Chapter 1

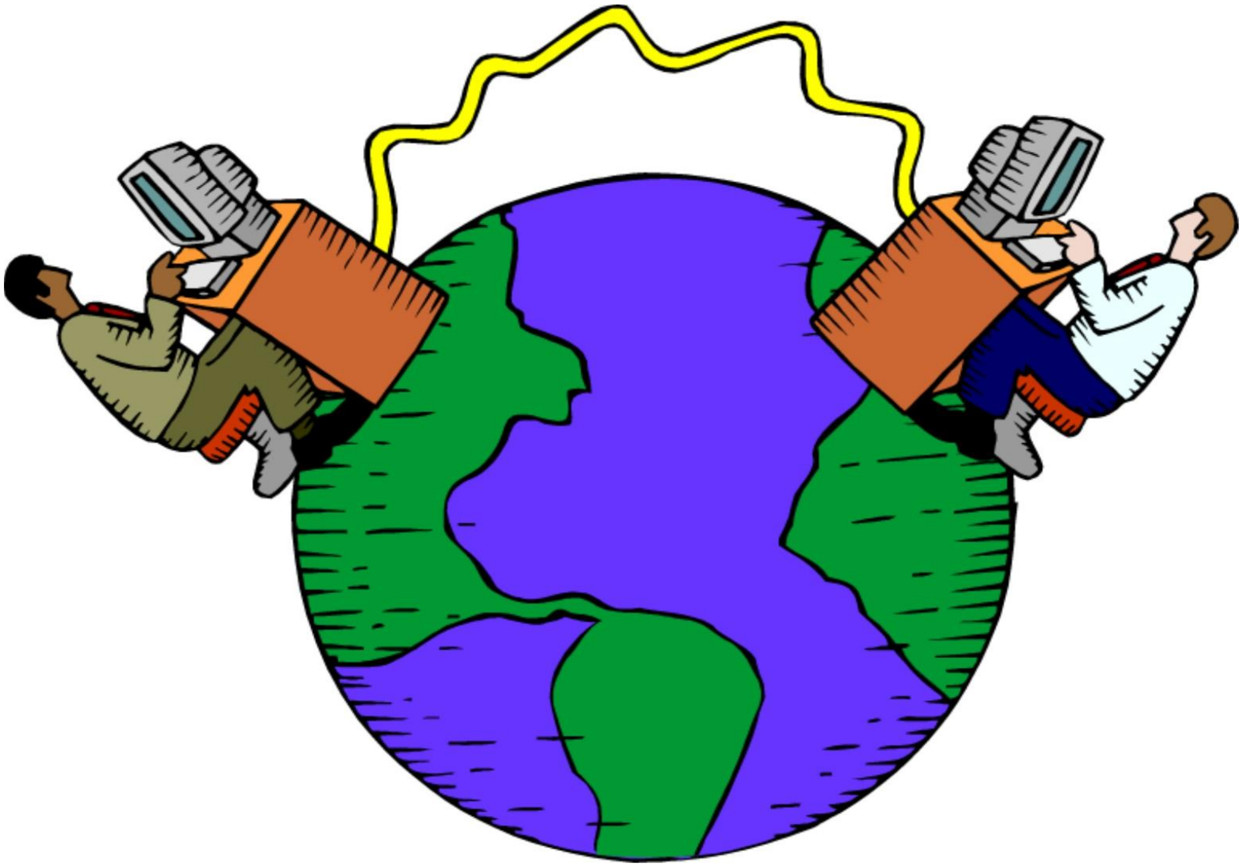
Computer Networks and the Internet

Nehal Patel
Assistant Professor
IT Department
CHARUSAT

Overview

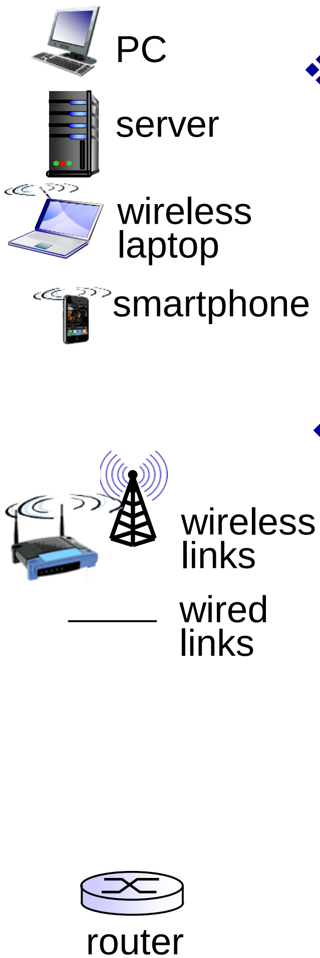
- what’s the Internet?
- what’s a protocol?
- network core: packet/circuit switching, Internet structure
- performance: loss, delay, throughput
- protocol layers, service models
- history

What's the Internet?

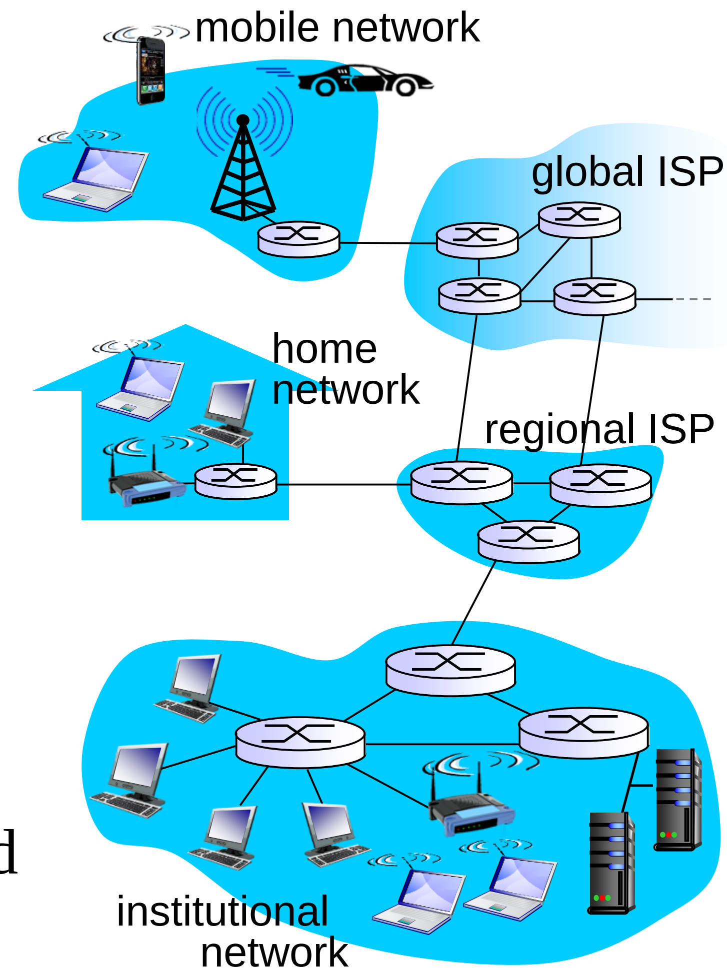


A **global computer network** providing a variety of **information** and **communication facilities**, consisting of interconnected networks using **standardized communication protocols**.

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

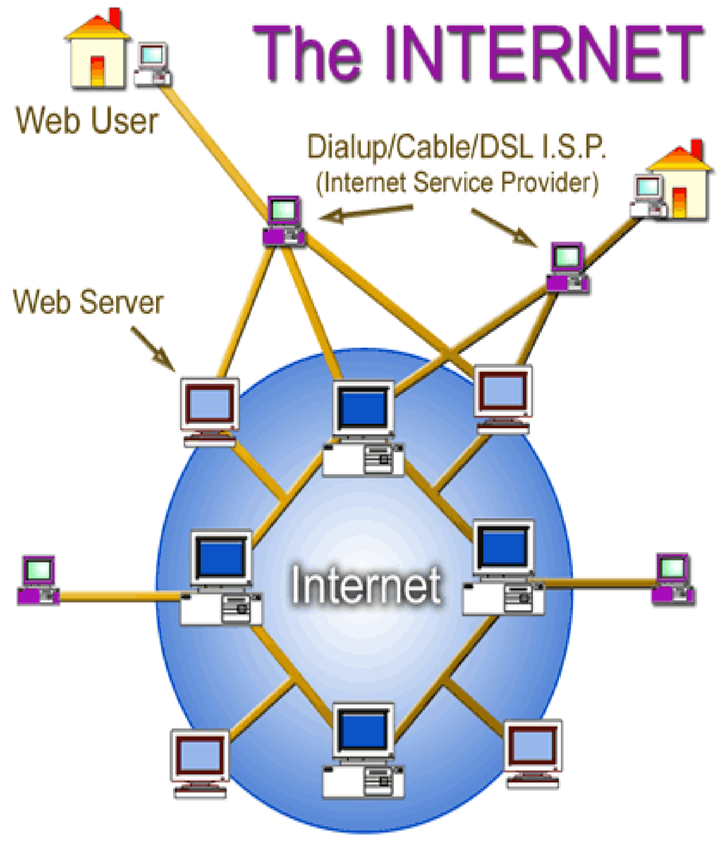
Internet
refrigerator

Slingbox: watch,
control cable TV remotely

Internet phones

What’s the Internet: “nuts and bolts” view

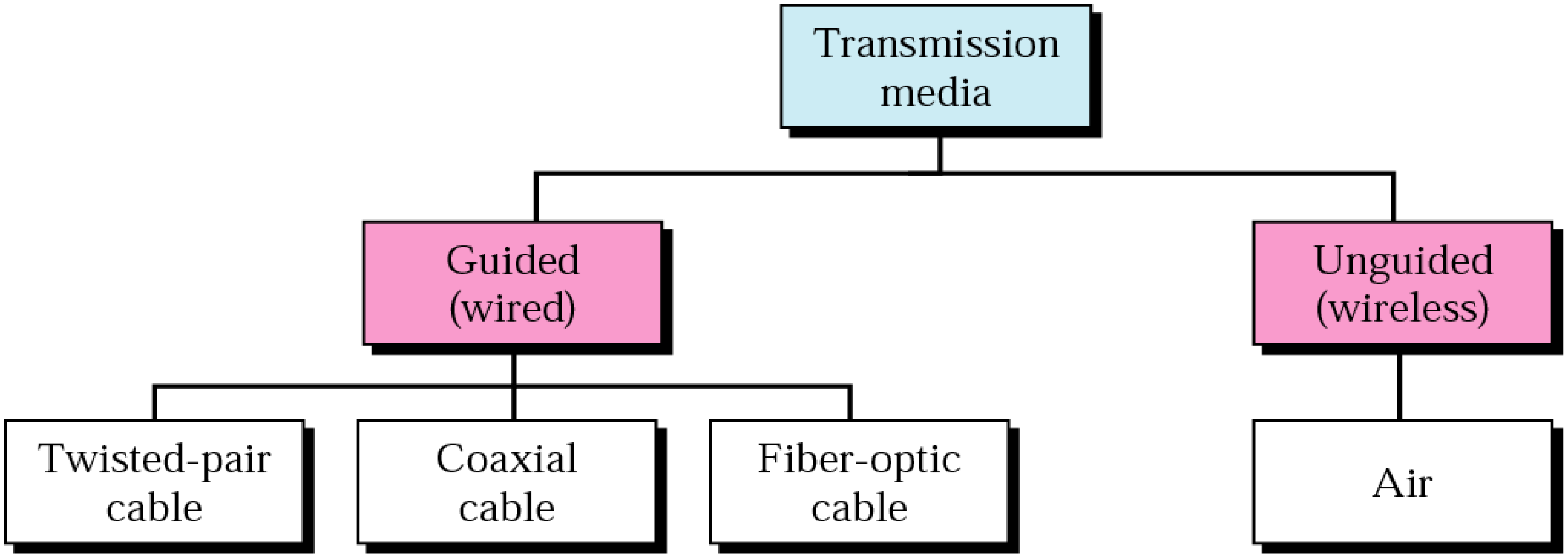
- *Internet:* “network of networks”
  - Interconnected ISPs
- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



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

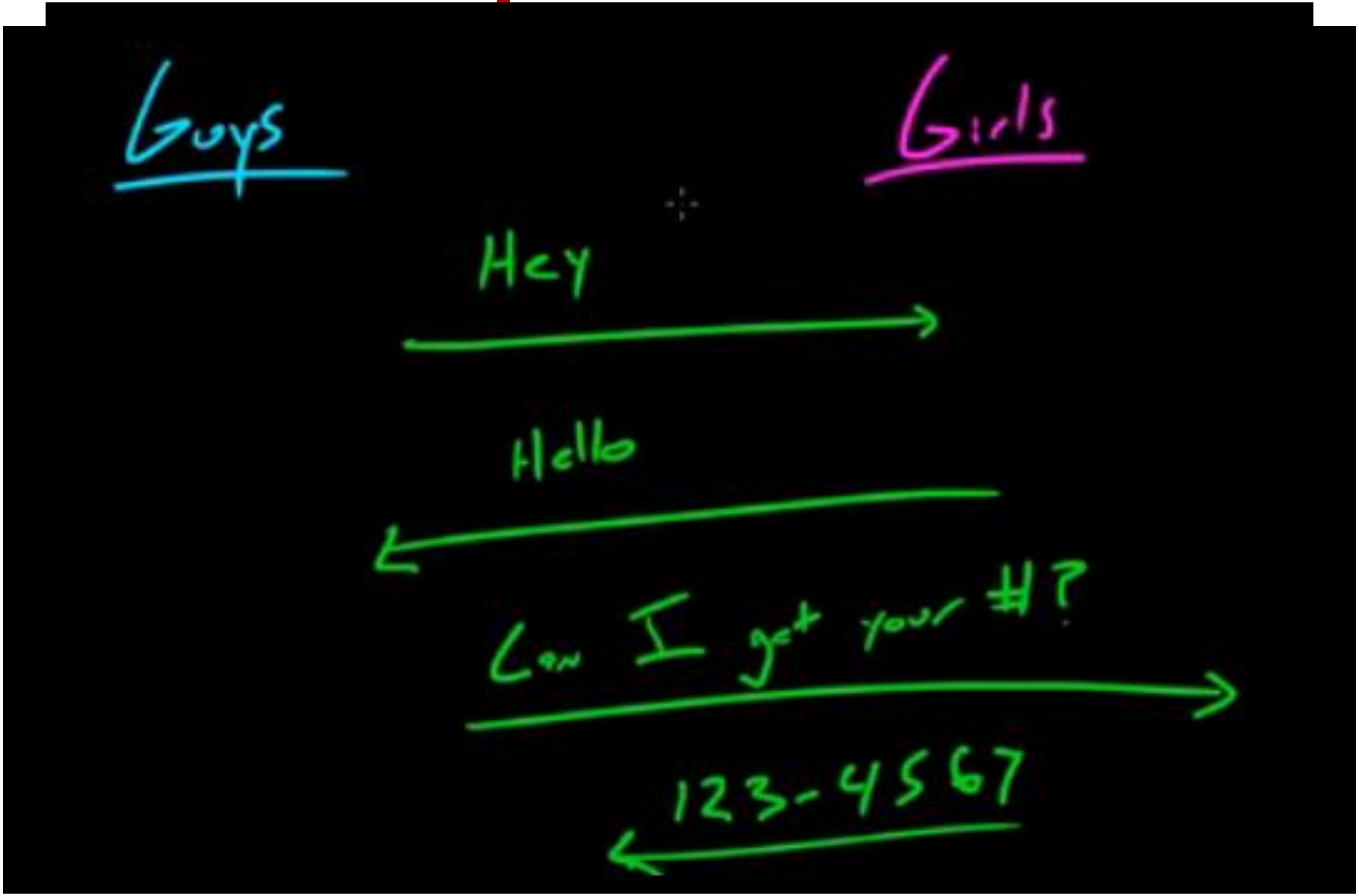
Classification of Transmission Media



Classification of Transmission Media

Twisted-Pair	Coaxial	Fiber-Optic	Infrared Light
			
Low Cost	Moderate Cost	High Cost	Moderate Cost
Best for short distances (330 ft.)	Moderate Distance (3300 ft. – thin) (8250 ft. – thick)	Long Distances (14,256 ft.)	Short distance (75 ft.)
Easy to Install	Professional Installation	Professional Installation	Easy to Install
Low Security	Average Security	High Security	Low Security
Low resistance to interference	Moderate resistance to interference	Very high resistance to interference	Very high resistance to interference

What’s a protocol?



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

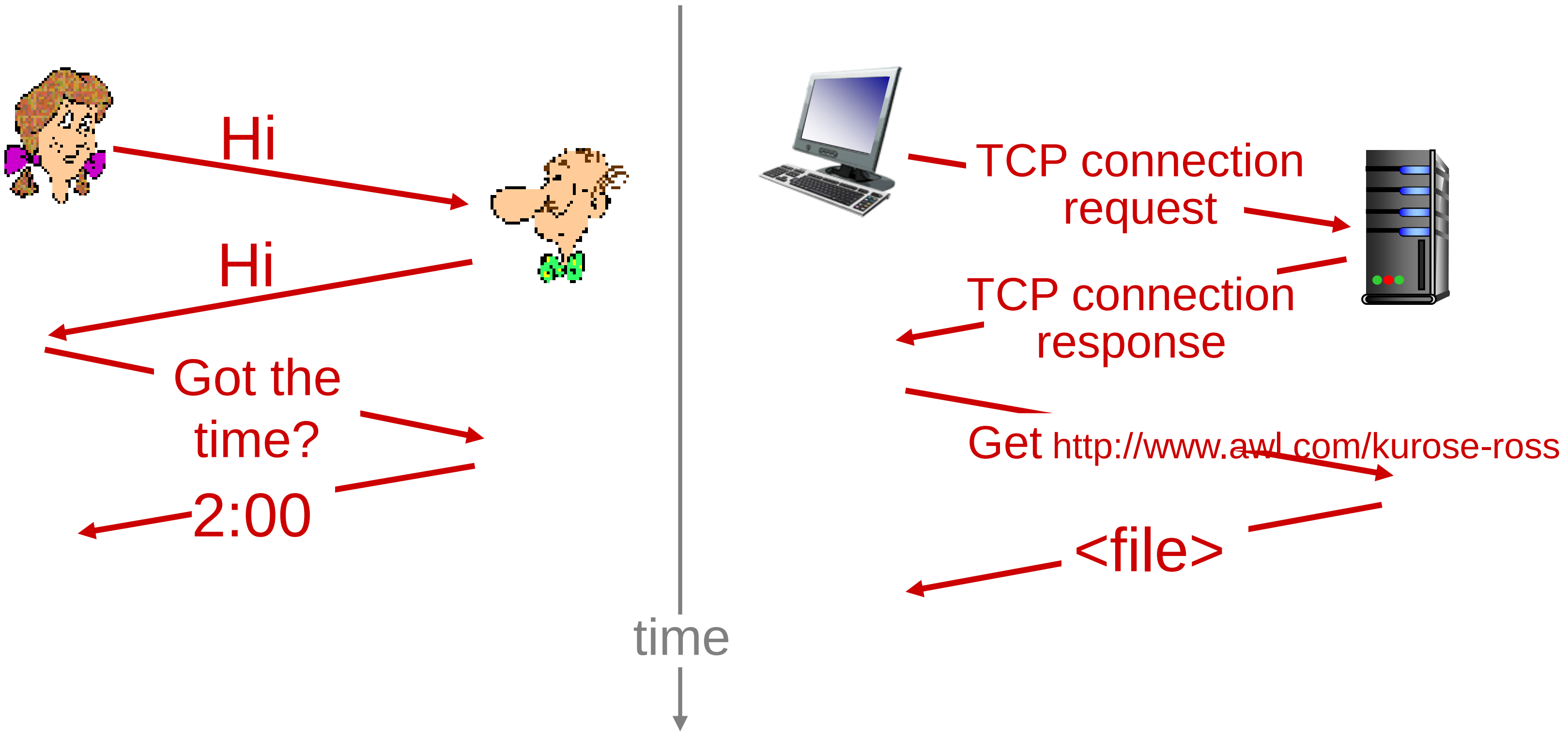
network protocols:

- 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:

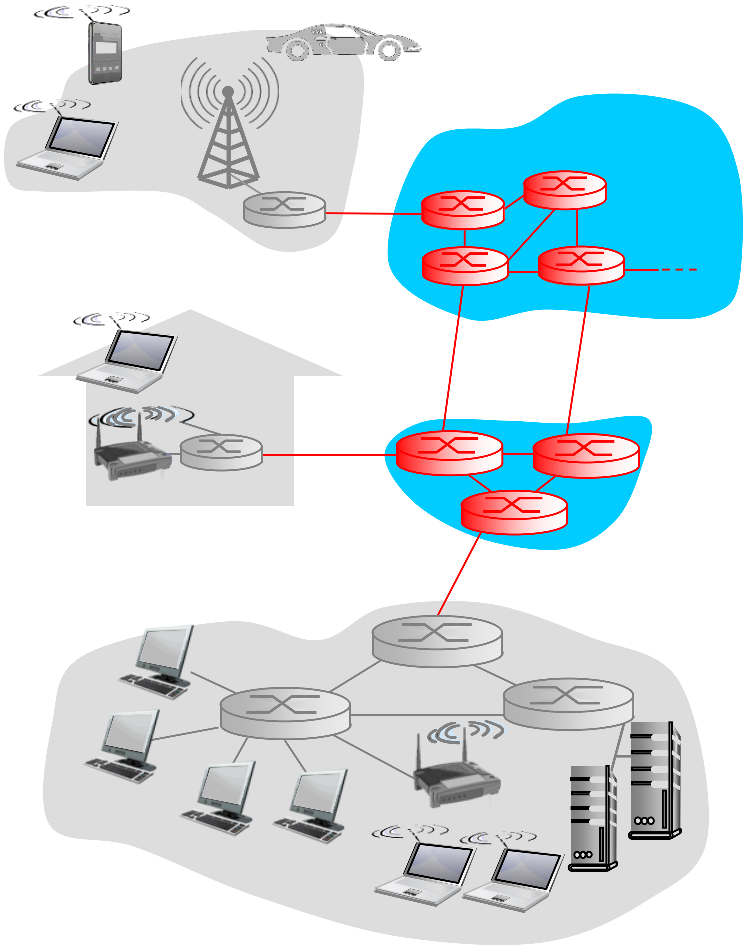


Q: other human protocols?

The network core

Circuit Switching

Packet Switching



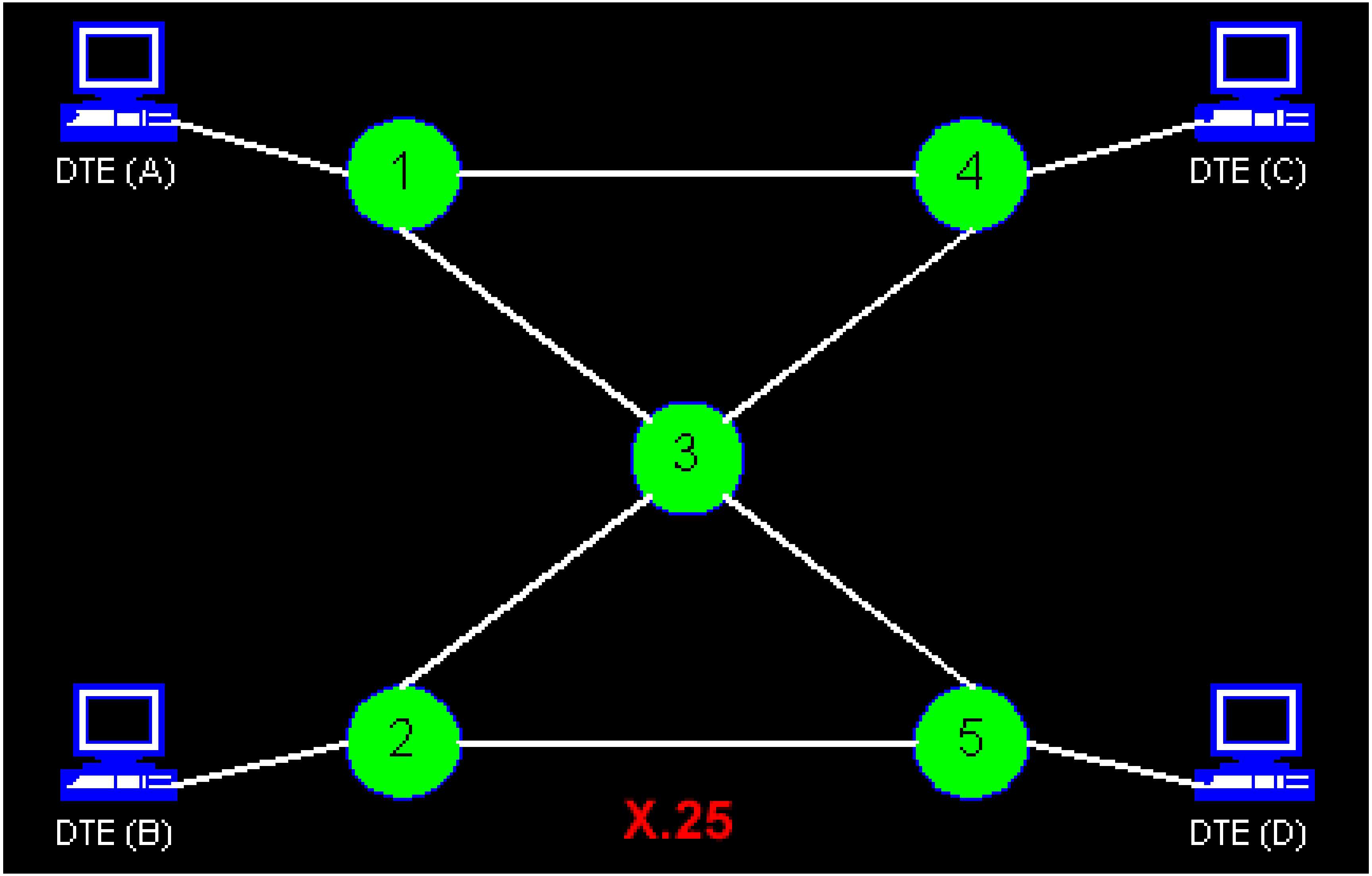
Packet Switching

The resources are not reserved; a session's messages use the resources on demand.

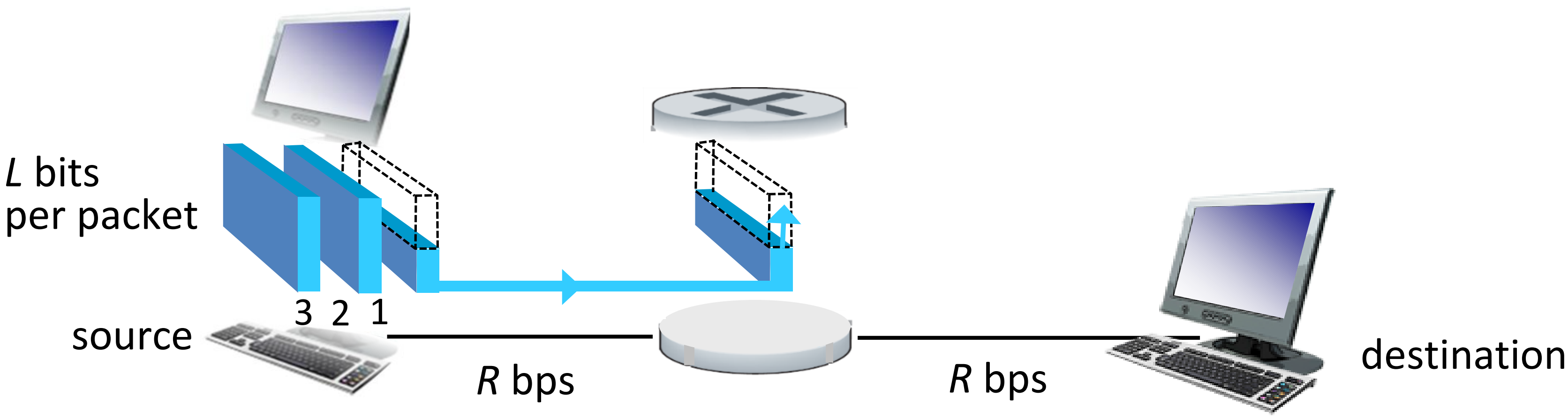
Example

Today's Internet

Packet Switching



Packet-switching: store-and-forward



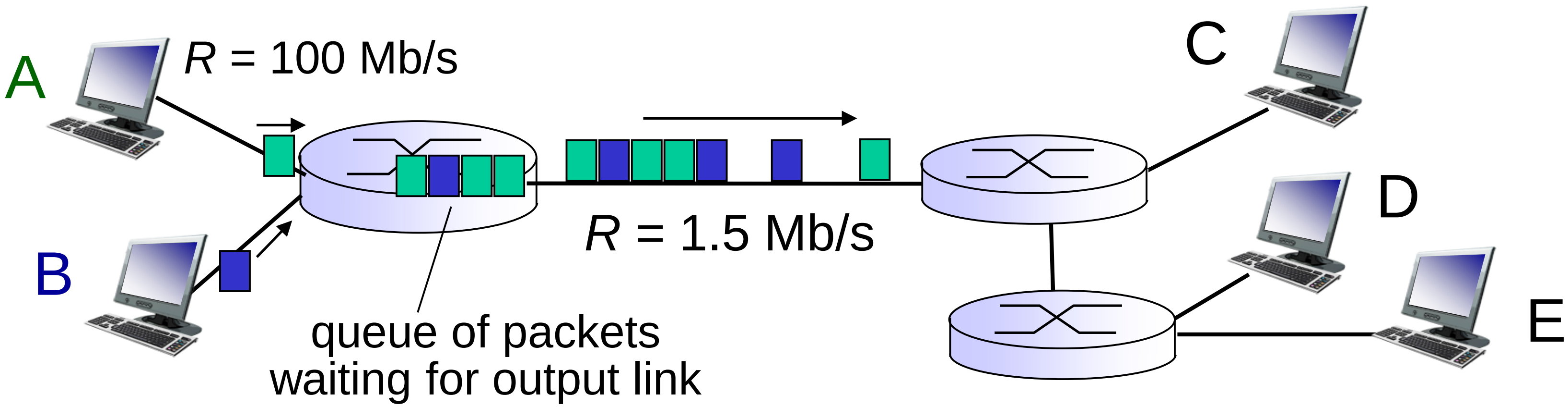
- takes L/R seconds to transmit (push out) L-bit packet into link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- **end-end delay = $2L/R$ (assuming zero propagation delay)**

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

Figure 4.3 *A connectionless packet-switched network*

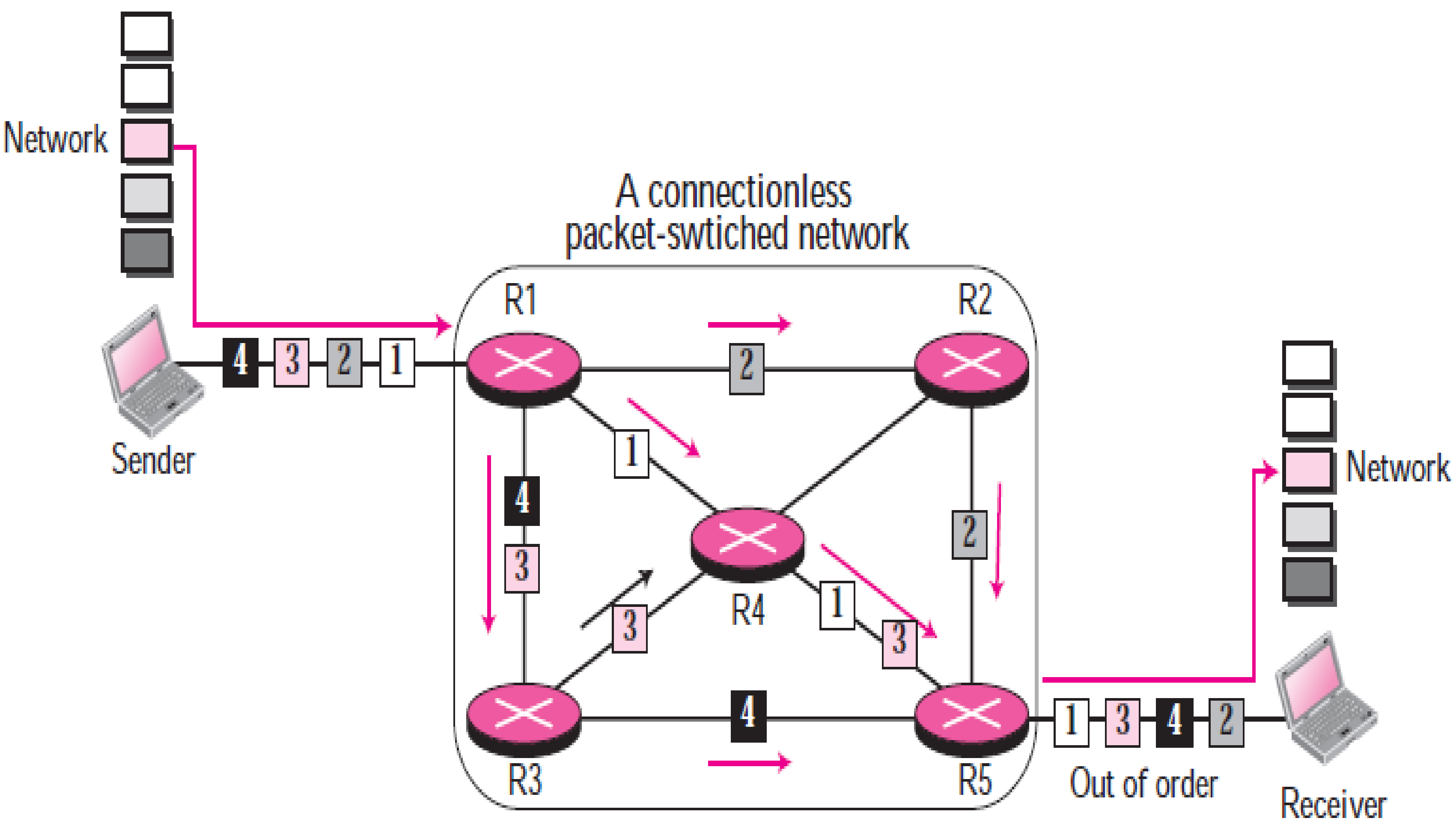
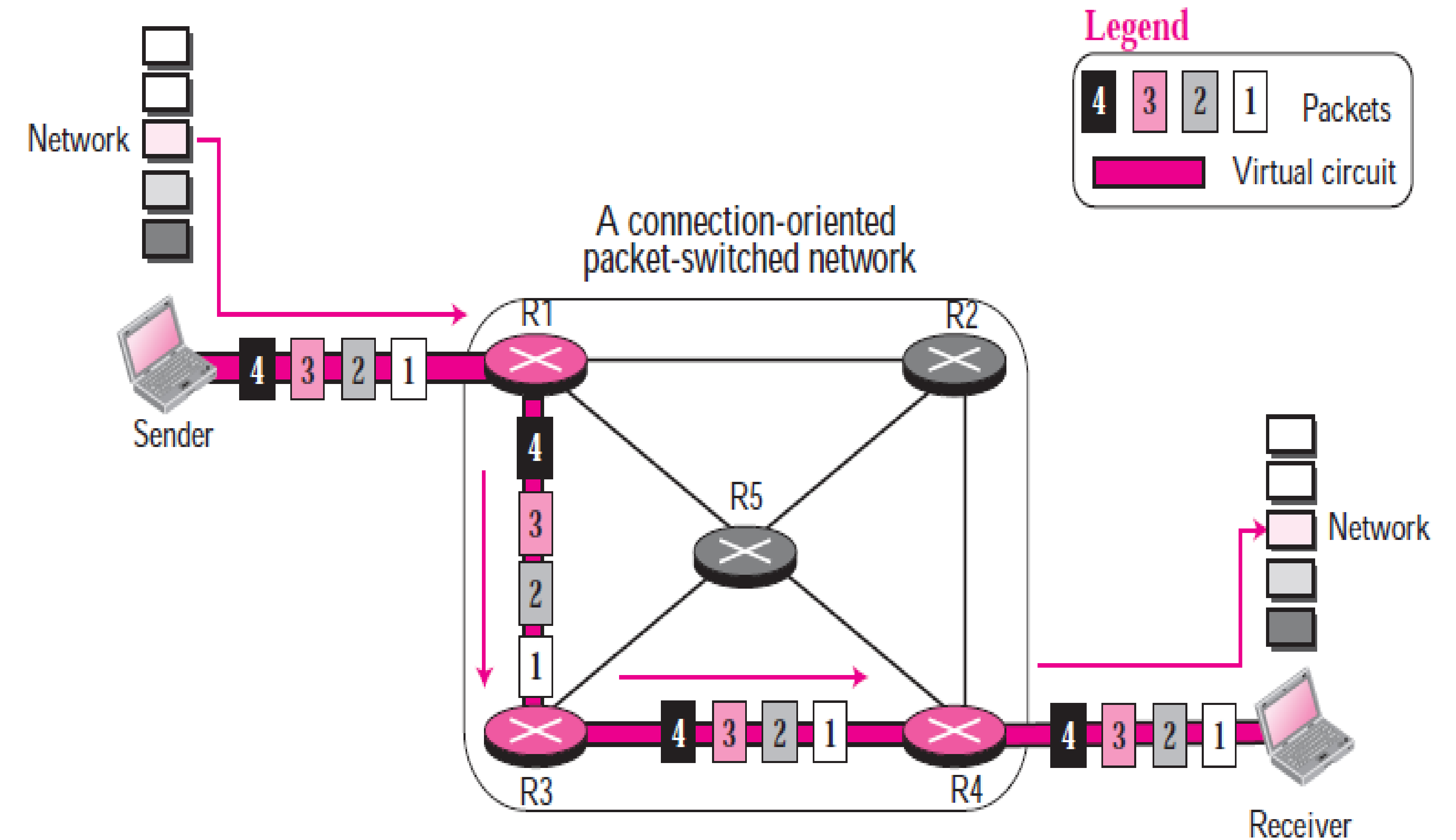


Figure 4.6 *A connection-oriented packet switched network*

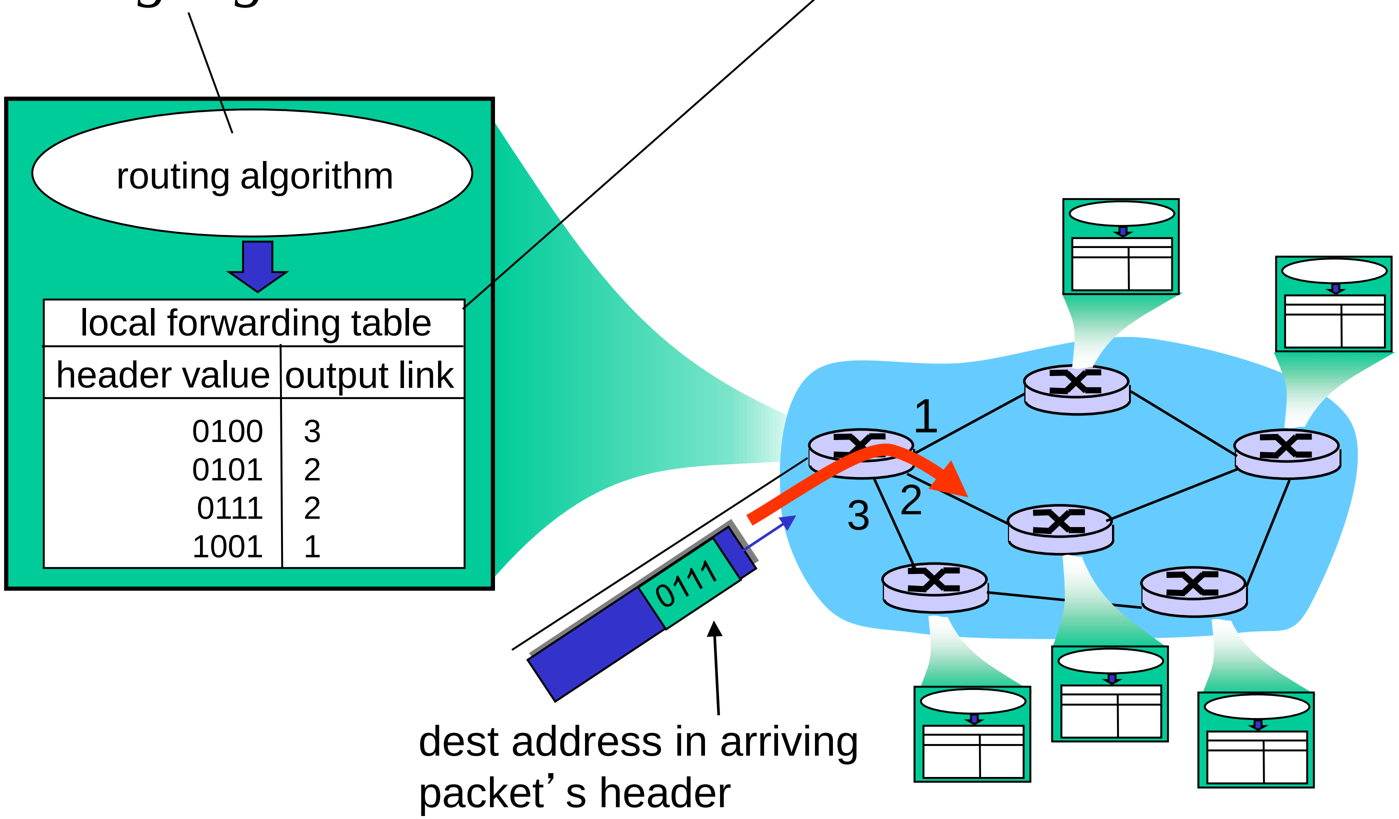


Two key network-core functions

routing: determines source-destination route taken by packets

- *routing algorithms*

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



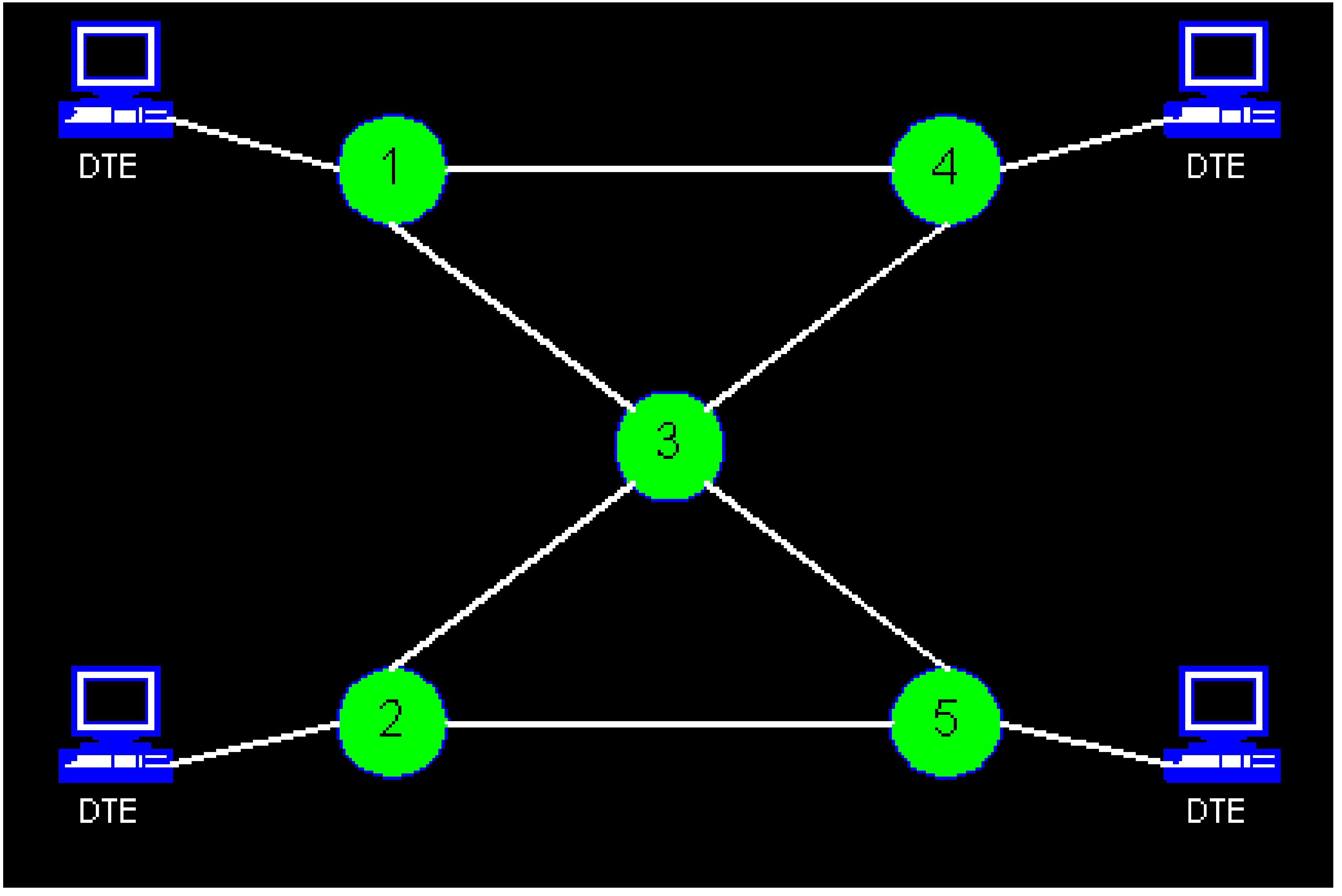
Circuit Switching

The resources needed along a path to provide for communication between the end systems are reserved for duration of the communication session between end systems.

Example

Telephone Network

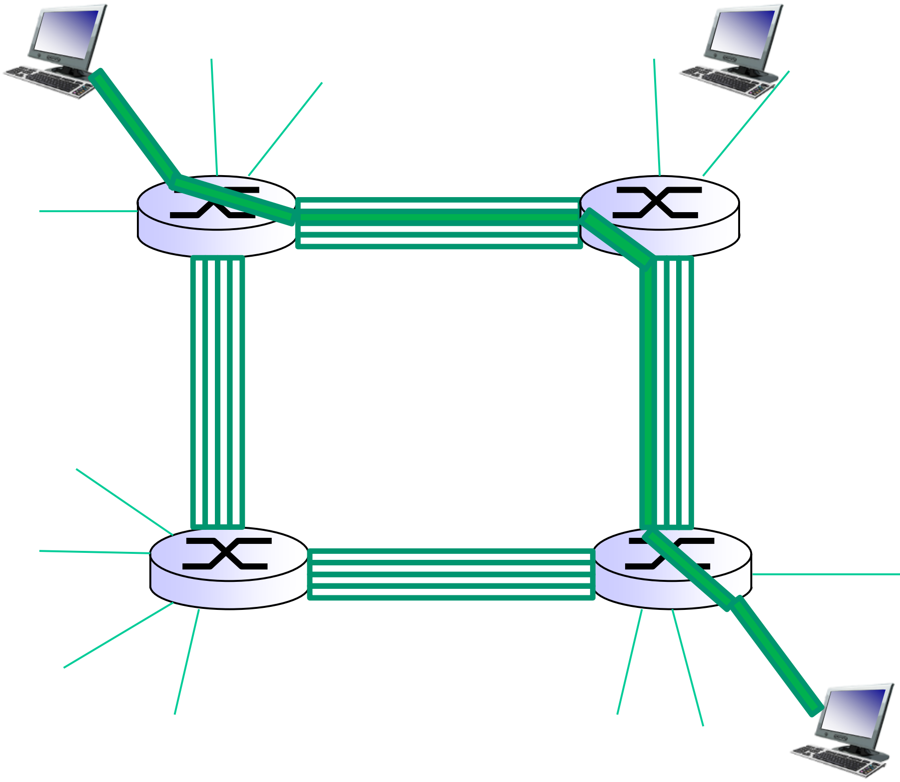
Circuit Switching



Alternative core: circuit switching

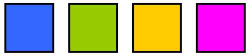
end-end resources allocated to, reserved for "call" between source & dest:

- 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

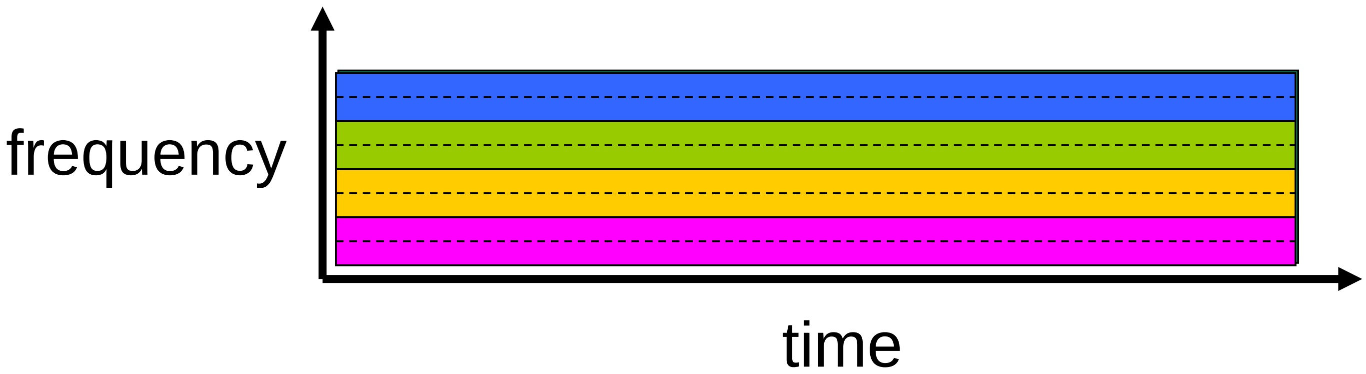


Circuit switching: FDM versus TDM

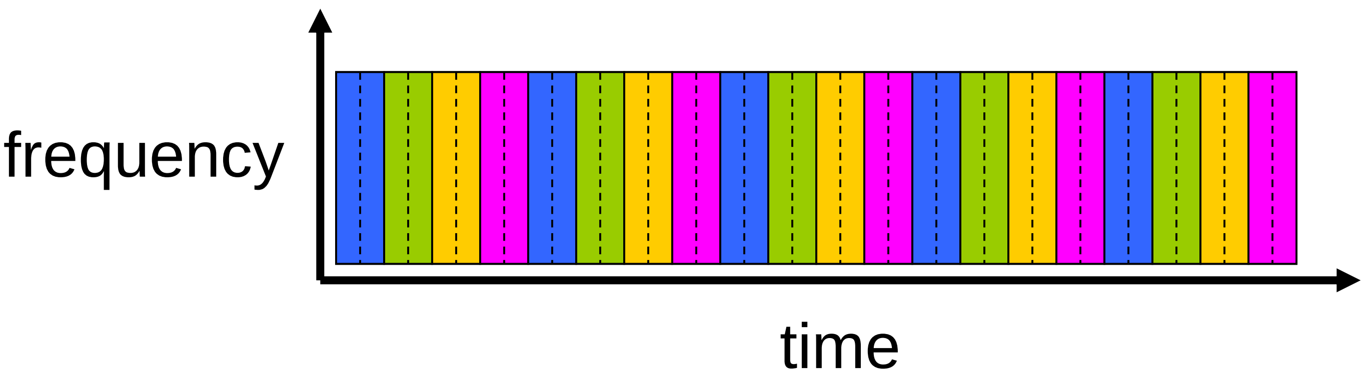
Example:

4 users 

FDM



TDM

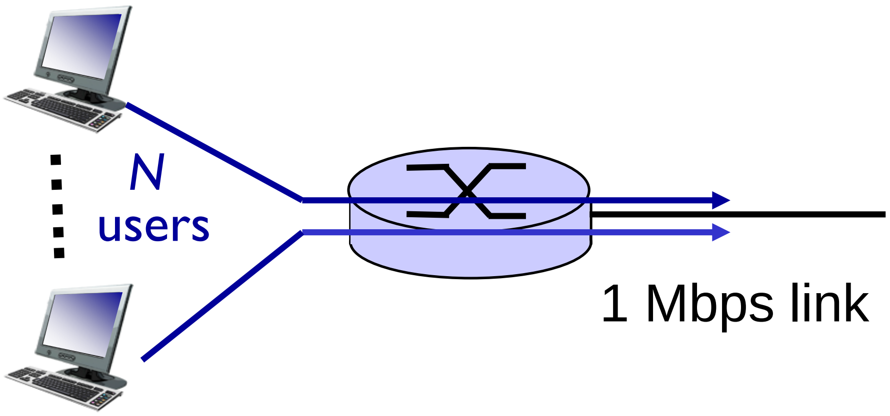


Packet switching versus circuit switching

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

Packet switching versus circuit switching

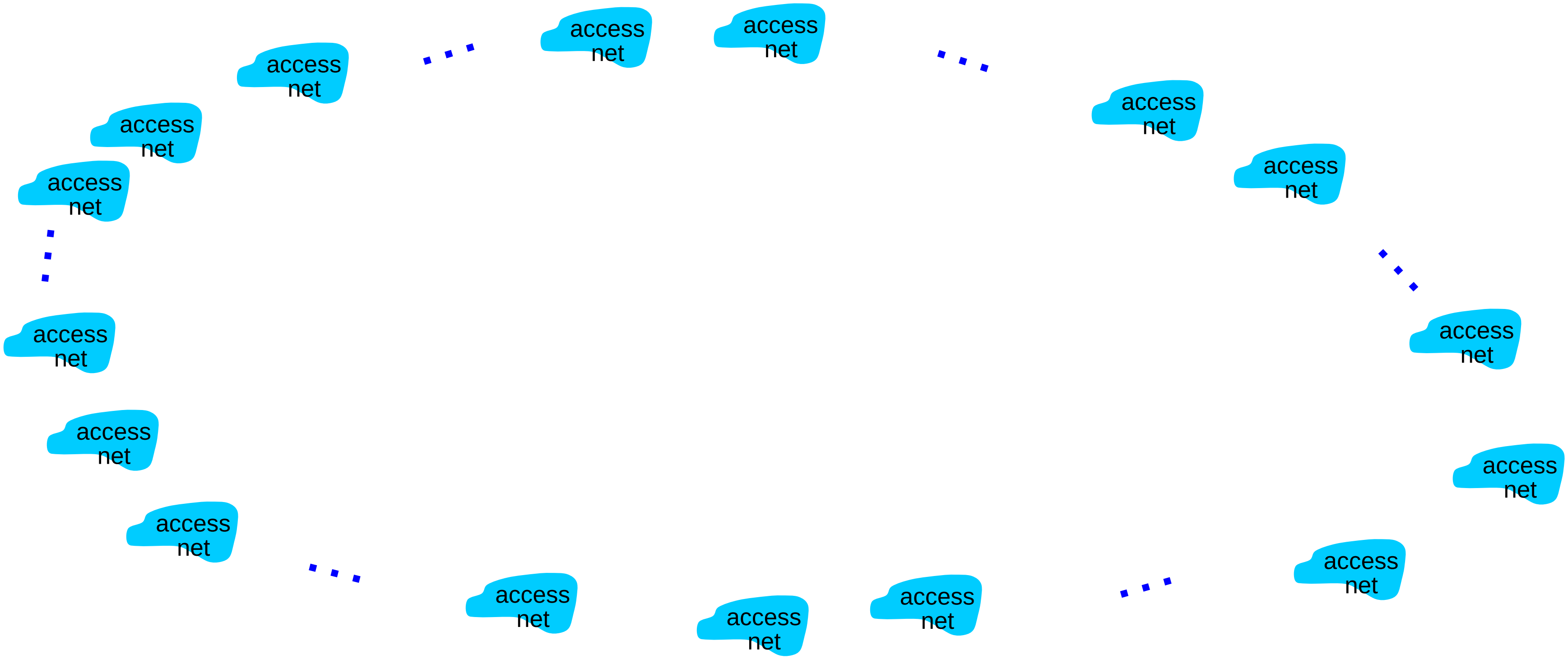
Circuit Switching	Packet Switching
Physical path between source and destination	No physical path
All packets use same path	Packets travel independently
Reserve the entire bandwidth in advance	Does not reserve
Bandwidth Wastage	No Bandwidth wastage
No store and forward transmission	Supports store and forward transmission

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

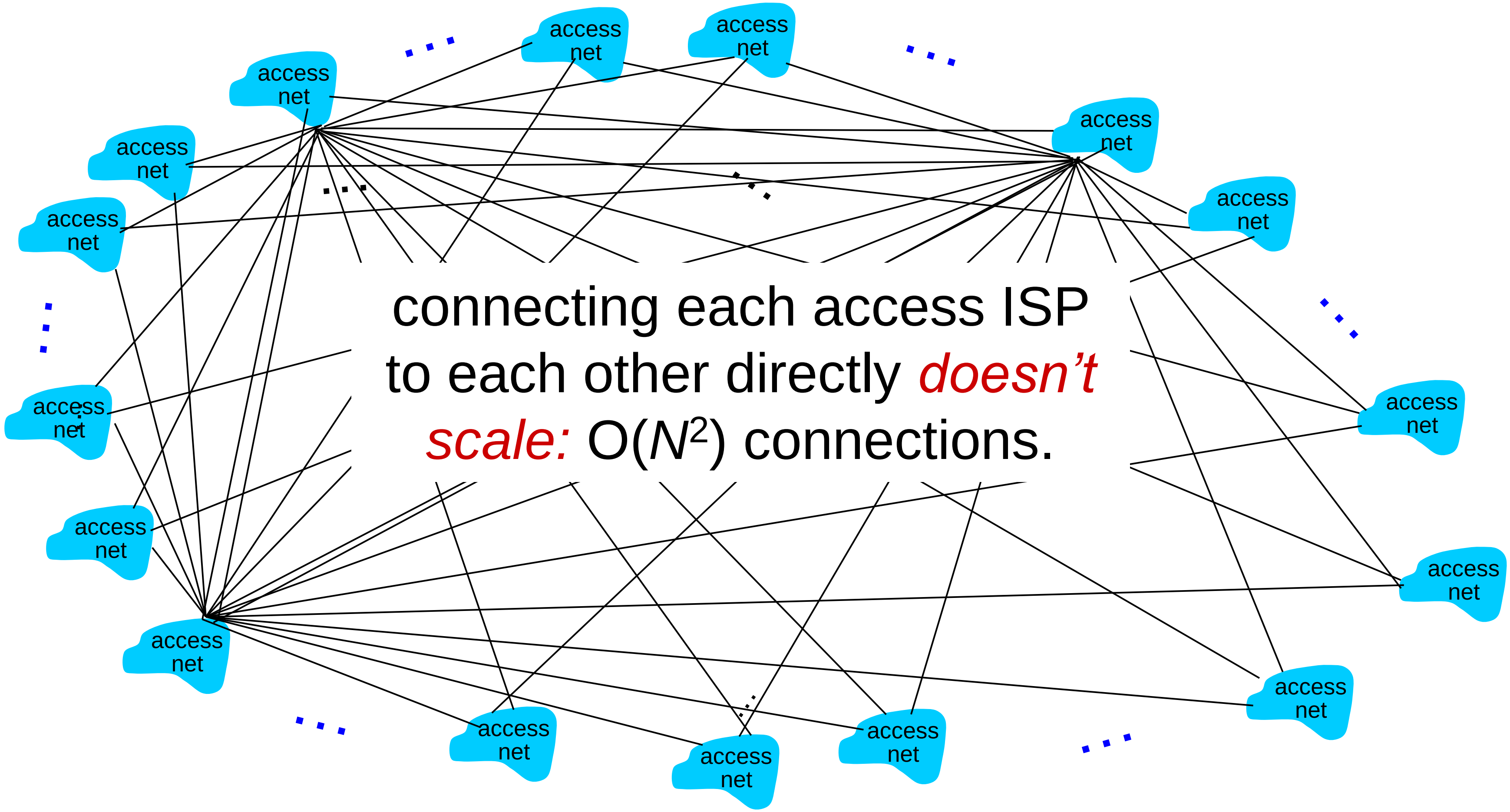
Question: given *millions* of access ISPs, how to connect them together?



overarching goal is to interconnect the access ISPs so that all end systems can send packets to each other.

Internet structure: network of networks

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

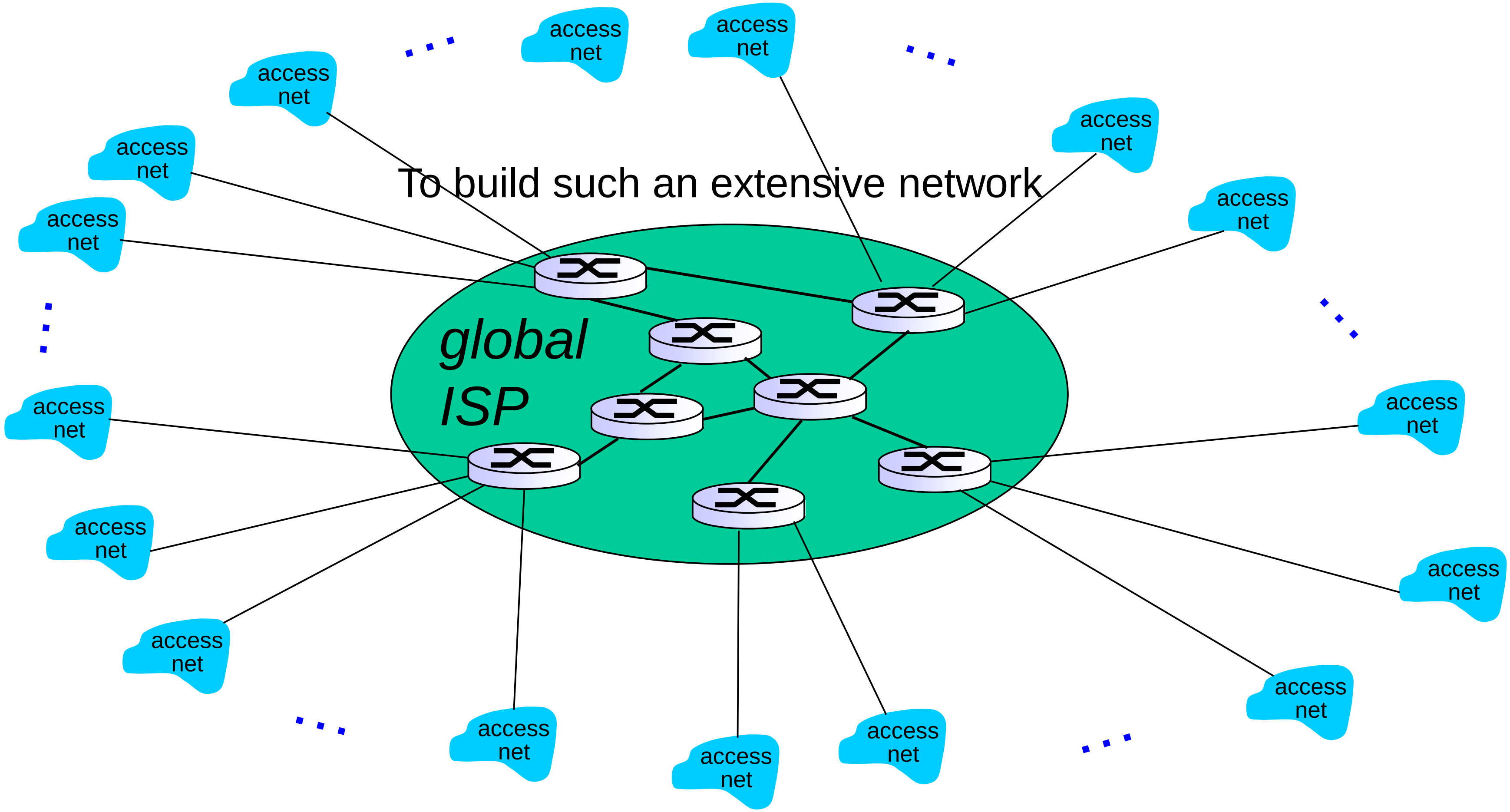


connecting each access ISP to each other directly *doesn't scale:* O(N^2) connections.

much too costly for the access ISPs- requires separate communication link

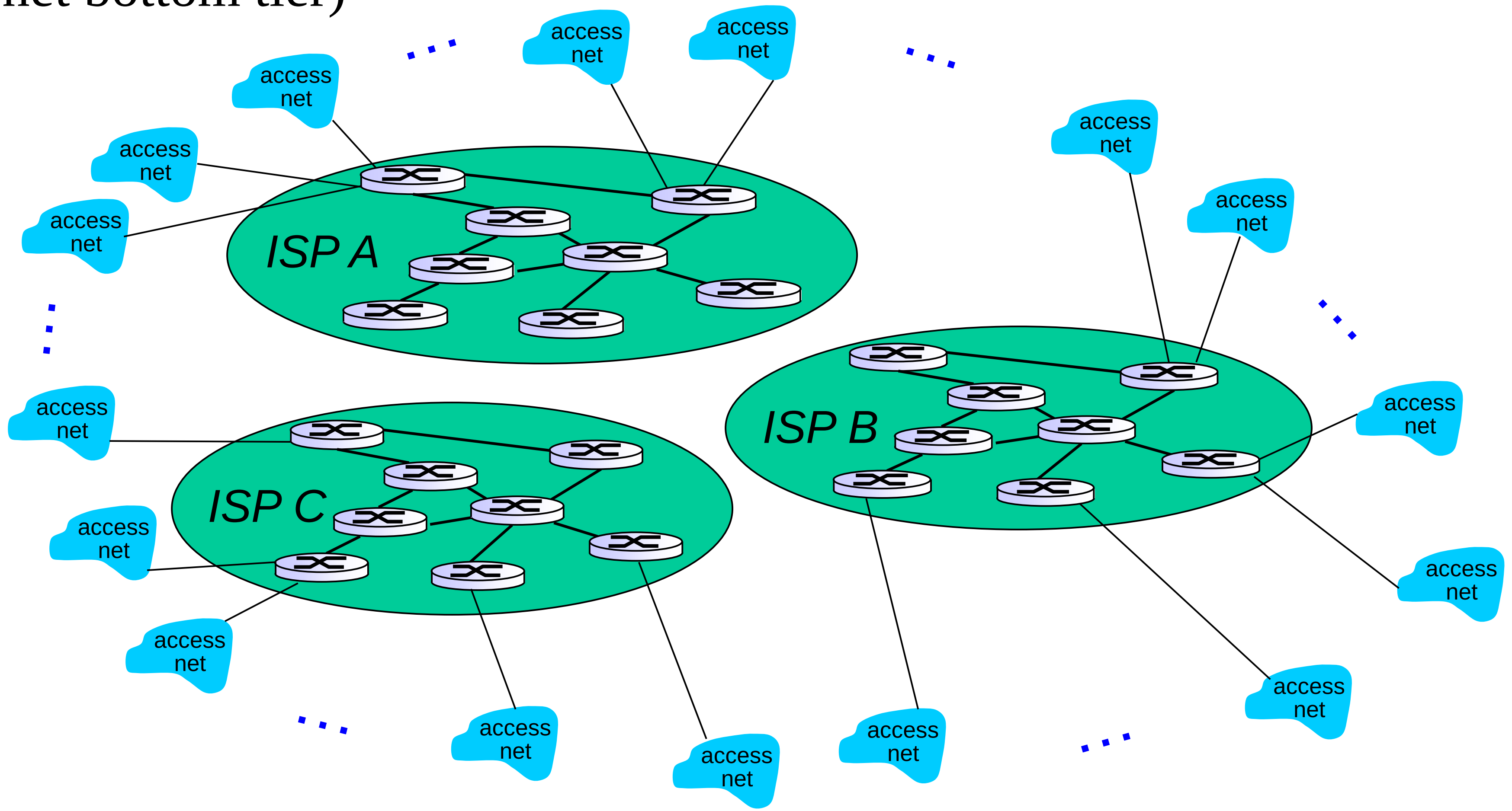
Internet structure: network of networks

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



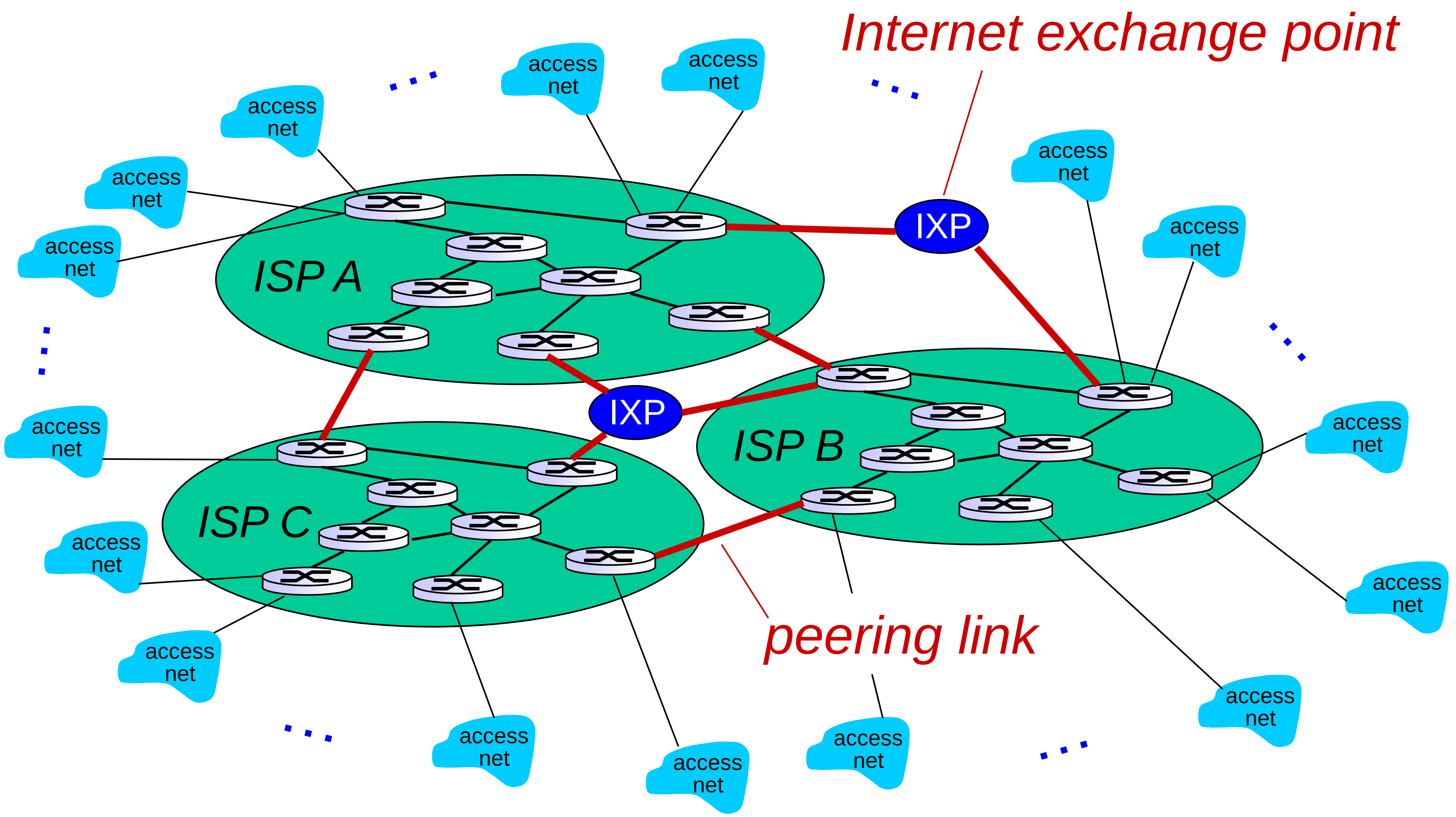
Internet structure: network of networks

But if one global ISP is viable business, there will be competitors.. Divide into tier-1 (isp-top tier) and tier-2 (access net bottom tier)



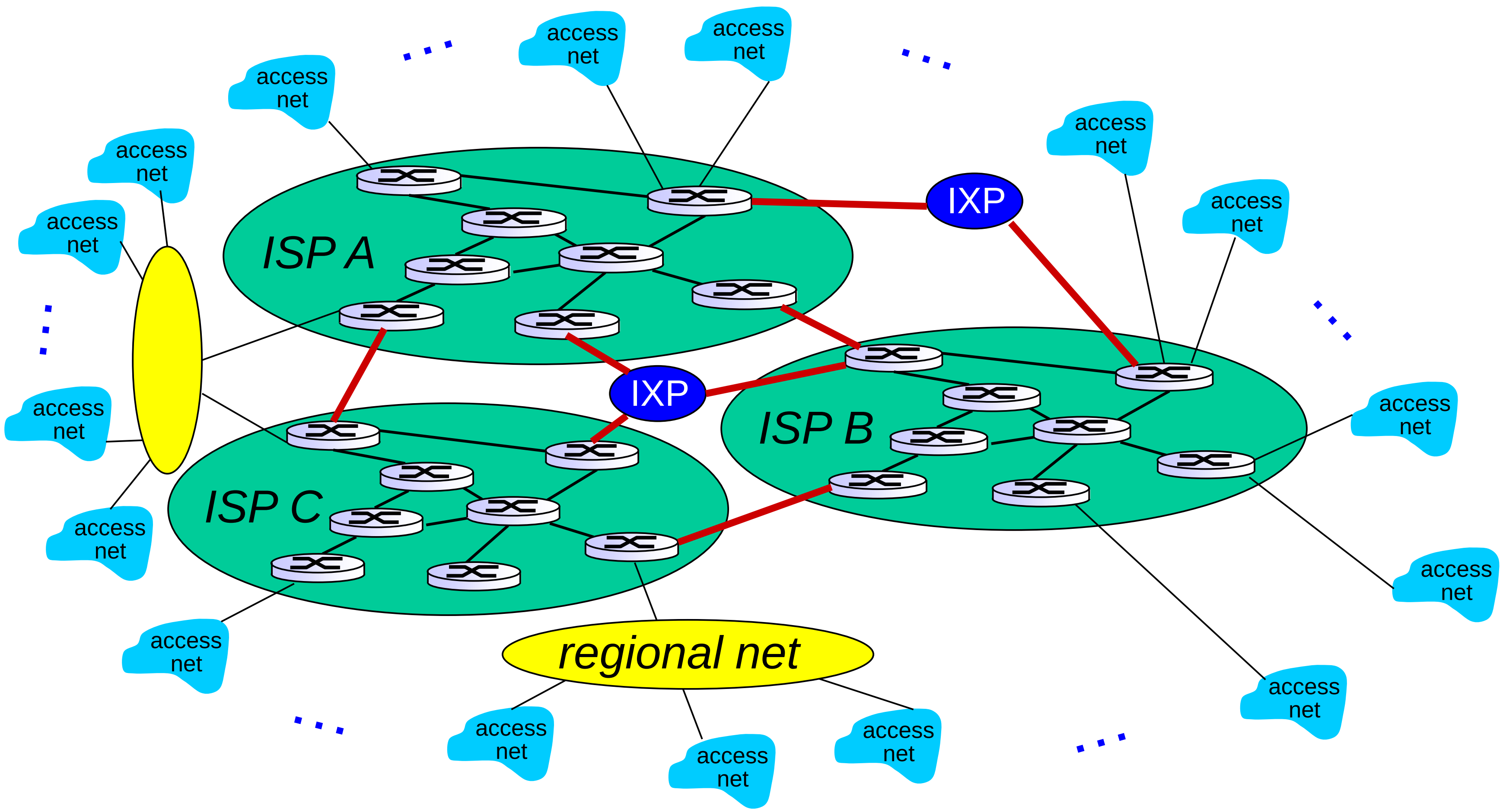
Internet structure: network of networks

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



Internet structure: network of networks

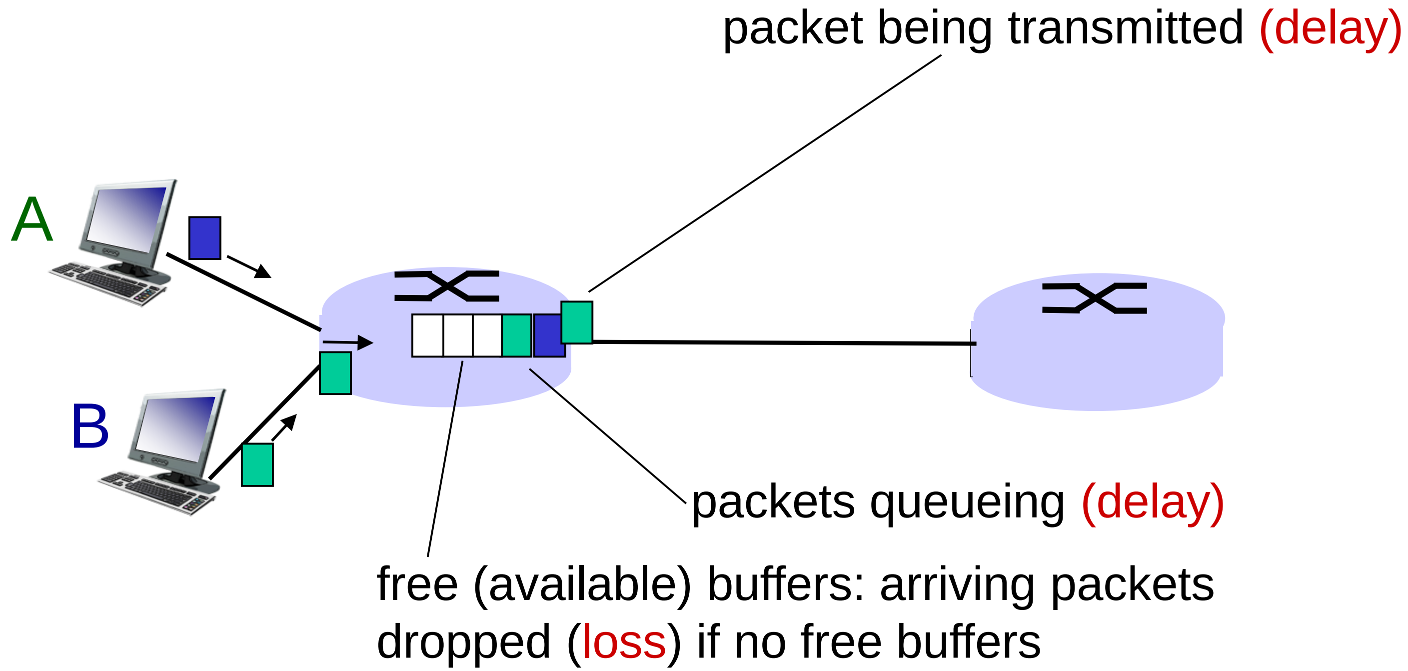
… and regional networks may arise to connect access nets to ISPS



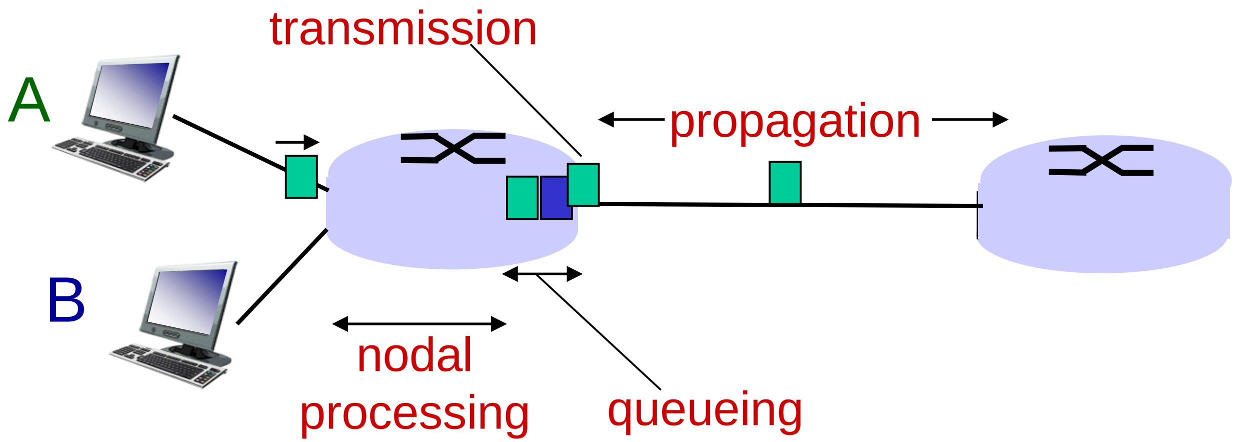
How do loss and delay occur?

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

1) **Processing Delay** is the time that is taken by the router to access the header of a packet and redirect it to the next path. This time is known as processing delay. Processing also include to checking for **any bit error** in the packets, that can occur during transmission of the packet.

2) **Queuing Delay** is the time that a packet has to wait in the queue before it can be transmitted over the link. Packets are put in the queue when the speed of incoming link to the router is faster than the outgoing link.

3) **Transmission Delay** is usually caused by the **data rate of the link.** It is the time taken to **push all the packet** bits on to the link.

For N=Number of bits, S=Size of packet, d=delay

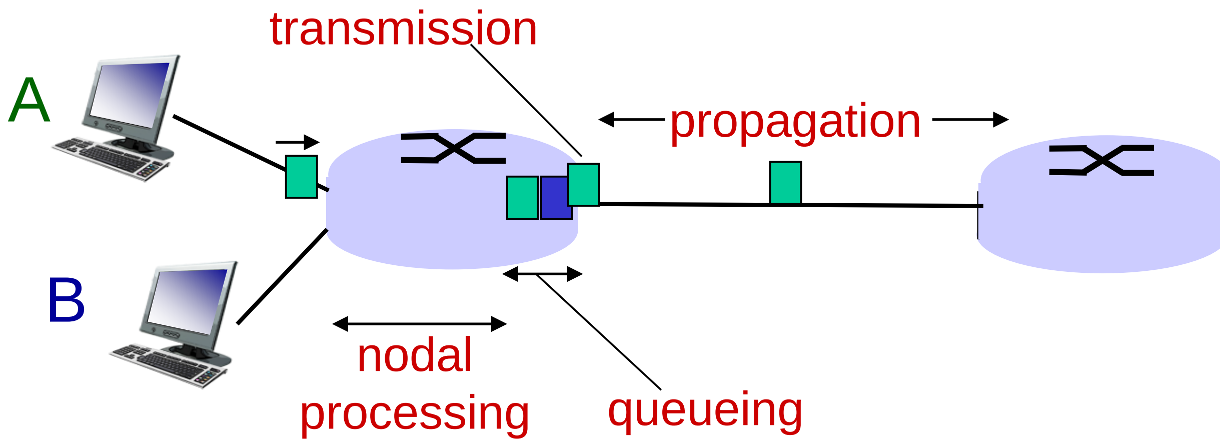
$$d = S/N$$

4) **Propagation Delay** is the time taken by the **1st bit of the packet to reach the receiver router.** It can be calculated by dividing the distance between the two routers and the speed of propagation of the link.

For d = distance, s = propagation velocity

$$PD = d/s$$

Four sources of packet delay



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

d_{trans}: transmission delay:

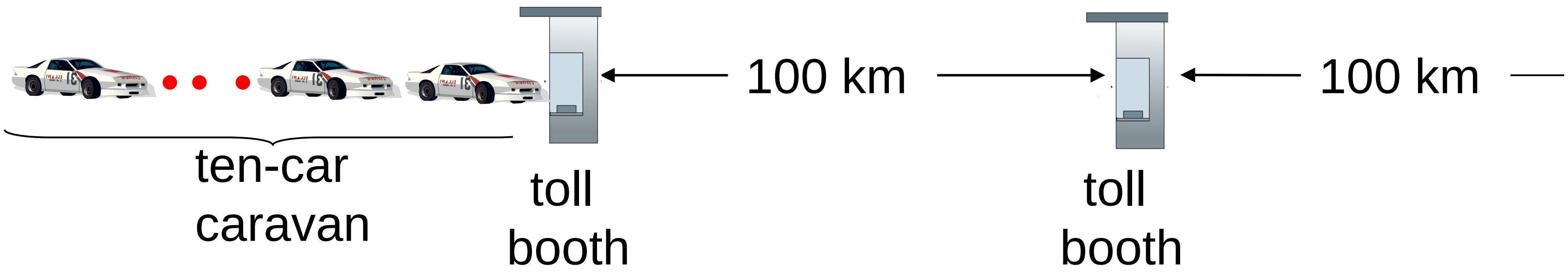
- *L*: packet length (bits)
- *R*: link *bandwidth (bps)*
- $d_{trans} = L/R$

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

d_{prop}: propagation delay:

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

Caravan analogy

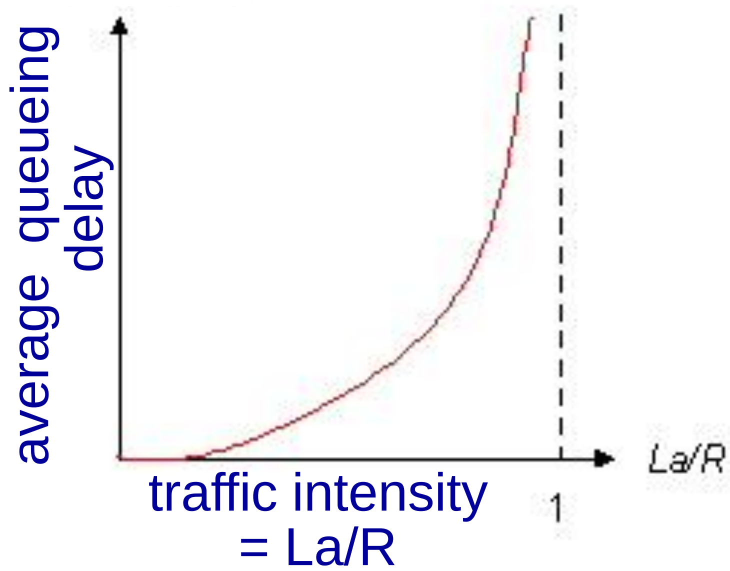


- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (bit transmission time)
- car~bit; caravan ~ packet
- *Q:* How long until caravan is lined up before 2nd toll booth?

- 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

Queueing delay (revisited)

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



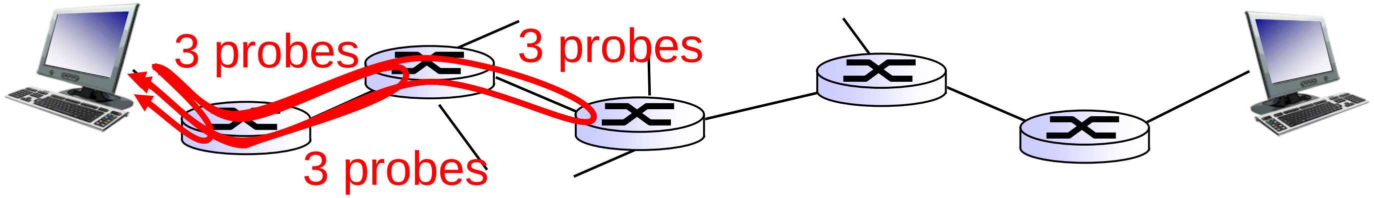
- *La/R* > 1: more "work" arriving than can be serviced, average delay infinite!
- *La/R* <= 1 no queueing delay (packets arrive periodically)

La/R ~ 0

Imp: A small percentage increase in the intensity will result in a much larger percentage-wise increase in delay.

"Real" Internet delays and routes-end-to-end delay

- 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 and routes

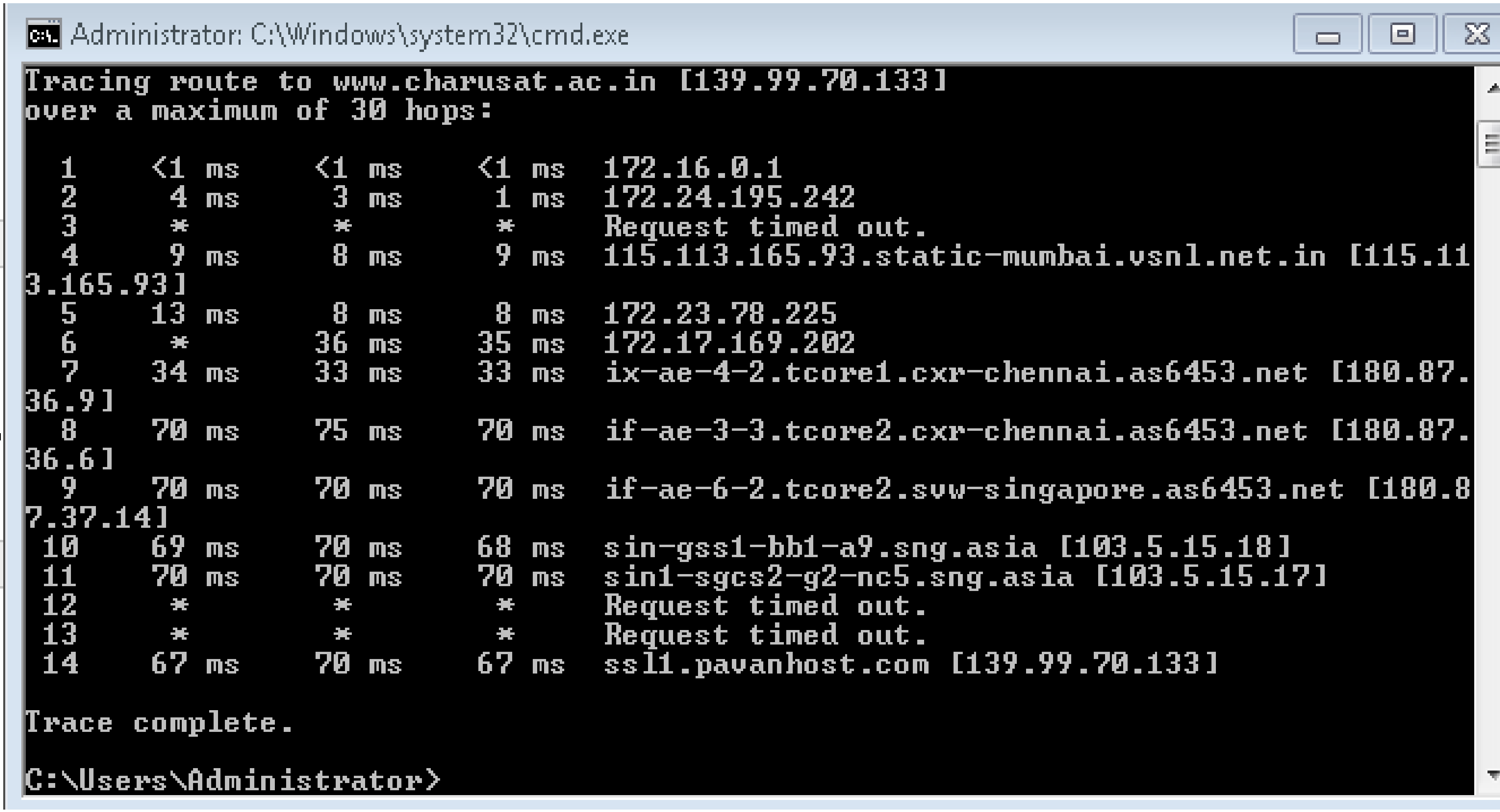
traceroute: gaia.cs.umass.edu to www.eurecom.fr

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

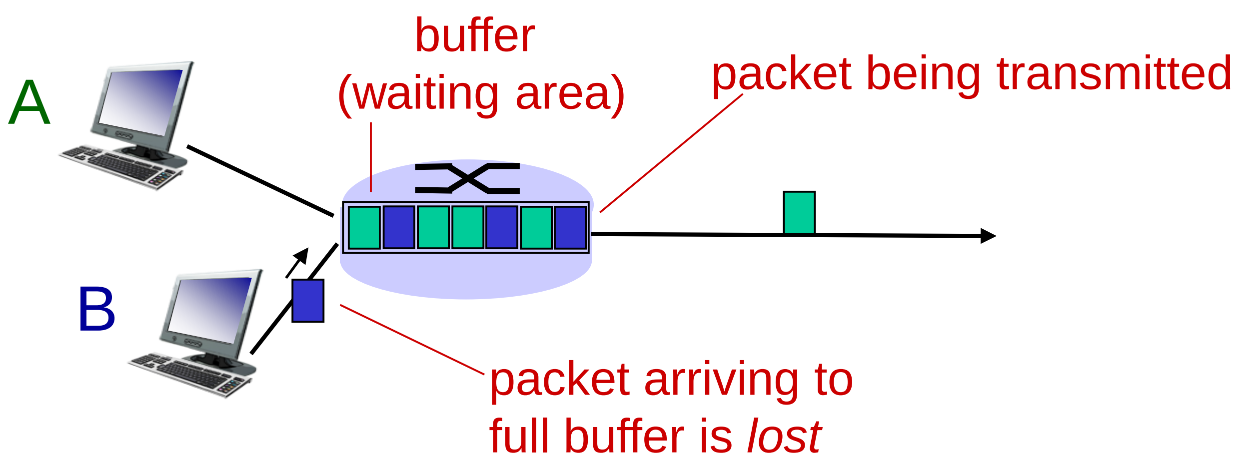
trans-oceanic link

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


Administrator: C:\Windows\system32\cmd.exe
Tracing route to www.charusat.ac.in [139.99.70.133]
over a maximum of 30 hops:
1 <1 ms <1 ms <1 ms 172.16.0.1
2 4 ms 3 ms 1 ms 172.24.195.242
3 * * * Request timed out.
4 9 ms 8 ms 9 ms 115.113.165.93.static-mumbai.vsnl.net.in [115.113.165.93]
5 13 ms 8 ms 8 ms 172.23.78.225
6 * 36 ms 35 ms 172.17.169.202
7 34 ms 33 ms 33 ms ix-ae-4-2.tcore1.cxr-chennai.as6453.net [180.87.36.9]
8 70 ms 75 ms 70 ms if-ae-3-3.tcore2.cxr-chennai.as6453.net [180.87.36.6]
9 70 ms 70 ms 70 ms if-ae-6-2.tcore2.svw-singapore.as6453.net [180.87.37.14]
10 69 ms 70 ms 68 ms sin-gss1-bb1-a9.sng.asia [103.5.15.18]
11 70 ms 70 ms 70 ms sin1-sgcs2-g2-nc5.sng.asia [103.5.15.17]
12 * * * Request timed out.
13 * * * Request timed out.
14 67 ms 70 ms 67 ms ssl1.pavanhost.com [139.99.70.133]
Trace complete.
C:\Users\Administrator>

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

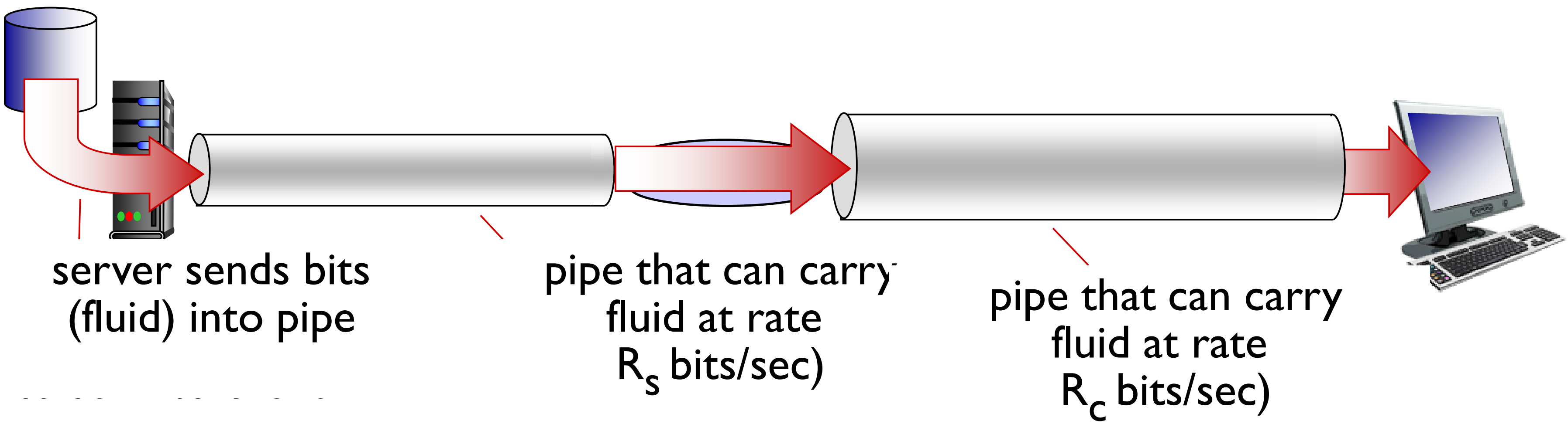
Throughput

- *throughput:* it is the amount of data moved successfully from one place to another in a given time period, and typically measured in bits per second (bps)
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time

Ex:- consider transferring a large file from Host A to Host B across a computer network. This transfer might be, for example, a large video clip from one peer to another in a P2P file sharing system. The **instantaneous throughput** at any instant of time is the rate (in bits/sec) at which Host B is receiving the file.

If the file consists of *F* bits and the transfer takes *T* seconds for Host B to receive all *F* bits, then the **average throughput** of the file transfer is *F/T* bits/sec.

Throughput



server sends bits (fluid) into pipe
pipe that can carry fluid at rate R_s bits/sec)
pipe that can carry fluid at rate R_c bits/sec)

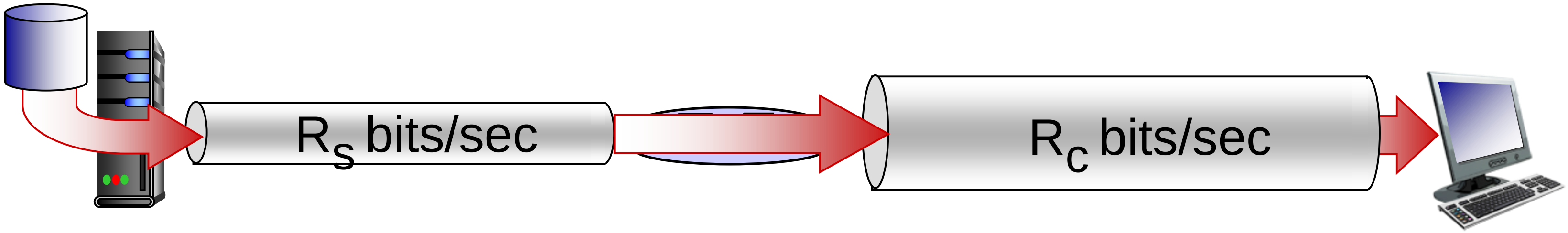
Throughput

- For some applications, such as Internet telephony, it is desirable to have a low delay and an instantaneous throughput consistently above some threshold (for example, over 24 kbps for some Internet telephony applications and over 256 kbps for some real time video applications).

- For other applications, including those involving file transfers, delay is not critical, but it is desirable to have the highest possible throughput.

Throughput (more)

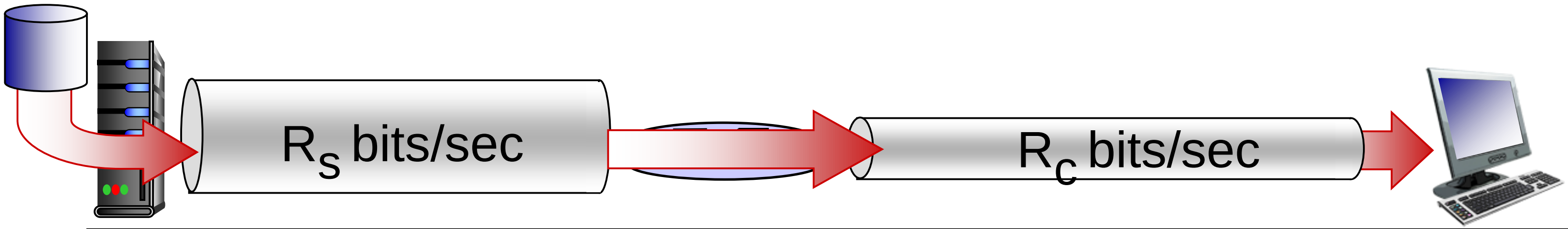
- $R_s < R_c$ What is average end-end throughput?



the **bits** pumped by the server will “flow” right through the router and arrive at the client at a rate of Rs bps and giving a throughput of *Rs* bps.

Throughput (more)

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



the router will not be able to forward bits as quickly as it receives them. In this case, bits will only leave the router at rate *Rc*, giving an end-to-end throughput of *Rc*

bottleneck link

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

Protocol "layers"

Networks are complex, with many "pieces":

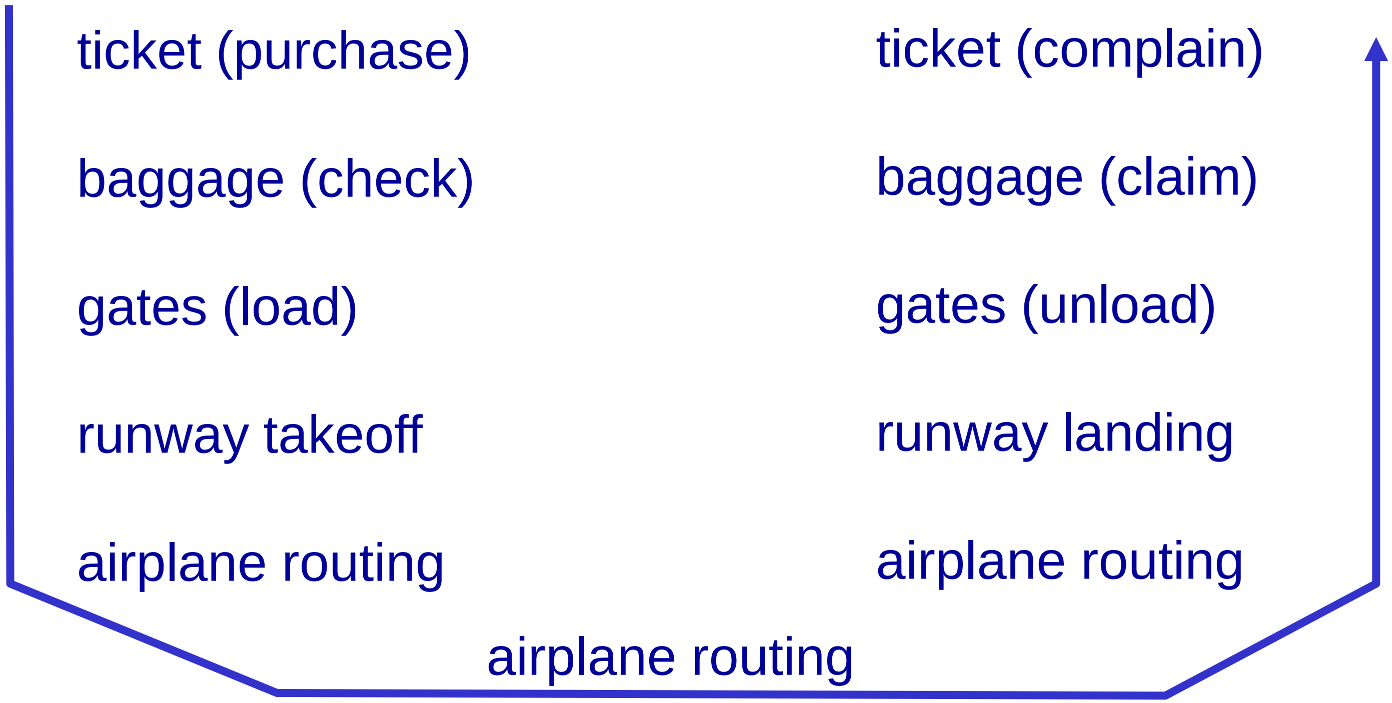
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

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

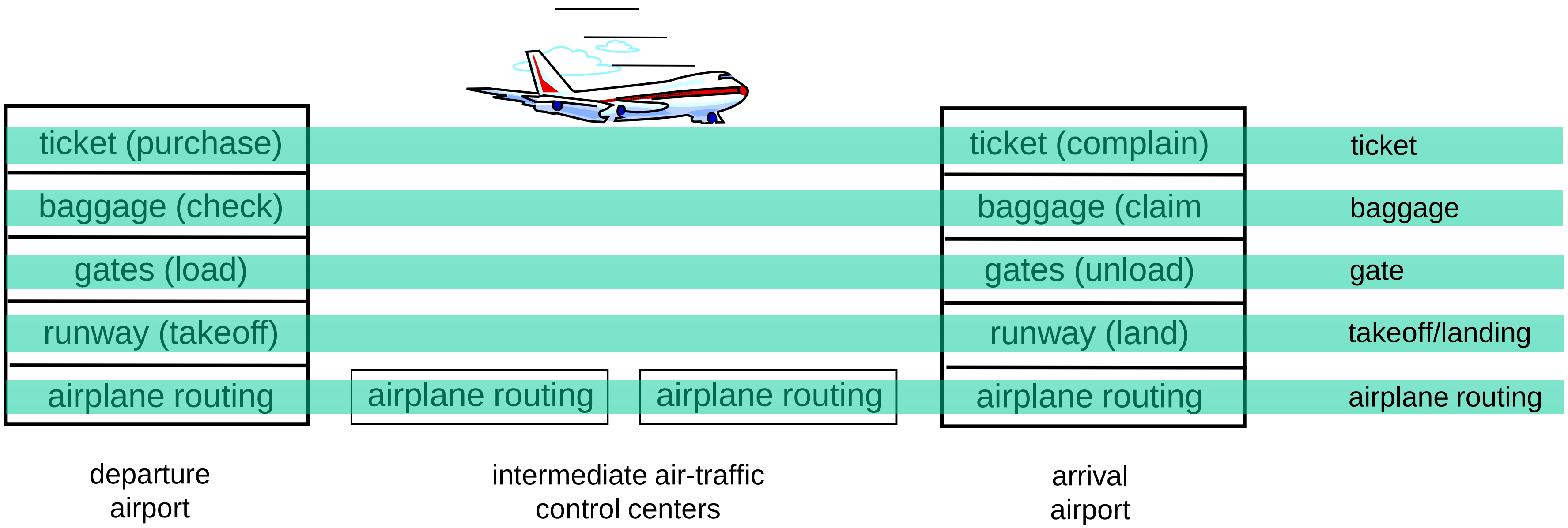
…. or at least our discussion of networks?

Organization of air travel



- a series of steps

Layering of airline functionality



layers: each layer implements a service

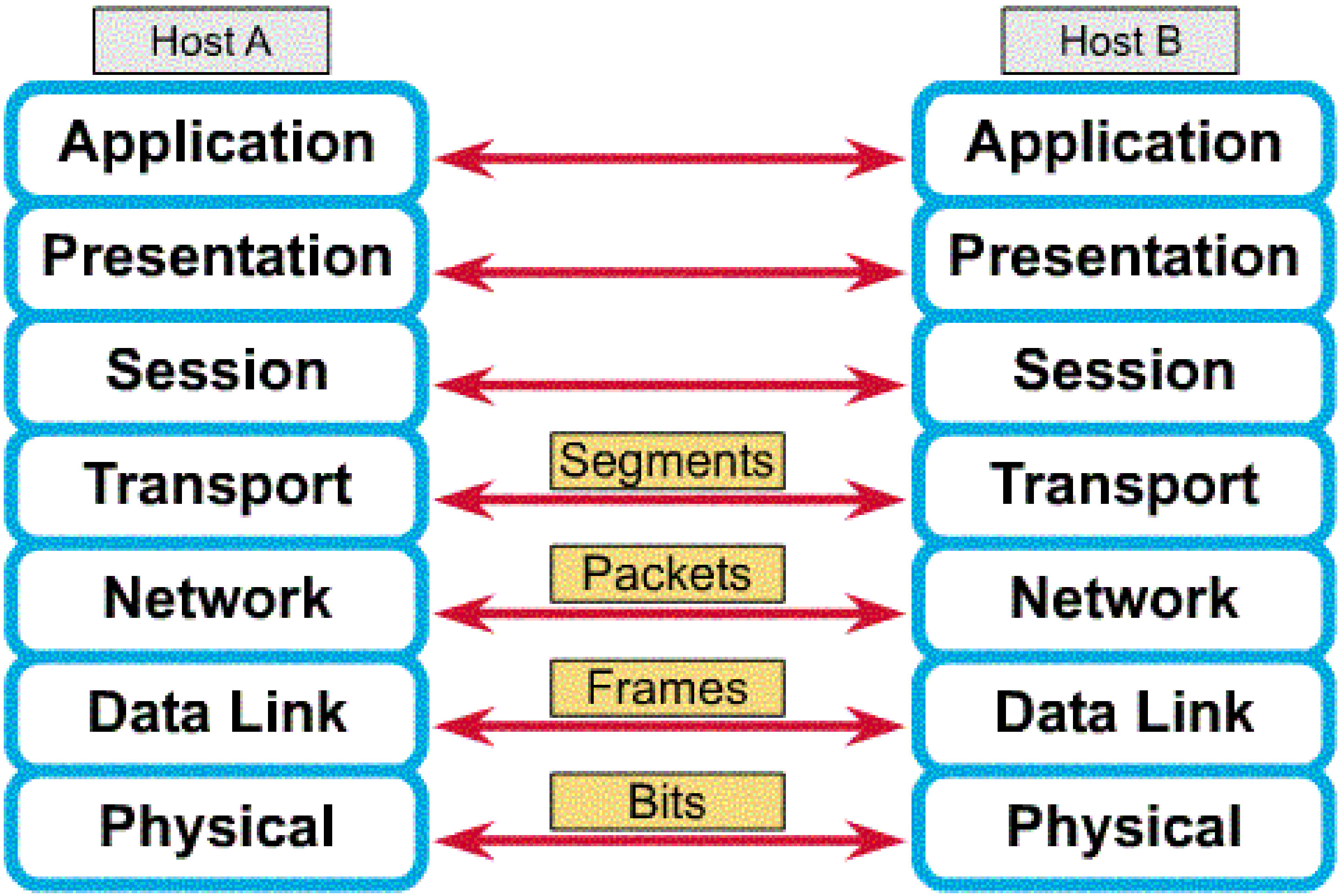
- via its own internal-layer actions
- relying on services provided by layer below

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



Internet protocol stack

- *application:* supporting network applications
  - FTP – transfer of files between two end systems
  - SMTP – transfer of e-mail messages
  - HTTP – provides for web document request and transfer
  - Packet of information - message
- *transport:* process-process data transfer
  - TCP – connection-oriented (guaranteed delivery of application- messages)
    - Breaks long messages into shorter segments
    - Congestion control mechanism
  - UDP (con-less)
    - No reliability, no flow control, and no congestion control

A state occurring in network layer when the message traffic is so heavy that it slows down network response time.

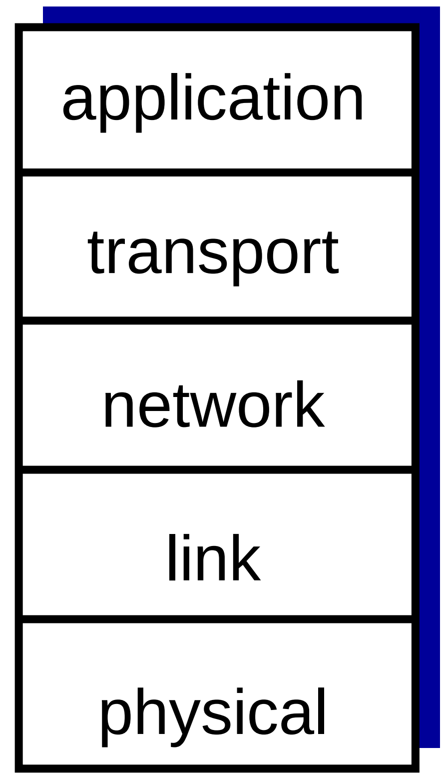
Effects of Congestion

•As delay increases, performance decreases.

•If delay increases, retransmission occurs, making situation worse.

•**Leaky Bucket Algorithm**

•**Token Bucket Algorithm**



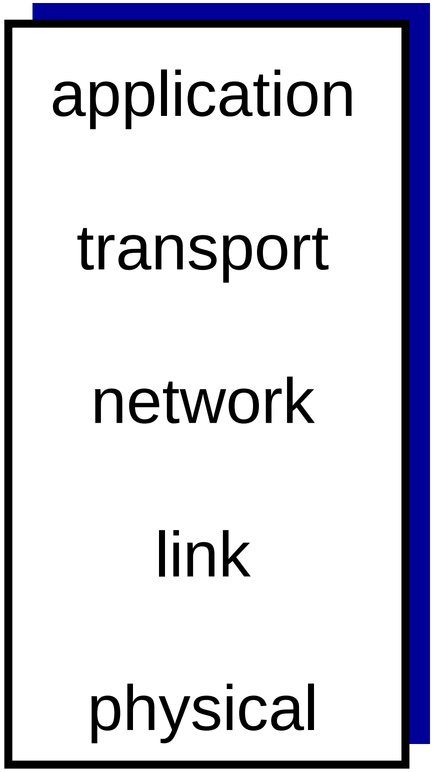
network: routing of datagrams from source to destination

IP, routing protocols (OSPF, BGP, RIP)

link: data transfer between neighboring network elements

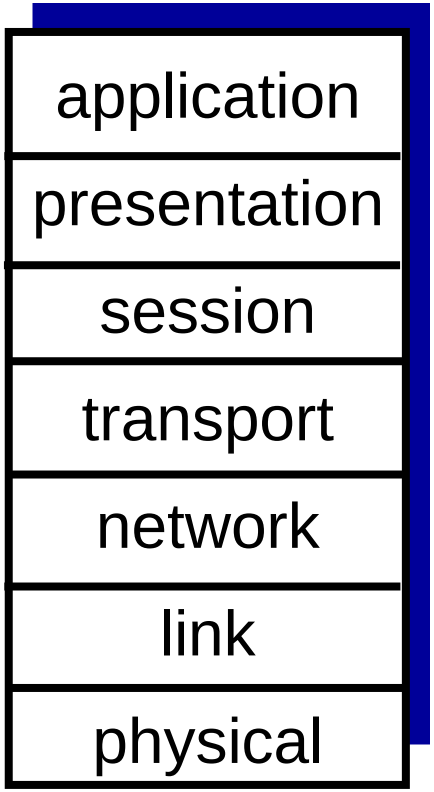
- Ethernet, 802.111 (WiFi), PPP(Point-to-Point Protocol
- Refer packets as frame

physical: bits "on the wire"



ISO/OSI reference model

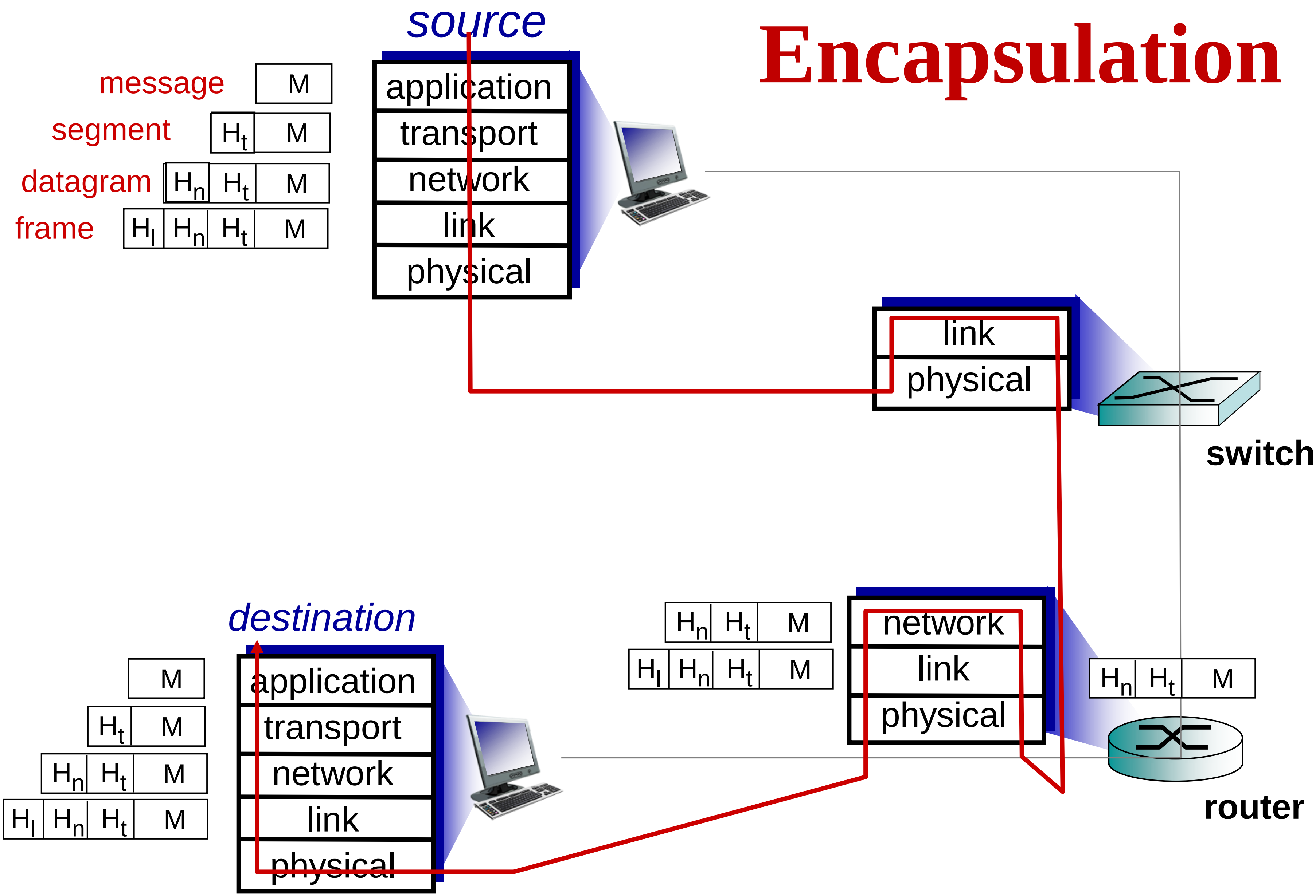
- *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session:* synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed*, must be implemented in application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



ISO/OSI reference model

TCP/IP	OSI Model	Protocols
Application Layer	Application Layer	DNS, DHCP, FTP, HTTPS, IMAP, LDAP, NTP,POP3, RTP, RTSP, SSH, SIP, SMTP, SNMP, Telnet, TFTP
	Presentation Layer	JPEG, MIDI, MPEG, PICT, TIFF
	Session Layer	NetBIOS, NFS, PAP, SCP, SQL, ZIP
Transport Layer	Transport Layer	TCP, UDP
Internet Layer	Network Layer	ICMP, IGMP, IPsec, IPv4, IPv6, IPX, RIP
Link Layer	Data Link Layer	ARP, ATM, CDP, FDDI, Frame Relay, HDLC, MPLS, PPP, STP, Token Ring
	Physical Layer	Bluetooth, Ethernet, DSL, ISDN, 802.11 Wi-Fi

Encapsulation



Thank You