

# 计算机网络

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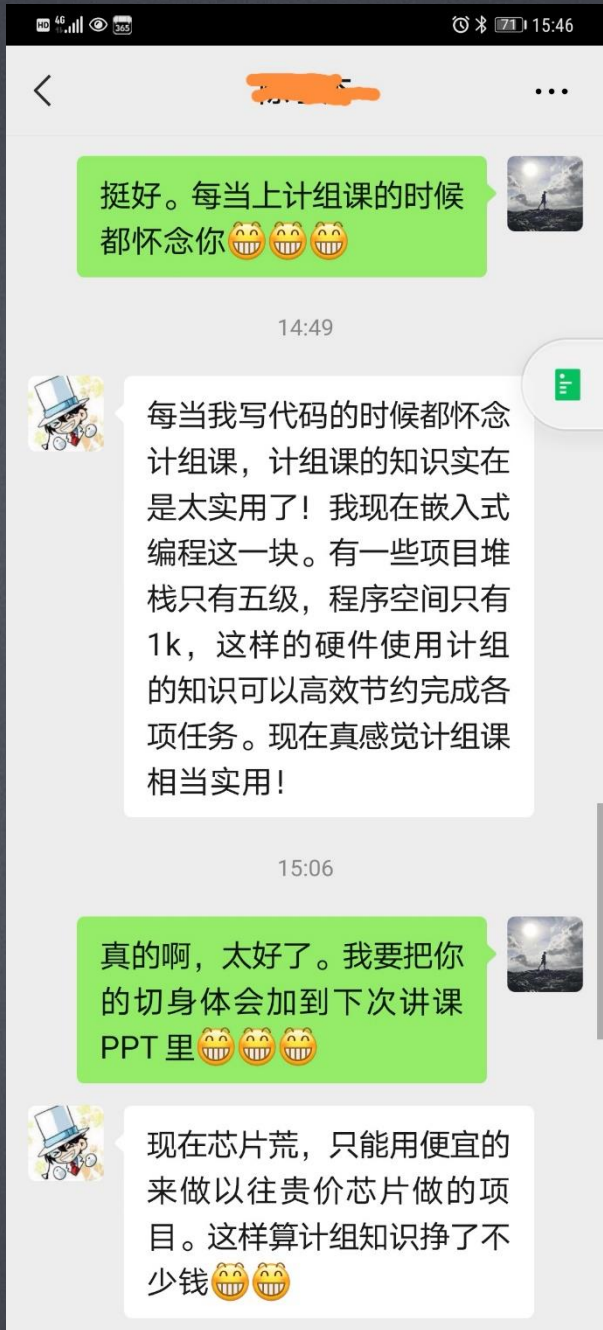
杨铮  
2022秋

# 当我们谈网络的时候，我们在谈什么

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“鸟会飞是因为有羽毛吗”

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□ 教材：《计算机网络：自顶向下方法》

- ❖ 对比了**5-7**版，大部分内容是一致的
- ❖ 大家手中已有的**5-7**版都可以继续使用，少部分内容只有第**7**版涉及
- ❖ 助教会把具体题目写在作业里

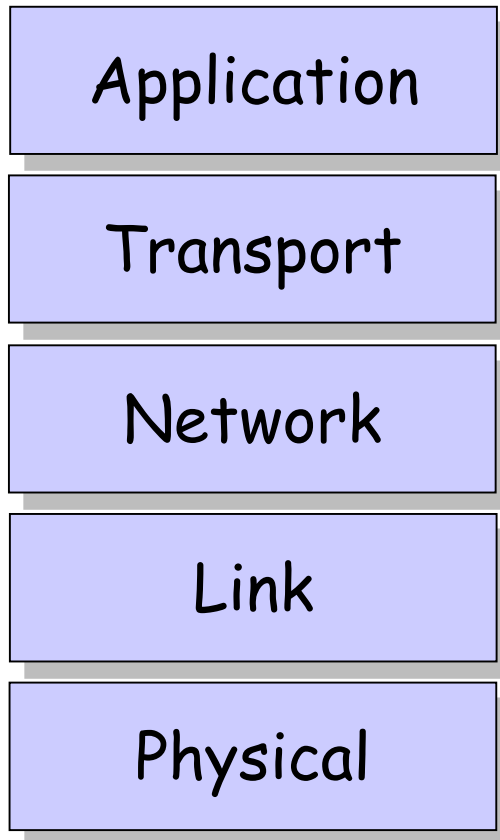
□ 助教：贺骁武、王泽宇

# Policies: Grading

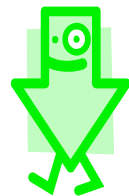
- ❑ Exams (60%)
- ❑ Labs (30%): weighted according to effort
  - ❖ Socket Programming (15%)
  - ❖ IP/Ethernet (15%)
- ❑ Assignment and others (10%)



# Philosophical Quandary: Top Down or Bottom Up?



- ❑ **Bottom Up:** Start with Physical (e.g., wires) layer and move up to Applications (e.g., mail, web browsers) layer explaining how functions are implemented



- ❑ **Top Down :** Start with Application layer and move down to Physical layer, explaining what expectations from applications, and how such services are implemented

# 思考题

- ❑ 因特网是计算机网络的一种形式；计算机网络不只因特网一种形式。
- ❑ 不同于电话网络，因特网核心简单、边缘复杂（智能）。
- ❑ 因特网的分层体系结构与“瘦腰”模型



# 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

- circuit switching, packet switching, network structure





## 1.4 Delay, loss and throughput in packet-switched networks

## 1.5 Protocol layers, service models

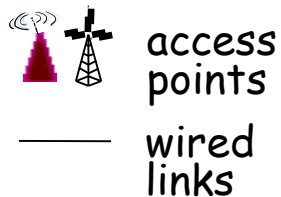
## 1.6 Networks under attack: security

## 1.7 History

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

-  PC
-  server
-  wireless laptop
-  cellular handheld
- ❑ Billions ~~millions~~ of connected computing devices: *hosts = end systems*
  - ❖ running *network apps*

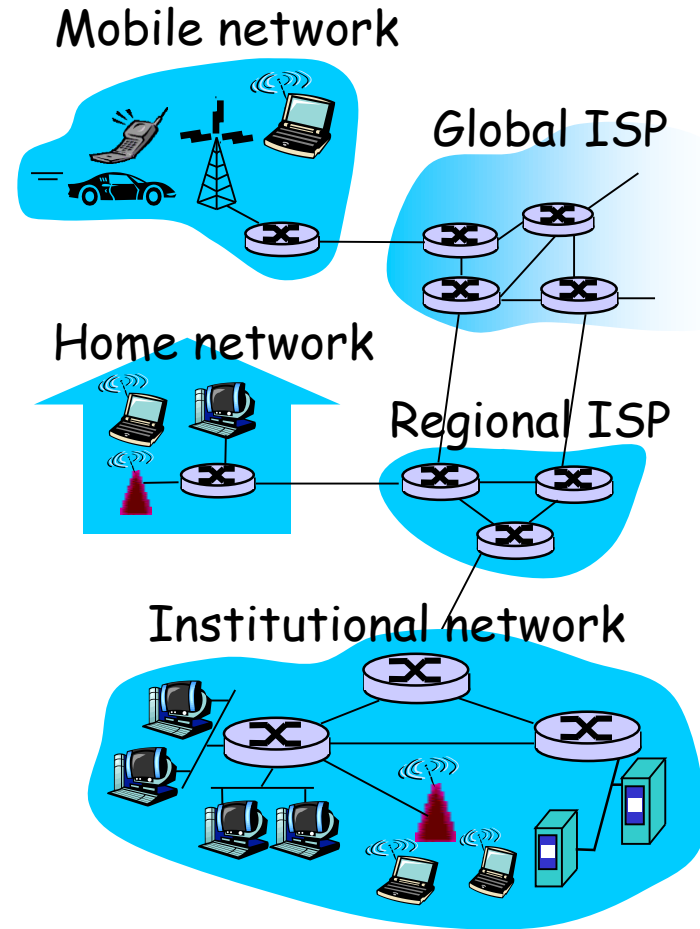
## ❑ *communication links*



- ❖ fiber, copper, radio, satellite
- ❖ transmission rate = *bandwidth*

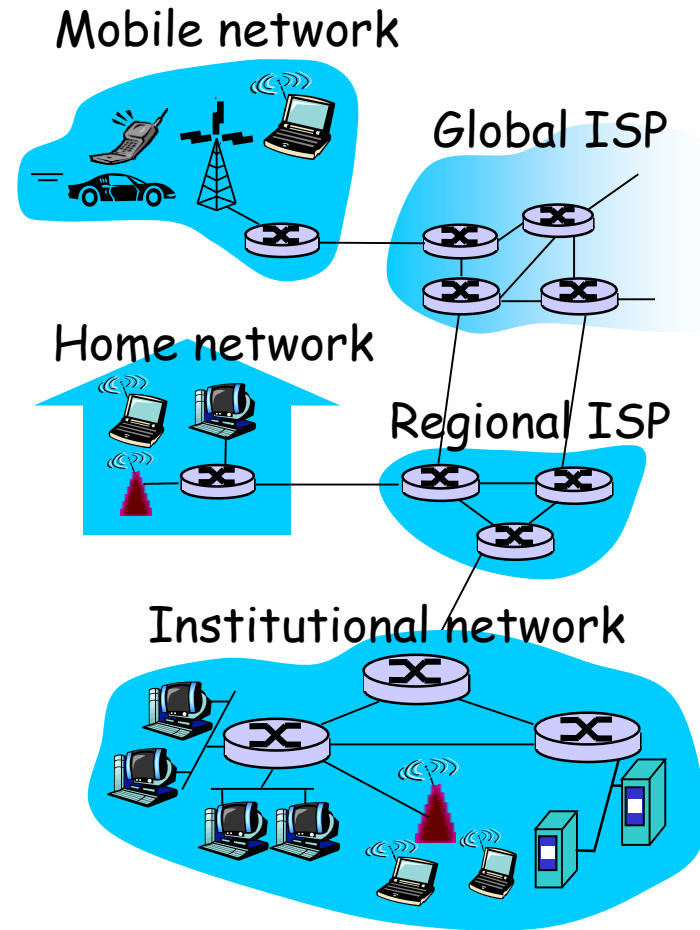


- ❑ *routers*: forward packets (chunks of data)



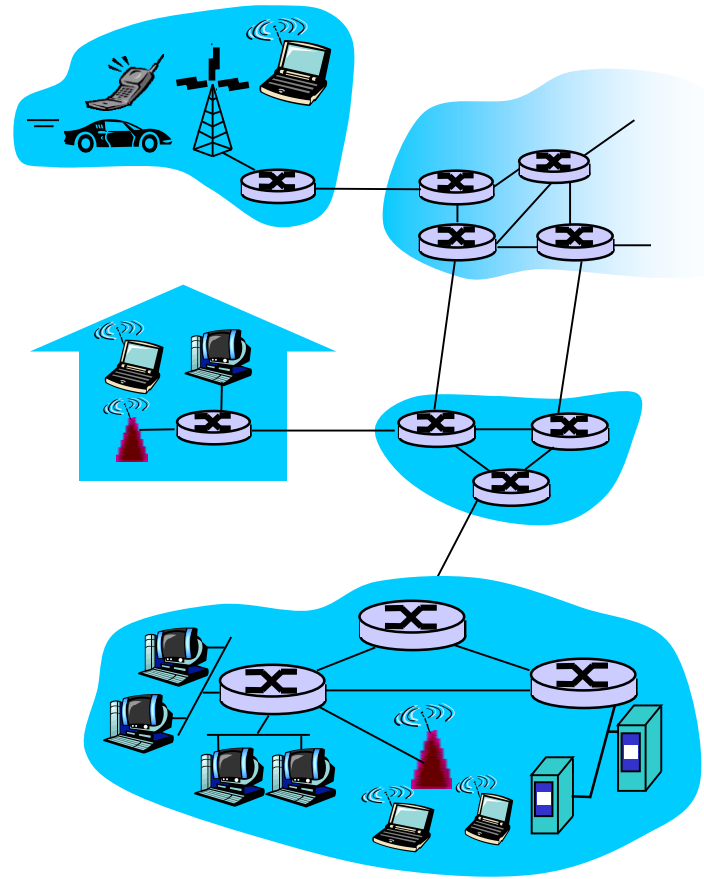
# What's the Internet: "nuts and bolts" view

- ❑ *protocols* control sending, receiving of msgs
  - ❖ e.g., TCP, IP, HTTP, Skype, Ethernet
- ❑ *Internet: "network of networks"*
  - ❖ loosely hierarchical
  - ❖ public Internet versus private intranet
- ❑ Internet standards
  - ❖ RFC: Request for comments
  - ❖ IETF: Internet Engineering Task Force



# 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



# 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

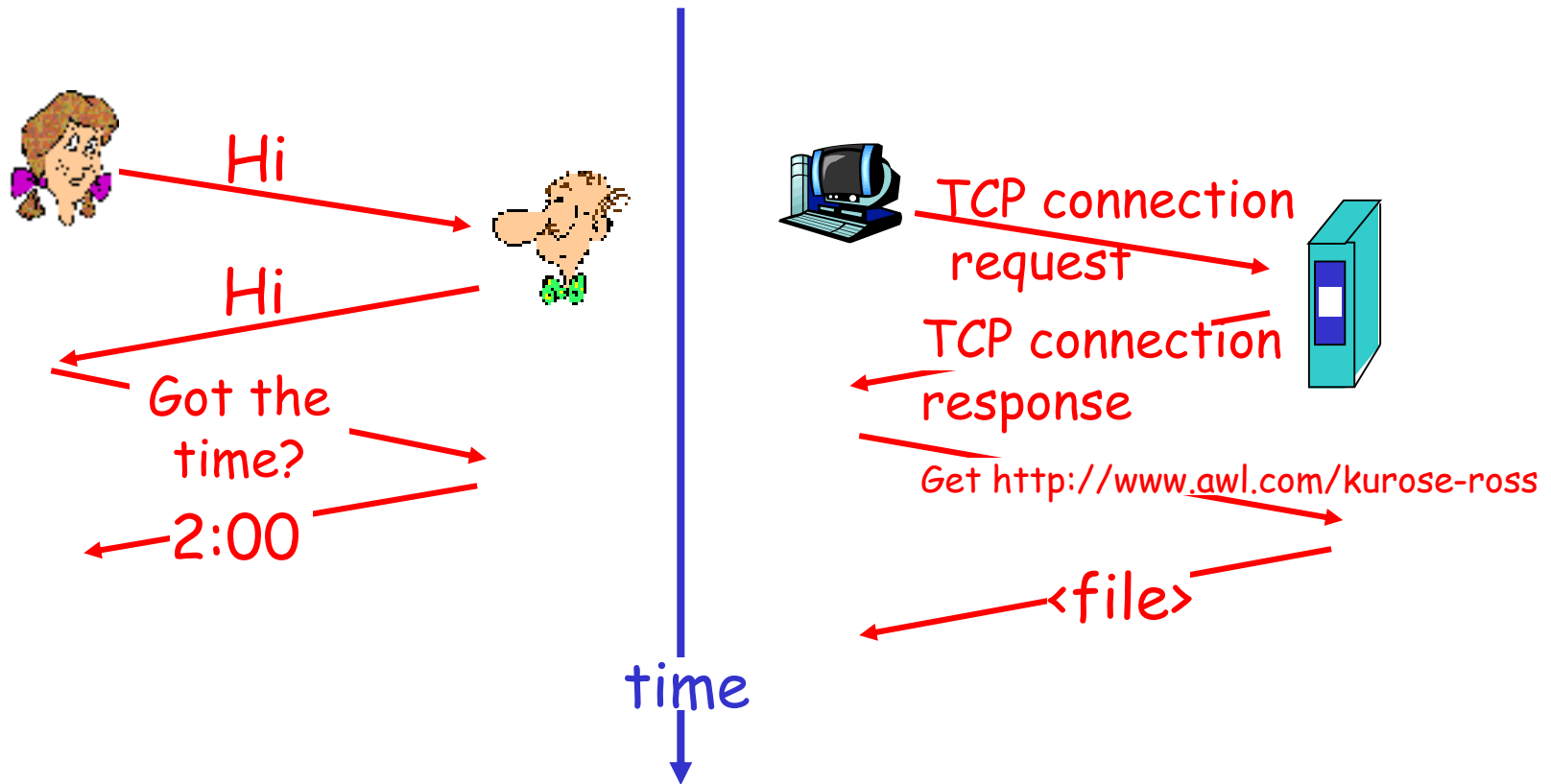
## network protocols:

- ❑ 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*

# What's a protocol?

a human protocol and a computer network protocol:



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

- circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks

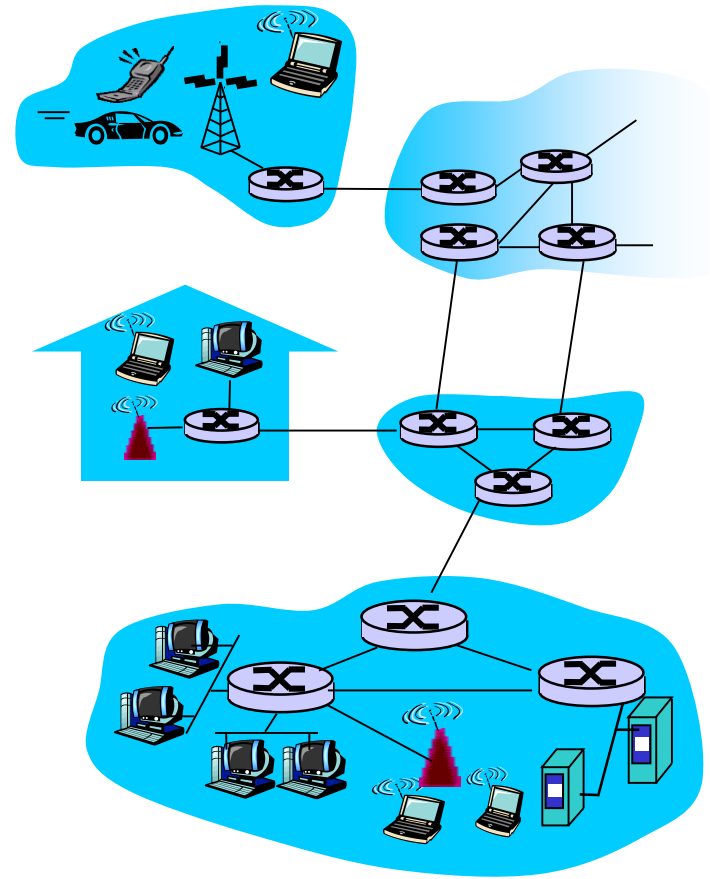
1.5 Protocol layers, service models

1.6 Networks under attack: security

1.7 History

# 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



# The network edge:

## ❑ end systems (hosts):

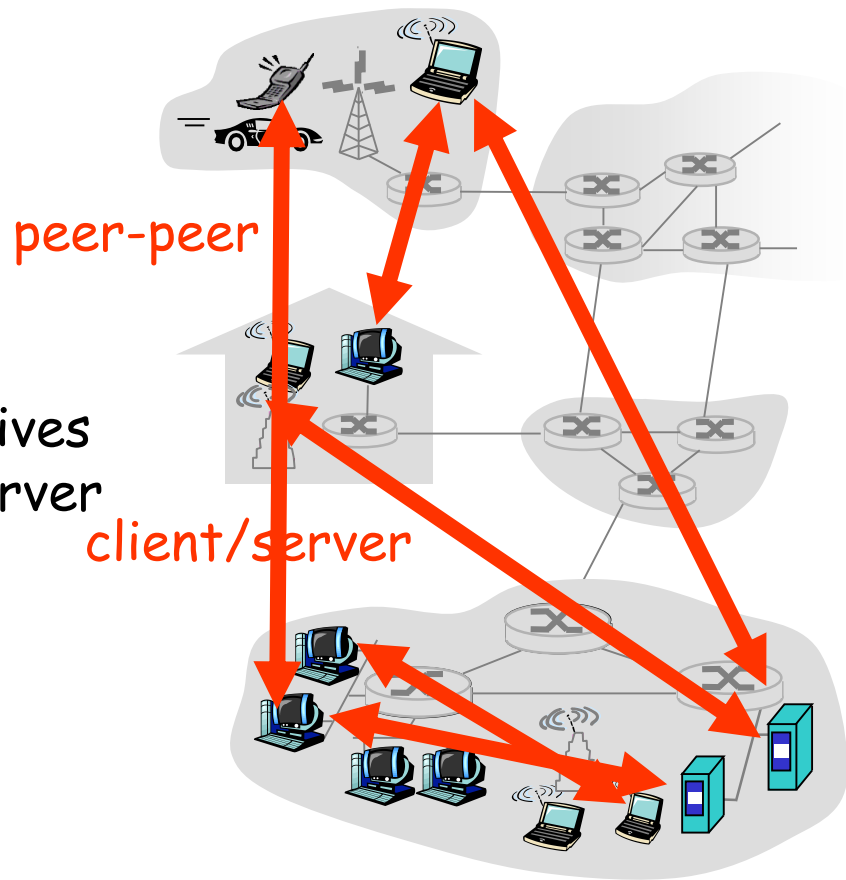
- ❖ run application programs
- ❖ e.g. Web, email
- ❖ at “edge of network”

## ❑ 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



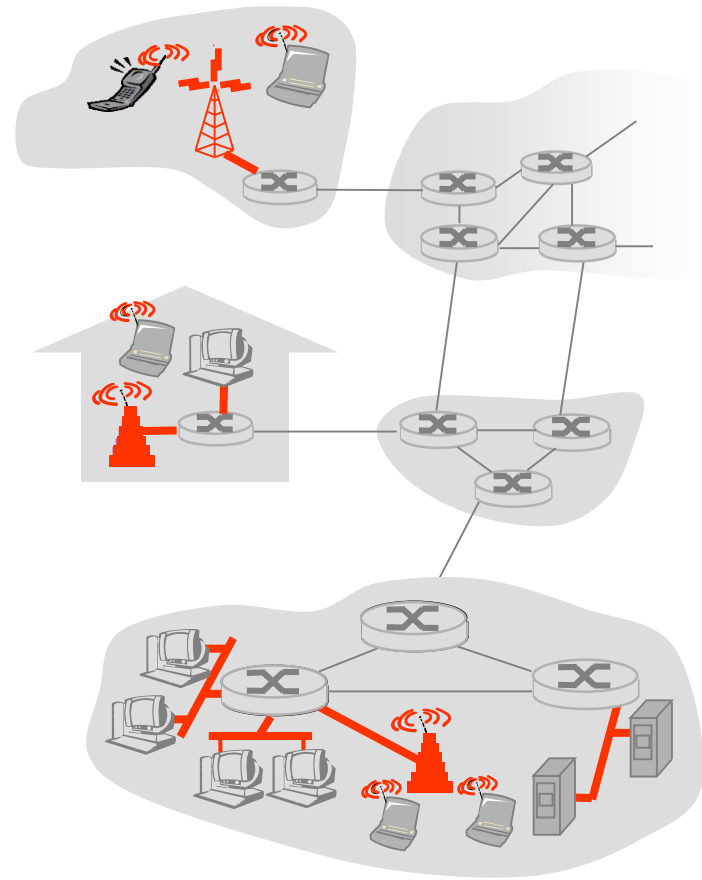
# Access networks and physical media

*Q: How to connect end systems to edge router?*

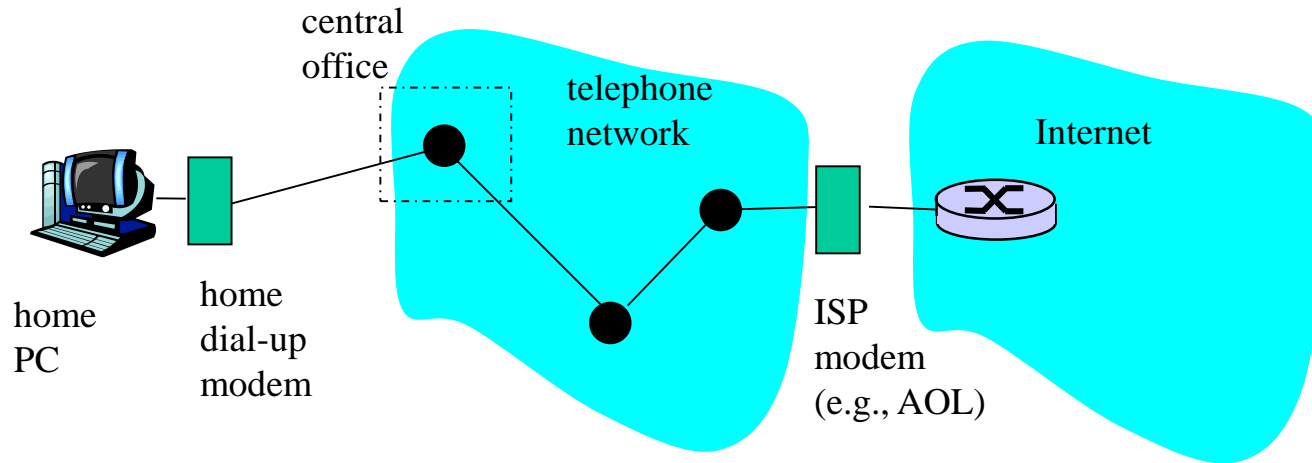
- ❑ residential access nets
- ❑ institutional access networks (school, company)
- ❑ mobile access networks

*Keep in mind:*

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

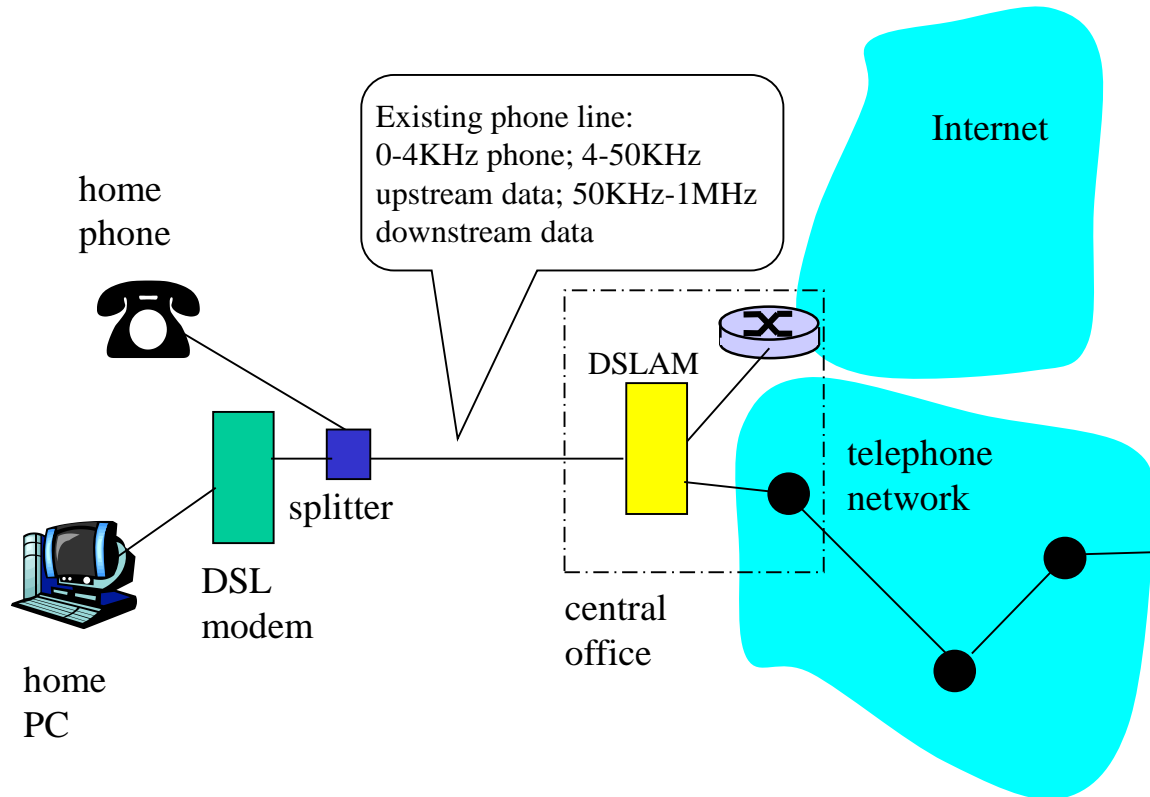


# Dial-up Modem



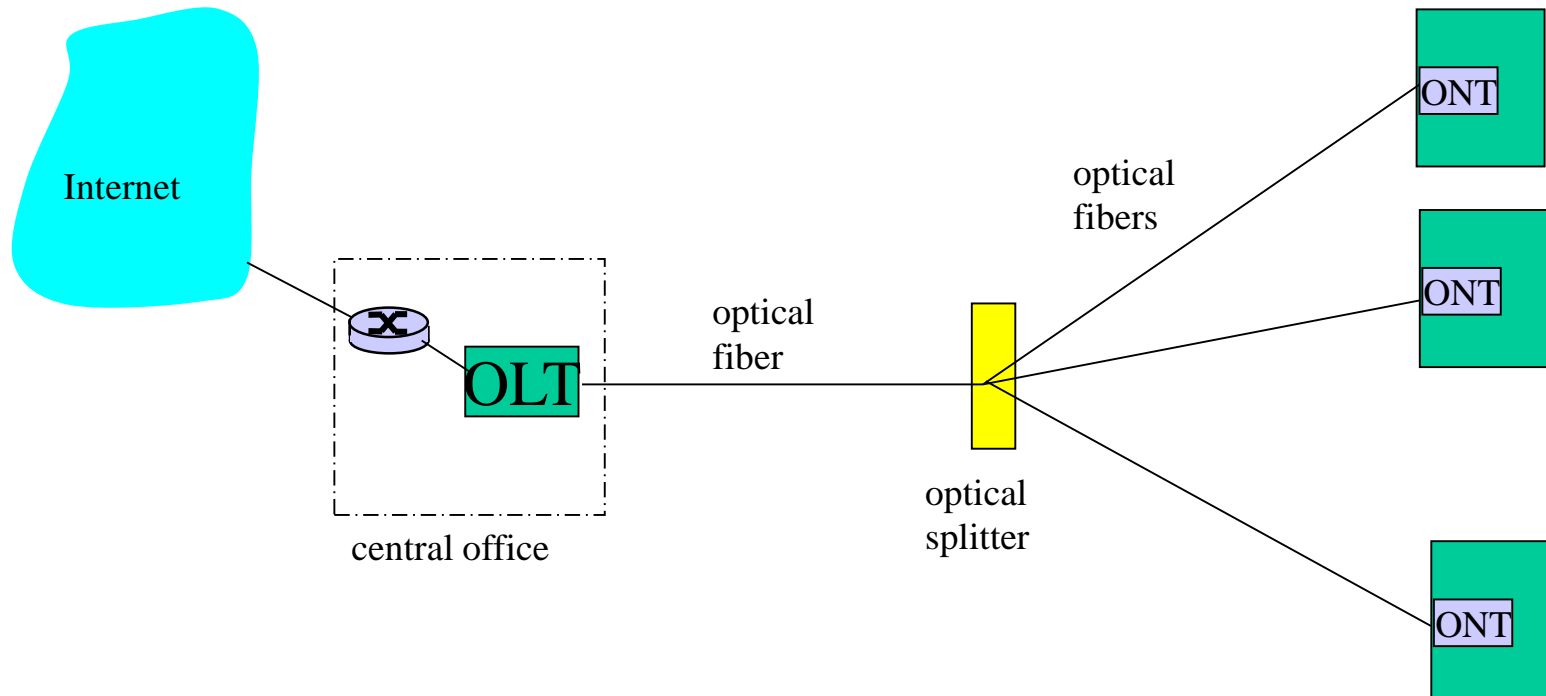
- ❖ Uses existing telephony infrastructure
  - ❖ Home is connected to **central office**
- ❖ up to 56Kbps direct access to router (often less)
- ❖ Can't surf and phone at same time: not **"always on"**

# Digital Subscriber Line (DSL)



- ❖ Also uses existing telephone infrastructure
- ❖ 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

# 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



# Fiber to the room

- ❑ FTTR将光纤铺设至每一个房间，通过部署光猫路由一体机，结合双频Wi-Fi解决覆盖问题。
- ❑ 在2020年9月，广东移动携手华为发布全球首个FTTR全光Wi-Fi商用。2021年5月，武汉第一用户。
- ❑ 目前还处在初步阶段



# Fiber to the room

什么是FTTR? : FTTR是光纤到房间, “网线”换成“光纤”的二次革命

中国光改历史: 就是光纤不断到房间的历史



> 网络演进: FTTC(Fiber to the Curb)-> FTTB(Building)->FTTH(Home)->FTTR(Fiber to the Room)

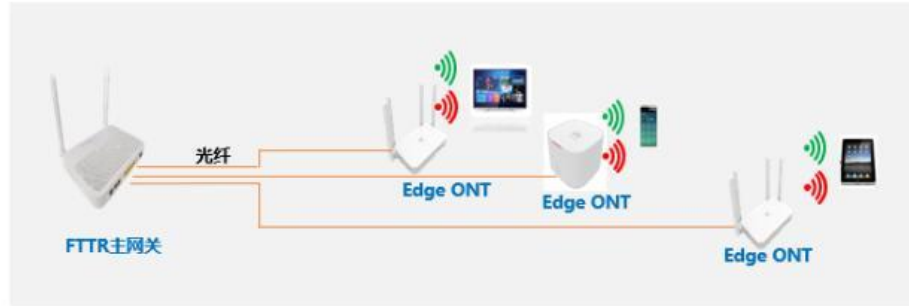
中国光改历史: 就是铜线换光纤的历史



> 介质演进: 电话线-> 网线-> 光纤  
> 业务演进: 语音-> 上网-> IPTV-> 4K/8K

# Fiber to the room

全光组网



网线组网



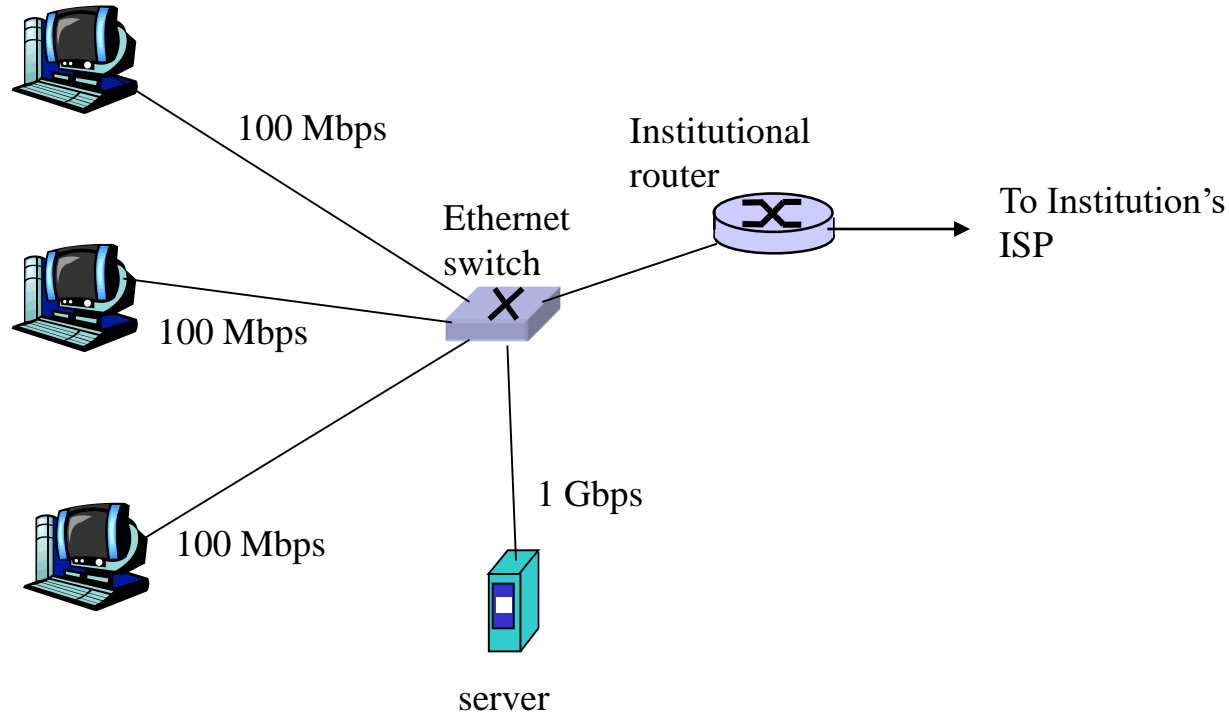
电力线组网



Wi-Fi中继组网



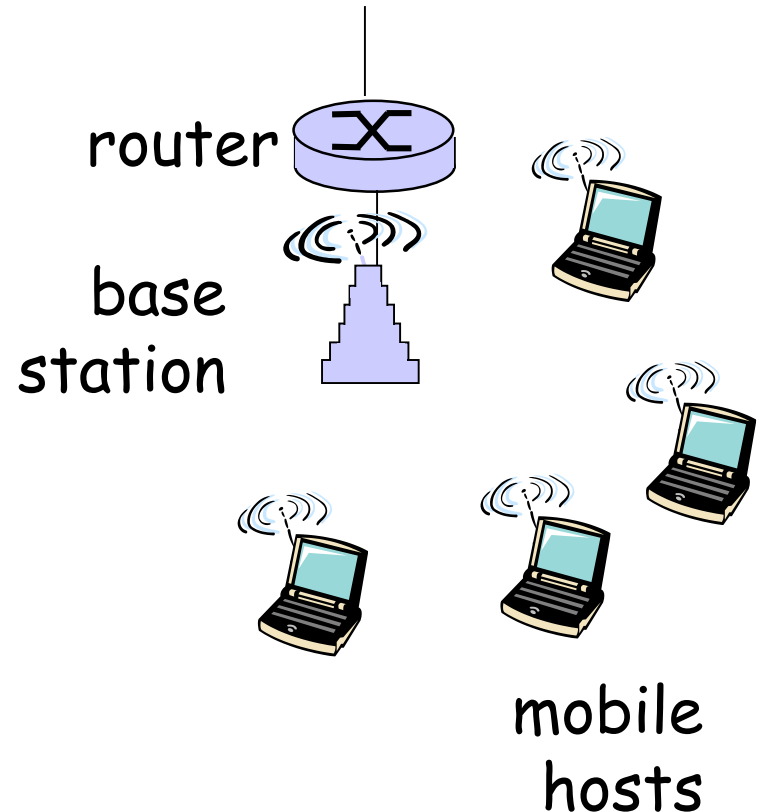
# Ethernet Internet access



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

# Wireless access networks

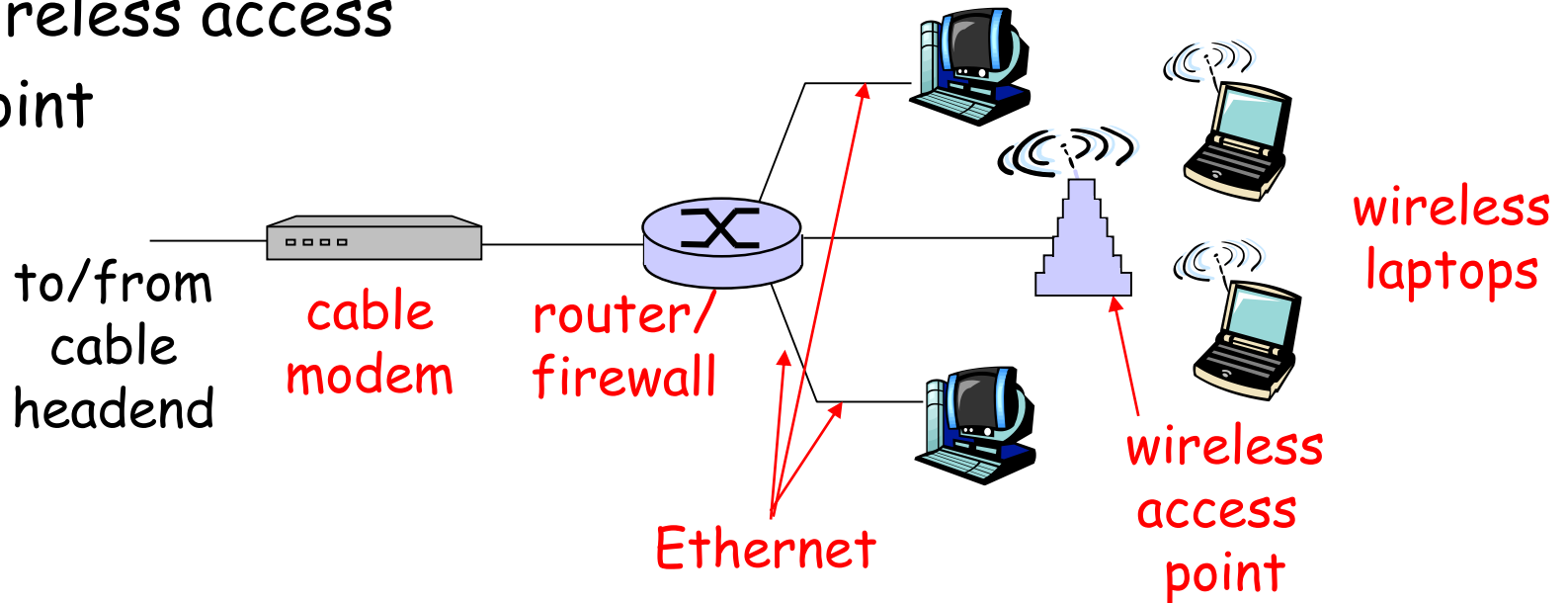
- ❑ shared *wireless* access network connects end system to router
  - ❖ via base station aka “access point”
- ❑ **wireless LANs: WiFi**
  - ❖ 802.11a/b/g/n/ac/ad
  - ❖ WiFi 6 (WiFi 7 in future)
- ❑ **wider-area wireless access**
  - ❖ provided by telco operator
  - ❖ 3G/4G/5G
  - ❖ next up ?



# 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 5: 100Mbps Ethernet
  - ❖ Category 5e/6/6e/7: 1000Mbps/10Gbps

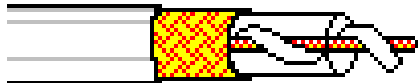




# Physical Media: coax, fiber

## 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)
  - ❖ 1000+ Mbps
- ❑ **wide-area** (e.g., cellular)
  - ❖ 5G: 1000+ Mbps (download)
- ❑ **satellite**
  - ❖ Kbps to 45Mbps channel (or multiple smaller channels)
  - ❖ 270 msec end-end delay
  - ❖ geosynchronous versus low altitude

# Chapter 1: roadmap

1.1 What is the Internet?

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1.3 Network core

- circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks

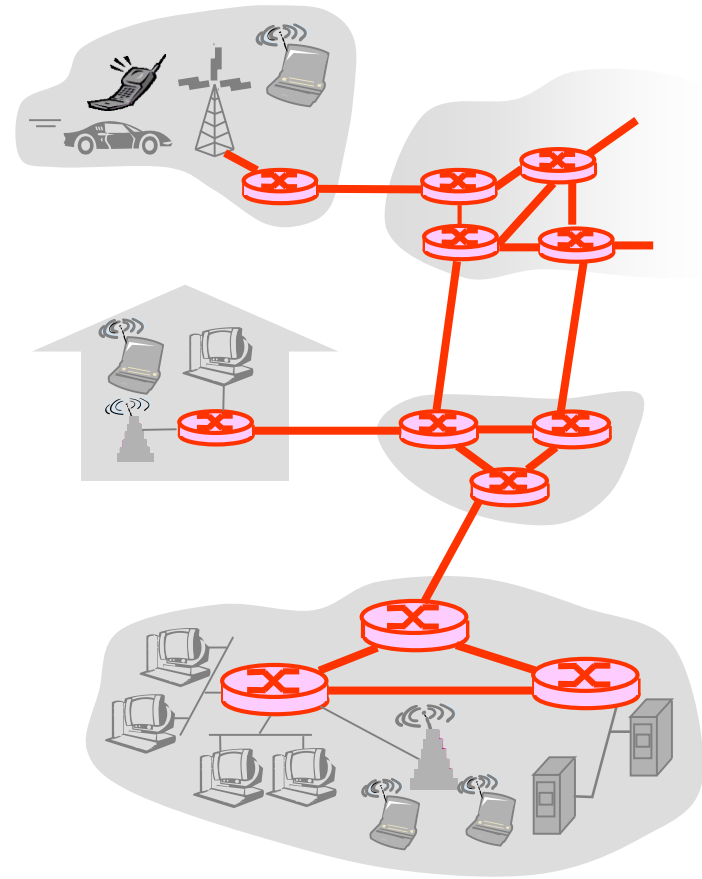
1.5 Protocol layers, service models

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# The Network Core

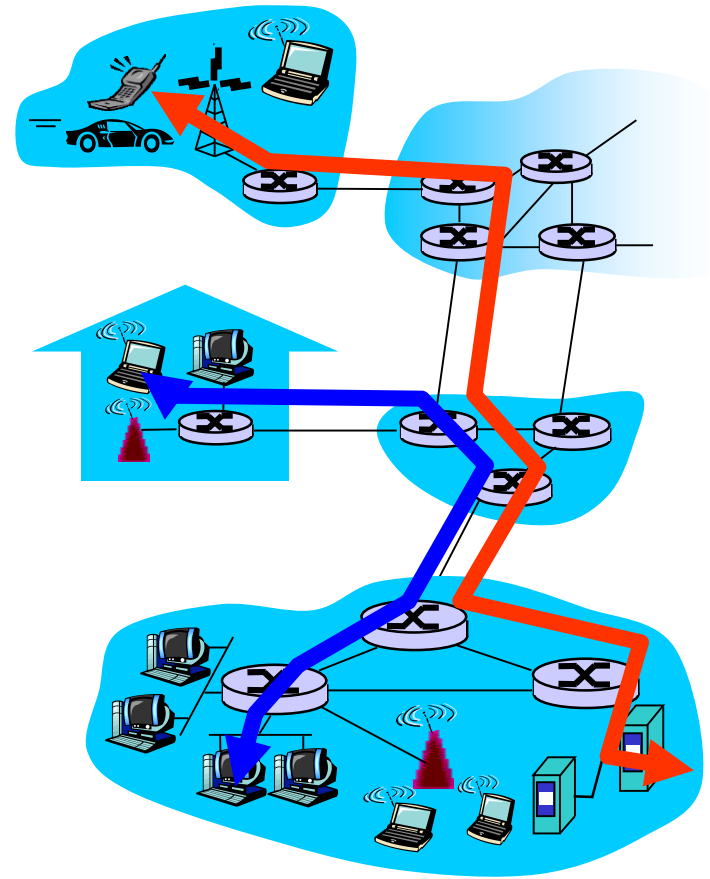
- mesh of interconnected routers
- the fundamental question: how is data transferred through net?
  - ❖ circuit switching: dedicated circuit per call: telephone net
  - ❖ packet-switching: data sent thru net in discrete "chunks"



# 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

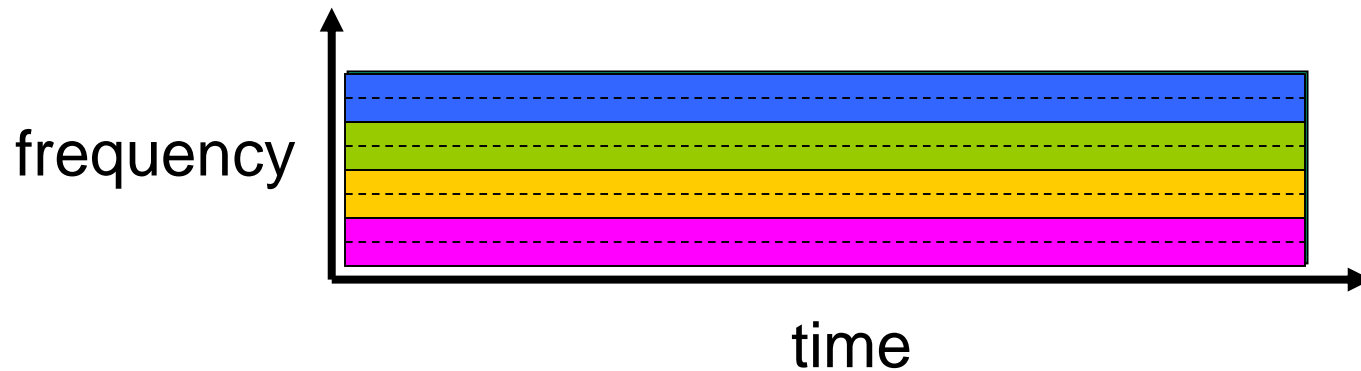
# Circuit Switching: FDM and TDM

Example:

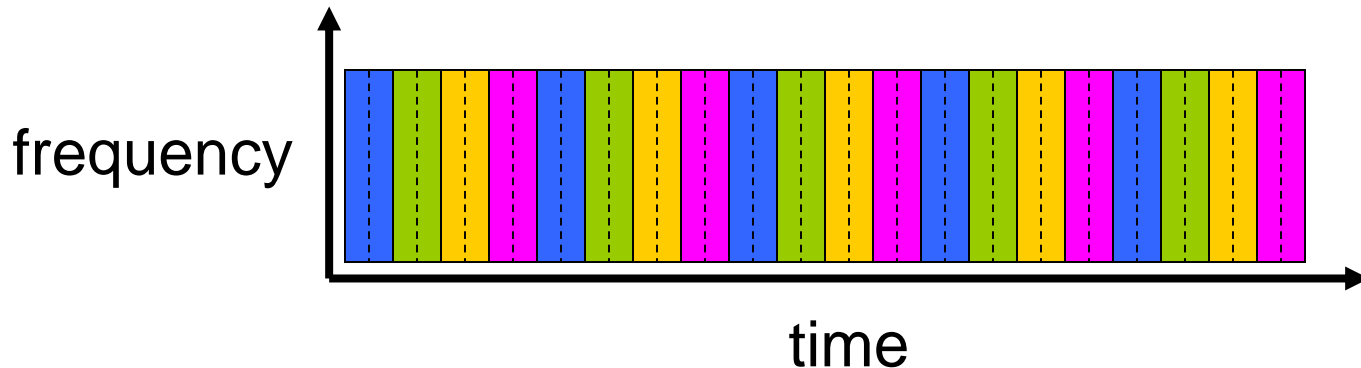
4 users



FDM



TDM





# 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

Let's work it out!

# 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"

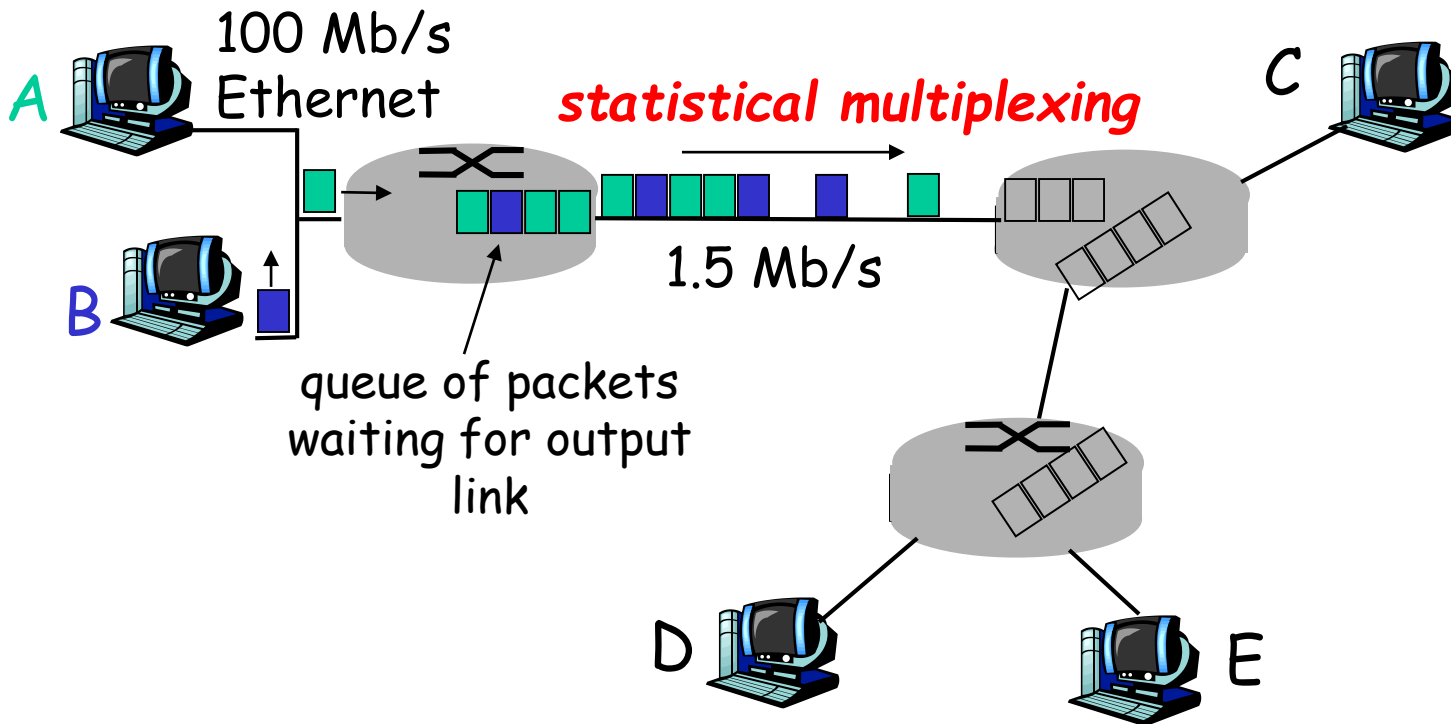
Dedicated allocation

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

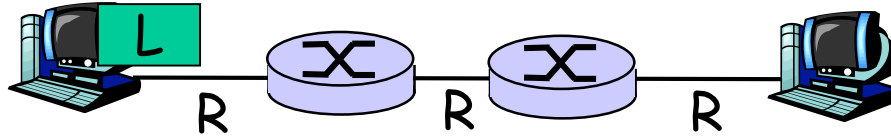
# Packet Switching: Statistical Multiplexing



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

} more on delay shortly ...

# Packet switching versus circuit switching

*Packet switching allows more users to use network!*

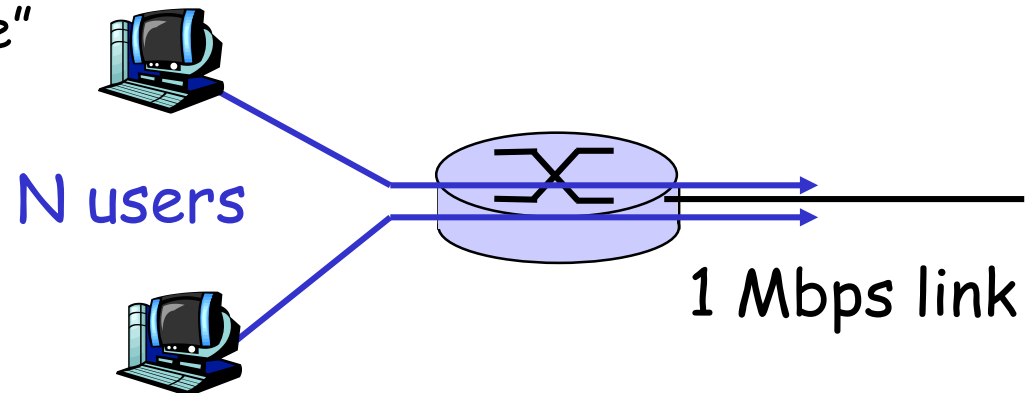
- ❑ 1 Mb/s link
- ❑ each user:
  - ❖ 100 kb/s when "active"
  - ❖ active 10% of time

- ❑ *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?

# Packet switching versus circuit switching

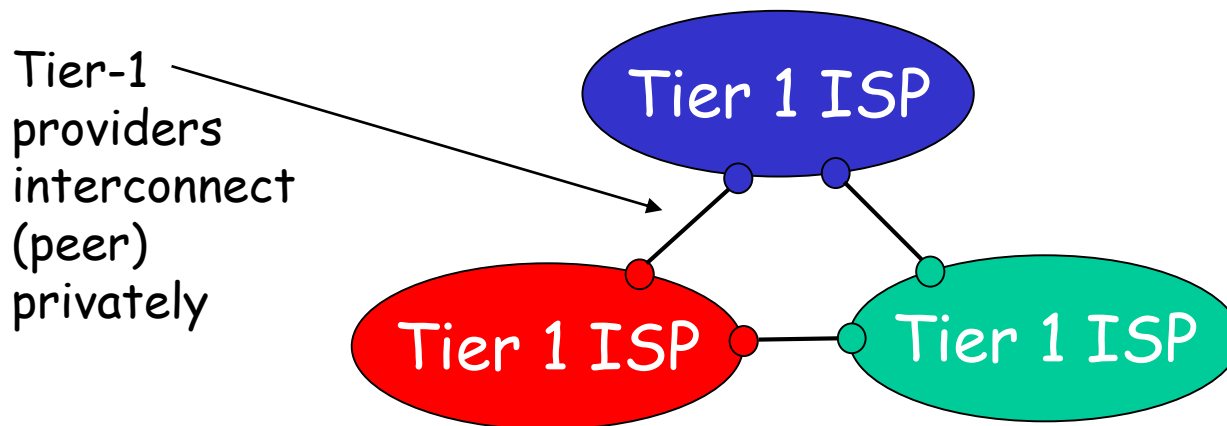
Is packet switching a “slam dunk winner?”

- ❑ 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)

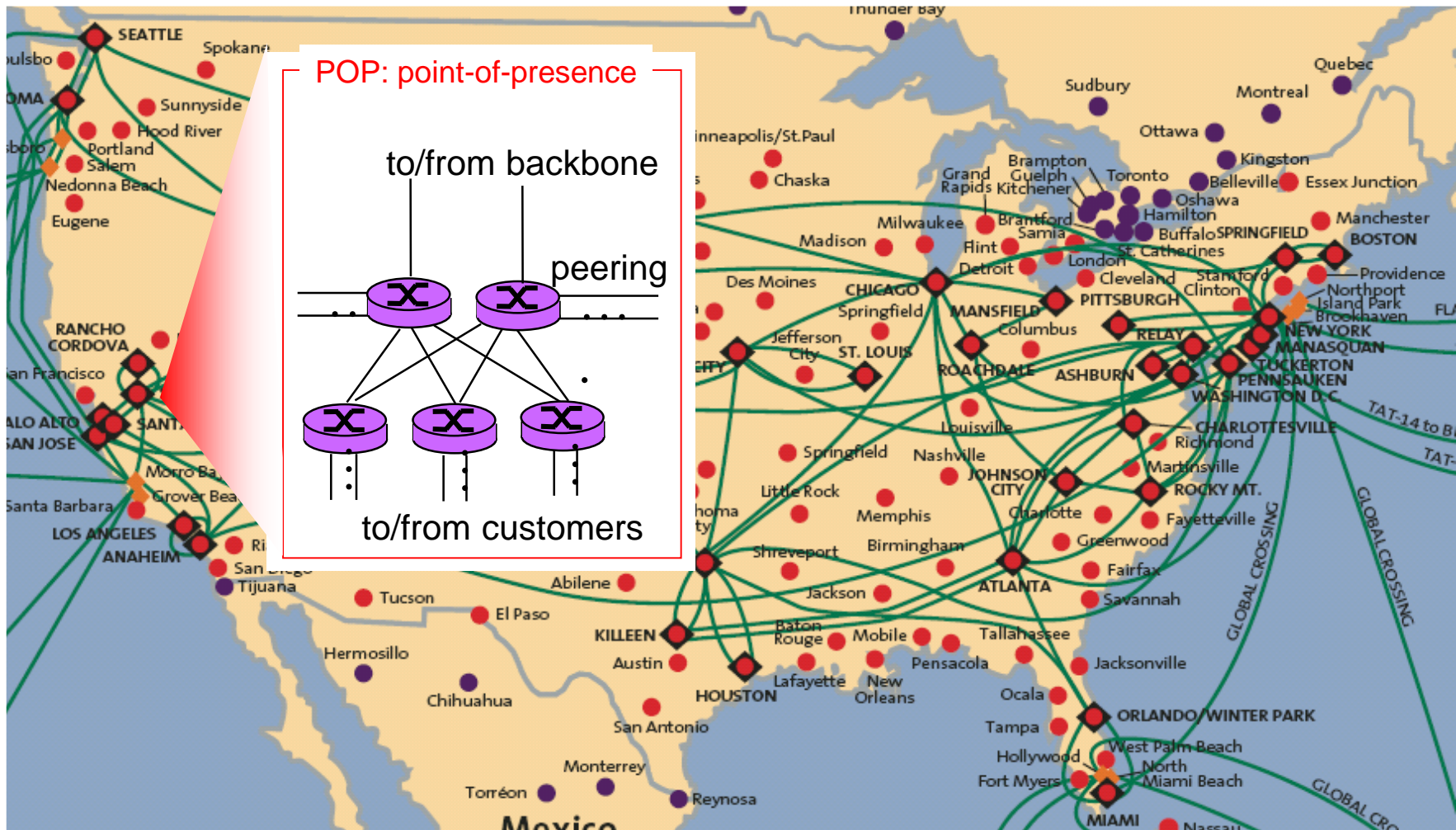
Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

# Internet structure: network of networks

- ❑ roughly hierarchical
- ❑ **at center: "tier-1" ISPs** (e.g., Verizon, Sprint, AT&T, Cable and Wireless), national/international coverage
  - ❖ treat each other as equals



# Tier-1 ISP: e.g., Sprint

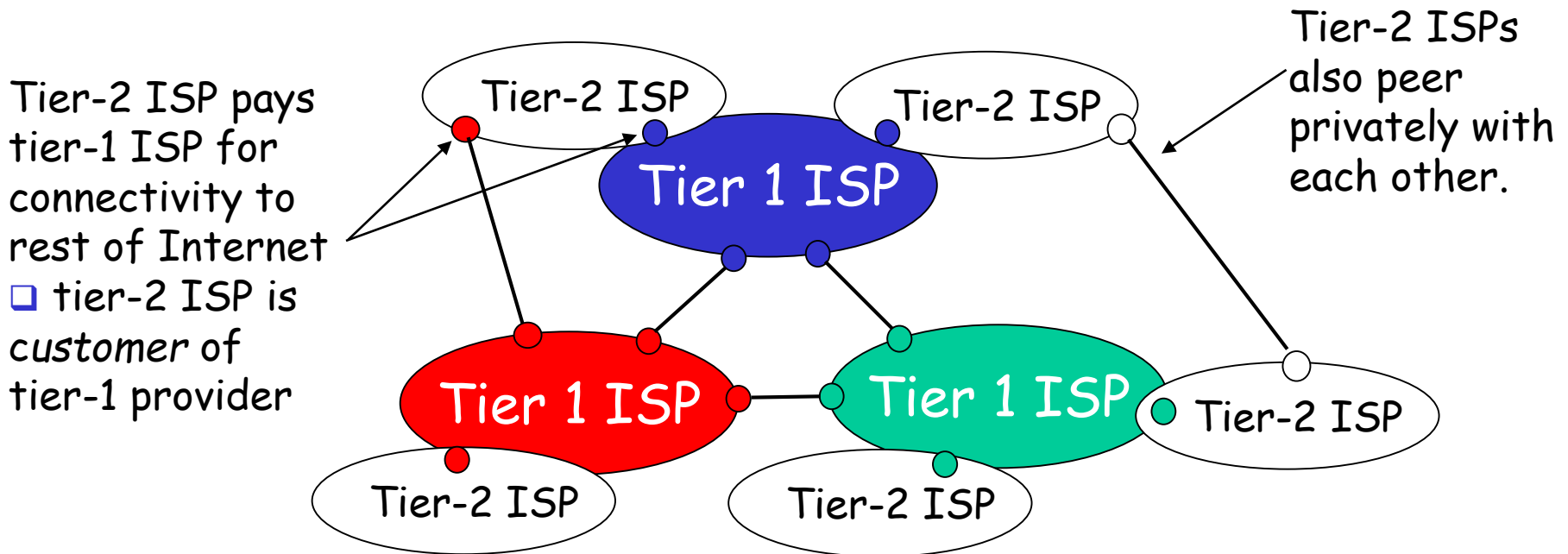




# Internet structure: network of networks

## ❑ "Tier-2" ISPs: smaller (often regional) ISPs

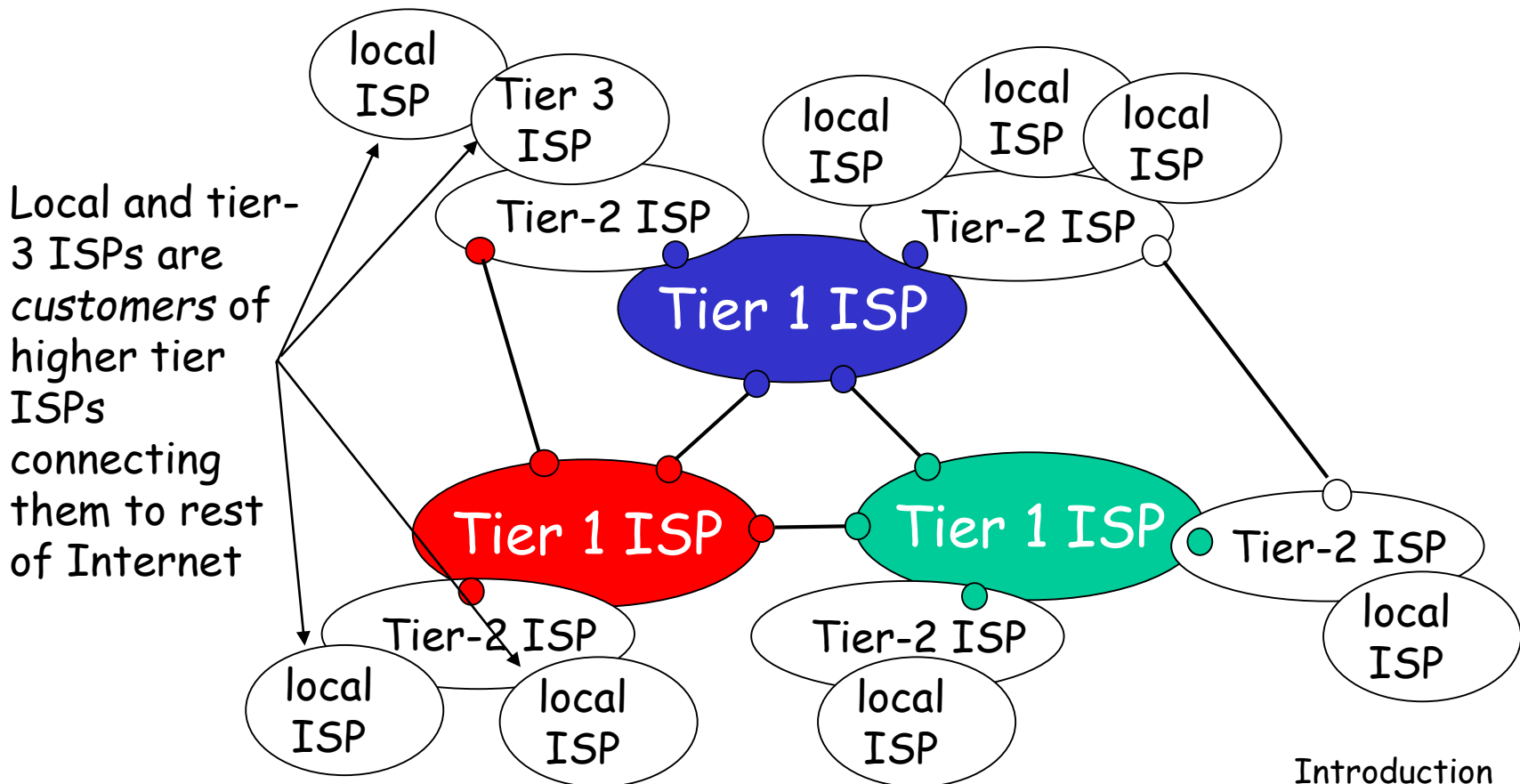
- ❖ Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs



# Internet structure: network of networks

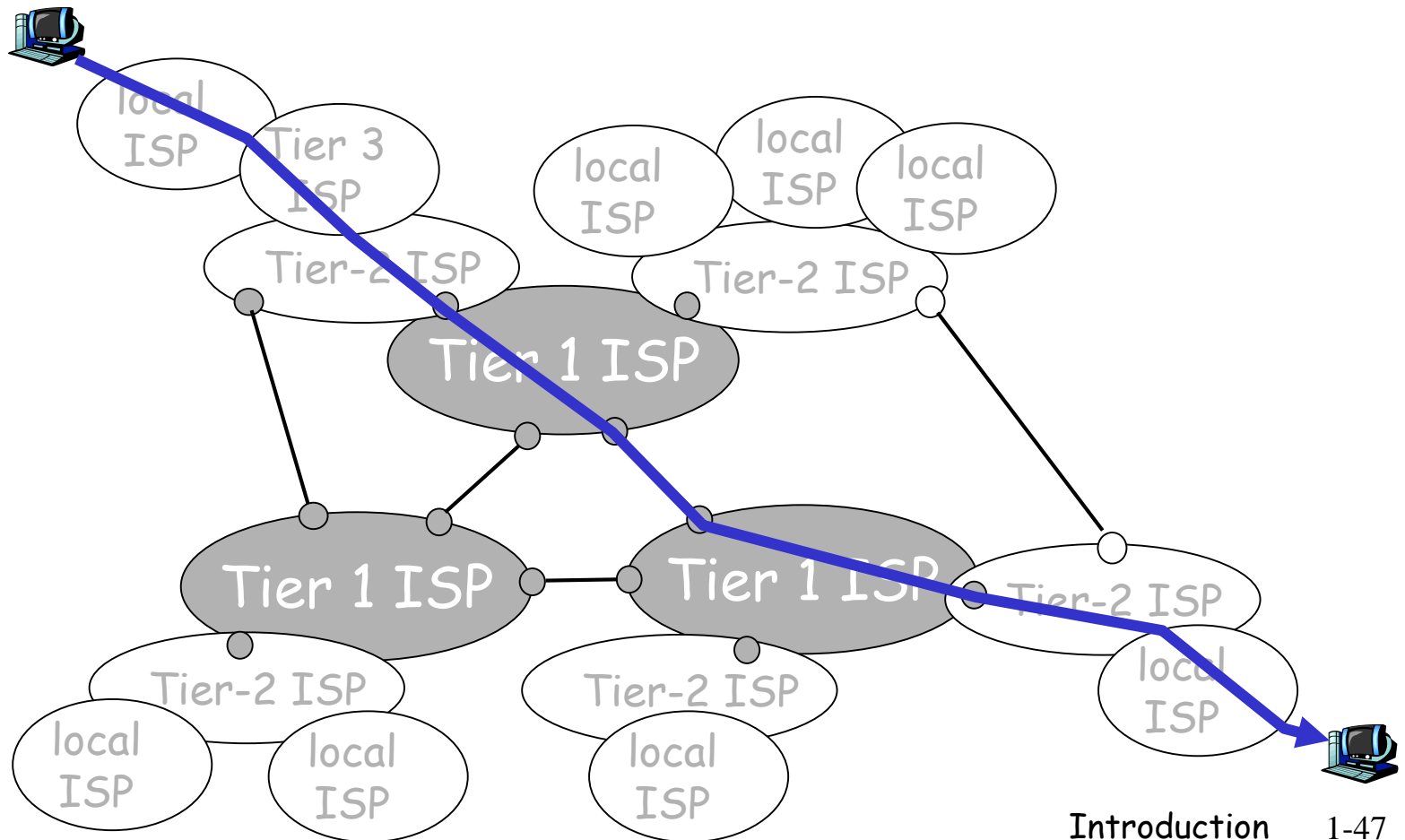
## ❑ "Tier-3" ISPs and local ISPs

- ❖ last hop ("access") network (closest to end systems)



# Internet structure: network of networks

- a packet passes through many networks!



# Chapter 1: roadmap

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1.5 Protocol layers, service models

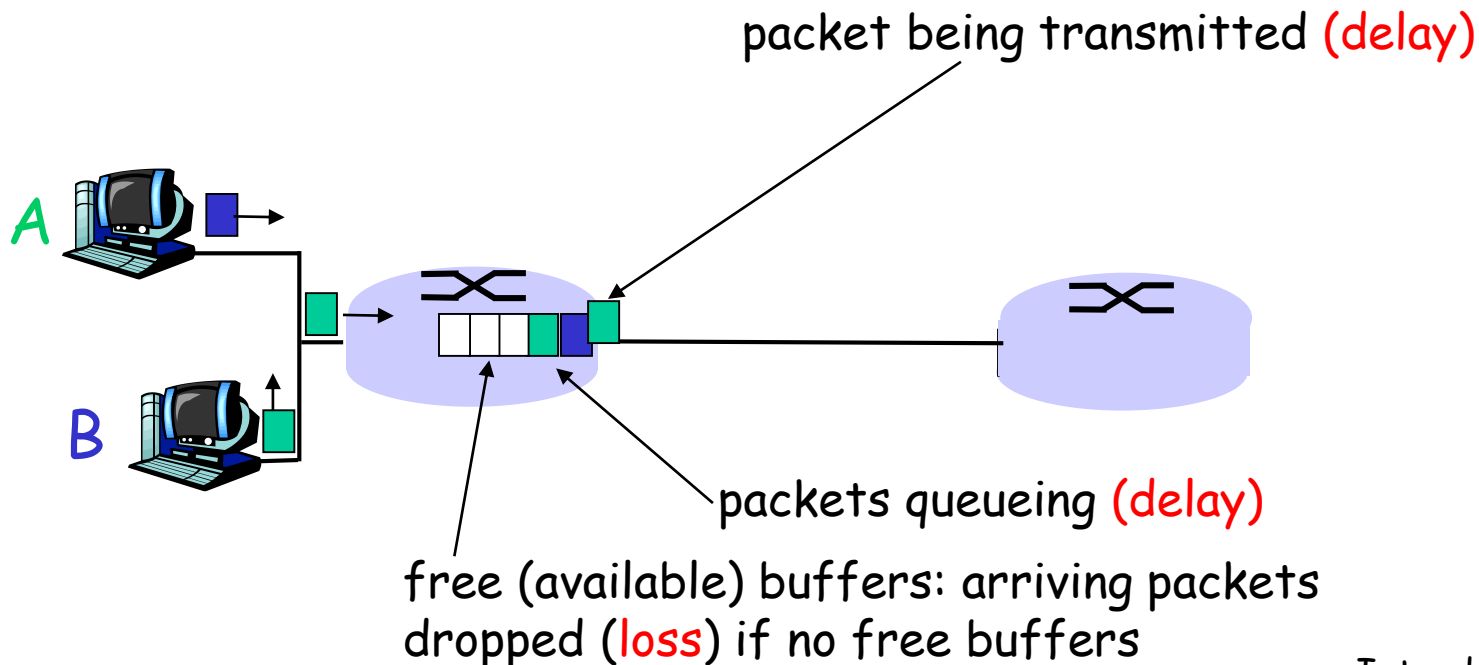
1.6 Networks under attack: security

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# How do loss and delay occur?

packets *queue* in router buffers

- ❑ packet arrival rate to link exceeds output link capacity
- ❑ packets queue, wait for turn



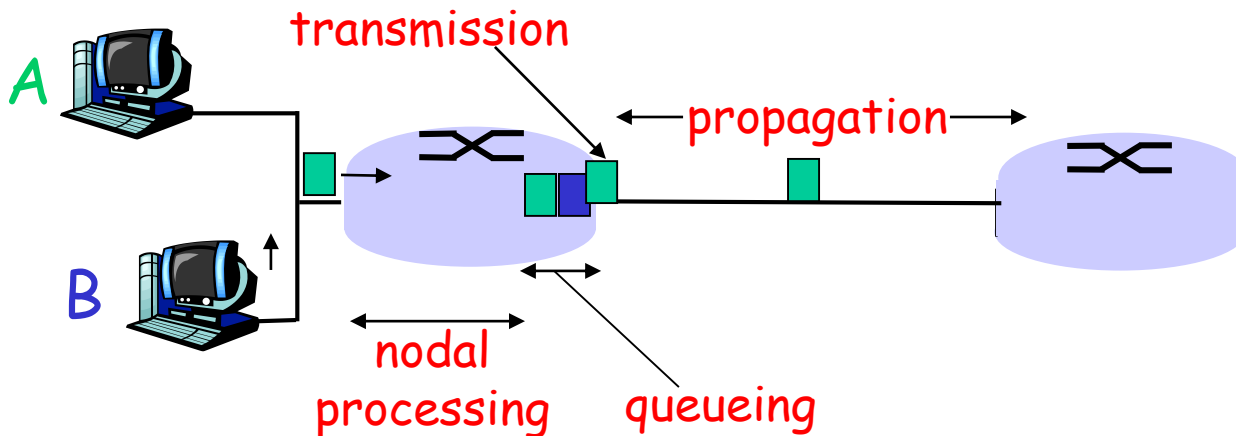
# Four sources of packet delay

## ❑ 1. nodal processing:

- ❖ check bit errors
- ❖ determine output link

## ❑ 2. queueing

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



# Delay in packet-switched networks

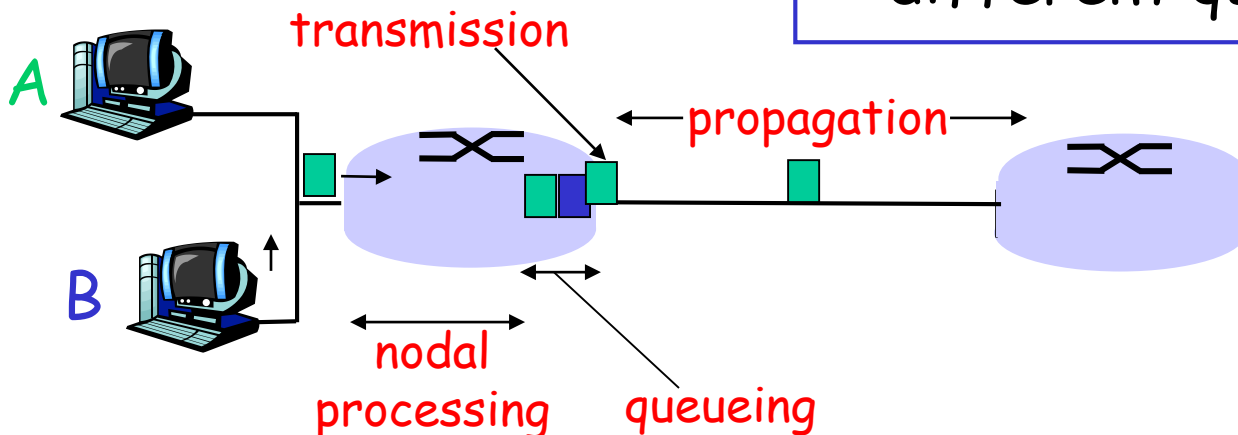
## 3. Transmission delay:

- ❑  $R$  = link bandwidth (bps)
- ❑  $L$  = packet length (bits)
- ❑ time to send bits into link =  $L/R$

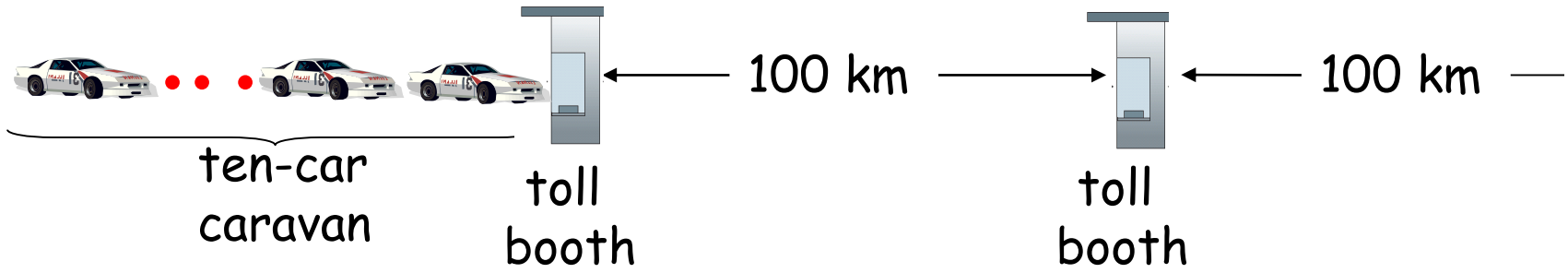
## 4. Propagation delay:

- ❑  $d$  = length of physical link
- ❑  $s$  = propagation speed in medium ( $\sim 2 \times 10^8$  m/sec)
- ❑ propagation delay =  $d/s$

**Note:**  $s$  and  $R$  are very different quantities!



# Caravan analogy

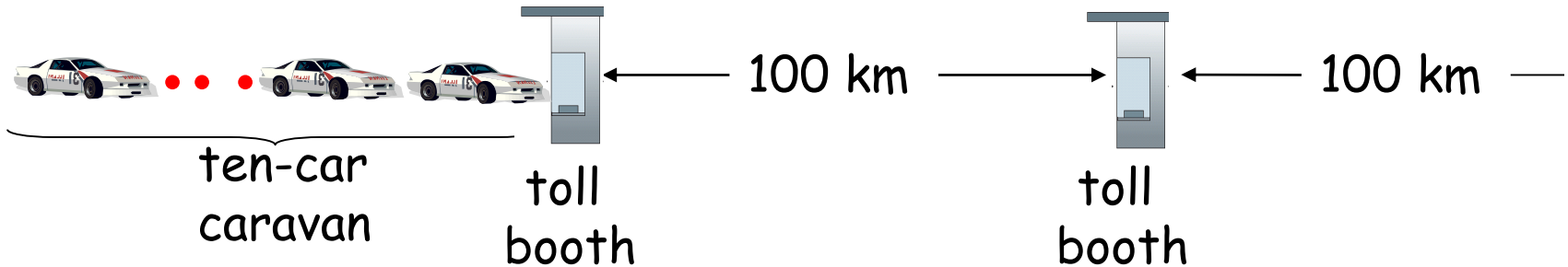


- ❑ cars "propagate" at 100 km/hr
- ❑ toll booth takes 12 sec to service car (transmission time)
- ❑ car~bit; caravan ~ packet
- ❑ Q: How long until caravan is lined up before 2nd toll booth?

- ❑ Time to "push" entire caravan through toll booth onto highway =  $12 \times 10 = 120$  sec
- ❑ Time for last car to propagate from 1st to 2nd toll booth:  
 $100\text{km} / (100\text{km/hr}) = 1$  hr
- ❑ A: 62 minutes



# Caravan analogy (more)



- ❑ Cars now "propagate" at 1000 km/hr
- ❑ Toll booth now takes 1 min to service a car
- ❑ **Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?**

- ❑ **Yes!** After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- ❑ 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!
  - ❖ See Ethernet applet at AWL Web site

# Nodal delay

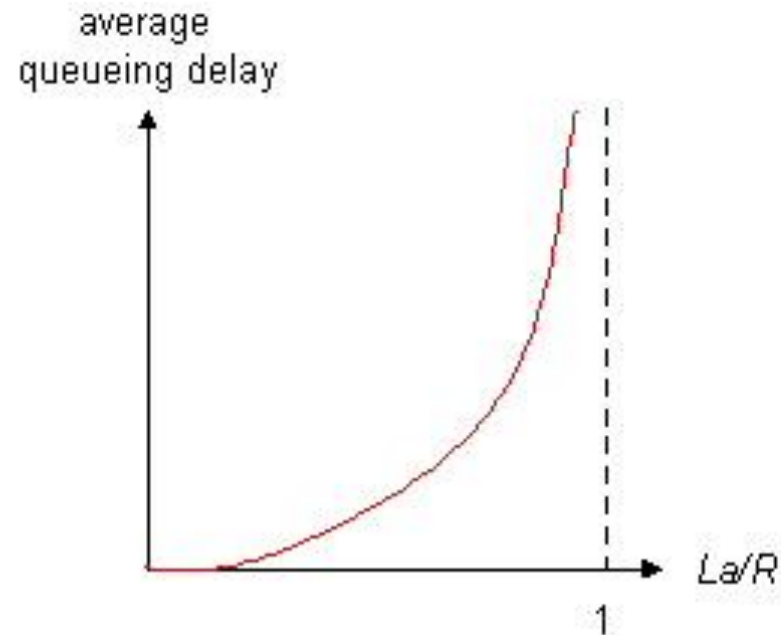
$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

- $d_{\text{proc}}$  = processing delay
  - ❖ typically a few microsecs or less
- $d_{\text{queue}}$  = queuing delay
  - ❖ depends on congestion
- $d_{\text{trans}}$  = transmission delay
  - ❖  $= L/R$ , significant for low-speed links
- $d_{\text{prop}}$  = propagation delay
  - ❖ a few microsecs to hundreds of msecs

# Queueing delay (revisited)

- $R$ =link bandwidth (bps)
- $L$ =packet length (bits)
- $a$ =average packet arrival rate

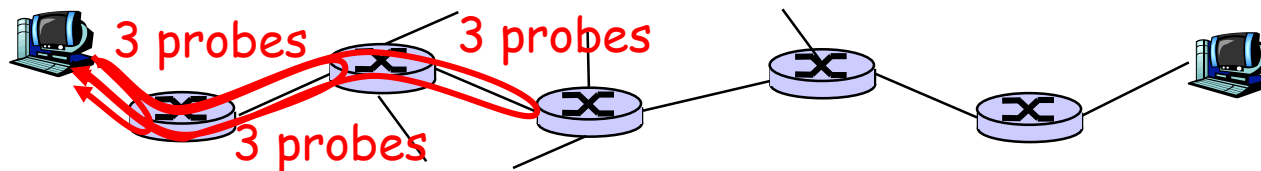
traffic intensity =  $La/R$



- $La/R \sim 0$ : average queueing delay small
- $La/R \rightarrow 1$ : delays become 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 and routes

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

Three 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)

## ❑ Traceroute: tracert www.ietf.org

```
C:\Users\hmilyyz>tracert www.ietf.org
```

通过最多 30 个跃点跟踪

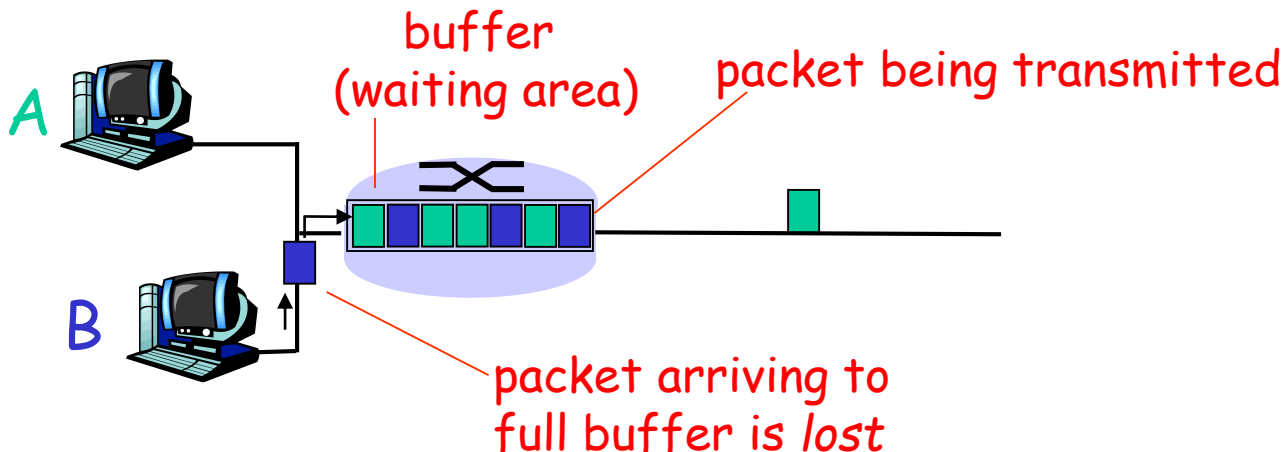
到 www.ietf.org.cdn.cloudflare.net [104.16.45.99] 的路由:

1	1 ms	1 ms	1 ms	166.111.80.10
2	14 ms	<1 毫秒	<1 毫秒	59.66.4.101
3	<1 毫秒	<1 毫秒	<1 毫秒	118.229.2.65
4	4 ms	1 ms	<1 毫秒	118.229.4.73
5	1 ms	1 ms	2 ms	202.112.38.9
6	5 ms	8 ms	2 ms	101.4.113.233
7	*	*	*	请求超时。
8	3 ms	2 ms	3 ms	101.4.117.98
9	148 ms	146 ms	146 ms	101.4.117.214
10	144 ms	144 ms	144 ms	ix-xe-9-1-5-0.tcore1.lvw-losangeles.as6453.net [66.110.59.181]
11	*	154 ms	*	if-ae-2-2.tcore2.lvw-losangeles.as6453.net [66.110.59.2]
12	154 ms	154 ms	154 ms	if-ae-13-2.tcore1.sqn-sanjose.as6453.net [63.243.205.65]
13	153 ms	153 ms	153 ms	104.16.45.99

跟踪完成。

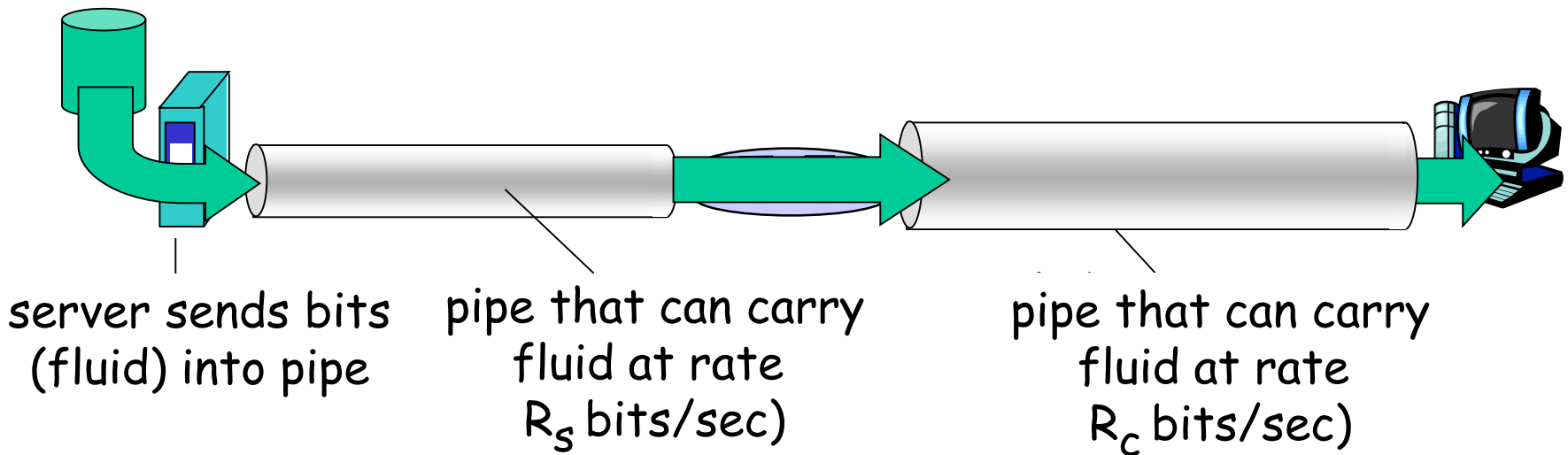
## Packet loss

- ❑ 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



# Throughput

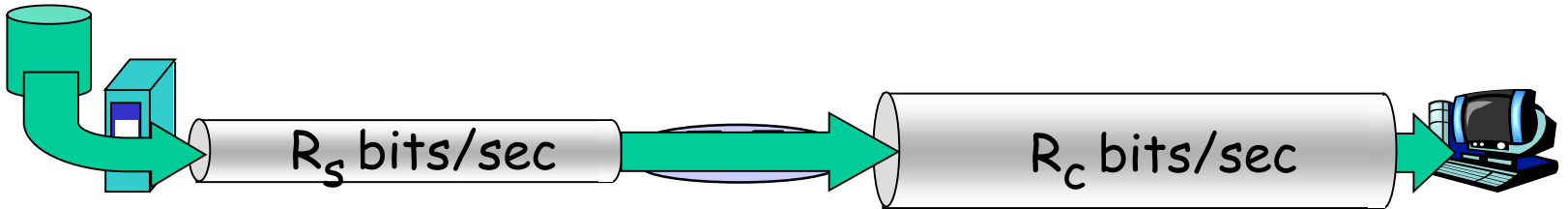
- ❑ *throughput*: rate (bits/time unit) at which bits transferred between sender/receiver
  - ❖ *instantaneous*: rate at given point in time
  - ❖ *average*: rate over longer period of time



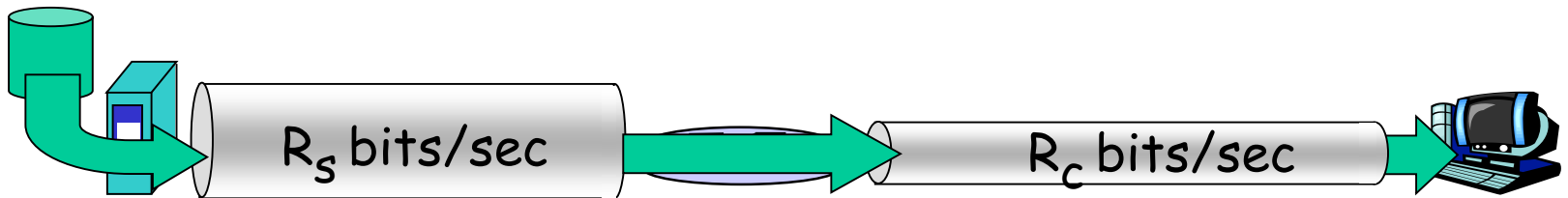


# Throughput (more)

□  $R_s < R_c$  What is average end-end throughput?



□  $R_s > R_c$  What is average end-end throughput?

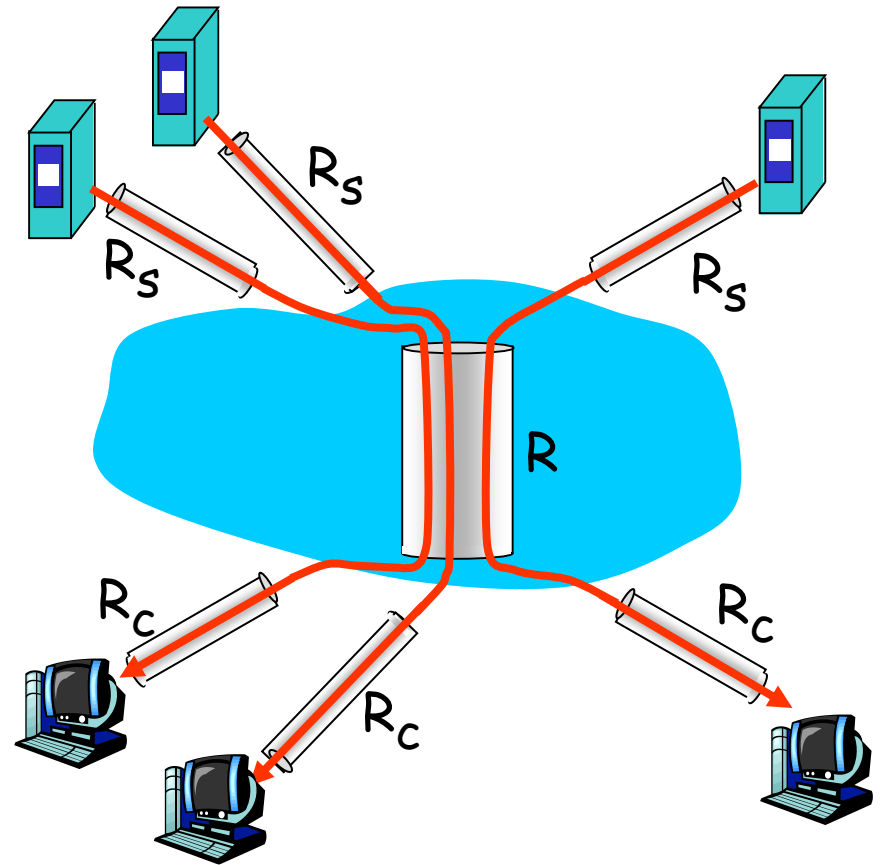


*bottleneck link*

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

# Chapter 1: roadmap

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1.5 Protocol layers, service models

1.6 Networks under attack: security

1.7 History

# Protocol "Layers"

## Networks are complex!

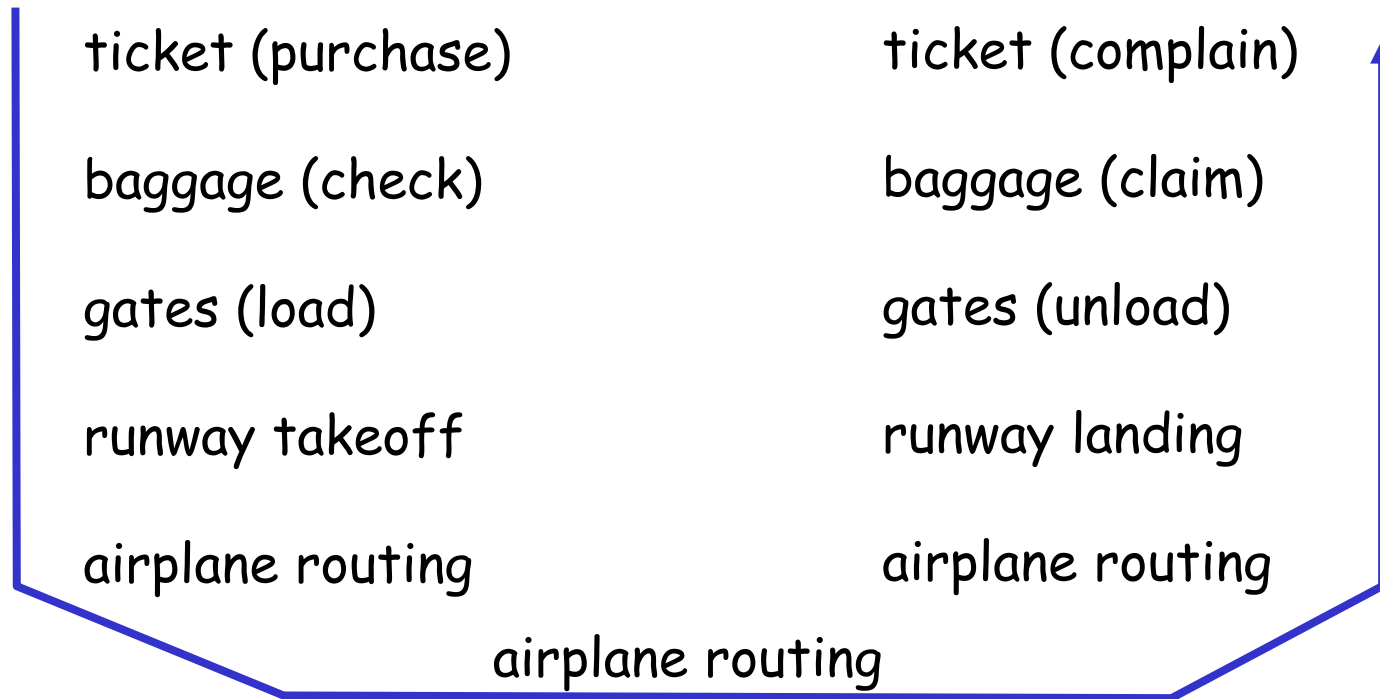
- ❑ many "pieces":
  - ❖ hosts
  - ❖ routers
  - ❖ links of various media
  - ❖ applications
  - ❖ protocols
  - ❖ hardware, software

## Question:

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

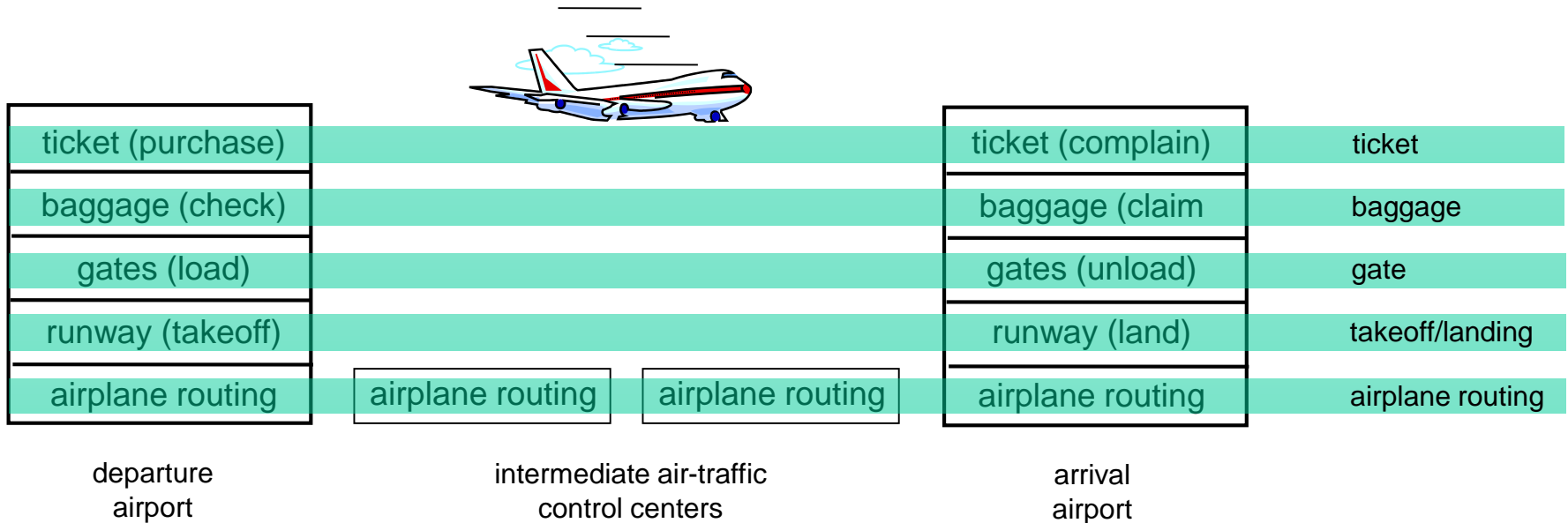
Or at least our discussion  
of networks?

# 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

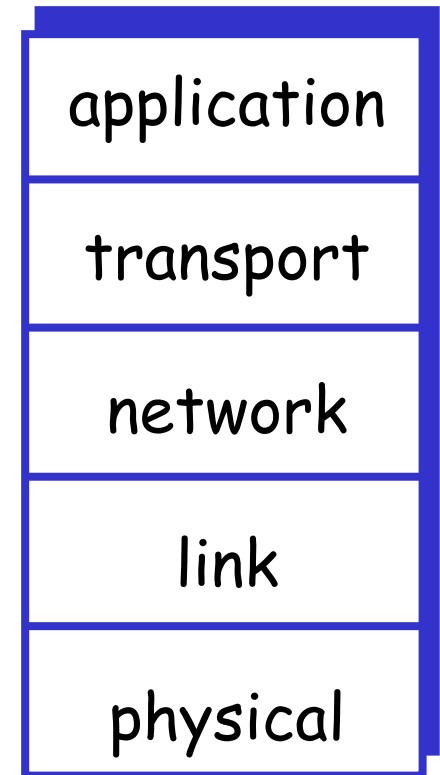
# Why layering?

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
- ❑ layering considered harmful?

# Internet protocol stack

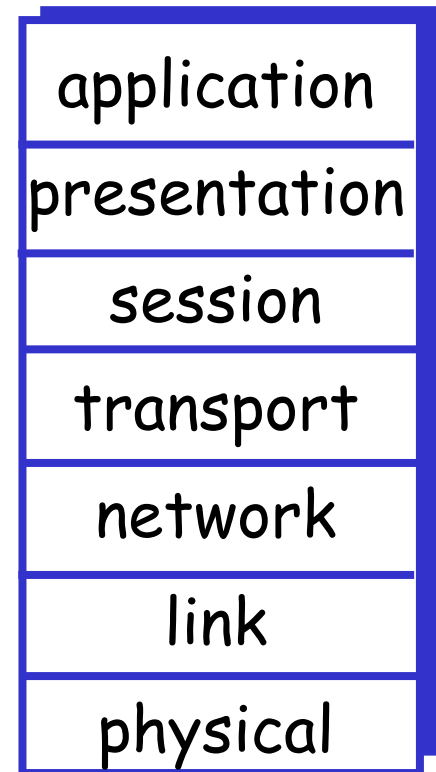
- ❑ **application:** supporting network applications
  - ❖ FTP, SMTP, HTTP
- ❑ **transport:** process-process data transfer
  - ❖ TCP, UDP
- ❑ **network:** routing of datagrams from source to destination
  - ❖ IP, routing protocols
- ❑ **link:** data transfer between neighboring network elements
  - ❖ PPP, Ethernet
- ❑ **physical:** bits “on the wire”



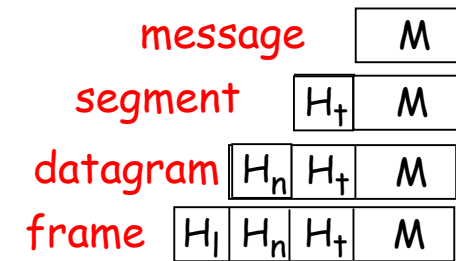


# ISO/OSI reference model

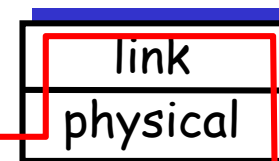
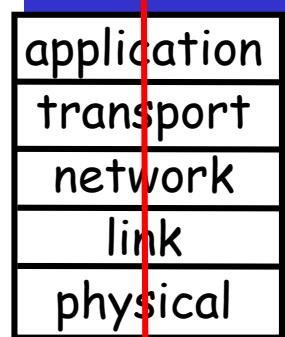
- ❑ **presentation:** allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- ❑ **session:** synchronization, checkpointing, recovery of data exchange
- ❑ Internet stack “missing” these layers!
  - ❖ these services, *if needed*, must be implemented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



# Encapsulation

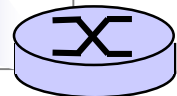
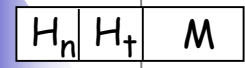
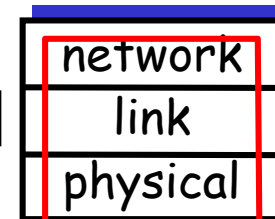
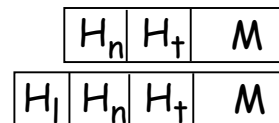
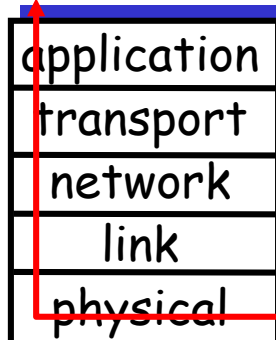


source



switch

destination



router

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1.7 History

# Network Security

- ❑ The field of network security is about:
  - ❖ 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 can put malware into hosts via Internet

- ❑ Malware can get in host from a **virus**, **worm**, or **trojan horse**.
- ❑ **Spyware malware** can record keystrokes, web sites visited, upload info to collection site.
- ❑ Infected host can be enrolled in a **botnet**, used for spam and DDoS attacks.
- ❑ Malware is often **self-replicating**: from an infected host, seeks entry into other hosts

# Bad guys can put malware into hosts via Internet

## ❑ Trojan horse

- ❖ Hidden part of some otherwise useful software
- ❖ Today often on a Web page (Active-X, plugin)

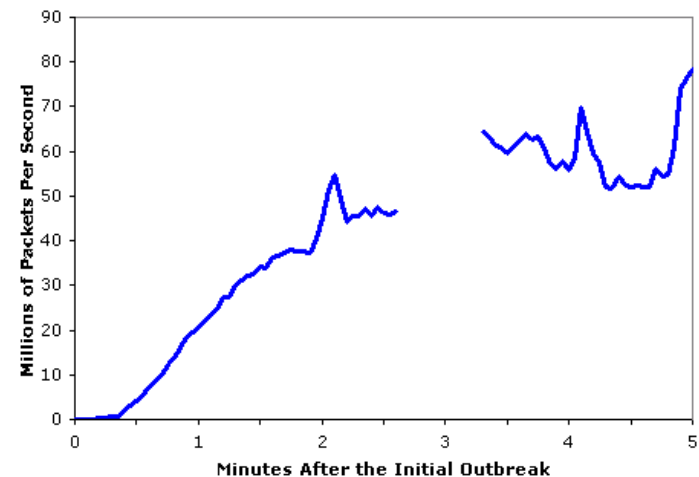
## ❑ Virus

- ❖ infection by receiving object (e.g., e-mail attachment), actively executing
- ❖ self-replicating: propagate itself to other hosts, users

## ❑ Worm:

- ❖ infection by passively receiving object that gets itself executed
- ❖ self-replicating: propagates to other hosts, users

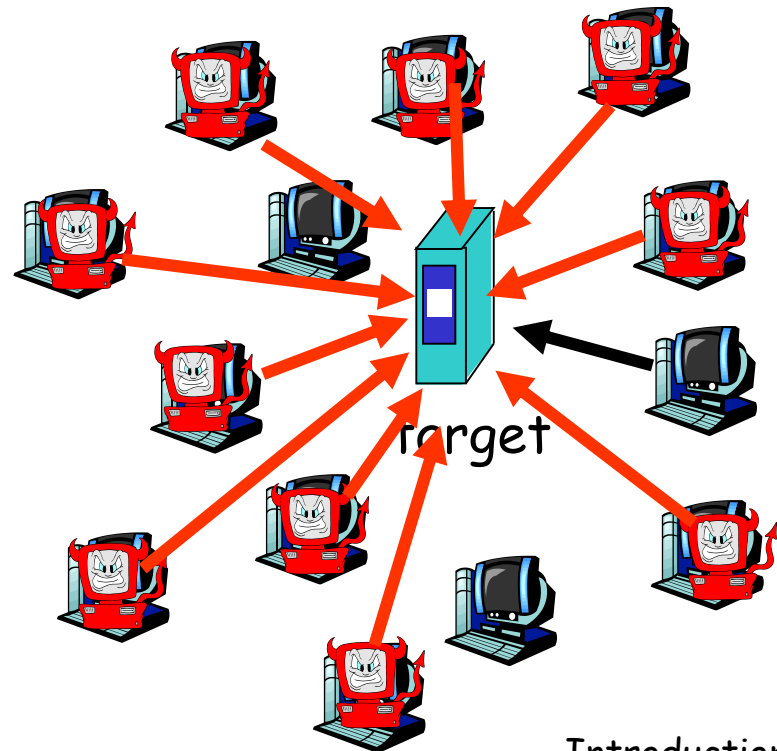
Sapphire Worm: aggregate scans/sec in first 5 minutes of outbreak (CAIDA, UWisc data)



# Bad guys can attack servers and network infrastructure

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

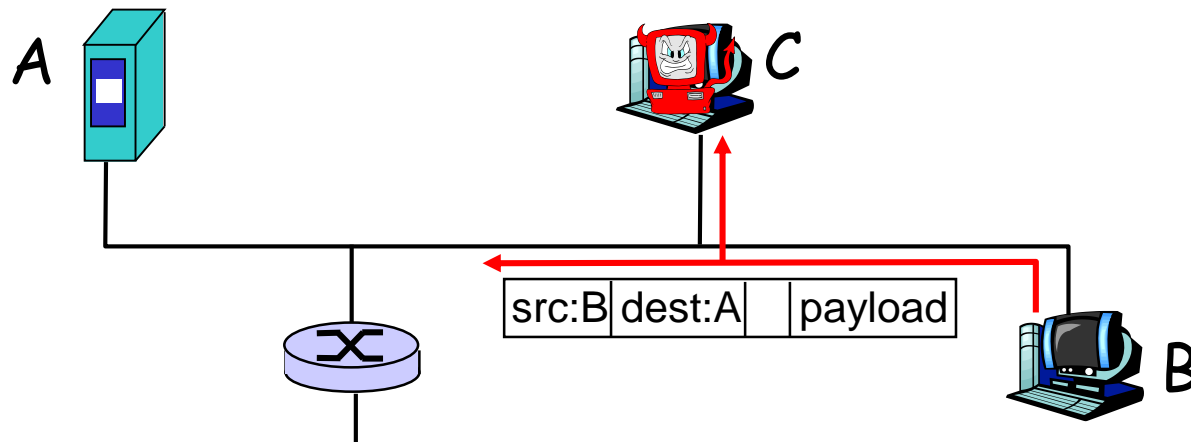
1. select target
2. break into hosts around the network (see botnet)
3. send packets toward target from compromised hosts



# The 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

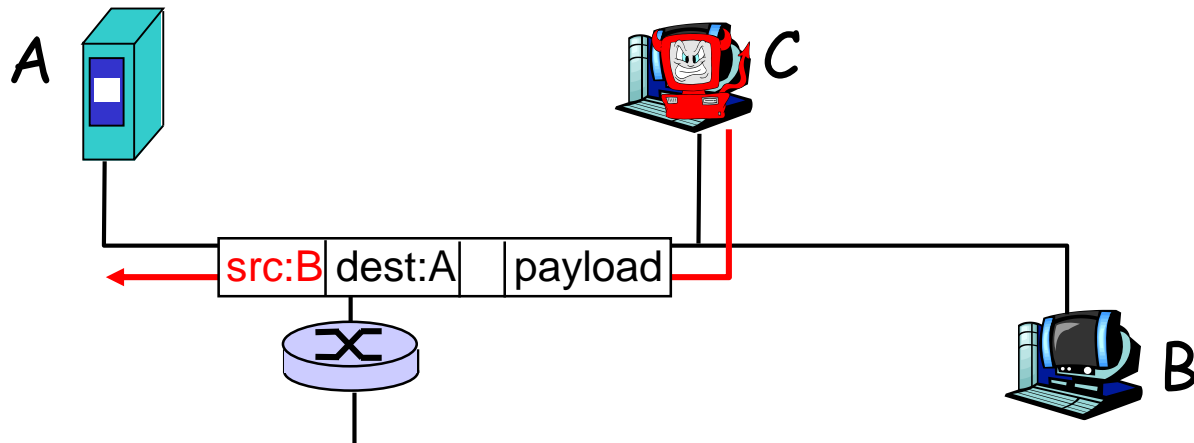


- ❖ Wireshark software used for end-of-chapter labs is a (free) packet-sniffer



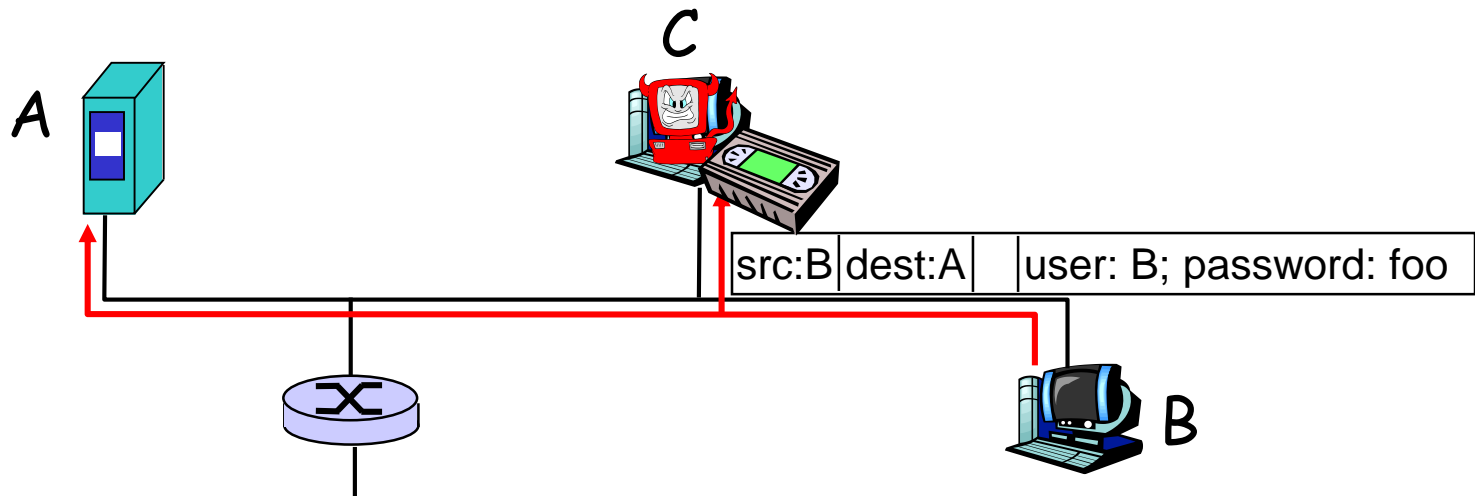
# The bad guys can use false source addresses

❑ *IP spoofing*: send packet with false source address



# The bad guys can record and playback

- ❑ *record-and-playback*: sniff sensitive info (e.g., password), and use later
  - ❖ password holder is that user from system point of view



# Network Security

- ❑ more throughout this course
- ❑ chapter 8: focus on security
- ❑ cryptographic techniques: obvious uses and not so obvious uses

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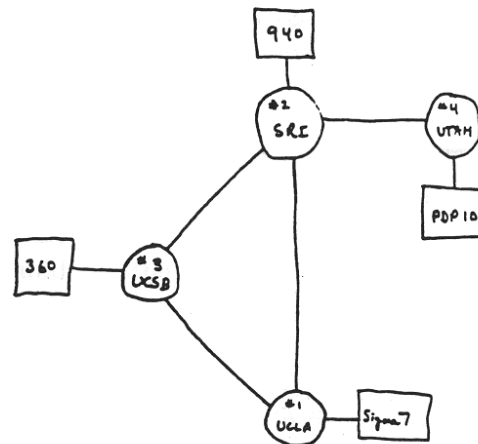
1.6 Networks under attack: security

1.7 History

# 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 demonstration
  - ❖ NCP (Network Control Protocol) first host-host protocol
  - ❖ first e-mail program
  - ❖ ARPAnet has 15 nodes



# Leonard Kleinrock

- ❑ Important contributions to networking
- ❑ In particular to the theoretical side of computer networking.
- ❑ Queuing theory



# 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
- ❑ late 70'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*

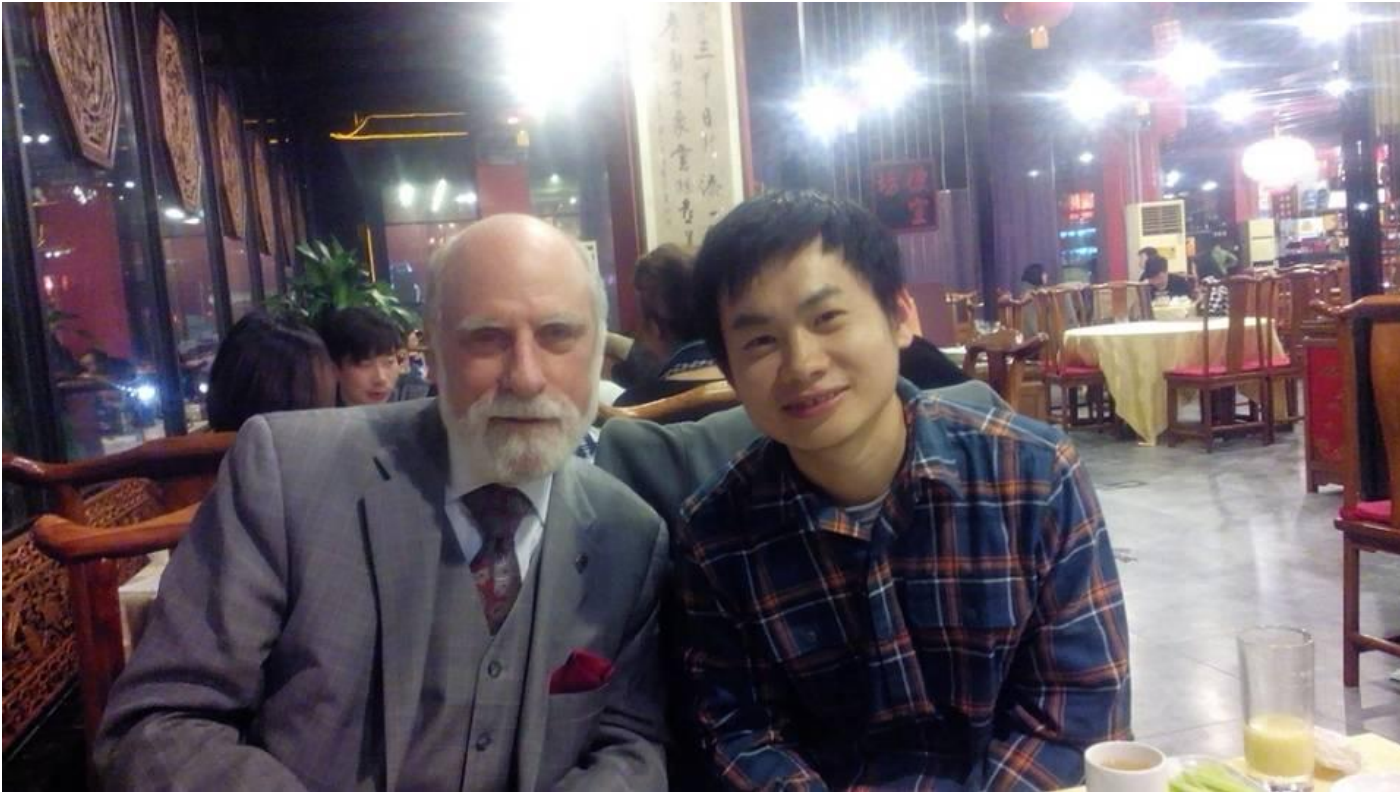
# Vint Cerf

- ❑ One of the fathers of Internet
- ❑ 2004 Turing Award Winner
- ❑ also known for his sartorial style, three-piece suit











# 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: Cset, 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

2007:

- ❑ ~500 million hosts
- ❑ Voice, Video over IP
- ❑ P2P applications: BitTorrent (file sharing) Skype (VoIP), PPLive (video)
- ❑ more applications: YouTube, gaming
- ❑ wireless, mobility

2010's -:

- ❑ Mobile apps: WeChat, Douyin, ...
- ❑ IoT devices: sensor, controller, embedded systems
- ❑ Extend to industrial scenarios

# 发展趋势

**互联网**深刻改变了社会生活。

联网终端数量即将突破**百亿**，超过全球人口数量。

未来将如何影响工业生产？



**1970s**

因特网

TCP/IP协议发明并应用

几十



**1990s**

万维网

WWW诞生并普及

百万



**2000s**

移动互联网

3G网络、智能手机

亿



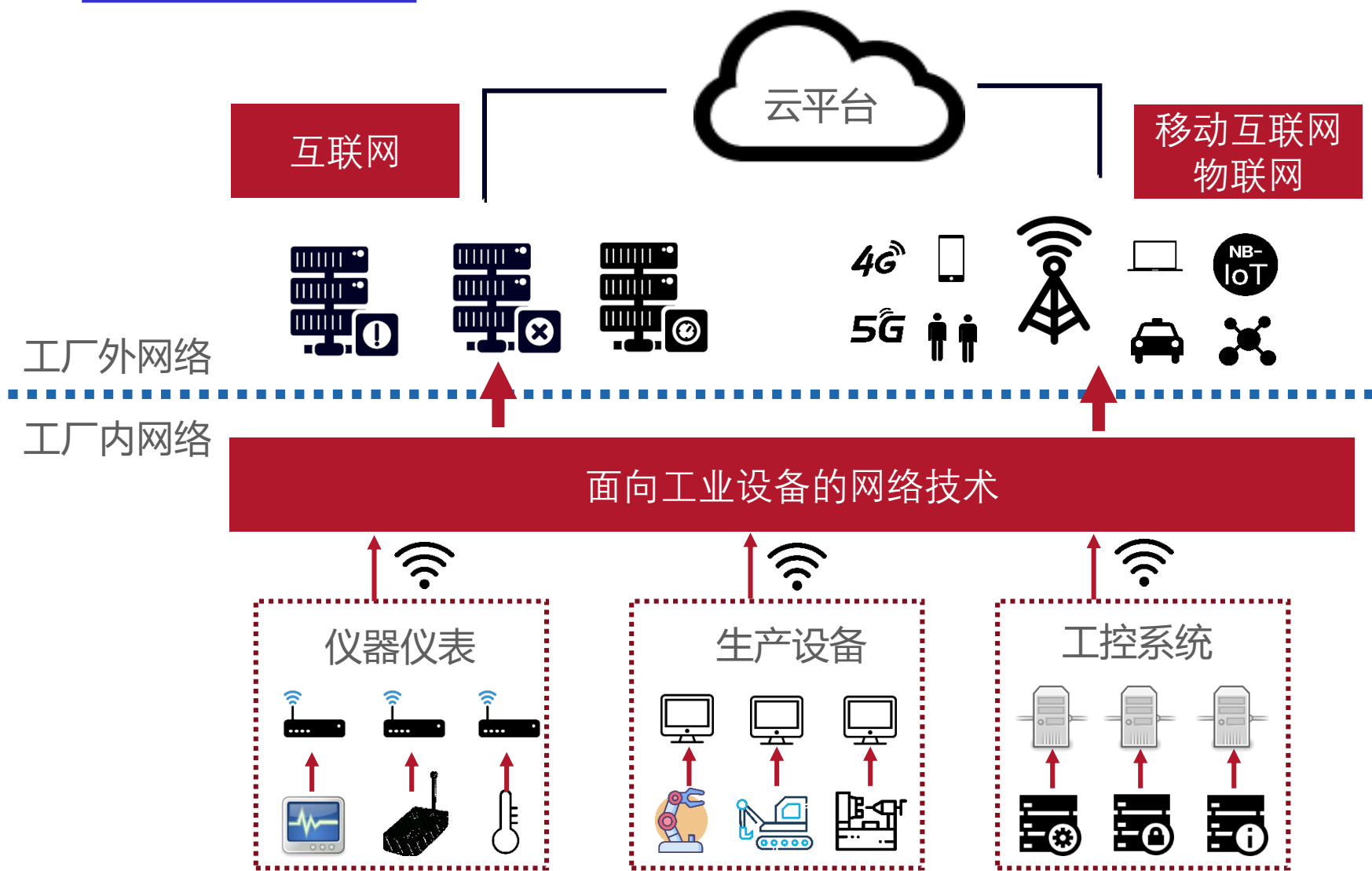
**2010s**

物联网

物联网、云计算、AI

十亿

# 发展趋势





# 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!