Chapter 1
Introduction

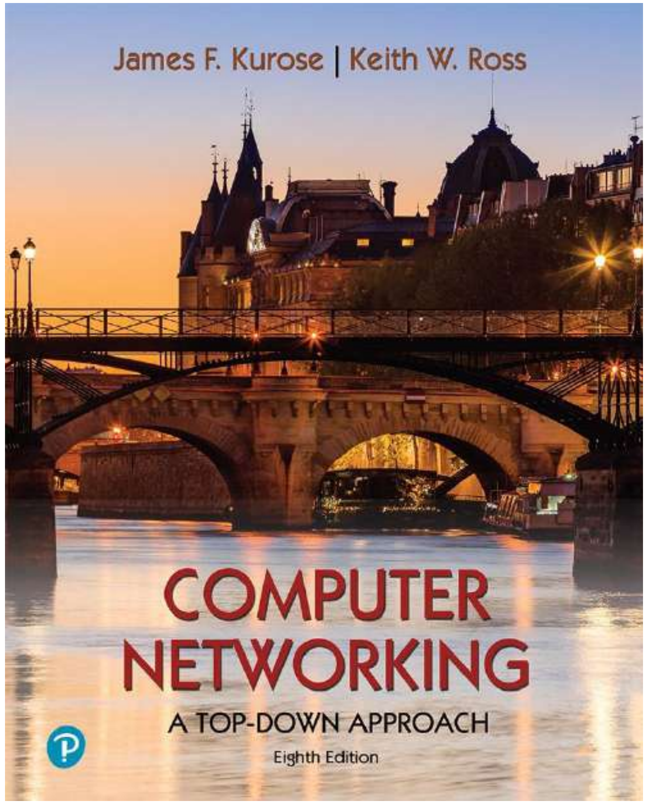
A note on the use of these PowerPoint slides:

We're making these slides freely available to all (faculty, students, readers). They're in PowerPoint form so you see the animations; and can add, modify, and delete slides (including this one) and slide content to suit your needs. They obviously represent a *lot* of work on our part. In return for use, we only ask the following:

- If you use these slides (e.g., in a class) that you mention their source (after all, we'd like people to use our book!)
- If you post any slides on a www site, that you note that they are adapted from (or perhaps identical to) our slides, and note our copyright of this material.

For a revision history, see the slide note for this page.

Thanks and enjoy! JFK/KWR



Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Chapter 1: introduction

Chapter goal:

- Get "feel," "big picture," introduction to terminology
  - more depth, detail *later* in course

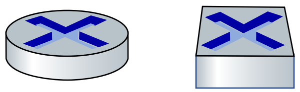
Overview/roadmap:

- What *is* the Internet? What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Protocol layers, service models
- Security ไม่ออกสอบ
- History ไม่ออกสอบ

The Internet: a "nuts and bolts" view

Billions of connected computing *devices*:

- *hosts = end systems*
- running *network apps* at Internet's "edge"



Packet switches: forward packets (chunks of data)

อุปกรณ์ใน Internet

- *routers, switches*

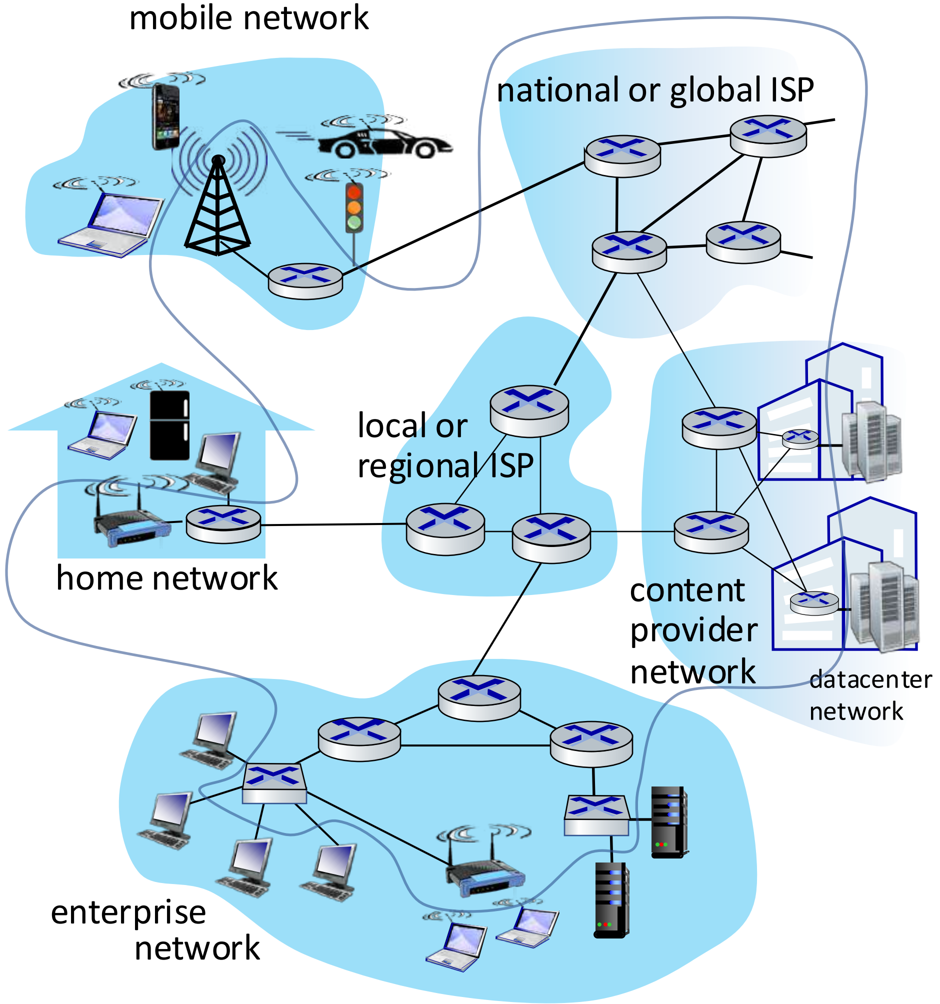
Communication links

จับต้องได้ จับต้องไม่ได้

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

Networks

- collection of devices, routers, links: managed by an organization



“Fun” Internet-connected devices

Amazon Echo

Internet refrigerator

IP picture frame

Pacemaker & Monitor

Tweet-a-watt: monitor energy use

bikes

cars

Web-enabled toaster + weather forecaster

Security Camera

Slingbox: remote control cable TV

AR devices

scooters

Internet phones

Gaming devices

sensorized, bed mattress

Fitbit

diapers

Others?

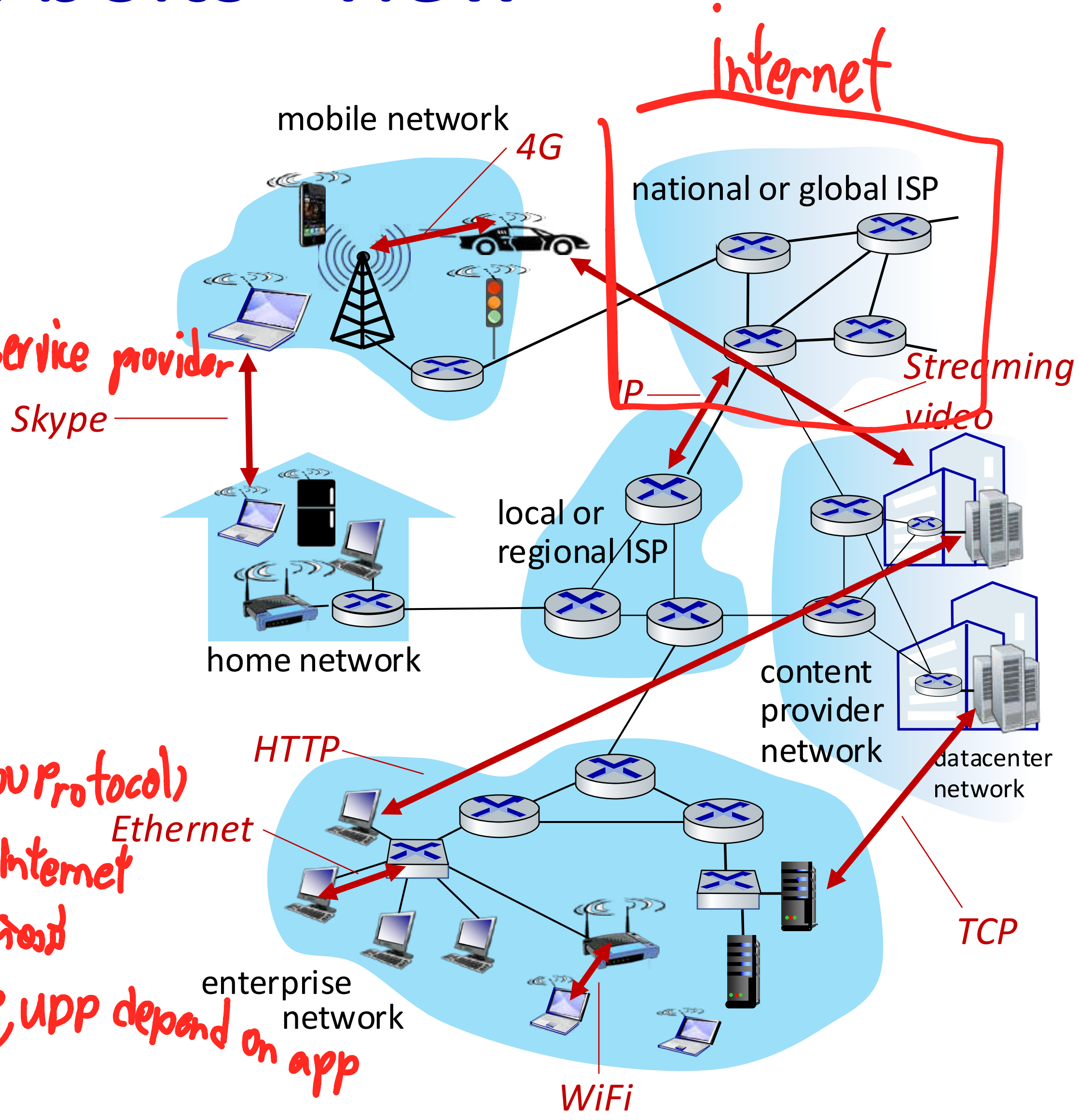
The Internet: a "nuts and bolts" view

internet : เครือข่ายทั่วไป

เครือข่ายระดับโลก

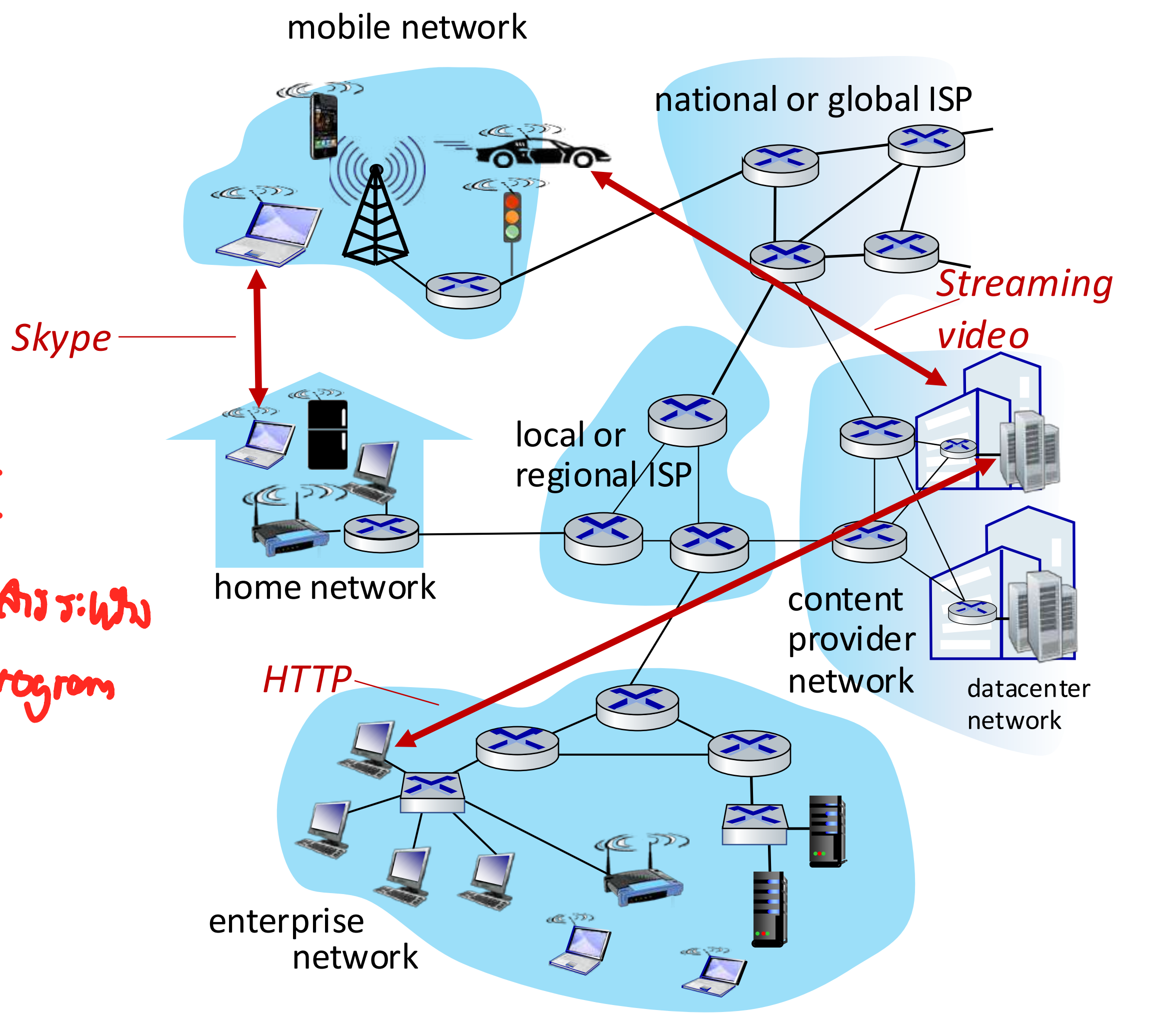
- *Internet:* "network of networks"
  - Interconnected ISPs เชื่อมระหว่างกันด้วย ISP internet service provider
- *protocols* are *everywhere*
  - control sending, receiving of messages
  - e.g., HTTP (Web), streaming video, Skype, TCP, IP, WiFi, 4/5G, Ethernet
- *Internet standards* กฎเกณฑ์ของ Internet (ออกแบบ Protocol)
  - RFC: Request for Comments : กำหนดมาตรฐาน Internet
    ↳ IP ต่างๆ
  - IETF: Internet Engineering Task Force : ดูแลมาตรฐานใหม่ Technology

TCP, UDP depend on app



The Internet: a "services" view

- *Infrastructure* that provides services to applications: คล้ายไฟฟ้า
  - Web, streaming video, multimedia teleconferencing, email, games, e-commerce, social media, inter-connected appliances, …
- provides *programming interface* API to distributed applications:
  ตัวสื่อสารระหว่าง Program
  - "hooks" allowing sending/receiving apps to "connect" to, use Internet transport service
  - provides service options, analogous to postal service



มารยาท, รูปแบบการสื่อสาร

What's a protocol?

Human protocols:

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

Rules for:

… specific messages sent

… specific actions taken when message received, or other events

Network protocols:

ทำให้อุปกรณ์สื่อสารกันได้
(รูปแบบเฉพาะในการร่วมกัน)

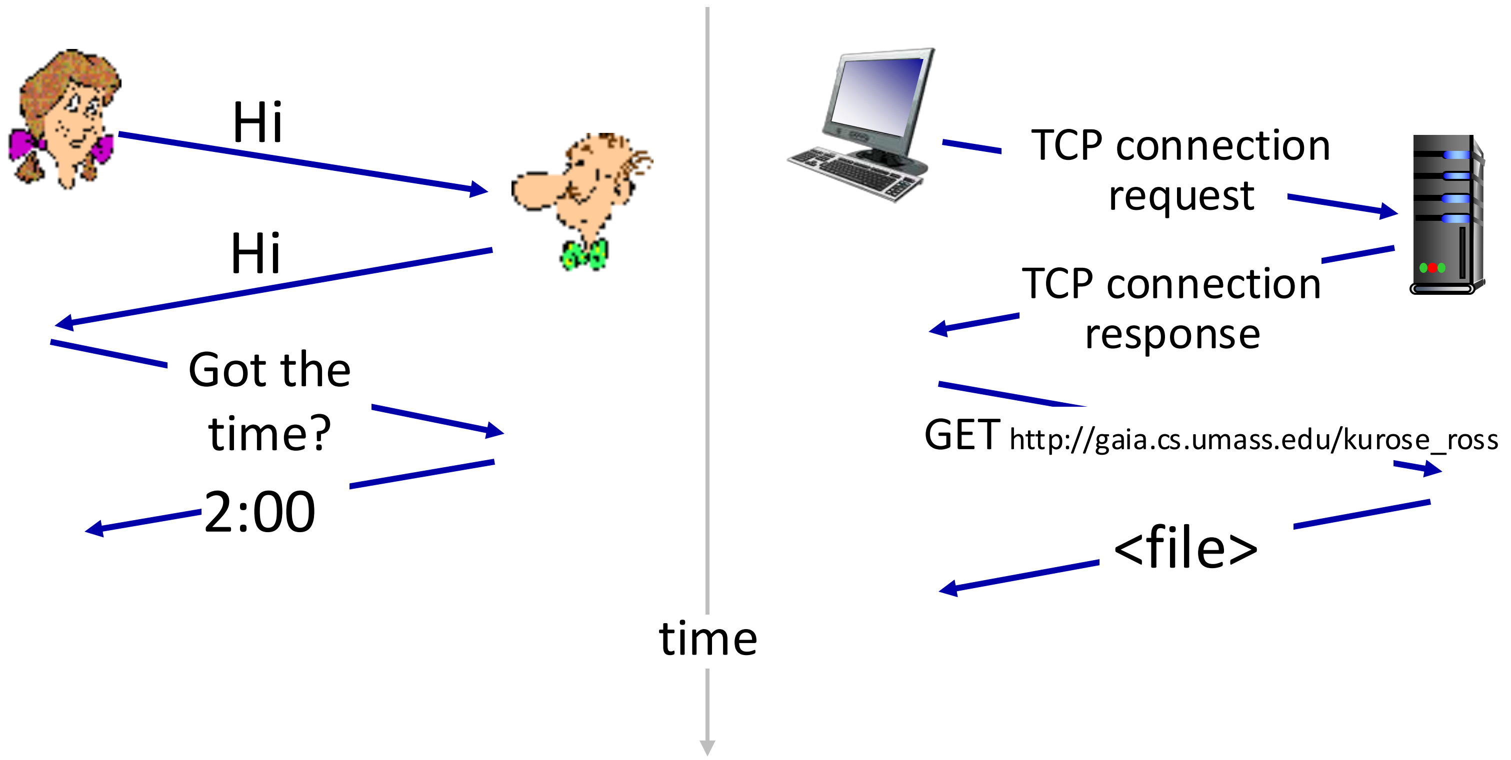
- computers (devices) rather than humans
- all communication activity in Internet governed by protocols

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

คล้ายภาษาอันหนึ่ง

What's a protocol?

A human protocol and a computer network protocol:



Q: other human protocols?

Chapter 1: roadmap

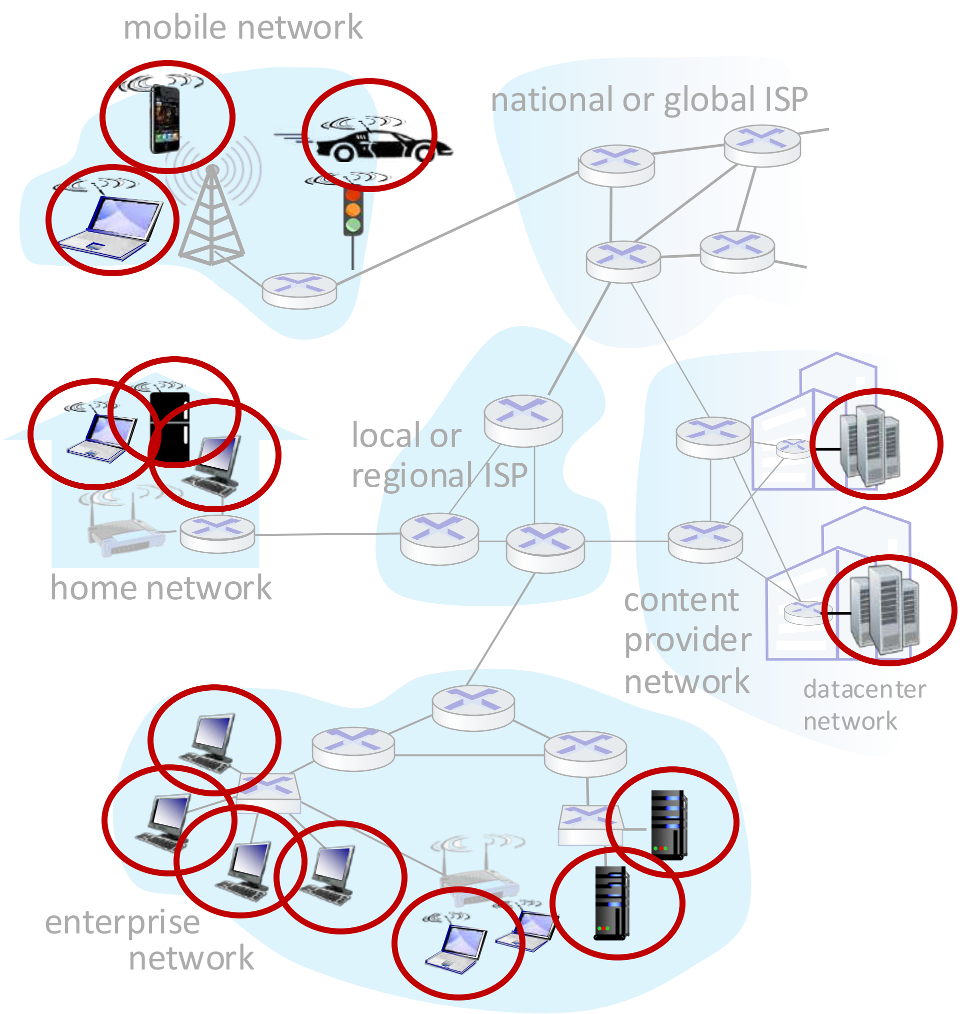
- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models
- History

A closer look at Internet structure

ปลายทางของ network → อุปกรณ์ (device)

Network edge:

2 ประเภท
- hosts: clients and servers
- servers often in data centers



A closer look at Internet structure

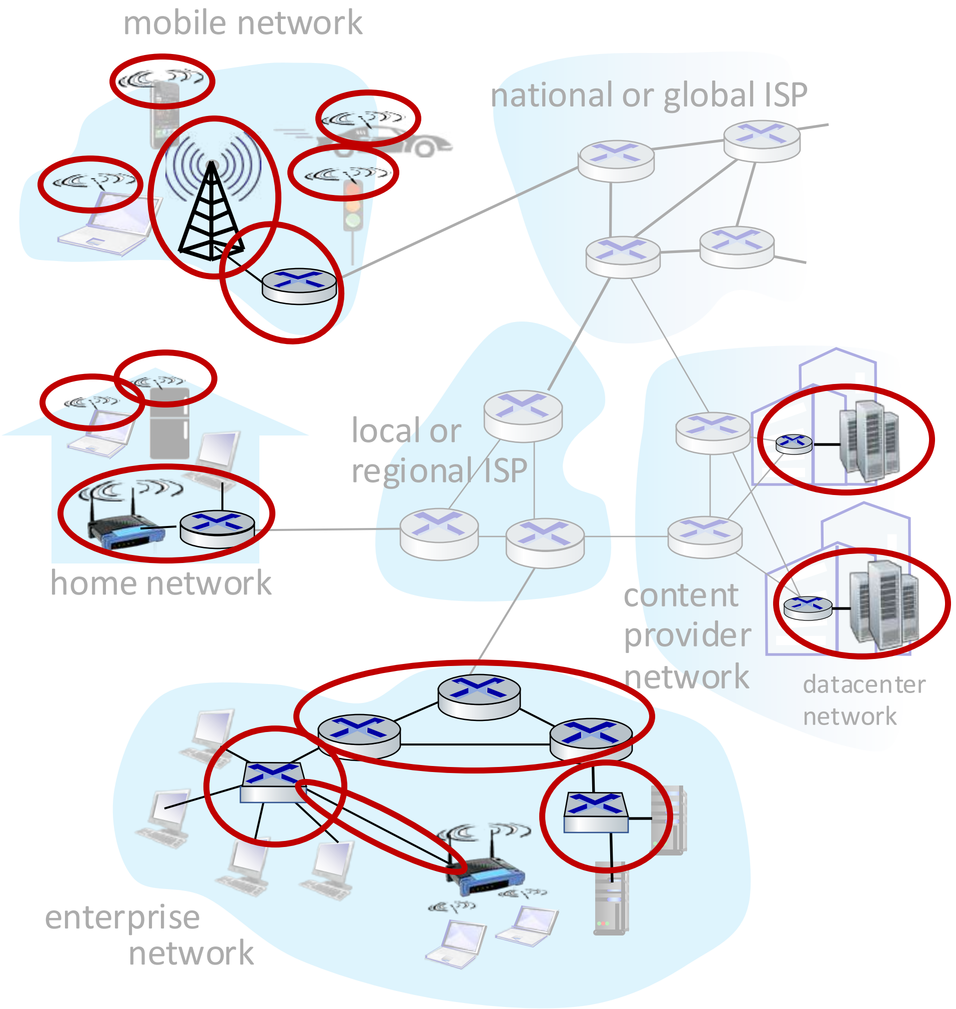
Network edge:

- hosts: clients and servers
- servers often in data centers

เข้าถึง Internet

Access networks, physical media:

- wired, wireless communication links



A closer look at Internet structure

Network edge:

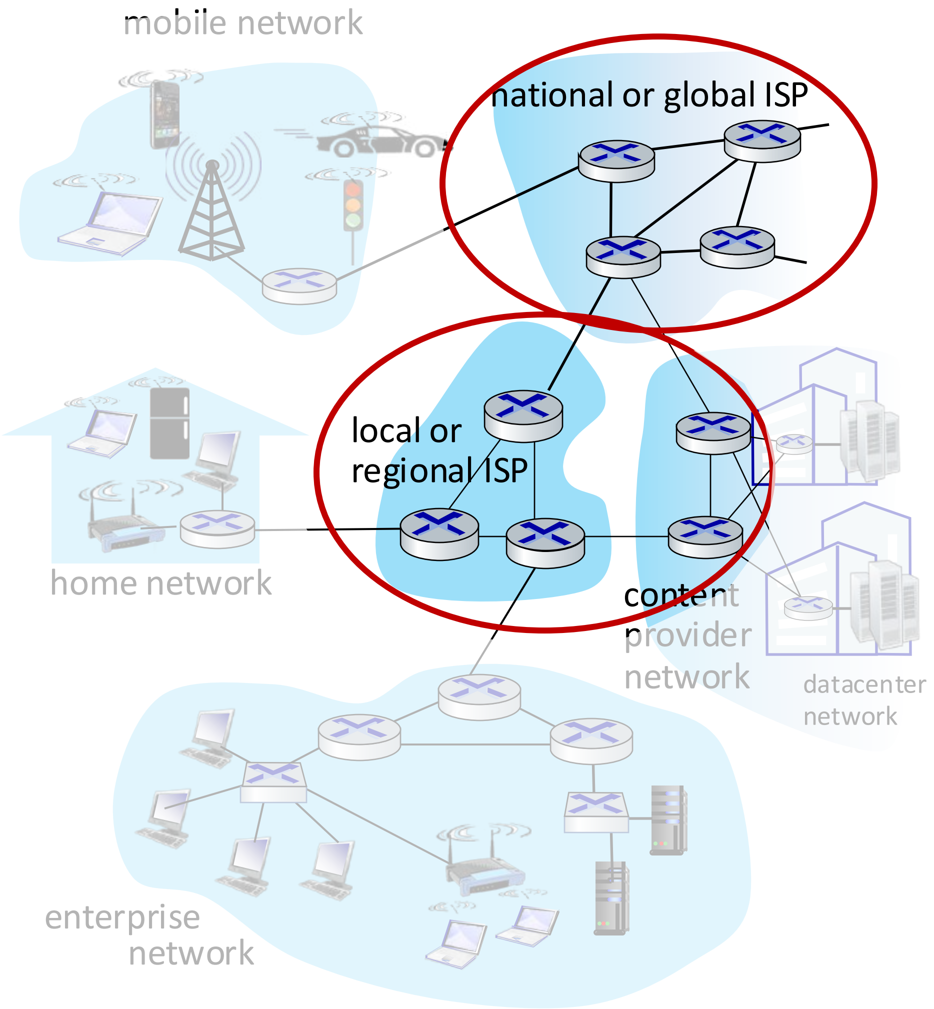
- hosts: clients and servers
- servers often in data centers

Access networks, physical media:

- wired, wireless communication links

Network core:

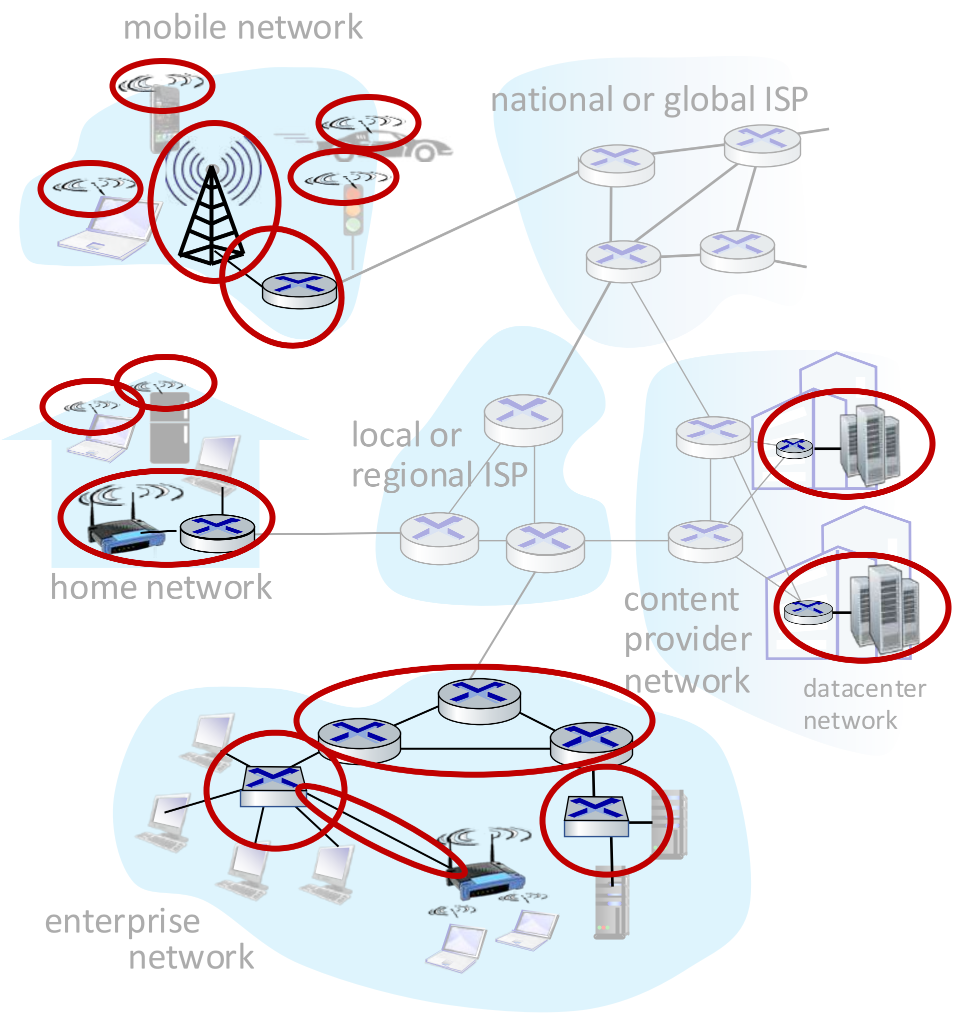
- interconnected routers
- network of networks



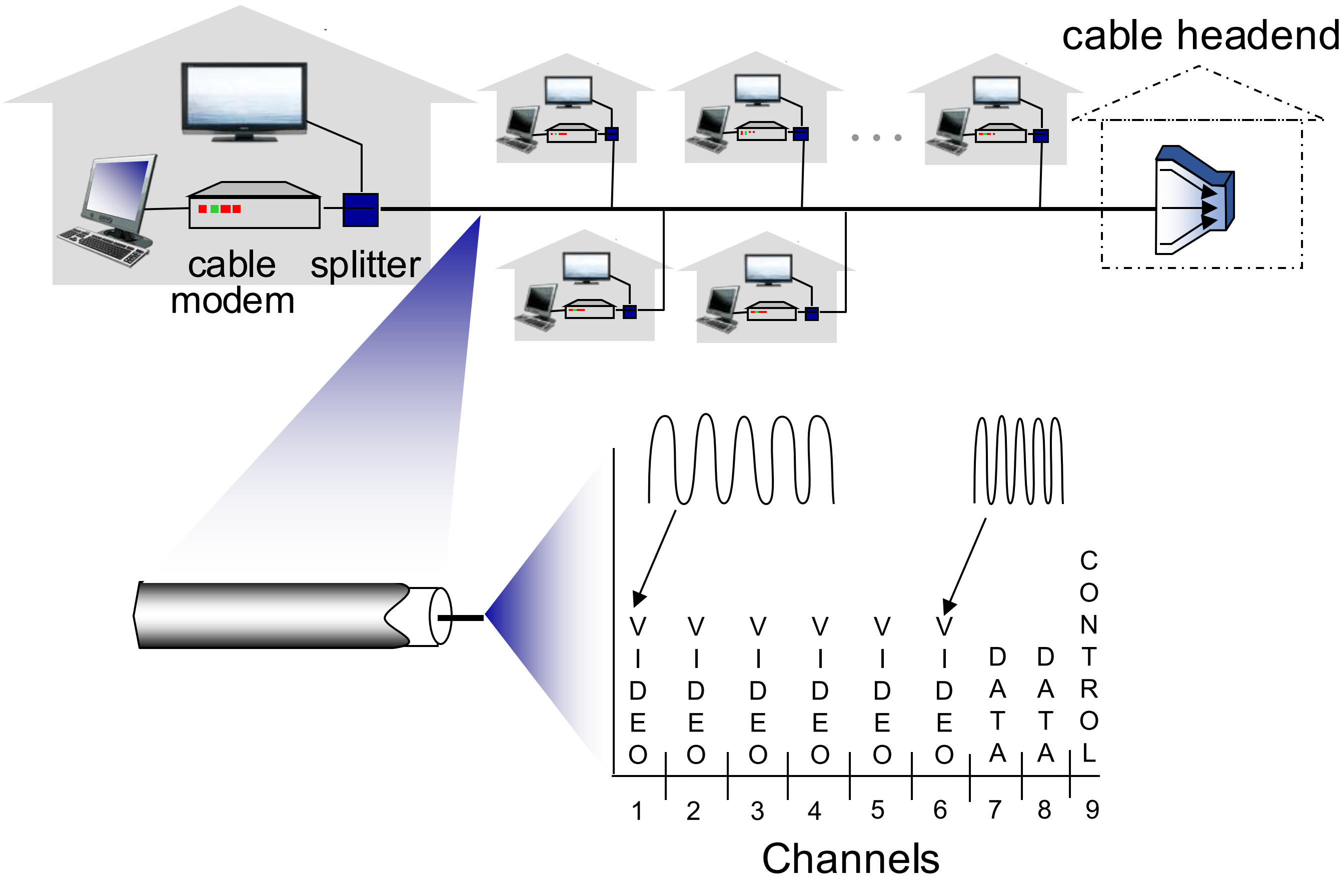
Access networks and physical media

Q: How to connect end systems to edge router?

- residential access nets ที่บ้าน
- institutional access networks (school, company) สถาบัน, องค์กร
- mobile access networks (WiFi, 4G/5G) เน็ต ทรศ

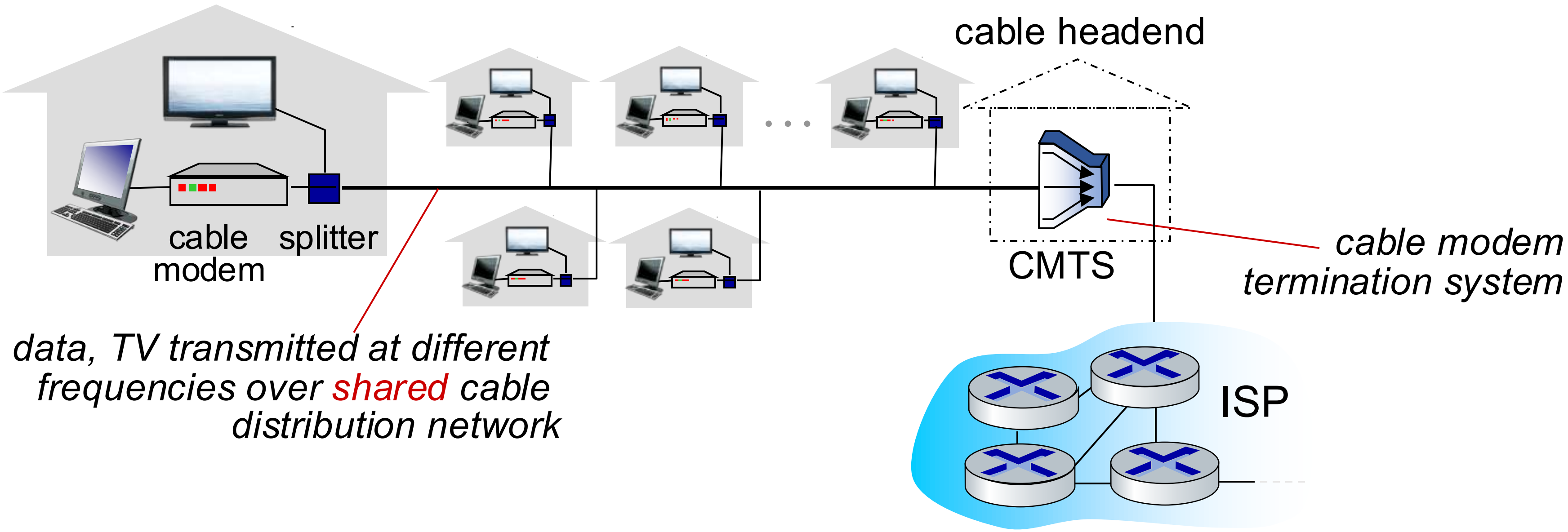


Access networks: cable-based access



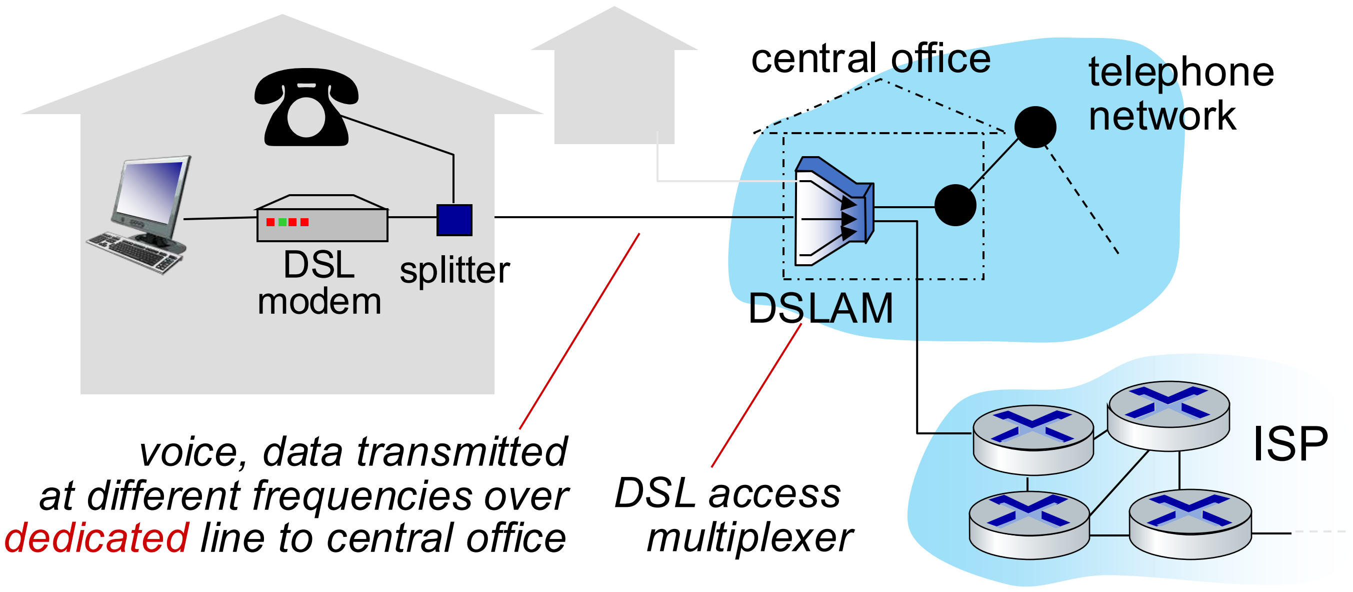
frequency division multiplexing (FDM): different channels transmitted in different frequency bands

Access networks: cable-based access



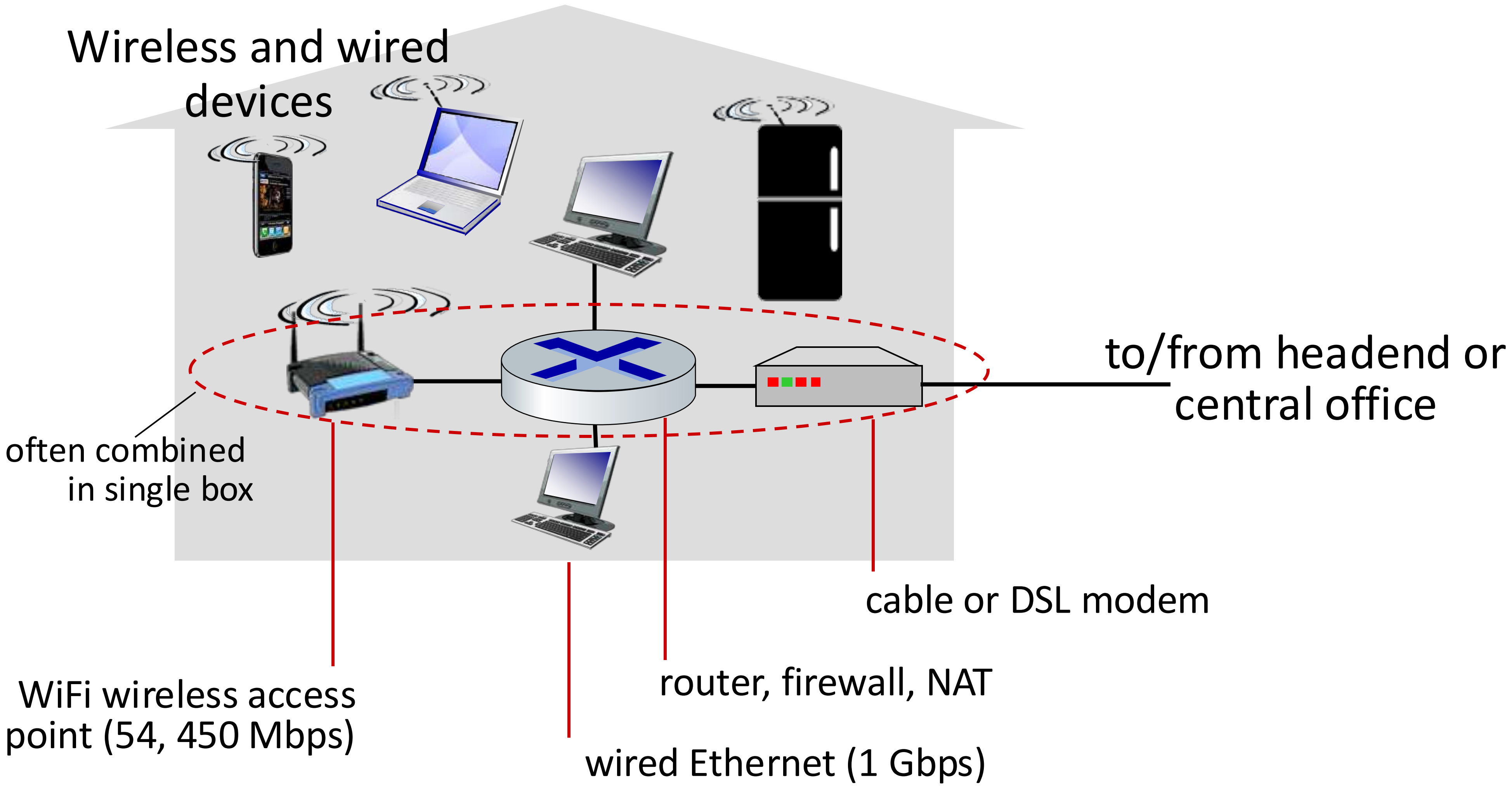
- HFC: hybrid fiber coax
  - asymmetric: up to 40 Mbps – 1.2 Gbps downstream transmission rate, 30-100 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable headend

Access networks: 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
- 24-52 Mbps dedicated downstream transmission rate
- 3.5-16 Mbps dedicated upstream transmission rate

Access networks: home networks



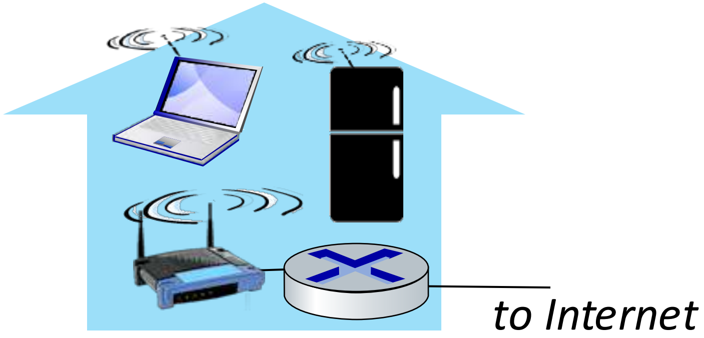
Wireless access networks

Shared *wireless* access network connects end system to router

- via base station aka “access point”

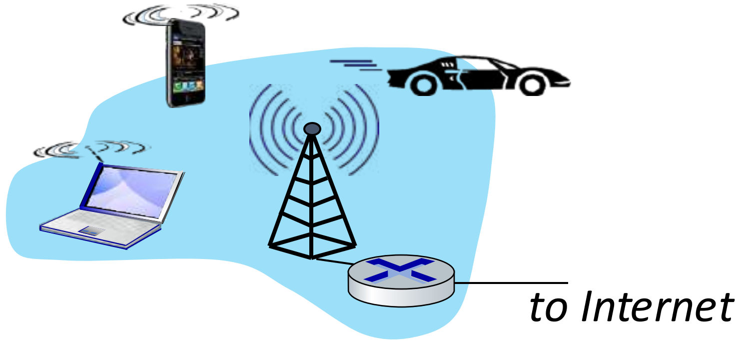
Wireless local area networks (WLANs)

- typically within or around building (~100 ft)
- 802.11b/g/n (WiFi): 11, 54, 450 Mbps transmission rate



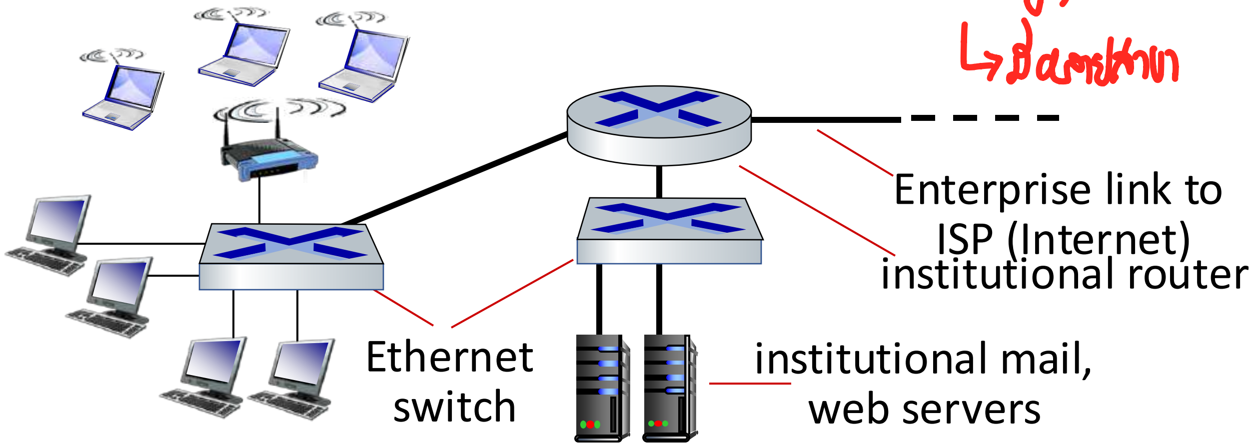
Wide-area cellular access networks

- provided by mobile, cellular network operator (10’s km)
- 10’s Mbps
- 4G/5G cellular networks



Access networks: enterprise networks

↳ องค์กรขนาดใหญ่, มหาลัย
↳ มีหลายสาขา

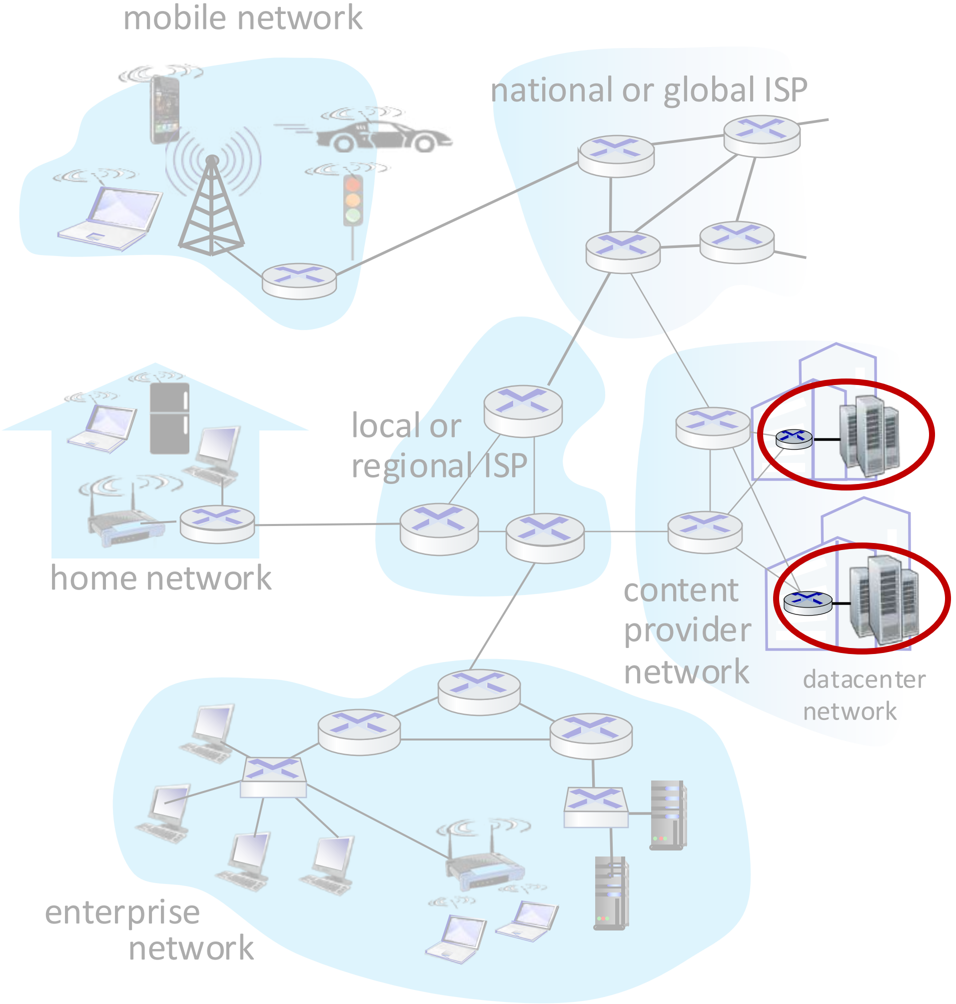


- companies, universities, etc.
- mix of wired, wireless link technologies, connecting a mix of switches and routers (we'll cover differences shortly)
  - Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps
  - WiFi: wireless access points at 11, 54, 450 Mbps

Access networks: data center networks

- high-bandwidth links (10s to 100s Gbps) connect hundreds to thousands of servers together, and to Internet

Courtesy: Massachusetts Green High Performance Computing Center (mghpcc.org)



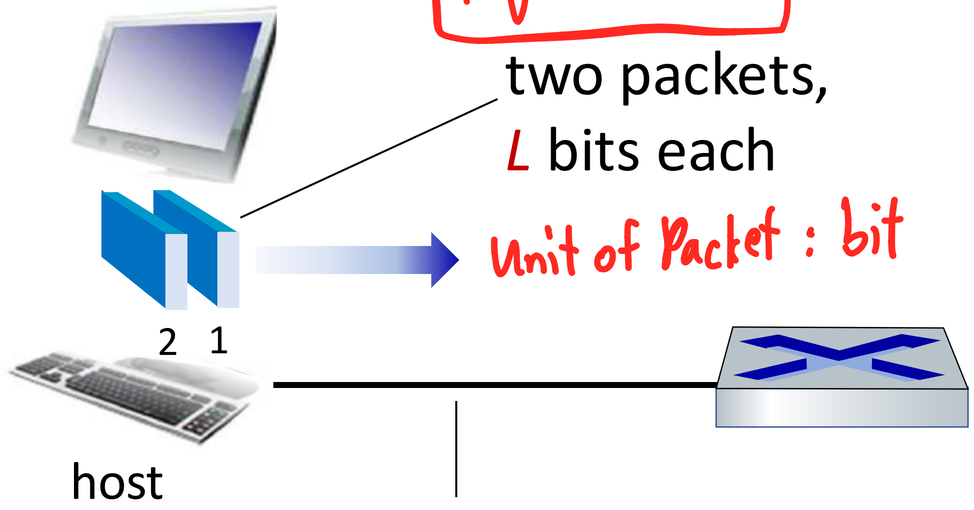
Host: sends *packets* of data

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* synonym

Unit : สำคัญ!!!

$\boxed{\text{1 byte = 8 bits}}$



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

→ เวลาที่ใช้

unit : sec

Links: physical media

ประเภทของlink

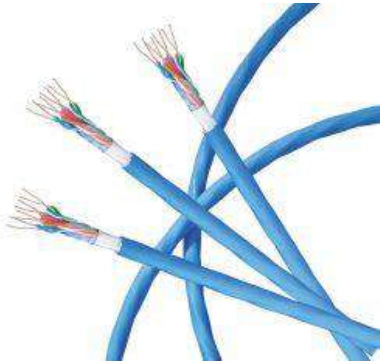
- bit: propagates between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver
- guided media: จับต้องได้
  - signals propagate in solid media: copper, fiber, coax
- unguided media: จับต้องไม่ได้
  - signals propagate freely, e.g., radio

UTP : unshield

Twisted pair (TP) ทองแดง : ราคาถูก

- two insulated copper wires
  - cat5 Category 5: 100 Mbps, 1 Gbps Ethernet สายLAN
  - Category 6: 10Gbps Ethernet

Protocolเล็กๆที่ใช้ในสายLAN



cons : ถูกรบกวนด้วยสัญญาณคลื่นแม่เหล็กไฟฟ้าได้ง่าย

Links: physical media

เก่า

Coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple frequency channels on cable
  - 100’s Mbps per channel

repeater : ขยายสัญญาณ → ทำให้ส่งได้ไกลขึ้น

ติดตั้งยากสุด

แพง, ดูแลยาก, Security สูง, ไวสุด

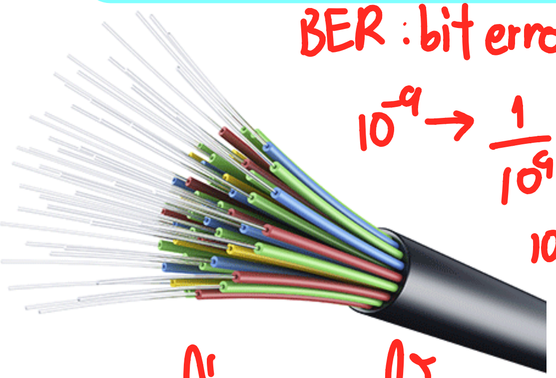
Fiber optic cable: ส่งสัญญาณในรูปแสง

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (10’s-100’s Gbps)
- low error rate: ข้อมูลผิดพลาดน้อย
  - repeaters spaced far apart
  - immune to electromagnetic noise

BER : bit error rate

$10^{-9} \rightarrow \frac{1}{10^9}$ bit error rate

10^9 bit ผิด 1 bit



performance ดีเยอะ:

Links: physical media

Wireless radio

- signal carried in various "bands" in electromagnetic spectrum
- no physical "wire"
- broadcast, "half-duplex" (sender to receiver)
- propagation environment effects:
  - reflection
  - obstruction by objects
  - Interference/noise

Radio link types:

- Wireless LAN (WiFi)
  - 10-100's Mbps; 10's of meters
- wide-area (e.g., 4G/5G cellular)
  - 10's Mbps (4G) over ~10 Km
- Bluetooth: cable replacement
  - short distances, limited rates
- terrestrial microwave
  - point-to-point; 45 Mbps channels
- satellite
  - up to < 100 Mbps (Starlink) downlink
  - 270 msec end-end delay (geostationary)

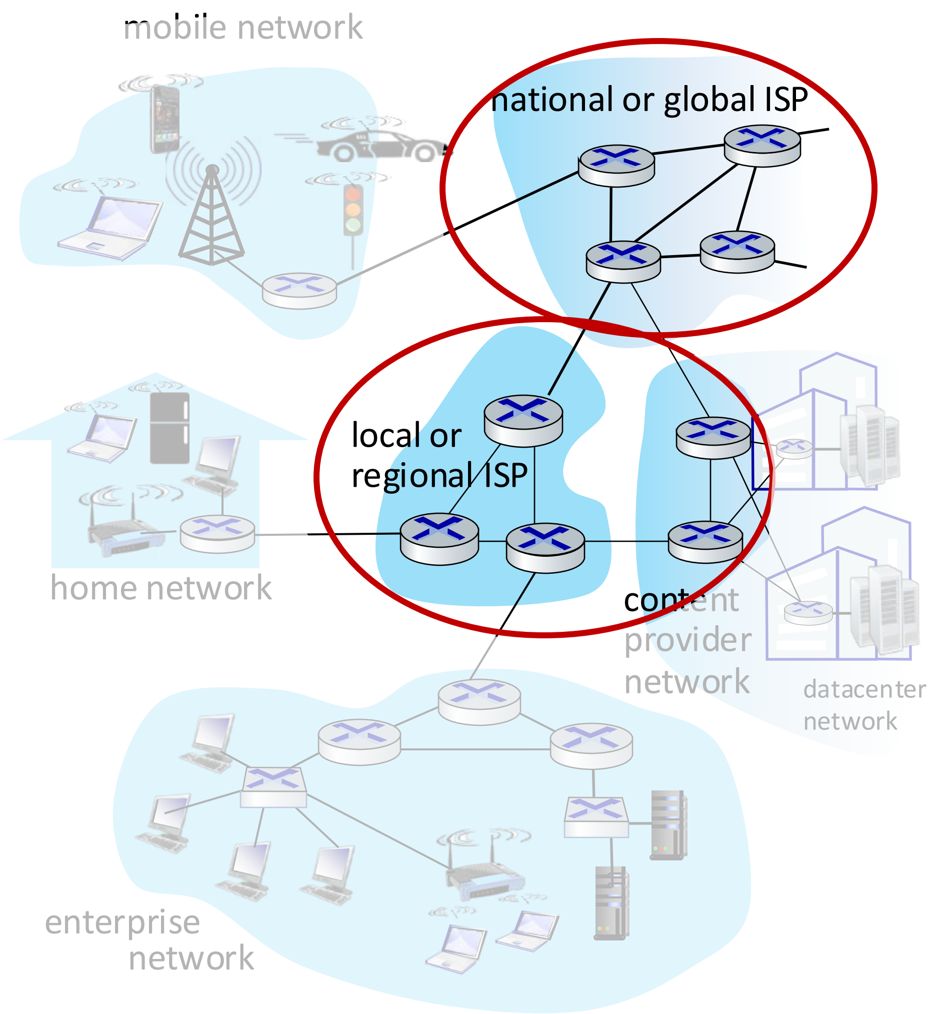
Chapter 1: roadmap

- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models
- History

The network core

- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into *packets* ส่ง Packet เป็นก้อน ๆ, ไม่ใช่ end to end
  - network forwards packets from one router to the next, across links on path from source to destination

source → 1 → 2 → destination



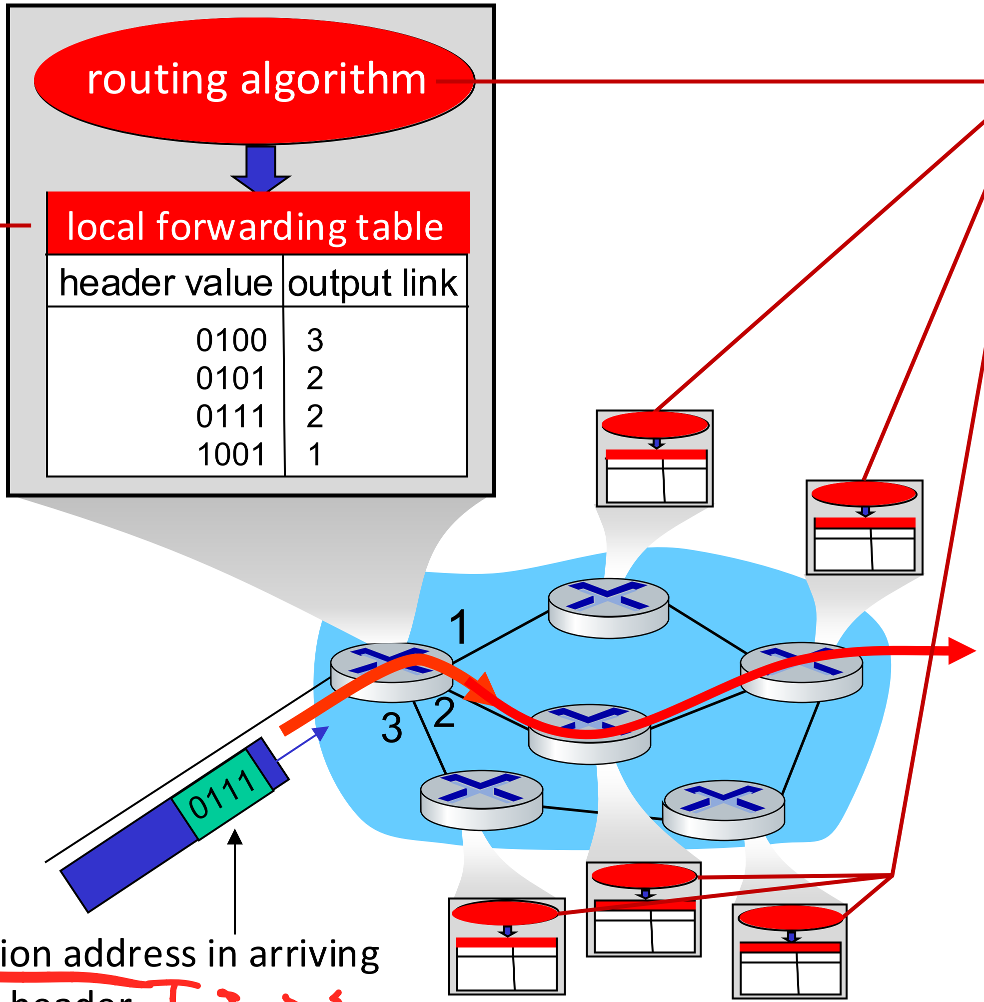
Two key network-core functions

แบ่งย่อย, each เส้นไปต่อยังไง

Forwarding:

- aka "switching"
- *local* action: move arriving packets from router's input link to appropriate router output link

each router ตัดสินใจ ตามalgo



destination address in arriving packet's header

↳ เป็นตัวเลือก output path

โดยรวม, จุดเริ่ม-จบ

Routing:

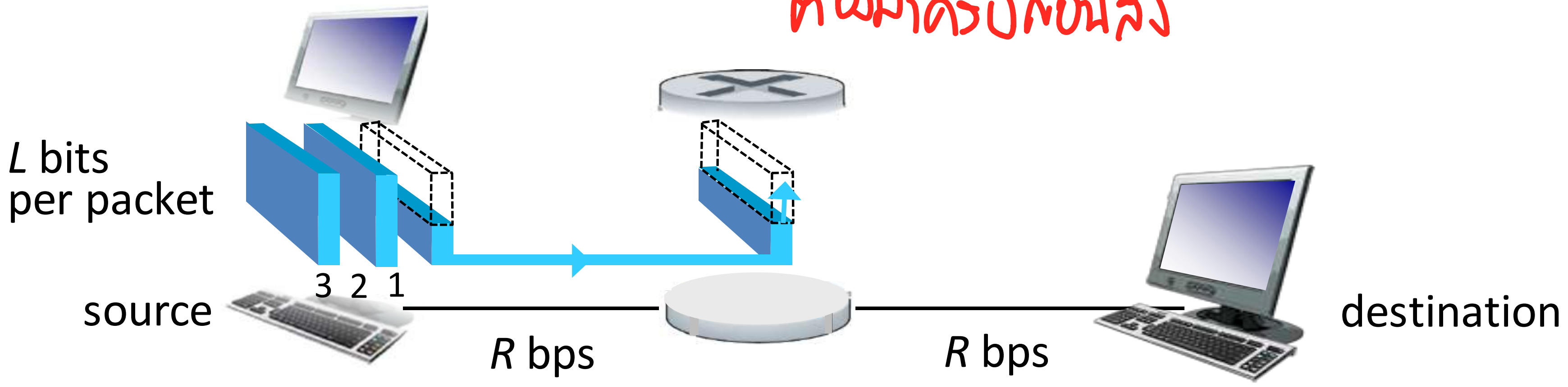
- *global* action: determine source-destination paths taken by packets
- routing algorithms


routing
45 h
3,053 miles
48 h
3,309 miles
United States
Victoria
Seattle
WASHINGTON
MONTANA
NORTH DAKOTA
MINNESOTA
Quebec City
Portland
Minneapolis
Montreal
Ottawa
MAINE
SOUTH DAKOTA
WISCONSIN
VERMONT
OREGON
IDAHO
MICHIGAN
Toronto
NEW HAMPSHIRE
WYOMING
Detroit
Chicago
IOWA
Northampton
CT
RI
NEVADA
PENNSYLVANIA
New York
ILLINOIS
INDIANA
OHIO
Philadelphia
NJ
Kansas City
Sacramento
UTAH
COLORADO
Indianapolis
MARYLAND
DE
San Francisco
WEST VIRGINIA
San Jose
KENTUCKY
VIRGINIA
CALIFORNIA
Las Vegas
Nashville
TENNESSEE
NORTH CAROLINA
OKLAHOMA
Los Angeles
ARIZONA
NEW MEXICO
ARKANSAS
Charlotte
Atlanta
SOUTH CAROLINA
MISSISSIPPI
San Diego
Phoenix
Dallas
ALABAMA
GEORGIA
Tucson
El Paso
TEXAS
BAJA CALIFORNIA
SONORA
Austin
Houston
LOUISIANA
Jacksonville
New Orleans
CHIHUAHUA
San Antonio
Orlando
Tampa
COAHUILA
FLORIDA


forwarding
forwarding
45 h
3,053 miles
48 h
3,309 miles
United States
San Jose
Northampton
Sacramento
Cleveland
Seattle
Portland
San Francisco
Los Angeles
San Diego
Las Vegas
Phoenix
Tucson
El Paso
Dallas
Austin
Houston
San Antonio
New Orleans
Kansas City
Minneapolis
Chicago
Detroit
Indianapolis
Nashville
Atlanta
Toronto
Ottawa
Montreal
Quebec City
New York
Tampa

Packet-switching: store-and-forward

ต้องมาครบก่อนส่ง



- packet transmission delay: takes L/R seconds to transmit (push out) L-bit packet into link at R bps

ต้องมาให้ครบ รอไม่ได้ continuous

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

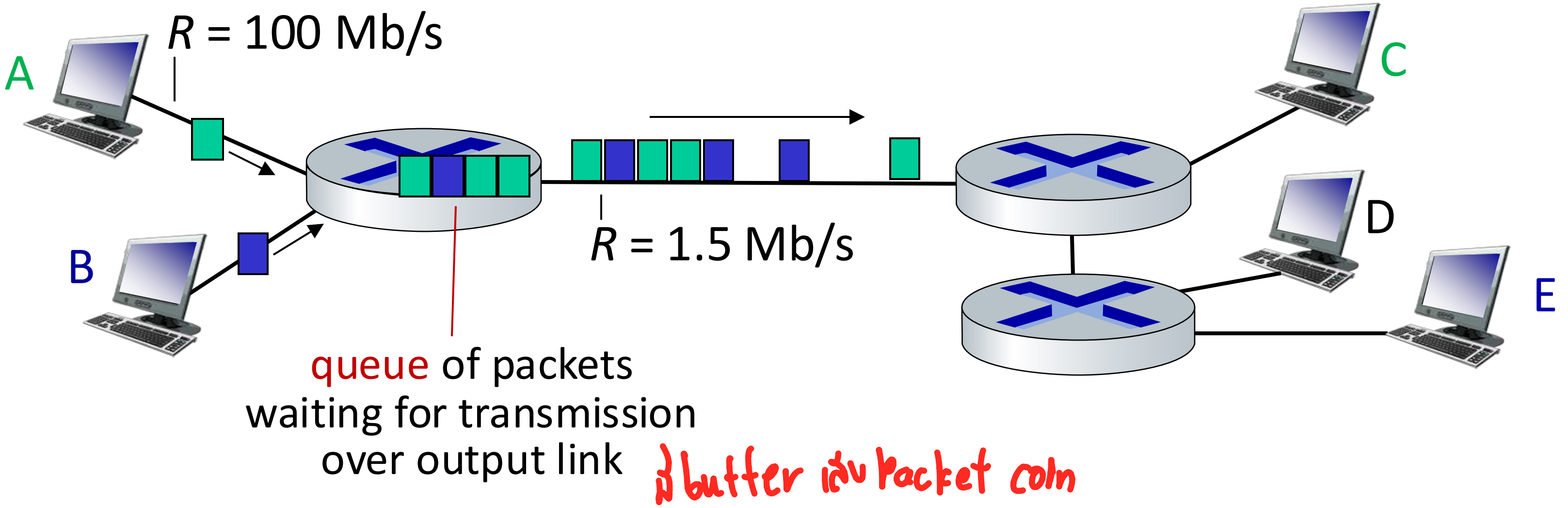
แต่ละสิ่ง transmission rate ไม่จำเป็นต้องเท่ากัน

1 hop

One-hop numerical example:
- L = 10 Kbits
- R = 100 Mbps
- one-hop transmission delay = 0.1 msec

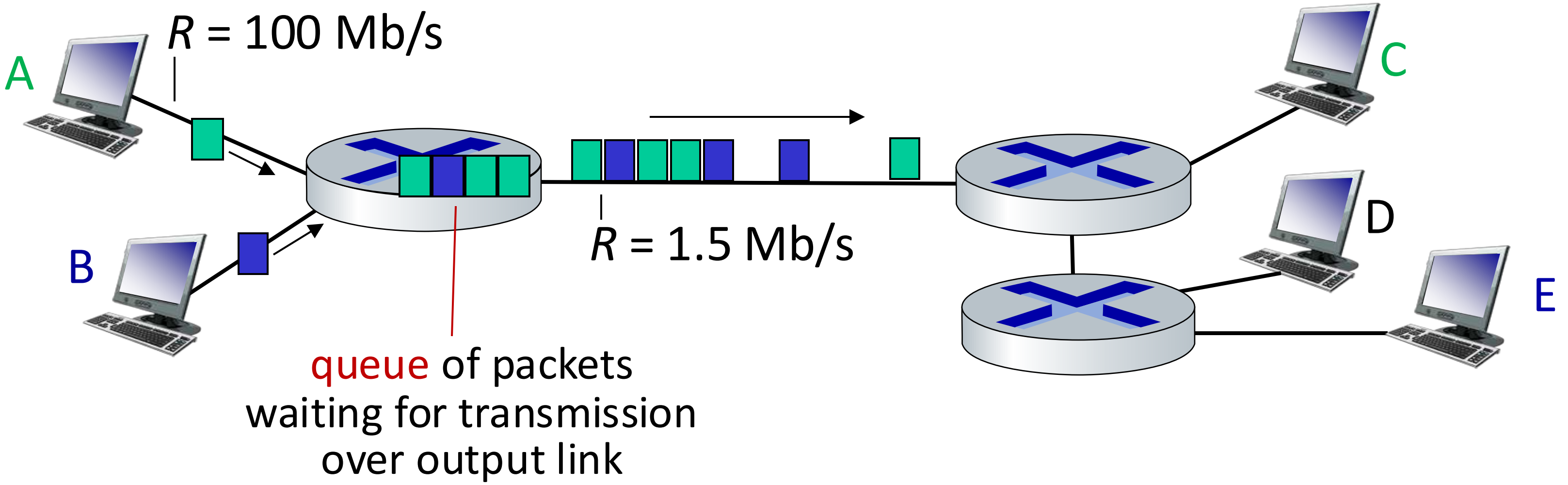
Packet-switching: queueing

รับเร็วส่งช้า



Queueing occurs when work arrives faster than it can be serviced:

Packet-switching: queueing



เกิดเมื่อ buffer overflow → Packet loss / Packet drop

Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) in router fills up

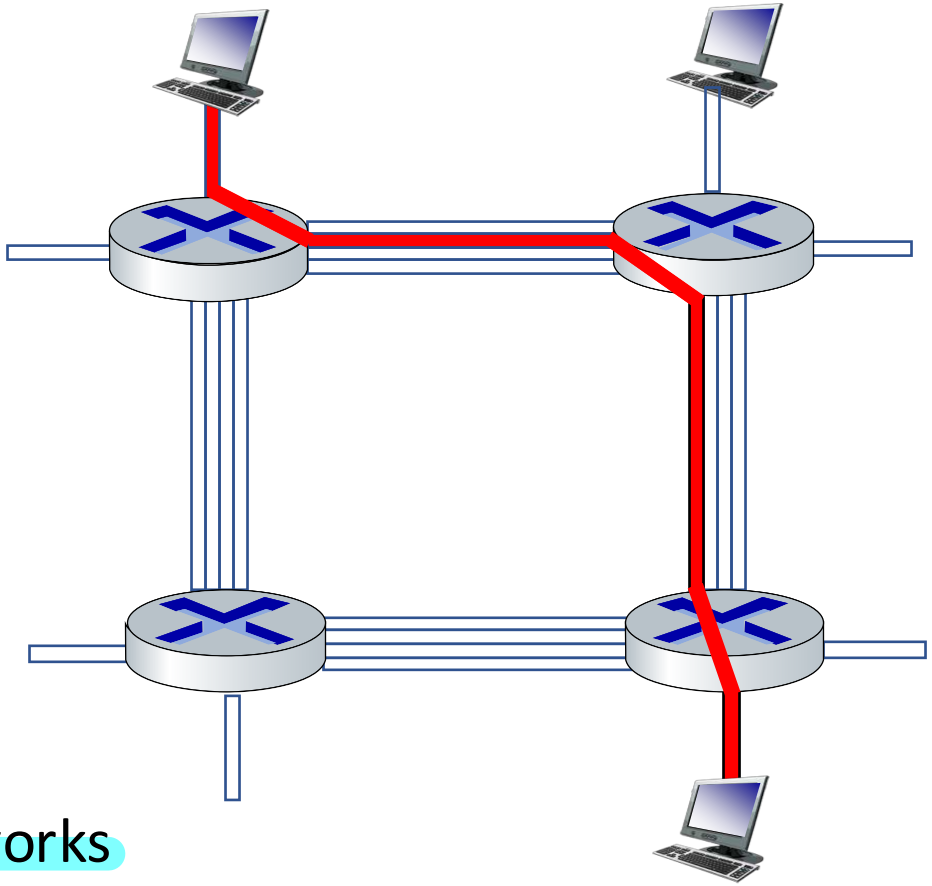
Alternative to packet switching: circuit switching

มีแค่ 1 เส้นทาง for 1 ความสัมพันธ์ but packet มีได้หลาย

ในโทรศัพท์ยุคเก่า

end-end resources allocated to, reserved for "call" between source and destination เส้นทางถูกจองทิ้งไว้

- 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



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

Circuit switching: FDM and TDM

Frequency Division Multiplexing (FDM)

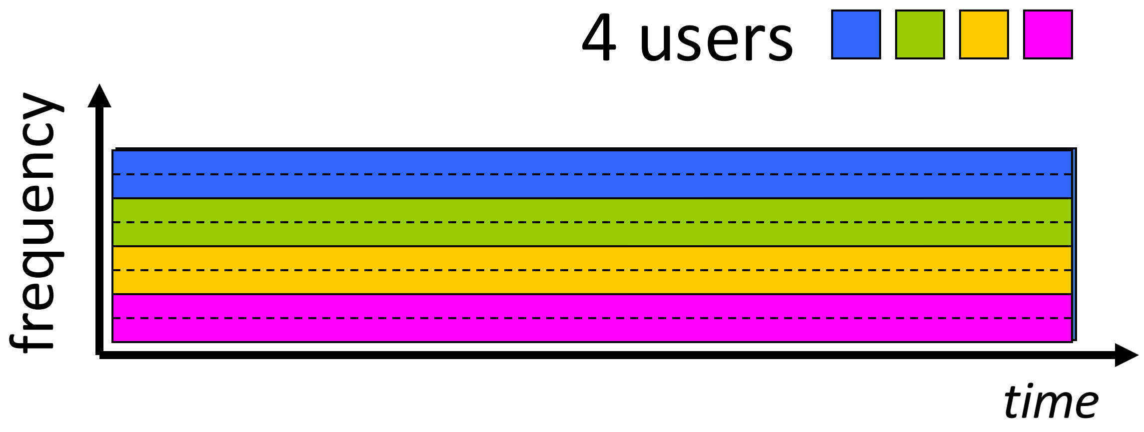
แบ่งตามช่องความถี่, มักเป็นพวก radio

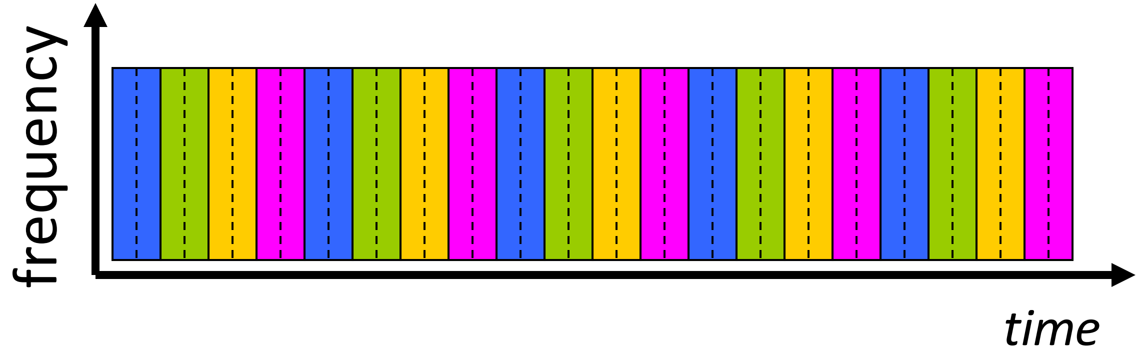
- optical, electromagnetic frequencies divided into (narrow) frequency bands
- each call allocated its own band, can transmit at max rate of that narrow band

Time Division Multiplexing (TDM)

- time divided into slots
- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band (only) during its time slot(s)

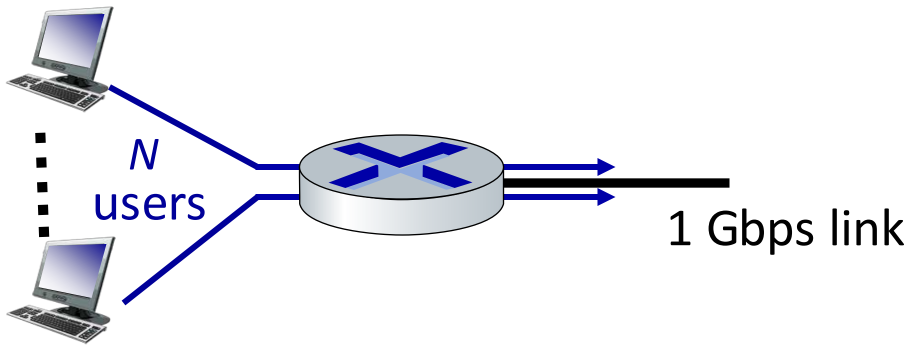
ใช้ในระบบโทรศัพท์





Packet switching versus circuit switching

example:
- 1 Gb/s link
- each user:
  - 100 Mb/s when "active"
  - active 10% of time



Q: how many users can use this network under circuit-switching and packet switching?

- *circuit-switching:* 10 users คงที่
- *packet switching:* มากสุด with 35 users, probability > 10 active at same time is less than .0004 *

Q: how did we get value 0.0004?

A: HW problem (for those with course in probability only)

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

Packet switching versus circuit switching

ยอดเยี่ยม

Is packet switching a “slam dunk winner”?

มาเป็นระลอก

- great for “bursty” data – sometimes has data to send, but at other times not
  - resource sharing ไม่ต้องใช้สาย
  - simpler, no call setup คล้ายพัสดุ

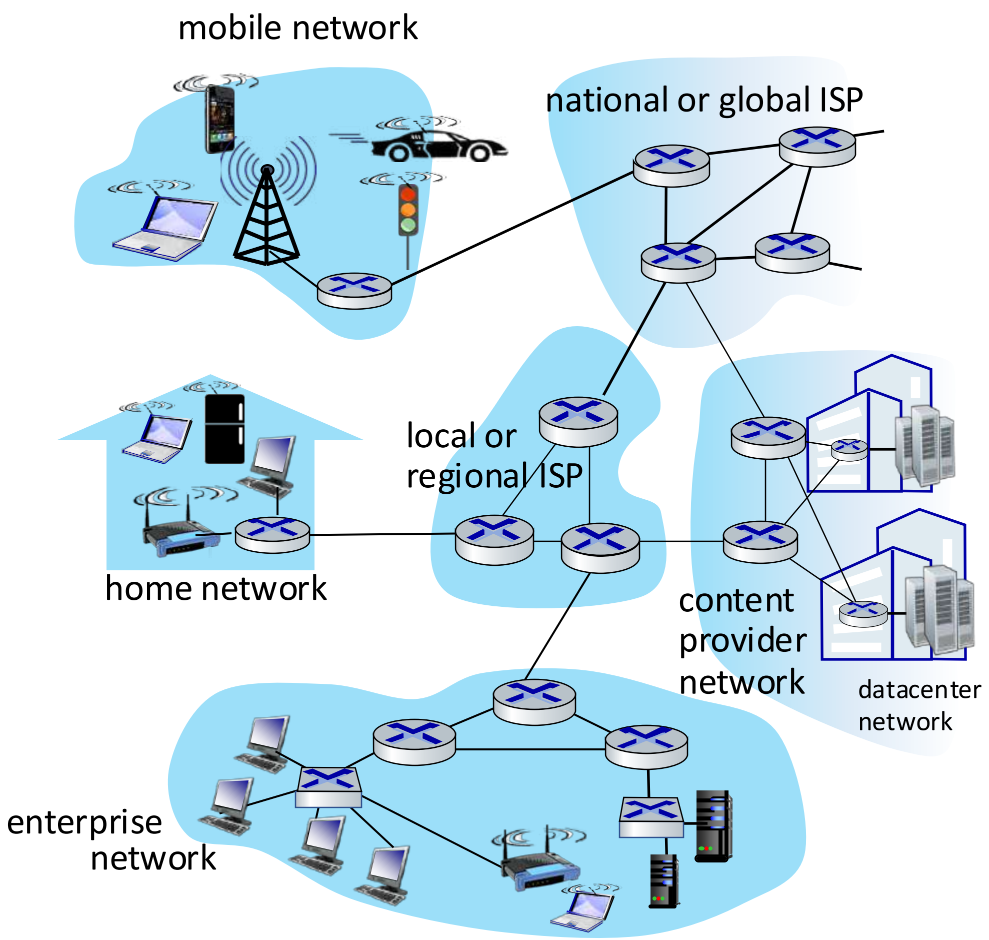
ความแออัด

- excessive congestion possible: packet delay and loss due to buffer overflow
  - protocols needed for reliable data transfer, congestion control หาทางแก้เพราะ: ไม่อยากให้ข้อมูลหาย
- *Q:* How to provide circuit-like behavior with packet-switching?
  - “It’s complicated.” but possible We’ll study various techniques that try to make packet switching as “circuit-like” as possible.

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

Internet structure: a "network of networks"

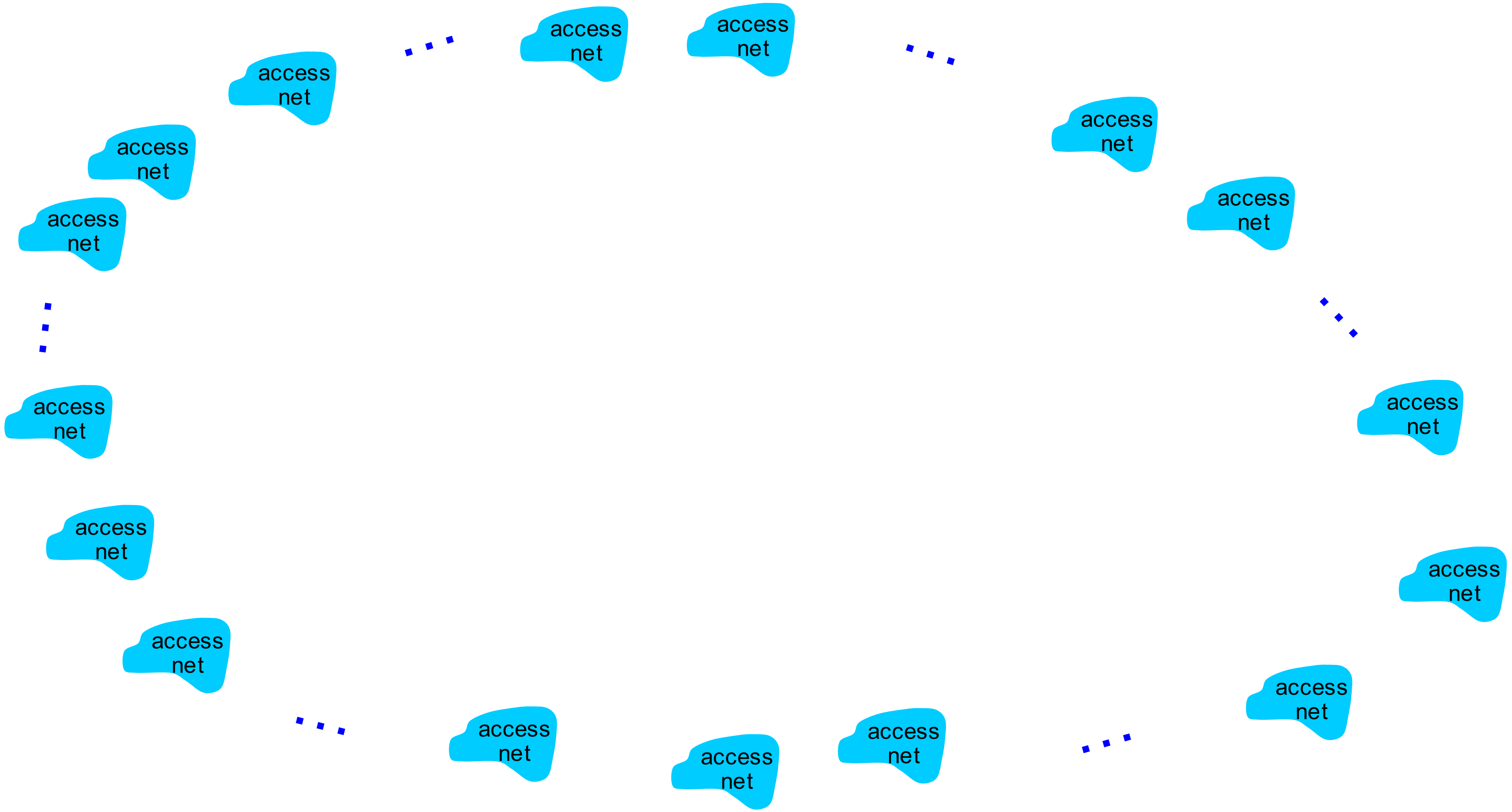
- hosts connect to Internet via access Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
  - so that *any* two hosts *(anywhere!)* can send packets to each other
- resulting network of networks is very complex
  - evolution driven by economics, national policies



Let's take a stepwise approach to describe current Internet structure

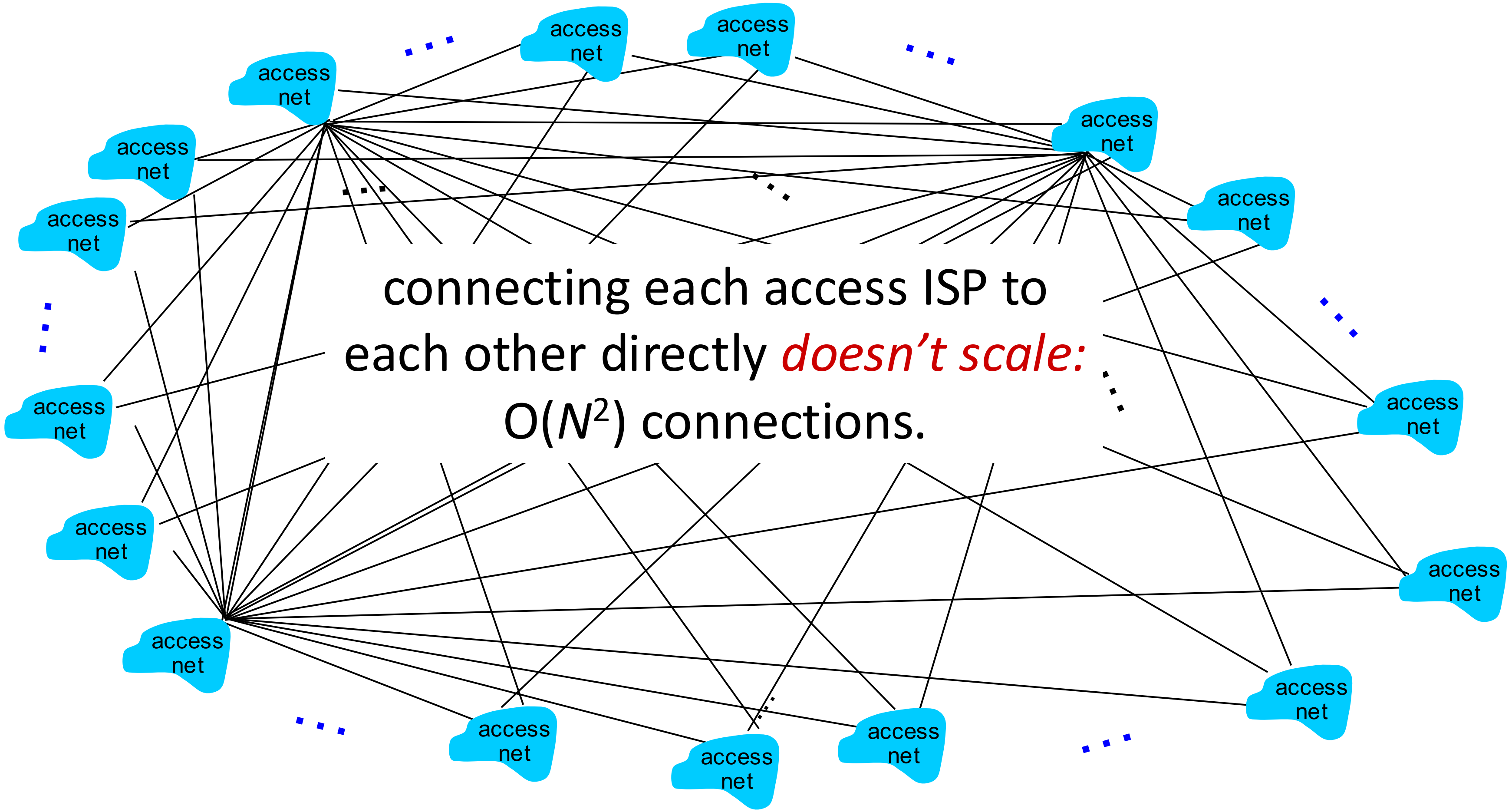
Internet structure: a "network of networks"

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



Internet structure: a "network of networks"

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

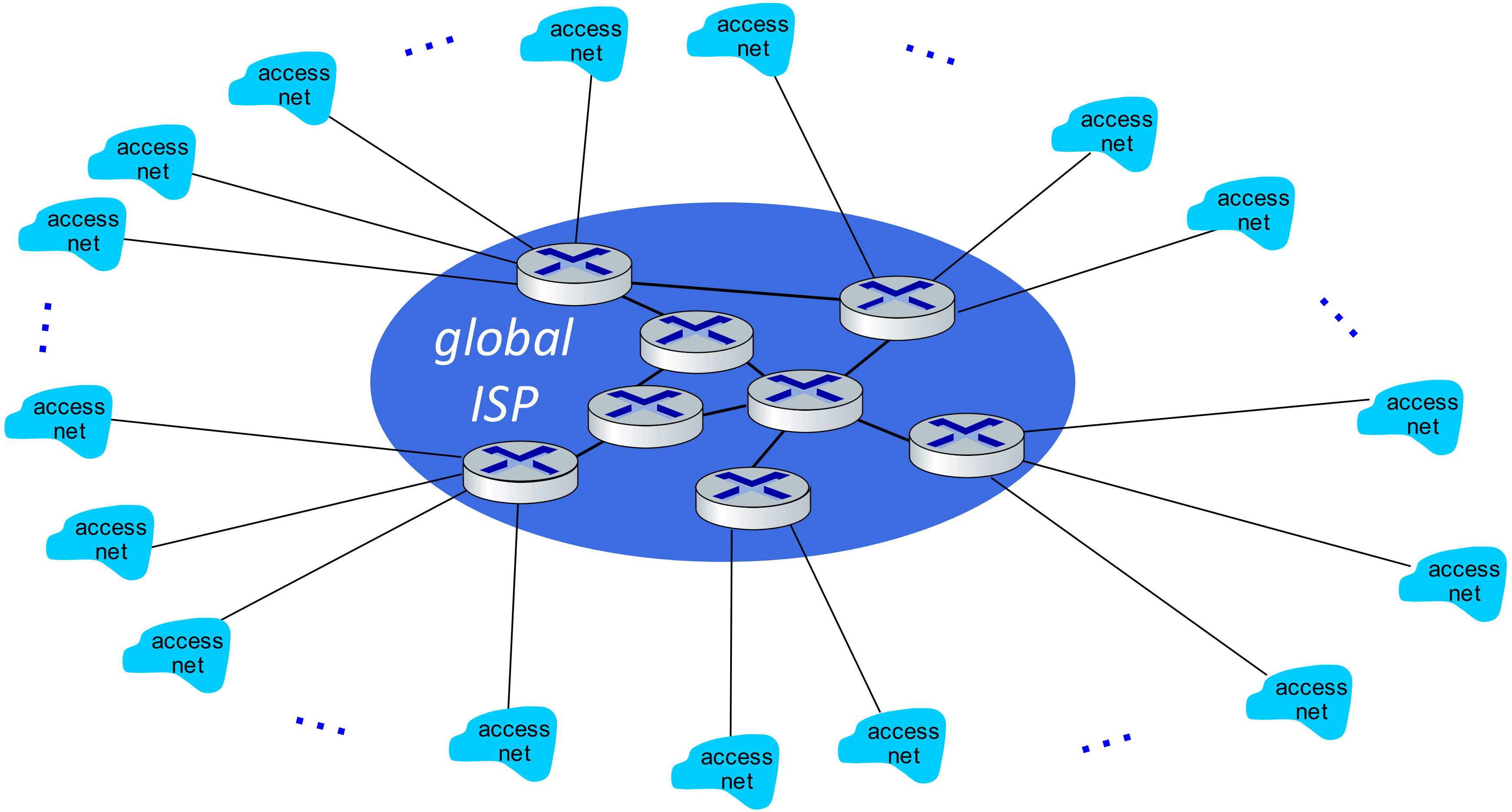


connecting each access ISP to each other directly *doesn't scale:* $O(N^2)$ connections.

Internet structure: a "network of networks"

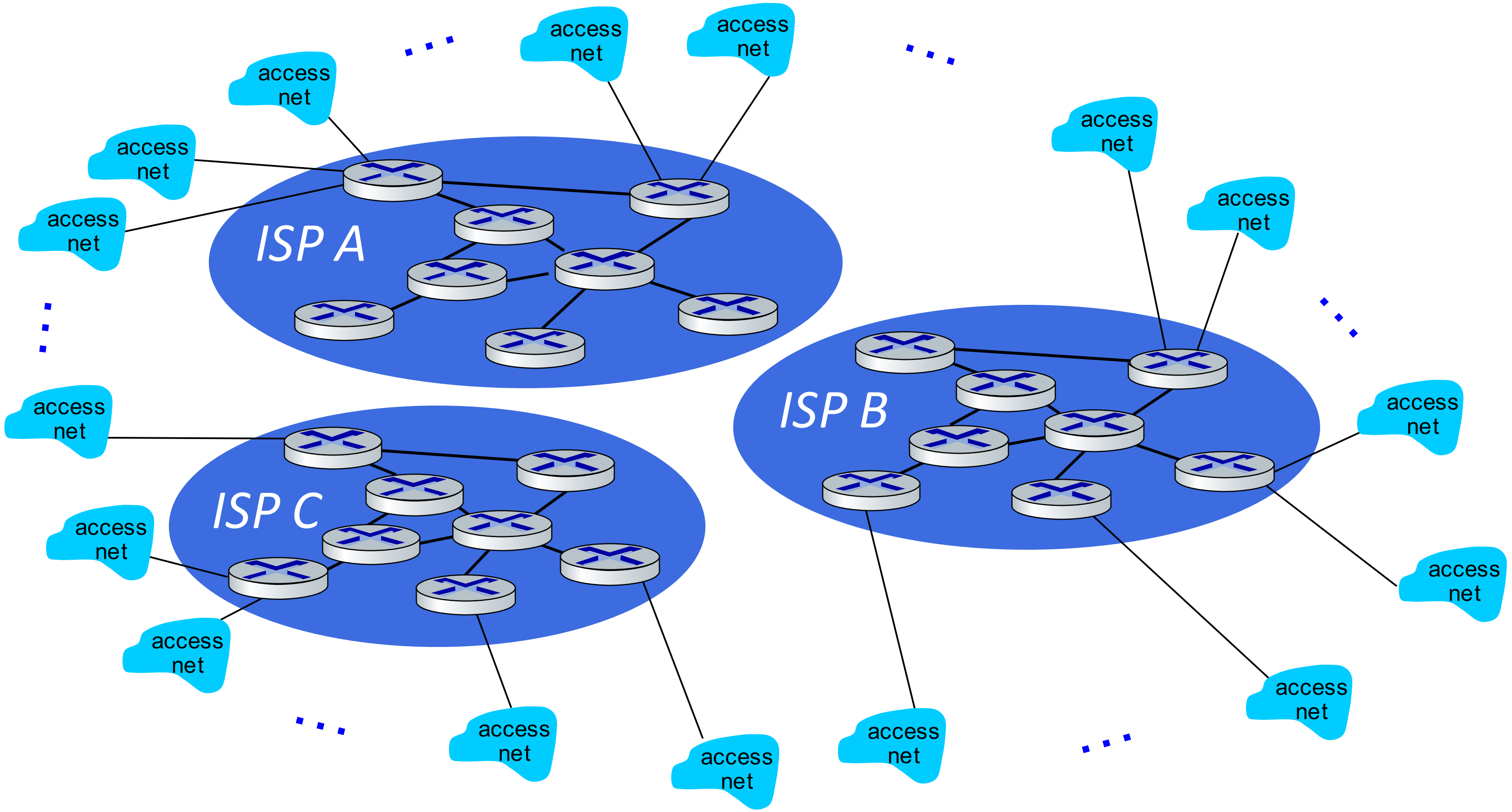
Option: connect each access ISP to one global transit ISP?

Customer and provider ISPs have economic agreement.



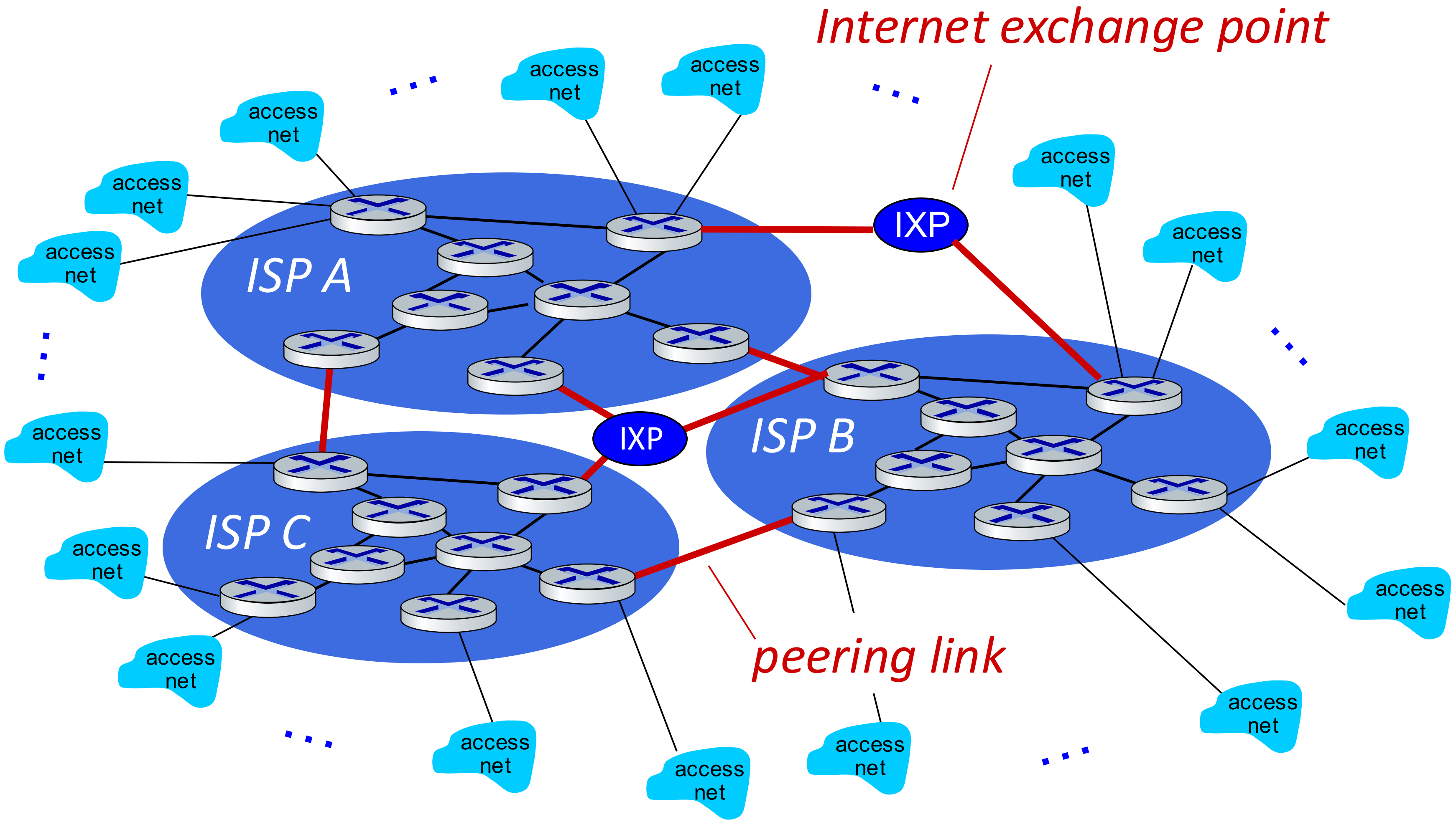
Internet structure: a "network of networks"

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



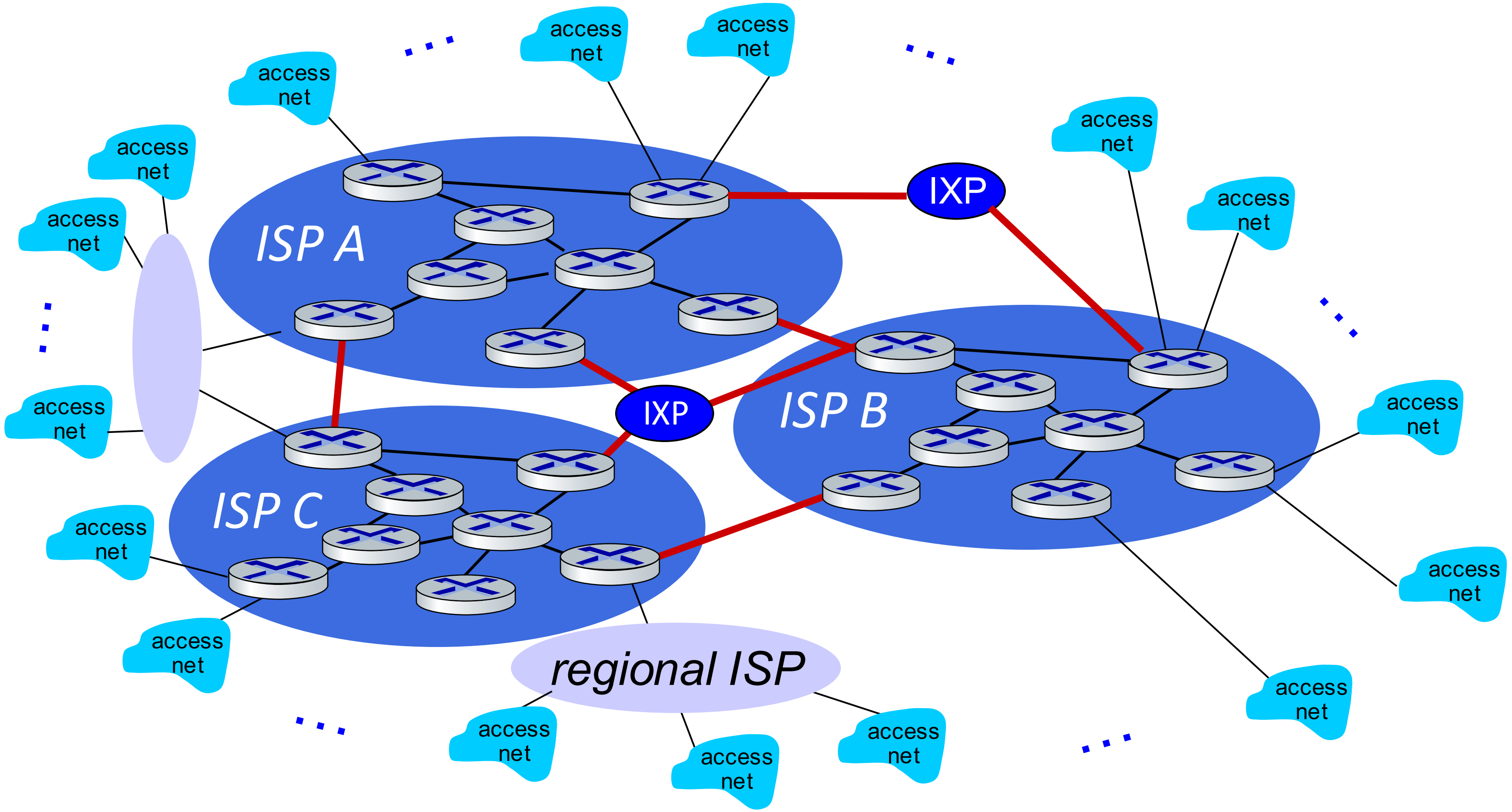
Internet structure: a "network of networks"

But if one global ISP is viable business, there will be competitors …. who will want to be connected



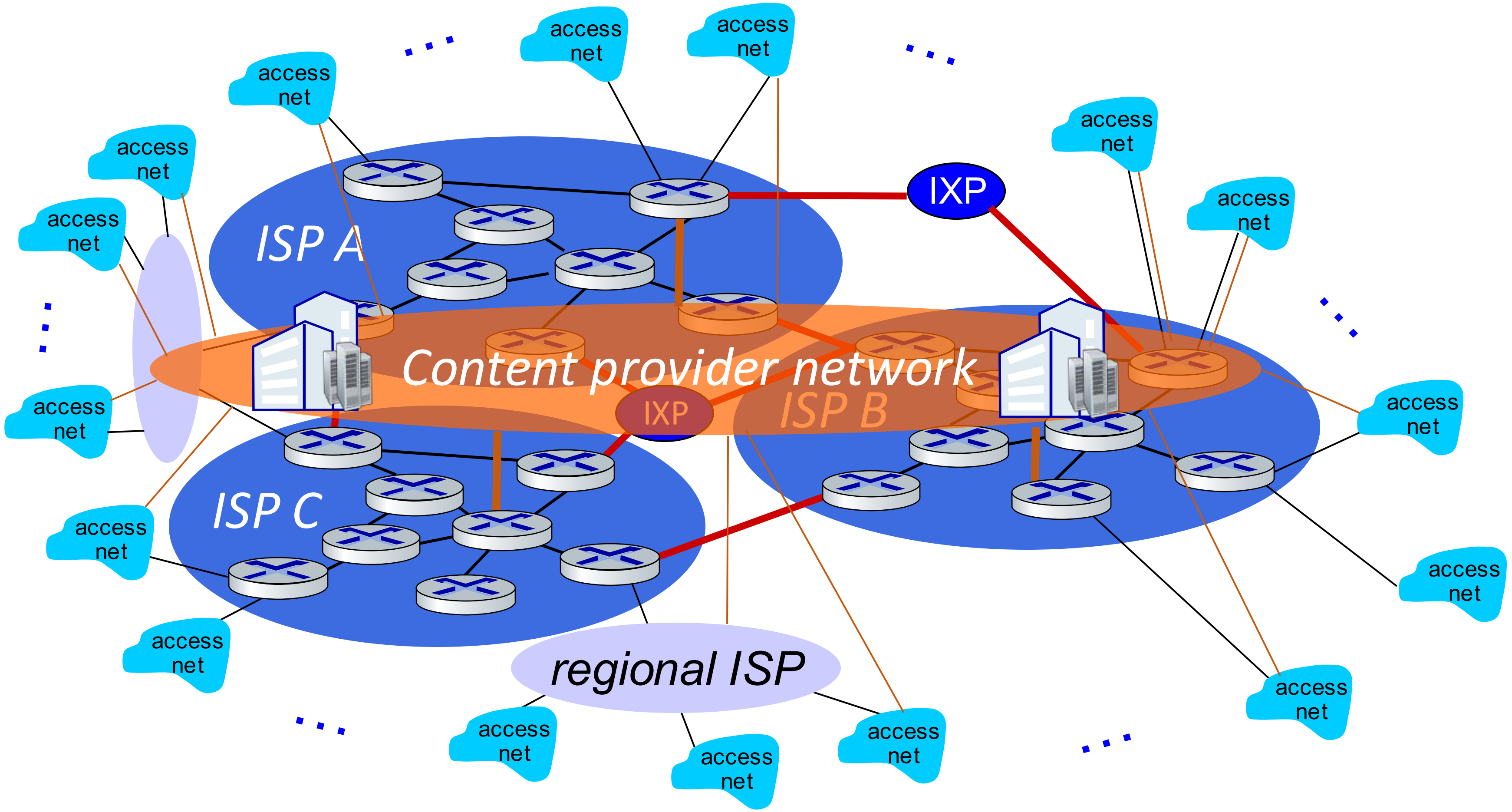
Internet structure: a "network of networks"

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

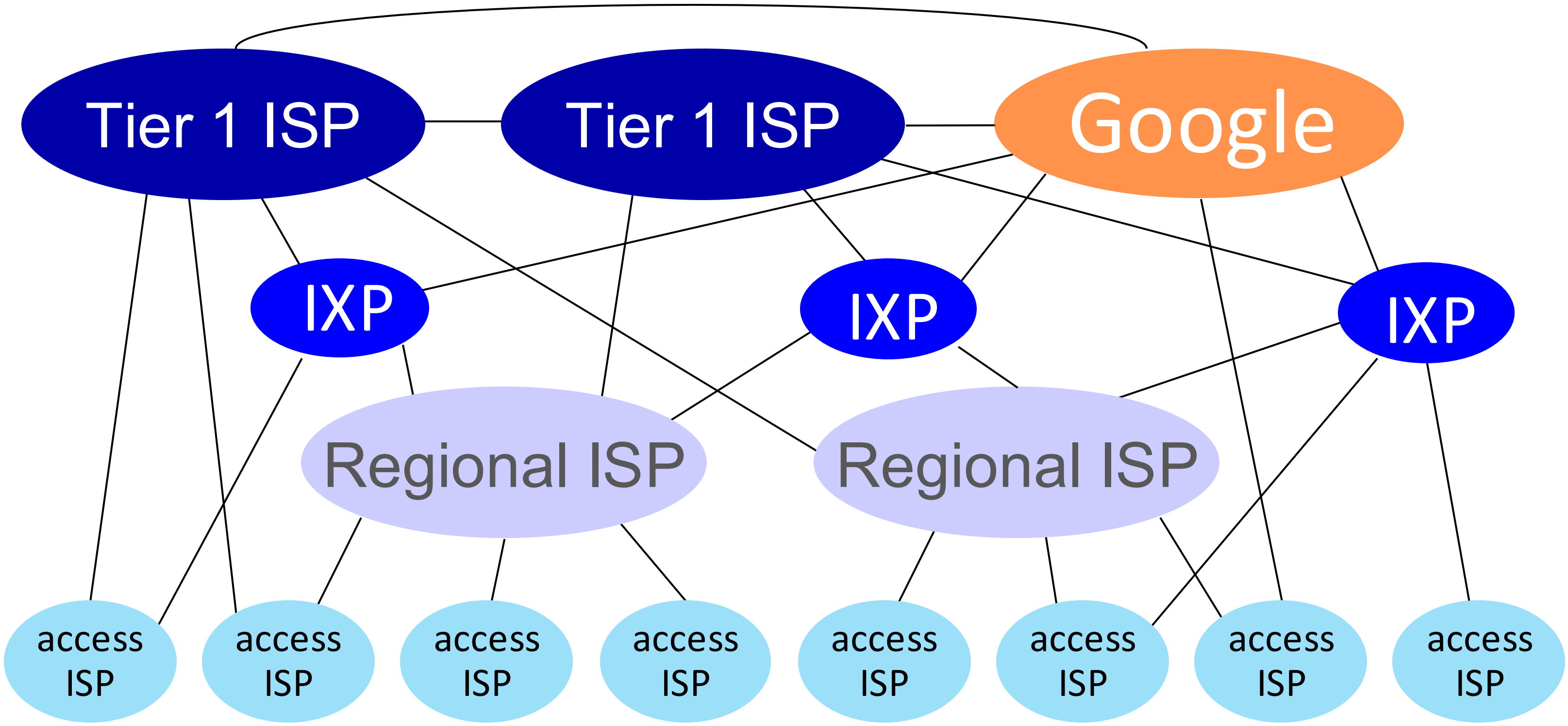


Internet structure: a “network of networks”

… and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users



Internet structure: a "network of networks"



At "center": small # of well-connected large networks

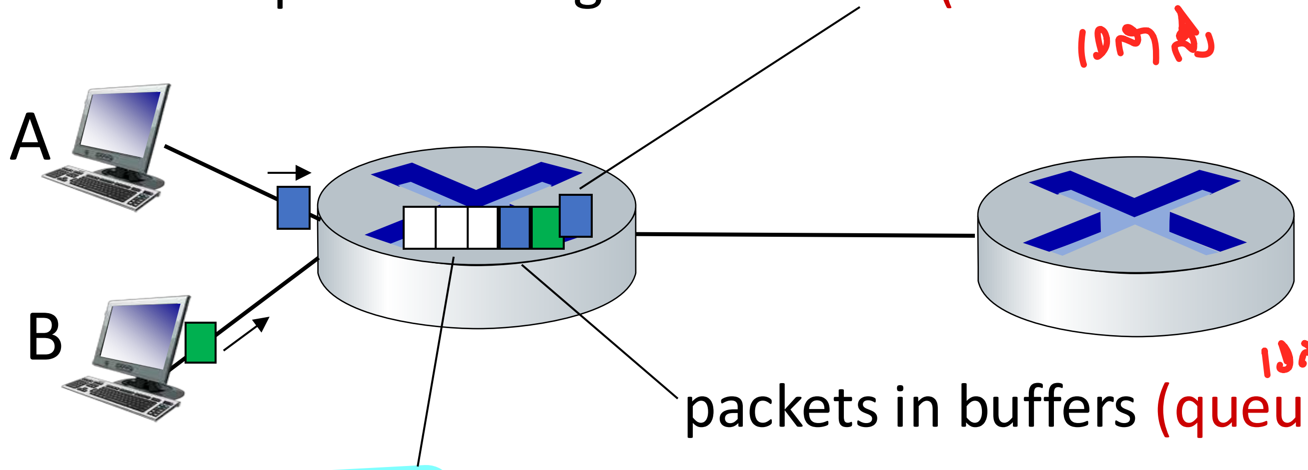
- "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
- content provider networks (e.g., Google, Facebook): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs

Chapter 1: roadmap

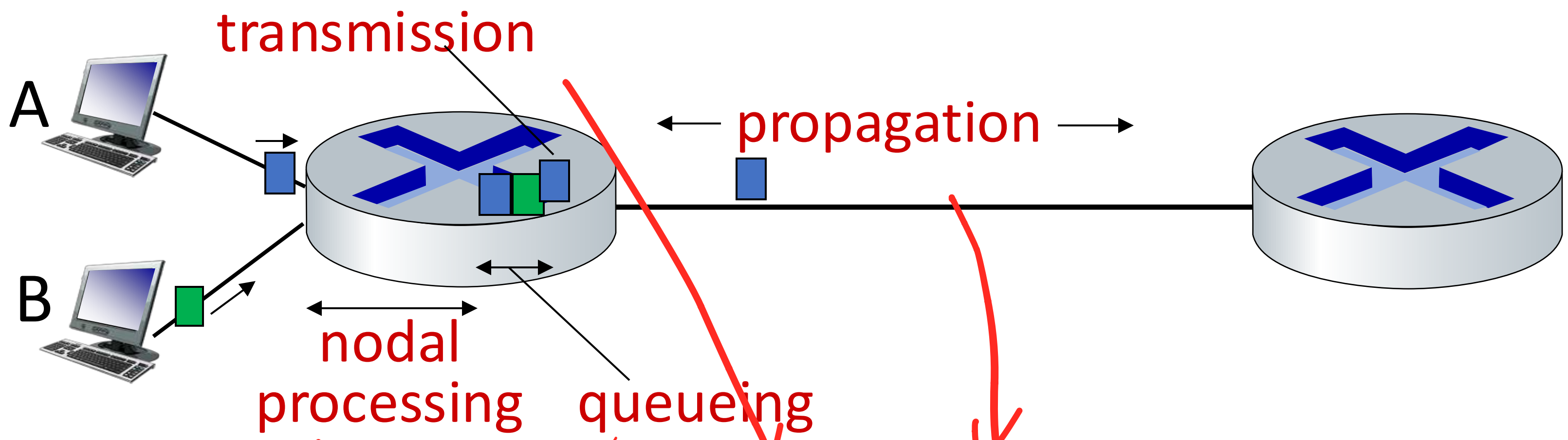
- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models
- History

How do packet delay and loss occur?

- packets *queue* in router buffers, waiting for turn for transmission
  - queue length grows when arrival rate to link (temporarily) exceeds output link capacity
- packet *loss* occurs when memory to hold queued packets fills up



Packet delay: four sources



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

ประมวล

d_{proc}: nodal processing

- check bit errors
- determine output link
- typically < microsecs :ไว

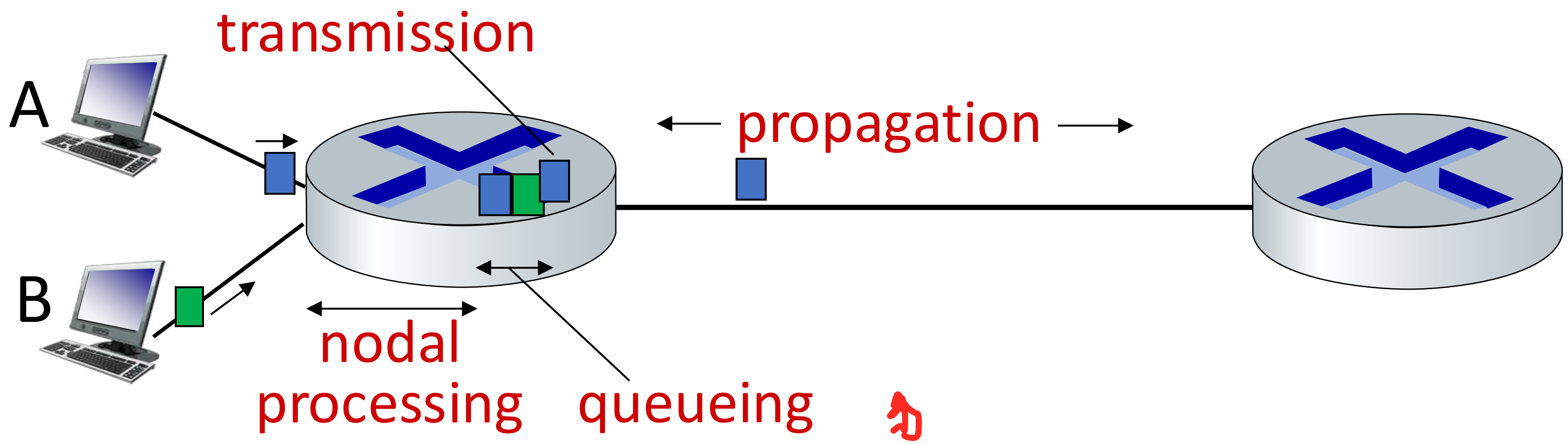
ไม่แคร์

d_{queue}: queueing delay

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

ซับซ้อน, ไม่ลงตัว ไม่แคร์

Packet delay: four sources



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

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

depend of packet

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

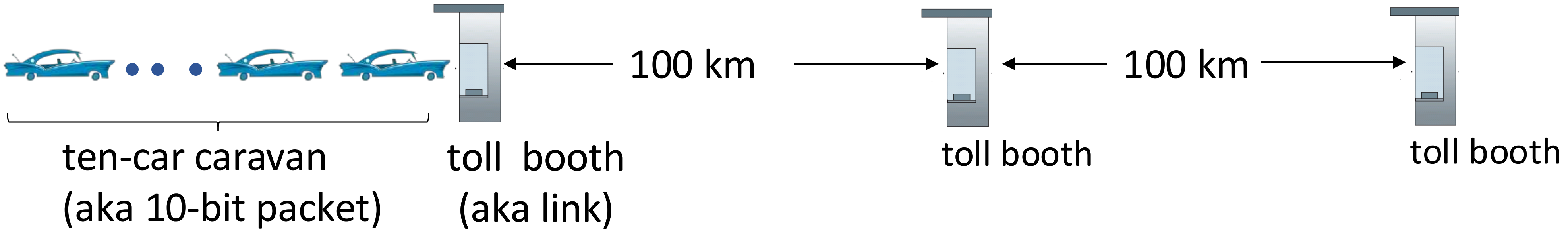
depend on ระยะ

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

distance
unit: m

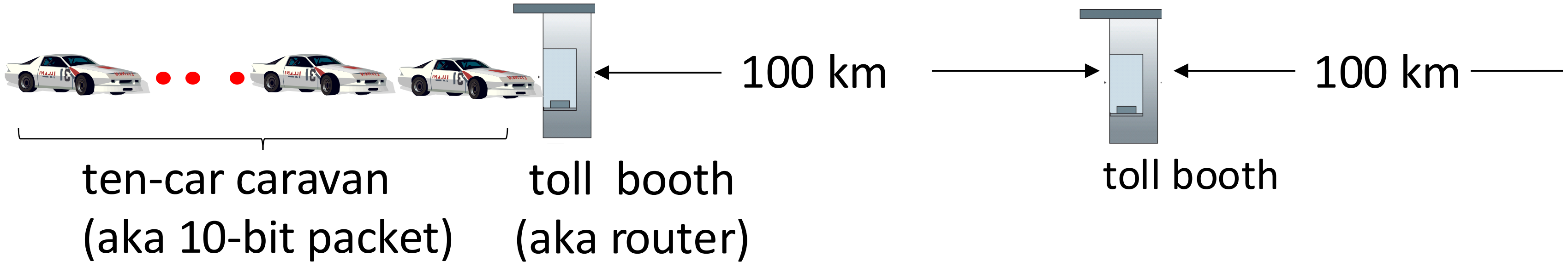
propagation speed ขึ้นกับสื่อ
(โจทย์กำหนด)

Caravan analogy



- car ~ bit; caravan ~ packet; toll service ~ link transmission
- toll booth takes 12 sec to service car (bit transmission time)
- "propagate" at 100 km/hr
- *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



- 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?*

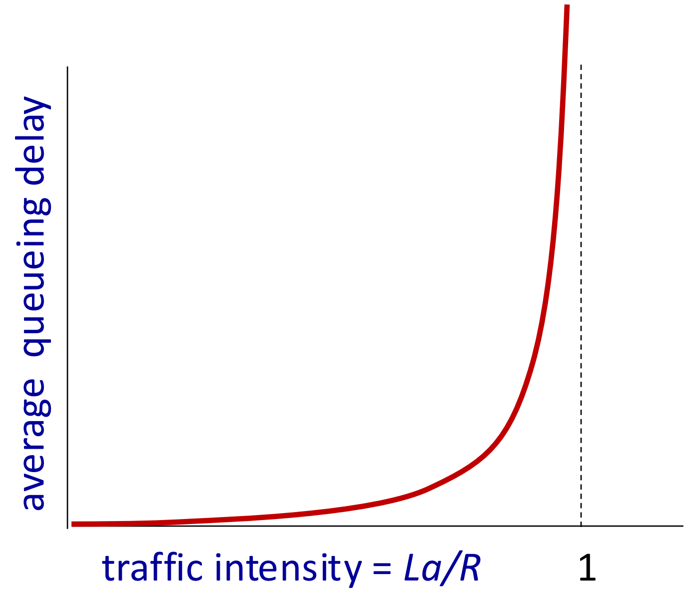
  A: Yes! after 7 min, first car arrives at second booth; three cars still at first booth

Packet queueing delay (revisited)

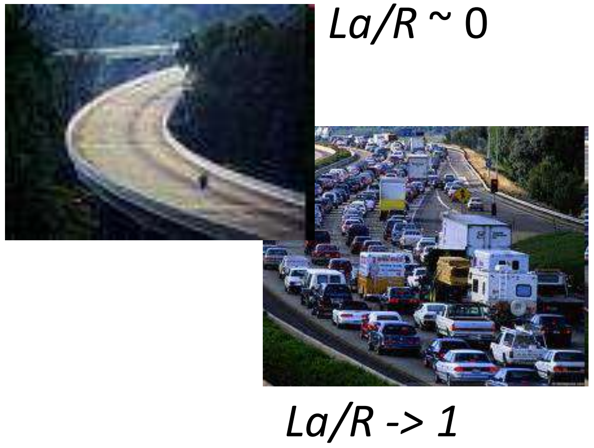
- *a:* average packet arrival rate
- *L:* packet length (bits)
- *R:* link bandwidth (bit transmission rate)

$$\frac{L \cdot a}{R} : \quad \frac{\text{arrival rate of bits}}{\text{service rate of bits}}$$

"traffic intensity"

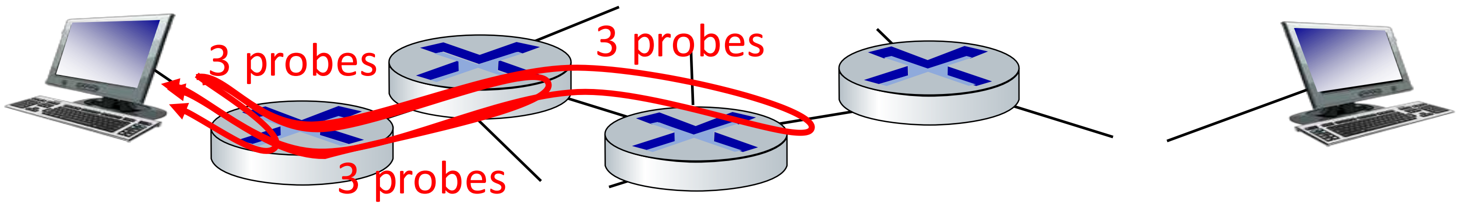


- *La/R* ~ 0: avg. queueing delay small
- *La/R* -> 1: avg. queueing delay large
- *La/R* > 1: more "work" arriving is more than can be serviced - average delay infinite!



"Real" Internet delays and routes

- what do "real" Internet delay & loss look like?
- **traceroute** program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
  - sends three packets that will reach router *i* on path towards destination (with time-to-live field value of *i*)
  - router *i* will return packets to sender
  - sender measures time 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
```

3 delay measurements
to border1-rt-fa5-1-0.gw.umass.edu

trans-oceanic link

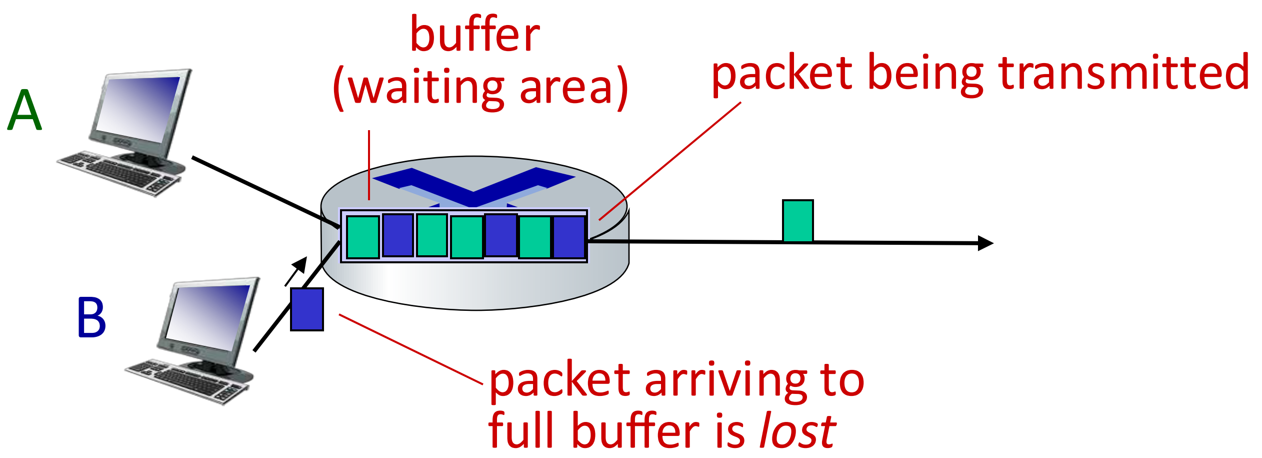
looks like delays *decrease*! Why?

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

* Do some traceroutes from exotic countries at www.traceroute.org

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 publisher's website) of queuing and loss

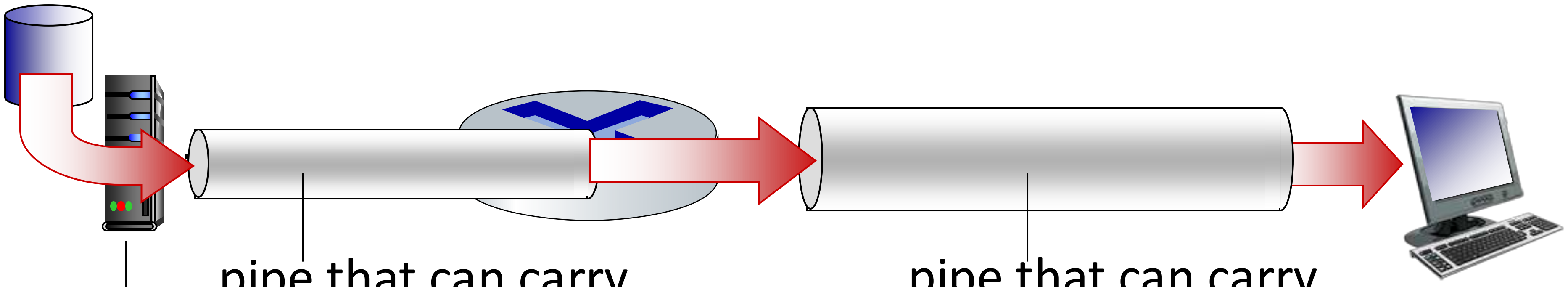
Throughput

จำนวน packet ที่ถูก จาก source to destination in time unit

- *throughput:* rate (bits/time unit) at which bits are being sent from sender to receiver

2 แบบ

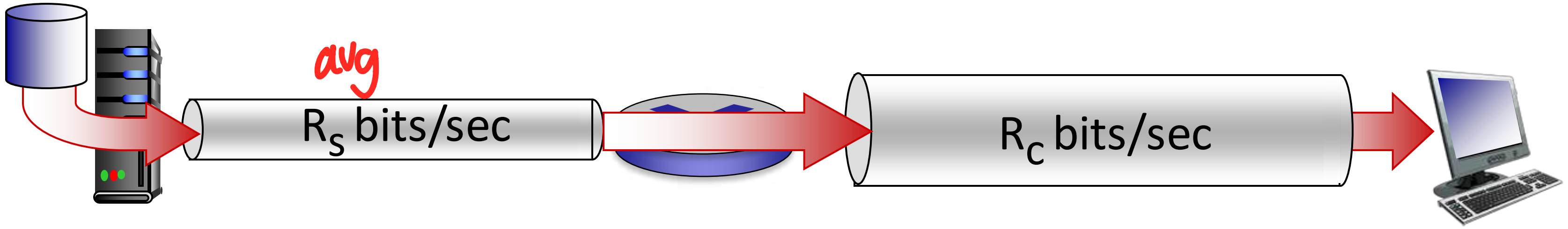
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time



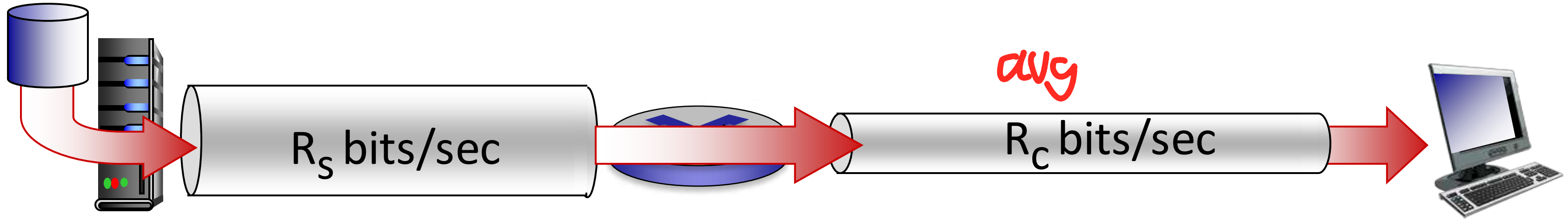
Throughput

average จะต้องเป็น min
เพราะ bottle neck ของ router

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



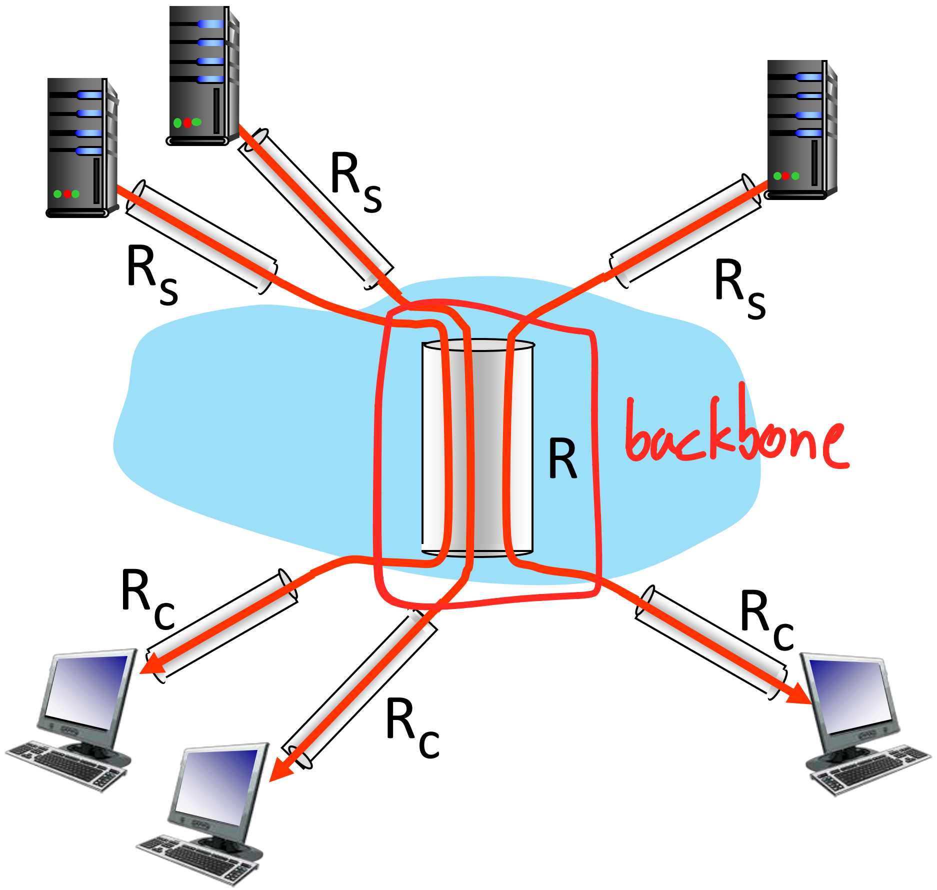
$R_s > R_c$ What is average end-end throughput?



bottleneck link

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

Throughput: network scenario



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

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

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

Chapter 1: roadmap

- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models
- History

Network security

- Internet not originally designed with (much) security in mind
  - *original vision:* "a group of mutually trusting users attached to a transparent network" ☺
  - Internet protocol designers playing "catch-up"
  - security considerations in all layers!
- We now need to think about:
  - how bad guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks

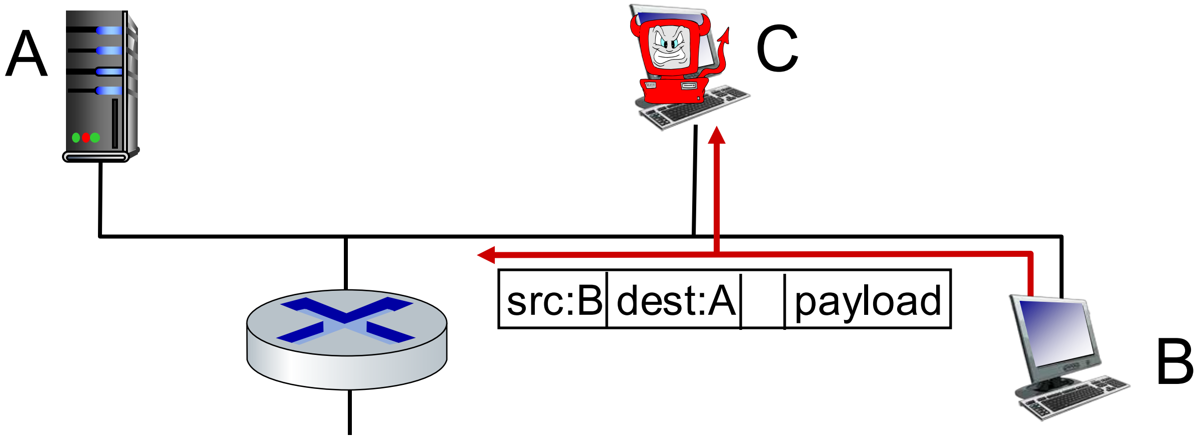
Network security

- Internet not originally designed with (much) security in mind
  - *original vision:* “a group of mutually trusting users attached to a transparent network” ☺
  - Internet protocol designers playing “catch-up”
  - security considerations in all layers!
- We now need to think about:
  - how bad guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks

Bad guys: packet interception

packet "sniffing":

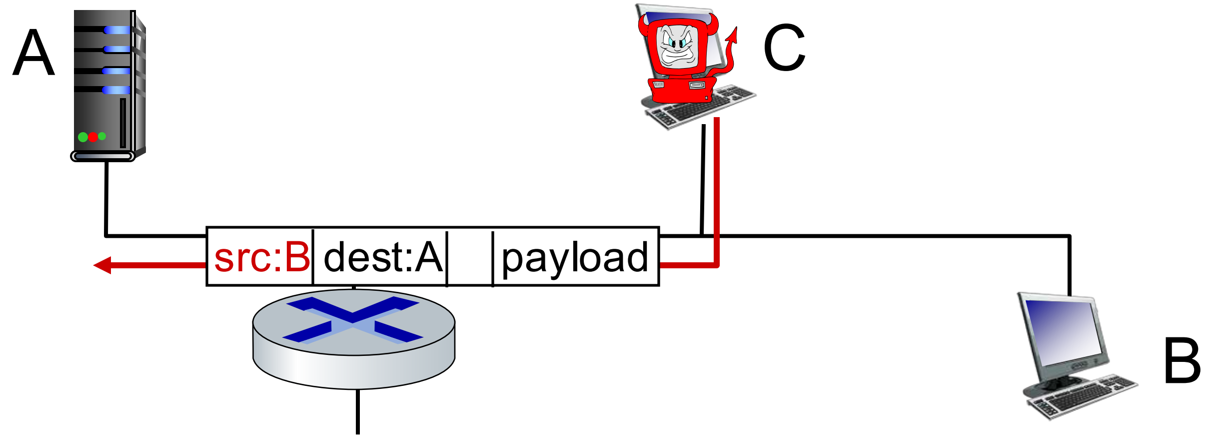
- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



Wireshark software used for our end-of-chapter labs is a (free) packet-sniffer

Bad guys: fake identity

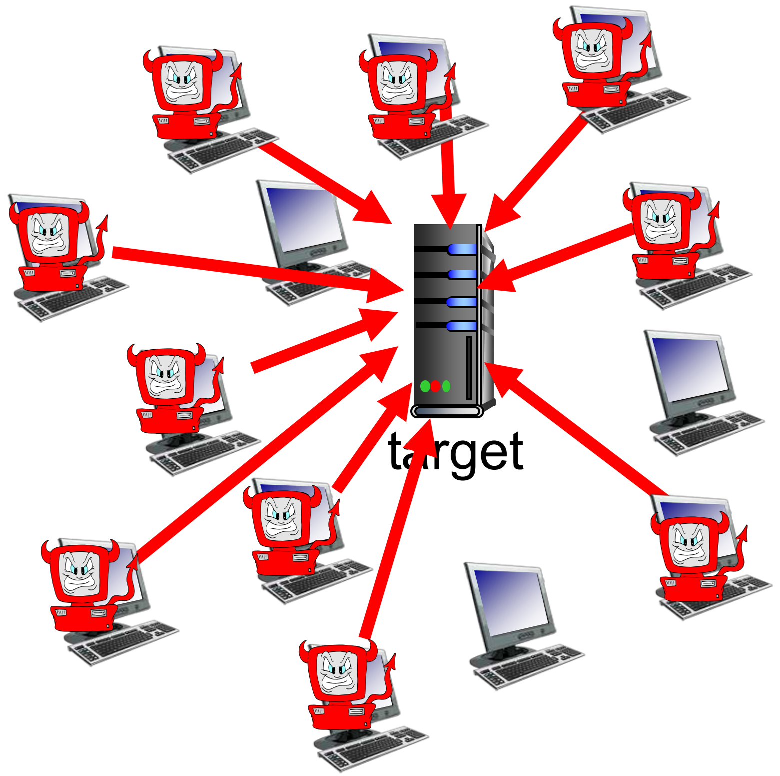
IP spoofing: injection of packet with false source address



Bad guys: denial of service

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



Lines of defense:

- authentication: proving you are who you say you are
  - cellular networks provides hardware identity via SIM card; no such hardware assist in traditional Internet
- confidentiality: via encryption
- integrity checks: digital signatures prevent/detect tampering
- access restrictions: password-protected VPNs
- firewalls: specialized “middleboxes” in access and core networks:
  - off-by-default: filter incoming packets to restrict senders, receivers, applications
  - detecting/reacting to DOS attacks

… lots more on security (throughout, Chapter 8)

Chapter 1: roadmap

- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models
- History

Protocol "layers" and reference models

เสนอวิธีจัดการ : layer system

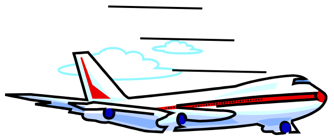
Networks are complex, with many "pieces":

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

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

- and/or our *discussion* of networks?

Example: organization of air travel



end-to-end transfer of person plus baggage

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

airplane routing

How would you *define/discuss* the *system* of airline travel?

- a series of steps, involving many services

Example: organization of air travel

layers: each layer implements a service

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

Why layering?

Approach to designing/discussing complex systems:

- explicit structure allows identification, relationship of system's pieces
  บอกได้ว่า each layer คืออะไรบ้าง
  - layered *reference model* for discussion
    แบ่งเป็น layer
- modularization eases maintenance, updating of system
  แบ่งเป็นส่วนๆ, ทำให้ ง่ายต่อการดูแล
  - change in layer's service *implementation*: transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system

Internet reference model

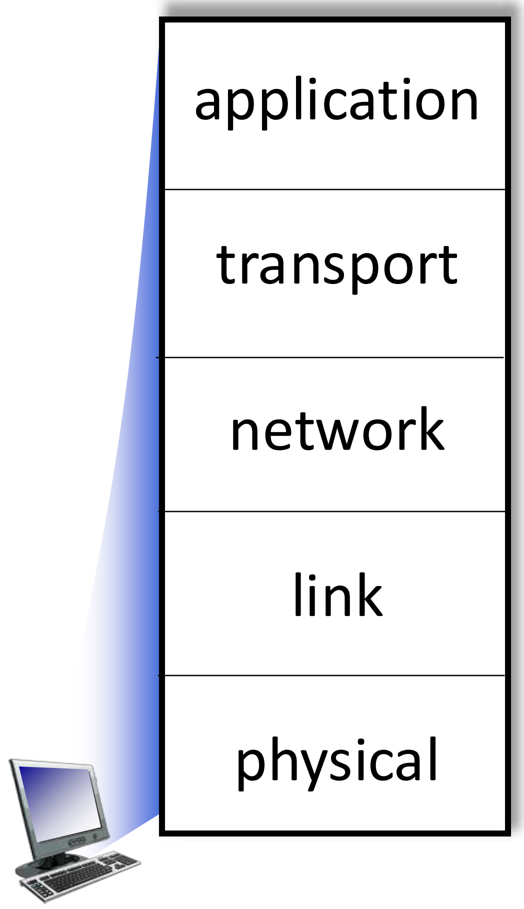
Layered Internet protocol stack

4-5 layers

- *application:* supporting network applications
  - HTTP, IMAP, SMTP, DNS หน่วยข้อมูล : message
- *transport:* process-process data transfer
  - TCP, UDP หน่วยข้อมูล : segment
- *network:* routing of datagrams from source to destination หน่วยข้อมูล : datagram, packet
  - IP, routing protocols
- *link:* data transfer between neighboring network elements หน่วยข้อมูล: frame
  - Ethernet, 802.11 (WiFi), PPP
- *physical:* bits "on the wire"
  → fiber optic, PA หน่วยข้อมูล : bit

application
transport
network
link
physical

Services, Layering and Encapsulation



source

M

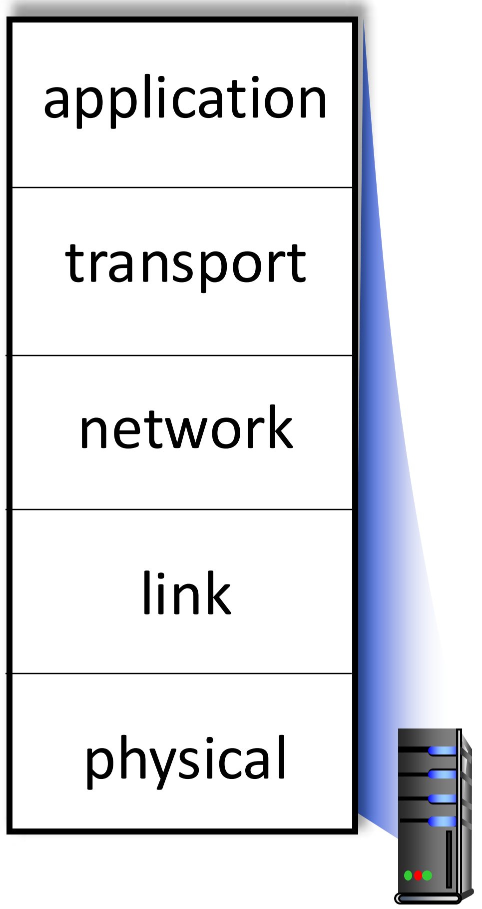
Application exchanges messages to implement some application service using *services* of transport layer

H_t M

Transport-layer protocol transfers M (e.g., reliably) from one *process* to another, using services of network layer

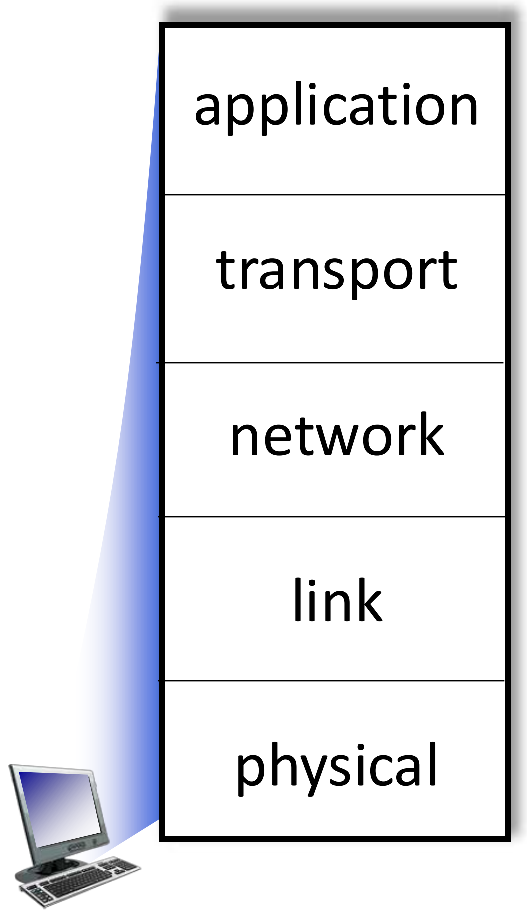
เพิ่มHeader

- transport-layer protocol encapsulates application-layer message, M, with *transport* layer-layer header H_t to create a transport-layer segment
  - H_t used by transport layer protocol to implement its service



destination

Services, Layering and Encapsulation



source

M

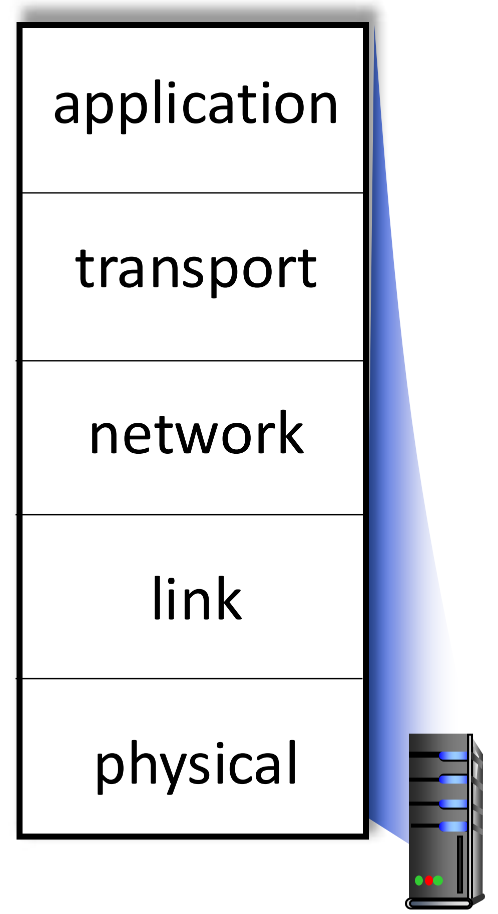
H_t | M

Transport-layer protocol transfers M (e.g., reliably) from one *process* to another, using services of network layer

H_n | H_t | M

Network-layer protocol transfers transport-layer segment [H_t | M] from one *host* to another, using link layer services

- network-layer protocol encapsulates transport-layer segment [H_t | M] with network layer-layer header H_n to create a network-layer datagram
  - H_n used by network layer protocol to implement its service



destination

Services, Layering and Encapsulation

application | transport | network | link | physical

M

H_t | M

H_n | H_t | M

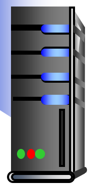
Network-layer protocol transfers transport-layer segment [H_t | M] from one *host* to another, using link layer services

H_l | H_n | H_t | M

Link-layer protocol transfers datagram [H_n| [H_t |M] from *host* to neighboring host, using network-layer services

- link-layer protocol encapsulates network datagram [H_n| [H_t |M], with link-layer header H_l to create a link-layer frame

source

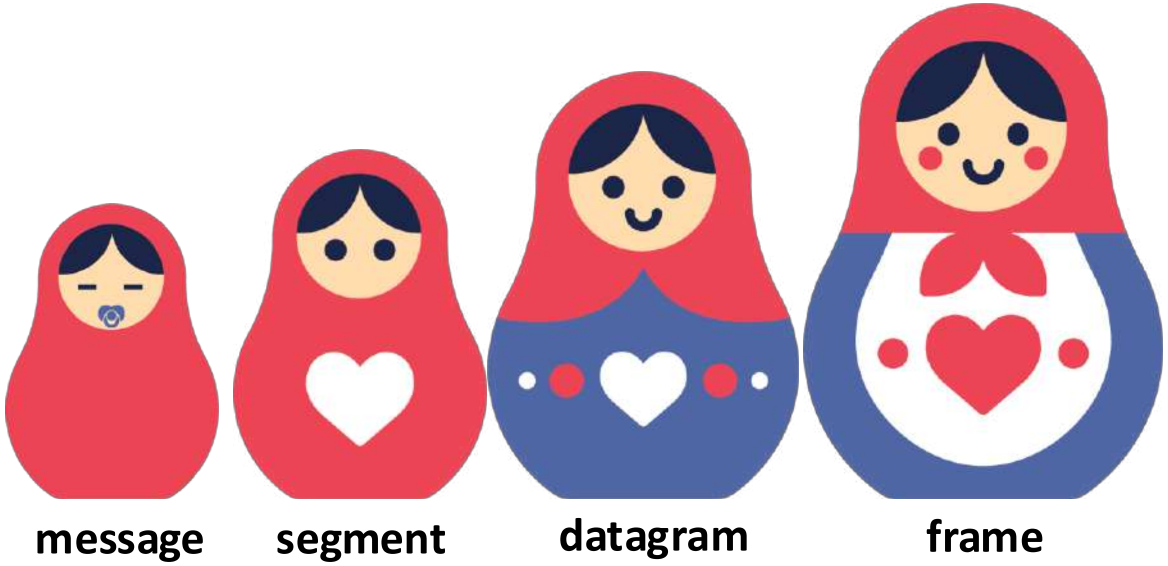


destination

application | transport | network | link | physical

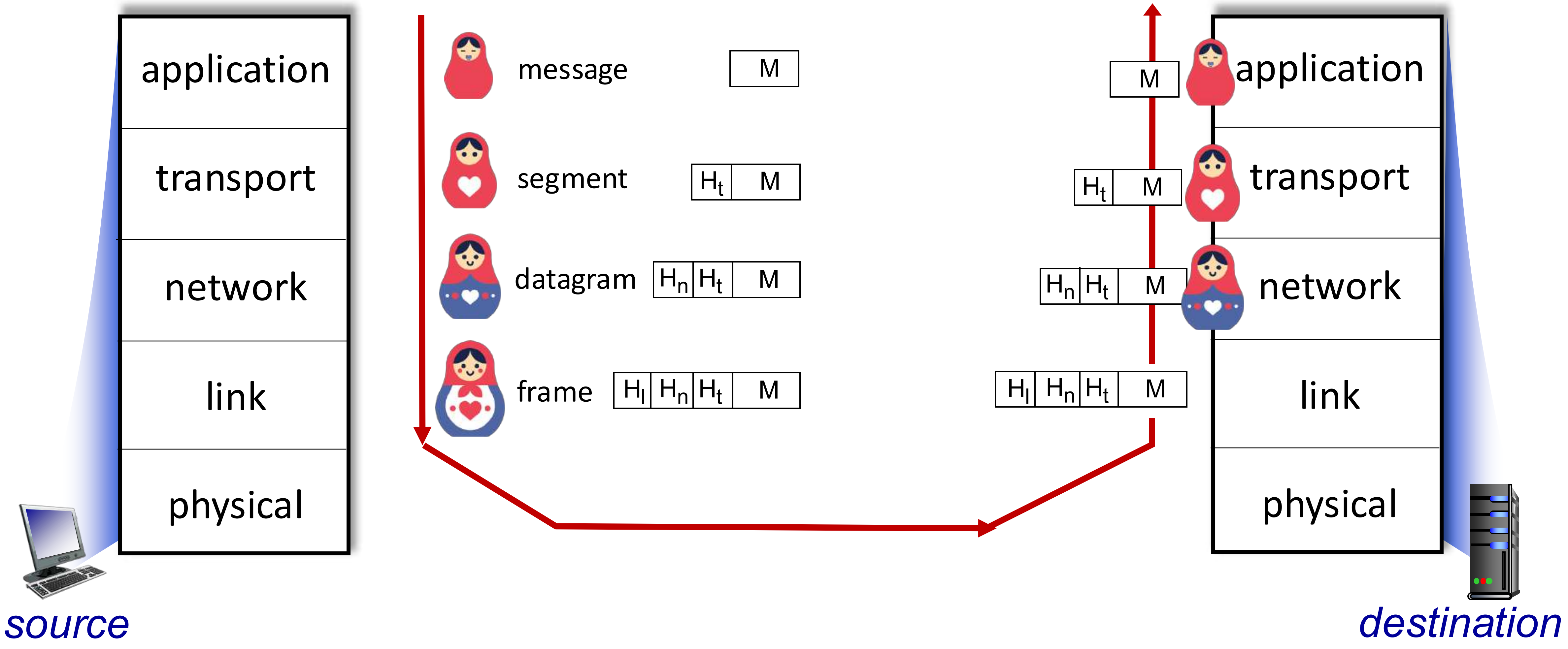
Encapsulation

Matryoshka dolls (stacking dolls)

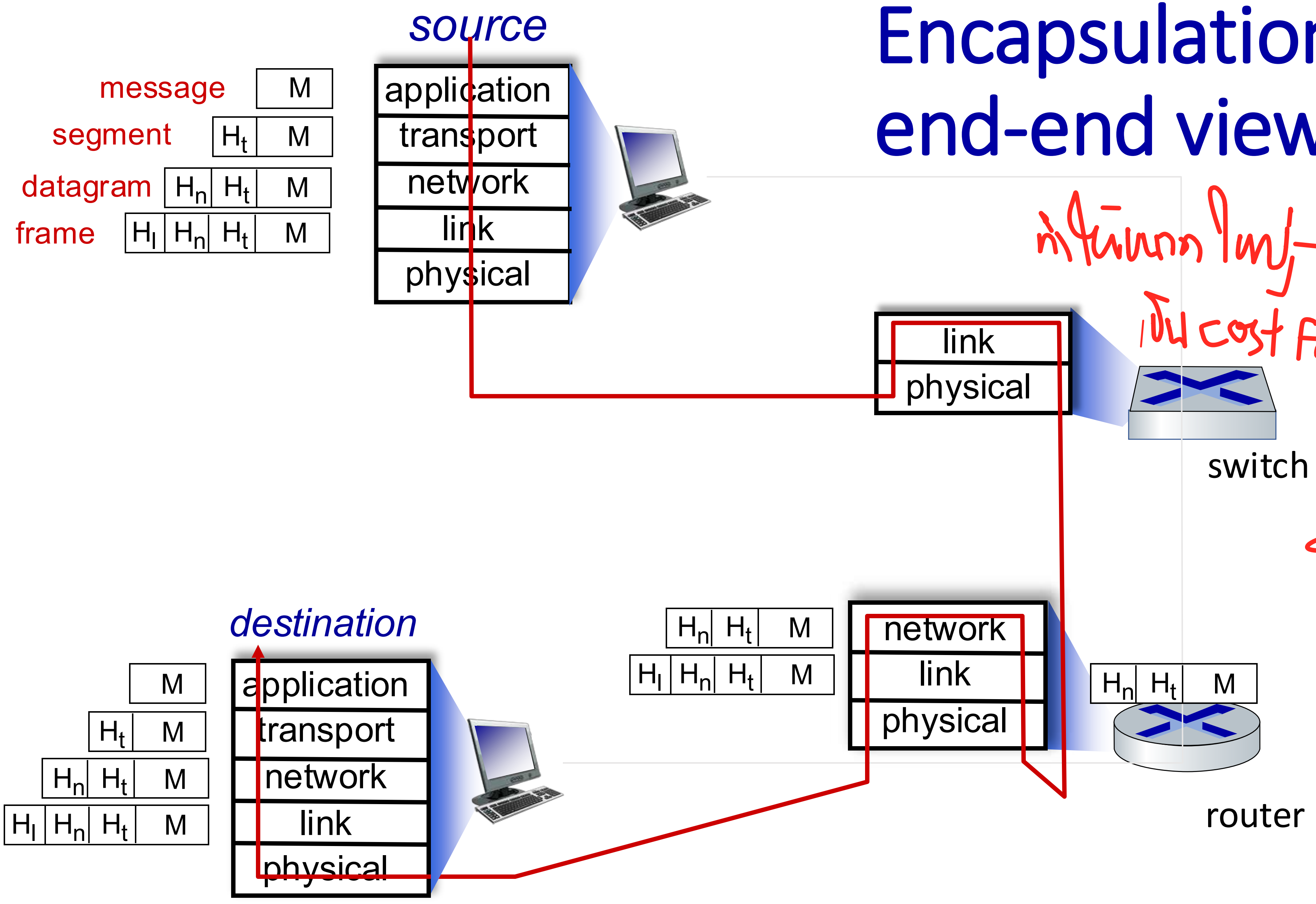


Credit: https://dribbble.com/shots/7182188-Babushka-Boi

Services, Layering and Encapsulation



Encapsulation: an end-end view



[illegible] → ดี
เป็น cost for layer system to handle complex thing

Chapter 1: roadmap

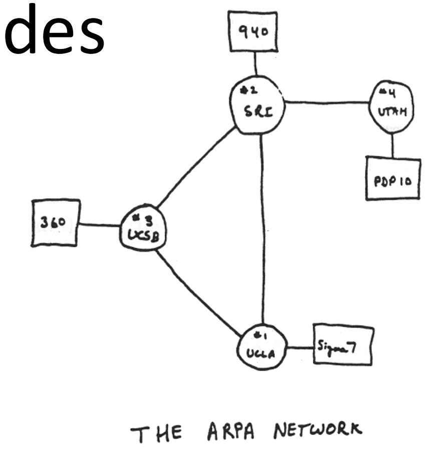
- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models
- History

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
- 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



Internet history

1972-1980: Internetworking, new and proprietary networks

- 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
- 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 routing
- decentralized control

define today's Internet architecture

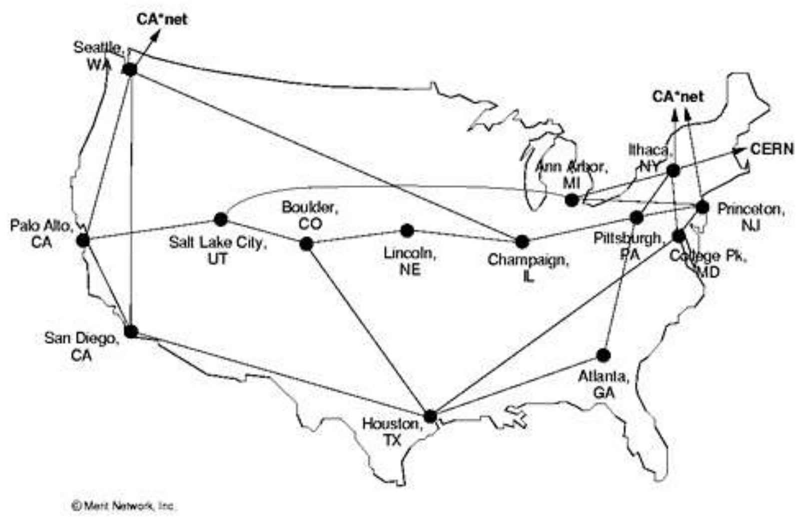
Internet history

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

NSFNET T1 Network 1991



Internet history

1990, 2000s: commercialization, the Web, new applications

- early 1990s: 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 1990s: commercialization of the Web

late 1990s – 2000s:

- 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: scale, SDN, mobility, cloud

- aggressive deployment of broadband home access (10-100's Mbps)
- 2008: software-defined networking (SDN)
- increasing ubiquity of high-speed wireless access: 4G/5G, WiFi
- service providers (Google, FB, Microsoft) create their own networks
  - bypass commercial Internet to connect "close" to end user, providing "instantaneous" access to social media, search, video content, …
- enterprises run their services in "cloud" (e.g., Amazon Web Services, Microsoft Azure)
- rise of smartphones: more mobile than fixed devices on Internet (2017)
- ~15B devices attached to Internet (2023, statista.com)

Chapter 1: summary

We've covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, access network, core
  - packet-switching versus circuit-switching
  - Internet structure
- performance: loss, delay, throughput
- layering, service models
- security
- history

You now have:

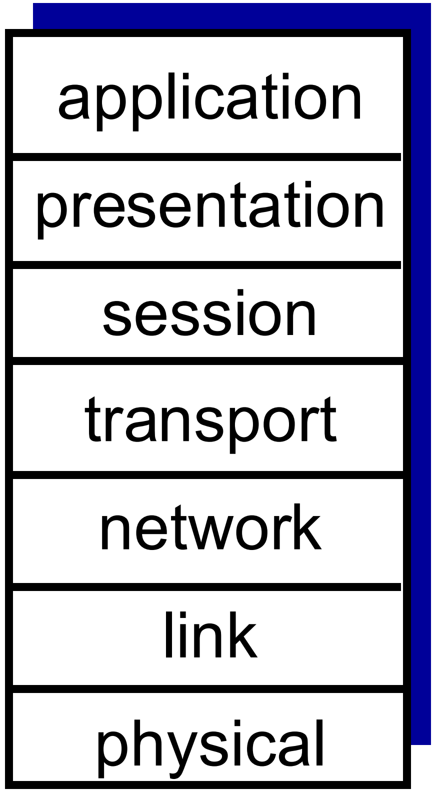
- context, overview, vocabulary, "feel" of networking
- more depth, detail, *and fun* to follow*!*

Additional Chapter 1 slides

ISO/OSI reference model

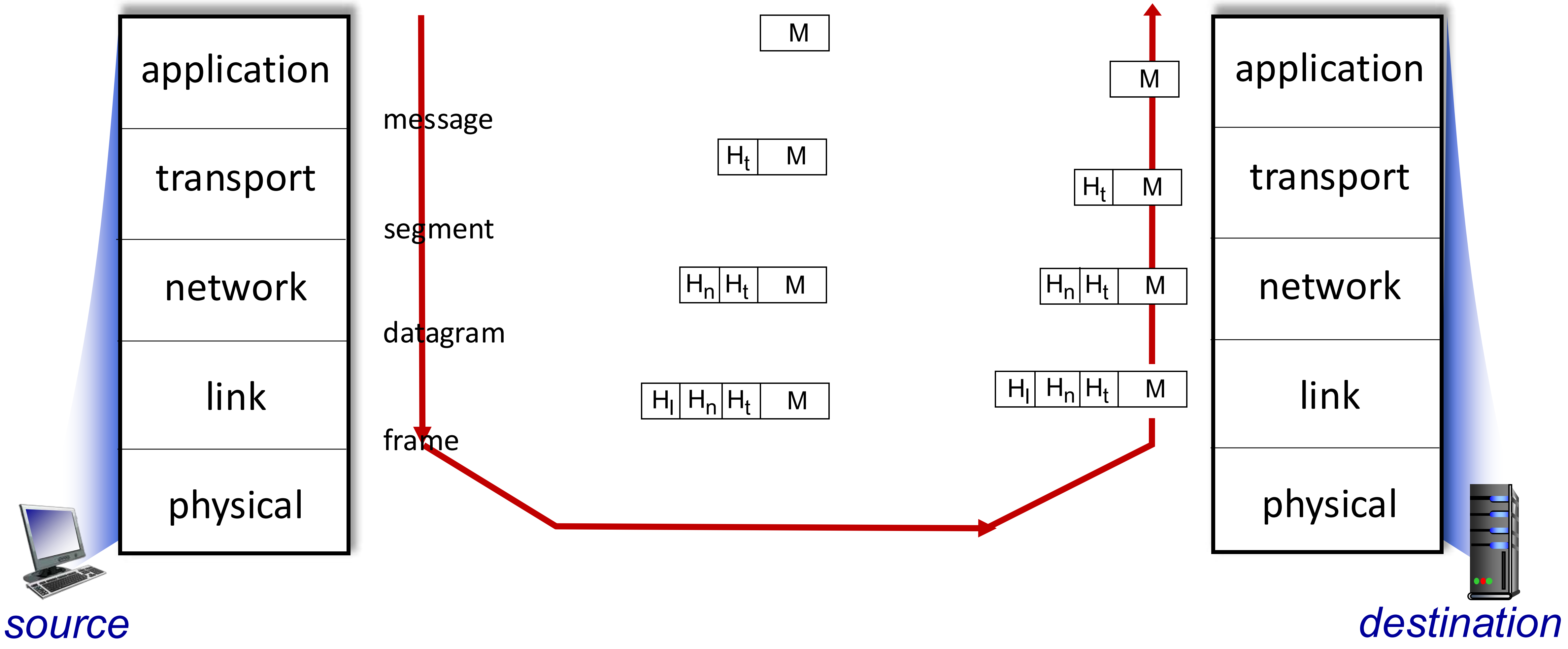
Two layers not found in Internet protocol stack!

- *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?

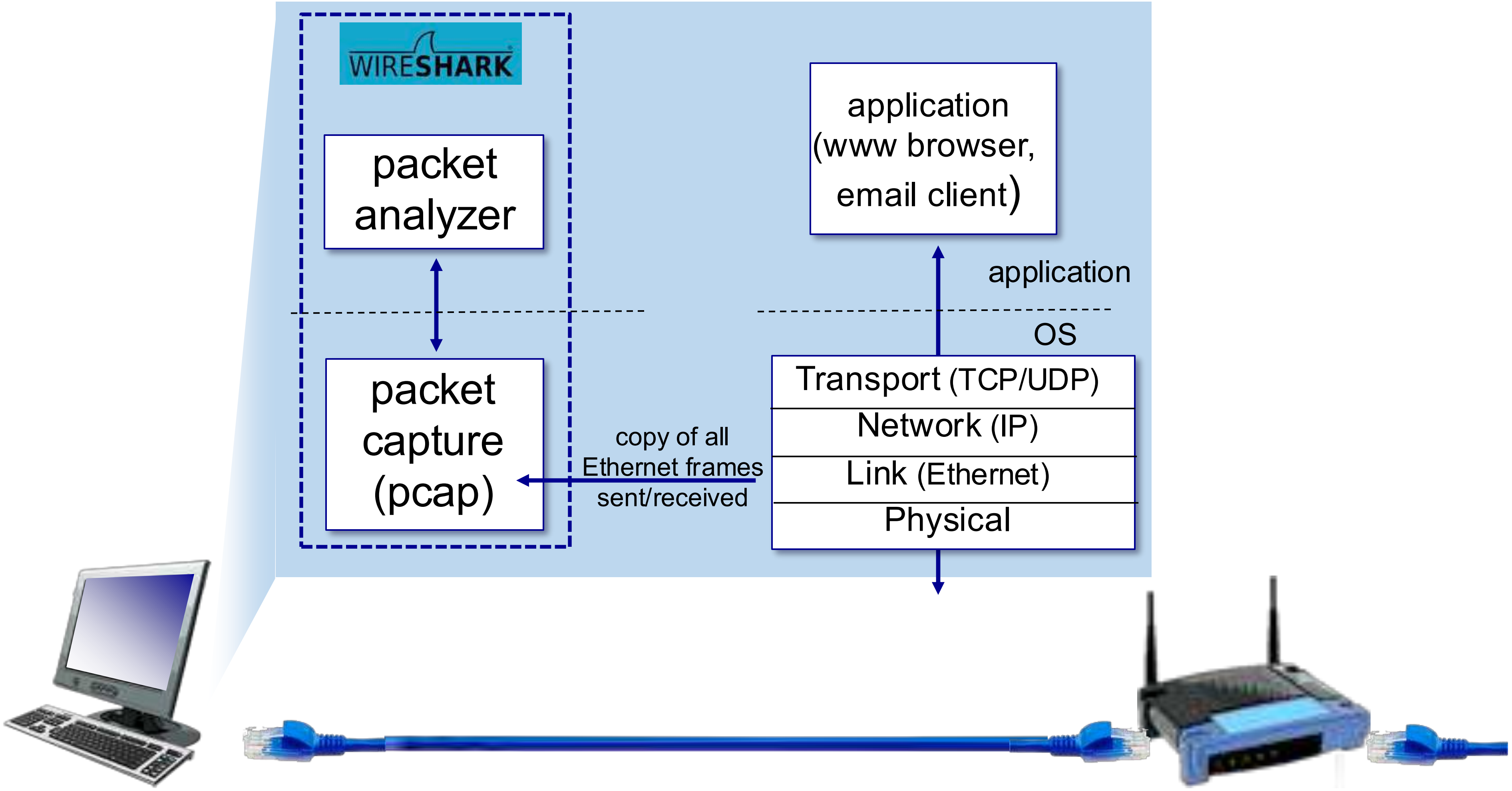


The seven layer OSI/ISO reference model

Services, Layering and Encapsulation



Wireshark


WIRESHARK
packet analyzer
packet capture (pcap)
copy of all Ethernet frames sent/received
application (www browser, email client)
application
OS
Transport (TCP/UDP)
Network (IP)
Link (Ethernet)
Physical