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

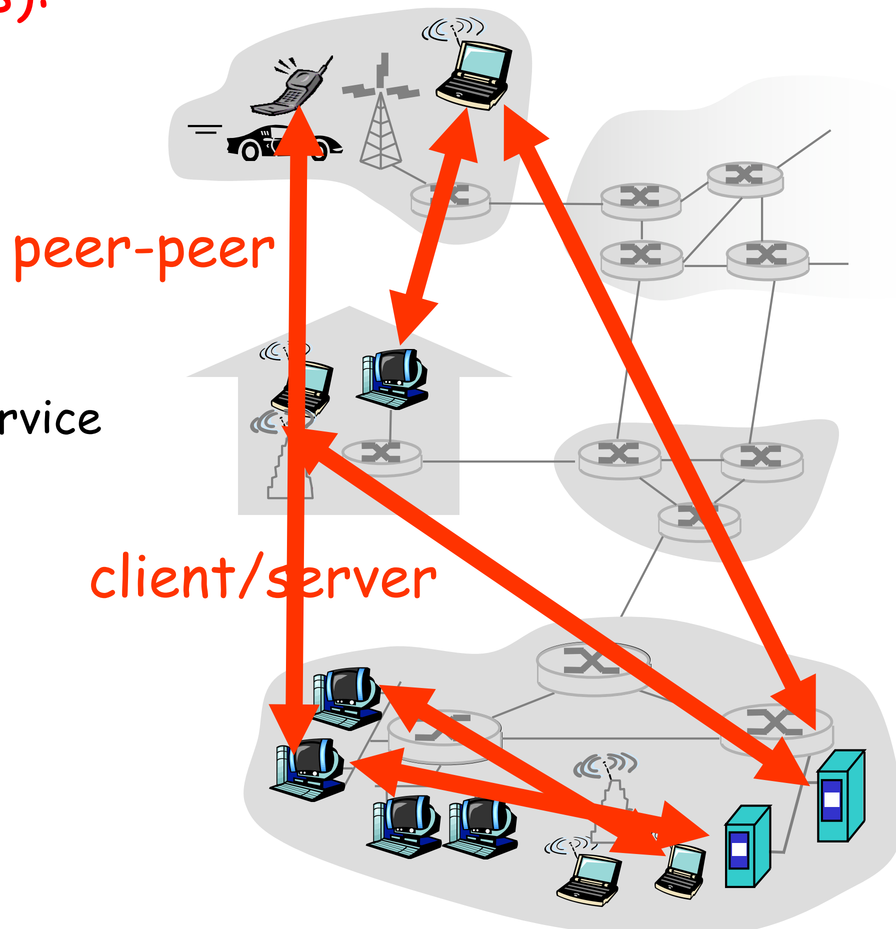
1.5 Protocol layers, service models

1.6 Networks under attack: security

1.7 History

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

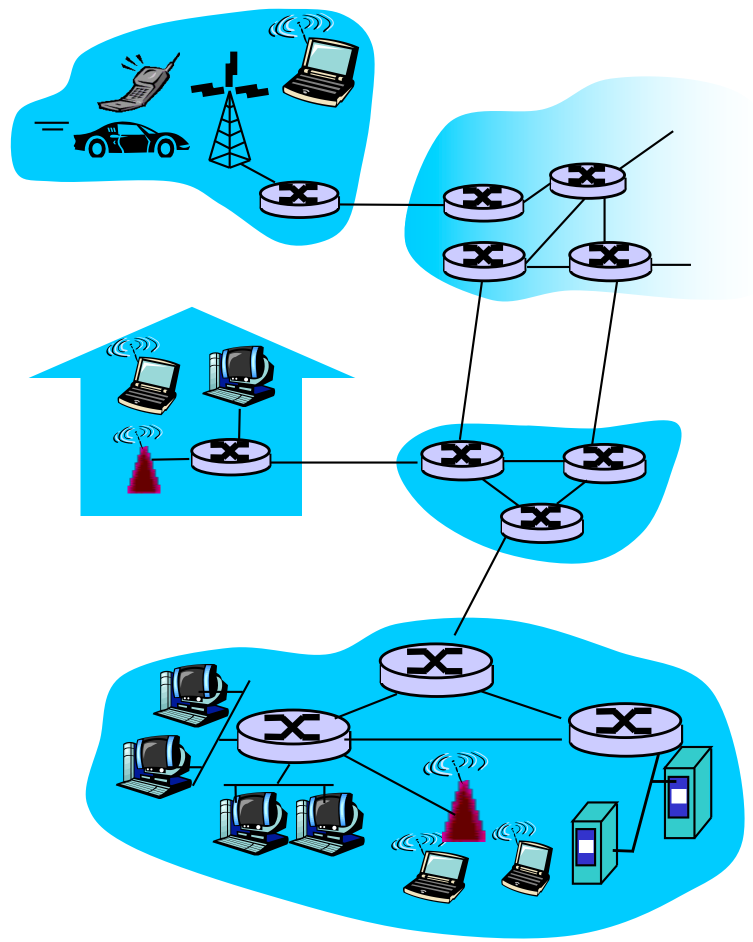


A closer look at network structure:

- network edge: applications and hosts

- access networks, physical media: wired, wireless communication links

- network core:
  - interconnected routers
  - network of networks



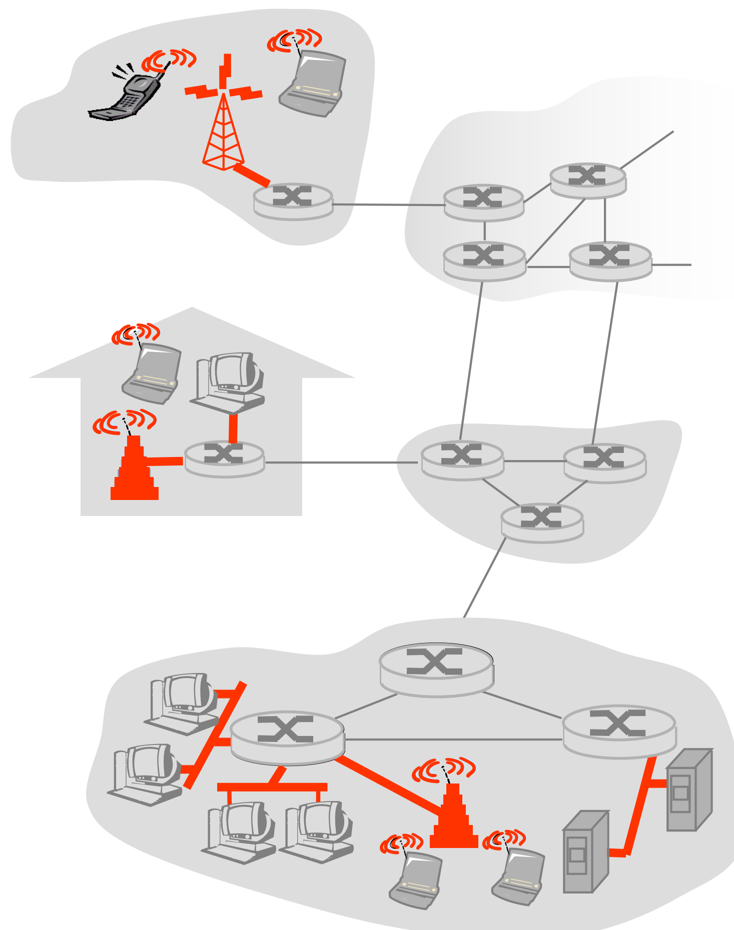
Access networks and physical media

Q: How to connect end systems to edge router?

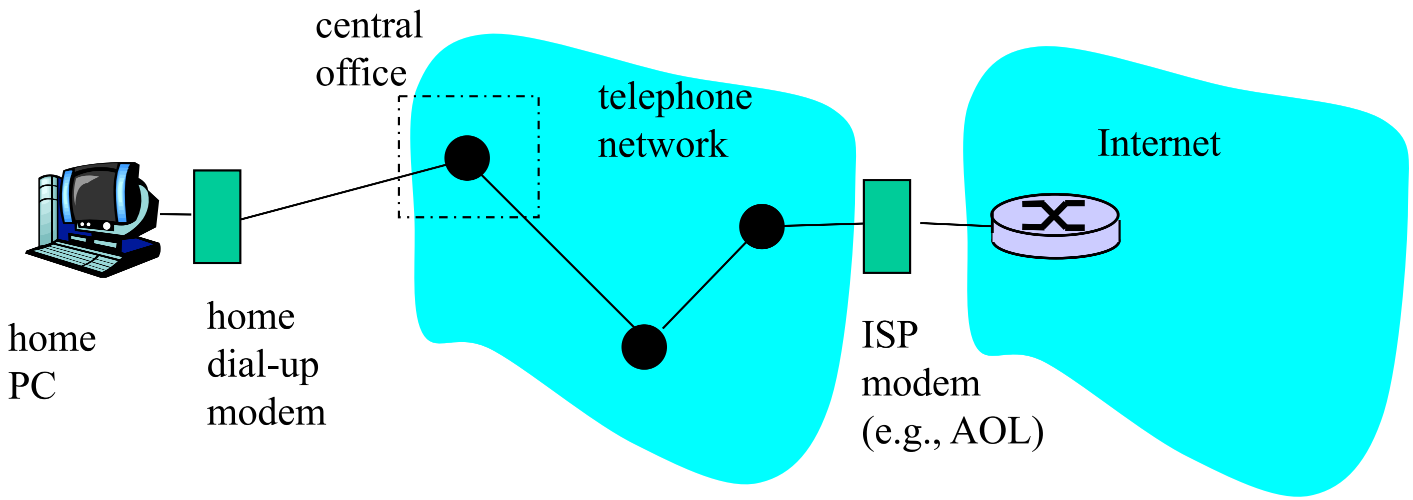
- residential access nets (local telco or TV company)
- institutional access networks (school, company)
- mobile access networks

Characteristics of access:

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

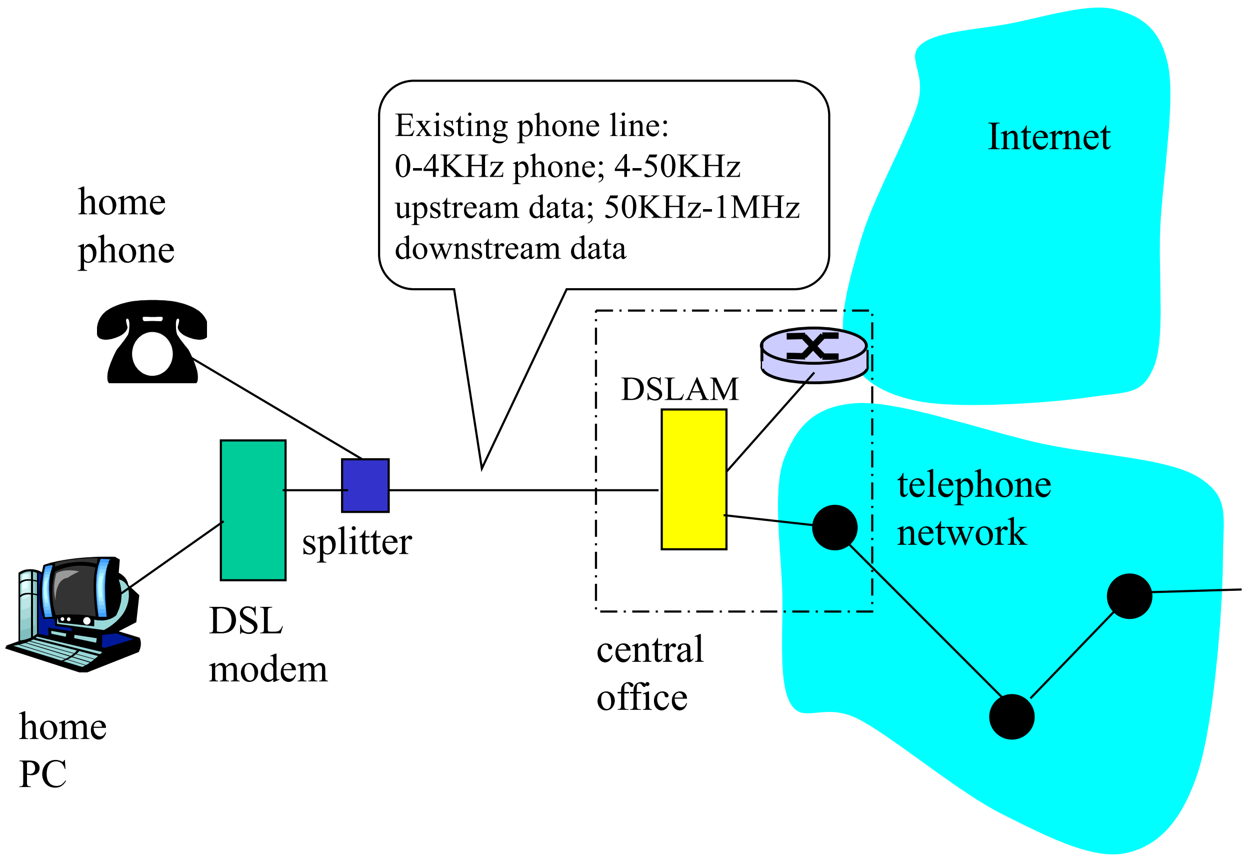


Access net: Dial-up Modem



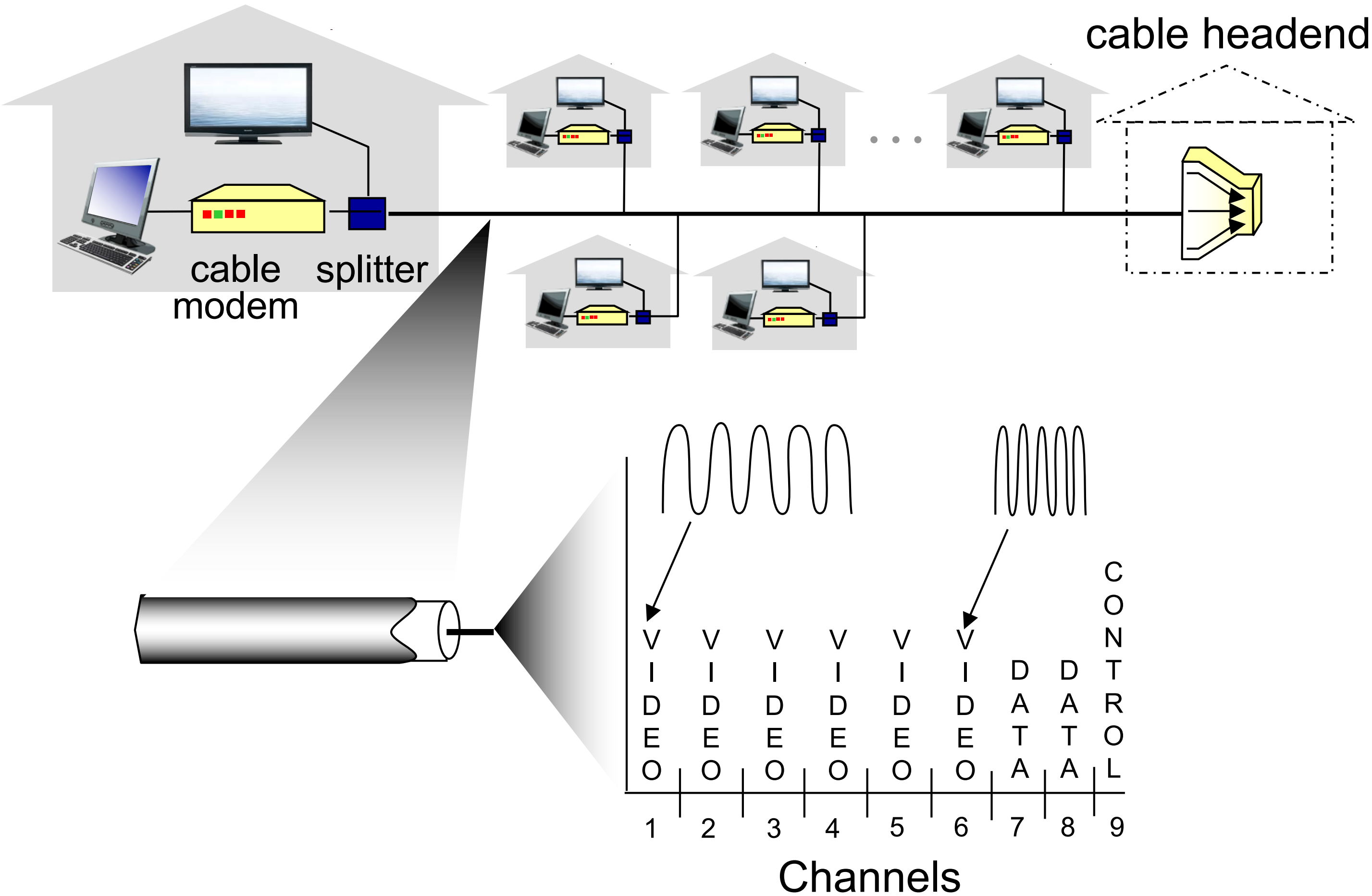
- uses *existing* telephony infrastructure
  - Twisted pair, convert digital to analog
  - home directly-connected to central office
- <56Kbps direct access to router (was 14Kbps ☺)
  - It sounded like this: https://www.youtube.com/watch?v=gsNaR6FRuO0
  - Data on the wire restricted to a band of ~= 4000Hz
  - 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)



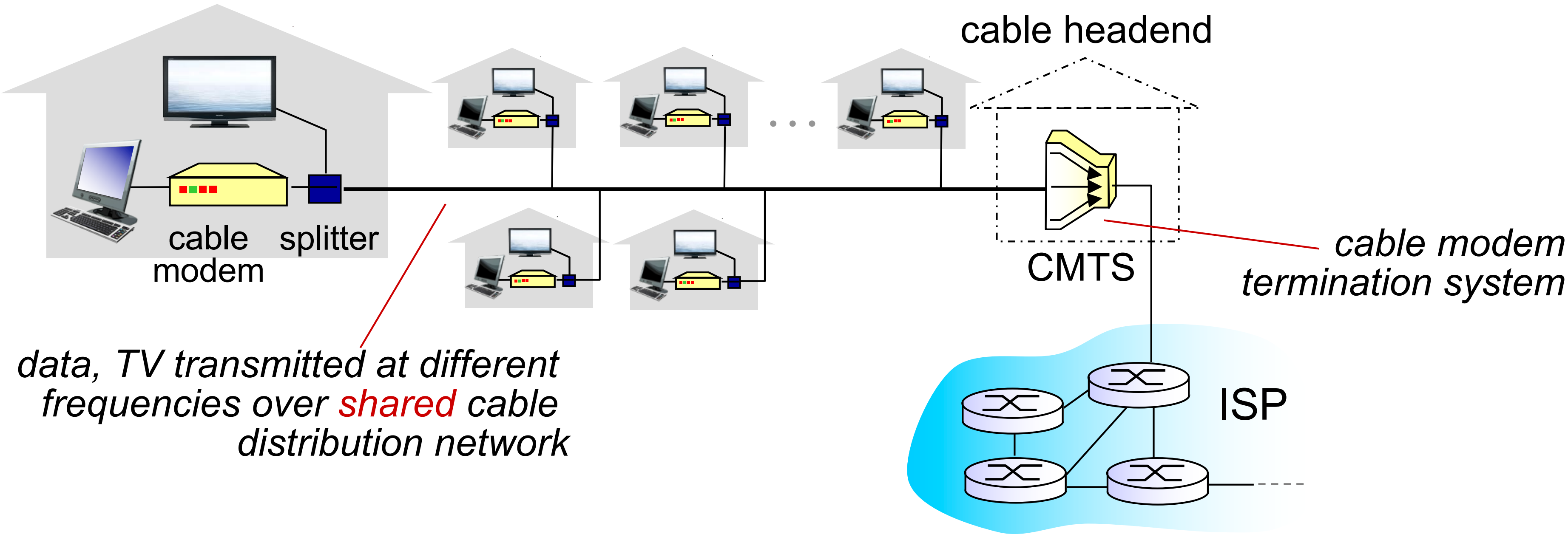
- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

Access network: cable network



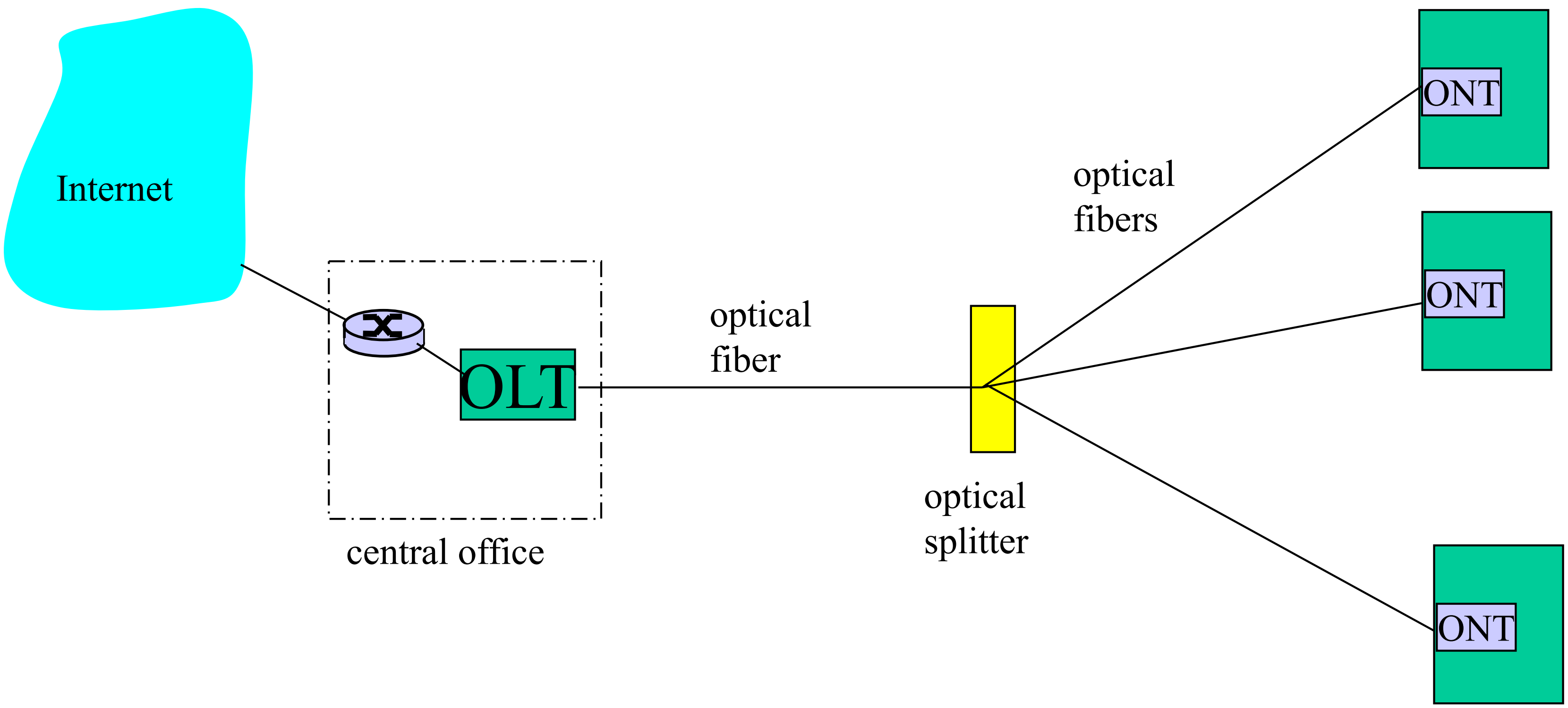
frequency division multiplexing: different channels transmitted in different frequency bands

Access net: Cable network



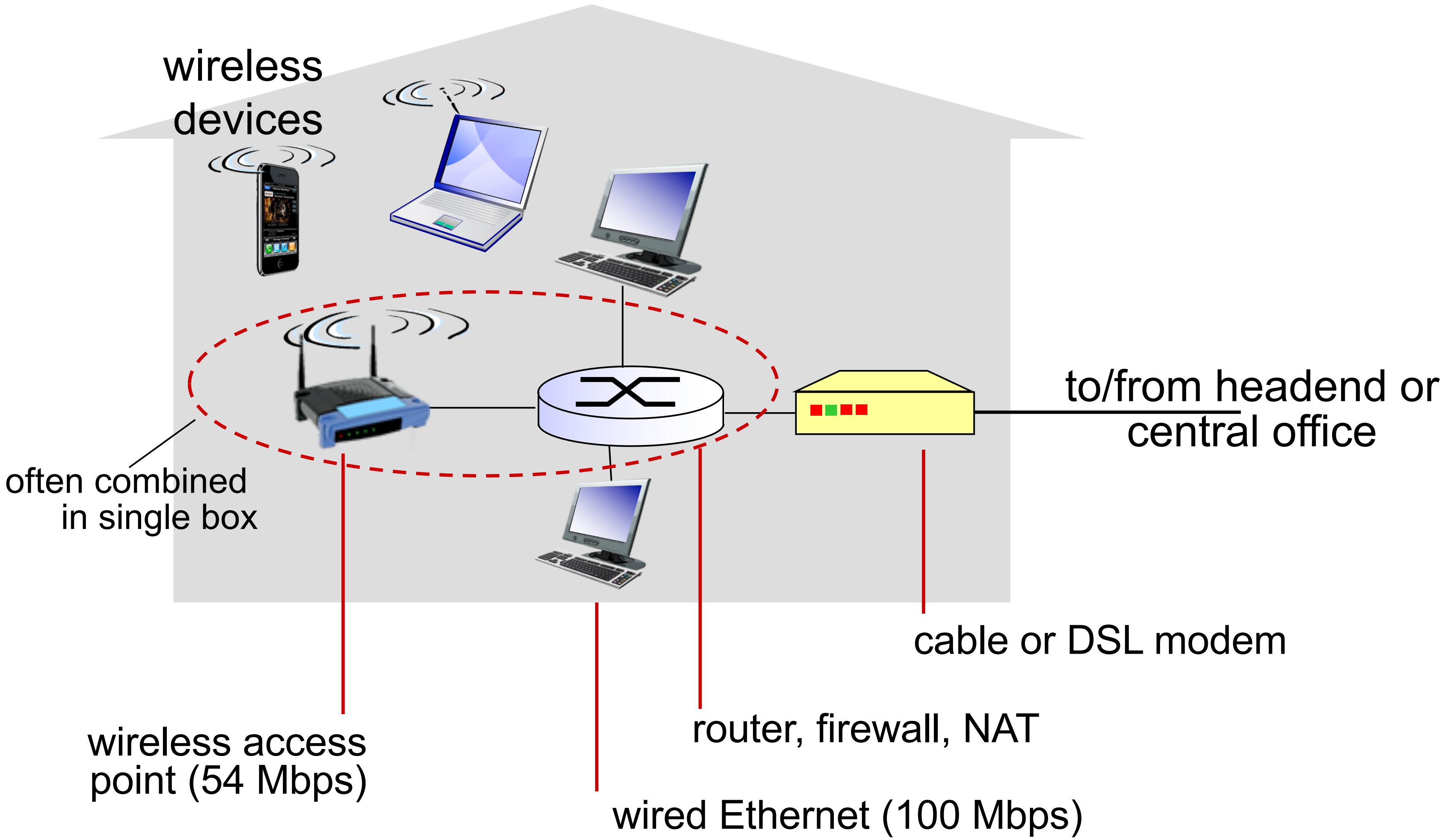
- Use *existing* cable TV infrastructure
- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
- network of cable+fiber attaches homes to ISP router
  - homes *share access network* to cable headend
  - unlike DSL, which has dedicated access to central office

Fiber to the Home (FTTH)

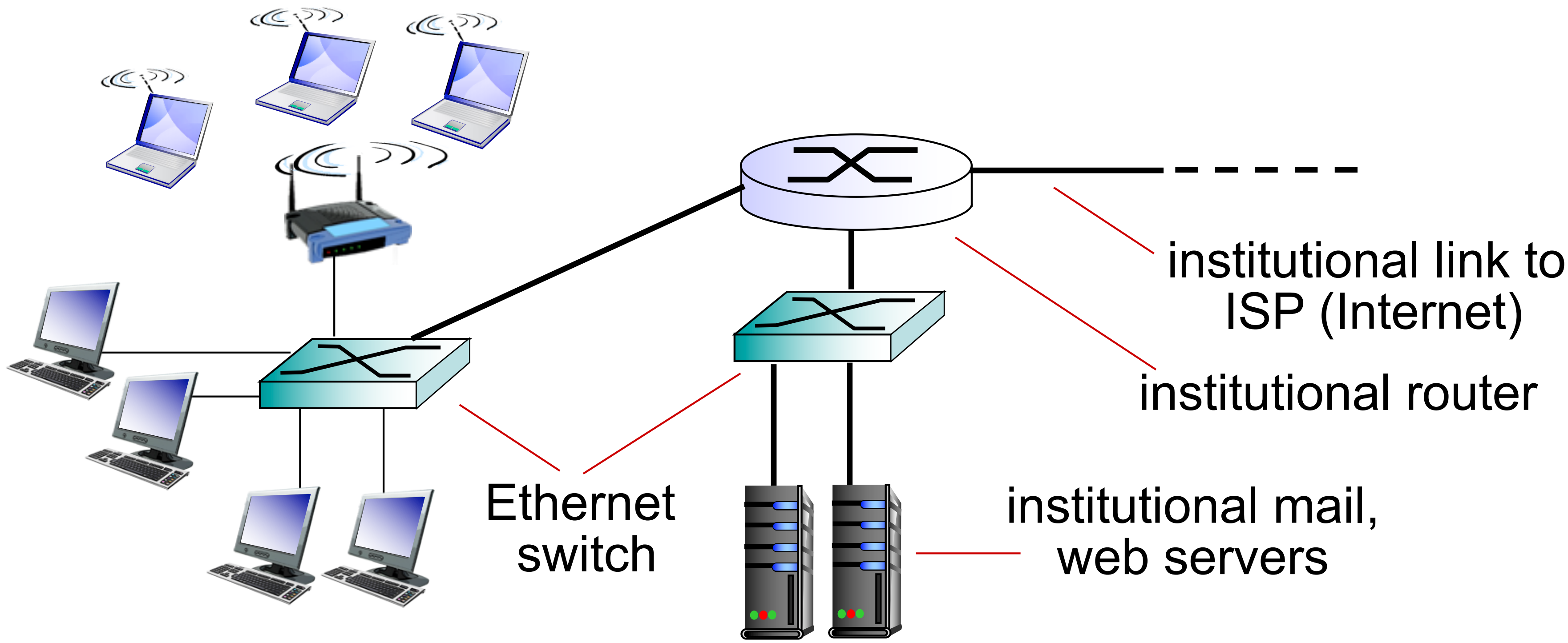


- optical links from central office to the home
- much higher rates; fiber also carries television and phone services
- fiber.google.com

Access net: home network



Enterprise access networks (Ethernet)



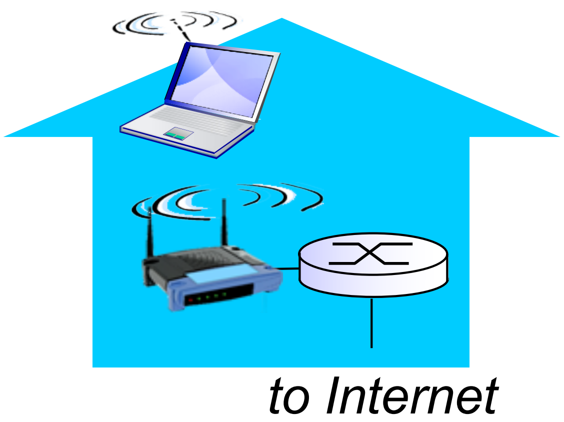
- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

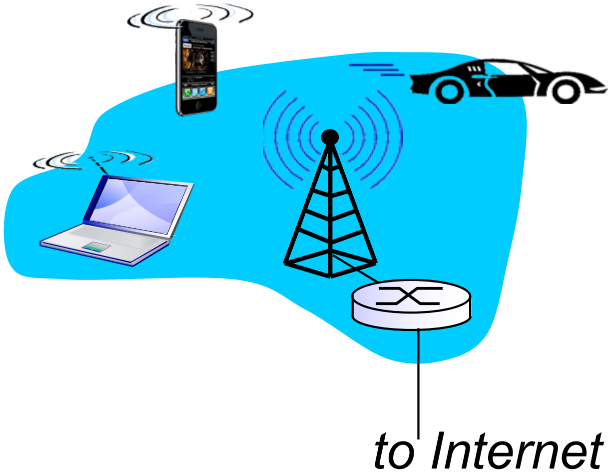
Wireless access networks

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

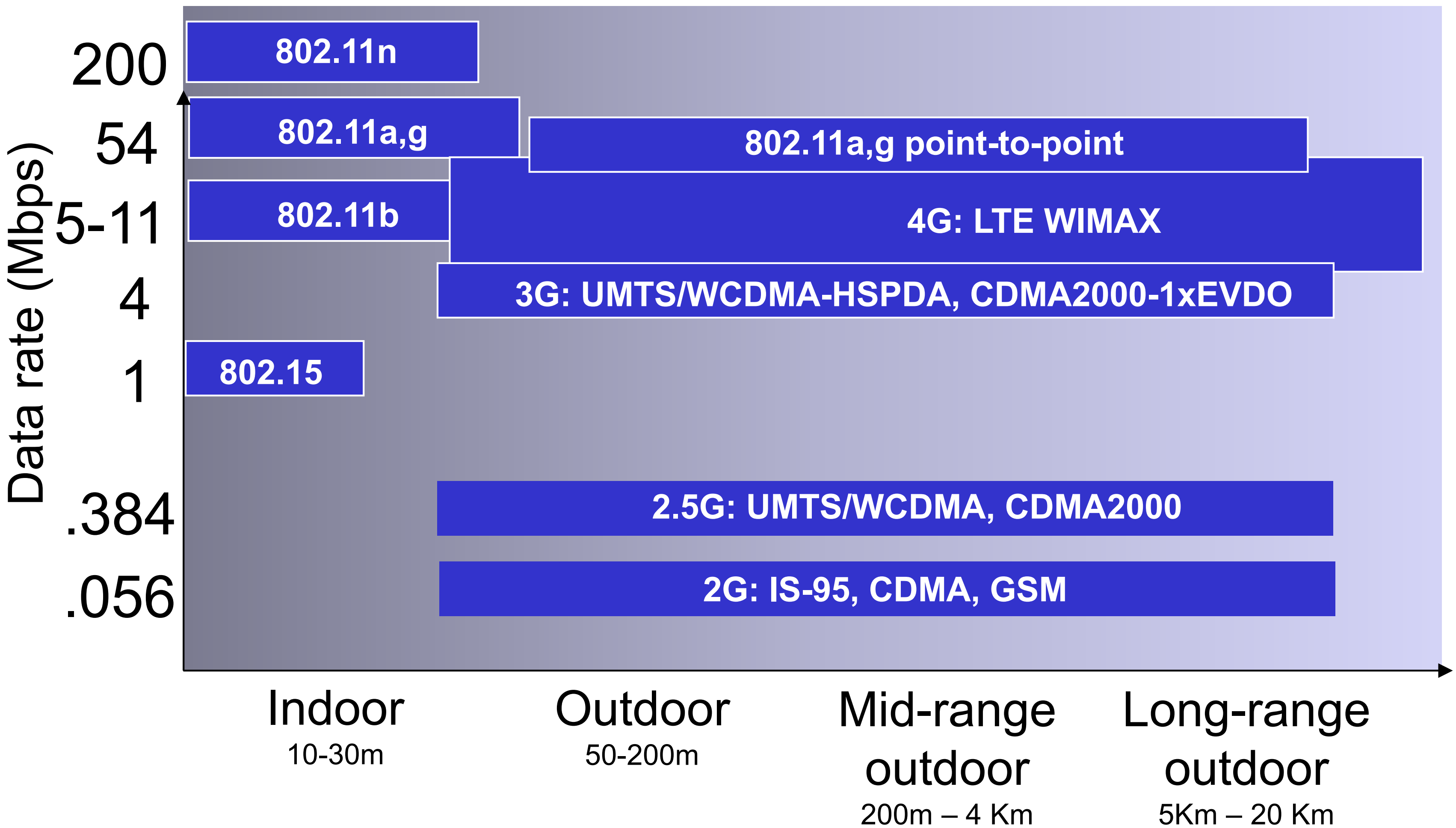
wireless LANs:
- within building (100 ft)
- 802.11b/g (WiFi): 11, 54 Mbps transmission rate
- 802.11n: up to 600 Mbps

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



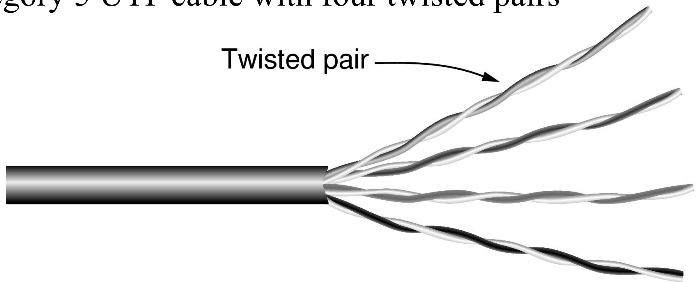
Physical media

- 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

Category 5 UTP cable with four twisted pairs

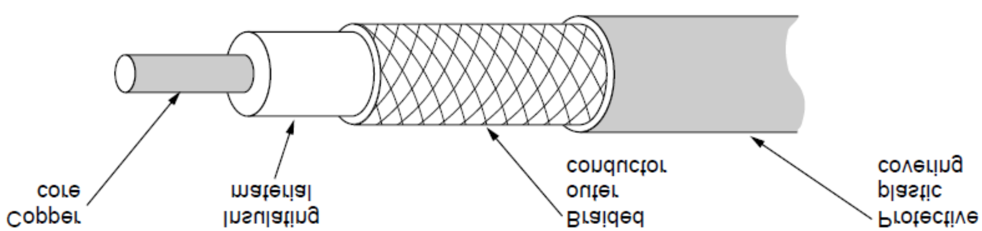


- Speed depends on material, thickness of wire, #twists, shielding, and distance

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

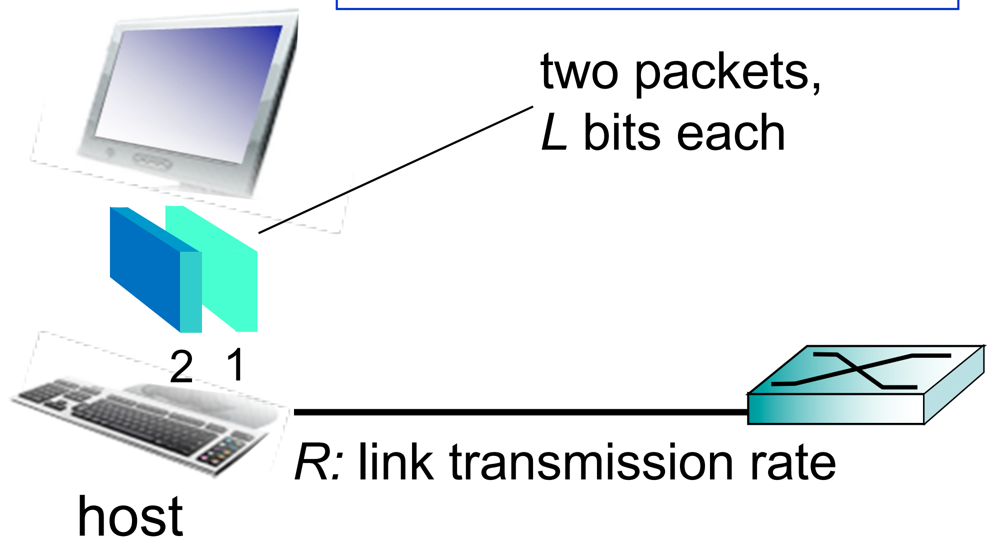
Transmission over a single point-to-point link

Notes on Bandwidth and Delay (Transmission vs. Propagation Delay)

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:

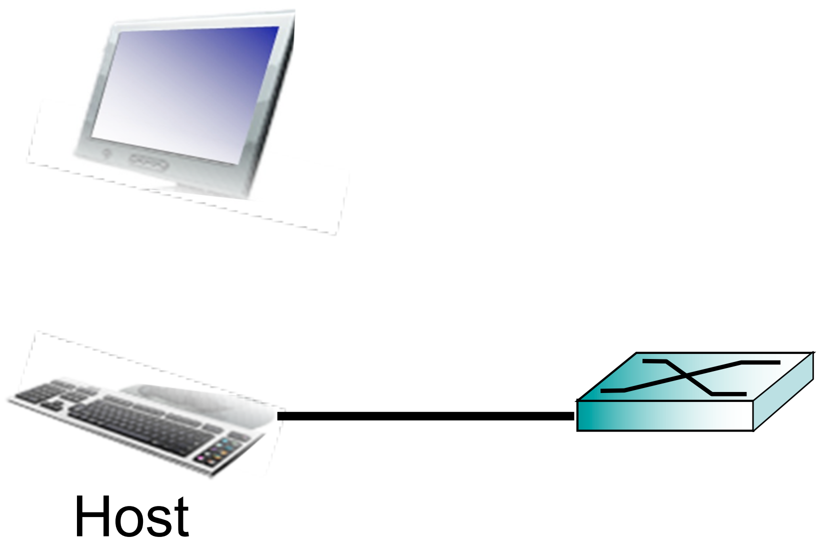
- L = 7.5 Mbits
- R = 1.5 Mbps
- one-hop transmission delay = L/R= 5 sec

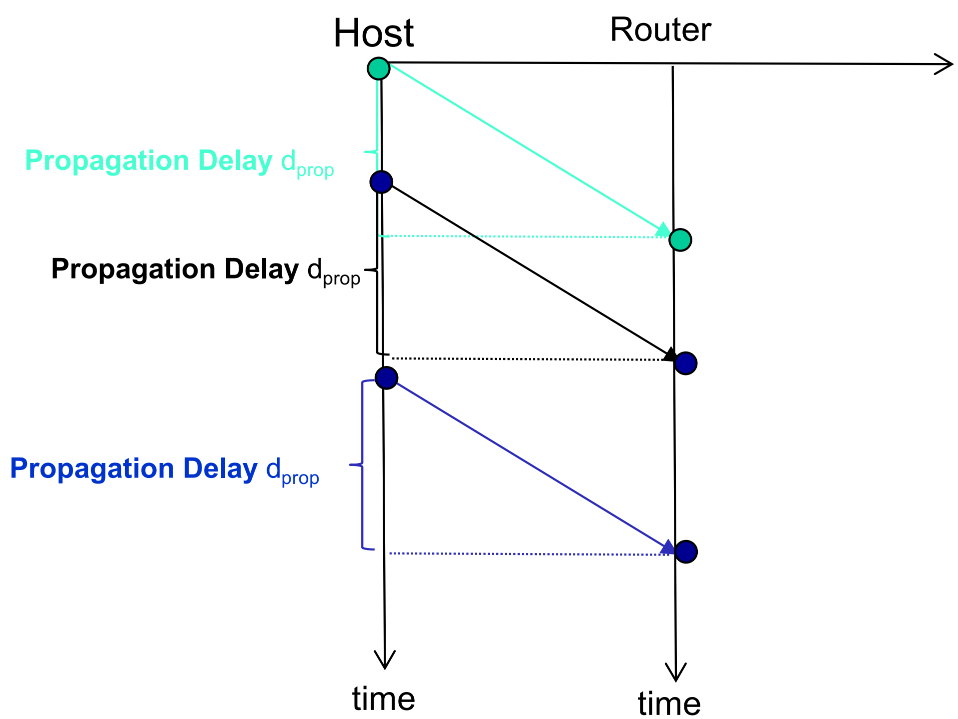
packet transmission delay = time needed to transmit L-bit packet into link = $\dfrac{L \text{ (bits)}}{R \text{ (bits/sec)}}$

Do not confuse Transmission with Propagation Delay!

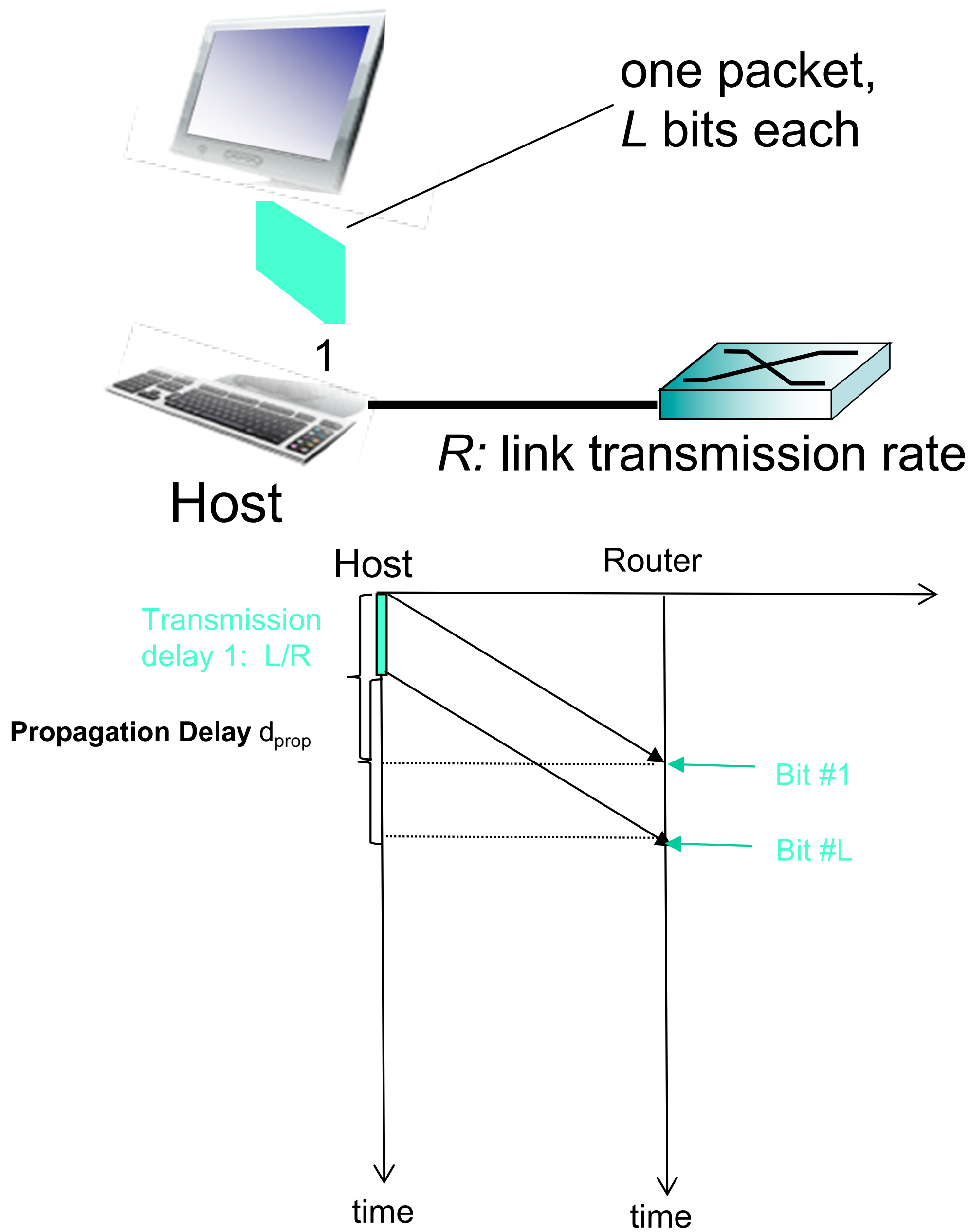
Check out the online interactive exercise:
http://gaia.cs.umass.edu/kurose_ross/interactive/one-hop-delay.php

Host sends one bit

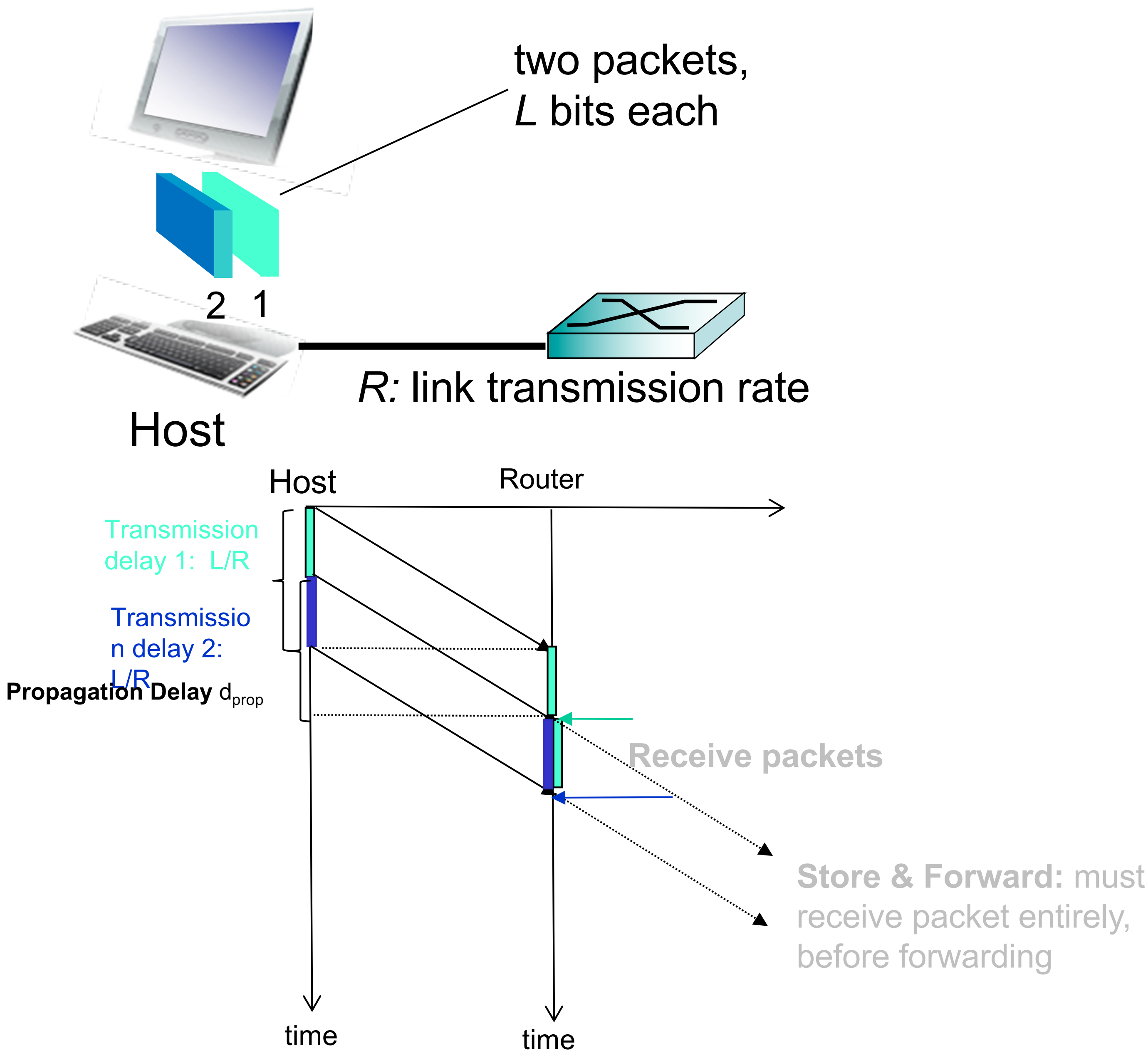




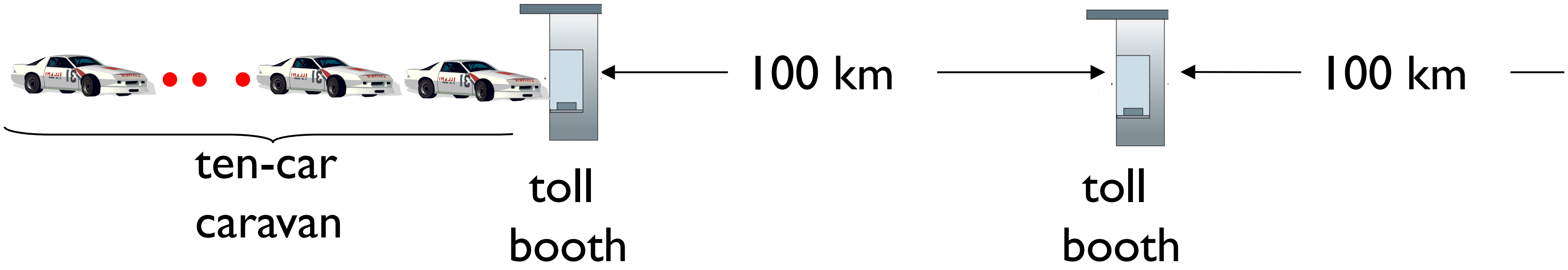
Host: sends one packet



Host: sends 2 packets of data



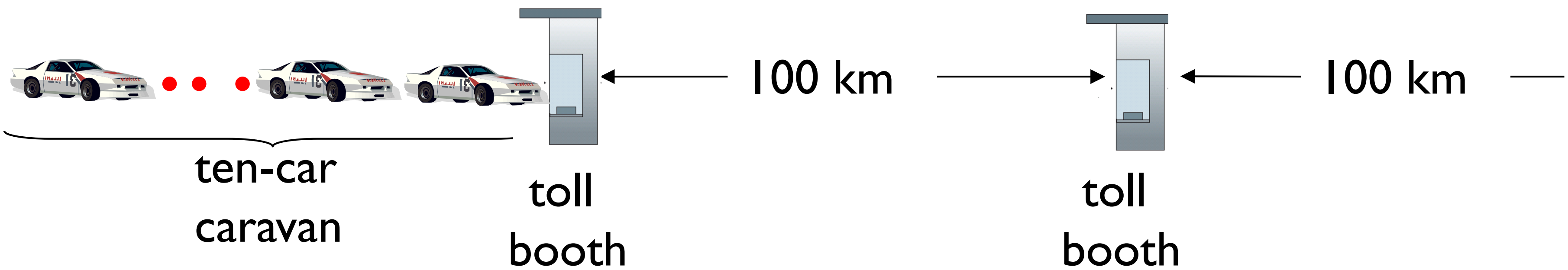
Caravan analogy: d_{trans} vs. d_{prop}

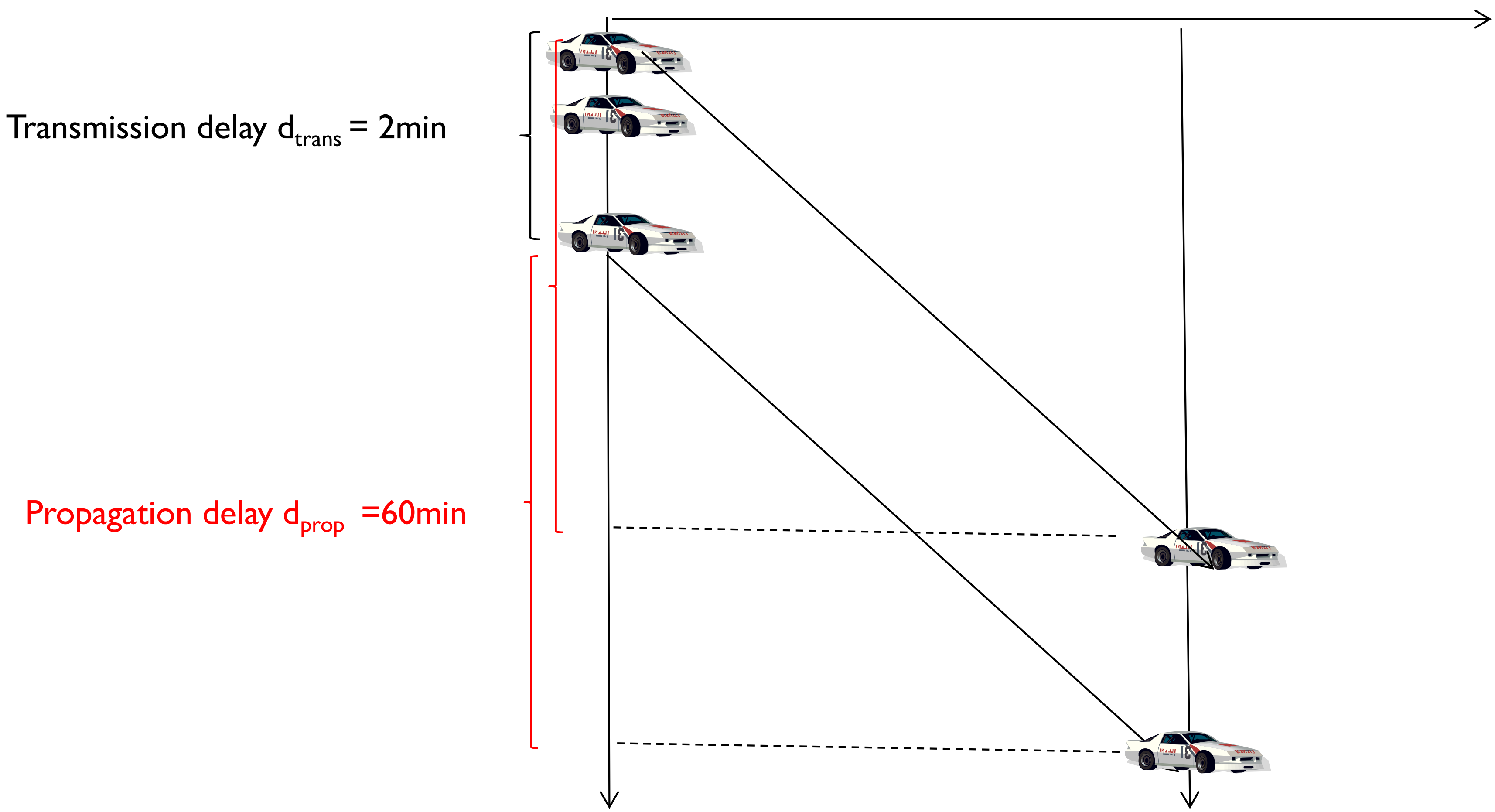


- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (transmission time)
- car~bit; caravan ~ packet
- Q: How long until caravan is lined up before 2nd toll booth?

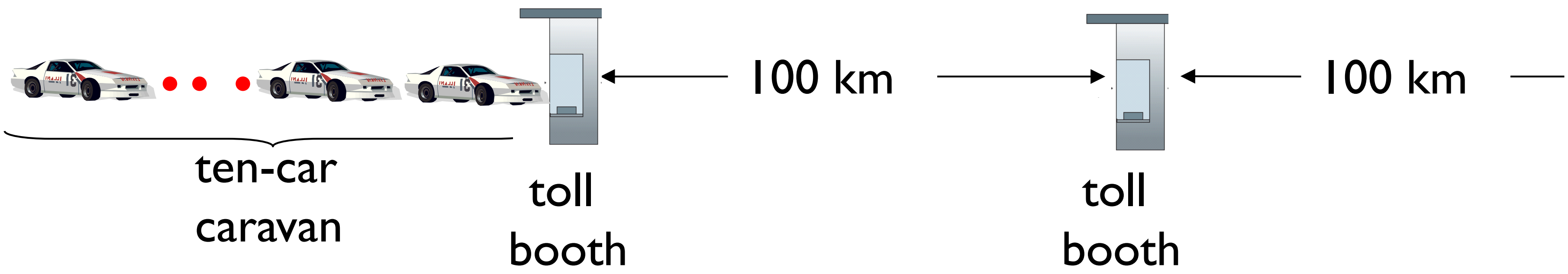
- time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec = 2min
- time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr=60min
- A: 62 minutes

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





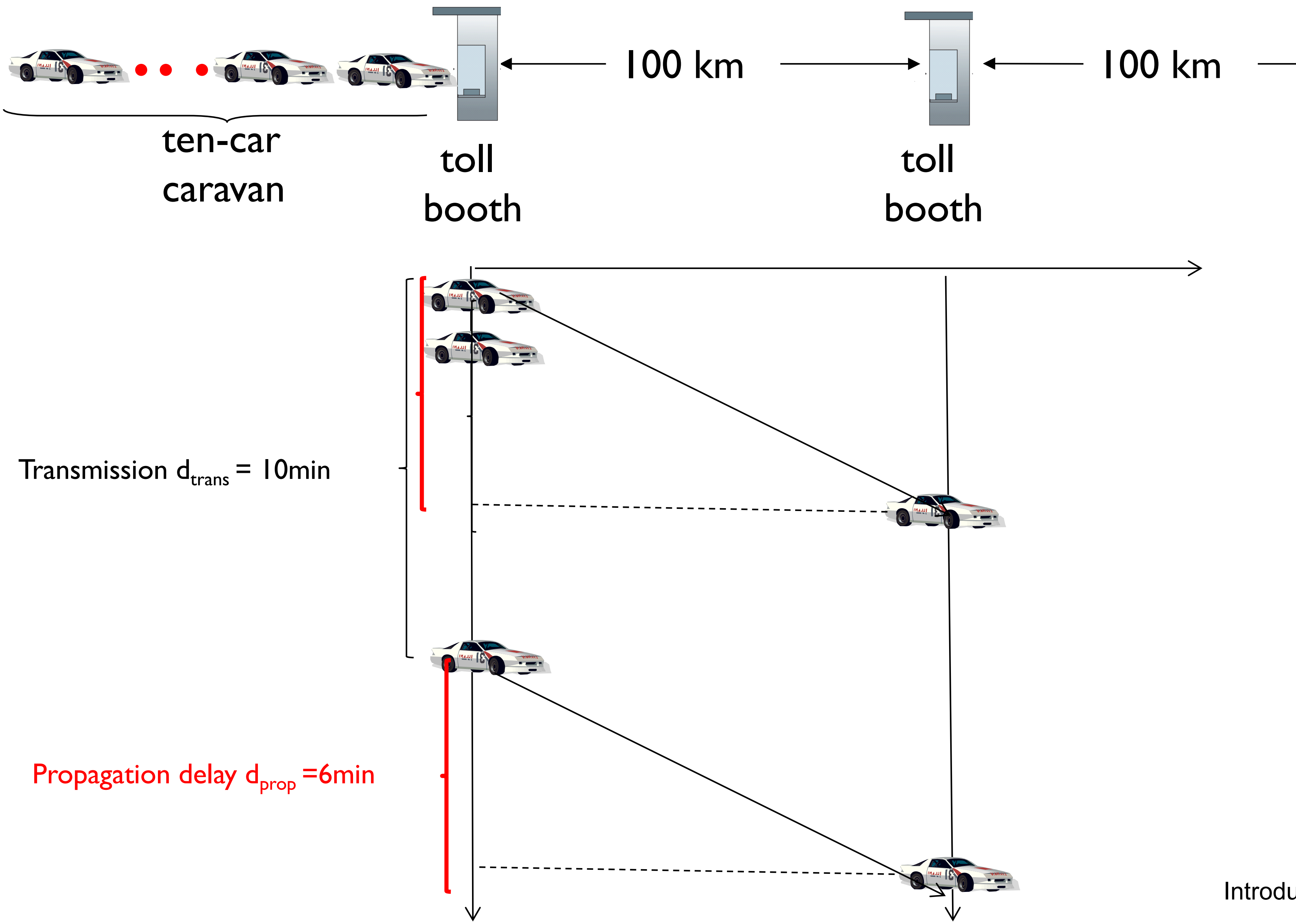
Caravan analogy: $d_{trans} > d_{prop}$



- 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: $d_{trans} > d_{prop}$



Throughput

- **throughput:** rate (bits/time unit) at which bits are transferred
  - **instantaneous**: rate at given point in time
  - **average:** rate over longer period of time
  - application throughput <= link rate (bandwidth)