

Chapter I

Introduction

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Introduction 1-1

Chapter I: introduction

our goal:

- get “feel” and terminology
- more depth, detail *later* in course
- approach:
 - use Internet as example

overview:

- what’s the Internet?
- what’s a protocol?
- network edge; hosts, access net, physical media
- network core: packet/circuit switching, Internet structure
- performance: loss, delay, throughput
- security
- protocol layers, service models
- history

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Chapter I: roadmap

I.1 what is the Internet?

I.2 network edge

- end systems, access networks, links

I.3 network core

- packet switching, circuit switching, network structure

I.4 delay, loss, throughput in networks

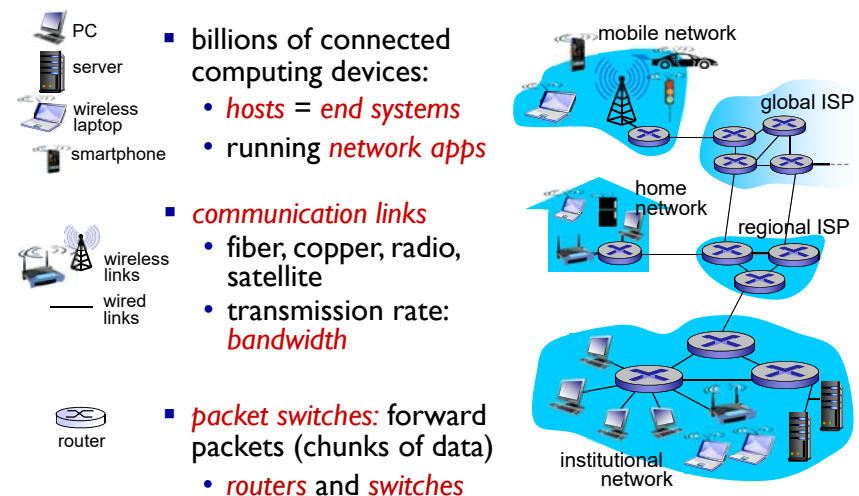
I.5 protocol layers, service models

I.6 networks under attack: security

I.7 history

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



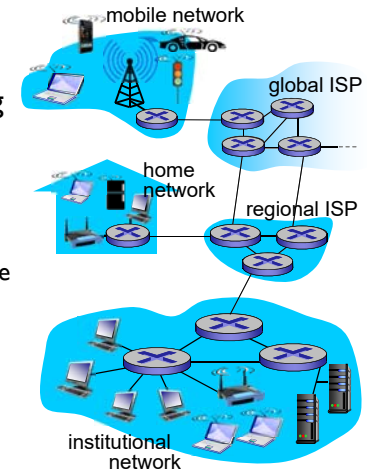
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“Fun” Internet-connected devices



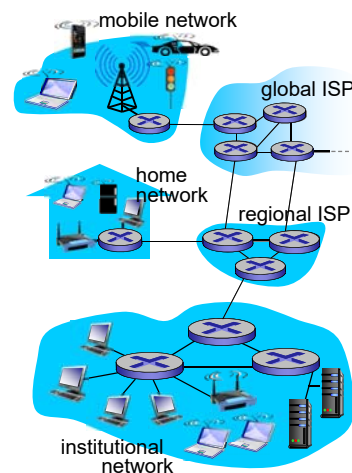
What’s the Internet: “nuts and bolts” view

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



What’s the Internet: a service view

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



What’s a protocol?

human protocols:

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

... specific messages sent

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

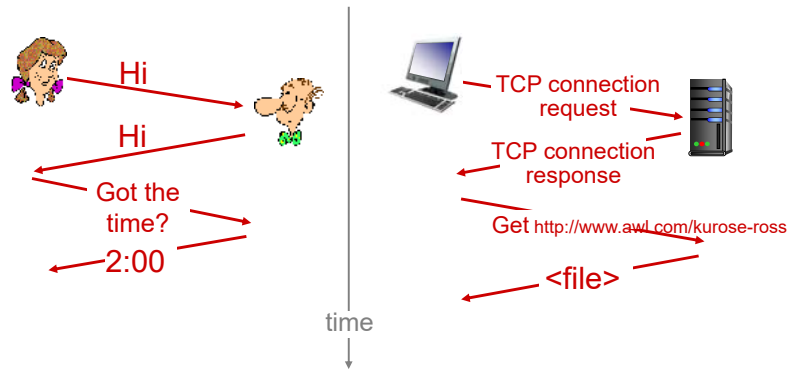
network protocols:

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

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

What's a protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

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Chapter I: roadmap

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1.5 protocol layers, service models

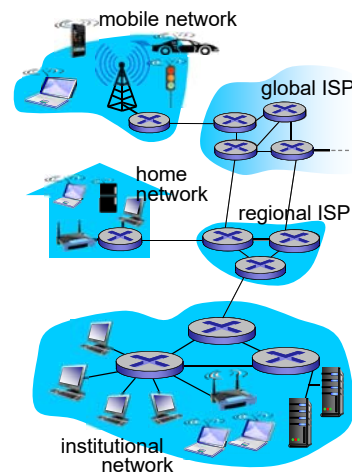
1.6 networks under attack: security

1.7 history

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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



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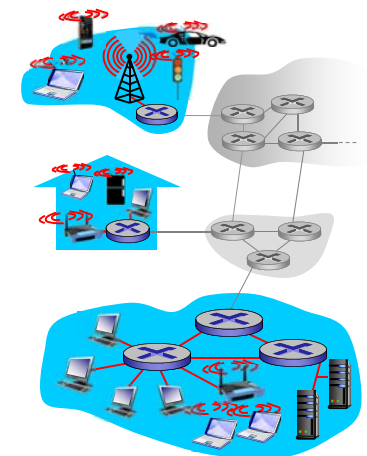
Access networks and physical media

Q: How to connect end systems to edge router?

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

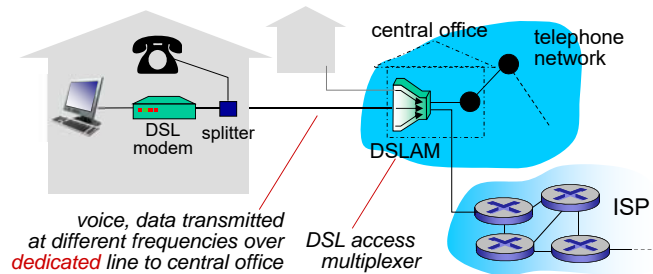
keep in mind:

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



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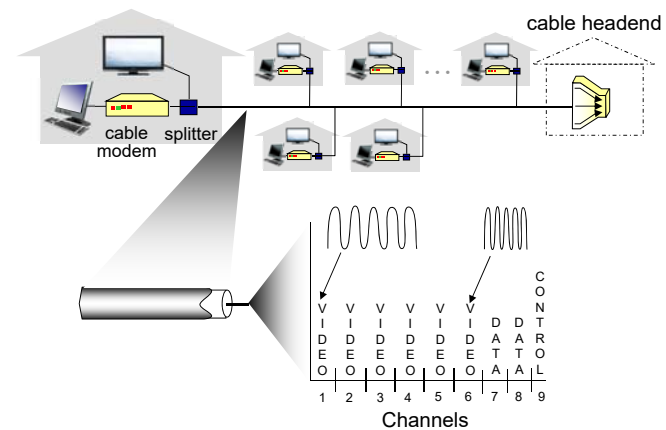
Access network: digital subscriber line (DSL)



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

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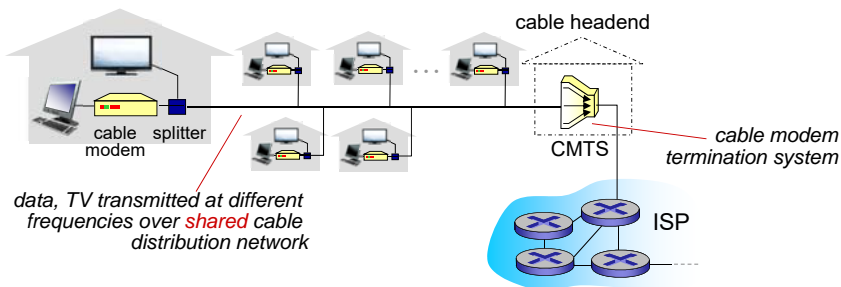
Access network: cable network



frequency division multiplexing: different channels transmitted in different frequency bands

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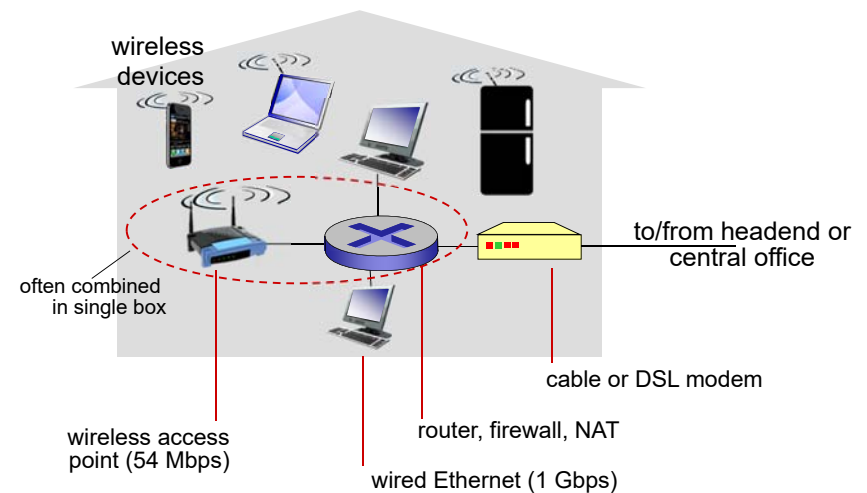
Access network: cable network



- HFC: hybrid fiber coax**
 - asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- network** of cable, fiber attaches homes to ISP router
 - homes **share access network** to cable headend
 - unlike DSL, which has dedicated access to central office

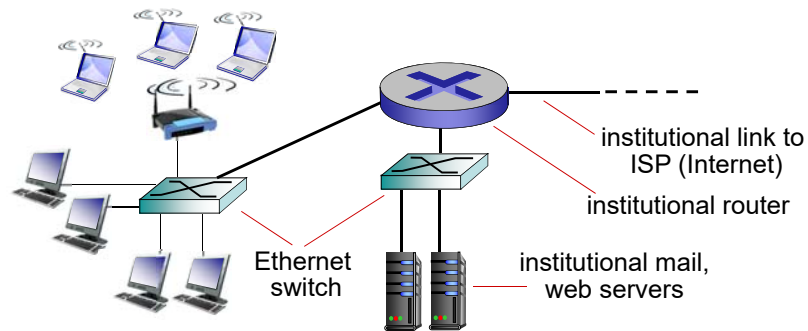
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Access network: home network



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Enterprise access networks (Ethernet)



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

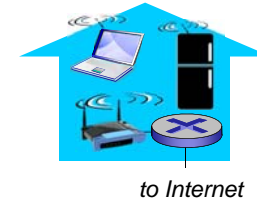
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Wireless access networks

- shared wireless access network connects end system to router
 - via base station aka “access point”

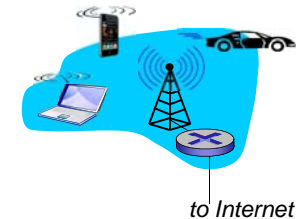
wireless LANs:

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



wide-area wireless access

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

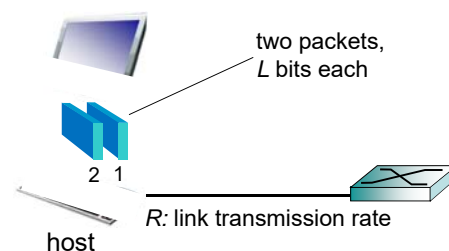


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Host: sends packets of data

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**



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

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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



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Physical media: coax, fiber

coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
 - multiple channels on cable
 - HFC



fiber optic cable:

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



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Physical media: radio

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

radio link types:

- **terrestrial microwave**
 - e.g. up to 45 Mbps channels
- **LAN** (e.g., WiFi)
 - 54 Mbps
- **wide-area** (e.g., cellular)
 - 4G cellular: ~ 10 Mbps
- **satellite**
 - Kbps to 45Mbps channel (or multiple smaller channels)
 - 270 msec end-end delay
 - geosynchronous versus low altitude

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Chapter 1: roadmap

1.1 what is the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- **packet switching, circuit switching, network structure**

1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

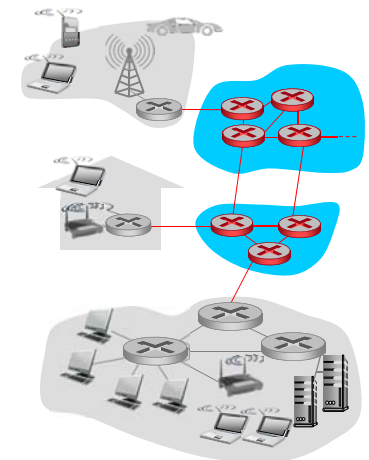
1.6 networks under attack: security

1.7 history

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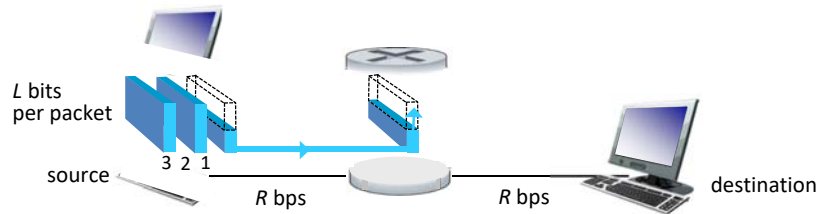
The network core

- 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



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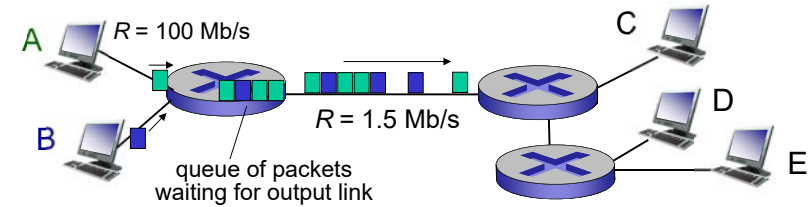
Packet-switching: store-and-forward



- 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)
- one-hop numerical example:*
- $L = 7.5$ Mbits
 - $R = 1.5$ Mbps
 - one-hop transmission delay = 5 sec
- } more on delay shortly ...

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Packet Switching: queueing delay, loss



queueing 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

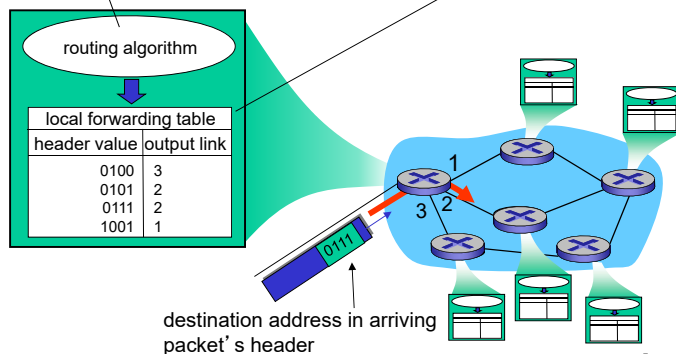
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Two key network-core functions

routing: determines source-destination route taken by packets

- routing algorithms

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

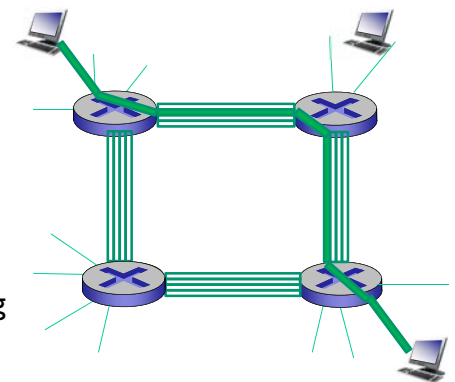


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Alternative core: circuit switching

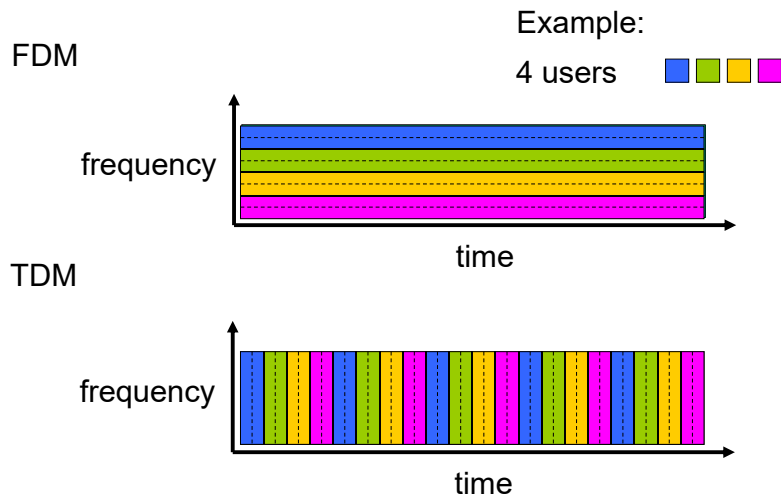
end-end resources allocated to, reserved for "call" between source & dest:

- 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



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Circuit switching: FDM versus TDM



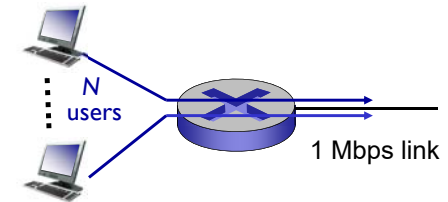
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Packet switching versus circuit switching

packet switching allows more users to use network!

example:

- 1 Mb/s link
- each user:
 - 100 kb/s when “active”
 - active 10% of time
- **circuit-switching:**
 - 10 users
- **packet switching:**
 - with 35 users, probability > 10 active at same time is less than .0004 *



Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

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Packet switching versus circuit switching

is packet switching a “slam dunk winner?”

- great for bursty data
 - resource sharing
 - simpler, no call setup
- **excessive congestion possible:** packet delay and loss
 - protocols needed for reliable data transfer, congestion control
- Q: **How to provide circuit-like behavior?**
 - bandwidth guarantees needed for audio/video apps
 - still an unsolved problem (chapter 7)

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

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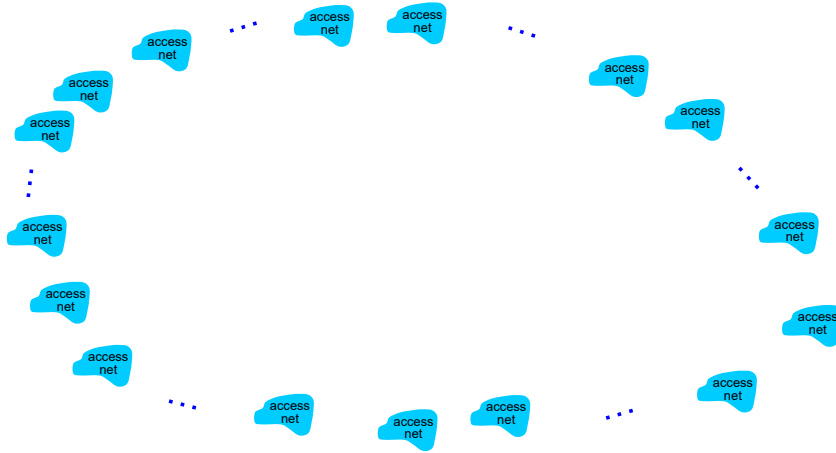
Internet structure: network of networks

- 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

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Internet structure: network of networks

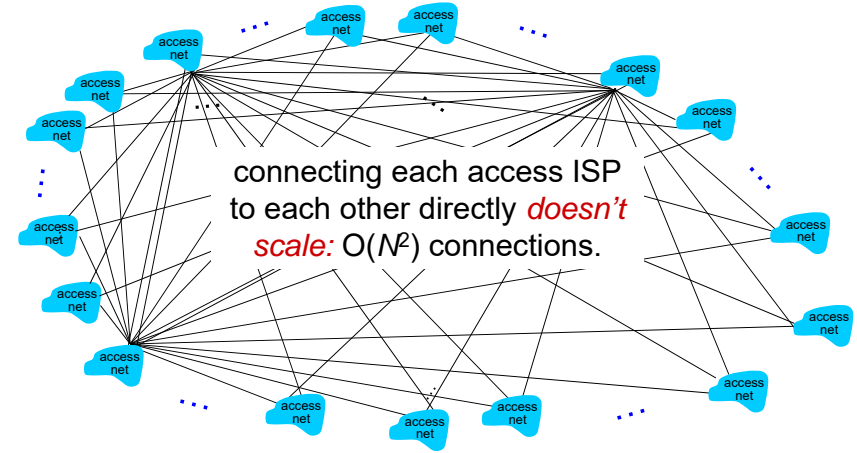
Question: given millions of access ISPs, how to connect them together?



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Internet structure: network of networks

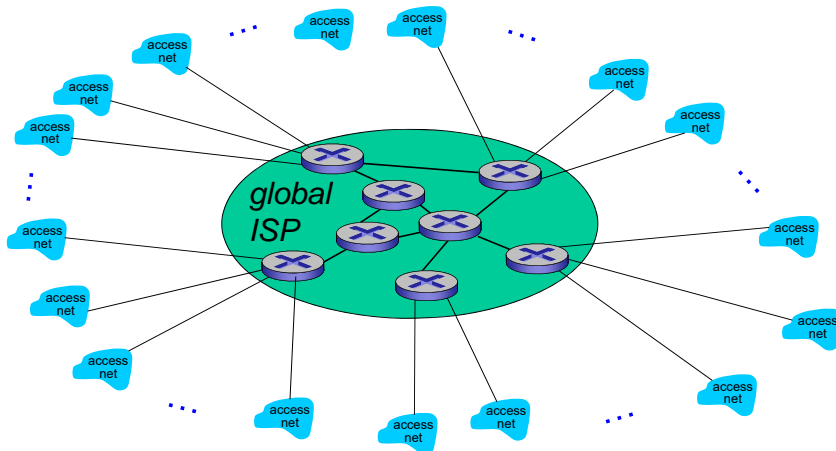
Option: connect each access ISP to every other access ISP?



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Internet structure: network of networks

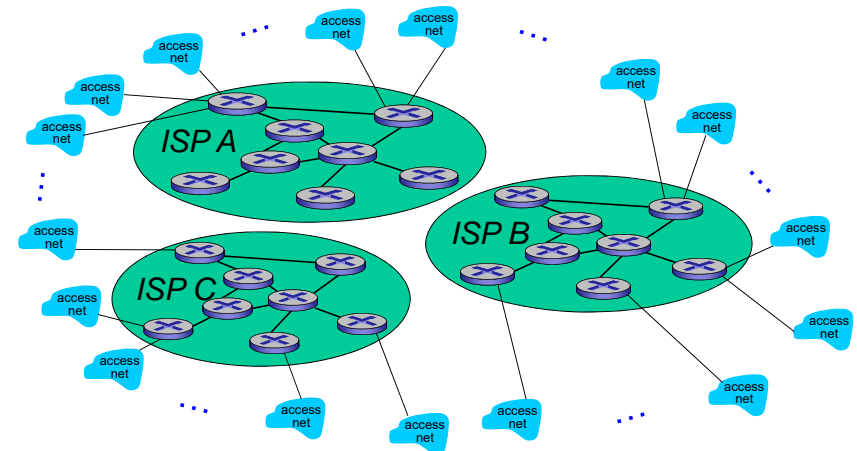
Option: connect each access ISP to one global transit ISP?
Customer and *provider* ISPs have economic agreement.



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Internet structure: network of networks

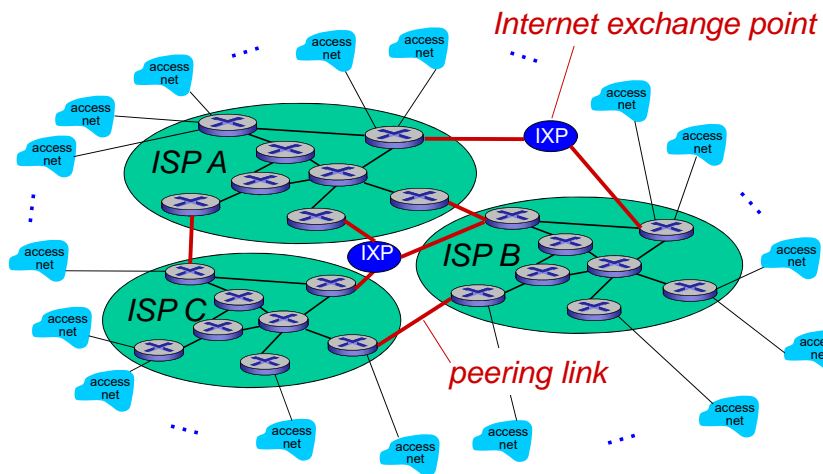
But if one global ISP is viable business, there will be competitors
....



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Internet structure: network of networks

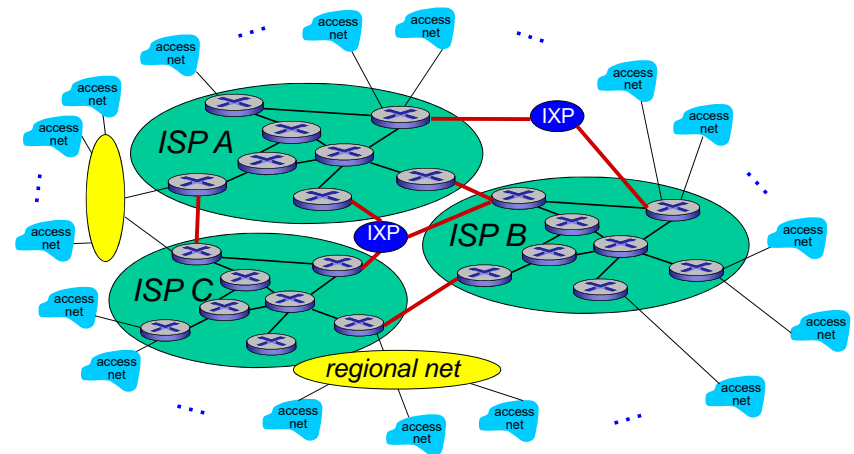
But if one global ISP is viable business, there will be competitors
.... which must be interconnected



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Internet structure: network of networks

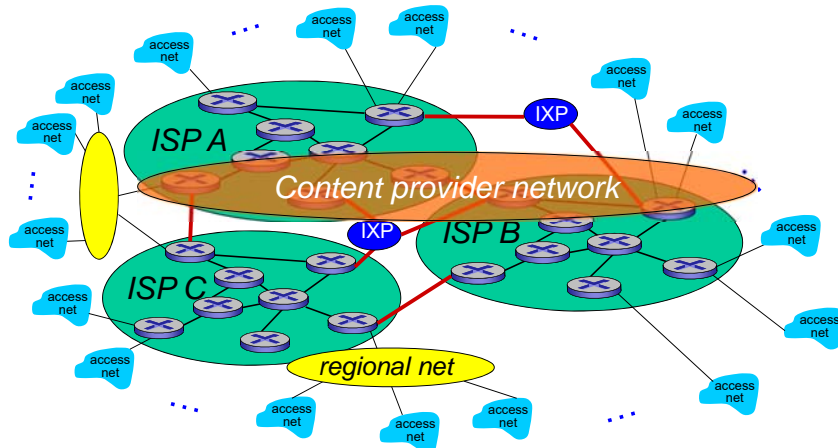
... and regional networks may arise to connect access nets to ISPs



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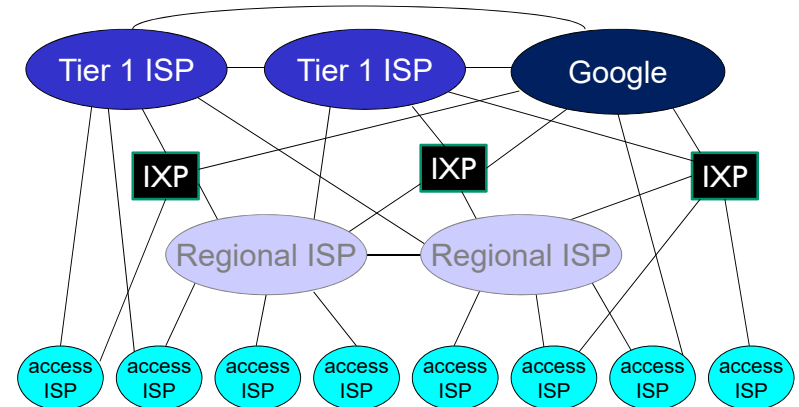
Internet structure: network of networks

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



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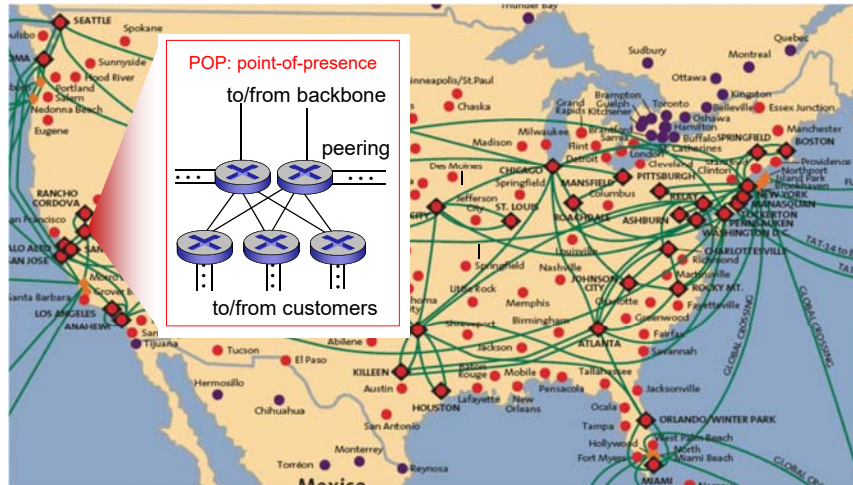
Internet structure: network of networks



- 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 network (e.g., Google): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs

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Tier-I ISP: e.g., Sprint



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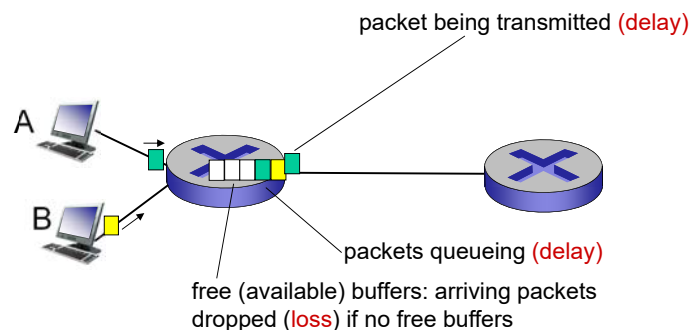
1.7 history

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How do loss and delay occur?

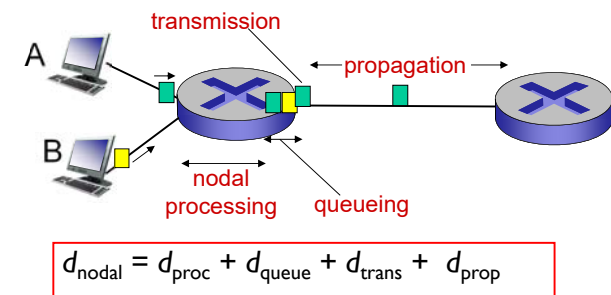
packets *queue* in router buffers

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



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Four sources of packet delay



d_{proc} : nodal processing

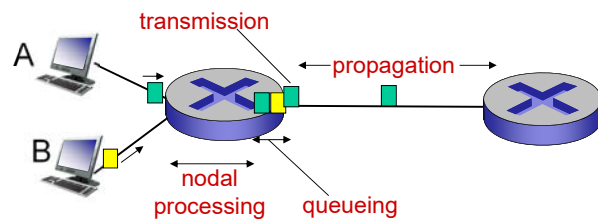
- check bit errors
- determine output link
- typically < msec

d_{queue} : queueing delay

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

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Four sources of packet delay



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

d_{trans} : transmission delay:

- L : packet length (bits)
- R : link bandwidth (bps)

$$d_{\text{trans}} = L/R$$

d_{trans} and d_{prop} very different

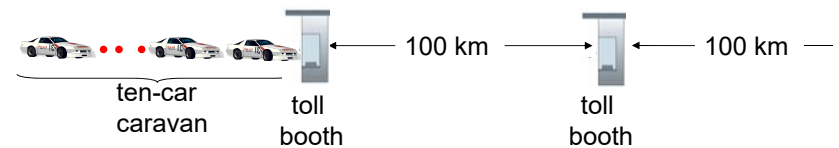
d_{prop} : propagation delay:

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

$$d_{\text{prop}} = d/s$$

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Caravan analogy

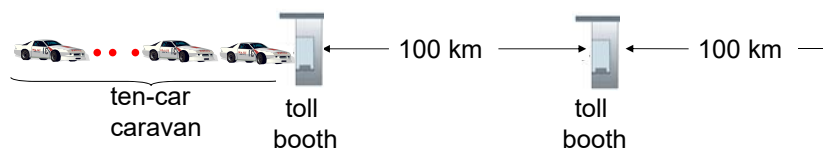


- cars “propagate” at 100 km/hr
- toll booth takes 12 sec to service car (bit transmission time)
- car \sim bit; caravan \sim packet
- **Q: How long until caravan is lined up before 2nd toll booth?**

- time to “push” entire caravan through toll booth onto highway = $12 \times 10 = 120$ sec
- time for last car to propagate from 1st to 2nd toll booth: $100 \text{ km} / (100 \text{ km/hr}) = 1$ hr
- **A: 62 minutes**

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Caravan analogy (more)

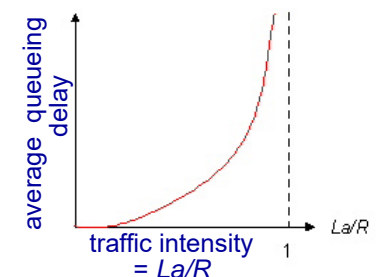


- suppose cars now “propagate” at 1000 km/hr
- and suppose toll booth now takes one min to service a car
- **Q: Will cars arrive to 2nd booth before all cars serviced at first booth?**
 - **A: Yes!** after 7 min, first car arrives at second booth; three cars still at first booth

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Queueing delay (revisited)

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



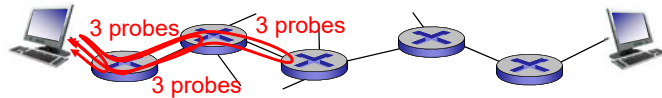
- $La/R \sim 0$: avg. queueing delay small
- $La/R \rightarrow 1$: avg. queueing delay large
- $La/R > 1$: more “work” arriving than can be serviced, average delay infinite!



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“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
 - router i will return packets to sender
 - sender times interval between transmission and reply.



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“Real” Internet delays, 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

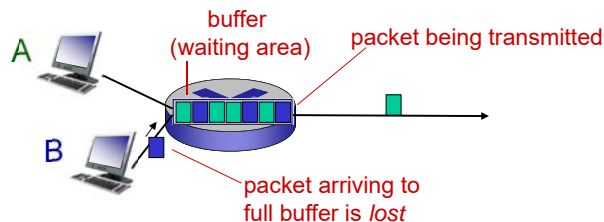
* means no response (probe lost, router not replying)

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

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Packet loss

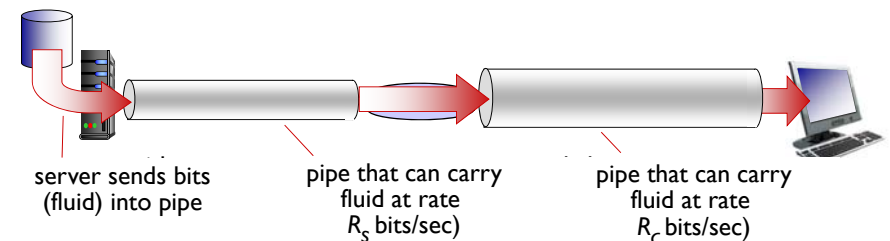
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



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Throughput

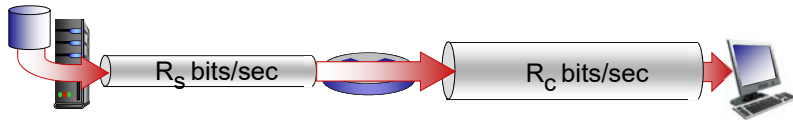
- throughput:** rate (bits/time unit) at which bits transferred between sender/receiver
 - instantaneous:** rate at given point in time
 - average:** rate over longer period of time



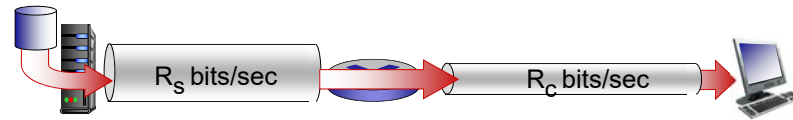
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Throughput (more)

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



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



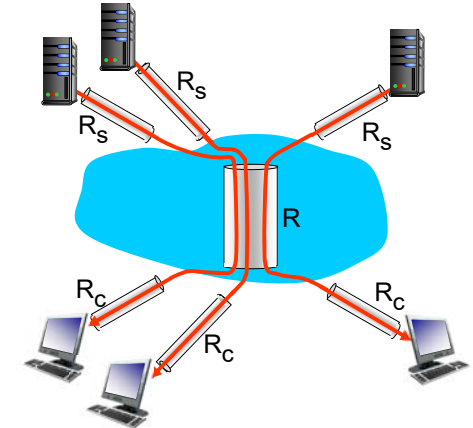
bottleneck link

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

Introduction 1-53

Throughput: Internet scenario

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



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

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Chapter I: roadmap

- I.1 what is the Internet?
- I.2 network edge
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 - packet switching, circuit switching, network structure
- I.4 delay, loss, throughput in networks
- I.5 protocol layers, service models
- I.6 networks under attack: security
- I.7 history

Introduction 1-55

Protocol “layers”

Networks are complex, with many “pieces”:

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

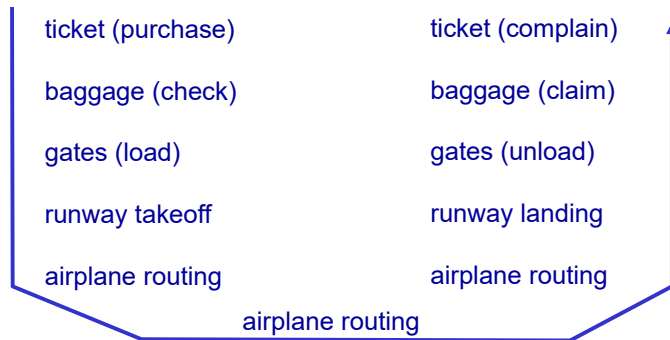
Question:

is there any hope of organizing structure of network?

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

Introduction 1-56

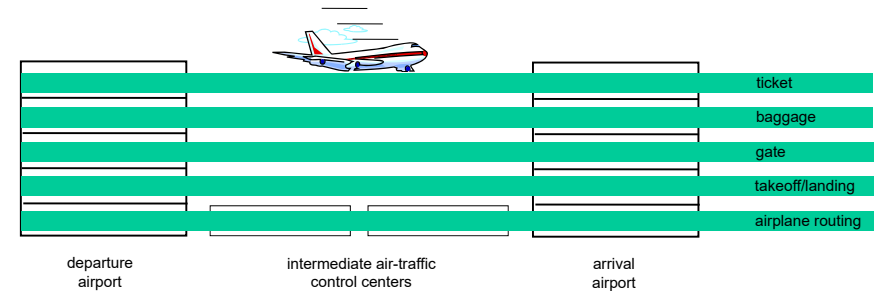
Organization of air travel



- a series of steps

Introduction 1-57

Layering of airline functionality



layers: each layer implements a service

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

Introduction 1-58

Why layering?

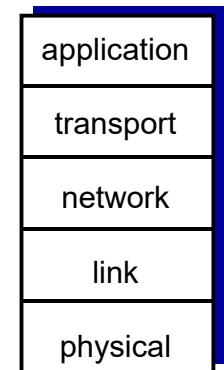
dealing with complex systems:

- 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?

Introduction 1-59

Internet protocol stack

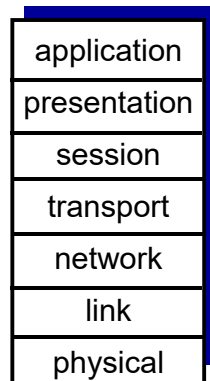
- **application:** supporting network applications
 - FTP, SMTP, HTTP
- **transport:** process-process data transfer
 - TCP, UDP
- **network:** routing of datagrams from source to destination
 - IP, routing protocols
- **link:** data transfer between neighboring network elements
 - Ethernet, 802.11 (WiFi), PPP
- **physical:** bits "on the wire"



Introduction 1-60

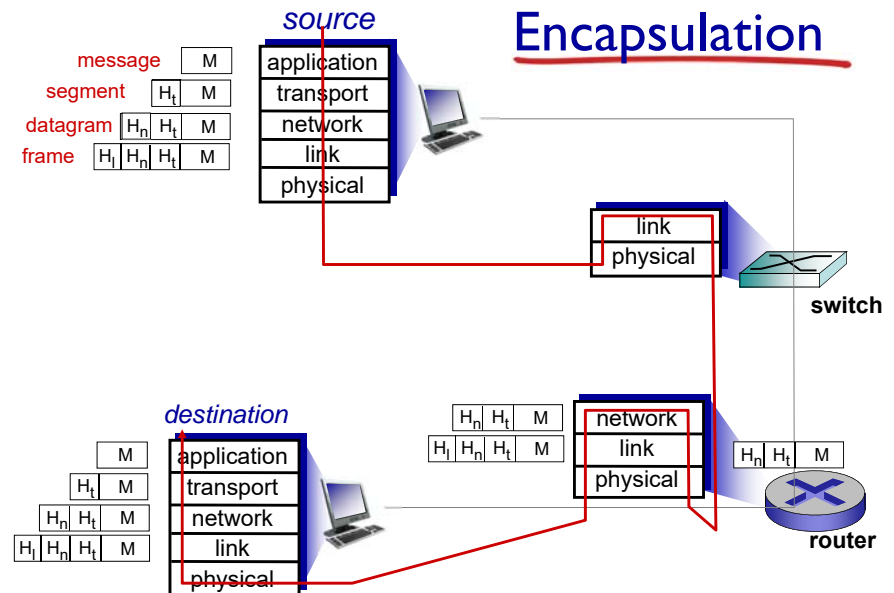
ISO/OSI reference model

- **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?



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Encapsulation



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Chapter I: roadmap

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Introduction 1-63

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!

Introduction 1-64

Bad guys: put malware into hosts via Internet

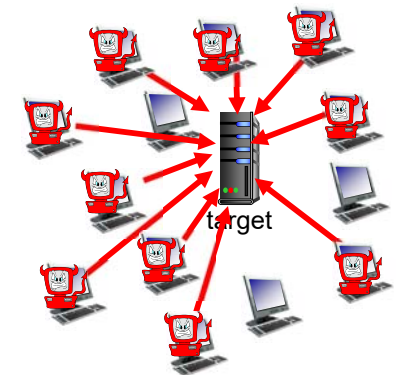
- malware can get in host from:
 - virus*: self-replicating infection by receiving/executing object (e.g., e-mail attachment)
 - worm*: self-replicating infection by passively receiving object that gets itself executed
- spyware malware** can record keystrokes, web sites visited, upload info to collection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

Introduction 1-65

Bad guys: attack server, network infrastructure

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

- select target
- break into hosts around the network (see botnet)
- send packets to target from compromised hosts

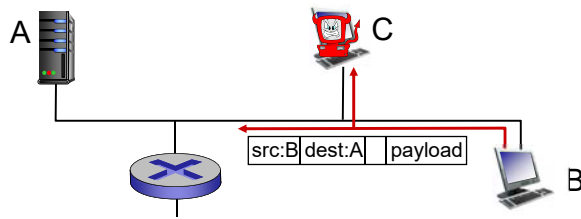


Introduction 1-66

Bad guys can sniff packets

packet “sniffing”:

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

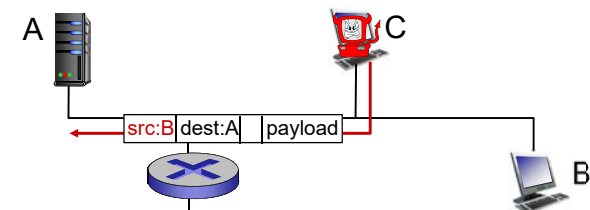


- wireshark software used for end-of-chapter labs is a (free) packet-sniffer

Introduction 1-67

Bad guys can use fake addresses

IP spoofing: send packet with false source address



... lots more on security (throughout, Chapter 8)

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Chapter 1: roadmap

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1.7 history

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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



THE ARPANET

Introduction 1-70

Internet history

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late 70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today's Internet architecture

Introduction 1-71

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

Introduction 1-72

Internet history

1990, 2000 's: commercialization, the Web, new apps

- early 1990' s: ARPAnet decommissioned
 - 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
 - early 1990s: Web
 - hypertext [Bush 1945, Nelson 1960' s]
 - HTML, HTTP: Berners-Lee
 - 1994: Mosaic, later Netscape
 - late 1990' s: commercialization of the Web
- late 1990' s – 2000' s:
 - more killer apps: instant messaging, P2P file sharing
 - network security to forefront
 - est. 50 million host, 100 million+ users
 - backbone links running at Gbps

Introduction 1-73

Internet history

2005-present

- ~5B devices attached to Internet (2016)
 - smartphones and tablets
- aggressive deployment of broadband access
- increasing ubiquity of high-speed wireless access
- emergence of online social networks:
 - Facebook: ~ one billion users
- service providers (Google, Microsoft) create their own networks
 - bypass Internet, providing “instantaneous” access to search, video content, email, etc.
- e-commerce, universities, enterprises running their services in “cloud” (e.g., Amazon EC2)

Introduction 1-74

Introduction: summary

covered a “ton” of material!

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

you now have:

- context, overview, “feel” of networking
- more depth, detail to follow!

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