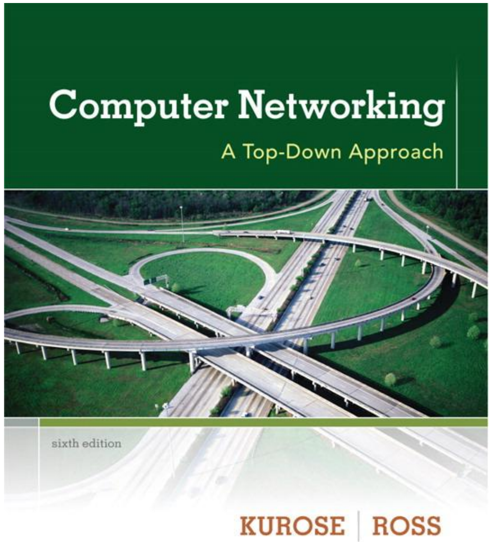
Chapter 1
Introduction



Computer Networking: A Top Down Approach
6^{th} edition
Jim Kurose, Keith Ross
Addison-Wesley
March 2012

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

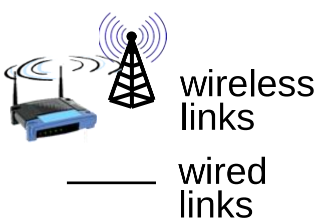
1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

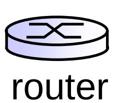
1.7 history

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

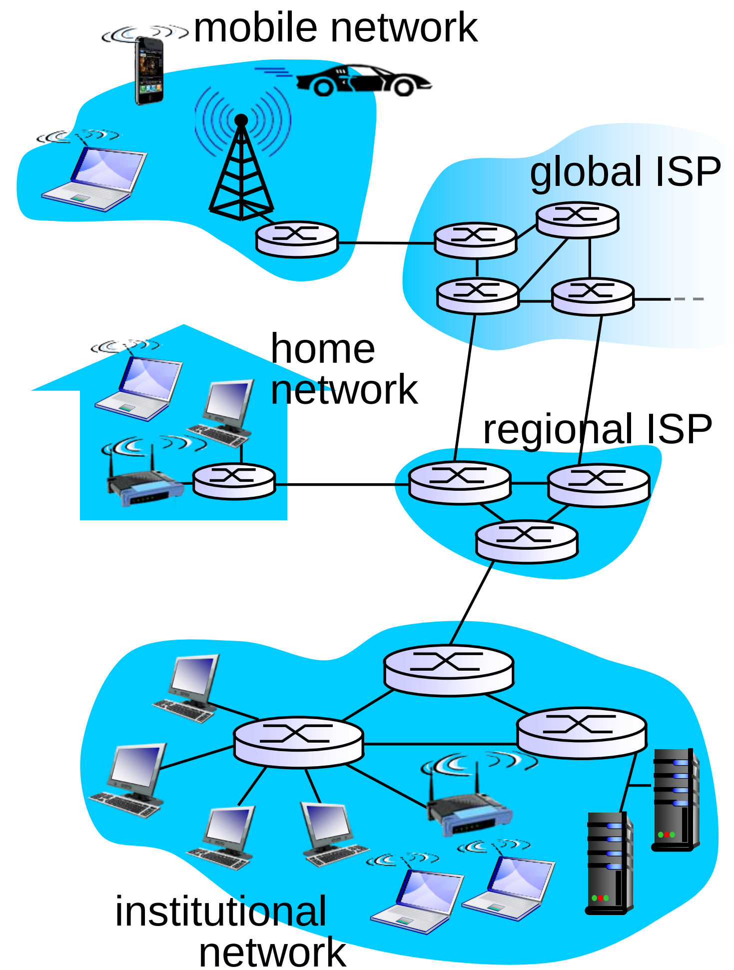
- millions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*



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



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



“Fun” internet appliances

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

Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

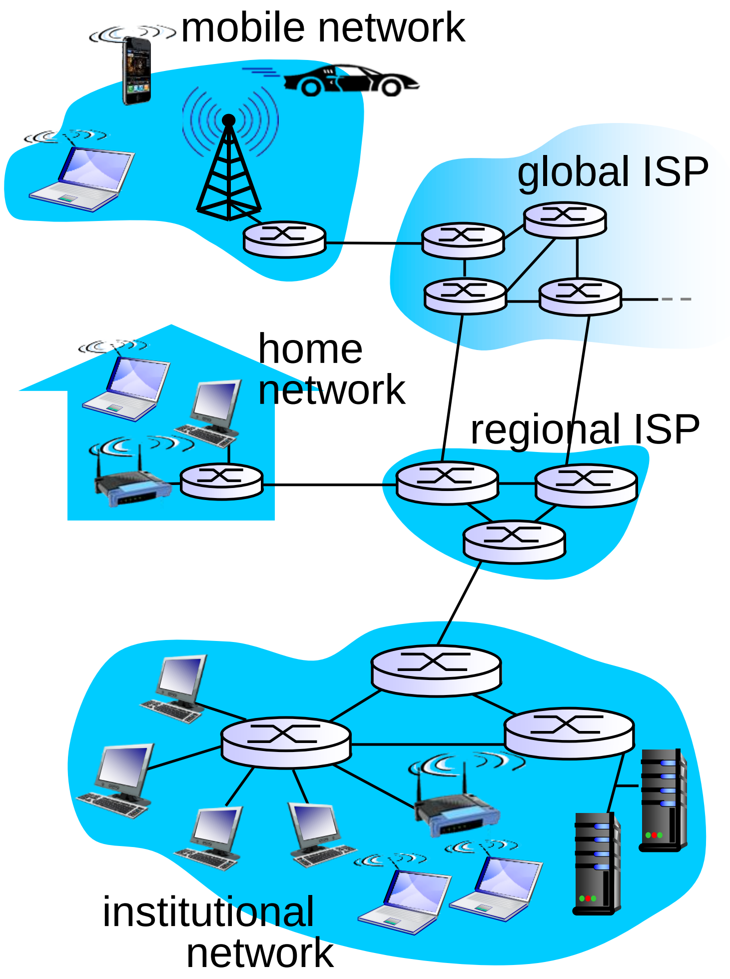
Internet
refrigerator

Slingbox: watch,
control cable TV remotely

Internet phones

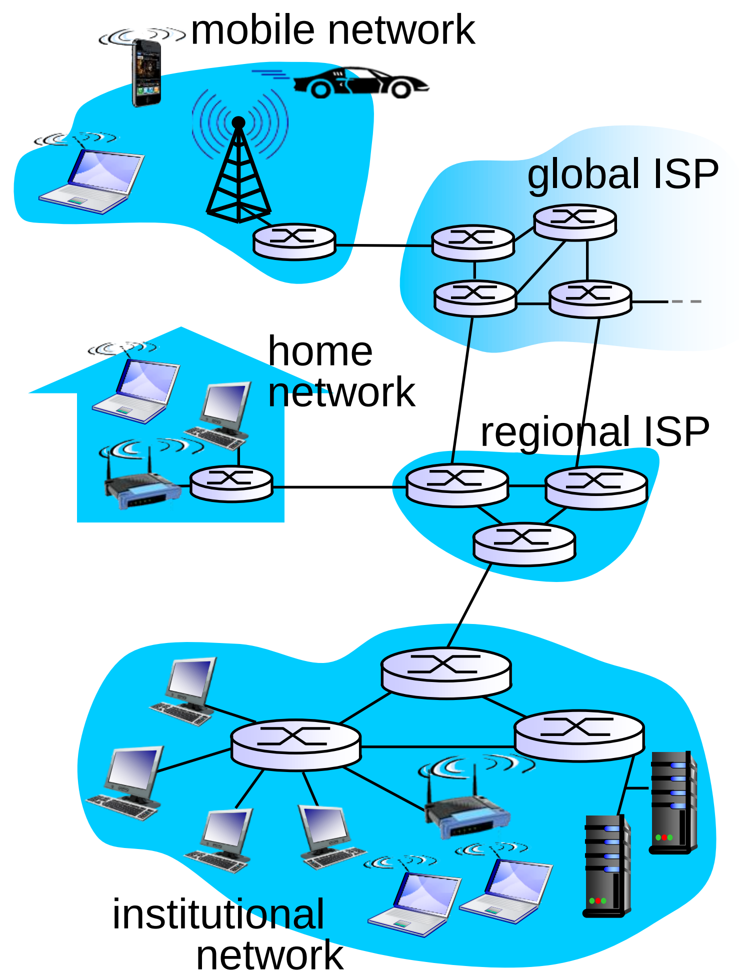
What's the Internet: "nuts and bolts" view

- *Internet: "network of networks"*
  - Interconnected ISPs
- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's the Internet: a service view

- *Infrastructure that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social nets, …
- *provides programming interface to apps*
  - hooks that allow sending and receiving app programs to "connect" to Internet
  - provides service options, analogous to postal service



What's a protocol?

human protocols:

- "what's the time?"
- "I have a question"
- introductions

… specific msgs sent

… specific actions taken when msgs received, or other events

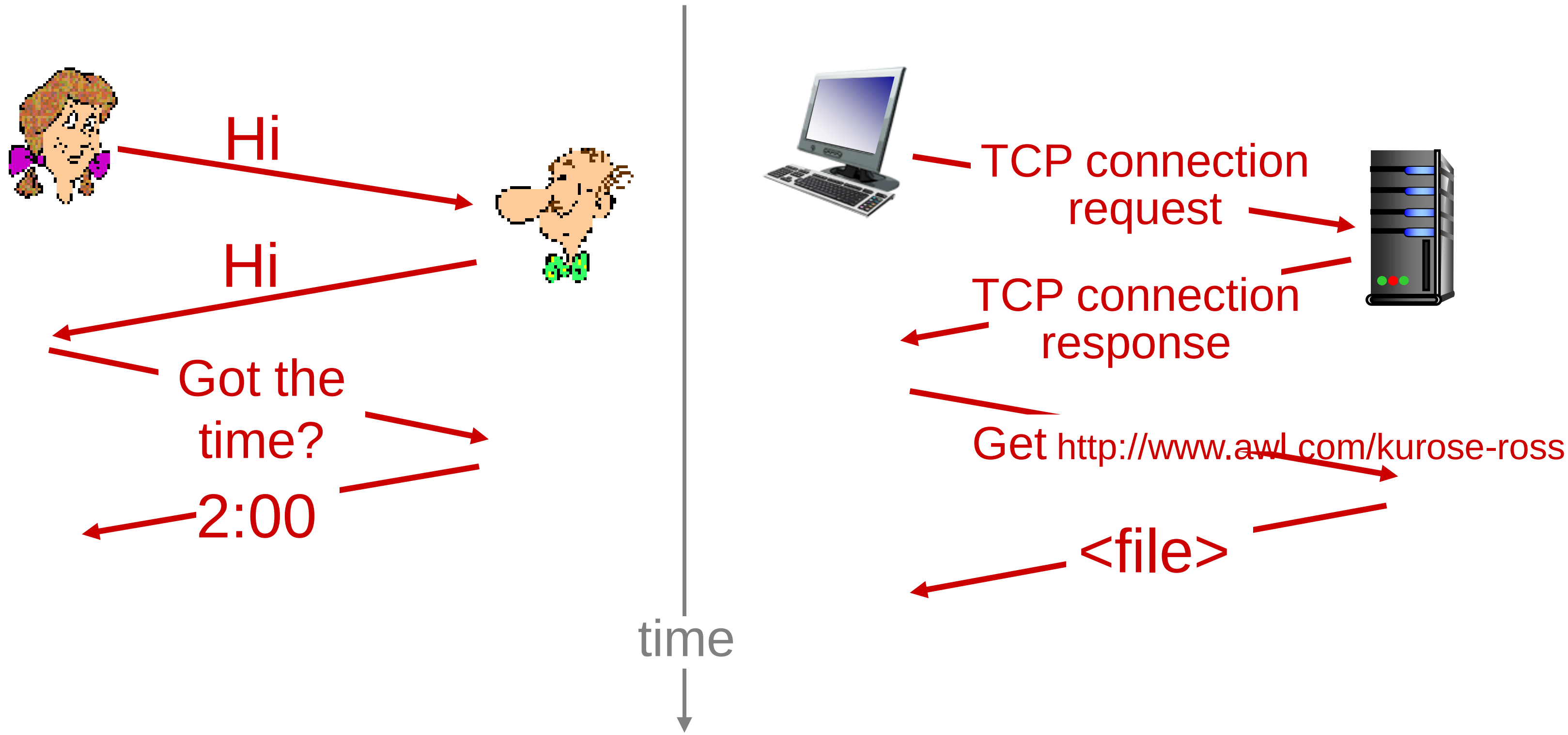
network protocols:

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

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

What's a protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

(Syntax, Semantics & Timing)

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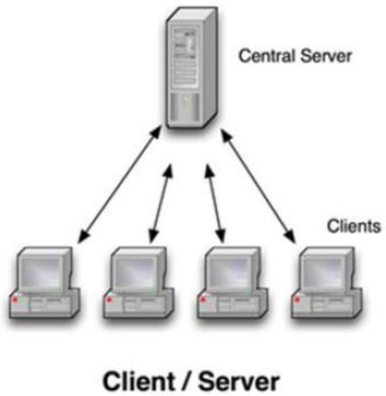
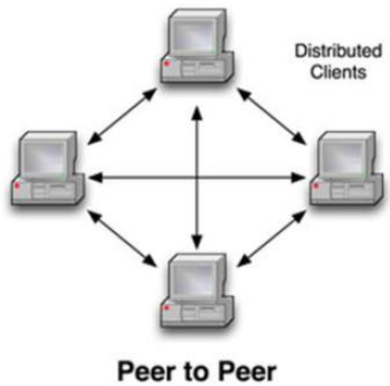
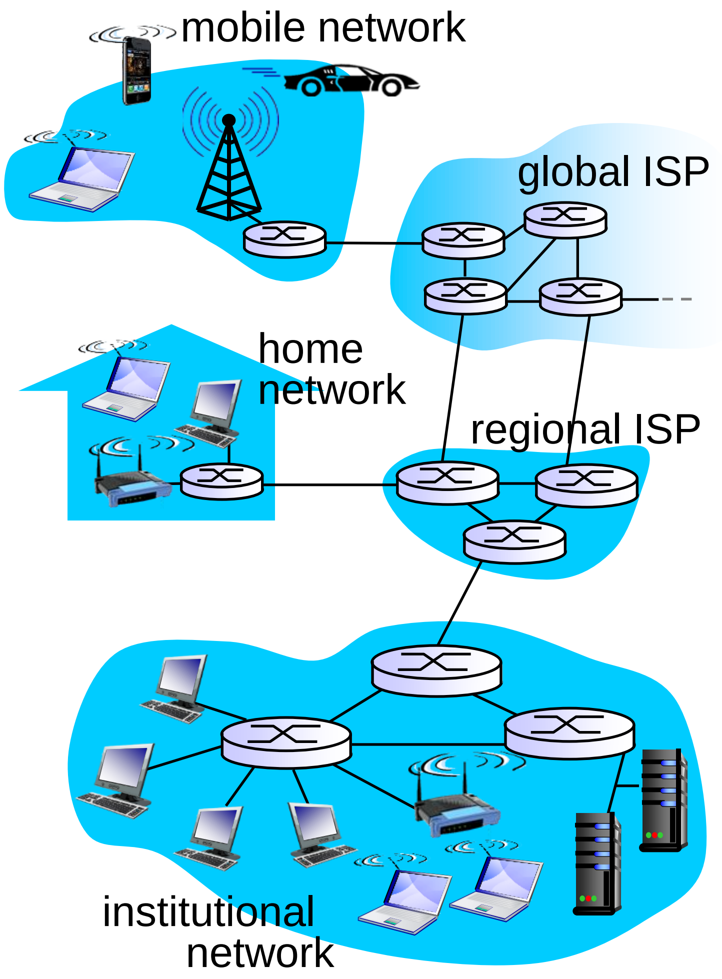
A closer look at network structure:

- *network edge:*
  - Clients and server Networks
  - servers often in data centers
  - Peer-to-peer Networks



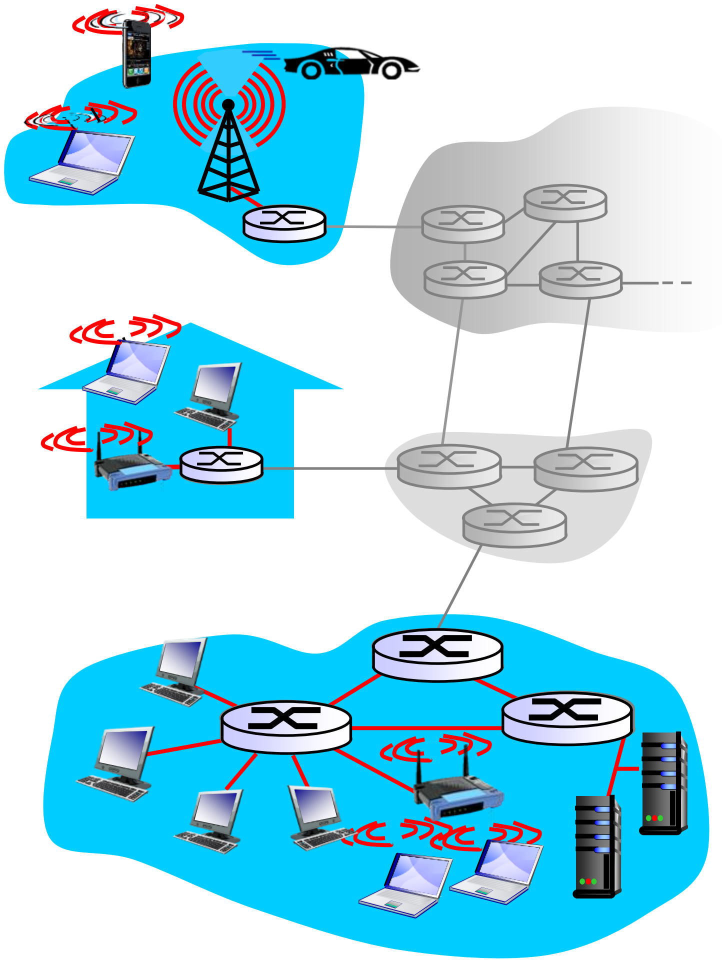




Access networks and physical media

Q: How to connect end systems to edge router?

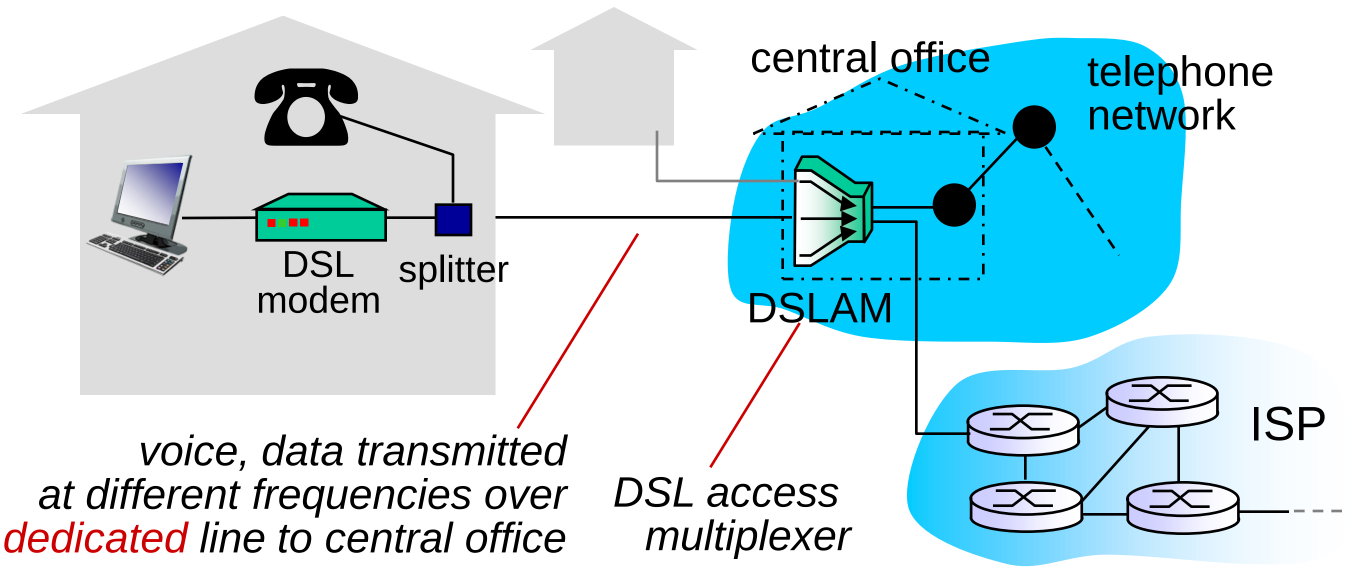
- residential access nets
- institutional access networks (school, company)
- mobile access networks



keep in mind:

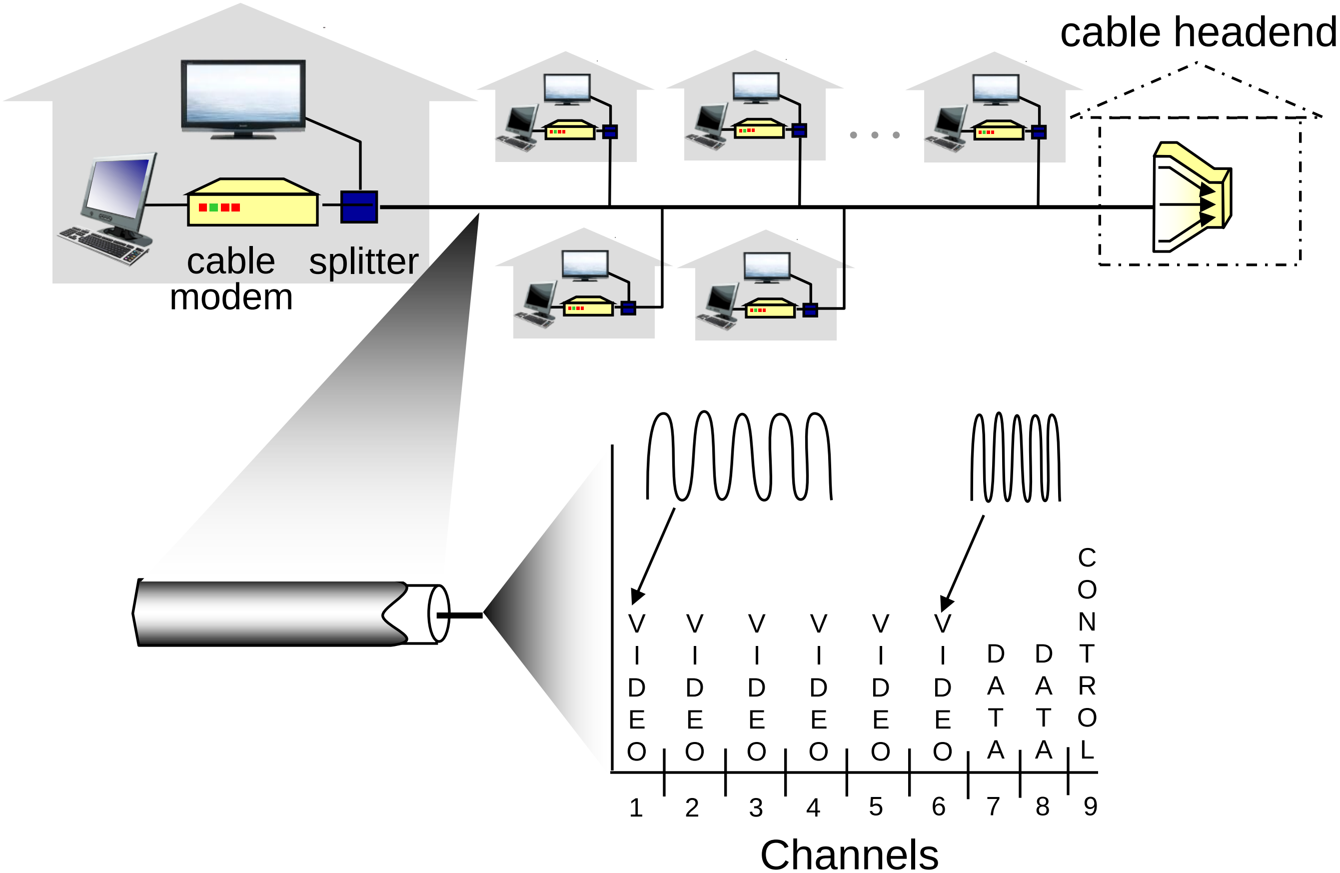
- bandwidth (bits per second) of access network?
- shared or dedicated?

Access net: digital subscriber line (DSL)



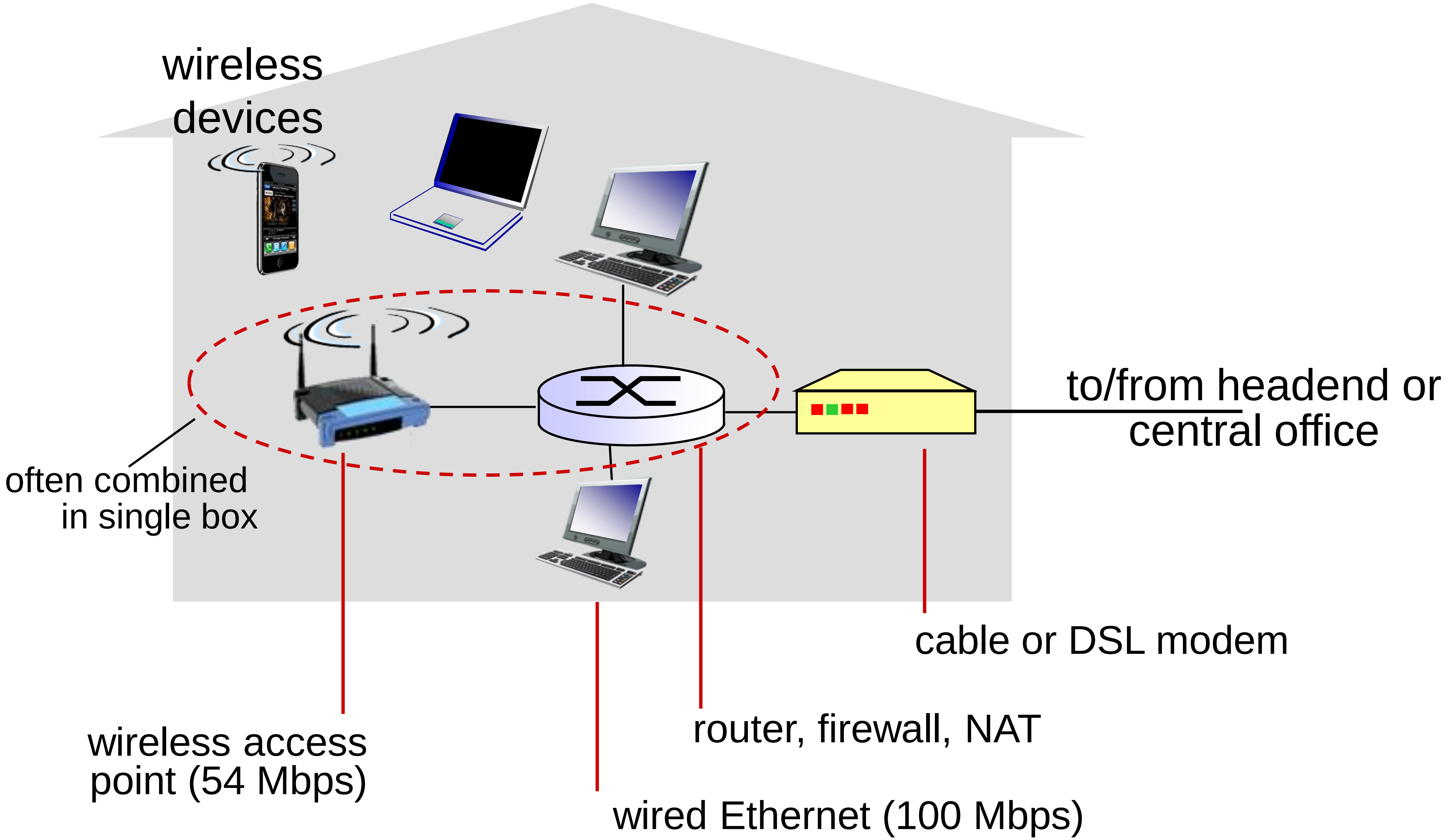
- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

Access net: cable network

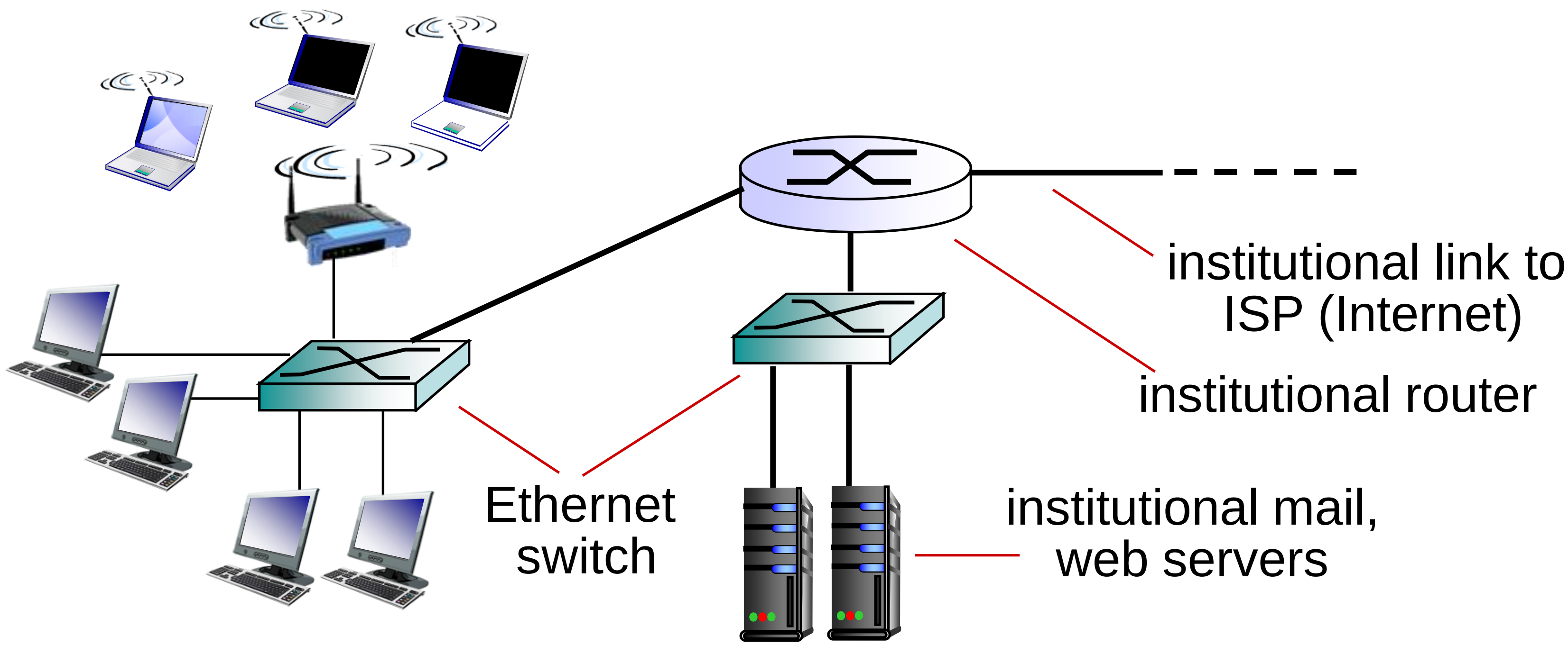


frequency division multiplexing: different channels transmitted in different frequency bands

Access net: home network



Enterprise access networks (Ethernet)



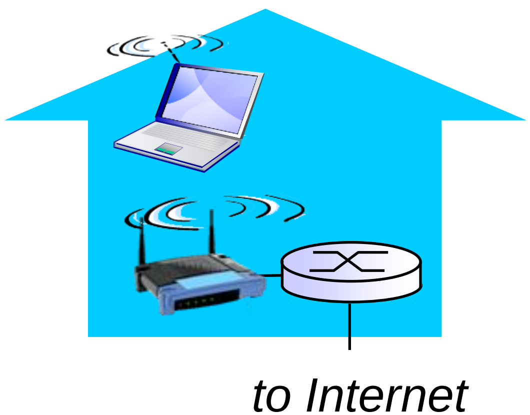
- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

Wireless access networks

- shared *wireless* access network connects end system to router
  - via base station aka "access point"

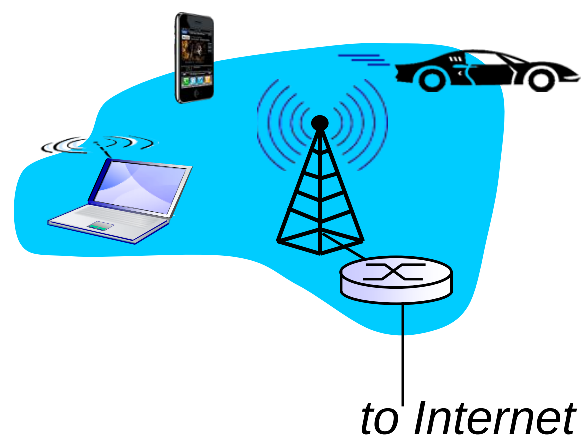
wireless LANs:

- within building (100 ft)
- 802.11b/g (WiFi): 11, 54 Mbps transmission rate



wide-area wireless access

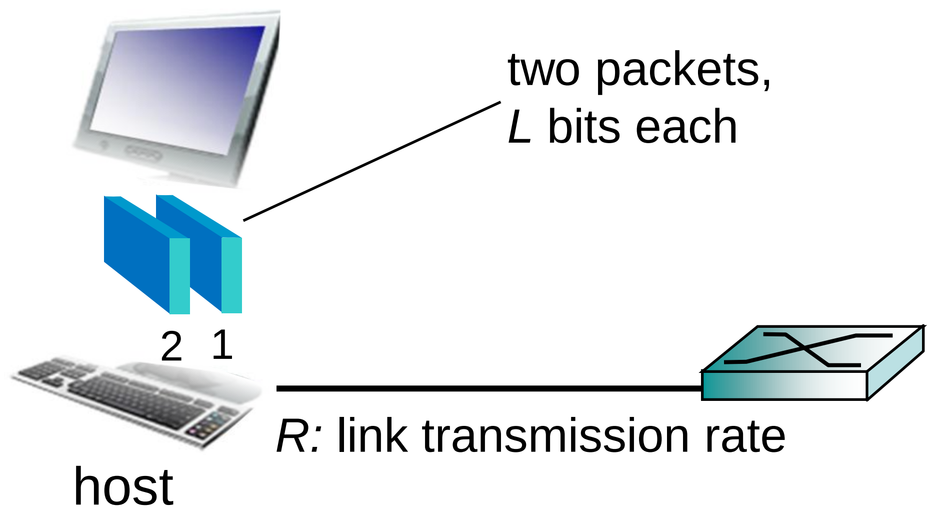
- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE (Long Term Evolution)



Host: sends *packets* of data

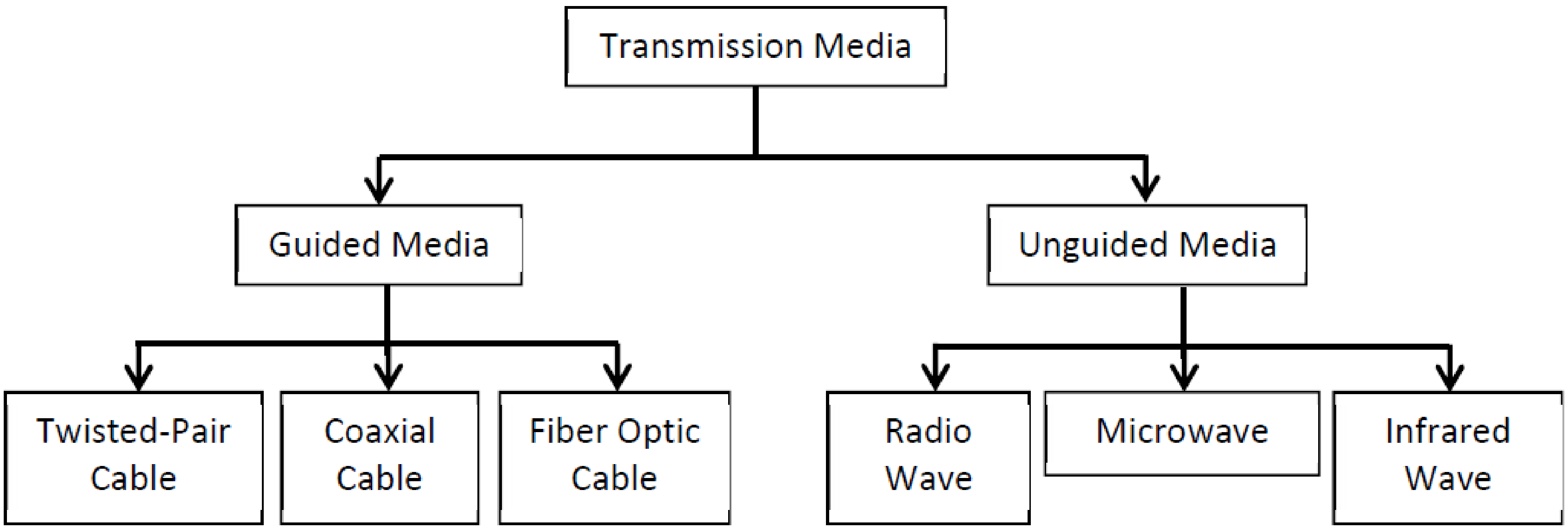
host sending function:

- 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*



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

Classification of Transmission Media



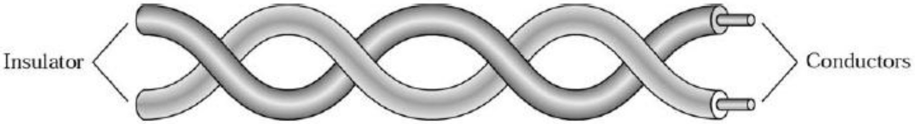
Guided (Physical/Wired) Transmission Media
Unguided (Wireless) Transmission Media

Physical media

- bit: propagates between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver
- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio

twisted pair (TP)

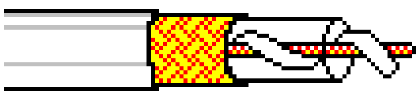
- two insulated copper wires
  - Category 5: 100 Mbps, 1 Gpbs Ethernet
  - Category 6: 10Gbps

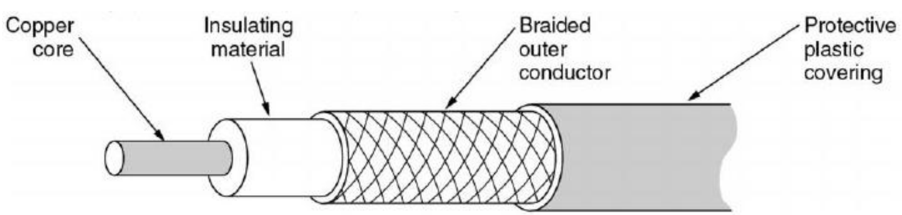


Physical media: coax, fiber

coaxial cable:

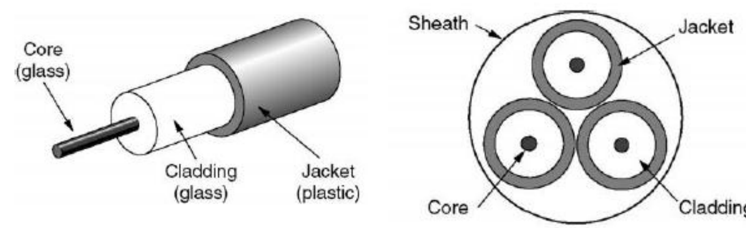
- two concentric copper conductors
- bidirectional
- broadband:
  - multiple channels on cable
  - Hybrid Fiber Coaxial





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 spaced far apart
  - immune to electromagnetic noise



Physical media: radio

- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

radio link types:

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WiFi)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ few Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

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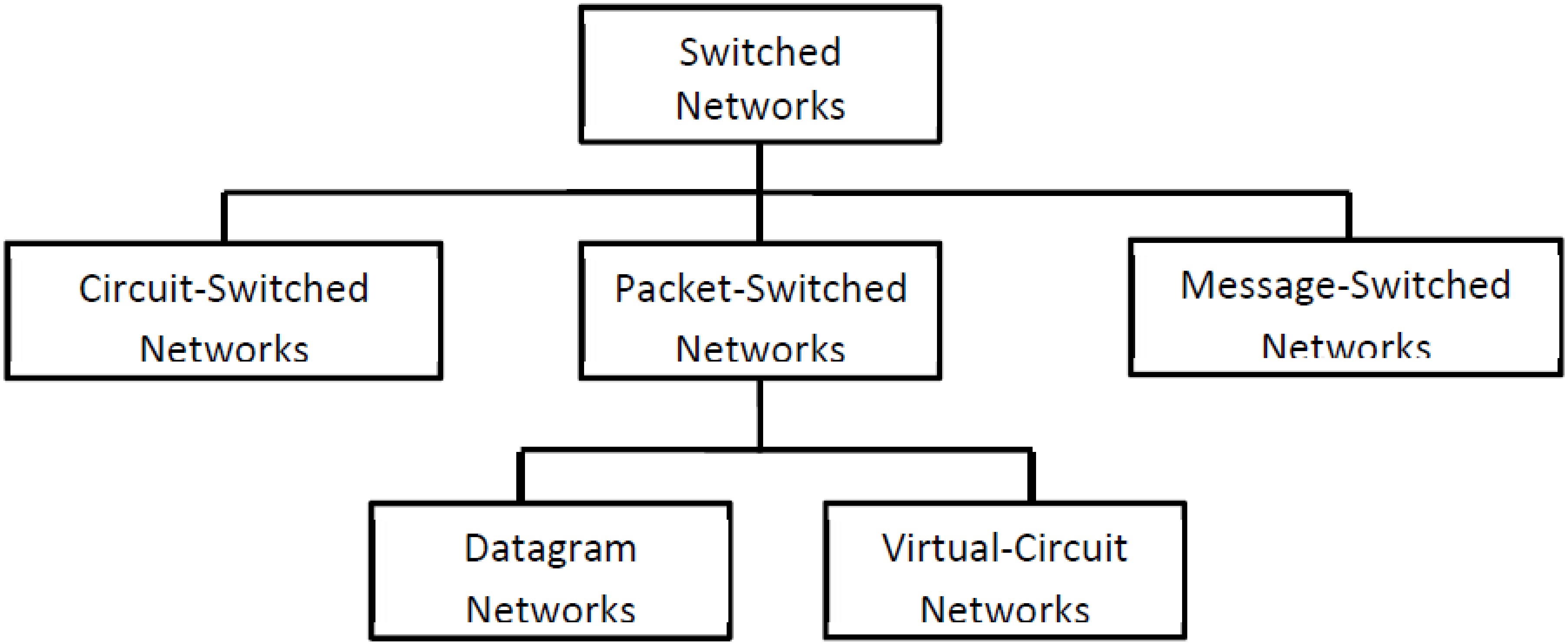
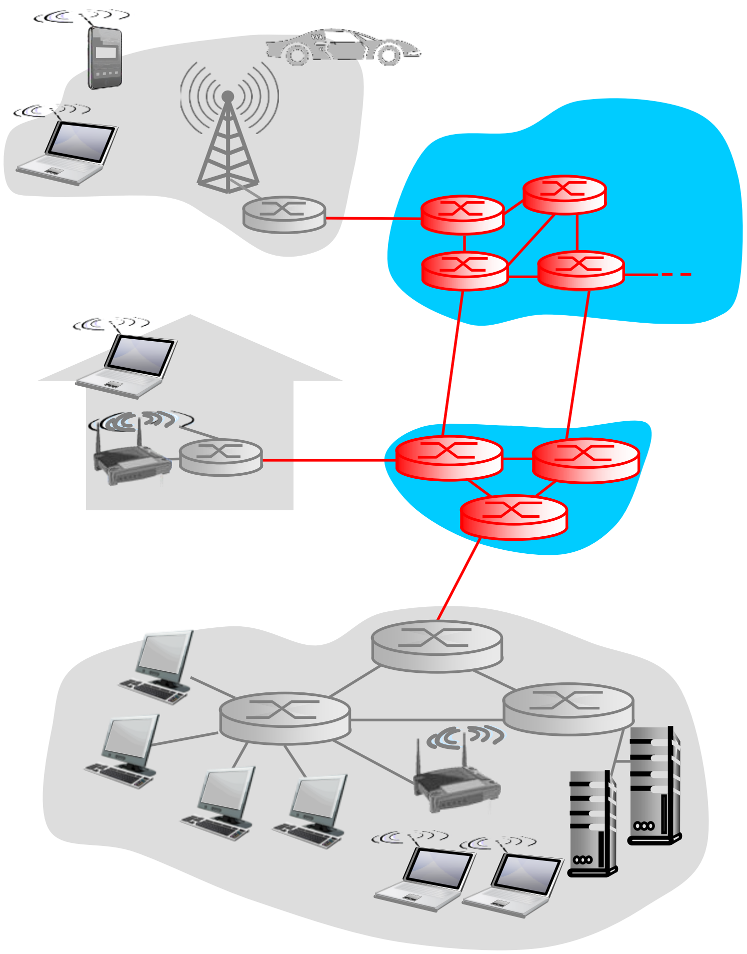
The network core

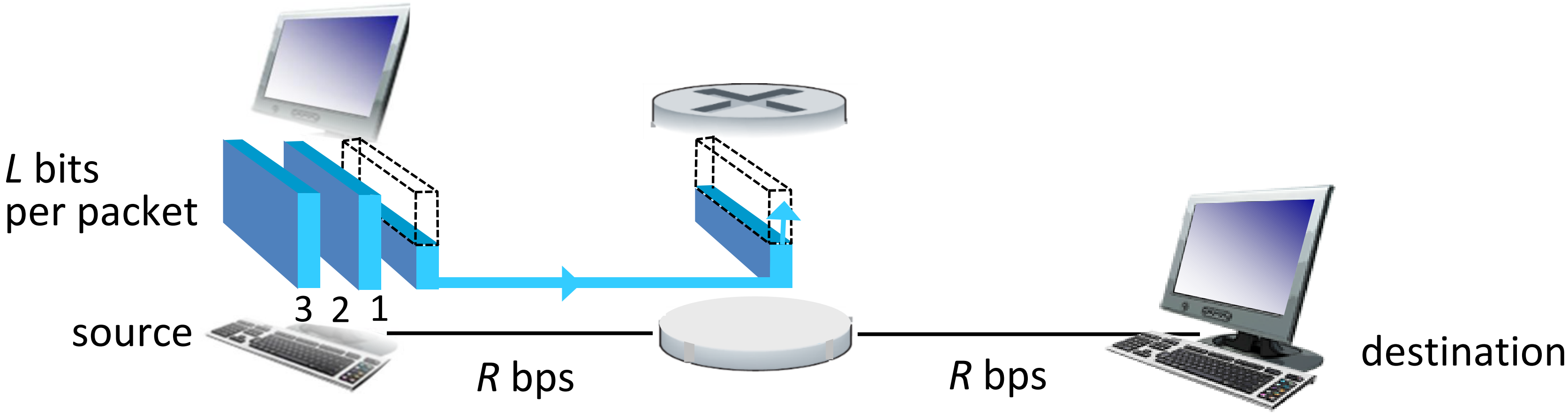


The network core

- 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



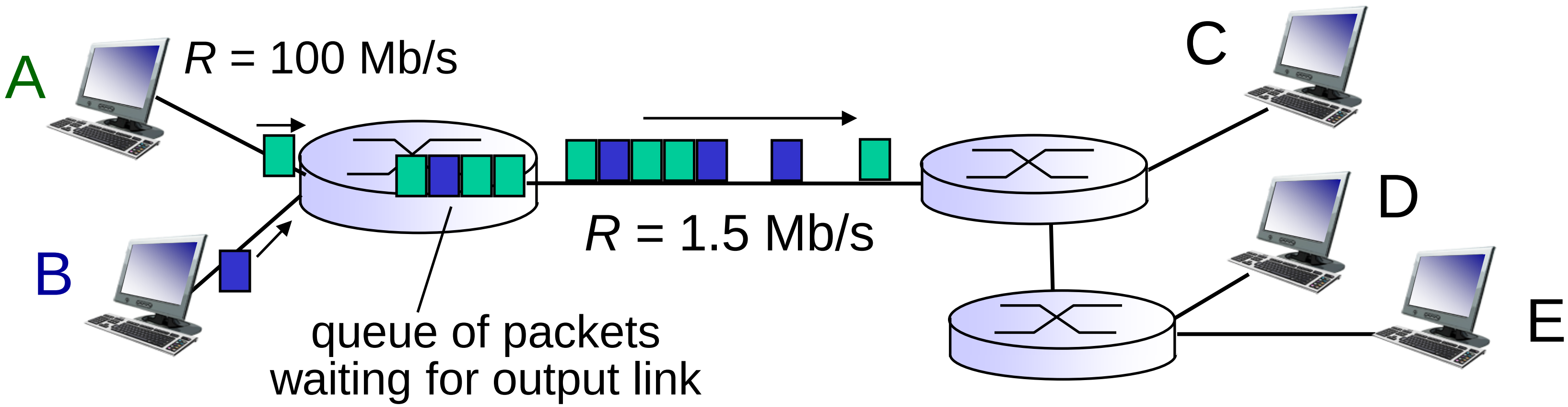
- takes *L/R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- end-end delay = 2*L/R* (assuming zero propagation delay)

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:

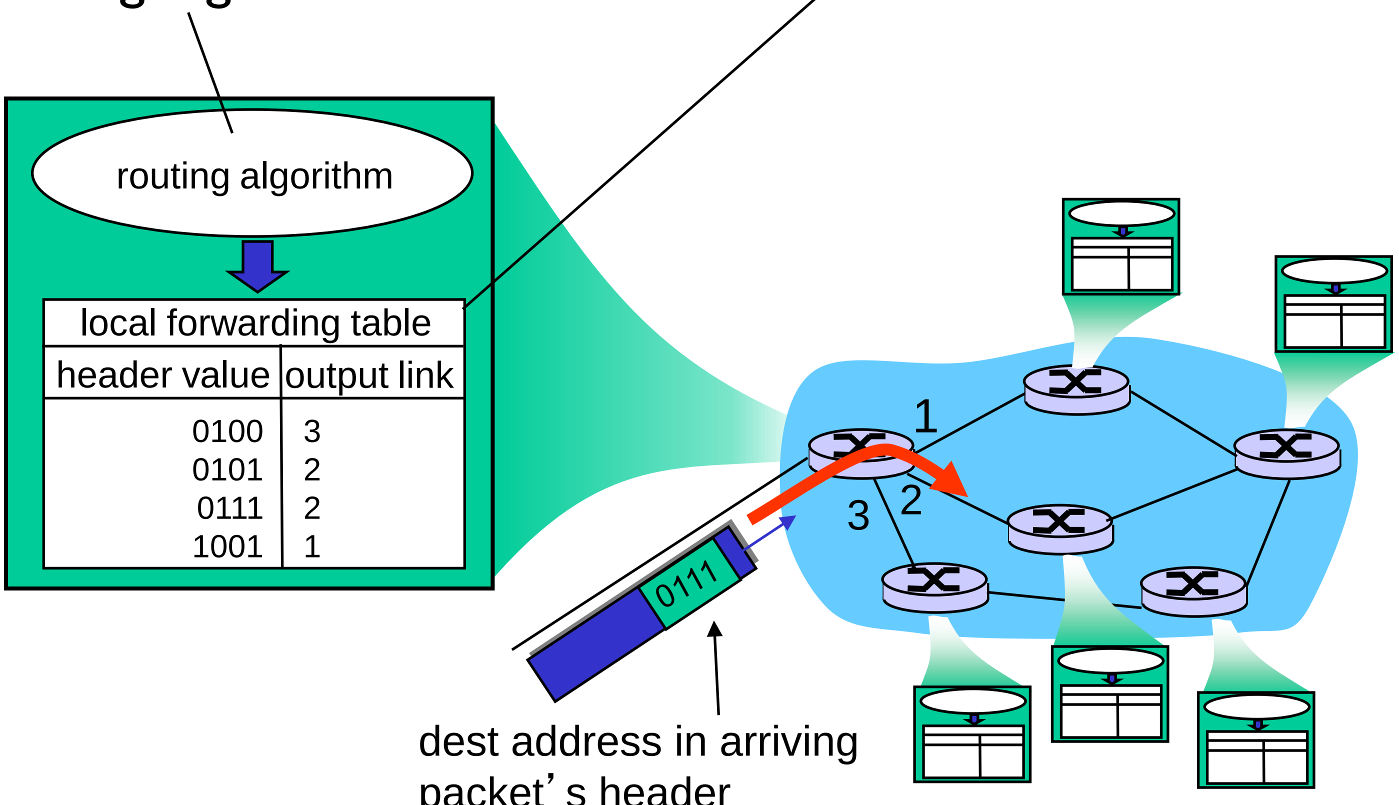
- If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

Two key network-core functions

routing: determines source-destination route taken by packets

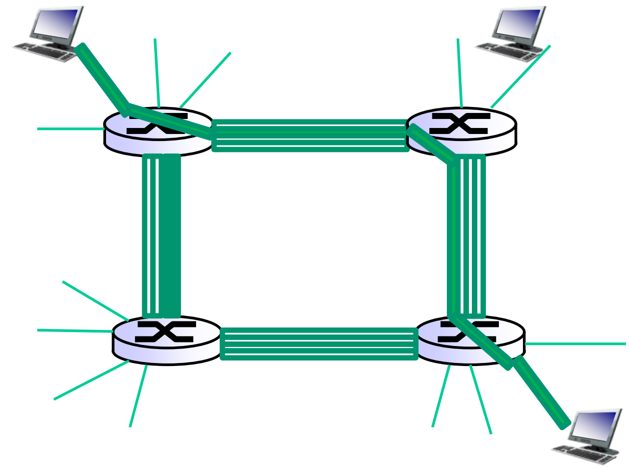
- *routing algorithms*

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

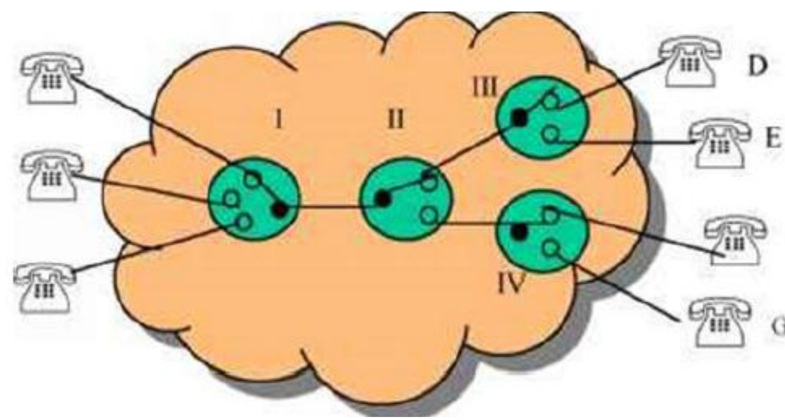


Alternative core: circuit switching

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



- In diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st 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

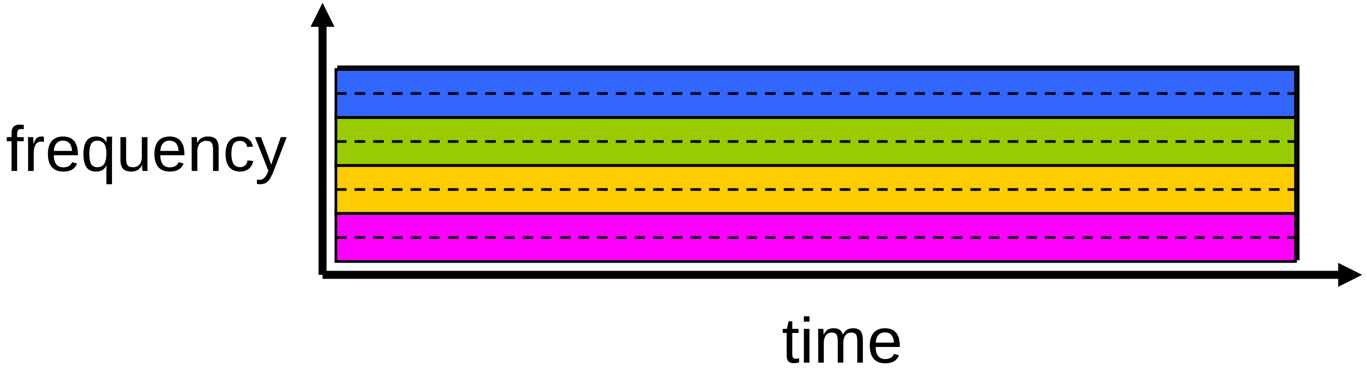


Circuit switching: FDM versus TDM

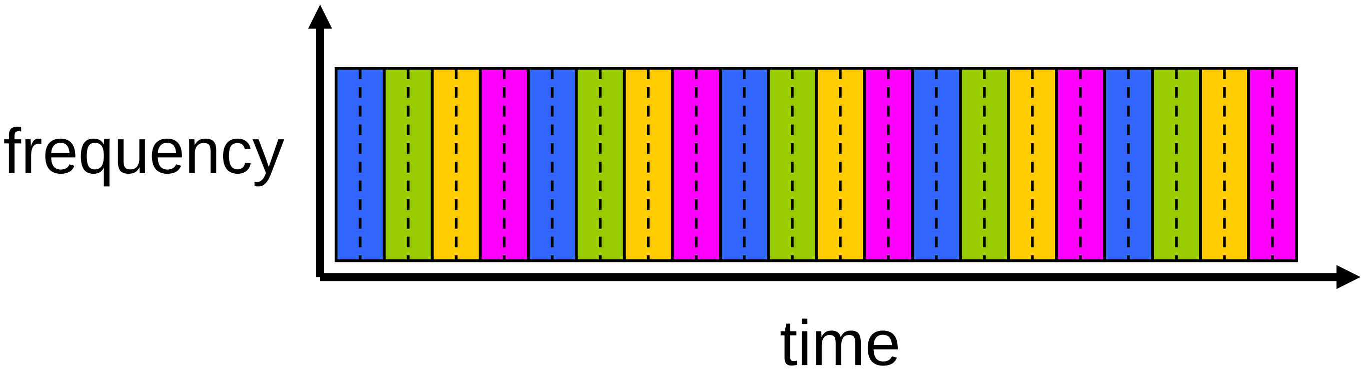
Example:

4 users

FDM



TDM



Packet switching versus circuit switching

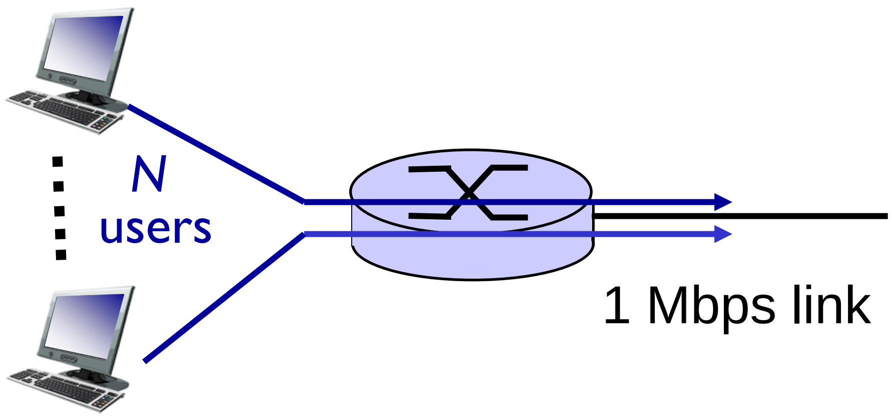
packet switching allows more users to use network!

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



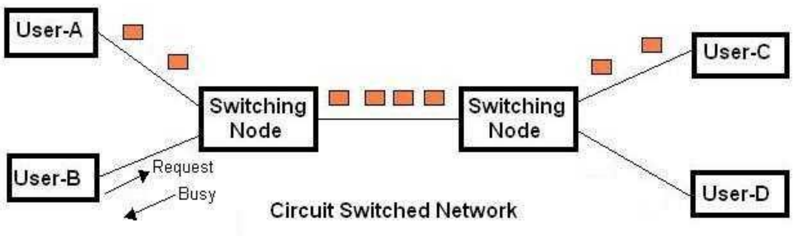
Packet switching versus circuit switching

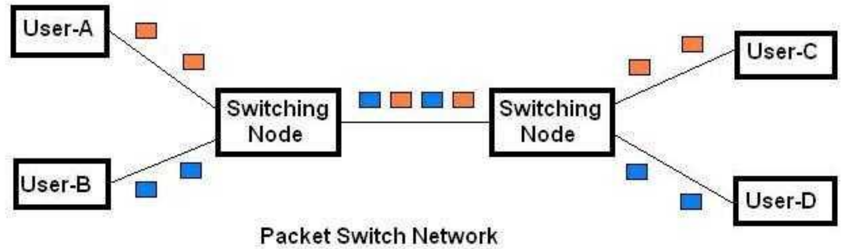
is packet switching a "slam dunk winner?"

- 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)?

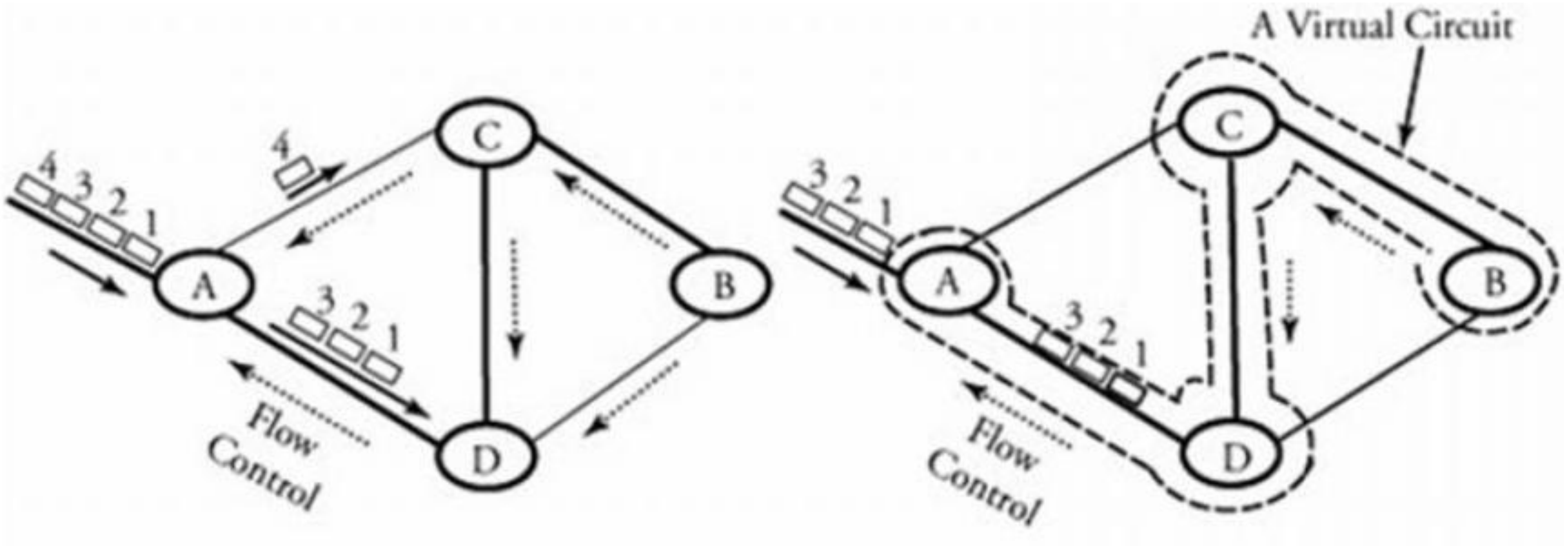
Packet switching versus circuit switching





Item	Circuit switched	Packet switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
Time of possible congestion	At setup time	On every packet
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Transparency	Yes	No
Charging	Per minute	Per packet

Connection-less versus Connection-oriented Networks



Connectionless Network

Connection-oriented Network

ex: UDP

1. Without Virtual Circuits (ex: TCP)
2. With Virtual Circuits (ex: X.25)

Connection-less versus Connection-oriented Networks

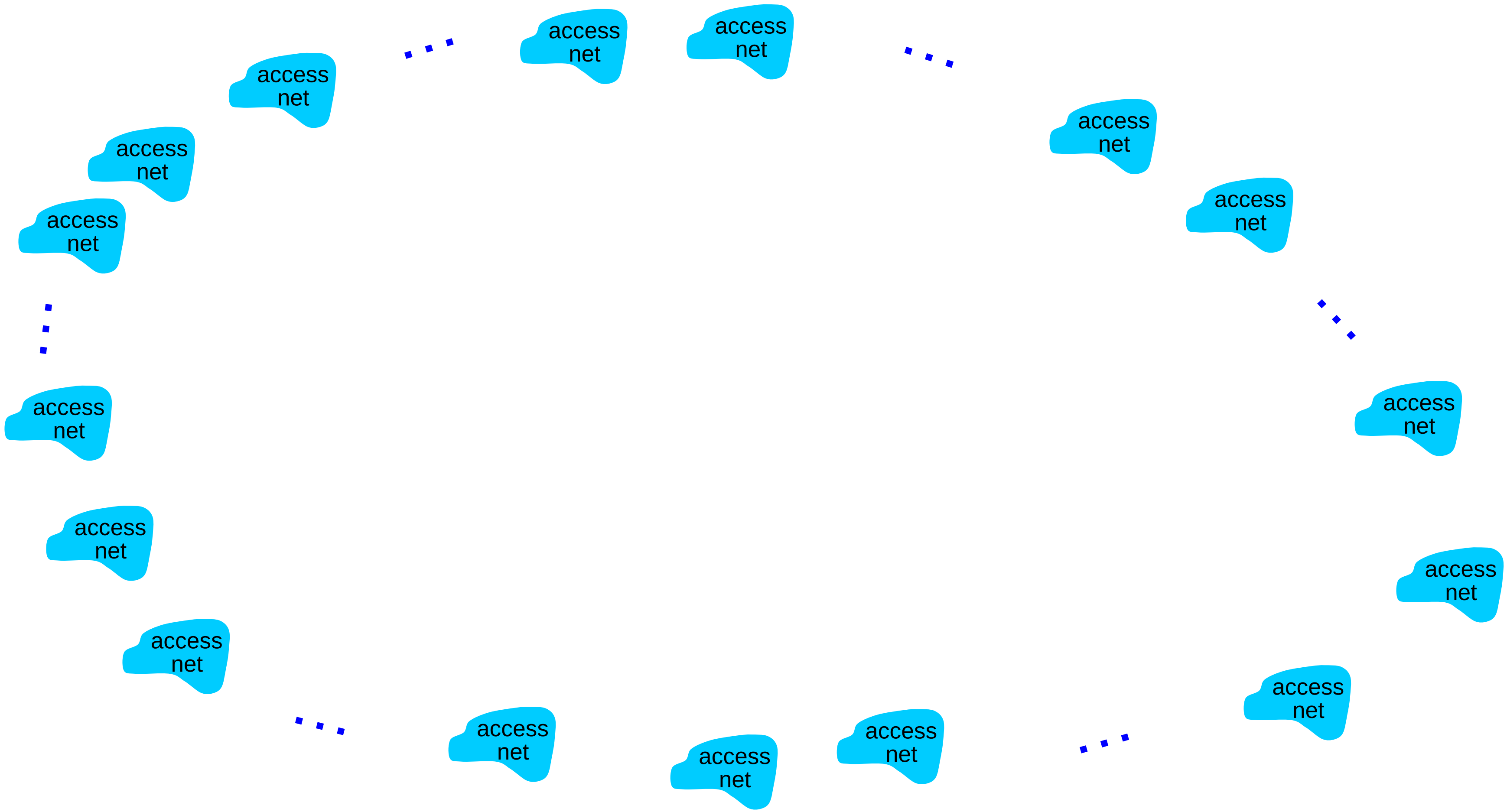
Feature	Connectionless	Connection-oriented
How is data sent?	one packet at a time	as continuous stream of packets
Do packets follow same route?	no	virtual circuit: yes without virtual circuit: no
Are resources reserved in network?	no	virtual circuit: yes without virtual circuit: no
Are resources reserved in communicating hosts?	no	yes
Is connection establishment done?	no	yes
Is state information stored at network nodes?	no	virtual circuit: yes without virtual circuit: no
What is impact of node/switch crash?	only packets at node are lost	all virtual circuits through node fail
What addressing information is needed on each packet?	full source and destination address	virtual circuit: a virtual circuit number without virtual circuit: full source and destination address

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

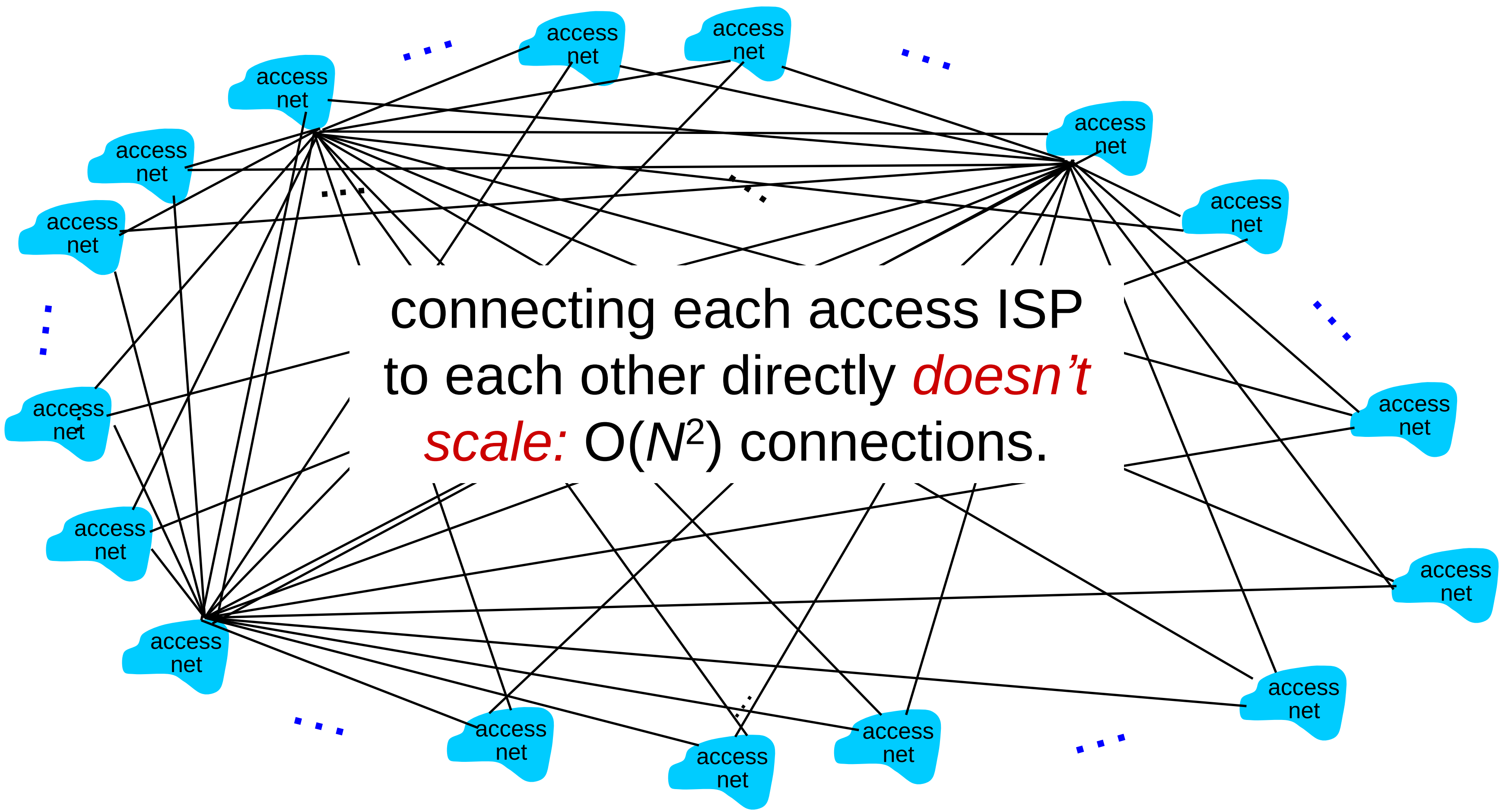
Internet structure: network of networks

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



Internet structure: network of networks

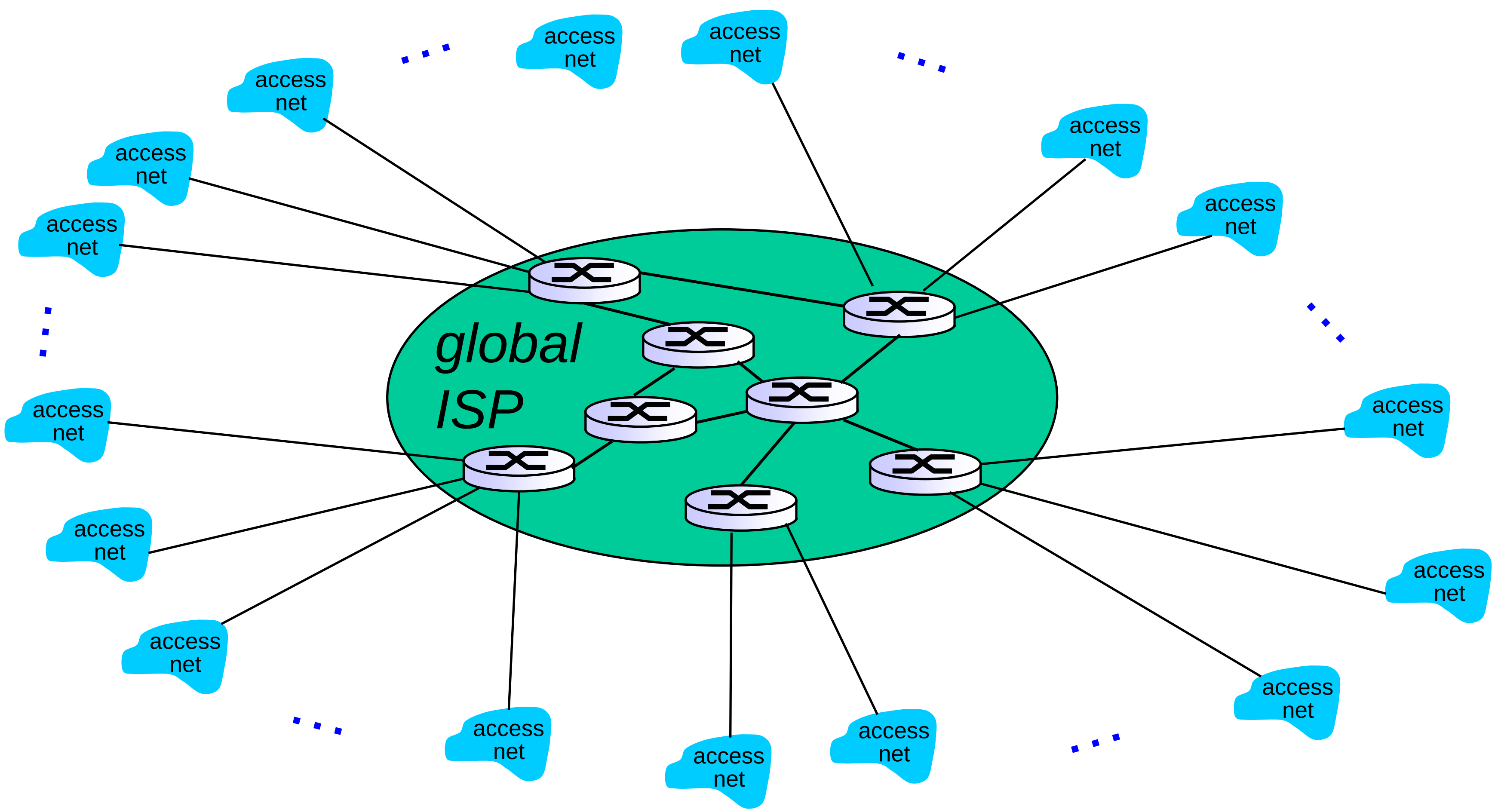
Option: connect each access ISP to every other access ISP?



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

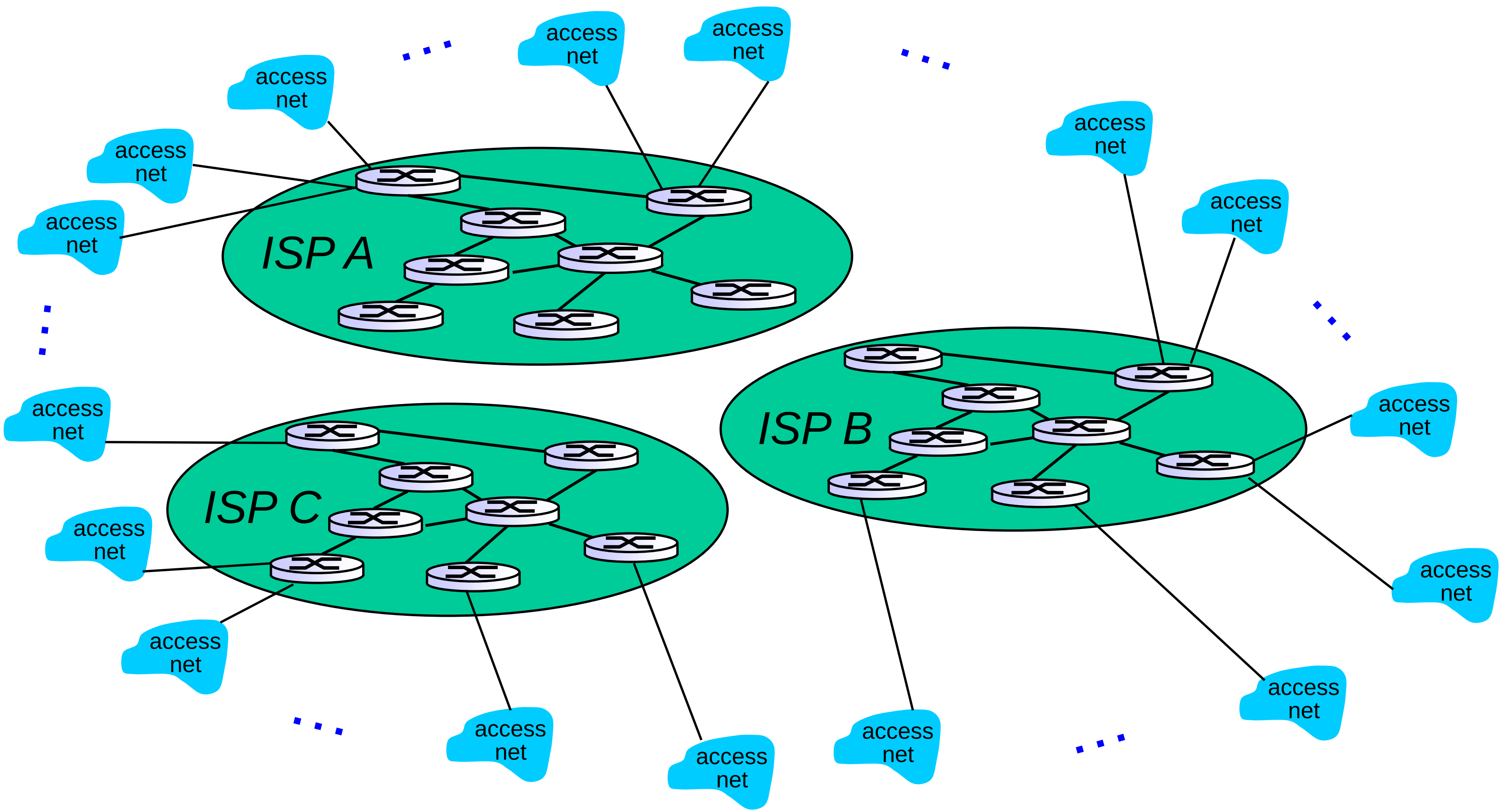
Internet structure: network of networks

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



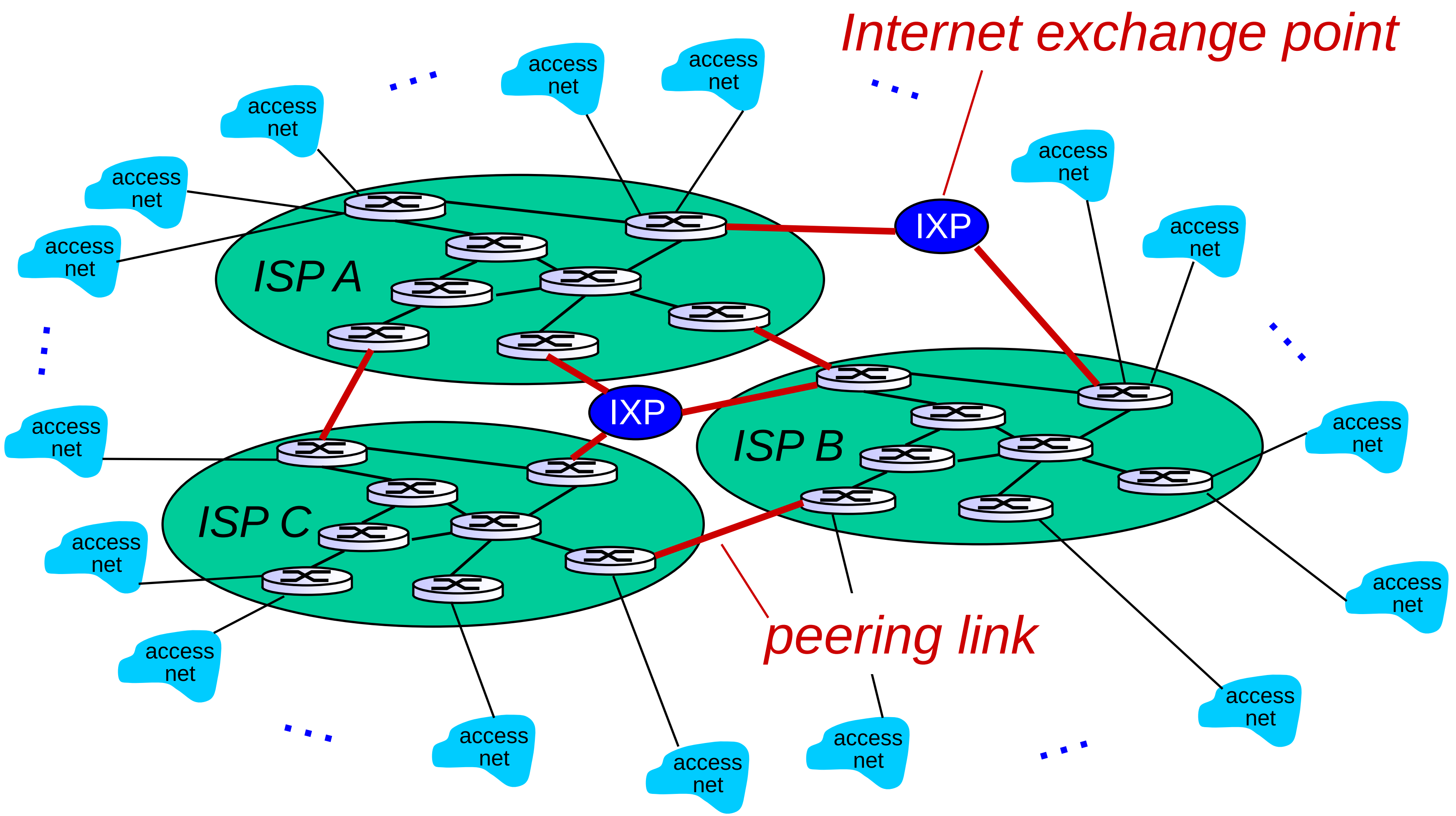
Internet structure: network of networks

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



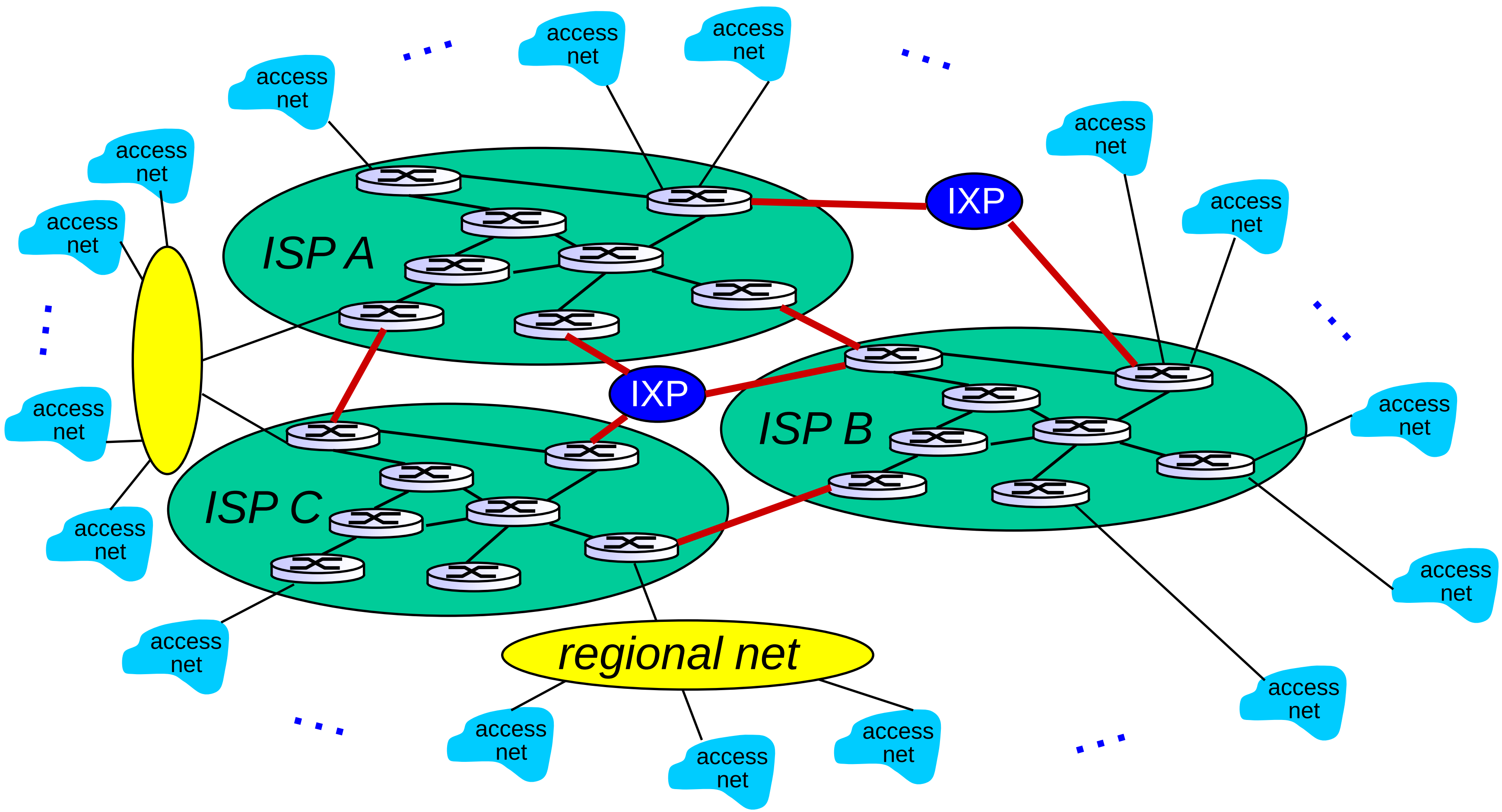
Internet structure: network of networks

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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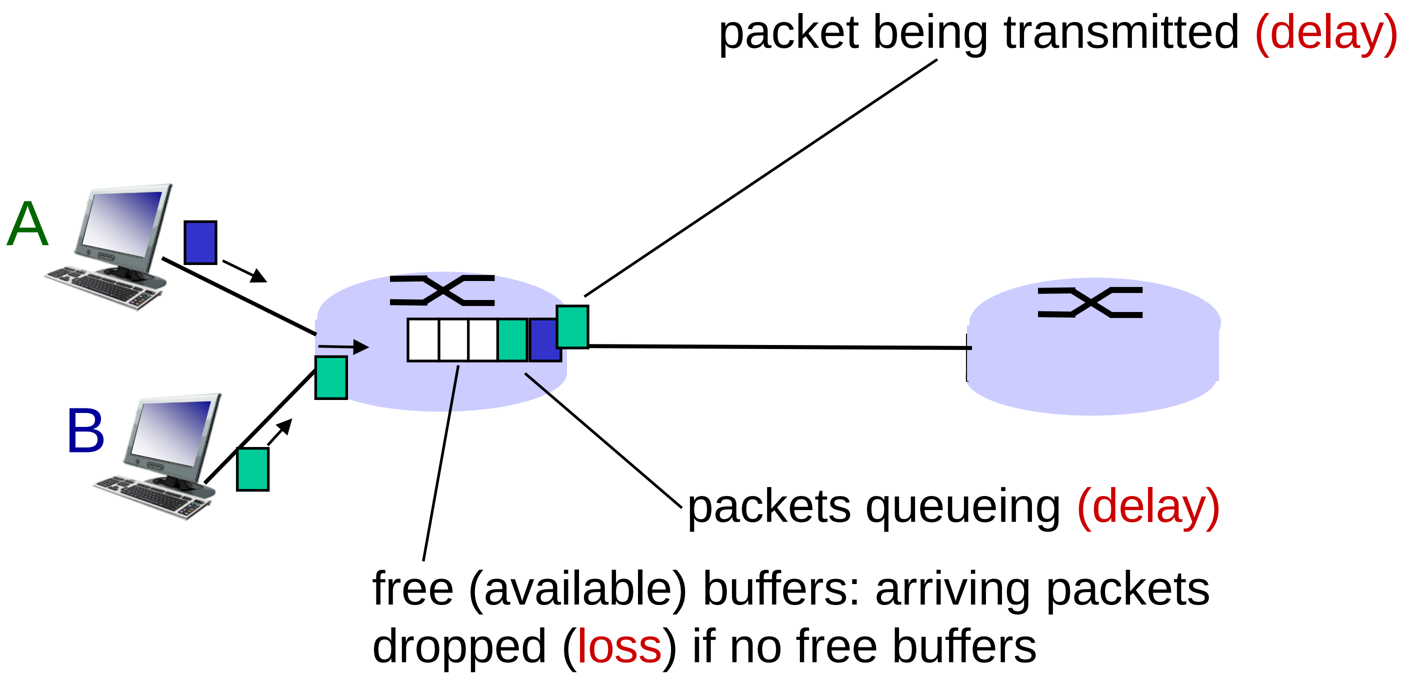
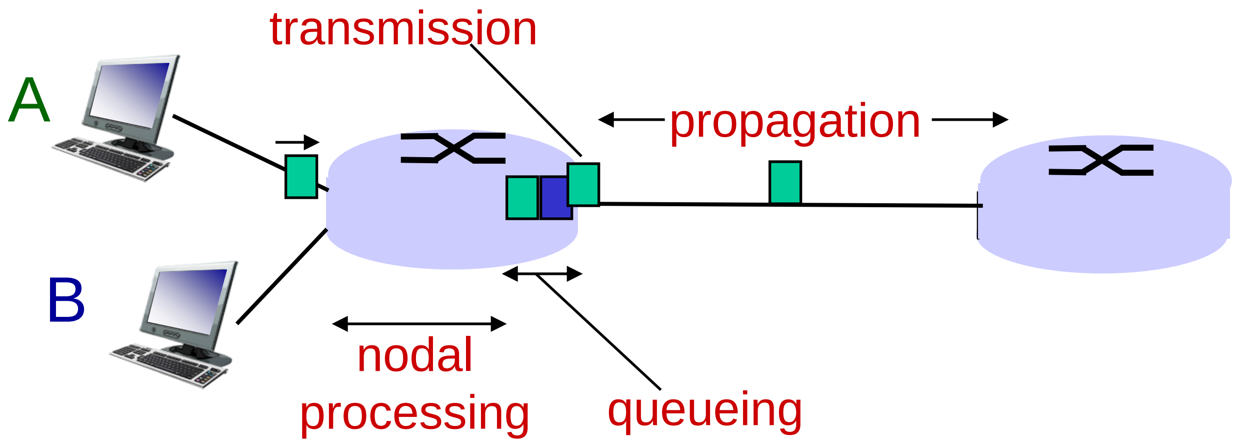
How do loss and delay occur?

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



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

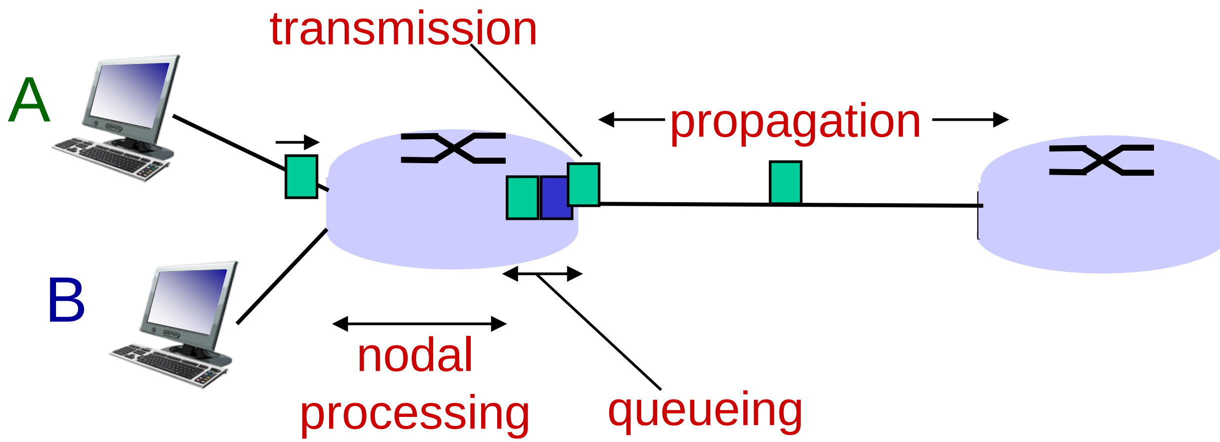
d_{proc}: nodal processing

- 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



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

d_{trans}: transmission delay:

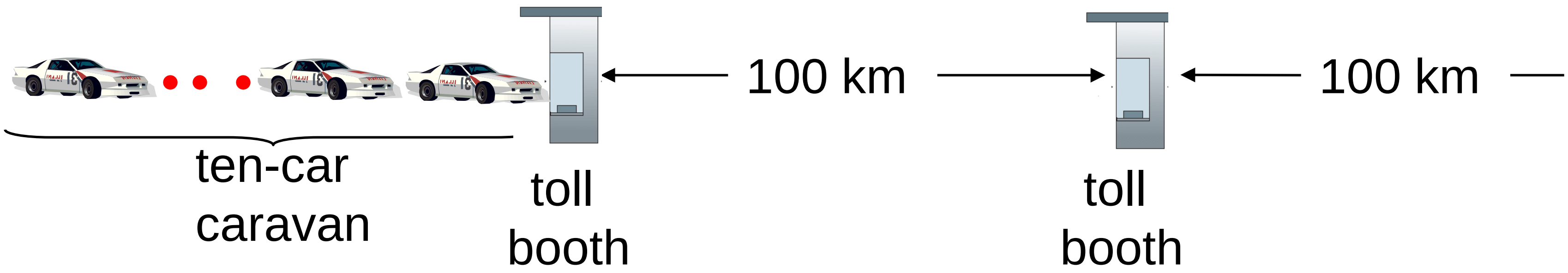
- *L*: packet length (bits)
- *R*: link *bandwidth (bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay:

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

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

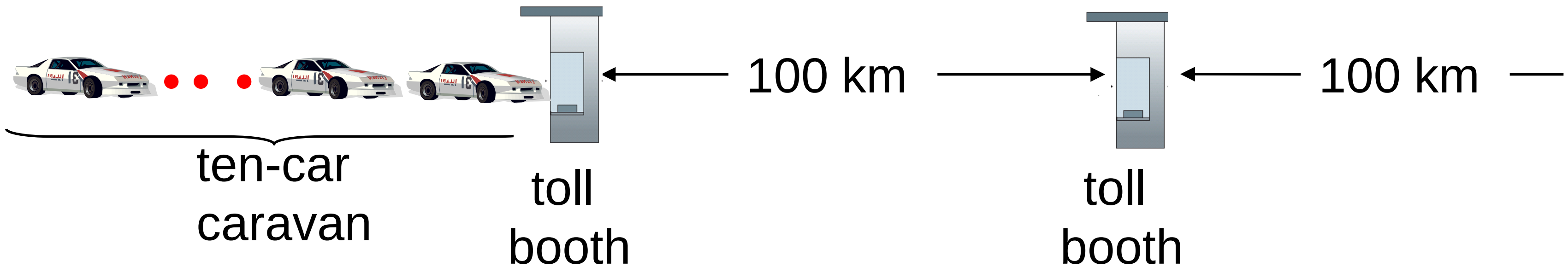
Caravan analogy



- 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?*

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

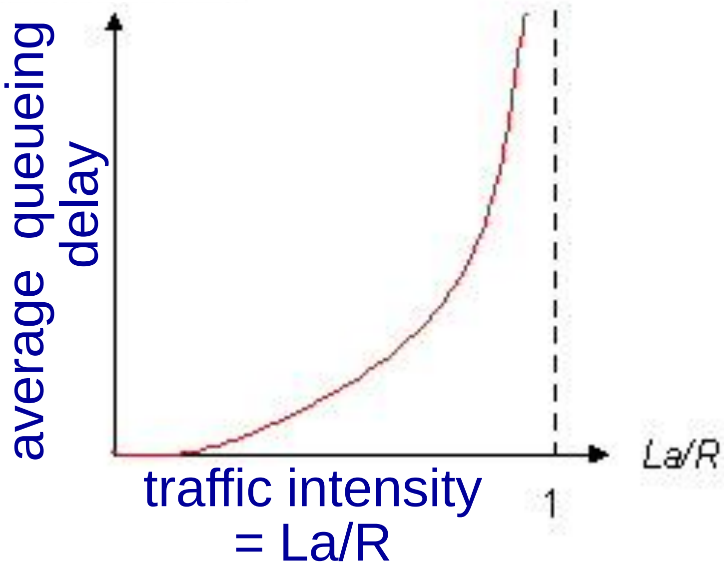
Caravan analogy (more)



- 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 (1 min + 6 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



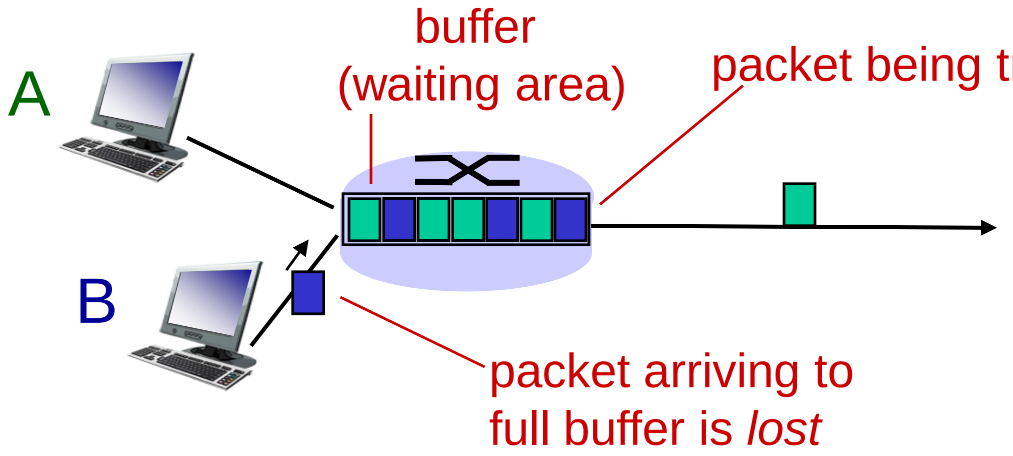
- *La/R* ~ 0: avg. queueing delay small
- *La/R* -> 1: avg. queueing delay large
- *La/R* > 1: more "work" arriving than can be serviced, average delay infinite!

La/R ~ 0

La/R -> 1

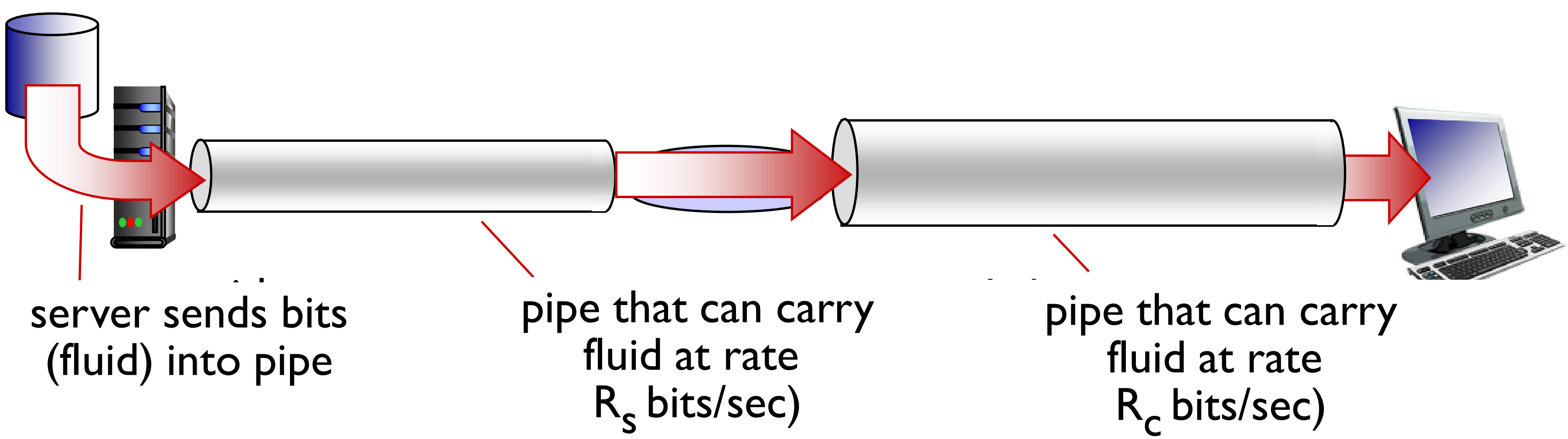
Packet loss

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



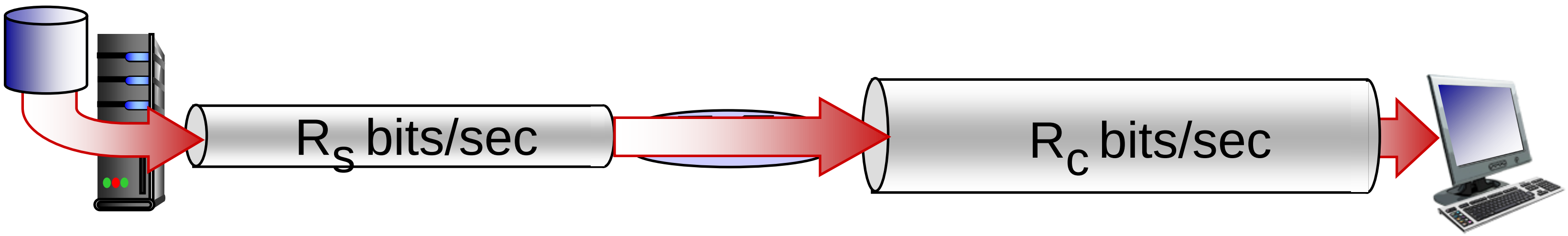
Throughput

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

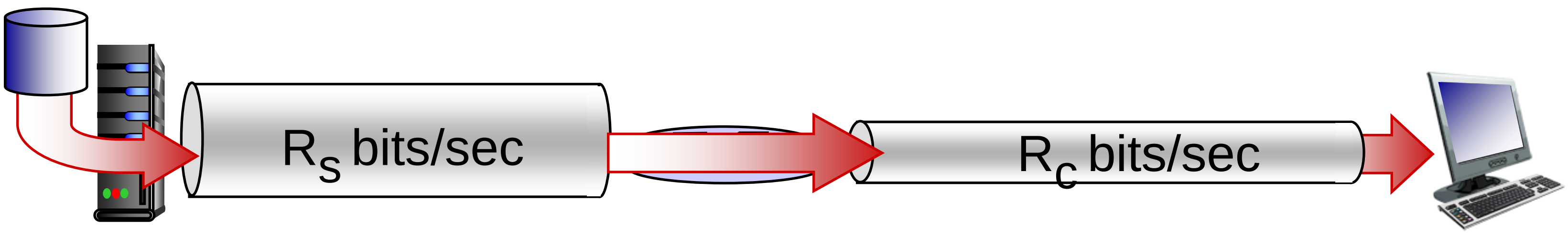


Throughput (more)

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



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

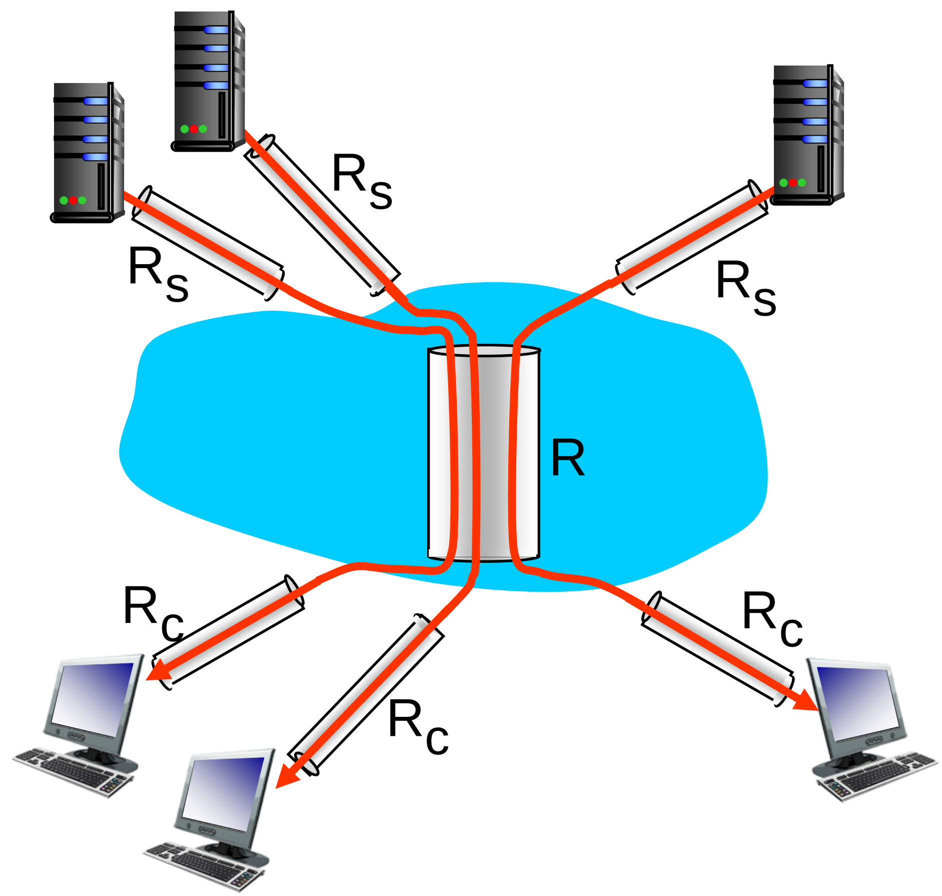


bottleneck link

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

Throughput: Internet scenario

- per-connection end-end throughput: $\min(R_c, R_s, R/10)$
- in practice: R_c or R_s is often bottleneck



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

Chapter 1: roadmap

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

1.7 history

Protocol "layers"

Networks are complex, with many "pieces":

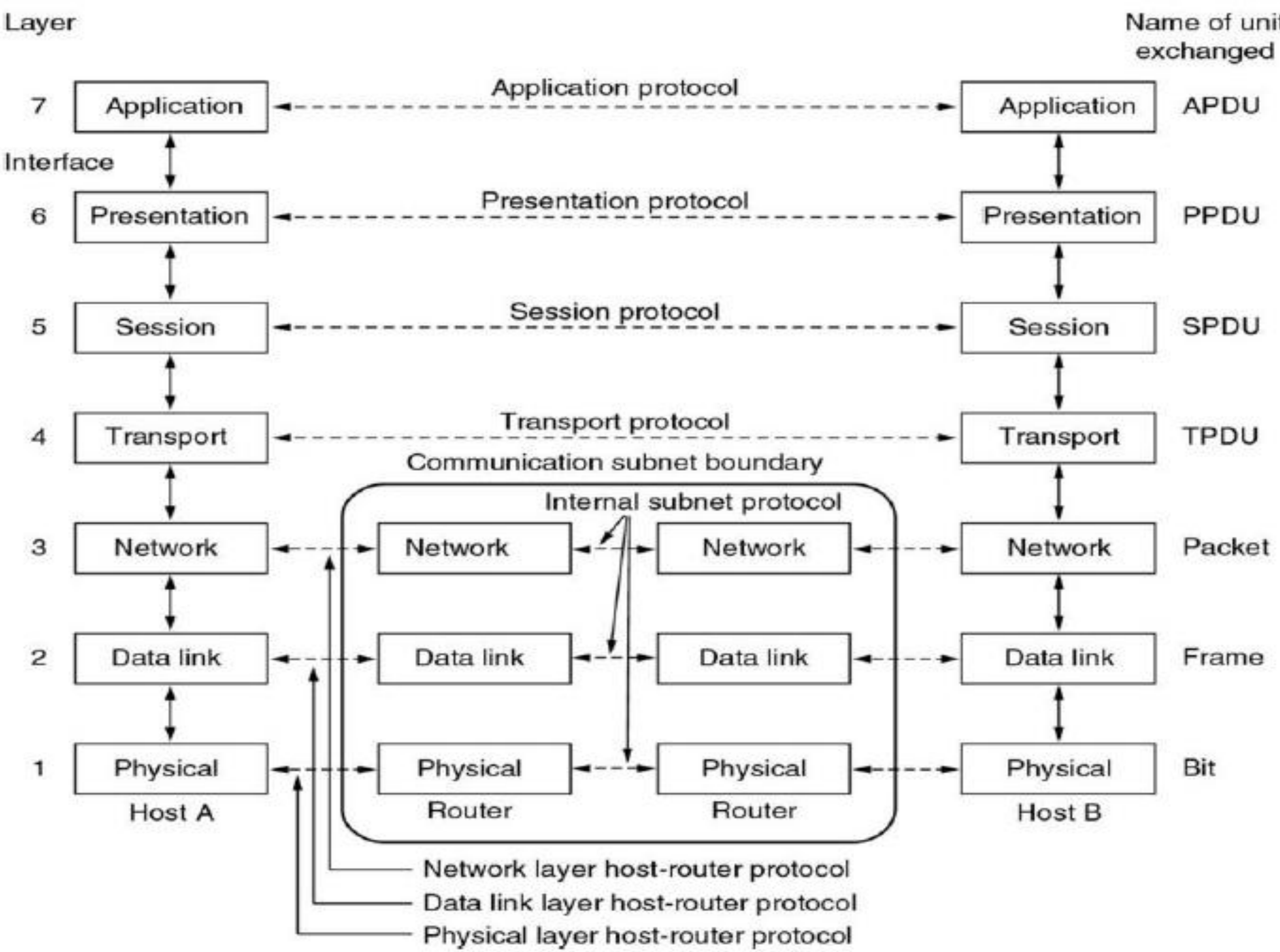
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

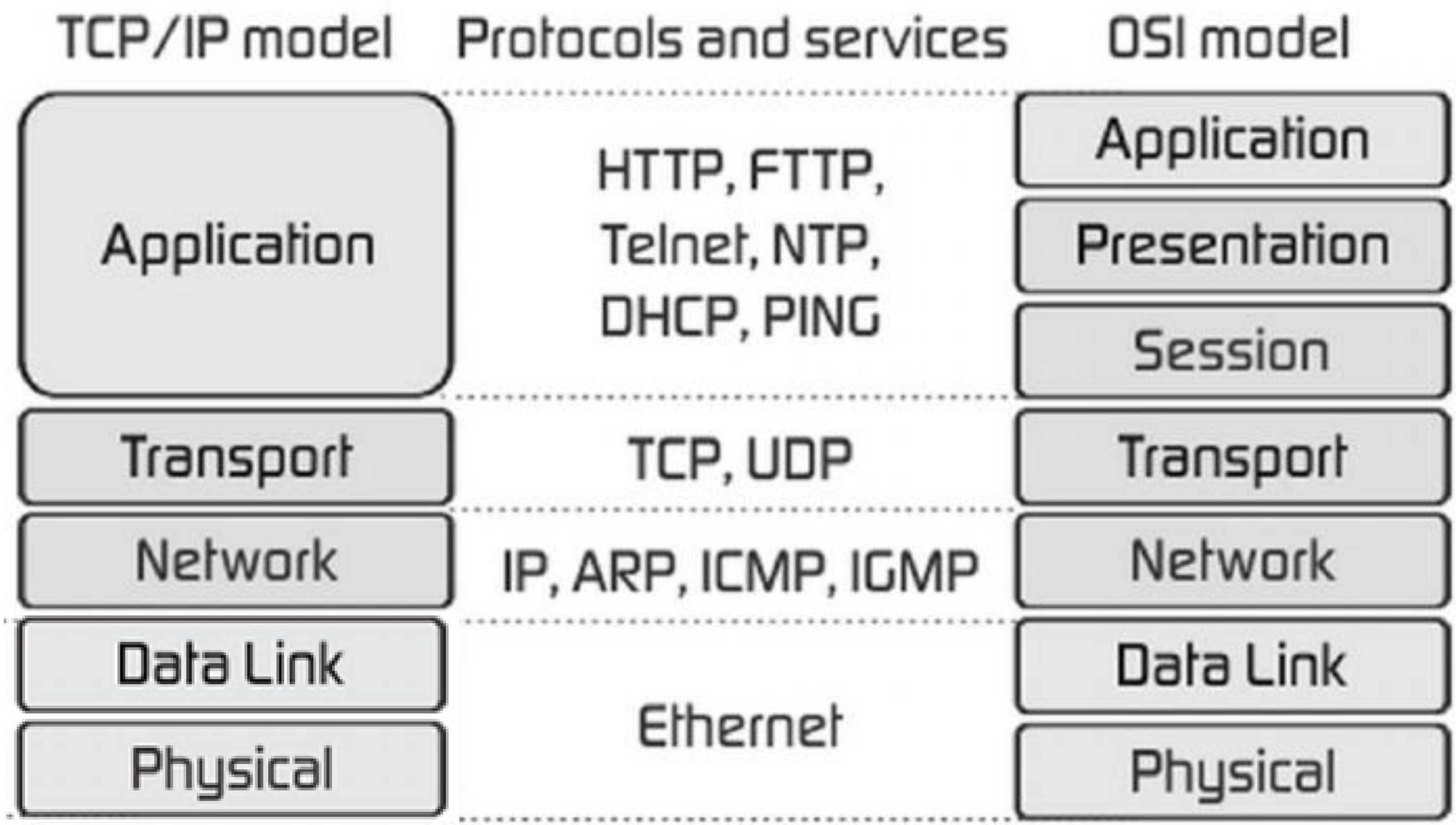
is there any hope of *organizing* structure of network?

…. or at least our discussion of networks?

ISO/OSI Reference Model



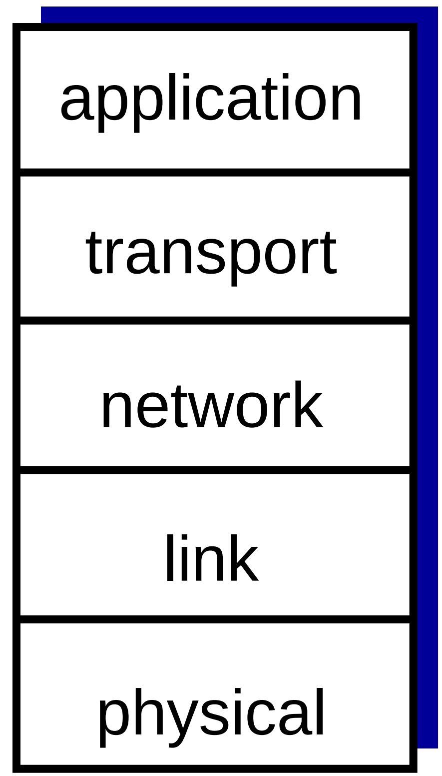
TCP/IP Reference Model



Internet Protocol Stack Layers

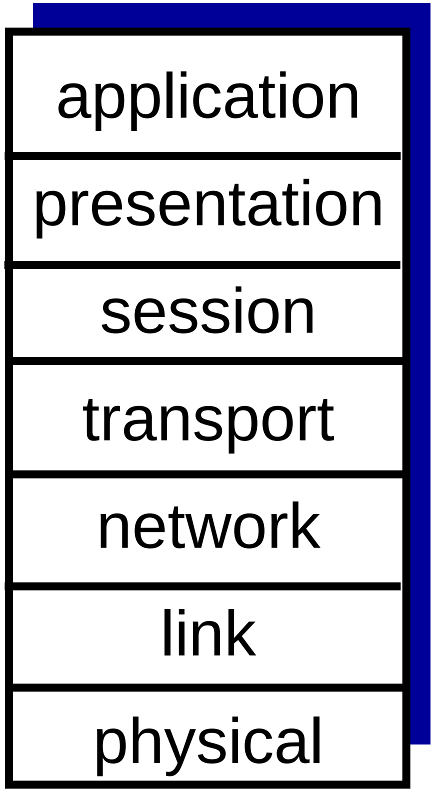
Internet protocol stack (TCP/IP)

- *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"

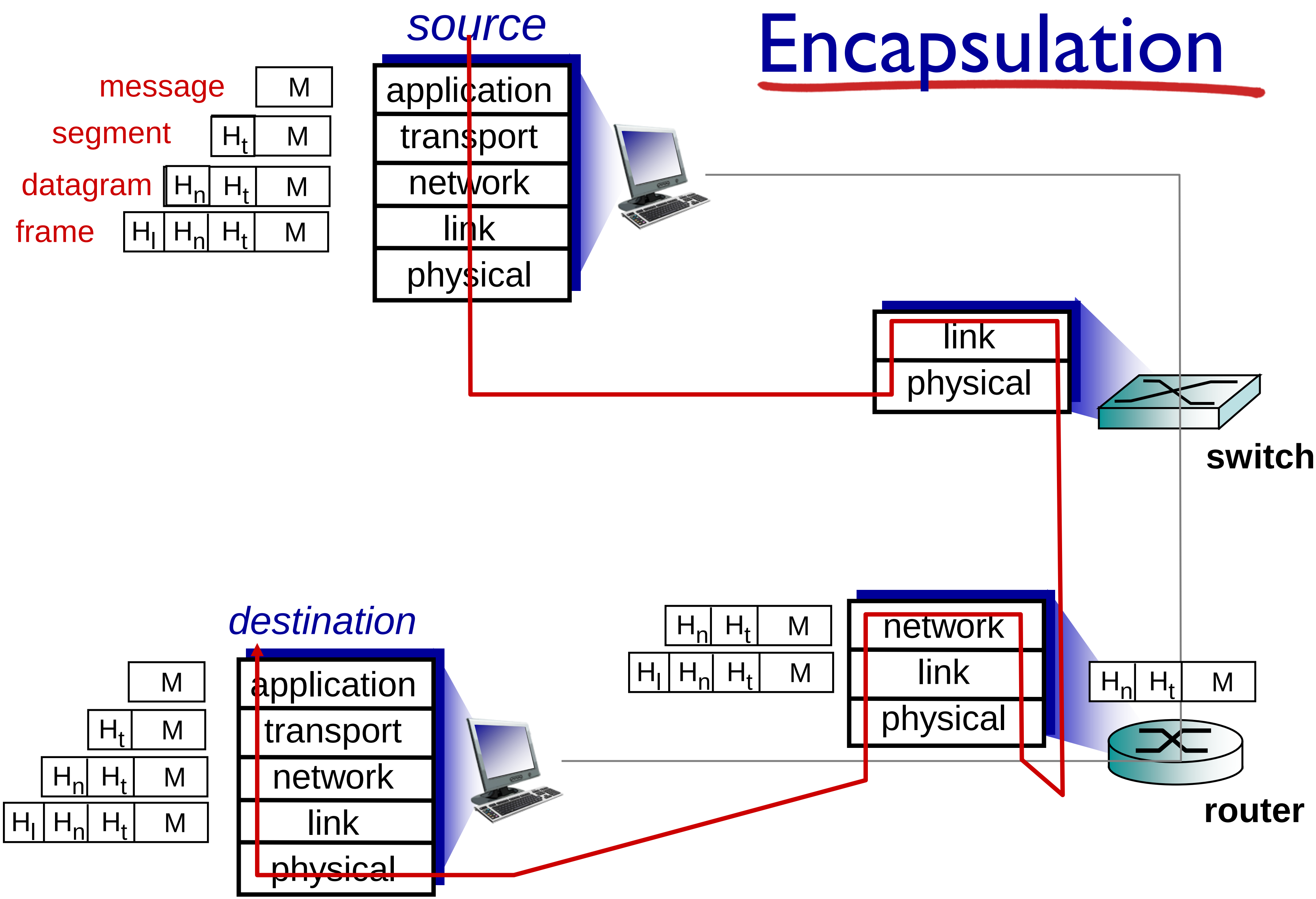


ISO/OSI reference model

- *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



Difference between OSI and TCP/IP Model

OSI(Open System Interconnection)	TCP/IP (Transmission Control Protocol/ Internet Protocol)
OSI provides layer functioning and also defines functions of all the layers.	TCP/IP model is more based on protocols and protocols are not flexible with other layers.
In OSI model the transport layer guarantees the delivery of packets	In TCP/IP model the transport layer does not guarantees delivery of packets.
Follows horizontal approach	Follows vertical approach.
OSI model has a separate presentation layer	TCP/IP doesn't have a separate presentation layer
OSI is a general model.	TCP/IP model cannot be used in any other application.
Network layer of OSI model provide both connection oriented and connectionless service.	The Network layer in TCP/IP model provides connectionless service.
OSI model has a problem of fitting the protocols in the model	TCP/IP model does not fit any protocol
Protocols are hidden in OSI model and are easily replaced as the technology changes.	In TCP/IP replacing protocol is not easy.
OSI model defines services, interfaces and protocols very clearly and makes clear distinction between them.	In TCP/IP it is not clearly separated its services, interfaces and protocols.
It has 7 layers	It has 4 layers

Chapter 1: roadmap

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1.5 protocol layers, service models

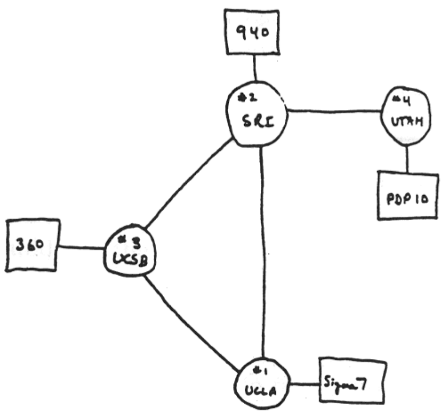
1.7 history

Internet history

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by **Advanced Research Projects Agency (ARPA)**
- 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)

Examples
Unit-1

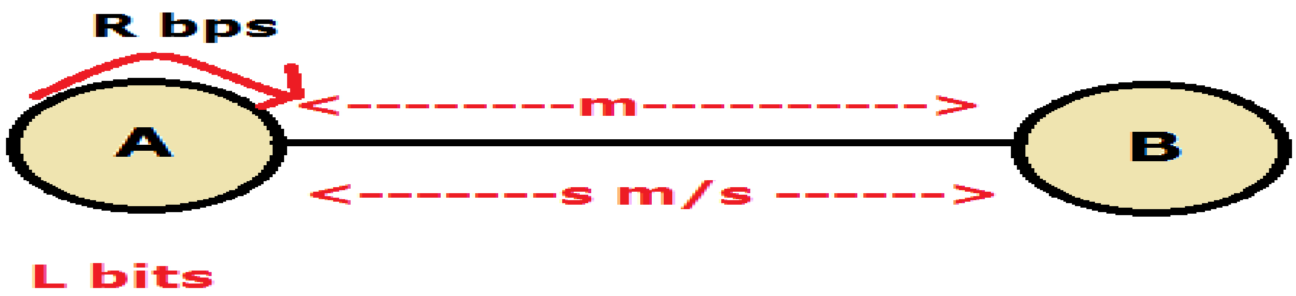
Example - 1

- How long does it take to send a file of 640,000 bits from host A to host B over a Circuit Switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

Answer:

- Each circuit has a transmission rate of (1.536 Mbps)/24
  1.536 X 1000000 = 15360000 / 24 = 64000 = 64 kbps
- So each circuit takes 640,000 bits / 64 kbps = 10 seconds to transmit a file.
- To this 10 seconds we add the circuit establishment time
  10 seconds + 500 msec = 10 + 0.5 = 10.5 seconds to send the file.

Example -2



Consider two hosts, A and B, Connected by a single link of Rate Rbps. Suppose that two hosts are separated by m meters and propagation speed along the link is s m/s . Host A is to send a packet of size L bits to Host B

A. Express propagation delay d_{prop} in terms of m and s.

B. Determine transmission delay d_{trans} in terms of L and R.

C. Obtain End to end Delay.

D. Suppose Host A start transmission at t = 0 at time t = d_{trans} where is last bit of packet.

E. If d_{prop} is greater than d_{trans} , at time t = d_{trans} , where is first bit of packet ?

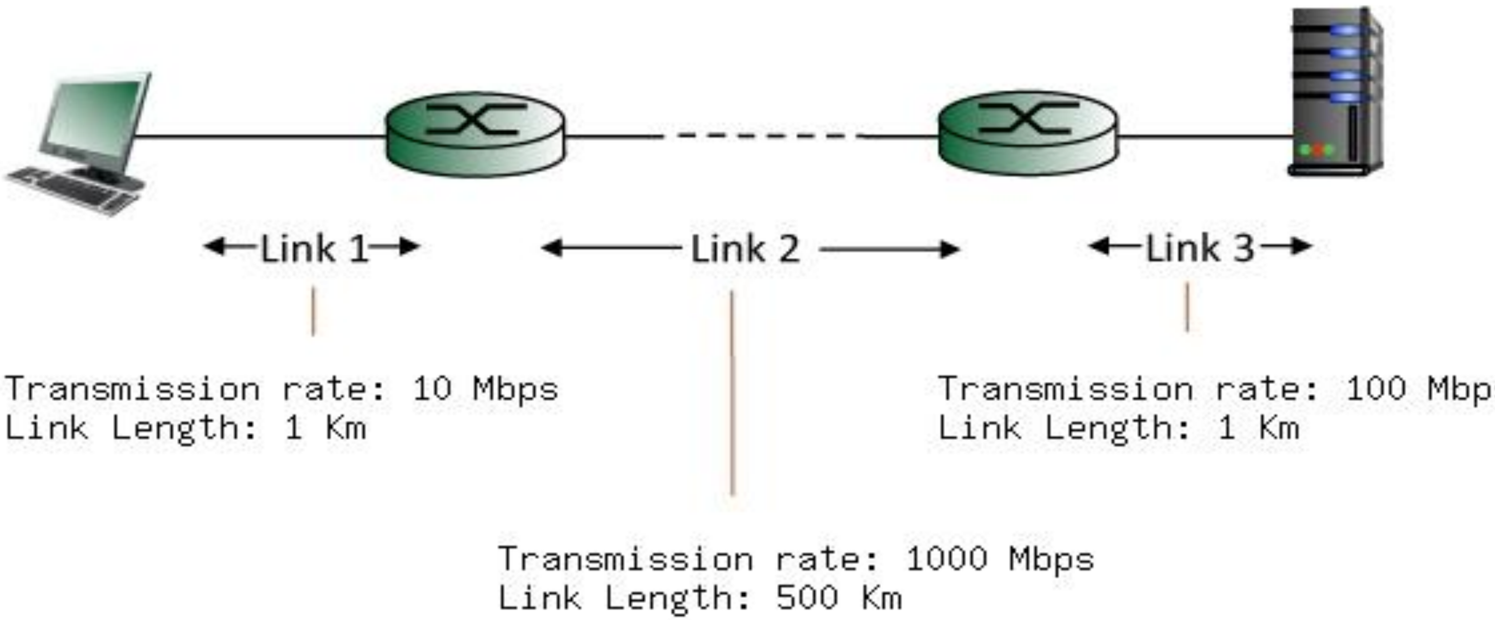
F. If d_{prop} is less than d_{trans} , at time t = d_{trans} , where is first bit of packet ?

G. If s = $2.5 * 10^8$, L = 120 bits and R = 56 Kbps , calc. distance m so that d_{prop} = $d_{trans.}$

Solutions

A. m/s
B. L/R
C. m/s + L/R
D. at starting of link between A to B
E. Somewhere on link
F. reached to B
G. m = Ls/R.

Example 3



- Find the end-to-end delay (including the transmission delays and propagation delays on each of the three links, but ignoring queuing delays and processing delays) from when the left host begins transmitting the first bit of a packet to the time when the last bit of that packet is received at the server at the right.
- The speed of light propagation delay on each link is 3×10^8 m/sec. Note that the transmission rates are in Mbps and the link distances are in Km. Assume a packet length of **16000** bits. Give your answer in milliseconds

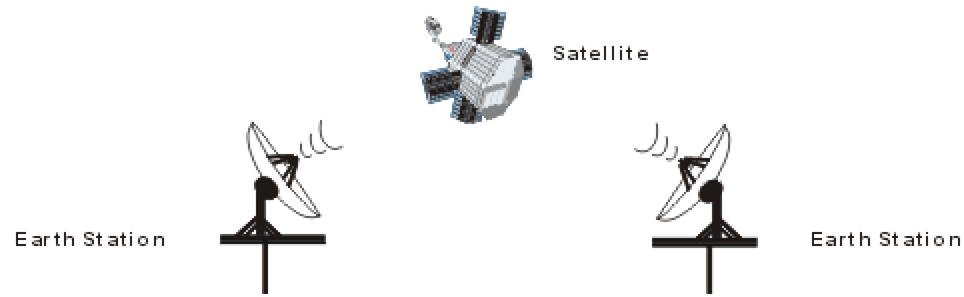
Solution

- Link 1 transmission delay = L/R = 16000 bits / 10 Mbps = 1.600000 msec.
- Link 1 propagation delay = d/s = 1 Km / $3*10^8$ m/sec = 0.003333 msec.
- Link 2 transmission delay = L/R = 16000 bits / 1000 Mbps = 0.016000 msec.
- Link 2 propagation delay = d/s = 500 Km / $3*10^8$ m/sec = 1.666667 msec.
- Link 3 transmission delay = L/R = 16000 bits / 100 Mbps = 0.160000 msec.
- Link 3 propagation delay = d/s = 1 Km / $3*10^8$ m/sec = 0.003333 msec.

Thus, the total end-to-end delay is the sum of these six delays: 3.449333 msecs.

Example 4

- Suppose there is a 10 Mbps microwave link between a geostationary satellite and its base station on Earth. Every minute the satellite takes a digital photo and sends it to the base station. Assume a propagation speed of $2.4 * 10^8$ meters/sec. The distance between earth and geostationary satellite approach to $3.6 \cdot 10^7$ m



a. What is the propagation delay of the link?

b. What is the bandwidth-delay product, $R \cdot Dprop$?

c. Let x denote the size of the photo. What is the minimum value of x for the microwave link to be continuously transmitting?

Solution

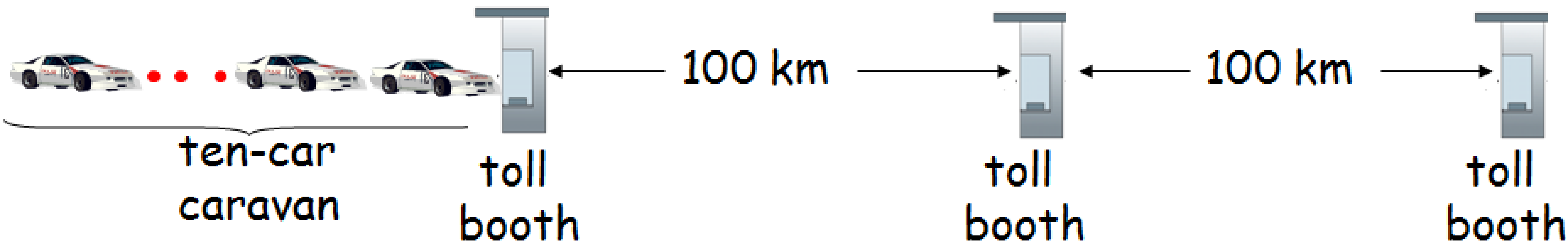
(a) $D_{prop} = d/s = 3.6 \cdot 10^7 / (2.4 \cdot 10^8) = 0.15$ s

(b) $R \cdot D_{prop} = 10^7 \cdot 0.15 = 1.5 \cdot 10^6$ bits

(c) $X = 10^7 \cdot 60 = 6 \cdot 10^8$ bits (every minute)

Example 5

- Consider an Highway which is having tollbooth at every 100 kilometer. Propagation speed of highway is 100 km/hr.
- Assume there is one caravan of prime minister which is having 10 cars. First car arrived at a tollbooth will wait for next 9. Tollbooth service capacity is 1 car per 12 second. Assume, though its prime minister caravan, there is no extra vehicle on highway.



A. Suppose caravan travels 200 km. beginning in front of one tollbooth, passing through a second tollbooth, and finishing just after 3rd tollbooth service. What is end-to-end delay?

B. Repeat (a), assume that 3 car of prime minister caravan is having fuel problem, that's why only 7 cars are travelling.

SOLUTION

- Tollbooths are 100 km apart, and the cars propagate at 100km/hr. A tollbooth services a car at a rate of one car every 12 seconds.

(a) There are ten cars. It takes 120 seconds, or 2 minutes, for the first tollbooth to service the 10 cars. Each of these cars has a propagation delay of 60 minutes (travel 100 km) before arriving at the second tollbooth. Thus, all the cars are lined up before the second tollbooth after 62 minutes. The whole process repeats itself for traveling between the second and third tollbooths. It also takes 2 minutes for the third tollbooth to service the 10 cars. Thus the total delay is 124 minutes.

(b) Delay between tollbooths is 7*12 seconds plus 60 minutes, i.e., 61 minutes and 24 seconds. The total delay is twice this amount plus 7*12 seconds, i.e., 122 minutes and 48seconds.

Examples 6

- **Suppose that two hosts A and B are separated by 10,000 km and are connected by direct link of R = 1 Mbps. Suppose propagation speed s over link is 2.5 * 10^8 meter/second.**

a. Calculate bandwidth delay product, R * propagation delay.
b. Consider sending a file of 400,000 bits from host A to B. File sanded continuously as a large message. What is maximum number of bits that will be in the link at any given time?
c. Define bandwidth delay product.
d. What is width of bit on the link?
e. Give expression for calculating width of bit in term of s,m,R.

Solutions

- A) $R*d_{prop}$ = R* (d/s) = 1Mbps* (10000km/2.5*10^8) = 40000
- B) 40000 (same as a.)
- C) The bandwidth-delay product of a link is the maximum

  number of bits that can be in the link.
- D) width of a bit = size of link / bandwidth delay product.

  = 10000 km / 40000 = 250
- E) s/R

Examples 7

- How long does it take a packet of length 1,000 bytes to propagate over a link of distance 2,500 km, propagation speed $2.5 \cdot 10^8$ m/s, and transmission rate 2 Mbps? More generally, how long does it take a packet of length L to propagate over a link of distance d, propagation speed s, and transmission rate R bps? Does this delay depend on packet length? Does this delay depend on transmission rate?

Answer 1: d/s = 2500km / $2.5 \cdot 10^8$ m/s = $2.5 \cdot 10^6 / 2.5 \cdot 10^8$ seconds

= 10^{-2} seconds = 10 msec

Answer 2: d/s

Answer 3: No

Answer 4: No

Examples 8

- Suppose Host A wants to send a large file to Host B. The path from Host A to Host B has three links, of rates R1 = 500 kbps, R2 = 2 Mbps, and R3 = 1 Mbps.

  a) Assuming no other traffic in the network, what is the throughput for the file transfer.

  b) Suppose the file is 4 million bytes. Dividing the file size by the throughput, roughly how long will it take to transfer the file to Host B?

  c) Repeat (a) and (b), but now with R2 reduced to 100 kbps.

Answer a) : 500 kbps (min of R1, R2, R3)

Answer b) : 64 seconds ($4 \times 10^6 \times 8$ bits / 500×10^3 bps)

Answer c) : 100 kbps ; 320 seconds

GTU Questions

Explain following terms: **08**

1) Processing Delay
2) Queuing Delay
3) Transmission Delay
4) Propagation Delay

(a) Draw the layered architecture of OSI reference model and write the at least two services provided by each layer of the model. **06**

1 For n devices in a network, what is the number of cable links required for a mesh topology?

2 __________ layer of OSI is responsible for process to process communication.

3 Source to Destination delivery of packet is responsibility of _________ layer.

Define: Protocol.

Which layer of OSI is responsible for physical addressing?

(a) What is topology? Explain star topology in brief. **03**

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network? **04**

$$\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2 \text{ Mbps}$$

The throughput is almost one-fifth of the bandwidth in this case.

(a) What is network? Explain in brief about LAN and MAN. 03

(b) Explain following terms: 04

i. Processing Delay

ii. Transmission Delay

(c) Draw the layered architecture of TCP/IP model and write at least two services provided by each layer of the model. 07

(a) What are the five layers in the Internet protocol stack? What are the principal responsibilities of each of these layers? 06

(b) Explain following terms: 06

1) Processing Delay
2) Transmission Delay
3) Propagation Delay

(a) Explain the working of Packet switched networks. 03

(b) What is DoS attack? Explain with categories. 04

(c) Differentiate IP stack and OSI reference model. 07

OR

(c) How encapsulation is helpful in data transmission? Explain with example on layered architecture of computer networks. 07

(a) What is client-server architecture? Discuss its merits and demerits. 03

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