

# Lecture 1: Overview

CIS 5617, Fall 2022

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Based on Slides created by JFK/KWR

7<sup>th</sup> edition

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Pearson/Addison Wesley

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# Lecture 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

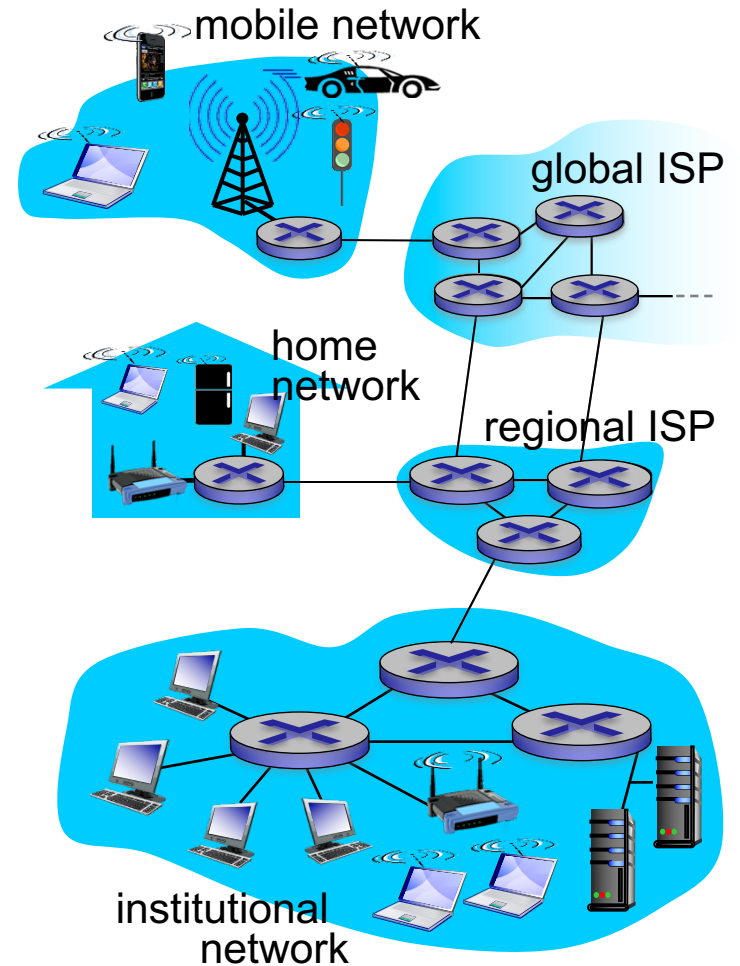
1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

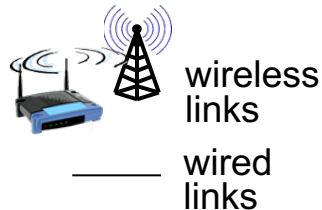
***Goal: use Internet as example to get “feel” and terminology***

# What's the Internet

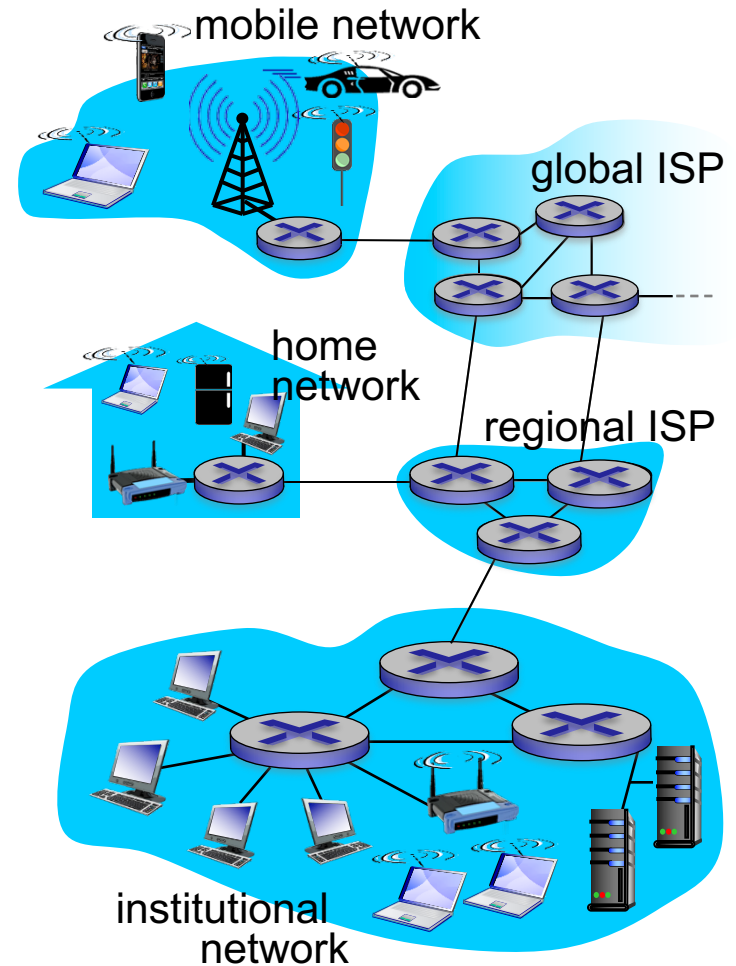
- *Internet*: “network of networks”
  - Interconnected ISPs



# What's the Internet



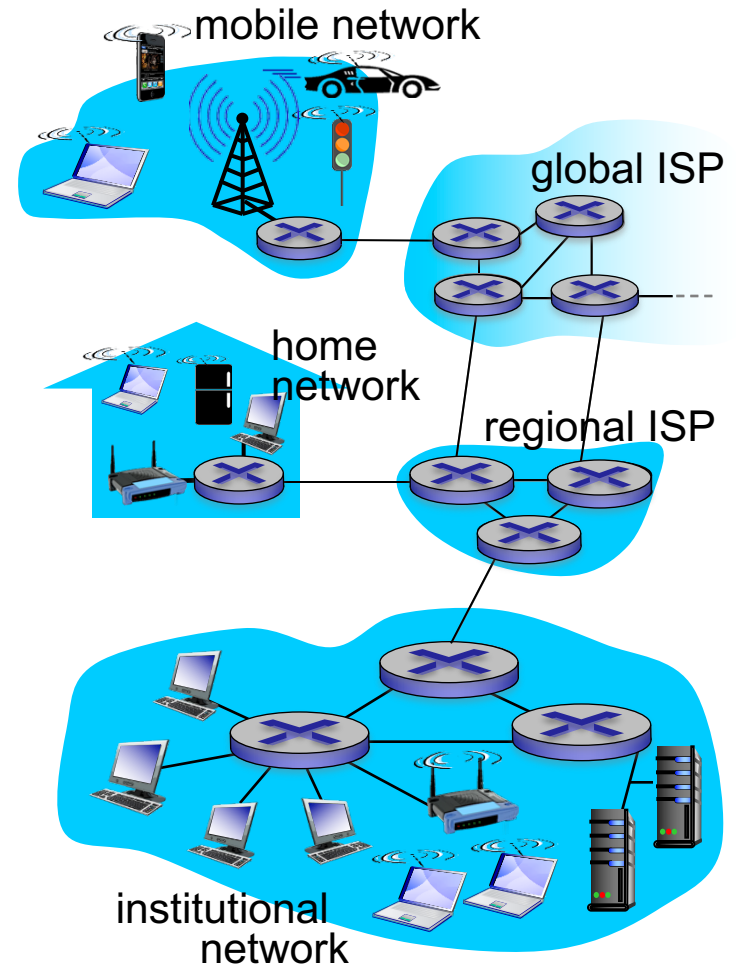
- billions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: *bandwidth*
- *packet switches*: forward packets (chunks of data)
  - *routers* and *switches*





# What's the Internet

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



# What's a protocol?

## *human protocols:*

- “what's the time?”
- “I have a question”

... specific messages sent

... specific actions taken  
when messages  
received, or other  
events

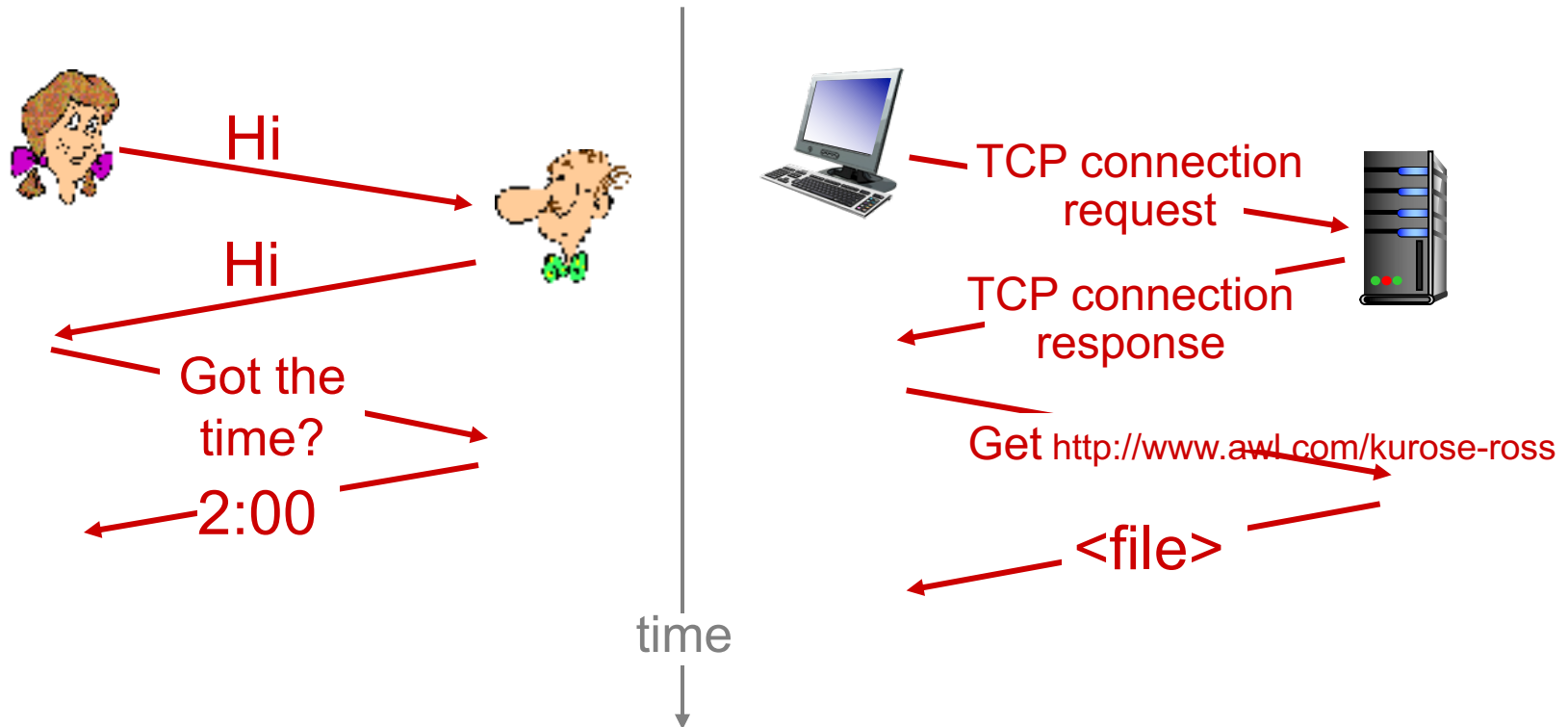
## *network protocols:*

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

*protocols define format, order of messages sent and received among network entities, and actions taken on message transmission, receipt*

# What's a protocol?

a human protocol and a computer network protocol:



**Q:** other human protocols?

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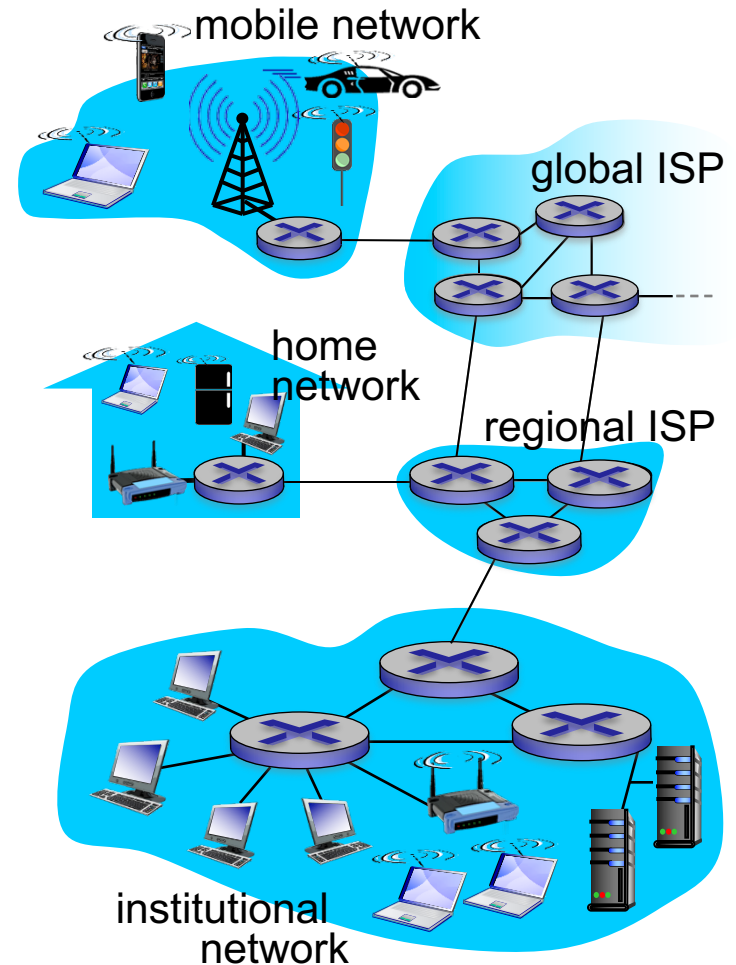
- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

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# A closer look at network structure:

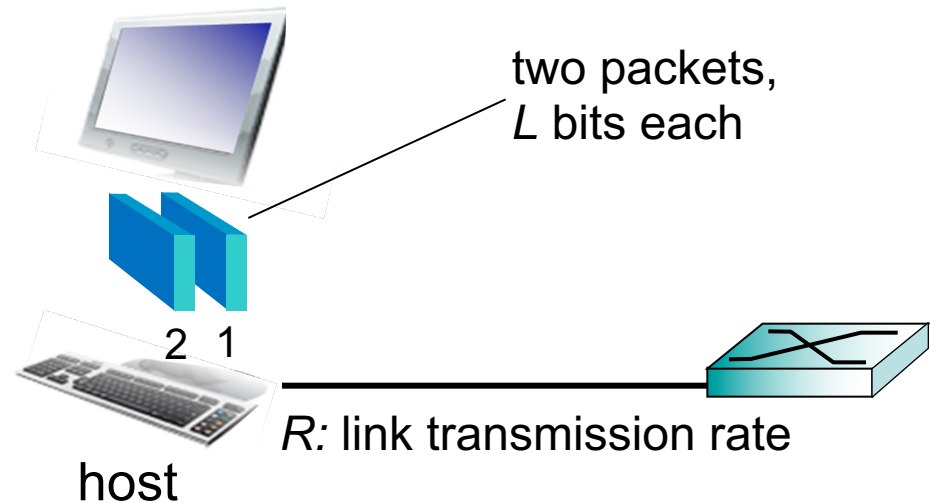
- *network edge:*
  - hosts: clients and servers
  - servers often in data centers
- *access networks, physical media:* wired, wireless communication links
- *network core:*
  - interconnected routers
  - network of networks



# 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 network at *transmission rate  $R$* 
  - link transmission rate, aka link *capacity*, aka *link bandwidth*



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

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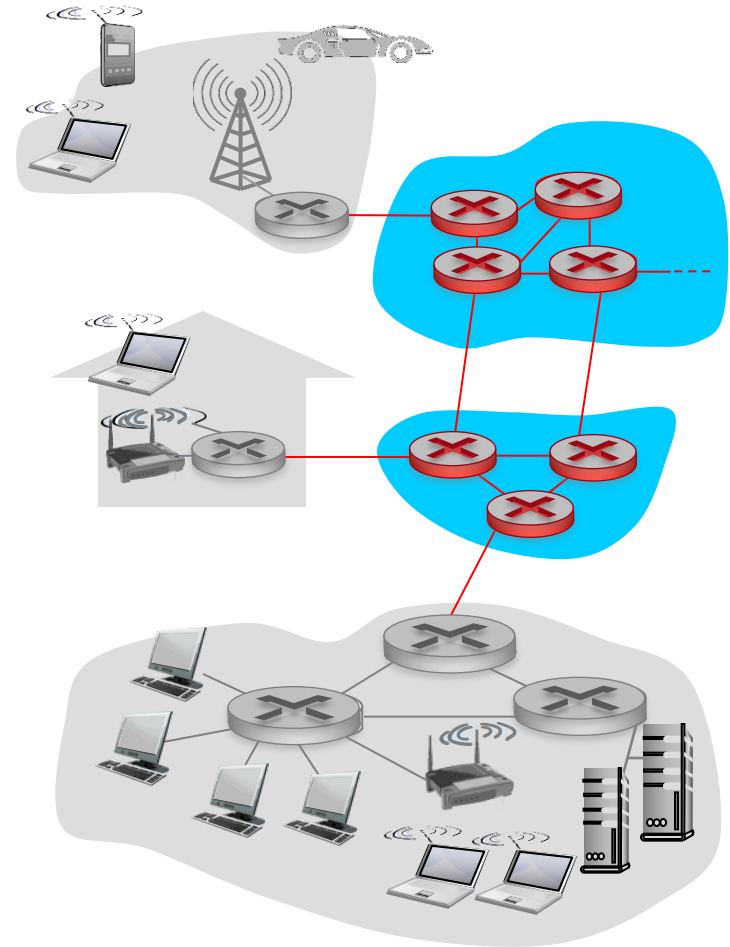
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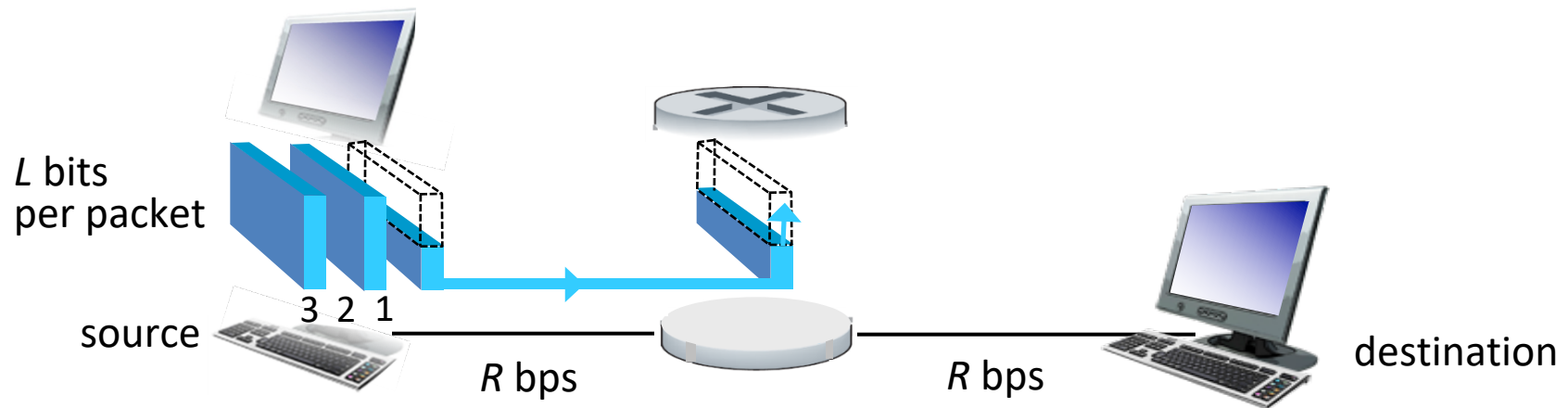
# The network core

- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into *packets*
  - forward packets from one router to the next, across links on path from source to destination
  - each packet transmitted at full link capacity





# Packet-switching: store-and-forward



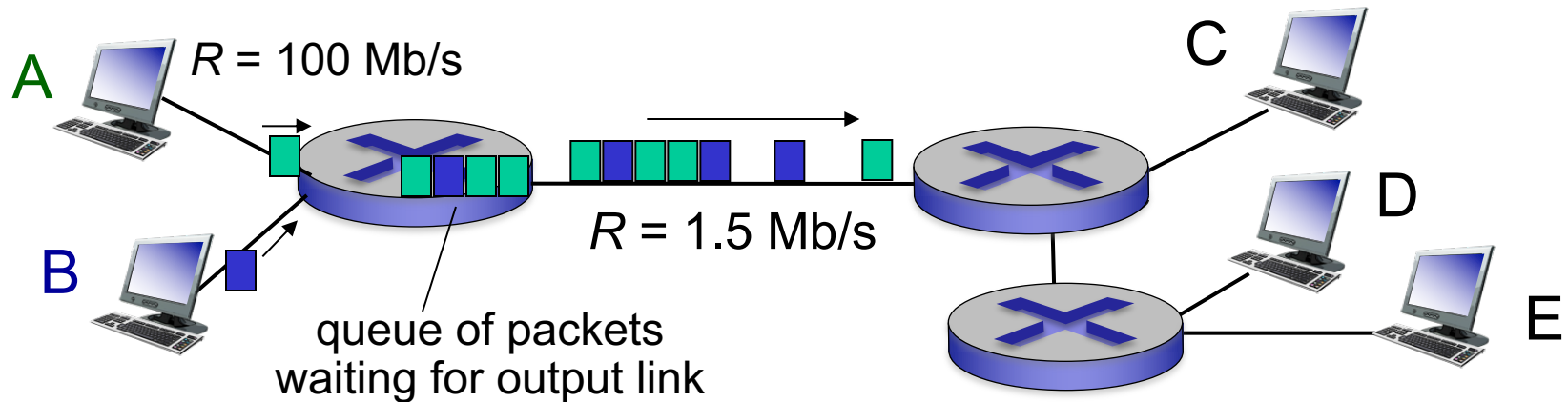
- takes  $L/R$  seconds to transmit (push out)  $L$ -bit packet into link at  $R$  bps
- *store and forward*: entire packet must arrive at router before it can be transmitted on next link
- end-end delay =  $2L/R$  (assuming zero propagation delay)

} more on delay shortly ...

## *one-hop numerical example:*

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

# Packet Switching: queueing delay, loss



## queuing and loss:

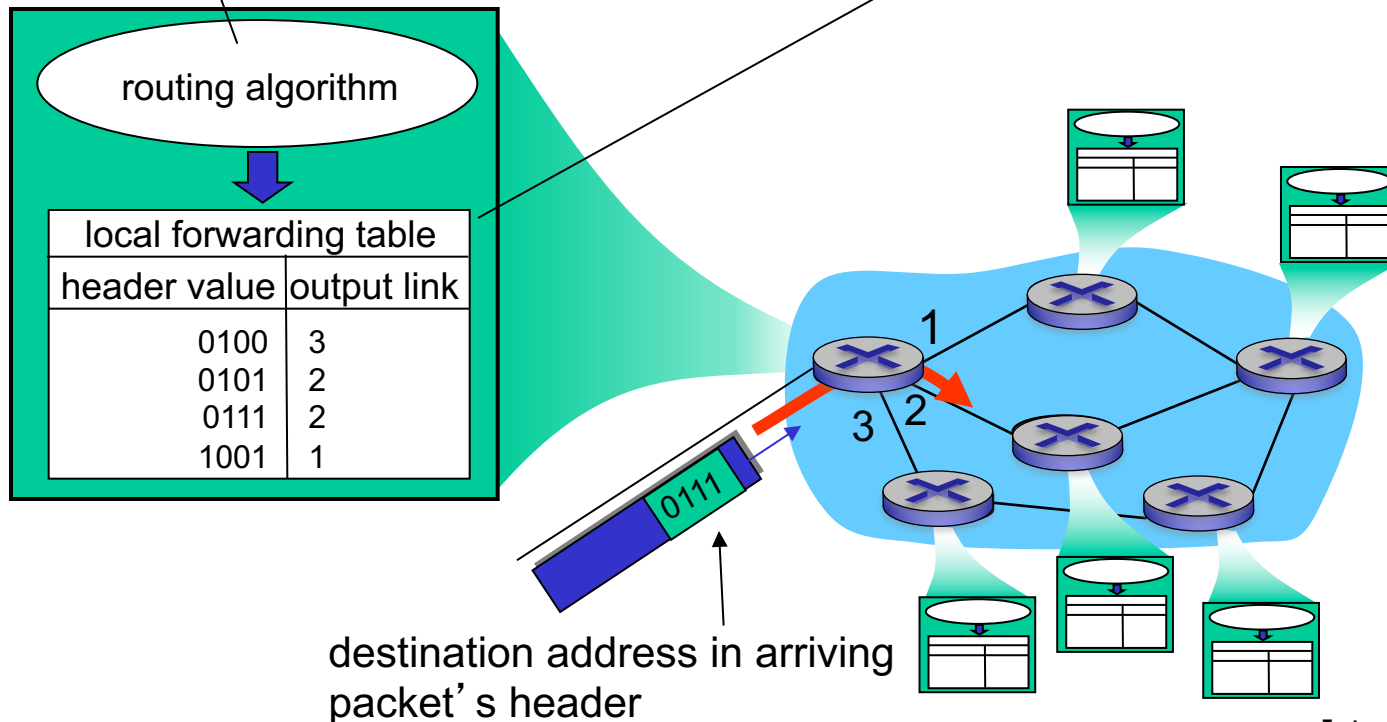
- if arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

# Two key network-core functions

**routing:** determines source-destination route taken by packets

- *routing algorithms*

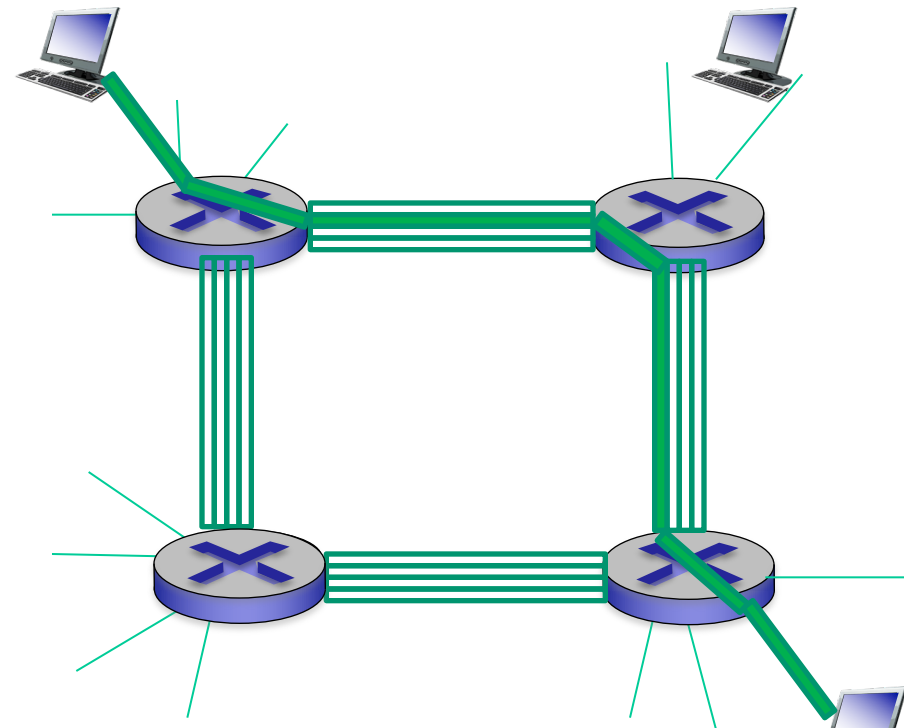
**forwarding:** move packets from router's input to appropriate router output



# Alternative core: circuit switching

end-end resources allocated to, reserved for “call” between source & dest:

- in diagram, each link has four circuits.
  - call gets 2<sup>nd</sup> circuit in top link and 1<sup>st</sup> circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call (*no sharing*)
- commonly used in traditional telephone networks

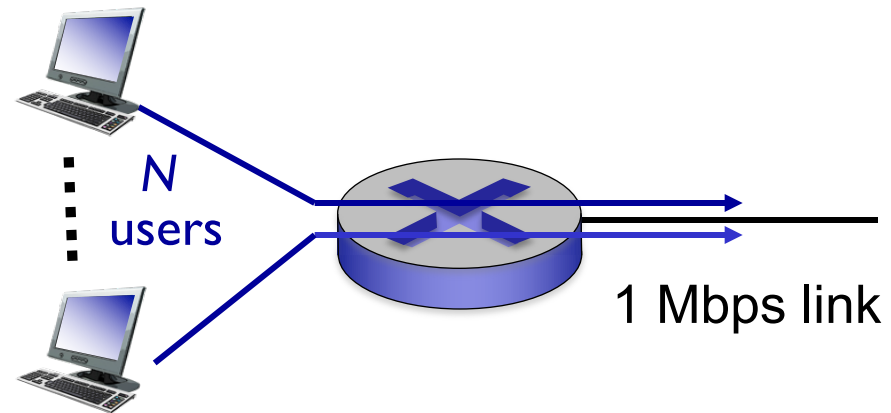


# Packet switching versus circuit switching

*packet switching allows more users to use network!*

example:

- 1 Mb/s link
- each user:
  - 100 kb/s when “active”
  - active 10% of time
- *circuit-switching*:
  - 10 users
- *packet switching*:
  - with 35 users, probability > 10 active at same time is less than .0004 \*



**Q:** how did we get value 0.0004?

**Q:** what happens if > 35 users ?

\* Check out the online interactive exercises for more examples: [http://gaia.cs.umass.edu/kurose\\_ross/interactive/](http://gaia.cs.umass.edu/kurose_ross/interactive/)

# Packet switching versus circuit switching

is packet switching a “slam dunk winner?”

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

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

# break

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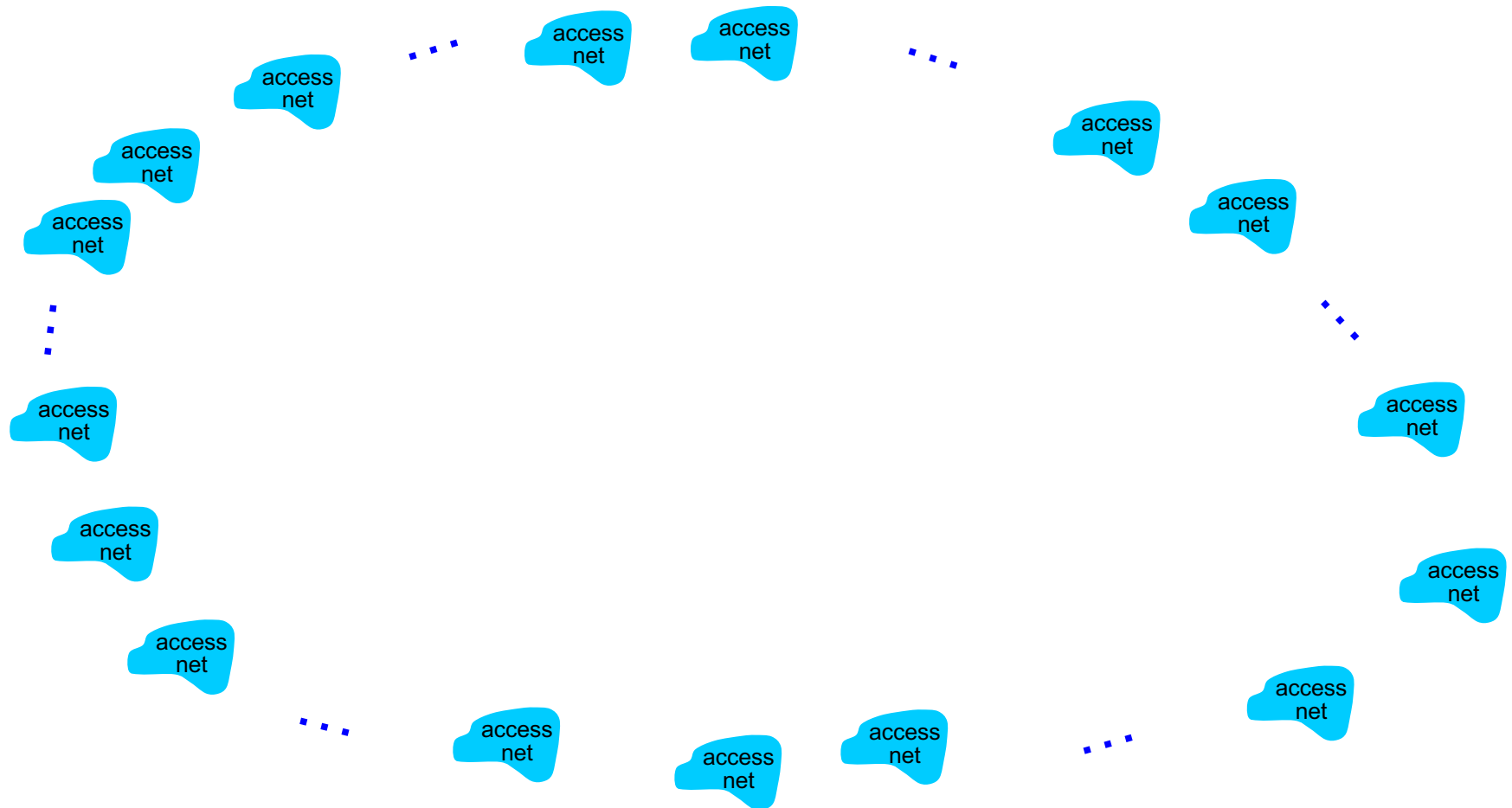


# Internet structure: network of networks

- 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***

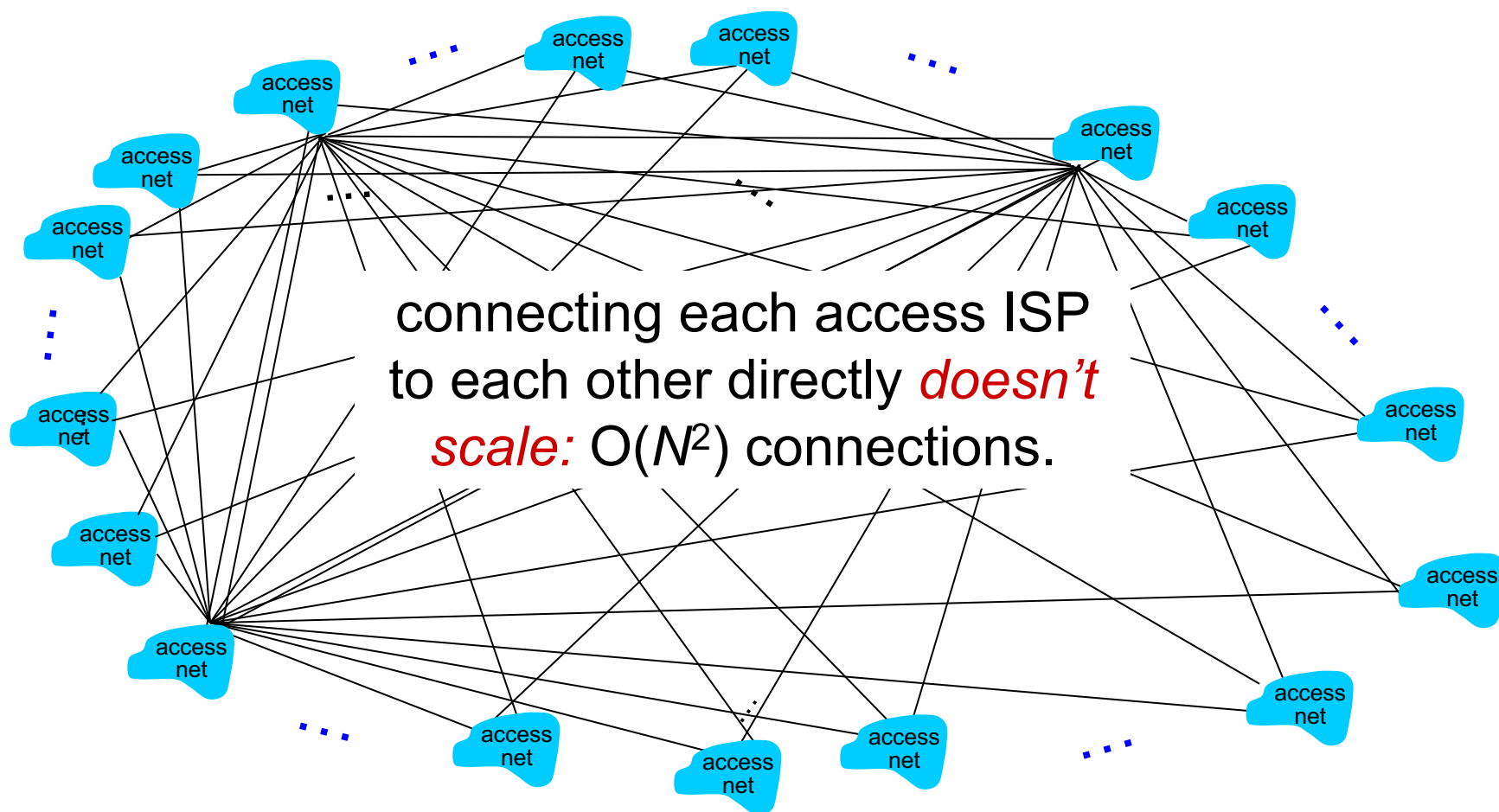
# Internet structure: network of networks

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



# Internet structure: network of networks

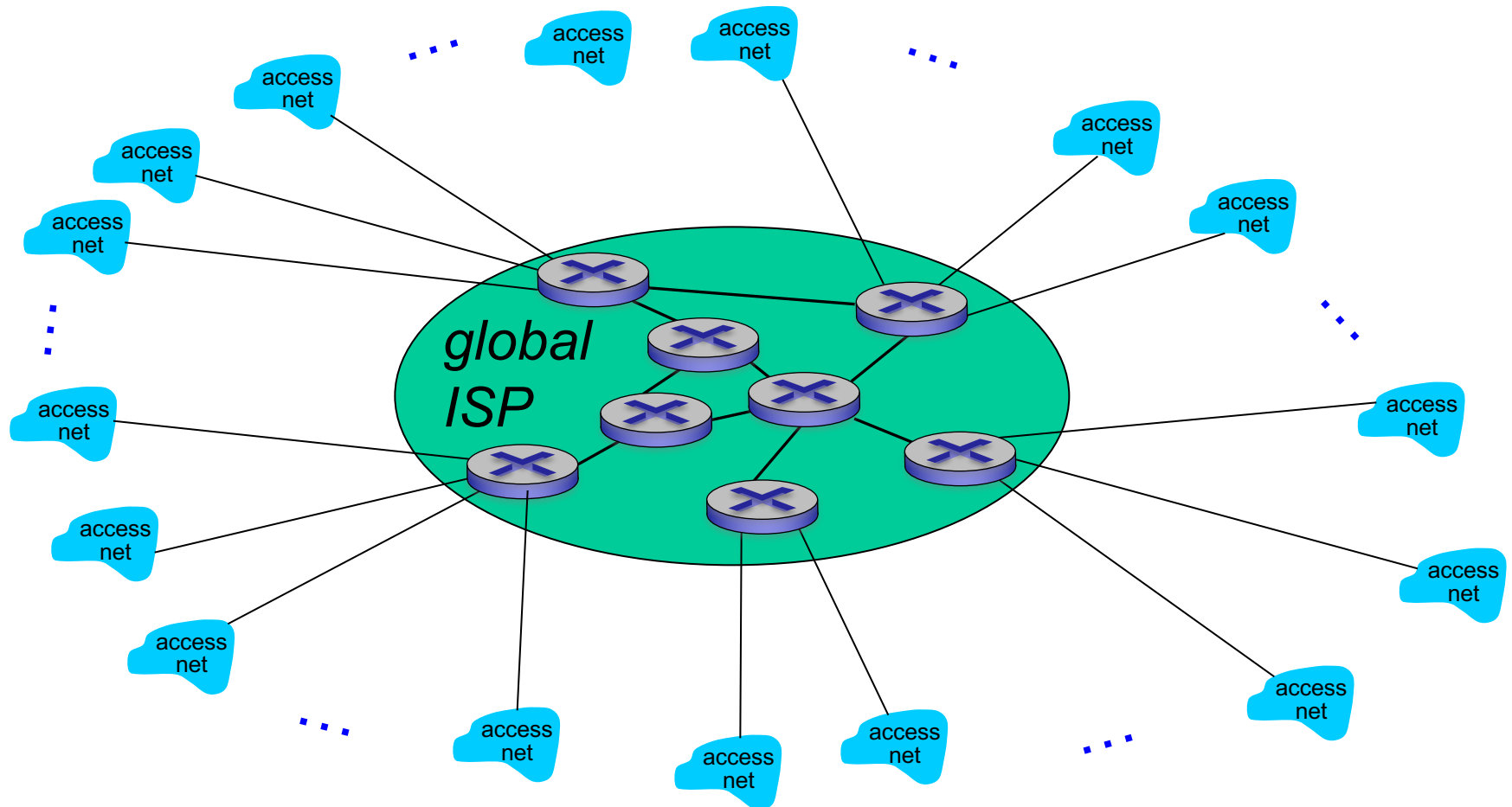
*Option:* connect each access ISP to every other access ISP?



# Internet structure: network of networks

*Option:* connect each access ISP to one global transit ISP?

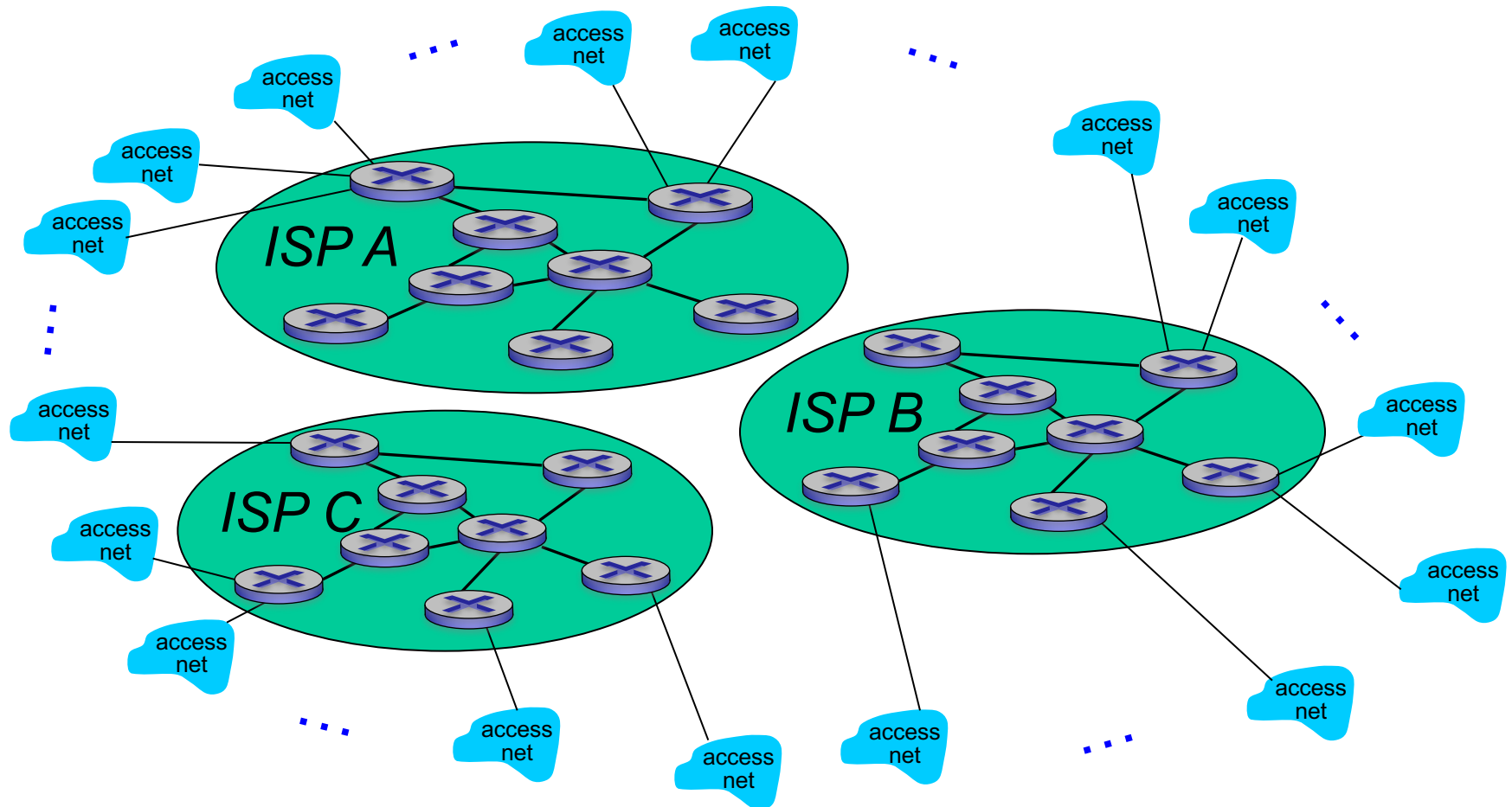
*Customer* and *provider* ISPs have economic agreement.



# Internet structure: network of networks

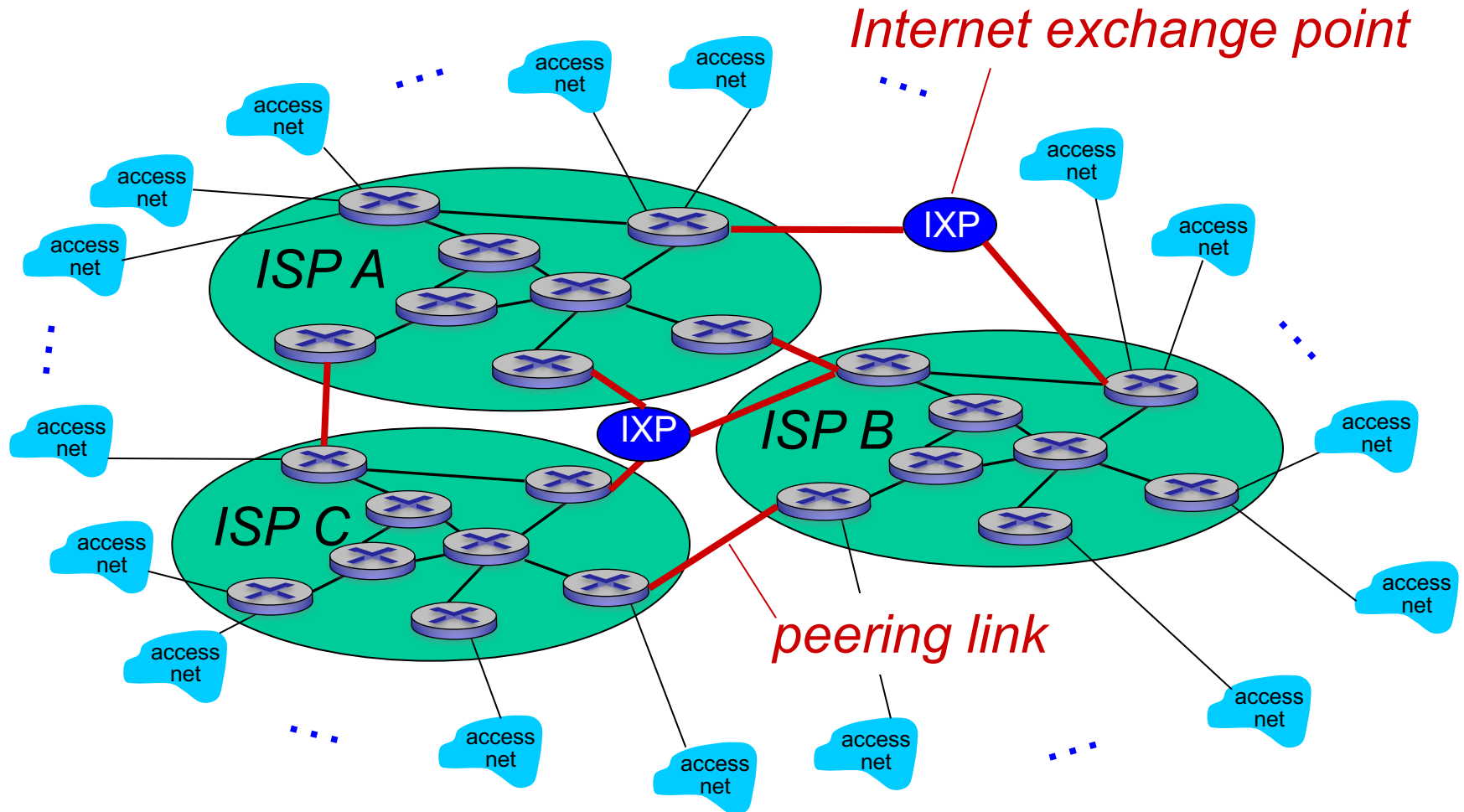
But if one global ISP is viable business, there will be competitors

....



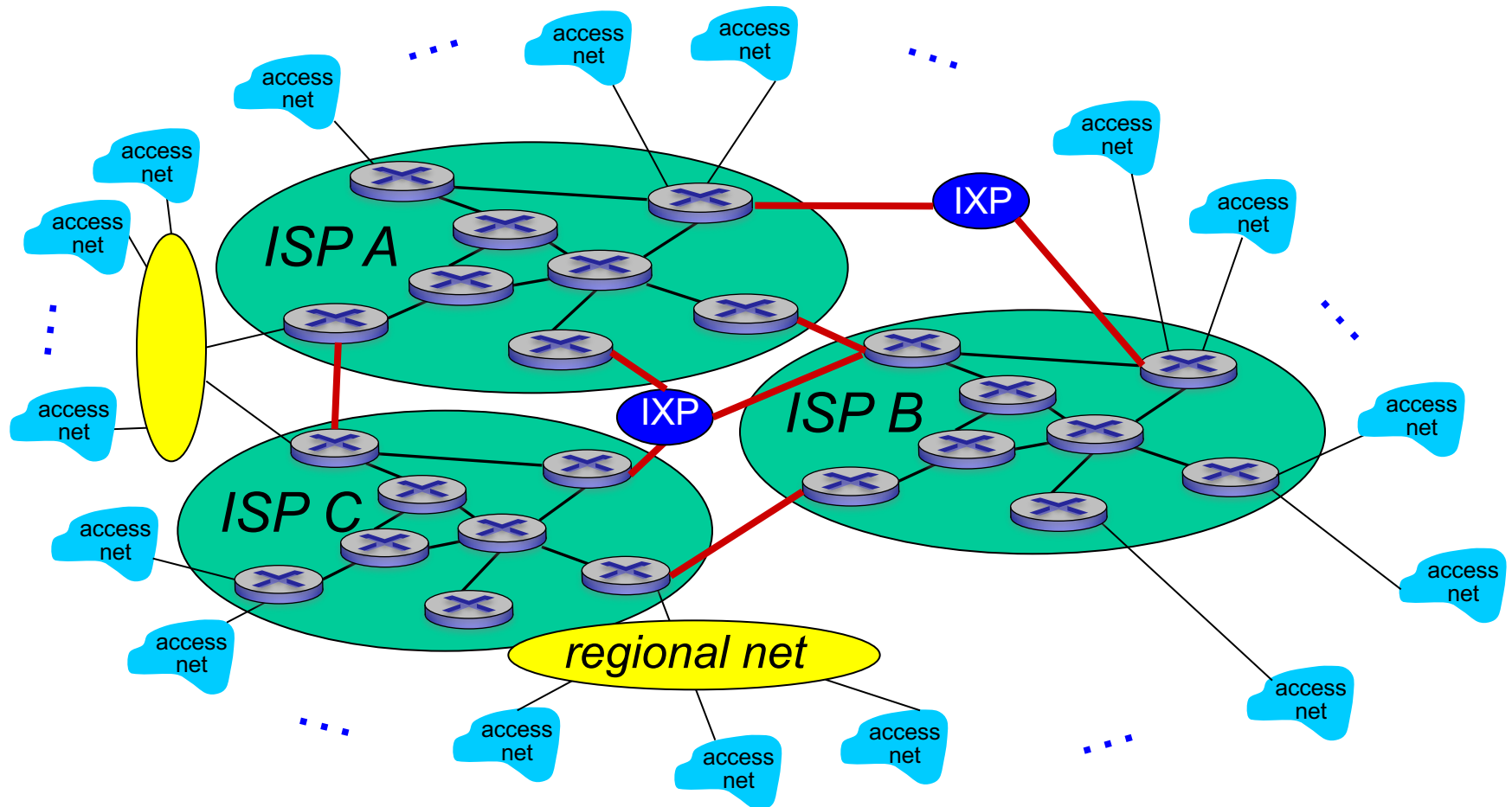
# Internet structure: network of networks

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



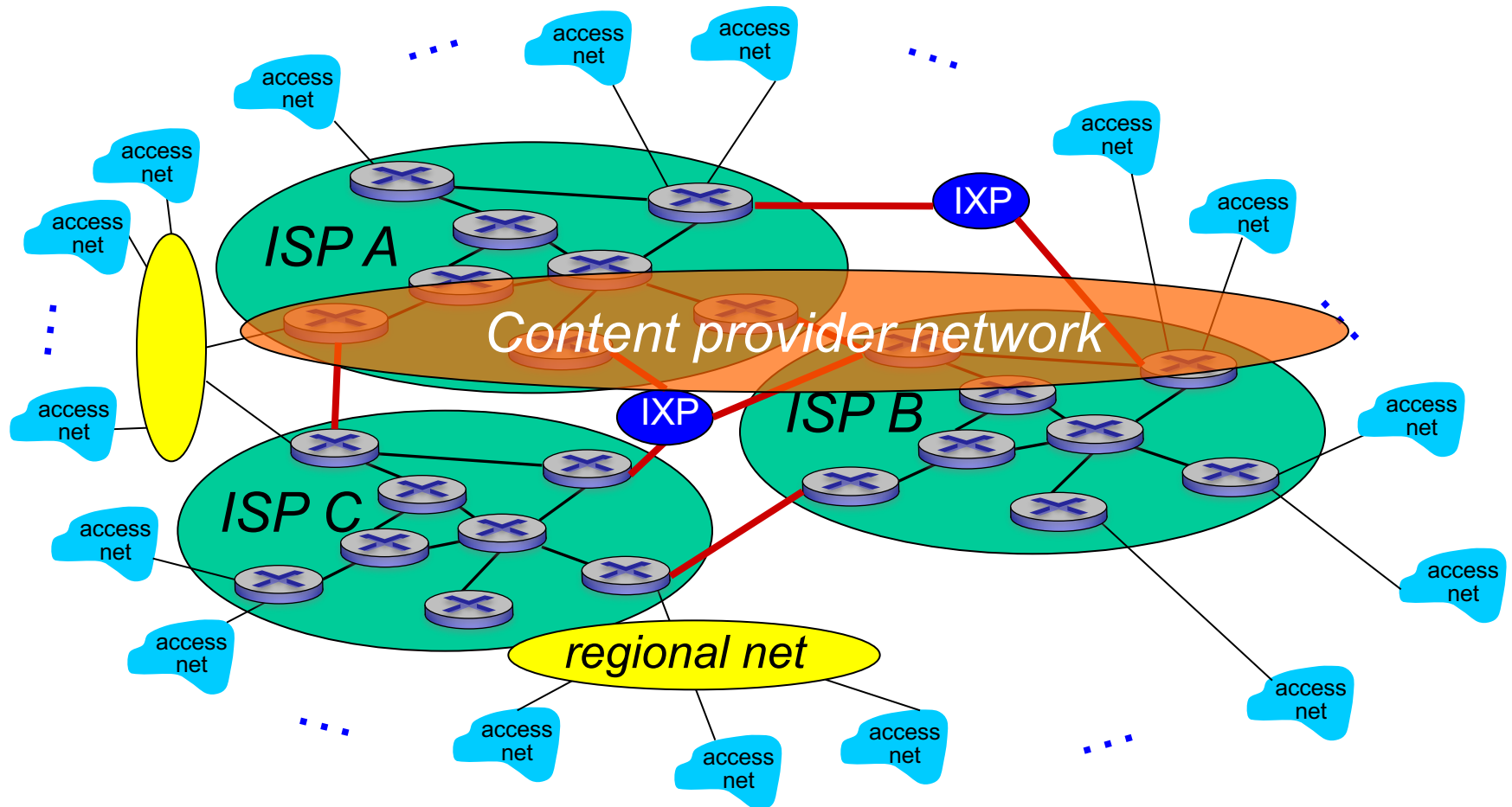
# Internet structure: network of networks

... and regional networks may arise to connect access nets to ISPs



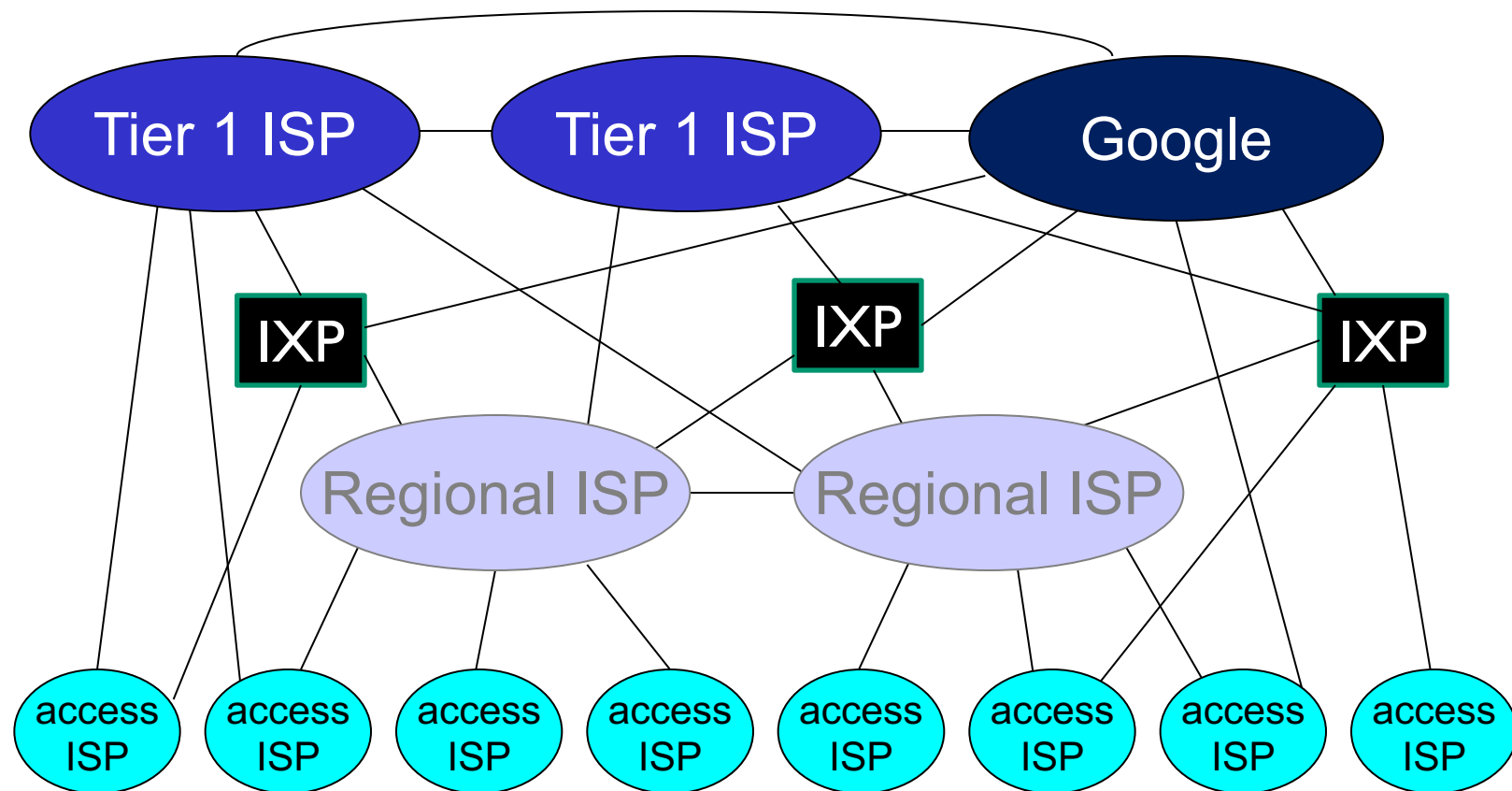
# Internet structure: network of networks

... 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 its data centers to Internet, often bypassing tier-1, regional ISPs

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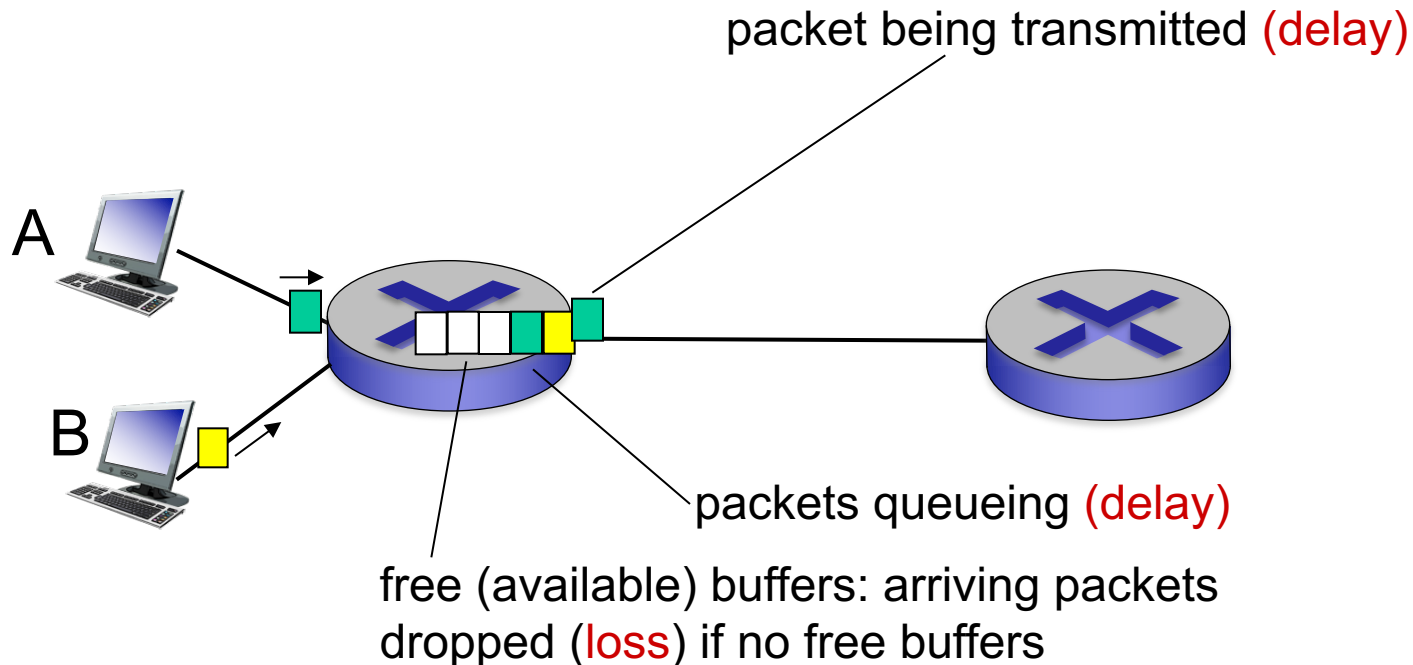
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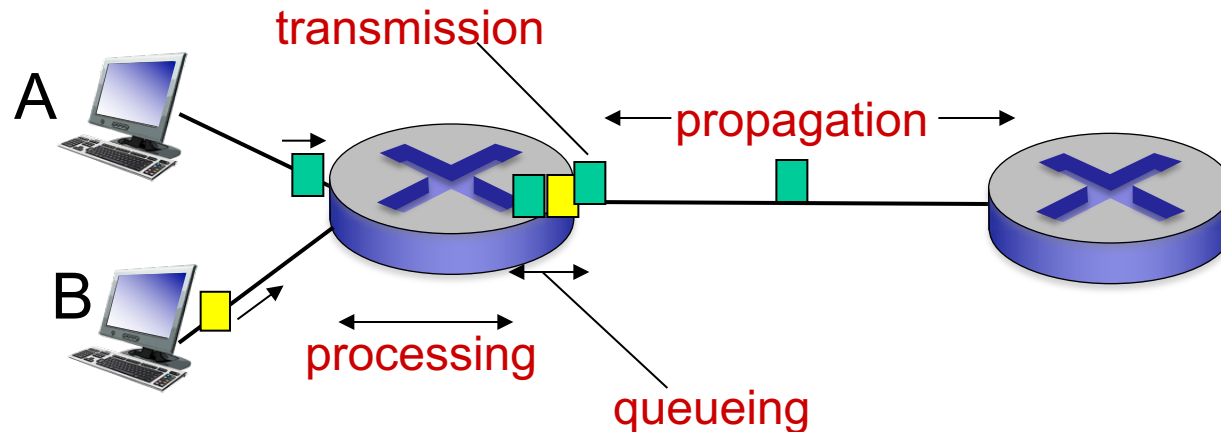
# How do loss and delay occur?

packets *queue* in router buffers

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



# Four sources of packet delay



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

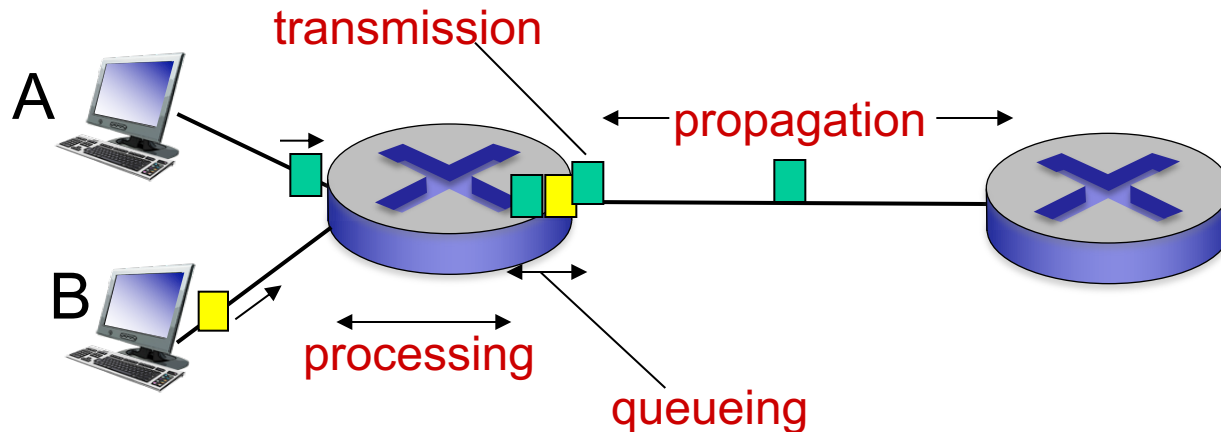
## $d_{\text{proc}}$ : processing delay

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

## $d_{\text{queue}}$ : queueing delay

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

# Four sources of packet delay



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

**$d_{\text{trans}}$ : transmission delay:**

- $L$ : packet length (bits)
- $R$ : link bandwidth (bps)

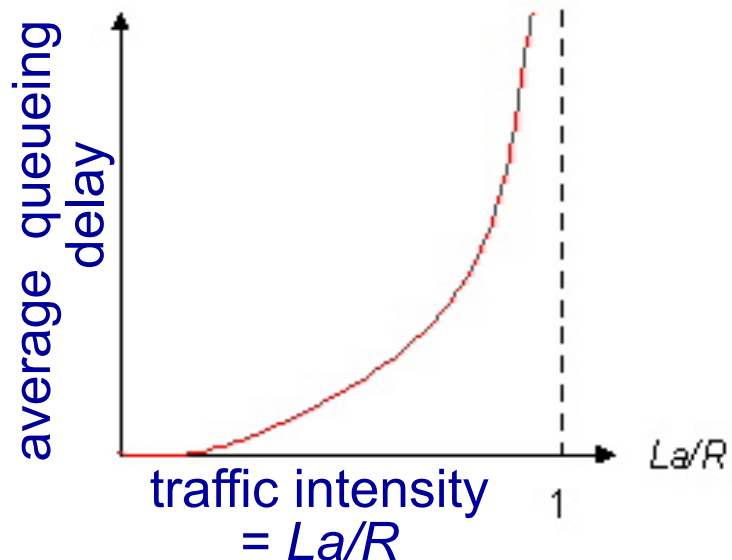
▪  $d_{\text{trans}} = L/R$  ←  $d_{\text{trans}}$  and  $d_{\text{prop}}$  →  
very different

**$d_{\text{prop}}$ : propagation delay:**

- $d$ : length of physical link
  - $s$ : propagation speed ( $\sim 2 \times 10^8$  m/sec)
- $d_{\text{prop}} = d/s$

# Queueing delay (revisited)

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



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



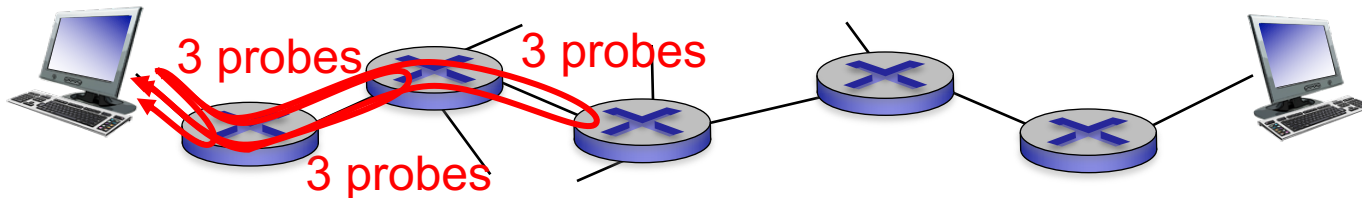
$La/R \sim 0$



$La/R \rightarrow 1$

# “Real” Internet delays and routes


- what do “real” Internet delay & loss look like?
- **traceroute** program: provides delay measurement from source to router along end-end Internet path towards destination. For all  $i$ :
  - sends three packets that will reach router  $i$  on path towards destination
  - router  $i$  will return packets to sender
  - sender times interval between transmission and reply.



# “Real” Internet delays, routes


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

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



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

trans-oceanic link



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


\* Do some traceroutes from exotic countries at [www.traceroute.org](http://www.traceroute.org)



# “Real” Internet delays, routes

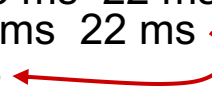
**traceroute:** gaia.cs.umass.edu to www.eurecom.fr

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




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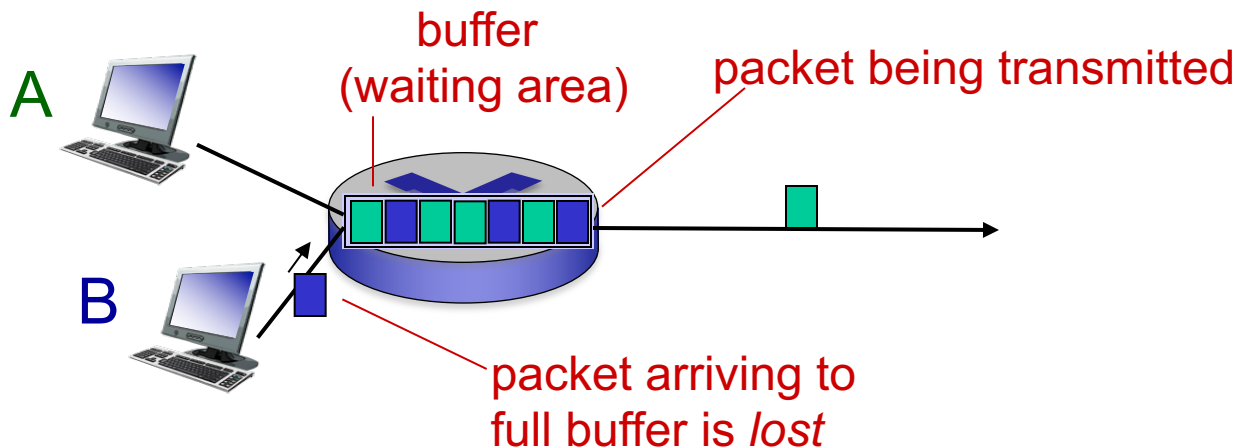
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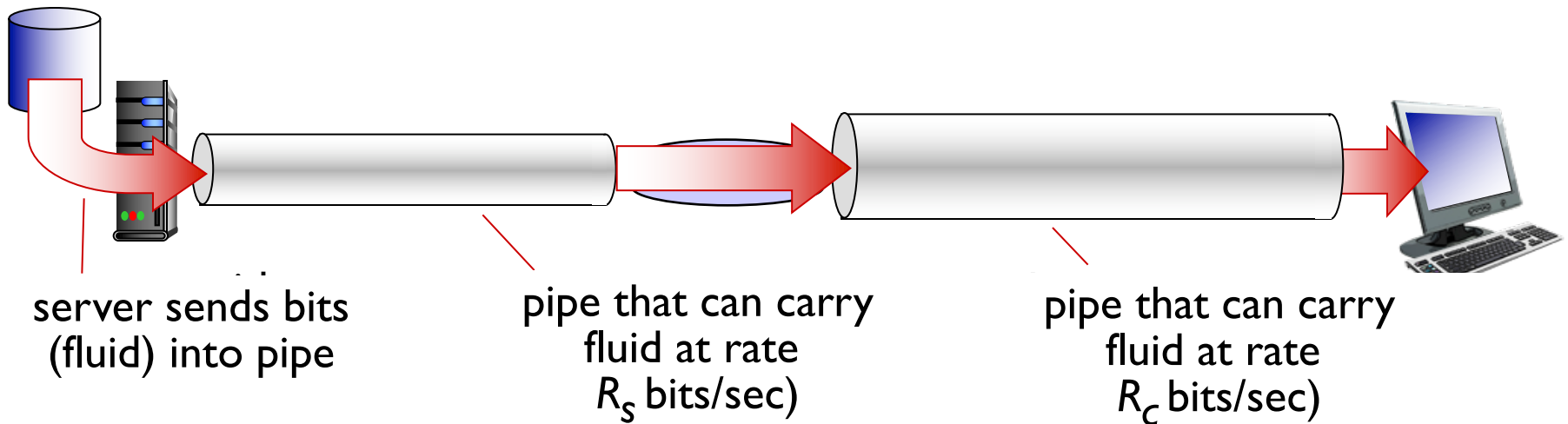
# Packet loss

- queue (aka buffer) preceding link 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



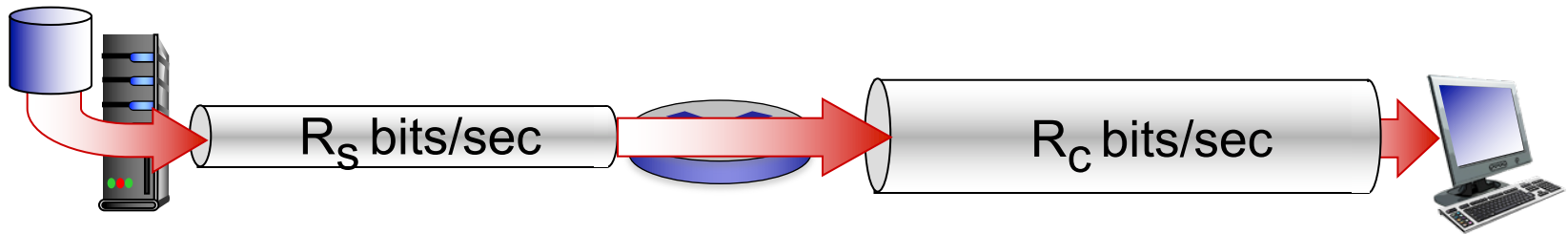
# Throughput

- **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

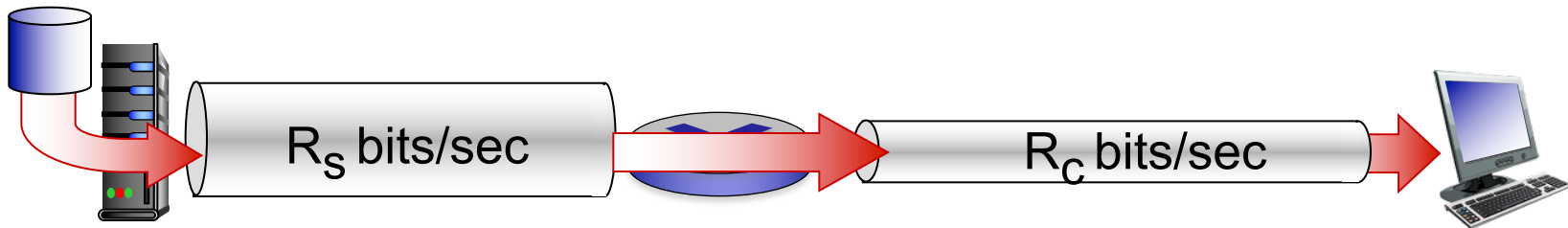


# Throughput (more)

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



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

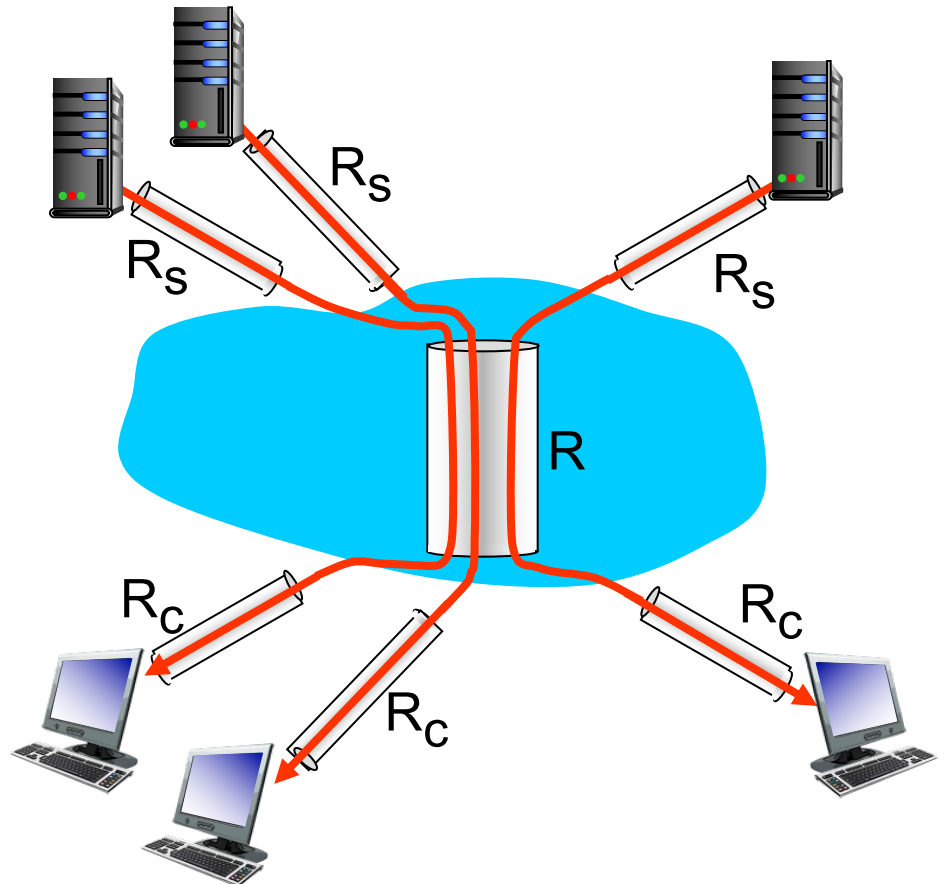


*bottleneck link*

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

# Throughput: Internet scenario

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



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

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# Protocol “layers”

*Networks are complex,  
with many “pieces”:*

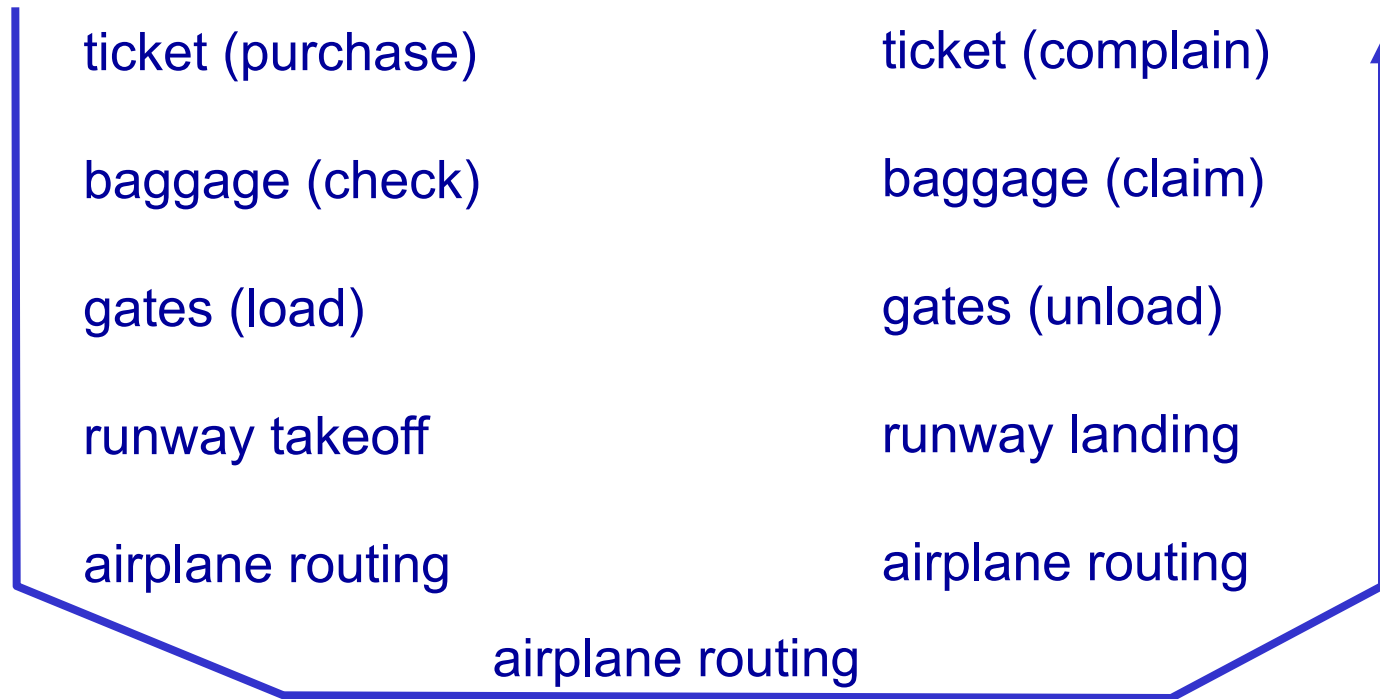
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

*Question:*

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

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

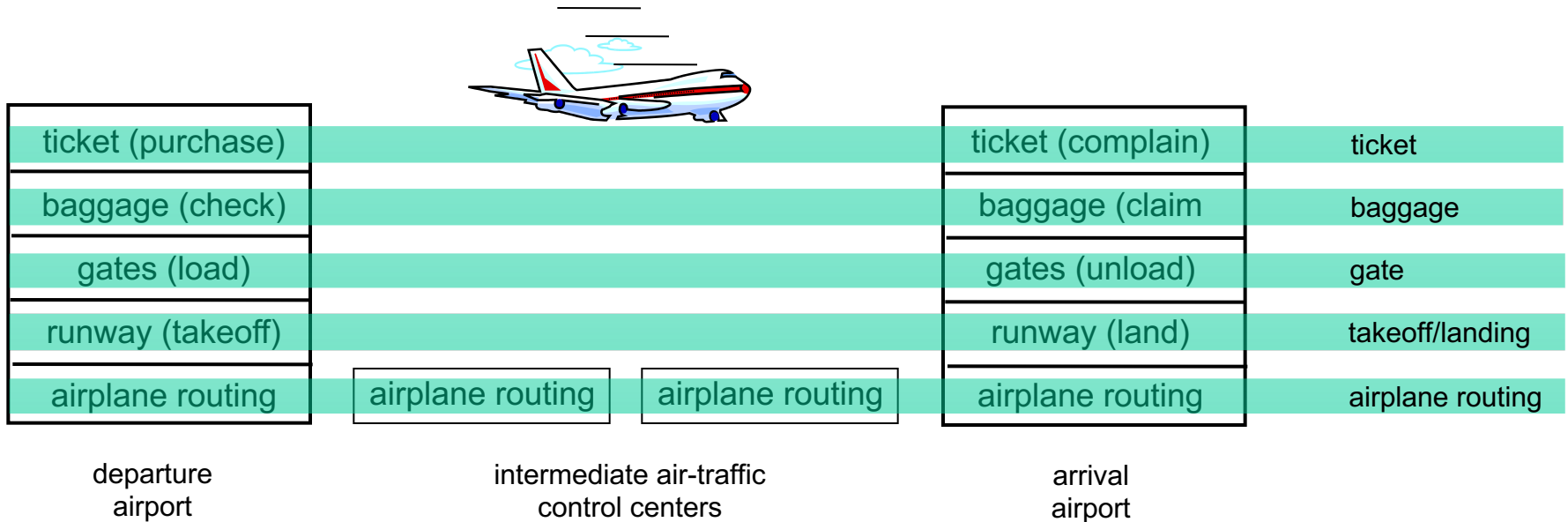
# Organization of air travel



- a series of steps



# Layering of airline functionality



**layers:** each layer implements a service

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

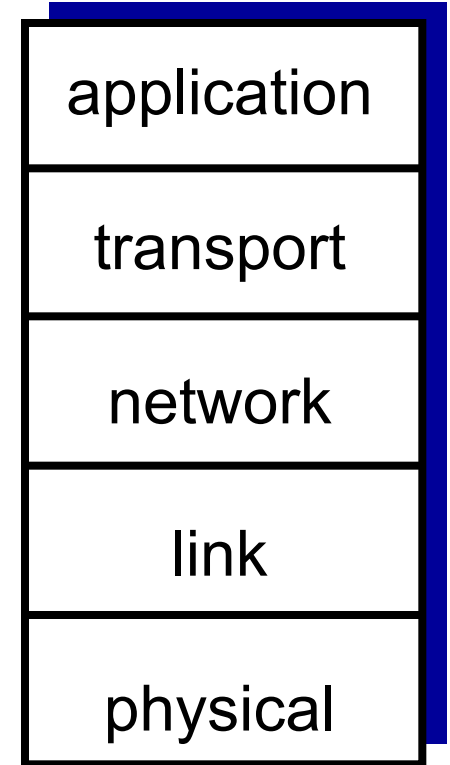
# Why layering?

dealing with complex systems:

- explicit structure allows identification, relationship of complex system's pieces
  - layered *reference model* for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system
- 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
  - Ethernet, 802.11 (WiFi), PPP
- *physical*: bits “on the wire”



# Encapsulation

