2. Internet Overview

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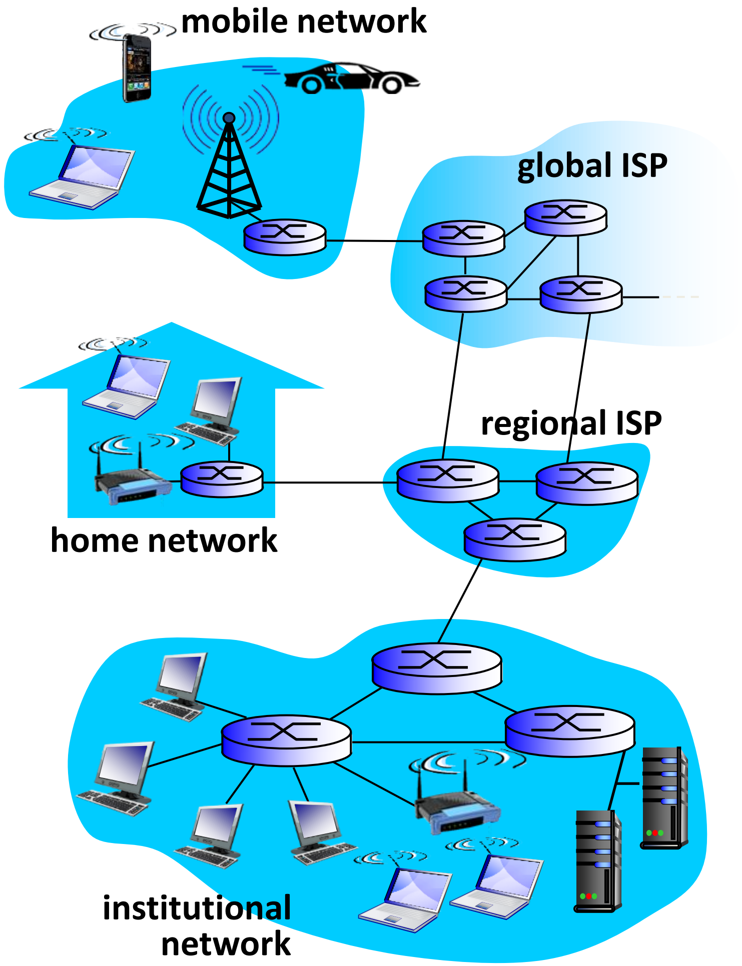
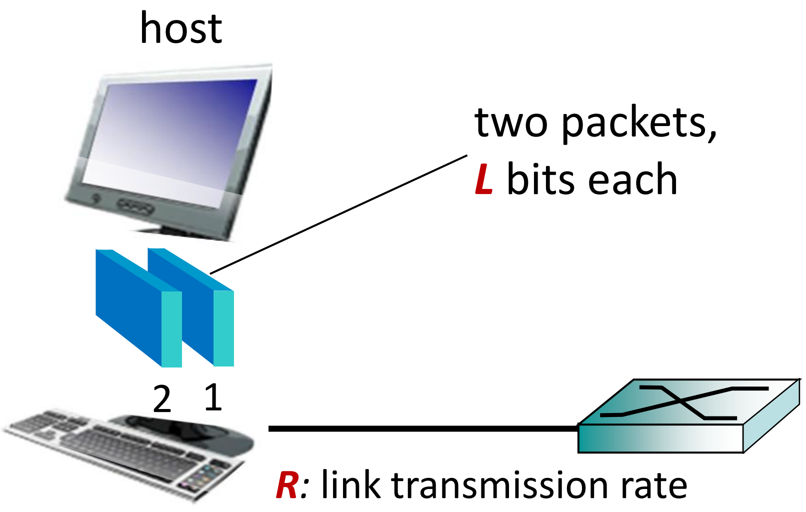
A closer look at network structure

- *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

- Breaks application data into smaller **packets** of length ***L*** bits
- Transmits a packet into access network at transmission rate ***R***
  - link **transmission rate**, aka link **capacity** or link **bandwidth**



host

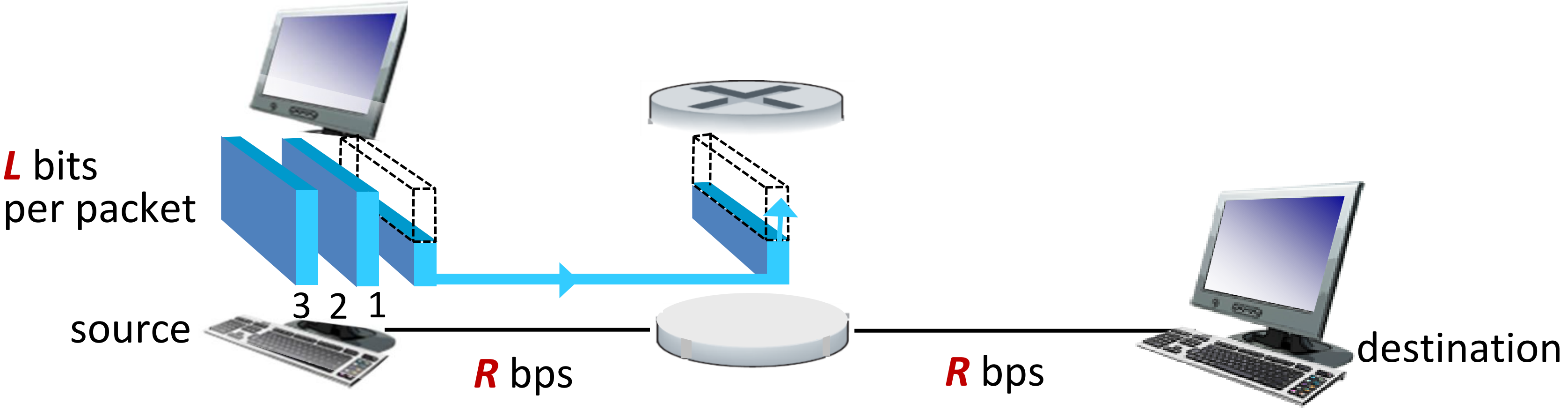
two packets, ***L*** bits each

2 1

R: link transmission rate

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

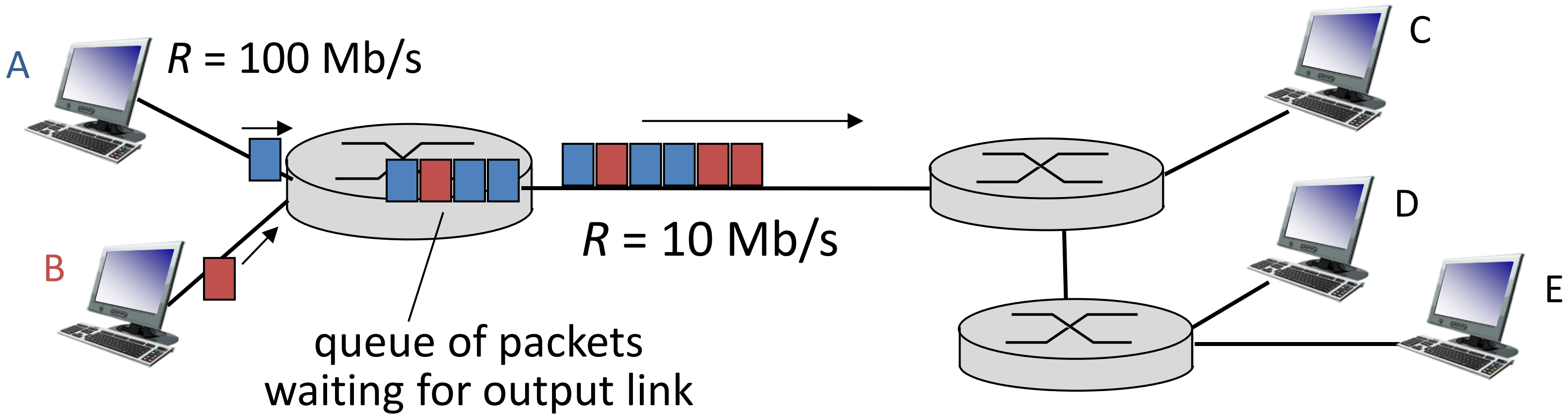
Packet Switching: store-and-forward



- ***Store and forward:*** entire packet must arrive at router before it can be transmitted on next link

- **(End-to-end) sum of transmission delays** = 2x(***L***/***R***)
  – If L = 1 Mbits and R = 1 Mbps, E2E transmission delay is 2 seconds.
  – How about other delays ? : propagation delay, queuing delay

Packet Switching: queueing delay, loss



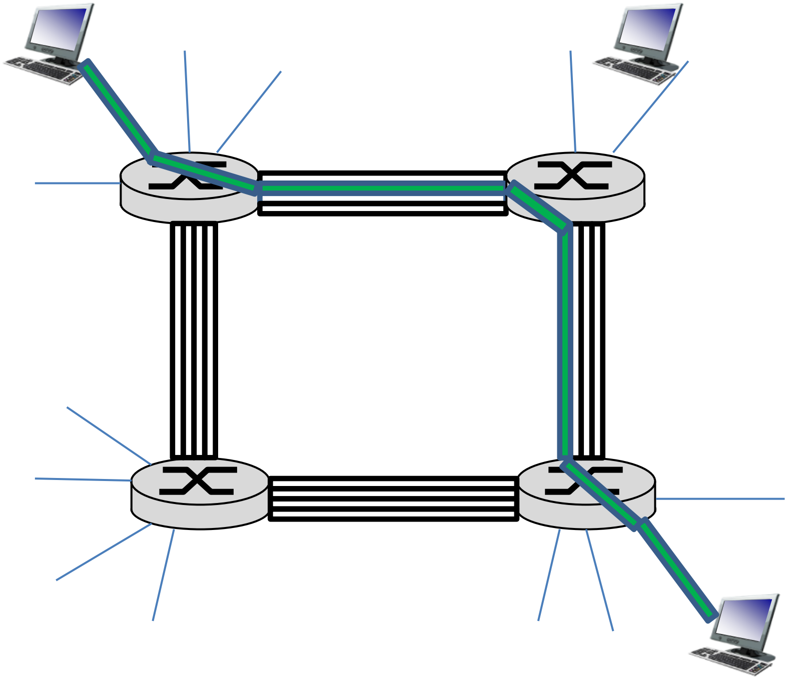
- If packet arrival rate **exceeds** packet forwarding rate;
  - Packets should wait to be transmitted on link
  - Packets can be **dropped** (lost) if queue (buffer) fills up

Alternative circuit switching

- End to end resources are **reserved** between src & dest:

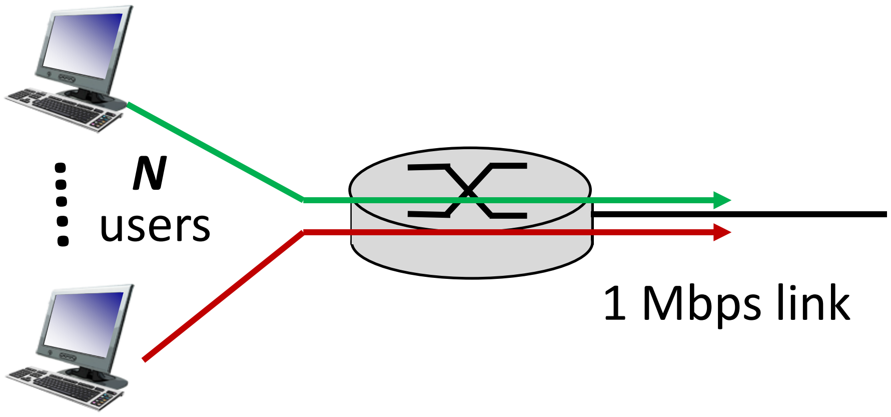
- Dedicated resources: **no sharing**
  - **guaranteed** performance

- Commonly used in traditional telephone networks



Packet switching vs. circuit switching

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



- **Circuit** switching:
  - 10 users

- **Packet** switching:
  - with 35 users, the probability in case of more than 10 active users at same time is less than 0.0004

- Packet switching allows more users to use network!

Packet switching vs. circuit switching

Is packet switching is always better ?

- Great for **bursty** data (only one user generates 1 Mbit data.)
  - better resource sharing
  - simpler, no call setup

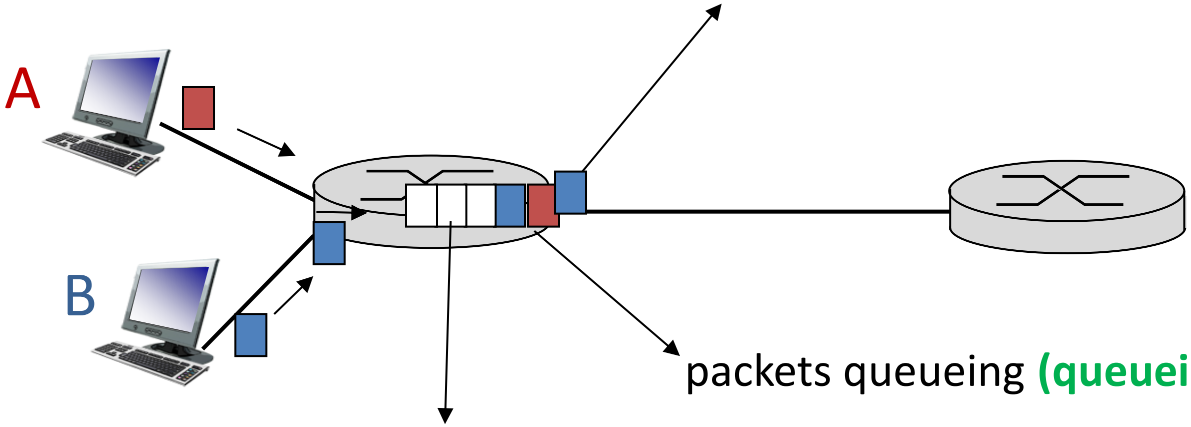
- **Excessive congestion** possible: packet delay and loss
  - Needed for reliable data transfer, congestion control

- How to provide **bandwidth guarantees** for audio/video apps ?

Delay, Loss, Throughput in packet switched networks

How do loss and delay occur?

- Packets **queue** in router buffers
  - Packet arrival rate to link (temporarily) **exceeds** output link capacity

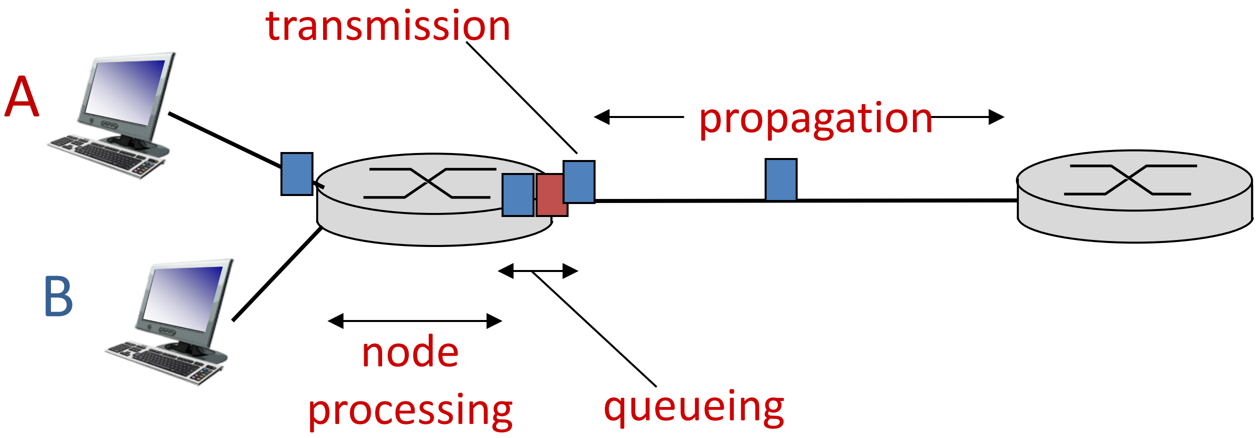


packet being transmitted **(transmission delay)**

packets queueing **(queueing delay)**

Free (available) buffers.
Arriving packets drop (**loss**) if no free buffers.

Four sources of packet delay



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

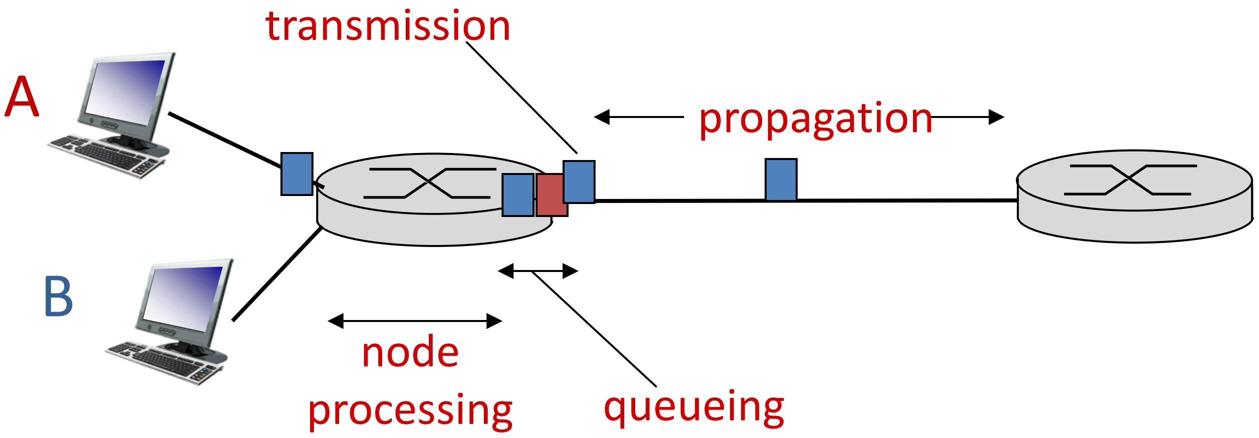
d_{trans}: transmission delay

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

d_{prop}: propagation delay

- D: distance of physical link
- S: propagation speed in medium (~$2\text{x}10^8$ m/sec)
- $d_{prop} = D/S$

Four sources of packet delay



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

$\boldsymbol{d}_{\textbf{proc}}$: processing delay

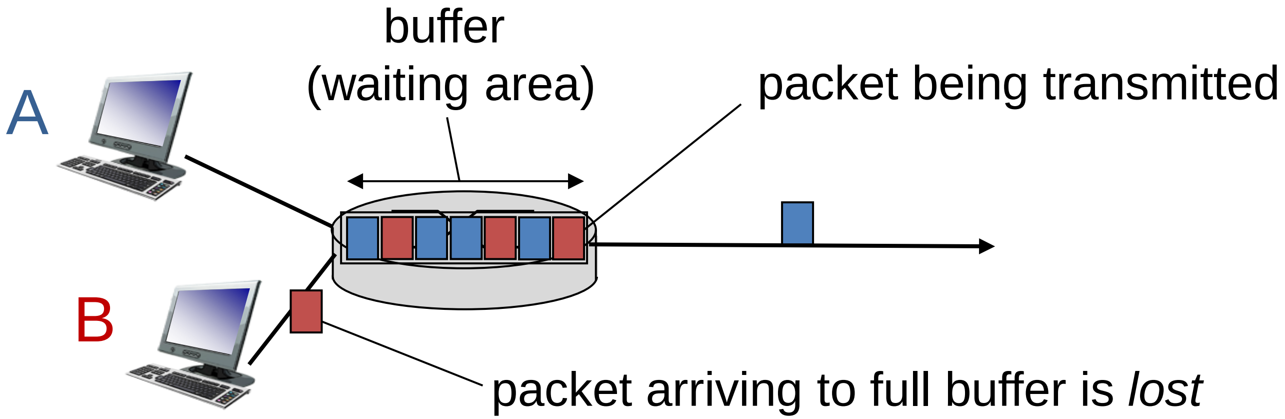
- check bit errors
- determine output link
- typically < msec

$\boldsymbol{d}_{\textbf{queue}}$: queueing delay

- time waiting for transmission
- depends on congestion level of router

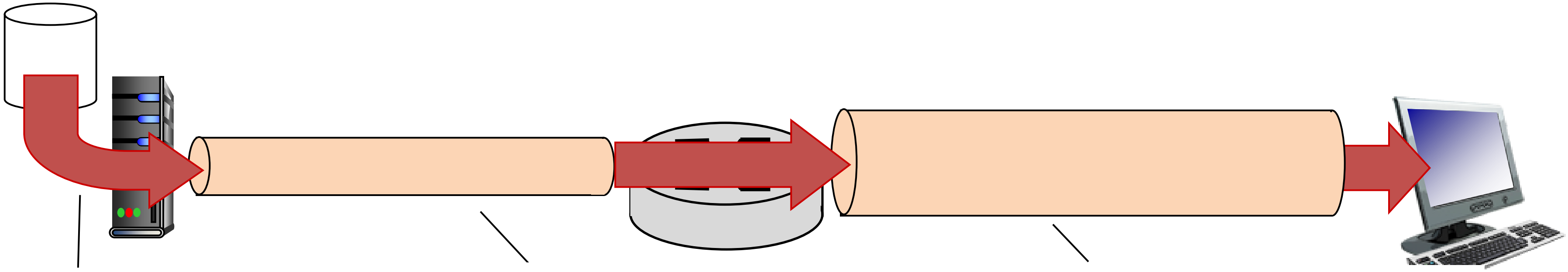
Packet loss

- Queue (or buffer) has **finite** capacity
- Packet arriving to full queue is **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



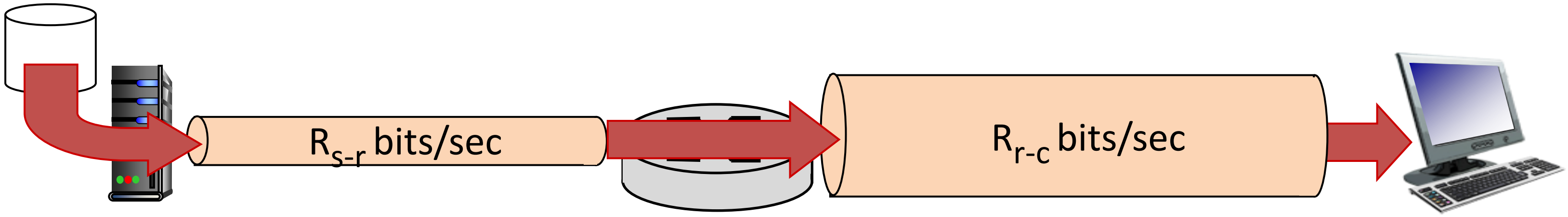
server sends bits (fluid) into pipe

pipe that can carry fluid at rate (R_{s-r} bits/sec)

pipe that can carry fluid at rate (R_{r-c} bits/sec)

Throughput (more)

- $R_{s\text{-}r} < R_{r\text{-}c}$ What is average end-end throughput?



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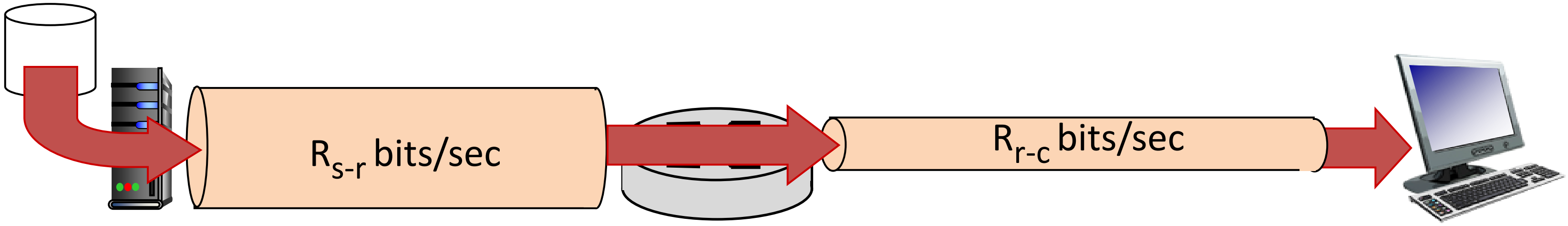
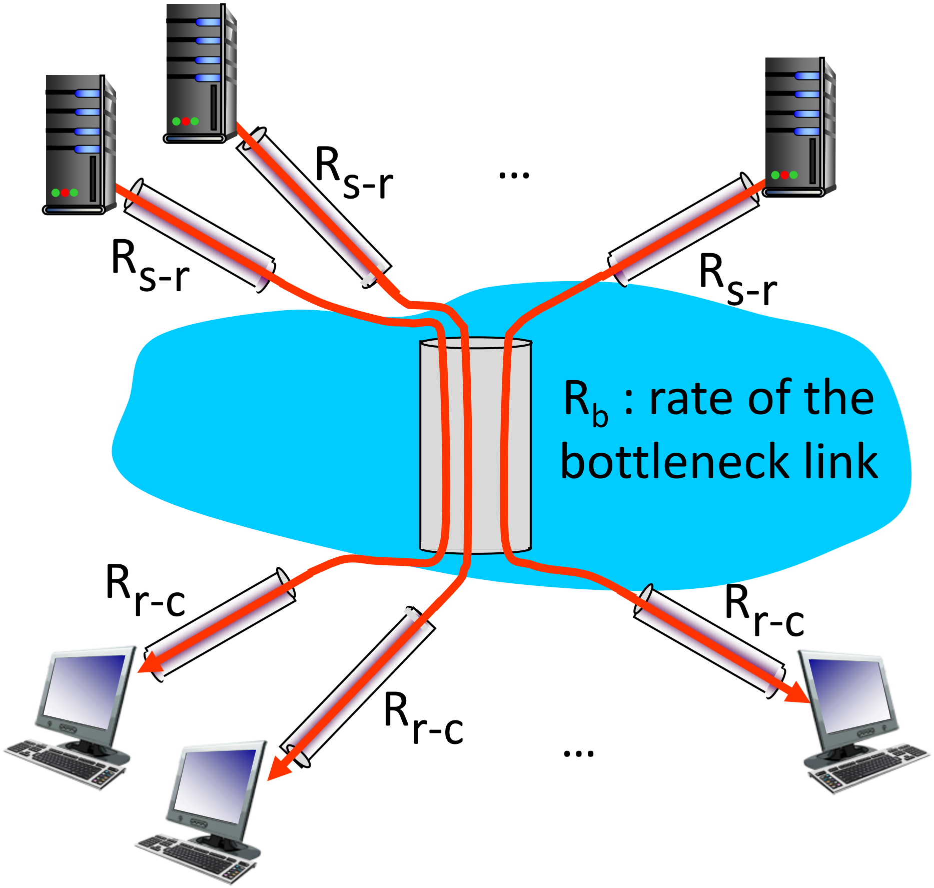


bottleneck link

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

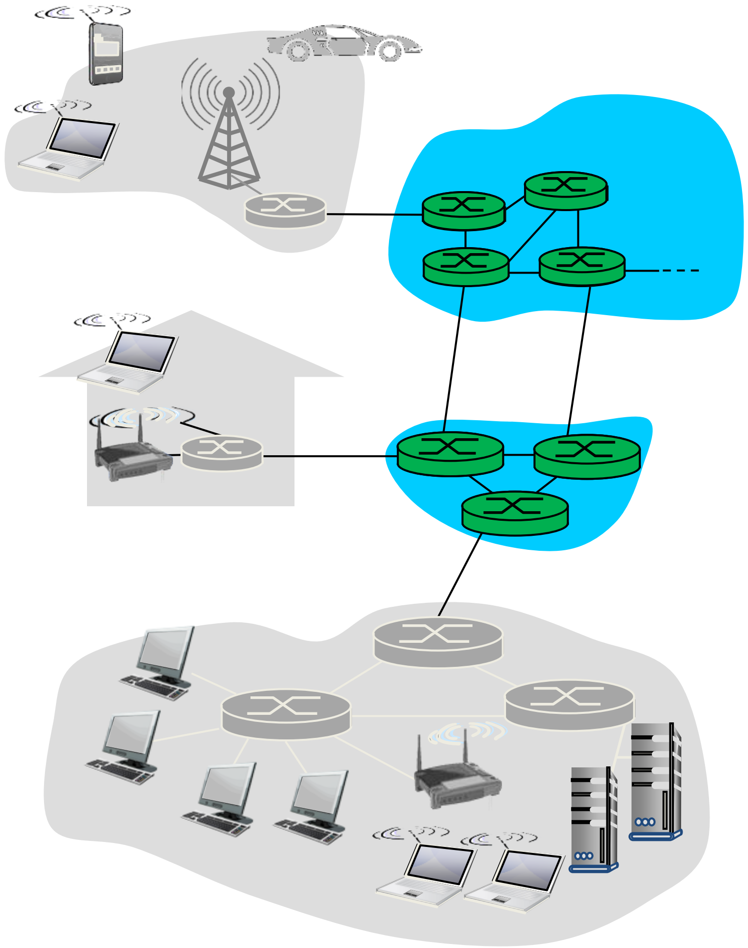
Throughput (more)



Question: How can multiple flows (fairly) share bottleneck link ?

The network core

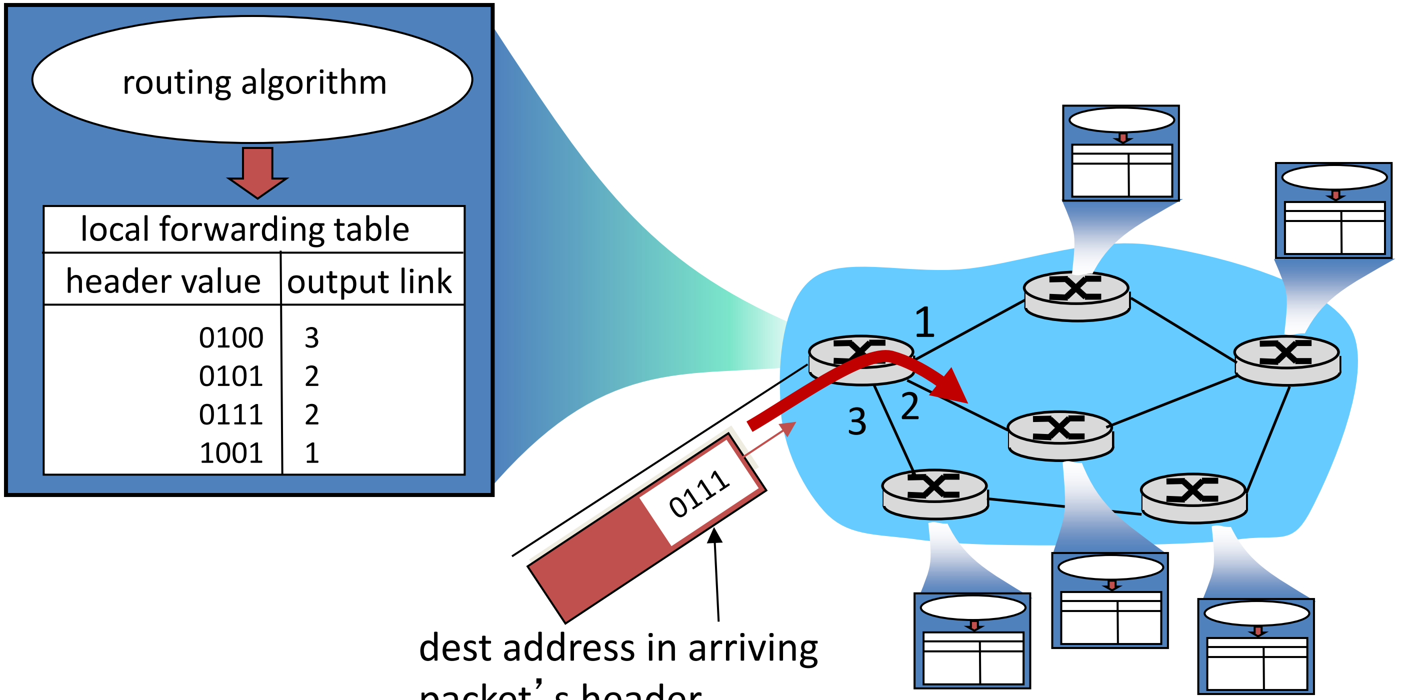
- Mesh of interconnected routers
- Routers forward packets to the next router on path from source to destination



Two key network-core functions

routing: determines route of packets by routing algorithms

forwarding: move packets from a router input to a router output



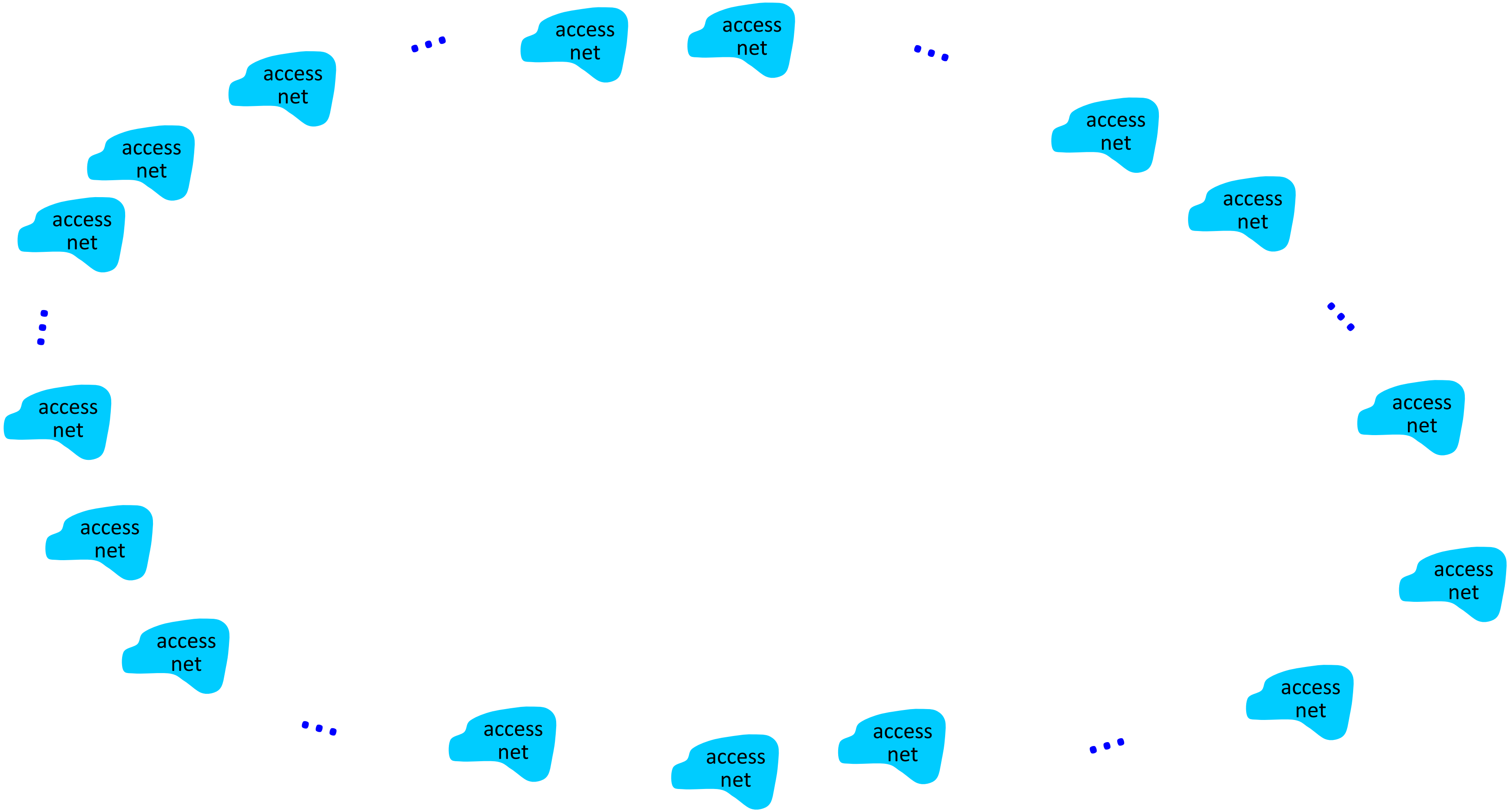
local forwarding table

header value	output link
0100	3
0101	2
0111	2
1001	1

dest address in arriving packet’s header

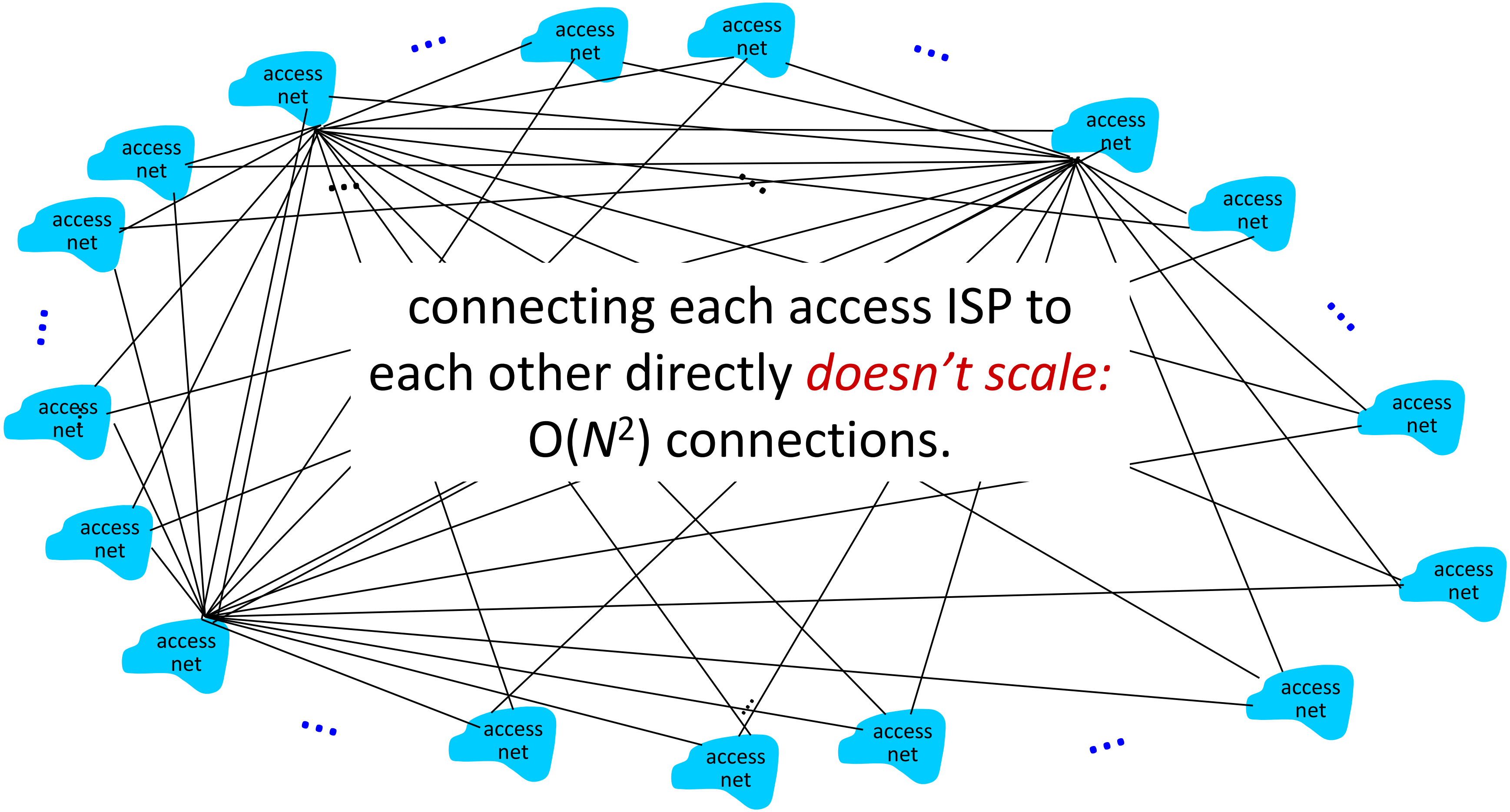
Internet structure: network of networks

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



Internet structure: network of networks

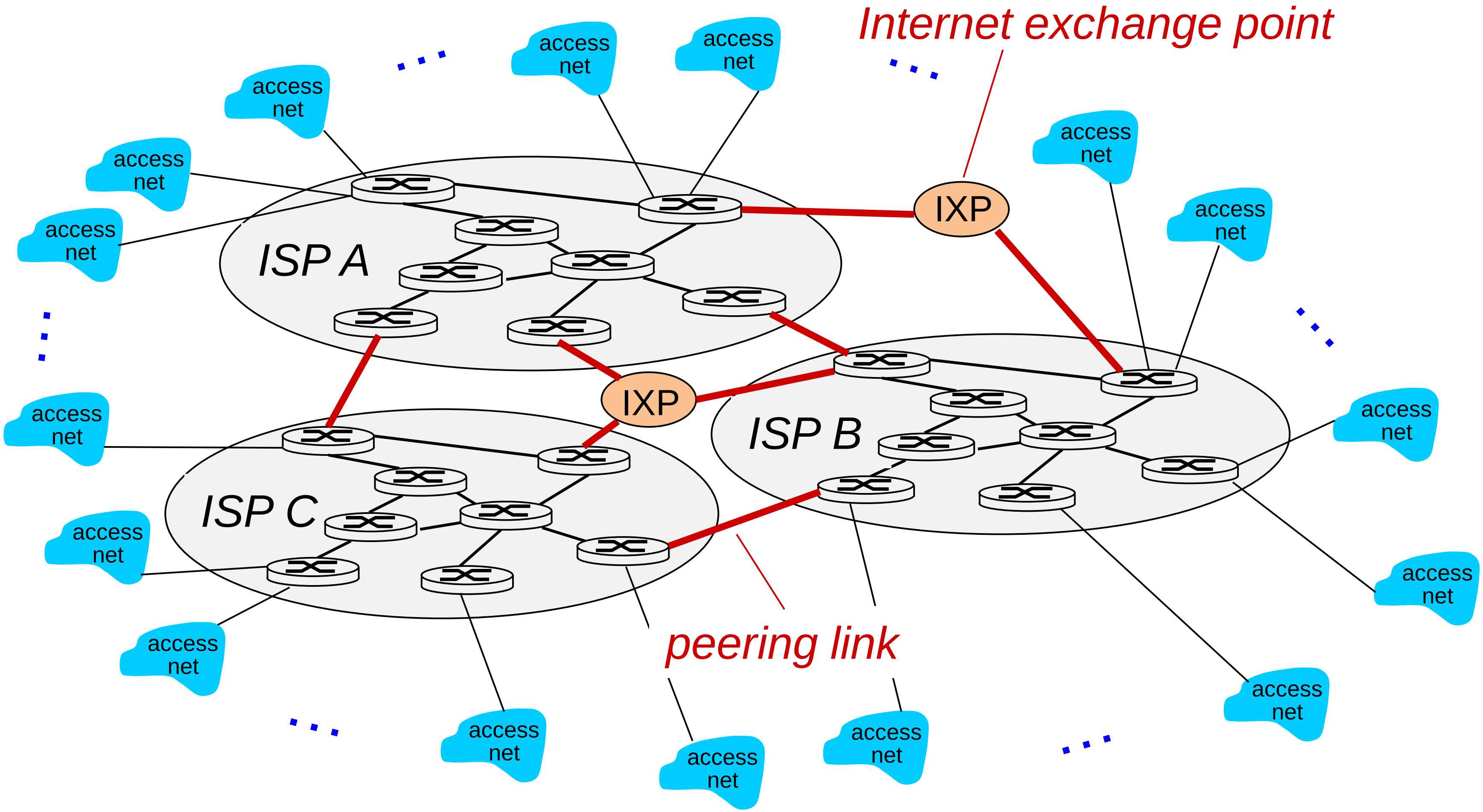
Option: connect each access ISP to every other access ISP?



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.



Protocol Layers and Encapsulation

What is a protocol?

Human protocols:

- "What time is it now?"
- "May I have a question?"
- "Would you like a coffee?"

… specific msgs sent

… specific actions taken when received msgs

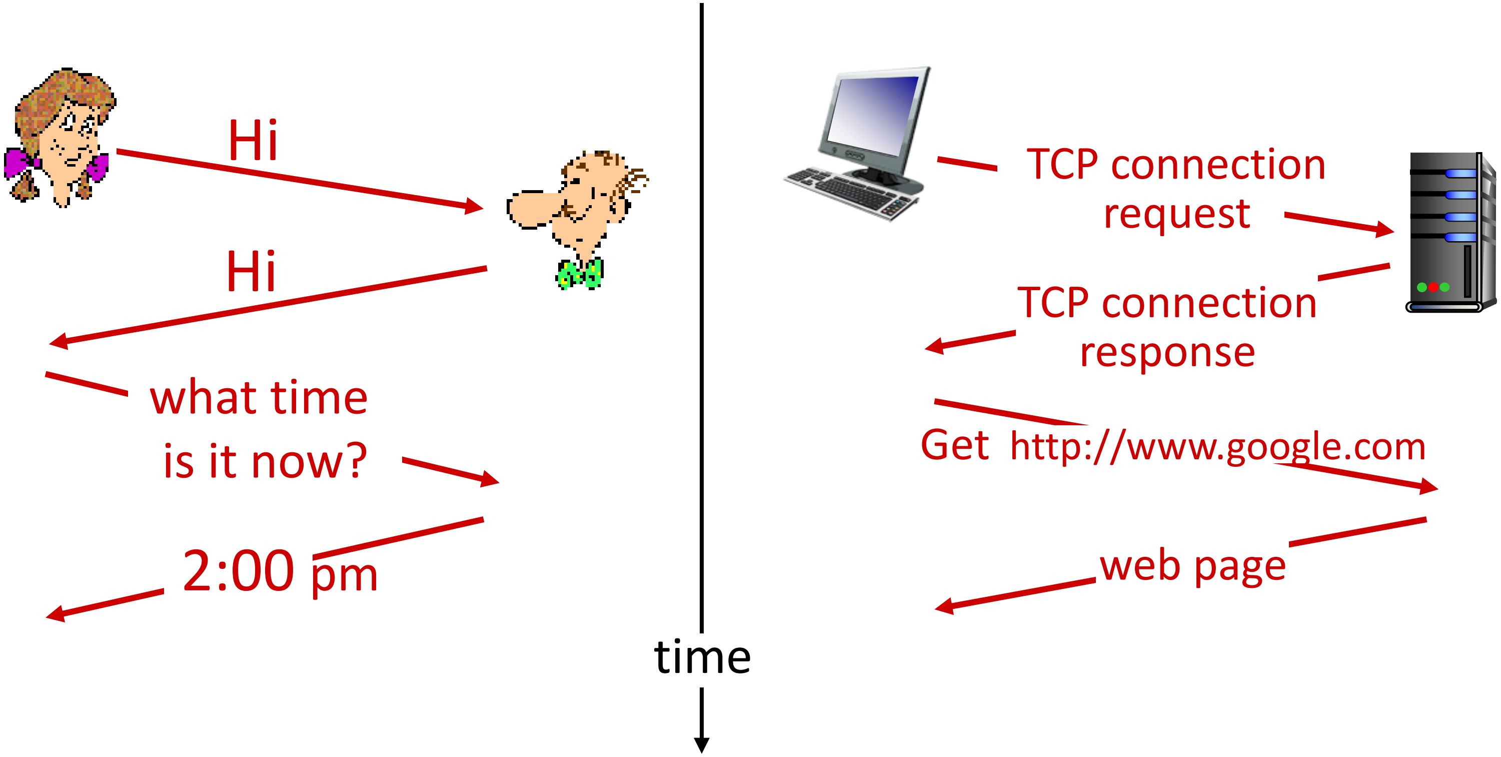
Network protocols:

- 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 receipt*

What is a protocol?

a human protocol and a computer network protocol:



Hi

Hi

what time
is it now?

2:00 pm

TCP connection
request

TCP connection
response

Get http://www.google.com

web page

time

Protocol “layers”

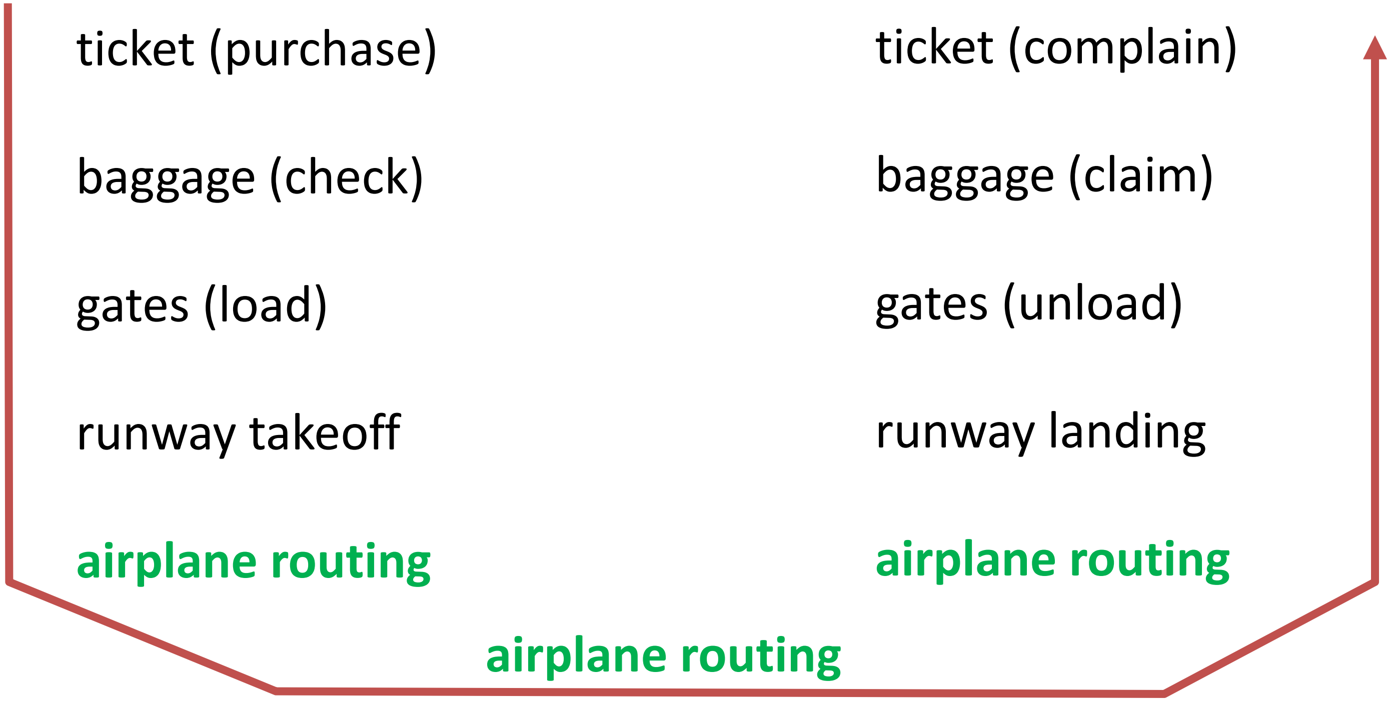
Networks are complex, with many “pieces”:

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

Question:

How to organize the network structure?

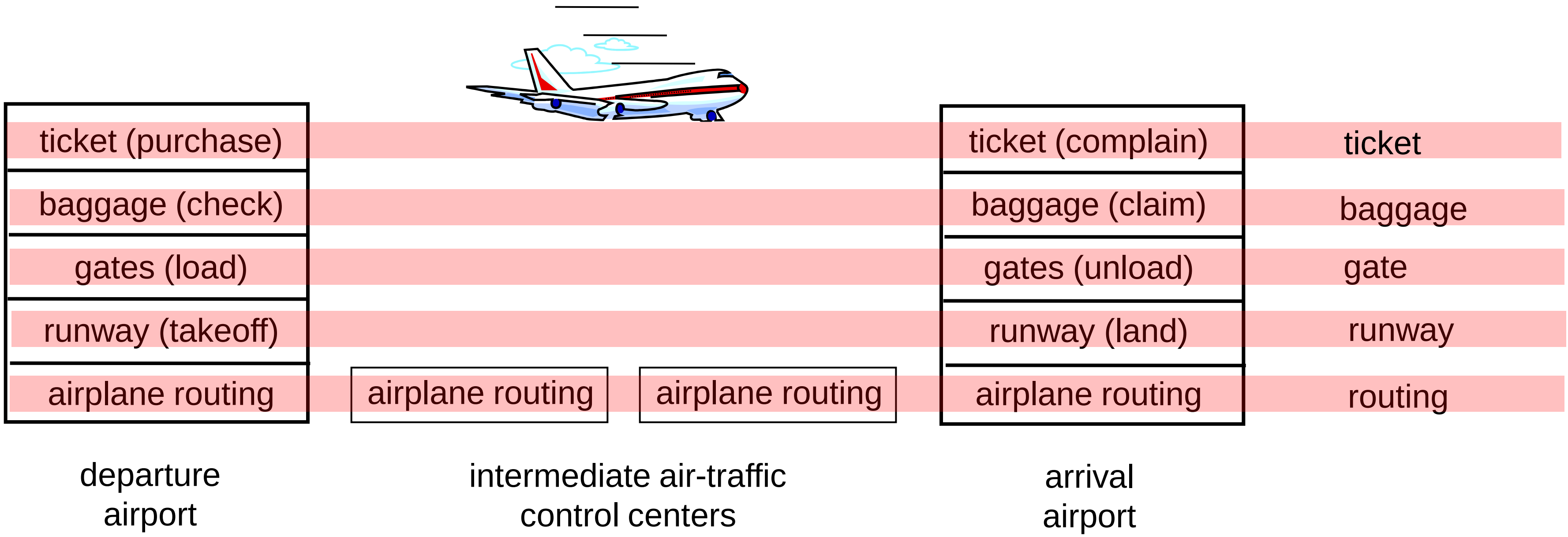
Organization of air travel



ticket (purchase)	ticket (complain)
baggage (check)	baggage (claim)
gates (load)	gates (unload)
runway takeoff	runway landing
airplane routing	**airplane routing**

airplane routing

Layering of airline functionality



departure airport	intermediate air-traffic control centers		arrival airport	
ticket (purchase)			ticket (complain)	ticket
baggage (check)			baggage (claim)	baggage
gates (load)			gates (unload)	gate
runway (takeoff)			runway (land)	runway
airplane routing	airplane routing	airplane routing	airplane routing	routing

layers: each layer implements a specific service

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

Why layering?

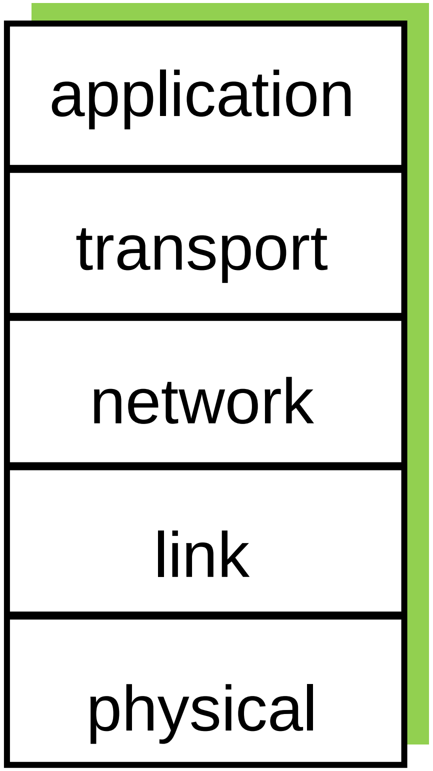
Dealing with complex systems:

- Layered architecture allows **identification**, **relationship** of complex system' s pieces

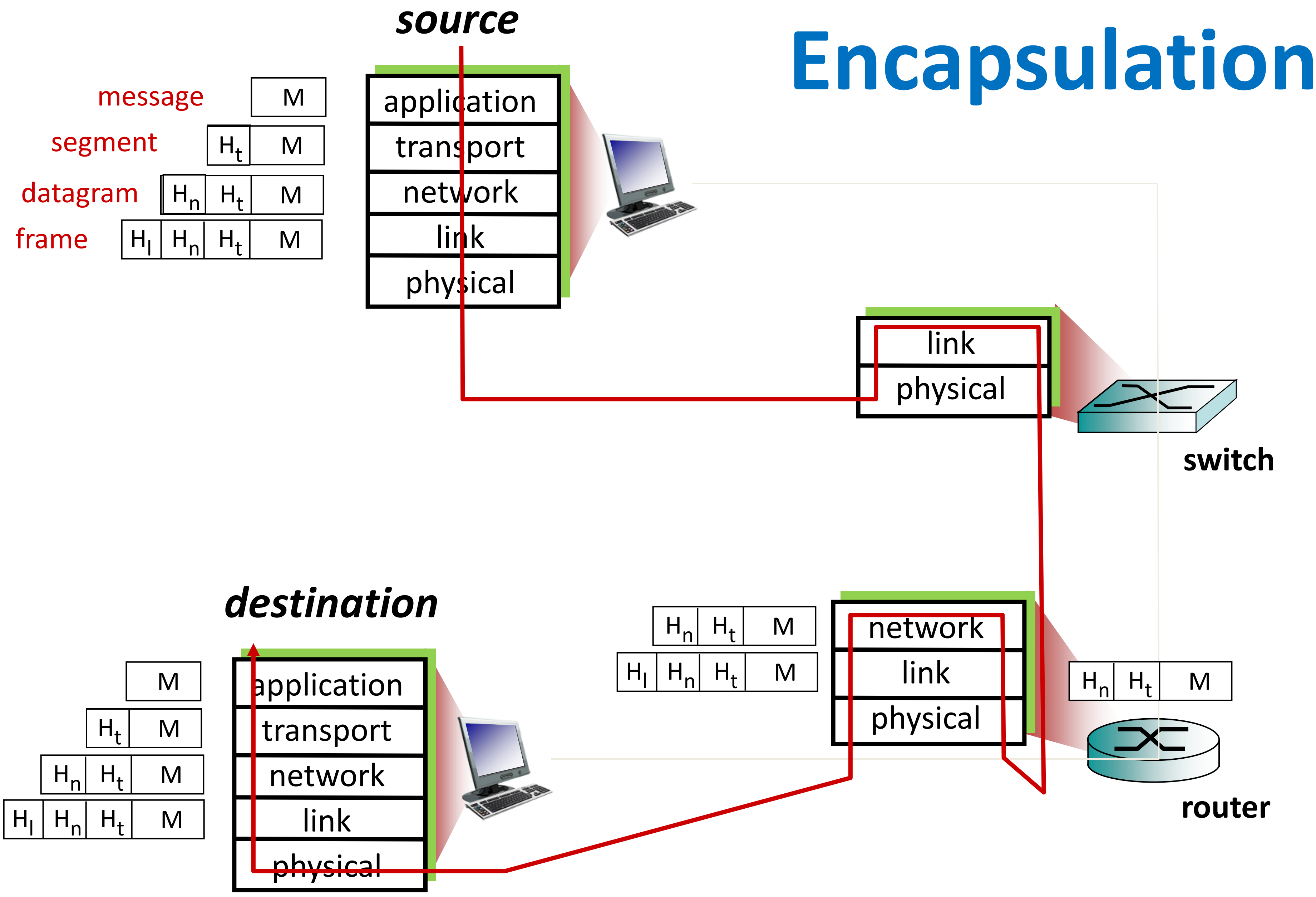
- Modularization eases **maintenance**, updating of system
  - change of implementation of layer's service transparent to rest of system

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), token ring
- ***physical:*** bits “on the wire”



Encapsulation


source
message
M
segment
H_t M
datagram
H_n H_t M
frame
H_l H_n H_t M
application
transport
network
link
physical
link
physical
switch
destination
M
H_t M
H_n H_t M
H_l H_n H_t M
application
transport
network
link
physical
H_n H_t M
H_l H_n H_t M
network
link
physical
H_n H_t M
router