

EII-4

Réseaux

Une première approche

Voir sur <http://www.i3s.unice.fr/~deneire/cours.html>

E-mail : luc.deneire@univ-cotedazur.fr

Qu'est-ce qu'un réseau ?

.Vos réponses

.

.Ce que vous attendez de ce cours

Une proposition : « passer » le CCNA-1

- .17 chapitres très courts
- .4-5 examens en ligne
- .1 examen sur Packet Tracer
- .1 examen de manipulation sur du matériel réseau

Un historique d'Internet

.Emprunté à Guillaume Urvoy-Keller

Principes de réseaux

- .Sur base du Livre : Computer Networks, a Top-Down Approach, Kuros-Ross
- .Quelques exercices « sur table », sur machine et sur simulateur

A note on the use of these PowerPoint slides:

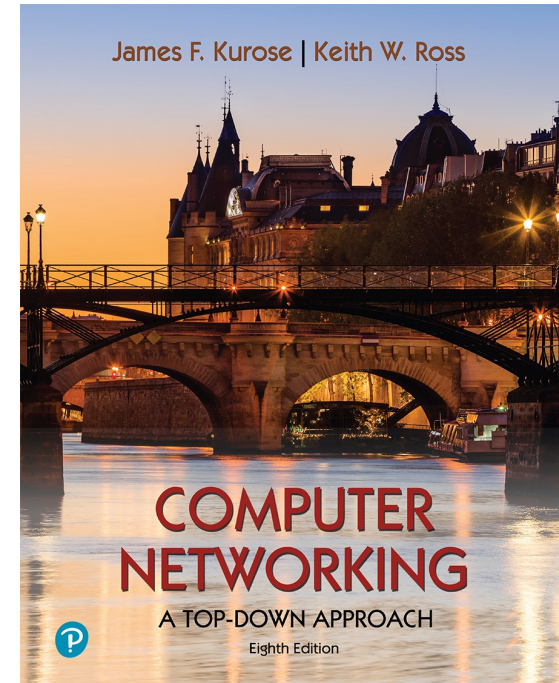
We're making these slides freely available to all (faculty, students, readers). They're in PowerPoint form so you see the animations; and can add, modify, and delete slides (including this one) and slide content to suit your needs. They obviously represent a *lot* of work on our part. In return for use,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

All material copyright 1996-2020
J.F Kurose and K.W. Ross, All Rights Reserved



Computer Networking: A Top-Down Approach

8th edition

Jim Kurose, Keith Ross
Pearson, 2020

Une proposition malhonnête d'organisation d'une séance

- .1/2 heure (voire plus) – questions sur les chapitres CCNA
- .1 heure environ de principes
- .1 heure et demi (voire plus:)) Exercices / Travaux pratiques

Notation (parce que vous le valez bien)

.CCNA : 50 % de la note

.Examen final écrit (théorie et exercices) : 50 %

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)

- *routers, switches*

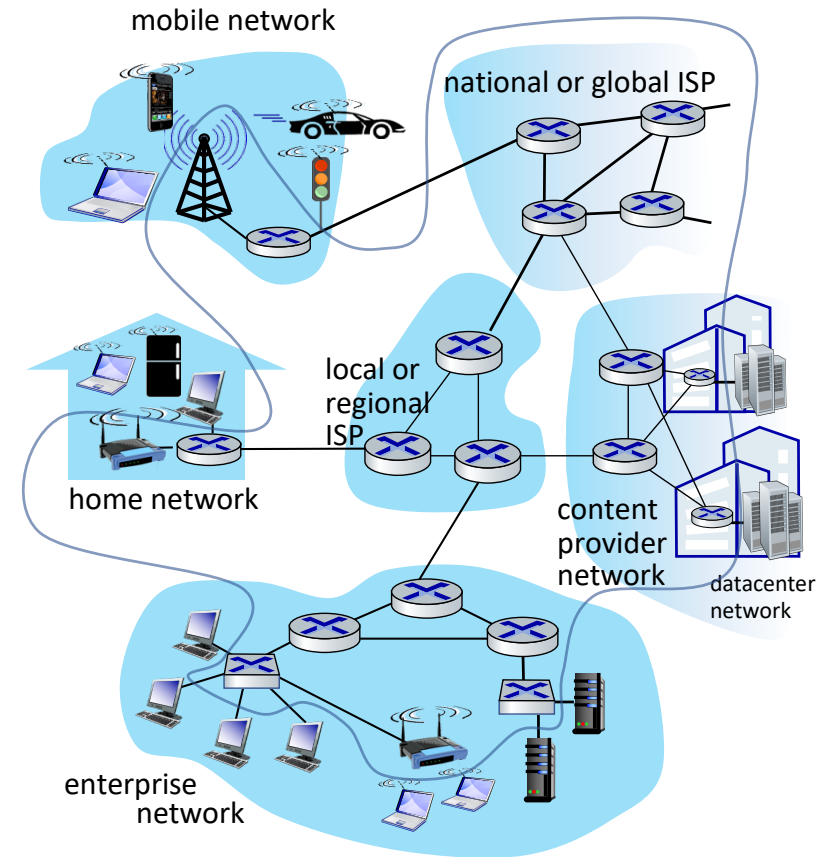


Communication links

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

Networks

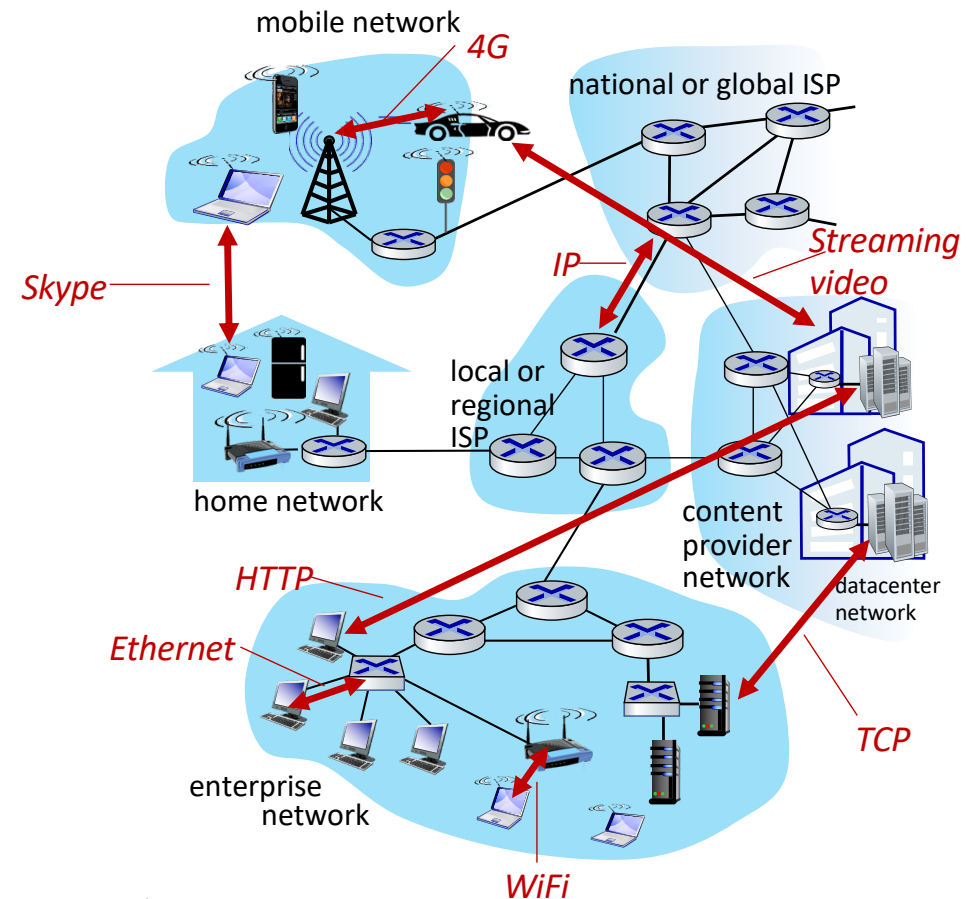
- collection of devices, routers, links: managed by an organization



The Internet: a “nuts and bolts” view

Internet: “network of networks”

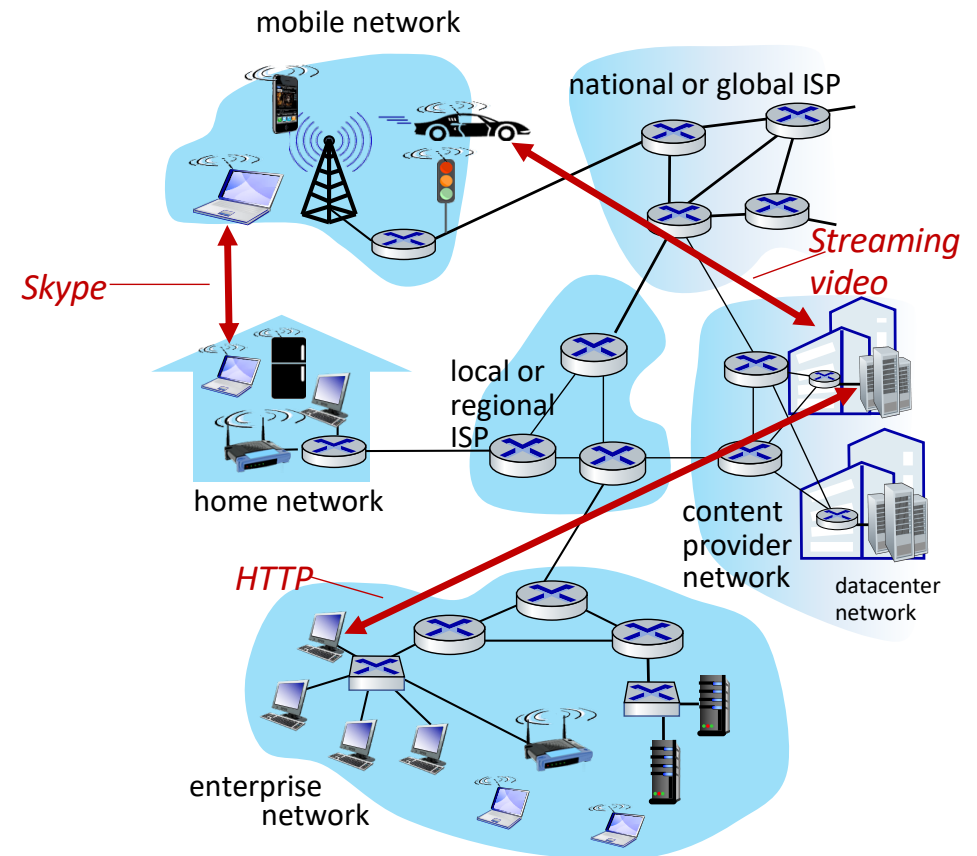
- Interconnected ISPs
- *protocols are everywhere*
 - control sending, receiving of messages
 - e.g., HTTP (Web), streaming video, Skype, TCP, IP, WiFi, 4G, Ethernet
- *Internet standards*
 - RFC: Request for Comments
 - IETF: Internet Engineering Task Force



The Internet: a “service” view

Infrastructure that provides services to applications:

- Web, streaming video, multimedia teleconferencing, email, games, e-commerce, social media, inter-connected appliances, ...
- provides *programming interface* to distributed applications:
 - “hooks” allowing sending/receiving apps to “connect” to, use Internet transport service
 - provides service options, analogous to postal service



What's a protocol?

Human protocols:

- “what’s the time?”
- “I have a question”
- introductions

... specific messages sent

... specific actions taken
when message received,
or other events

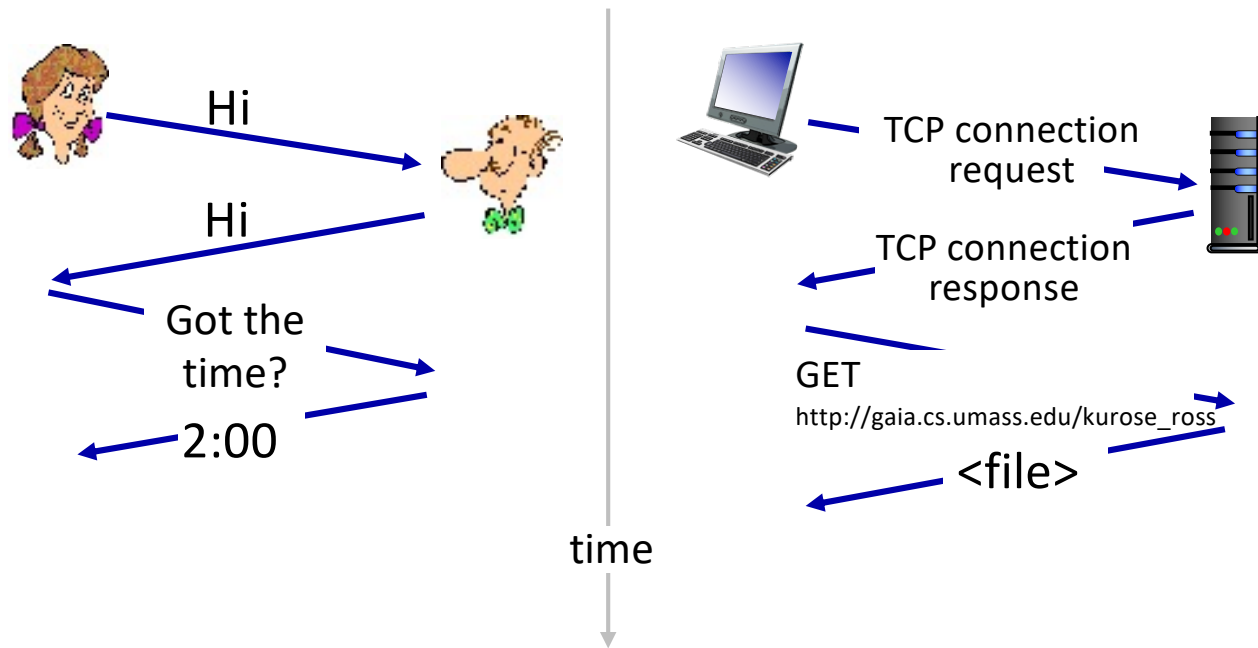
Network protocols:

- 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 msg transmission, receipt

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

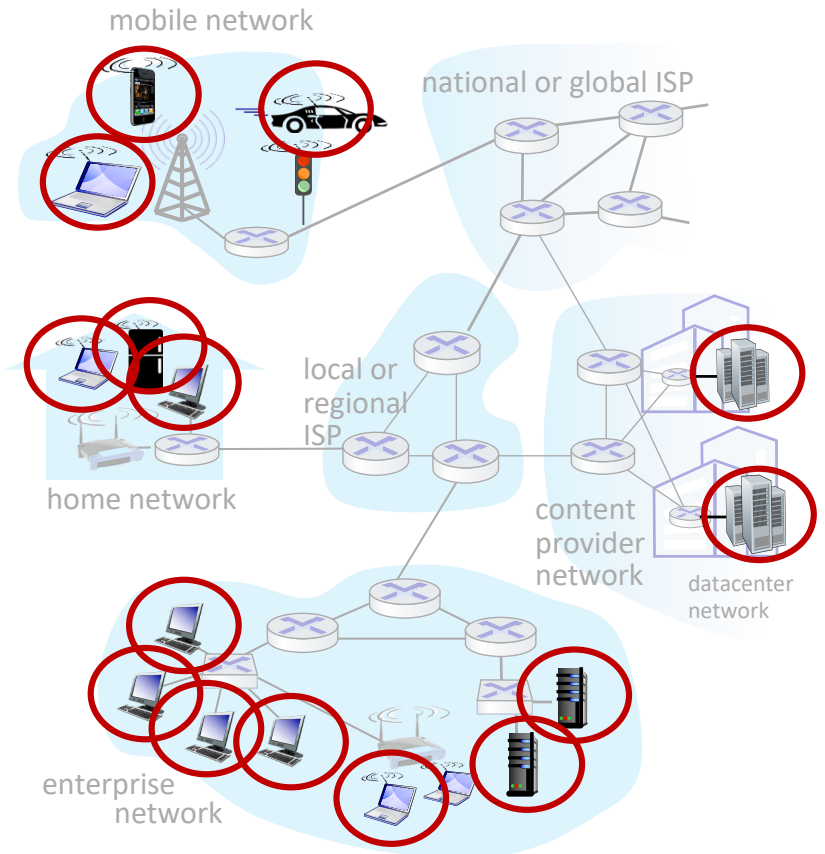


A closer look at Internet structure

Network edge:

hosts: clients and servers

servers often in data centers



A closer look at Internet structure

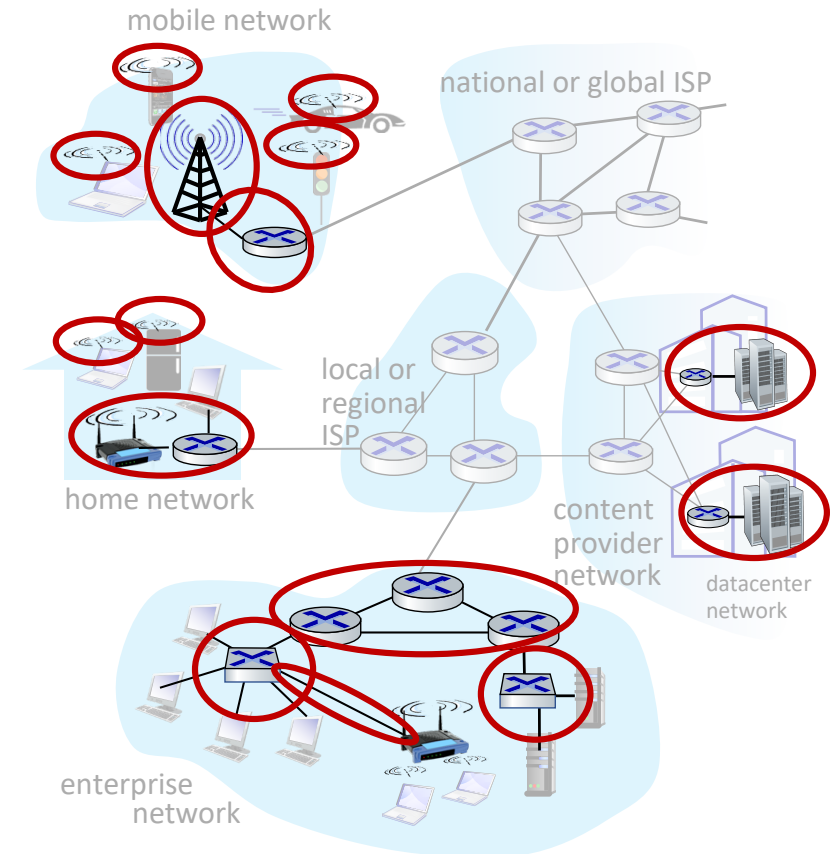
Network edge:

hosts: clients and servers

servers often in data centers

Access networks, physical media:

wired, wireless communication links



A closer look at Internet structure

Network edge:

hosts: clients and servers

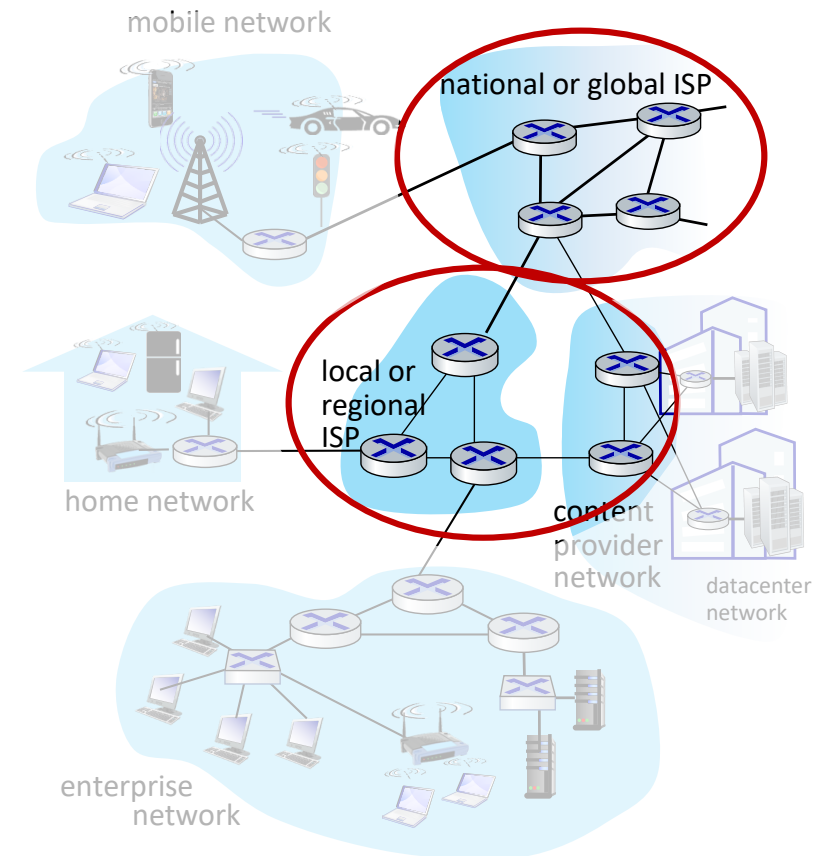
servers often in data centers

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?

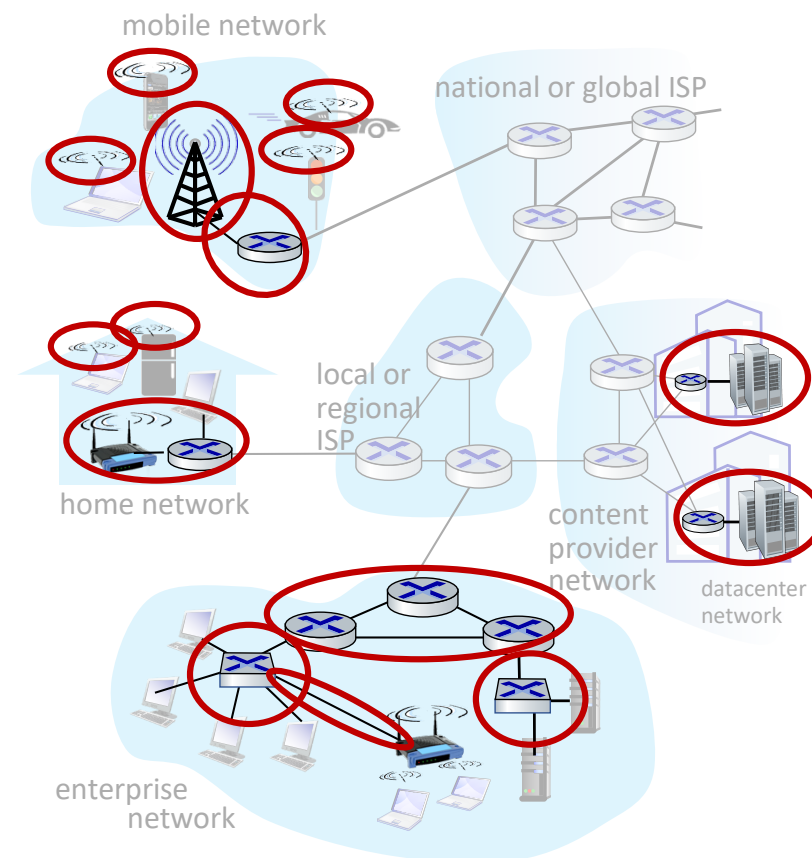
residential access nets

institutional access networks (school, company)

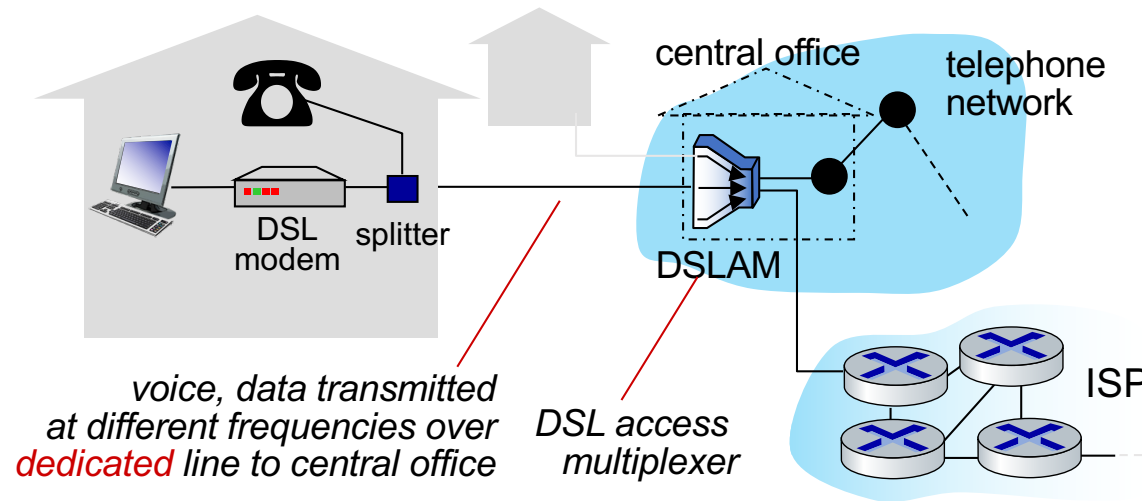
mobile access networks (WiFi, 4G/5G)

What to look for:

- transmission rate (bits per second) of access network?
- shared or dedicated access among users?

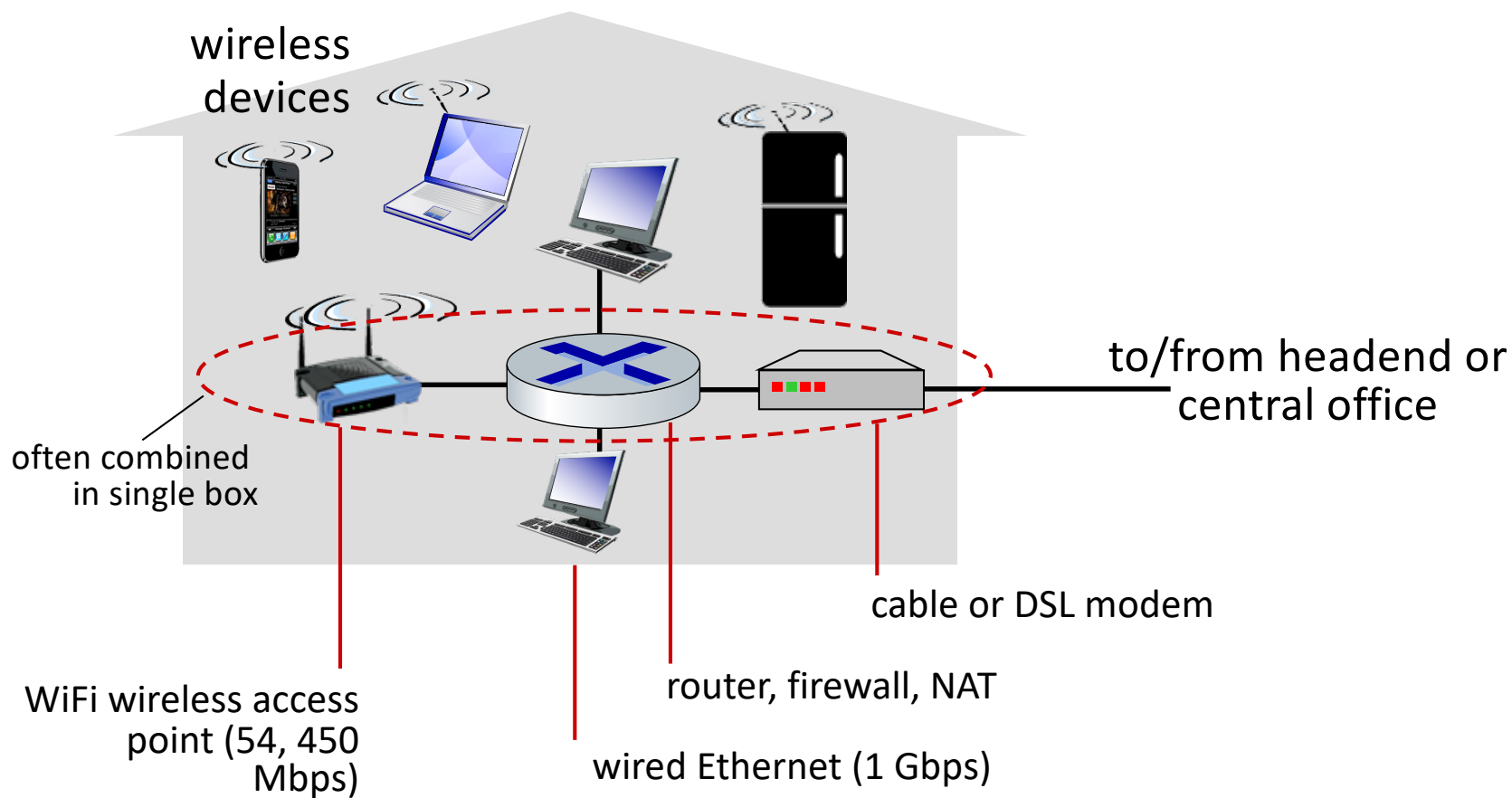


Access networks: digital subscriber line (DSL)



- 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



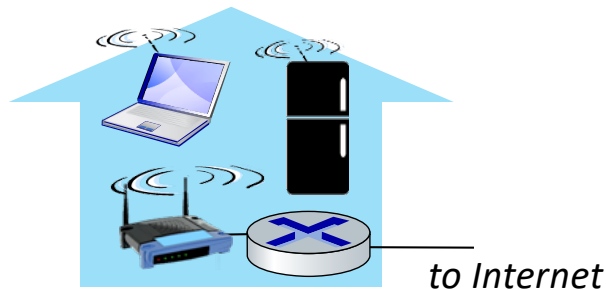
Wireless access networks

Shared *wireless* access network connects end system to router

- via base station aka “access point”

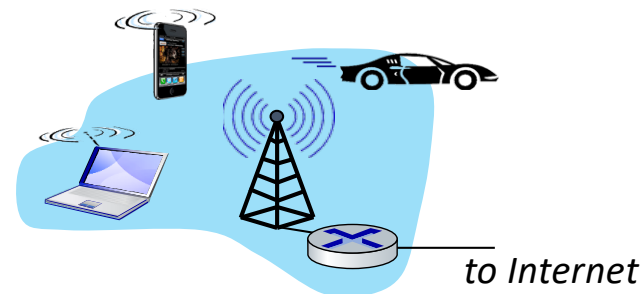
Wireless local area networks (WLANs)

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

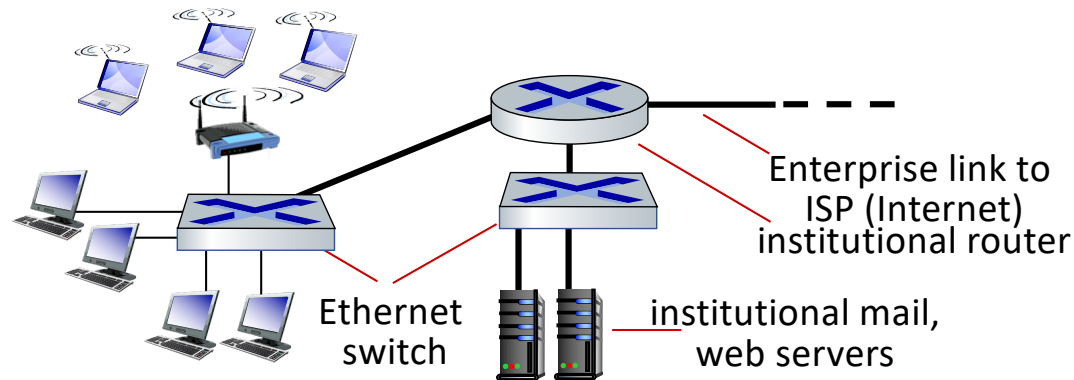


Wide-area cellular access networks

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



Access networks: enterprise networks

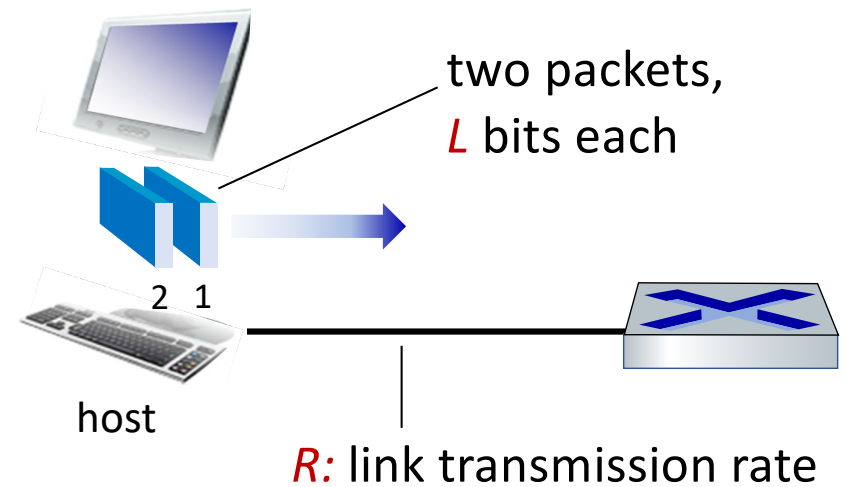


- companies, universities, etc.
- mix of wired, wireless link technologies, connecting a mix of switches and routers (we'll cover differences shortly)
 - Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps
 - WiFi: wireless access points at 11, 54, 450 Mbps

Host: sends *packets* of data

host sending function:

- takes application message
- breaks into smaller chunks, known as *packets*, of length L bits
- transmits packet into access network at *transmission rate R*
 - link transmission rate, aka link *capacity, aka link bandwidth*



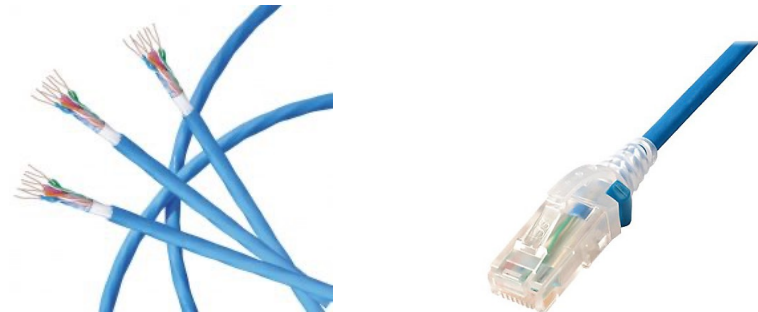
$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Links: 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 Gbps Ethernet
 - Category 6: 10Gbps Ethernet



Links: physical media

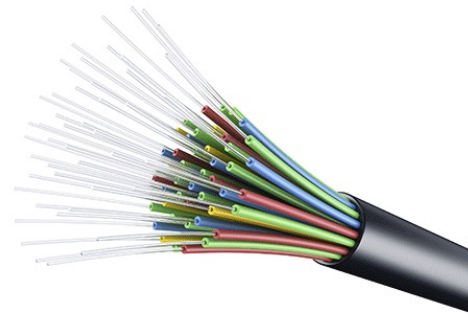
Coaxial cable:

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



Fiber optic cable:

- 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:
 - repeaters spaced far apart
 - immune to electromagnetic noise



Links: physical media

Wireless radio

- signal carried in electromagnetic spectrum
- no physical “wire”
- broadcast and “half-duplex” (sender to receiver)
- propagation environment effects:
 - reflection
 - obstruction by objects
 - interference

Radio link types:

- **terrestrial microwave**
 - up to 45 Mbps channels
- **Wireless LAN (WiFi)**
 - Up to 100’s Mbps
- **wide-area (e.g., cellular)**
 - 4G cellular: ~ 10’s Mbps
- **satellite**
 - up to 45 Mbps per channel
 - 270 msec end-end delay
 - geosynchronous versus low-earth-orbit

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

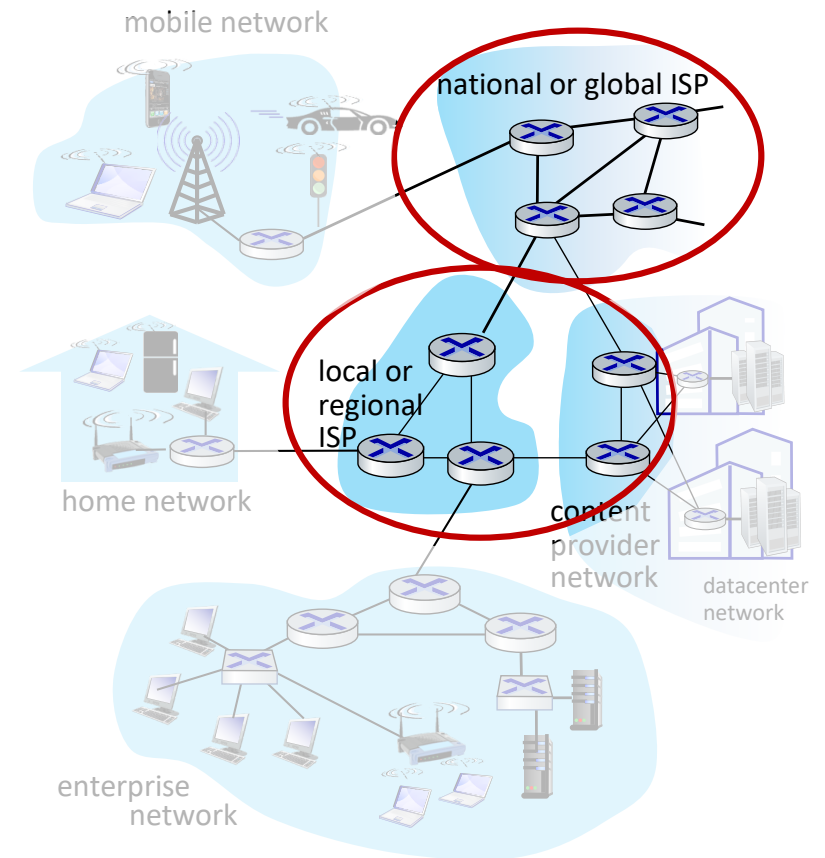


The network core

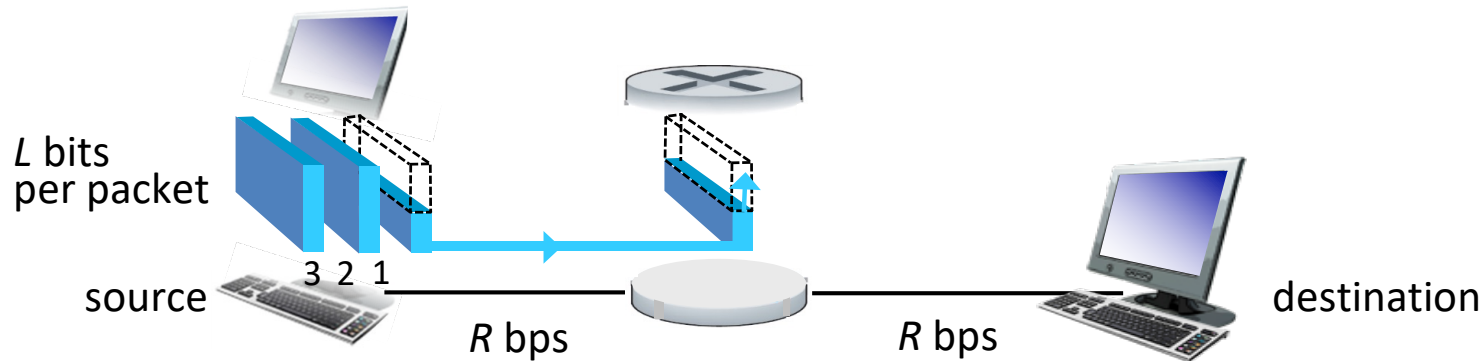
mesh of interconnected routers

packet-switching: hosts break application-layer messages into *packets*

- 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



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

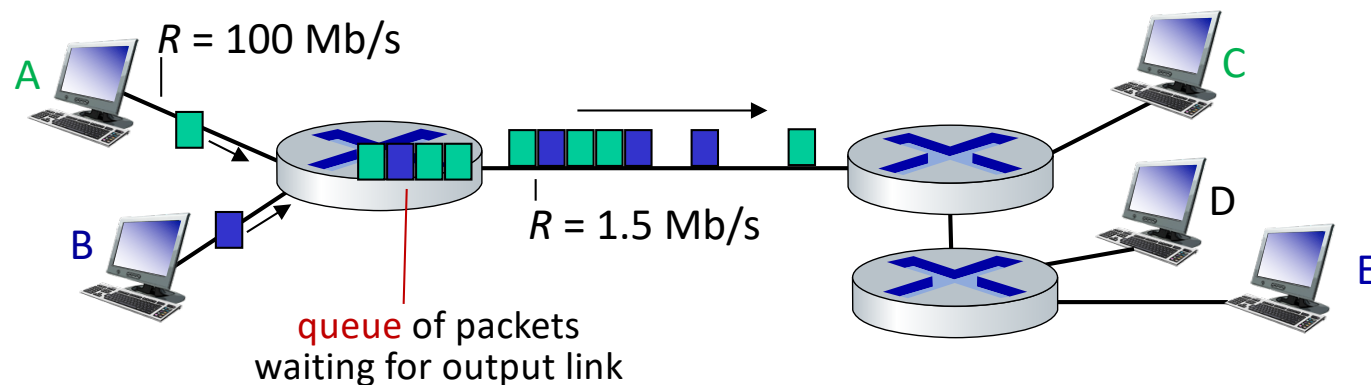
Store and forward: entire packet must arrive at router before it can be transmitted on next link

End-end delay: $2L/R$ (above), assuming zero propagation delay (more on delay shortly)

One-hop numerical example:

- $L = 10$ Kbits
- $R = 100$ Mbps
- one-hop transmission delay = 0.1 msec

Packet-switching: queueing delay, loss



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

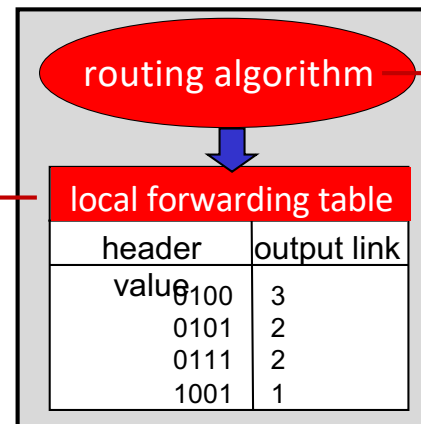
packets will queue, waiting to be transmitted on output link

packets can be dropped (lost) if memory (buffer) in router fills up

Two key network-core functions

Forwarding:

local action: move arriving packets from router's input link to appropriate router output link

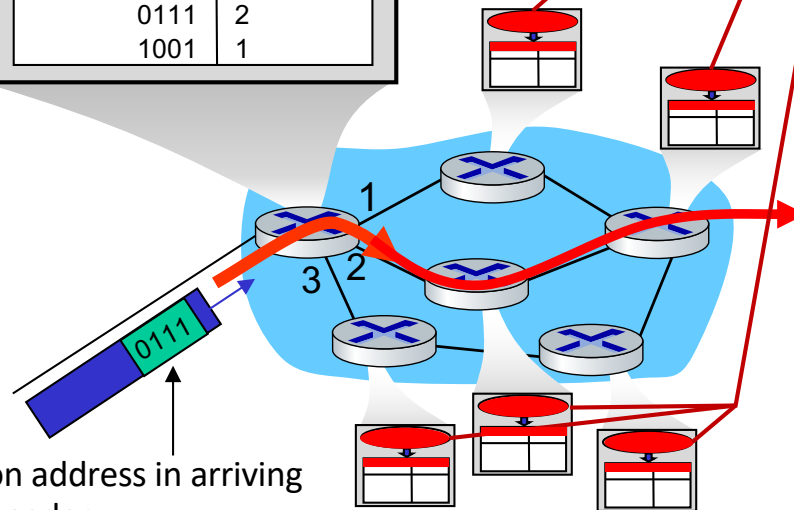


destination address in arriving packet's header

Réseaux – EII – 4. L. Deneire

Routing:

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



Alternative to packet switching: circuit switching

end-end resources allocated to, reserved for “call” between source and destination

in diagram, each link has four circuits.

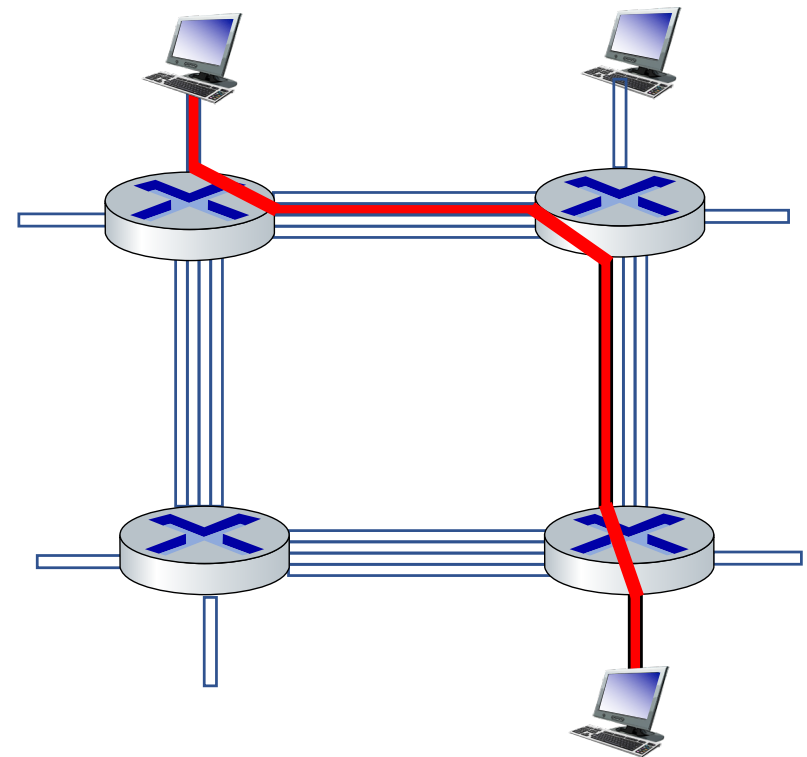
- call gets 2nd circuit in top link and 1st circuit in right link.

dedicated resources: no sharing

- circuit-like (guaranteed) performance

circuit segment idle if not used by call (no sharing)

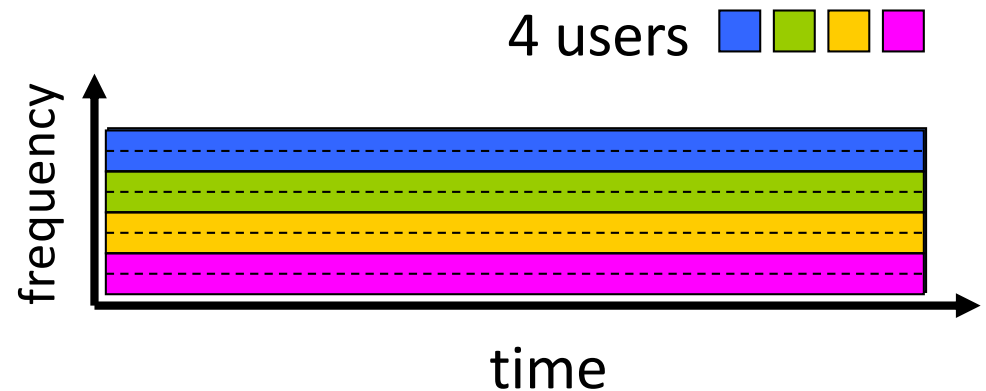
commonly used in traditional telephone networks



Circuit switching: FDM and TDM

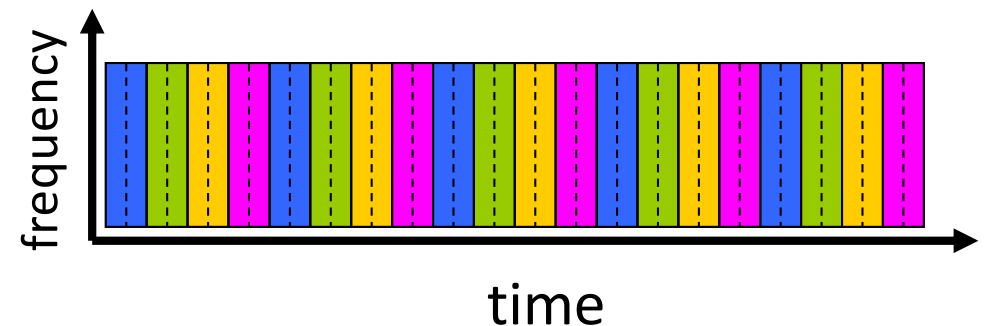
Frequency Division Multiplexing (FDM)

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, but only during its time slot(s)

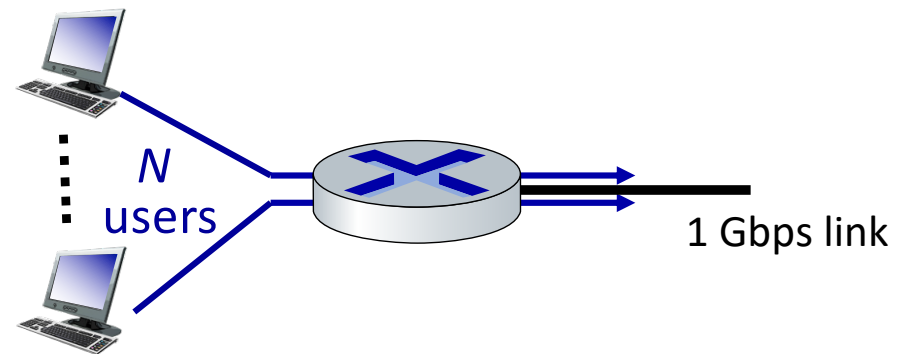


Packet switching versus circuit switching

packet switching allows more users to use network!

Example:

- 1 Gb/s link
- each user:
 - 100 Mb/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 *



Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive
Réseaux – EII – 4. L. Deneire

Packet switching versus circuit switching

Is packet switching a “slam dunk winner”?

- great for “bursty” data – sometimes has data to send, but at other times not
 - resource sharing
 - simpler, no call setup
- **excessive congestion possible:** packet delay and loss due to buffer overflow
 - protocols needed for reliable data transfer, congestion control
- **Q: How to provide circuit-like behavior?**
 - bandwidth guarantees traditionally used for audio/video applications

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)

- residential, enterprise (company, university, commercial) ISPs

Access ISPs in turn must be interconnected

- so that any two hosts can send packets to each other

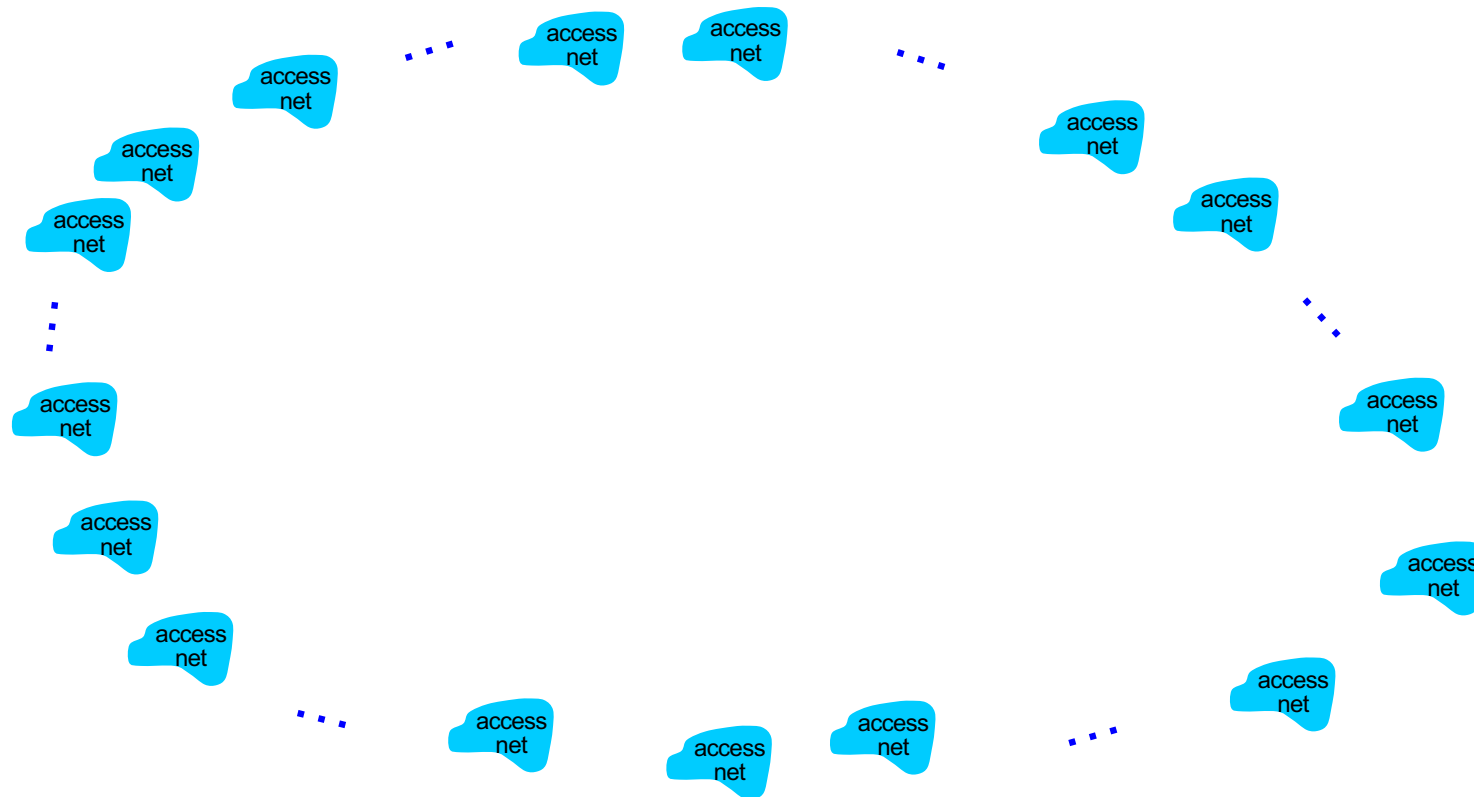
Resulting network of networks is very complex

- evolution was driven by **economics** and **national policies**

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

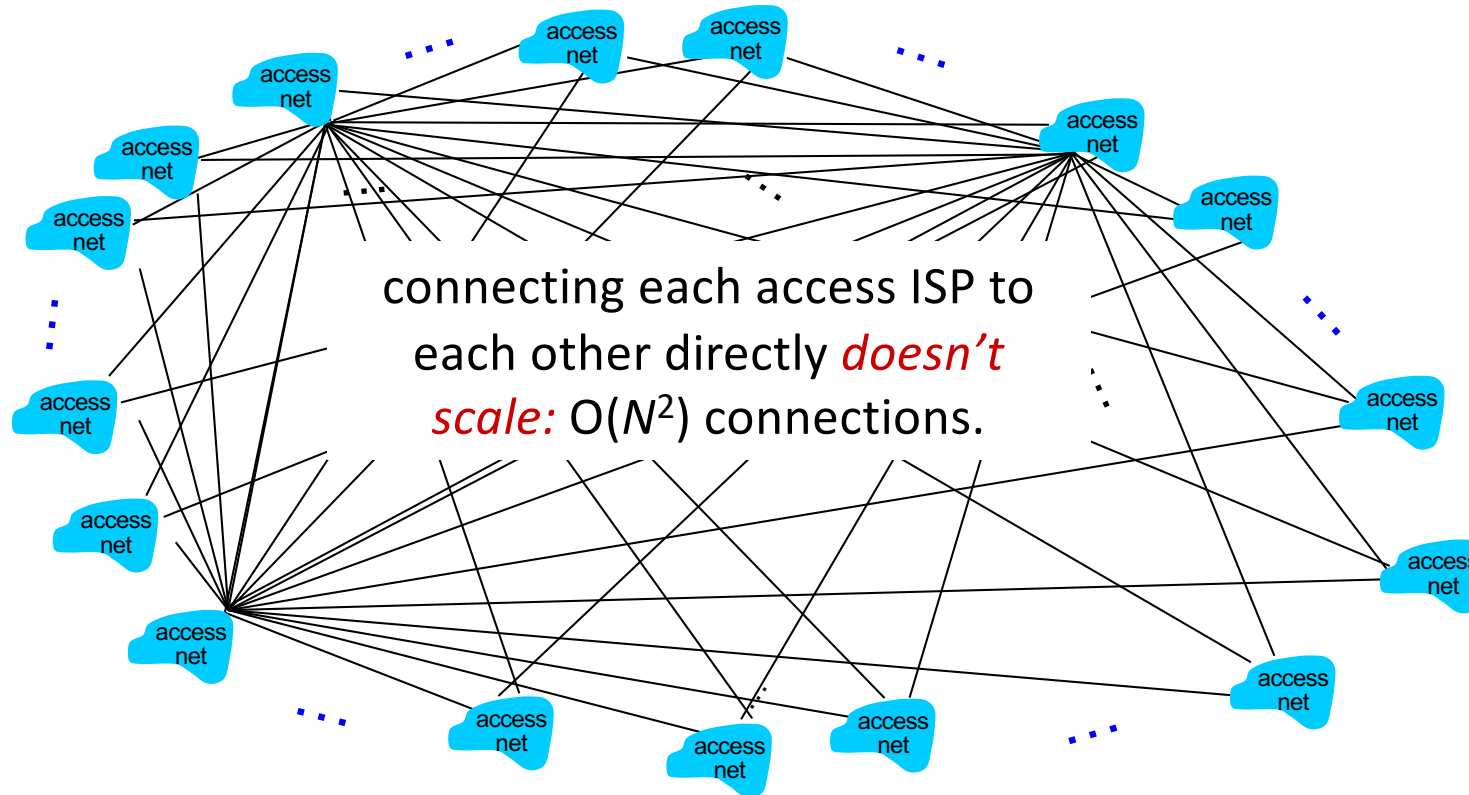
Internet structure: a “network of networks”

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



Internet structure: a “network of networks”

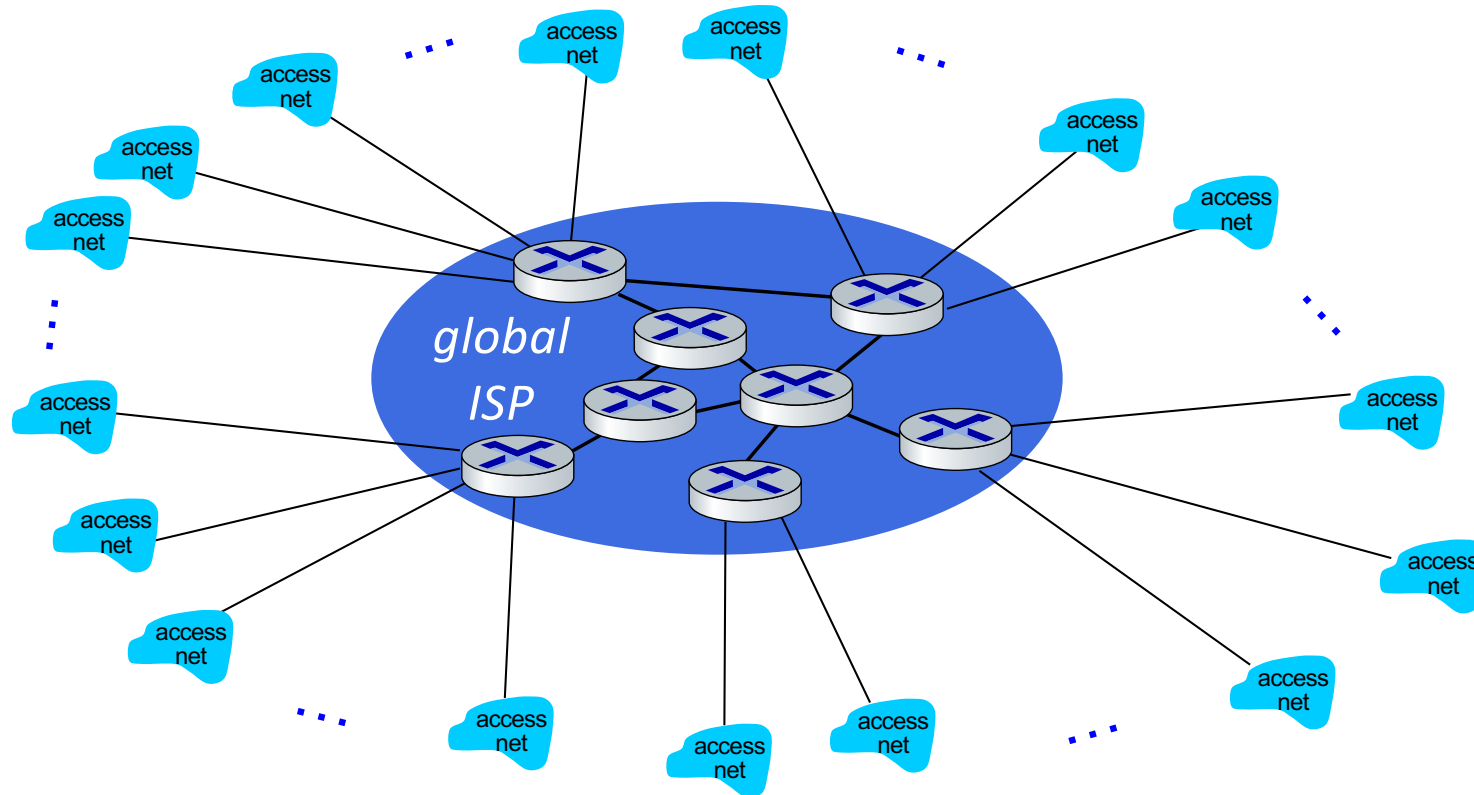
Question: given millions of access ISPs, how to connect them together?



Internet structure: a “network of networks”

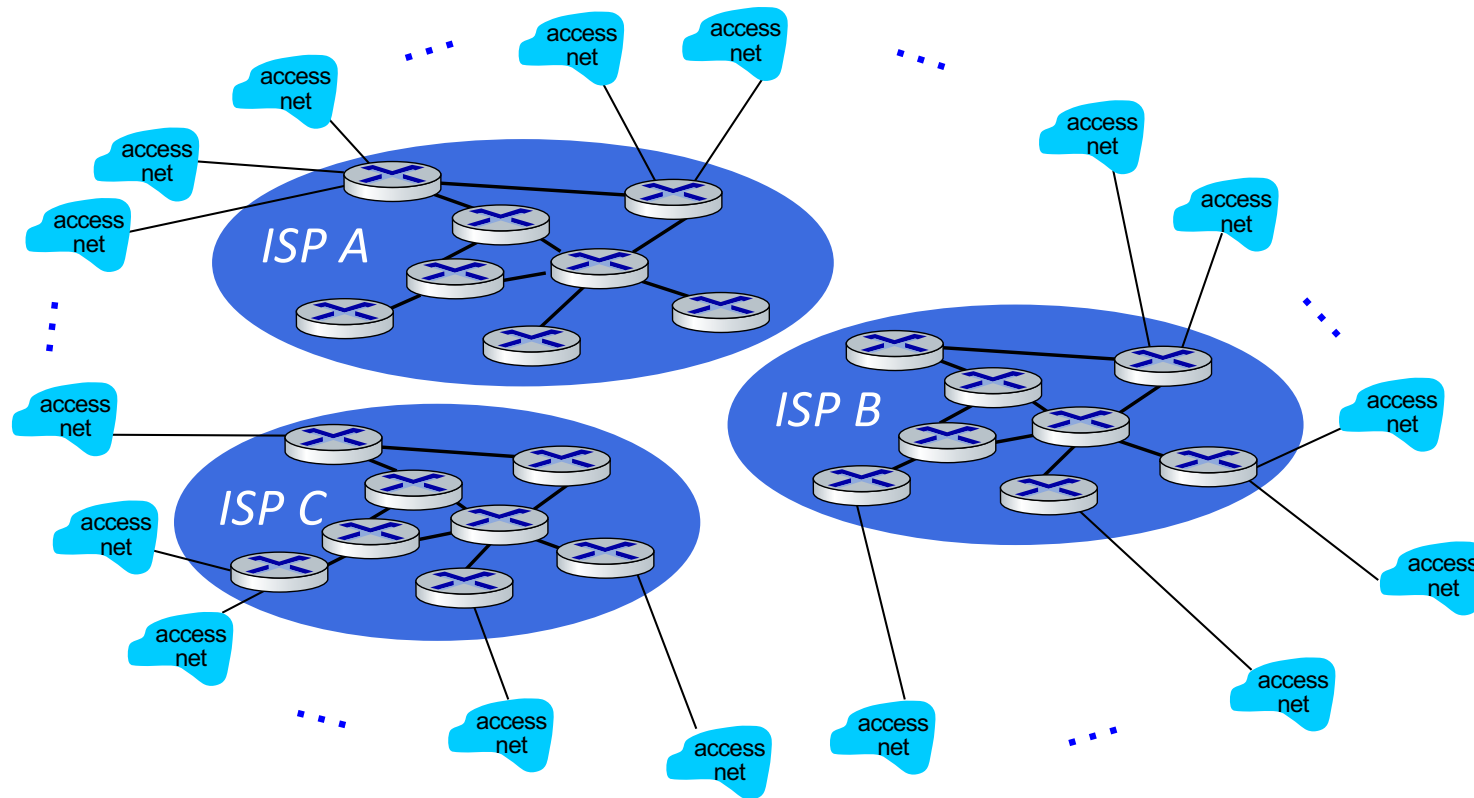
Option: connect each access ISP to one global transit ISP?

Customer and provider ISPs have economic agreement.



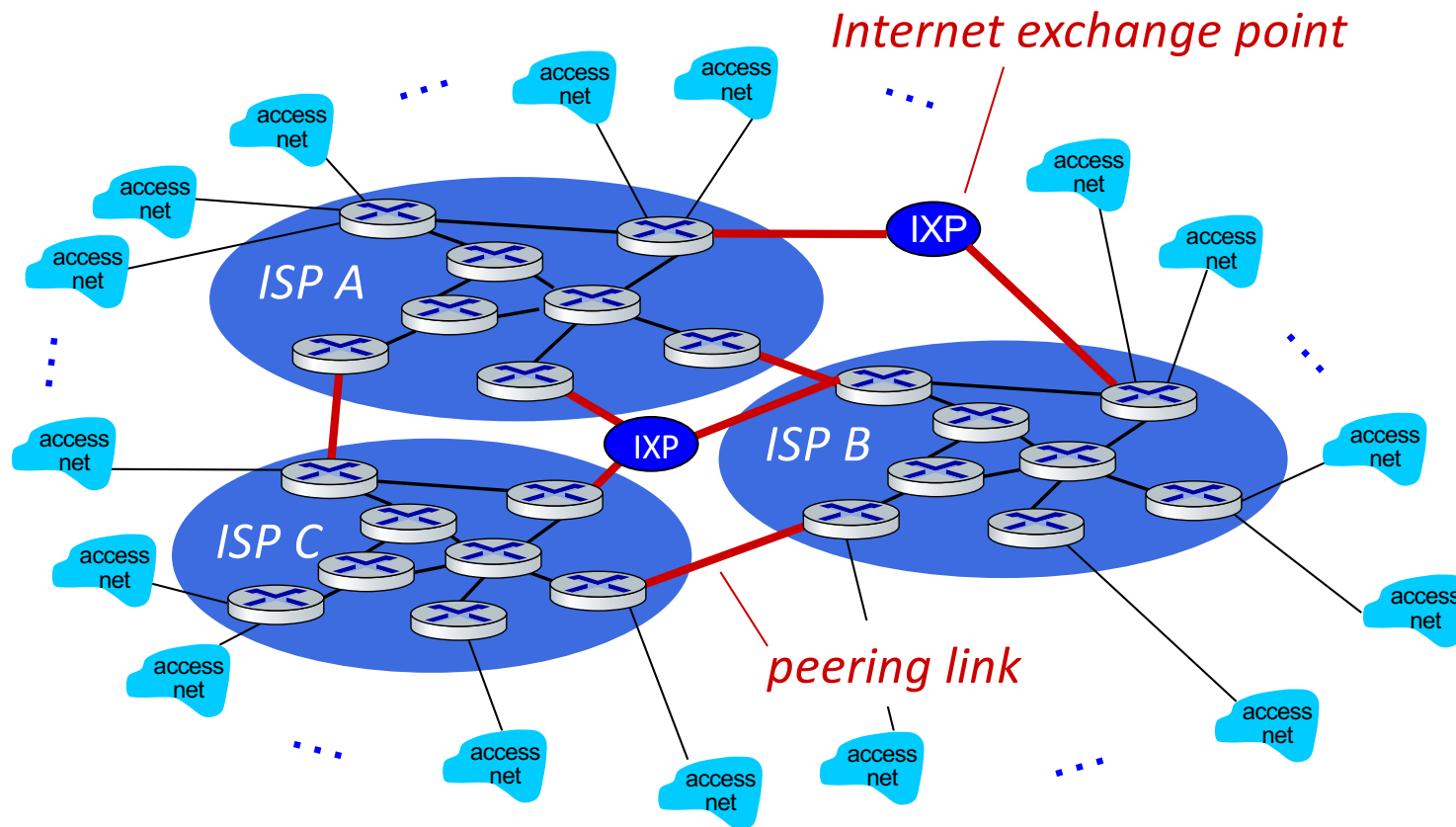
Internet structure: a “network of networks”

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



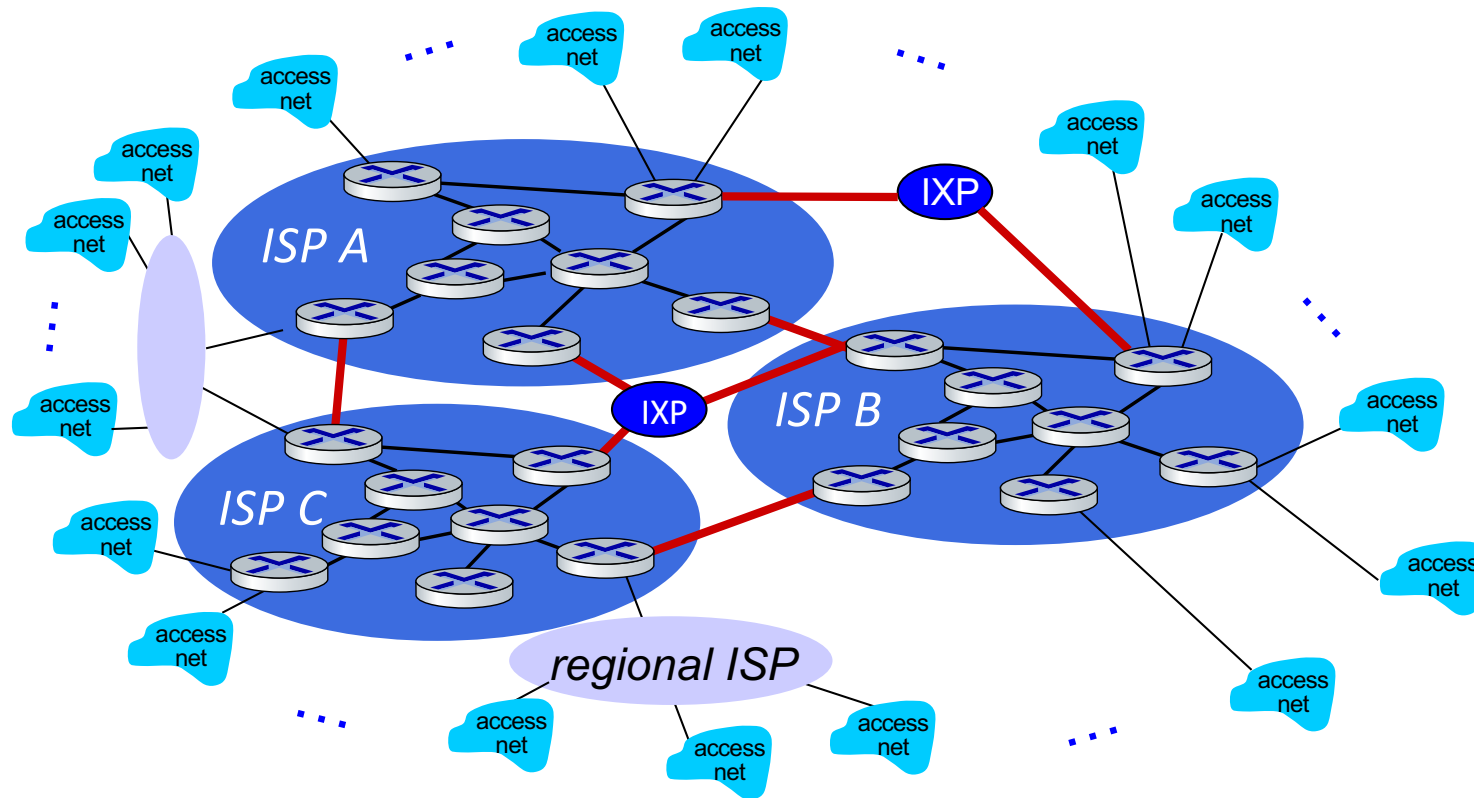
Internet structure: a “network of networks”

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



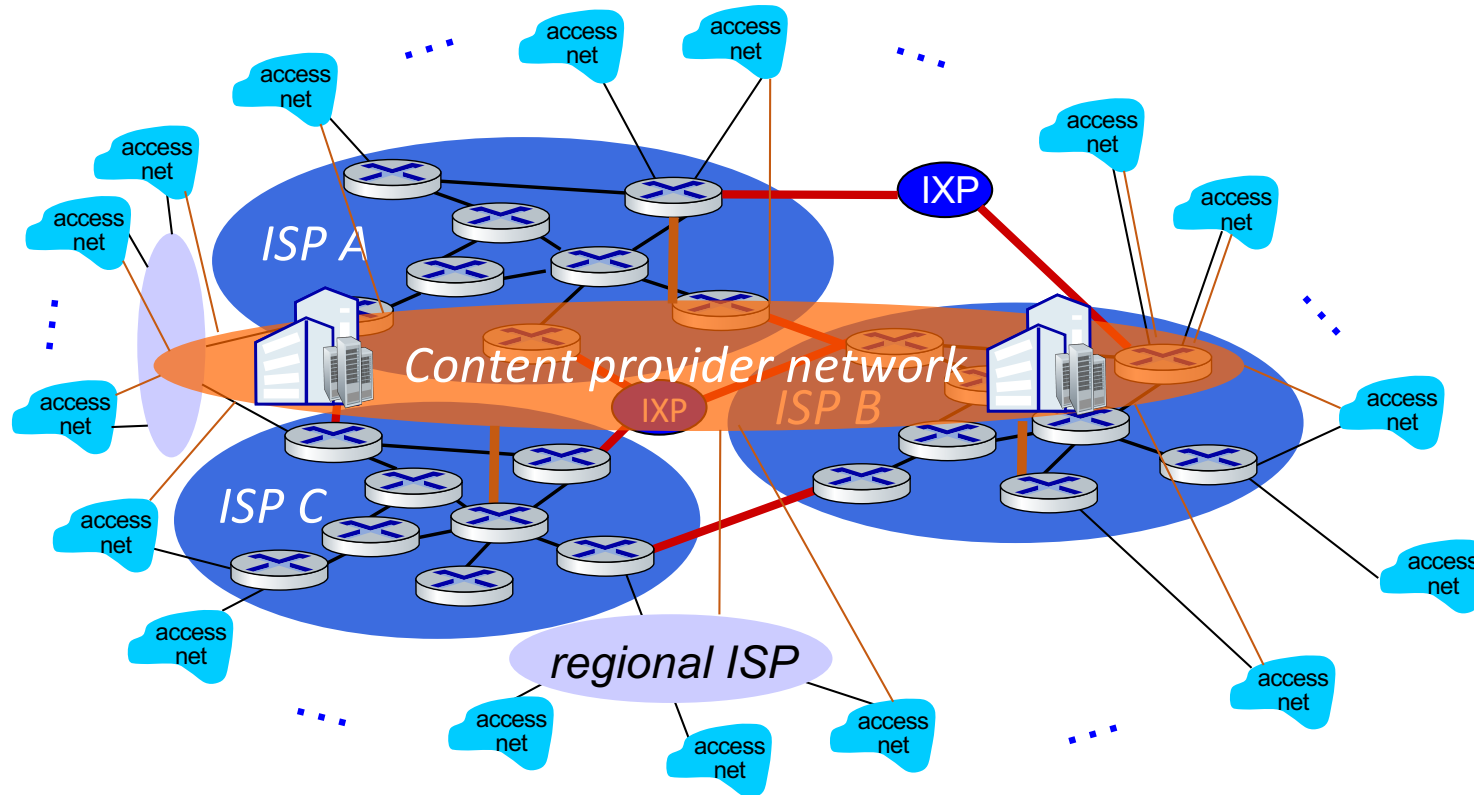
Internet structure: a “network of networks”

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

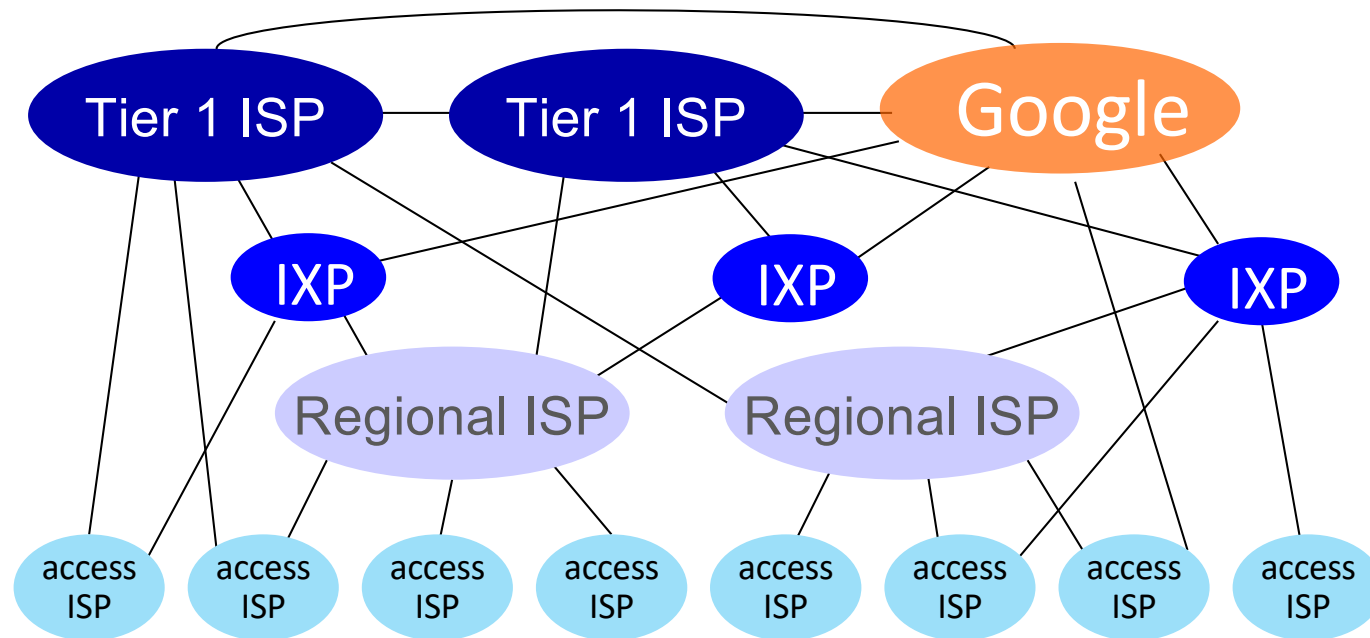


Internet structure: a “network of networks”

... 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

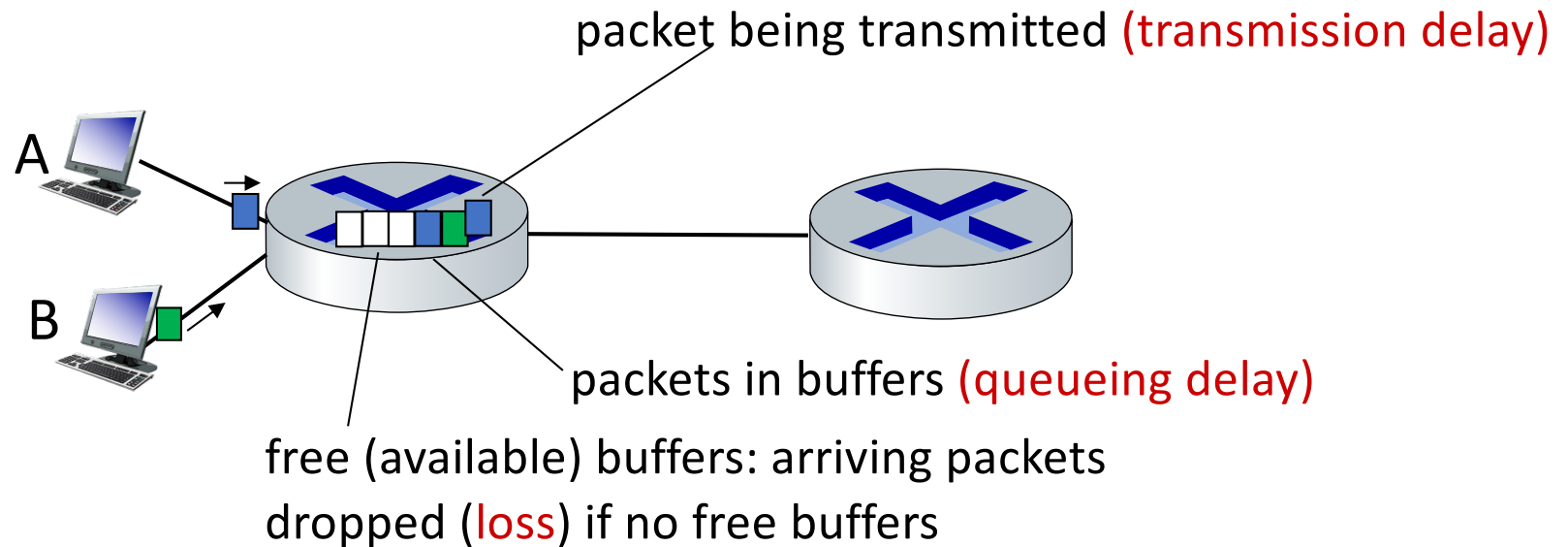
History



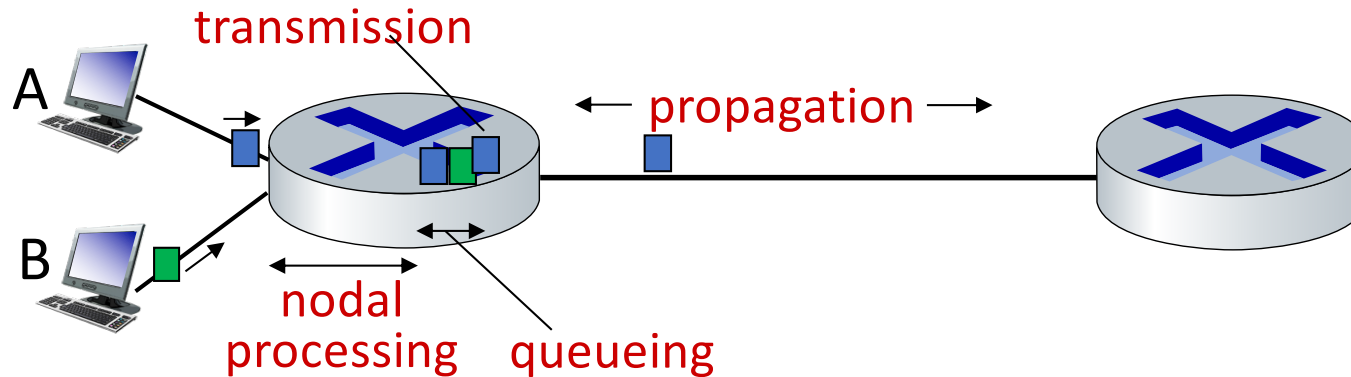
How do packet loss and delay occur?

packets *queue* in router buffers

- packets queue, wait for turn
- arrival rate to link (temporarily) exceeds output link capacity: packet loss



Packet delay: four sources



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

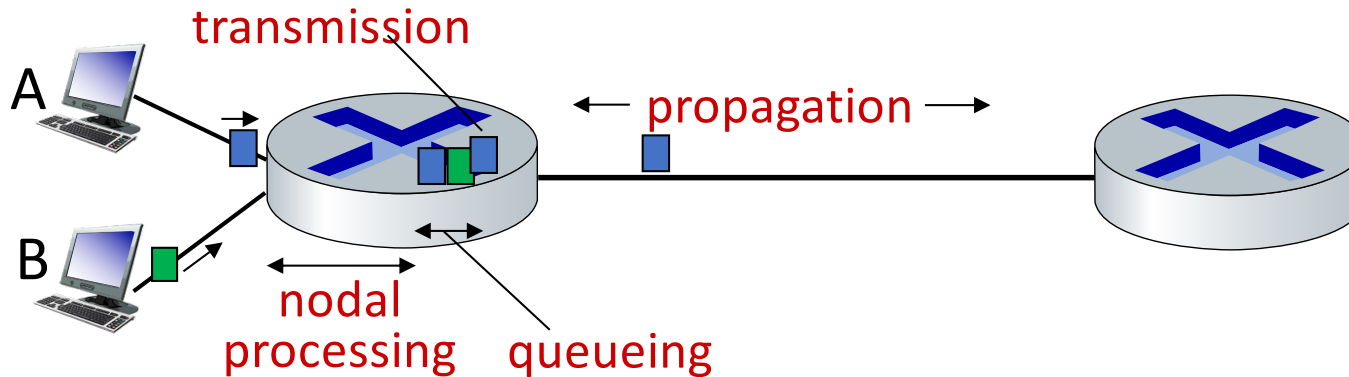
d_{proc} : nodal processing

- 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

Packet delay: four sources



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

d_{trans} : transmission delay:

- L : packet length (bits)
- R : link transmission rate (bps)

▪ $d_{\text{trans}} = L/R$

d_{prop} : propagation delay:

- d : length of physical link
- s : propagation speed ($\sim 2 \times 10^8$ m/sec)

▪ $d_{\text{prop}} = d/s$

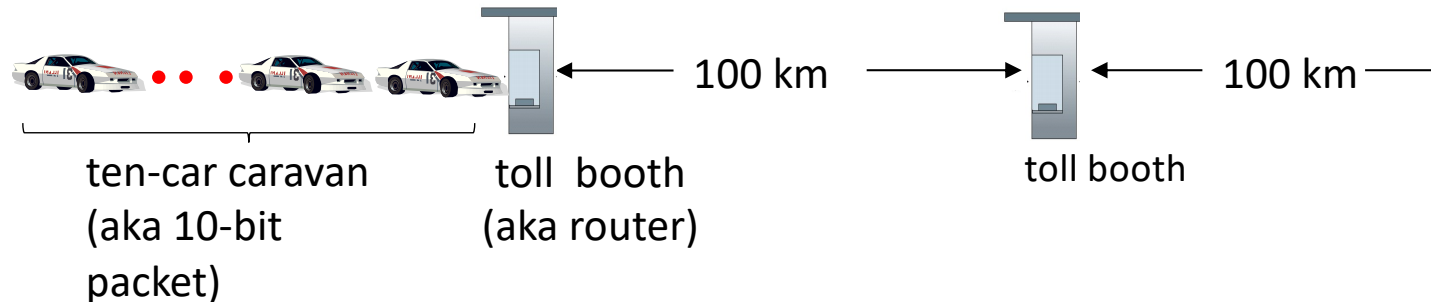
d_{trans} and d_{prop}

very different

Réseaux – EII – 4. L. Deneire

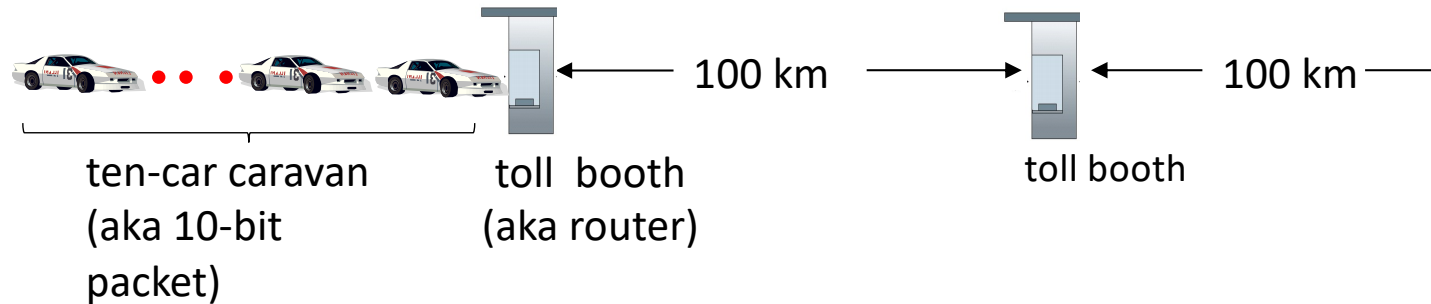
* Check out the online interactive exercises:
http://gaia.cs.umass.edu/kurose_ross

Caravan analogy



- cars “propagate” at 100 km/hr
- toll booth takes 12 sec to service car (bit transmission time)
- car \sim bit; caravan \sim 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: $100\text{km}/(100\text{km/hr}) = 1$ hr
- **A: 62 minutes**

Caravan analogy

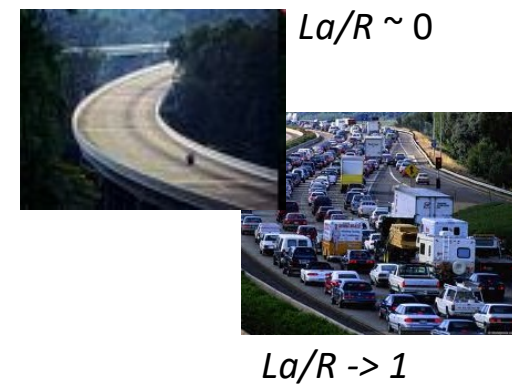
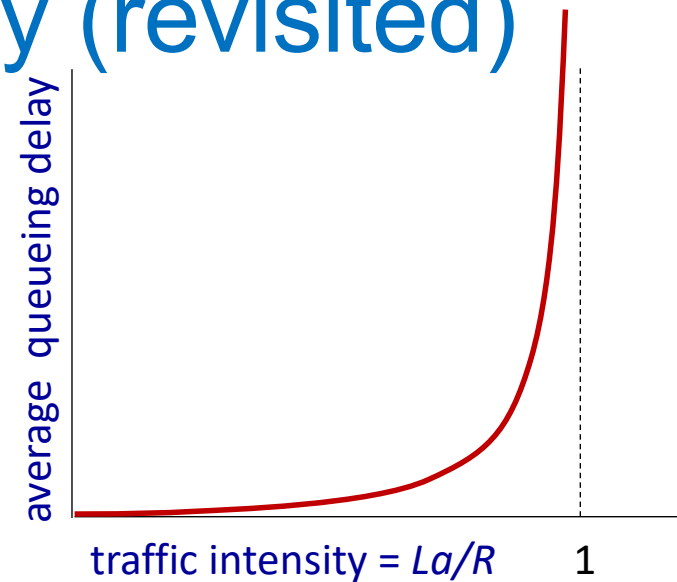


- suppose cars now “propagate” at 1000 km/hr
- and suppose toll booth now takes one min to service a car
- **Q: Will cars arrive to 2nd booth before all cars serviced at first booth?**
A: Yes! after 7 min, first car arrives at second booth; three cars still at first booth

Packet queueing delay (revisited)

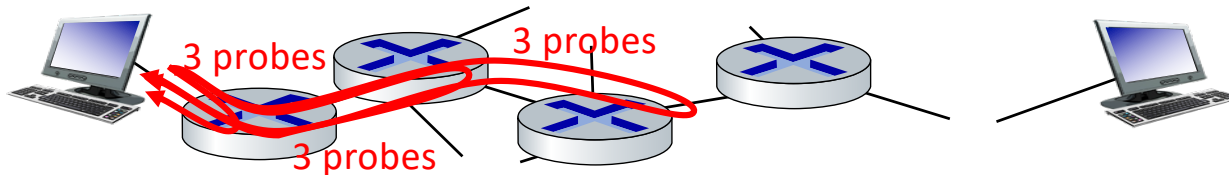
- R : link bandwidth (bps)
- L : packet length (bits)
- a : average packet arrival rate

- $La/R \sim 0$: avg. queueing delay small
- $La/R \rightarrow 1$: avg. queueing delay large
- $La/R > 1$: more “work” arriving is more than can be serviced - average delay infinite!



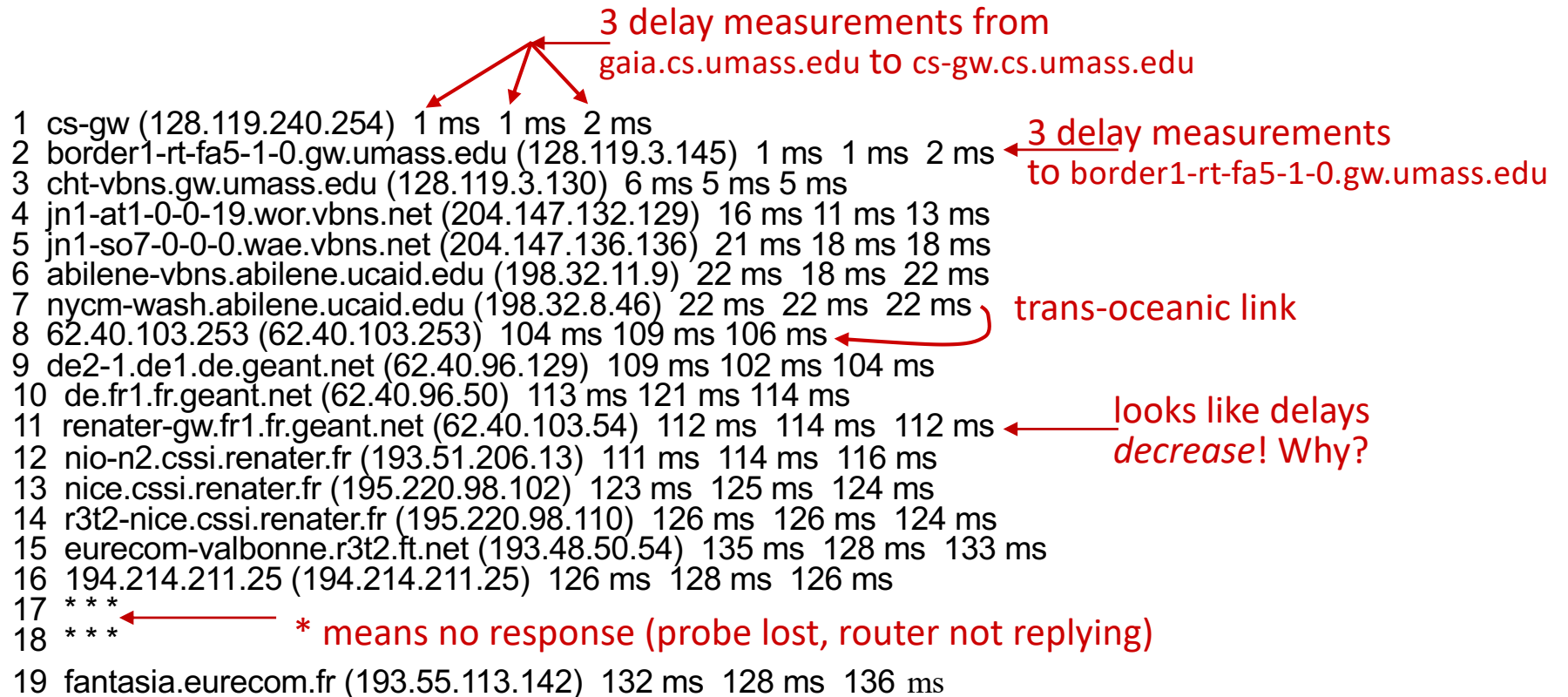
“Real” Internet delays and routes

- 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

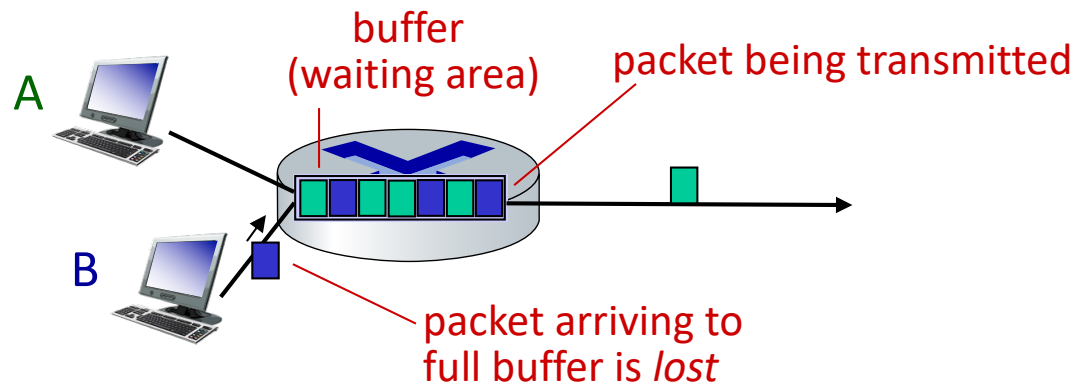
traceroute: gaia.cs.umass.edu to www.eurecom.fr



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

Packet loss

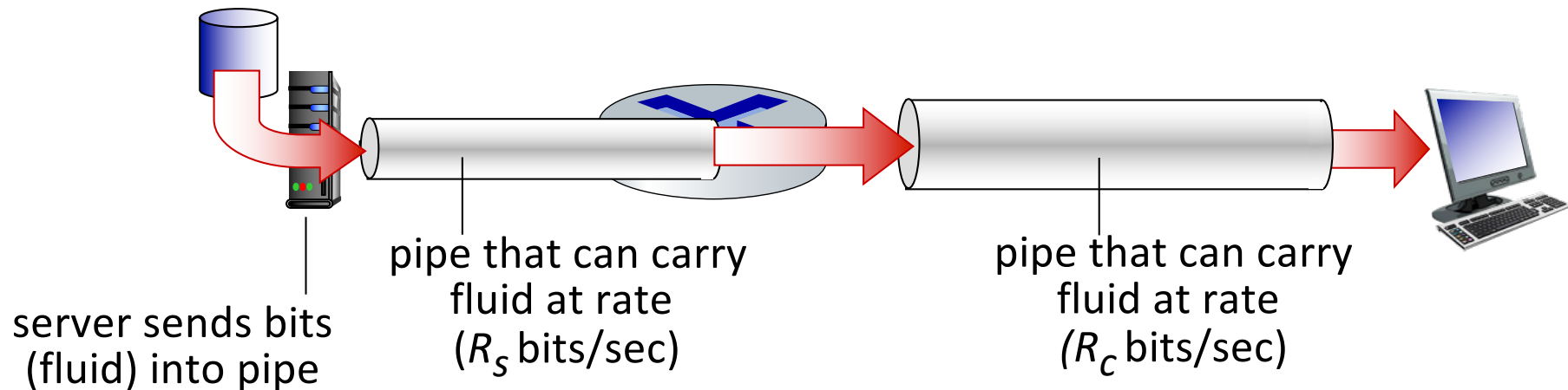
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



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

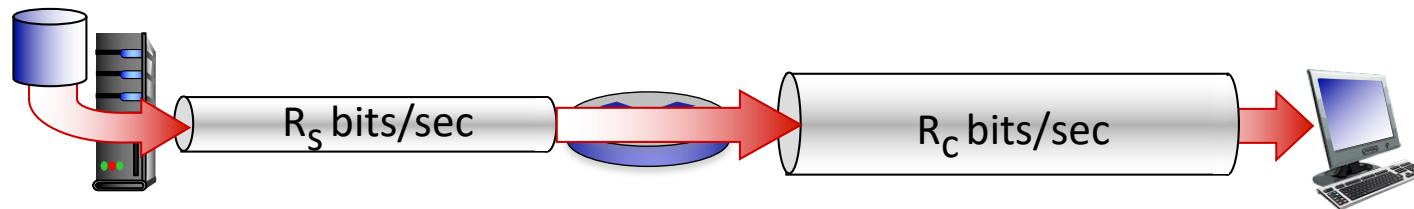
Throughput

- **throughput**: rate (bits/time unit) at which bits are being sent from sender to receiver
 - **instantaneous**: rate at given point in time
 - **average**: rate over longer period of time

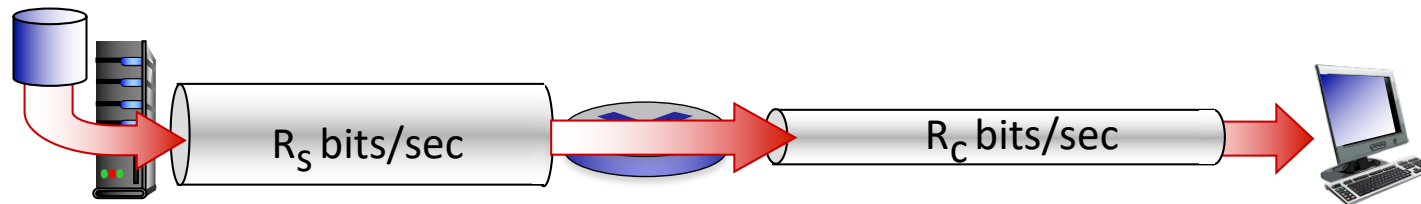


Throughput

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



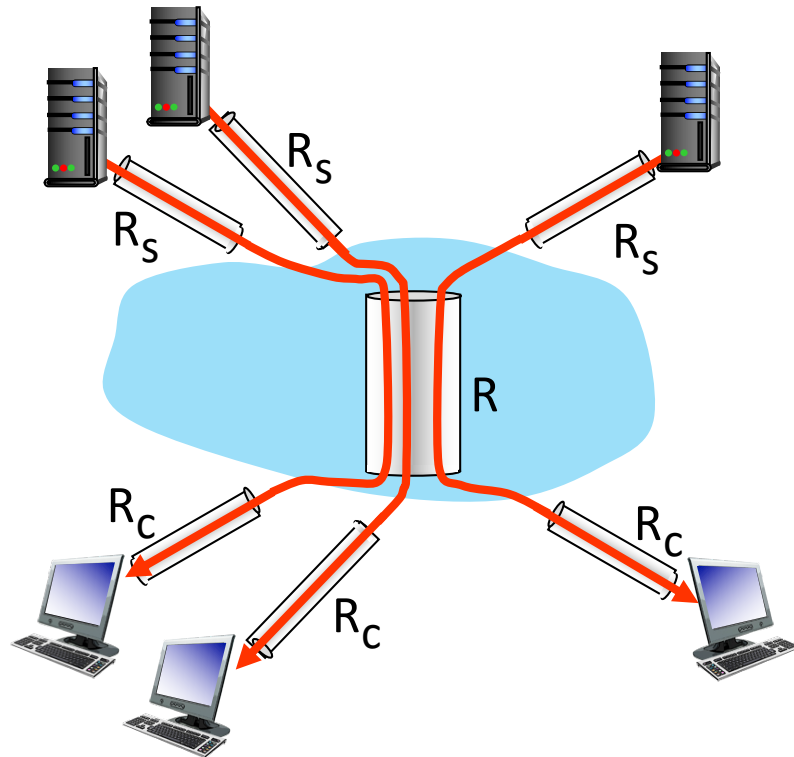
$R_s > R_c$ What is average end-end throughput?



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

- **field of network security:**
 - how bad guys can attack computer networks
 - how we can defend networks against attacks
 - how to design architectures that are immune to attacks
- **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!

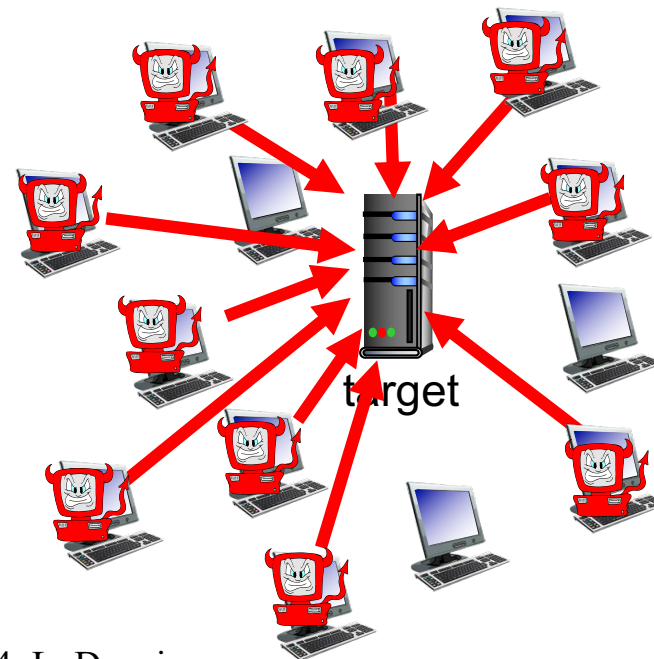
Bad guys: malware

- malware can get in host from:
 - *virus*: self-replicating infection by receiving/executing object (e.g., e-mail attachment)
 - *worm*: self-replicating infection by passively receiving object that gets itself executed
- **spyware malware** can record keystrokes, web sites visited, upload info to collection site
- infected host can be enrolled in **botnet**, used for spam or distributed denial of service (DDoS) attacks

Bad guys: denial of service

Denial of Service (DoS): attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

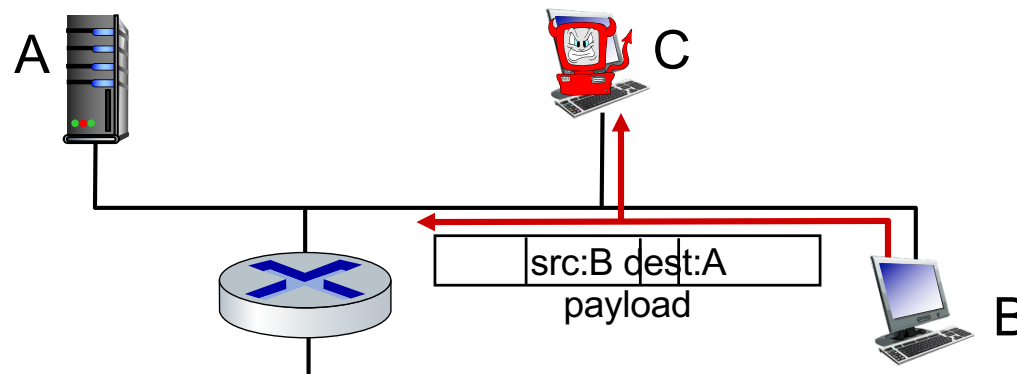
1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts



Bad guys: packet interception

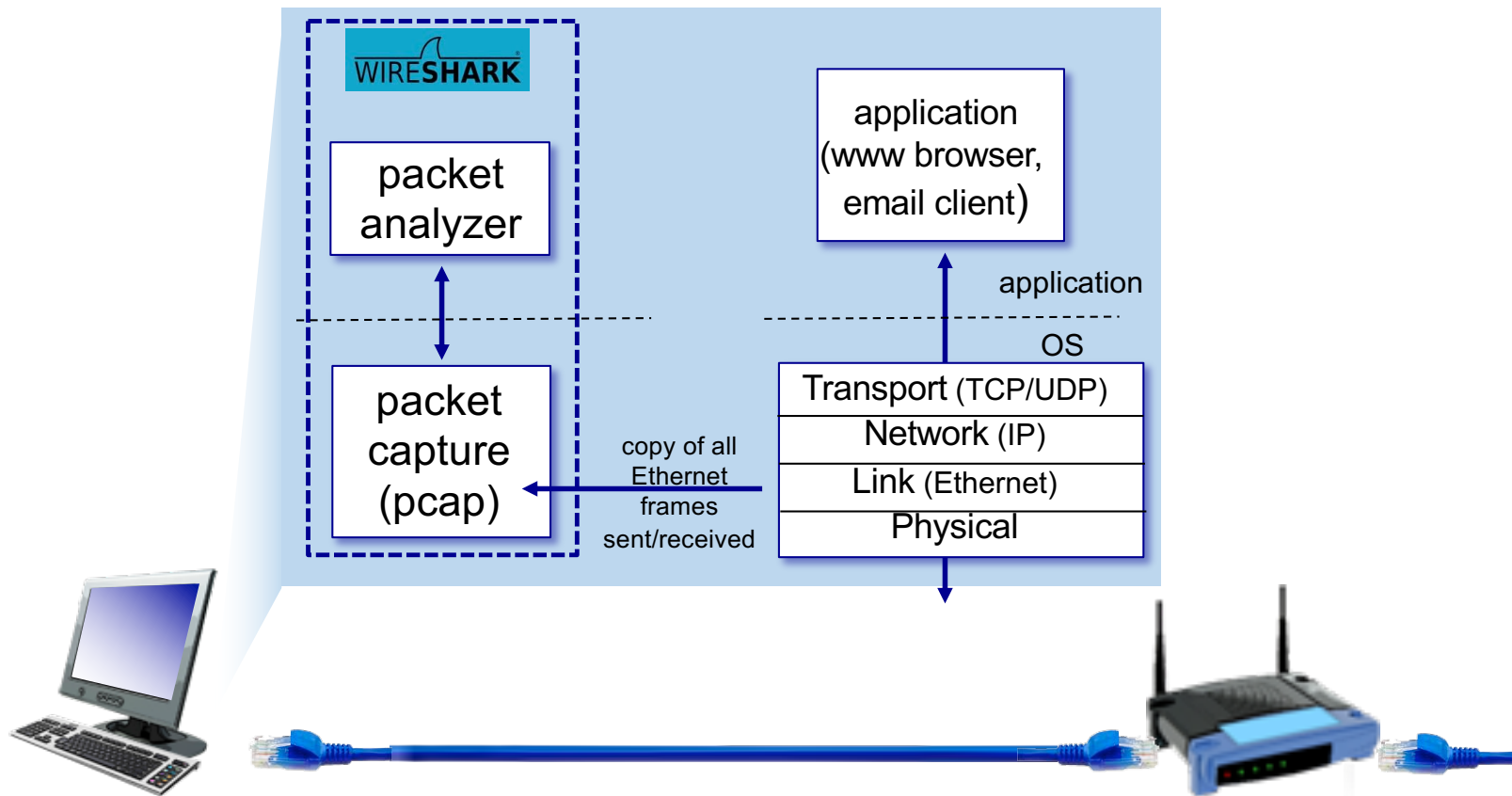
packet “sniffing”:

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



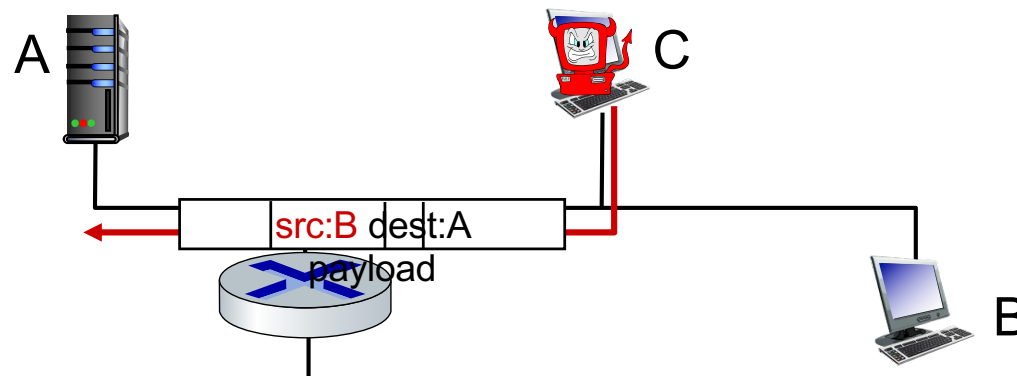
Wireshark software used for our end-of-chapter labs is a (free) packet-sniffer

Wireshark



Bad guys: fake identity

IP spoofing: send packet with false source address



... 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

*Networks are complex,
with many “pieces”:*

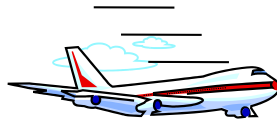
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

is there any hope of
organizing structure of
network?

.... or at least our
discussion of networks?

Example: organization of air travel



ticket (purchase)

baggage (check)

gates (load)

runway takeoff

airplane routing

ticket (complain)

baggage (claim)

gates (unload)

runway landing

airplane routing

airplane routing

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

Q: describe in words the service provided in each layer above

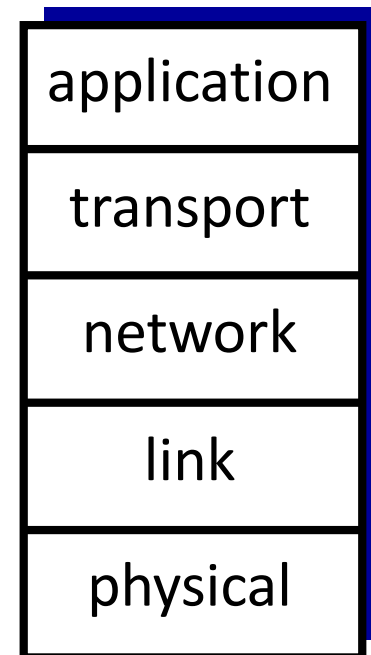
Why layering?

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 in layer's service *implementation*: transparent to rest of system
 - e.g., change in gate procedure doesn't affect rest of system
- layering considered harmful?
- layering in other complex systems?

Internet protocol stack

- **application:** supporting network applications
 - IMAP, 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), PPP
- **physical:** bits “on the wire”



Encapsulation

