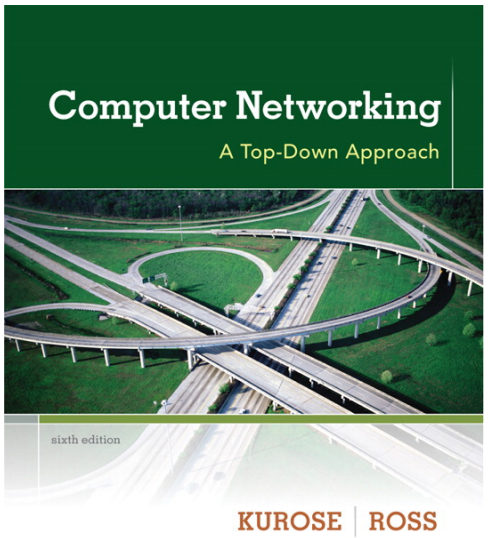
Chapter 1



- Get the overview and terminology
- …… depth coming up later in course
- Approach: use Internet as example

Computer Networking: A Top Down Approach
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
March 2012

Slides by Athina Markopoulou.
Adapted from J.F Kurose and K.W. Ross, Addison-Wesley.
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Chapter 1: roadmap

1.1 What is the Internet?

1.2 Network edge

- end systems, access networks, links

1.3 Network core

- circuit switching, packet switching, network structure

1.4 Performance

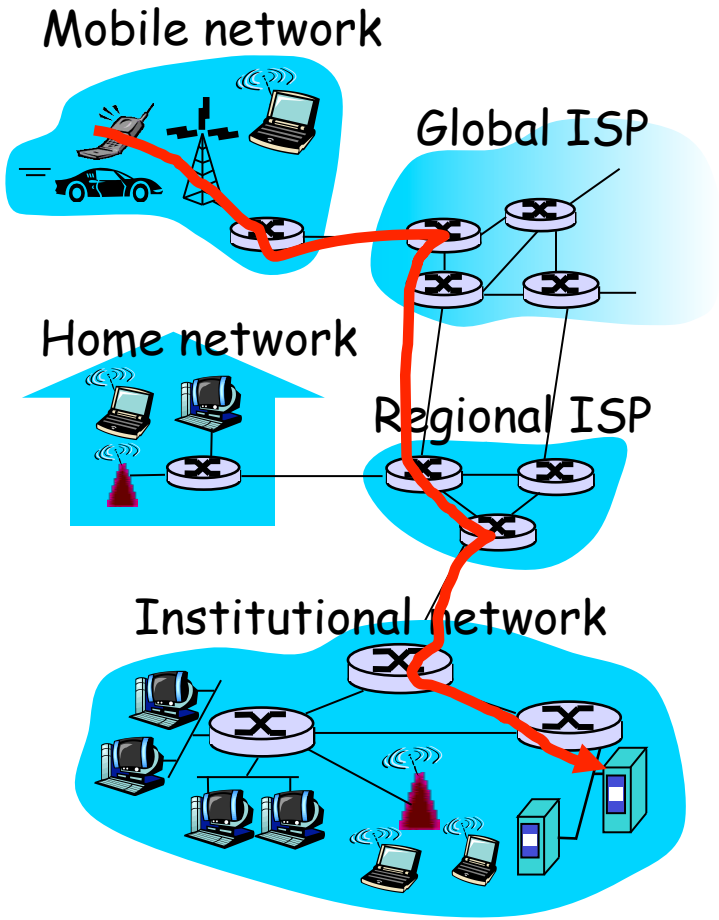
- delay, loss and throughput

1.5 Protocol layers, service models

1.6 Networks under attack: security

1.7 History

What is the Internet?



What is the Internet: "nuts and bolts" view


PC


server


wireless laptop


cellular handheld

- millions of connected computing devices:
  - hosts = end systems
  - running network apps

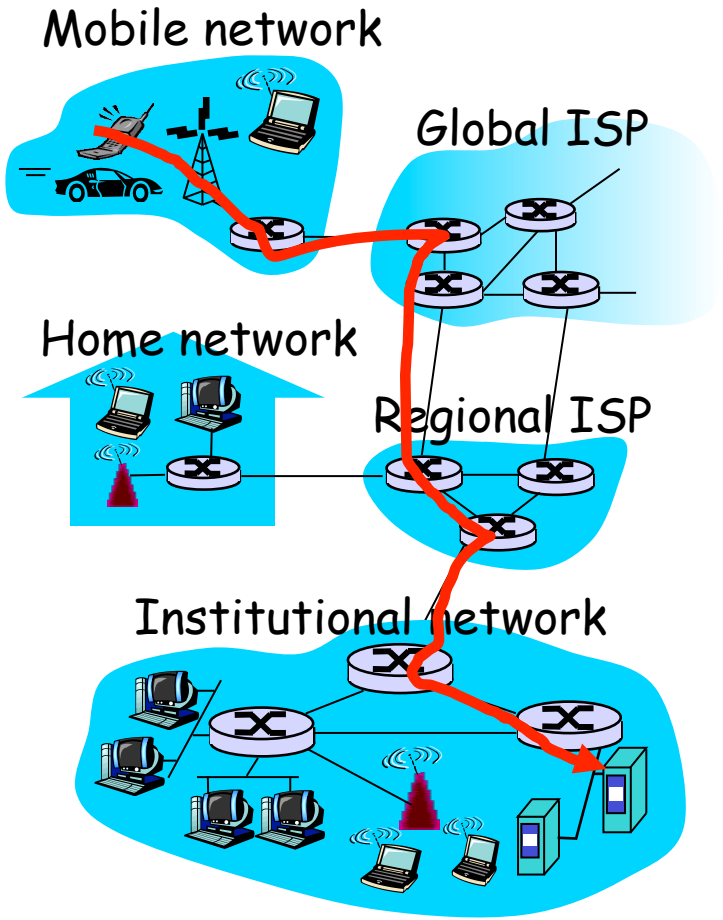

access points

wired links

- communication links
  - fiber, copper, radio, satellite
  - transmission rate = *bandwidth*


router

- routers: forward packets
  - routers or switches



… to Internet of (Every)Things

IP Phones

Smartphones

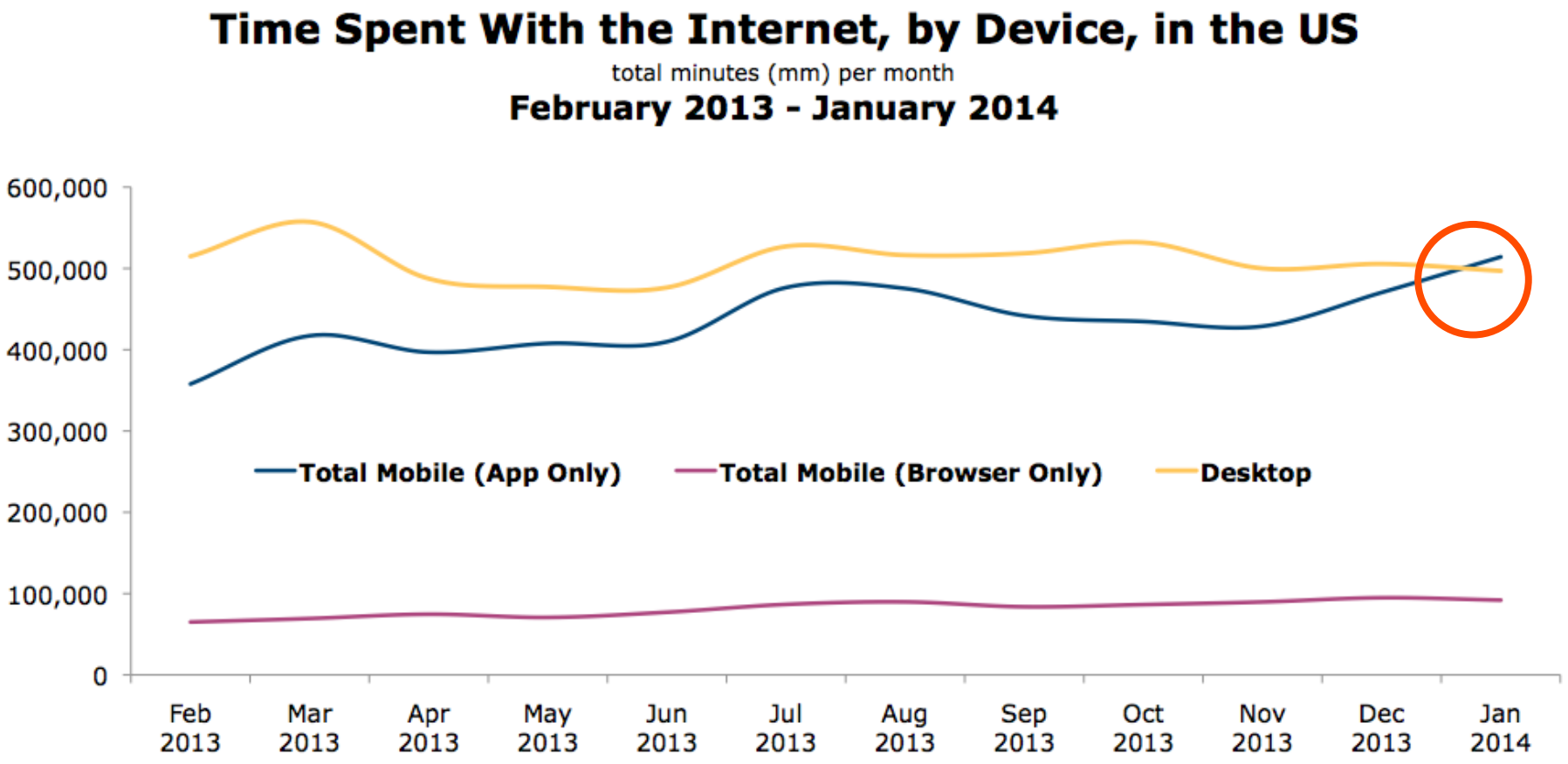
Home Appliances

Sensors

Wearables

Drones

Mobile is King



ComScore 2014

- 7.7B mobile-connected devices vs 7.1B world's population
- 1.4B smartphones vs. 2B PCs

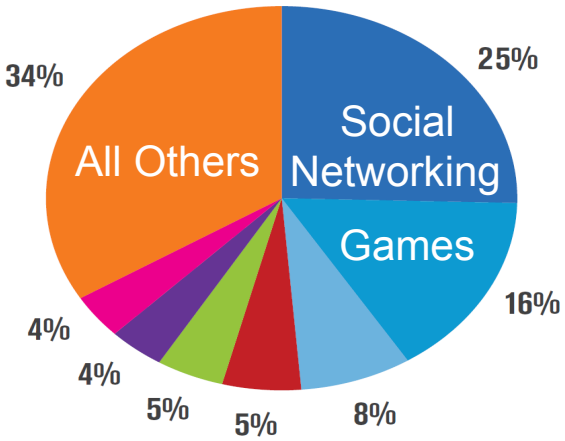
Cisco VNI 2014

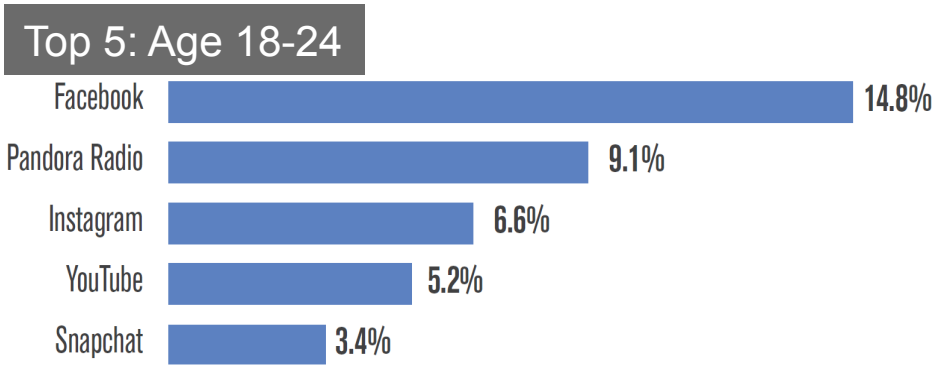
Mobile and Social

TOTAL POPULATION	ACTIVE INTERNET USERS	UNIQUE MOBILE USERS	ACTIVE MOBILE SOCIAL ACCOUNTS
7.2 Billion	3.0 Billion	3.6 Billion	1.7 Billion

We are social, Global Digital Snapshot, Jan 2015

Time Spent on Mobile Apps





ComScore, June 2014

What is the Internet: "nuts and bolts" view


PC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cellular handheld

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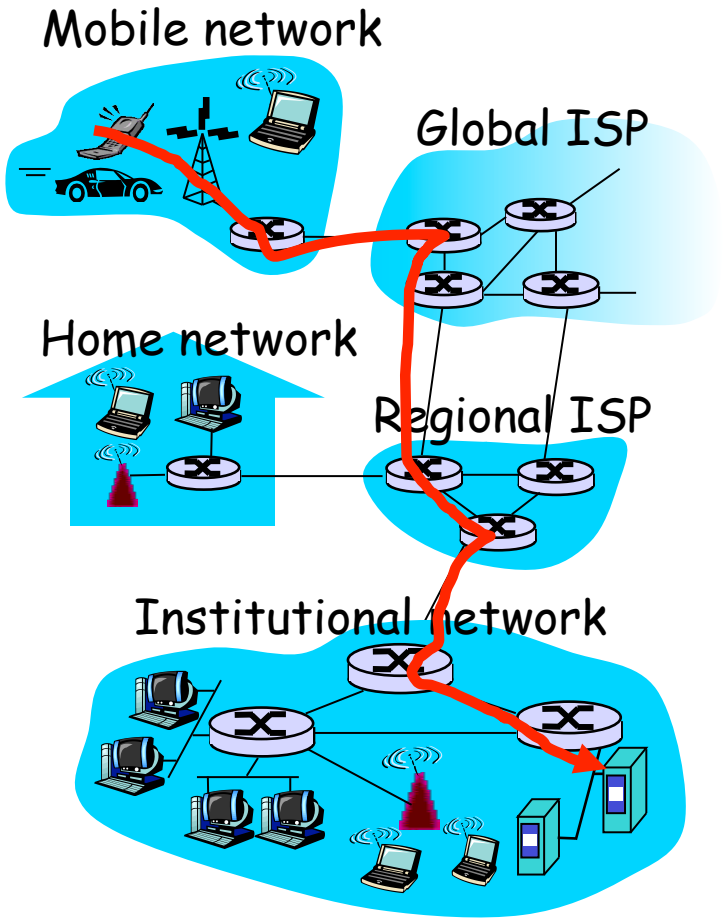
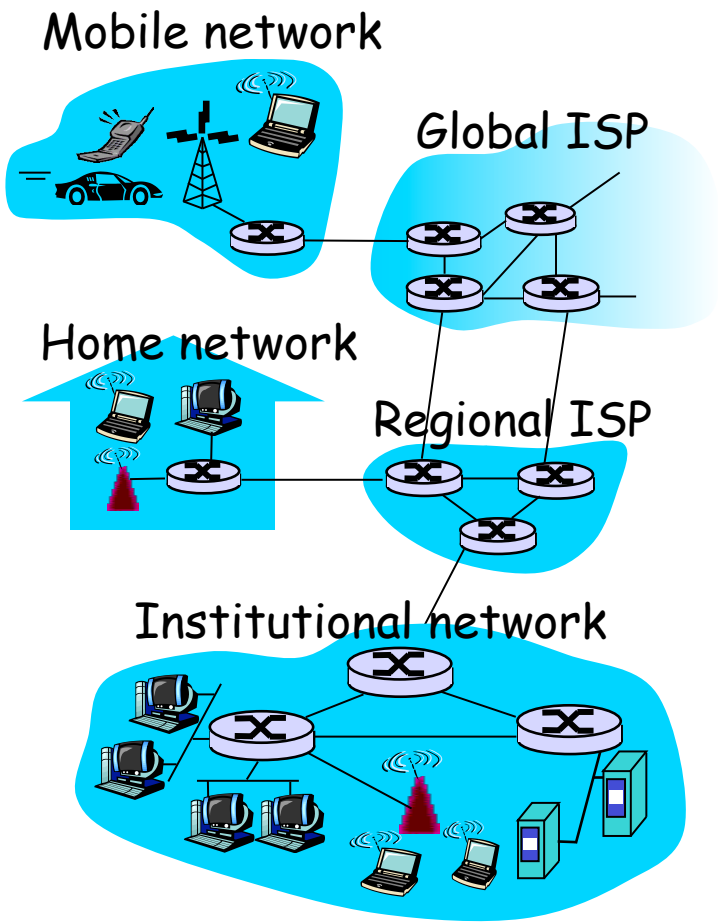


What is the Internet: "nuts and bolts" view

These components interoperate via protocols and standards

- Internet: "network of networks"
  - loosely hierarchical
- protocols control sending+ receiving of msgs. E.g.:
  - HTTP, Skype
  - **TCP/IP**
  - WiFi (802.11)
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force

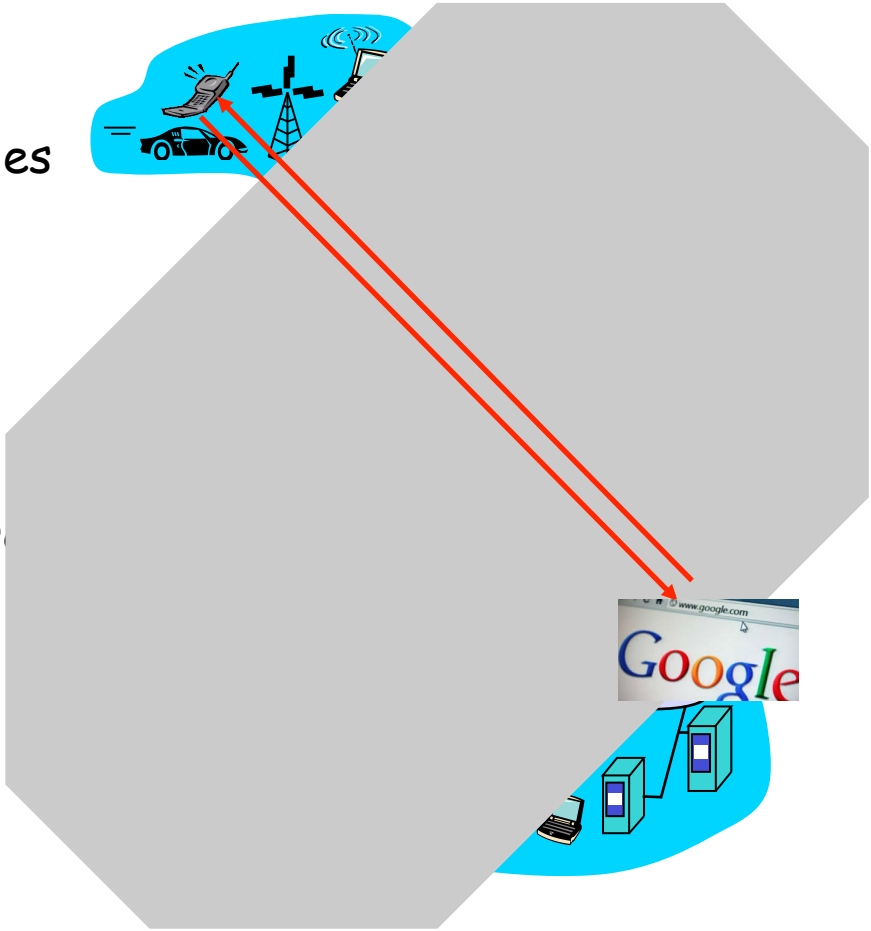


What is the Internet: a "service" view

From an application developer's point-of-view, it seems like an API.

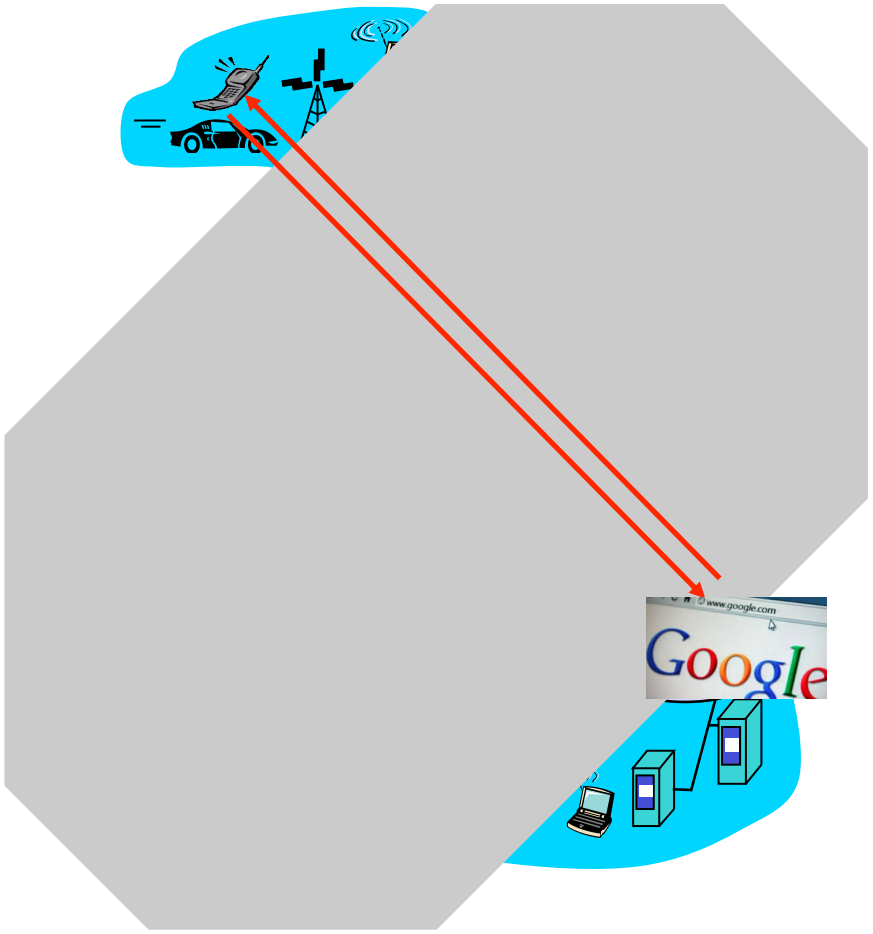
- communication infrastructure enables distributed applications:
  - Web, VoIP, email, games, e-commerce, file sharing
- communication services provided to applications:
  - reliable data delivery from sour to destination
  - "best effort" (unreliable) data delivery

- Analogy: Postal Service.

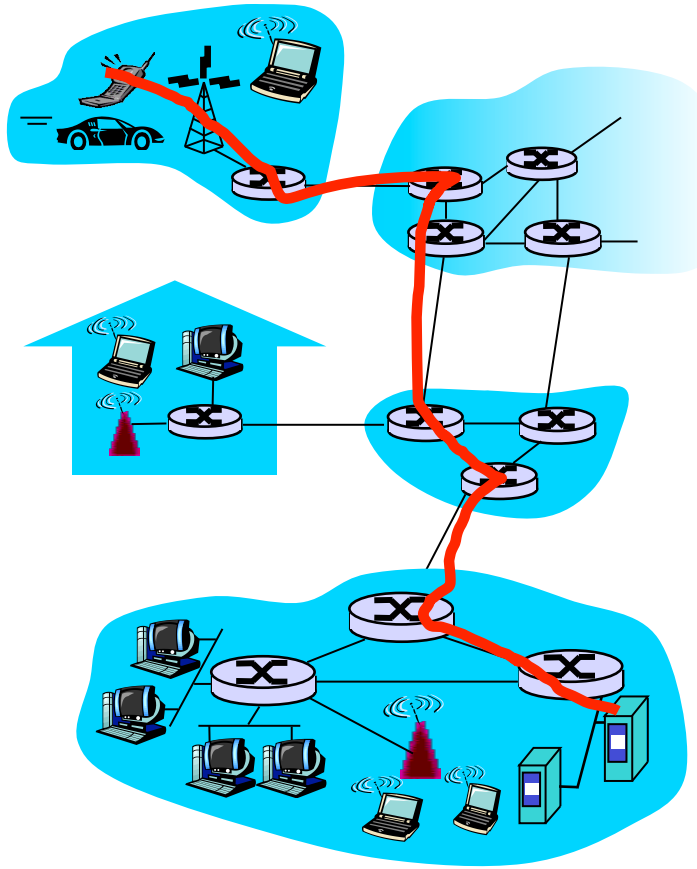


What is the Internet: two views

"Service" View



"Nuts and bolts" View



It all works because of protocols.

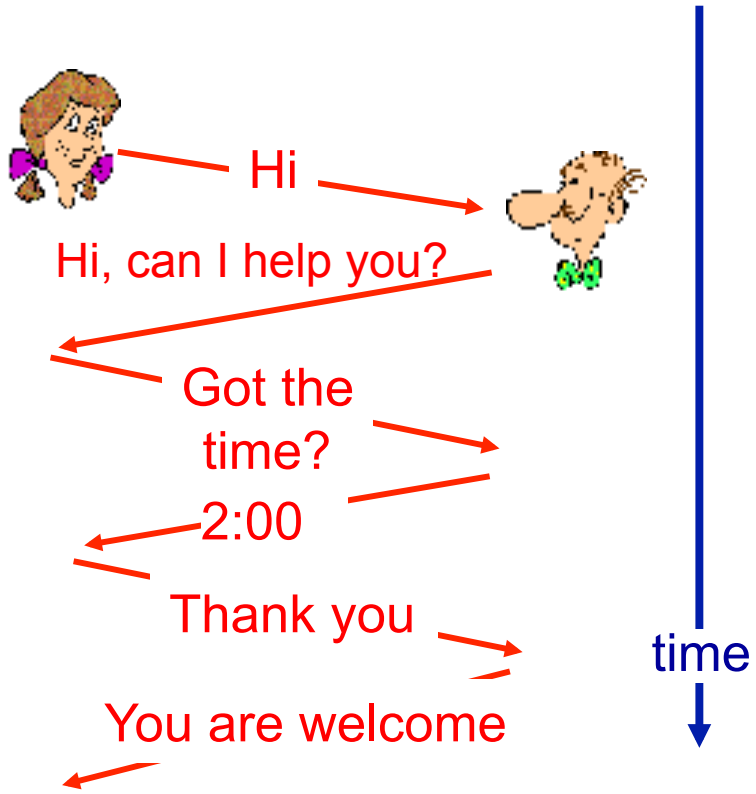
What is a protocol?

human protocols:

- "what's the time?"

… specific msgs sent

… specific actions taken when msgs received, or other events



Q: Other examples of human protocols?

A: Q & A in class, introductions, automated phone service (airline, banking, healthcare), ordering coffee at starbucks, bank, ….

What is a protocol?

human protocols:

- "what's the time?"

… specific msgs sent

… specific actions taken when msgs received, or other events

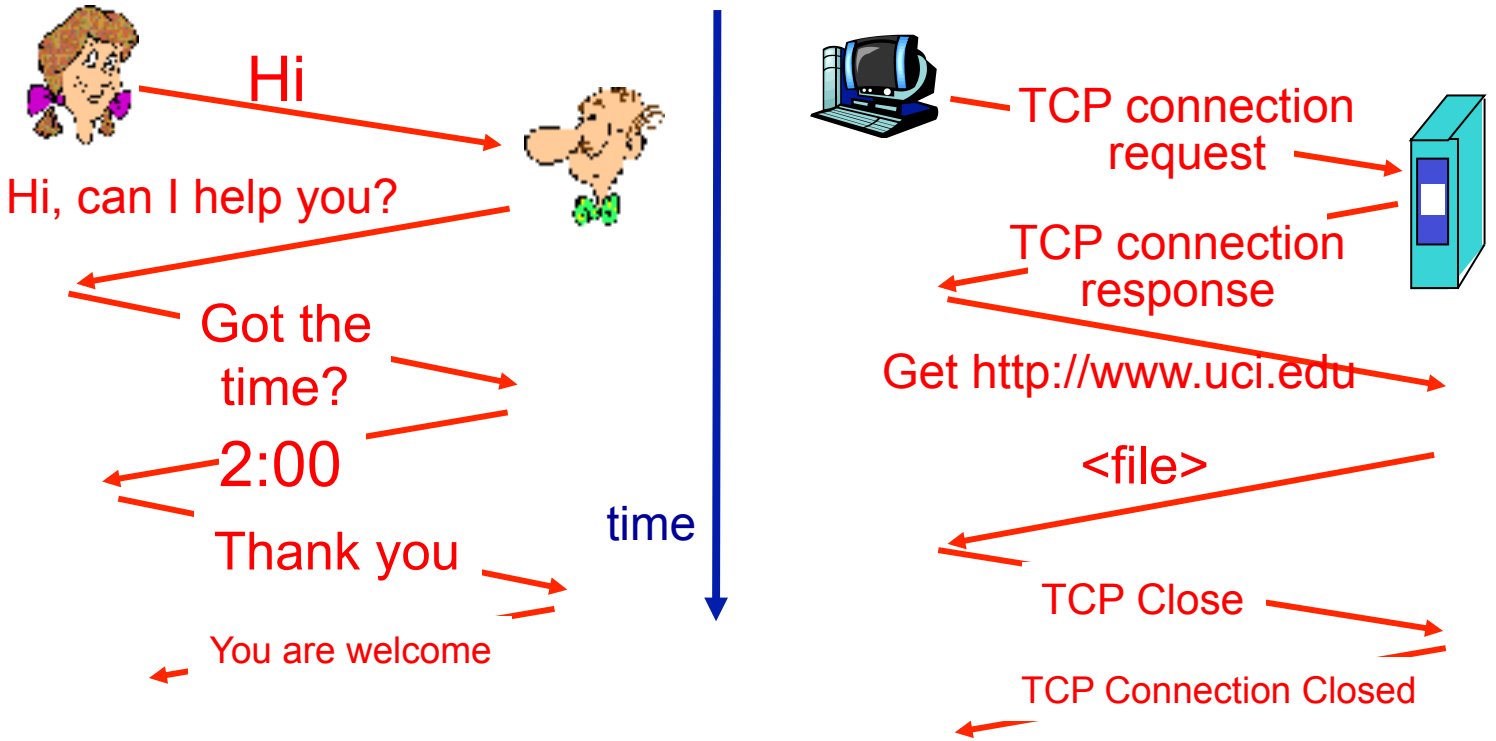
network protocols:

- machines rather than humans

- all communication activity in Internet is governed by protocols

What is a protocol?

Human vs. computer network protocol:



- protocols define format, order of msgs sent and received among network entities, and actions taken on msg Tx/Rx
- protocols do NOT define the content

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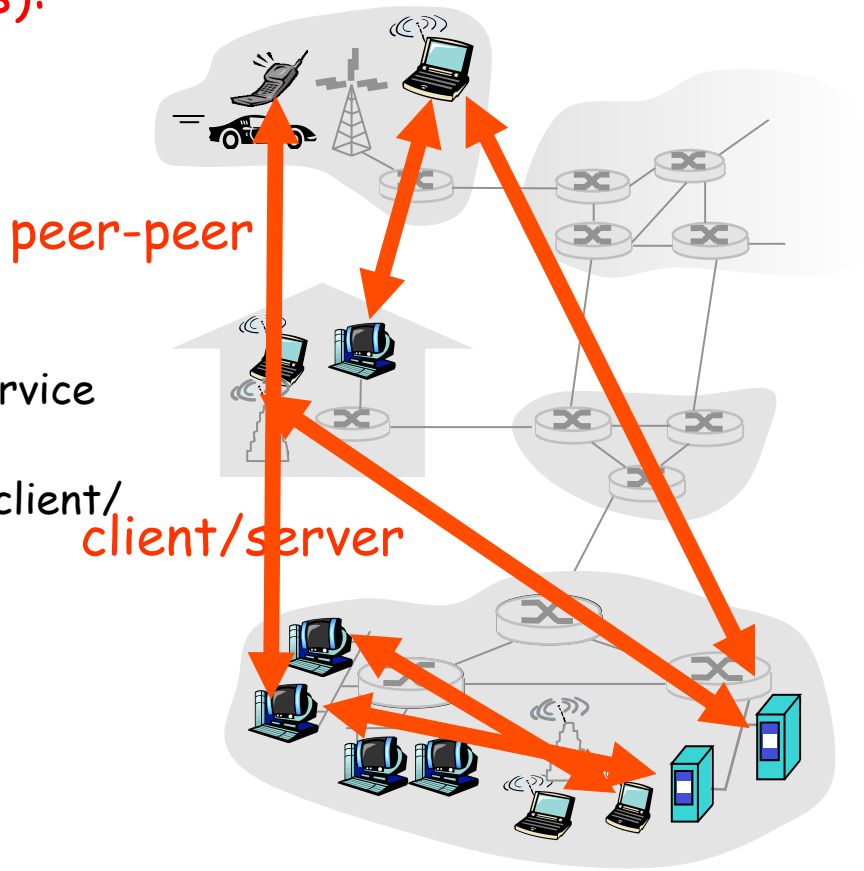
1.7 History

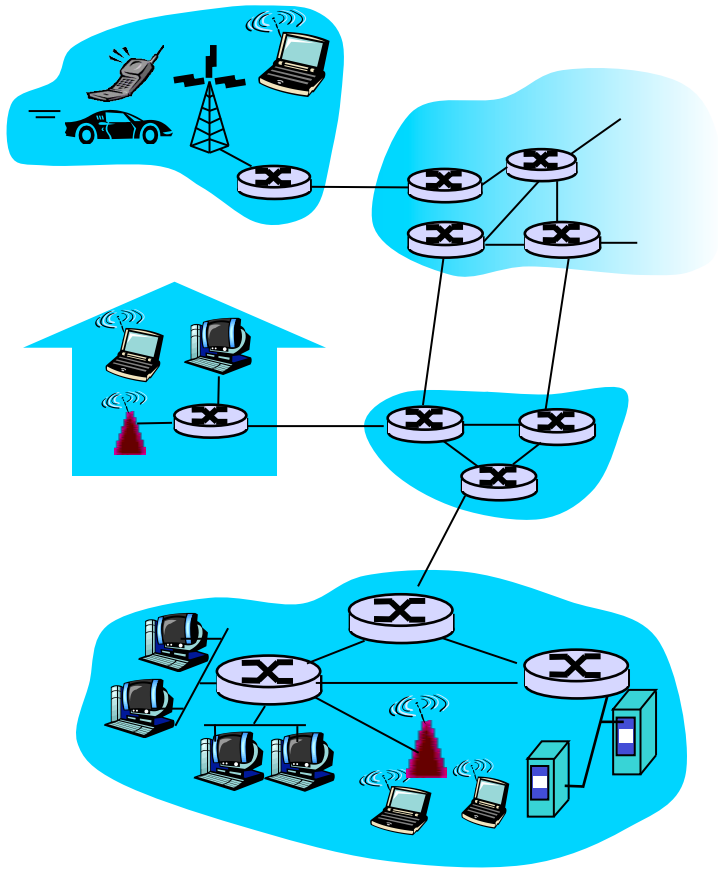
Goal: connect end-systems

- end systems (hosts or servers):
  - run application programs
  - e.g. Web, email
  - at "edge of network"
- client/server model
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- peer-peer model:
  - minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrent



A closer look at network structure:

- network edge: applications and hosts
- access networks, physical media: wired, wireless communication links
- network core:
  - interconnected routers
  - network of networks



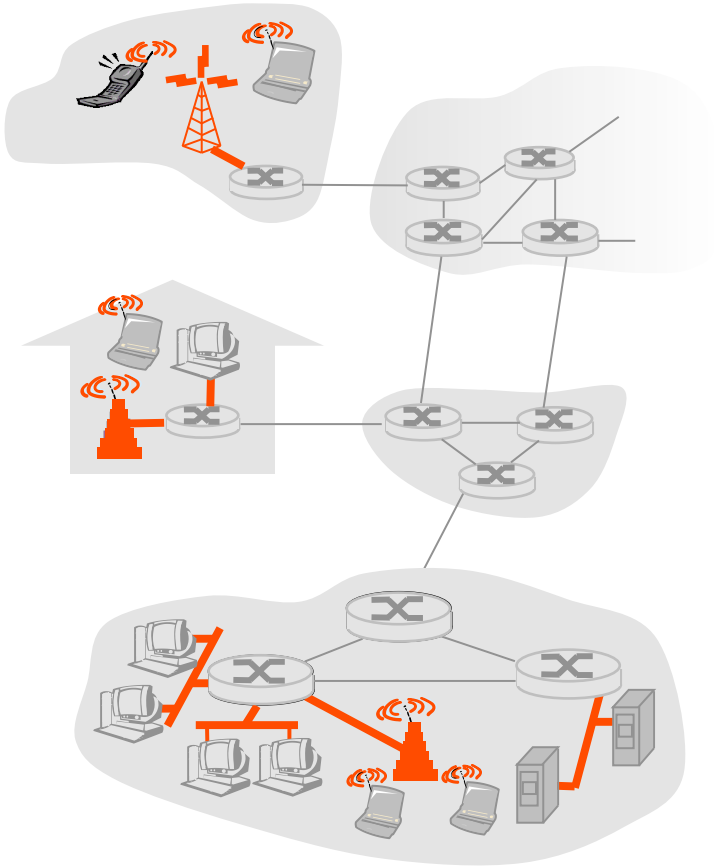
Access networks and physical media

Q: How to connect end systems to edge router?

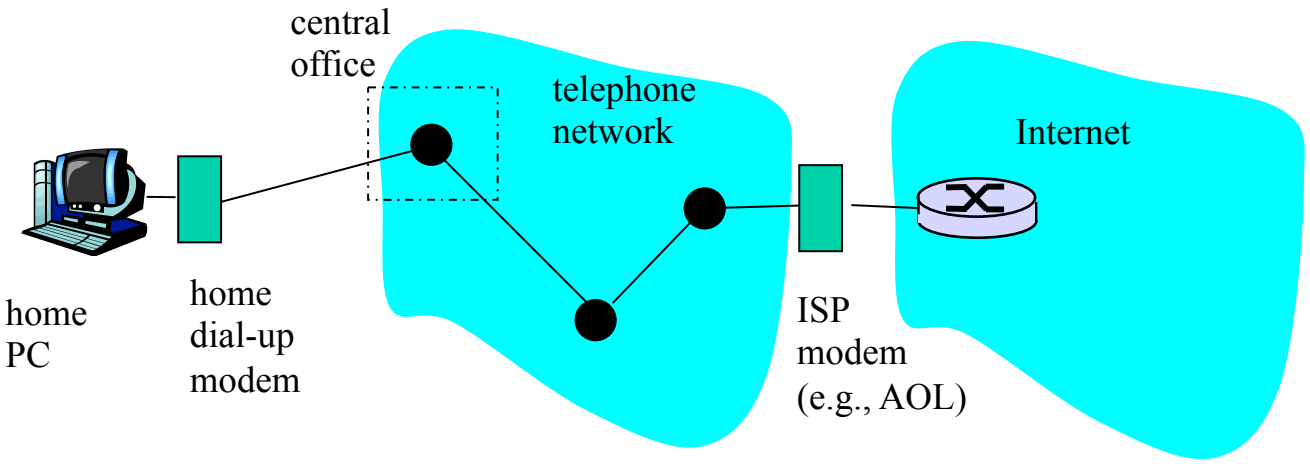
- residential access nets (local telco or TV company)
- institutional access networks (school, company)
- mobile access networks

Characteristics of access:

- bandwidth (bits per second) of access network?
- shared or dedicated?
- other?

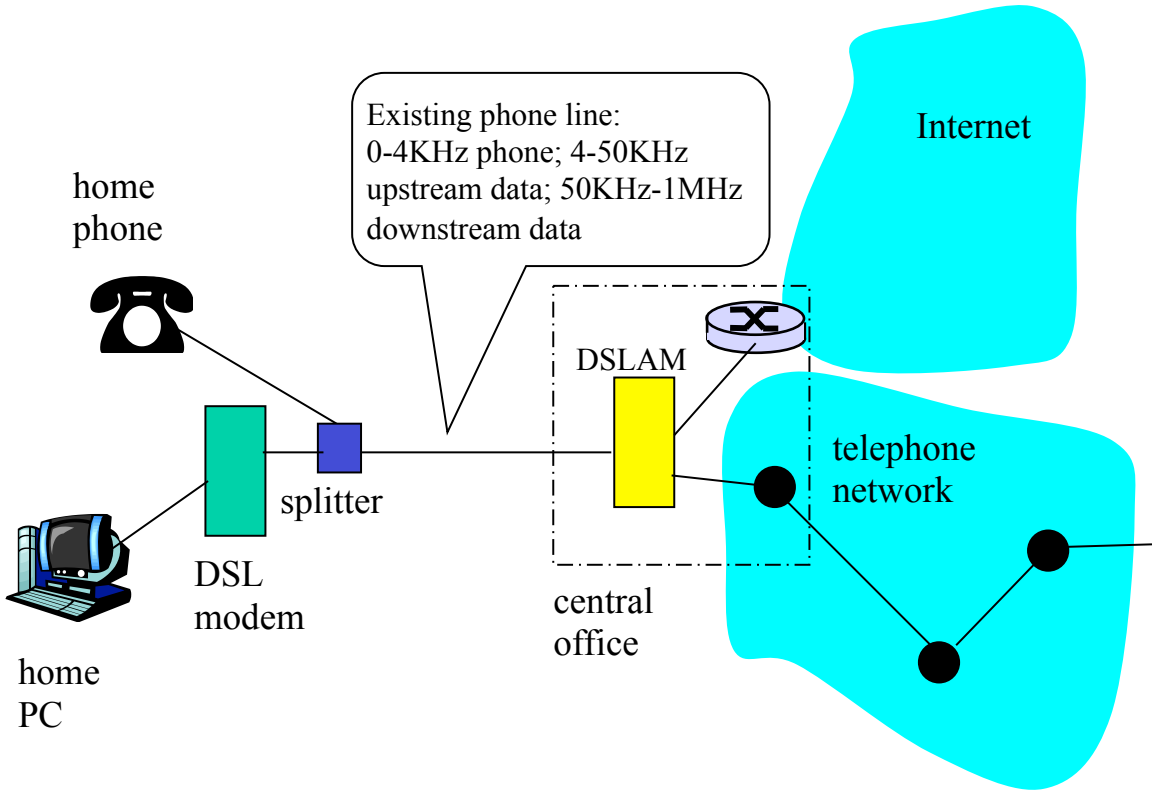


Access net: Dial-up Modem



- uses *existing* telephony infrastructure
  - Twisted pair, convert digital to analog
  - home directly-connected to central office
- <56Kbps direct access to router (was 14Kbps ☺)
  - It sounded like this: https://www.youtube.com/watch?v=gsNaR6FRuO0
  - Data on the wire restricted to a band of ~= 4000Hz
  - 8000 samples per sec; 8 bits per sample (1 bit for control); 56,000bits/sec= 56kbps
- Couldn't surf and phone at same time: not "always on"

Access net: Digital Subscriber Line (DSL)



- 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
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

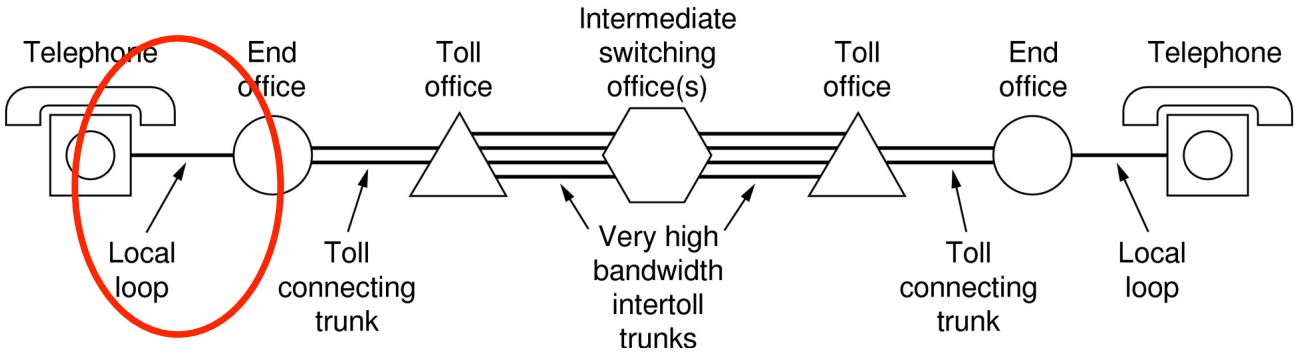
Q: Why Modem is Worse than DSL over same medium??

PSTN for carrying voice calls made of:

- Local loops, mostly *analog* twisted pairs to houses
- Trunks, *digital* fiber optic links that carry calls
- Switching offices, that move calls among trunks
- Local loops/last mile has frequency band 0-1MHz

Modem and DSL use similar (analog-to-digital) approach over same local loop

Q: Why does Modem get 56 kbps and DSL gets 10Mbps?



Modem (POTS):

- POTS apply filter 0-4000Hz at end-office, to match human voice
- In fact filter is 300-3400Hz (3dB points, but cutoffs not sharp),
- Data on the wire restricted to a band of ~= 4000Hz
- 8000 samples per sec (Nyquist) ; 8bits per sample 1 bit for control); 56,000bits/sec= 56kbps

[Local loop (1): modems]

Telephone modems send digital data over an 3.1 KHz analog voice channel interface to the POTS

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- In fact filter is 300-3400Hz (3dB points, but cutoffs not sharp),
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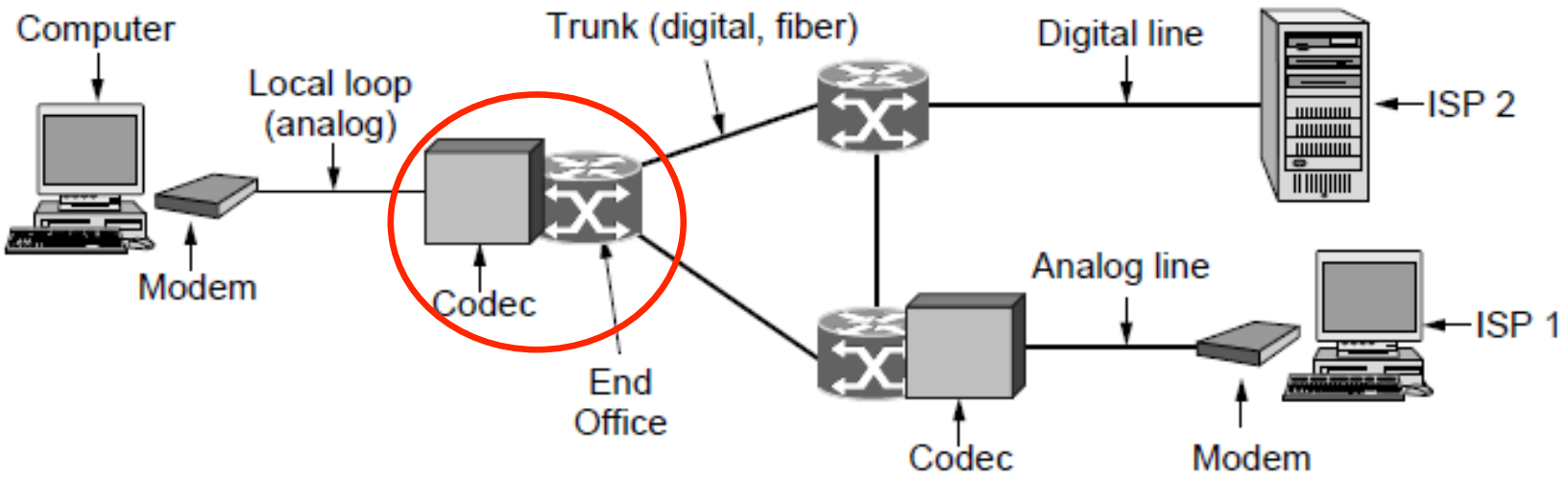
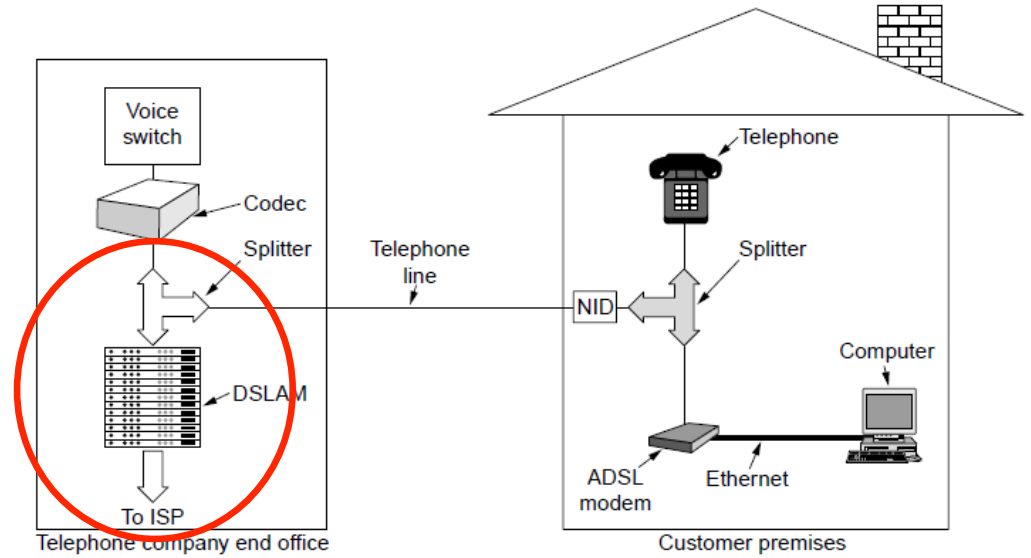


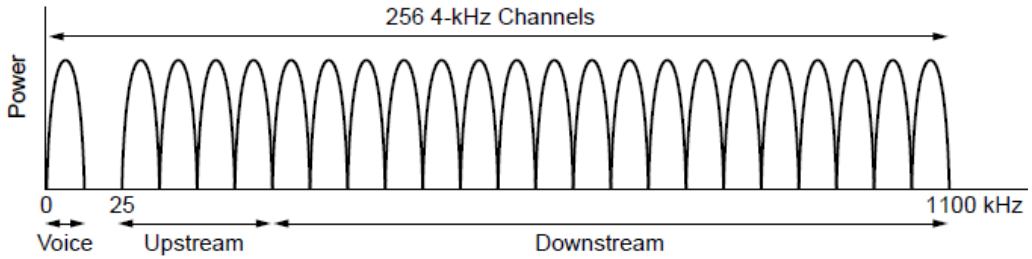
CN5E by Tanenbaum & Wetherall, © Pearson Education-Prentice Hall and D. Wetherall, 2011

[Local loop (2): DSL]

DSL broadband sends data over the local loop to the local office using frequencies that are not used for POTS

- Incoming line connected to different switch that does NOT filter data
- Telephone/computers attach to the same old phone line
- Rates vary with line
  - Limit 1MGHz > 3.1Khz
  - 2,000,000 samples/sec, 8bbps → 16Mbps
  - OFDM is used up to 1.1 MHz for ADSL2
  - ADSL2 up to 12 Mbps





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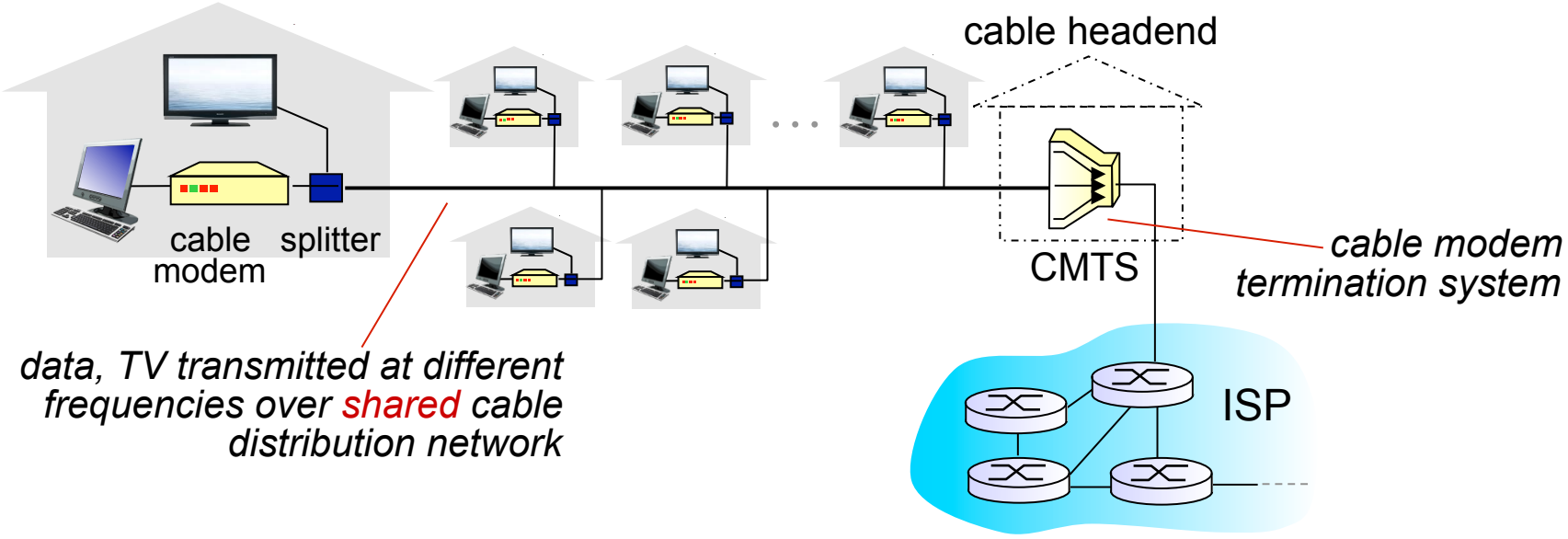
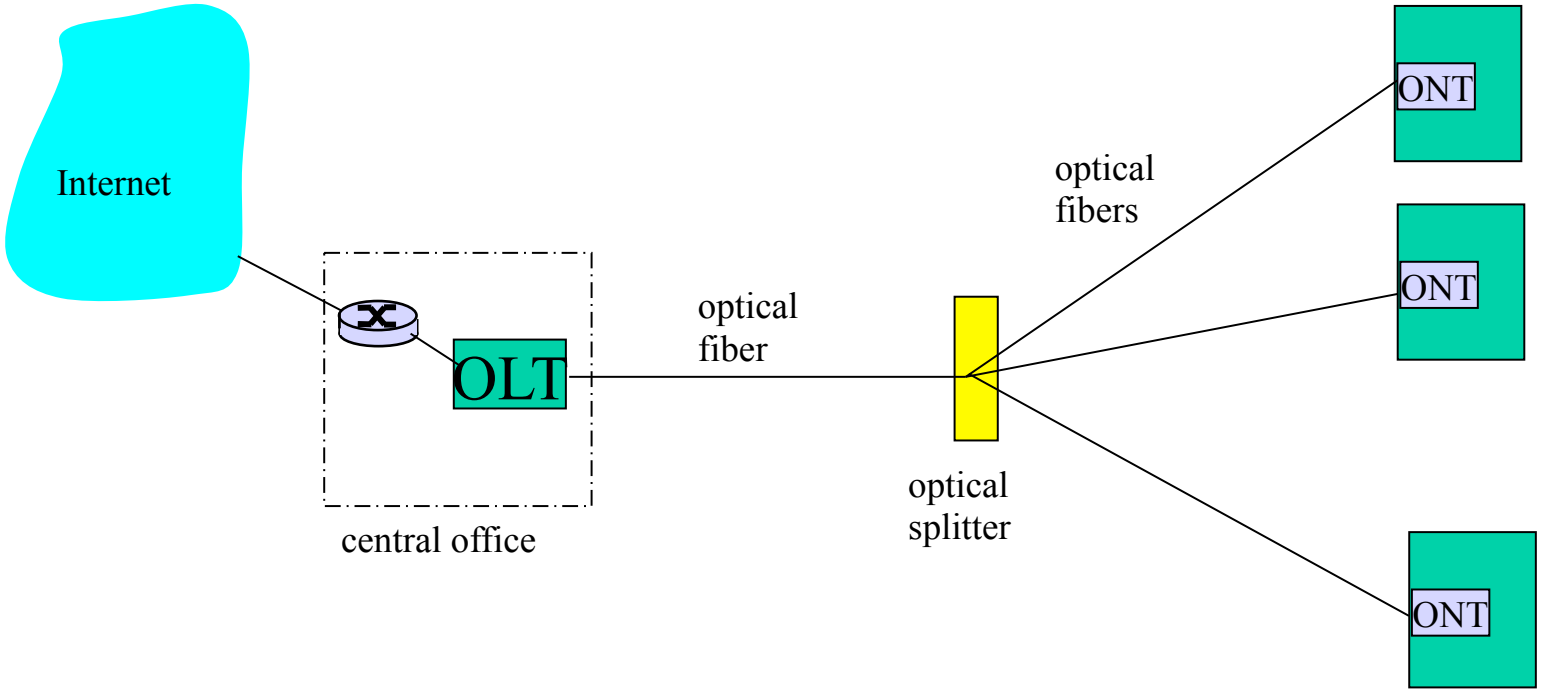
Access net: Cable network



- Use *existing* cable TV infrastructure
- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
- network of cable+fiber attaches homes to ISP router
  - homes *share access network* to cable headend
  - unlike DSL, which has dedicated access to central office

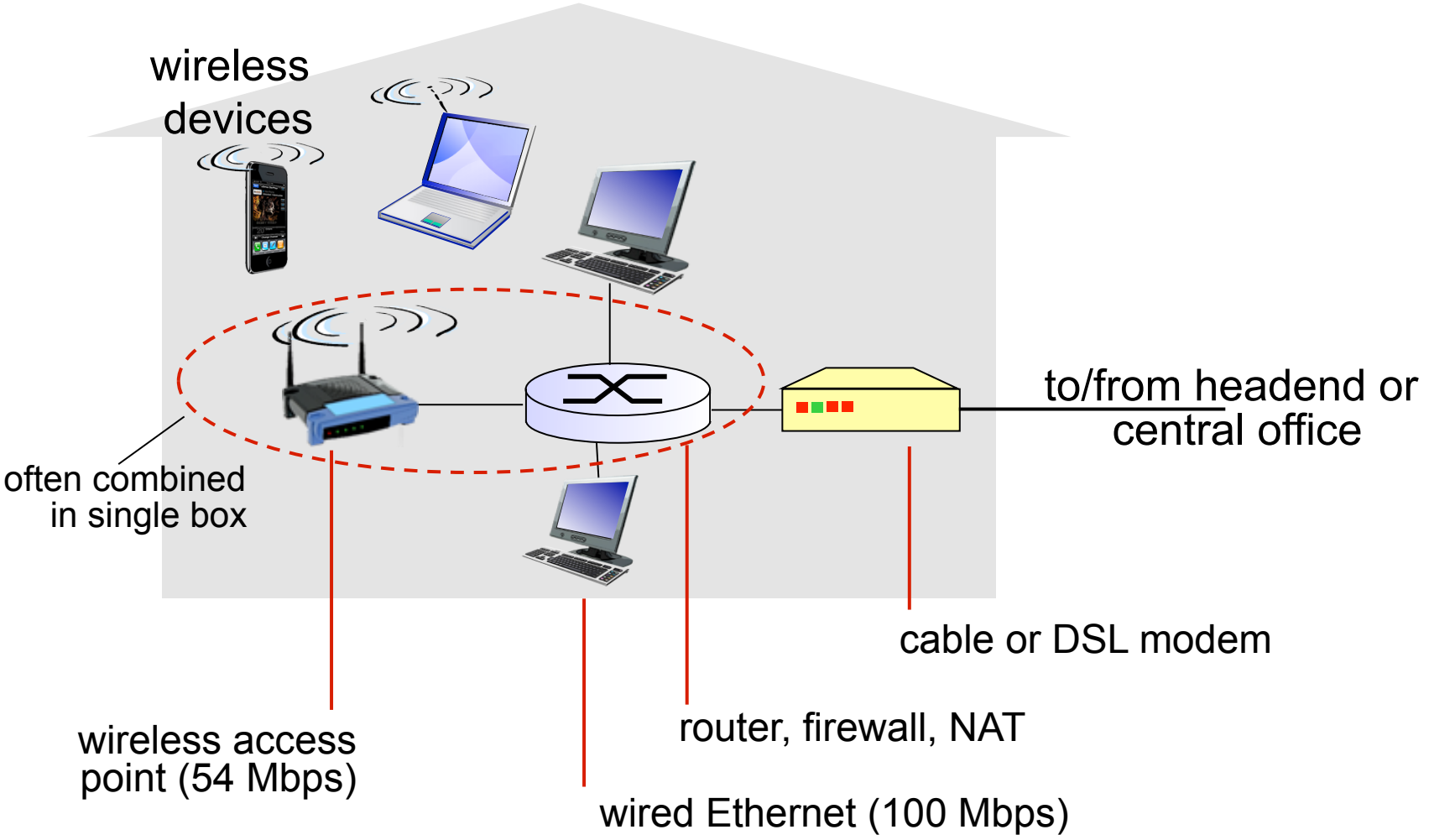
Fiber to the Home (FTTH)



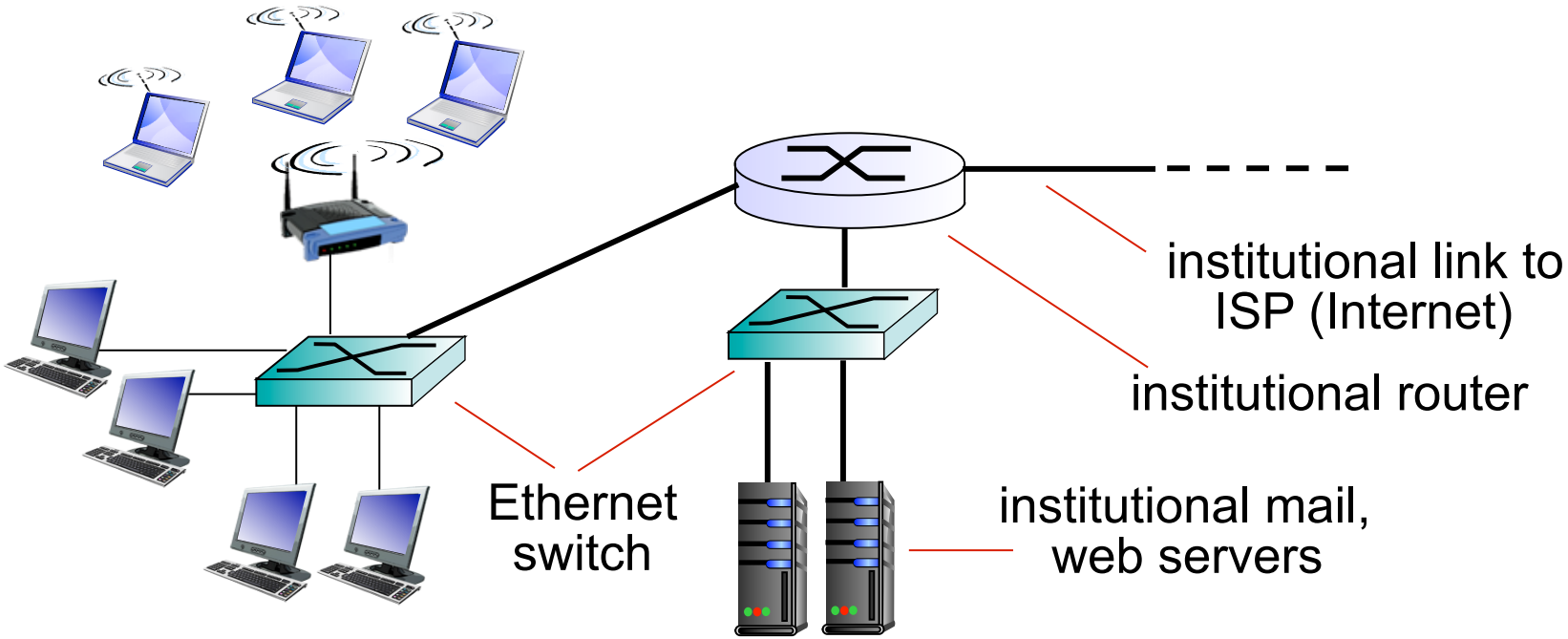
- optical links from central office to the home
- much higher rates; fiber also carries television and phone services

- fiber.google.com

Access net: home network



Enterprise access networks (Ethernet)



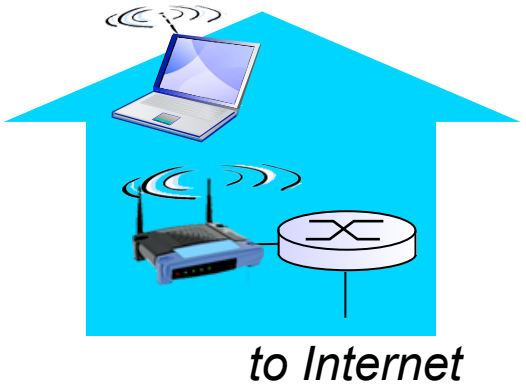
- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

Wireless access networks

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

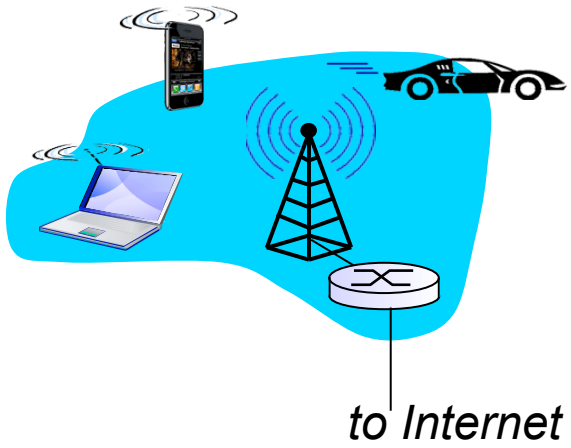
wireless LANs:

- within building (100 ft)
- 802.11b/g (WiFi): 11, 54 Mbps transmission rate
- 802.11n: up to 600 Mbps

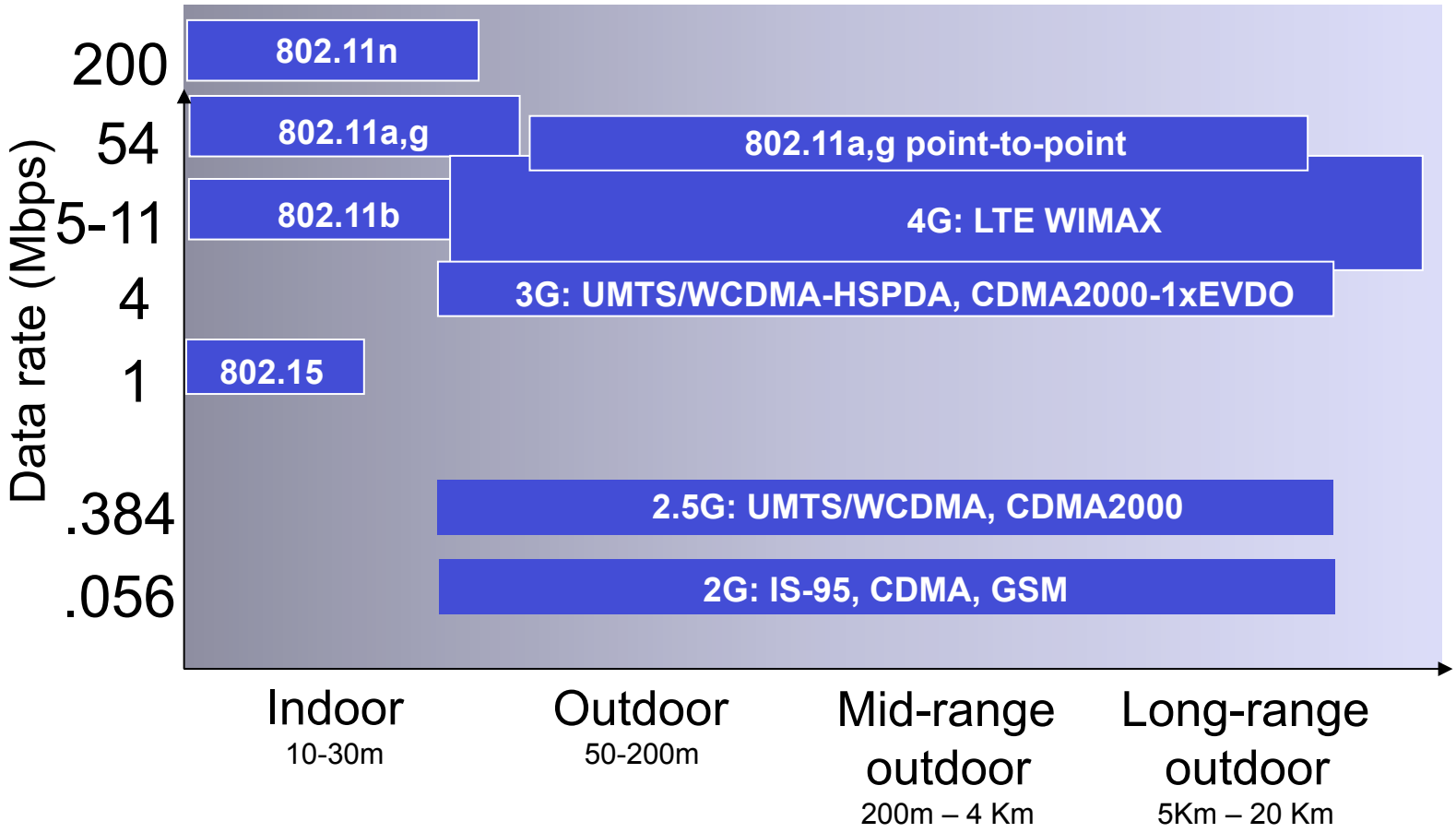


wide-area wireless access

- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE, 5G



Characteristics of selected wireless links



Roadmap

1.1 What is the Internet?

- network connecting end-systems, end-systems, "nuts and bolts" vs "service" view, protocols

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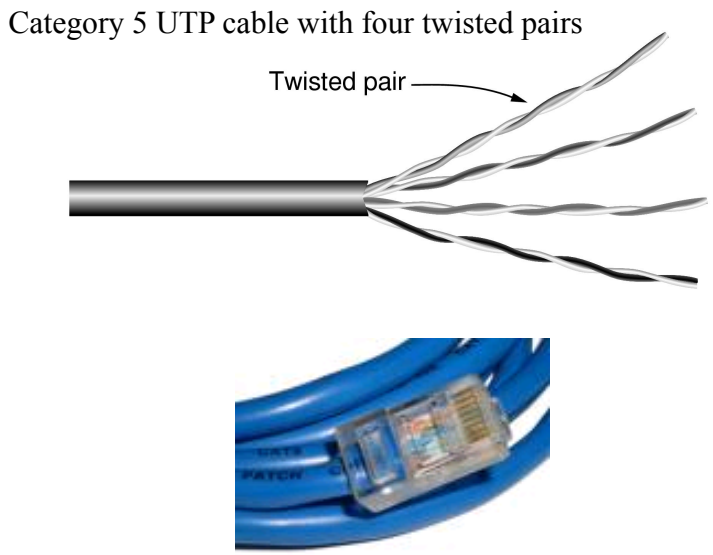
Physical media

- 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

Physical media – twisted pair (TP)

- two insulated copper wires
  - Category 3: traditional telephone network
  - Category 5: 100 Mbps, 1 Gbps Ethernet
  - Category 6a: 10Gbps up to 100m

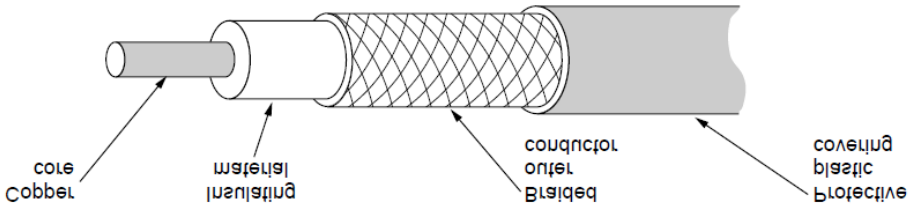


- Speed depends on material, thickness of wire, #twists, shielding, and distance

Physical Media: coax, fiber

Coaxial cable:

- two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- broadband:
  - multiple channels on cable
  - HFC



Fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed point-to-point transmission
  - e.g., 10's-100's Gpbs
- low error rate:
  - low attenuation up to 100s kms
  - repeaters spaced far apart
  - immune to electromagnetic noise
- Hard to tap
- Top-choice for long distance
- Residential: fiber.google.com

Physical media: radio

- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

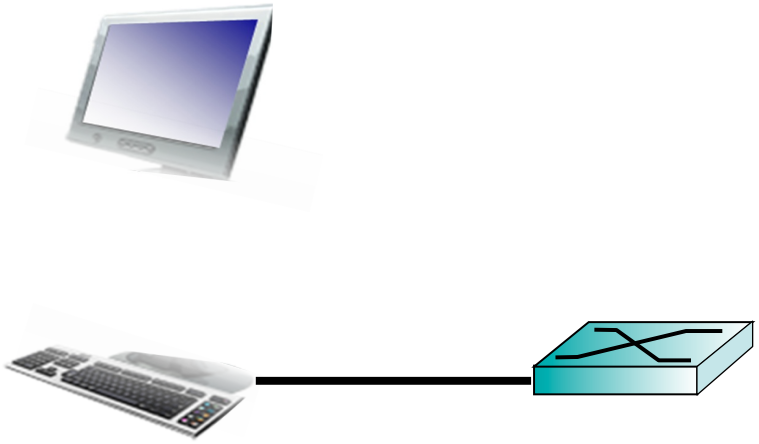
radio link types:

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WiFi)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ few Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

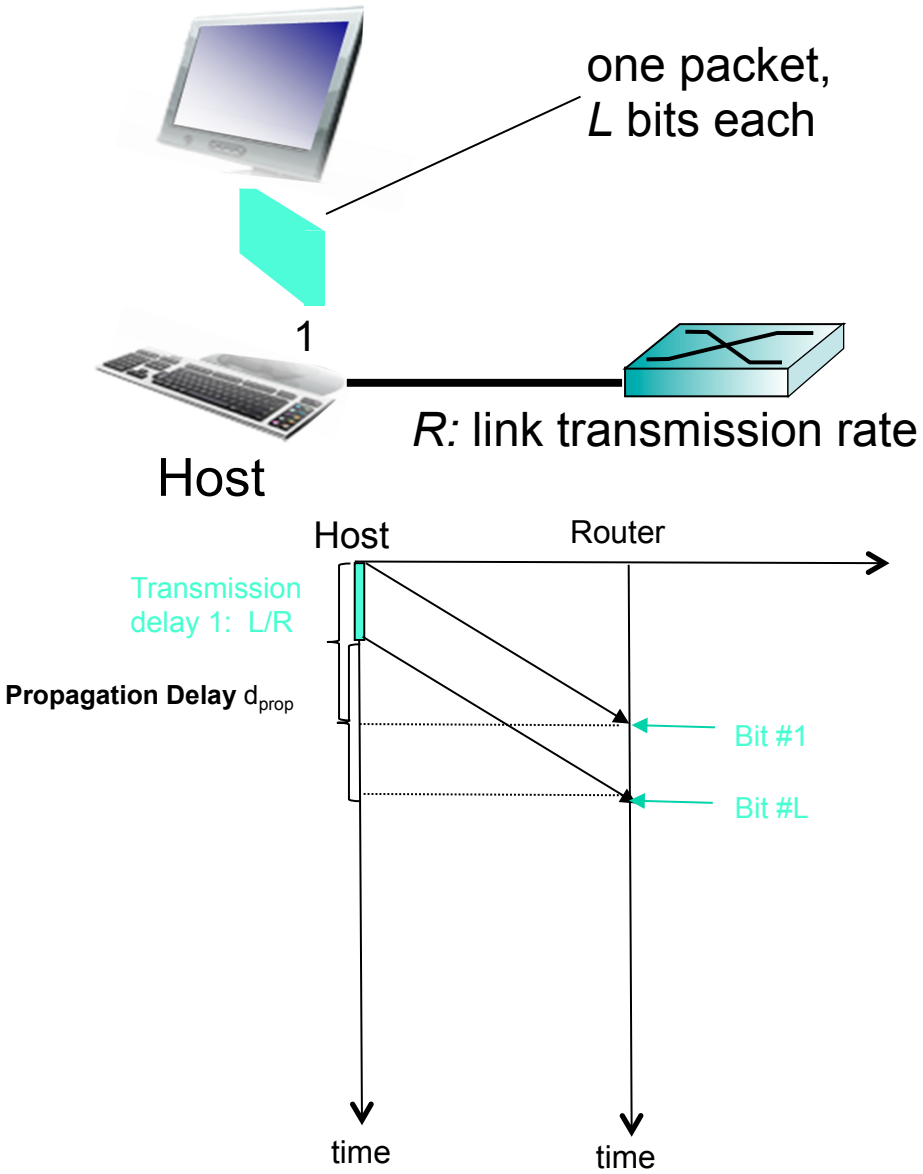
Transmission over a single point-to-point link

Notes on Transmission vs. Propagation Delay

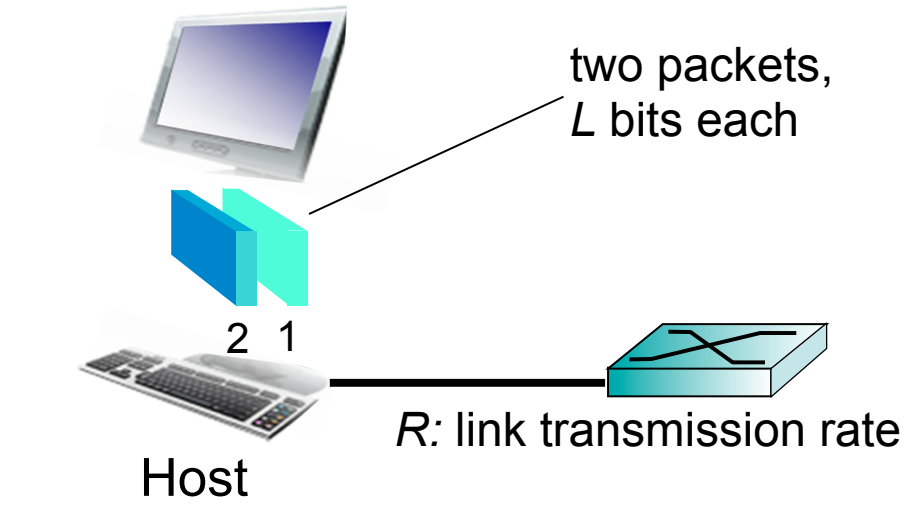
Host sends one bit

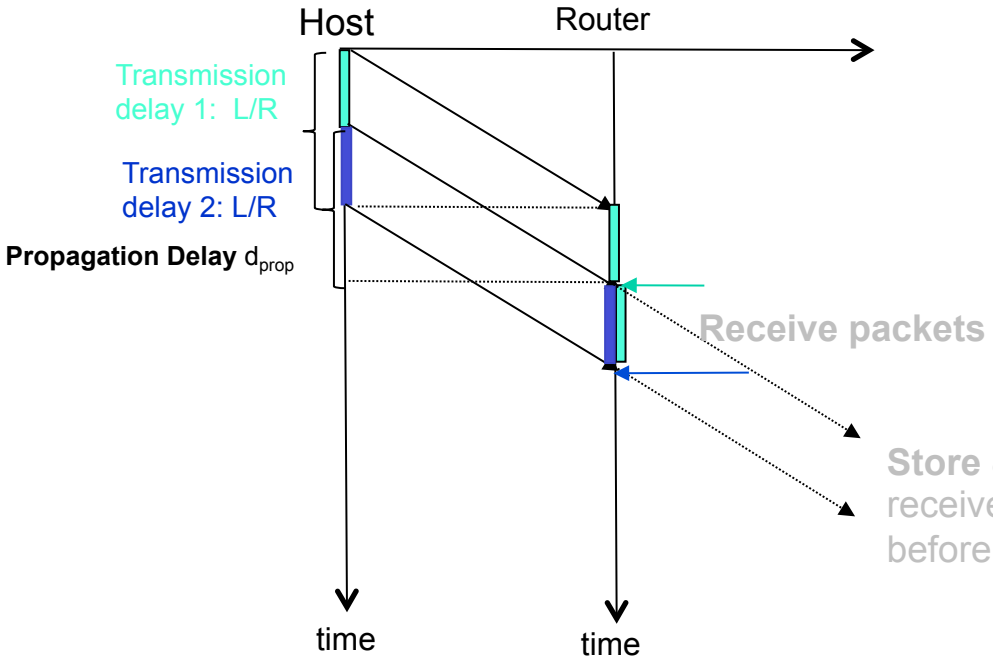


Host: sends one packet



Host: sends 2 packets of data





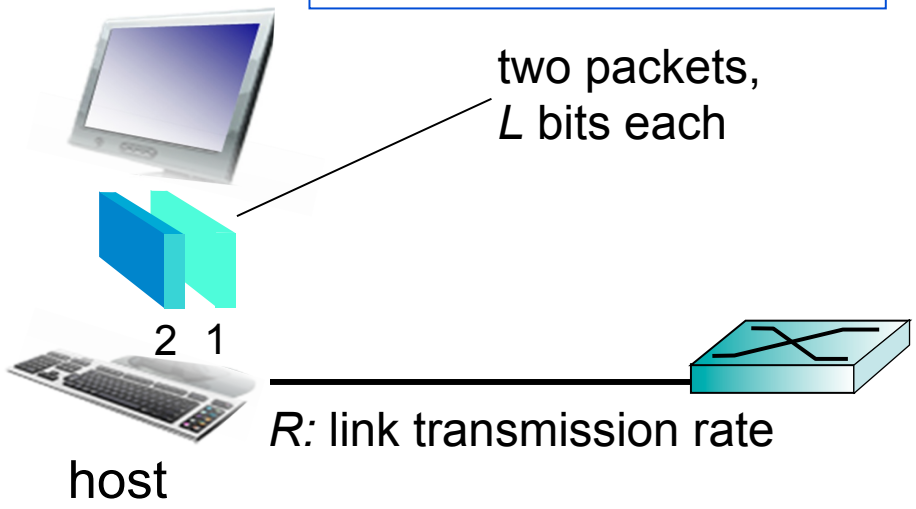
Host: sends *packets* of data

host sending function:

- takes application message
- breaks into smaller chunks, known as *packets*, of length *L* bits
- transmits packet into access network at link *transmission rate R*
  - aka link *capacity, aka link bandwidth*

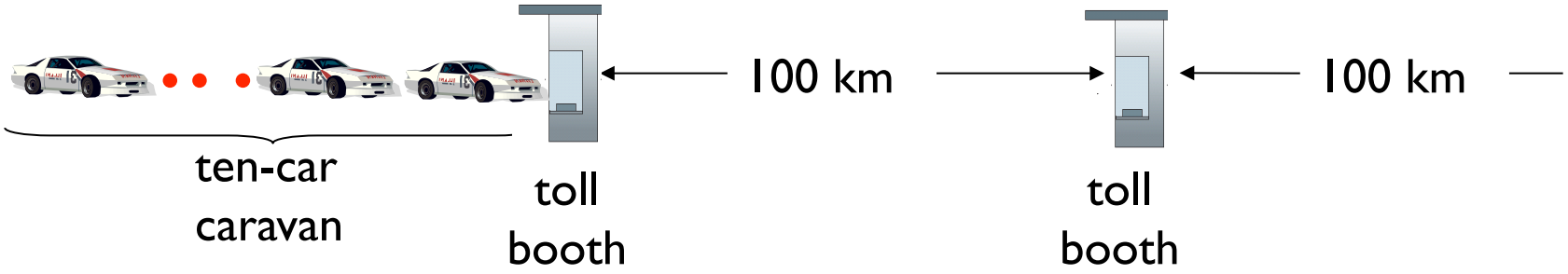
one-hop numerical example:

- *L* = 7.5 Mbits
- *R* = 1.5 Mbps
- one-hop transmission delay = L/R= 5 sec



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

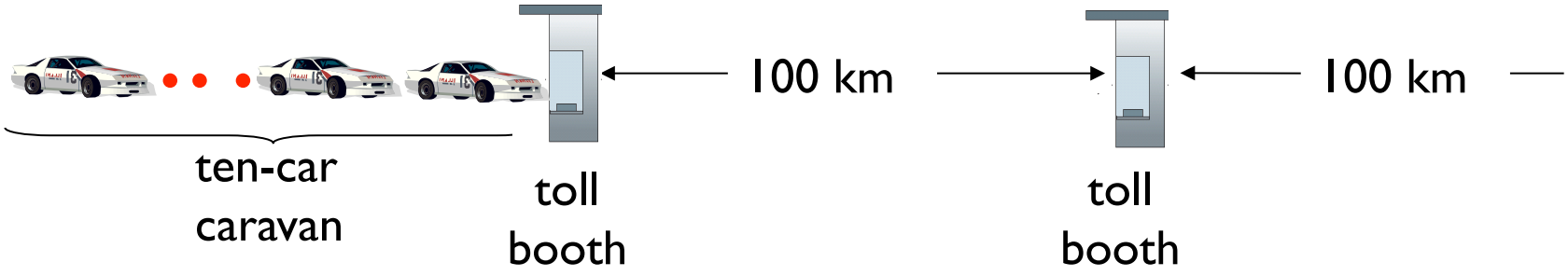
Caravan analogy: d_{trans} vs. d_{prop}

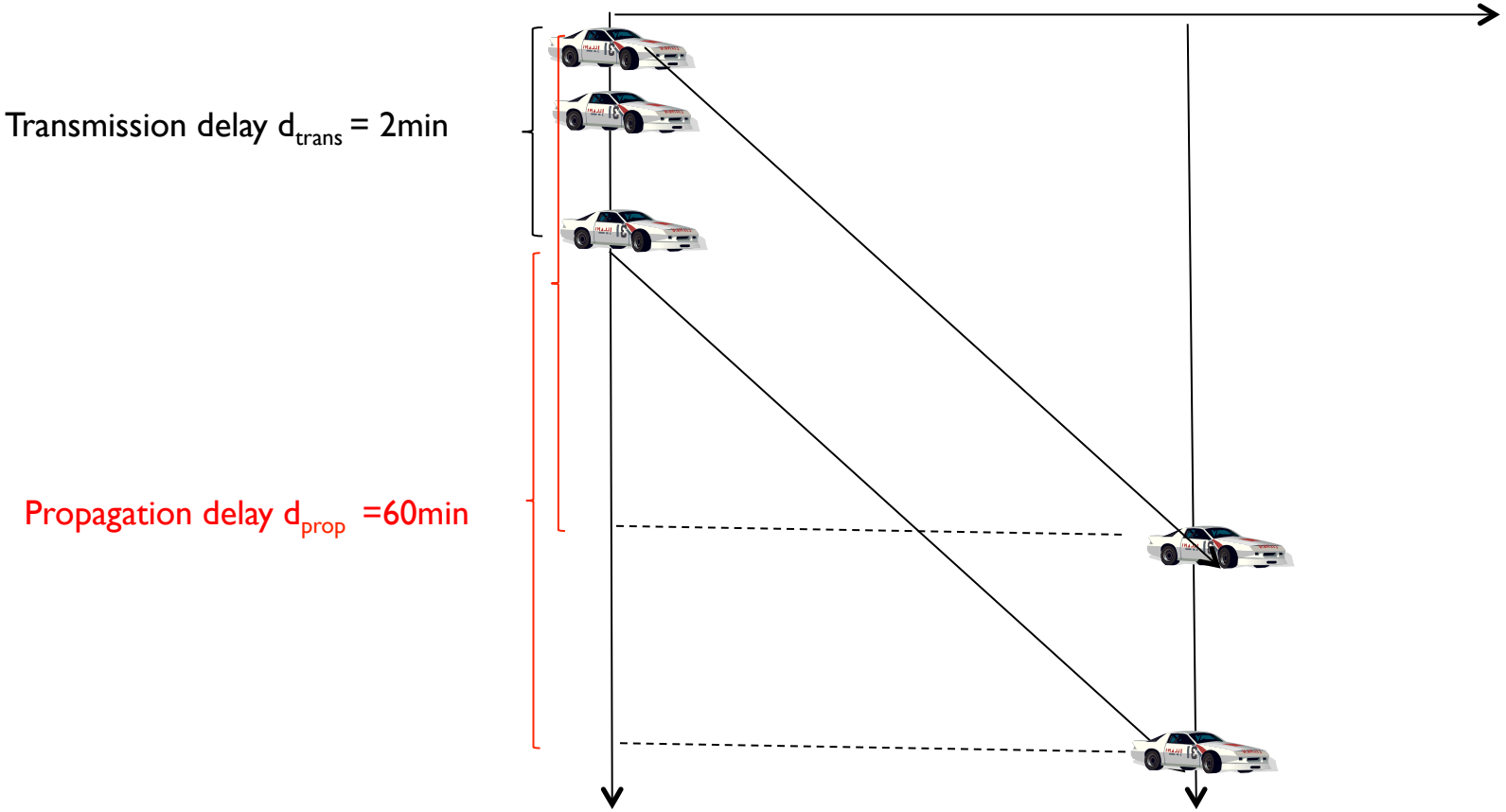


- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (transmission time)
- car~bit; caravan ~ packet
- Q: How long until caravan is lined up before 2nd toll booth?

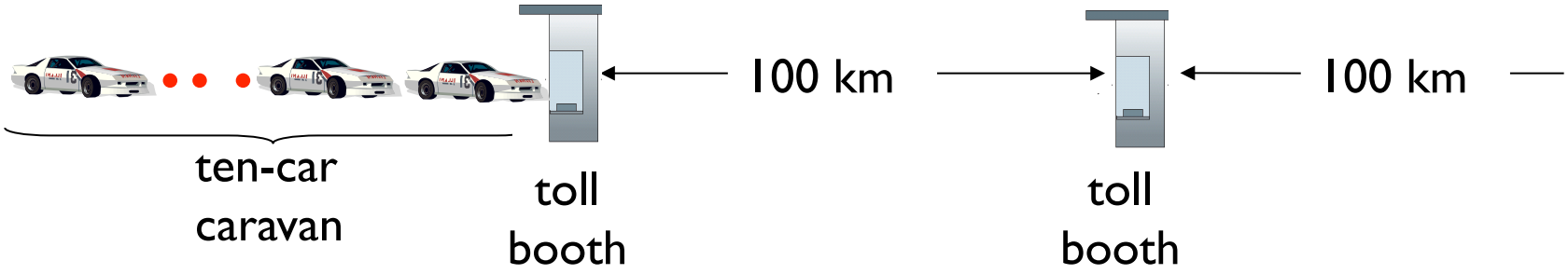
- time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec = 2min
- time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr=60min
- A: 62 minutes

Caravan analogy: $d_{trans} < d_{prop}$





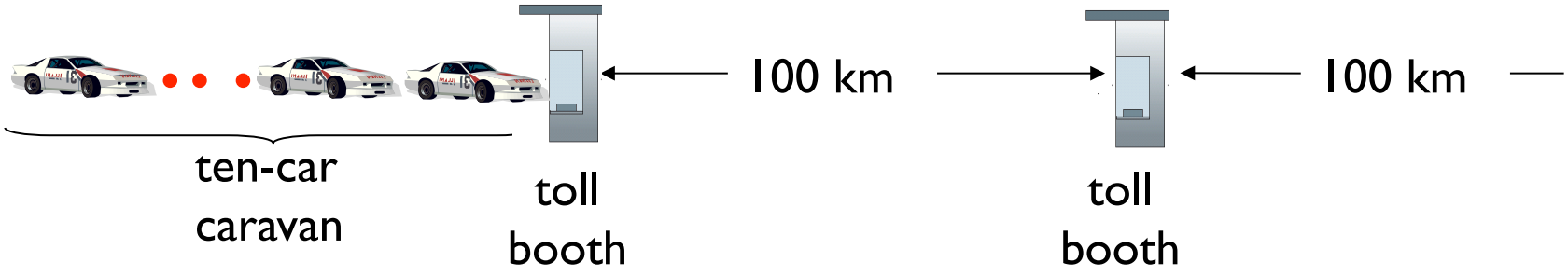
Caravan analogy: $d_{trans} > d_{prop}$

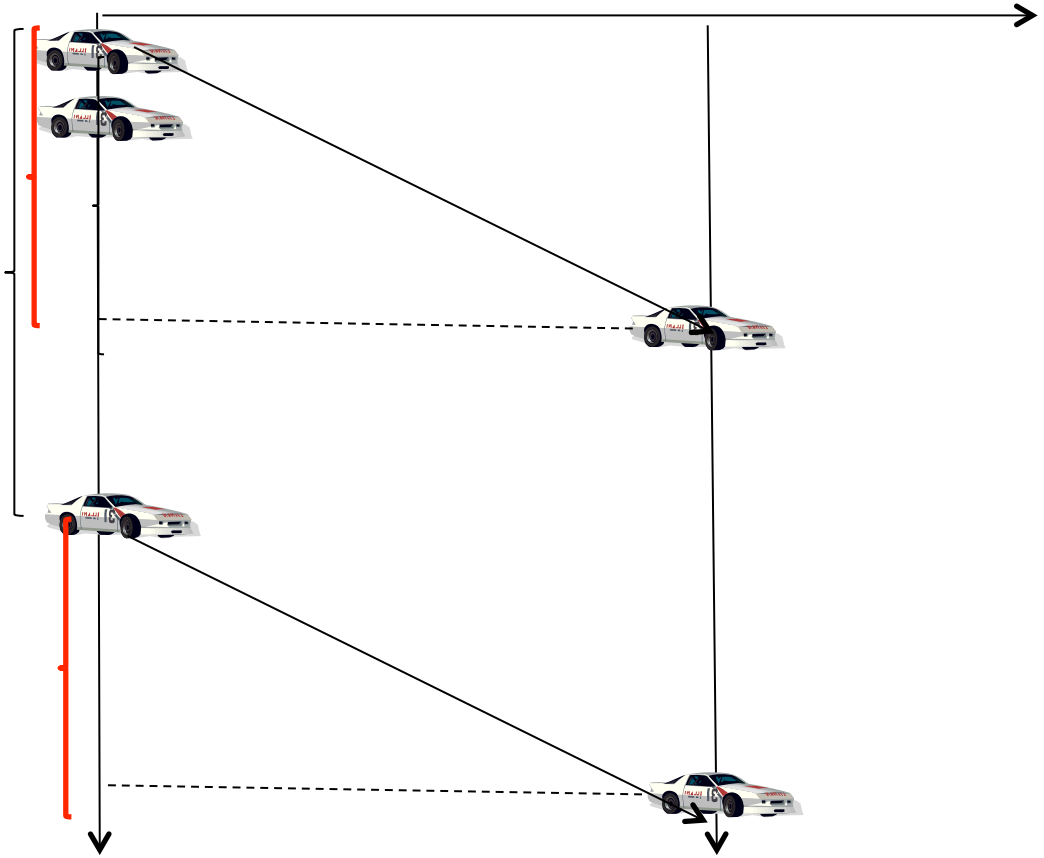


- cars now "propagate" at 1000 km/hr, i.e. 6min
- toll booth now takes 1 min to service a car
- *Q:* Will cars arrive to 2nd booth before all cars serviced at 1st booth?

  - *A: Yes!* After 7 min, 1st car arrives at second booth; three cars still at 1st booth.
  - 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router! (see applet at AWL Web site)

Caravan analogy: $d_{trans} > d_{prop}$





Transmission d_{trans} = 10min

Propagation delay d_{prop} =6min

Throughput <= Link Rate

- throughput: rate (bits/time unit) at which bits are transferred
  - instantaneous: rate at given point in time
  - average: rate over longer period of time