四川大學 SICHUAN UNIVERSITY 软件学院

COMPUTER NETWORK

CHAPTER 1

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

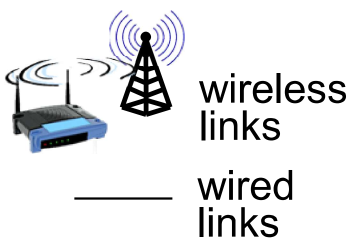
1.5 protocol layers, service models

1.6 networks under attack: security

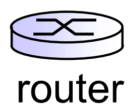
1.7 history

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

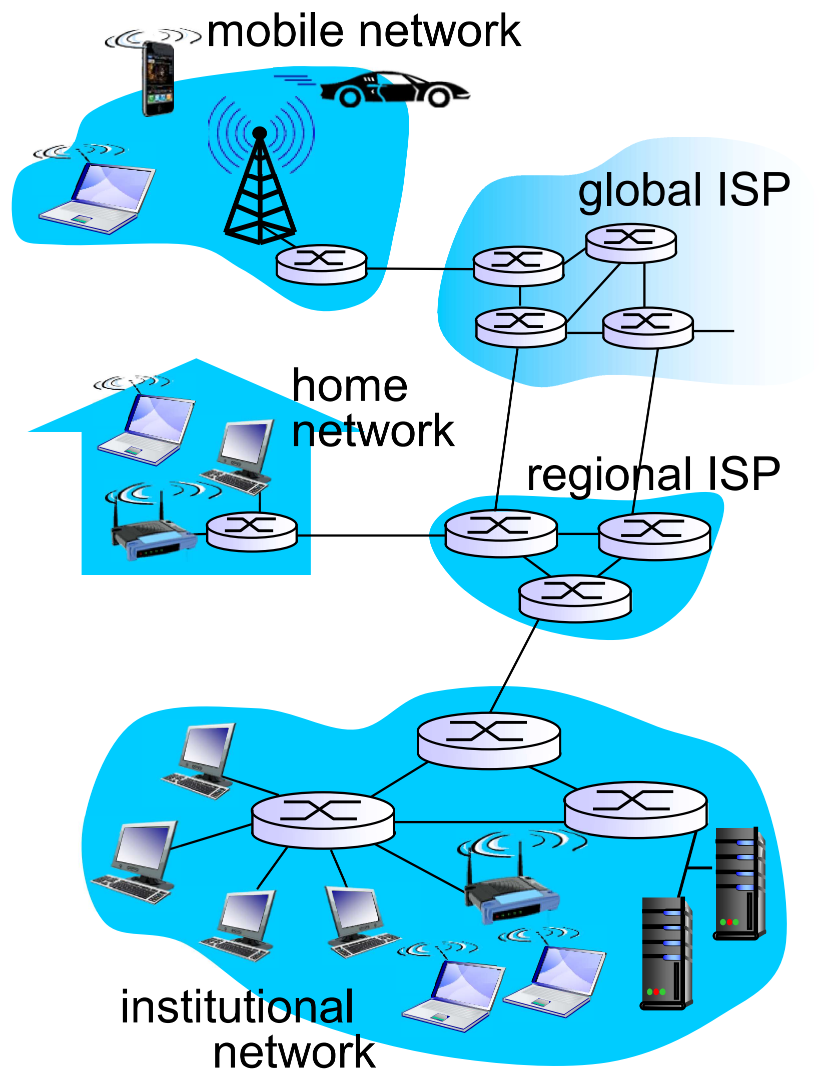
- millions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*



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



- *Packet switches:* forward packets (chunks of data)
  - *routers* and *switches*

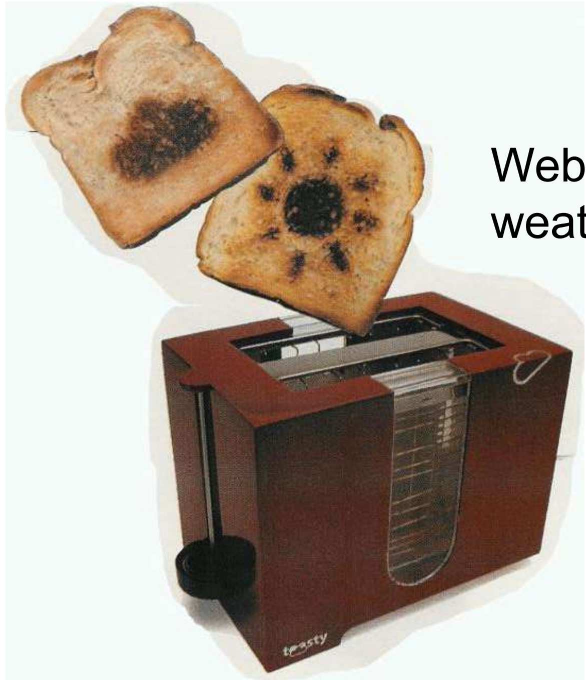


End System

- The Internet interconnects hundreds of millions of traditional and nontraditional Internet devices.
  - desktop PCs, Linux workstations, and servers
  - laptops, smartphones, tablets, TVs, gaming consoles, Web cams, automobiles, environmental sensing devices, picture frames, and home electrical and security systems （ host or end system ）
- End systems are connected together by a network of communication links and packet switches.

“Fun” internet appliances

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



Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

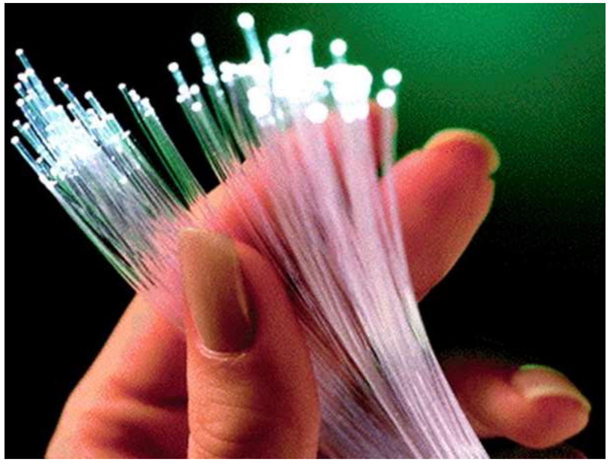
Internet
refrigerator

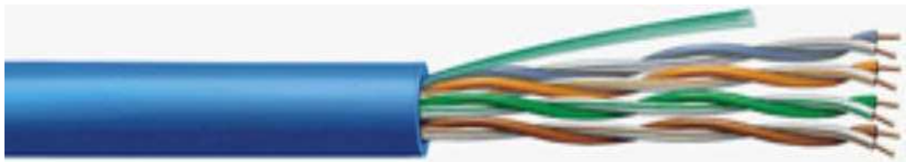
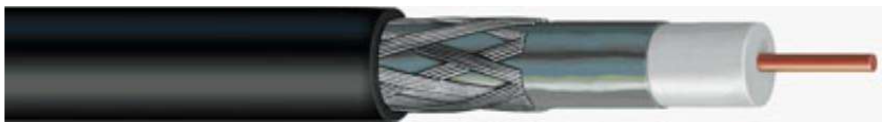
Slingbox: watch,
control cable TV remotely

Internet phones

Communication Links

- Many types of communication links made up of different types of physical media
  - coaxial cable, copper wire, optical fiber, and radio spectrum
- Different links can transmit data at different rates
  - the transmission rate: bits/second



Packet Switch

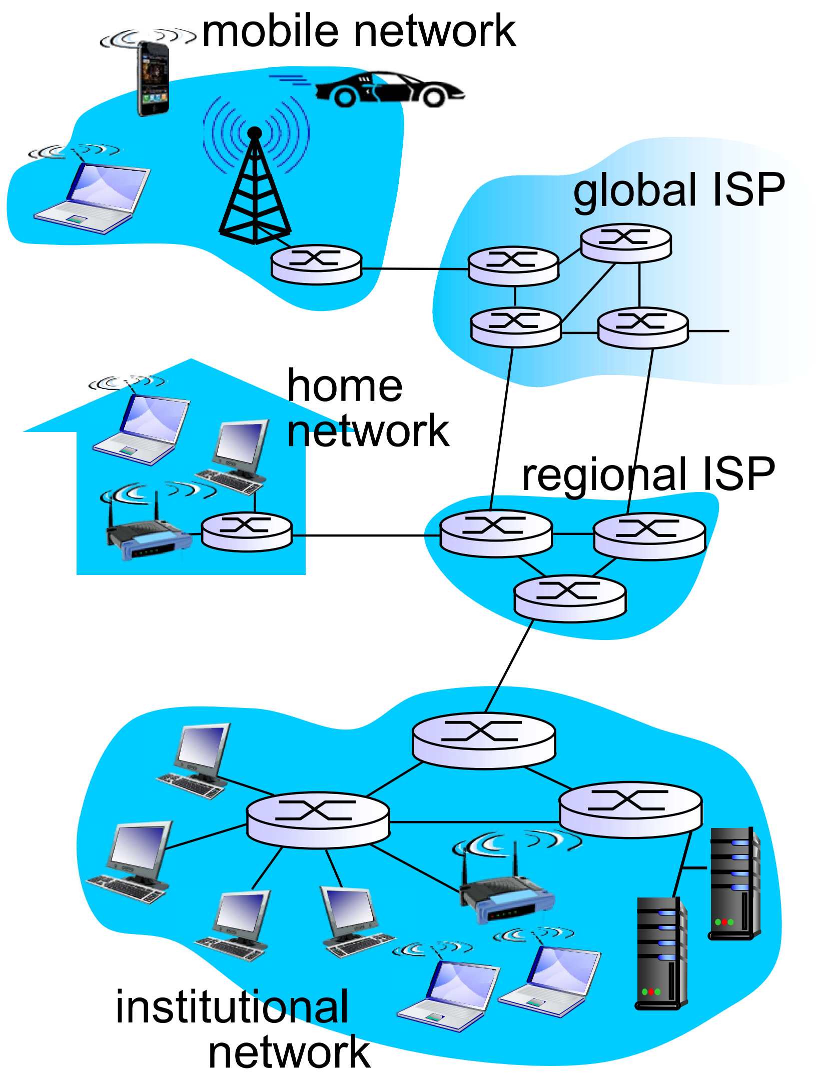
- packet: the sending end system segments the data and adds header bytes to each segment.
- packet switch: forward packets
  - link-layer switch : typically used in access networks
  - router : typically used in the network core
- route or path: the sequence of communication links and packet switches traversed by a packet from the sending end system to the receiving end system



Packet-switched networks-Transportation networks

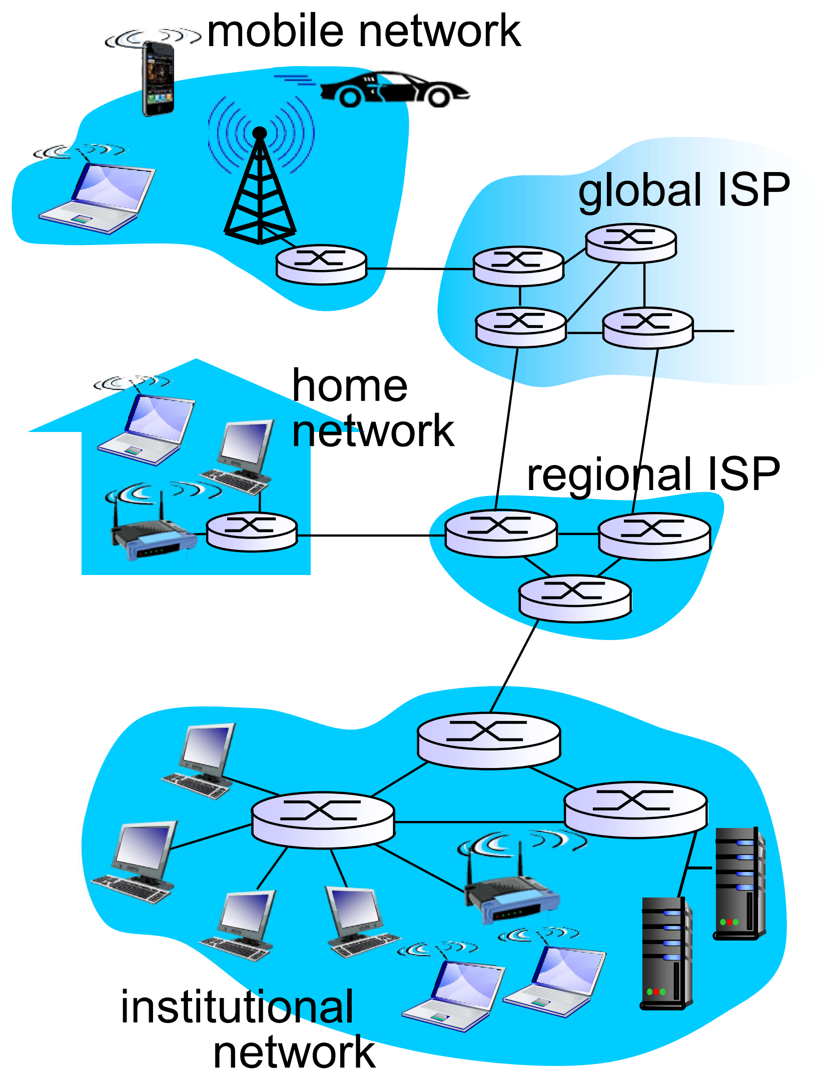
ISP

- ISP
  - residential ISPs
  - corporate ISPs; university ISPs;
  - ISPs that provide WiFi access.
- Each ISP is in itself a network of packet switches and communication links
- Networks of networks
  - Interconnected end systems
  - Interconnected ISPs



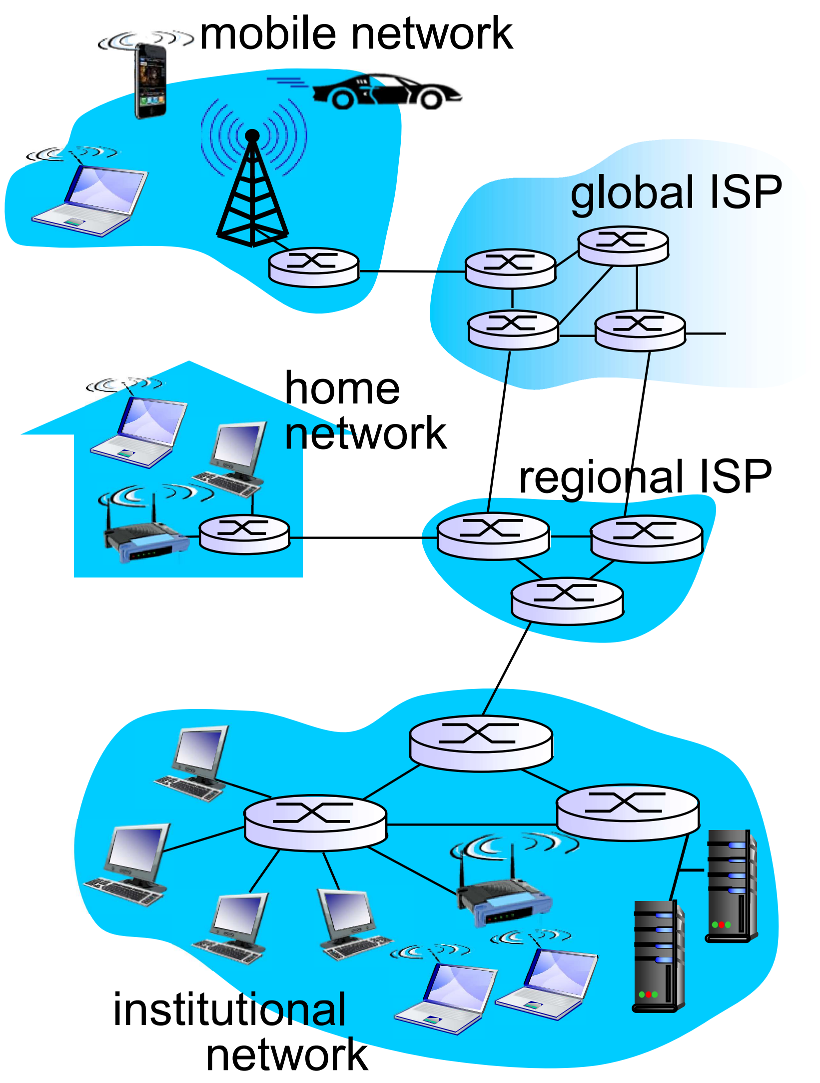
Protocol

- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  - IETF: Internet Engineering Task Force
  - RFC: Request for comments
    - www.ietf.org/rfc.html
  - More than 6,000 RFCs
    - TCP, IP,
    - HTTP (for the Web)
    - SMTP (for e-mail)



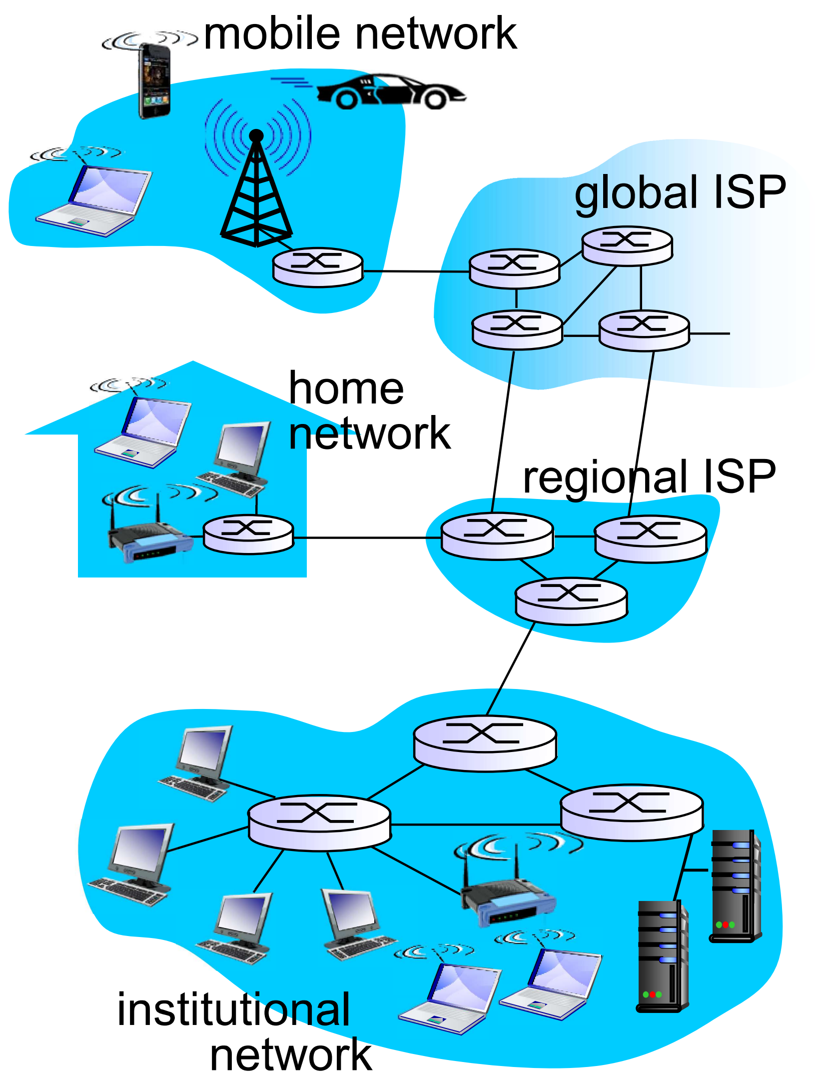
What's the Internet: a service view

- *Infrastructure that provides services to applications:*
  - distributed application: Web, VoIP, email, games, e-commerce, social nets, …
  - how to deliver data?
    - Internet is described as a platform for applications
    - End systems provide an Application Programming Interface (API)



What's the Internet: a service view

- *application programming interface (API) provided to apps*
  - Internet API is a set of rules that the sending program must follow
  - hooks that allow sending and receiving app programs to "connect" to Internet
  - provides service options, analogous to postal service
    - *example: Alice send a letter to Bob*



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:

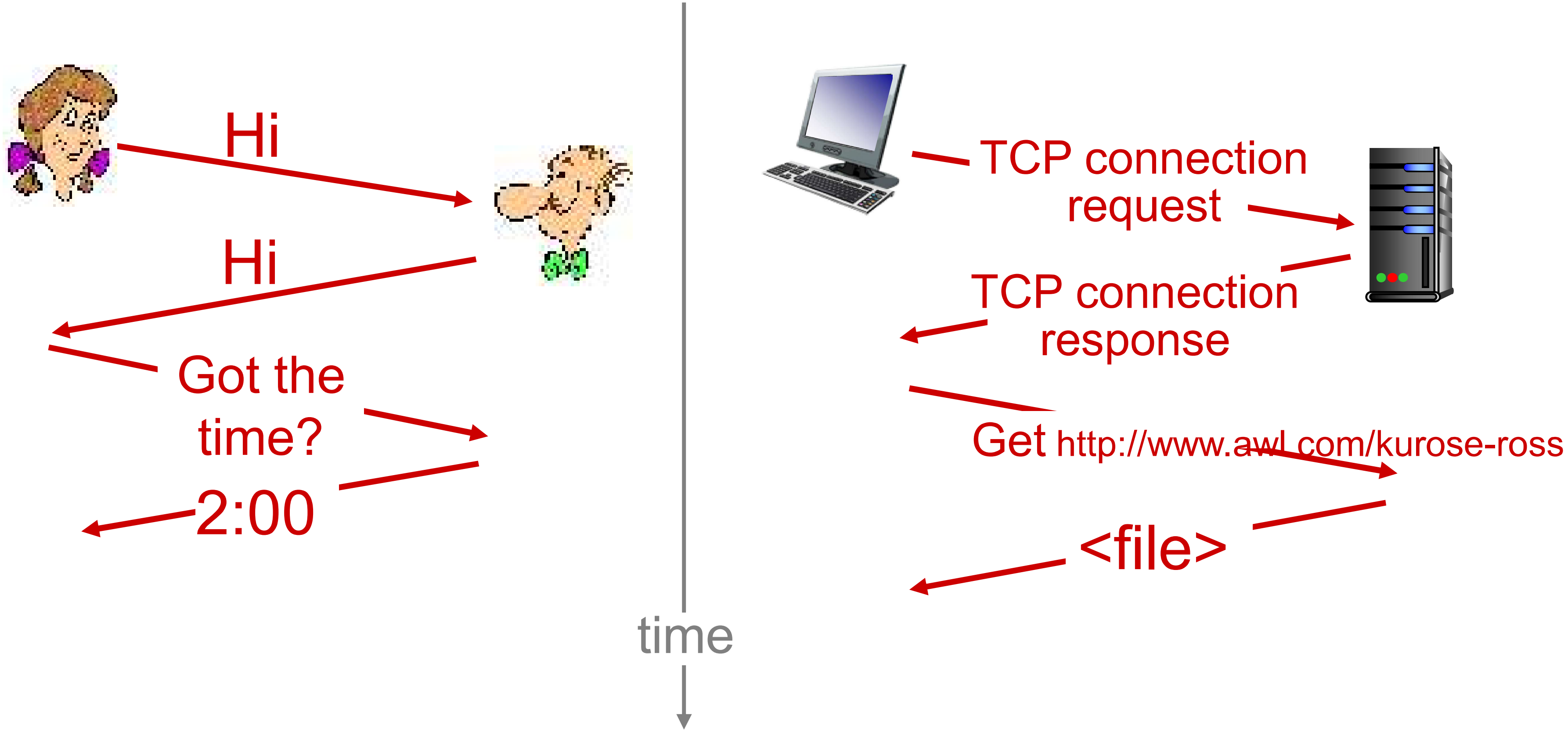
- machines rather than humans
- all communication activity in Internet governed by protocols

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

- ***Mastering the field of computer networking is equivalent to understanding the what, why, and how of networking protocols.***

What's a protocol?

a human protocol and a computer network protocol:



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

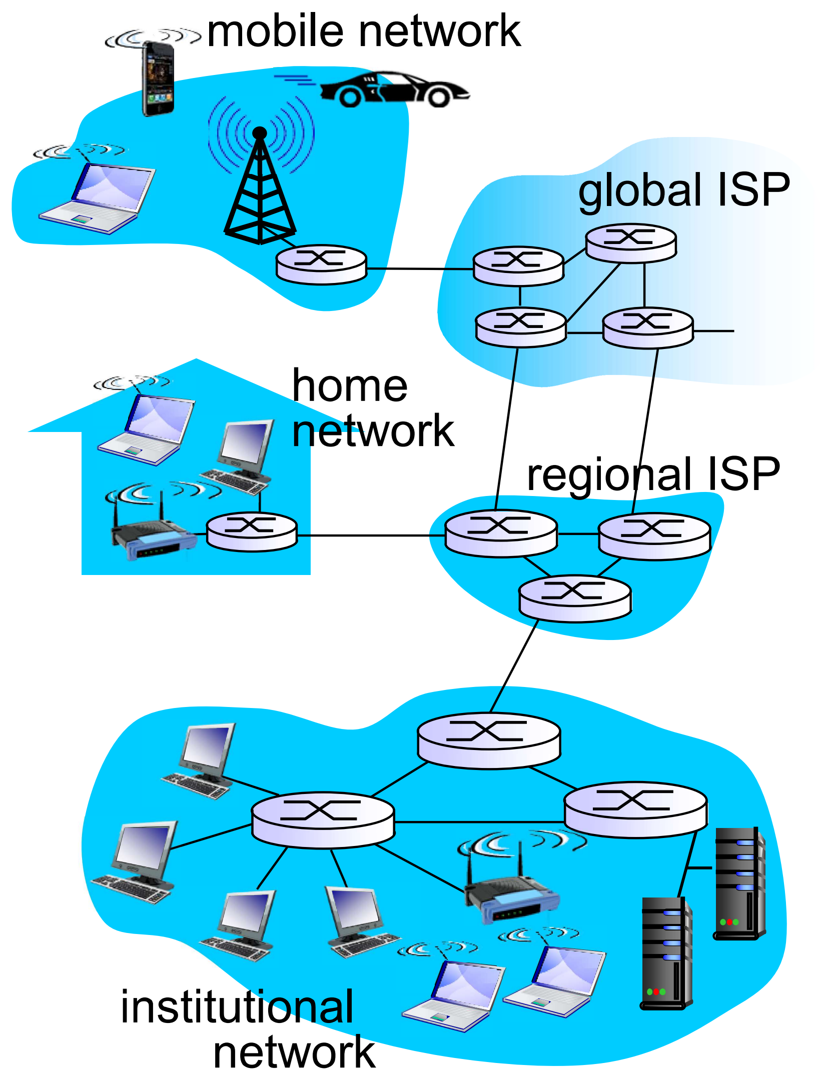
1.5 protocol layers, service models

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



The network edge:

- end systems
  - at "edge of network"
    - desktop computers
    - servers
    - mobile computers
    - non-traditional devices
- host = end systems
  - run(host) application programs(Web, email
  - clients:
    - desktop and mobile PCs, smartphones
  - servers:
    - more powerful machines
    - store and distribute Web pages, stream video, relay e-mail,
    - most reside in large data centers

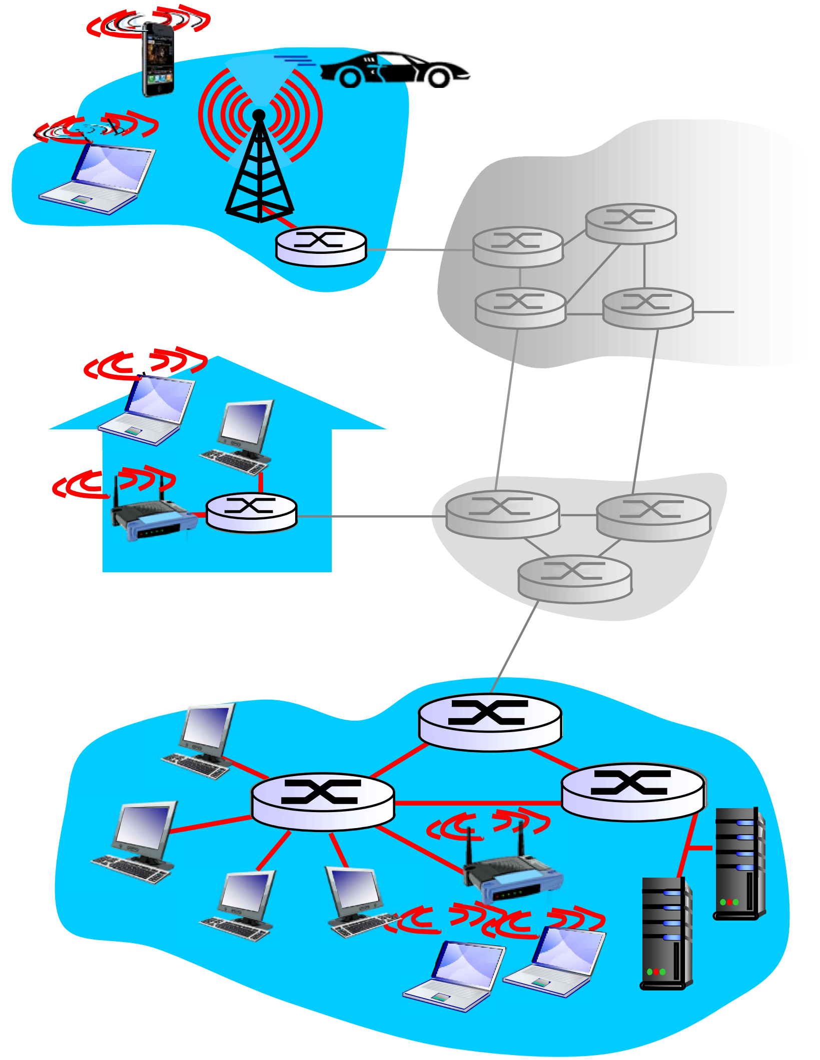
Access networks and physical media

access network: the network that physically connects an end system to the edge router.

edge router: the first router on a path from the end system to any other distant end system.

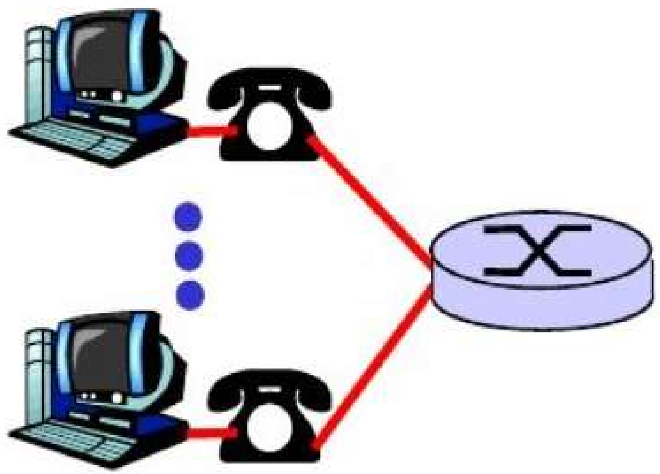
Q: How to connect end systems to edge router?

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

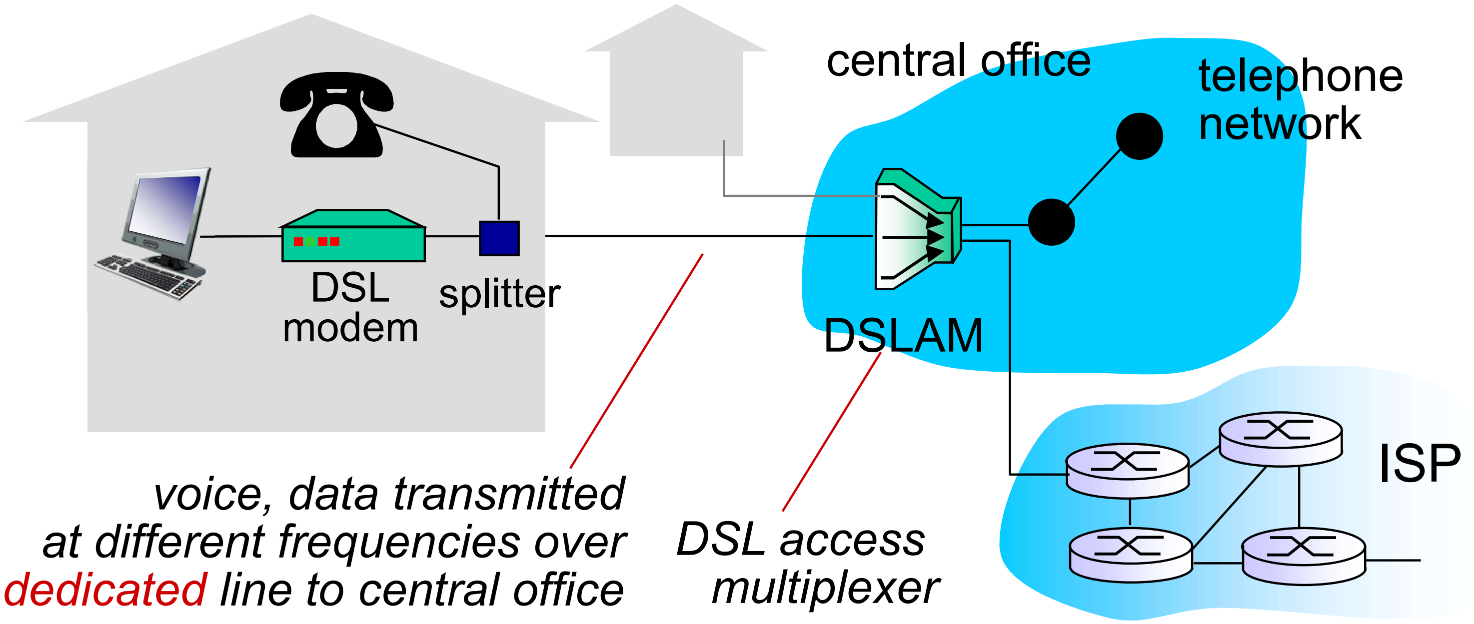


Home access: Dial-Up(拨号上网）

- Dial-up access over traditional phone lines
  - a home modem connects over a phone line to a modem in the ISP.
  - dial-up access is excruciatingly slow at 56 kbps.
  - Can't access the Internet and make phone calls at the same time

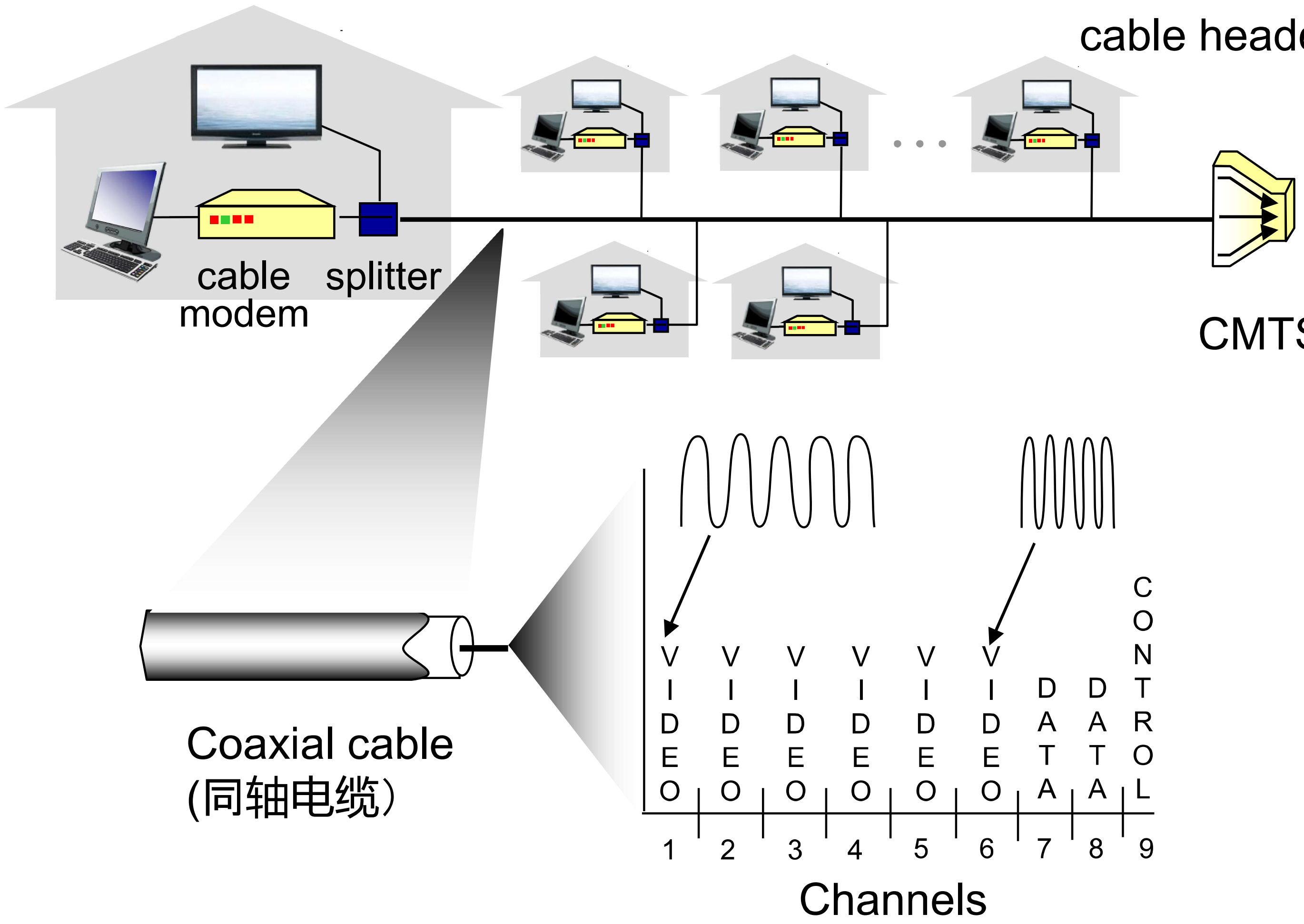


Home Access: digital subscriber line (DSL)



- 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
  - phone: 0-4kHz upstream:4-50KHz downstream: 50KHz-1MHz
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

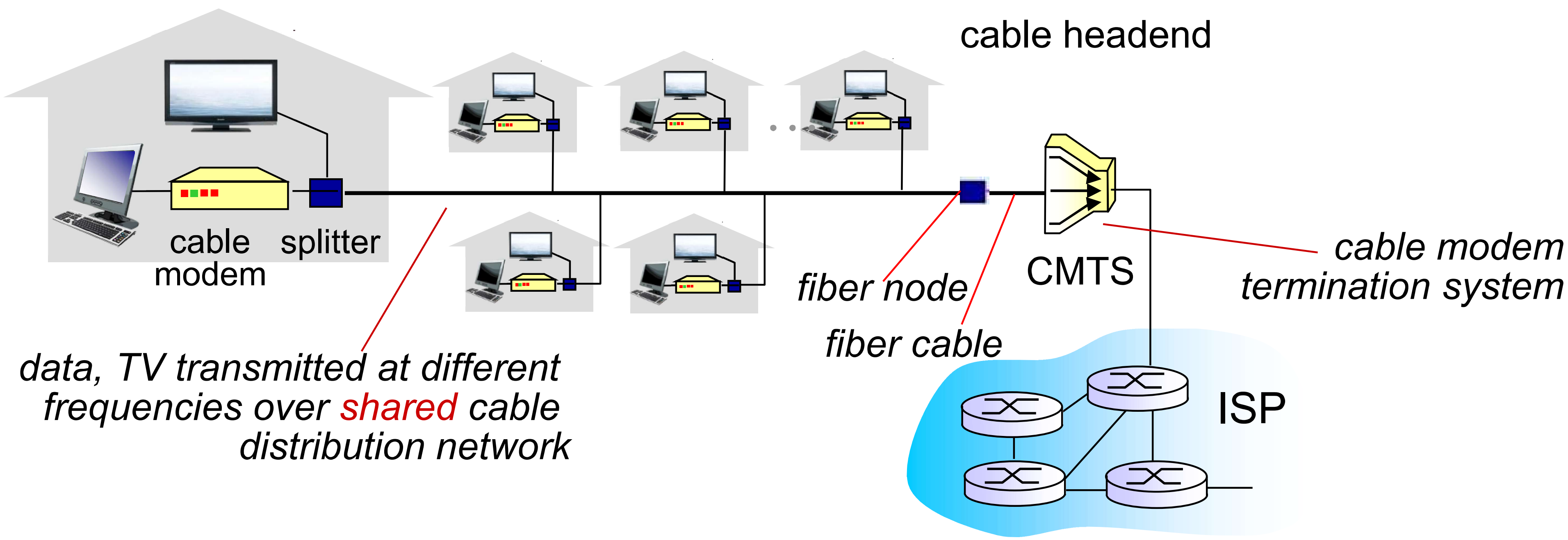
Access net: cable network（电缆网络接入）



Up: 30.7Mbps
Down: 42.8Mbps

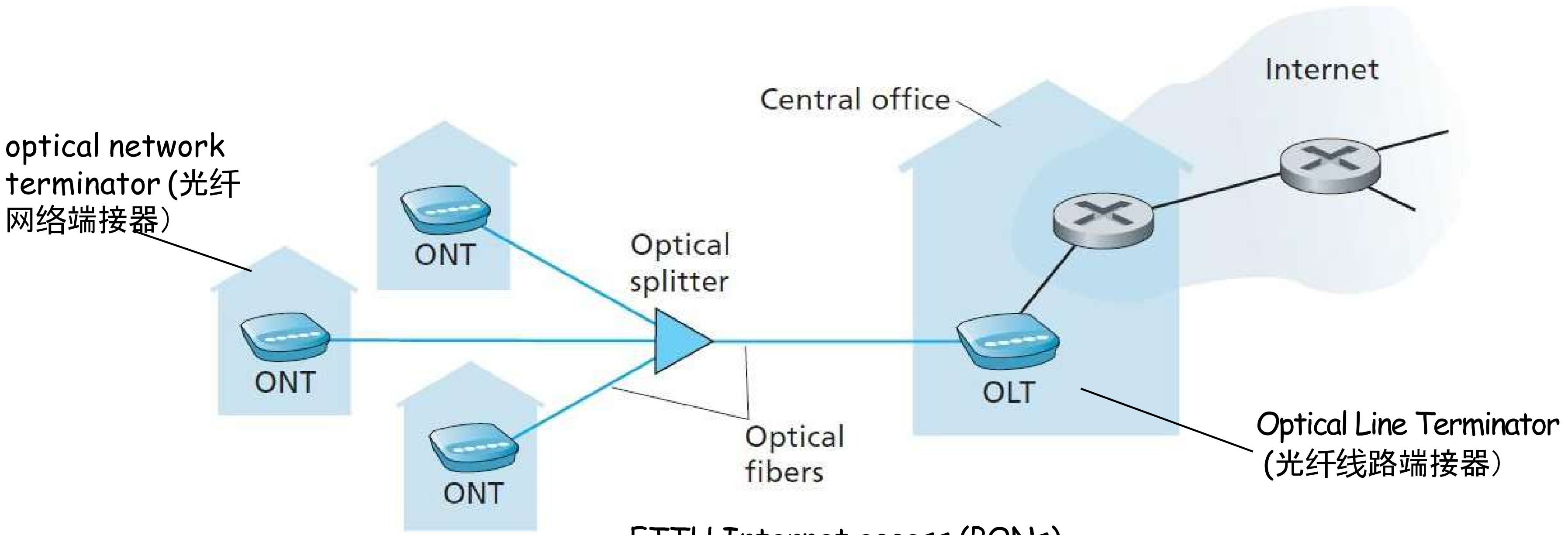
frequency division multiplexing: different channels transmitted in different frequency bands

Access net: cable network（电缆网络接入）



- HFC: hybrid fiber coax（混合光纤同轴）
  - 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(500~5000)
  - unlike DSL, which has dedicated access to central office

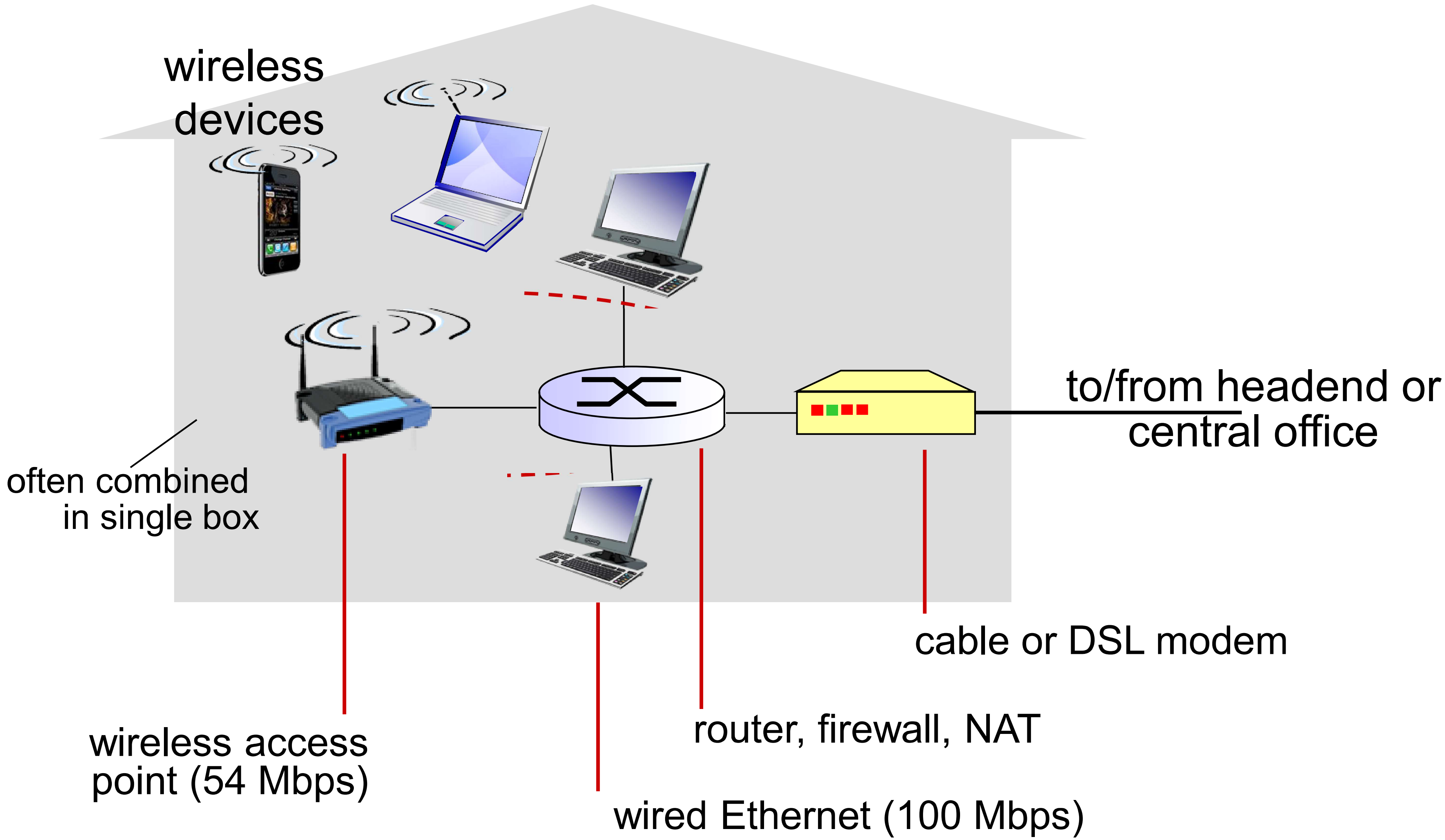
Home Access: fiber to the home(FTTH)



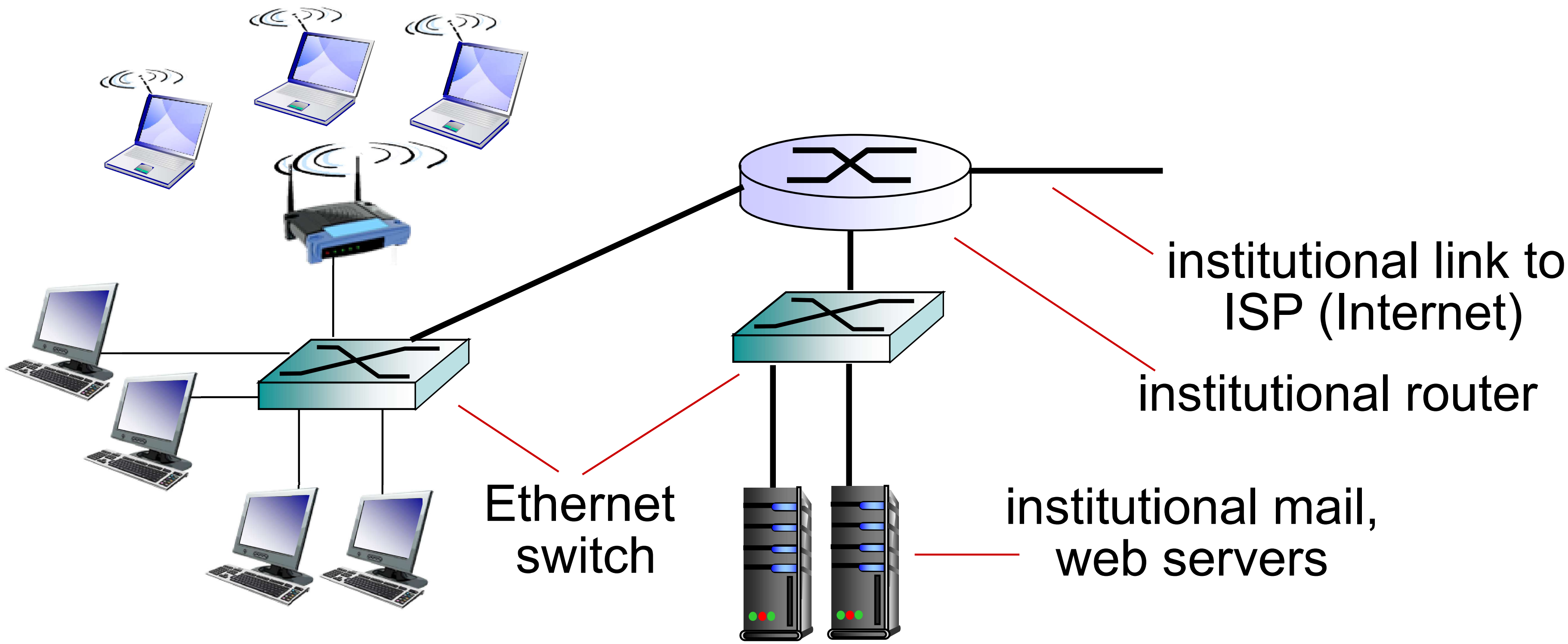
FTTH Internet access (PONs)

- optical-distribution network architectures:
  - active optical network (AON)
  - passive optical network (PON)
- Each home has ONT, which is connected by dedicated optical fiber to a neighborhood splitter.
  - OLT provides conversion between optical and electrical signals
  - Splitter combines a number of homes (typically <100) onto a single, shared optical fiber（光纤）(from home to OLT)

Typical home network



Enterprise access networks (Ethernet)

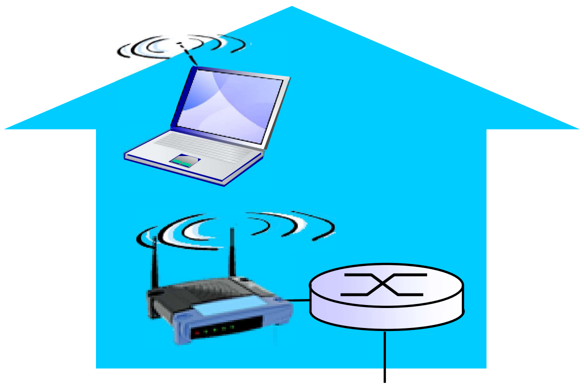


- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch
- Wireless LAN access based on IEEE 802.11 technology(WiFi) is now about everywhere.

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/n (WiFi): 11, 54,600 Mbps transmission rate



wide-area wireless access
- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE

Physical media

- bit: propagates between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver
- Examples of physical media
  - twisted-pair copper wire (双绞铜线), coaxial cable (同轴电 缆), multimode fiber-optic (多 模 光 纤), terrestrial radio spectrum (地面无线频谱), and satellite radio spectrum (卫星 无线频谱)
- guided media:
  - signals propagate in solid media:
    - fiber-optic cable, twisted-pair copper wire, coaxial cable
- unguided media:
  - signals propagate in atmosphere and in outer space
    - terrestrial(地面) radio spectrum, satellite radio spectrum

Physical media: twisted pair Copper Wire

- two insulated copper wires
  - wires are twisted together to reduce the electrical interference
  - The data rates can be achieved depend on the thickness of the wire and the distance between transmitter and receiver
    - Category 3: traditional telephone lines, 10Mbps Ehternet
    - Category 5: 100 Mbps, 1 Gbps Ethernet
    - Category 6: 10Gbps
- UTP and STP
  - UTP: Unshielded Twisted Pair
  - STP : Shielded Twisted-Pair

twisted pair Copper Wire(双绞线)


网线

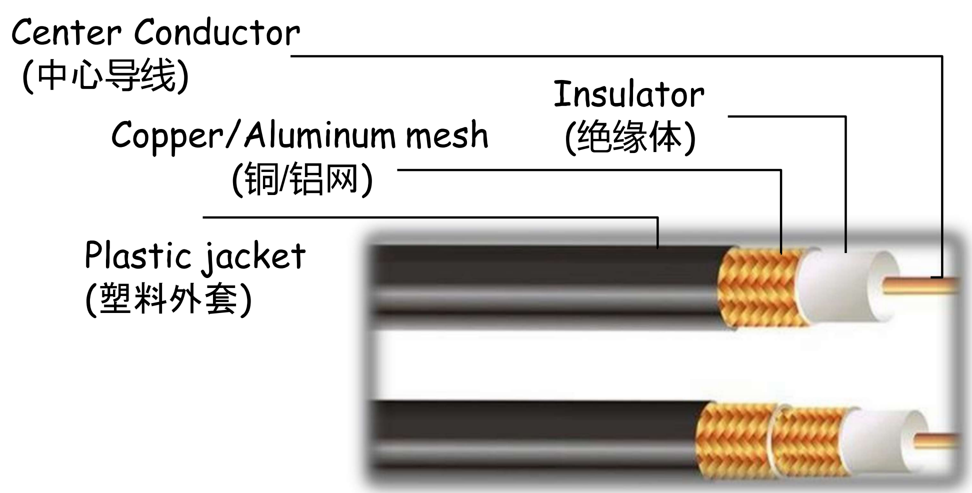

Unshielded Twisted Pair
(非屏蔽双绞线)


Shielded Twisted-Pair
(屏蔽双绞线)

Physical media: coax, fiber

coaxial cable:

- two concentric copper conductors（两个同心铜导体）
- bidirectional
- broadband:
  - multiple channels on cable
  - common in cable television (HFC)
  - tens of Mbps transmission rate



Physical media: fiber

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(中继器）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 radio channels
  - short distance(e.g. Bluetooth)
  - LAN (e.g., WiFi)
  - wide-area (e.g., cellular)
- satellite radio channels
  - hundreds of Mbps speed, but about 280 ms end-end delay
  - often used in areas without access to DSL or cable-based Internet access
  - geosynchronous satellites（同步卫星） versus low-earth orbiting satellites（近地轨道卫星）

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- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

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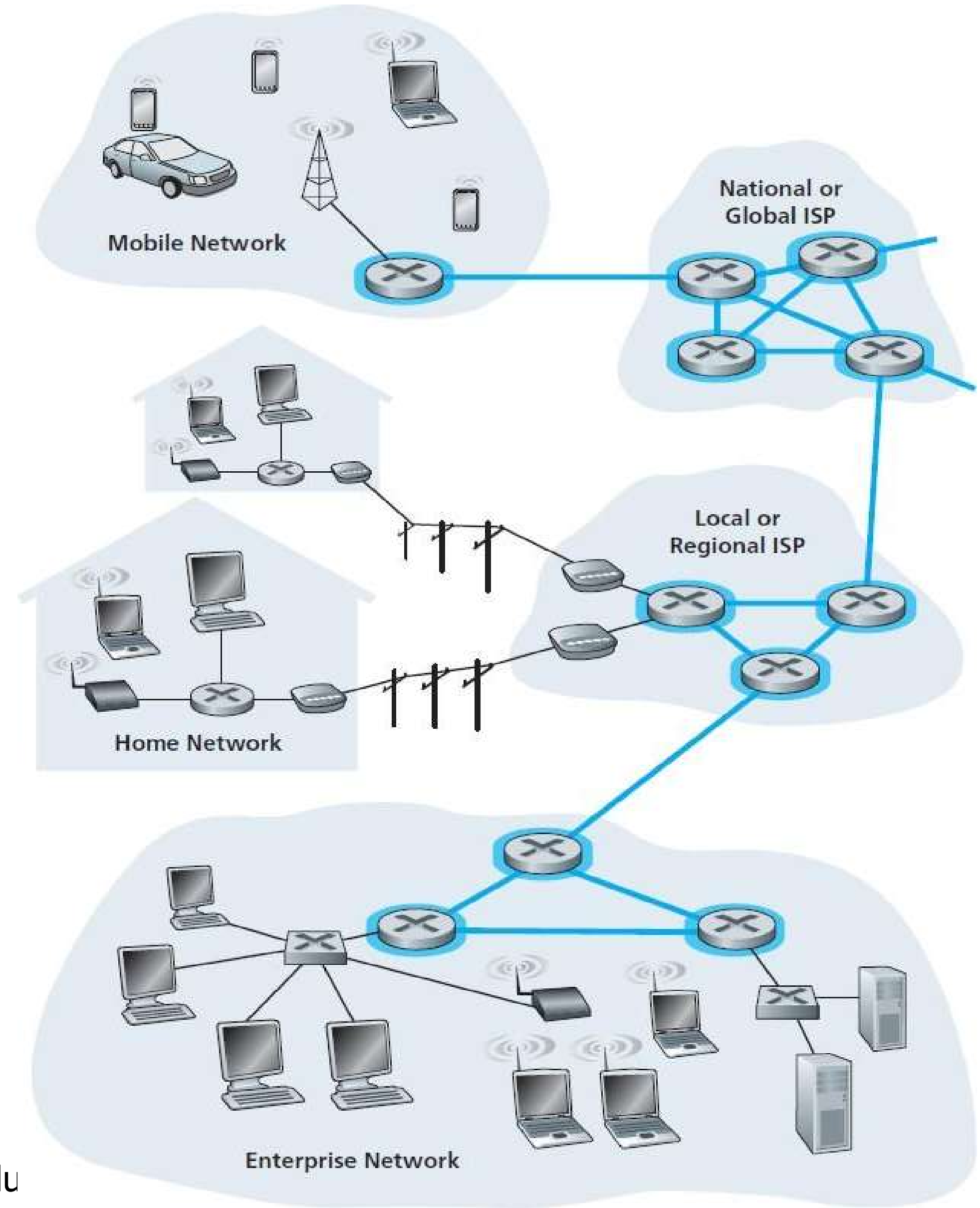
The network core

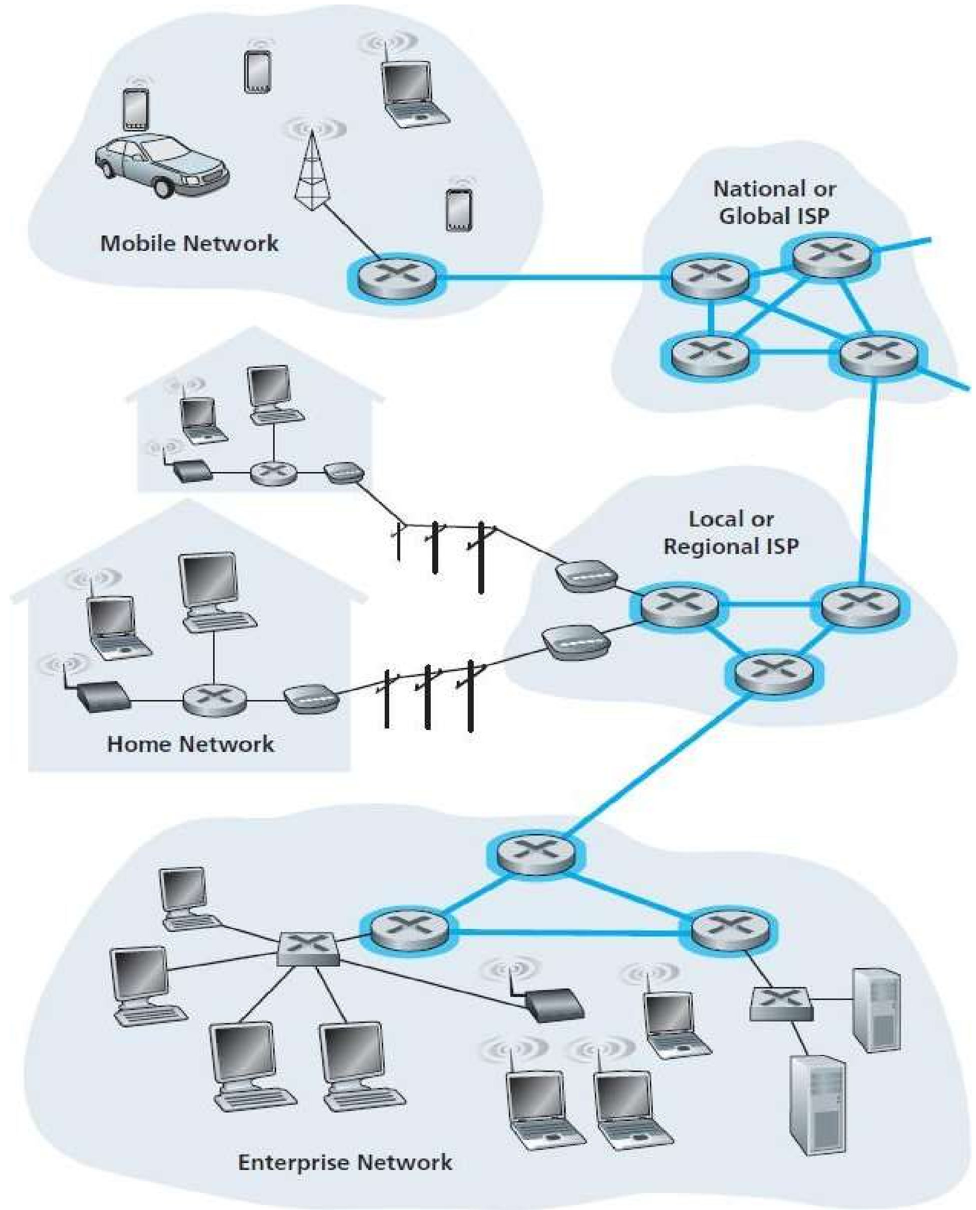
- *network core:* mesh of interconnected routers and links that interconnects routers
- two fundamental approaches to moving data: circuit switching and packet switching
- circuit-switched networks: the resources needed along a path for communication between the end systems are reserved
- packet-switched networks: these resources are not reserved; a session's messages use the resources on demand



- Introdu

The network core : Packet Switching

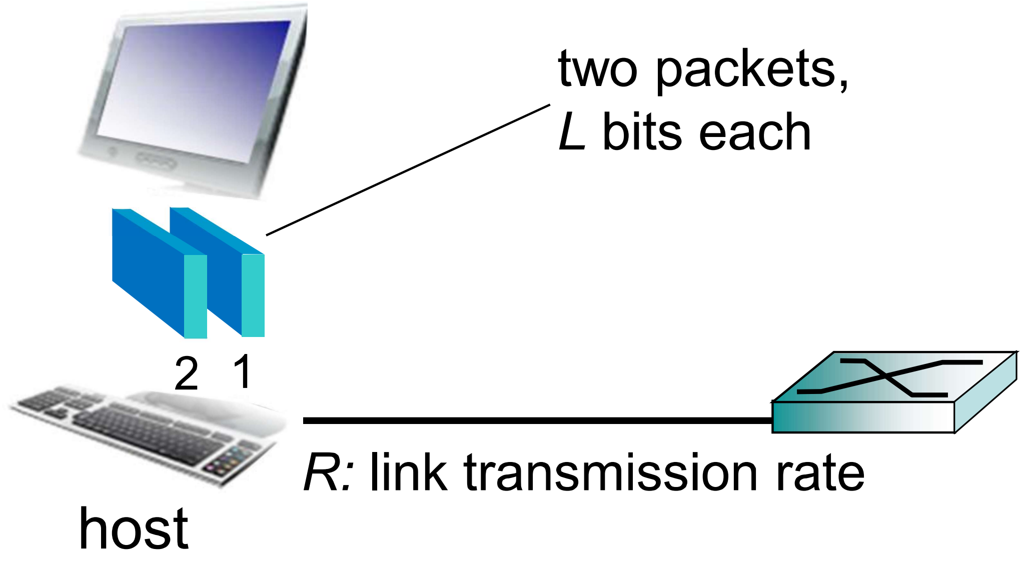
- end systems exchange messages(报文)with each other
- packet-switching: hosts break application-layer messages into *packets*（分组）
  - forward packets from one router to the next, across links on path from source to destination
  - each packet transmitted at full link capacity



Host: sends *packets* of data

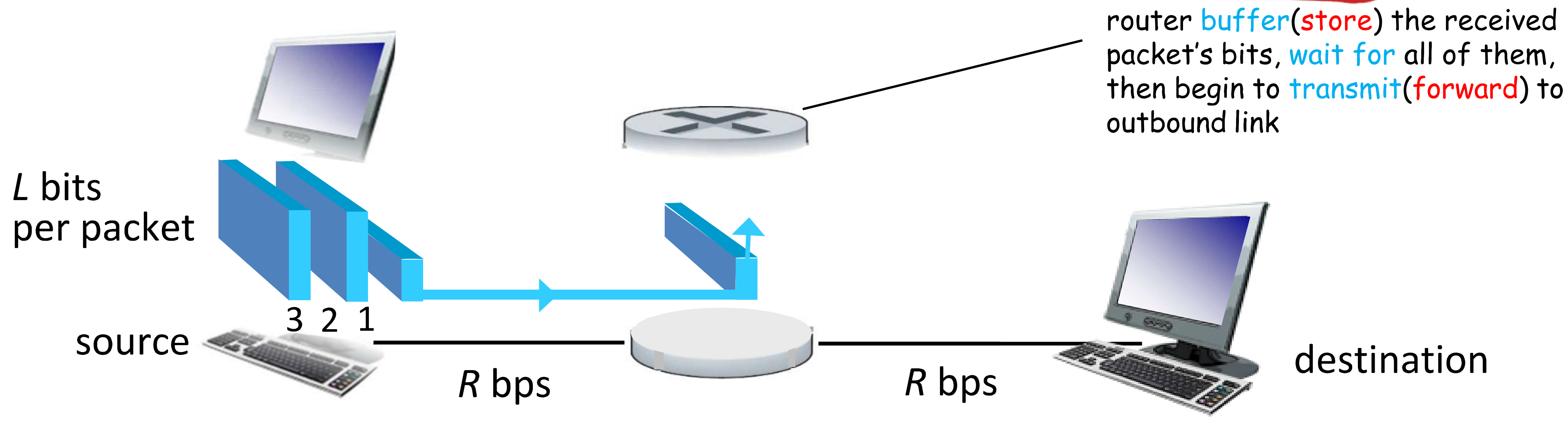
host sending function:

- 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*



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

Packet-switching: store-and-forward

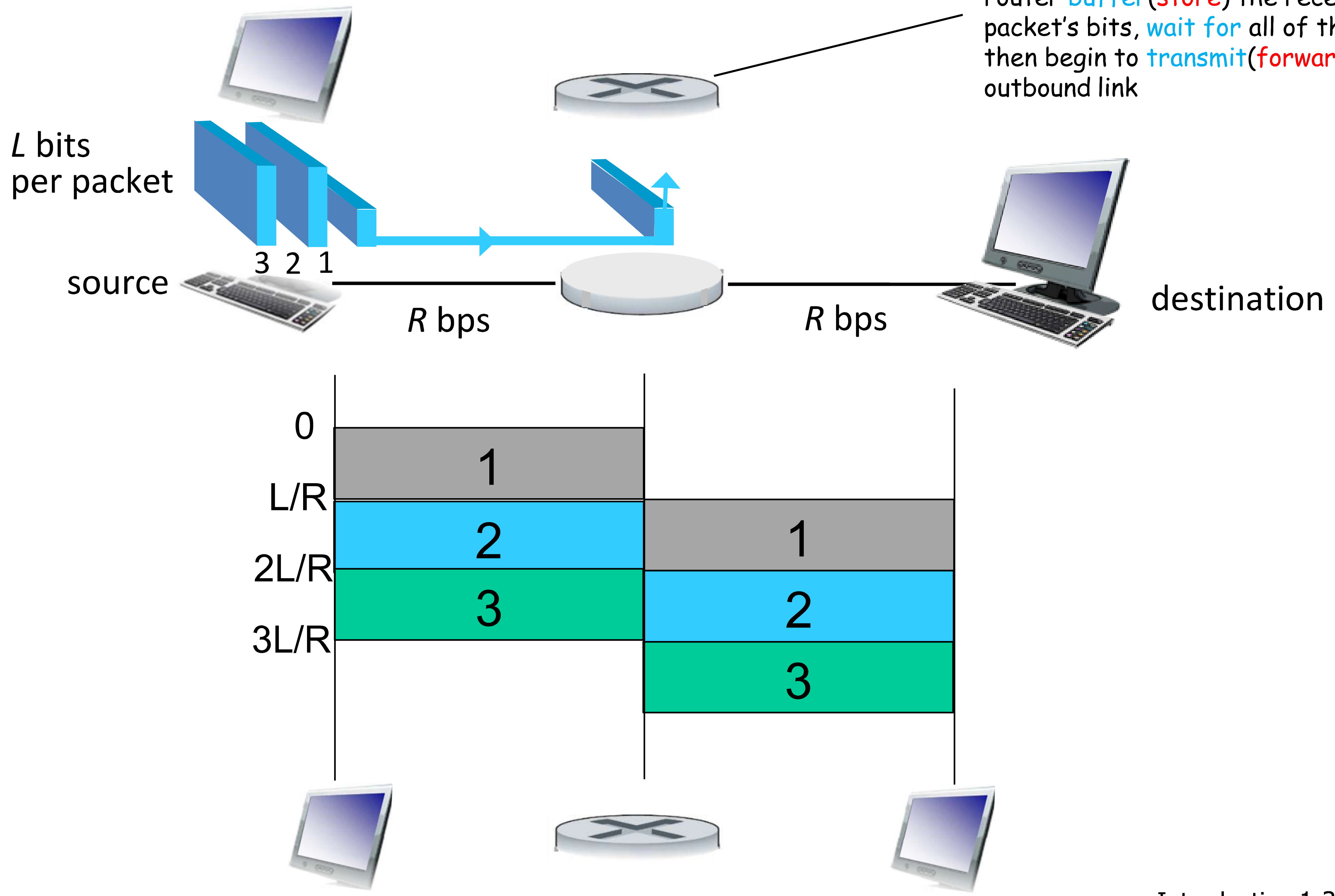


- takes L/R seconds to transmit (push out) L-bit packet into link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link

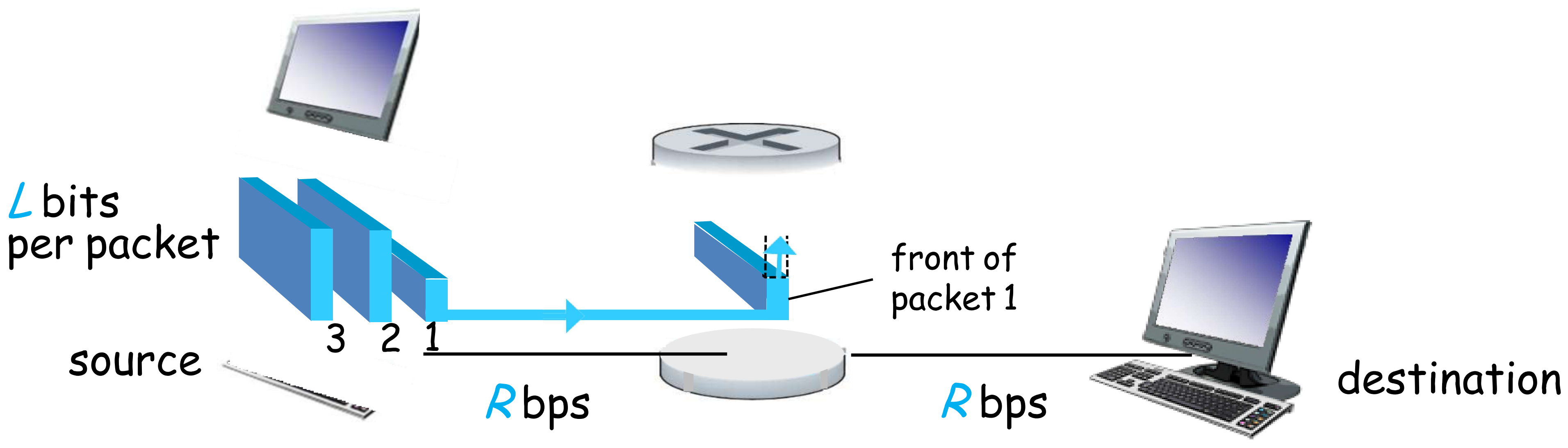
- Most packet switches use store-and-forward transmission
- end-end delay = $2L/R$ (assuming zero propagation delay) for one packet
- How long for three packets？
  - 4L/R

Packet-switching: store-and-forward

router buffer(store) the received packet's bits, wait for all of them, then begin to transmit(forward) to outbound link

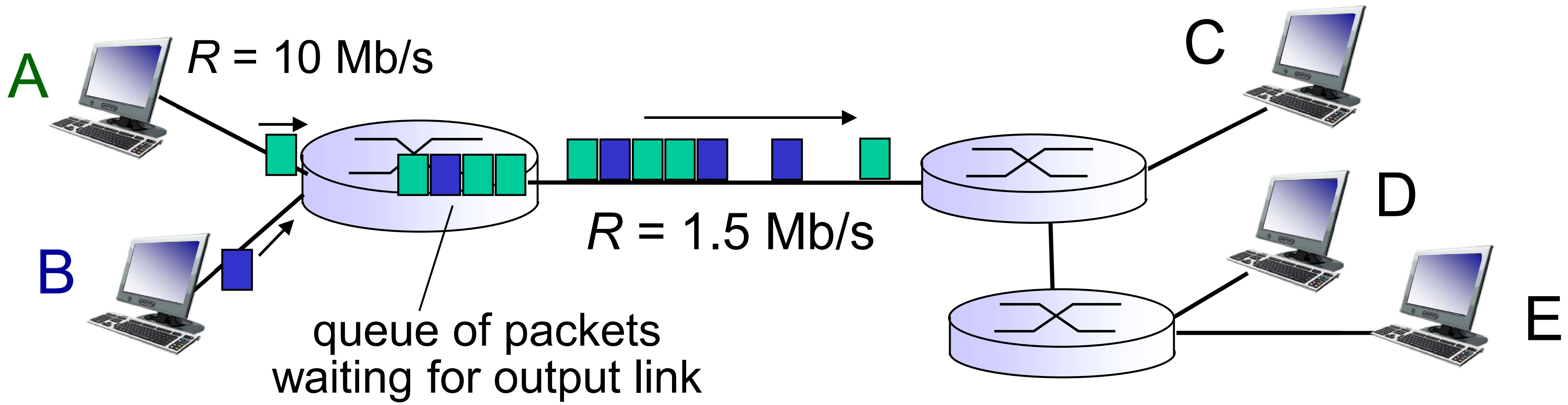


Packet-switching : store-and-forward



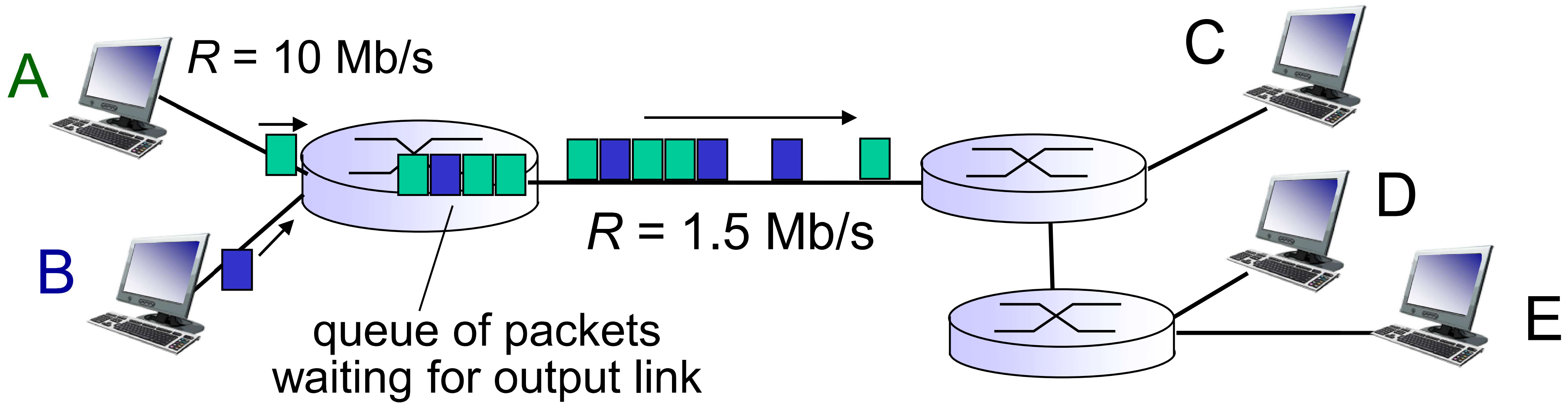
- General case : one packet (L bits), over a path consisting of N links each of rate R (N-1 routers)
- End to end delay: $d_{\text{end-to-end}} = N \frac{L}{R}$

Packet Switching: queueing delay, loss



- each packet switch has multiple links, each link has an output buffer
- output buffer also called output queue, stores packets that router is about to send into that link
- queuing delays: If link is busy, arriving packet must wait in output buffer
- packet loss: if buffer is completely full, the arriving packet or one of the already-queued packets will be dropped.

Packet Switching: queueing delay, loss



queuing and loss:

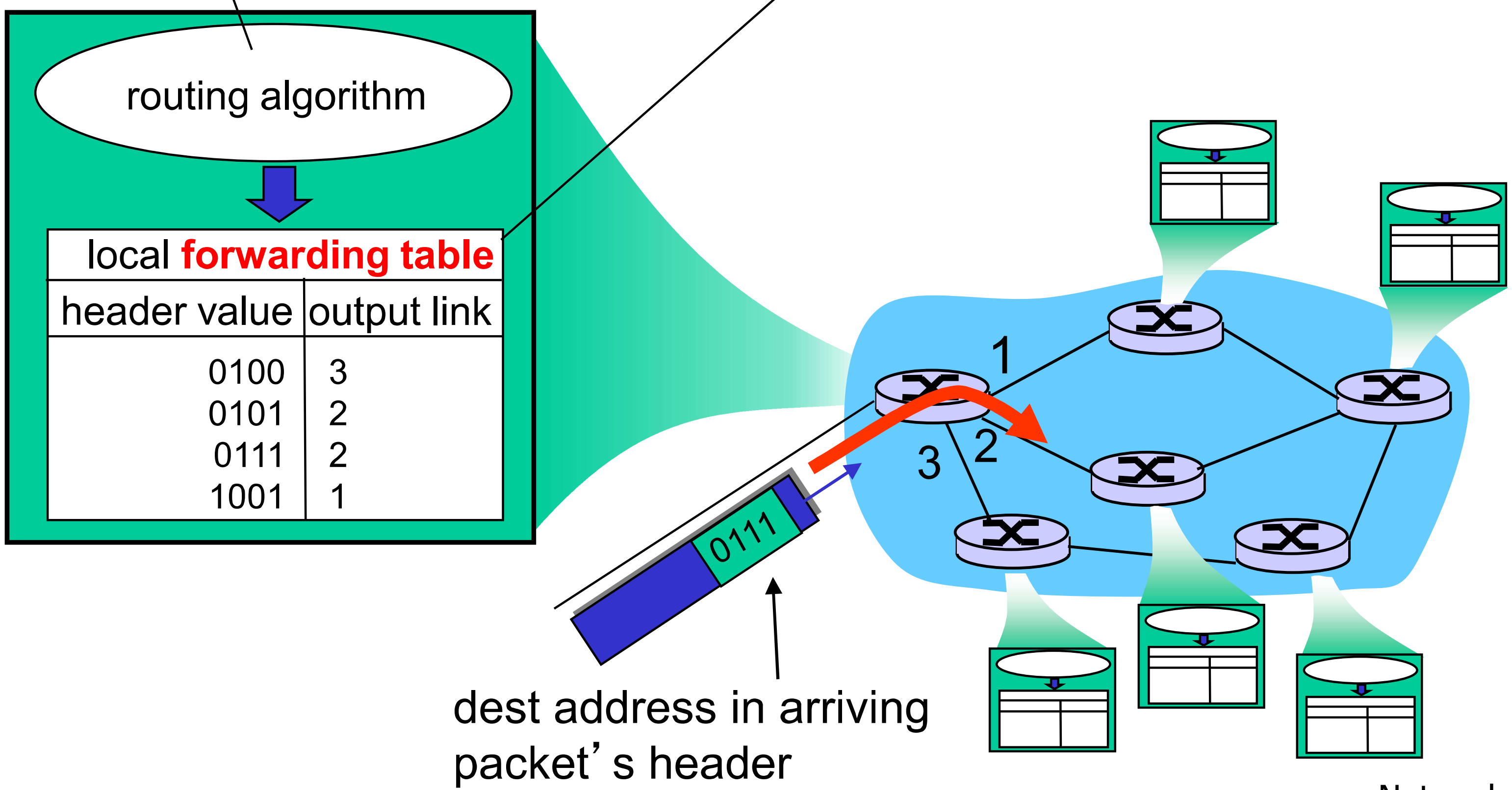
- If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link, congestion will occur at the router
  - packets can be dropped (lost) if memory (buffer) fills up

Two key network-core functions

routing: determines source-destination route taken by packets

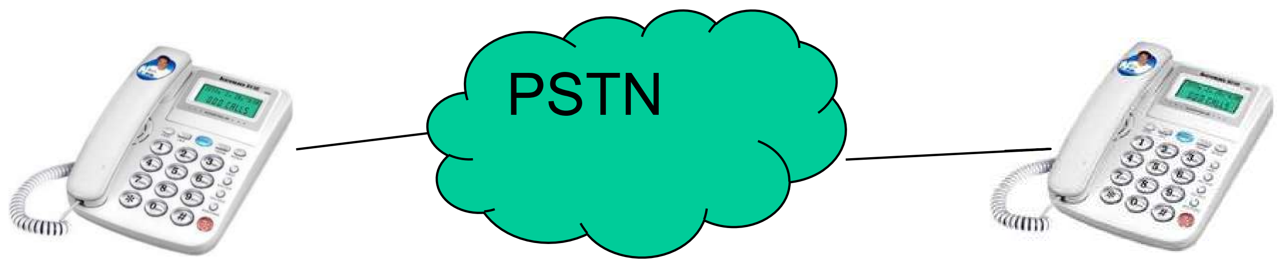
- *routing algorithms*

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



Alternative core: circuit switching

- Circuit switching : end-end resources (buffers, link transmission rate) allocated to, reserved for duration of the communication session between source & dest.
  - Commonly used in traditional telephone networks
- Packet switching: these resources are not reserved, use the resource on demand
  - Internet
- Example: the restaurants require reservation and not.

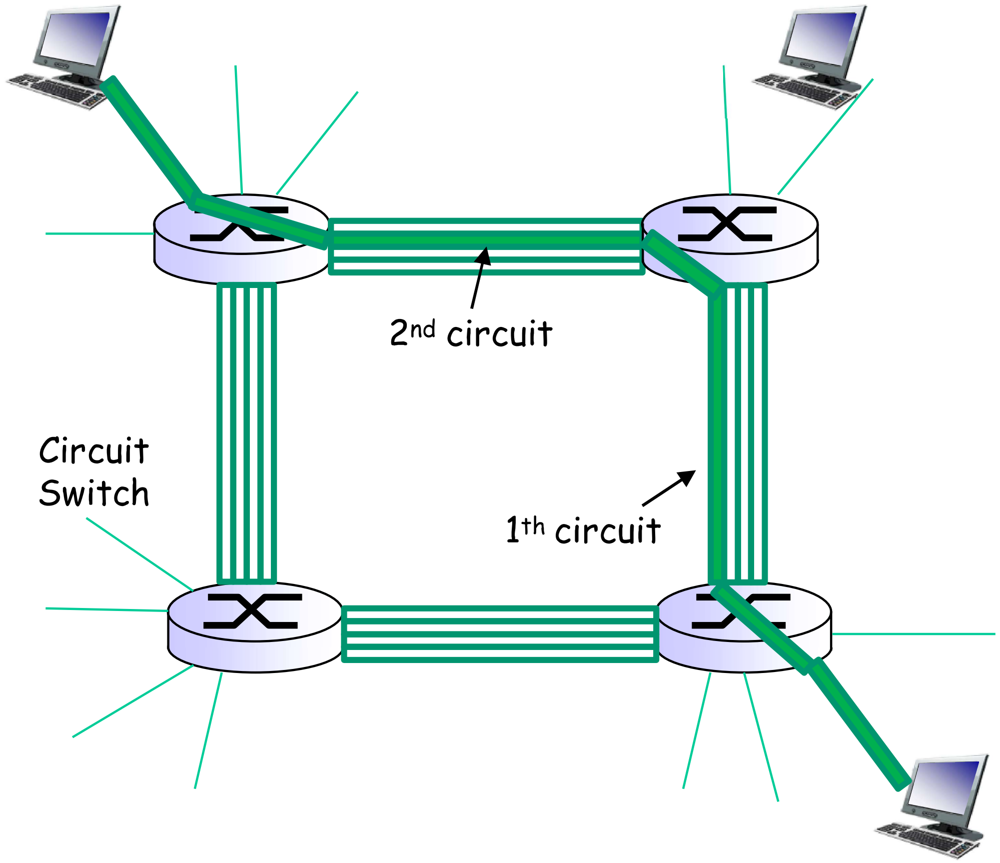


a connection (circuit) between the sender and the receiver reserves a constant transmission rate

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 (reserve one circuit).
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
  - connection gets 1/4 of the link's total transmission capacity
- circuit segment idle if not used by call *(no sharing)*

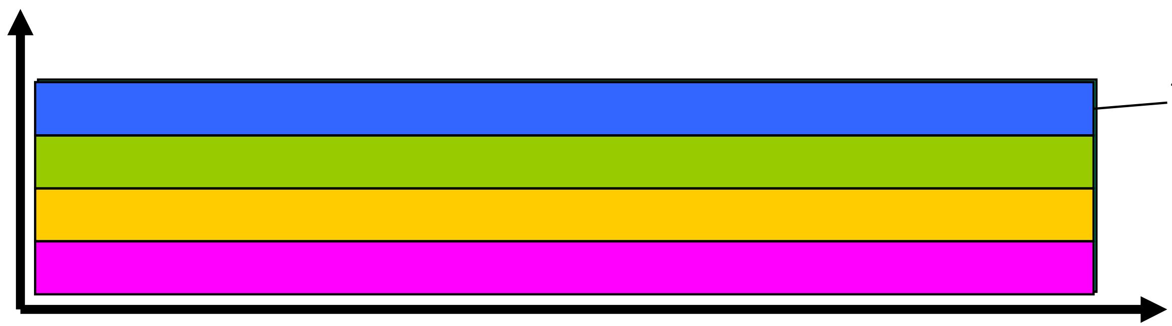


Circuit switching: FDM versus TDM

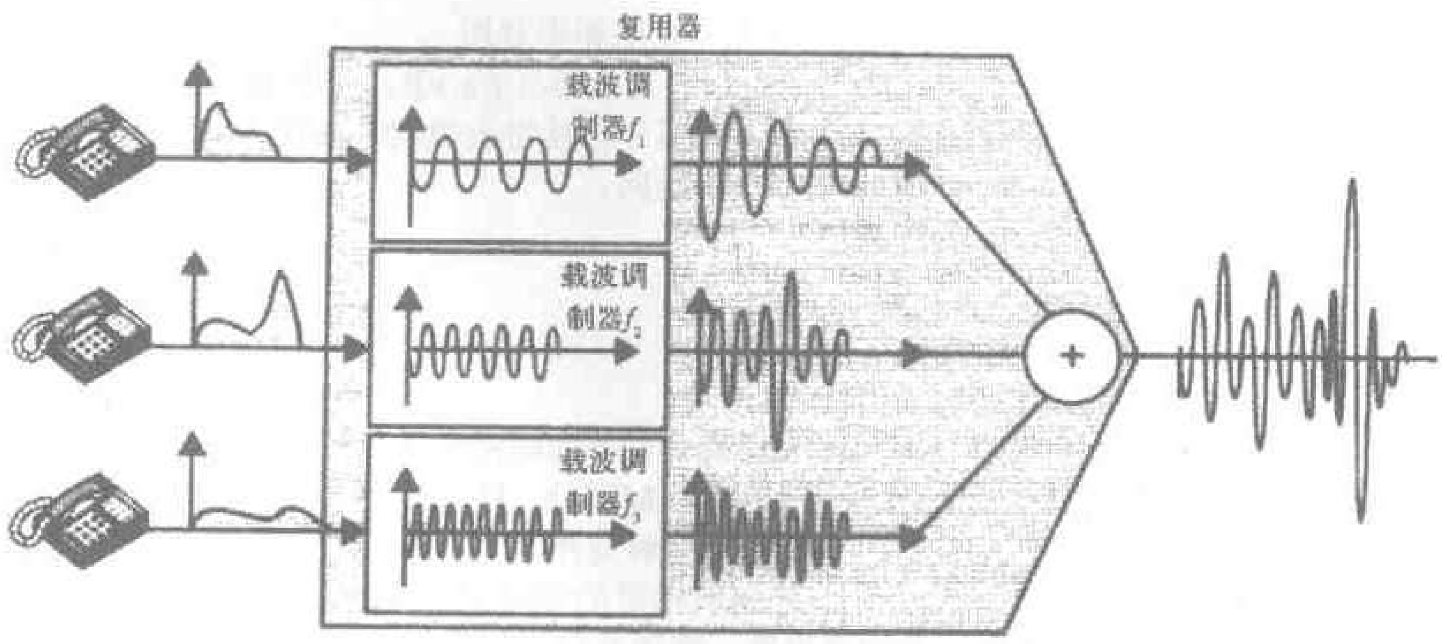
Example:

4 users

FDM



each circuit continuously gets a fraction of the bandwidth



Circuit switching: FDM versus TDM

Example:

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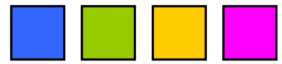
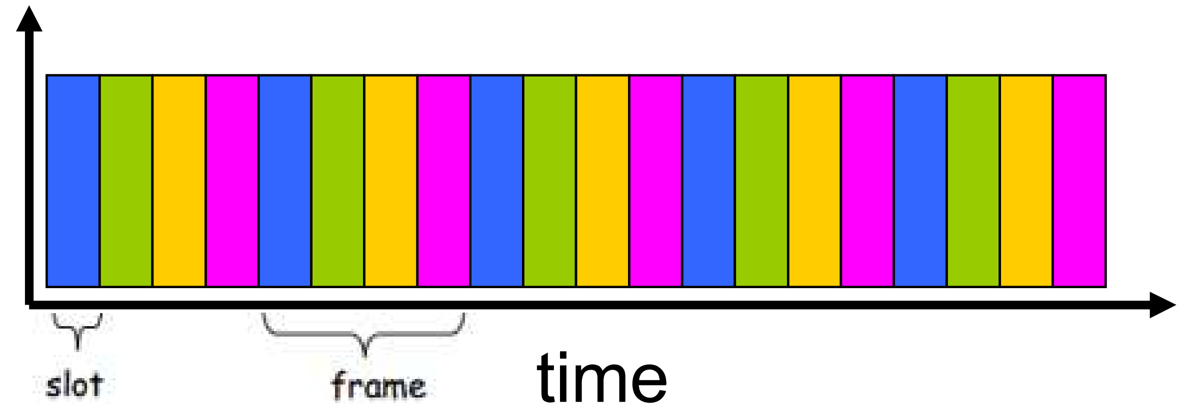


TDM



- time->frame->slot
- All blue slots are dedicated to a specific sender-receiver pair
- each circuit gets all of the bandwidth periodically during brief intervals of time (slots)

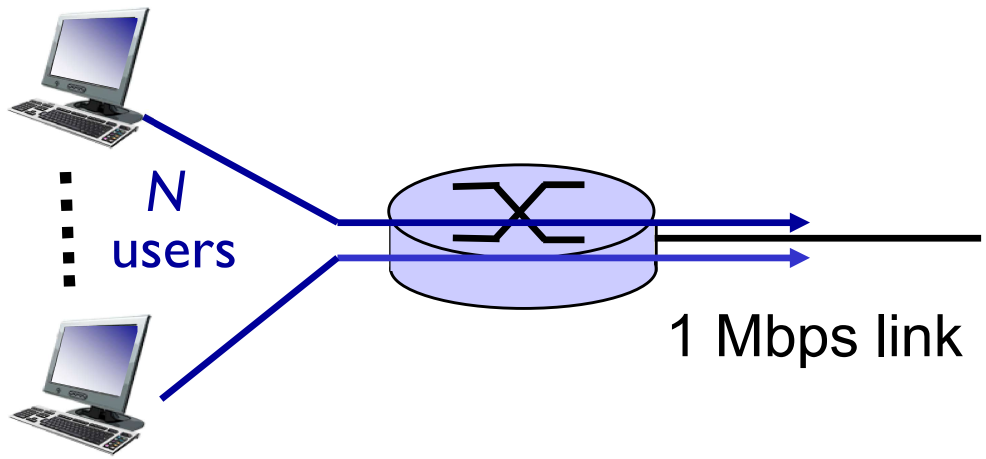
Packet switching versus circuit switching

- Critics of packet switching :
  - packet switching is not suitable for real-time services (for example, telephone calls and video conference calls) because of its variable and unpredictable end-to-end delays
- Proponents of packet switching:
  - it offers better sharing of transmission capacity than circuit switching
  - is simpler, more efficient, and less costly to implement than circuit switching.
- people who do not like to hassle with restaurant reservations prefer packet switching to circuit switching !

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
  - aggregate arrival rate of data <= 1Mbps

Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

* Check out the online interactive exercises for more examples

Packet switching versus circuit switching

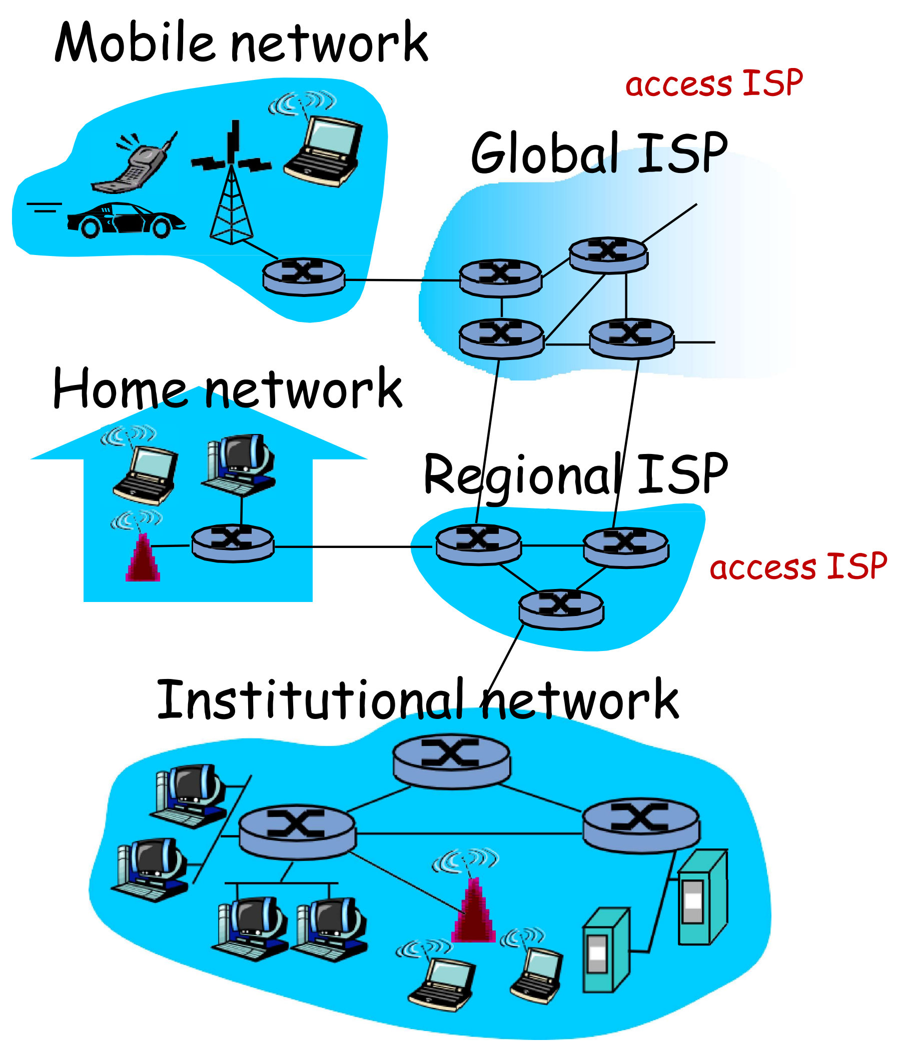
is packet switching a "slam dunk winner?"

- 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)?

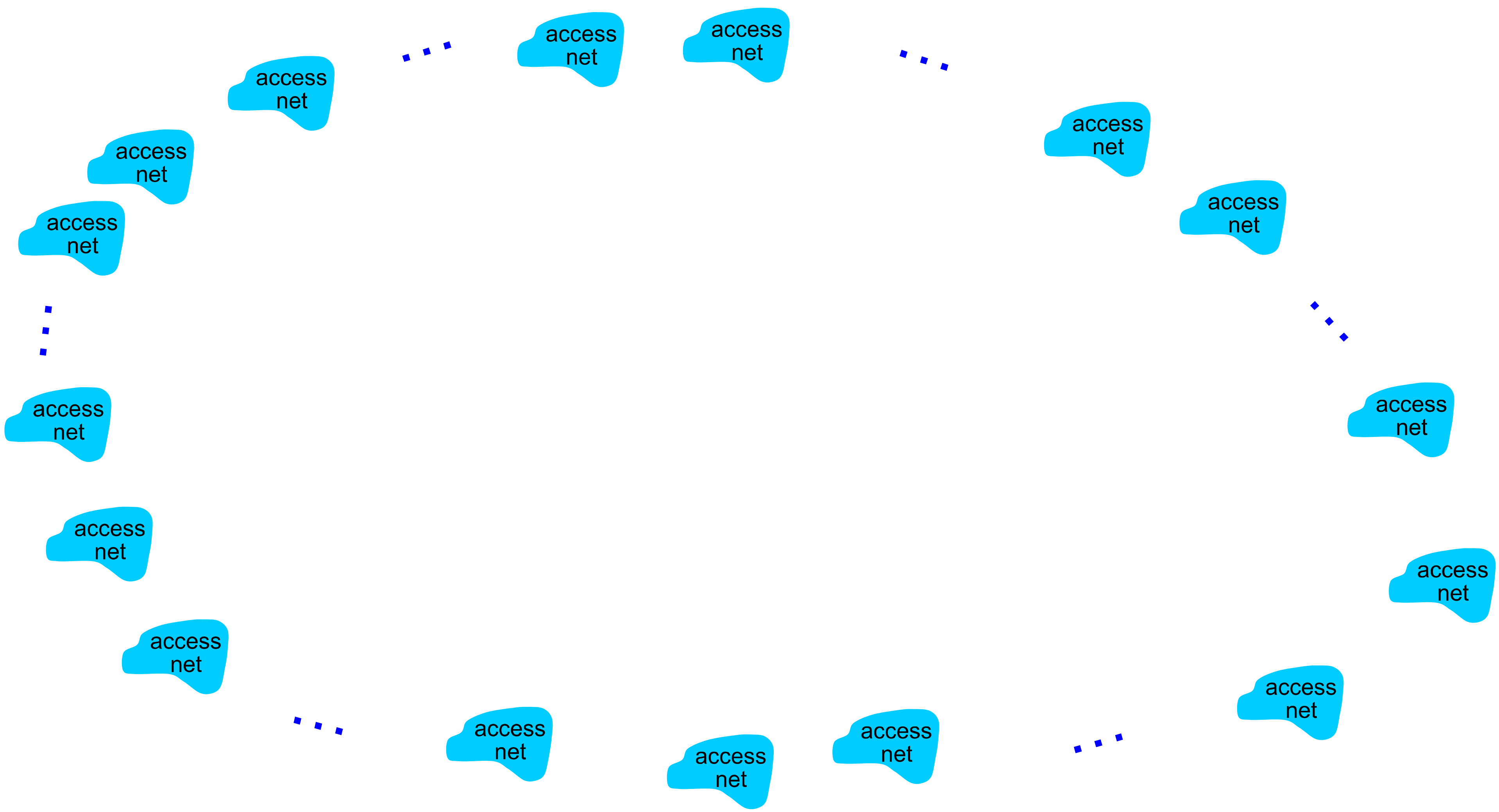
Internet structure: network of networks

- 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



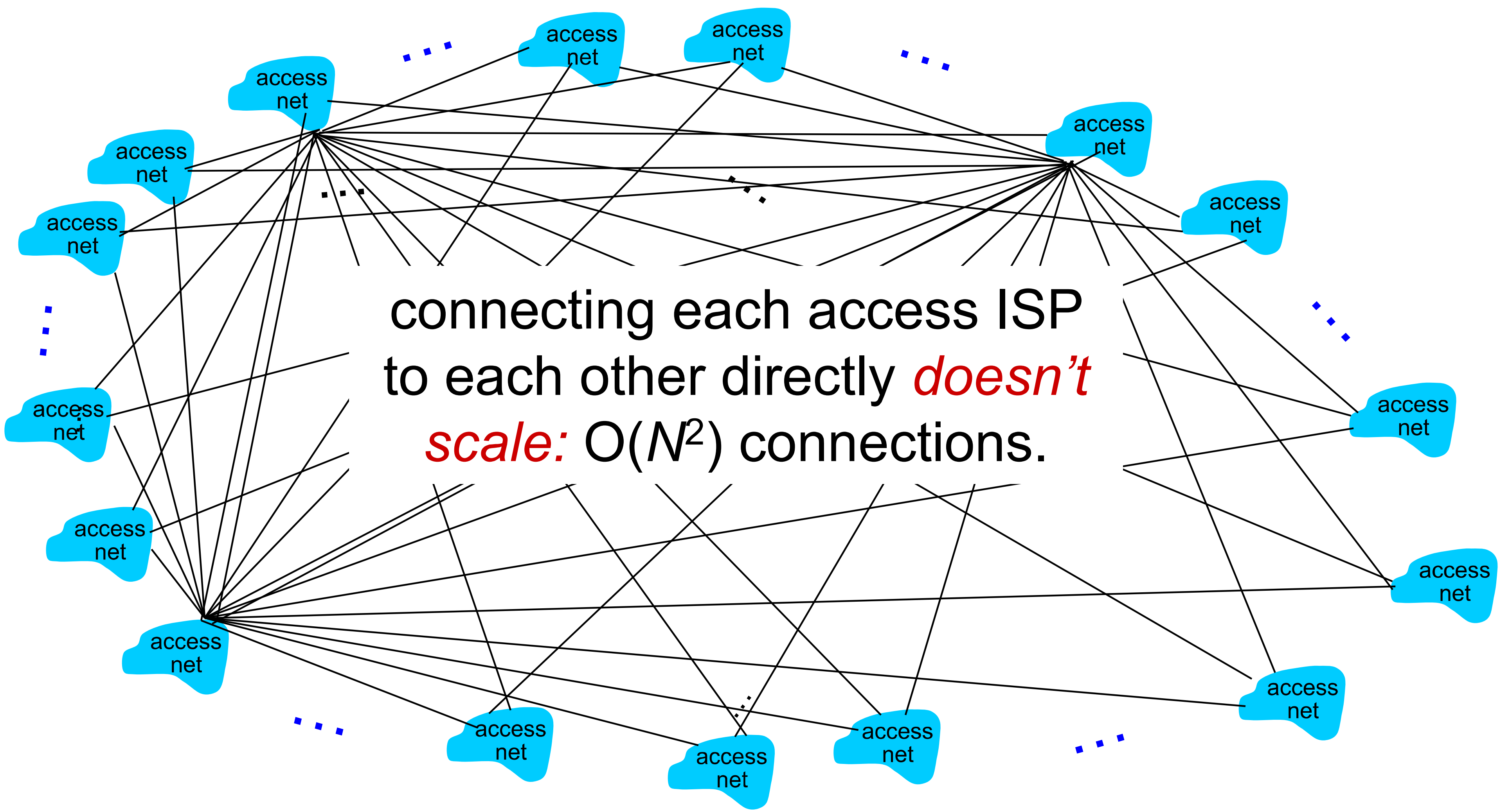
Internet structure: network of networks

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



Internet structure: network of networks

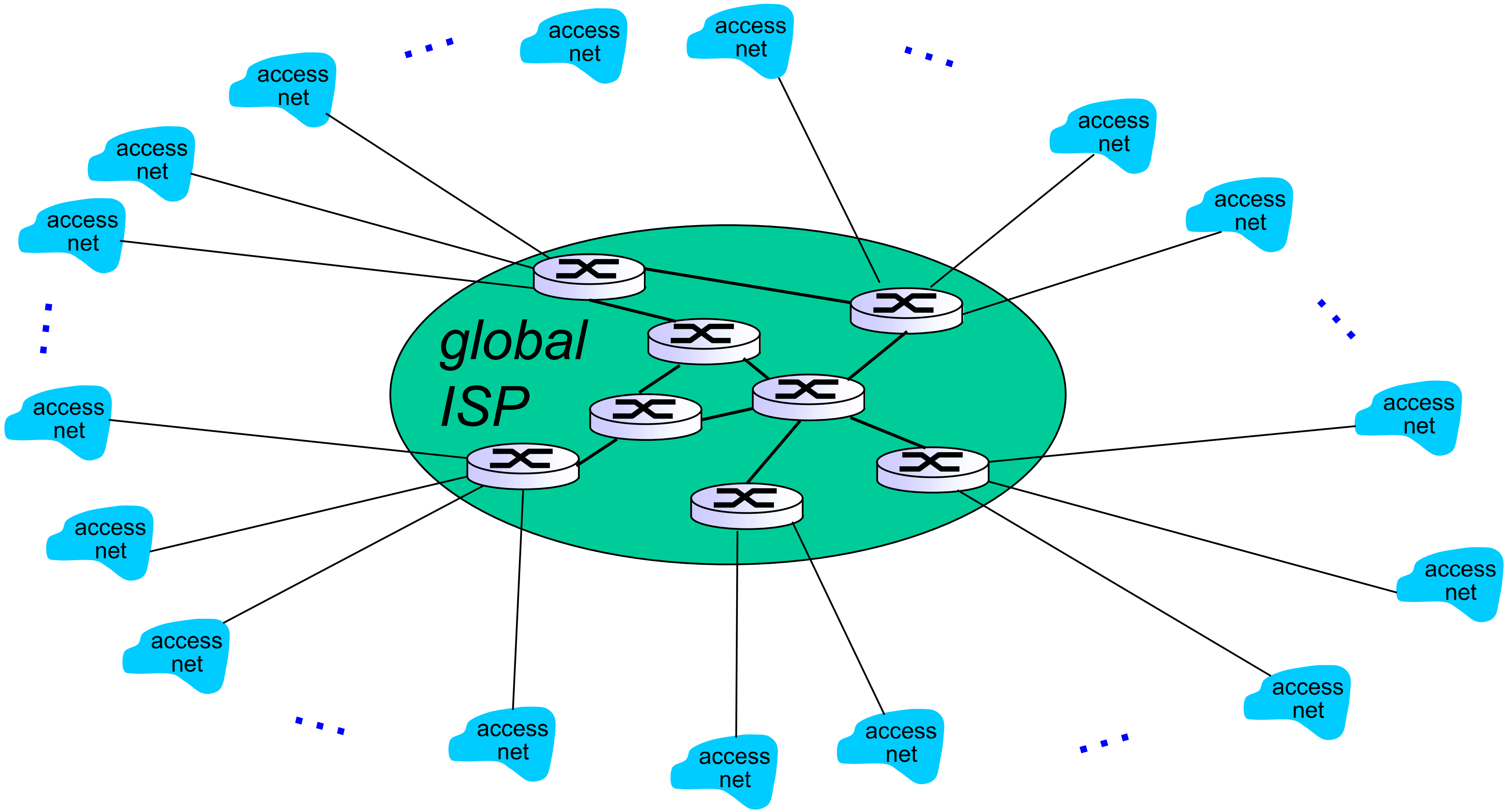
Option: connect each access ISP to every other access ISP?



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

Internet structure: network of networks

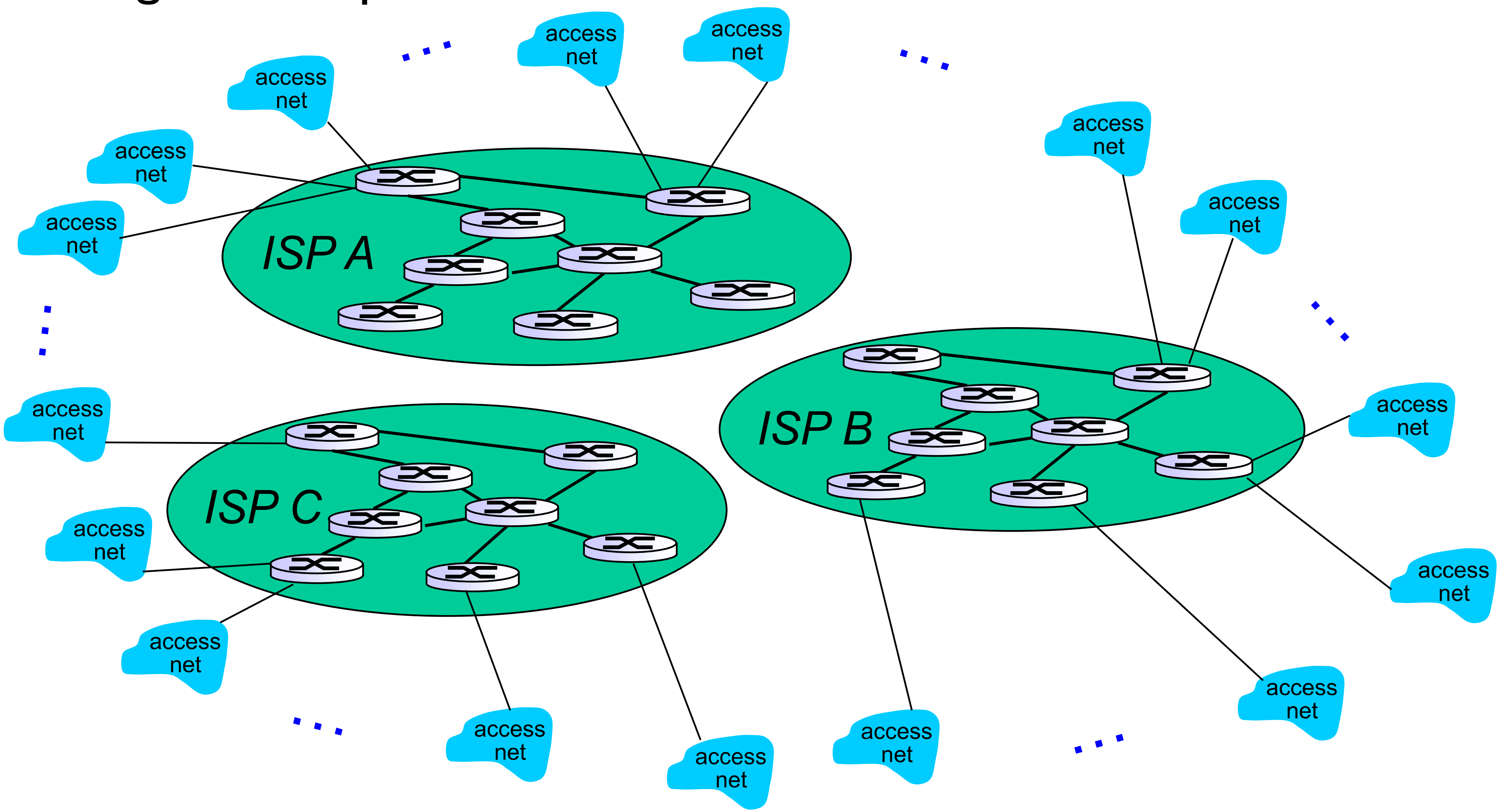
Option: connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.



single global ISP

Internet structure: network of networks

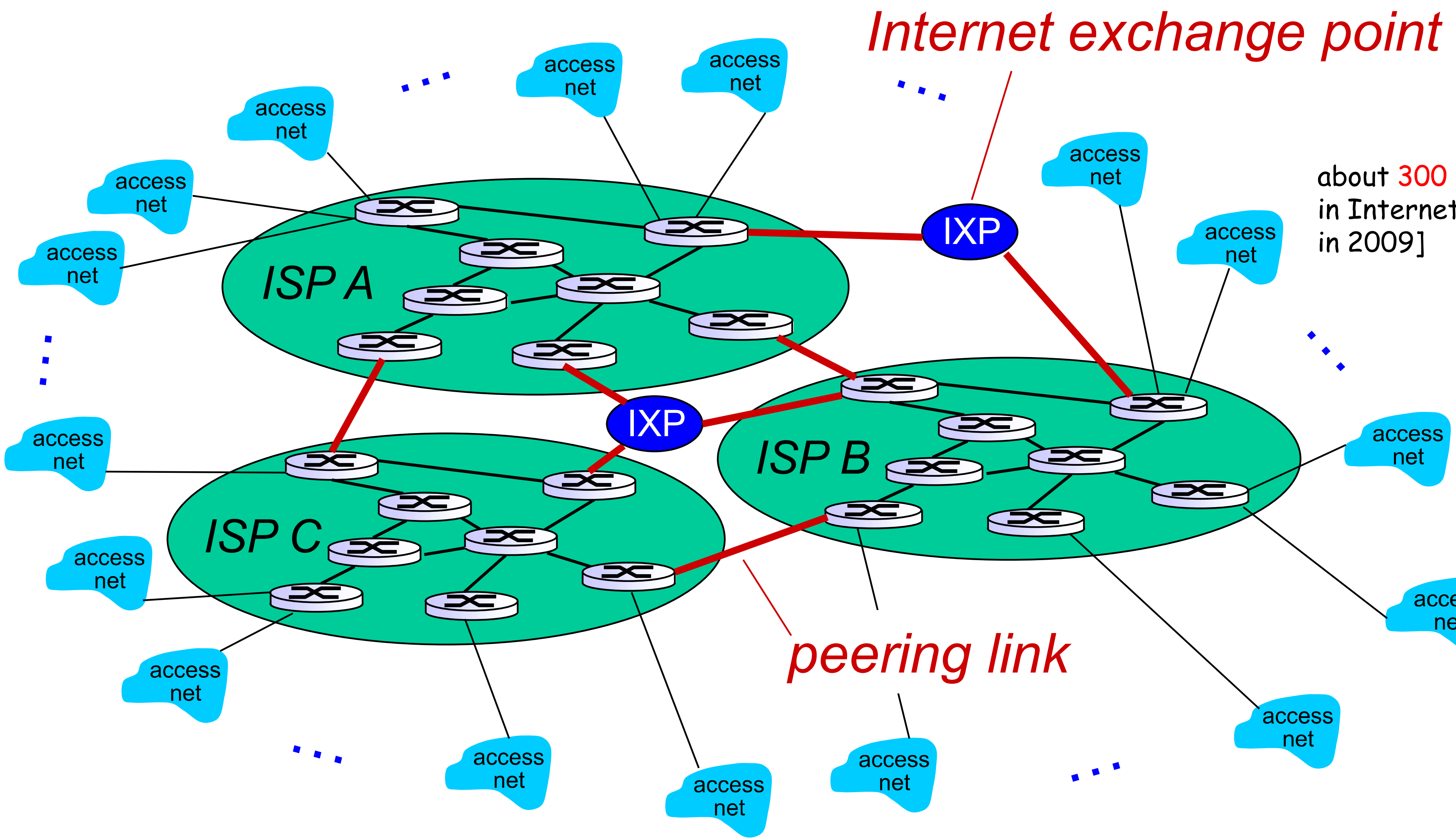
But if one global ISP is viable business, there will be competitors … The access ISPs certainly prefer it for choosing among the competitors.



multiple global ISP

Internet structure: network of networks

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

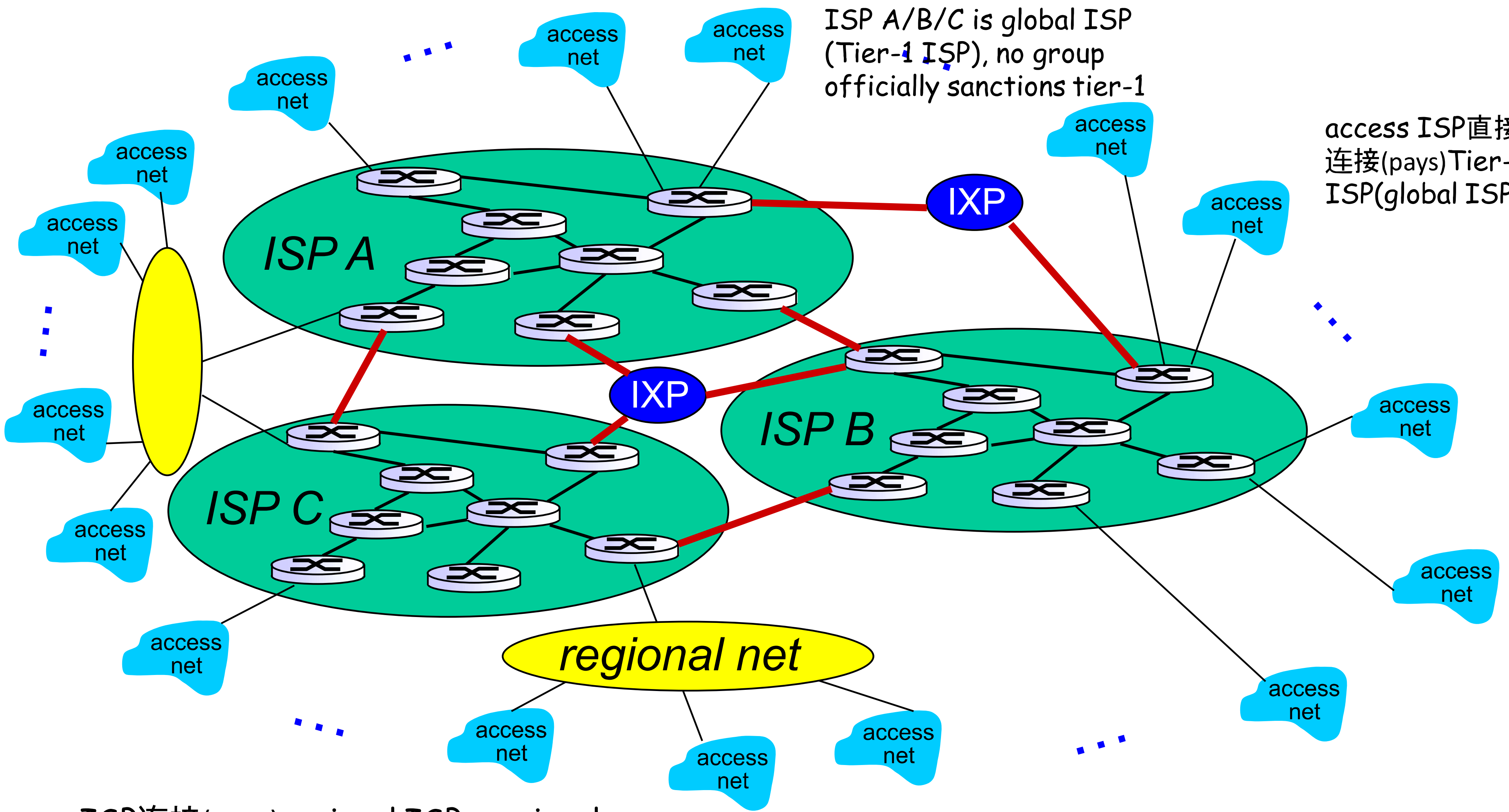


about 300 IXP in Internet [Aug. in 2009]

IXP: a meeting point where multiple ISPs can peer together

Internet structure: network of networks

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



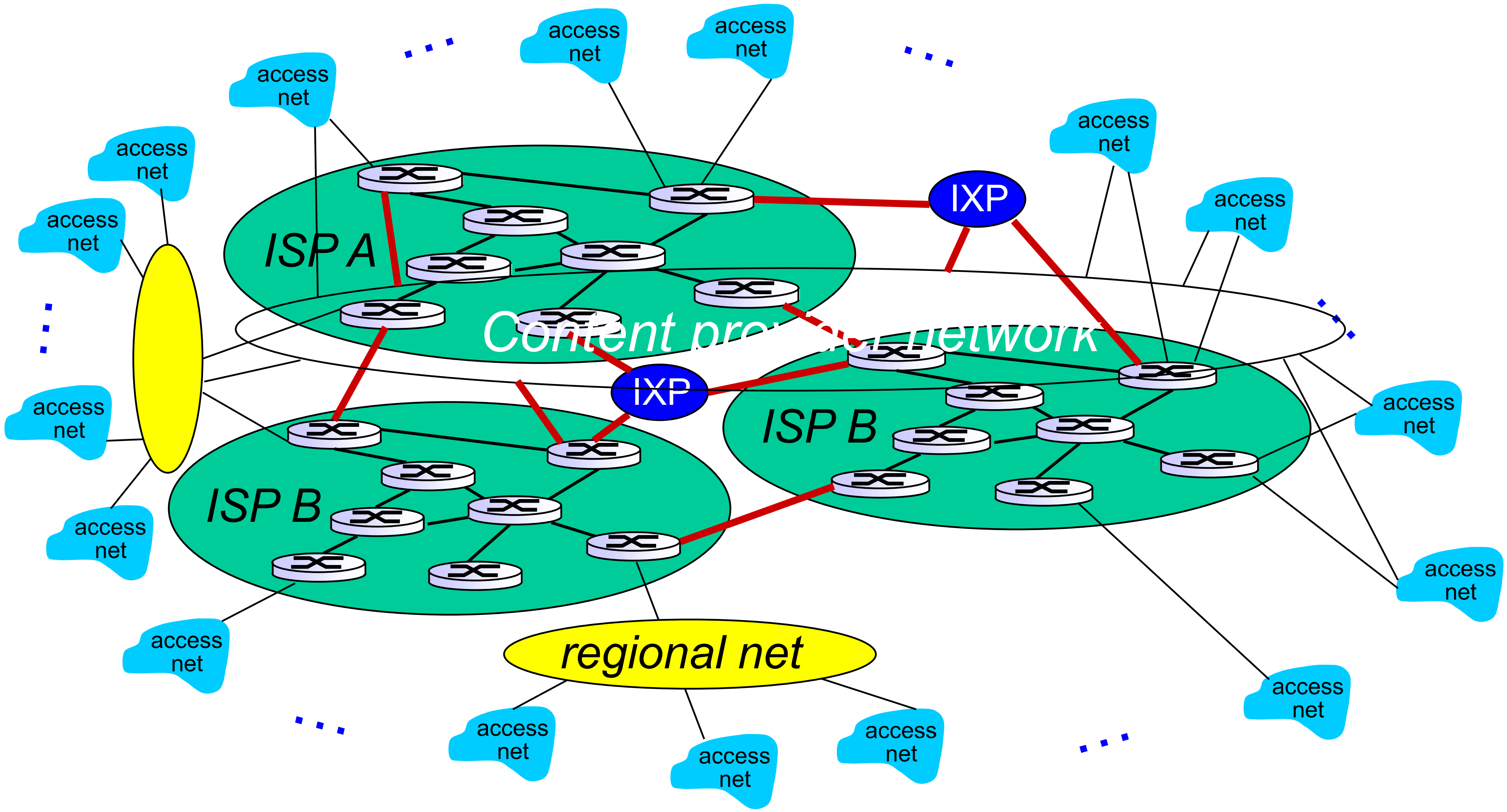
ISP A/B/C is global ISP (Tier-1 ISP), no group officially sanctions tier-1

access ISP直接连接(pays)Tier-1 ISP(global ISP)

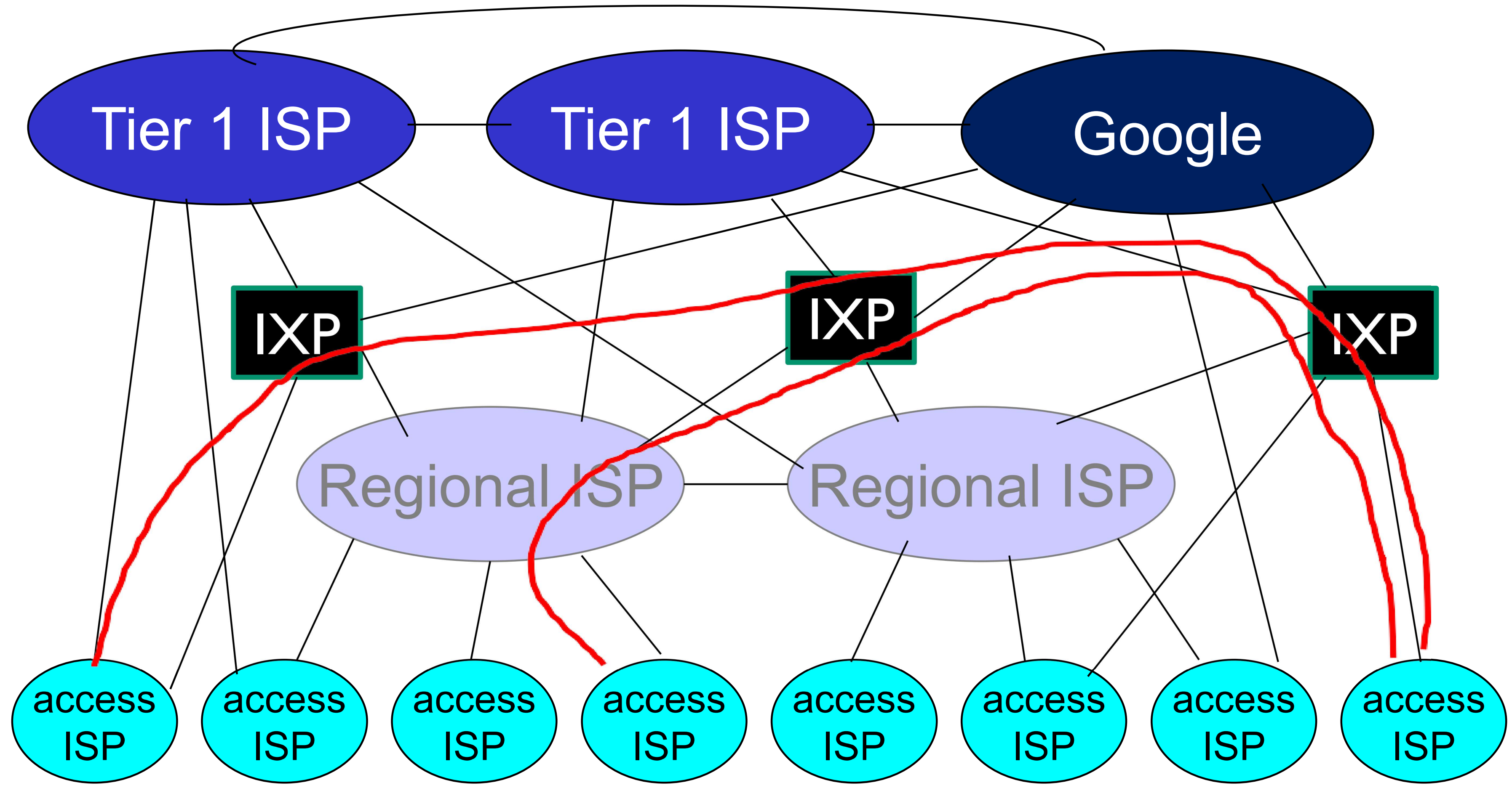
access ISP连接(pays)regional ISP，regional ISP再连接(pays)到Tier-1 ISP (global ISP)

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

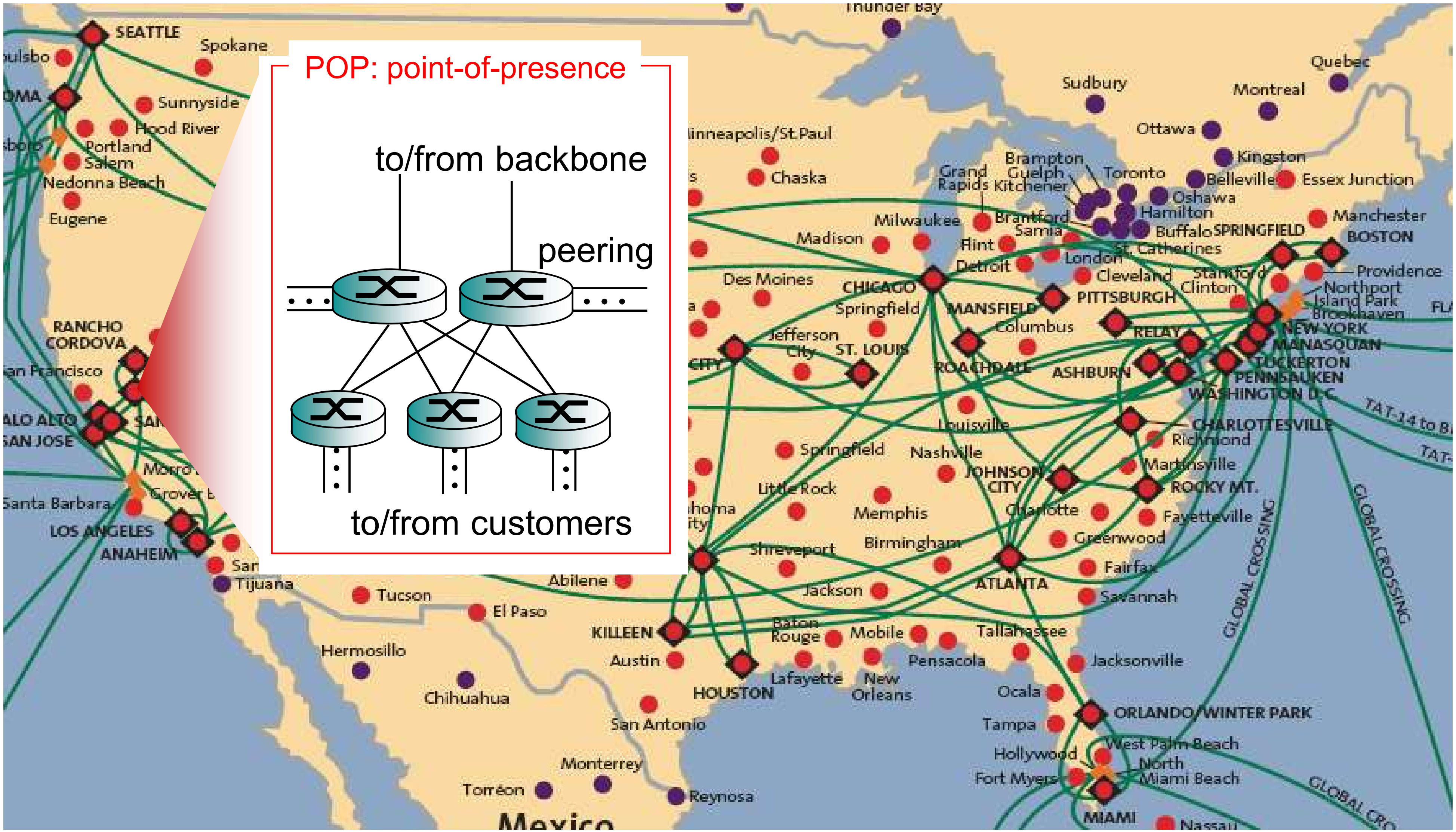


Internet structure: network of networks



- 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

Tier-1 ISP: e.g., Sprint



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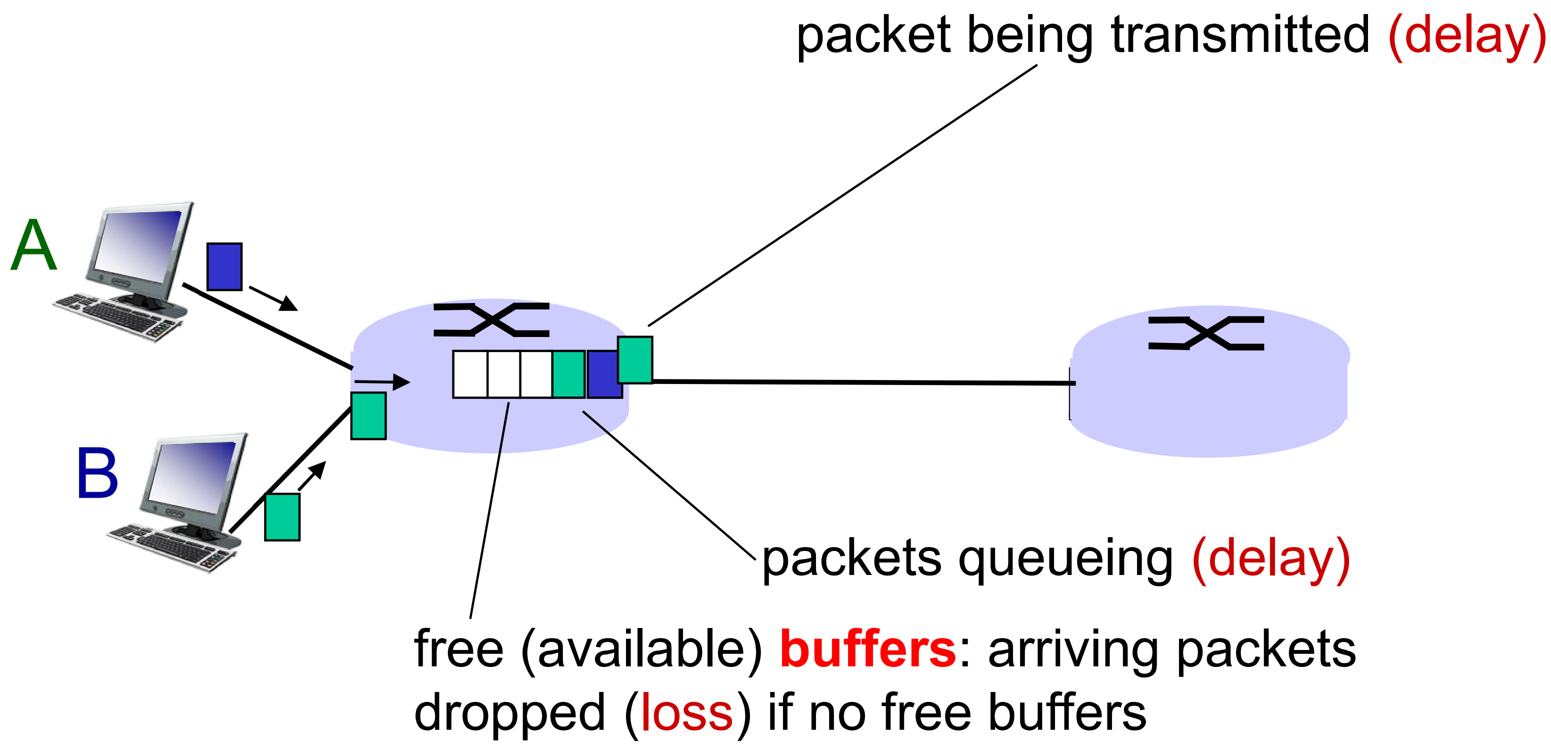
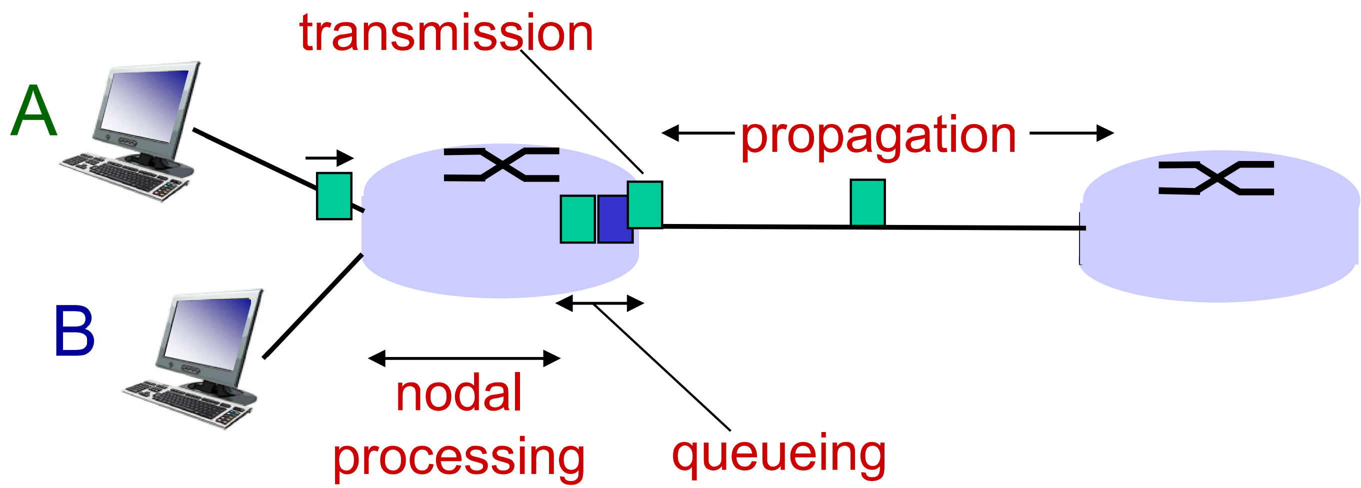
How do loss and delay occur?

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



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

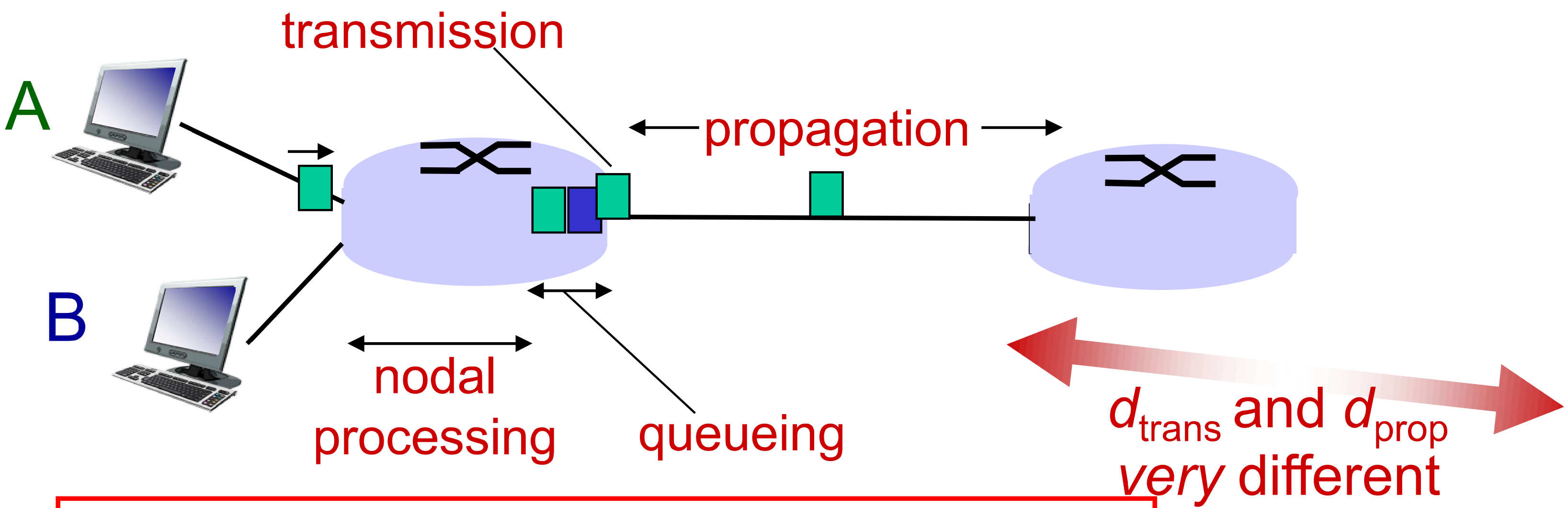
d_{proc}: nodal processing

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

d_{queue}: queueing delay

- time waiting at output link for transmission
- depends on congestion level of router
- typically microseconds to milliseconds

Four sources of packet delay



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

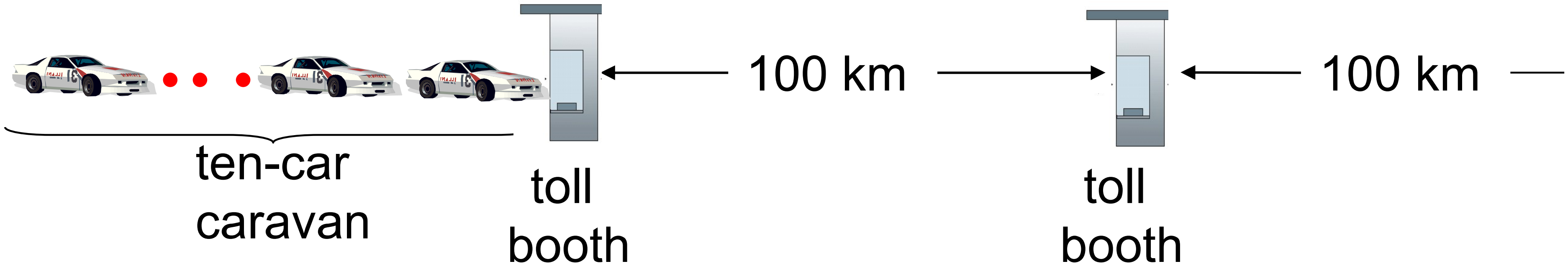
d_{trans}: transmission delay:

- *the amount of time required to transmit (push) all of the packet's bits into the link*
- *L*: packet length (bits)
- *R*: link *bandwidth (bps)*
- $d_{trans} = L/R$
- typically microseconds to milliseconds

d_{prop}: propagation delay:

- the time required to propagate from the beginning of the link to next router
- *d*: length of physical link
- *s*: propagation speed in medium (2×10^8 m/sec~ 3×10^8 m/sec)
- $d_{prop} = d/s$
- typically milliseconds（广域网）

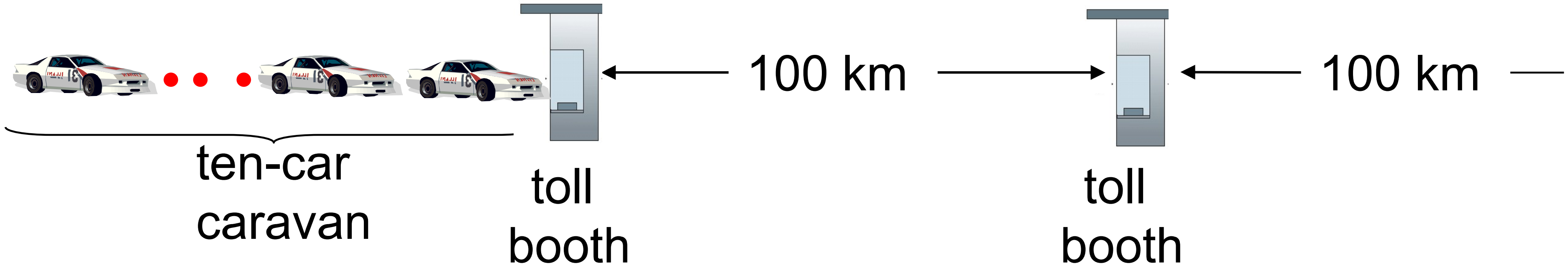
Caravan analogy



- 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?

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

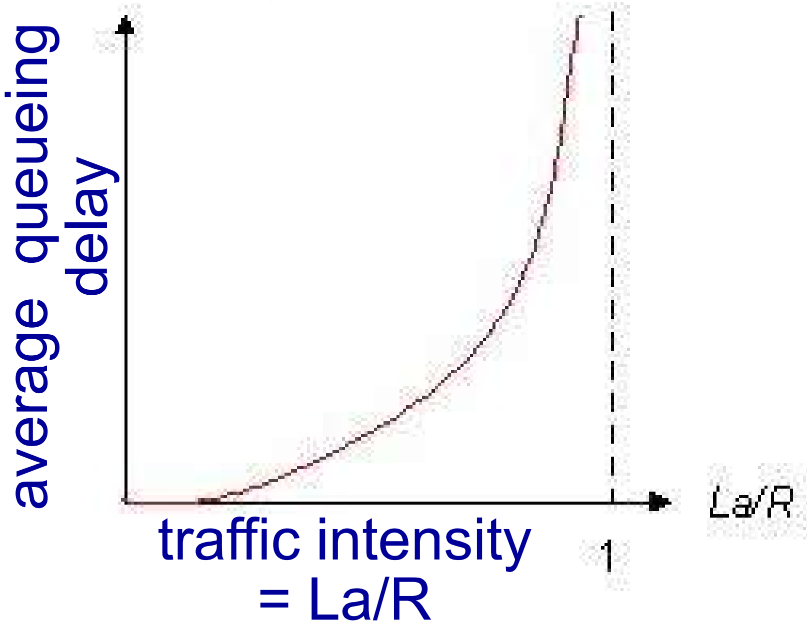
Caravan analogy (more)



- 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.

Queueing delay (revisited)

- *R:* link bandwidth (bps)
- *L:* packet length (bits)
- a: average packet arrival rate(packets/s)
- traffic intensity (流量强度) = La/R



- *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!

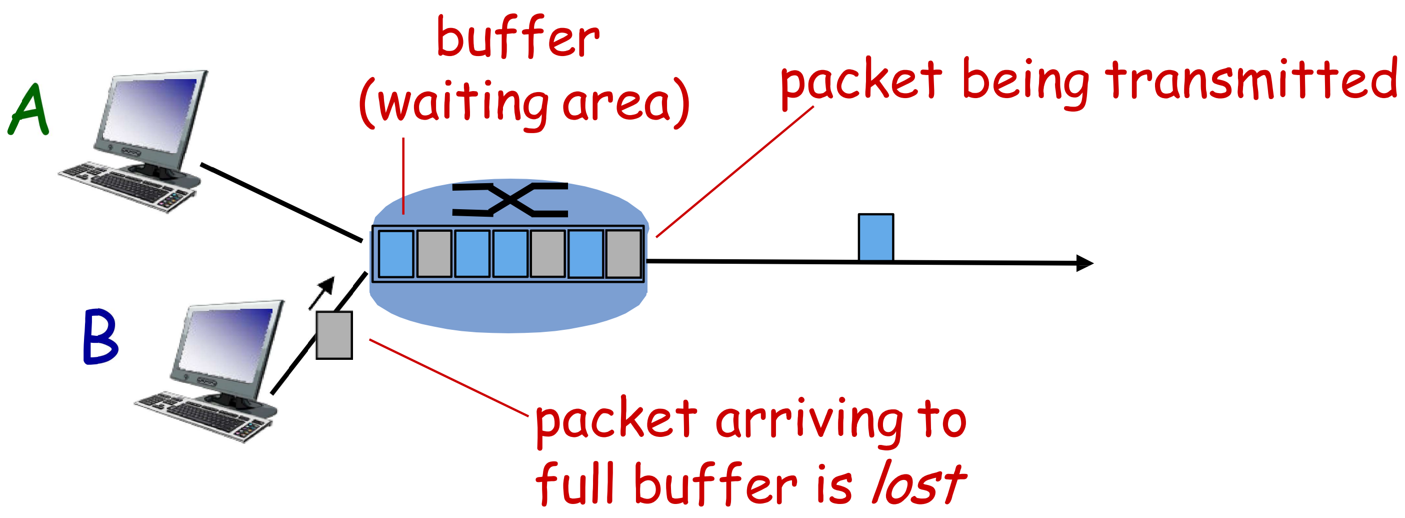
La/R ~ 0

La/R -> 1

Note: assumed that the queue is capable of holding an infinite number of packets

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

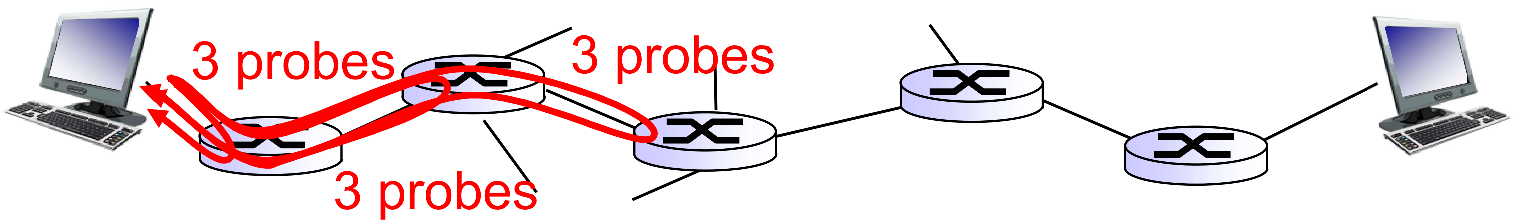


End-to-End Delay

- suppose for the moment that the network is uncongested (so that queuing delays are negligible)
- there are N-1 routers between the source host and the destination host
- a generalization of end-to-end equation
  - $d_{\text{end-to-end}} = N(d_{\text{proc}} + d_{\text{trans}} + d_{\text{prop}})$

"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 includes its name and address.
  - 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

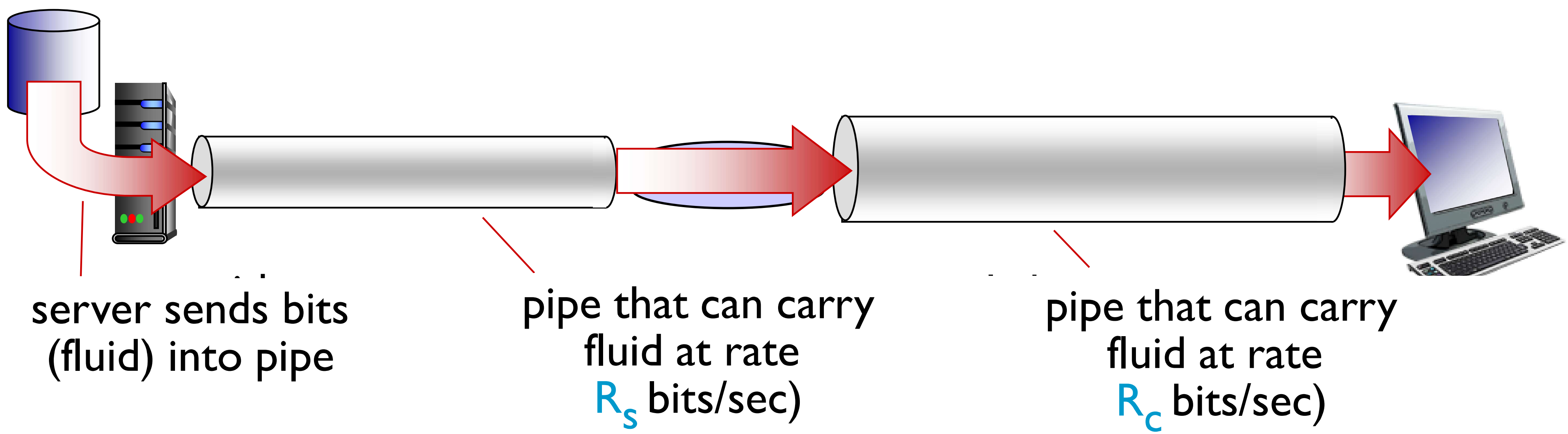
the queuing delay is varying with time

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

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

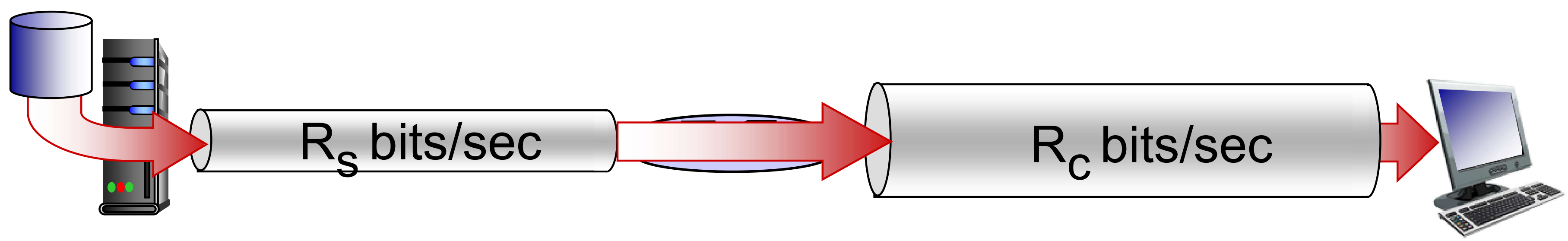
Throughput

- *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 （bps）

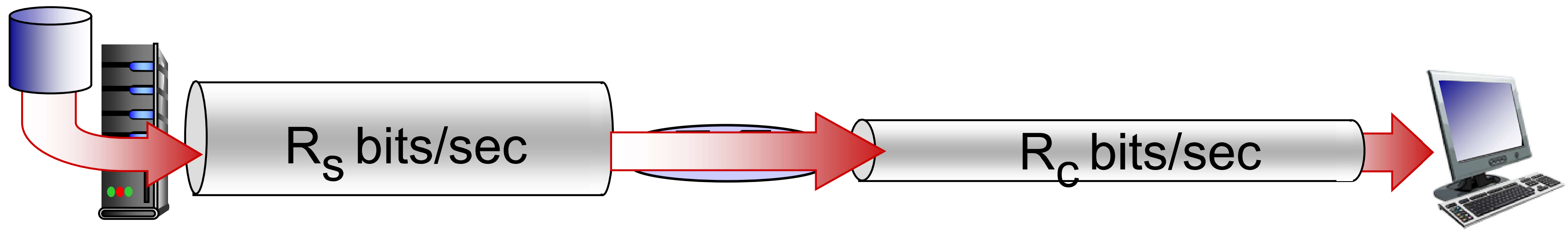


Throughput (more)

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



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

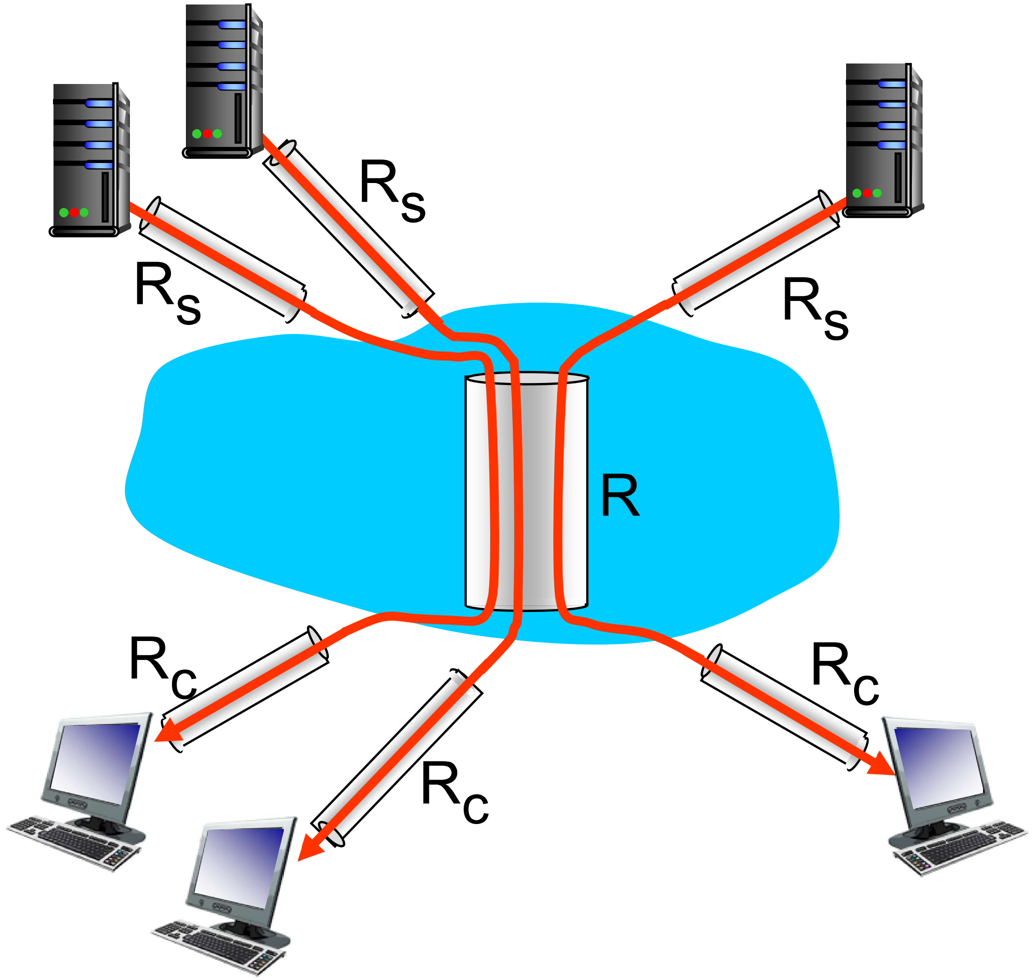


bottleneck link

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

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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?

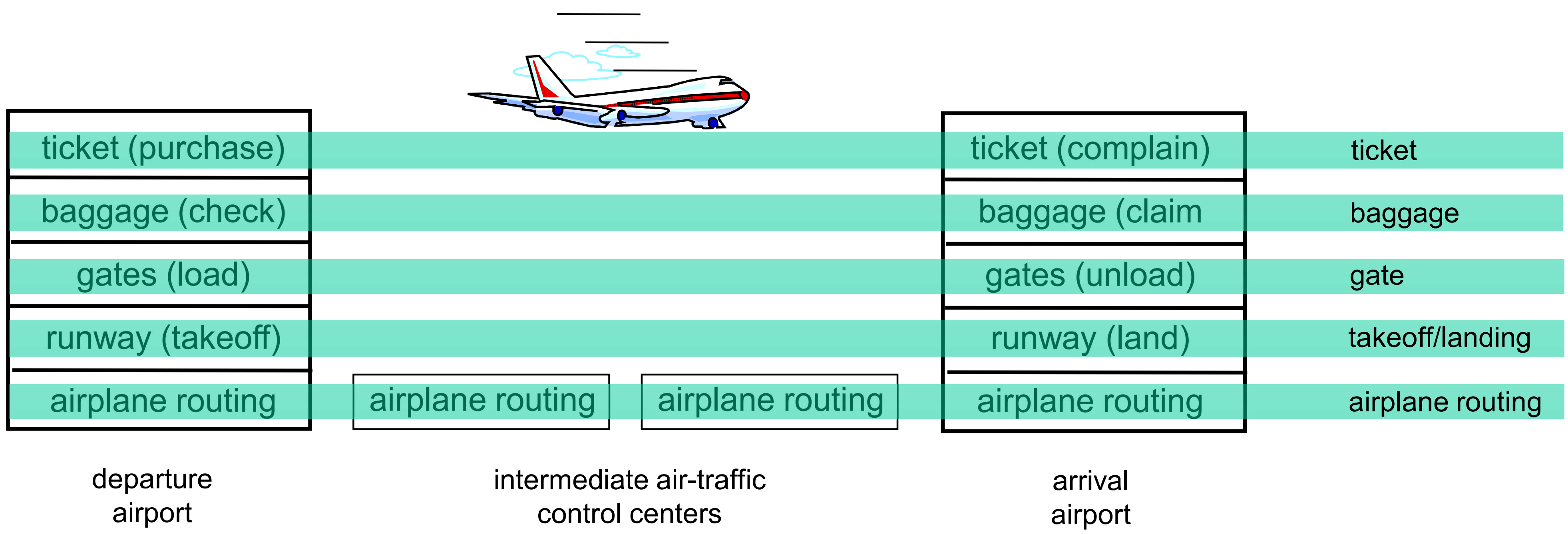
Organization of air travel

ticket (purchase)	ticket (complain)
baggage (check)	baggage (claim)
gates (load)	gates (unload)
runway takeoff	runway landing
airplane routing	airplane routing

airplane routing

- 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

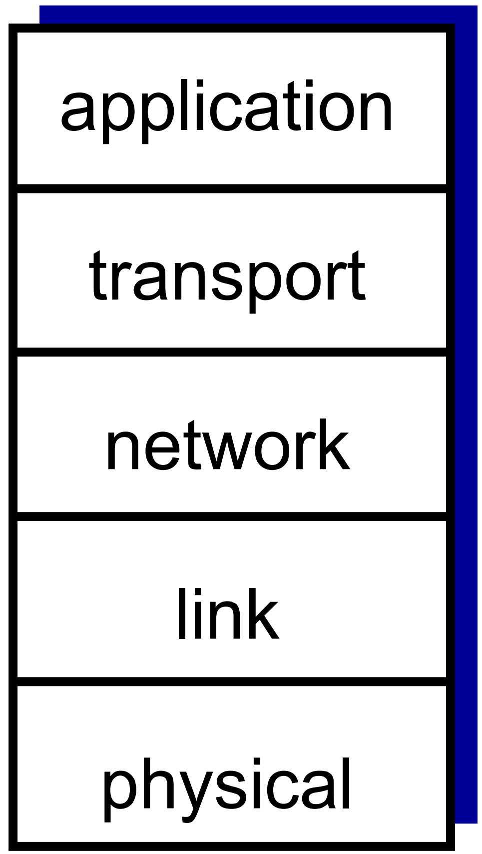
Why layering?

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(disembark by height) doesn't affect rest of system
- layering considered harmful?
  - one layer may duplicate lower-layer functionality
  - functionality at one layer may need information (e.g. timestamp value) that is present only in another layer

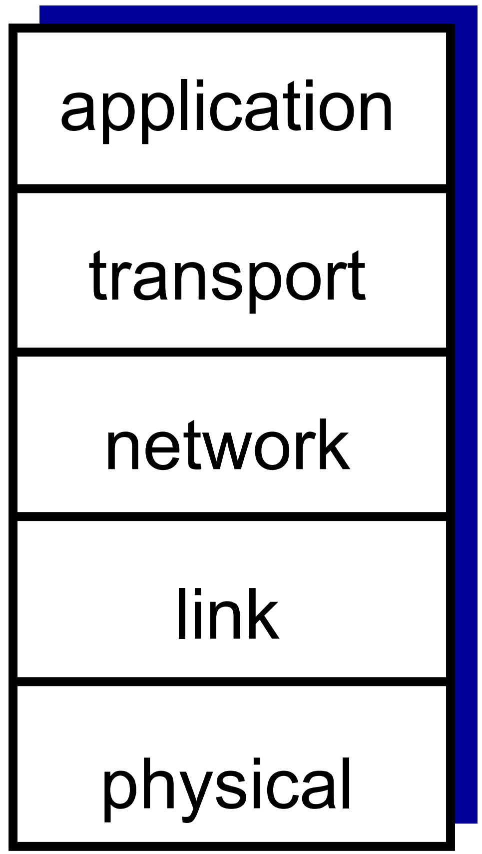
Internet protocol stack

- *application:* supporting network applications
  - FTP, SMTP, HTTP， DNS
  - message(消息/报文)
- *transport:* process-process data transfer
  - TCP, UDP
  - segment (报文段)
- *network:* routing of datagrams from source to destination
  - IP, routing protocols
  - often a mixed implementation of hardware and software
  - datagrams(数据报)



Internet protocol stack

- *link:* data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
  - typically implemented in a network interface
  - frames(帧)
- *physical:* bits "on the wire"
  - typically implemented in a network interface
  - The protocols in this layer depend on the actual transmission medium of the link

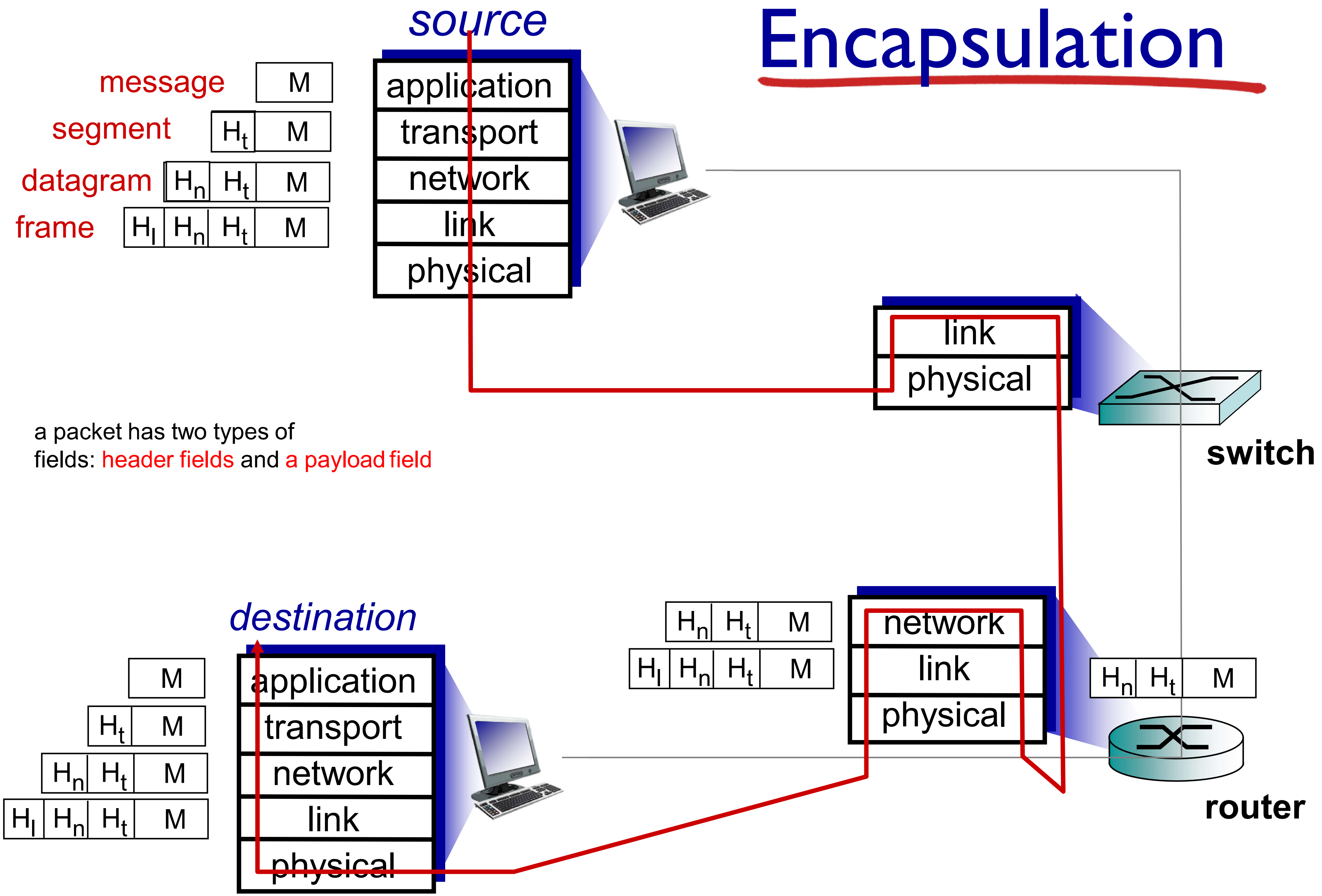


ISO/OSI reference model

- OSI: Open System Interconnect, 开放 系统互连
- *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?

application
presentation
session
transport
network
link
physical

Encapsulation



a packet has two types of fields: header fields and a payload field

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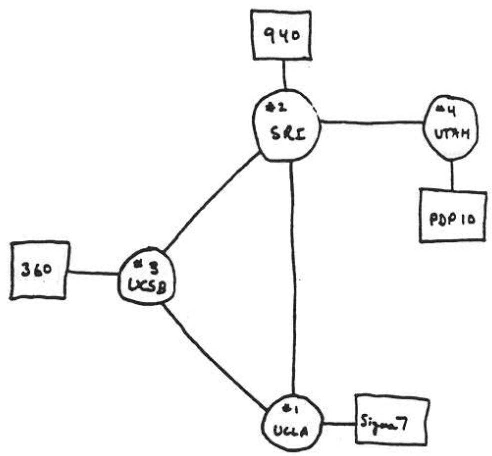
Internet history

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!*