Part A
Introduction

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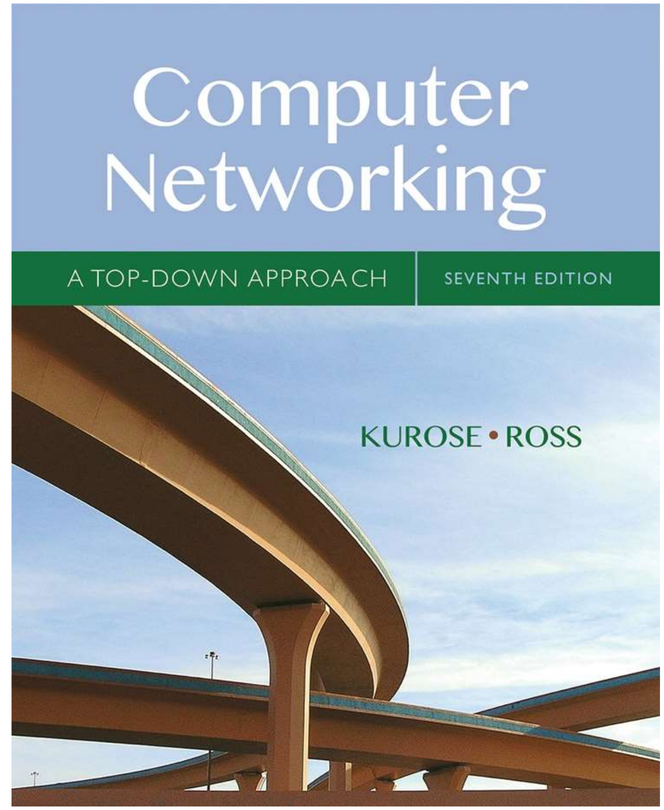


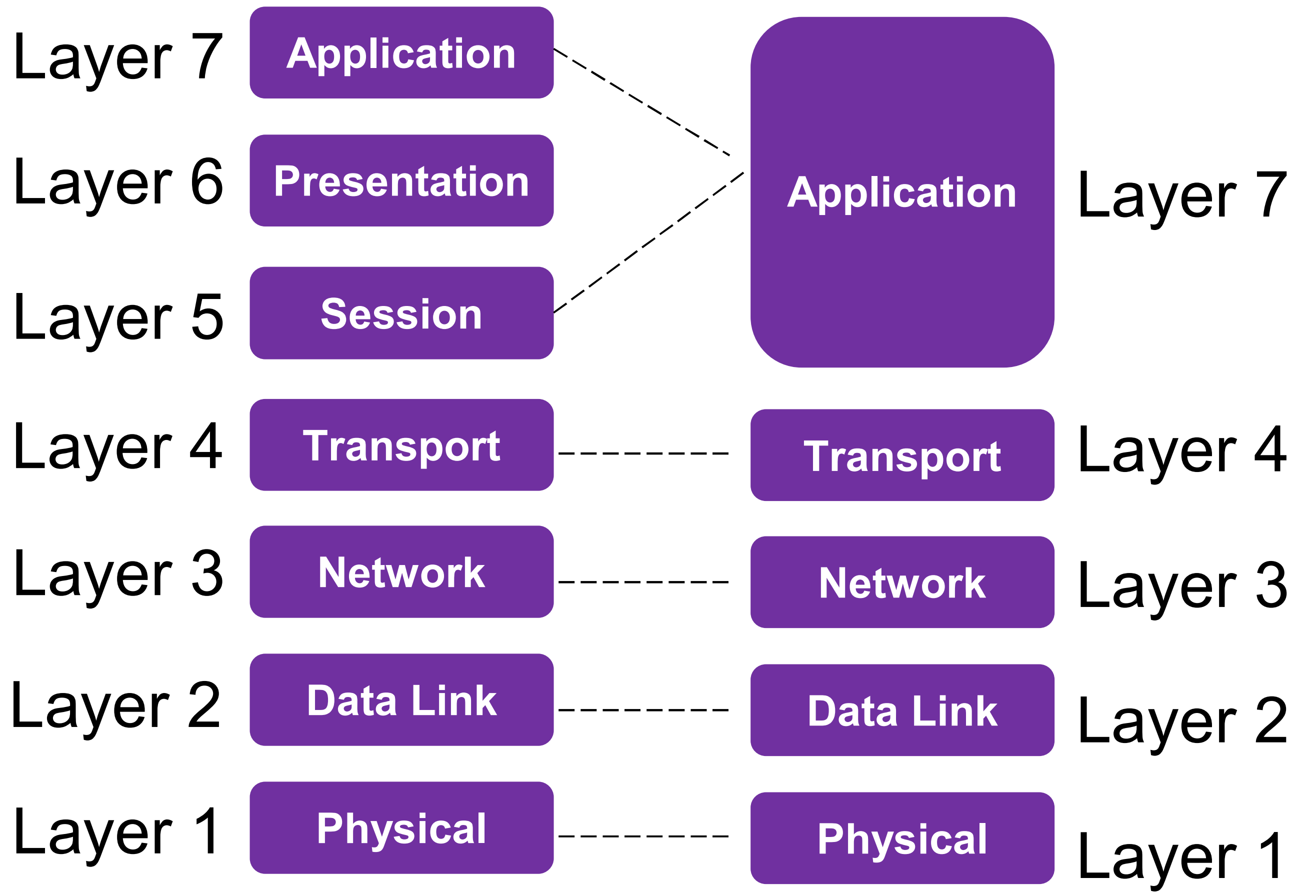
Computer Networking: A Top Down Approach

7th edition
Jim Kurose, Keith Ross
Pearson/Addison Wesley
April 2016

Structure of course

- Part A
  - Introduction to IP Networks
  - The Transport layer (part 1)
- Part B
  - The Transport layer (part II)
  - The Network layer (part I)
  - Class test
- Part C
  - The Network layer (part II)
  - The Data link layer (part I)
  - Router lab tutorial (assessed lab work after this week)
- Part D
  - The Data link layer (part II)
  - Network management and security
  - Class test

ISO/OSI (left) vs TCP/IP (right)



ISO/OSI (left) vs TCP/IP (right)

- Why two models of layers?
- International Standards Office/Open Systems Interconnection model planned by committee.
  - Planning took a long time.
  - Model is idealized.
- Transmission Control Protocol/Internet Protocol built by engineers
  - Built up over time to “get things working”.
  - New applications and changes to protocols through experience.
- When ISO/OSI design completed TCP/IP already “too big to change”.
  - Would it be better if we had ISO/OSI?
  - Session layer presentation layer useful but don’t exist today.
  - Perhaps but we can’t get there from where we are.

How to remember the layers

- Please Do Not Throw Sausage + Pizza Away
- **P**lease – **P**hysical
- **D**o – **D**atalink
- **N**ot – **N**etwork
- **T**hrow – **T**ransport
- **S**ausage – **S**ession
- **P**izza – **P**resentation
- **A**way – **A**pplication

TCP/IP layers

- Layer 7 – Application layer – this is the data for programs you use on your computer
  - HTTP (www) data, SMTP (sent emails), FTP (file transfer) and specific formats for games, torrent etc.
- Layer 6 – Presentation layer
  - Related to character sets and presentation of data (unused in TCP/IP or real Internet)
- Layer 5 – Session layer
  - Related to whole lifetime of connection – is the connection real time (unused in TCP/IP or real Internet)
- Layer 4 – Transport layer – this is for the end-to-end connection between machines.
  - Information related to reliability
  - Information related to which program on machine sent/receives data.

TCP/IP layers

- Layer 3 – Network (Internet) layer – this is to get the data the whole journey from its start computer to its end computer (Internet, between networks)
  - Address of computer on internet (IP address)
  - Checksum to see if data is corrupted
- Layer 2 – Data link layer – this is to get the data to nearby computers (on same local network)
  - Media Access Control (MAC address) specific to individual computer (see later lectures)
- Layer 1 – Physical layer (how bits 1s and 0s are actually transmitted)
  - Think of cables in the ground or radio waves in the air

Layers model and this module

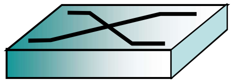
- This module focuses on these layers:
  - Transport (layer 4)
  - Network (layer 3)
  - Datalink (layer 2)
- Application layer is about programming, this is covered in other modules.
- If you understand layer 2,3,4 you know all you need to know to program applications.
- Layer 1 (physical layer) is about physics and electronics.
- Layer 5 and layer 6 (session and presentation) not implemented so no need to spend time.

What layer? 什么层

- Answer quickly using mentimeter (or chat if mentimeter is not working) the number of the layer. If you don't know take a guess as to which fits best.
- Co-axial cable.
    - Physical (layer 1)
- Responsible for reliable in order traffic delivery.
    - Transport (layer 4) – [TCP]
- Delivers traffic to "neighbouring" routers/hosts.
    - Datalink (layer 2)
- Router.
    - Network (layer 3)
- Switch
    - Datalink (layer 2)

Devices for layers

- Router
  - This is a layer 3 device – it reads a layer 3 address and works out which direction a packet should go.
  - It is typically more complex and adaptive than a switch.



- Switch
  - This is a layer 2 device – it reads a layer 2 address and works out which nearby computer should get a message.
  - Typically simpler than a router.
- Repeater
  - This is a layer 1 device – it strengthens or reconstructs a corrupted signal and carries on sending it.

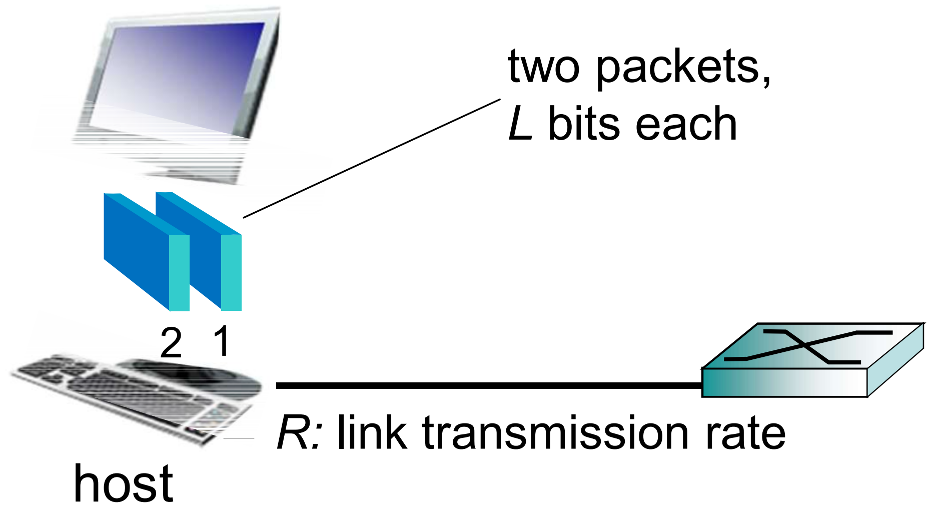
Network basics bits and bytes

- A bit is a “binary digit” – a single 0 or 1.
- A byte is a group of eight bits – can be thought of as a number from 0 to 255 (or -128 to 127) or as two digits of “hexadecimal” (eg A0, FF, 10).
- Amounts of data are usually specified in bytes.
  - 1KB = 1 kilobyte = 1000 bytes = 8000bits
  - 1MB = 1 megabyte = 1 million bytes = 8 million bits
  - 1GB = 1 gigabyte = 1000 million bytes = 8000 million bits
- BUT speeds are usually in bits per second (not bytes)
  - 1b/s (or bps) = 1 bit per second
  - 1Kb/s = 1000 bits per second
  - 1Mb/s = 1 million bits per second
  - 1Gb/s = 1000 million bits per second

Host: sends *packets* of data

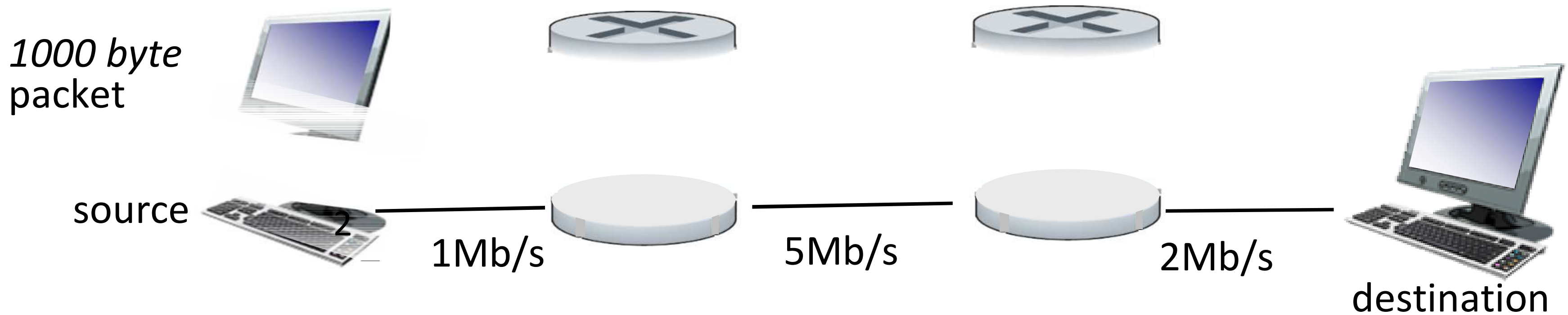
host sending function:

- 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*



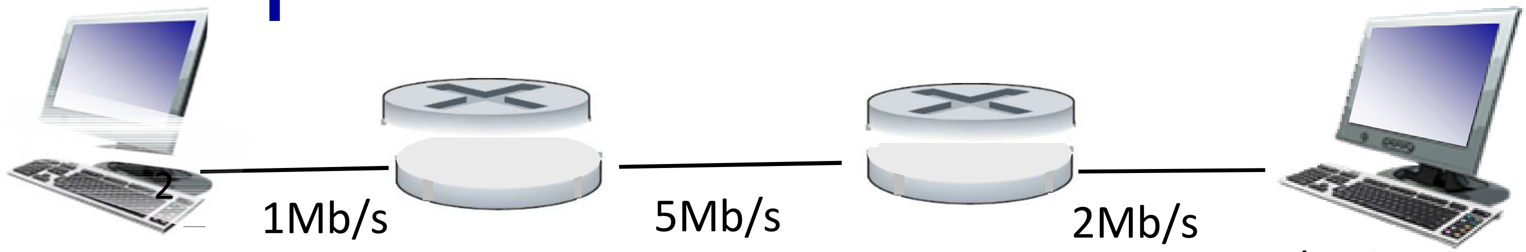
$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Practice question



- A 1000 byte packet is sent from source to destination through 3 links 1Mb/s, 5Mb/s, 2Mb/s
- Counting only transmission delay:
  - a) What is the end-to-end delay?
  - b) What is the round-trip-time (RTT)?
  - c) How long will it be between starting sending until the 3rd packet reaches the destination?

Practice question



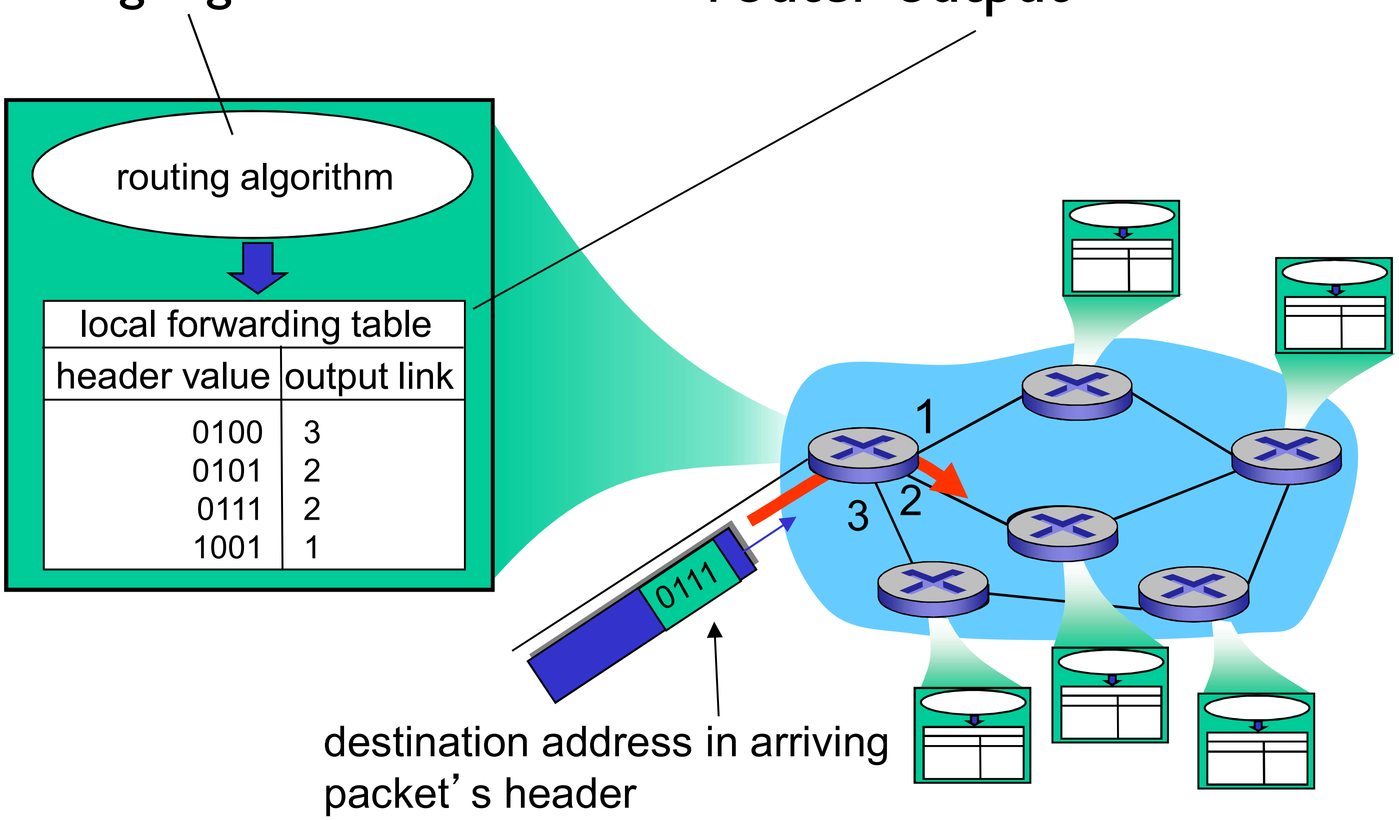
- 1000 bytes = 8000 bits.
- 5Mb/s = 5000000 bits/second
- Delay to first router = 8000/1000000secs= 0.008sec = 8 ms
- Delay to first to second router = 1.6ms
- Delay second to third router = 4ms
- **a) End-to-end delay = 8+4+1.6 ms = 13.6 ms**
- **b) RTT = 2x end-to-end = 27.2ms**
- Second packet starts transmission 1.6ms after first.
- Third packet starts transmission 1.6x2ms = 3.2 ms after first.
- **c) Third packet arrives after 13.6+8x2ms = 29.6ms.**

Two key network-core functions

routing: determines source-destination route taken by packets

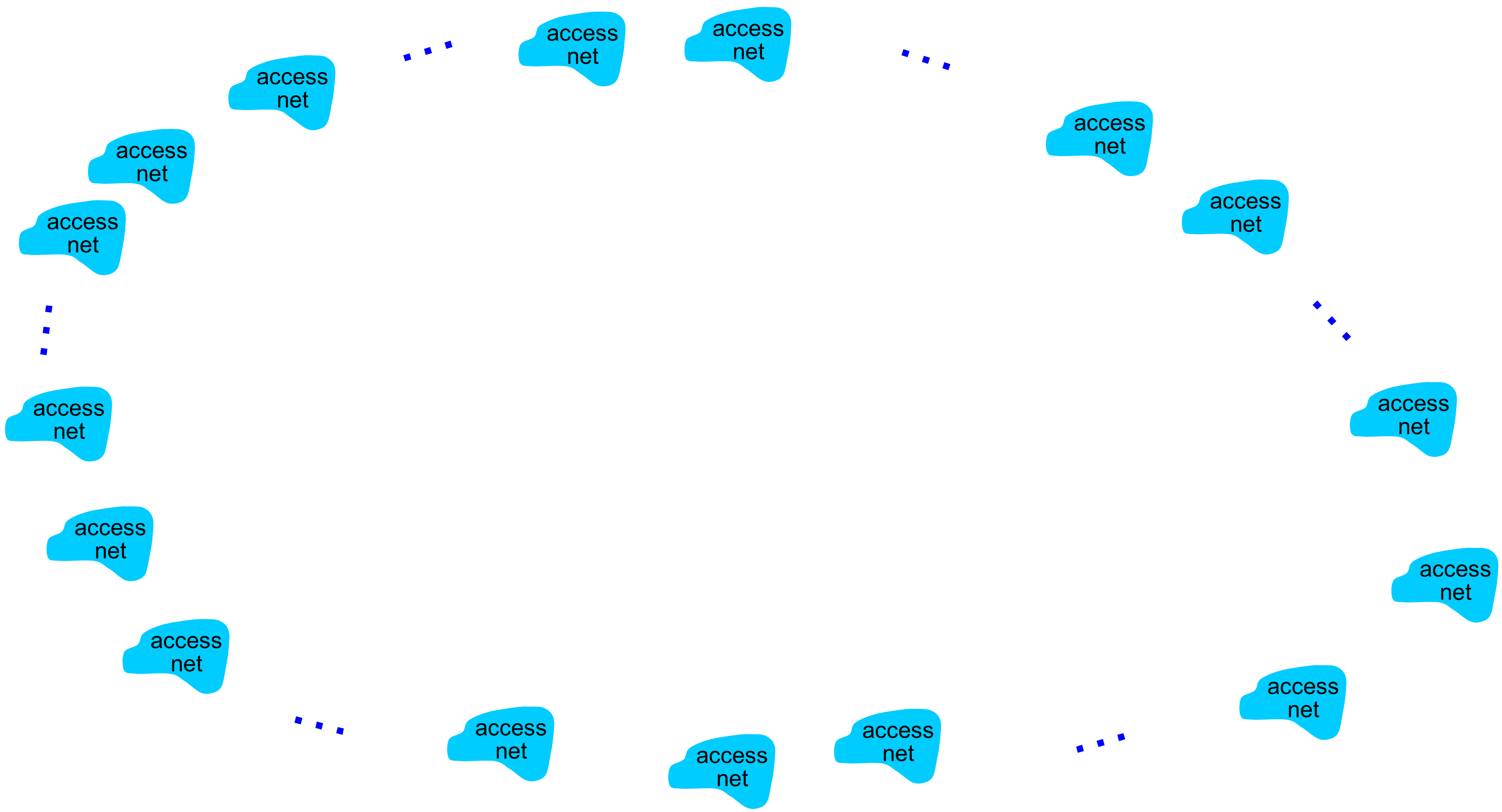
- *routing algorithms*

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



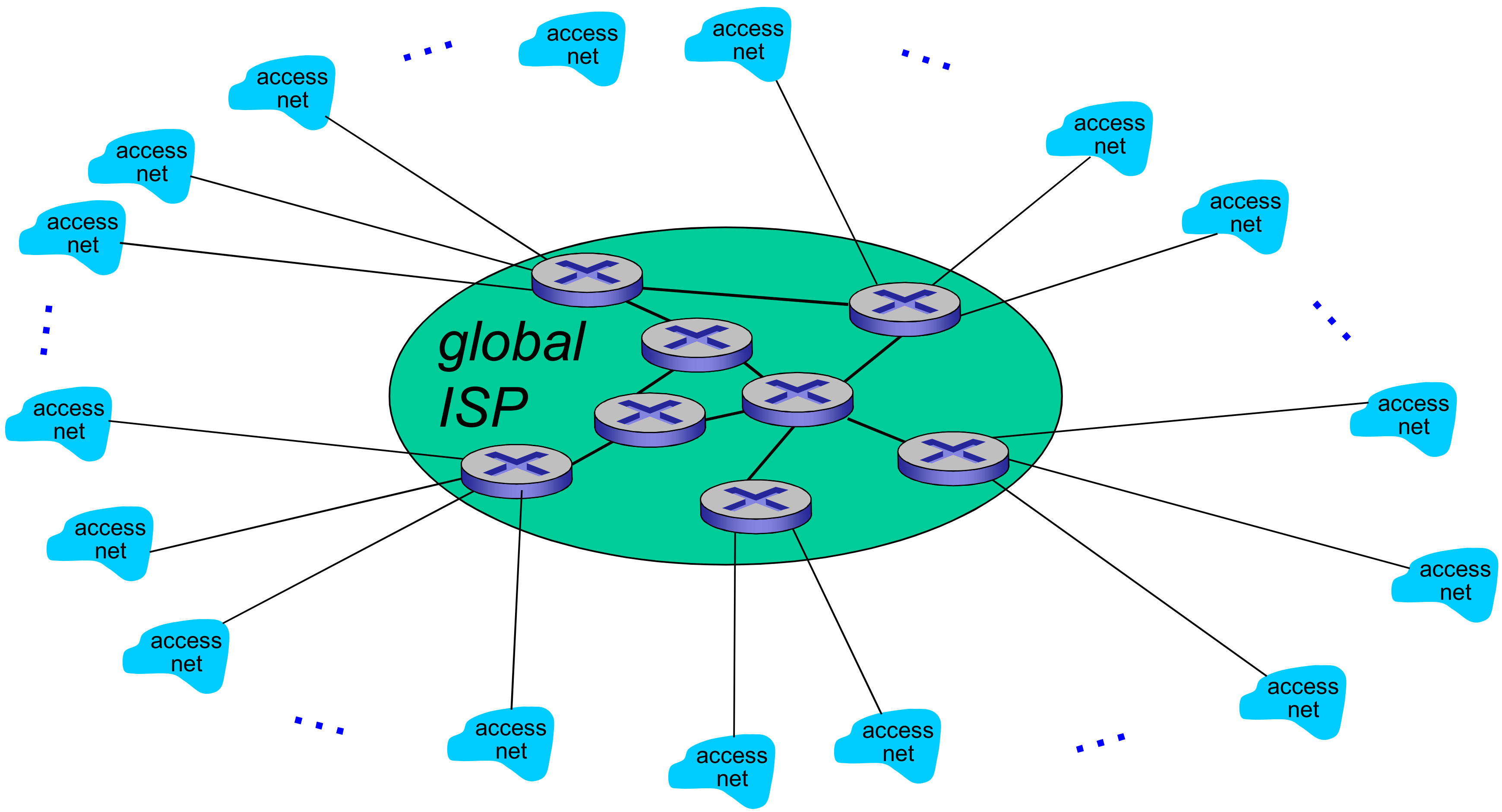
Internet structure: network of networks

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



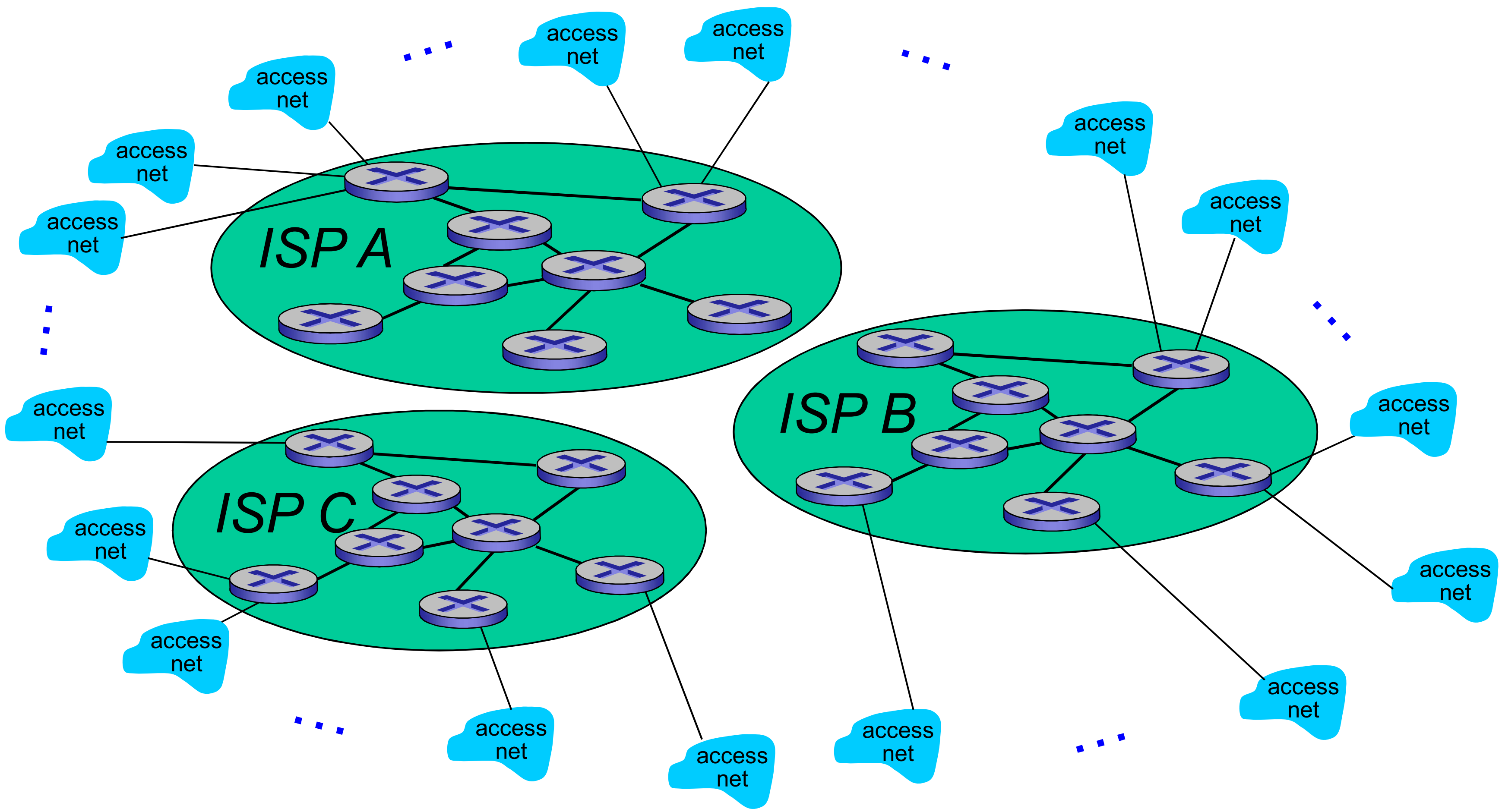
Internet structure: network of networks

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



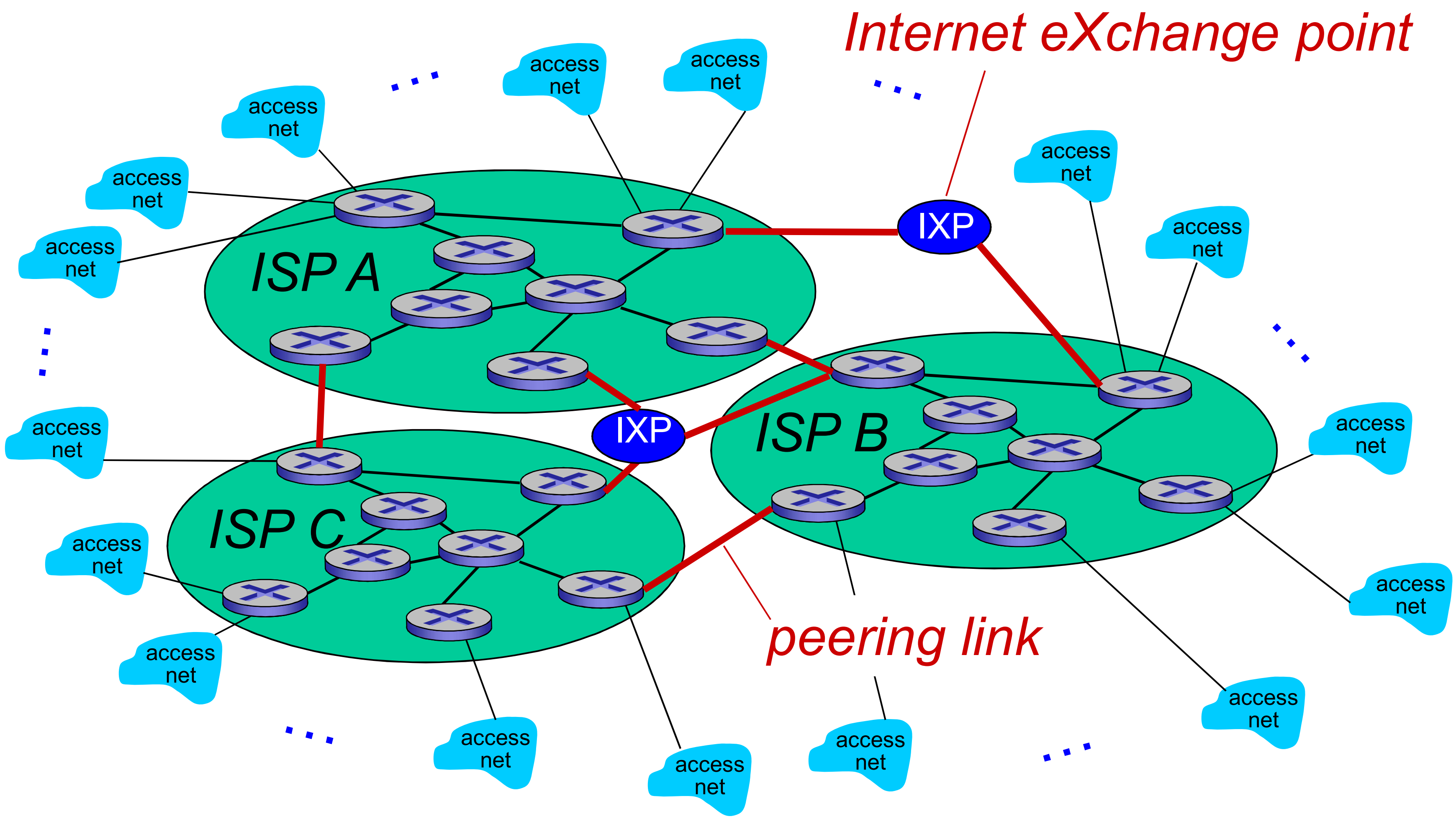
Internet structure: network of networks

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



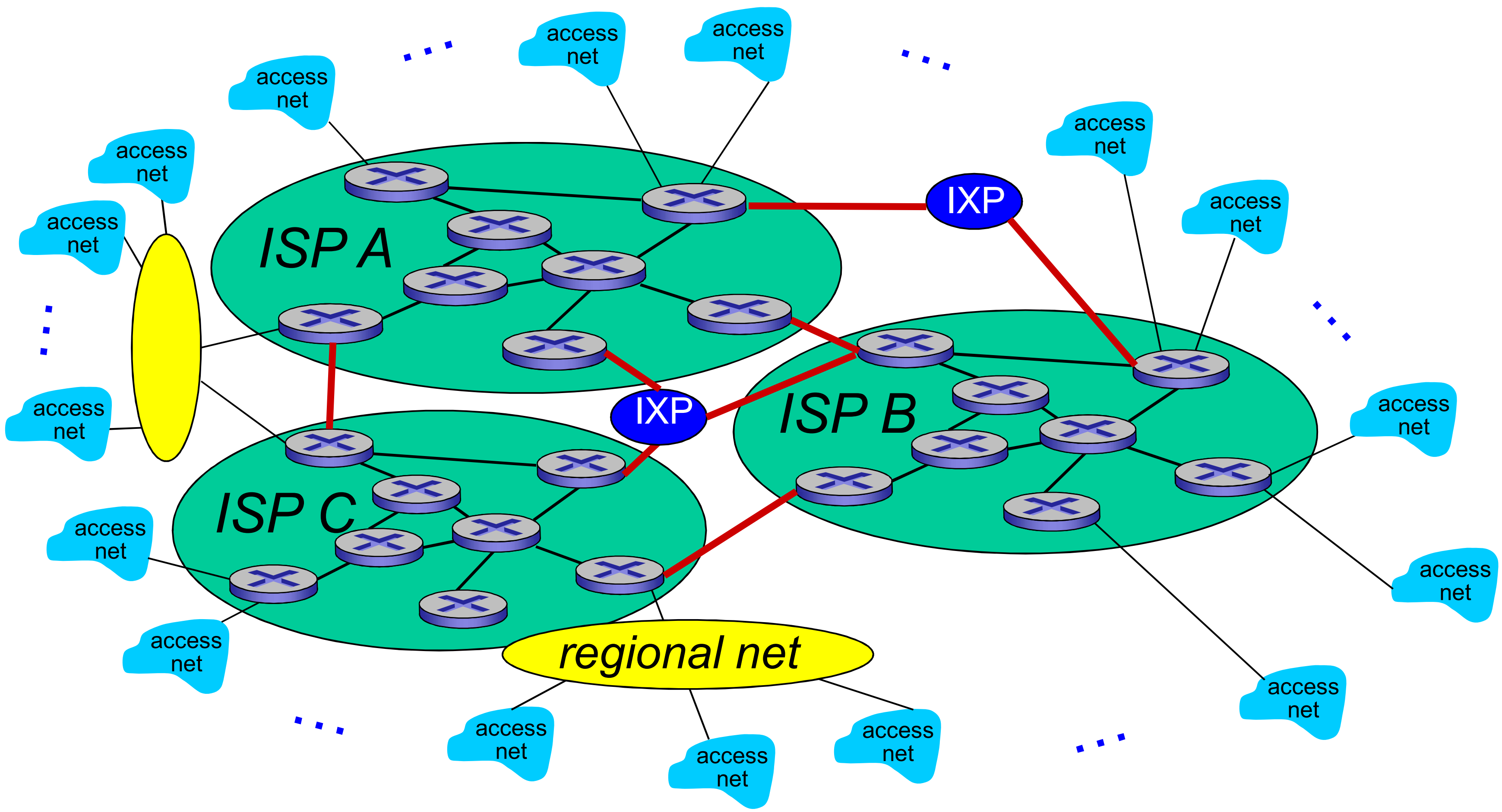
Internet structure: network of networks

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



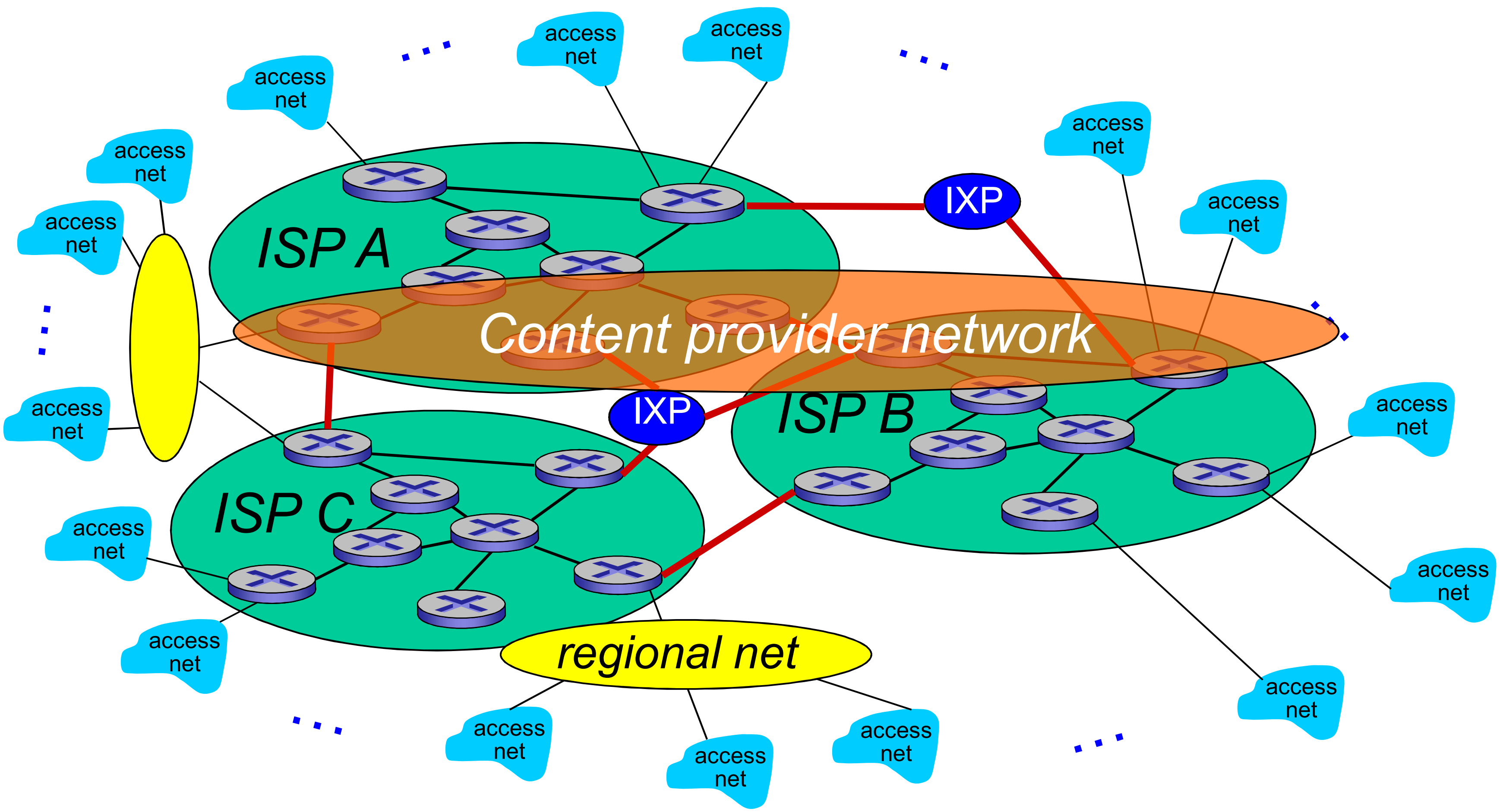
Internet structure: network of networks

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

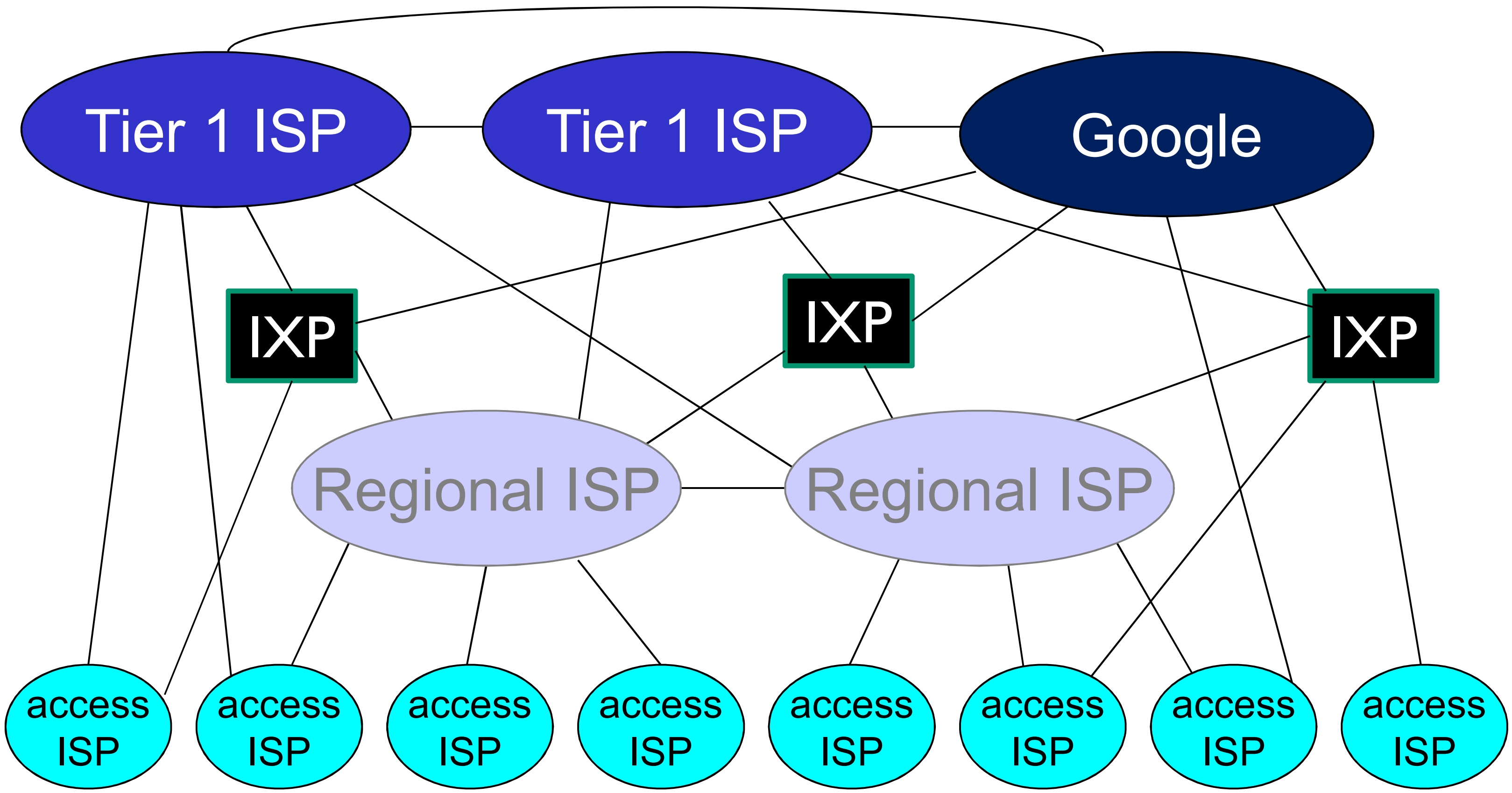


Internet structure: network of networks

… 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 it data centers to Internet, often bypassing tier-1, regional ISPs

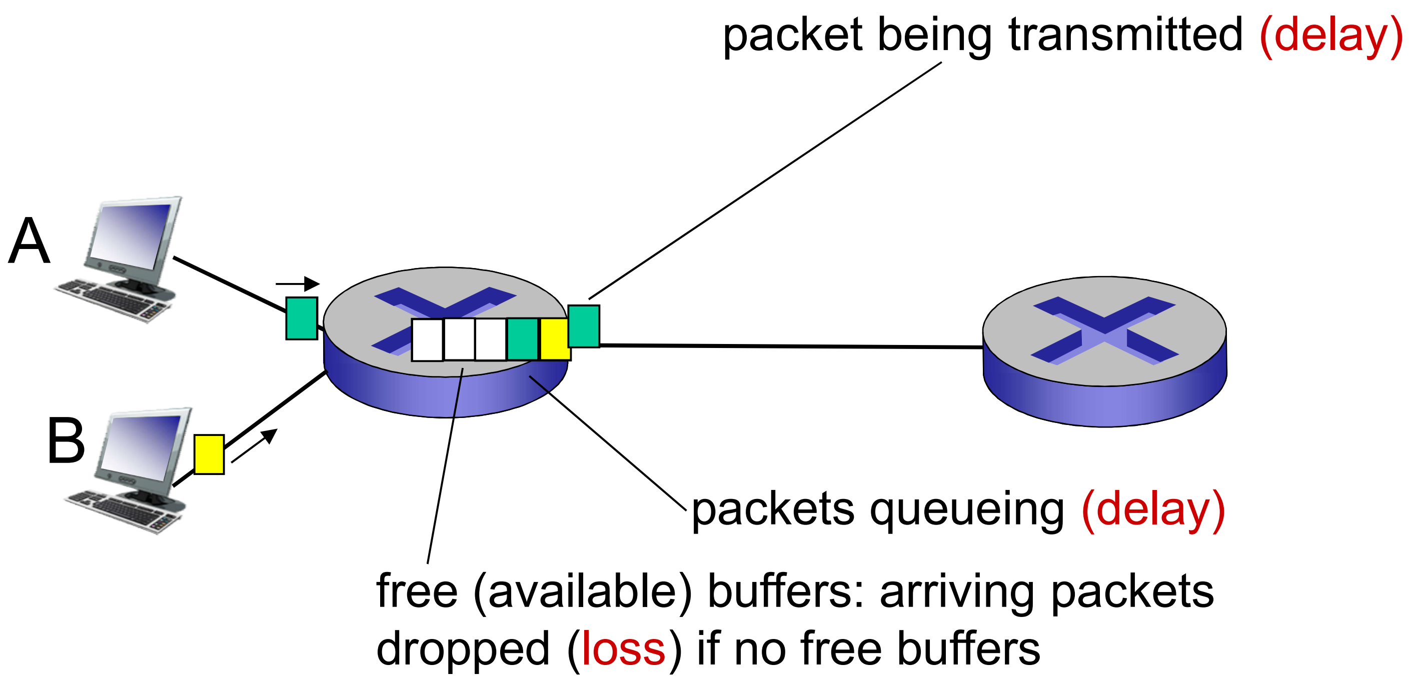
Practice question: Edge or core

- Where do you find the following: network core or network edge or both
- Options:
  - (A) WiFi access point
    - Network edge (allows end user devices access to network)
  - (B) Content distribution network
    - Core (but near the network edge)
  - (C) Switches
    - Both (necessary all over the network for layer 2 connections some switches are tiny cheap devices and some are huge)
  - (D) Web server
    - Edge (although web servers can be powerful large computers they are end hosts).

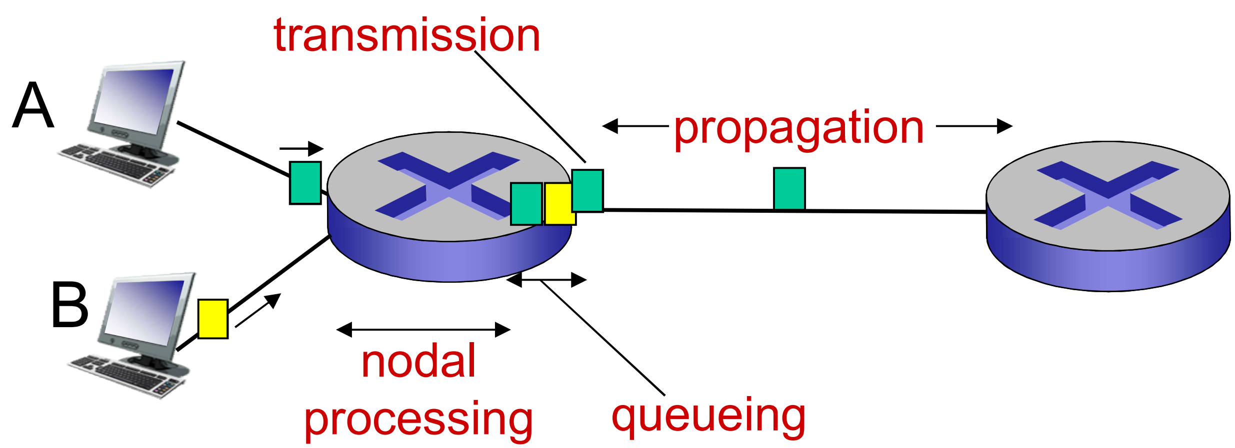
How do loss and delay occur?

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



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

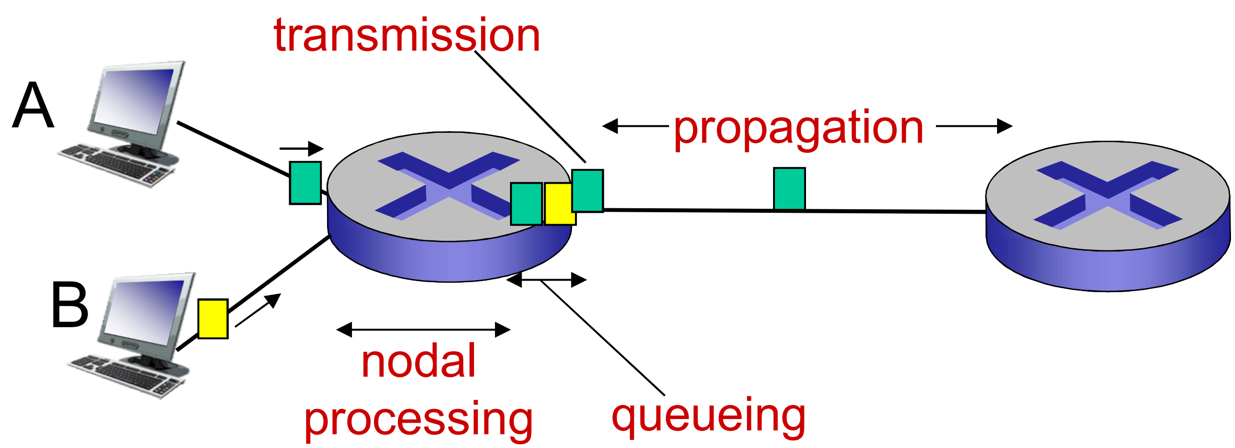
d_{proc}: nodal processing

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

d_{queue}: queueing delay

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

Four sources of packet delay



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

d_{trans}: transmission delay:
- *L*: packet length (bits)
- *R*: link *bandwidth (bps)*
- $d_{trans} = L/R$

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

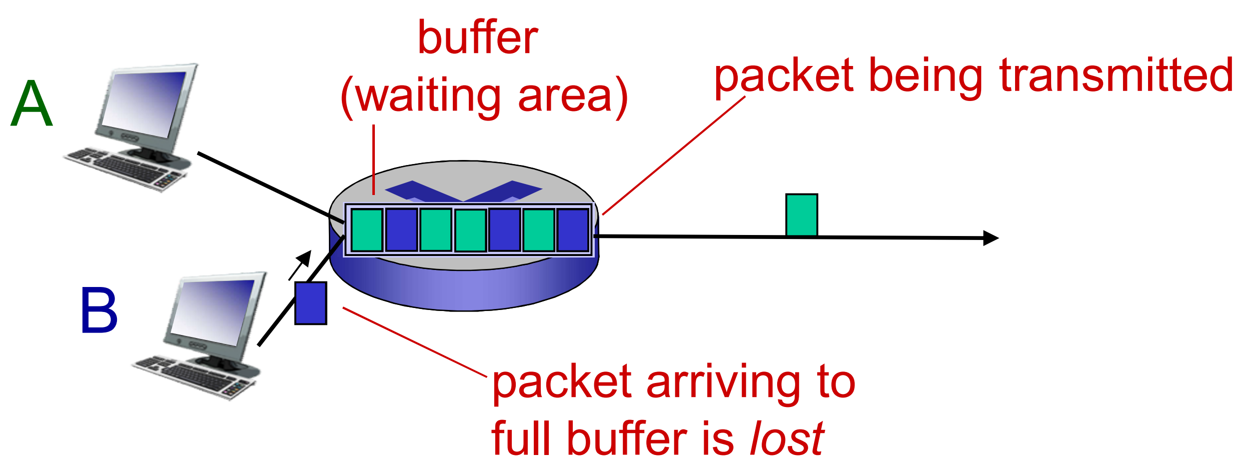
d_{prop}: propagation delay:
- *d*: length of physical link
- *s*: propagation speed (~2x10^8 m/sec)
- $d_{prop} = d/s$

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

* Check out the Java applet for an interactive animation on trans vs. prop delay

Packet loss

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



* Check out the Java applet for an interactive animation on queuing and loss

Example question

- A packet of 1500B arrives at a router:
  - The router takes 2ms to process the packet.
  - The router takes 1ms to work out which outbound link it should be sent to.
  - The packet waits behind four other packets each of which takes 0.5 ms to transmit.
  - The router sends the packet down a 1Mb/s link.
  - The packet travels at 200,000,000 m/s (2/3 speed of light) down a 1,000 km fibre optic link under the ocean.
- Calculate how much delay in each of the four types. What is the total delay?

Example question

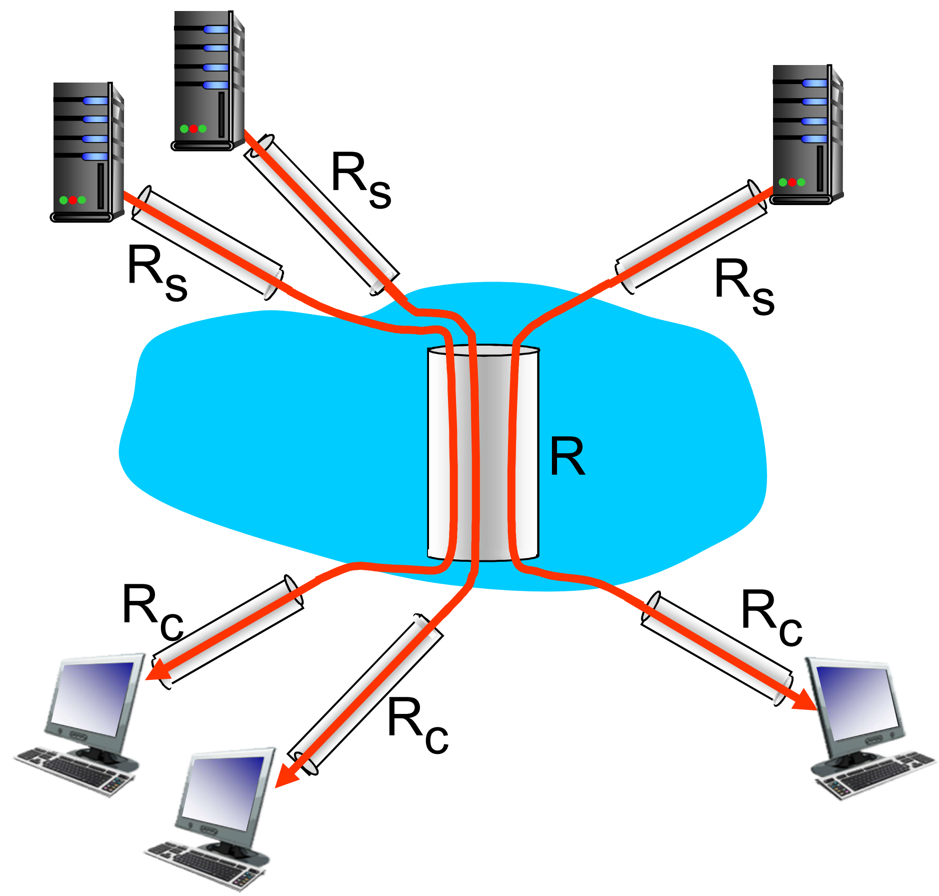
- A packet of 1500B arrives at a router:
- Name the four sources of delay and how much delay each is. What is the total delay?
  - The router takes 2ms to process the packet.
  - The router takes 1ms to work out which outbound link it should be sent to.
  - **Total 3ms nodal processing delay.**
  - The packet waits behind four other packets each of which takes 0.5 ms to transmit.
  - **Total 2ms queuing delay**

Example question

- A packet of 1500kB arrives at a router:
- Name the four sources of delay and how much delay each is. What is the total delay?
  - The router sends the packet down a 1Mb/s link.
  - 1500 bytes = 1500x8bits= 12000 bits
  - Time =L/R = 12000/1000000 sec = 12ms
  - **Transmission delay 12ms**
  - The packet travels at 200,000,000 m/s (2/3 speed of light) down a 1,000 km fibre optic link under the ocean.
  - 1,000km= 1,000,000m
  - Time = 1,000,000/200,000,000 seconds = 0.005sec
  - **Propagation delay = 5ms**
- **Total delay = 3+2+12+5 ms= 22ms**

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

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/

Example question

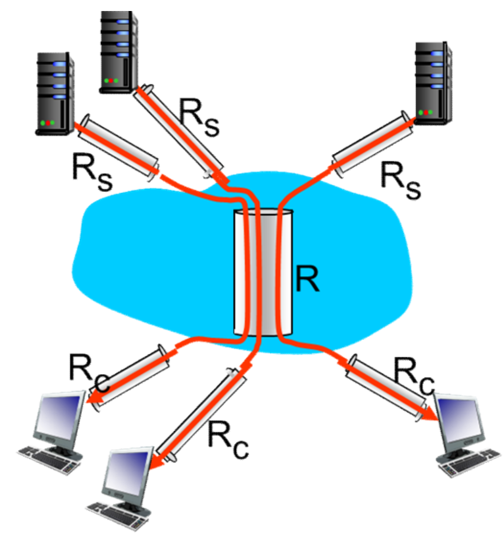
- What is the bandwidth of the connections if:

A)

R_c=1Mb/s
R_s=512kb/s
R= 8Mb/s
n=10

B)

R_c=1.5Mb/s
R_s=1300kb/s
R= 5Mb/s
n= 4



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

Example question

- What is the bandwidth of the connections if:

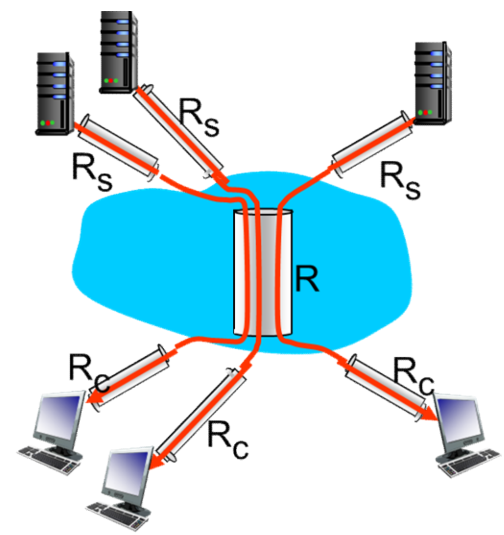
A)

R_c=1Mb/s
R_s=512kb/s =0.512Mb/s
R= 8Mb/s
n=10 = 0.8 Mb/s each
R_s is bottleneck – 512kb/s

B)

R_c=1.5Mb/s
R_s=1300kb/s = 1.3Mb/s
R= 5Mb/s
n= 4 =1.25 Mb/s each

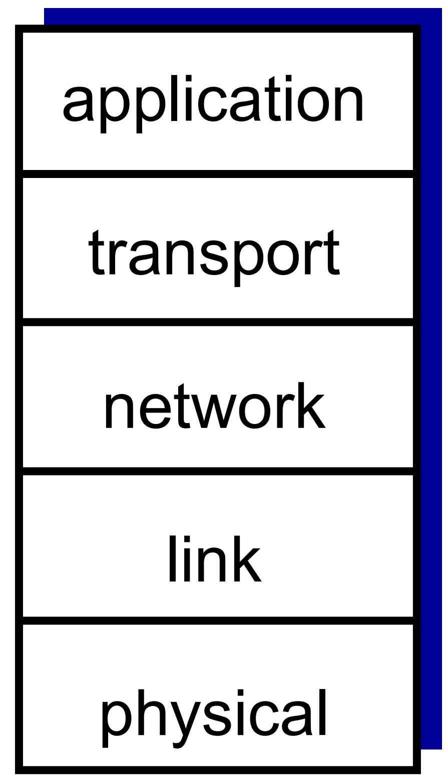
R is bottleneck -- 1.25MB/s



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

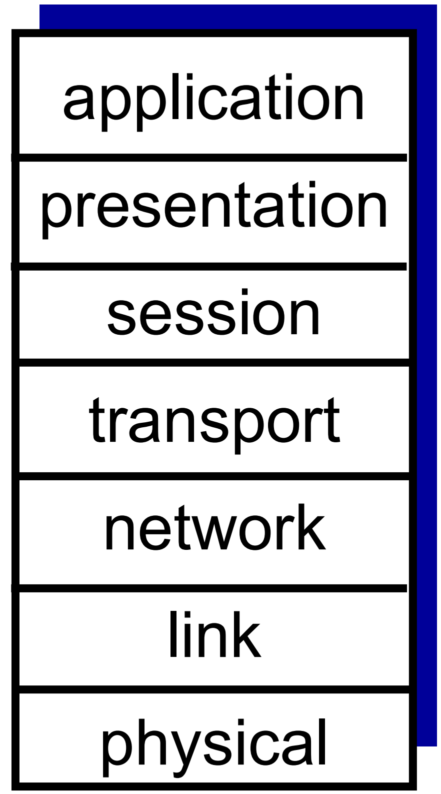
TCP/IP model (internet model)

- *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”



ISO/OSI reference model

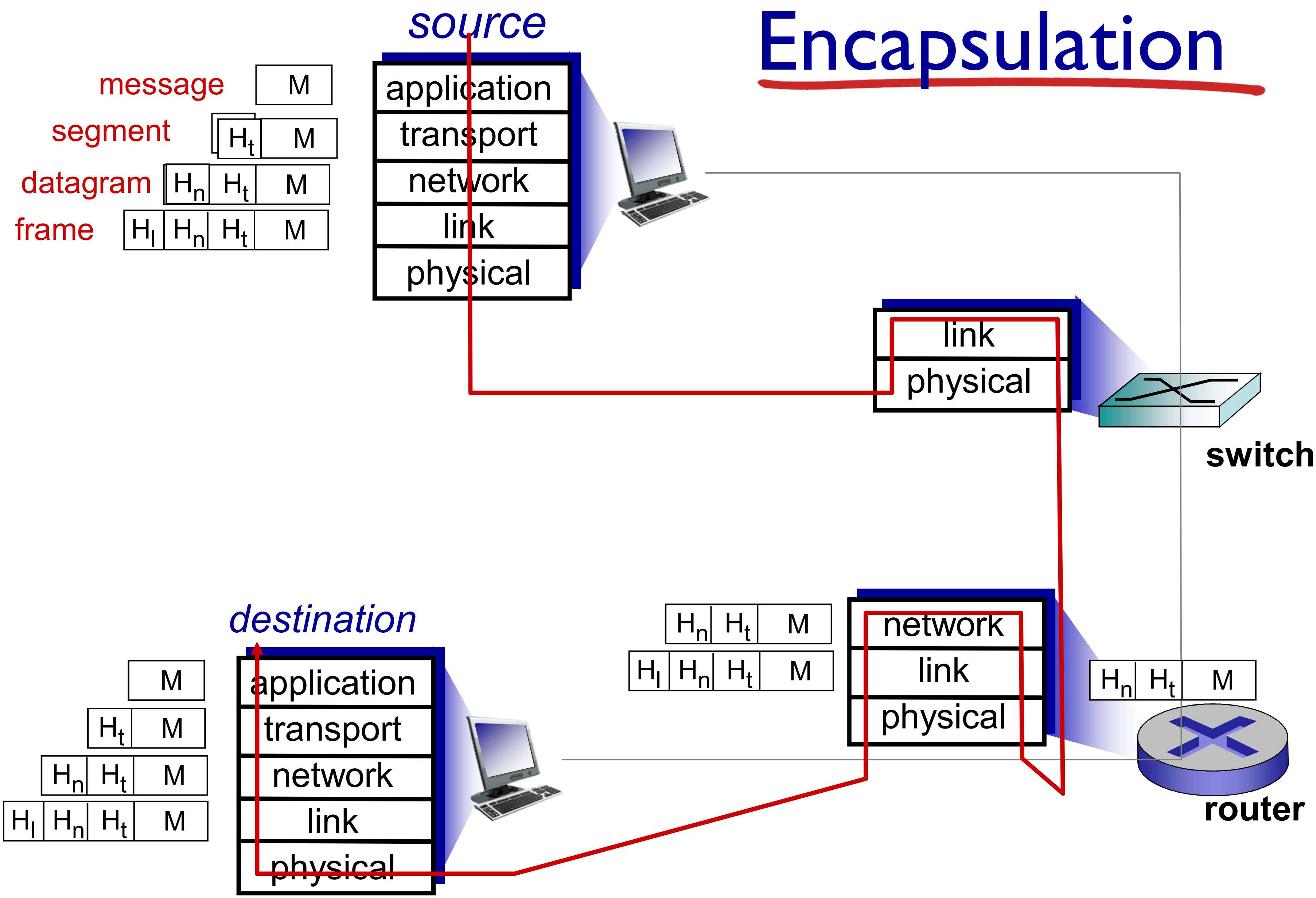
- ISO = International Standards Office
- OSI = Open Systems Interconnection
- *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session:* synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed*, must be implemented in application
  - needed?



Layering and headers

- Most layers of the TCP/IP model are associated with a particular type of "header" or sometimes a "header and trailer".
- What is a header?
  - Information separate from the data being sent that says things about that data.
  - Which computer is it being sent to?
  - Which program on that computer must receive it?
  - How long is this data?
- For example layer 3 (network) has a "network address" which identifies the host that should receive the data.
- Layer 4 (transport) has a port that identifies which program should receive it.
- At each lower layer a new header is added incorporating the headers underneath. A layer 2 packet has a layer 2 header but includes headers from layer 3 and 4.

Encapsulation



Practice question

- M is the message being sent
- H_l,H_n,H_t headers for link, network, transport layers.
- L_l,L_n,L_t are the lengths of these headers in bytes.
- L_m is the length of the message in bytes
- A) How many bytes are present at the transport layer?
- B) How many bytes are present at the link layer?
- C) The user only cares about the bytes in the message. What is the efficiency if we define:
    - Efficiency= bytes layer 7 receives /bytes sent at layer two

Practice question

- M is the message being sent
- H_l,H_n,H_t headers for link, network, transport layers.
- L_l,L_n,L_t are the lengths of these headers in bytes.
- L_m is the length of the message in bytes
- A) How many bytes are present at the transport layer?
  - Message + H_t only present – L_m+L_t bytes
- B) How many bytes are present at the link layer?
  - Message + H_t + H_n + H_l = L_m+L_t +L_n+L_l bytes
- C) The user only cares about the bytes in the message. What is the efficiency if we define:
  - Efficiency= bytes layer 7 receives /bytes sent at layer two
  - Efficiency = L_m/L_m+L_t +L_n+L_l

What have we learned?

- Internet performance:
  - Delay and loss together limit throughput.
  - Loss of packets when network busy (but not a problem – a normal part of network function).
- Protocol layers create Internet:
  - OSI/ISO: Physical, Datalink, Network, Transport, Session, Presentation, Application
  - TCP/IP: No Presentation + Session Layer
  - Layers simplify engineering. Layers only need to interface with layers above and below.