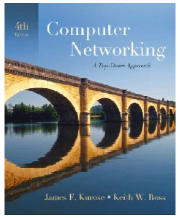
# Chapter 1 Introduction




*Computer Networking: A Top Down Approach* , 4th edition.
Jim Kurose, Keith Ross
Addison-Wesley, July 2007.

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# Chapter 1: 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
- protocol layers, service models



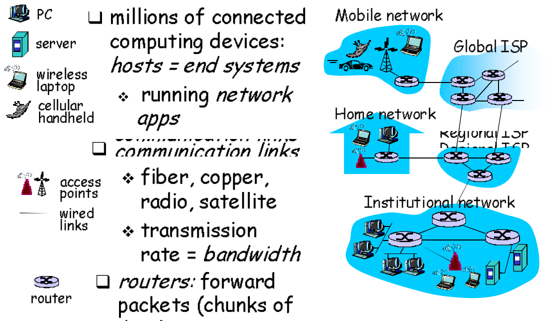
# Chapter 1: roadmap





# What's the Internet: "nuts and bolts" view

- millions of connected computing devices: *hosts = end systems*
  - running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate = *bandwidth*
- *routers:* forward packets (chunks of data)

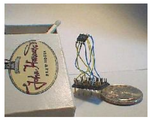





# "Cool" internet appliances


IP picture frame
http://www.ceiva.com/


Web-enabled toaster + weather forecaster

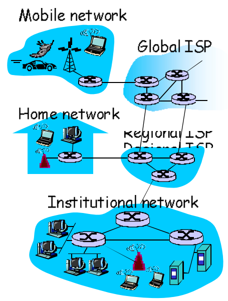

World's smallest web server
http://www-ccs.cs.umass.edu/~shri/iPic.html


Internet phones



# What's the Internet: "nuts and bolts" view

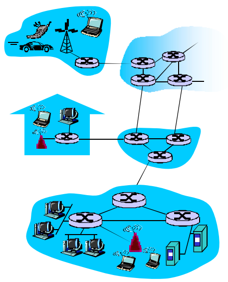
- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, Ethernet
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force






# What's the Internet: a service view

- communication *infrastructure* enables distributed applications:
  - Web, VoIP, email, games, e-commerce, file sharing
- communication services provided to apps:
  - reliable data delivery from source to destination
  - "best effort" (unreliable) data delivery





# What's a protocol?

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

… specific msgs sent
… specific actions taken when msgs received, or other events

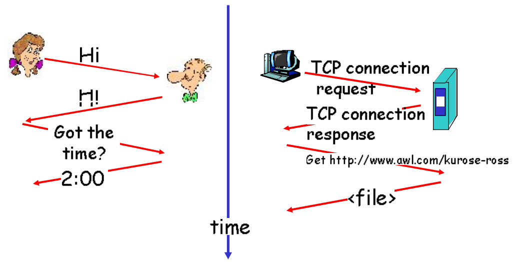
network protocols:
- machines rather than humans
- all communication activity in Internet governed by protocols

*protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt*



# What's a protocol?

a human protocol and a computer network protocol:




Q: Other human protocols?

# Chapter 1: roadmap

1.1 What *is* the Internet?
1.2 Network edge
- end systems, access networks, links

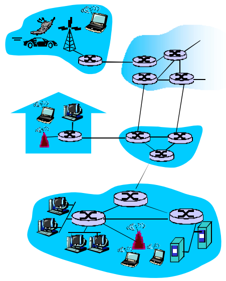
1.3 Network core
- circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks
1.5 Protocol layers, service models



# A closer look at network structure:

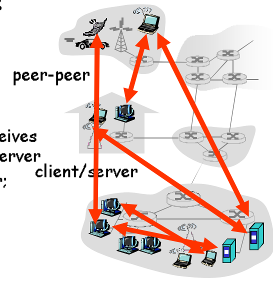
- network edge: applications and hosts
- access networks, physical media: wired, wireless communication links
- network core:
  - interconnected routers
  - network of networks





# The network edge:

- end systems (hosts):
  - run application programs
  - e.g. Web, email
  - at "edge of network"
- client/server model
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- peer-peer model:
  - minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrenth






# Network edge: reliable data transfer service

***Goal:*** data transfer between end systems
- *handshaking:* setup (prepare for) data transfer ahead of time
  - Hello, hello back human protocol
  - *set up "state"* in two communicating hosts
- TCP - Transmission Control Protocol
  - Internet's reliable data transfer service

**TCP service** [RFC 793]
- *reliable, in-order* byte-stream data transfer
  - loss: acknowledgements and retransmissions
- *flow control:*
  - sender won't overwhelm receiver
- *congestion control:*
  - senders "slow down sending rate" when network congested



# Network edge: best effort (unreliable) data transfer service

***Goal:*** data transfer between end systems
- same as before!
- UDP - User Datagram Protocol [RFC 768]:
  - connectionless
  - unreliable data transfer
  - no flow control
  - no congestion control

**App's using TCP:**
- HTTP (Web), FTP (file transfer), Telnet (remote login), SMTP (email)

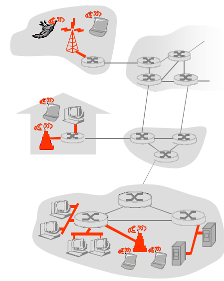
**App's using UDP:**
- streaming media, teleconferencing, DNS, Internet telephony



# 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

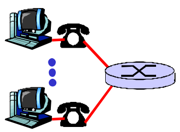
*Keep in mind:*
- bandwidth (bits per second) of access network?
- shared or dedicated?





# Residential access: point to point access

- Dialup via modem
  - up to 56Kbps direct access to router (often less)
  - Can't surf and phone at same time: can't be "always on"



- DSL: digital subscriber line
  - deployment: telephone company (typically)
  - up to 1 Mbps upstream (today typically < 256 kbps)
  - up to 8 Mbps downstream (today typically < 1 Mbps)
  - dedicated physical line to telephone central office



# Residential access: cable modems

- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream, 2 Mbps upstream
- network of cable and fiber attaches homes to ISP router
  - homes share access to router
- deployment: available via cable TV companies



# Residential access: cable modems

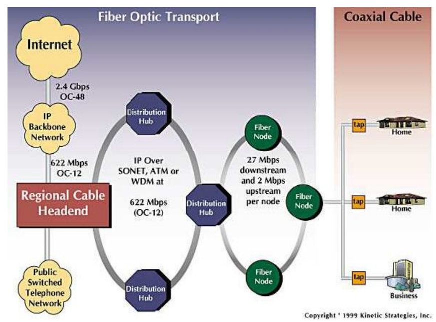
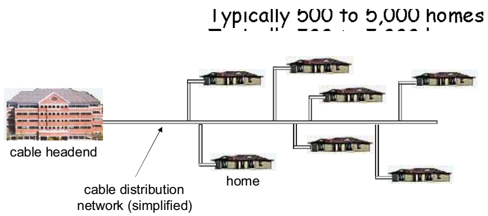


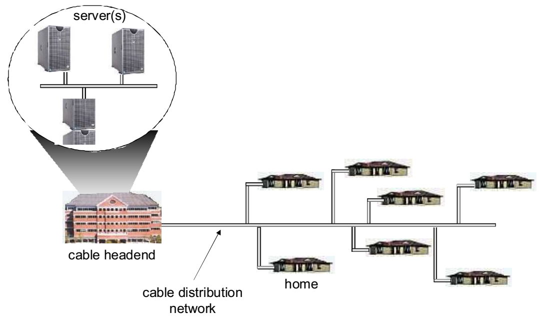

Diagram: http://www.cabledatacomnews.com/cmic/diagram.html

## Cable Network Architecture: Overview



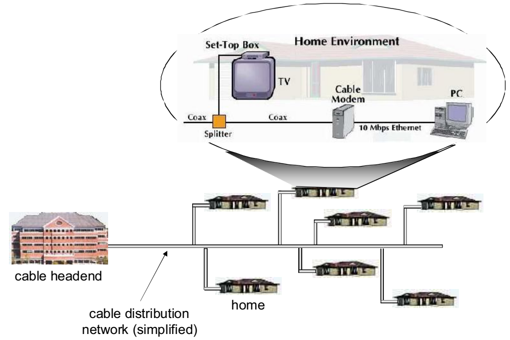



## Cable Network Architecture: Overview





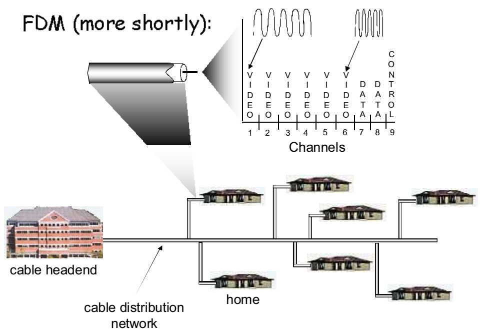

## Cable Network Architecture: Overview






## Cable Network Architecture: Overview

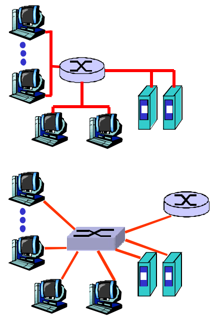
FDM (more shortly):






## Company access: local area networks

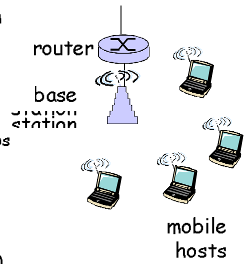
- company/univ local area network (LAN) connects end system to edge router
- Ethernet:
  - 10 Mbs, 100Mbps, 1Gbps, 10Gbps Ethernet
  - modern configuration: end systems connect into *Ethernet switch*
- LANs: chapter 5





## Wireless access networks

- shared *wireless* access network connects end system to router
  - via base station aka "access point"
- wireless LANs:
  - 802.11b/g (WiFi): 11 or 54 Mbps
- wider-area wireless access
  - provided by telco operator
  - ~1Mbps over cellular system (EVDO, HSDPA)
  - next up (?): WiMAX (10's Mbps) over wide area

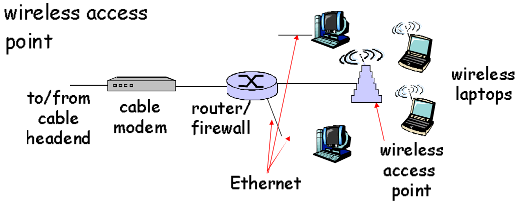





## Home networks

Typical home network components:

- DSL or cable modem
- router/firewall/NAT
- Ethernet
- wireless access point






## Physical Media

- Bit: propagates between transmitter/rcvr 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 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5: 100Mbps Ethernet



## Physical Media: coax, fiber

### Coaxial cable:

- two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- 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 Gps)
- low error rate: repeaters spaced far apart ; immune to electromagnetic noise

## 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)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ 1 Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude



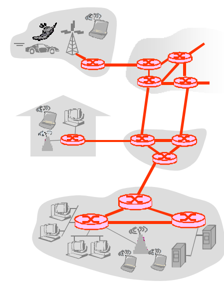
## Chapter 1: roadmap





## The Network Core

- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"

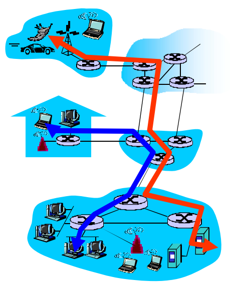




## Network Core: Circuit Switching

End-end resources reserved for "call"

- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup required





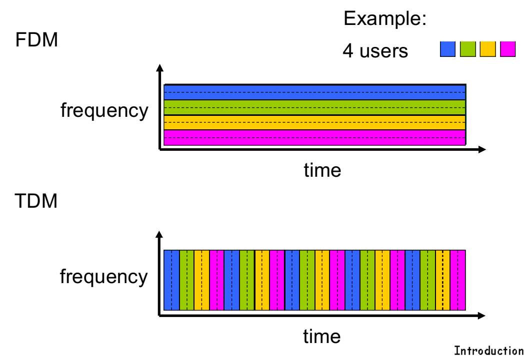
## Network Core: Circuit Switching

network resources (e.g., bandwidth) divided into "pieces"

- pieces allocated to calls
- resource piece *idle* if not used by owning call *(no sharing)*
- dividing link bandwidth into "pieces"
  - frequency division
  - time division



## Circuit Switching: FDM and TDM






## Numerical example

- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

Let's work it out!



## Network Core: Packet Switching

each end-end data stream divided into *packets*

- user A, B packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*

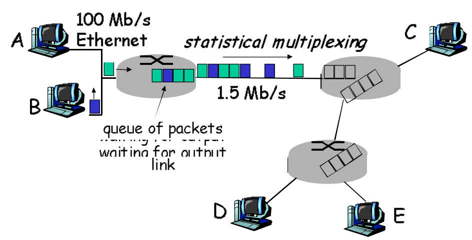
Bandwidth division into "pieces"
Dedicated allocation
Resource reservation

resource contention:

- aggregate resource demand can exceed amount available
- congestion: packets queue, wait for link use
- store and forward: packets move one hop at a time
  - Node receives complete packet before forwarding



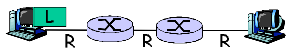
## Packet Switching: Statistical Multiplexing




Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand ➔ *statistical multiplexing.*

TDM: each host gets same slot in revolving TDM frame.

## Packet-switching: store-and-forward




- takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- delay = 3L/R (assuming zero propagation delay)

Example:
- L = 7.5 Mbits
- R = 1.5 Mbps
- transmission delay = 15 sec

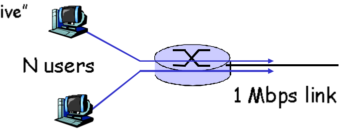
more on delay shortly …



## Packet switching versus circuit switching

*Packet switching allows more users to use network!*

- 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?



## Packet switching versus circuit switching

Is packet switching a "slam dunk winner?"

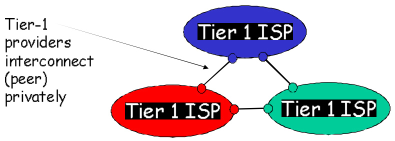
- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- Q: How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved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

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



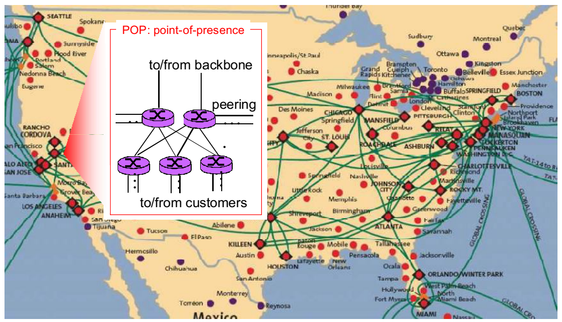
## Internet structure: network of networks

- roughly hierarchical
- at center: "tier-1" ISPs (e.g., Verizon, Sprint, AT&T, Cable and Wireless), national/international coverage
  - treat each other as equals





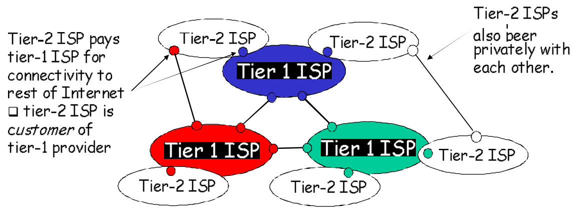

## Tier-1 ISP: e.g., Sprint






## Internet structure: network of networks

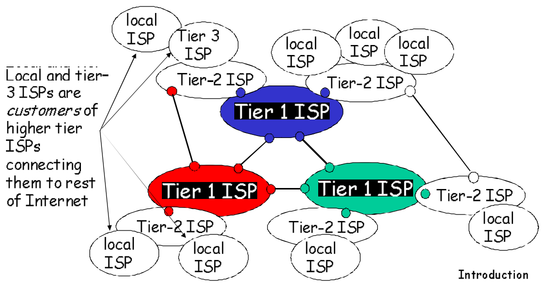
- "Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs






## Internet structure: network of networks

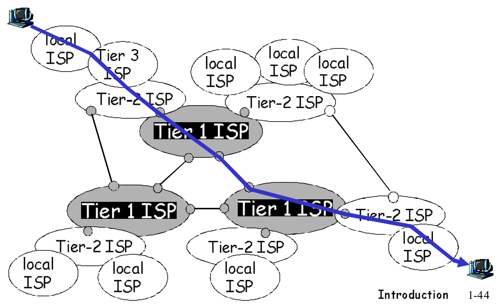
- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)






## Internet structure: network of networks

- a packet passes through many networks!






## Chapter 1: roadmap

1.1 What *is* the Internet?

1.2 Network edge
- end systems, access networks, links

1.3 Network core
- circuit switching, packet switching, network structure

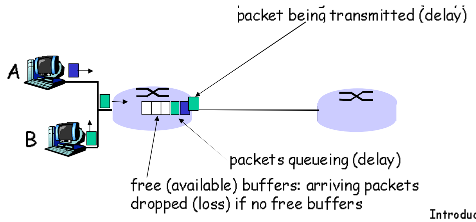
1.4 Delay, loss and throughput in packet-switched networks

1.5 Protocol layers, service models

# How do loss and delay occur?

packets *queue* in router buffers

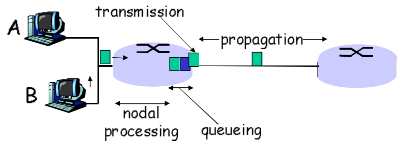
- ❑ packet arrival rate to link exceeds output link capacity
- ❑ packets queue, wait for turn






# Four sources of packet delay

- ❑ 1. nodal processing:
  - ❖ check bit errors
  - ❖ determine output link
- ❑ 2. queueing
  - ❖ time waiting at output link for transmission
  - ❖ depends on congestion level of router






# Delay in packet-switched networks

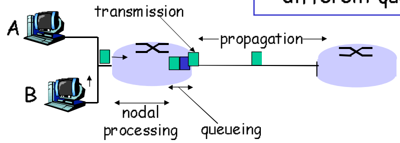
3. Transmission delay:

- ❑ R=link bandwidth (bps)
- ❑ L=packet length (bits)
- ❑ time to send bits into link = L/R

4. Propagation delay:

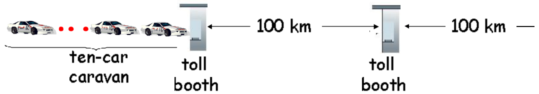
- ❑ d = length of physical link
- ❑ s = propagation speed in medium (~$2x10^8$ m/sec)
- ❑ propagation delay = d/s

Note: s and R are *very* different quantities!





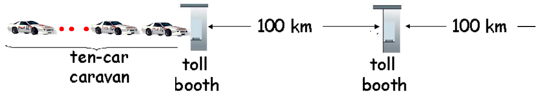

# Caravan analogy




- ❑ cars "propagate" at 100 km/hr
- ❑ toll booth takes 12 sec to service car (transmission time)
- ❑ car~bit; caravan ~ packet
- ❑ Q: How long until caravan is lined up before 2nd toll booth?
- ❑ Time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec
- ❑ Time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr
- ❑ A: 62 minutes



# Caravan analogy (more)




- ❑ Cars now "propagate" at 1000 km/hr
- ❑ Toll booth now takes 1 min to service a car
- ❑ Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?
- ❑ Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- ❑ 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!
  - ❖ See Ethernet applet at AWL Web site



# Nodal delay

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

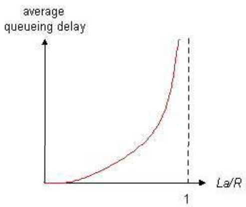
- ❑ $d_{proc}$ = processing delay
  - ❖ typically a few microsecs or less
- ❑ $d_{queue}$ = queuing delay
  - ❖ depends on congestion
- ❑ $d_{trans}$ = transmission delay
  - ❖ = L/R, significant for low-speed links
- ❑ $d_{prop}$ = propagation delay
  - ❖ a few microsecs to hundreds of msecs



# Queueing delay (revisited)

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

traffic intensity = La/R

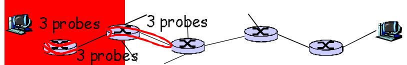



- ❑ La/R ~ 0: average queueing delay small
- ❑ La/R -> 1: delays become large
- ❑ La/R > 1: more "work" arriving than can be serviced, average delay infinite!



# "Real" Internet delays and routes

- ❑ What do "real" Internet delay & loss look like?
- ❑ program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i*:
  - ❖ sends three packets that will reach router *i* on path towards destination
  - ❖ router *i* will return packets to sender
  - ❖ sender times interval between transmission and reply.






# "Real" Internet delays and routes

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

Three delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

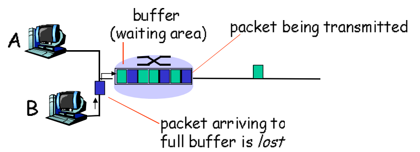
```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

trans-oceanic link

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

# Packet loss

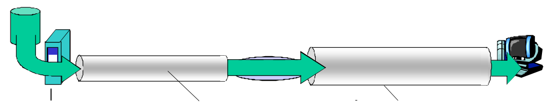
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all






# Throughput

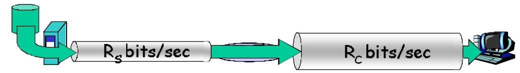
- *throughput:* rate (bits/time unit) at which bits transferred between sender/receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over long(er) period of time



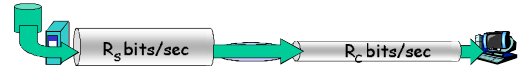



# Throughput (more)

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




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



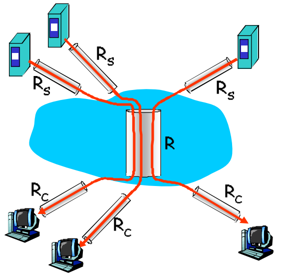

*bottleneck link*

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



# 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



# Chapter 1: roadmap

1.1 What *is* the Internet?
1.2 Network edge
- end systems, access networks, links

1.3 Network core
- circuit switching, packet switching, network structure

1.4 Delay, loss and throughput in packet-switched networks
1.5 Protocol layers, service models



# Protocol "Layers"

Networks are complex!
- many "pieces":
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

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

Or at least our discussion of networks?



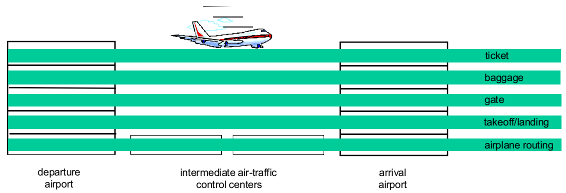
# Organization of air travel

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

- a series of steps



# Layering of airline functionality




Layers: each layer implements a service
- via its own internal-layer actions
- relying on services provided by layer below

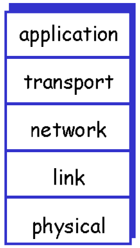


# Why layering?

Dealing with complex systems:
- explicit structure allows identification, relationship of complex system's pieces
  - layered reference model for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system
- layering considered harmful?

# Internet protocol stack

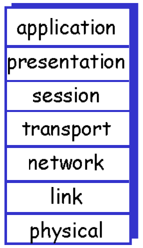
- application: supporting network applications
  - FTP, SMTP, HTTP
- transport: process-process data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - PPP, Ethernet
- physical: bits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





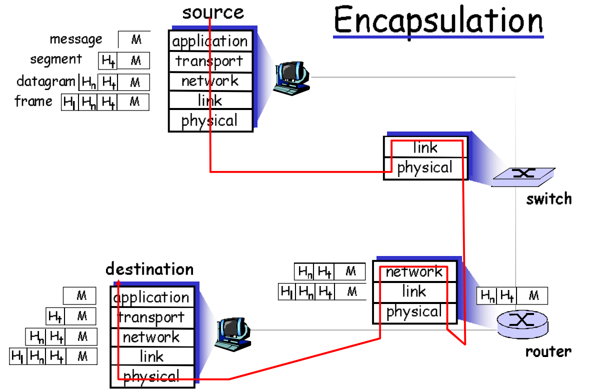

# ISO/OSI reference model

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






# Encapsulation






# 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!*