CS 305: Computer Networks

Fall 2022

Lecture 2：Introduction

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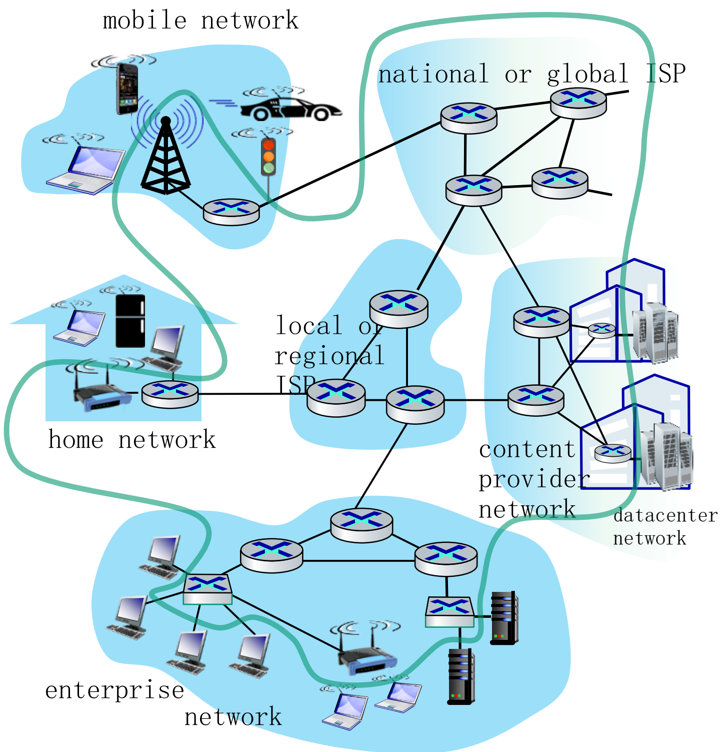
Chapter 1: roadmap

The Internet: a "service" view

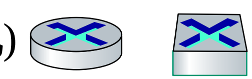


The Internet is a computer network that interconnects billions of computing devices throughout the world.

- hosts = end systems
- Internet applications run on end systems—they do not run in the packet switches in the network core

End systems are connected together by a network of communication links and packet switches.

- Communication links
- Packet switches: forward packets (包)
  - Routers (路由器), switches (交换机)



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

Internet: "network of networks"

- Interconnected ISPs

A closer look at Internet structure

Network edge:

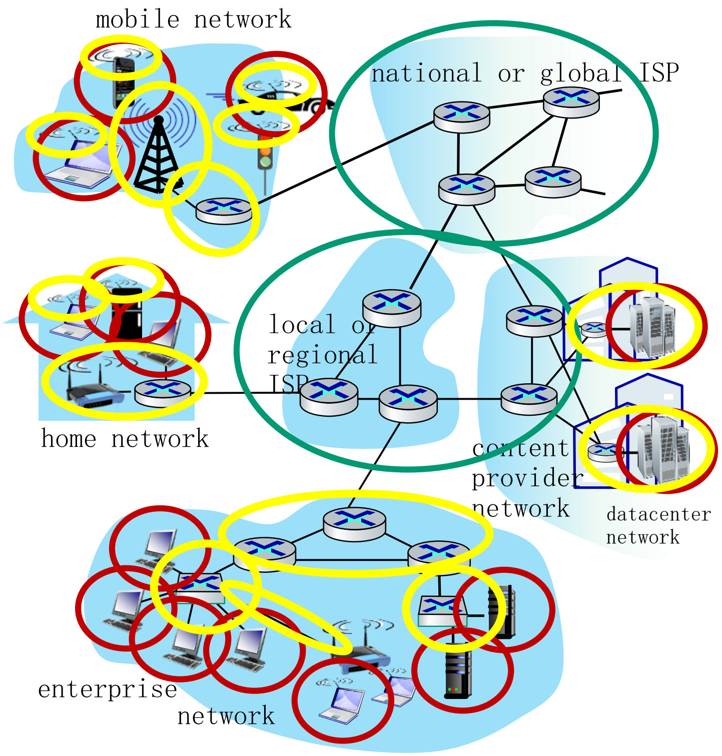
- End systems and hosts
- Host: Clients and servers
- Servers often in data centers

Access networks（接入网）, physical media:

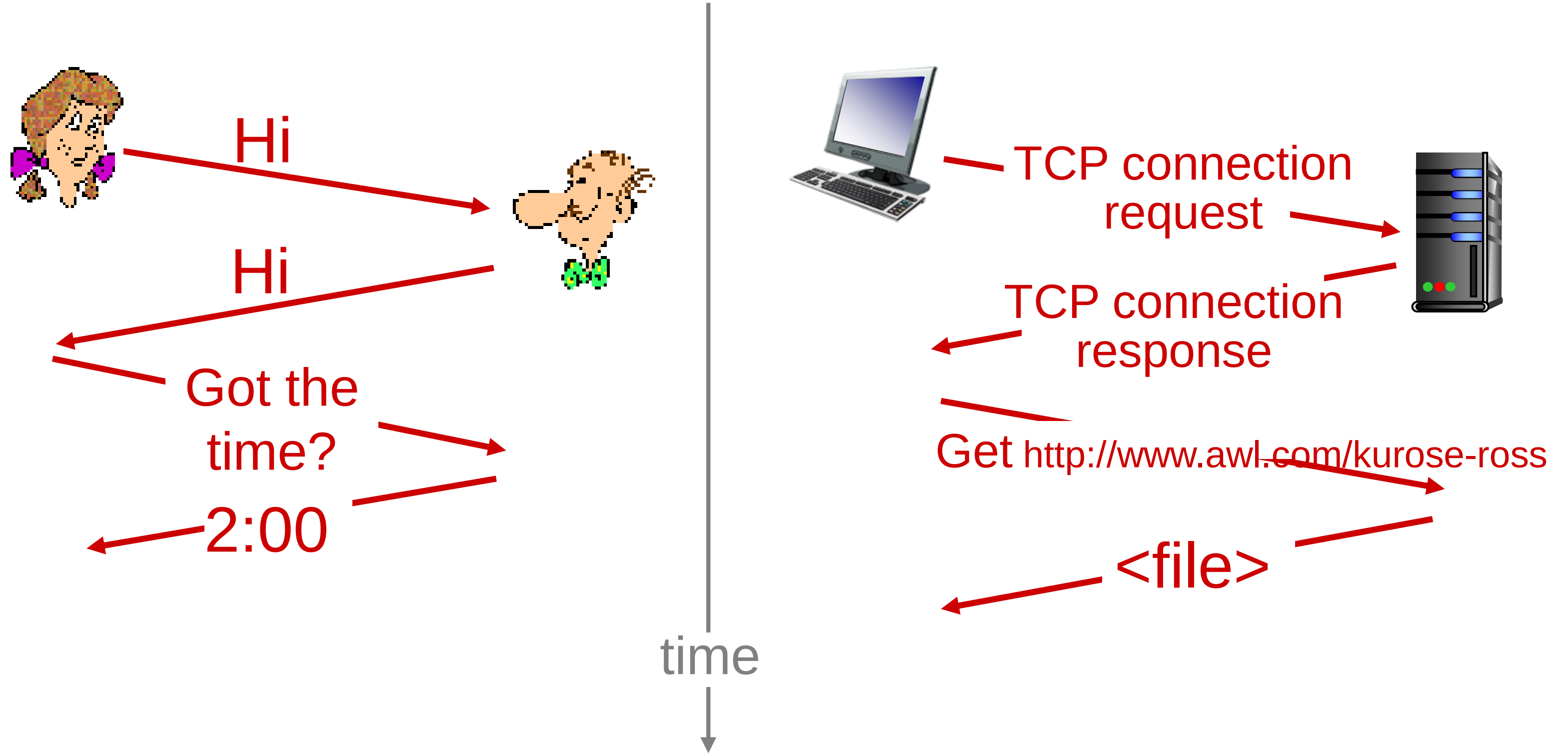
- wired, wireless communication links

Network core:

- Interconnected routers
- Network of networks



What’s a protocol?



Protocols define format, order of messages sent and received among network entities, and actions taken on message transmission and/or receipt

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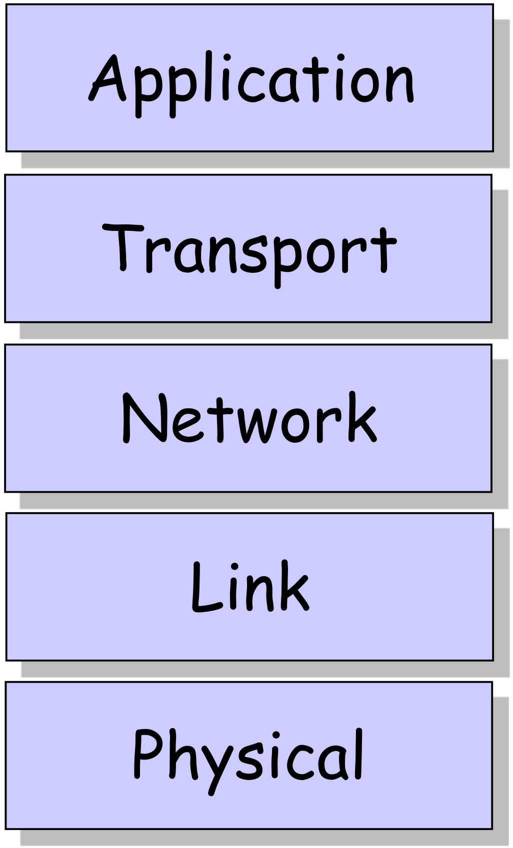
Internet protocol stack

- Application: supporting network applications
  - IMAP, SMTP, HTTP
- Transport: process-process data transfer
  - TCP, UDP
- Network: routing of datagrams from source to destination
  - IP, routing protocols
- Link: data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi), PPP
- Physical: bits “on the wire”



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

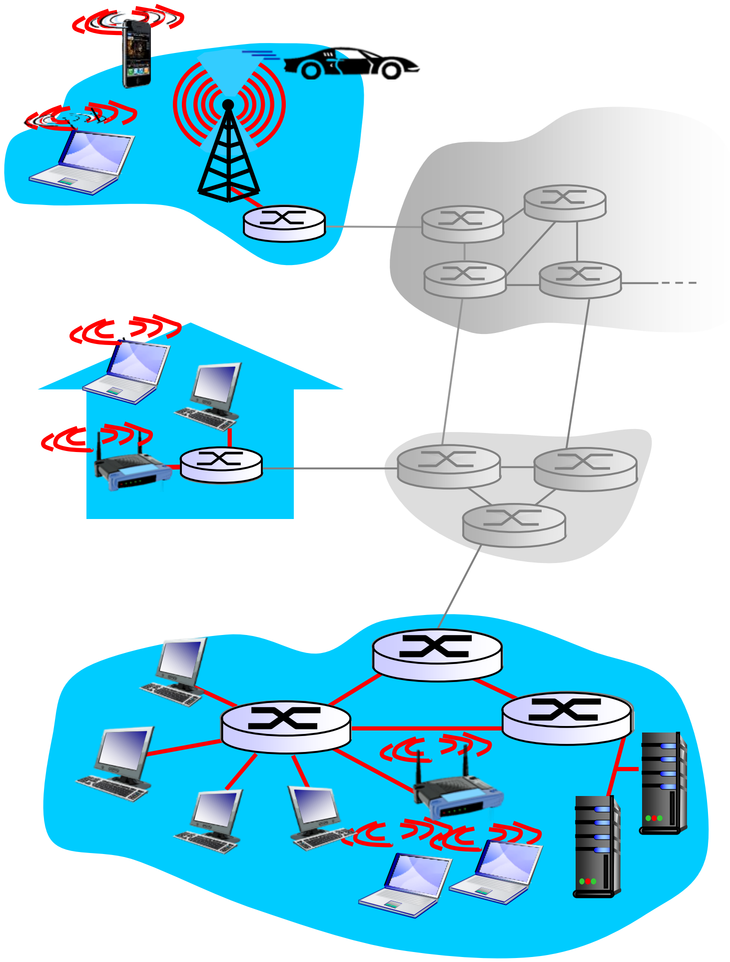
1.6 networks under attack: security

1.7 history

Access networks

The network that physically connects an end system to the first router (edge router) on a path from the end system to any other distant end system.

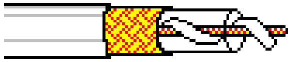
Cable network
Digital subscriber line (DSL)
Home network
Wireless access network
Enterprise access network
…



Physical media

- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio (无线电)

- Twisted pair (双扭线)
- Coaxial cable（同轴电缆）
- Fiber optic cable（光纤）
- Radio
  - terrestrial microwave (近地微波)
  - LAN (e.g., WiFi)
  - wide-area (e.g., cellular (蜂窝网络))
  - Satellite (卫星)



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1.1 what is the Internet?

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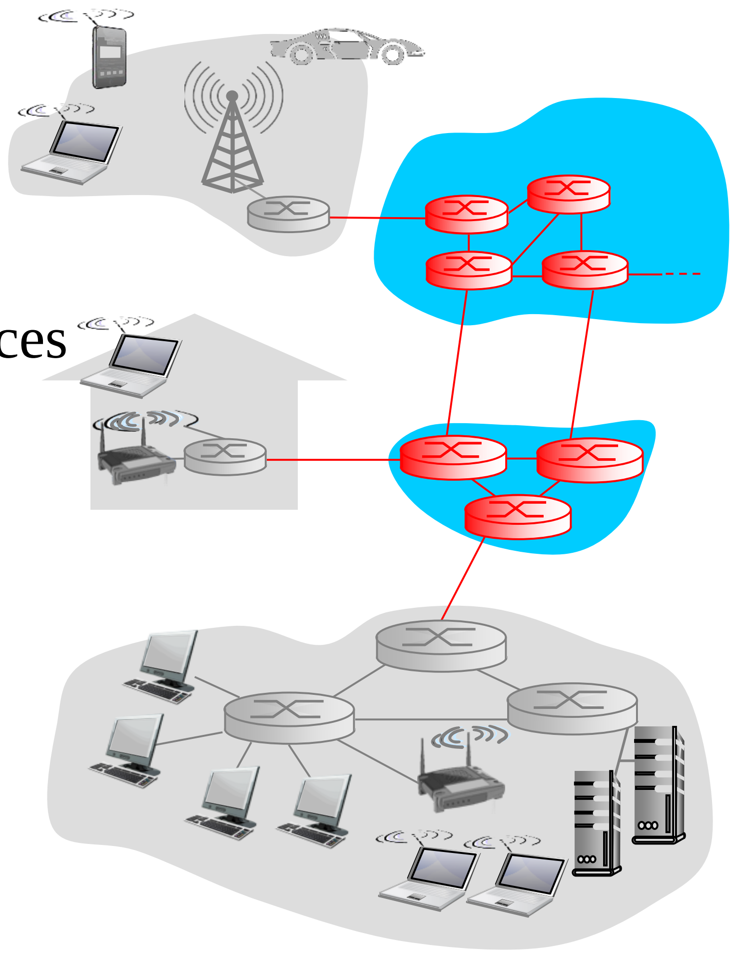
The network core

Network Core: The mesh of **packet switches and links** that interconnects the Internet's end systems.



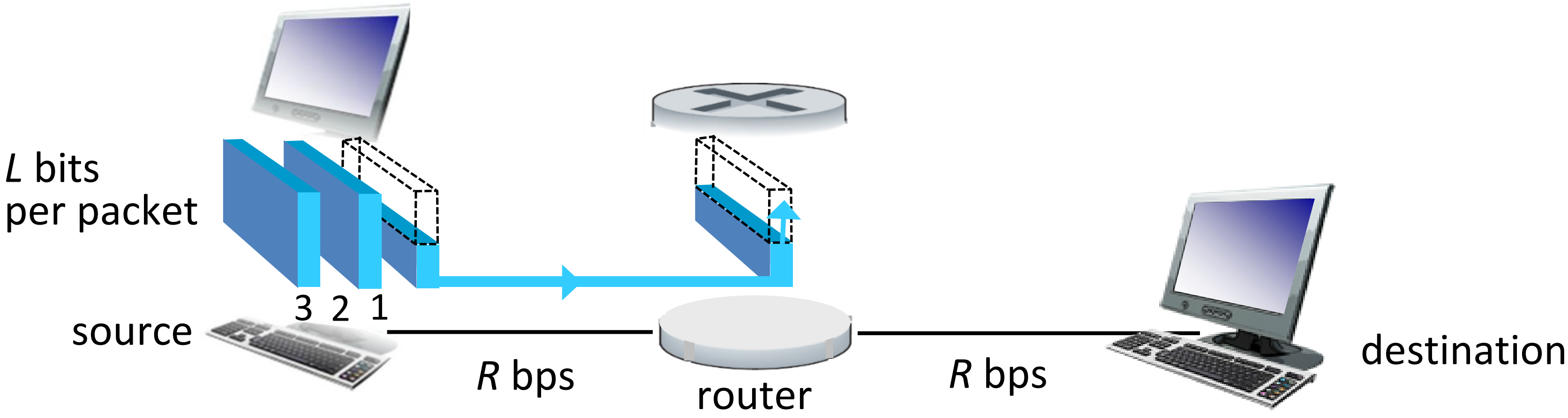
How to exchange messages?

- Packet switching: not reserve (预留) resources
- Circuit switching (e.g., telephone): reserve

Packet switching: hosts break long messages into packets

- Each packet travels through communication links and packet switches
- 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

more on delay shortly …

Example:

- L = 7.5 Mbits; R = 1.5 Mbps
- One-hop transmission delay = L/R = 5 sec
- End-to-end delay = $2L/R$ (assuming zero propagation delay)

How about one packet of length L sending over a path of N links, each of rate R?

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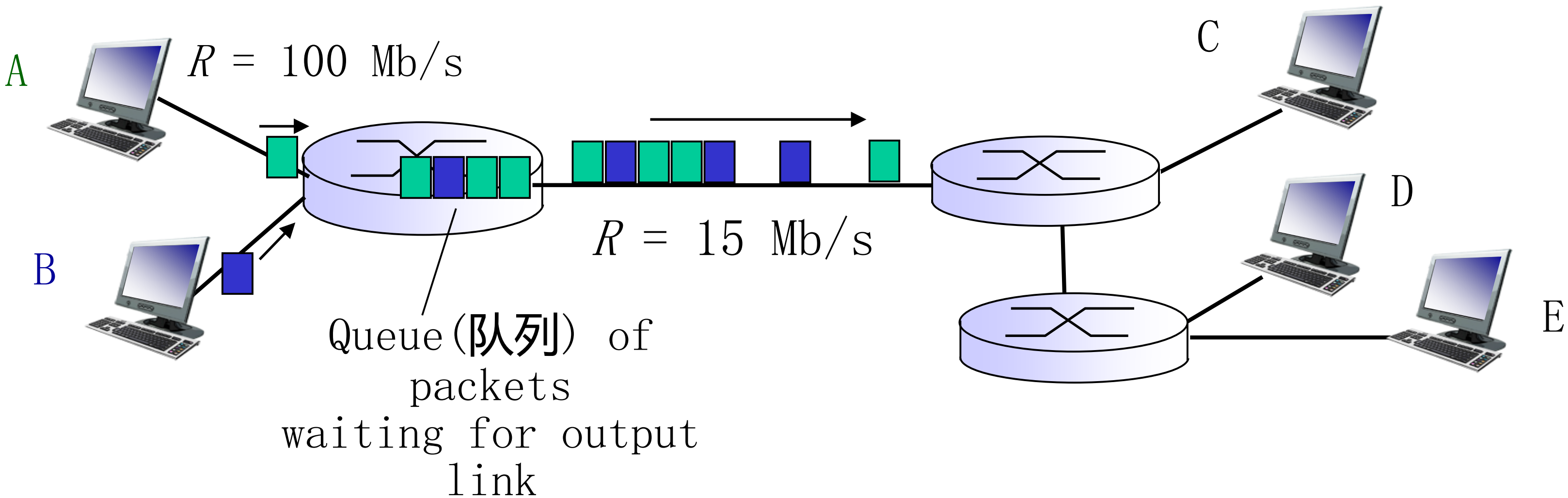
Packet Switching: queueing delay, loss



Output buffer stores packets that the router is about to send into that link.

If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:

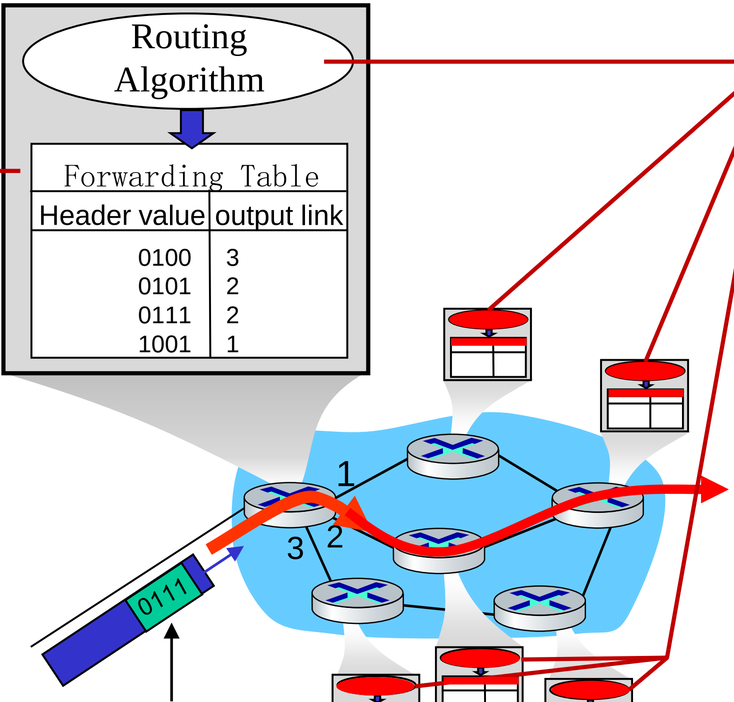
- packets will queue, wait to be transmitted on link → queuing delay
- packets can be dropped (lost) if memory (buffer) fills up → packet loss

[Queuing and Loss Interactive Animation (unicam.it)]

Two key network-core functions

Forwarding:

local action: move arriving packets from router's input link to appropriate router output link



destination address in arriving packet's header

Routing:

- global action: determine source-destination paths taken by packets
- routing algorithms

Alternative core: circuit switching

Packet switching: on demand; may wait

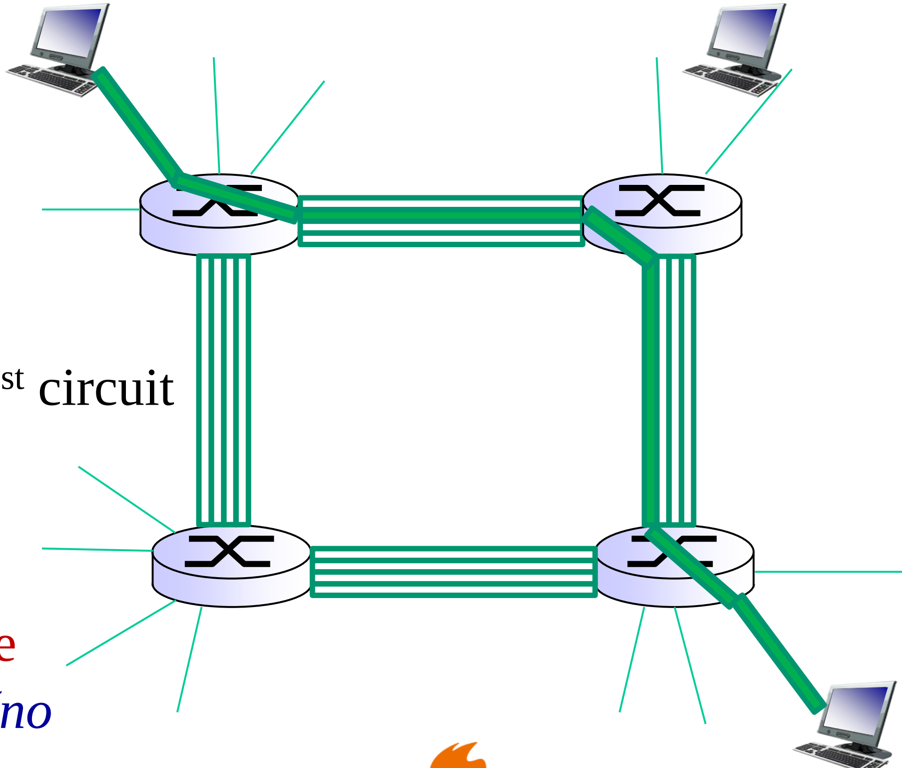
Circuit switching: end-to-end resources reserved for "call" between source and destination; guaranteed rate

- (buffer, link, transmission rate)
- commonly used in traditional telephone networks

In diagram, each link has four circuits.

  - call gets 2nd circuit in top link and 1st circuit in right link.

- dedicated resources: no sharing
  - a fraction of each link's capacity
  - circuit-like; guaranteed constant rate
- circuit segment idle if not used by call *(no sharing)*



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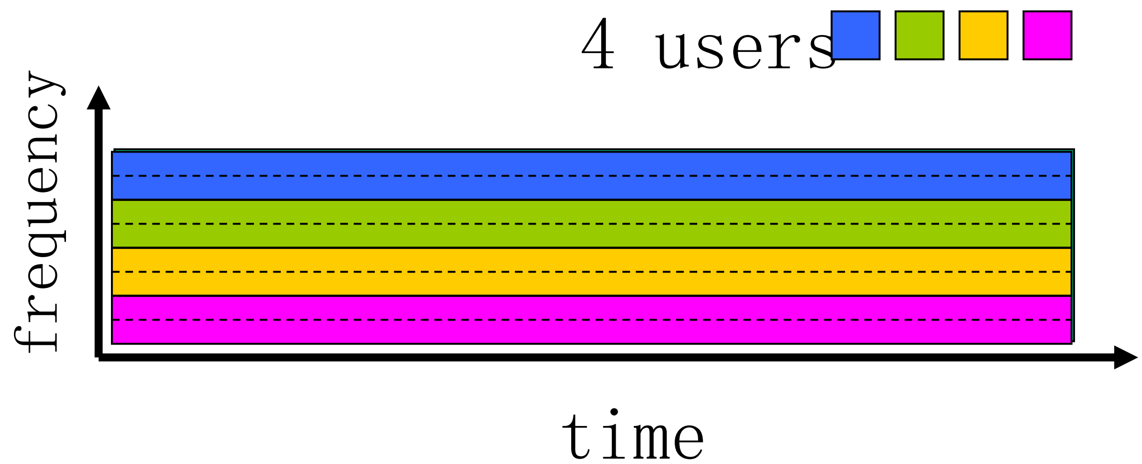
Circuit switching: FDM versus TDM

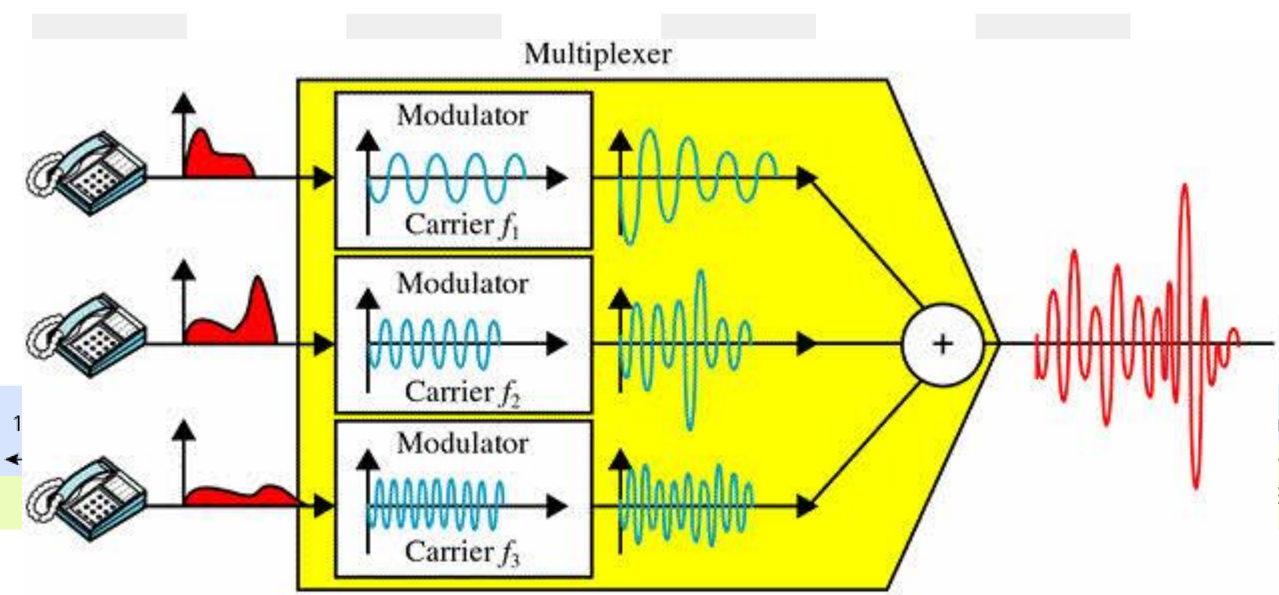
Frequency Division Multiplexing (FDM)

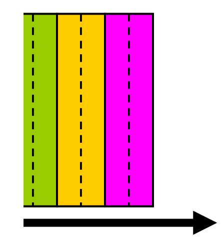
- Optical, electromagnetic frequencies divided into (narrow) frequency bands → bandwidth
- At max rate of that narrow band



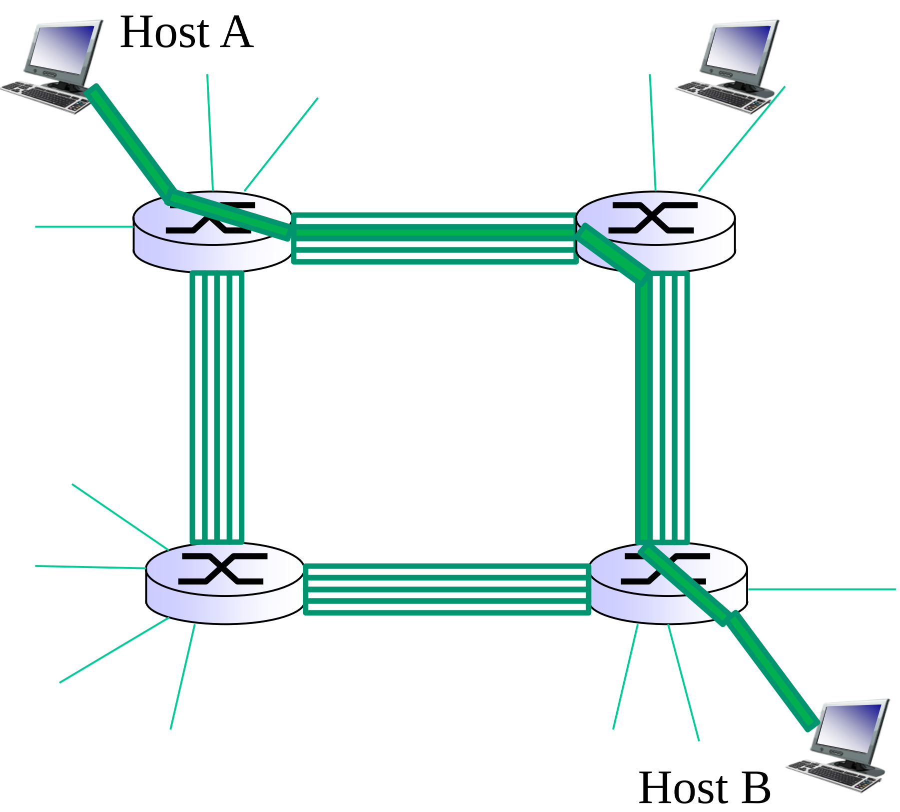
Time Div
Multiplex

- Time d
- At max (wider) band, b its time





Circuit Switching: Delay



- A file of 640,000 bits
- All links in the network use TDM with 24 slots and have a bit rate of 1.536 Mbps.
- It takes 500 msec to establish an end-to-end link.

How long does it take to send the file?

- Each circuit has a transmission rate of 1.536 Mbps/24 = 64 kbps
- It takes 640,000 bits / 64 kbps = 10 sec
- Total: 10 sec + 500 msec = 10.5 sec

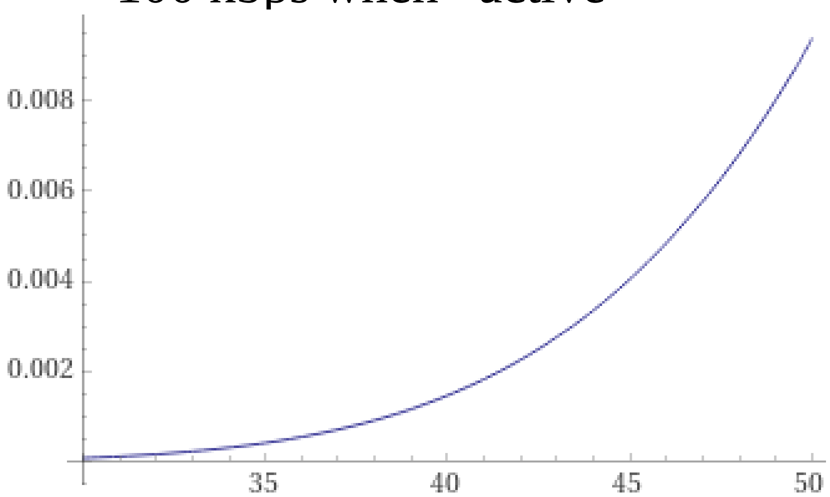
Packet switching versus circuit switching

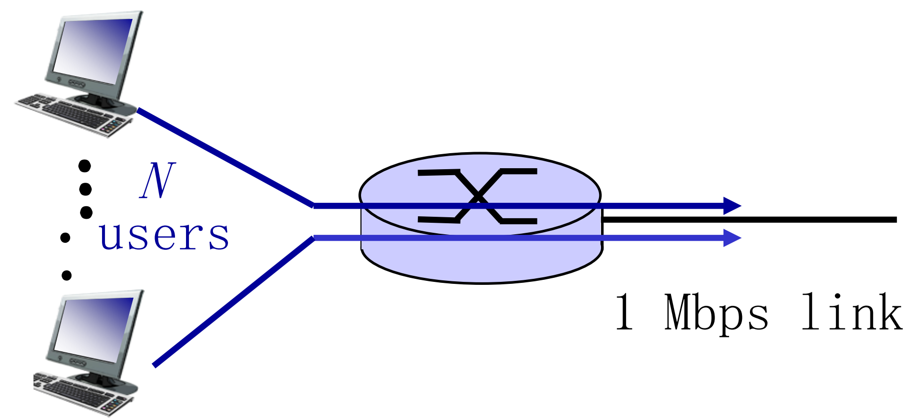
Packet switching allows more users to use network!

- **Circuit switching** pre-allocates use of the transmission link regardless of demand, with allocated but unneeded link time going unused.
- **Packet switching** on the other hand allocates link use *on demand.*

Example:

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





Q: how did we get value 0.0004?

$$\sum_{n=11}^{35} 0.1^n \times 0.9^{35-n} \binom{35}{n}$$

Q: what happens if > 35 users ?

Packet switching versus circuit switching

Packet switching:

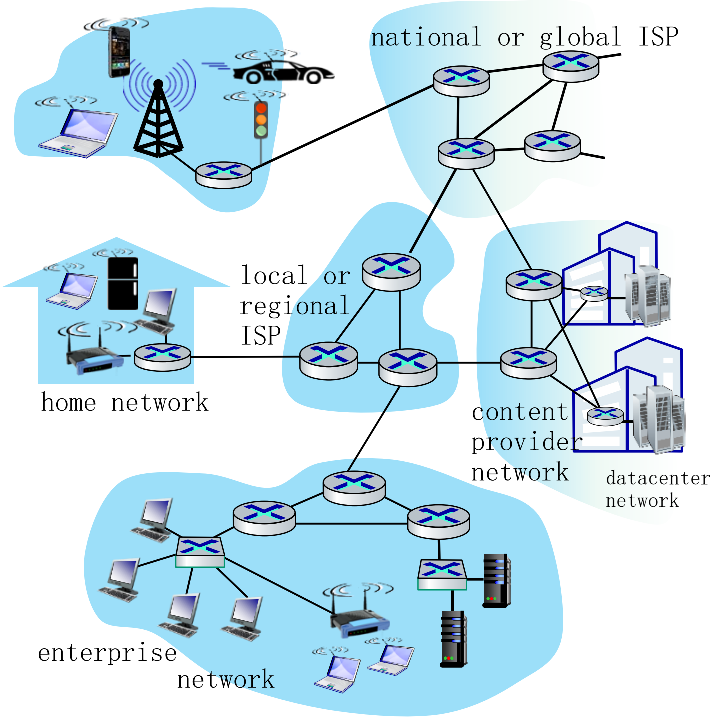
- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- *Q:* How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still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

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

Internet structure: network of networks

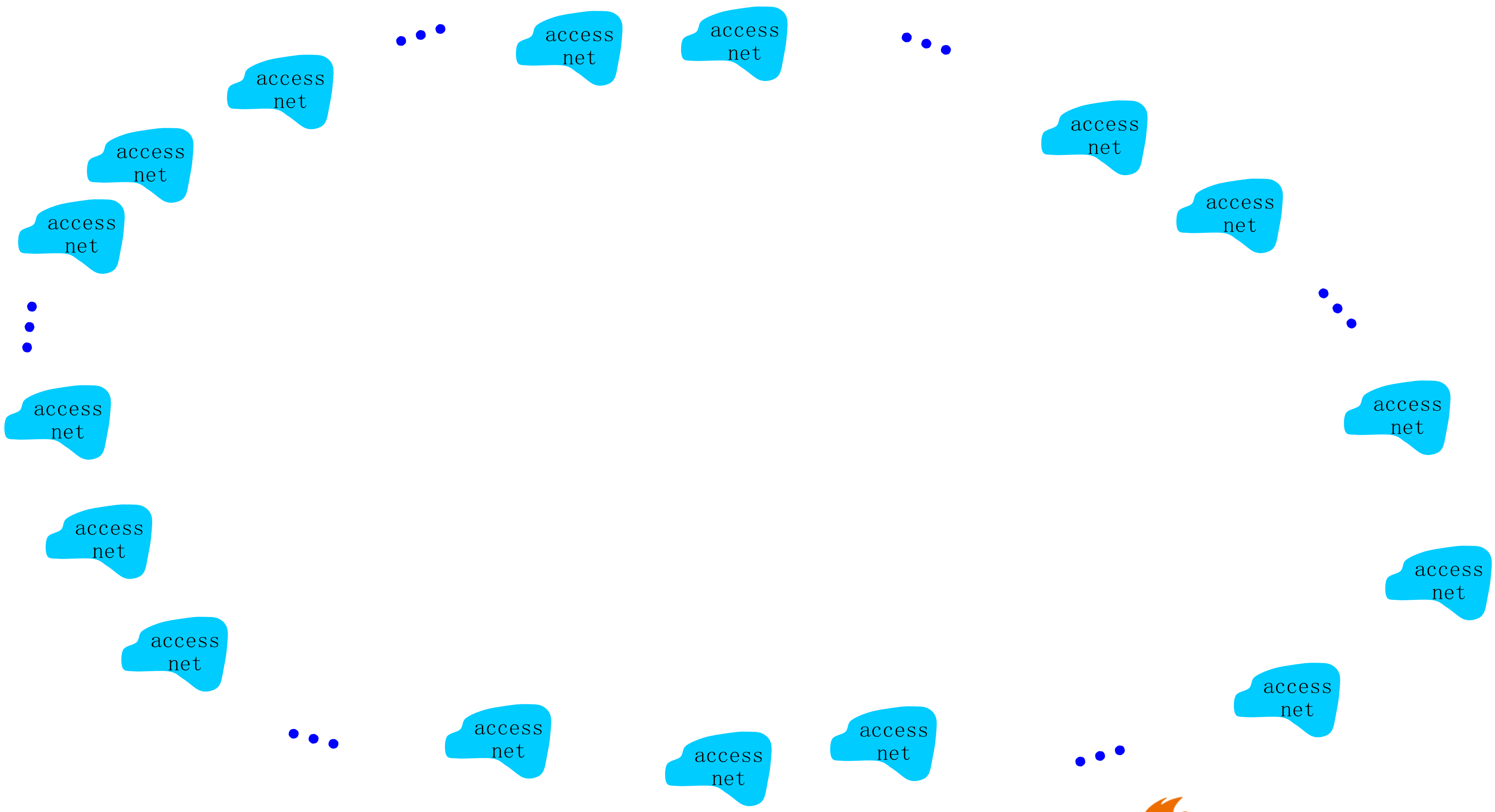
- End systems connect to Internet via access ISPs (Internet Service Providers)
  - Residential, company and university ISPs
  - E.g., China Mobile, university.
- Access ISPs in turn must be interconnected.
  - So that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - Evolution was driven by economics and national policies

Let's take a stepwise approach to describe current Internet structure.



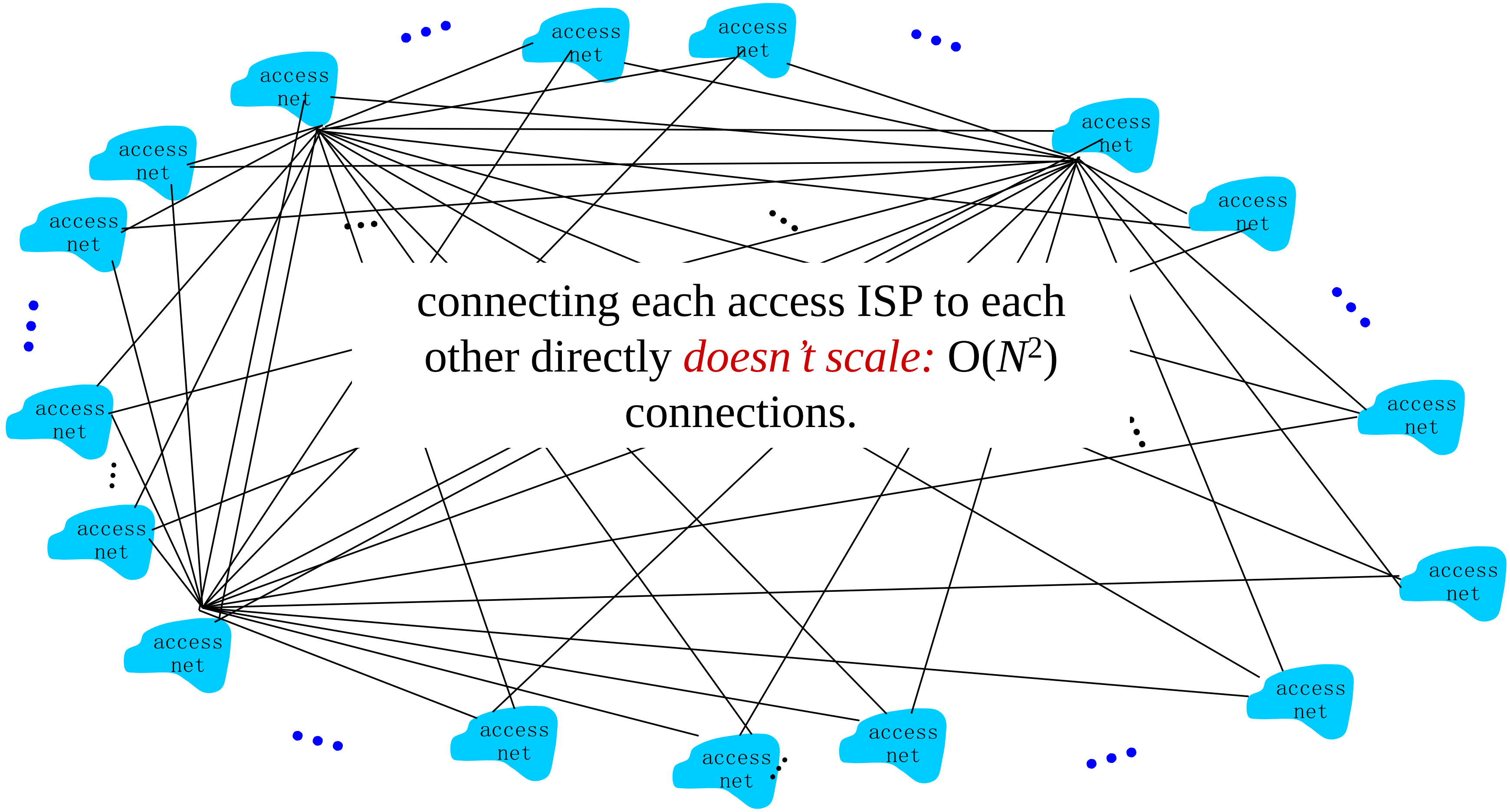
Internet structure: network of networks

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



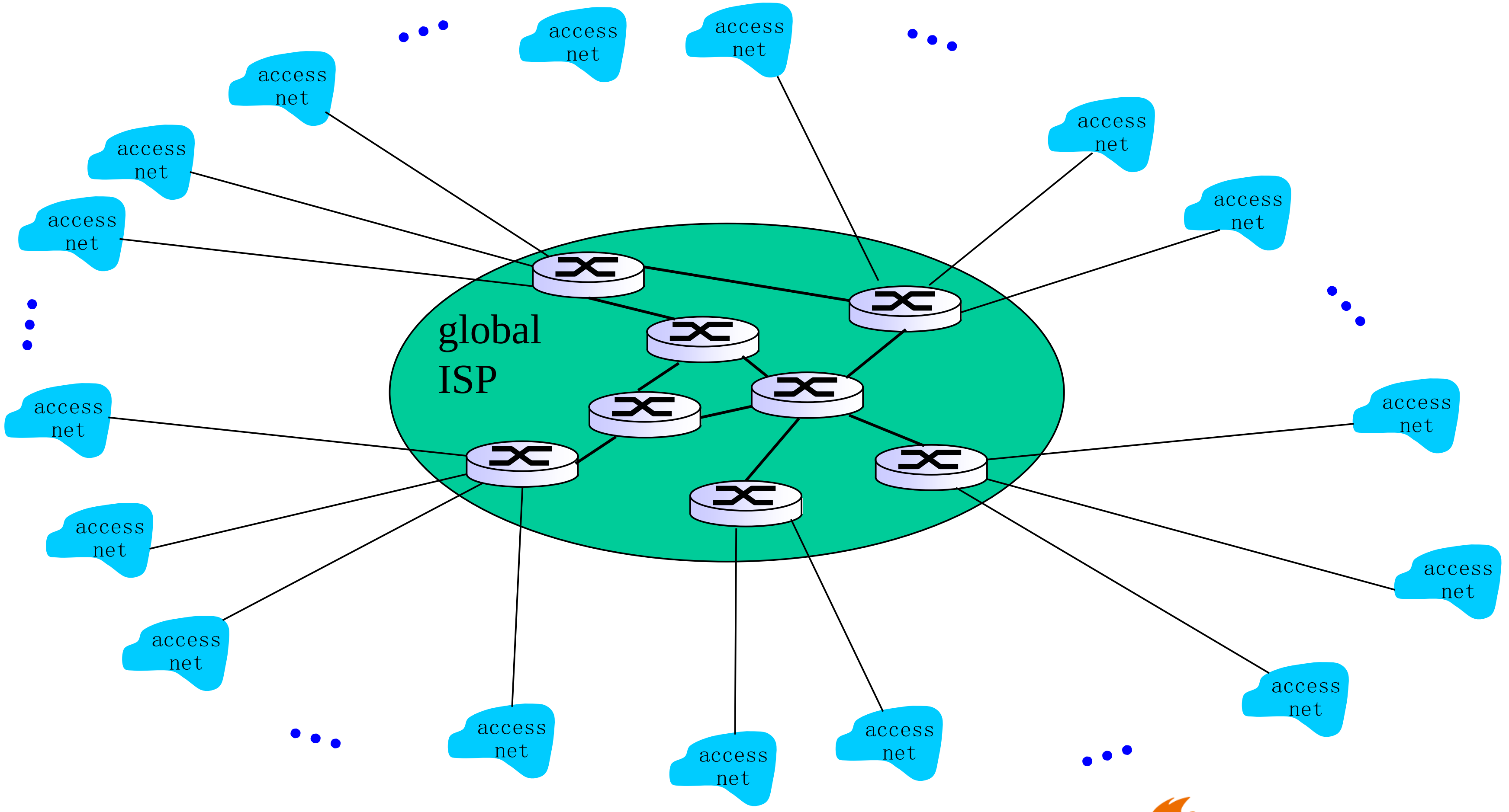
Internet structure: network of networks

Option 1: connect each access ISP to every other access ISP?



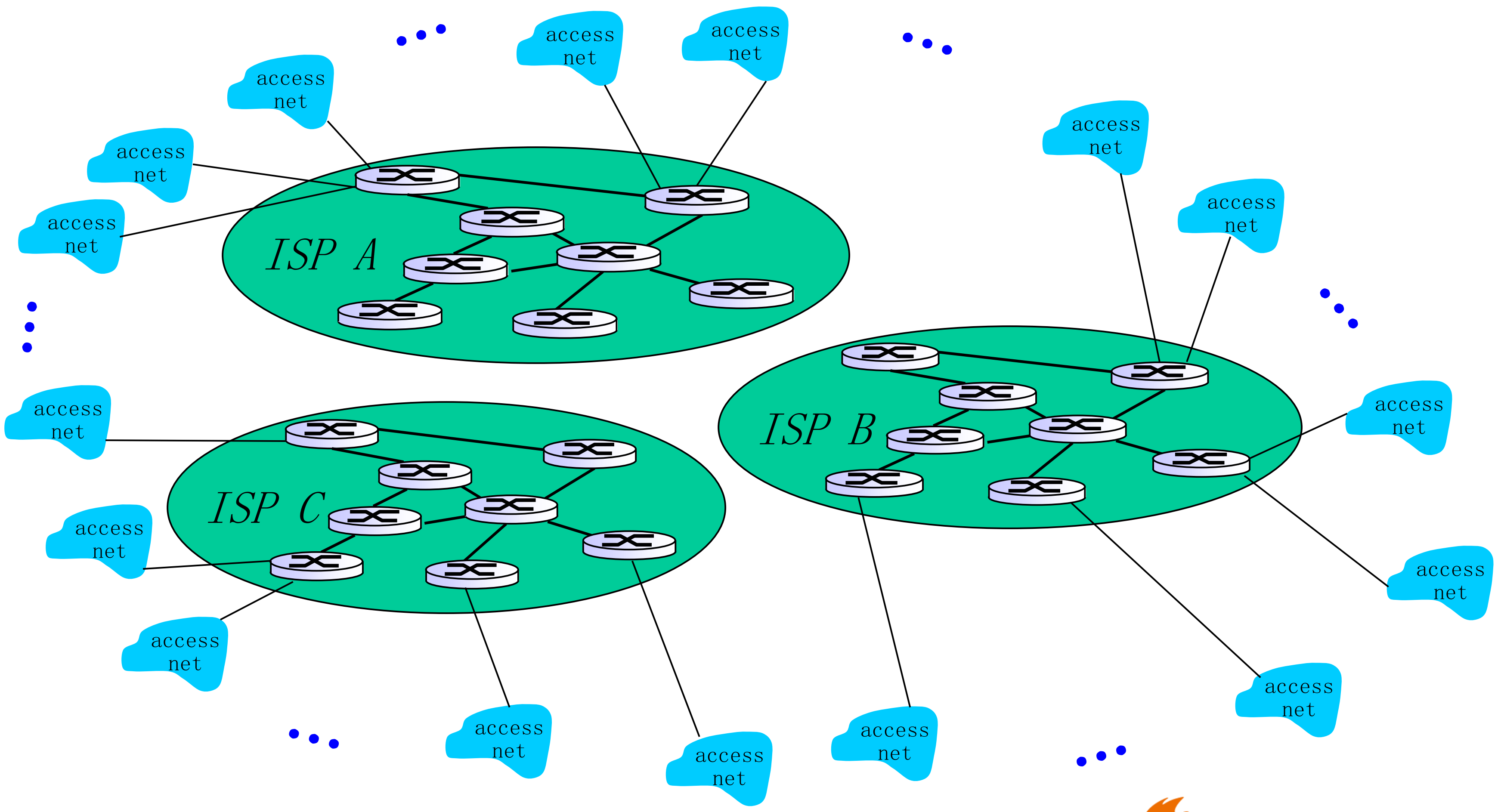
Internet structure: network of networks

Option 2: connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.



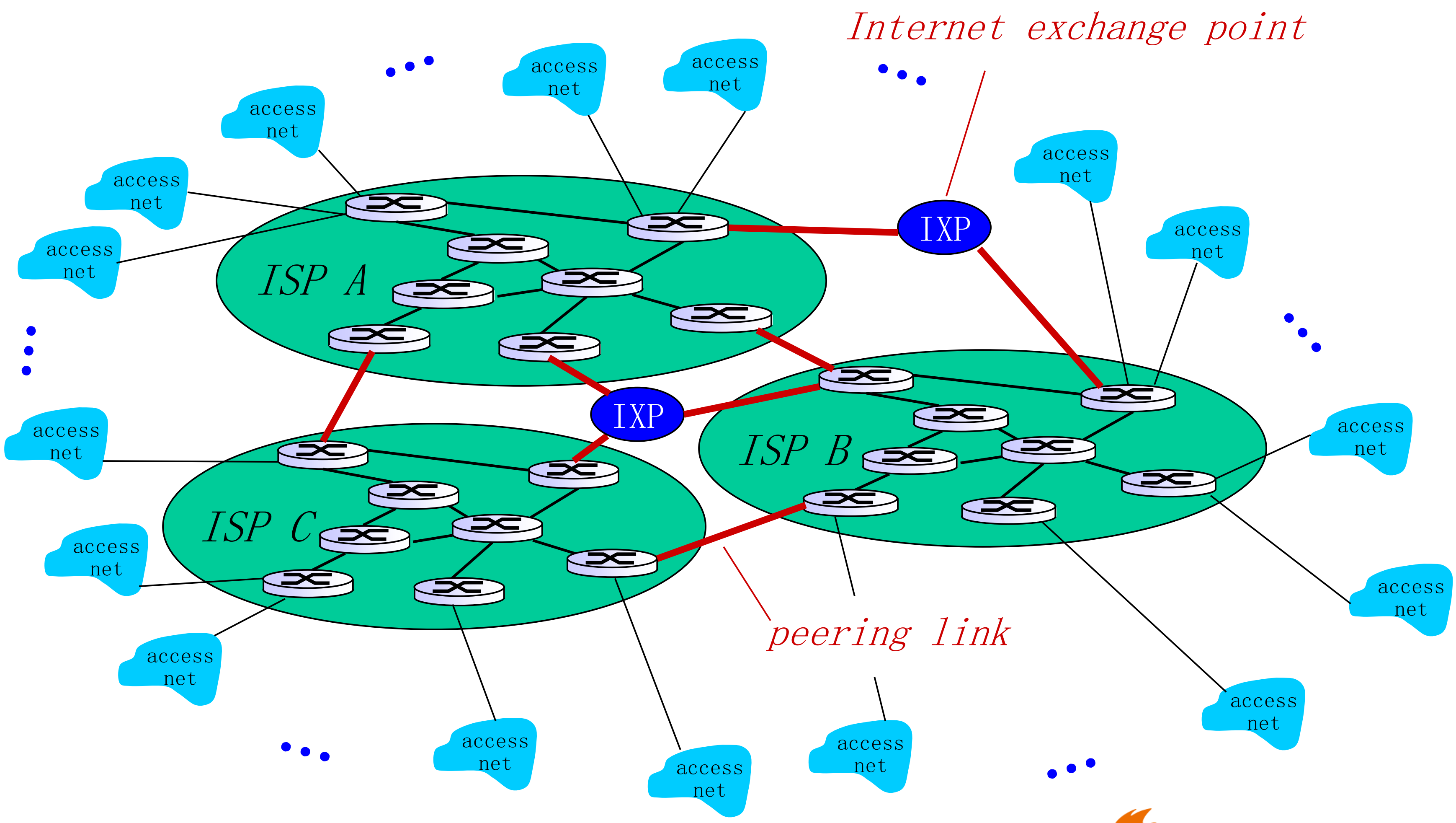
Internet structure: network of networks

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



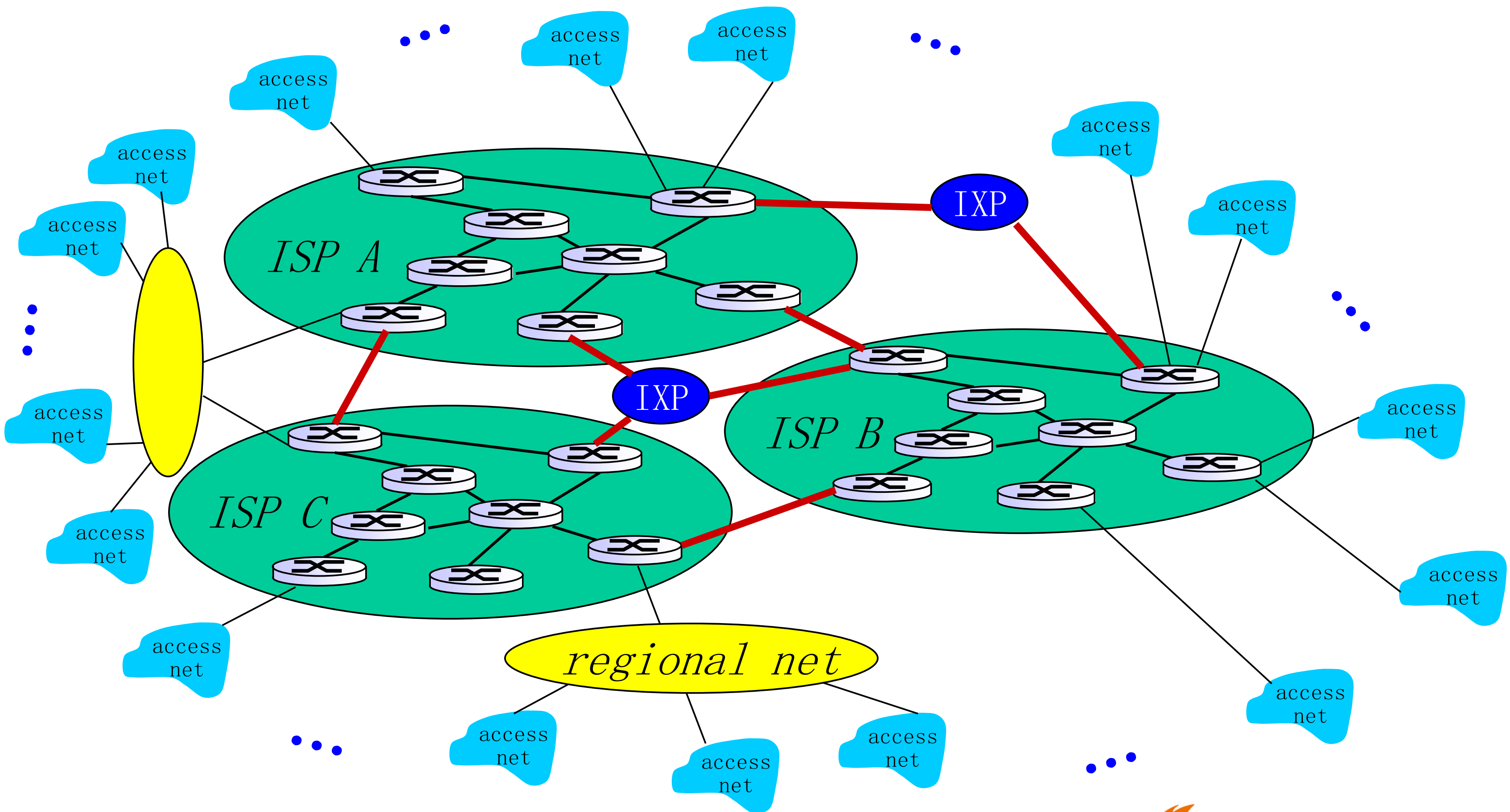
Internet structure: network of networks

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



Internet structure: network of networks

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



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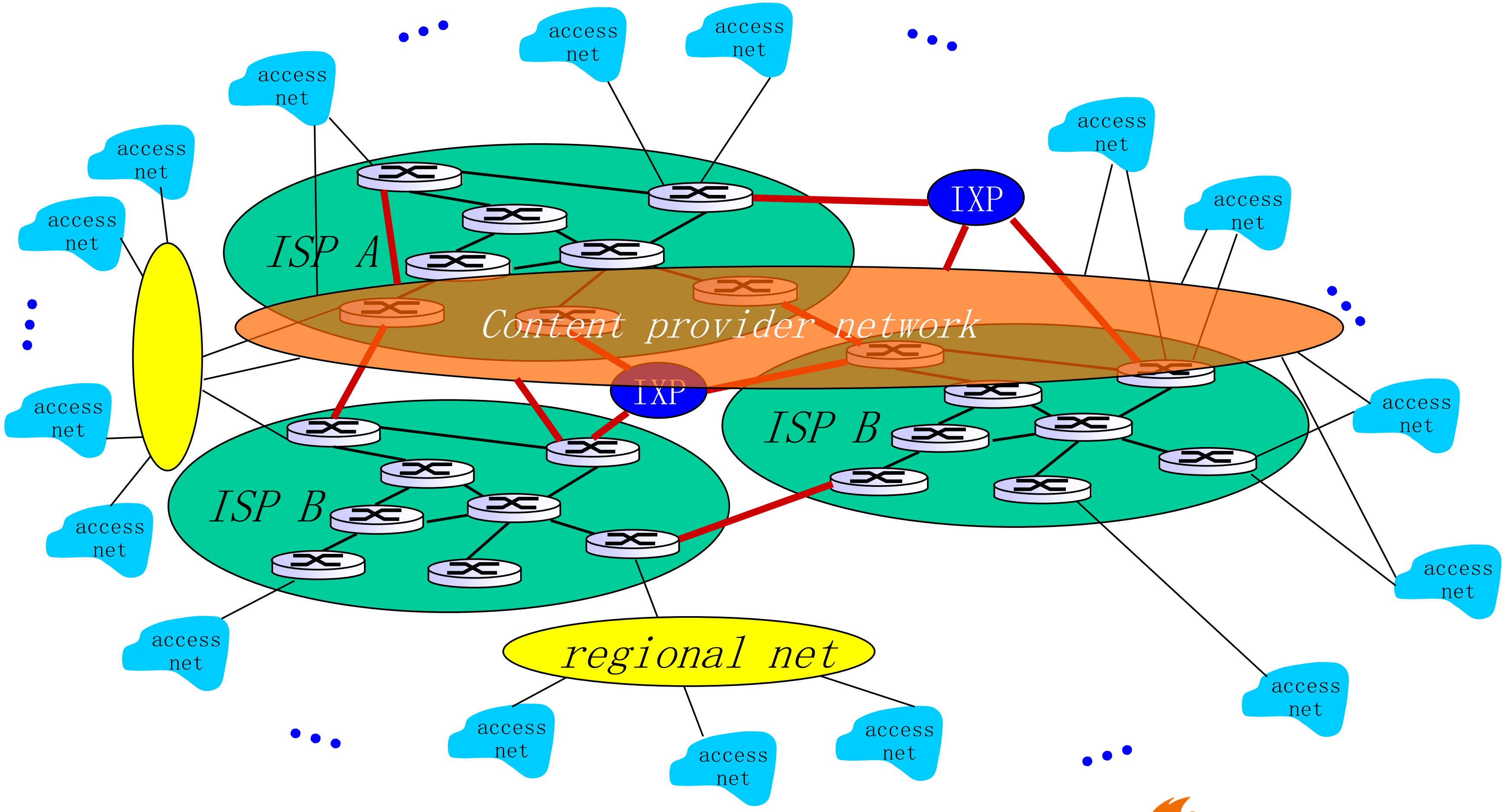
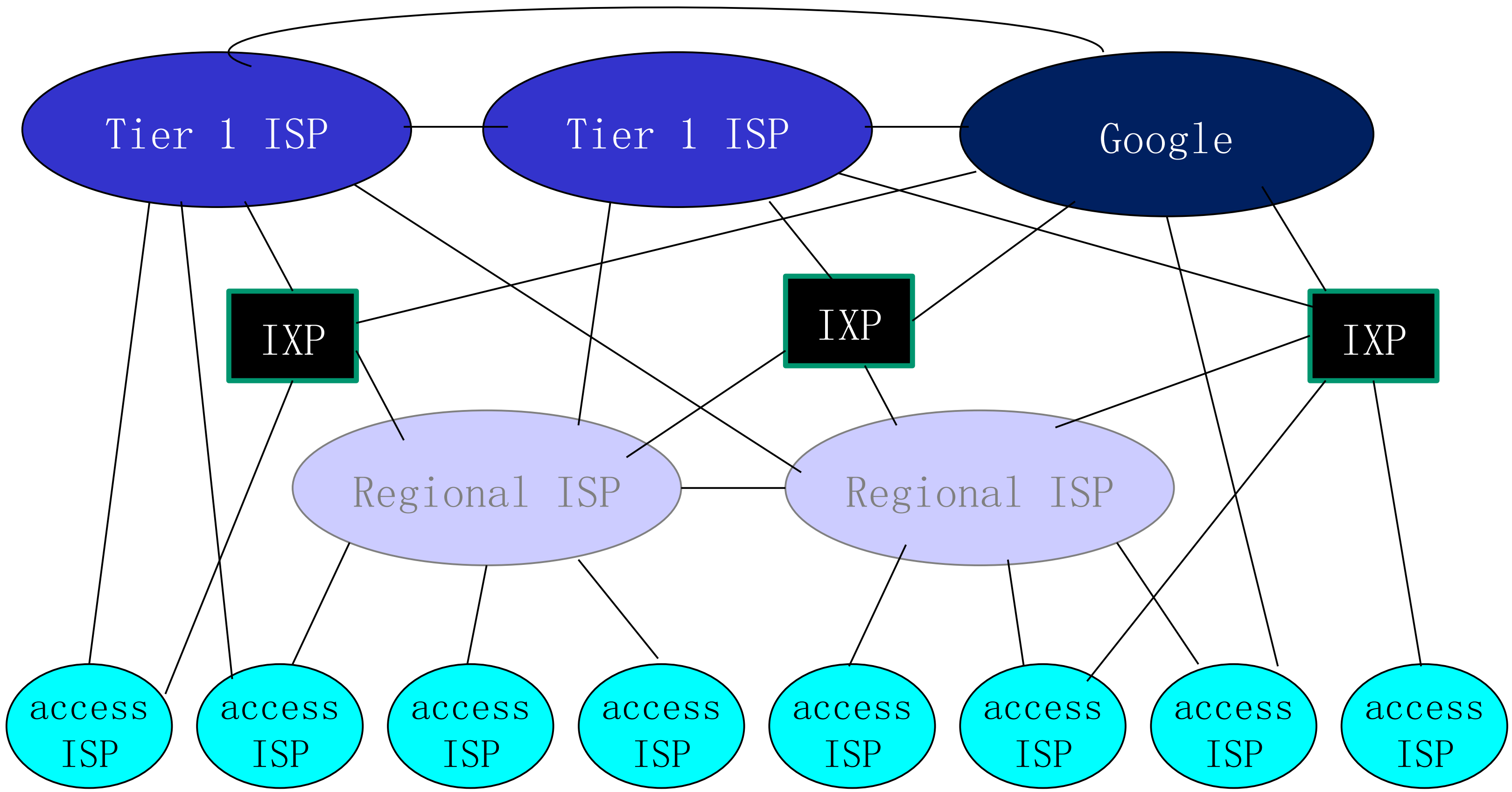
Internet structure: network of networks

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



Internet structure: network of networks



- "Tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
- Multi-homing: to connect to two or more provider ISPs
- Peer: a pair of nearby ISPs at the same level
- Content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

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Performance Metric

We would like Internet services to be able to move as much data as we want between any two end systems, instantaneously, without any loss of data.

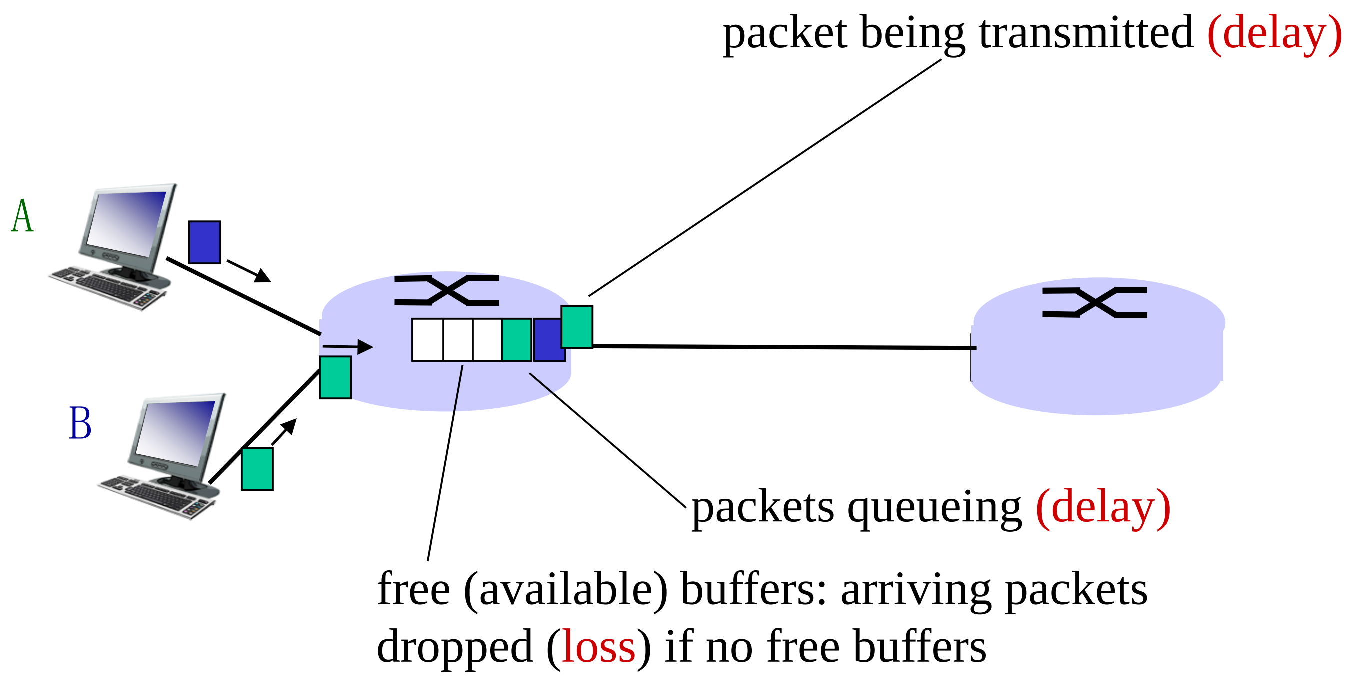
In Packet-Switched Networks:

- Throughput: the amount of data per second that can be transferred between end systems
- Delay
- Packet loss

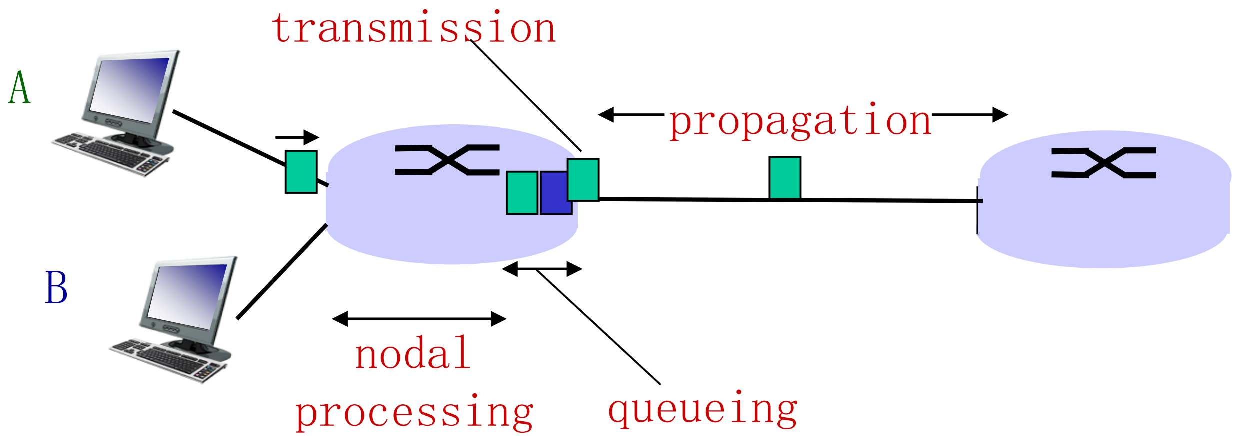
How do loss and delay occur?

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



Nodal (节点) delay

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

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

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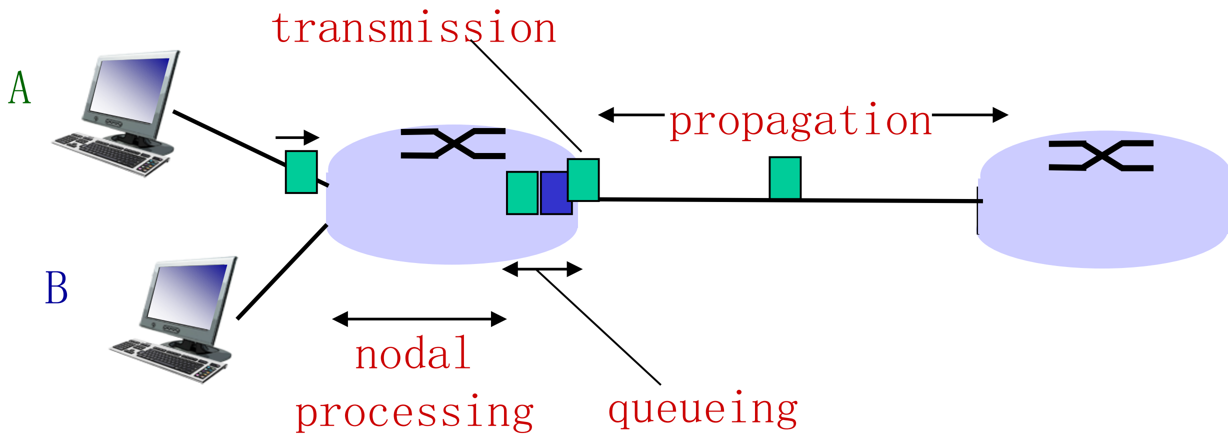
Four sources of packet delay



Nodal (节点) delay

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

d_{trans}: transmission delay (传输时延):

- L: packet length (bits)
- R: transmission rate (bps)
- $d_{trans} = L/R$

d_{prop}: propagation delay (传播时延):

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

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

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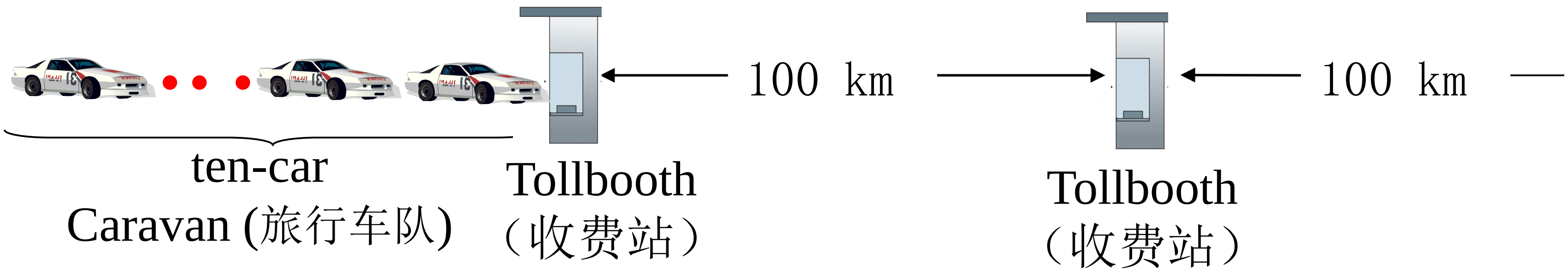
Caravan analogy

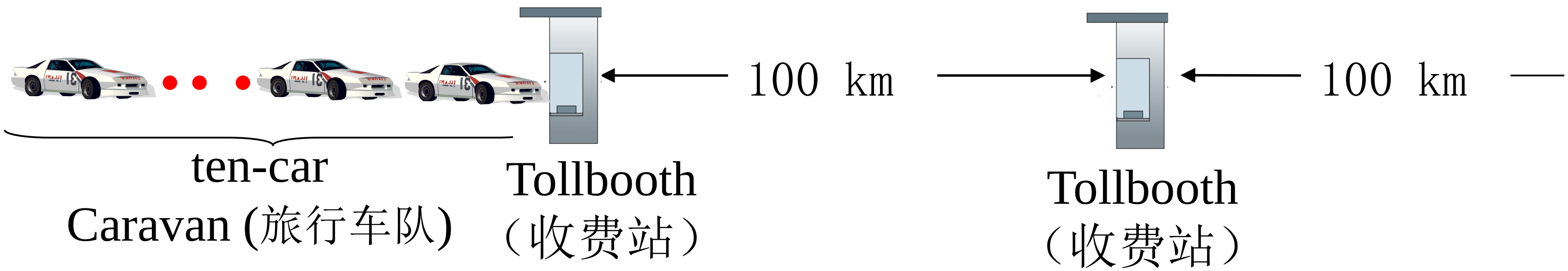


- Cars "propagate" at 100 km/hr
- Tollbooth takes 12 sec to service one car (bit transmission time)
- car~bit; caravan ~ packet

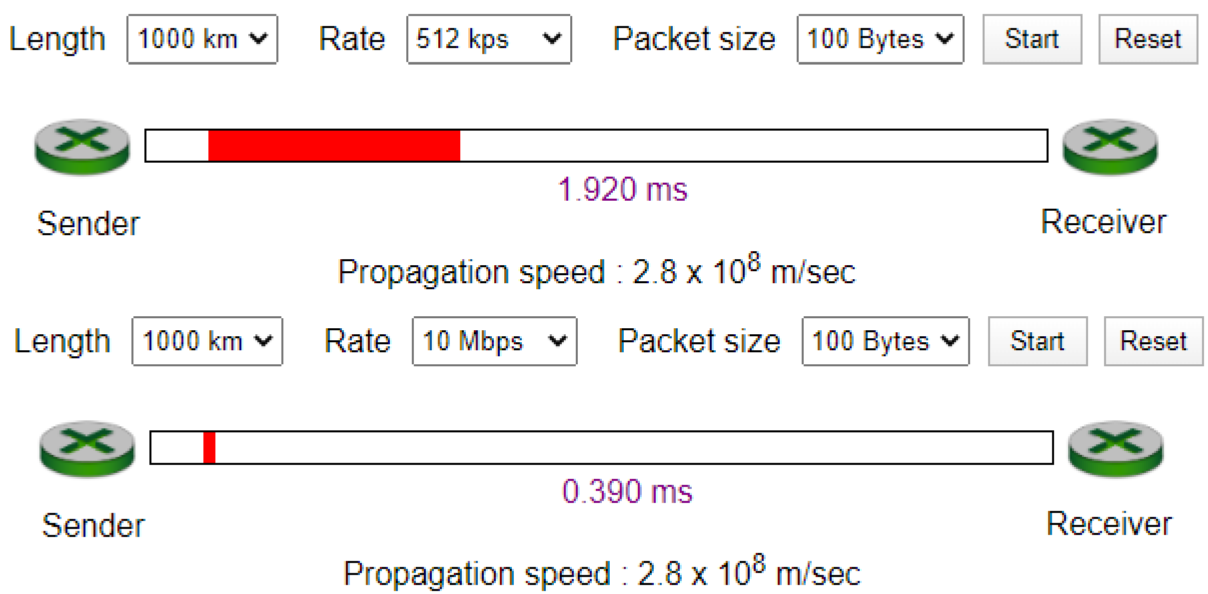
Q: How long does it take the first car to arrive at the 2nd tollbooth?

- Transmission delay : time to "push" entire caravan through tollbooth 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
- and suppose tollb
- *Q: Will cars arriv booth?*
  - *A: Yes!* after 7 cars still at 1st



[Transmission versus Propagation Delay Interactive Animation (unicam.it)]

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Queueing delay (revisited)

Nodal (节点) delay

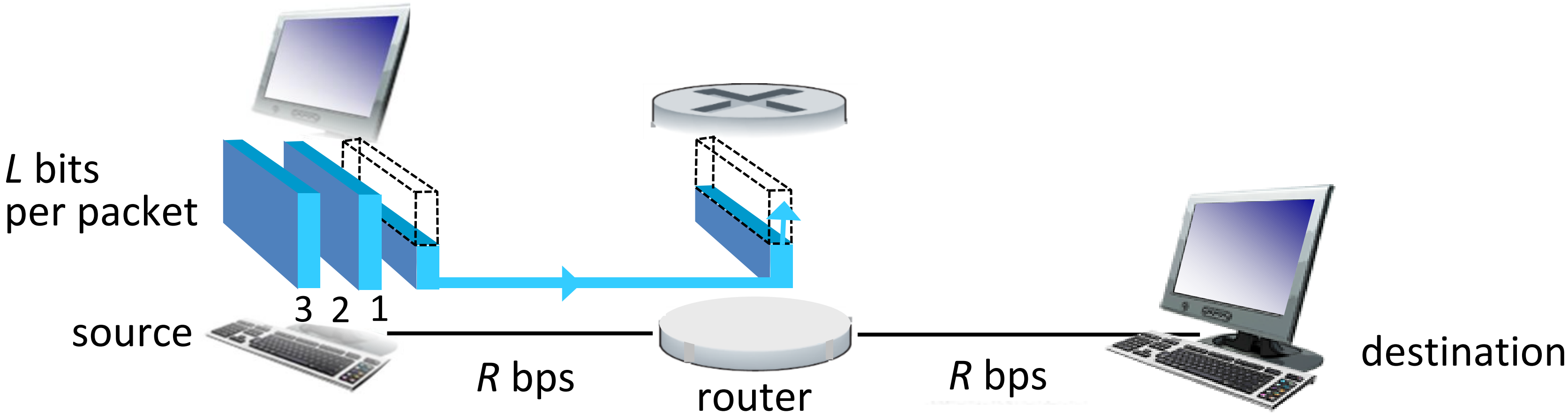
$$d_{\mathrm{nodal}} = d_{\mathrm{proc}} + d_{\mathrm{queue}} + d_{\mathrm{trans}} + d_{\mathrm{prop}}$$

Unlike the other three delays (namely, d_{proc}, d_{trans}, d_{prop}), the queuing delay can vary from packet to packet.

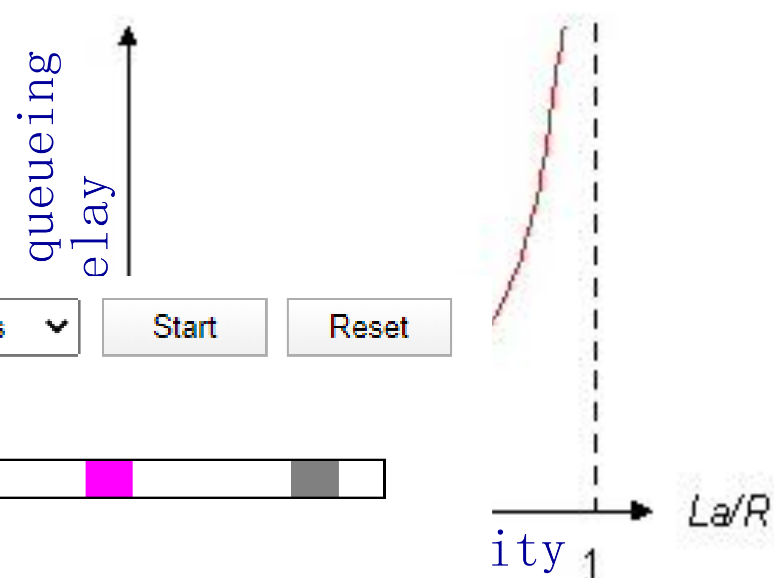
When characterizing queuing delay, statistical measures:

- average queuing delay
- variance of queuing delay
- the probability that the queuing delay exceeds some specified value

Queueing delay (revisited)



- R: transmission rate (bps)
- L: packet length (bits)
- a: average packet arrival rate (packets per sec)



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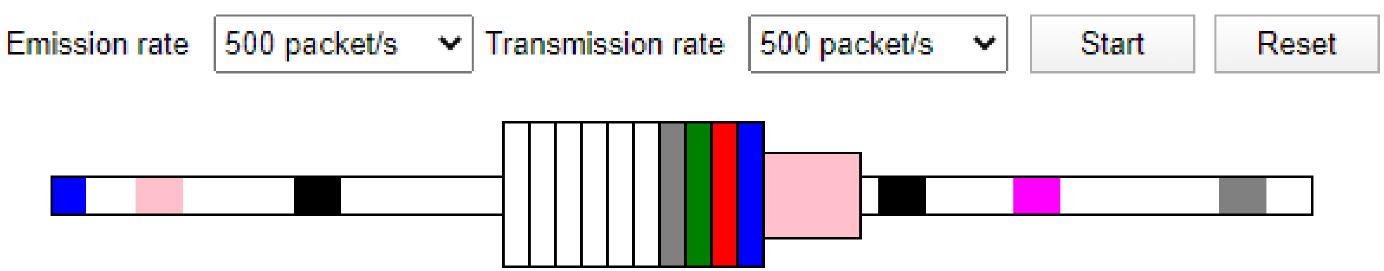
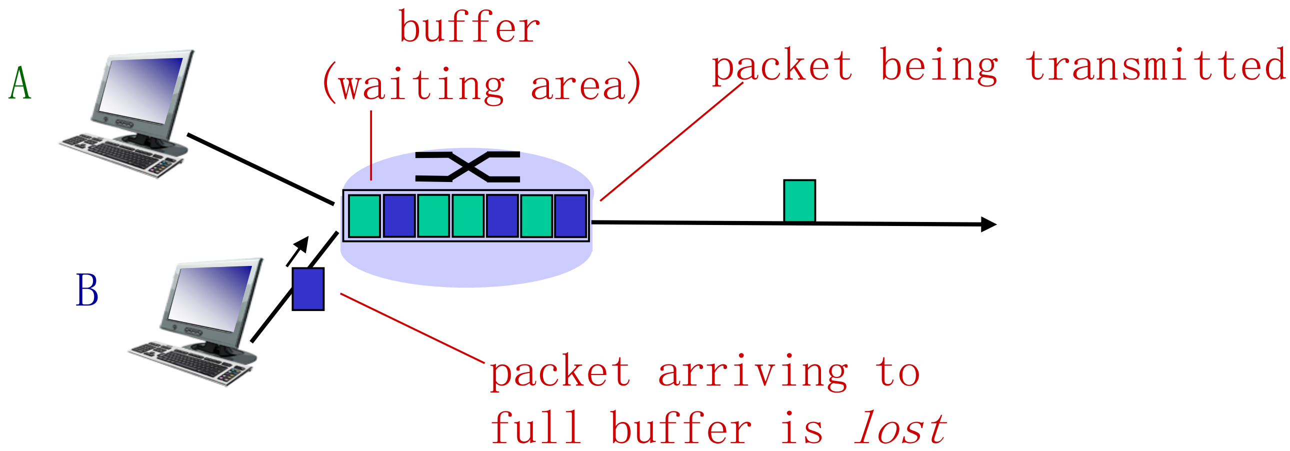


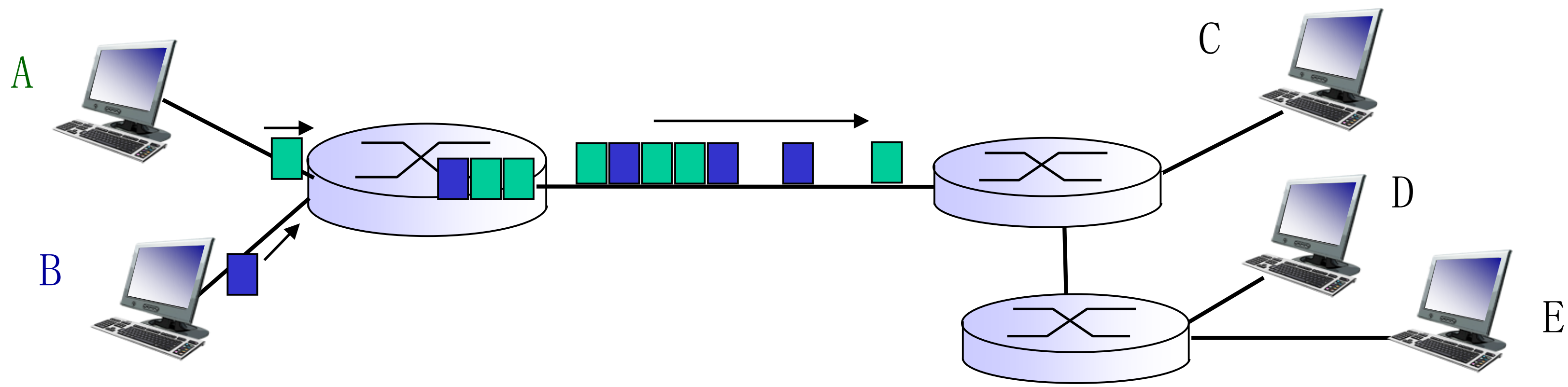
[Queuing and Loss Interactive Animation (unicam.it)]

Packet loss

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



End-to-End Delay



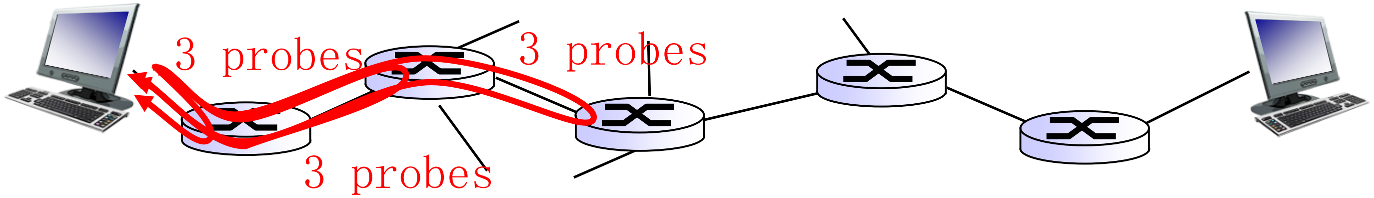
Suppose d_{queue} is negligible; *N-1* routers between two hosts

End-to-End delay

$$\boxed{d_{\text{end-end}} = N\,(d_{\text{proc}} + d_{\text{trans}} + d_{\text{prop}})}$$

"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
  - sender times interval between transmission and reply.



N-1 routers, send *3N* packets

"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

looks like delays *decrease*! Why?

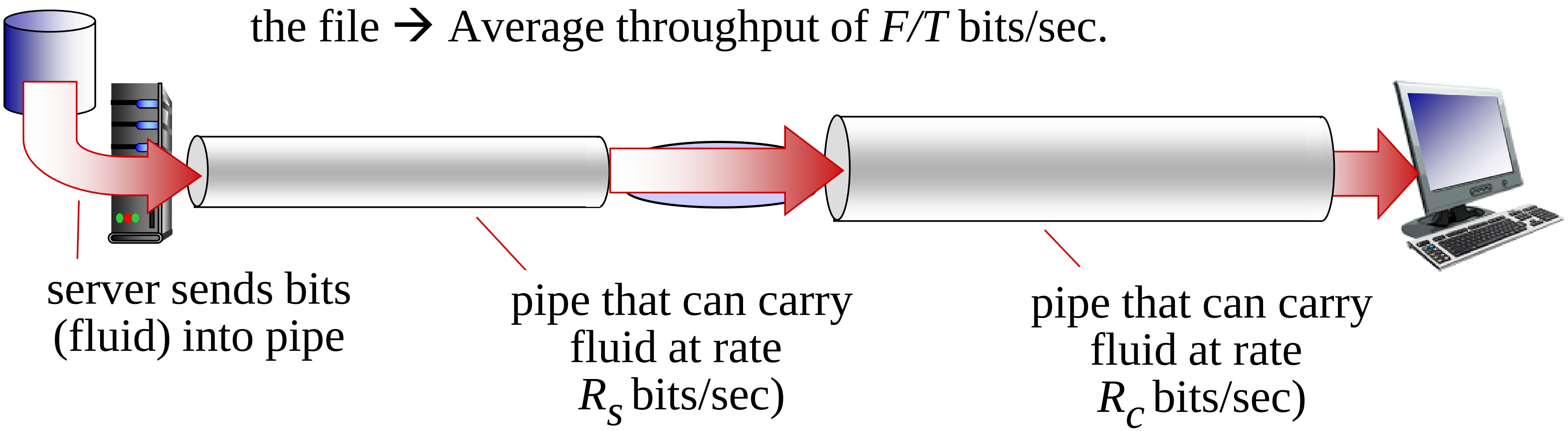
* means no response (probe lost, router not replying)

* 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
    - A file of F bits; it takes T seconds for the receiver to receive the file → Average throughput of F/T bits/sec.

The rate (bits/time unit) at which the receiver is receiving the file.



What is the server-to-client throughput?

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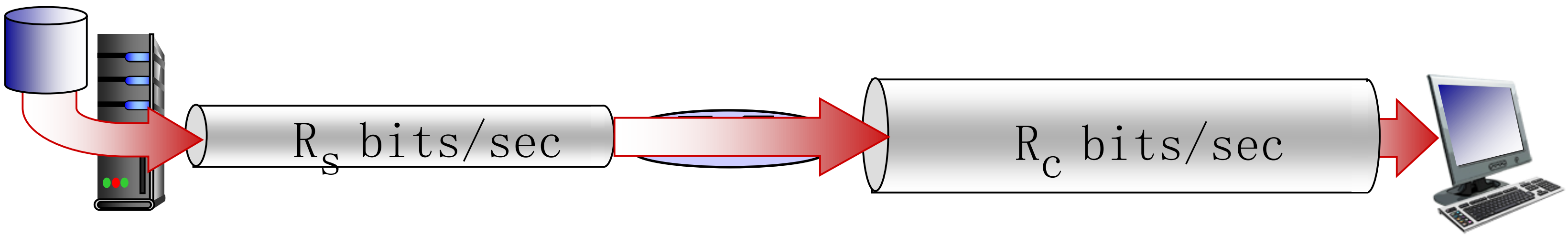
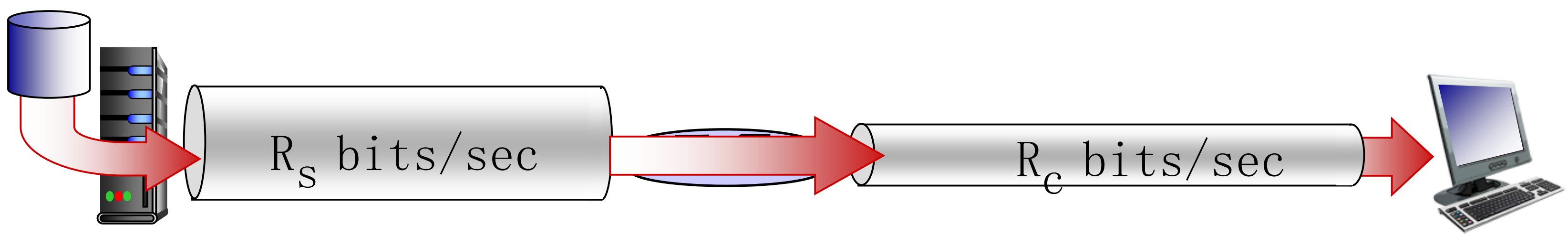
Throughput (more)

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



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

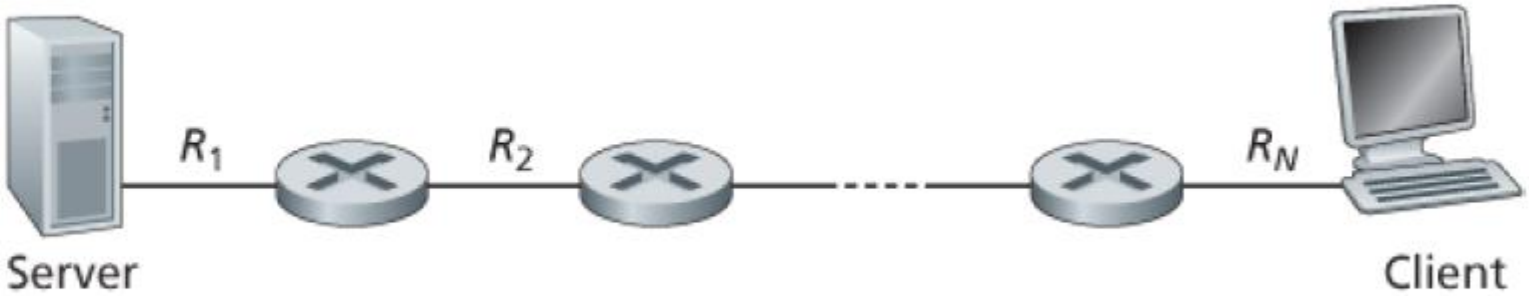


min{R_s, R_c}

bottleneck link

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

Throughput (more)



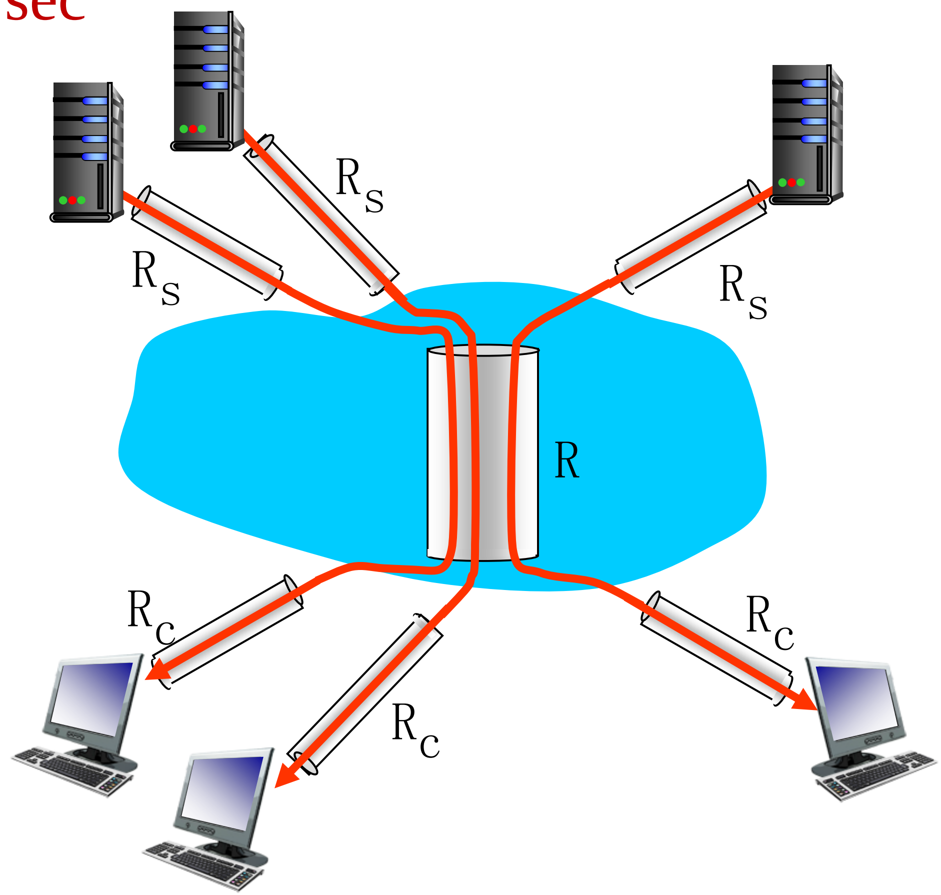
What is average end-end throughput?

min{R_1, R_2, …, R_N}

Throughput: Internet scenario

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

- Per-connection end-end throughput: $\min\{R_c, R_s, R/10\}$
- In practice: R_c or R_s is often bottleneck



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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

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?

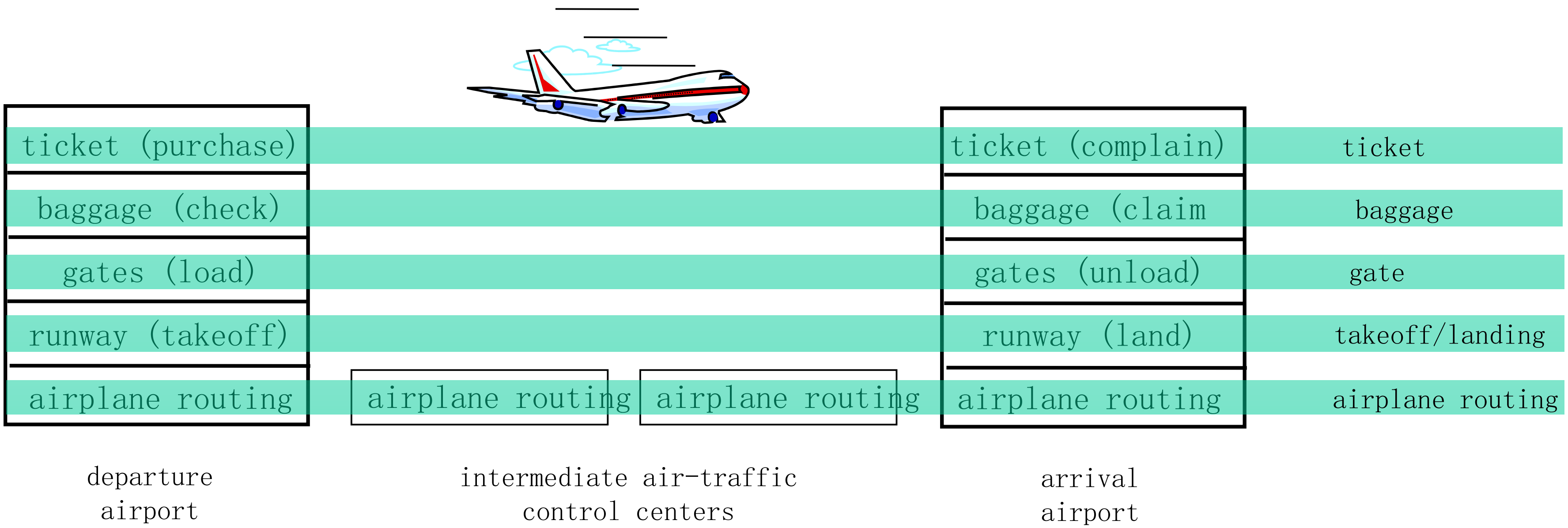
…. or at least our discussion of networks?

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

Layering of airline functionality



Layers: Each layer provide services to the layer above

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

Layering of functionality

Layers: Each layer provide services to the layer above

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

For example, reliable delivery of messages at layer *n*:

- Adding layer *n* functionality to detect and retransmit lost messages
- Using an unreliable message delivery service at layer *n-1*

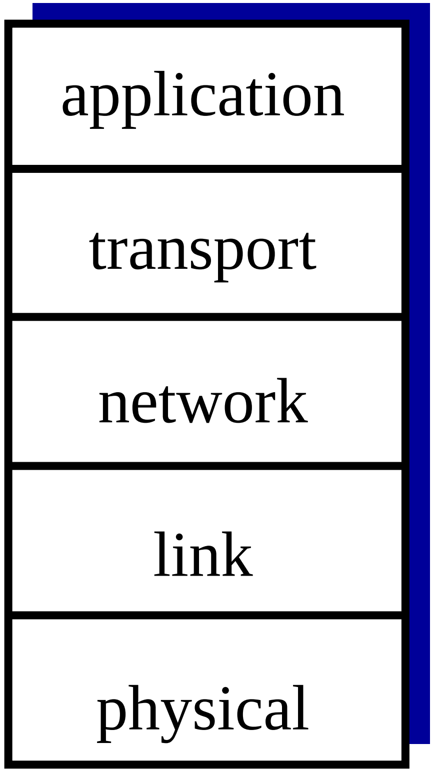
Why layering?

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
- drawback?
  - One layer may duplicate lower layer functionality
  - Functionality at one layer may need information that is present only in another layer

Internet protocol stack

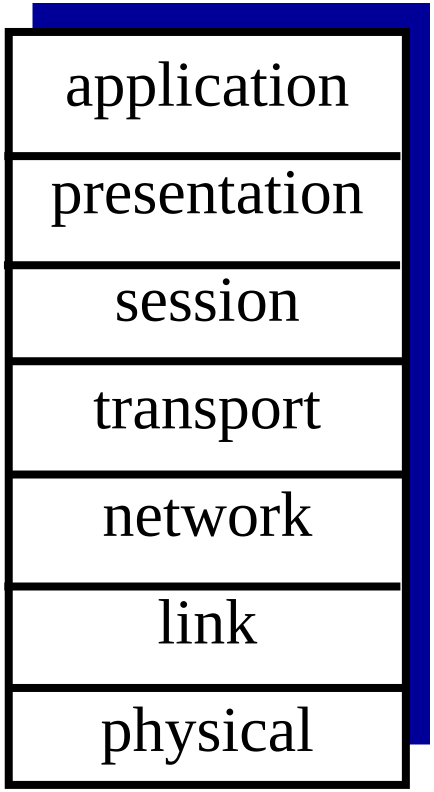
- Application: supporting network applications
  - FTP, SMTP, HTTP
- Transport: process-process data transfer
  - TCP, UDP
- Network: routing of datagrams from source to destination
  - IP, routing protocols
- Link: data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- Physical: bits "on the wire"



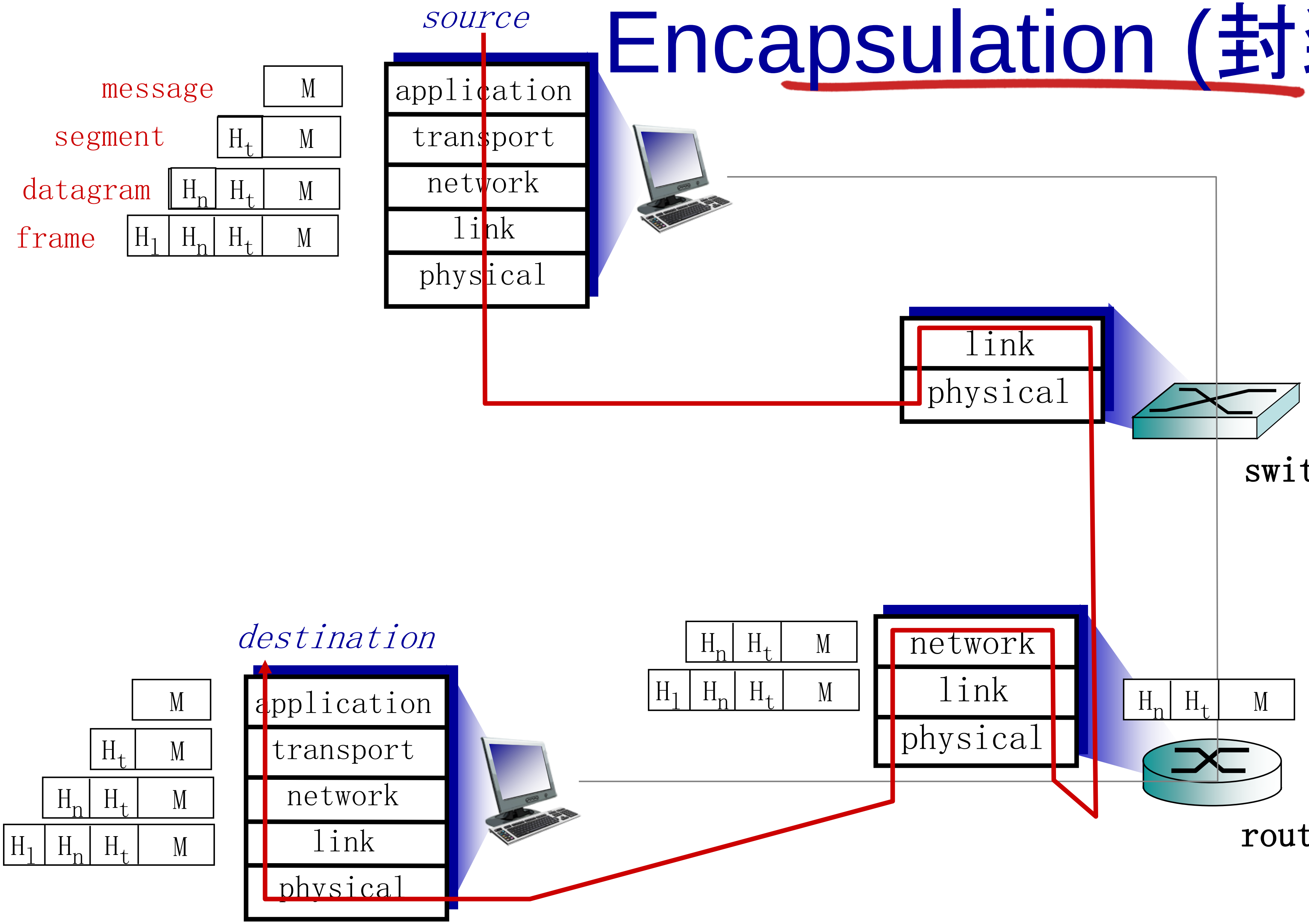
Internet protocol stack

ISO/OSI reference model

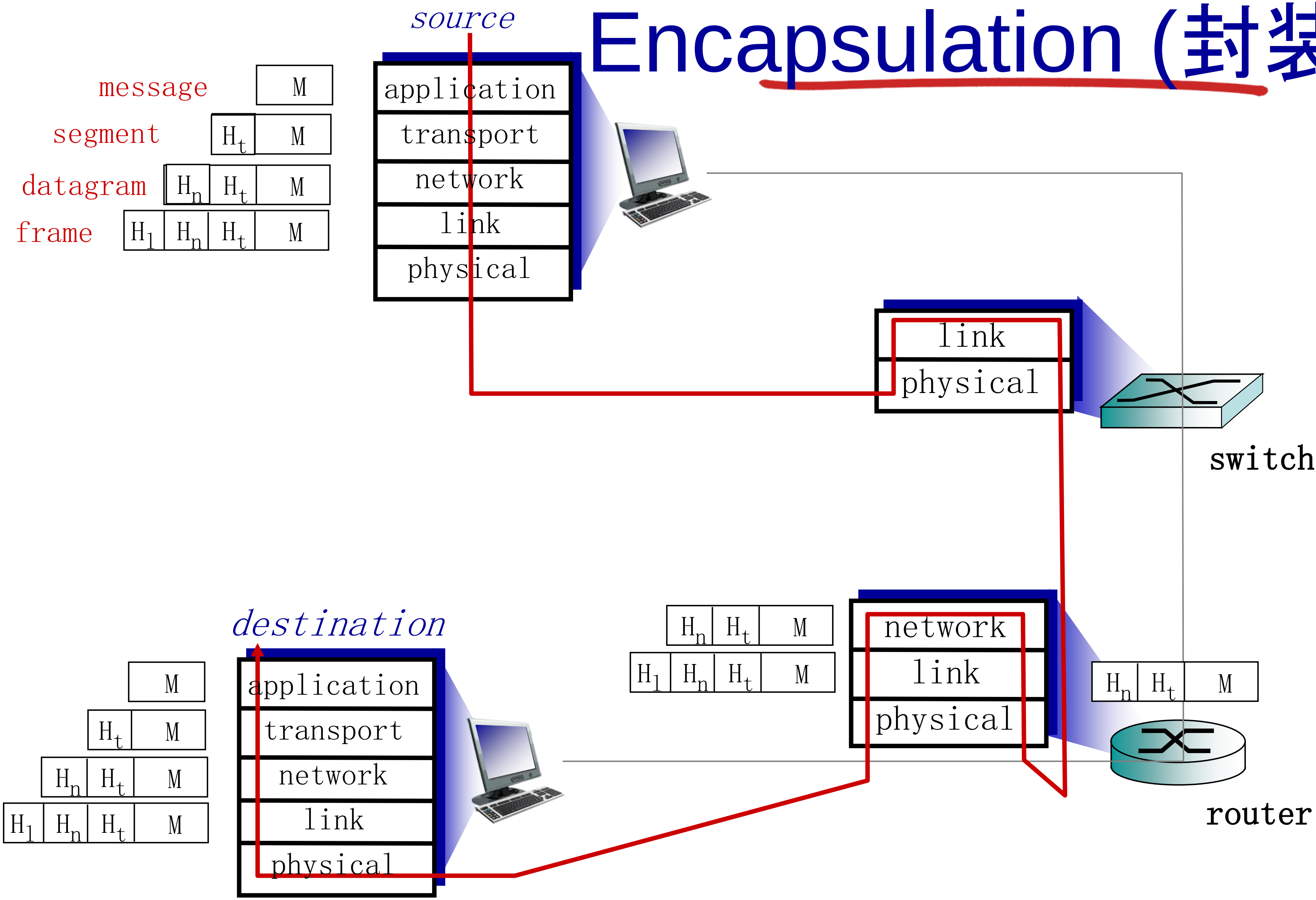
- Presentation: allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- Session: synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed*, must be implemented in application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



Encapsulation (封装)



Encapsulation (封装)



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Network security

We attach devices to the Internet because we want to receive/send data from/to the Internet

- 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 (恶意软件) into hosts via Internet

- malware can get in host from:
  - *virus:* self-replicating infection by receiving/executing object (e.g., e-mail attachment) – with user interaction
  - *worm:* self-replicating infection by passively receiving object that gets itself executed – without user interaction
- spyware malware can record keystrokes, web sites visited, upload info to collection site
- infected host can be enrolled in botnet (僵尸网络), used for spam. DDoS attacks

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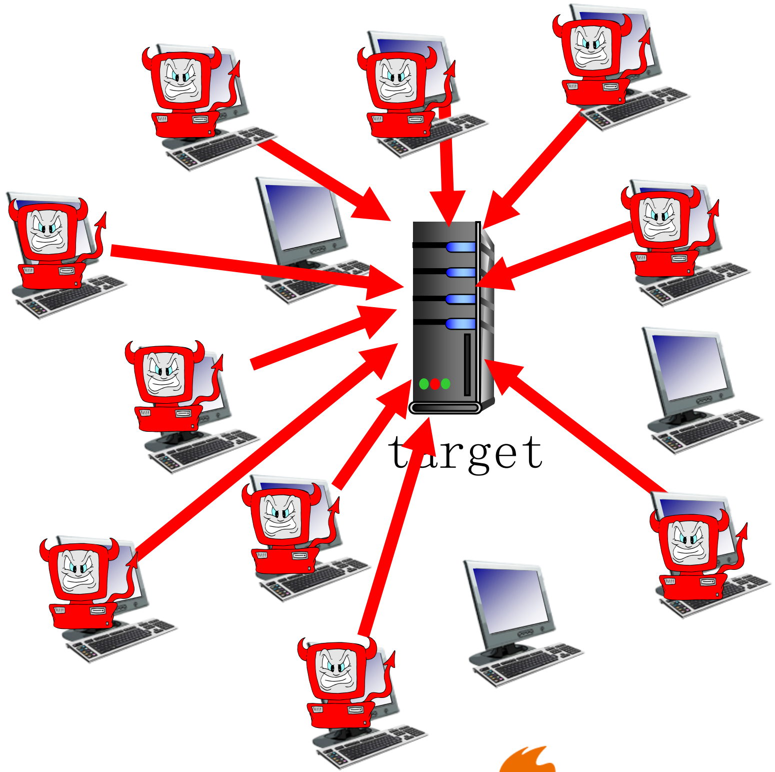
Bad guys: attack server, network infrastructure

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

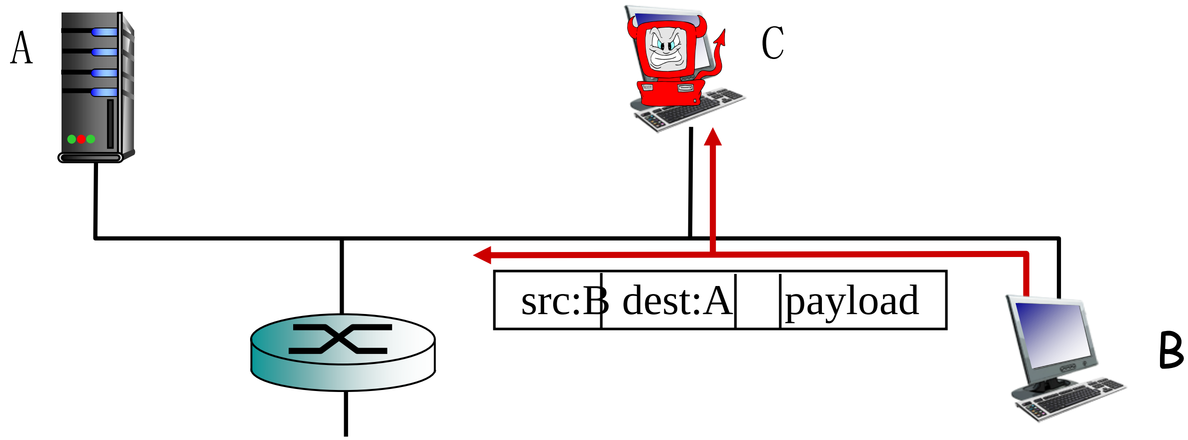
1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts



Bad guys can sniff packets

Packet "sniffing":

- Broadcast media (shared ethernet, wireless)
- Reads/records all packets (e.g., including passwords!) passing by
- They are difficult to detect



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

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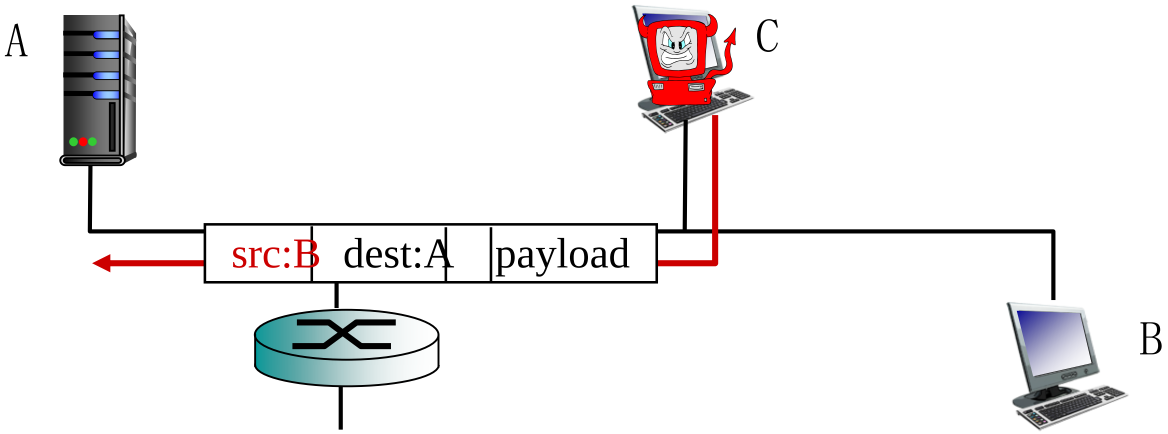
Bad guys can use fake addresses

IP spoofing: send packet with false source address



Network under Attack

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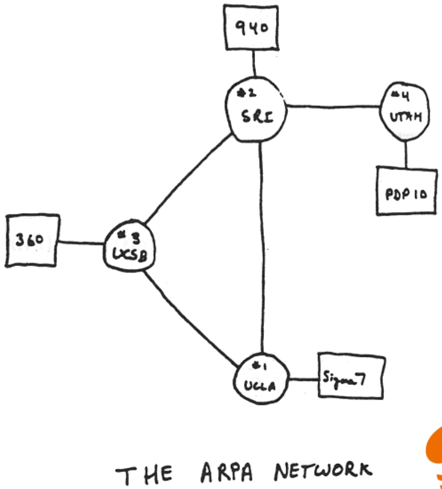
Internet history

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



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)

Internet history

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!*