Computer Networks Introduction

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What is the Internet?

Internet – largest engineered system ever created by mankind!

Network of networks: all about connecting

Let’s try to understand it and how it works

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 Delay, loss and throughput in packet-switched networks

1.5 Protocol layers, service models

What is the Internet?

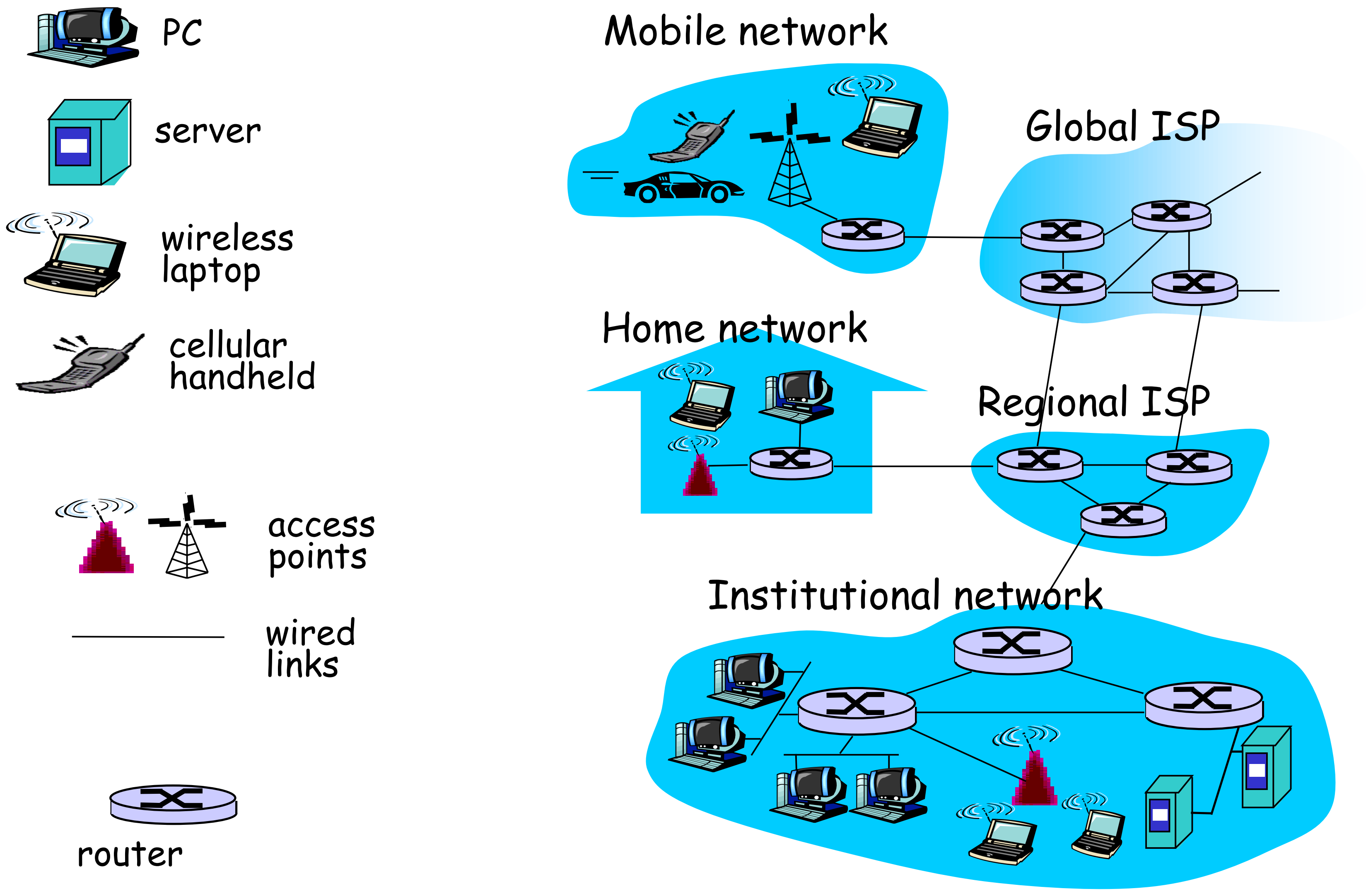
Internet – largest engineered system ever created by mankind

End systems: connected together by a network of

communication links and **packet switches**

Let's try to understand it and how it works

What's the Internet: "nuts and bolts" view



- millions of connected computing devices: *hosts = end systems*
- transmission rate = *bandwidth*
  - Packets = chunks of data
- *Packet Switch – receives and forward*
  - *Routers – core n/w*
  - *Link layer switches – Access n/w*
- *communication links*
  - Coaxial
  - Copper wire
  - Fiber
  - Radio
- *Route / Path*
  - Sequence of links & packet switches
- *ISPs (Internet Service Providers)*
  - End systems access internet

The Internet is all about connecting end systems to each other. So the ISPs that provide access to end systems must also be interconnected

Packet-switched networks VS transportation networks

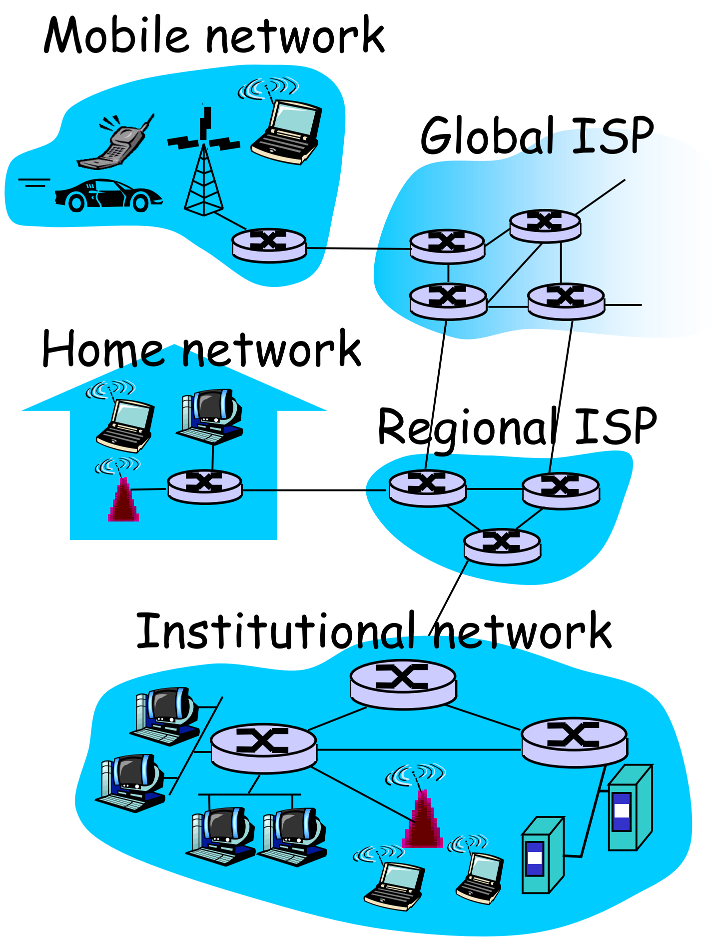
- Packet-switched networks - transport
- Transportation networks - transport vehicles
- Analogy:
  - packets to trucks,
  - communication links to highways and roads,
  - packet switches to intersections, and
  - end systems are analogous to buildings.
- Just as a truck takes a path through the transportation network, a packet takes a path through a computer network.

Protocols

- End systems, packet switches, and other pieces of the Internet run **protocols** that control the sending and receiving of information within the Internet.
- Most important protocols in the internet
  - The **Transmission Control Protocol (TCP)** and
  - The **Internet Protocol (IP)**
- The Internet's principal protocols are collectively known as **TCP/IP**.

Importance of protocols

- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, Ethernet
- *Internet: "network of networks"*
  - Important that everyone agrees
  - To create interoperable systems/products
- Internet standards
  - IETF: Internet Engineering Task Force
  - RFC: Request for comments



What is the Internet?

Internet – an infrastructure that provides services to applications

Applications:

Email, Web surfing, social networks, instant messaging, Voiceover-IP (VoIP),

video streaming, distributed games, peer-to-peer (P2P) file sharing,

television over the Internet, remote login and much more!

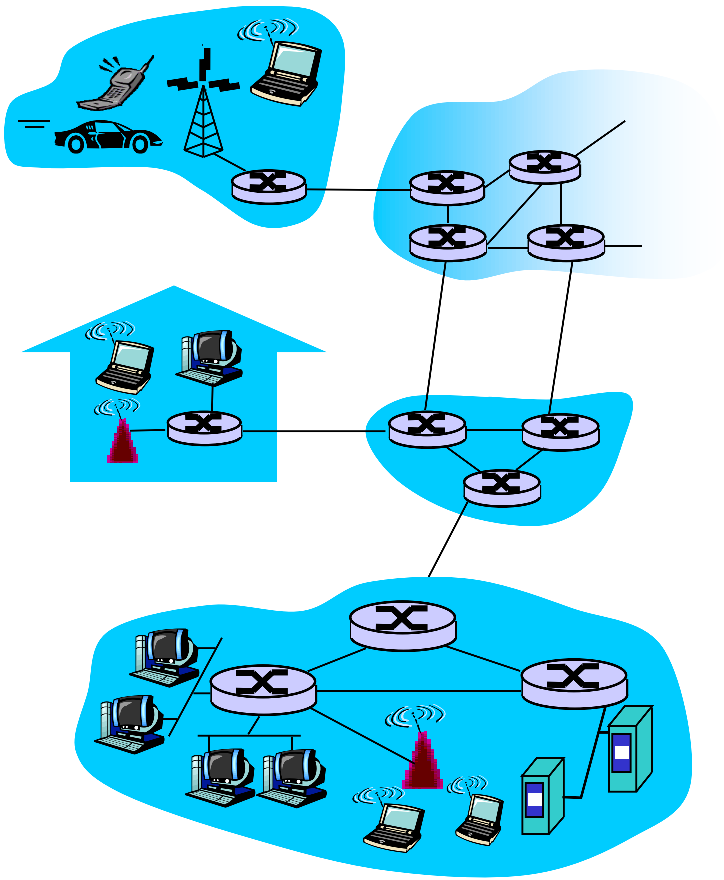
Internet applications: Distributed applications

run on end systems—they do not run in the packet switches in the network core

Let’s try to understand it and how it works

What’s the Internet: A service view

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



Application Programming Interface (API)

- Specifies how a program running on one end system asks the Internet infrastructure to deliver data to a specific destination program running on another end system.

- **Set of rules** that the sending program must follow so that the Internet can deliver the data to the destination program.

Analogy: API with postal service

- The Internet has an API that the program sending data must follow to have the Internet deliver the data to the program that will receive the data.

- Postal service's services:
  - Express delivery, reception confirmation, ordinary use, etc.
- Similarly internet provides multiple services to its applications.
- When one develop an Internet application
  - Choose one of the Internet's services

What is an Internet

- In terms of its hardware and software components
- The other in terms of an infrastructure for providing services to distributed applications.

What’s a protocol?

human protocols:

- “what’s the time?”
- “I have a question”
- introductions

... specific msgs sent

... specific actions taken when msgs received, or other events

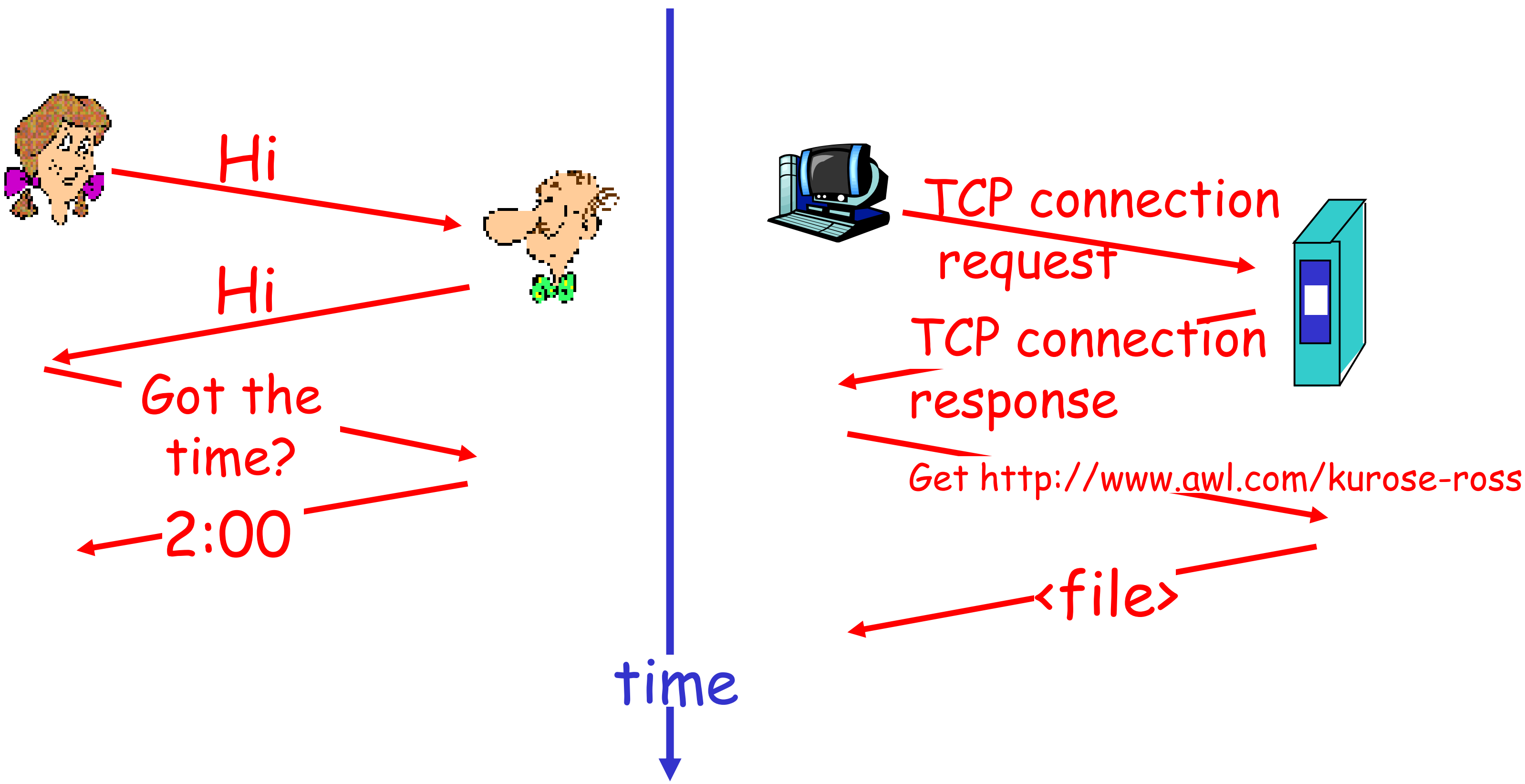
network protocols:

- machines rather than humans
- all internet communication activities governed by protocols

protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

What’s a protocol?

a human protocol and a computer network protocol:



Protocols

- Flow control protocols – flow of bits between wires
- Congestion control protocols – rate of transmission
- Routing protocols - packet’s path from source to destination.
- Understanding computer networking = understanding the what, why, and how of networking protocols

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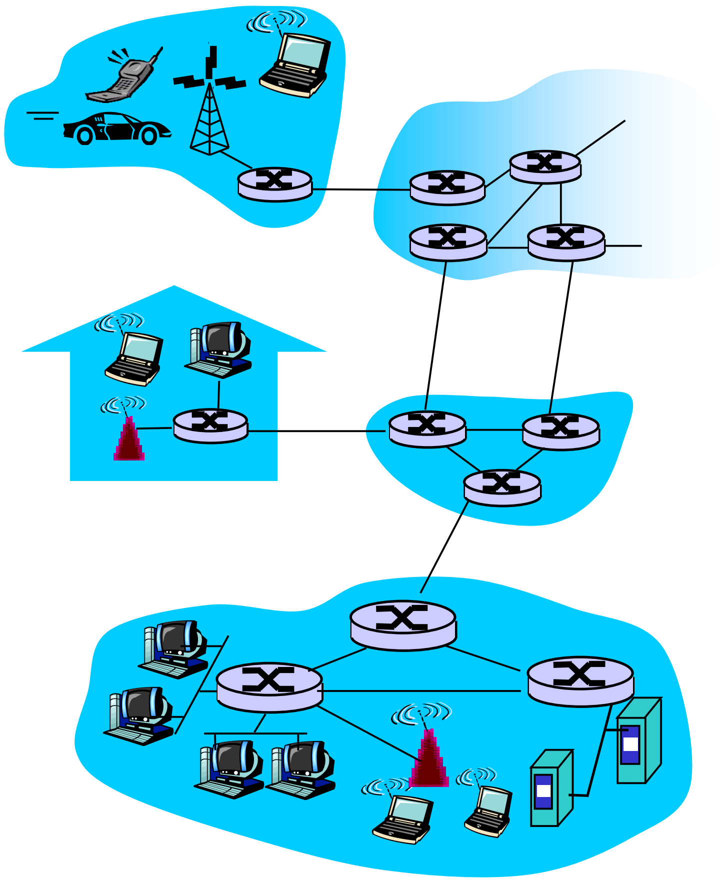
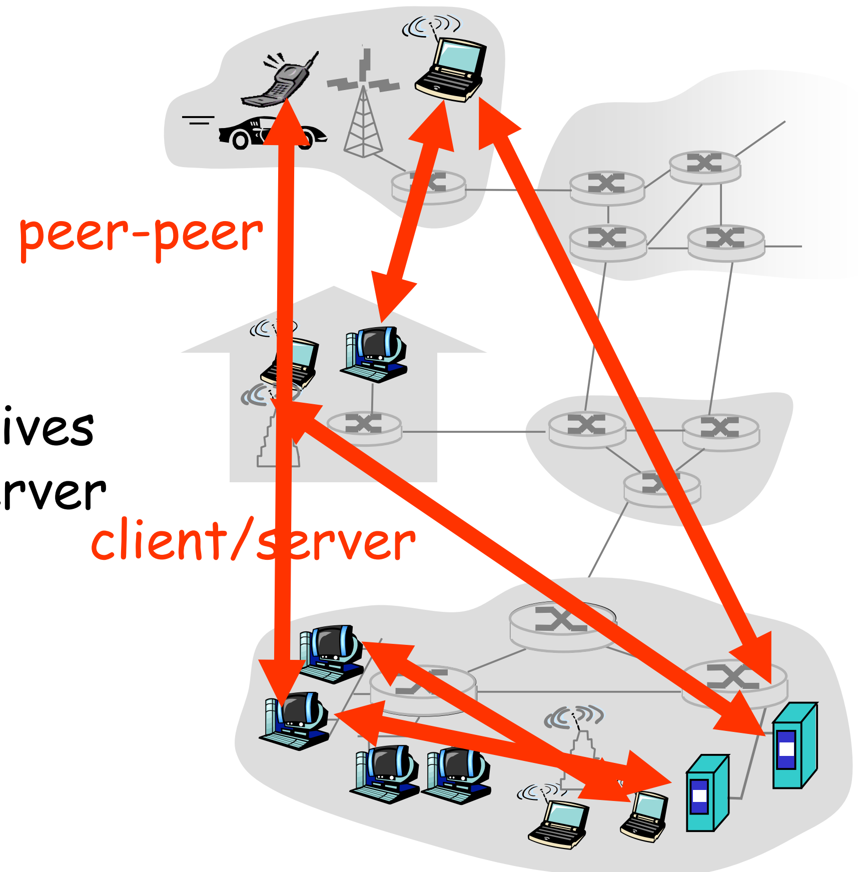
A closer look at network structure:

- network edge = end systems = hosts
  - applications and hosts
- access networks, physical media:
  - wired, wireless, optical
- network core:
  - interconnected routers
  - network of networks



The network edge

- end systems (hosts):
  - 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



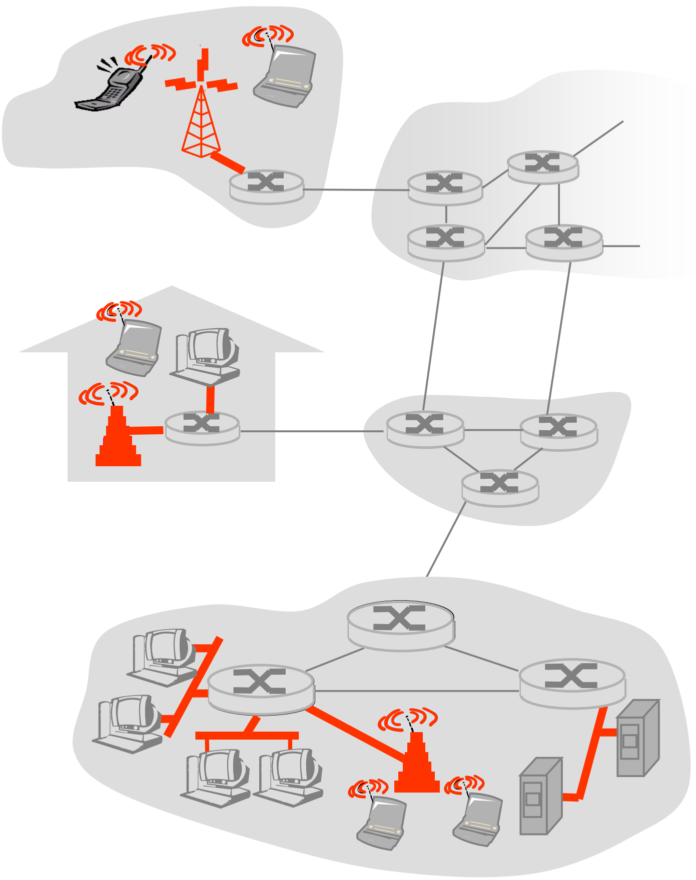
Access networks and physical media

Q: How to connect end systems to edge router?

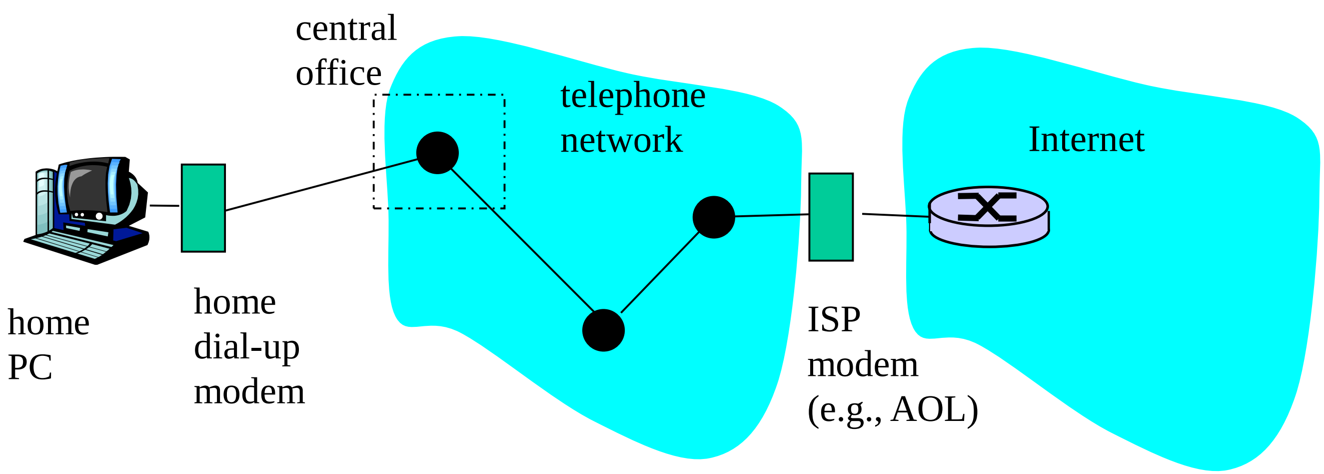
- residential access nets
- institutional access networks (school, company)
- mobile access networks

Keep in mind:

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



Dial-up Modem

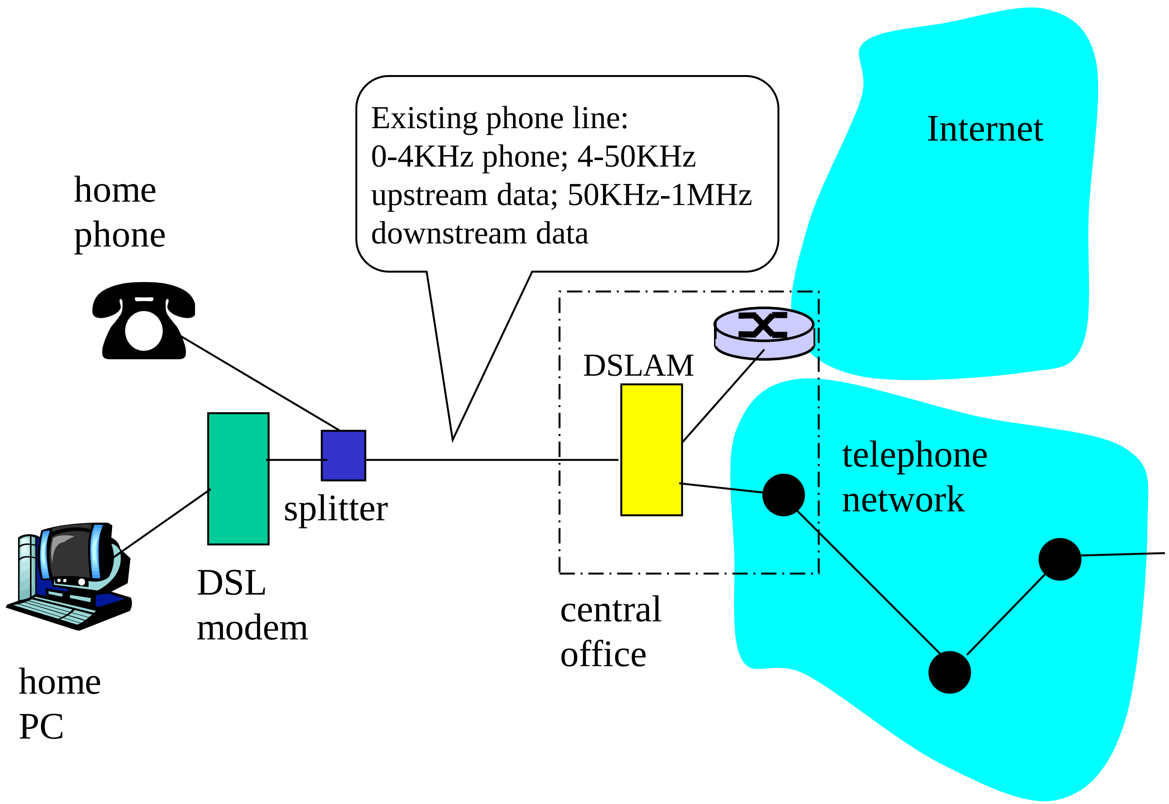


- Uses existing telephony infrastructure
  - Home is connected to central office
- up to 56Kbps direct access to router (often less)
- Can't surf and phone at same time: not "always on"

Broadband residential access

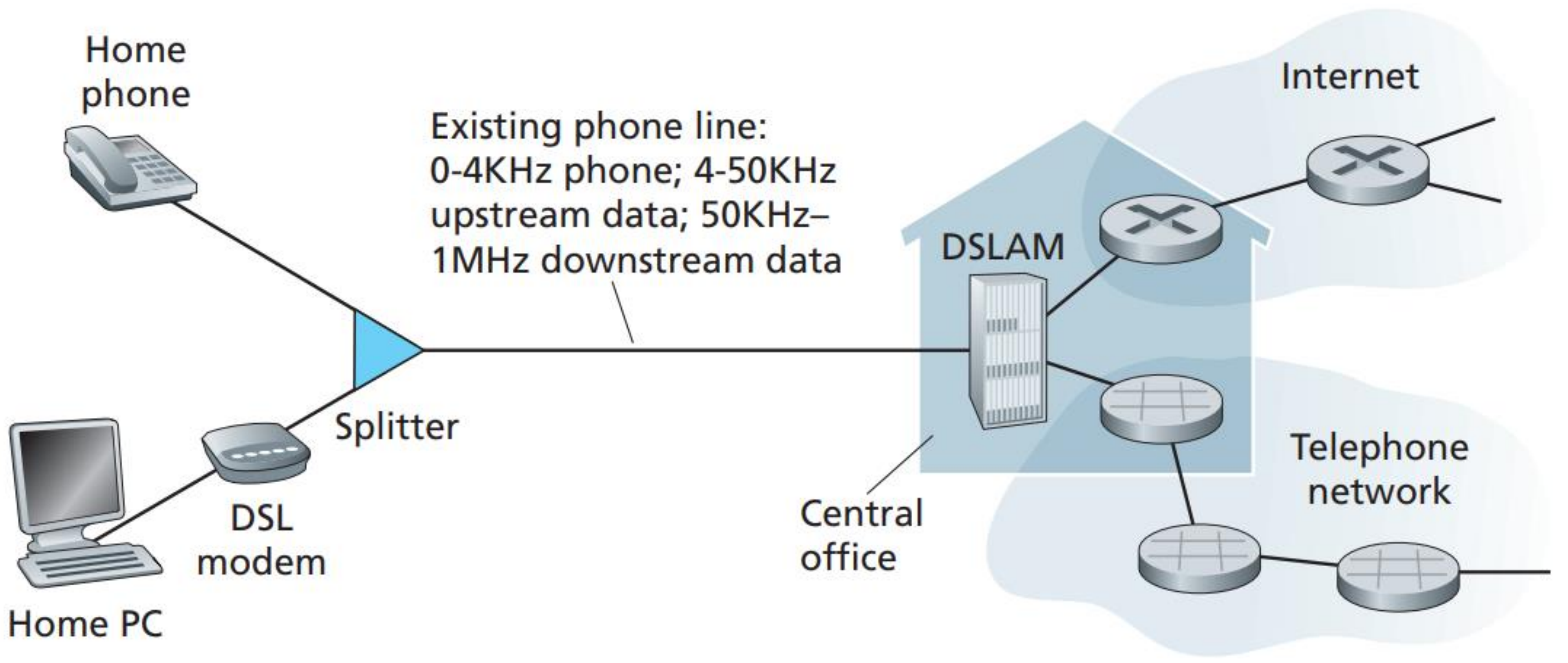
- DSL – Digital Subscriber Line
  - Provided by telephone company
- HFC – hybrid fiber-coaxial cable
  - Extension of current cable network used for broadcasting cable television

Digital Subscriber Line (DSL)



- Also uses existing telephone infrastruture
- up to 1 Mbps upstream (today typically < 256 kbps)
- up to 8 Mbps downstream (today typically < 1 Mbps)
- dedicated physical line to telephone central office

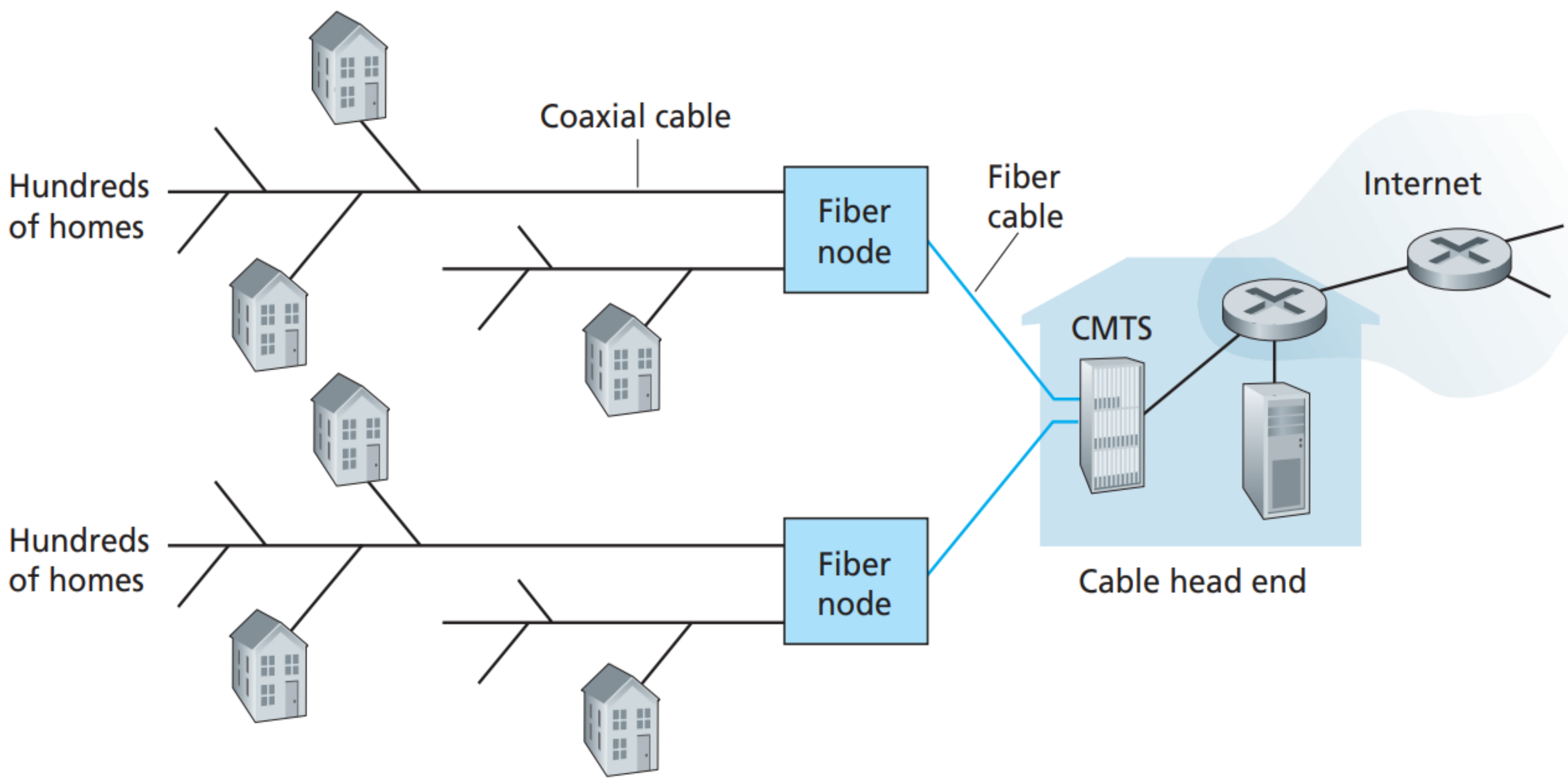
DSL Internet Access



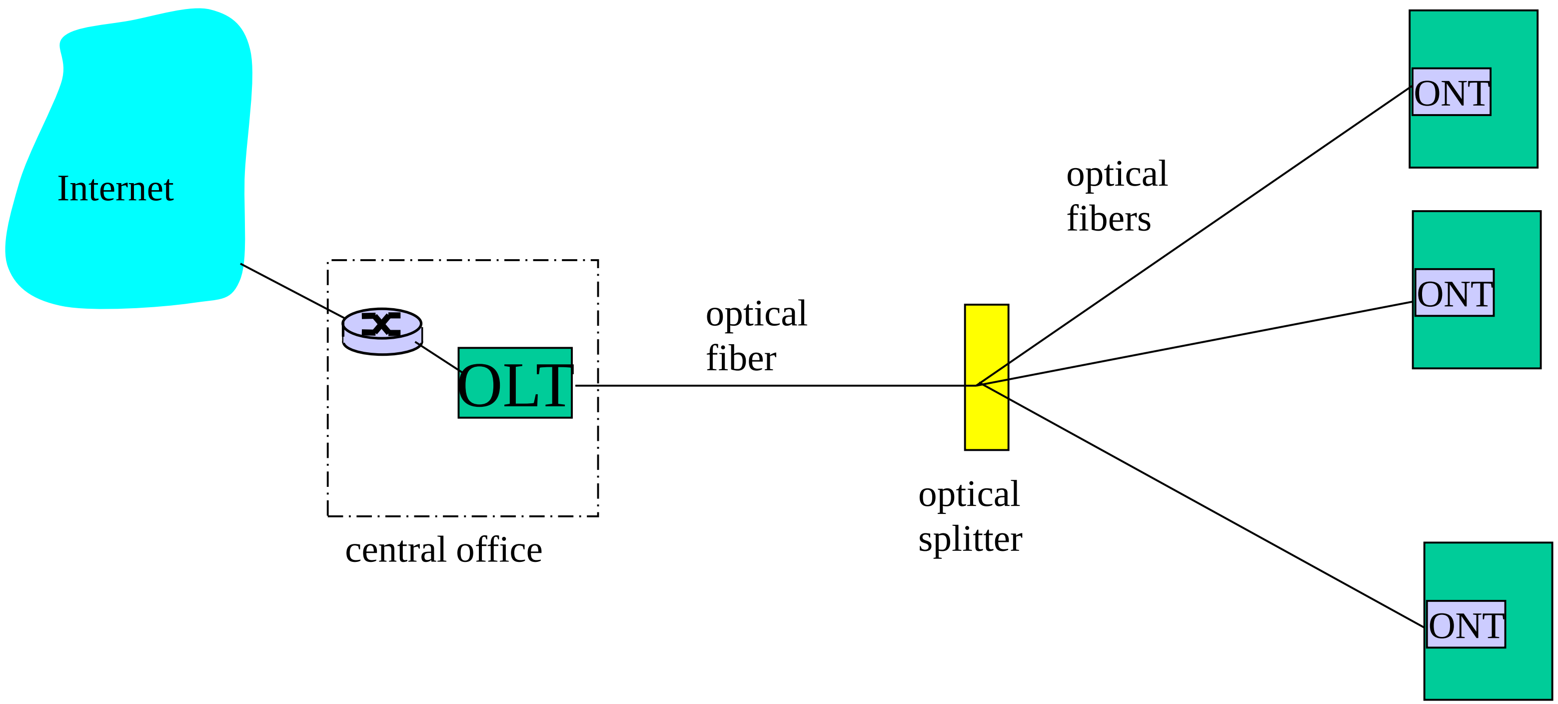
Residential access: cable modems

- Does not use telephone infrastructure
  - Instead uses cable TV infrastructure
- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
- network of cable and fiber attaches homes to ISP router
  - homes share access to router
  - unlike DSL, which has dedicated access

A hybrid fiber-coaxial access network

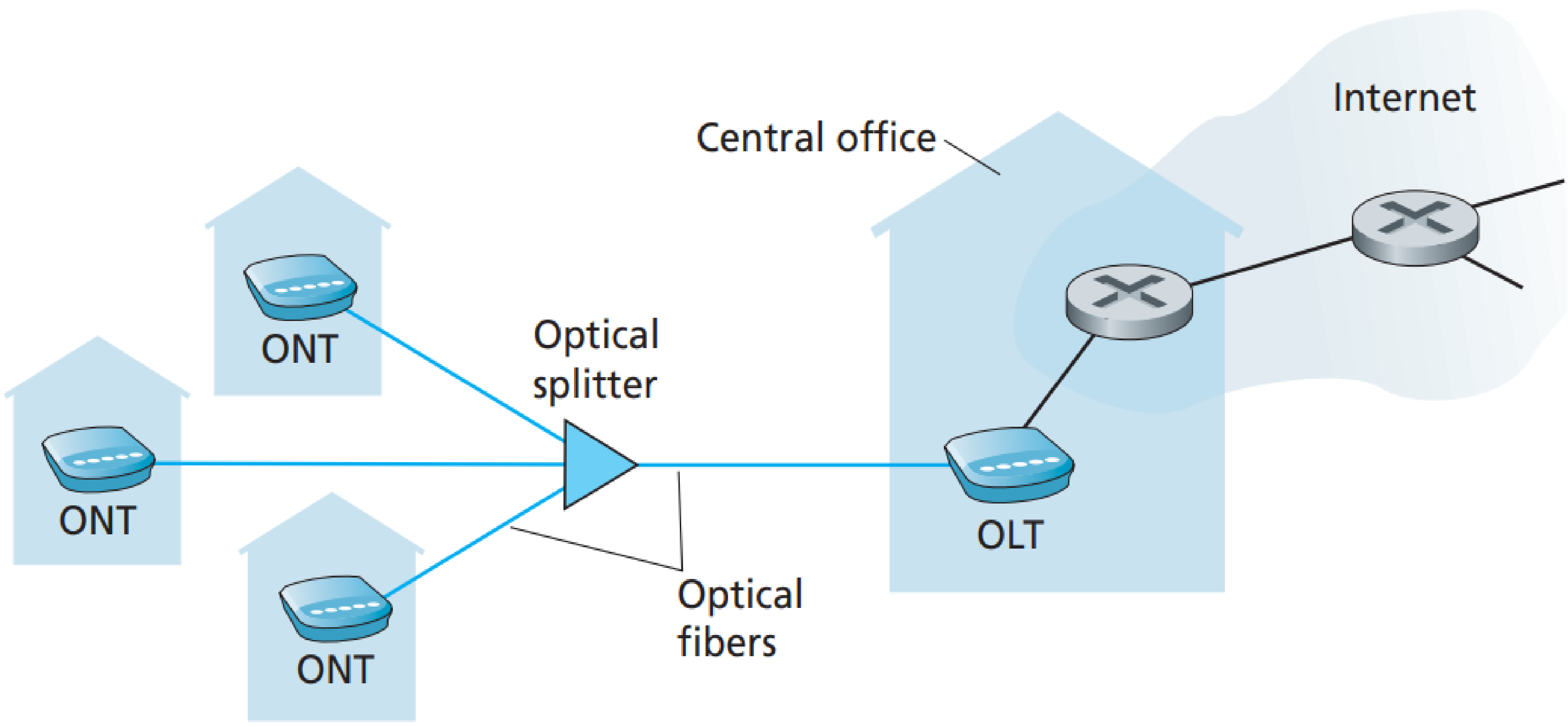


Fiber to the Home

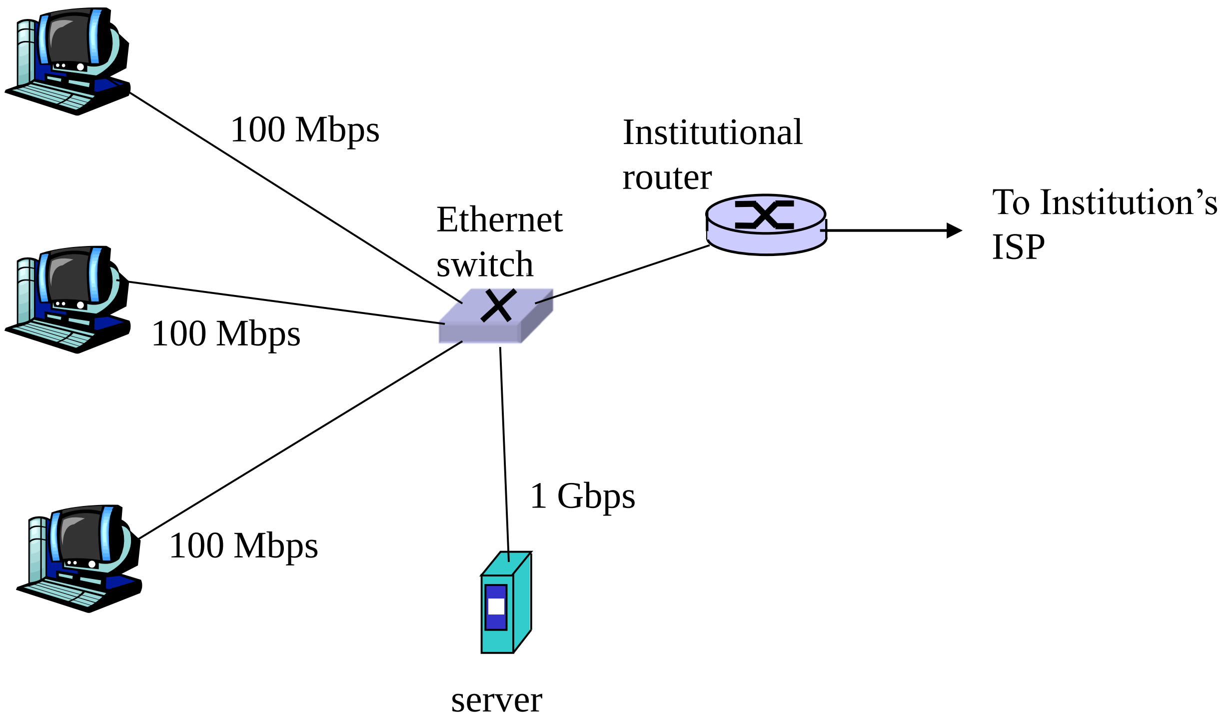


- Optical links from central office to the home
- Two competing optical technologies:
  - Passive Optical network (PON)
  - Active Optical Network (PAN)
- Much higher Internet rates; fiber also carries television and phone services

FTTH Internet access



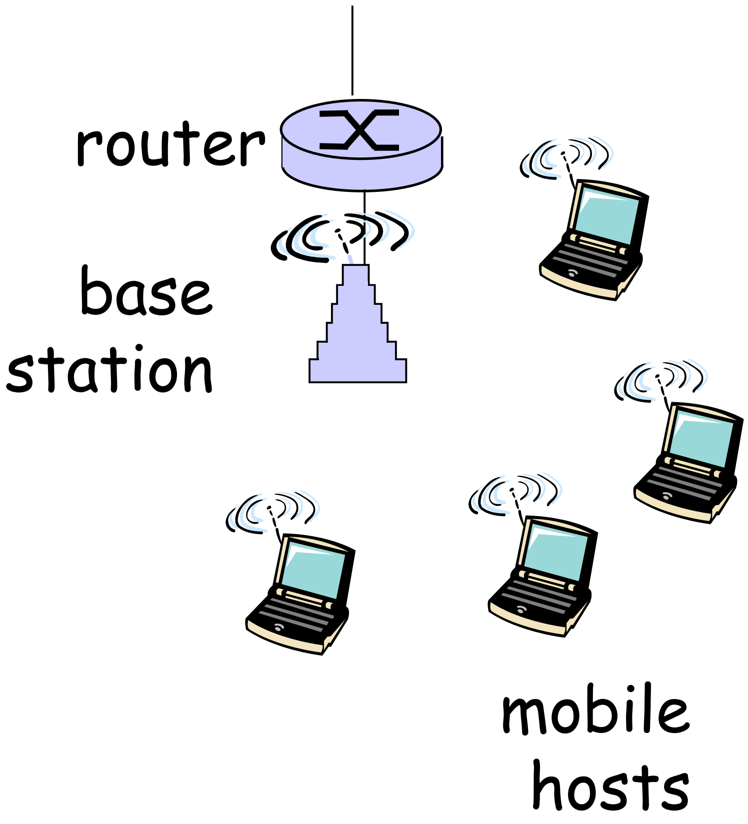
Ethernet Internet access



- Typically used in companies, universities, etc
- 10 Mbs, 100Mbps, 1Gbps, 10Gbps Ethernet
- Today, end systems typically connect into Ethernet switch

Wireless access networks

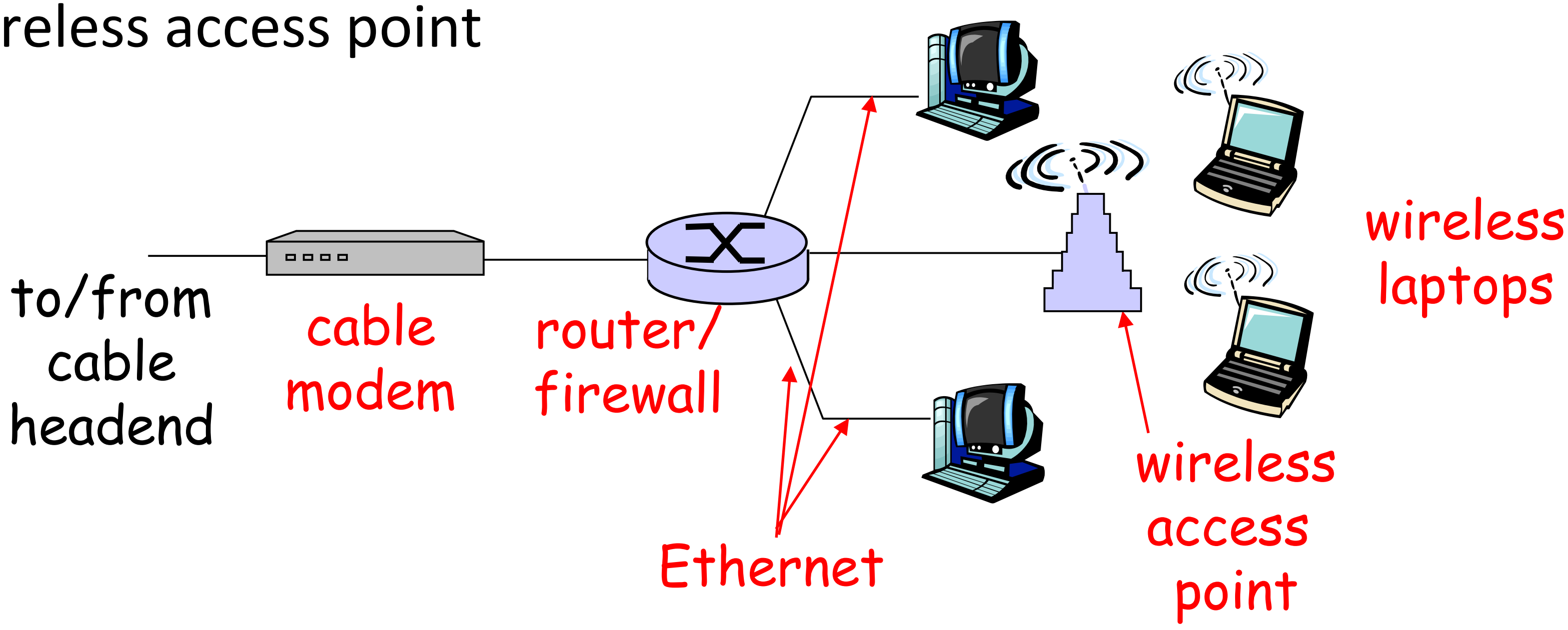
- shared *wireless* access network connects end system to router
  - via base station aka “access point”
- wireless LANs:
  - 802.11b/g (WiFi): 11 or 54 Mbps
- wider-area wireless access
  - provided by telco operator
  - ~1Mbps over cellular system (EVDO, HSDPA)
  - next up (?): WiMAX (10’s Mbps) over wide area



Home networks

Typical home network components:

- DSL or cable modem
- router/firewall/NAT
- Ethernet
- wireless access point



Physical Media

- Bit: propagates between transmitter/rcvr 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

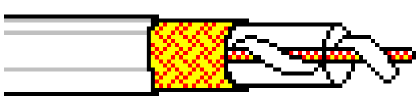
Twisted Pair (TP)

- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5: 100Mbps Ethernet

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 operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gps)
- low error rate: repeaters spaced far apart ; immune to electromagnetic noise

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: ~ 1 Mbps
- Satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

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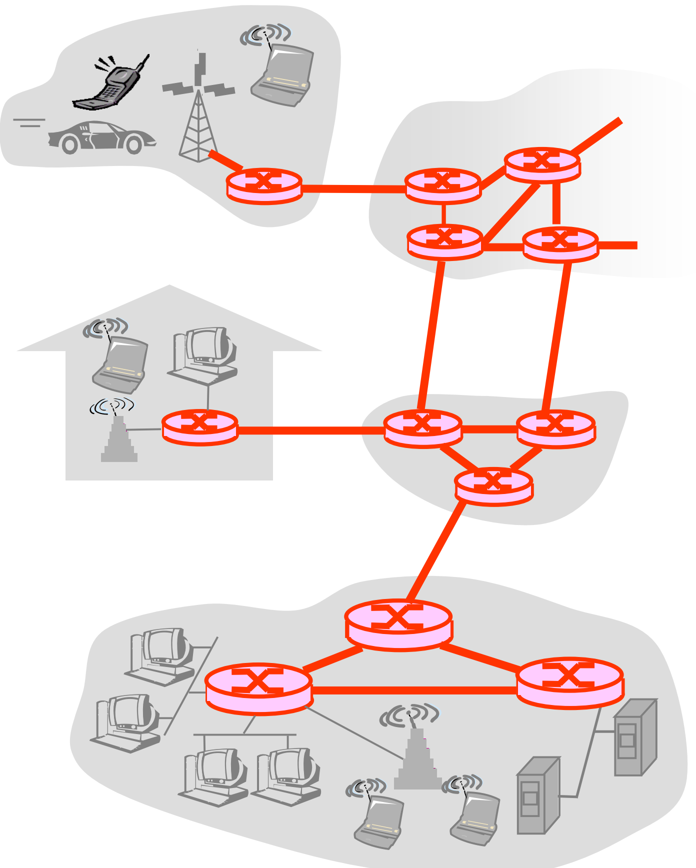
The Network Core

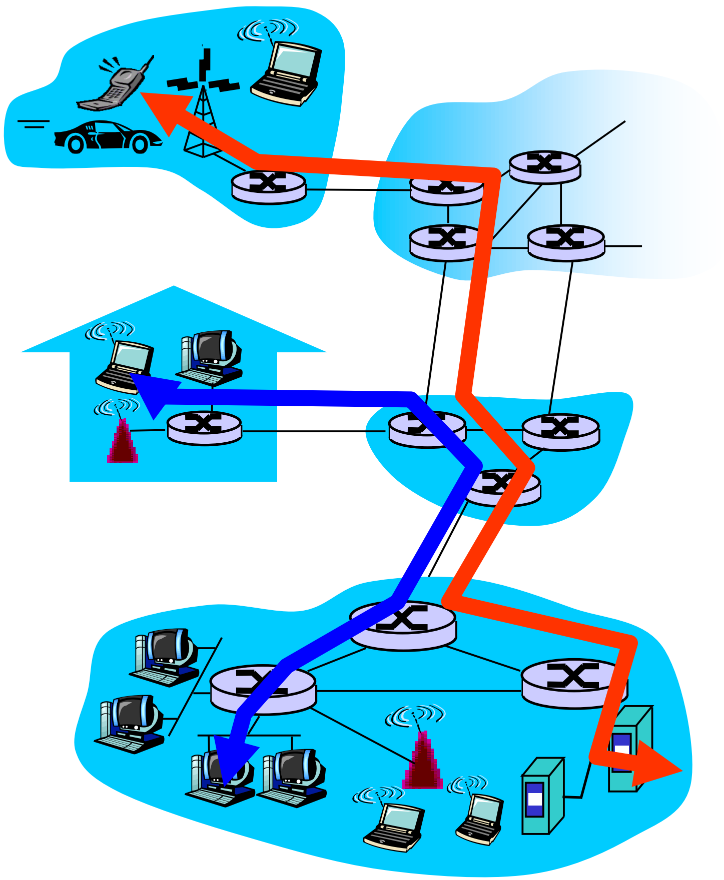
- Mesh of interconnected routers
- Fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



Network Core: Circuit Switching

End-end resources reserved for "call"

- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup required



Network Core: Circuit Switching

network resources (e.g., bandwidth) divided into "pieces"

- pieces allocated to calls
- resource piece *idle* if not used by owning call *(no sharing)*

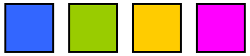
- dividing link bandwidth into "pieces"
  - frequency division
  - time division

Analogy: Restaurant Booking

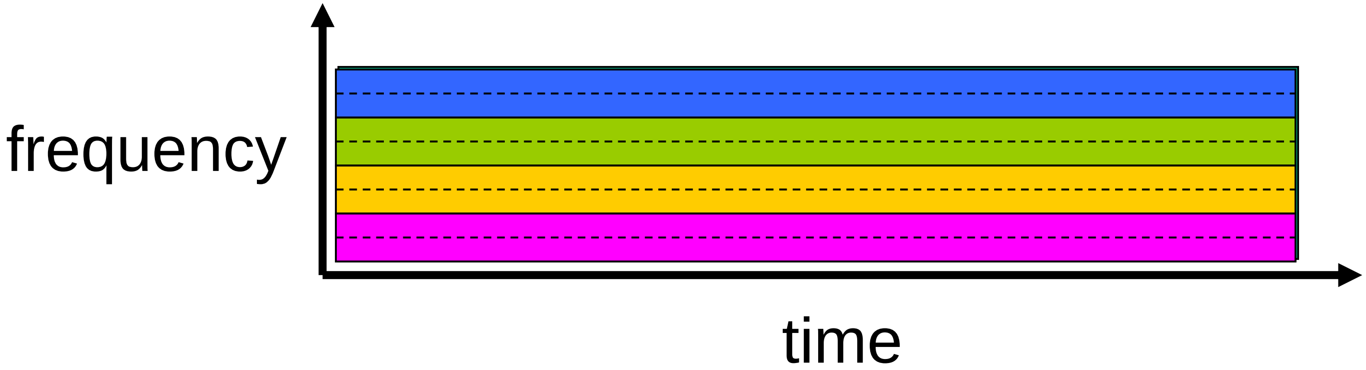
Circuit Switching: FDM and TDM

Example:

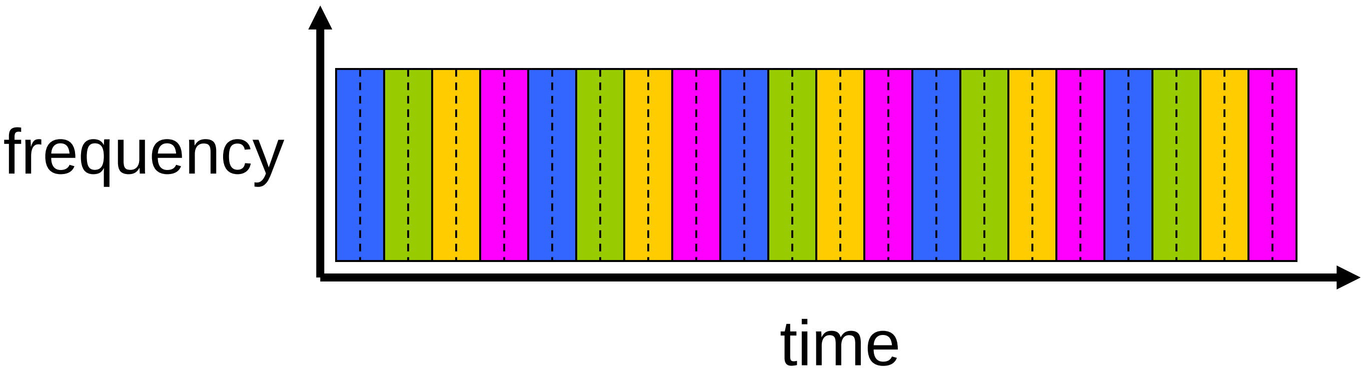
4 users



FDM



TDM



Packet Switching

- Sending message: source to a destination end system
  - the source breaks long messages into smaller chunks of data known as **packets**.
  - Between source and destination, each packet travels through **communication links** and **packet switches** (routers and switches).
  - Packets are transmitted over each communication link at a rate equal to the ***full*** **transmission rate** of the link.
  - **So, if a source end system or a packet switch is sending a packet of *L* bits over a link with transmission rate *R* bits/sec, then the time to transmit the packet is *L/R* seconds**

Network Core: Packet Switching

each end-end data stream divided into *packets*

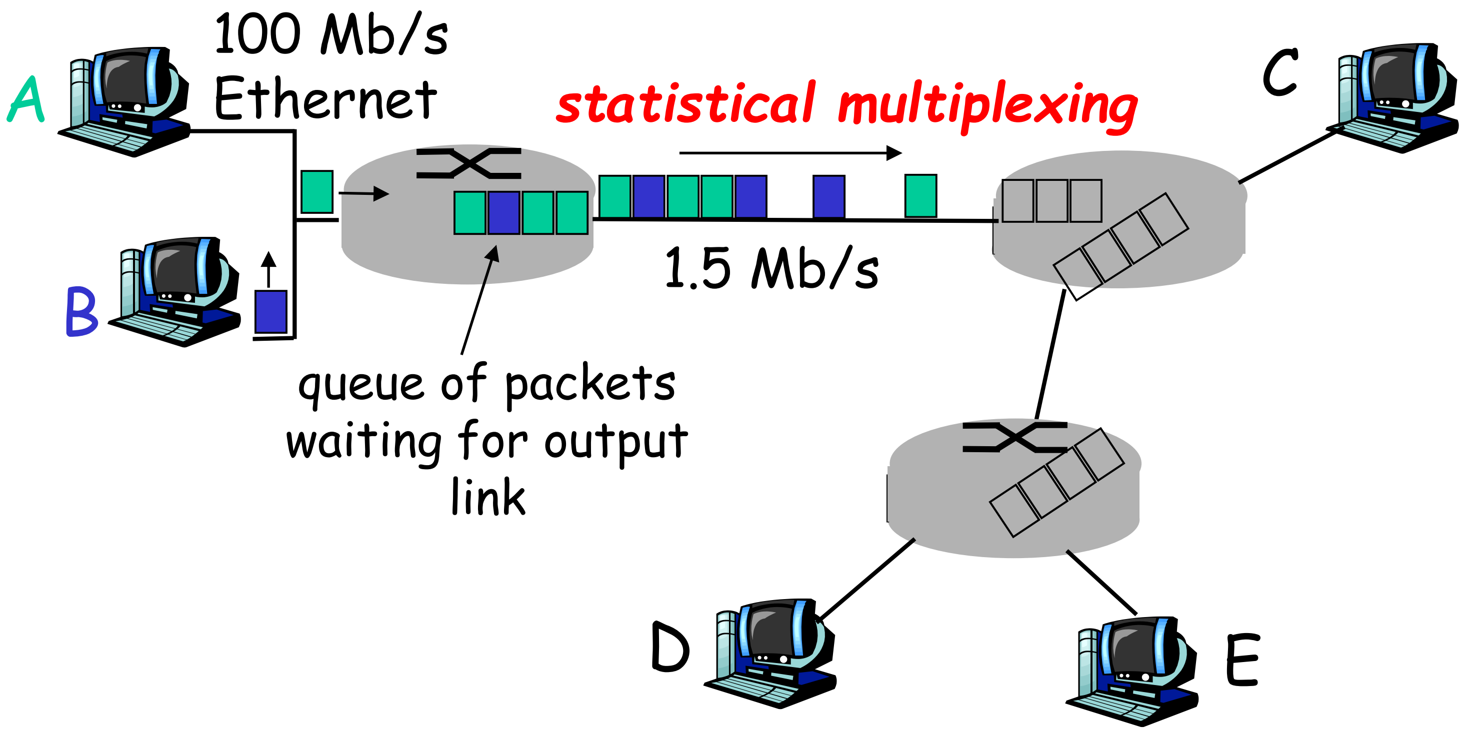
- user A, B packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*

~~Bandwidth division into "pieces"~~
~~Dedicated allocation~~
~~Resource reservation~~

resource contention:

- aggregate resource demand can exceed amount available
- congestion: packets queue, wait for link use
- store and forward: packets move one hop at a time
  - Node receives complete packet before forwarding

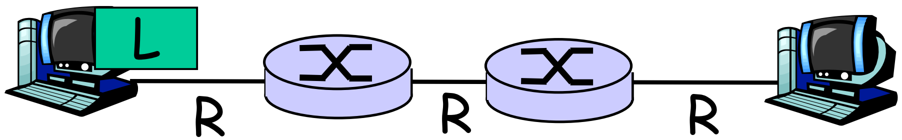
Packet Switching: Statistical Multiplexing



Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand ➔ ***statistical multiplexing***.

TDM: each host gets same slot in revolving TDM frame.

Packet-switching: store-and-forward



- takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- delay = 3L/R (assuming zero propagation delay)

Example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- transmission delay = 15 sec *[(7.5/1.5)*3]*
- *Transmission delay is actually time taken to push the date into the link by router/host.*

Packet switching VS circuit switching

- Packet Switch:
  - great for bursty data
    - resource sharing
    - simpler, no call setup
  - excessive congestion: packet delay and loss
    - protocols needed for reliable data transfer, congestion control
- Q: How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (chapter 7)

Numerical example

- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

- Link speed = 1.536 Mbps and link uses 24 slots/sec
- Transmission Rate of a circuit (slot) = 1.536/24 = 64kbps
- Time taken to send the file = 640,000/64,000=10 sec
- Total time taken = 10.5 sec

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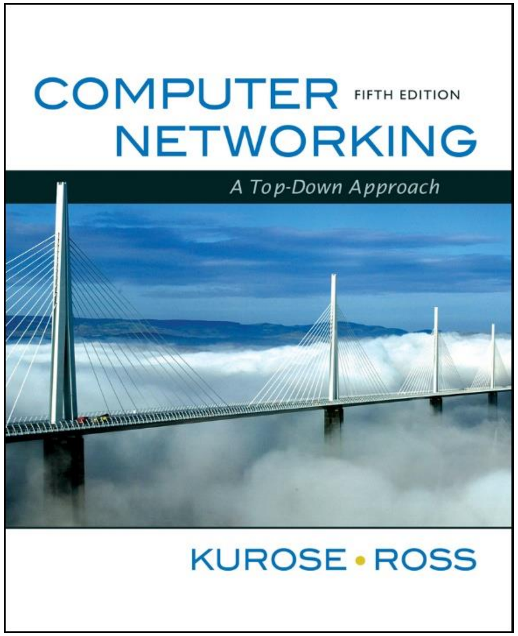

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Computer Networking: A Top Down Approach , 5th edition.
Jim Kurose, Keith Ross
Addison-Wesley, April 2009.

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