L1: 1-24
L2: 25-57

Chapter 1 Introduction

Tutorials start with Chap 1 questions (tutor). Students to use text book and research to answer questions

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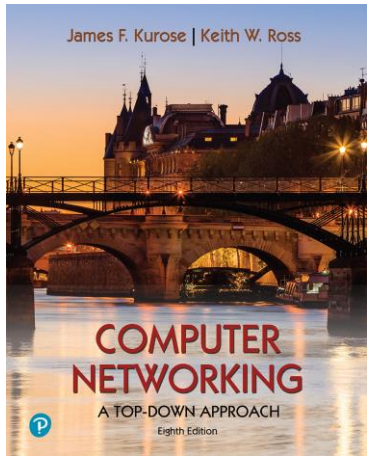


Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Chapter 1: introduction

Chapter goal:

Get "feel," "big picture," introduction to terminology

more depth, detail *later* in course

Approach:

use Internet as example

Overview/roadmap:

What *is* the Internet?

What *is* a protocol?

Network edge: hosts, access network, physical media

Network core: packet/circuit switching, internet structure

Performance: loss, delay, throughput

Security

Protocol layers, service models

History

“Fun” Internet-connected devi s

Amazon Echo

Internet refrigerator

IP picture frame

Pacemaker & Monitor

Tweet-a-watt: monitor energy use

Security Camera

Slingbox: remote control cable TV

Web-enabled toaster + weather forecaster

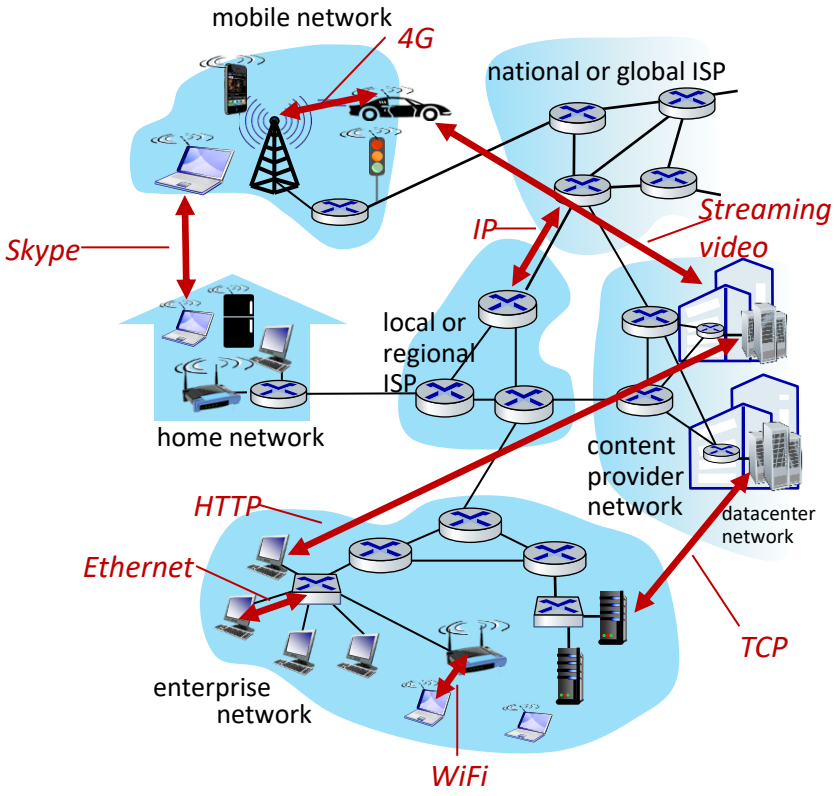
Internet phones

Fitbit

Internet: "network of networks"

Interconnected ISPs

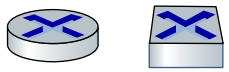
- *protocols* are *everywhere*
  - control sending, receiving of messages
  - e.g., HTTP (Web), streaming video, Skype, TCP, IP, WiFi, 4G, Ethernet
- *Internet standards*
  - RFC: Request for Comments
  - IETF: Internet Engineering Task Force. The IETF is a large open international community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet.



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)

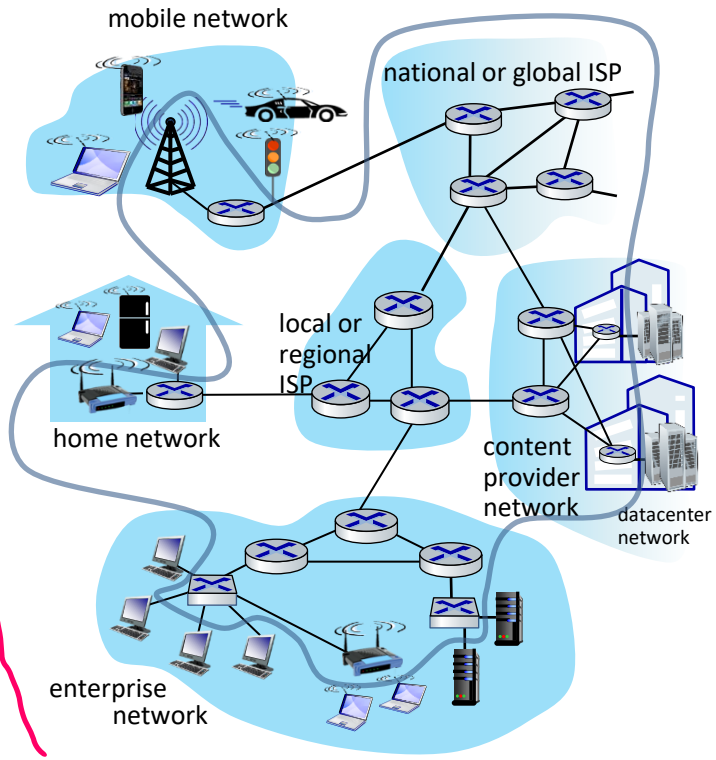
- *routers, switches*

Communication links

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

Networks

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

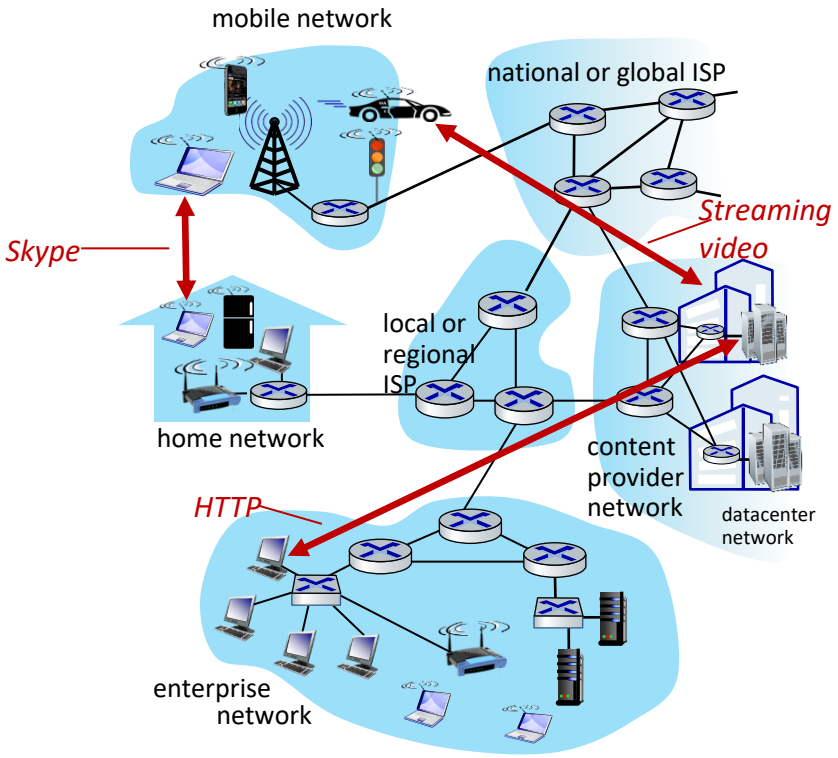


The Internet: a "service" view

Infrastructure that provides services to applications:

Web, streaming video, multimedia teleconferencing, email, games, e-commerce, social media, inter-connected appliances, …

- provides *programming interface* to distributed applications:
  - "hooks" allowing sending/receiving apps to "connect" to, use Internet transport service
  - provides service options, analogous to postal service



Hooks allow a programmer to insert customized code. Eg implement chat program but TCP/IP code present

What's a protocol?

Human protocols:

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

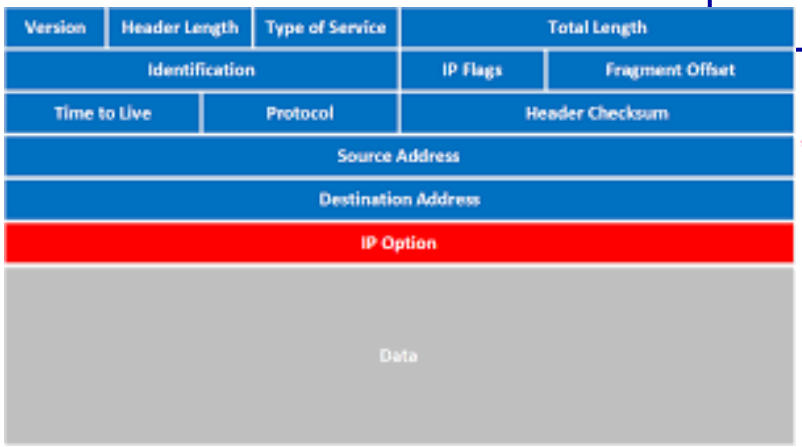
… specific messages sent

… specific actions taken when message received, or other events

Network protocols:

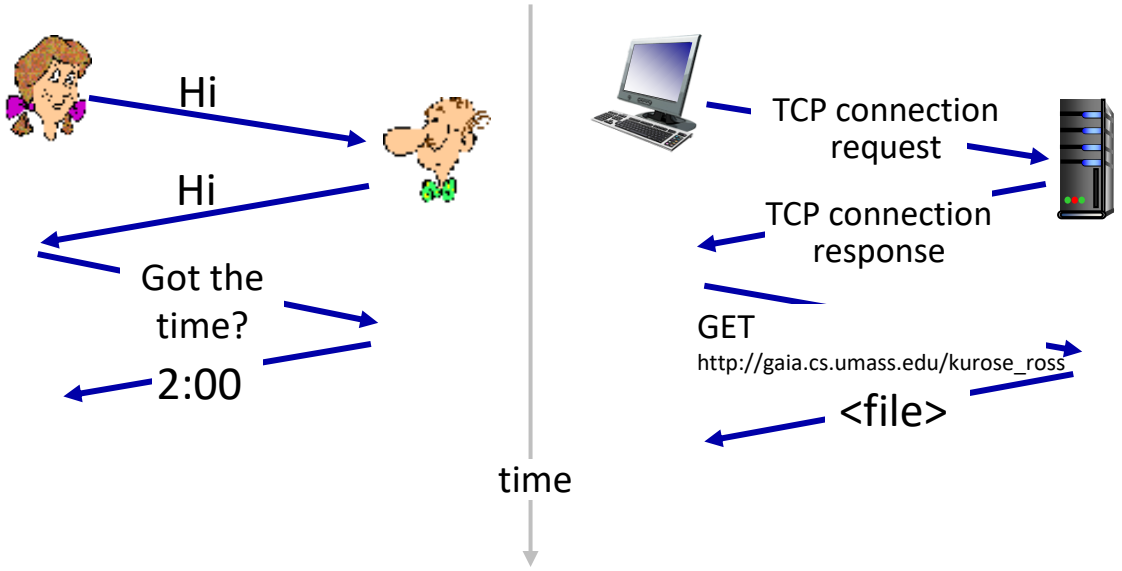
- computers (devices) rather than humans
- all communication activity in Internet governed by protocols

Protocols define the format, order of messages 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:



Q: other human protocols?

Chapter 1: roadmap

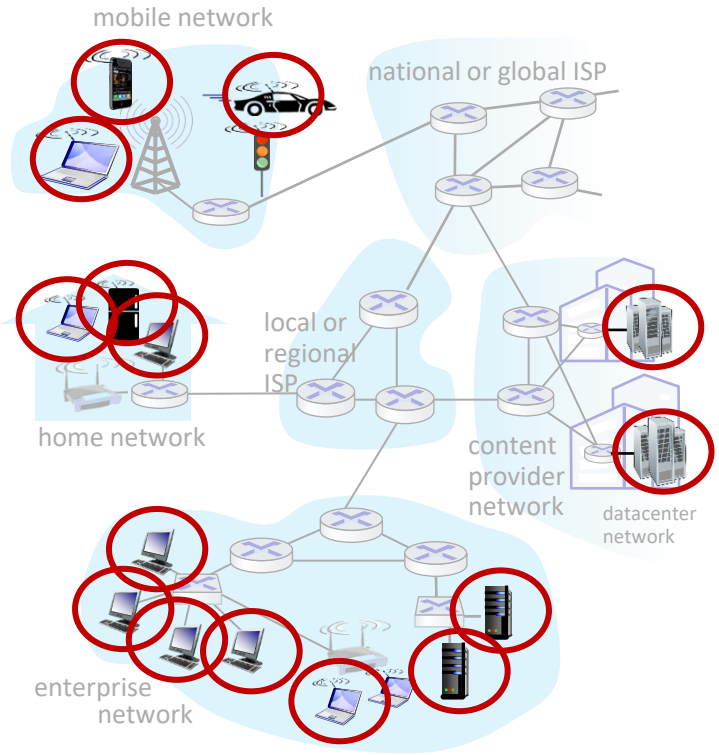
- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models
- History

A closer look at Internet structure

Network edge:

hosts: clients and servers

servers often in data centers



Data centre-a large group of networked computer servers typically used by organizations for the remote storage, processing, or distribution of large amounts of data.

A closer look at Internet structure

Network edge:

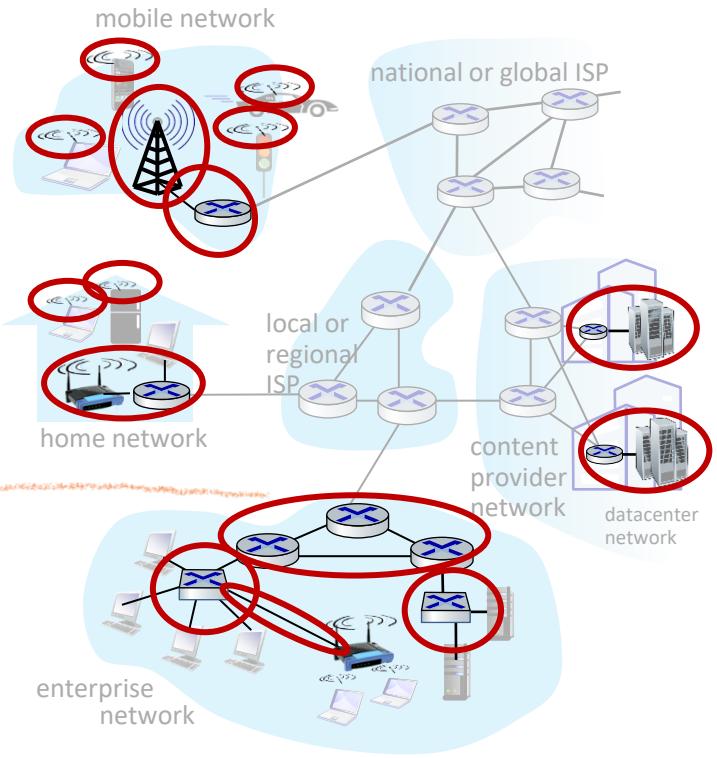
hosts: clients and servers

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

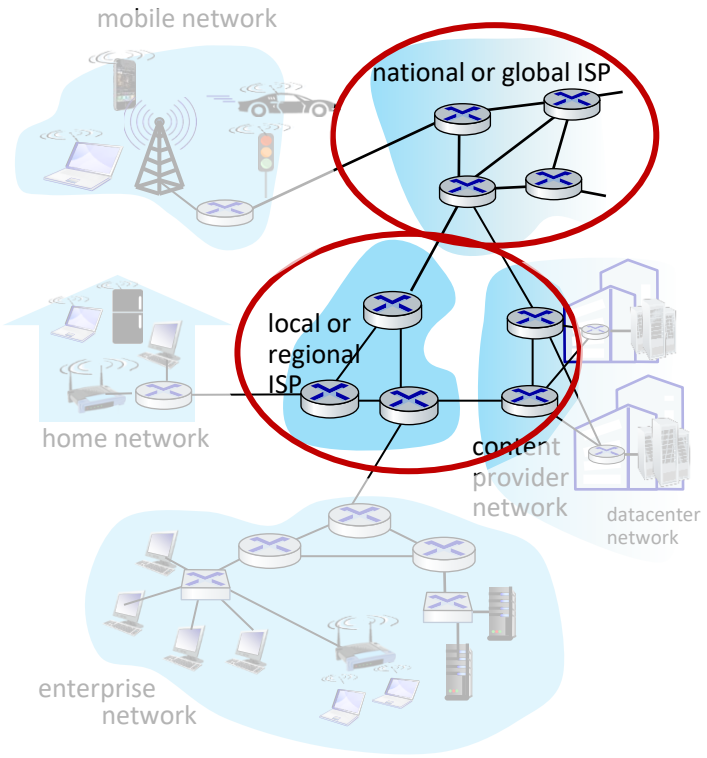
servers often in data centers

Access networks, physical media:

wired, wireless communication links

Network core:

- interconnected routers
- network of networks



Access networks and physical media

Q: How to connect end systems to edge router?

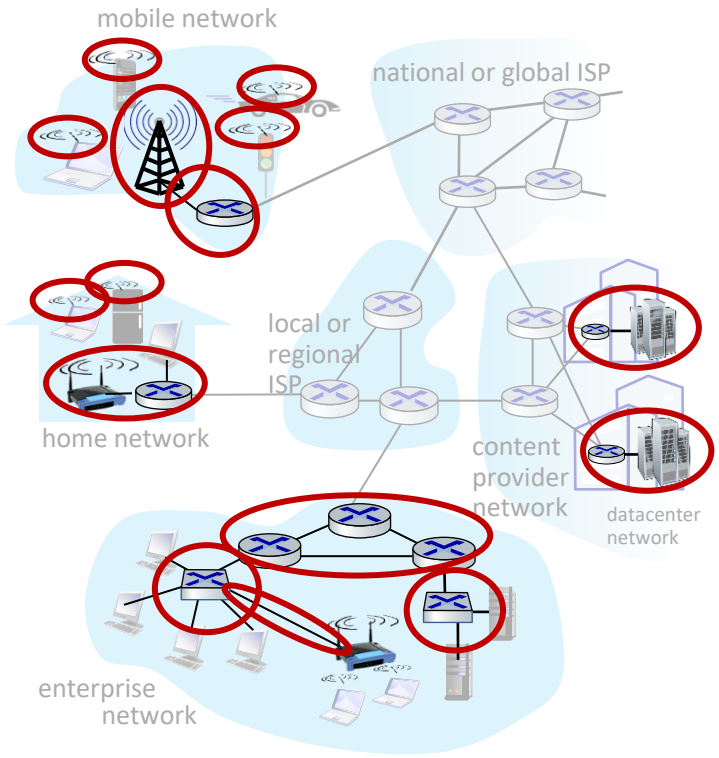
residential access nets

institutional access networks (school, company)

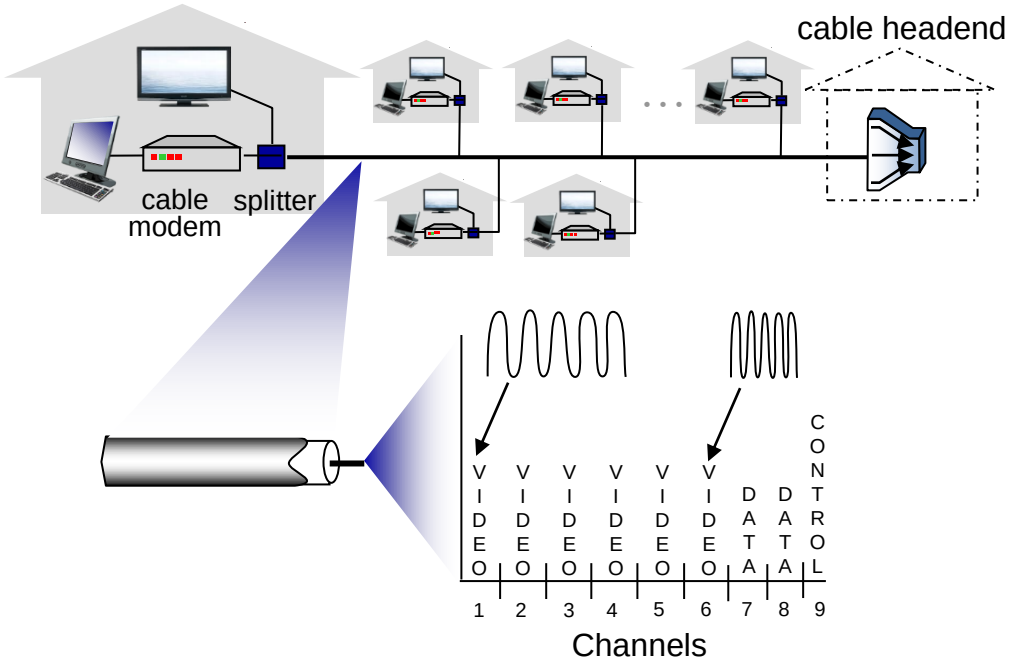
mobile access networks (WiFi, 4G/5G)

What to look for:

- transmission rate (bits per second) of access network?
- shared or dedicated access among users?

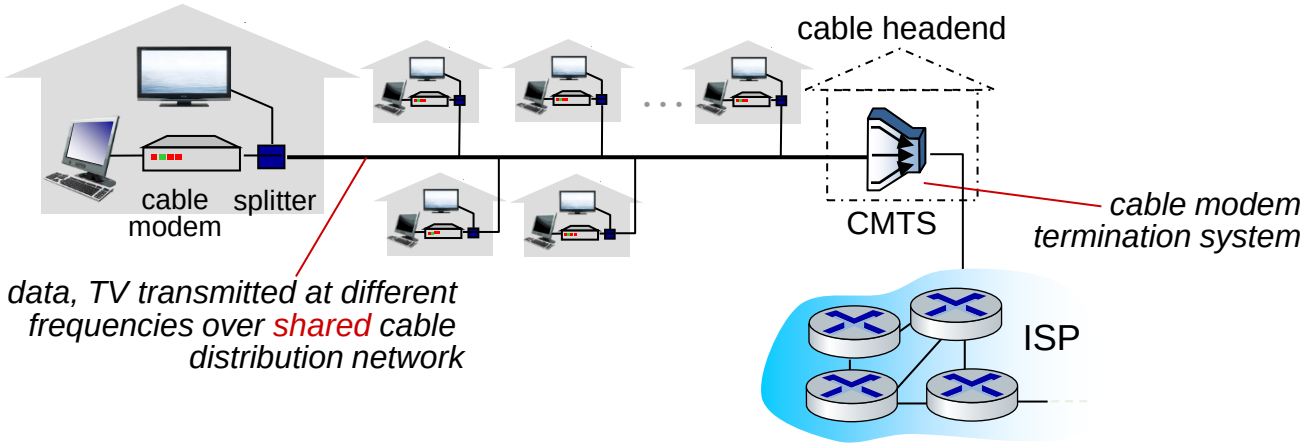


Access networks: cable-based access



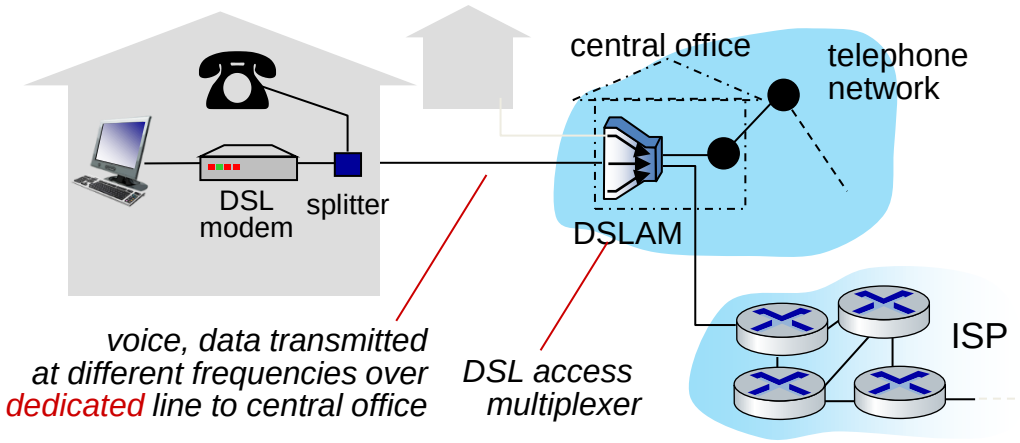
frequency division multiplexing (FDM): different channels transmitted in different frequency bands

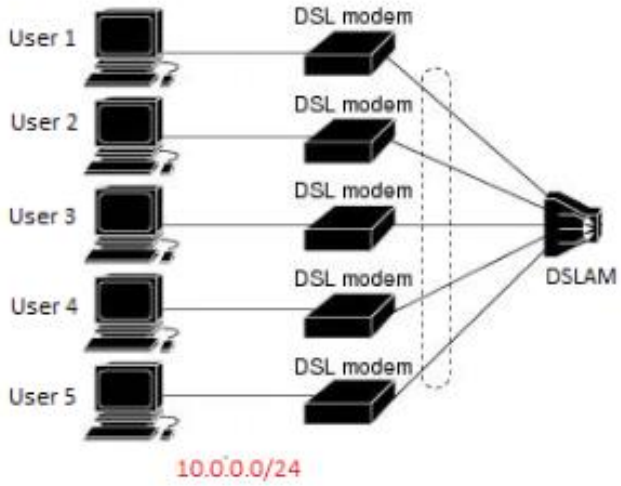
Access networks: cable-based access



- HFC: hybrid fiber coax
  - asymmetric: up to 40 Mbps – 1.2 Gbs downstream transmission rate, 30-100 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable headend

Access networks: digital subscriber line (DSL)

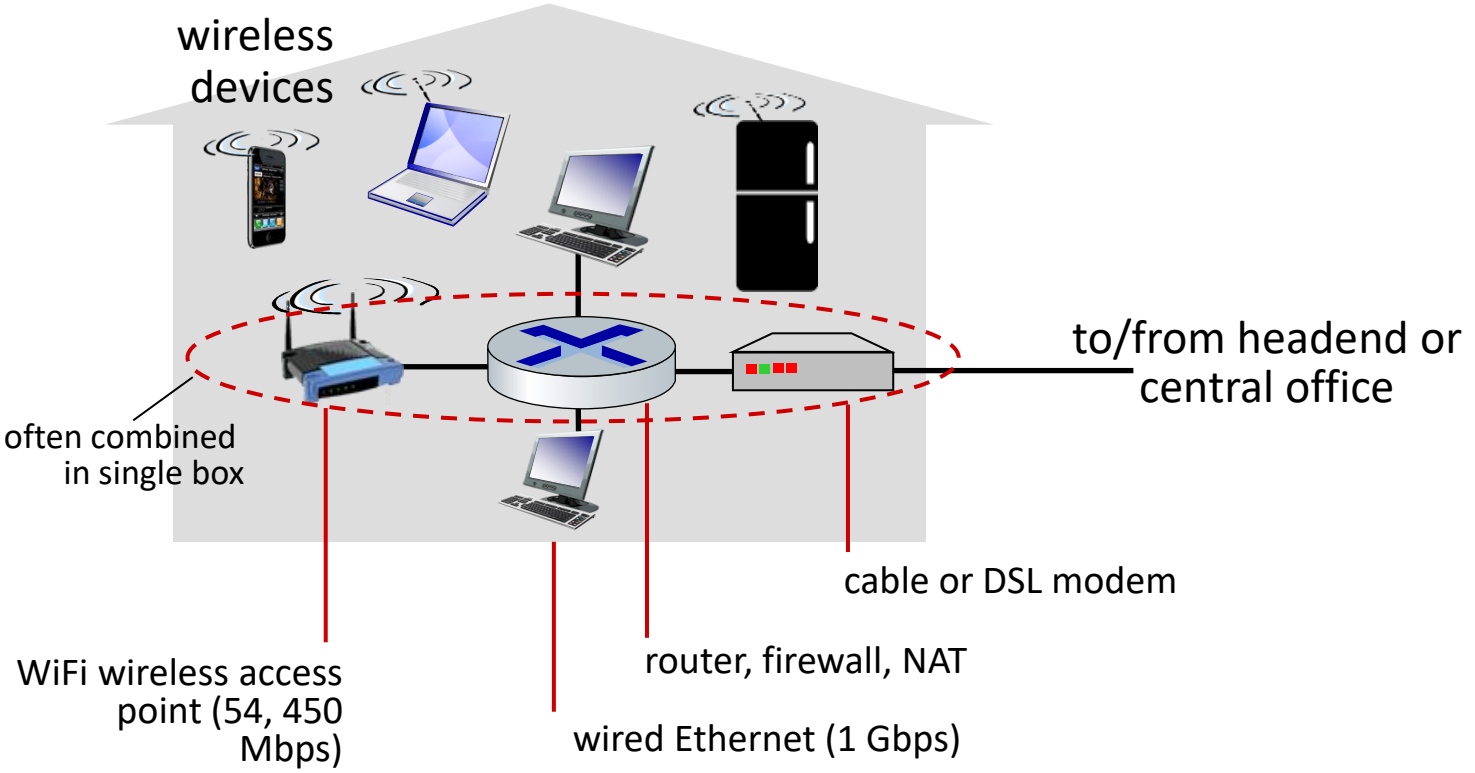




- use *existing* telephone line to central office D
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- 24-52 Mbps dedicated downstream transmission rate
- 3.5-16 Mbps dedicated upstream transmission rate

DSLAM connects multiple DSL subscribers to one Internet backbone.

Access networks: home networks



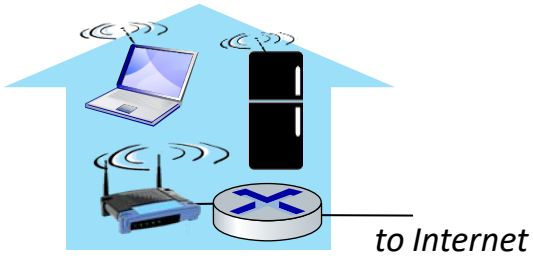
Wireless access networks

Shared *wireless* access network connects end system to router

- via base station aka “access point”

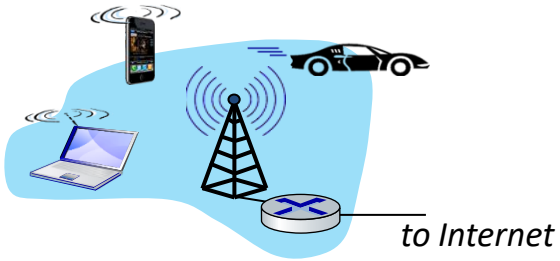
Wireless local area networks (WLANs)

- typically within or around building (~100 ft)
- 802.11b/g/n (WiFi): 11, 54, 450 Mbps transmission rate

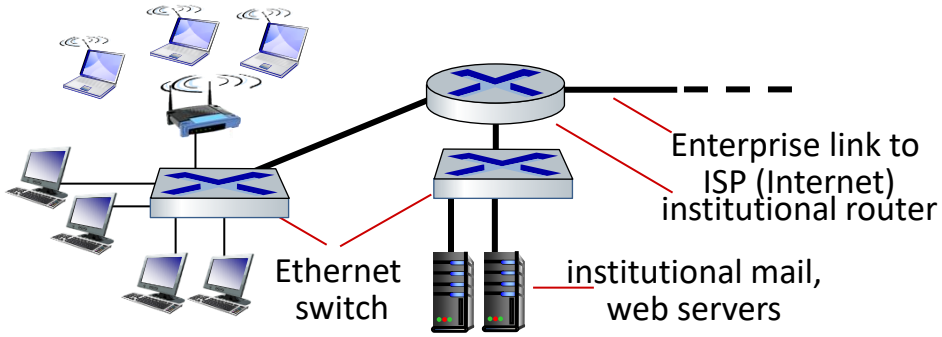


Wide-area cellular access networks

- provided by mobile, cellular network operator (10’s km)
- 10’s Mbps
- 4G cellular networks (5G coming)



Access networks: enterprise networks

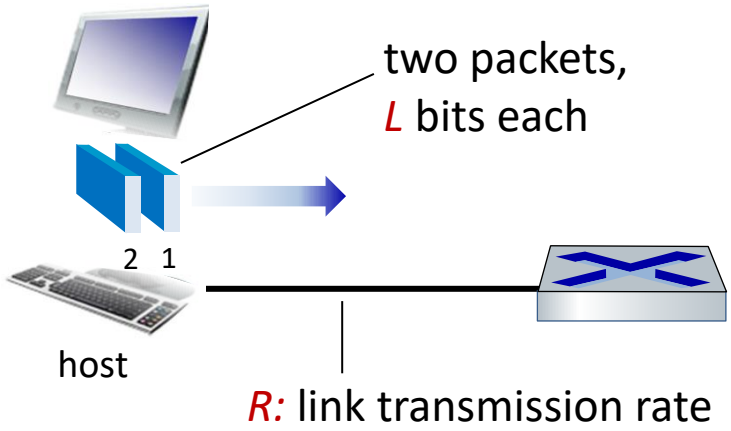


- companies, universities, etc.
- mix of wired, wireless link technologies, connecting a mix of switches and routers (we'll cover differences shortly)
  - Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps
  - WiFi: wireless access points at 11, 54, 450 Mbps

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*



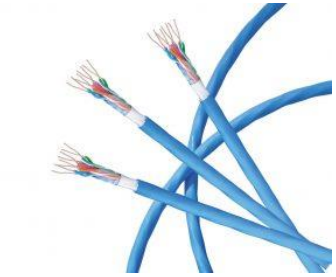
$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

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



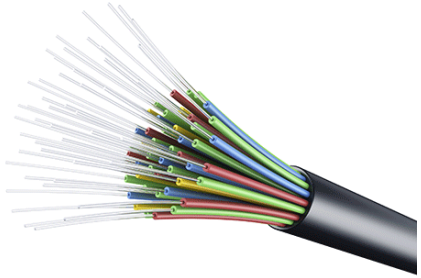
Links: physical media

Coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple frequency channels on cable
  - 100's Mbps per channel

Fiber optic cable:

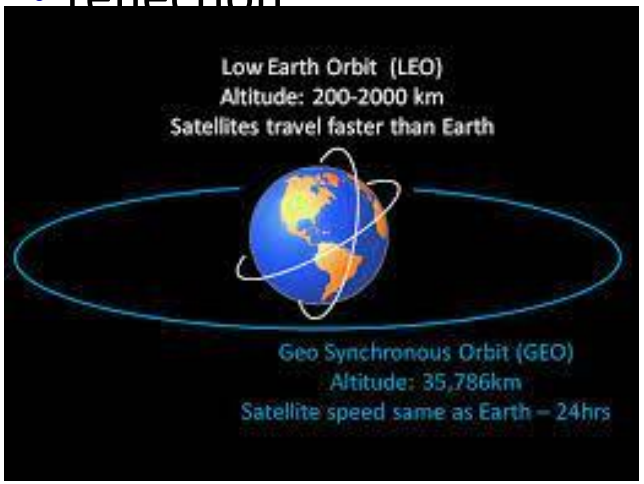
- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (10's-100's Gbps)
- low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise



Links: physical media

Wireless radio

- signal carried in electromagnetic spectrum
- no physical "wire"
- broadcast and "half-duplex" (sender to receiver)
- propagation environment effects:
  - reflection



Radio link types:

- terrestrial microwave
  - up to 45 Mbps channels
- Wireless LAN (WiFi)
  - Up to 100's Mbps
- wide-area (e.g., cellular)
  - 4G cellular: ~ 10's Mbps
- satellite
  - up to 45 Mbps per channel
  - 270 msec end-end delay
  - geosynchronous versus low-earth-orbit

Chapter 1: roadmap

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- What *is* a protocol?
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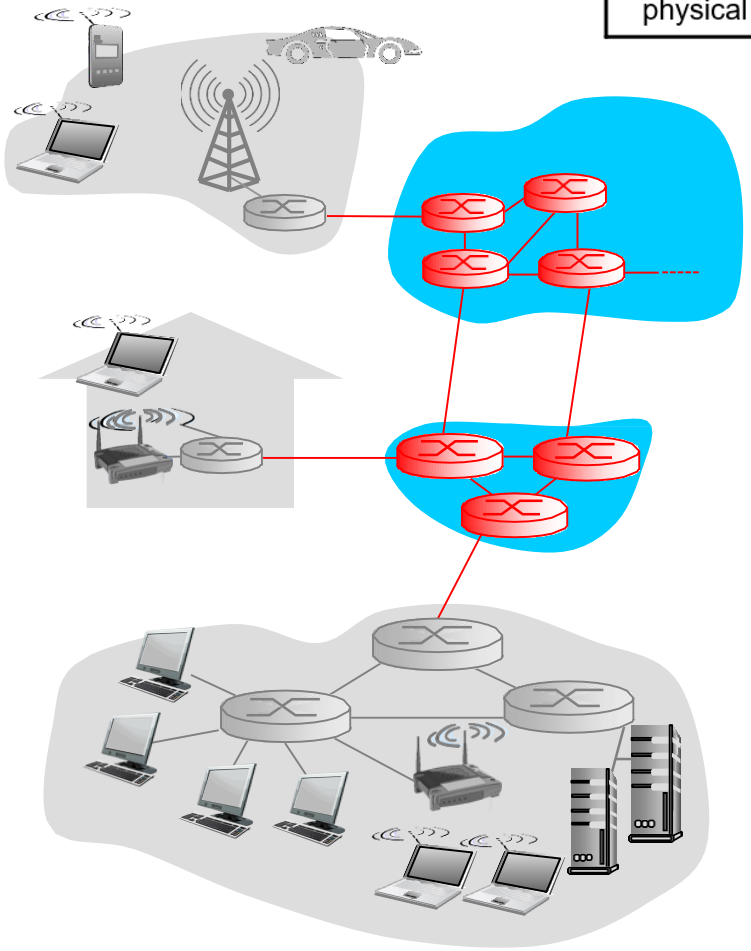
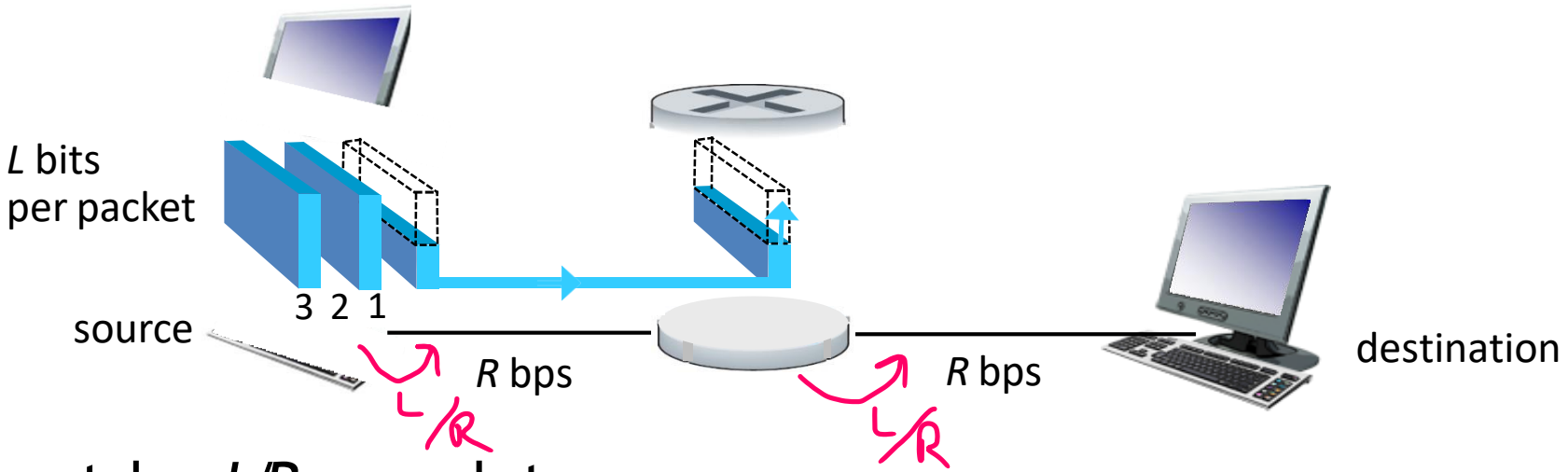
The network core

- 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



Packet-switching: store-and-forward



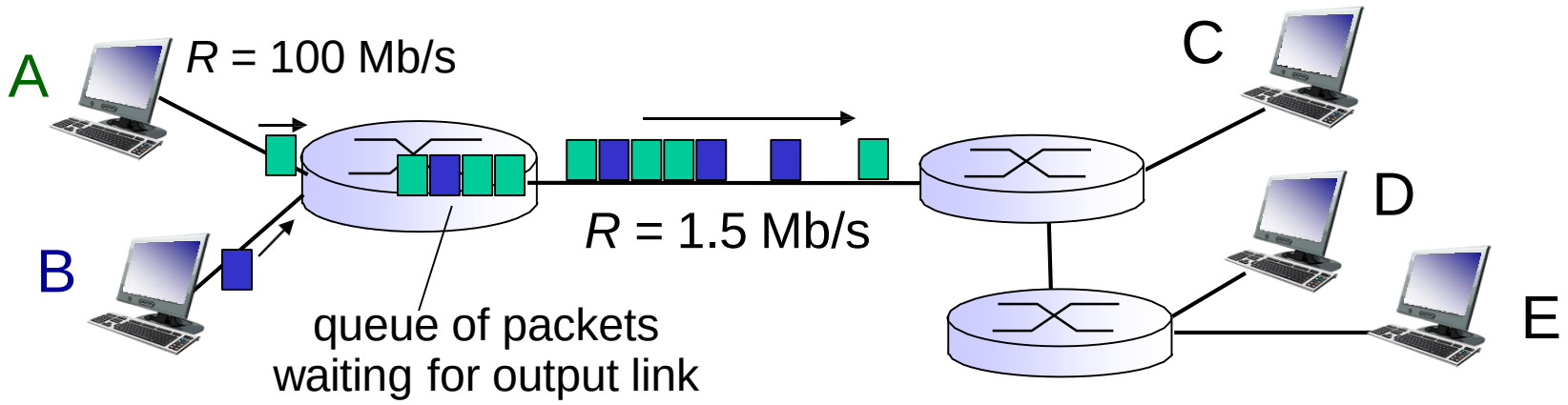
- takes *L/R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
- *store and forward*: entire packet must arrive at router before it can be transmitted on next link
- end-end delay = 2*L/R* (assuming zero propagation delay)

one-hop numerical example:

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

more on delay shortly …

Packet Switching: queueing delay, loss



queuing and loss:

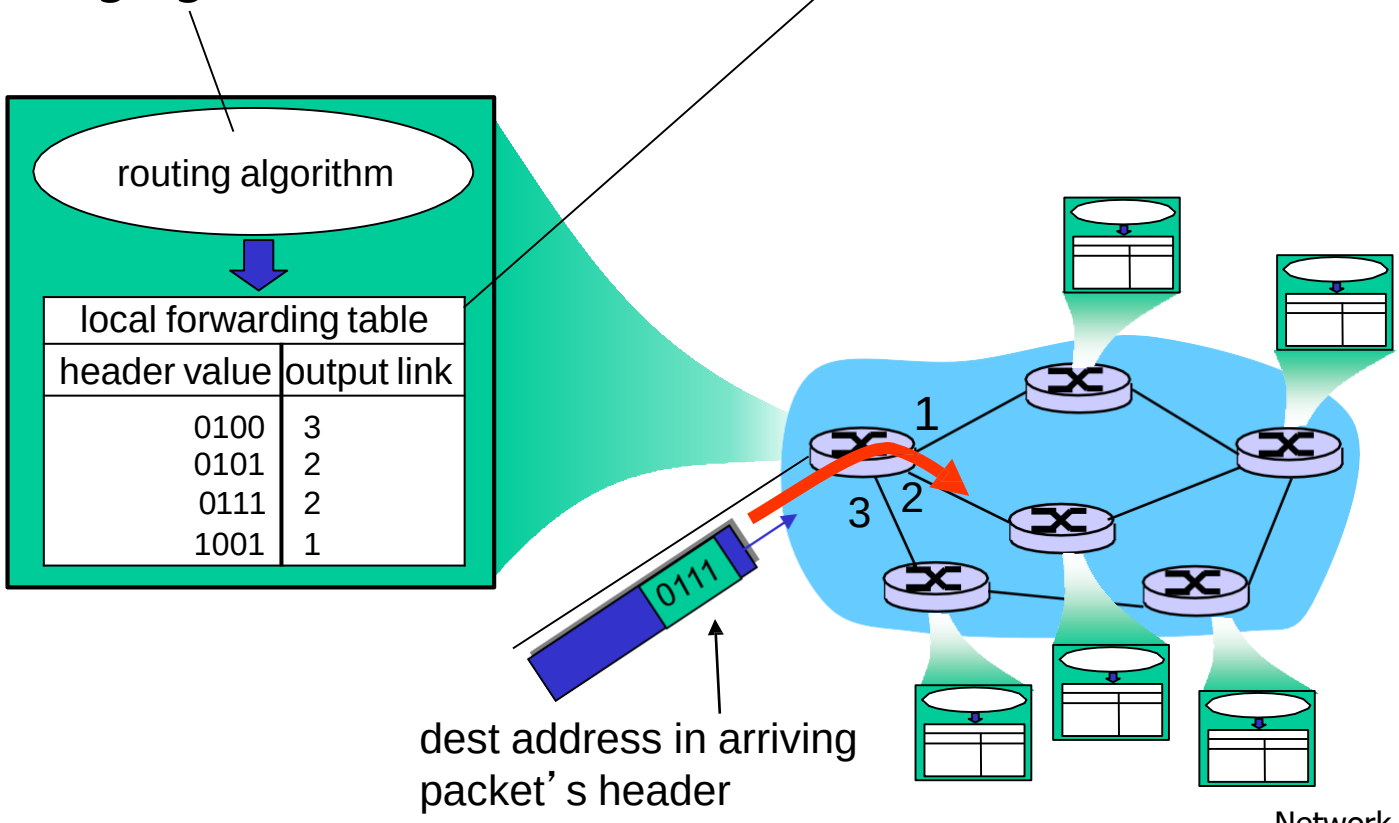
- If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

Two key network-core functions

routing: determines source-destination route taken by packets

- *routing algorithms*

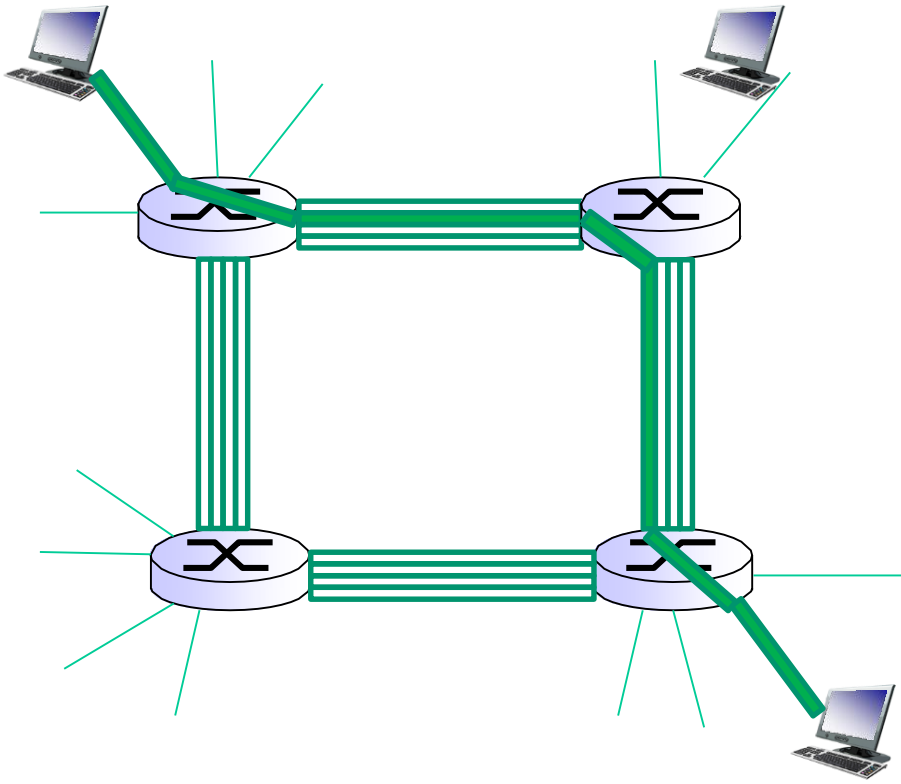
forwarding: move packets from router's input to appropriate router output



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

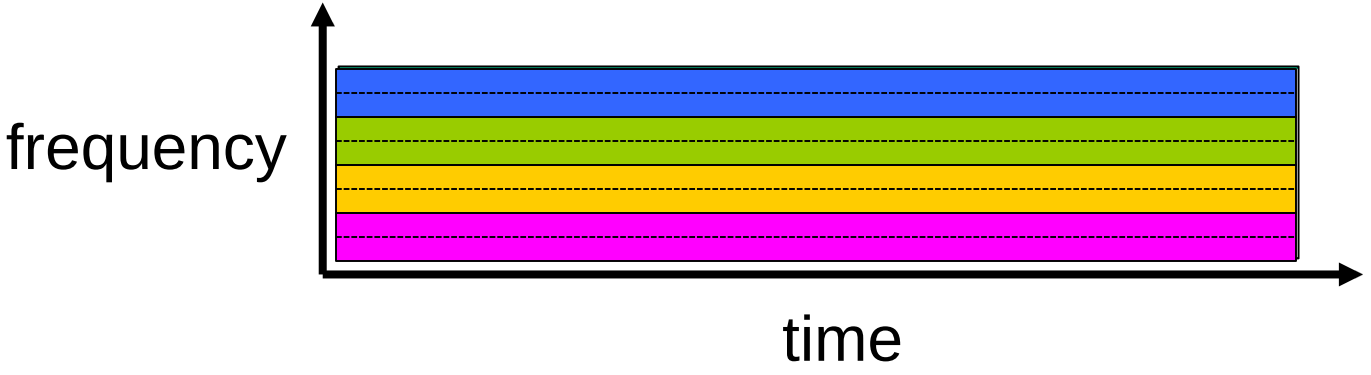


Circuit switching: FDM versus TDM

Example:

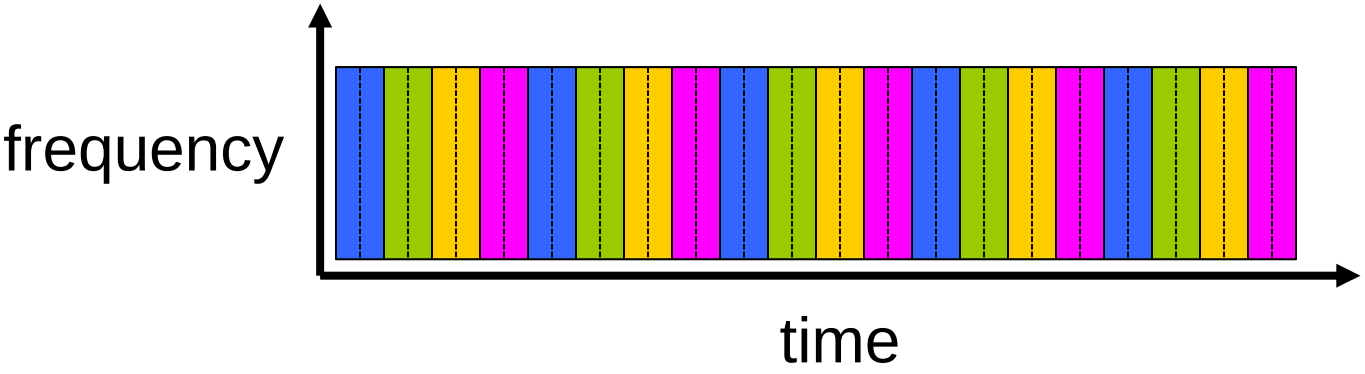
4 users

FDM



TDM

(Full bandwidth for a certain time)



Packet switching versus circuit switching

is packet switching a "slam dunk winner?"

- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: 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

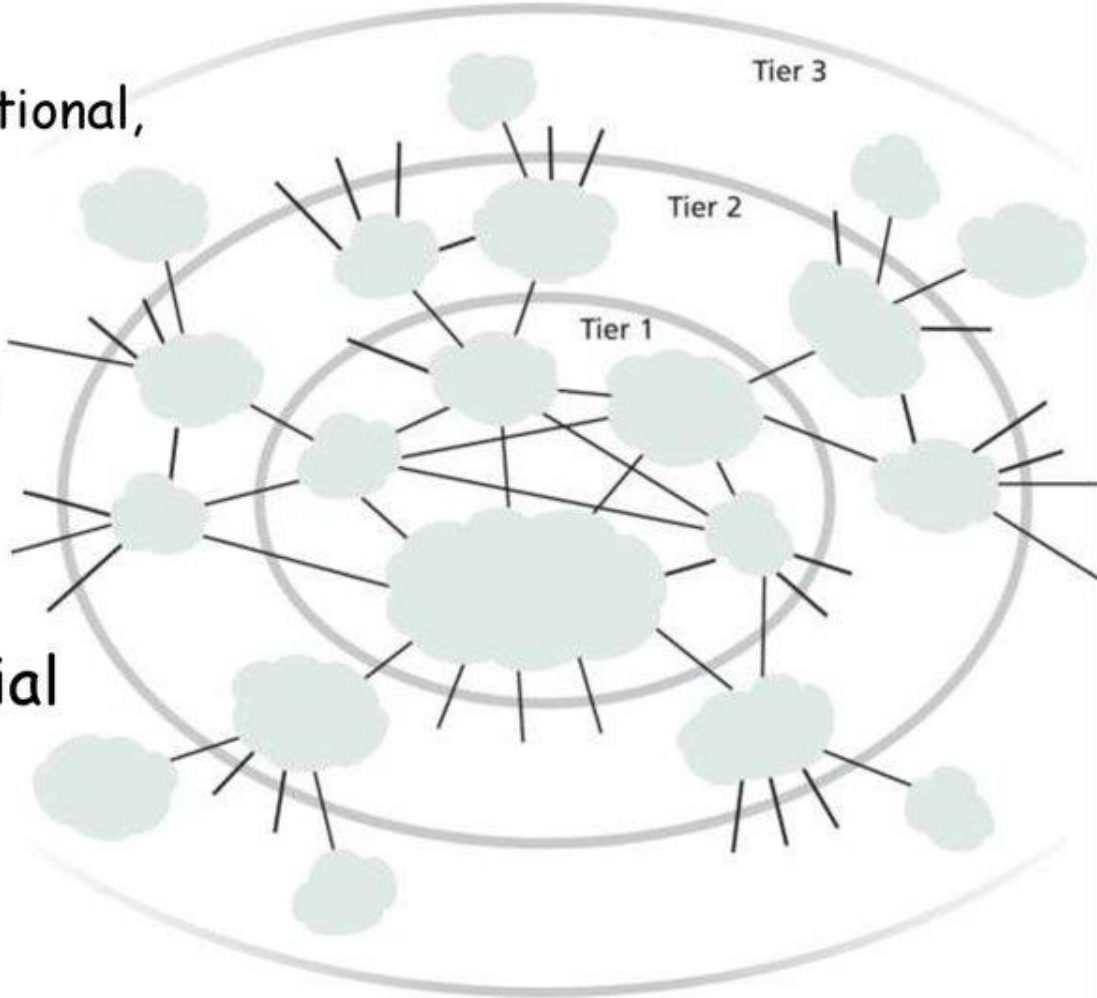
Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

Internet structure: network of networks

- End systems connect to Internet via access ISPs (Internet Service Providers)
  - Residential, company and university ISPs
- Access ISPs in turn must be interconnected.
  - So that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - Evolution was driven by economics and national policies
- Let's take a stepwise approach to describe current Internet structure

A Network of Networks

- roughly hierarchical
  - Tier-1 ISPs provide national, international coverage
  - Tier-2 ISPs provide regional coverage
  - Tier-3 and lower levels provide local coverage
- any tier may sell to business and residential customers
- any ISP may have a link to any other ISP (not strictly hierarchical)



D. Hollinger

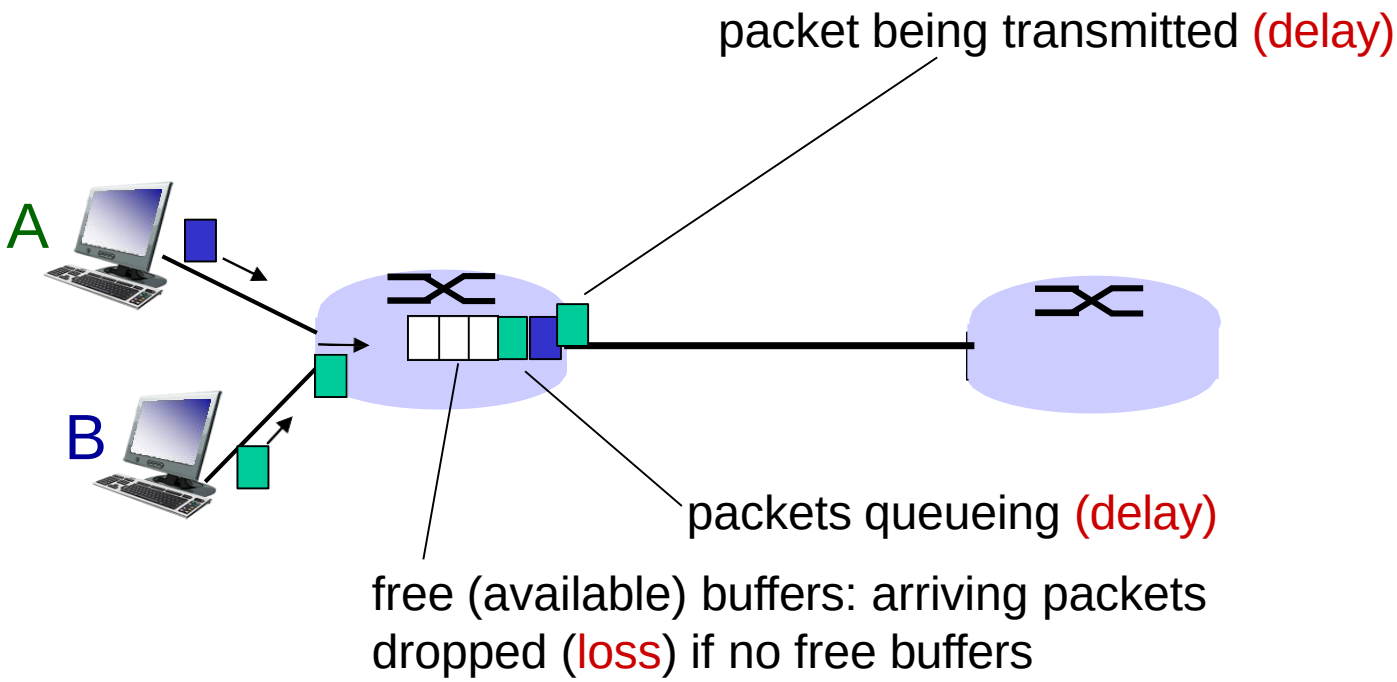
Chapter 1: roadmap

1. what *is* the Internet?
2. network edge
   - end systems, access networks, links
3. network core
   - packet switching, circuit switching, network structure
4. delay, loss, throughput in networks
5. protocol layers, service models
6. networks under attack: security
7. history

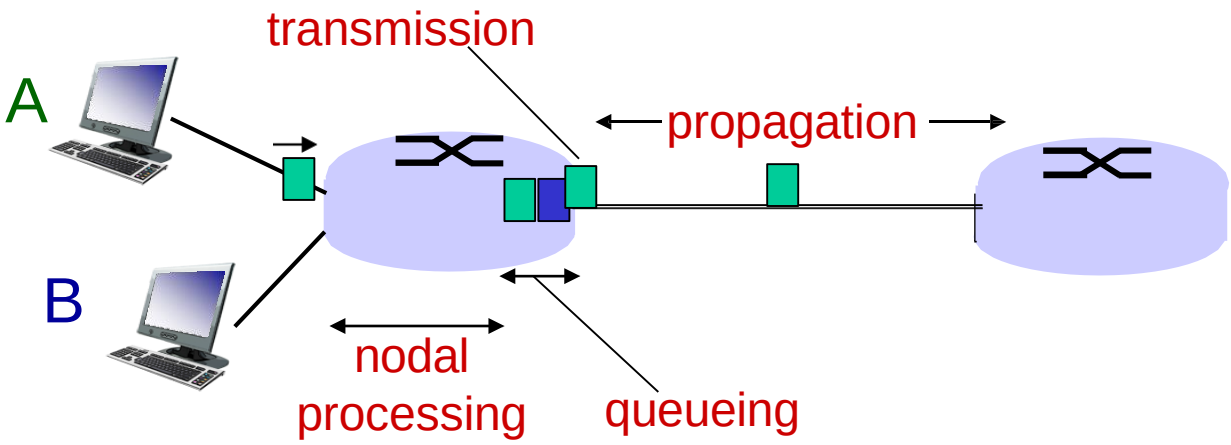
How do loss and delay occur?

packets *queue* in router buffers

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



Four sources of packet delay



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

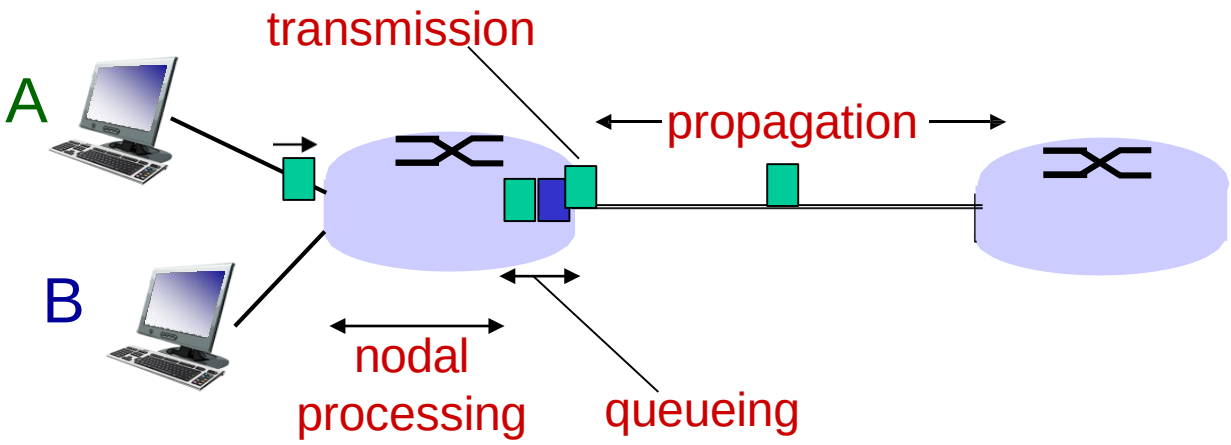
d_{proc}: nodal processing

- check bit errors
- determine output link
- typically < msec

d_{queue}: queueing delay

- time waiting at output link for transmission
- depends on congestion level of router

Four sources of packet delay



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{trans}: transmission delay:

- L: packet length (bits)
- R: link *bandwidth (bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay:

- d: length of physical link
- s: propagation speed in medium (~2×10^8 m/sec)
- $d_{prop} = d/s$

d_{trans} and d_{prop} *very* different

* Check out the Java applet for an interactive animation on trans vs. prop delay

Packet delay

Transmission delay

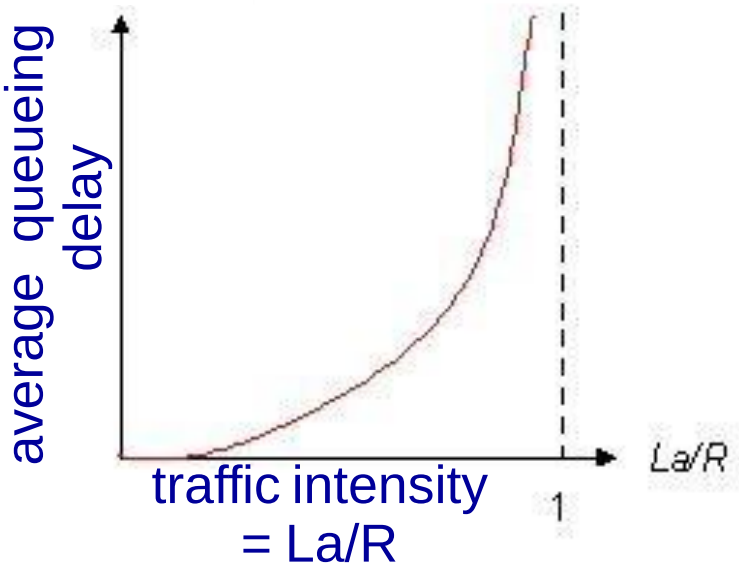
The **transmission delay** is
L/R. This is the amount of time required to push (that is, transmit) all of the packet's bits into the link.

Propagation Delay

Once a bit is pushed into the link, it needs to propagate to router B. The time required to propagate from the beginning of the link to router B is the propagation delay. The bit propagates at the propagation speed of the link. The propagation speed depends on the physical medium of the link (that is, fiber optics, twisted-pair, copper wire, and so on)
The propagation delay is
the distance between two routers divided by the propagation speed. That is, the propagation delay is d/s, where d is the distance between router A and router B and s is the propagation speed of the link.

Queueing delay (revisited)

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



average rate at which bits arrive at the queue is *La* bits/sec

R is the ability to service load La

- *La/R* ~ 0: avg. queueing delay small - La much smaller than R
- *La/R* -> 1: avg. queueing delay large - La meeting R capacity
- *La/R* > 1: more "work" arriving than can be serviced, average delay infinite! - packets lost

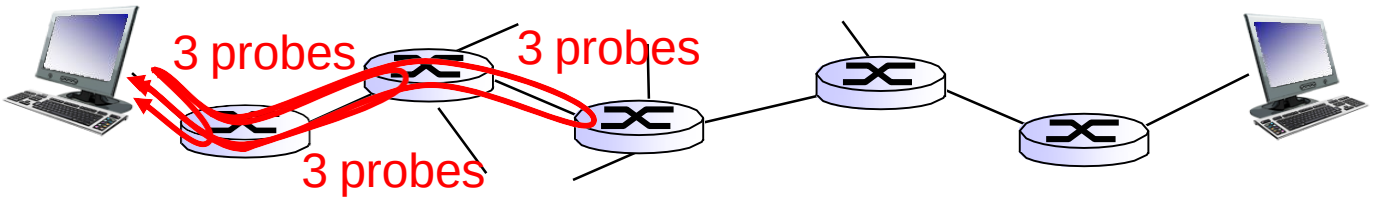
La/R ~ 0

La/R -> 1

* Check out the Java applet for an interactive animation on queuing and loss

"Real" Internet delays and routes

- what do "real" Internet delay & loss look like?
- `traceroute` program: 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 times interval between transmission and reply.



"Real" Internet delays, routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

3 delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7nycm-wash.abilene.ucaid.edu (198.32.8.46) 22 ms  22 ms  22 ms 8
62.40.103.253 (62.40.103.253) 104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

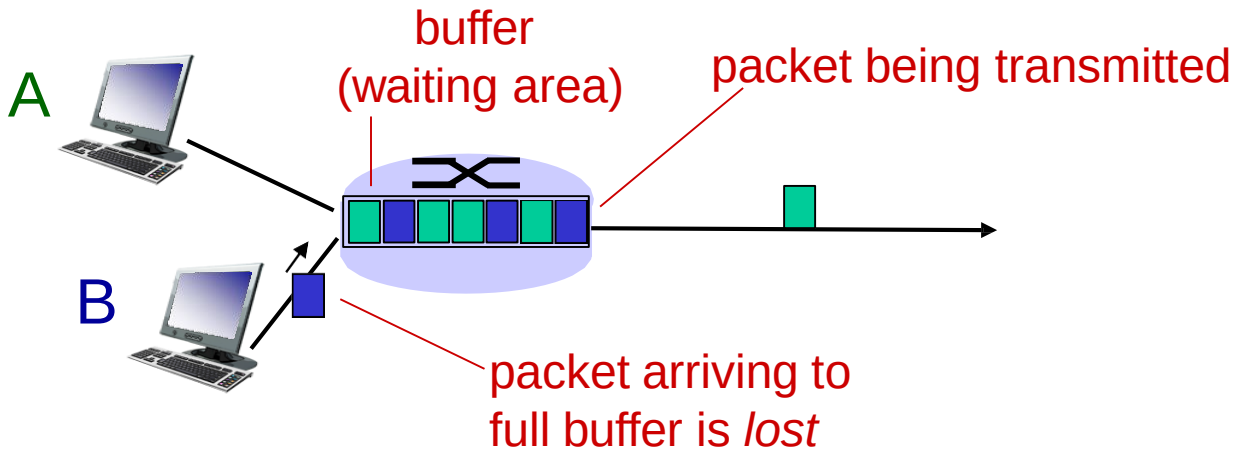
trans-oceanic link

* means no response (probe lost, router not replying)

* Do some traceroutes from exotic countries at www.traceroute.org

Packet loss

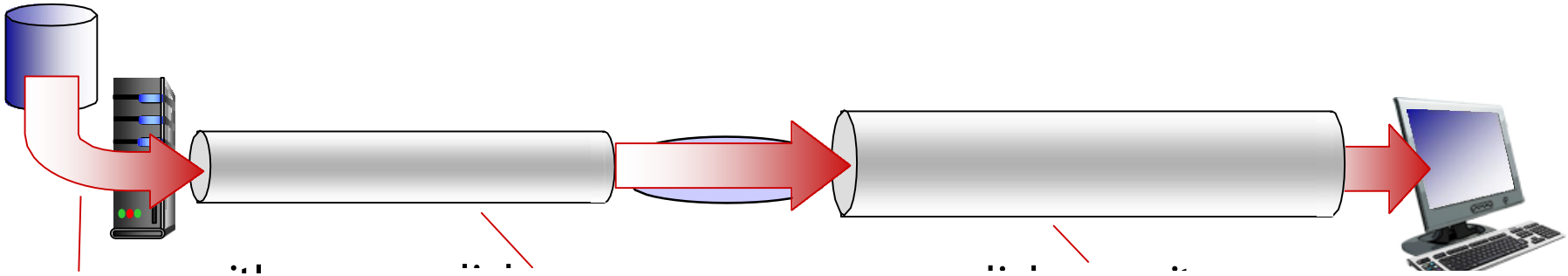
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



* Check out the Java applet for an interactive animation on queuing and loss

Throughput

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



Chapter 1: roadmap

1. what *is* the Internet?
2. network edge
   - end systems, access networks, links
3. network core
   - packet switching, circuit switching, network structure
4. delay, loss, throughput in networks
5. protocol layers, service models
6. networks under attack: security
7. history

Protocol "layers"

Networks are complex, with many "pieces":

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

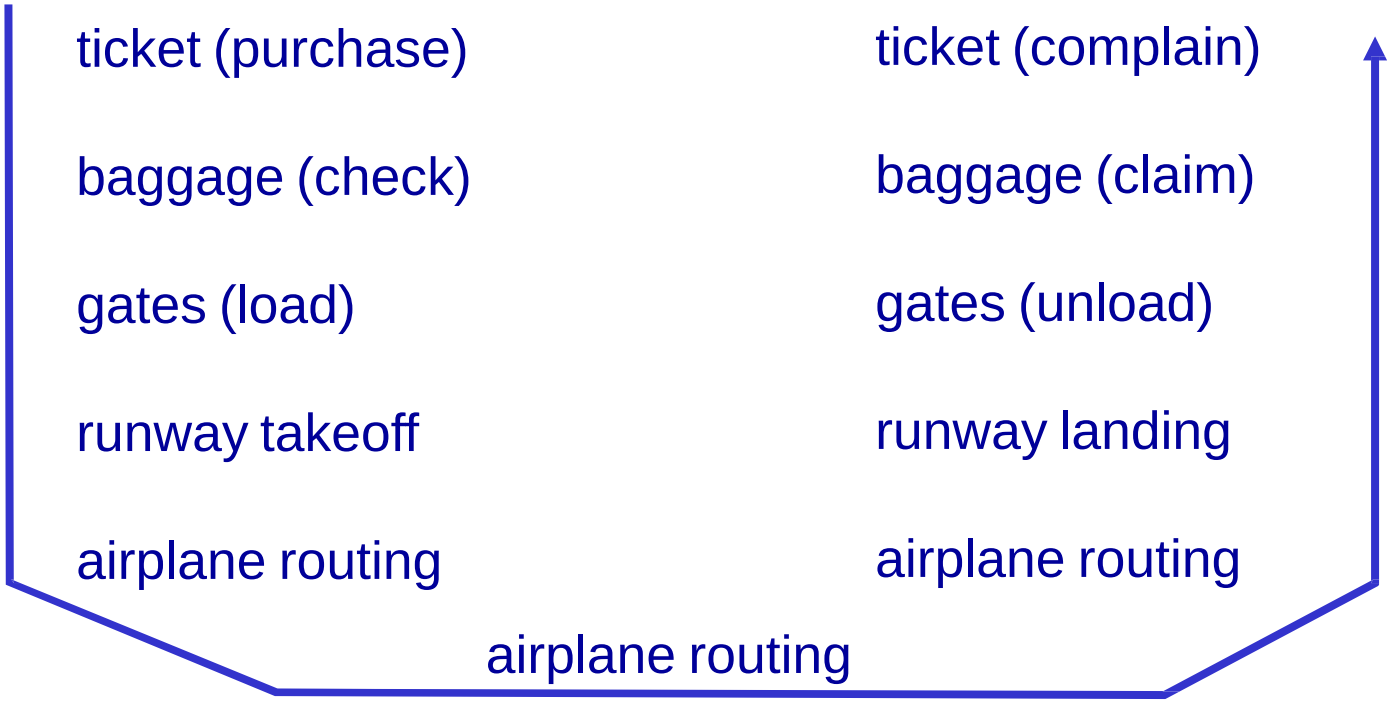
, software

Question:

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

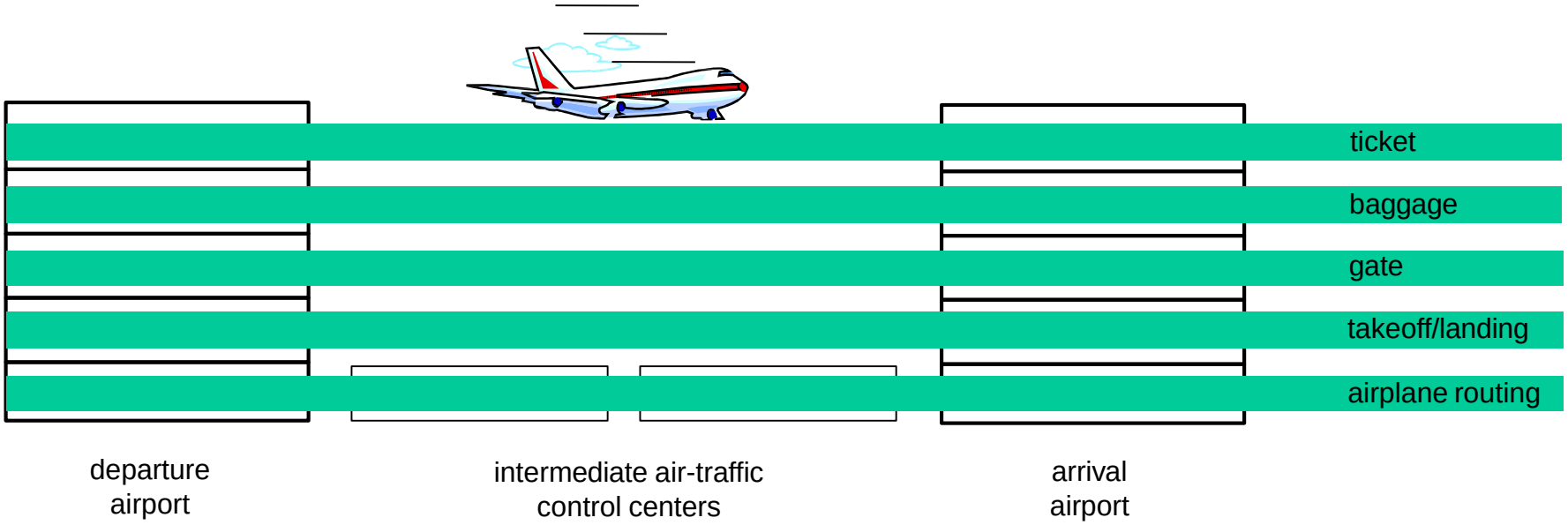
.... or at least our discussion of networks?

Organization of air travel



- a series of steps

Layering of airline functionality



layers: each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below

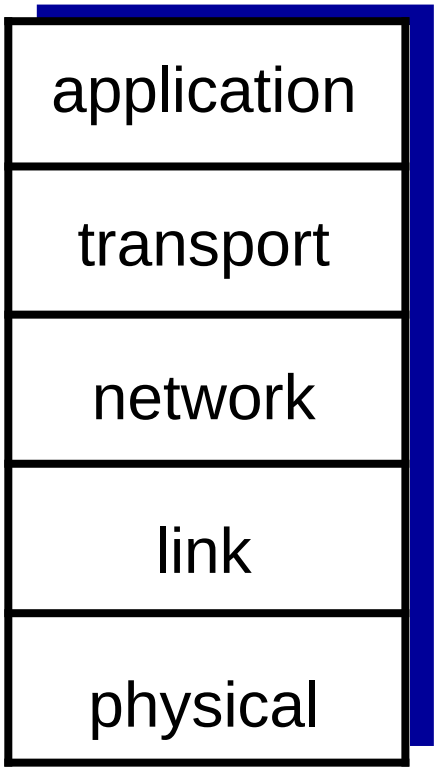
Why layering?

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

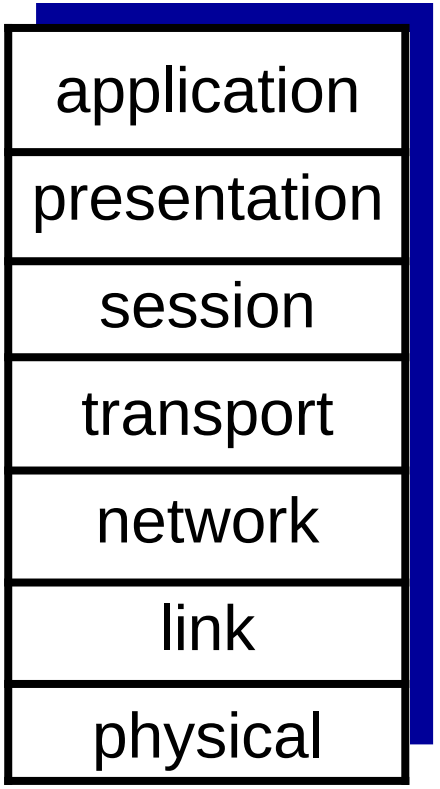
Internet protocol stack

- *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, 802.11 (WiFi), PPP
- *physical:* bits "on the wire"

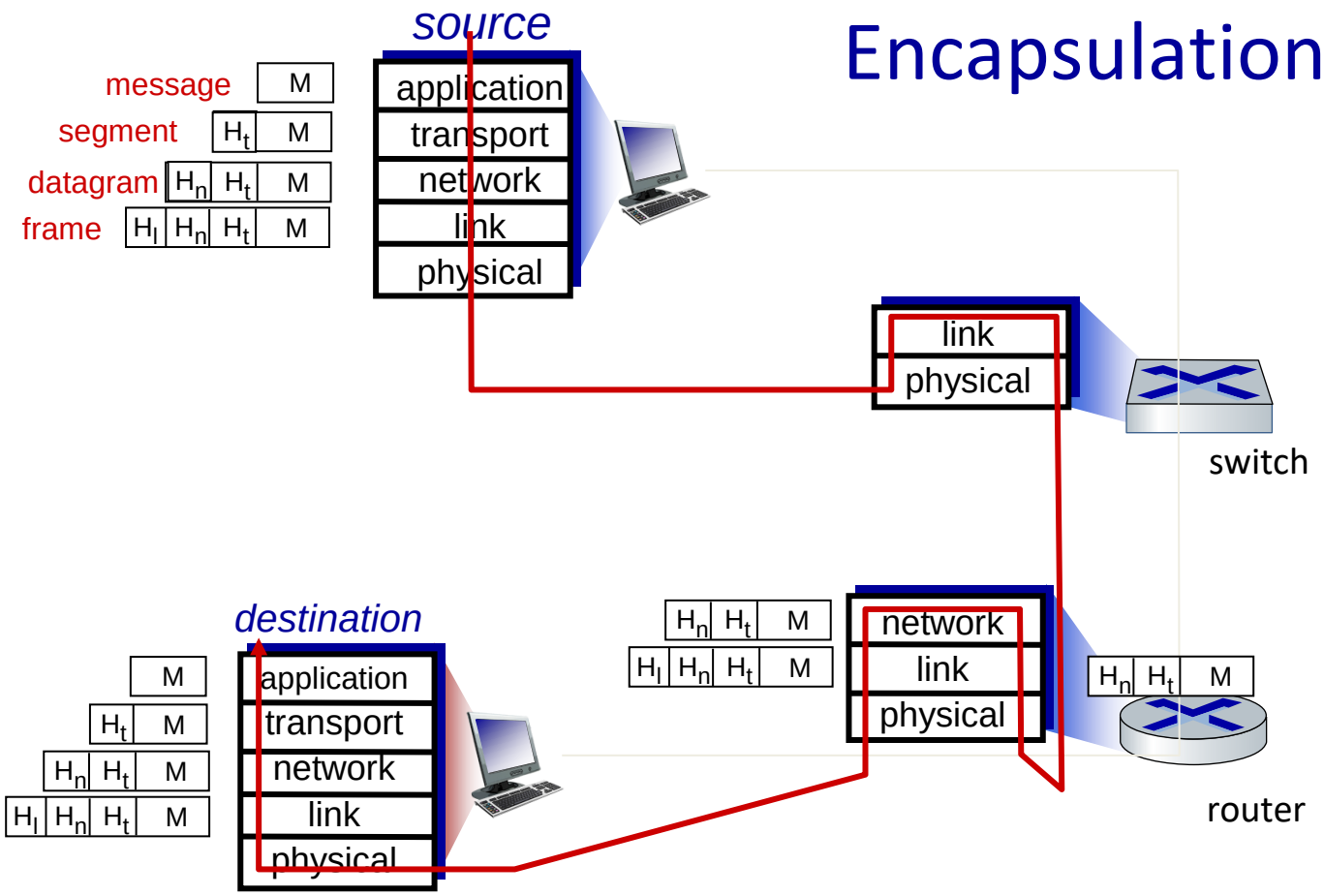


ISO/OSI reference model

- *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session:* synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed*, must be implemented in application
  - needed?



Encapsulation



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Network security

- field of network security:
  - how bad guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks
- Internet not originally designed with (much) security in mind
  - *original vision*: "a group of mutually trusting users attached to a transparent network" ☺
  - Internet protocol designers playing "catch-up"
  - security considerations in all layers!

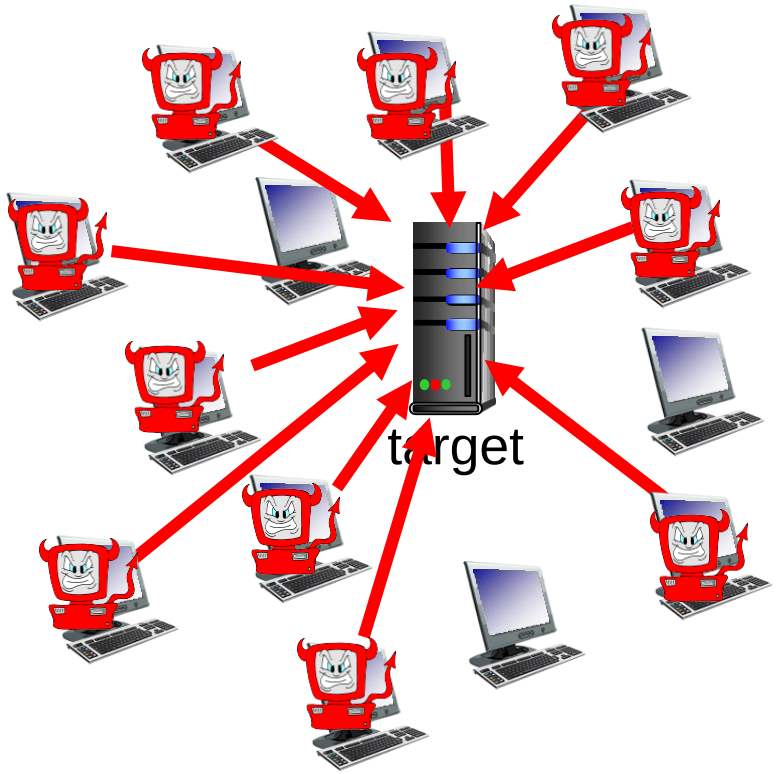
Bad guys: put malware into hosts via Internet

- malware can get in host from:
  - *virus:* self-replicating infection by receiving/executing object (e.g., e-mail attachment)
  - *worm:* self-replicating infection by passively receiving object that gets itself executed
- spyware malware can record keystrokes, web sites visited, upload info to collection site
- infected host can be enrolled in botnet, used for spam. D D o S attacks

Bad guys: attack server, network infrastructure

Denial of Service (DoS): attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

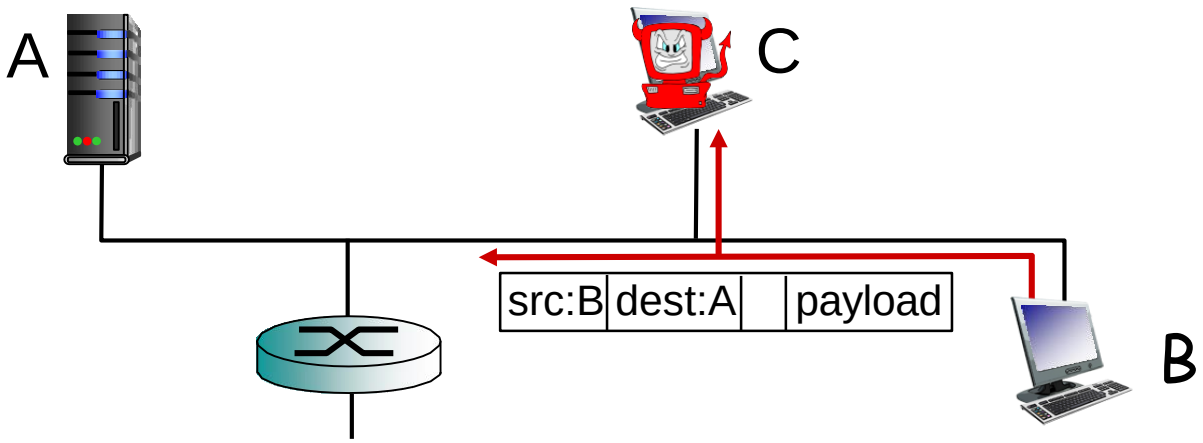
1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts



Bad guys can sniff packets

packet "sniffing":

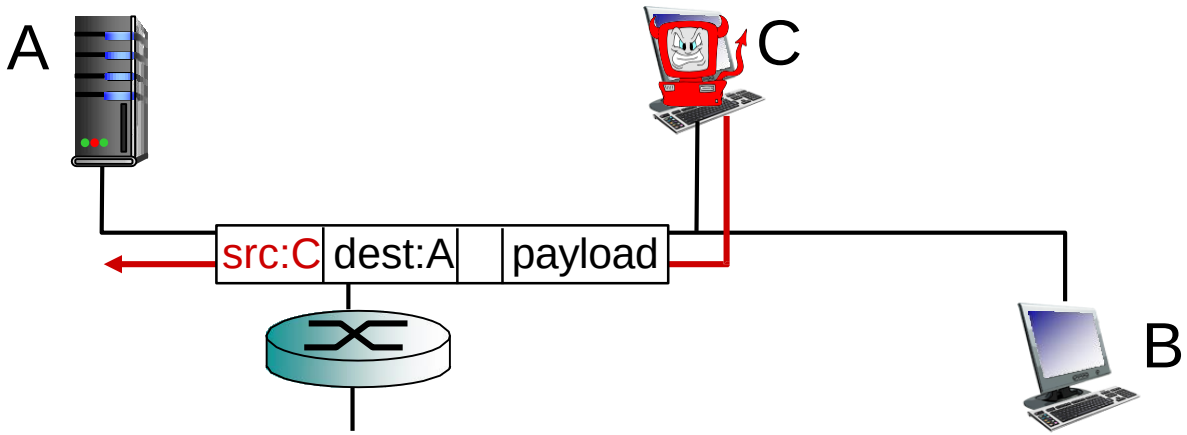
- broadcast media (shared ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



- wireshark software used for end-of-chapter labs is a (free) packet-sniffer

Bad guys can use fake addresses

IP spoofing: send packet with false source address



… *lots more on security (throughout, Chapter 8)*

Introduction: summary

covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
  - Internet structure
- performance: loss, delay, throughput
- layering, service models
- security
- history

you now have:

- context, overview, "feel" of networking
- more depth, detail *to follow!*