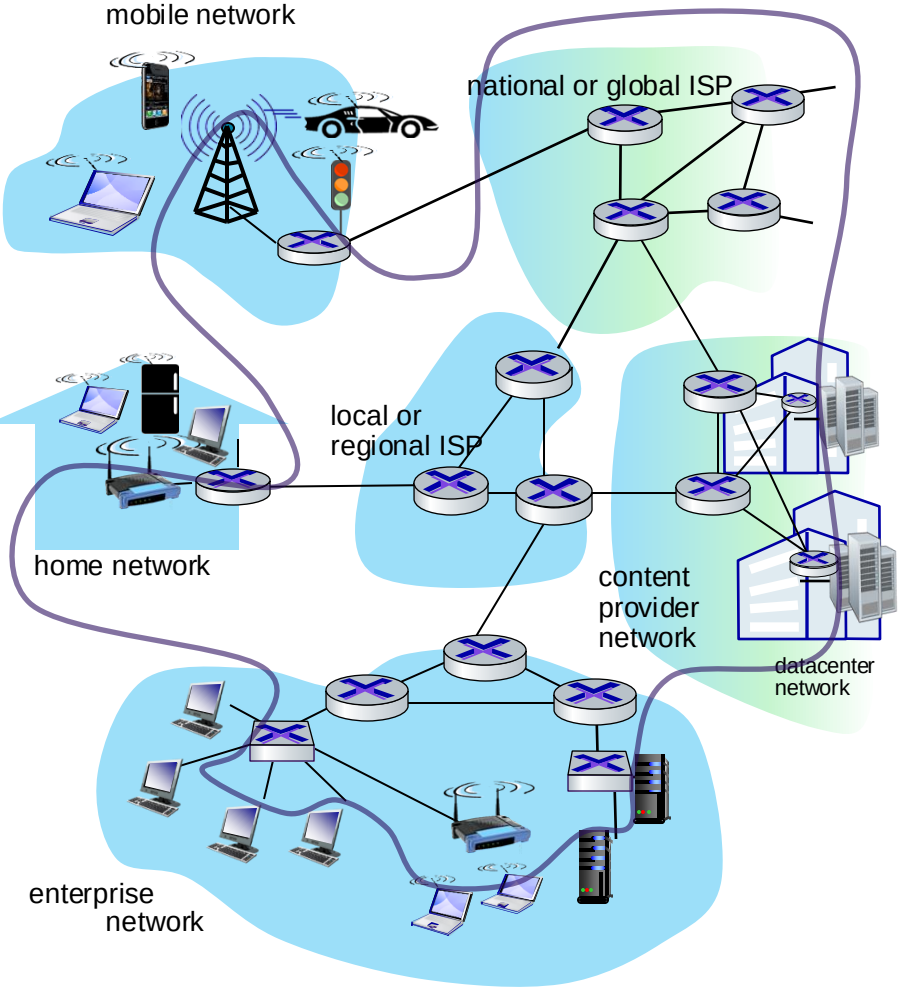
- *routers*, *switches*

Communication links

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

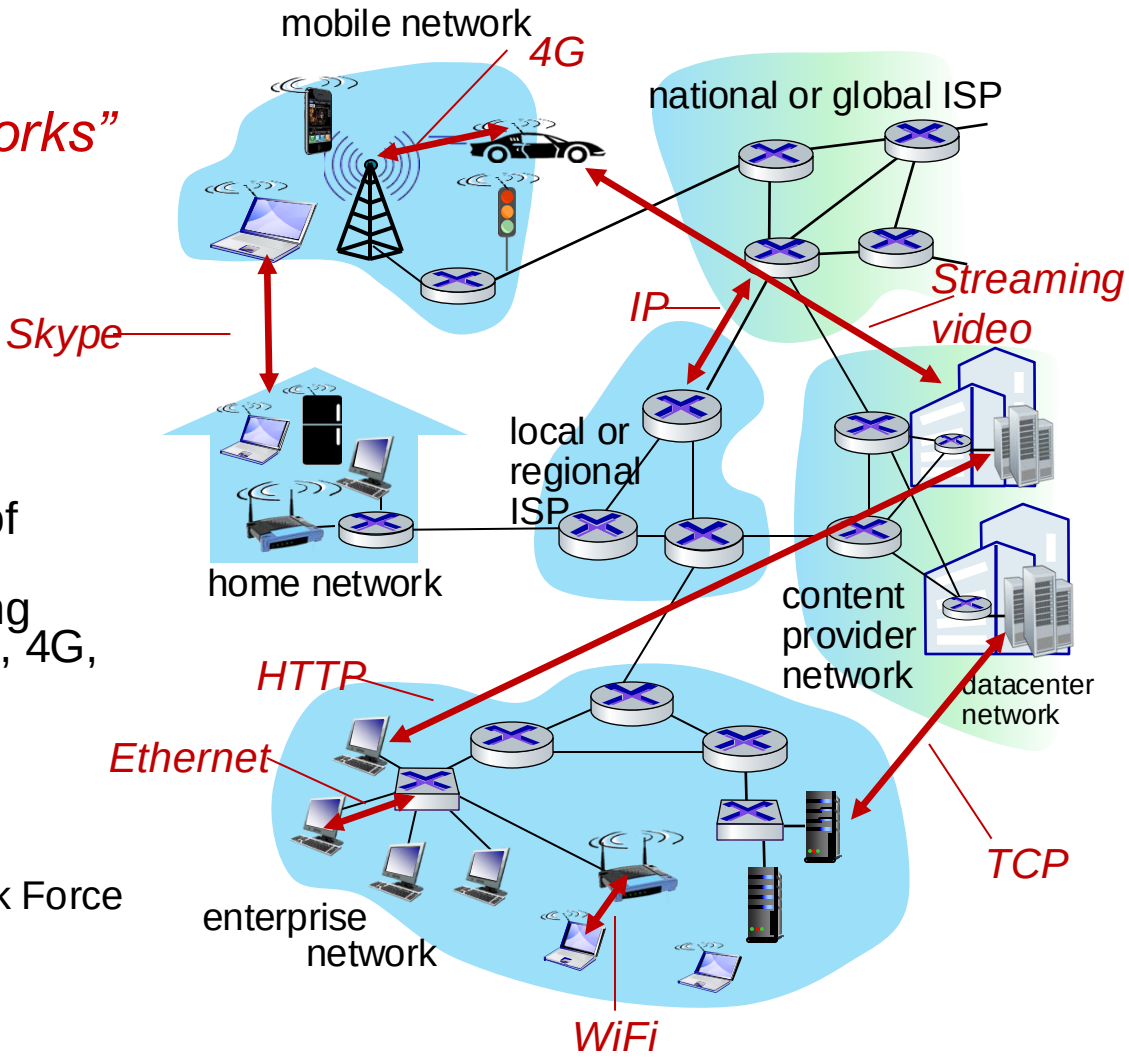
Networks

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



The Internet: a "nuts and bolts" 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, 4G, Ethernet
- *Internet standards*
  - **IETF**: Internet Engineering Task Force
    - RFC: Request for Comments
  - **IEEE**: Institute of Electrical and Electronics Engineers
  - **ITU-T**: International Telecommunication Union - Telecommunications



What's a protocol?

human protocols:

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

… specific messages sent

… specific actions taken when messages received, or other events

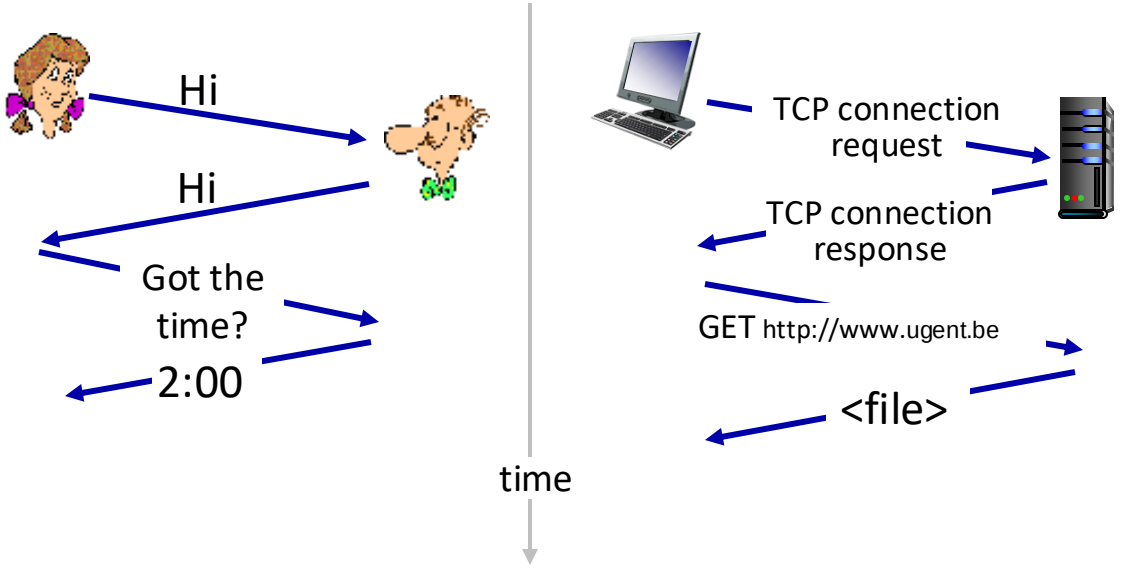
network protocols:

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

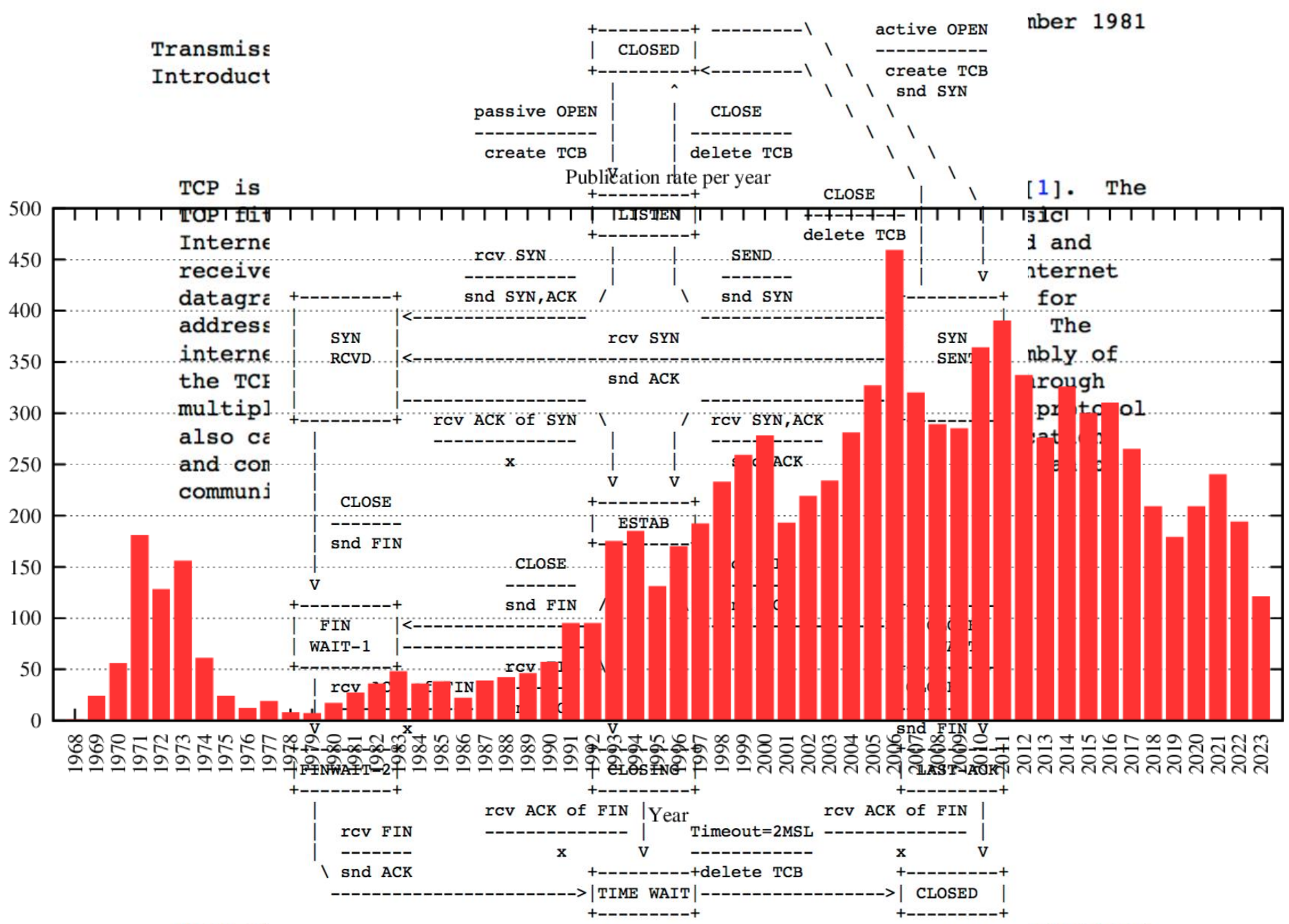
protocols define **format**, **order** of **messages sent and received** among network entities, and **actions taken** on message transmission, receipt

What's a protocol?

A human protocol and a computer network protocol:



Q: other human protocols?



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TCP Connection State Diagram
Figure 6.

Chapter 1 outline

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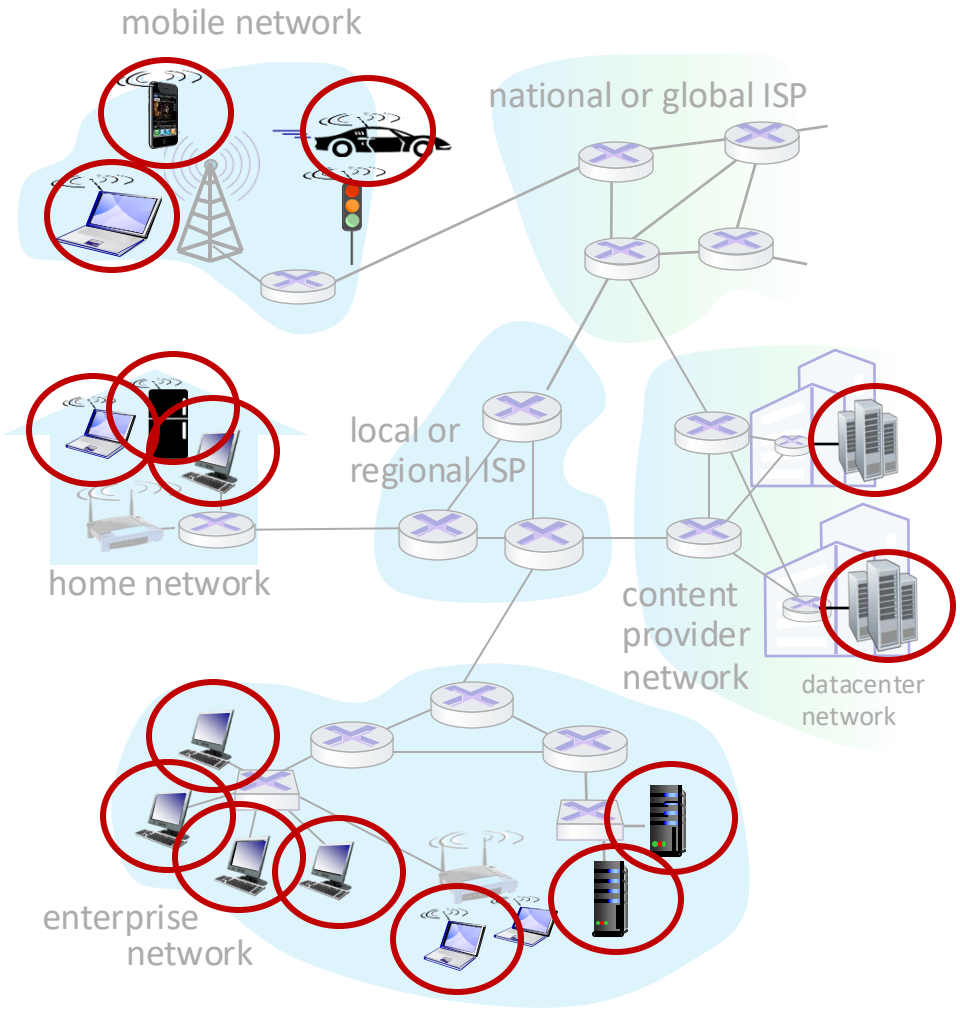
A closer look at Internet structure

Network edge:

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



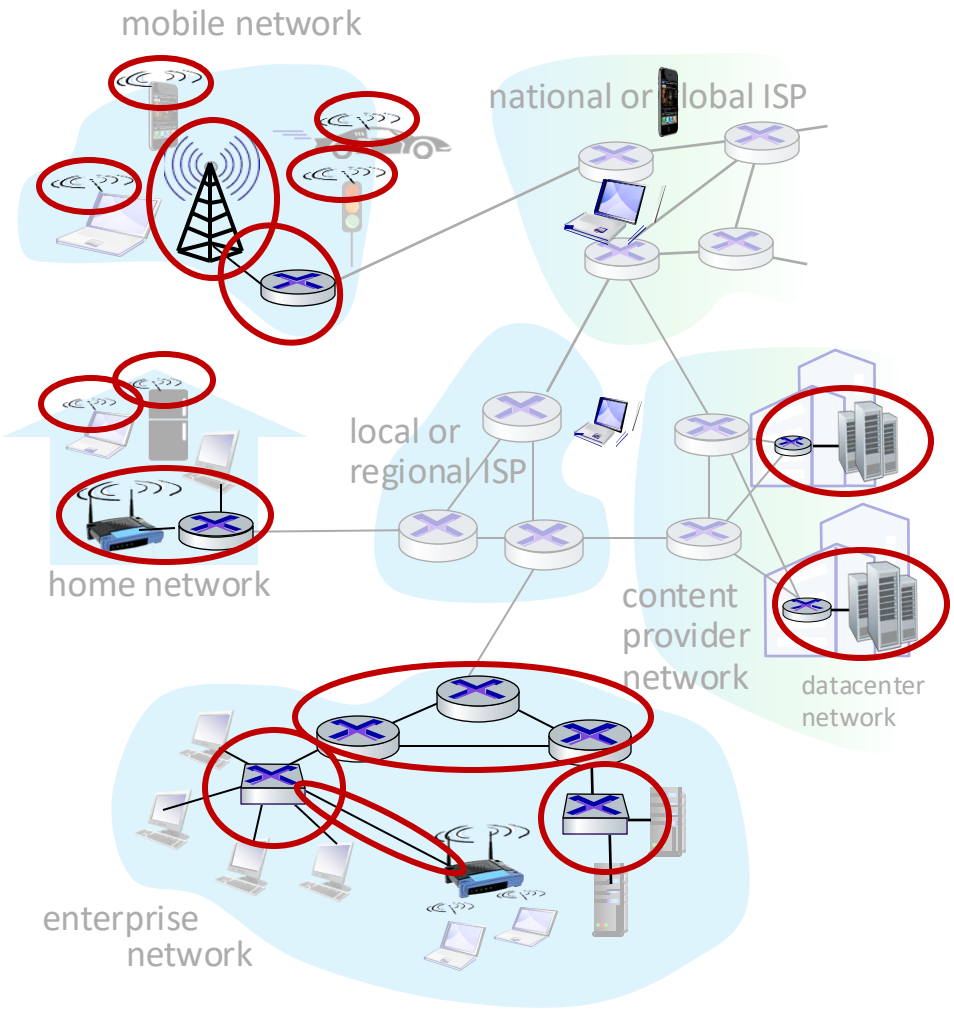
A closer look at Internet structure

Network edge:

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

Access networks, physical media:

- wired, wireless communication links



A closer look at Internet structure

Network edge:

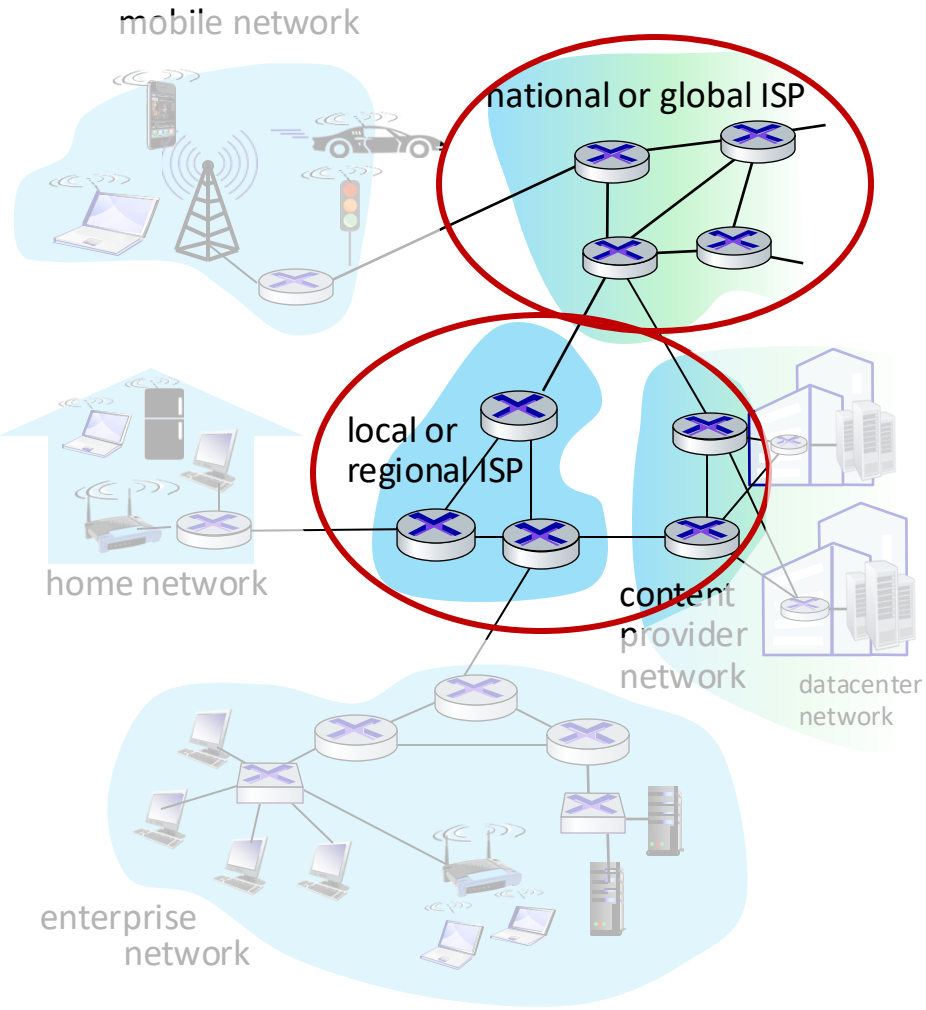
- hosts: clients and servers
- servers often in data centers

Access networks, physical media:

- wired, wireless communication links

Network core:

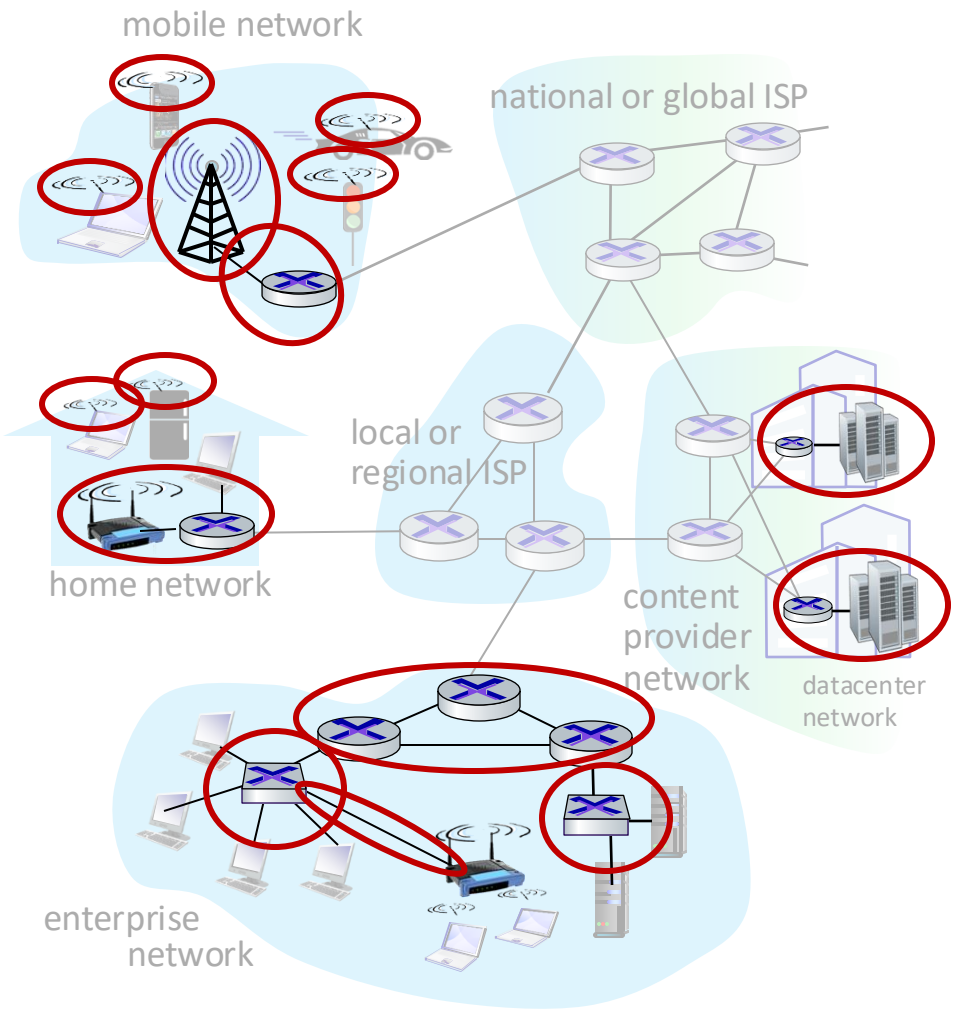
- interconnected routers
- network of networks



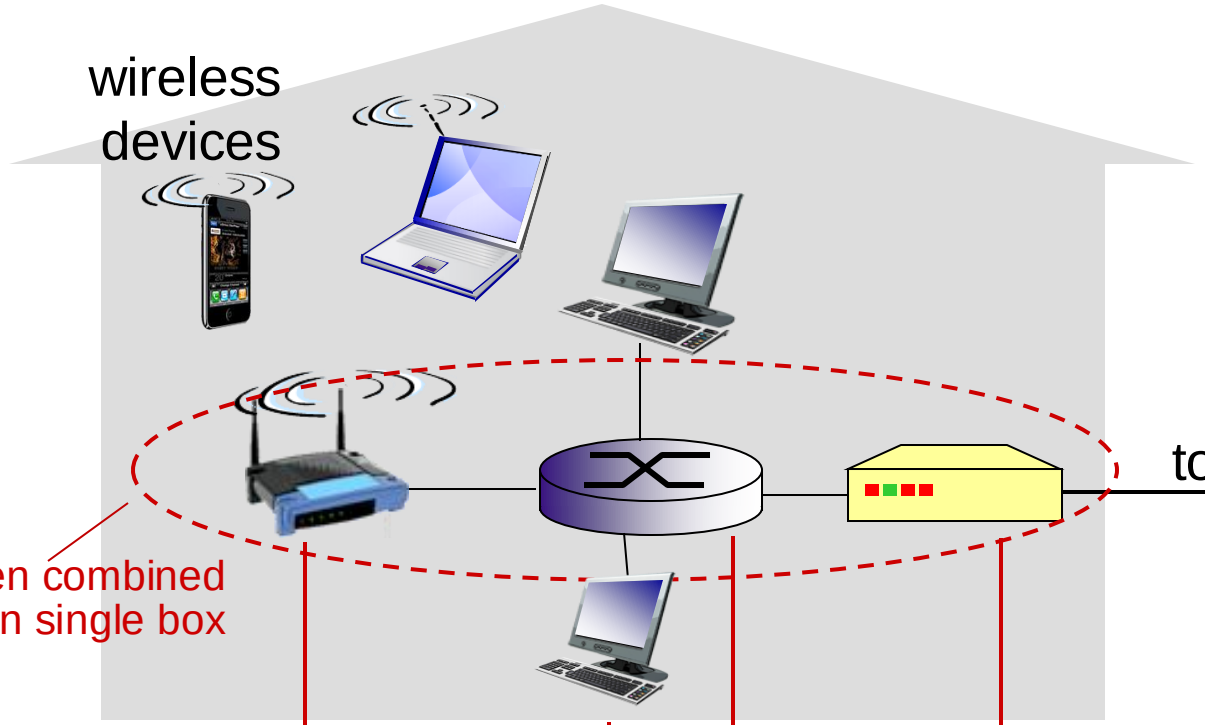
Access networks

Q: How to connect end systems to edge router?

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



Access net: home network

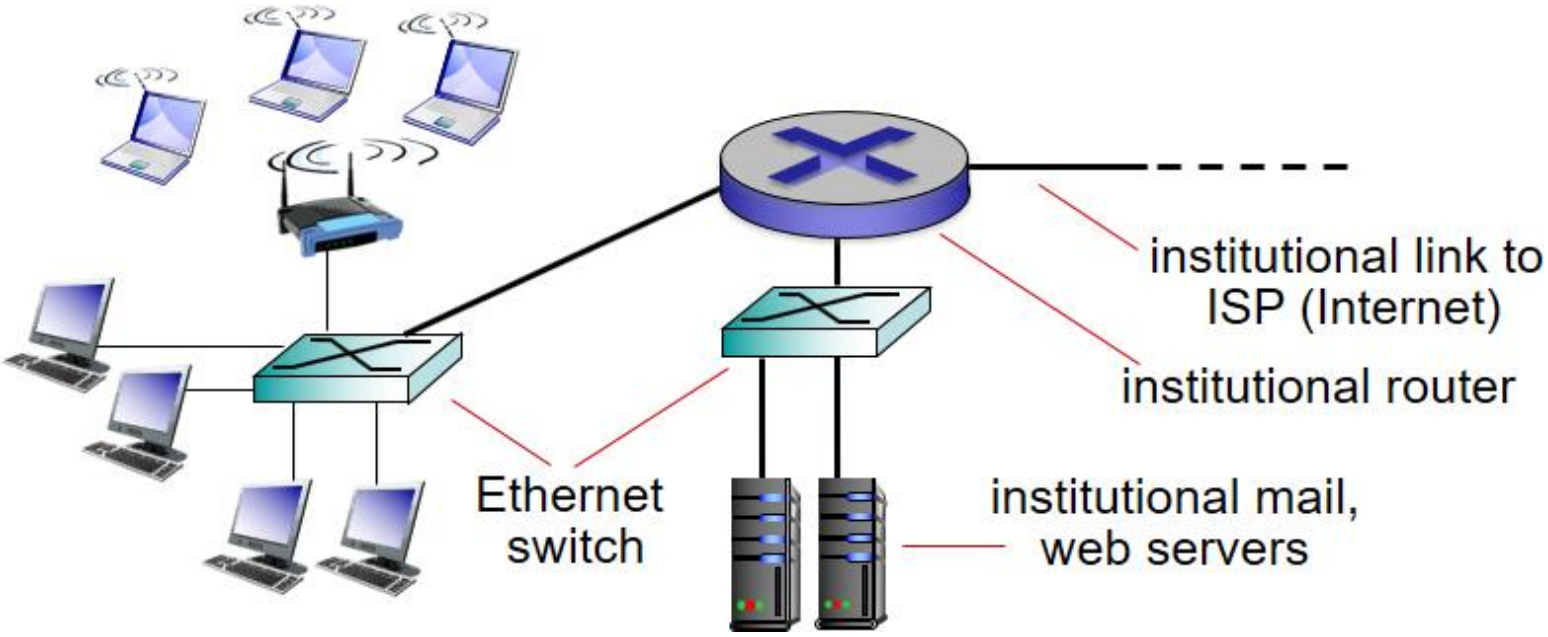


*DSL: <=100 Mbps downstream /<= 20 Mbps upstream

cable: <= 300 Mbps downstream/<=20 Mbps upstream

NAT: Network Address Translation - see Network Layer

Enterprise Access Networks (Ethernet)



- typically used in companies, universities, etc.
- 1Gbps, 10Gbps, 100Gbps transmission rates
- today, end systems typically connect into Ethernet switch

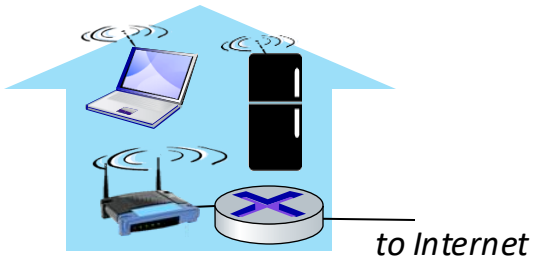
Wireless access networks

Shared *wireless* access network connects end system to router

- via base station aka “access point”

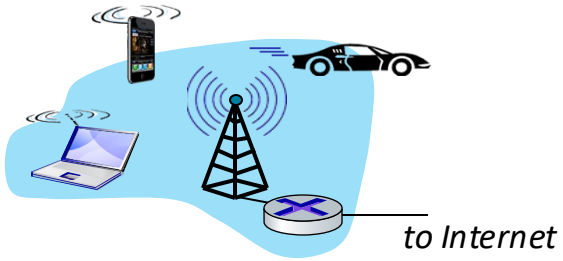
Wireless local area networks (WLANs)

- typically within or around building (~50 m)
- 802.11b/g/n/ax (WiFi): 11, 54, 600, 9608 Mbps transmission rate



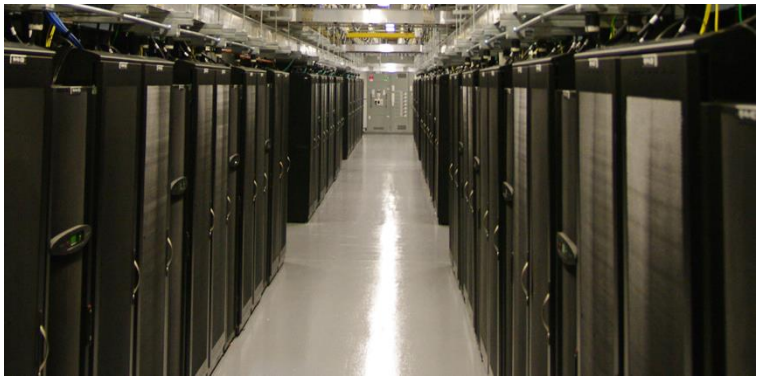
Wide-area cellular access networks

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

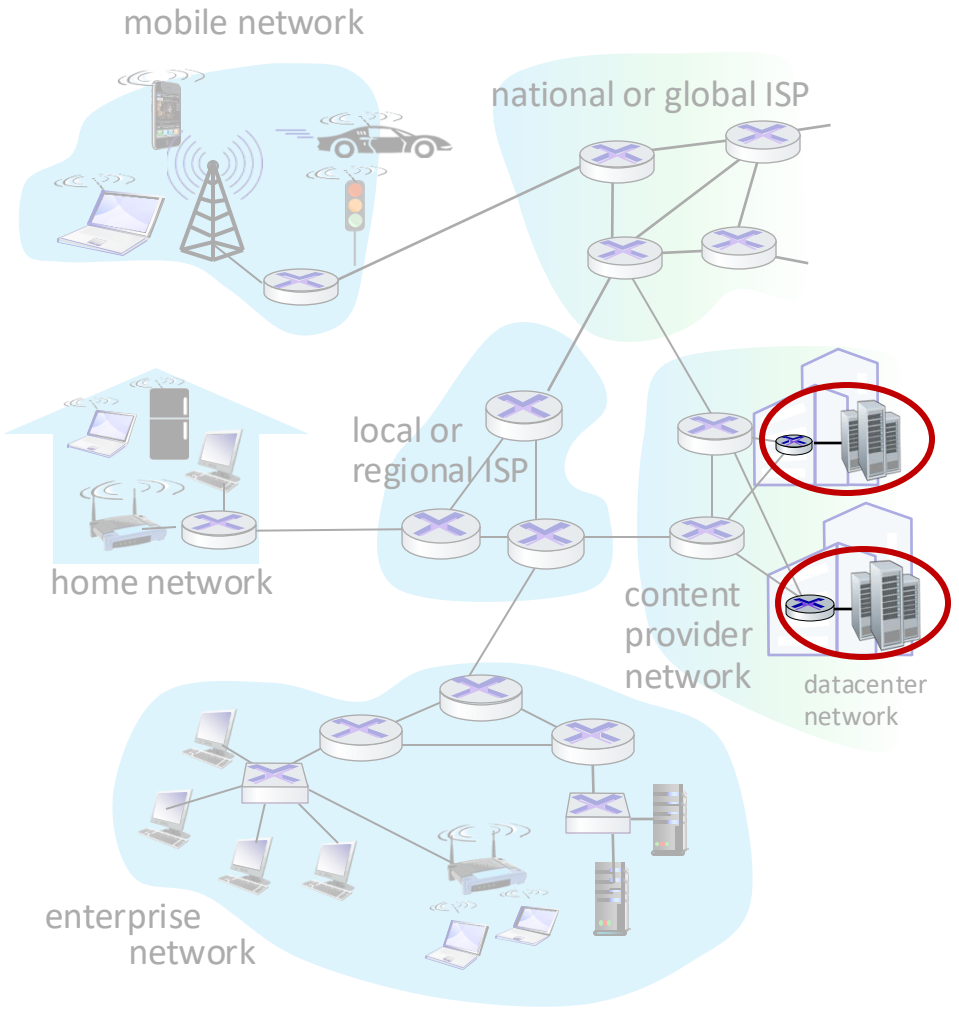


Access networks: data center networks

- high-bandwidth links (100 to 400 Gbps) connect hundreds to thousands of servers together, and to Internet



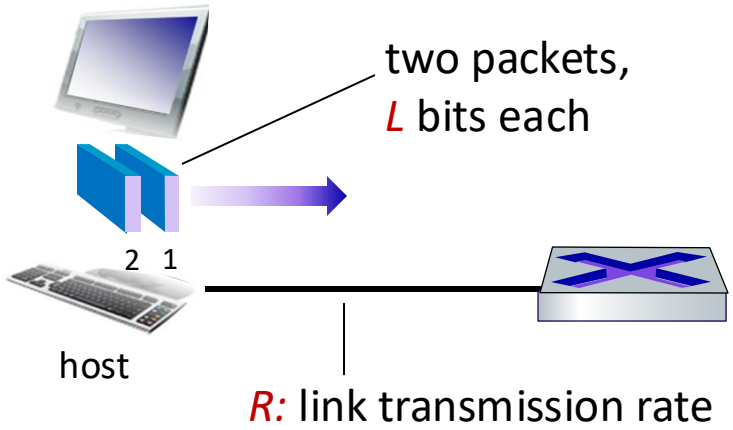
Courtesy: Massachusetts Green High Performance Computing Center (mghpcc.org)



(End-)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*



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

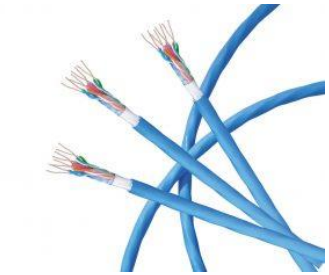
Introduction: 1-26

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



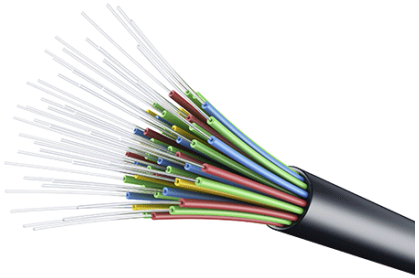
Links: physical media

Coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple frequency channels on cable
  - Gbps 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



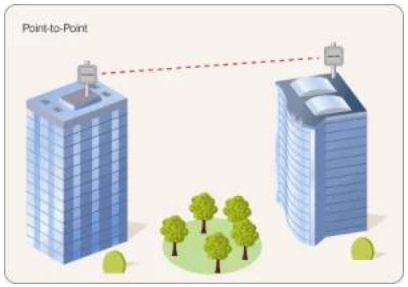
Links: physical media

Wireless radio

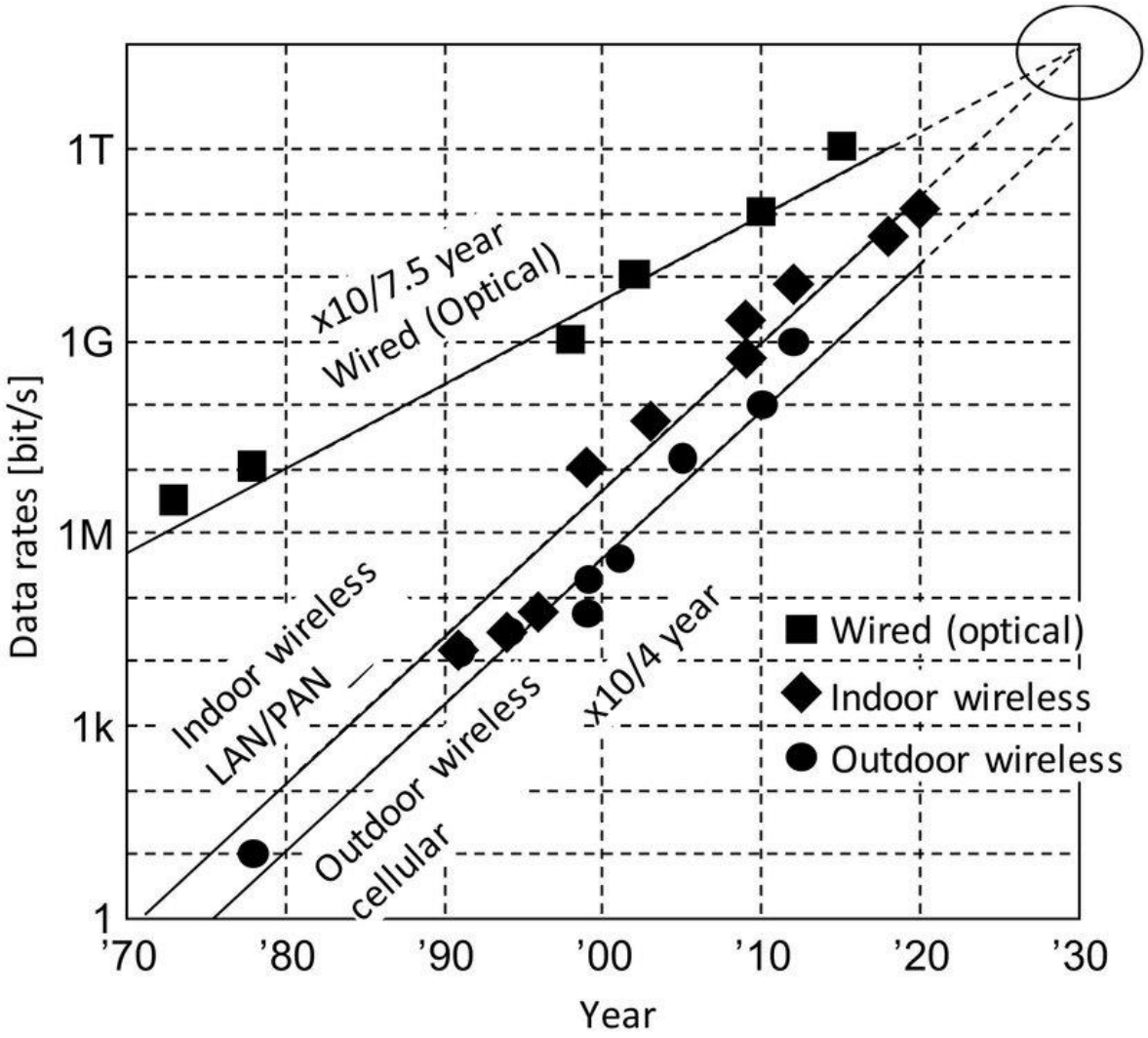
- signal carried in various "bands" in electromagnetic spectrum
- no physical "wire"
- broadcast, "half-duplex" (sender to receiver)
- propagation environment effects:
  - reflection
  - obstruction by objects
  - Interference/noise

Radio link types:

- Wireless LAN (WiFi)
  - Up to 9,6 Gbps (Wifi 6); 10's of meters
- wide-area (e.g., 5G cellular)
  - Up to 20 Gbps over max 5 Km
- Bluetooth: cable replacement
  - short distances, limited rates
- terrestrial microwave
  - point-to-point; up to 10 Gbps channels
- satellite
  - up to 500 Mbps per channel (Starlink)
  - 30 msec end-end delay



Data rate evolution



Fujishima, Minoru. "Key technologies for THz wireless link by silicon CMOS integrated circuits." *Photonics*. Vol. 5. No. 4. Multidisciplinary Digital Publishing Institute, 2018.

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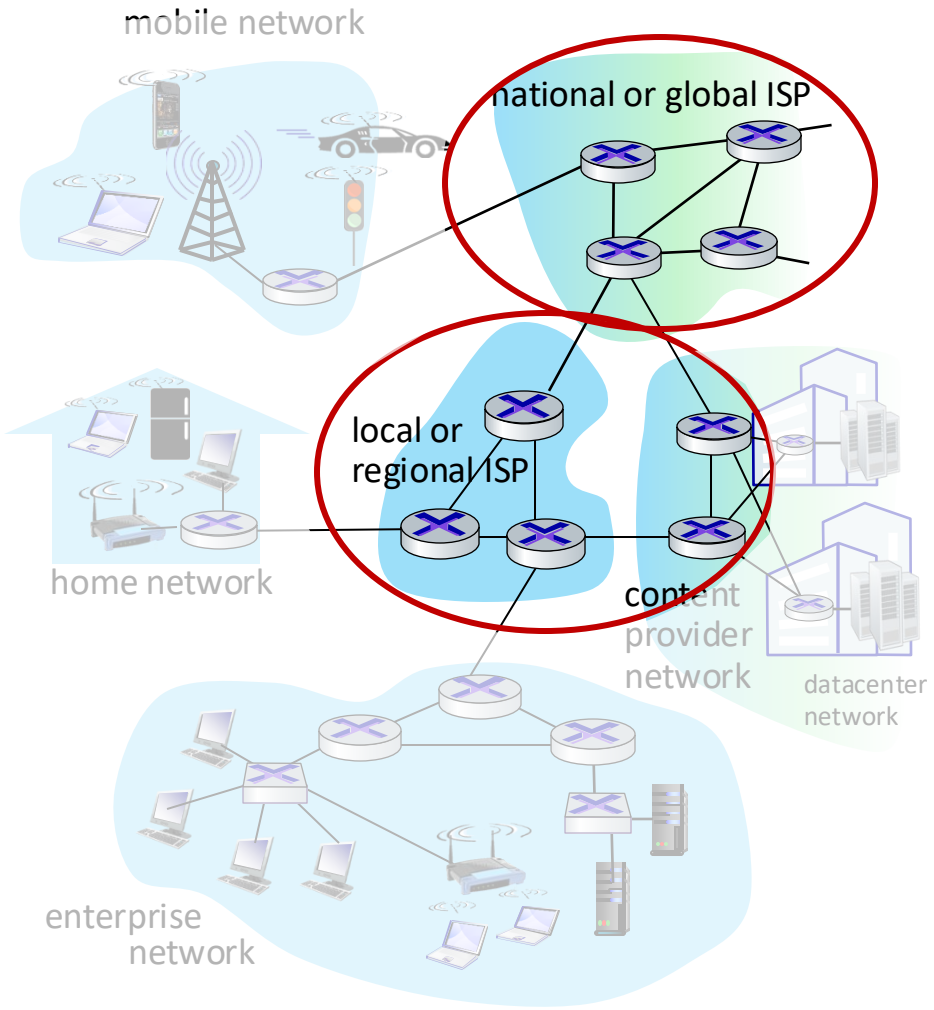
The Network Core

- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into packets
  - forward packets from one router to the next, across links on path from source to destination
  - each packet transmitted at full link capacity

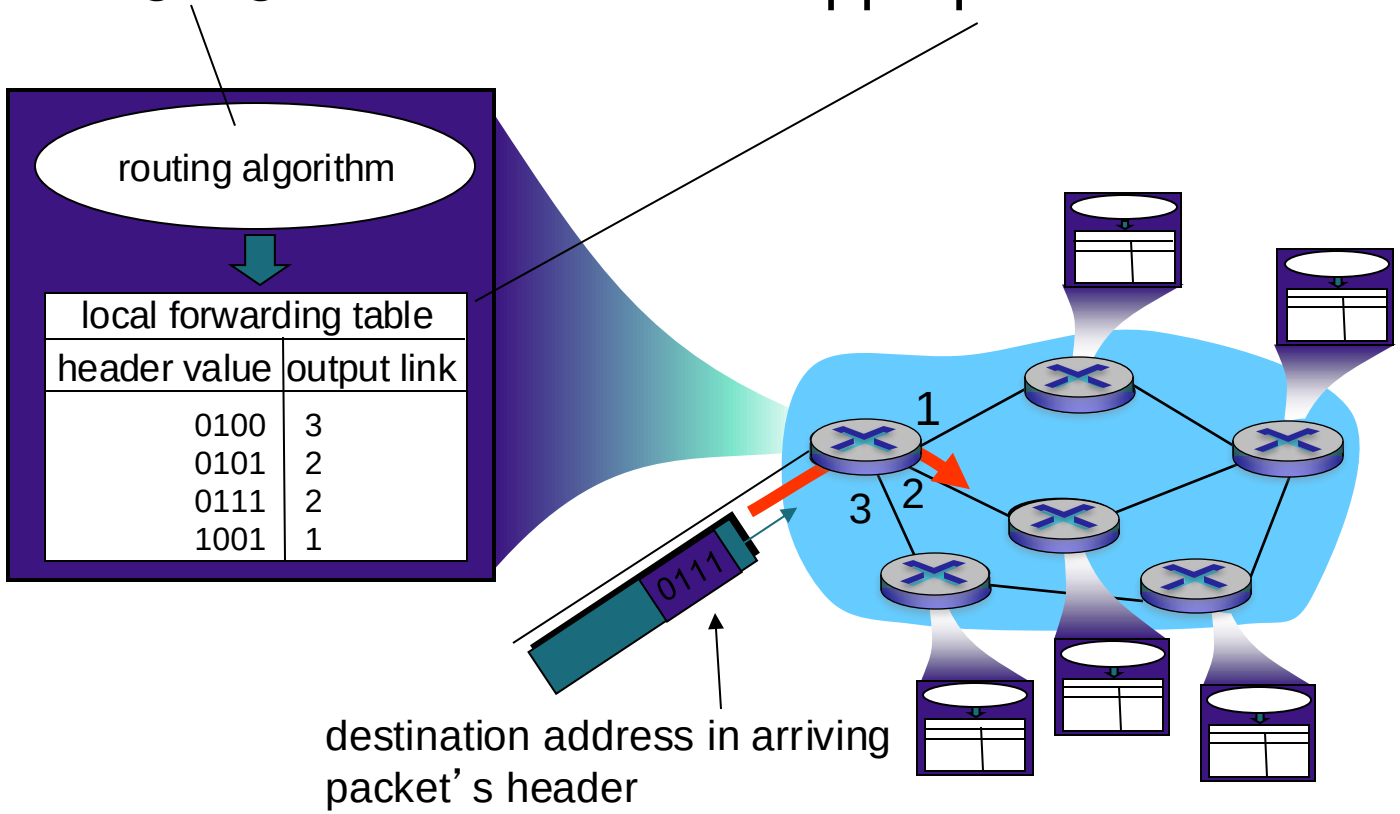


Two key network-core functions

routing: determines source-destination route taken by packets

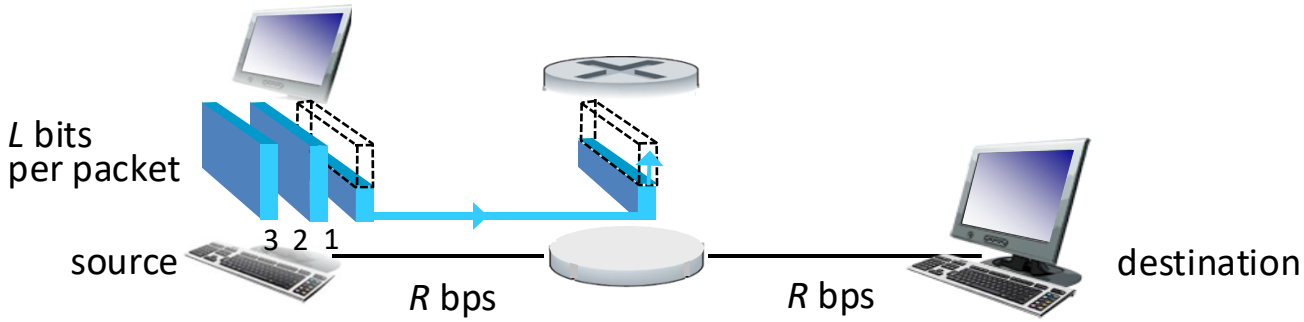
- *routing algorithms*

forwarding: move packets from router's input to appropriate router output



Packet-switching: store-and-forward

Paul Baran

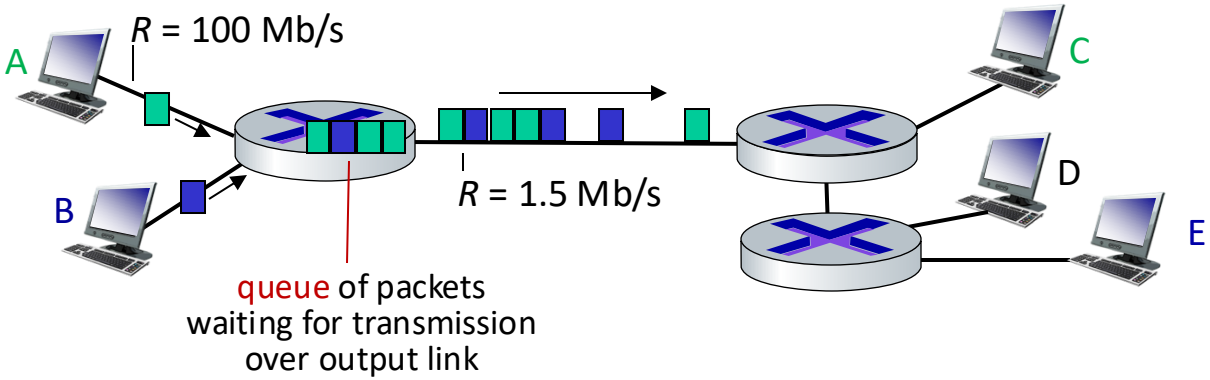


- packet transmission delay: takes *L*/*R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
- *store and forward: entire* packet must arrive at router before it can be transmitted on next link

One-hop numerical example:

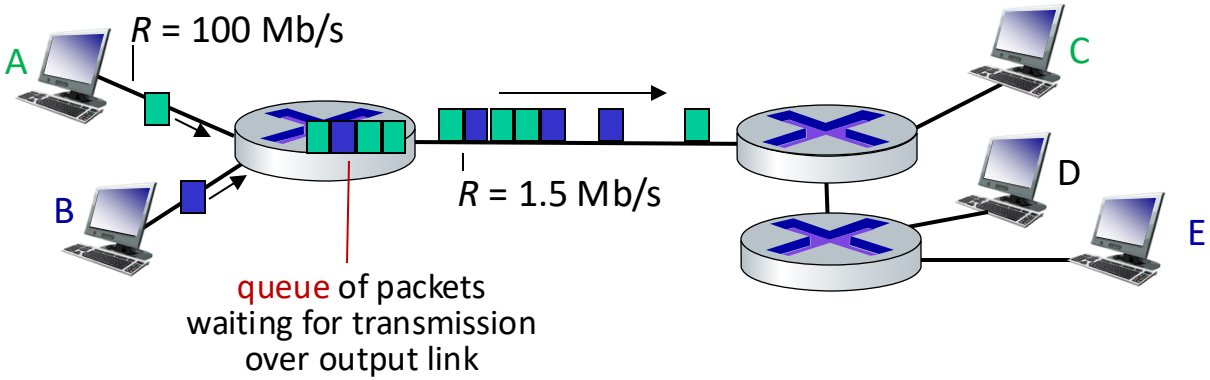
- *L* = 10 Kbits
- *R* = 100 Mbps
- one-hop transmission delay = 0.1 msec

Packet-switching: queueing



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

Packet-switching: queueing



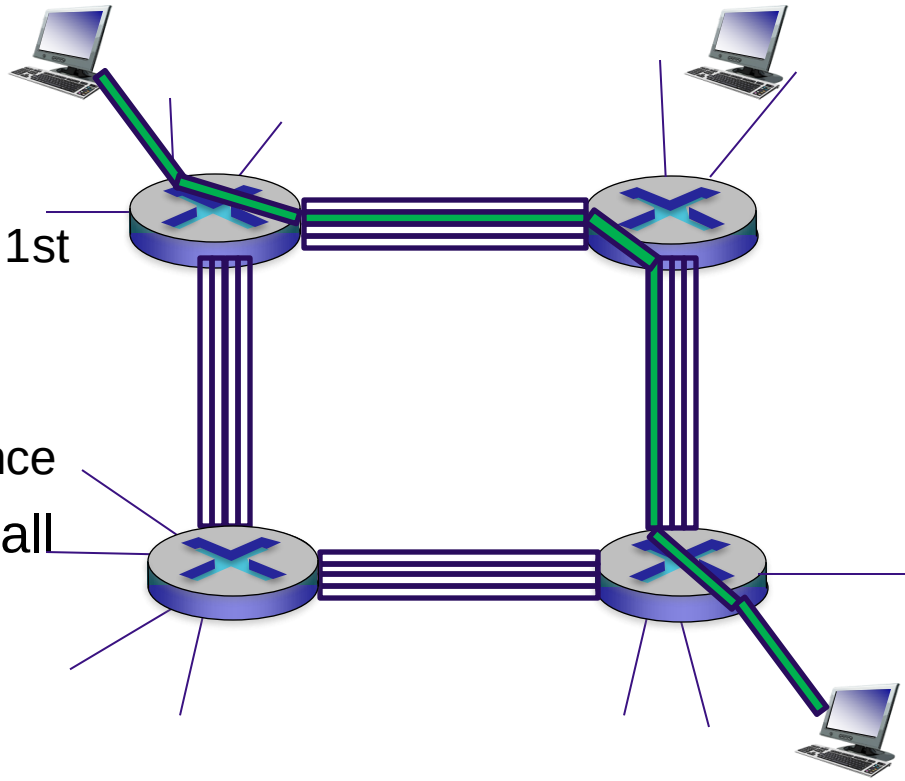
Packet queuing and loss: If arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

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

Alternative core: circuit switching

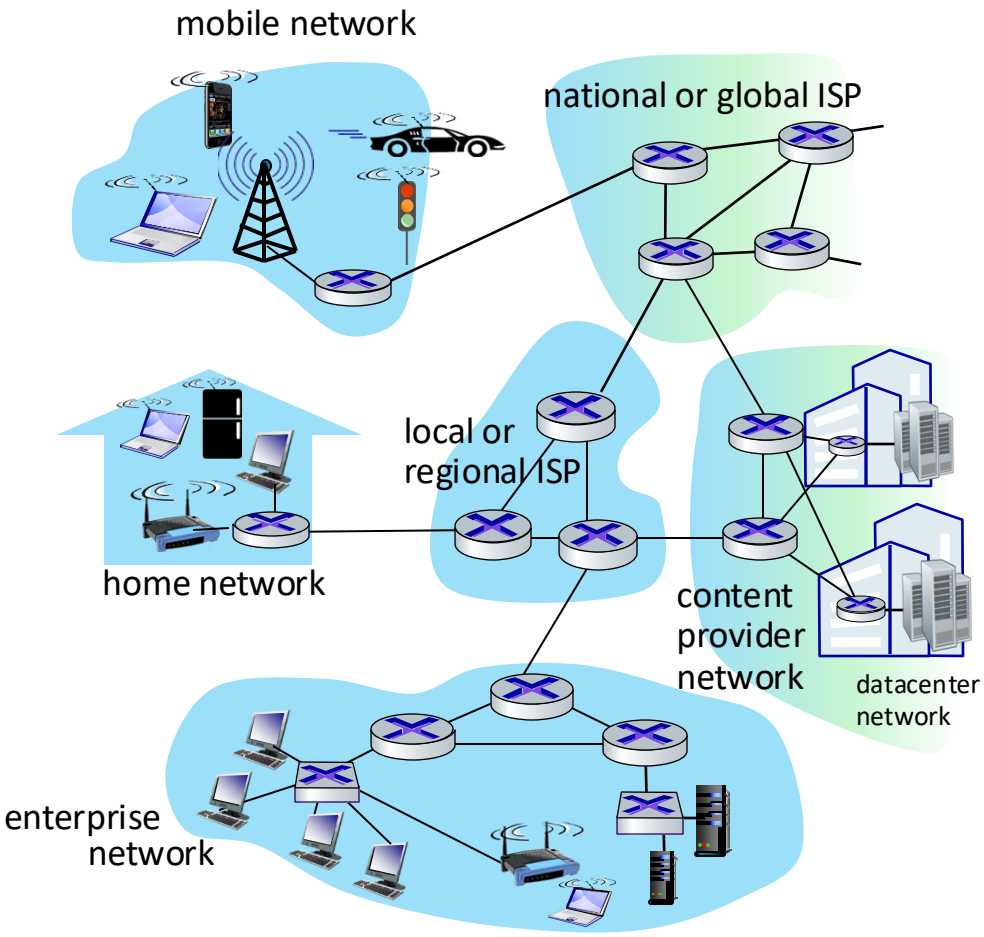
end-end resources allocated to, **reserved** for "call" between source & dest:

- 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



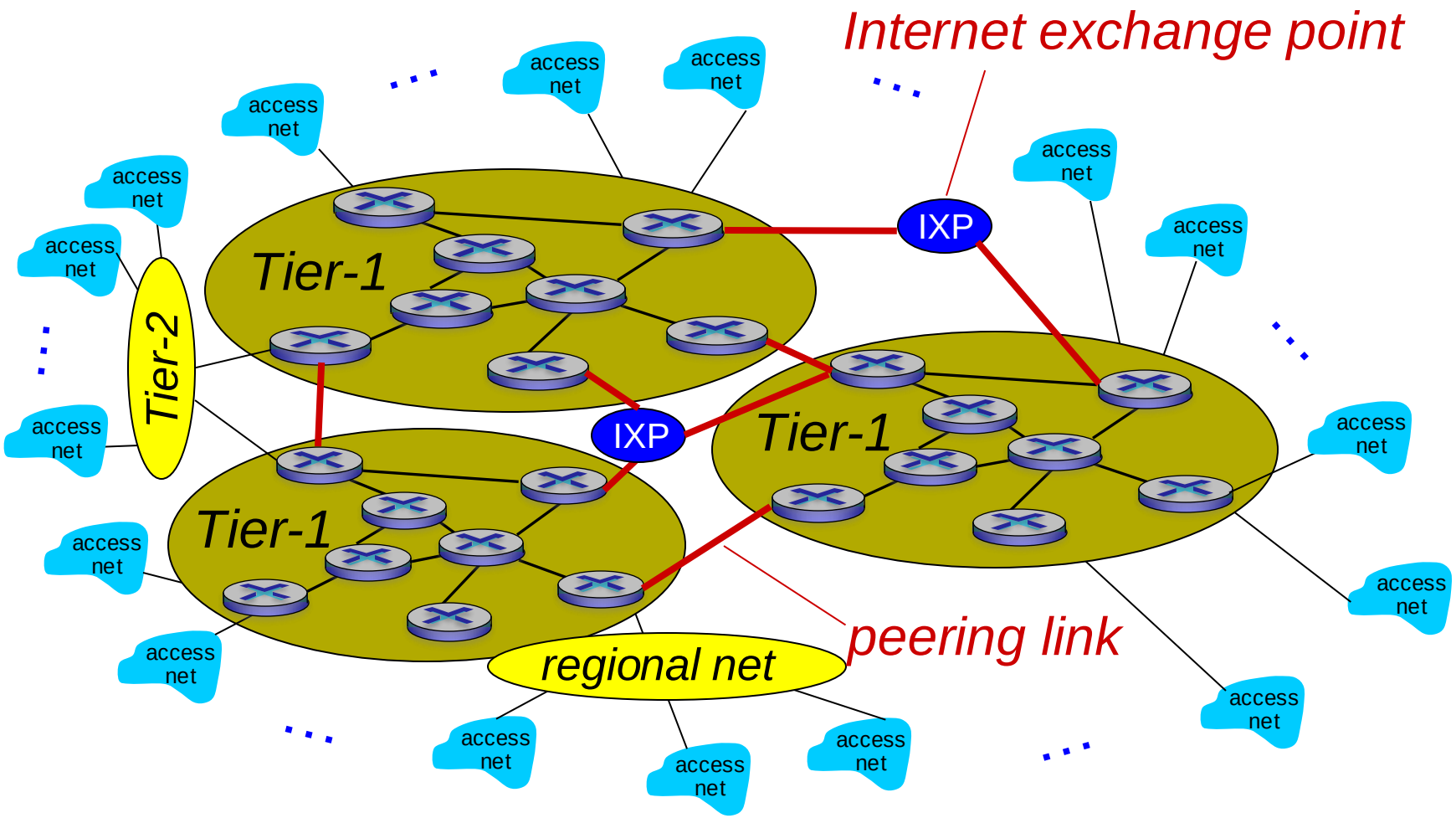
Internet structure: a "network of networks"

- hosts connect to Internet via access Internet Service Providers (ISPs)

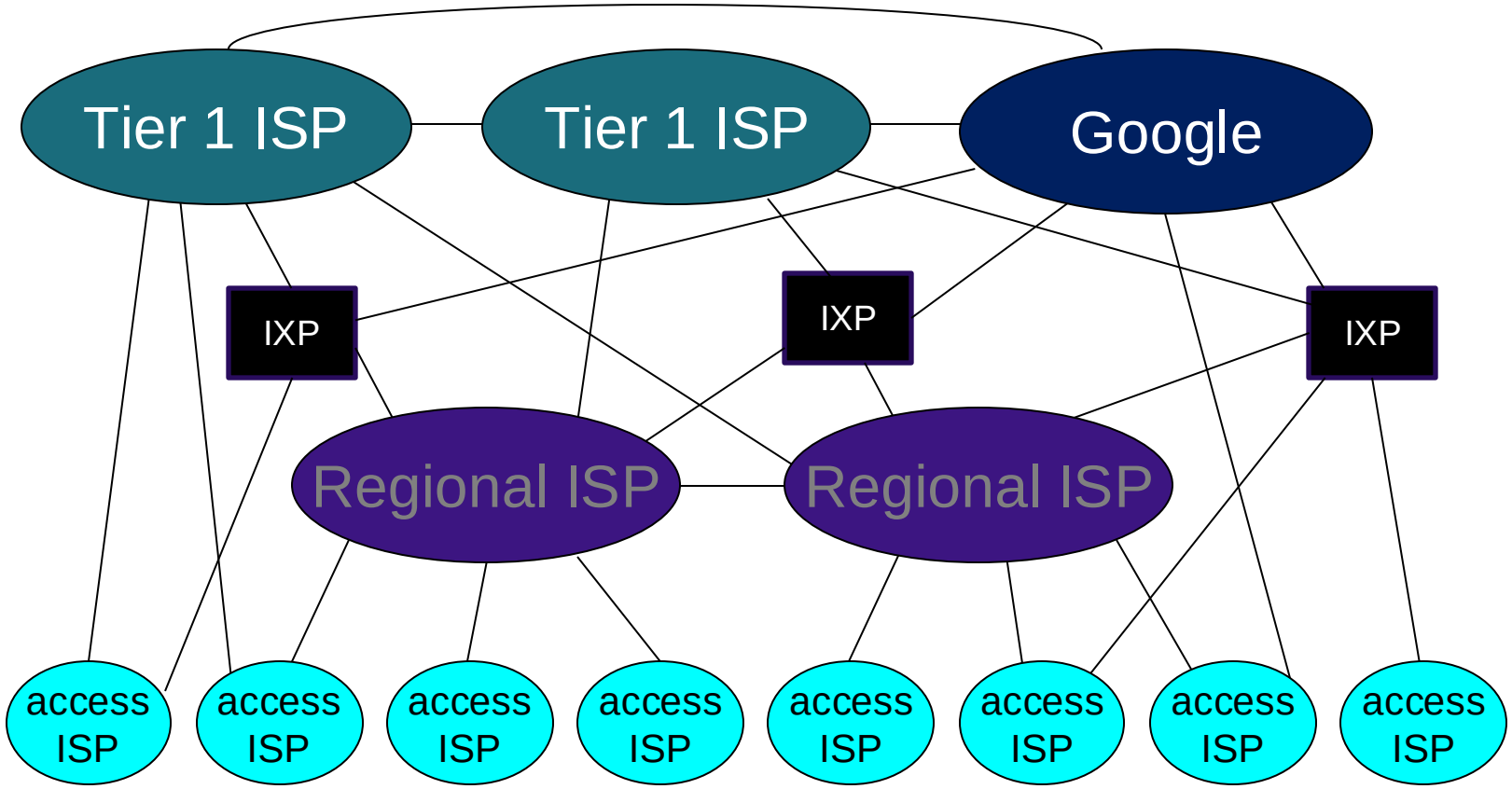


Internet structure: network of networks

Q: How are access networks interconnected world wide?



Internet structure: network of networks



- at center: small number of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g., Google, Akamai): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Chapter 1 outline

1.1 what is the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

[1.4 delay, loss, throughput in networks]

1.5 protocol layers, service models

[1.6 networks under attack: security]

[1.7 history]

Protocol “Layers”

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?

…. or at least our discussion of networks?

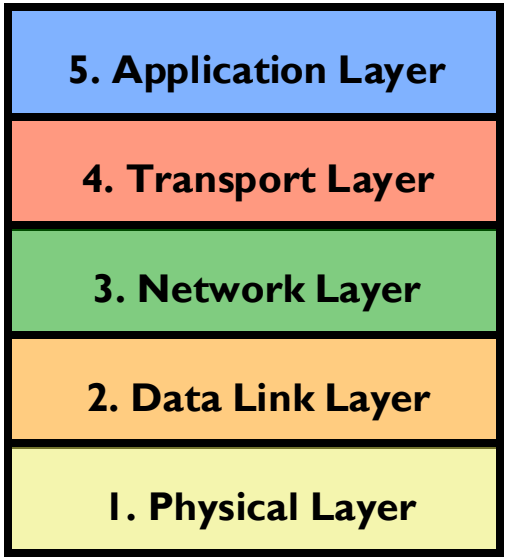
Why Layering?

dealing with complex systems:

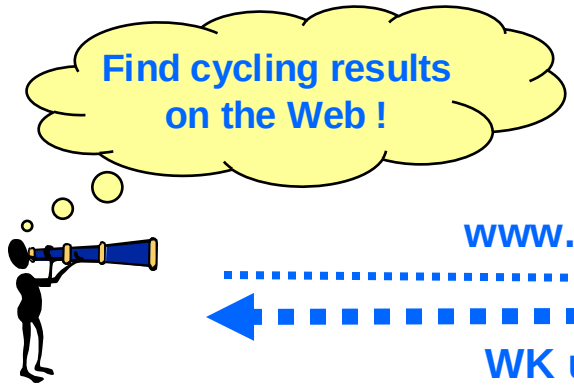
- explicit structure allows identification, relationship of complex system's pieces
  - layered **reference model** for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system
- layering considered harmful?

Internet protocol stack

- **application**: supporting network applications:
  - Example: FTP, SMTP, HTTP, DNS, …
- **transport**: host-host data transfer,
  - Example: TCP, UDP
- **network**: routing of datagrams from source to destination
  - Example: IP, routing protocols, IPv6
- **data link**: data transfer between neighboring network elements
  - Example: PPP, Ethernet, WLan
- **physical**: bits “on the wire”,
  - Example: fiber, “in the air”



An example : web access



www.sporza.be

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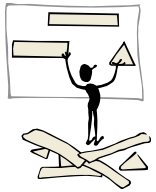
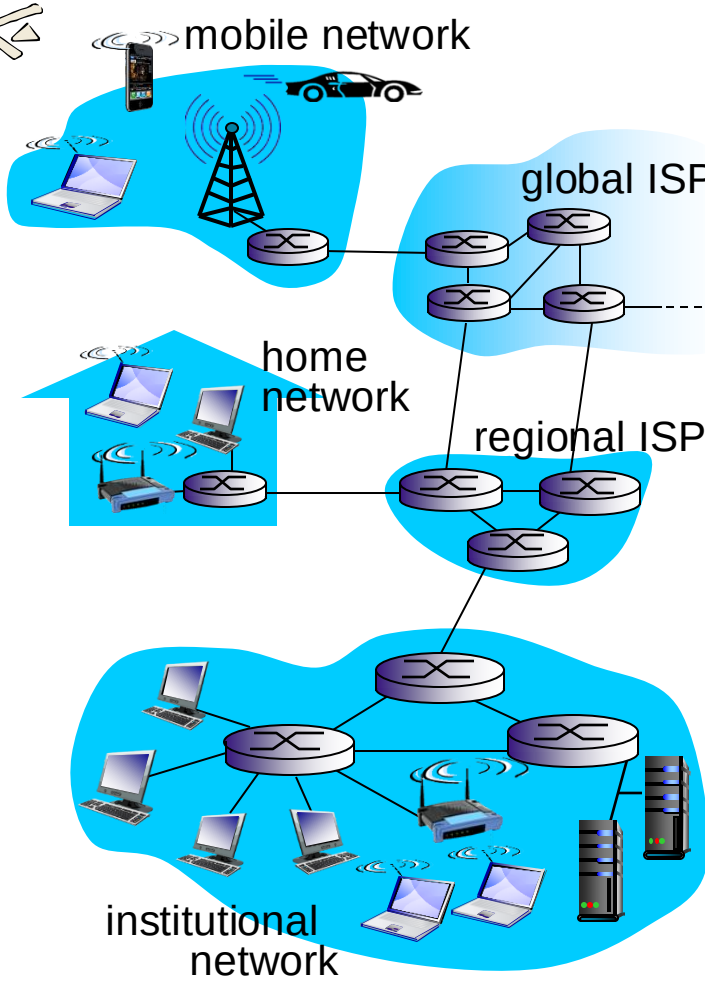
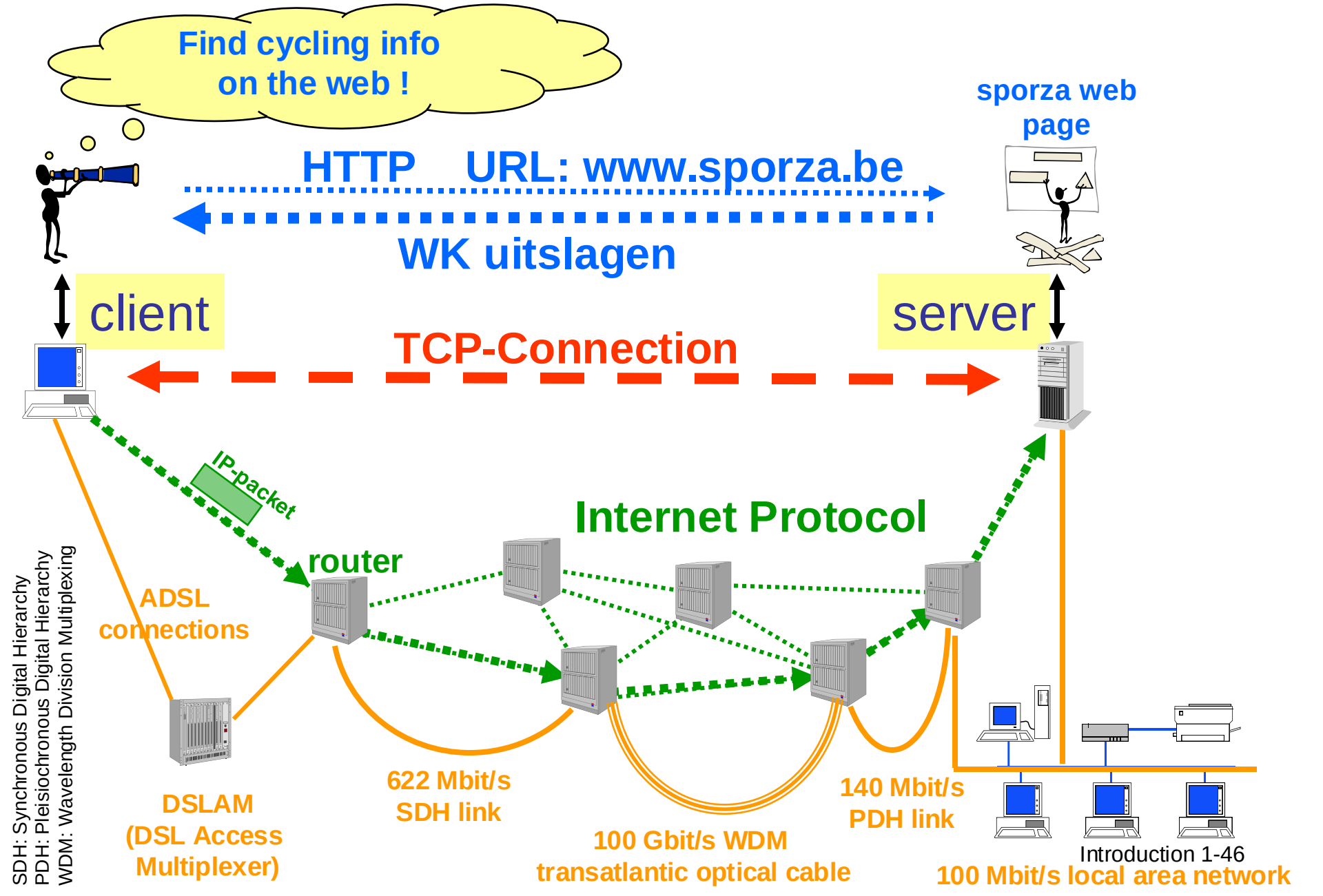
sporza web
page



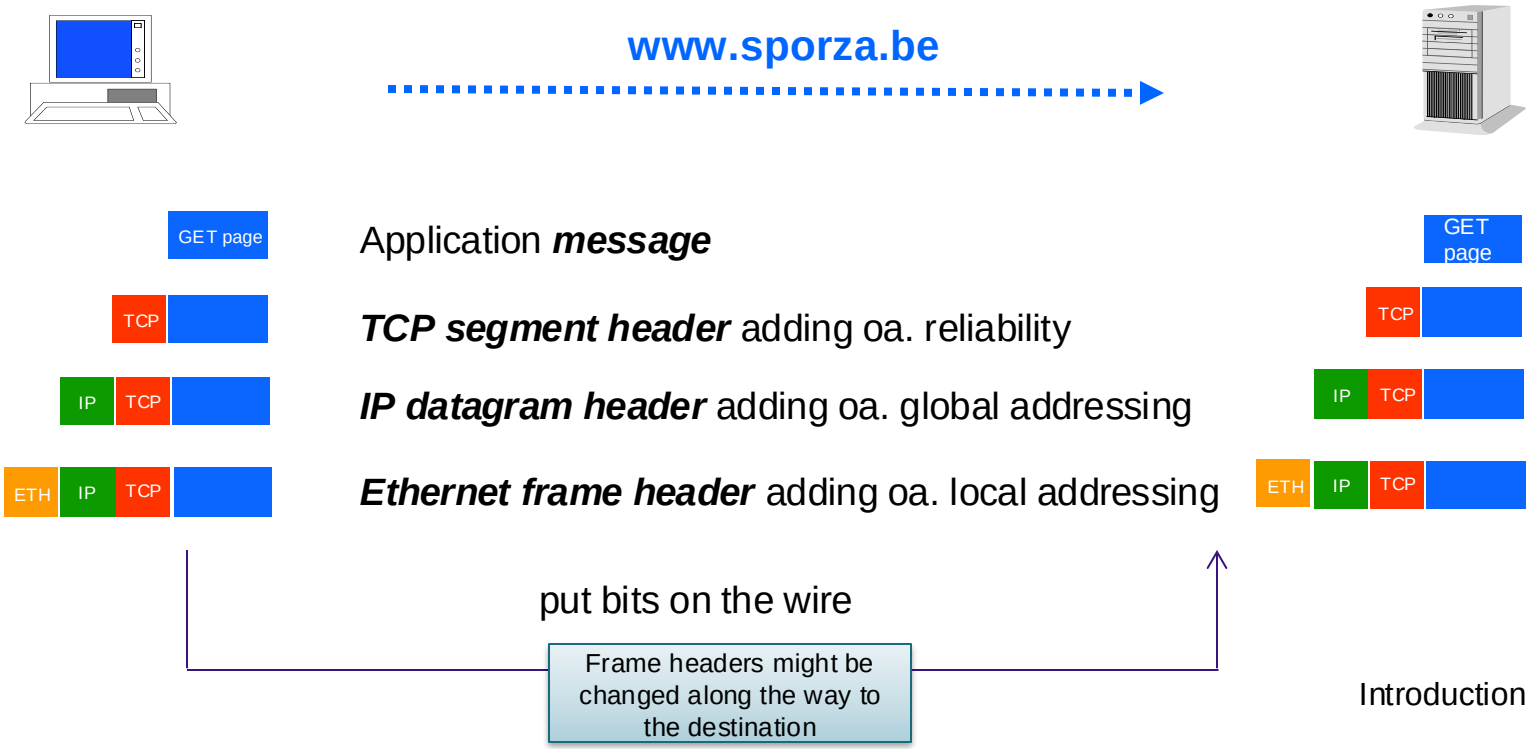


An example : web access



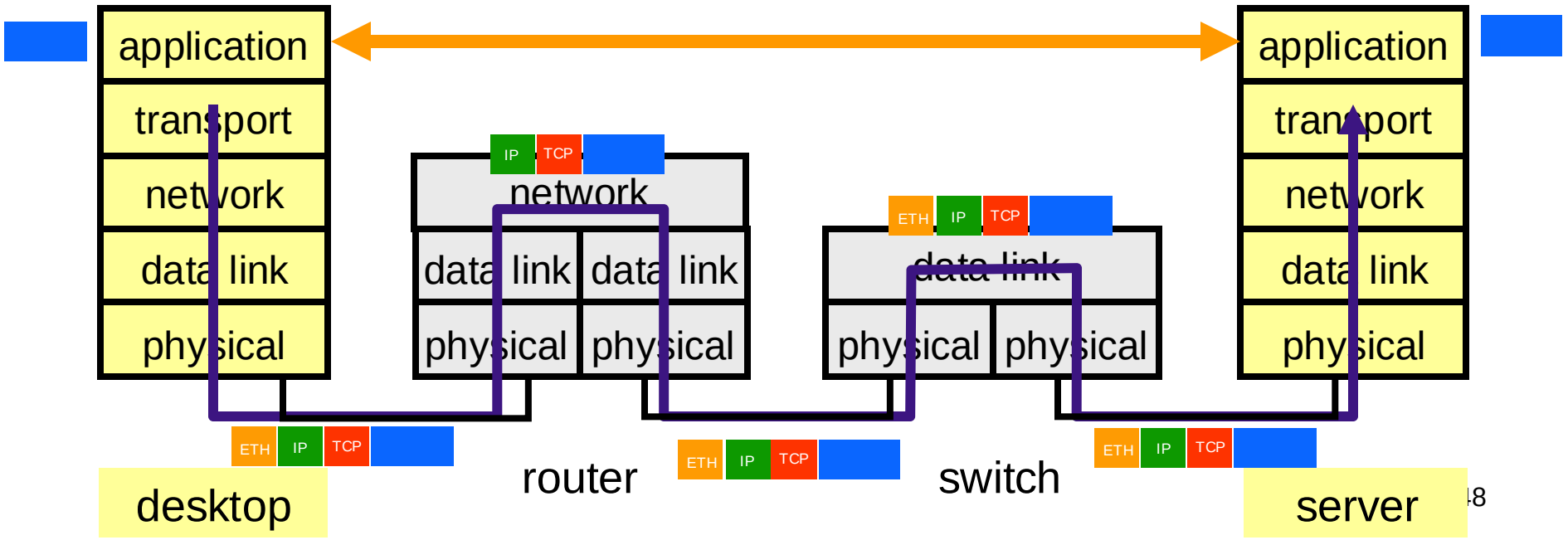
Encapsulation and decapsulation

- Lower layers provide service to high layers
- To implement a service, a layer can add additional headers = ***encapsulation***
- At the endpoints (and possibly intermediately), headers need to be stripped to provide a transparent service = ***decapsulation***

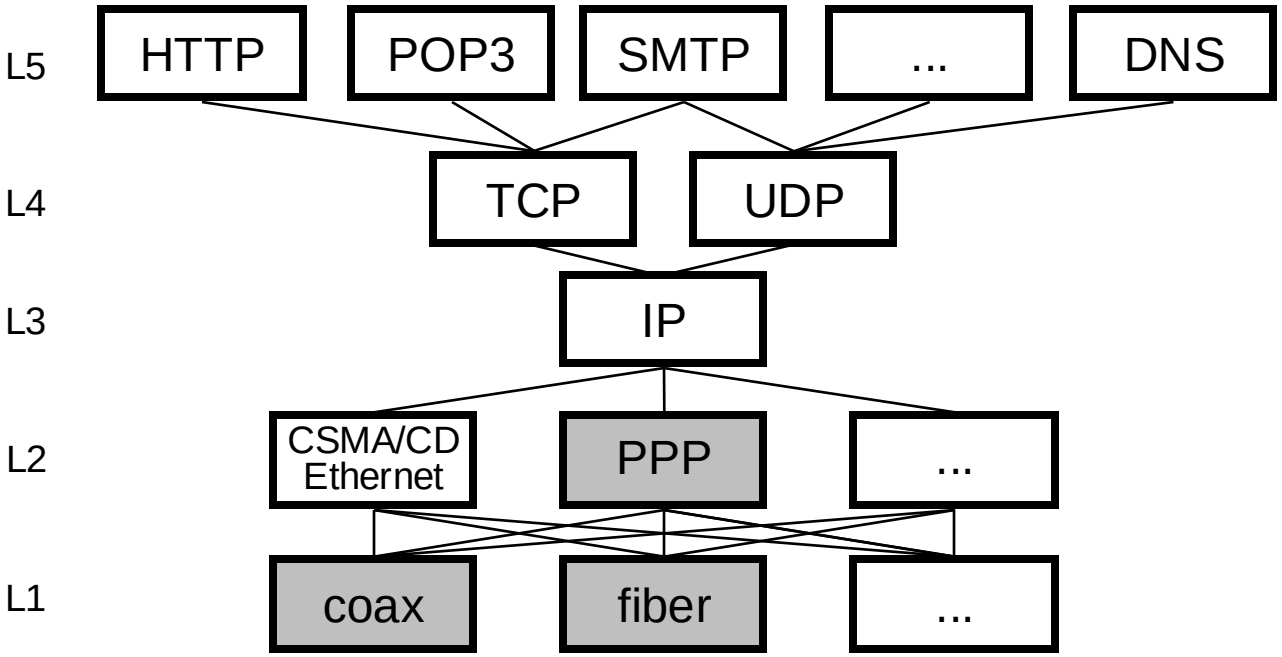


Routers and switches

- Not all Internet devices work at all layers
- End-host = terminal = end-point operate at L1-L5
- Routers operate on L3 (and below)
  - Forward datagram based on the IP header towards (global) destination
- Switches operate on L2 (and below)
  - Forward frame based on the Ethernet header towards other LAN device



Internet's narrow waist/hourglass



- Despite many protocols at all layers, the network layer (L3) has converged to a single protocol: the ***Internet Protocol (IP)***
  - Two versions: IPv4 and IPv6
- IP is responsible for **global addressing and reachability** of connected devices
  - IP(v4) address (e.g.:*157.193.122.1*)
  - IPv6 address (e.g.: *2001:0660:30F3:AC01:0000:0000:6D43:210F*)

Important levels of identification

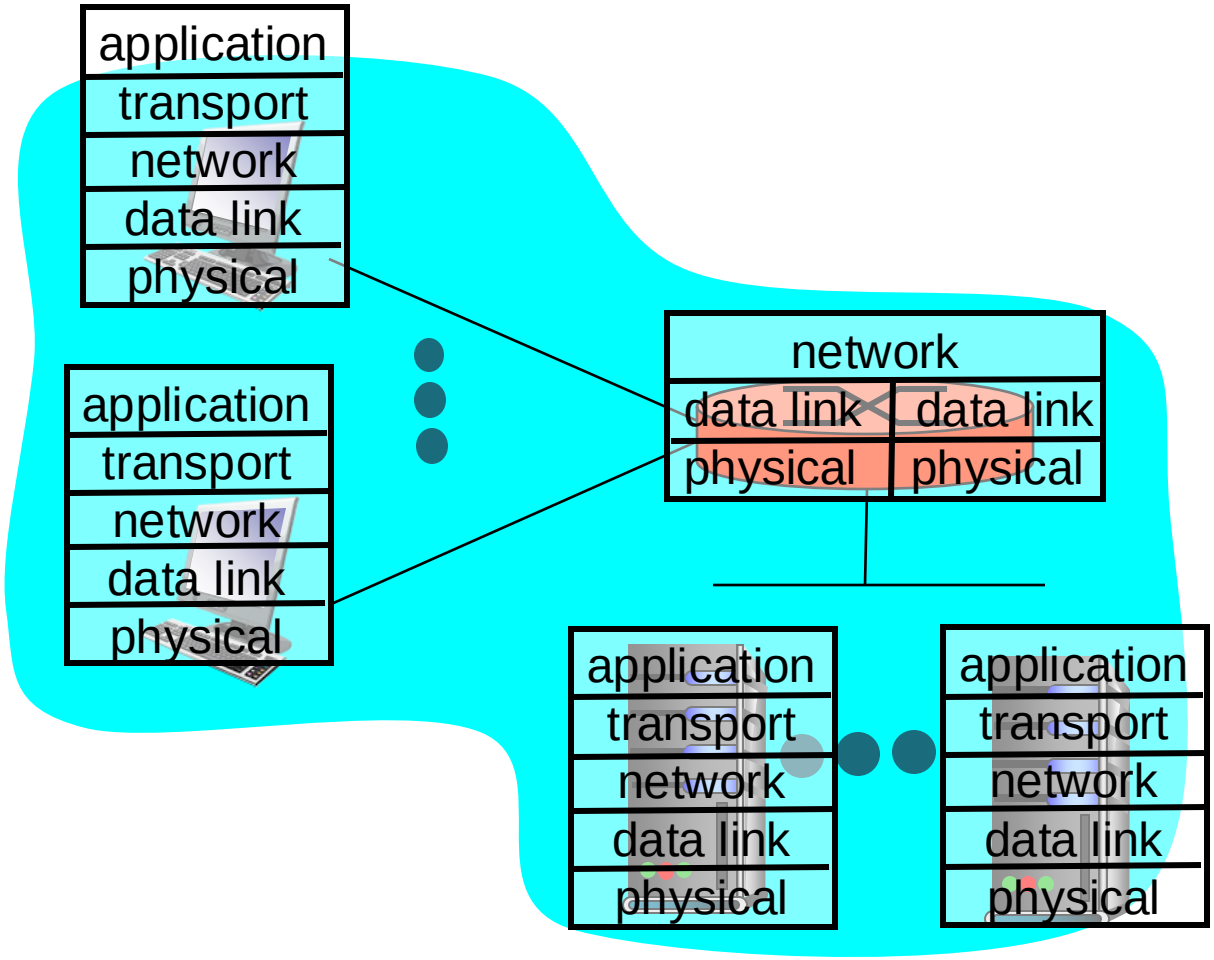
- Application layer
  - **Application** is identified by a ***16-bit port number*** on a given machine, such that messages can be delivered to the right application on a given machine
  - Stored in the *L4 header* (e.g. TCP or UDP as port number) for demultiplexing during decapsulation -> “to which application should payload be provided”
  - Server-side applications by convention, e.g. 80 for web server
  - Client-side application use ephemeral port numbers (eg.>32000)
- Network layer
  - A network **host** (i.e., network interface) is assigned **an IP address**, usually for global reachability
  - Stored in the *L3 header* (e.g. IPv4 header) for source and destination
- Link layer
  - A network **host** (i.e., network interface) is assigned **a MAC address** for reachability within the local area network
  - Stored in the *L2 header* (e.g. Ethernet header) for source and destination

Additional Background

Layering: logical communication

Each layer:

- distributed
- "entities" implement layer functions in the node
- entities perform actions, exchange messages with peers

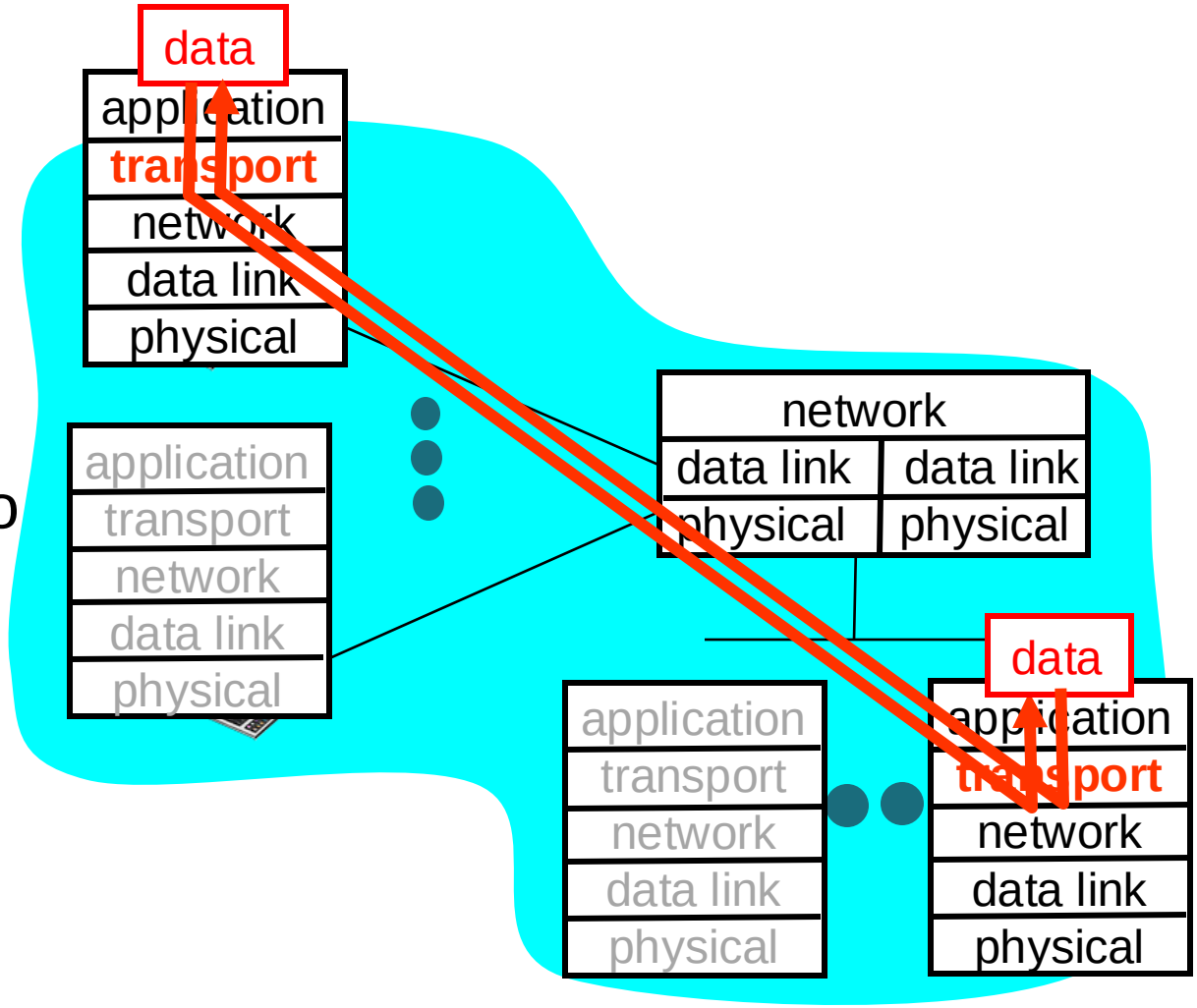


"entities" = PC, router, server, …

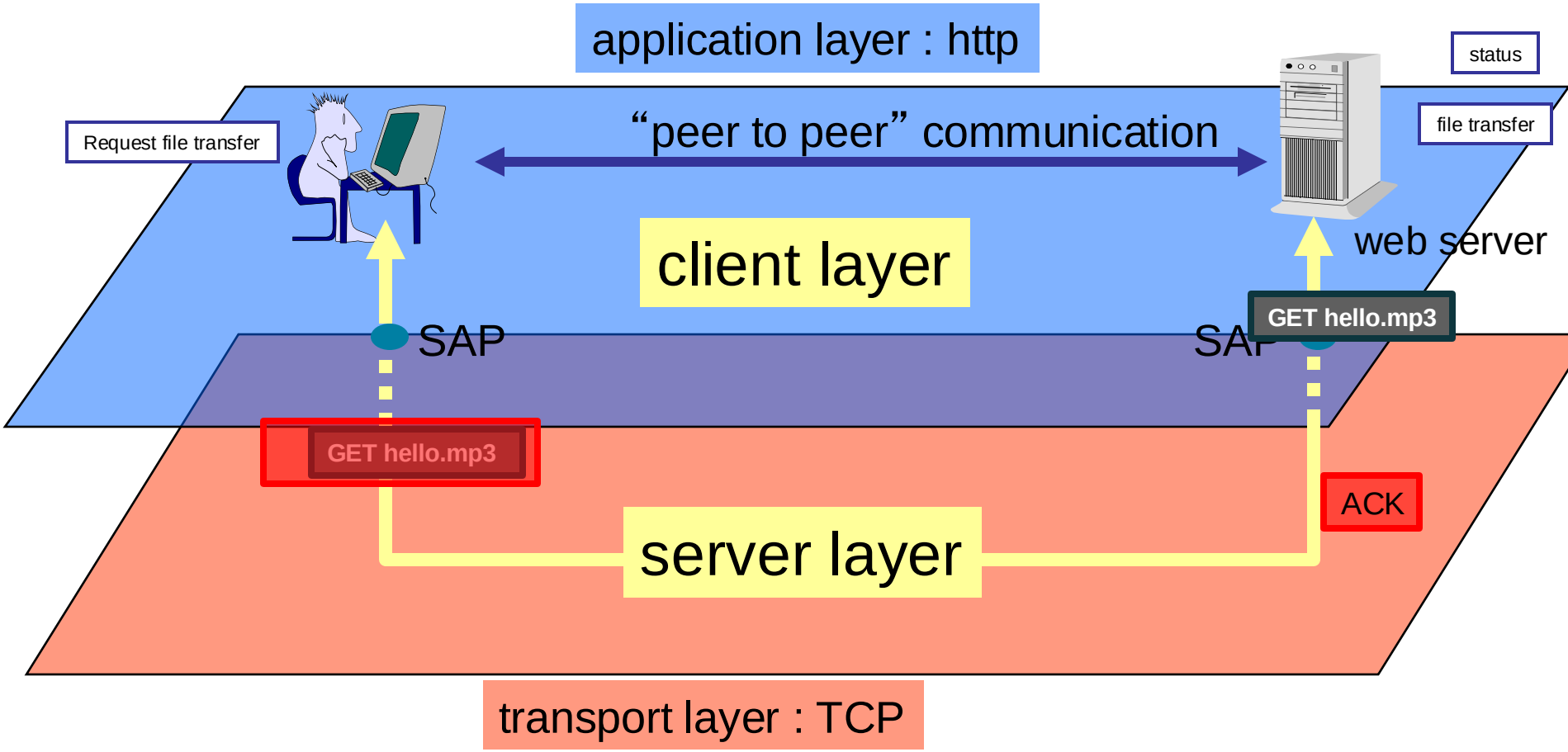
Layering: logical communication

E.g.: transport

- take data from application layer
- add addressing, reliability check, info to form “segment”
- send segment to peer
- wait for peer to ack receipt



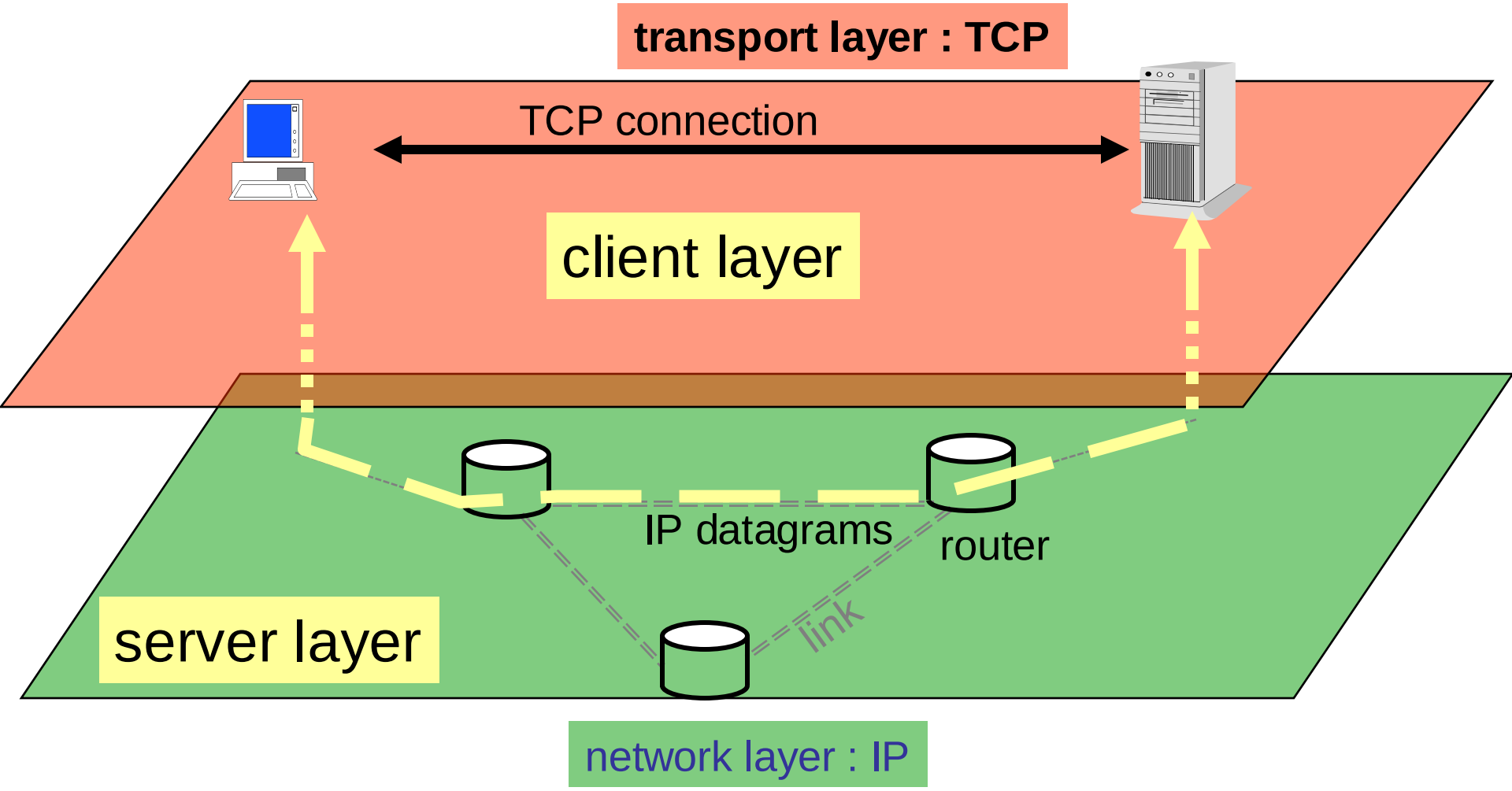
Application/Transport Layer



SAP : Service Access point

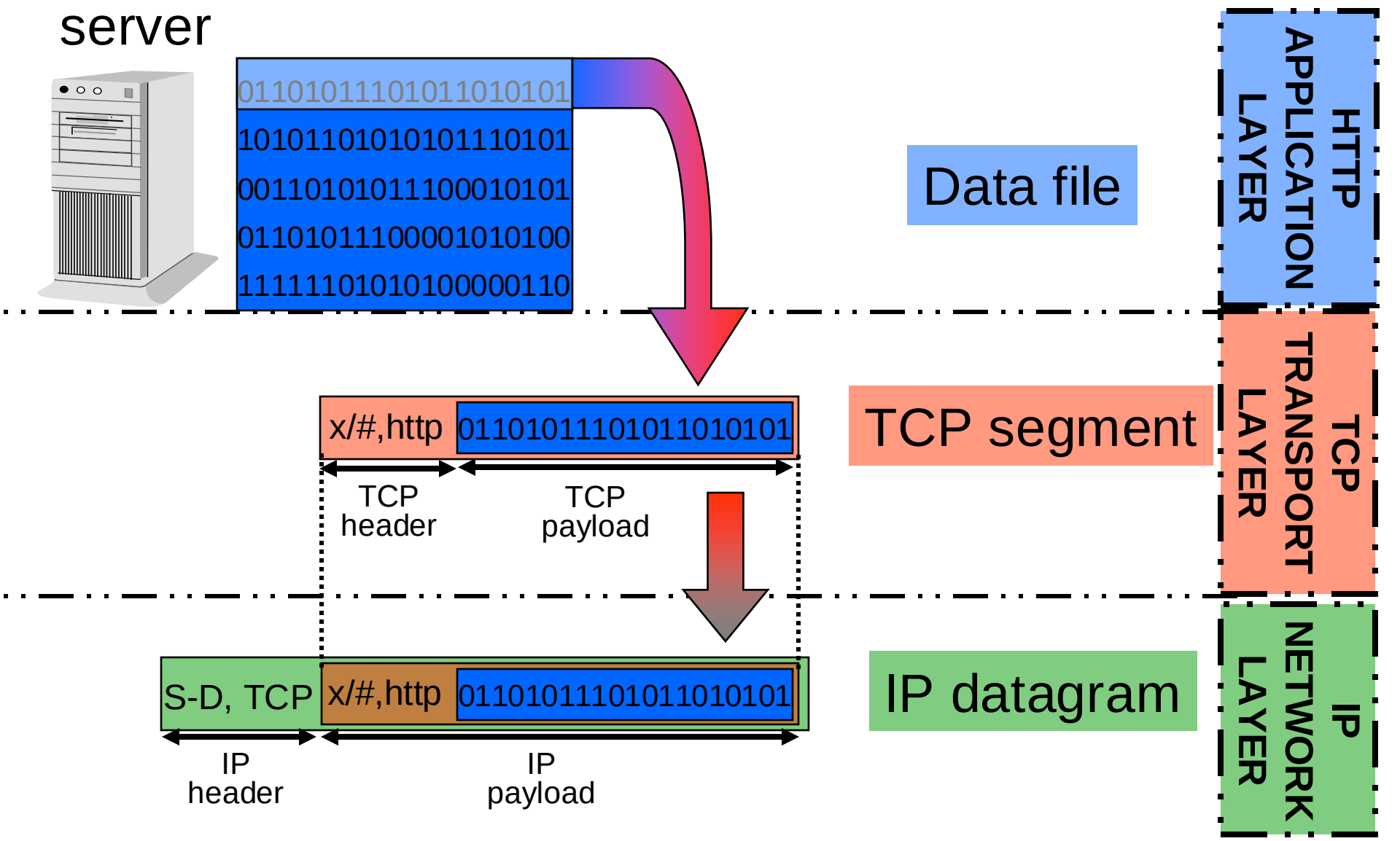
Remark : client - server

Transport/Network Layer



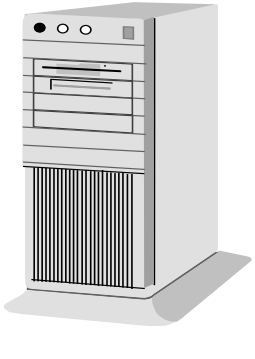
SERVICE : Transfer TCP segment from source to destination
SOLUTION : Encapsulate TCP segment in IP datagram (destination indicated !).
IP network layer will transfer IP datagram over links and routers to destination.

Encapsulation example: HTTP/TCP/IP



Encapsulation example: raw bytes

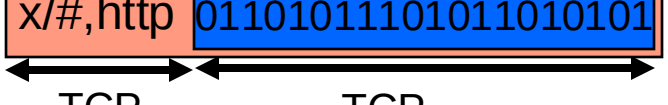
server



01101011101011010101
10101101010101110101
00110101011100010101
01101011100001010100
11111101010100000110

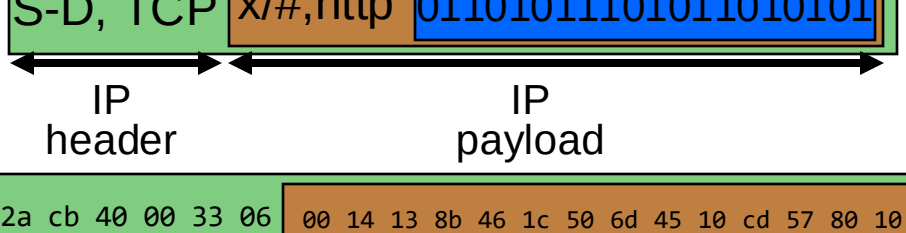
hello.mp3

0d0a5472616e73706f7274204c6179657220536563757...
6620576f726b696e672047726f75703a0d0a0d0a54686...
6d6f64650d0d0a656e6372797074696f6e20284354522...
2020207375697465732000d0a0d0a202020446f6e65204...
0d0a0d0a4a616e203230303220417567203230303620d...



00 14 13 8b 46 1c 50 6d 45 10 cd 57 80 10 05 b4
bc e0 00 00 01 01 08 0a 04 f1 7b 05 00 00 00 00

0d0a5472616e73706f7274204c6179657220536563757...



45 00 03 0e 2a cb 40 00 33 06
f8 6e 9c 9a 10 95 9d c1 d6 bf

00 14 13 8b 46 1c 50 6d 45 10 cd 57 80 10 05 b4
bc e0 00 00 01 01 08 0a 04 f1 7b 05 00 00 00 00

0d0a5472616e73706f7274204c6179657

Network/Data Link/Physical Layer