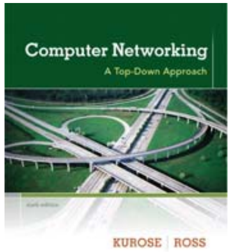
Chapter 1
Introduction



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

Chapter 1: introduction

our goal:

- get "feel" and terminology
- more depth, detail *later* in course
- approach:
  - use Internet as example

overview:

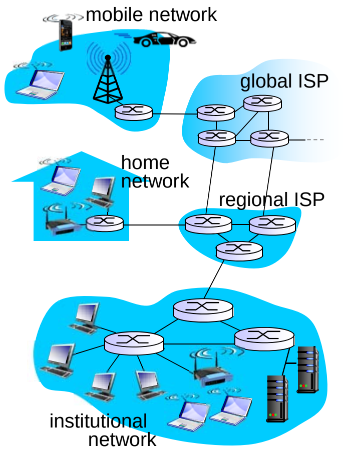
- what's the Internet?
- what's a protocol?
- network edge; hosts, access net, physical media
- network core: packet/circuit switching, Internet structure
- performance: loss, delay, throughput
- security
- protocol layers, service models
- history

Chapter 1: roadmap

- 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

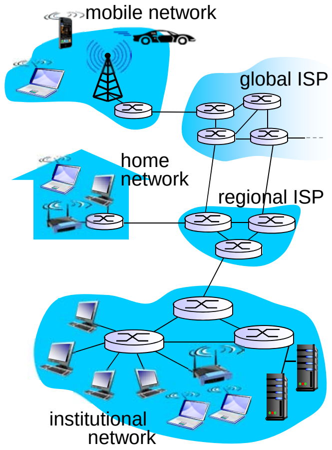
What's the Internet: "nuts and bolts" view

- millions of connected computing devices:
    - *hosts = end systems*
    - running *network apps*
- *communication links*
    - fiber, copper, radio, satellite
    - transmission rate: *bandwidth*
- *Packet switches:* forward packets (chunks of data)
    - *routers* and *switches*



What’s the Internet: a service view

- *Infrastructure that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social nets, …
- *provides programming interface to apps*
  - hooks that allow sending and receiving app programs to “connect” to Internet
  - provides service options, analogous to postal service
- *Internet:* “network of networks”
  - Interconnected ISPs



“Fun” internet appliances


IP picture frame
http://www.ceiva.com/


Web-enabled toaster +
weather forecaster


Tweet-a-watt:
monitor energy use


Internet
refrigerator


Slingbox: watch,
control cable TV remotely


Internet phones

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 communication activity in Internet governed by protocols

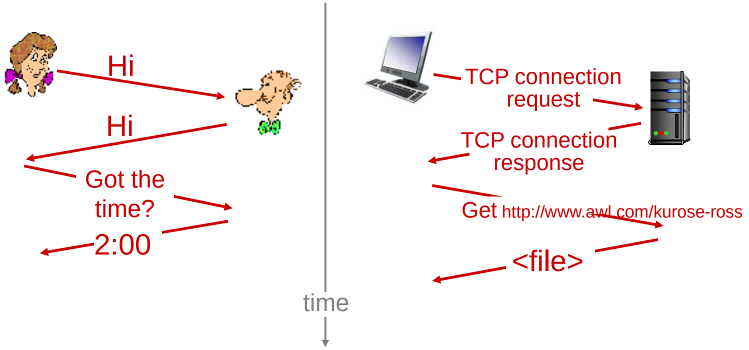
> *protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt*

Internet communication:

- *protocols* control sending, receiving of msgs
  e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  RFC: Request for comments
  IETF: Internet Engineering Task Force

What’s a protocol?

a human protocol and a computer network protocol:



Hi

Hi

Got the time?

2:00

TCP connection request

TCP connection response

Get http://www.awl.com/kurose-ross

<file>

time

Q: other human protocols?

Chapter 1: roadmap

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

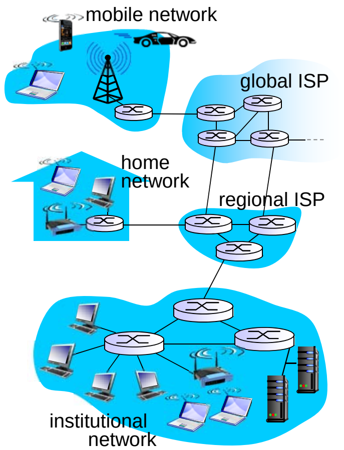
1.5 protocol layers, service models

1.6 networks under attack: security

1.7 history

A closer look at network 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



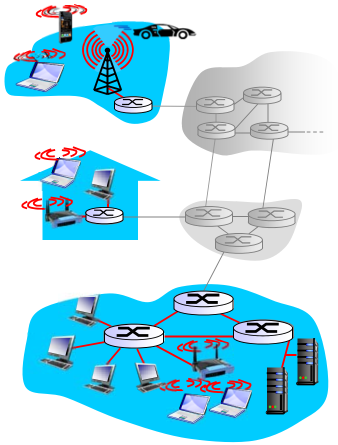
Access networks and physical media

Q: How to connect end systems to edge router?

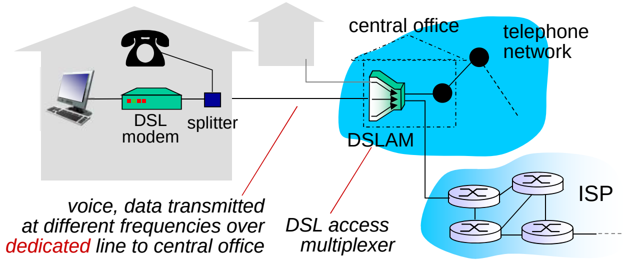
- residential access nets
- institutional access networks (school, company)
- mobile access networks

keep in mind:

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

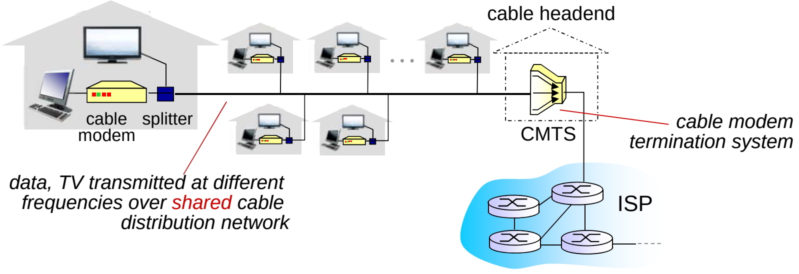


Access net: digital subscriber line (DSL)



- 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)

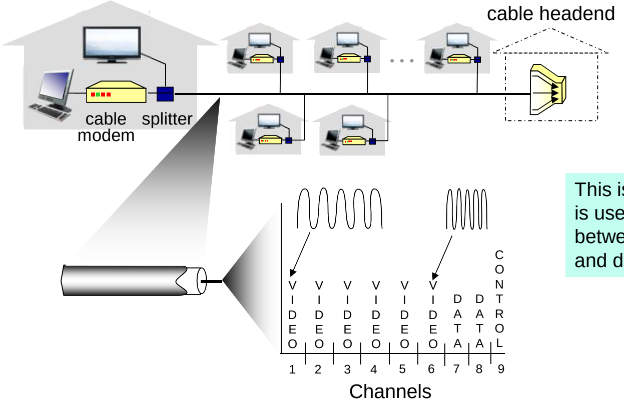
Access net: cable network



data, TV transmitted at different frequencies over shared cable distribution network

- **HFC: hybrid fiber coax**
  - asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- **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

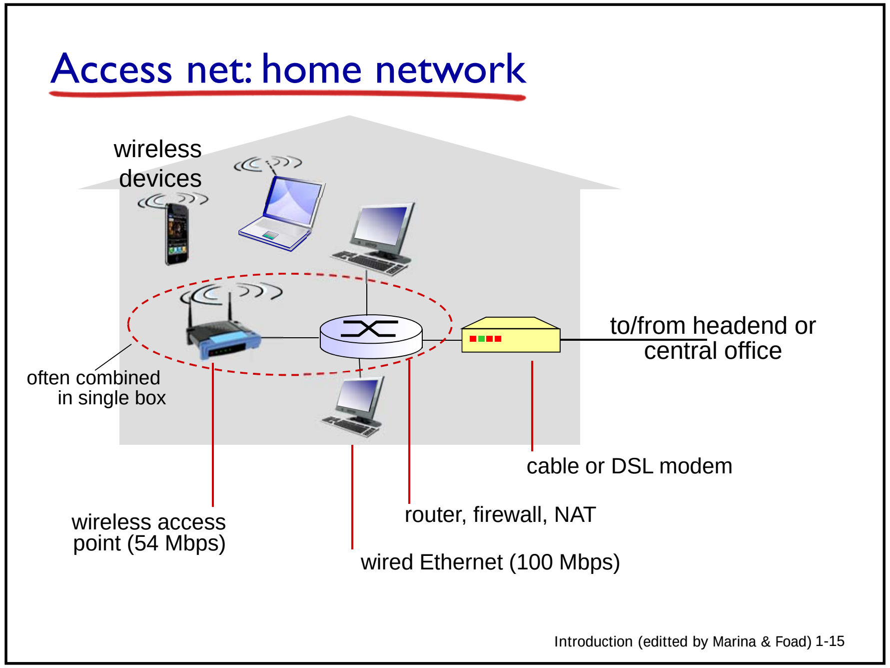
Access net: cable network



This is where the splitter is usefull – to split between voice (phone) and data (computer)

frequency division multiplexing:

- different channels transmitted in different frequency bands



Access net: home network

wireless devices

often combined in single box

to/from headend or central office

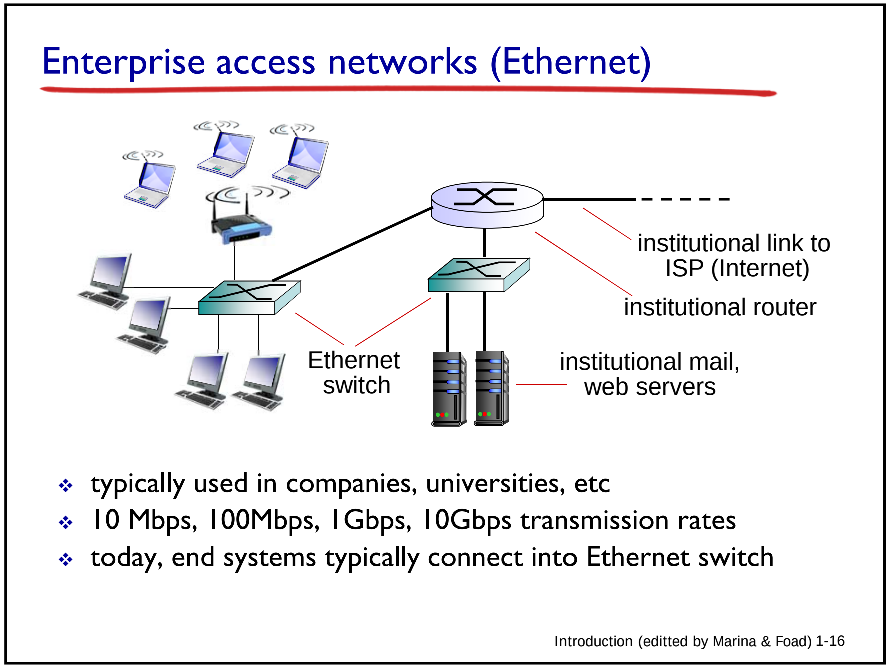
cable or DSL modem

router, firewall, NAT

wireless access point (54 Mbps)

wired Ethernet (100 Mbps)

Introduction (editted by Marina & Foad) 1-15



Enterprise access networks (Ethernet)

institutional link to ISP (Internet)

institutional router

Ethernet switch

institutional mail, web servers

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

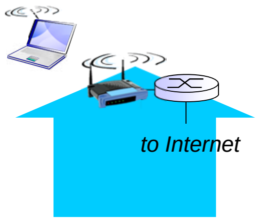
Introduction (editted by Marina & Foad) 1-16

Wireless access networks

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

wireless LANs:

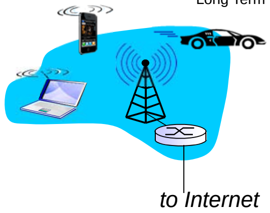
- within building (100 ft)
- 802.11b/g (WiFi): 11, 54 Mbps transmission rate



wide-area wireless access

- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G (e.g. 7.2Mbps), 4G: LTE (e.g. 326Mbps)

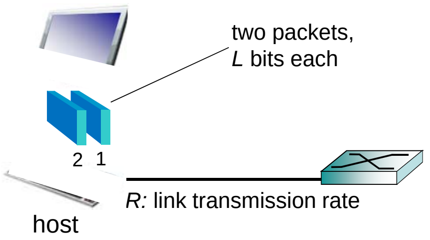
Long Term Evolution



Host: sends *packets* of data

host sending function:

- takes application message
- breaks into smaller chunks, known as *packets*, of length *L* bits (e.g. 1KB=1024 bit)
- transmits packet into access network at *transmission rate R* (e.g 1Mbps)
  - link transmission rate, aka link *capacity, aka link bandwidth*



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

Example L=30Mbit, R=10Mbps, trans packet delay = L/R = 30M/10Mbps = 3s

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

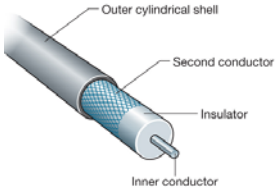
twisted pair (TP)

- two insulated copper wires
  - Category 5: 100 Mbps, 1 Gpbs Ethernet
  - Category 6: 10Gbps

Physical media: coax, fiber

coaxial cable:

- two concentric copper conductors
- bidirectional
- 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 Gpbs transmission rate)
- 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: ~ few Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

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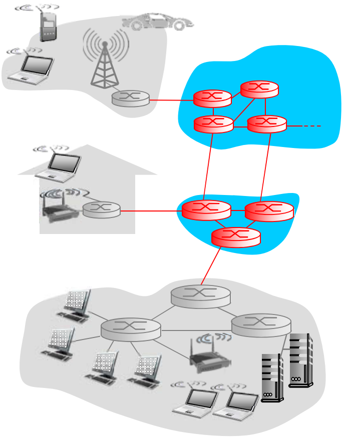
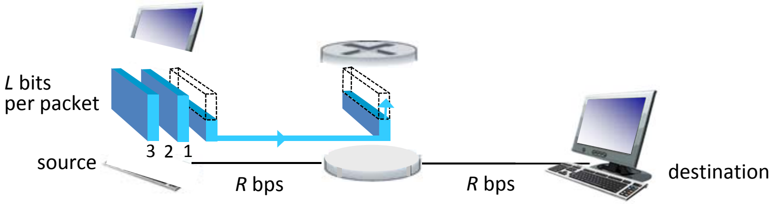
The network core

- mesh of interconnected routers
- 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



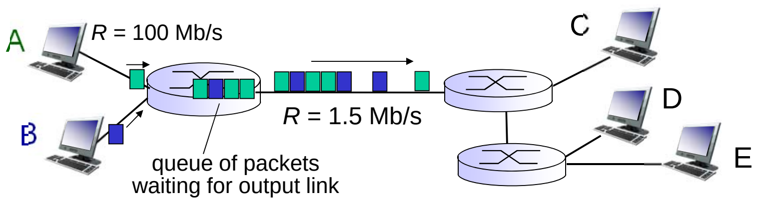
- takes *L*/*R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- end-end delay = 2*L*/*R* (assuming zero propagation delay)

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

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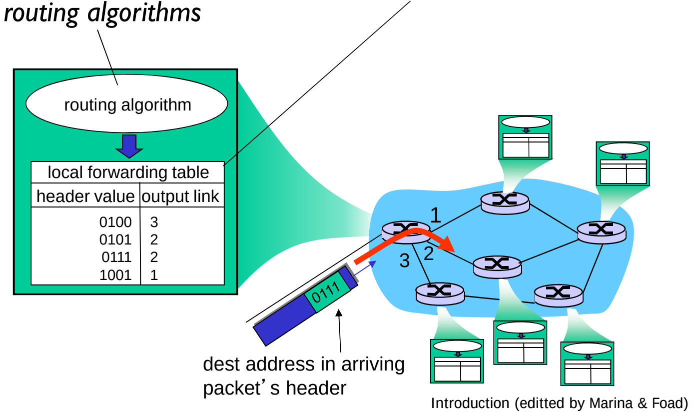
Two key network-core functions

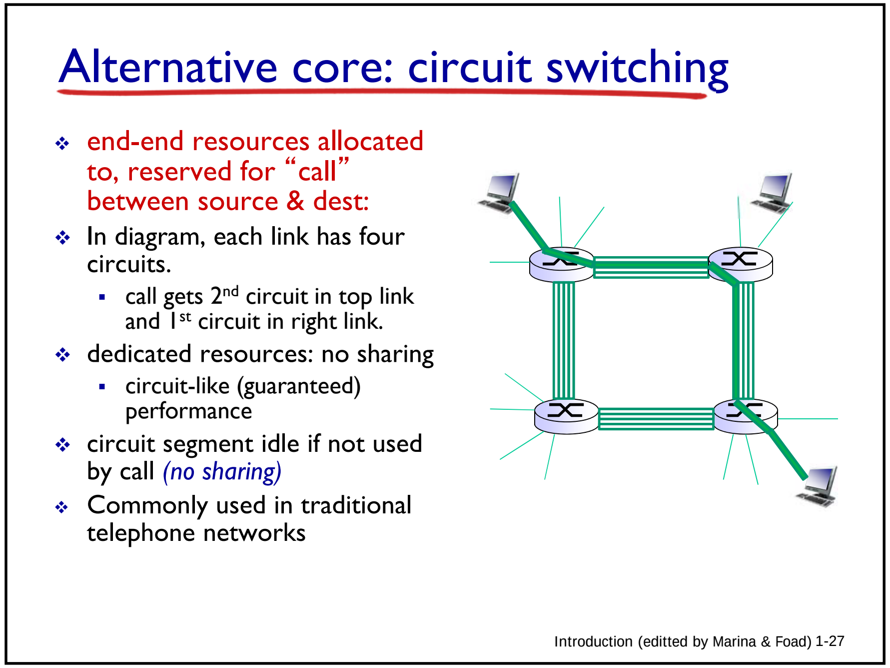
routing: determines source-destination route taken by packets

- *routing algorithms*

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

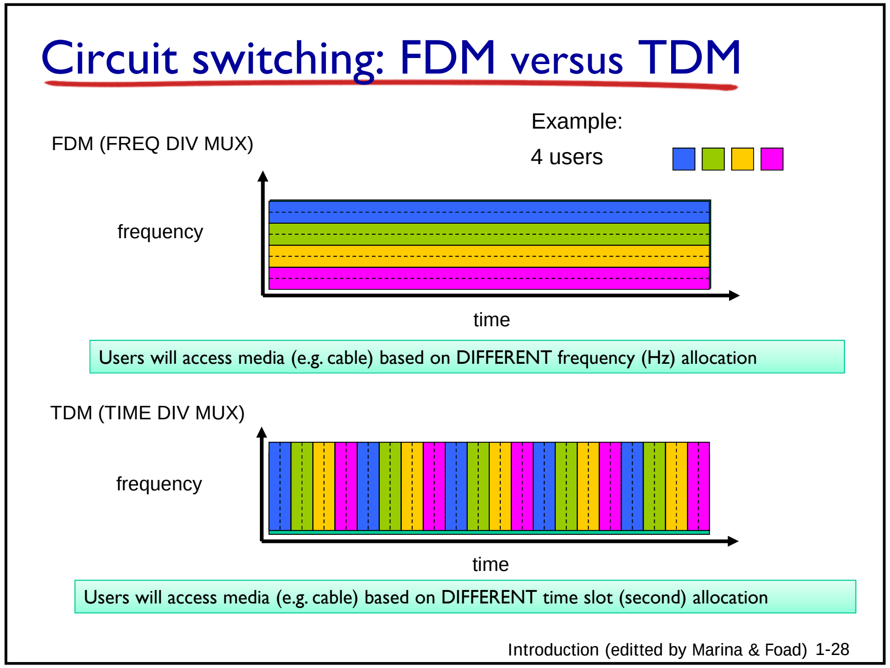


header value	output link
0100	3
0101	2
0111	2
1001	1



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

Users will access media (e.g. cable) based on DIFFERENT frequency (Hz) allocation

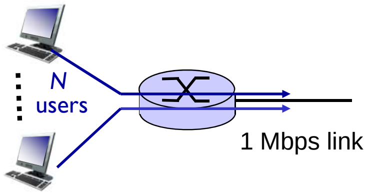
Users will access media (e.g. cable) based on DIFFERENT time slot (second) allocation

Packet switching versus circuit switching

packet switching allows more users to use network!

example:

- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time



- *circuit-switching:*
  - 10 users
- *packet switching:*
  - with 35 users, probability > 10 active at same time is less than .0004 *

Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

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 (chapter 7)

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

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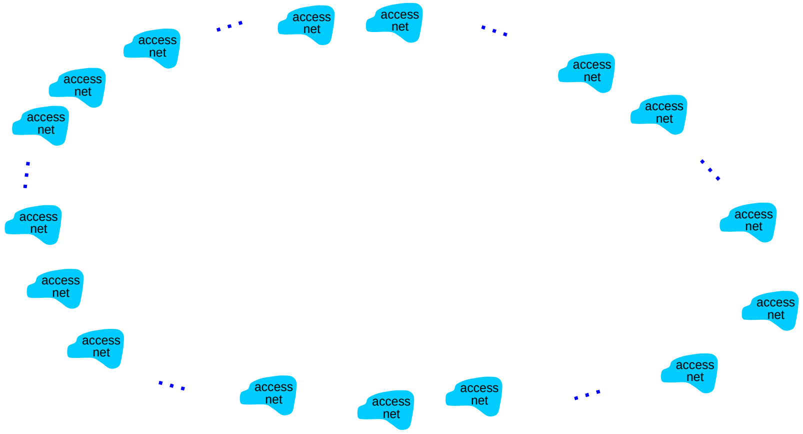
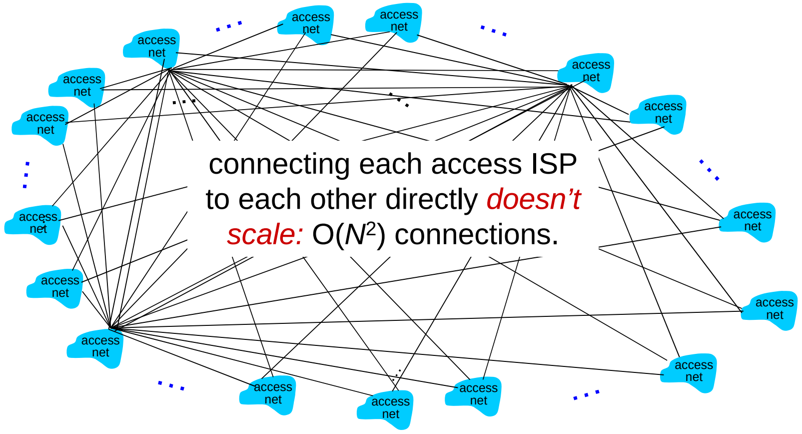
Internet structure: network of networks

Question: given *millions* of access ISPs, how to connect them together?



Internet structure: network of networks

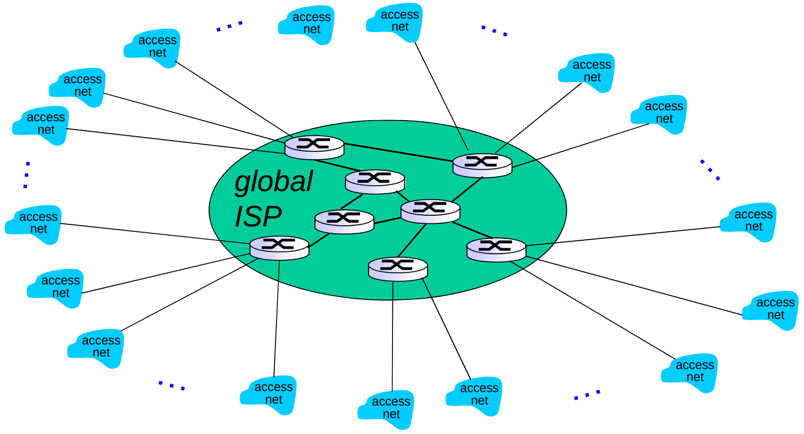
Option: connect each access ISP to every other access ISP?

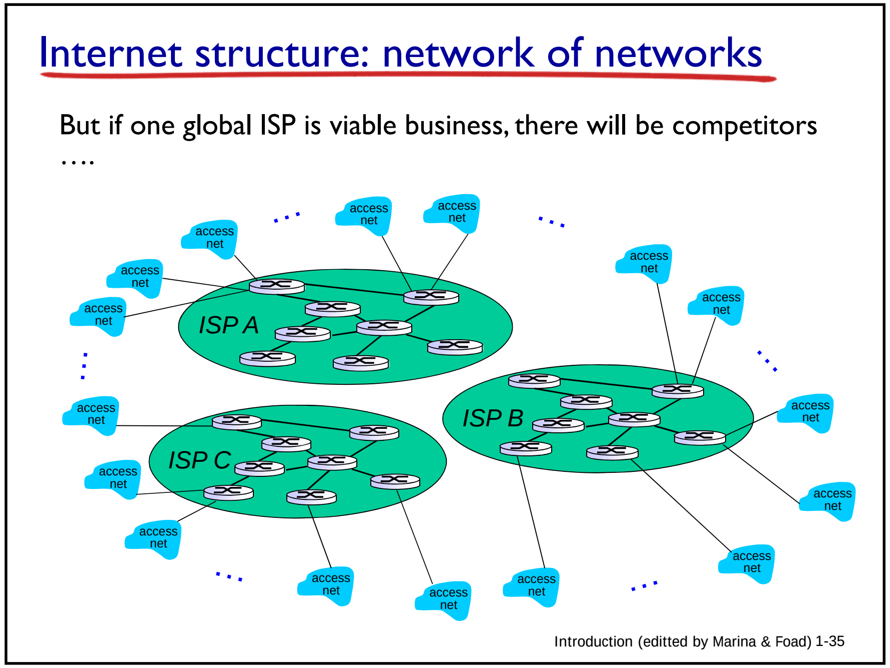


connecting each access ISP to each other directly *doesn't scale:* O(N^2) connections.

Internet structure: network of networks

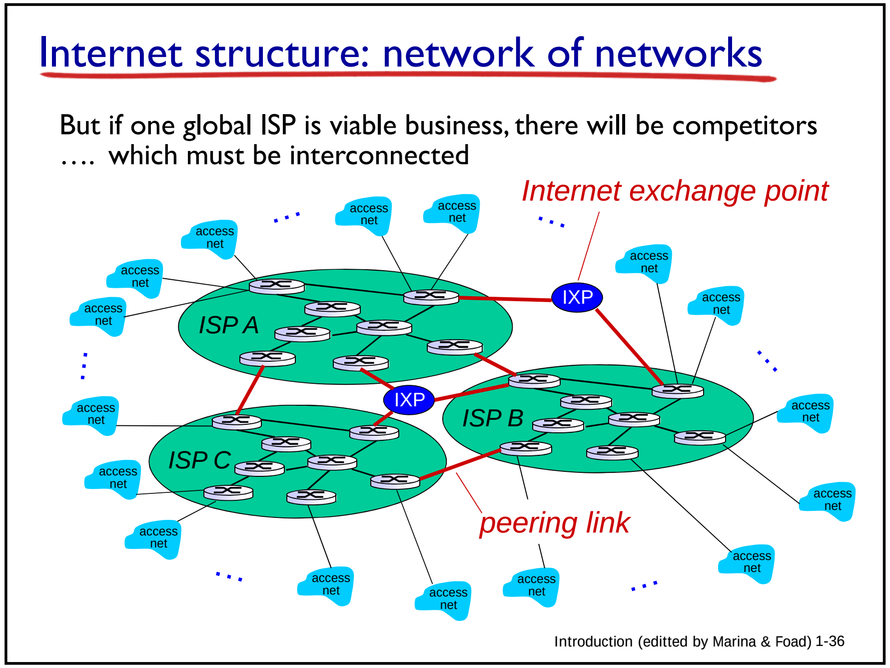
Option: connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.





Internet structure: network of networks

But if one global ISP is viable business, there will be competitors ….

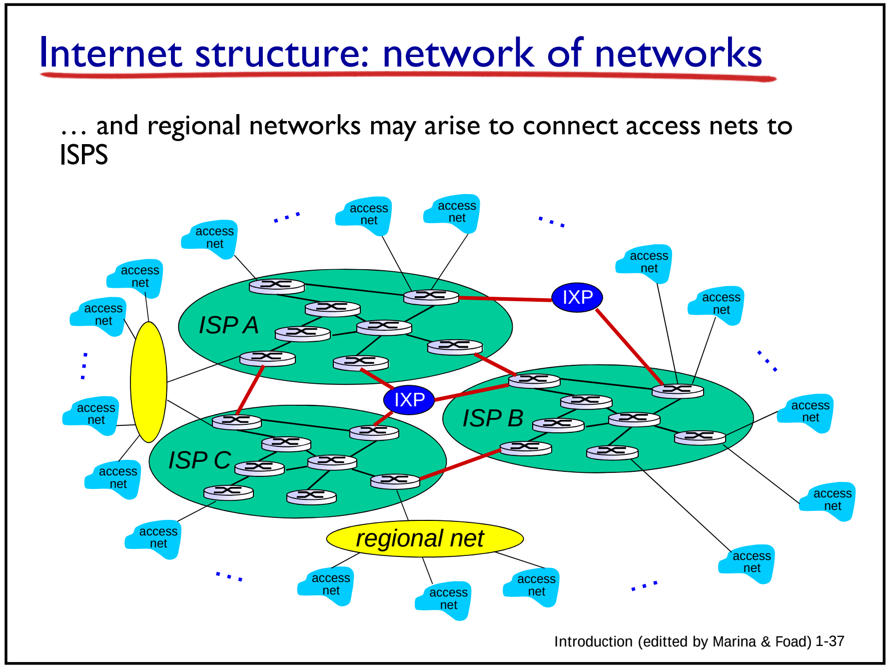


Internet structure: network of networks

But if one global ISP is viable business, there will be competitors …. which must be interconnected

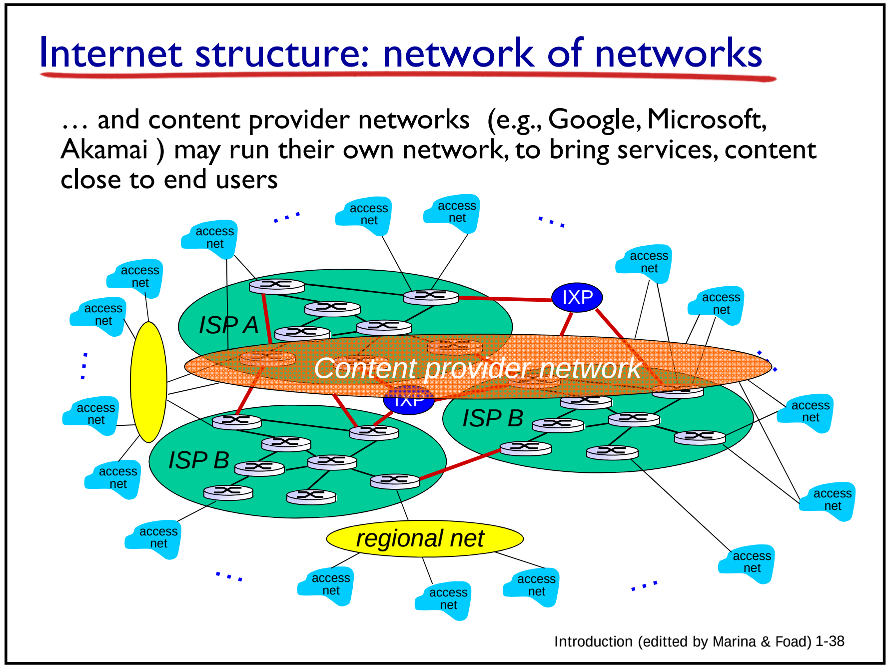
Internet exchange point

peering link



Internet structure: network of networks

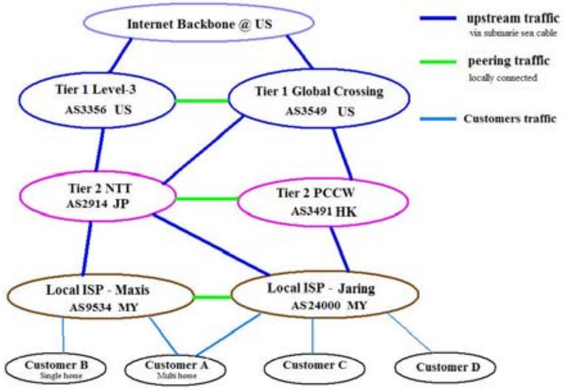
… and regional networks may arise to connect access nets to ISPS



Internet structure: network of networks

… and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users

Internet structure: network of networks



- at center: small # 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): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs
  - Example ISP list in Malaysia: List , Service Offer , Service Cost

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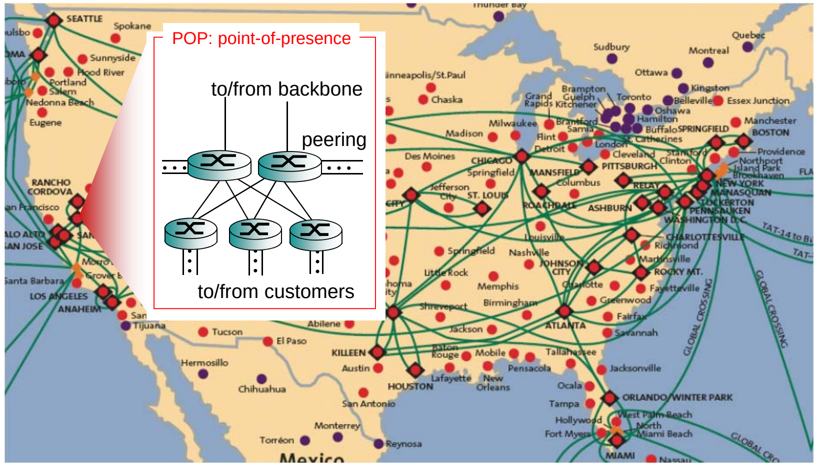
Tier-1 ISP: e.g., Sprint



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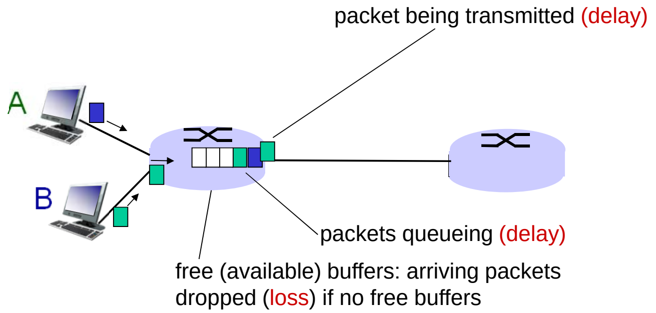
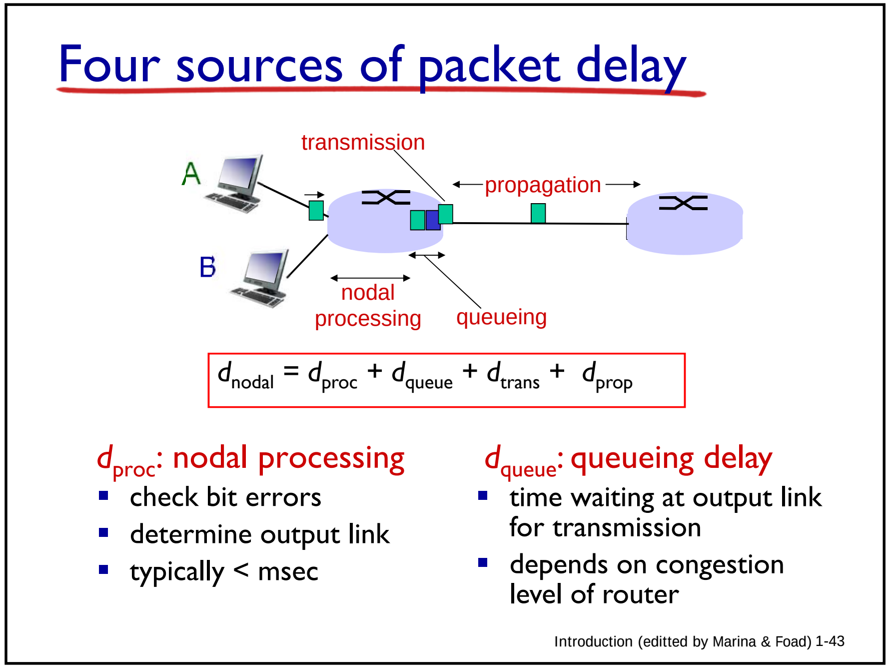
How do loss and delay occur?

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

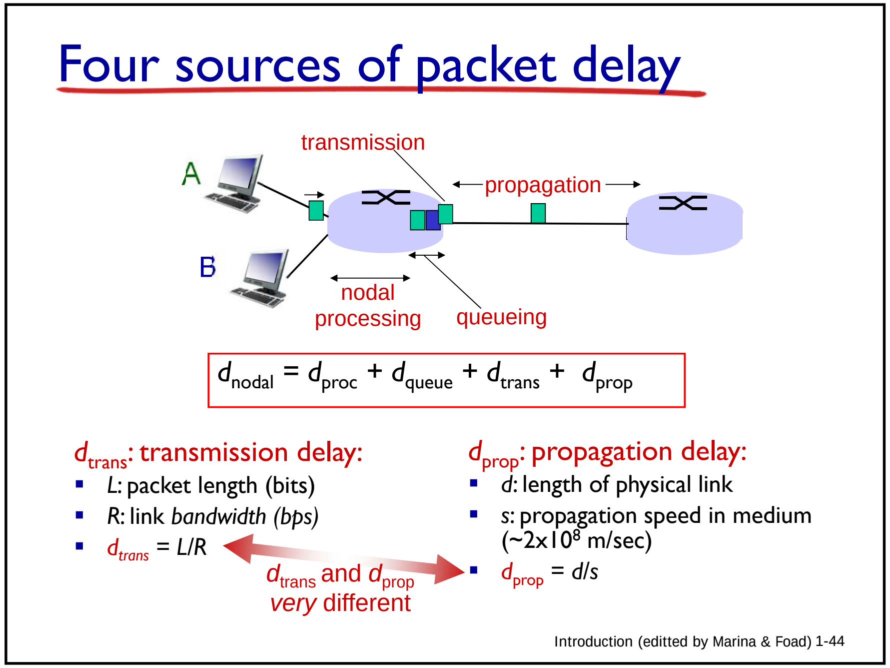
$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

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

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

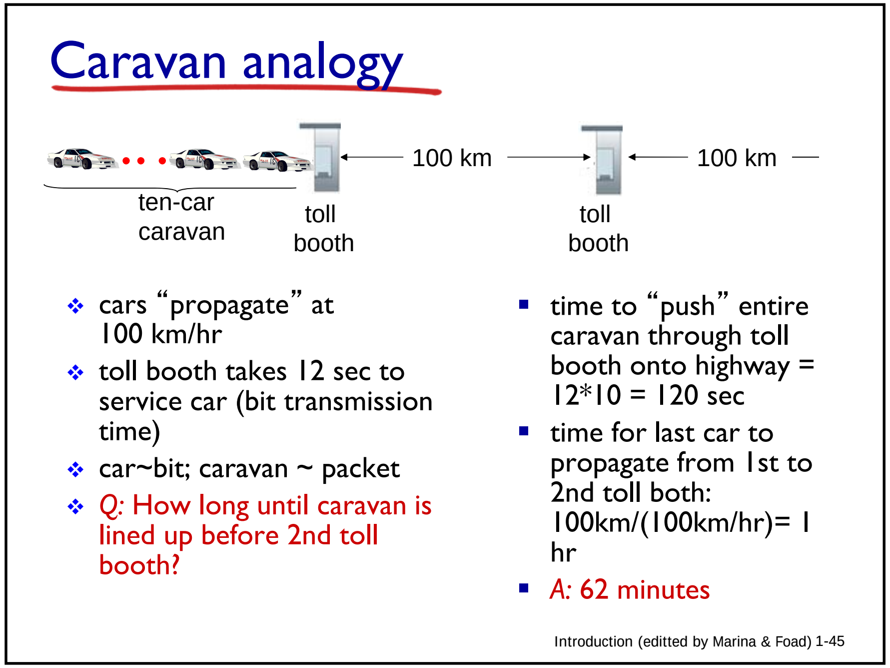
d_{trans}: transmission delay:

- *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 ($\sim 2\text{x}10^8$ m/sec)
- $d_{\text{prop}} = d/s$

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



Caravan analogy

ten-car caravan

toll booth

100 km

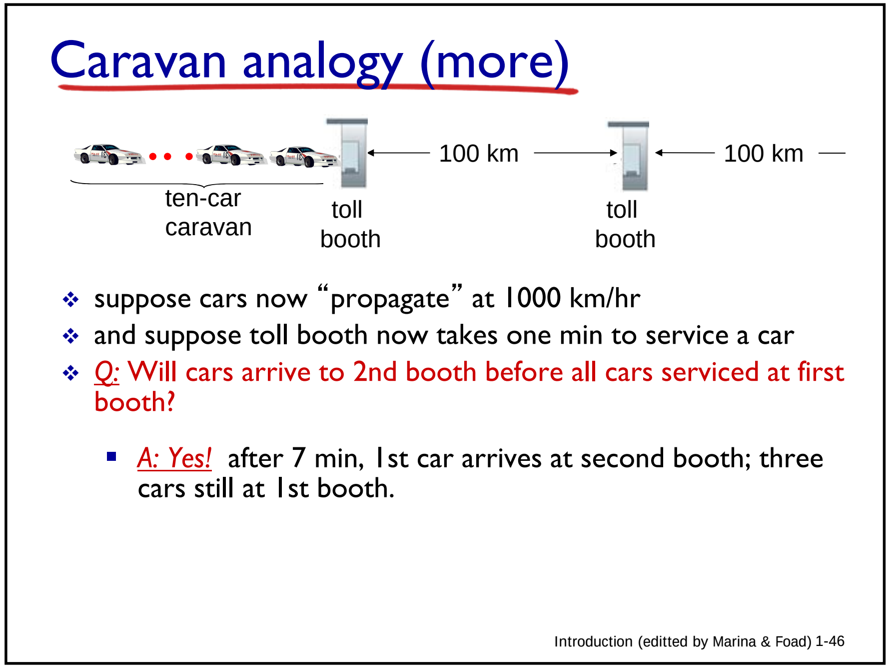
toll booth

100 km

- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (bit 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
- time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr
- *A:* 62 minutes

Introduction (editted by Marina & Foad) 1-45



Caravan analogy (more)

ten-car caravan

toll booth

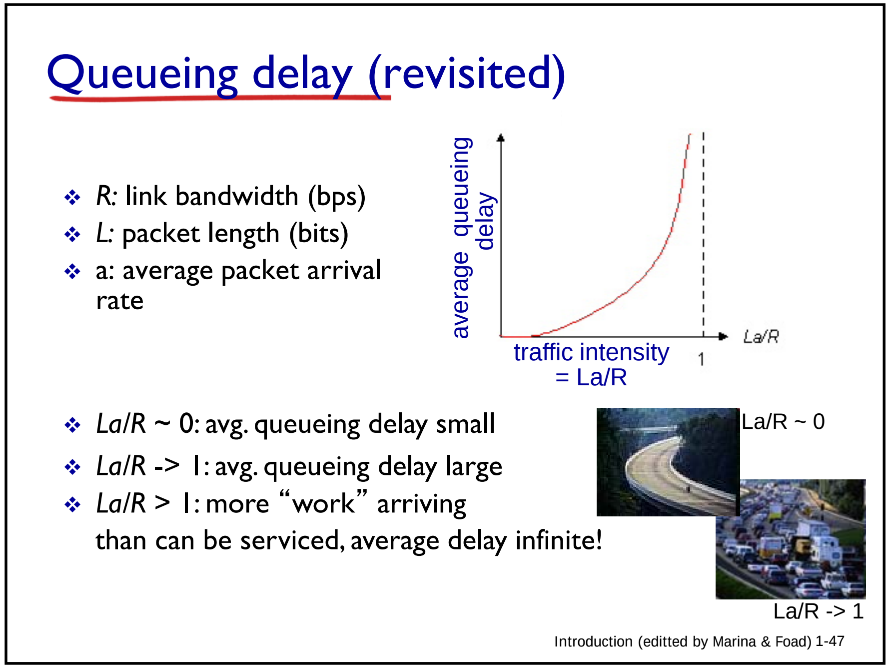
100 km

toll booth

100 km

- suppose cars now "propagate" at 1000 km/hr
- and suppose toll booth now takes one min to service a car
- *Q:* Will cars arrive to 2nd booth before all cars serviced at first booth?
  - *A: Yes!* after 7 min, 1st car arrives at second booth; three cars still at 1st booth.

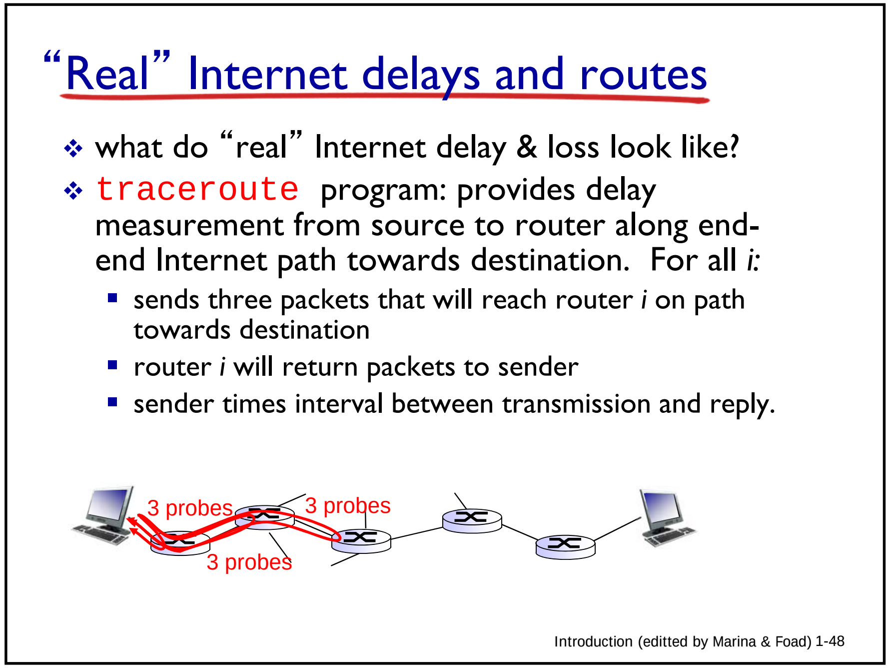
Introduction (editted by Marina & Foad) 1-46



Queueing delay (revisited)

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

- *La/R* ~ 0: avg. queueing delay small
- *La/R* -> 1: avg. queueing delay large
- *La/R* > 1: more “work” arriving than can be serviced, average delay infinite!



“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
7  nycm-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
```

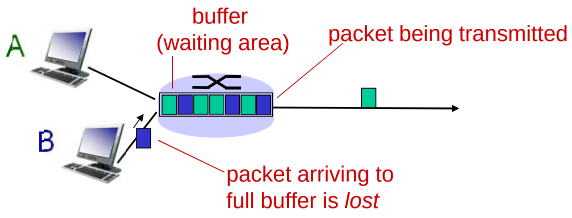
trans-oceanic link

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

* Do some traceroutes at www.traceroute.org

Packet loss

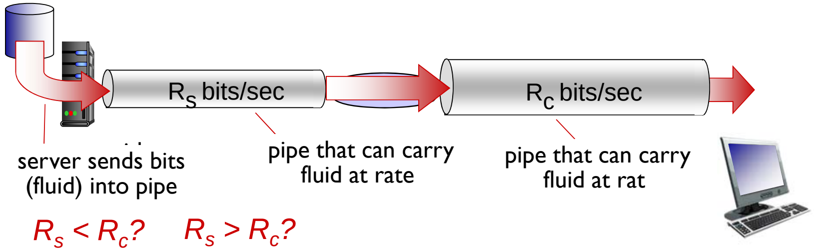
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



* Check out the Java applet 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



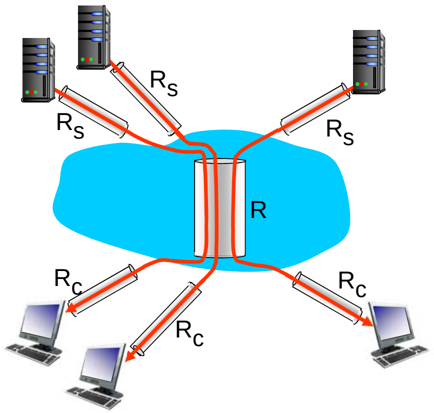
$R_s < R_c$? *$R_s > R_c$?*

bottleneck link

link on end-end path that constrains end-end throughput

Throughput: Internet scenario

- per-connection end-end throughput: $\min(R_c, R_s, R/10)$
- in practice: R_c or R_s is often bottleneck



10 connections (fairly) share backbone bottleneck link R bits/sec

Calculation: Example 1

Suppose Host A wants to send a large file to Host B. The path from Host A to Host B has 3-links, of rate R_1=150kbps, R_2=2Mbps, and R_3=1Mbps.

i) Assuming no other traffic in the network, what is the throughput for the file transfer? Justify your answer. [2 mark]

Throughput = min(R)=150 kbps

ii) Suppose the file is 4 million bytes. Roughly, how long will it take to transfer the file to Host B? [5 marks]

Time transfer=$4*10^6*8/(150*10^3)$=213.3 seconds

Calculation: Example 2

Host A wants to send a 30-Mbit MP3 file to host B. All the links in the path between source and destination have a transmission rate of 10Mbps. Assume that the propagation speed is $2*10^8$ meters/sec, and the distance between source and destination is 10km. Initially suppose there is only one link between the source and the destination. Also suppose that the entire MP3 file is sent as one packet (Ignore processing delay and queuing delay). Show your workings.

i) Calculate the transmission delay?

transmission delay = L/R = 30M/10Mbps = 3s

ii) What will be the end-to-end delay?

$D_{prob} = d/s = 10000/2*10^8 = 0.00005$

D_{total} = 3+0.05 = 3. 00005s

iii) How many bits will the source have transmitted when the first bit of the MP3 file arrives at the destination?

R* D_{prob} = 10Mbps*0.00005s=500bit

Chapter 1: roadmap

1.1 what *is* the Internet?

1.2 network edge

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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":

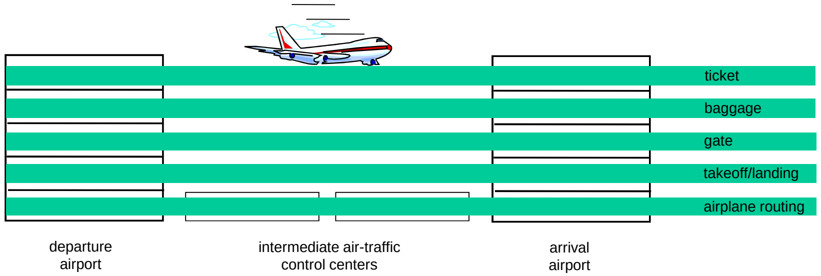
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

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

…. or at least our discussion of networks?

Layering of airline functionality



- a series of steps

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
- layering considered harmful?

ISO/OSI reference model

O*pen* ***S****ystem* ***I****nterconnection (OSI)* model defines a **generic** networking framework to implement protocols in seven (7) layers

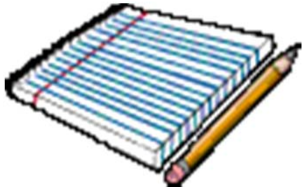
Generic OSI Model

	Data unit	Layer	Function
Host layers	Data	7. Application	Network process to application
		6. Presentation	allow applications to interpret meaning of data, e.g. data representation, encryption and decryption, convert machine dependent data to machine independent data
		5. Session	Interhost communication, managing sessions between applications, synchronization, data recovery
	Segments	4. Transport	Reliable delivery of packets between points on a network.
Media layers	Packet/Datagram	3. Network	Addressing, routing and (not necessarily reliable) delivery of datagrams between points on a network.
	Bit/Frame	2. Data link	A reliable direct point-to-point data connection.
	Bit	1. Physical	A (not necessarily reliable) direct point-to-point data connection.

OSI Model: AN Analogy: Application Layer - Source Host

After riding your new bicycle a few times in Tokyo, you decide that you want to give it to a friend who studies in UTM, JB.

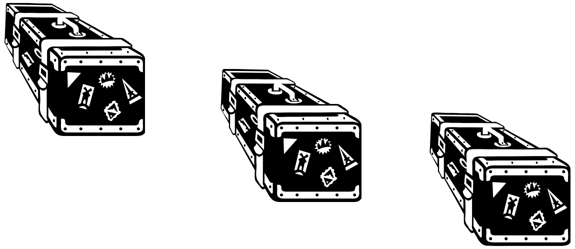
Presentation & SESSION Layer - Source Host



PRESENTATION:
Make sure you have the proper directions to disassemble and reassemble the bicycle.

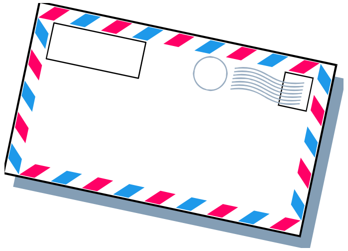
SESSION:
Call your friend and make sure you have his correct address.

OSI Model Analogy :Transport Layer - Source Host



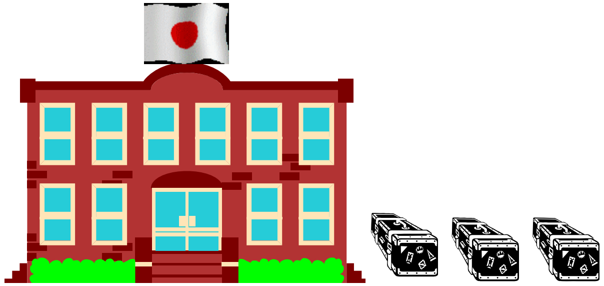
Disassemble the bicycle and put different pieces in different boxes. The boxes are labeled
“1 of 3”, “2 of 3”, and “3 of 3”.

OSI Model Analogy: Network Layer - Source Host

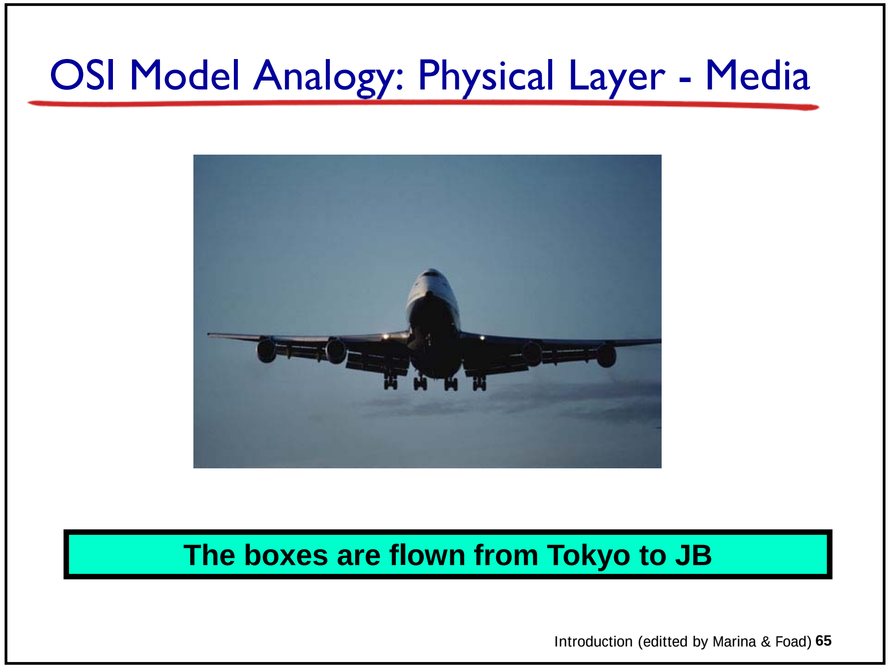


Put your friend's complete mailing address (and yours) on each box. Since the packages are too big for your mailbox (and since you don’t have enough stamps) you determine that you need to go to the post office.

OSI Model Analogy: Data Link Layer – Source Host

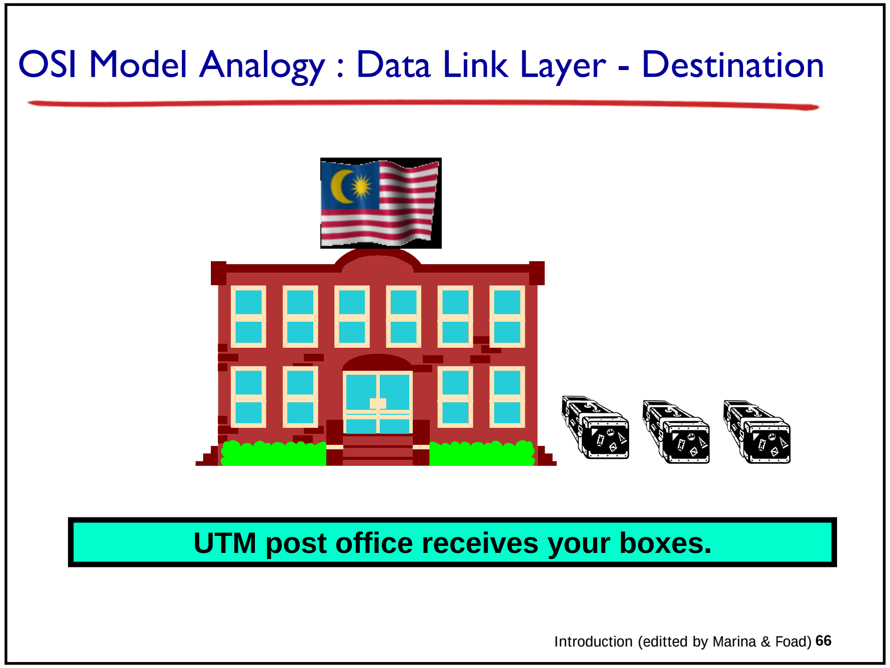


Tokyo post office takes possession of the boxes.



OSI Model Analogy: Physical Layer - Media

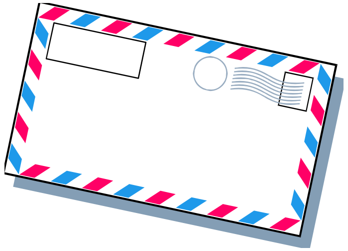
The boxes are flown from Tokyo to JB



OSI Model Analogy : Data Link Layer - Destination

UTM post office receives your boxes.

OSI Model Analogy: Network Layer - Destination



Upon examining the destination address, UTM post office determines that your boxes should be delivered to the written home address.

OSI Model Analogy : Transport Layer - Destination

Your friend calls you and tells you he got all 3 boxes and he is having another friend named FARIS reassemble the bicycle.

Session & PRESENTATION Layer - Destination

SESSION:
Your friend hangs up because he is done talking to you.

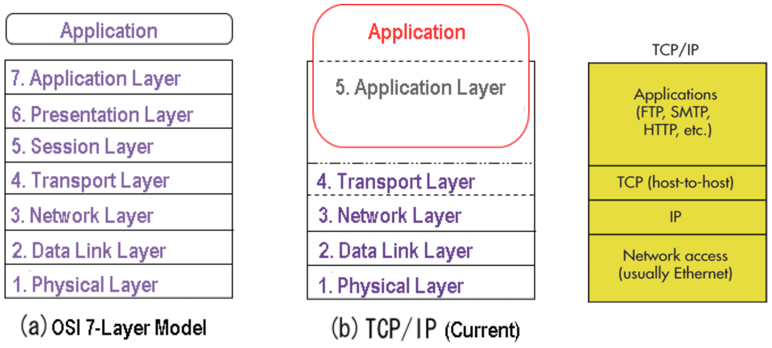
PRESENTATION:
FARIS is finished and "presents" the bicycle to your friend. Another way to say it is that your friend is finally getting his "present".

OSI Model Analogy : Application Layer - Destination

Your friend enjoys riding his new bicycle in UTM.

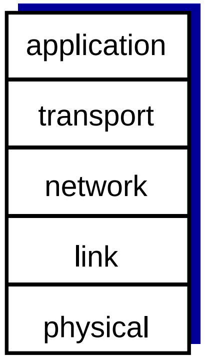
Internet protocol stack (TCP/IP model)

TCP/IP was developed by Advanced Research Projects Agency (ARPA) to build a nationwide packet data network in 1960s. It was first used in UNIX-based computers in universities and government installations. Today, it is the main protocol used in all Internet operations.



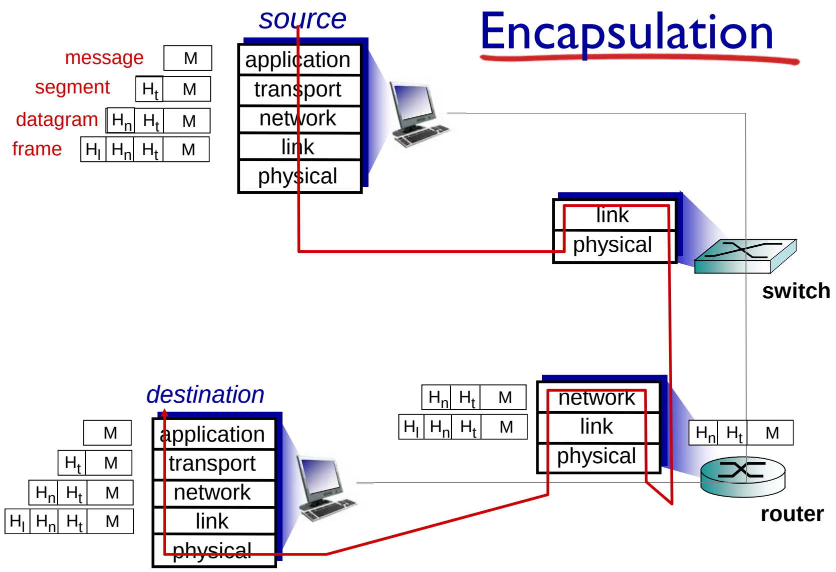
Internet protocol stack

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



TCP/IP Model

Encapsulation



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1.6 networks under attack: security

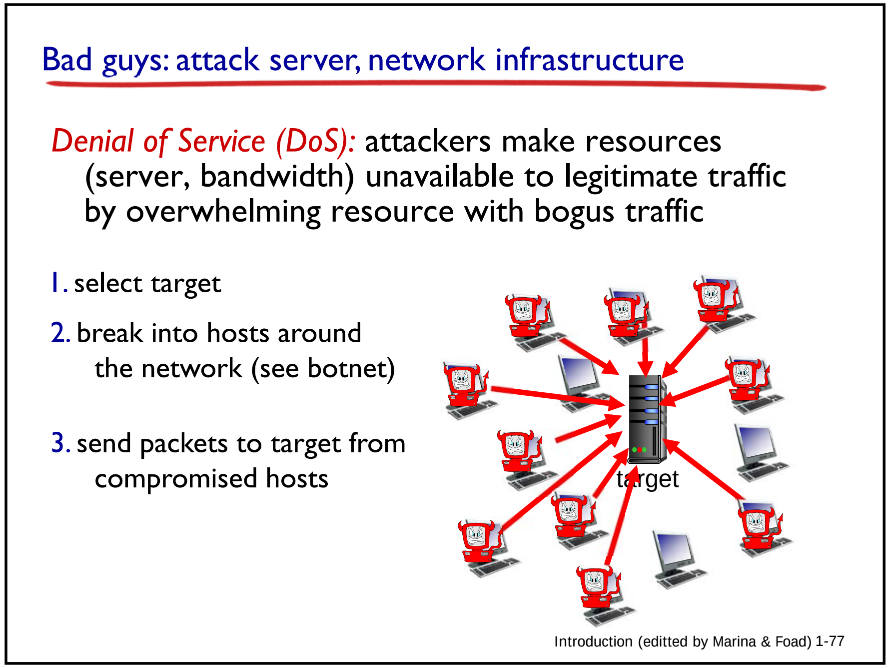
1.7 history

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

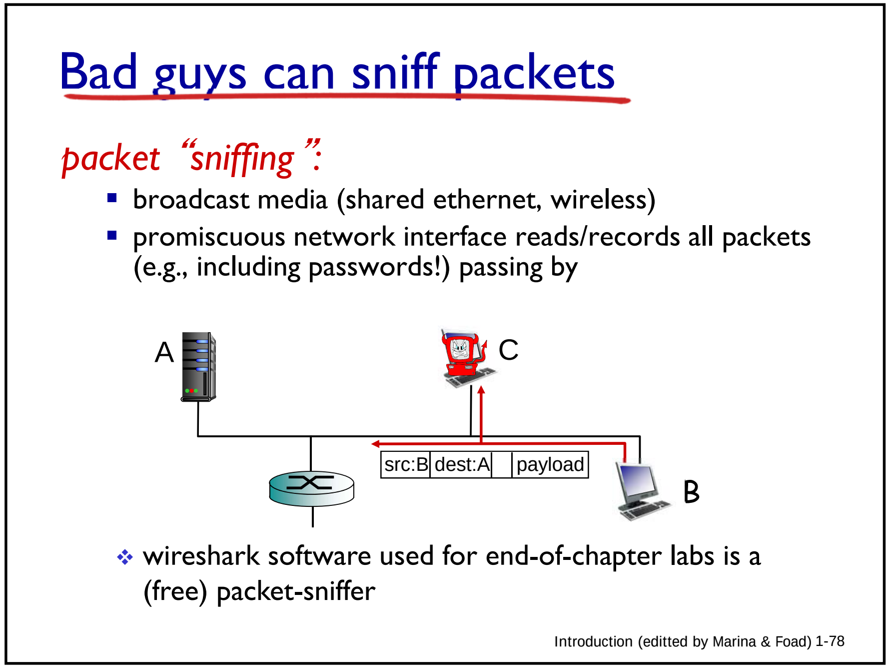
- malware can get in host from:
  - *virus:* self-replicating infection by receiving/executing object (e.g., e-mail attachment)
  - *worm:* self-replicating infection by passively receiving object that gets itself executed
- spyware malware can record keystrokes, web sites visited, upload info to collection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

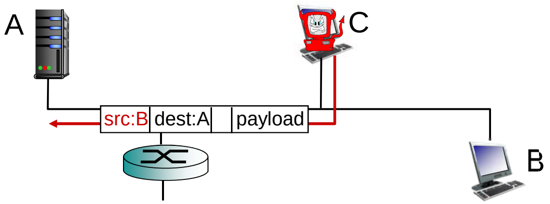
packet "sniffing":

- 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)*

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Internet history

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1972:
  - ARPAnet public demo
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

THE ARPA NETWORK

Internet history

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late70' s: proprietary architectures: DECnet, SNA, XNA
- late 70' s: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn' s internetworking principles:
- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today' s Internet architecture

Internet history

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1988: TCP congestion control
- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

Internet history

1990, 2000's: commercialization, the Web, new apps

- early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

late 1990's – 2000's:

- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

Internet history

2005-present

- ~750 million hosts
  - Smartphones and tablets
- Aggressive deployment of broadband access
- Increasing ubiquity of high-speed wireless access
- Emergence of online social networks:
  - Facebook: soon one billion users
- Service providers (Google, Microsoft) create their own networks
  - Bypass Internet, providing "instantaneous" access to search, emai, etc.
- E-commerce, universities, enterprises running their services in "cloud" (eg, Amazon EC2)

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!*