Part I: Introduction

Chapter goal:

- get context, overview, "feel" of networking
- more depth, detail *later* in course
- approach:
  - descriptive
  - use Internet as example

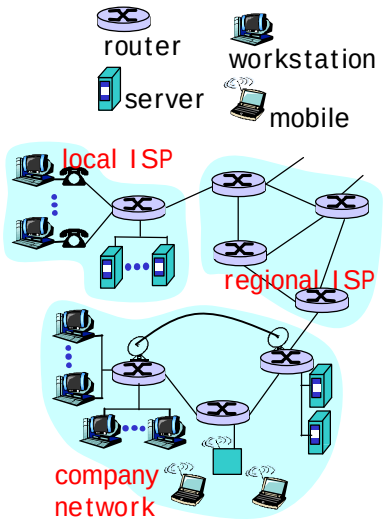
Overview:

- what's the Internet
- what's a protocol?
- network edge
- network core
- access net, physical media
- performance: loss, delay
- protocol layers, service models
- backbones, NAPs, ISPs
- history
- ATM network

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

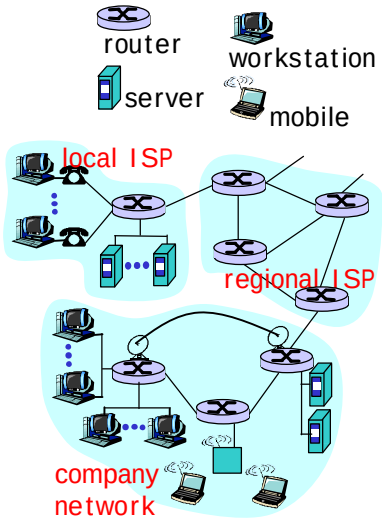
- millions of connected computing devices: *hosts, end-systems*
  - pc's workstations, servers
  - PDA's phones, toasters

  running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
- *routers:* forward packets (chunks) of data thru network



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

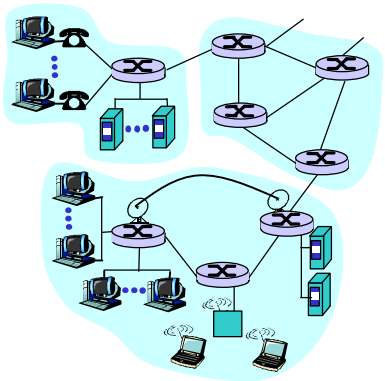
- *protocols*: control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, FTP, PPP
- *Internet:* "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



What's the Internet: a service view

- communication *infrastructure* enables distributed applications:
  - WWW, email, games, e-commerce, database., voting,
  - more?
- communication services provided:
  - connectionless
  - connection-oriented
- cyberspace [Gibson]:

  "a consensual hallucination experienced daily by billions of operators, in every nation, ..."



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

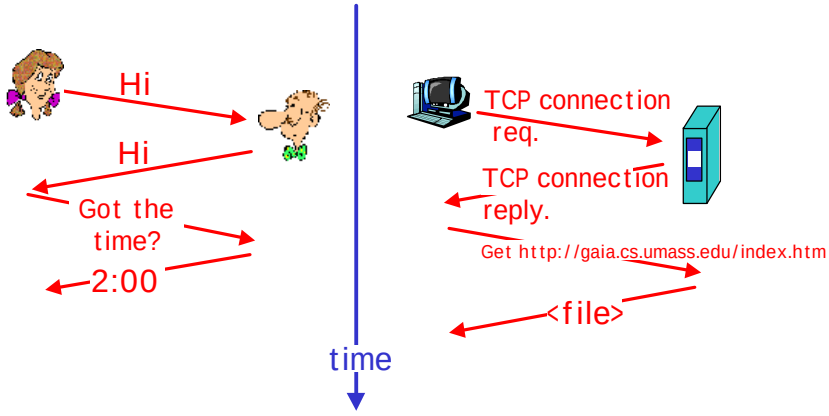
network protocols:

- 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?

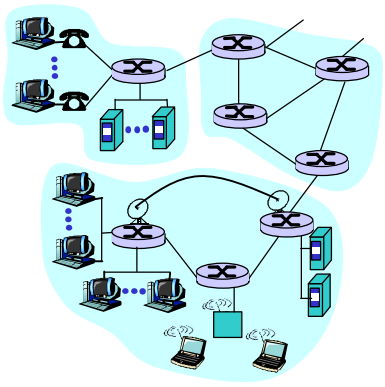
a human protocol and a computer network protocol:



Q: Other human protocol?

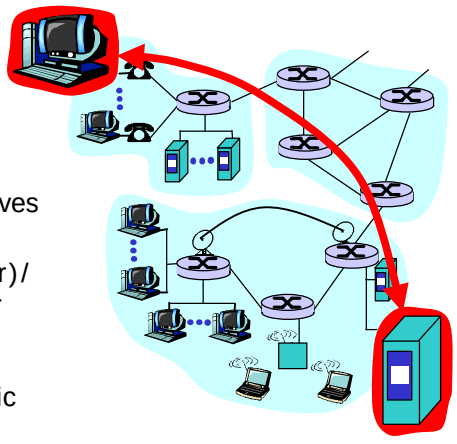
A closer look at network structure:

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



The network edge:

- end systems (hosts):
  - run application programs
  - e.g., WWW, email
  - at "edge of network"
- client/server model
  - client host requests, receives service from server
  - e.g., WWW client (browser)/ server; email client/server
- peer-peer model:
  - host interaction symmetric
  - e.g.: teleconferencing, Naspter, Gnutella



Network edge: connection-oriented service

Goal: data transfer between end sys.

- *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 connection-oriented 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: connectionless service

Goal: data transfer between end systems

- same as before!

- UDP - User Datagram Protocol [RFC 768]: Internet's connectionless service
  - unreliable data transfer
  - no flow control
  - no congestion control

App's using TCP:

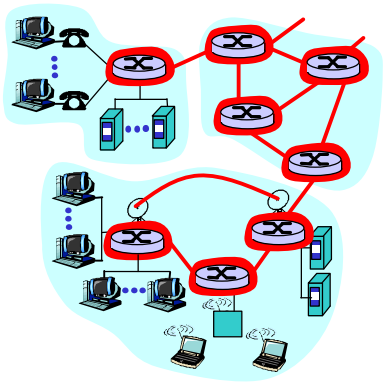
- HTTP (WWW), FTP (file transfer), Telnet (remote login), SMTP (email)

App's using UDP:

- streaming media, teleconferencing, Internet telephony

The Network Core

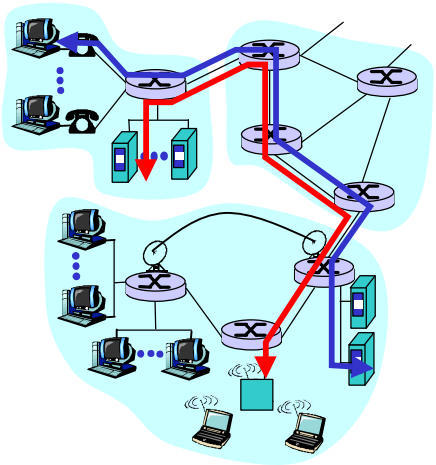
- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete "chunks"



Network Core: Circuit Switching

End-end resources reserved for "call"

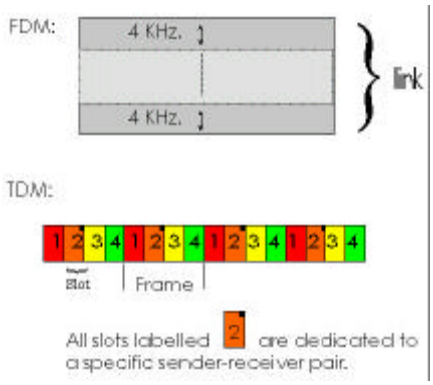
- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup required



Network Core: Circuit Switching (Multiplexing)

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

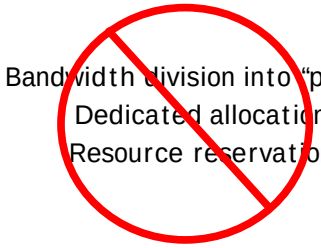
- pieces allocated to calls
- resource piece *idle* if not used by owning call *(no sharing)*
- dividing link bandwidth into "pieces"
  - frequency division
  - time division



Network Core: Packet Switching

each end-end data stream divided into *packets*

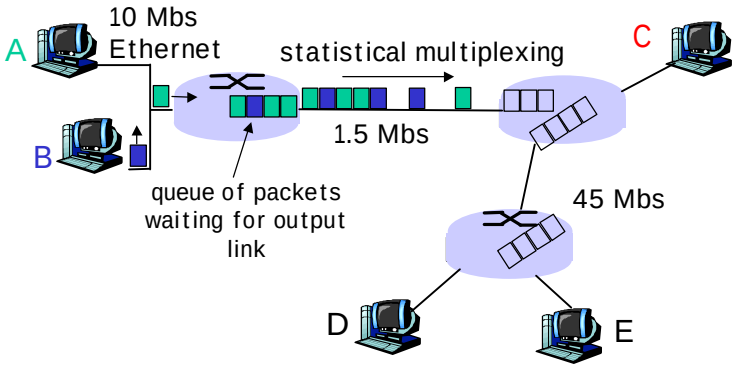
- user A, B packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*,



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
  - transmit over link
  - wait turn at next link

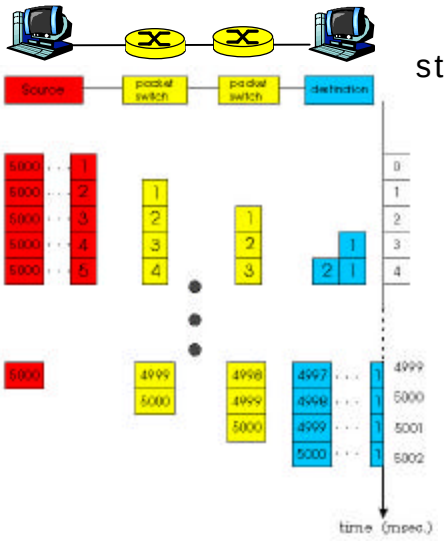
Network Core: Packet Switching



Packet-switching versus circuit switching: human restaurant analogy

- other human analogies?

Network Core: Packet Switching



Packet-switching: store and forward behavior

Q links, each link ***R*** bps
each packet: ***(h+L)*** bits

To transfer ***M*** packets requires

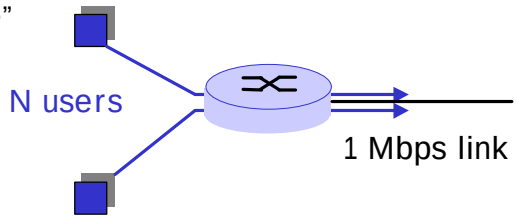
$$Q*(h+L)/R + (M-1)*(h+L)/R$$

1st packet arrives

Packet switching versus circuit switching

Packet switching allows more users to use network!

- 1 Mbit link
- each user:
  - 100Kbps when "active"
  - active 10% of time
- circuit-switching:
  - 10 users
- packet switching:
  - with 35 users, probability > 10 active less that .004



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Packet switching versus circuit switching

Is packet switching a "slam dunk winner?"

- Great for bursty data
  - resource sharing
  - 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 6)

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Packet-switched networks: routing

- *Goal:* move packets among routers from source to destination
  - we'll study several path selection algorithms (chapter 4)
- datagram network:
  - *destination address* determines next hop
  - routes may change during session
  - analogy: driving, asking directions
- virtual circuit network:
  - each packet carries tag (virtual circuit ID), tag determines next hop
  - fixed path determined at *call setup time*, remains fixed thru call
  - routers maintain per-call state

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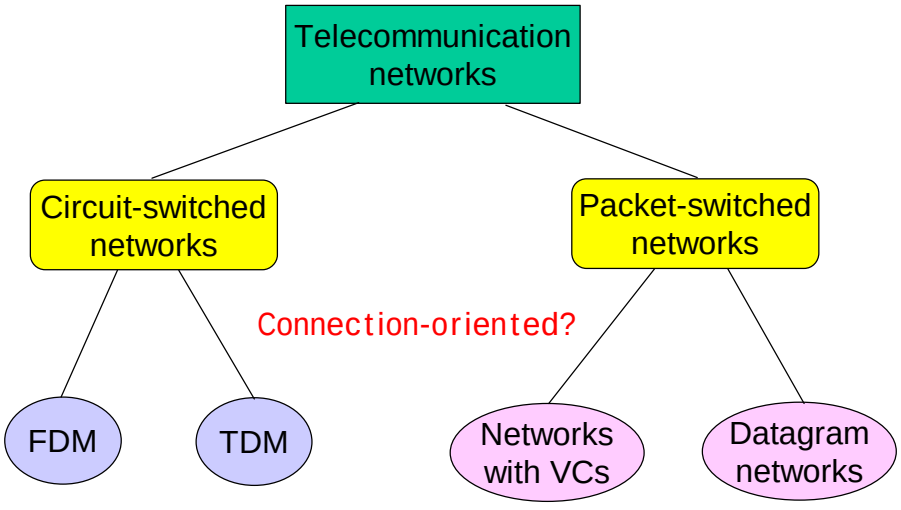
Network Taxonomy



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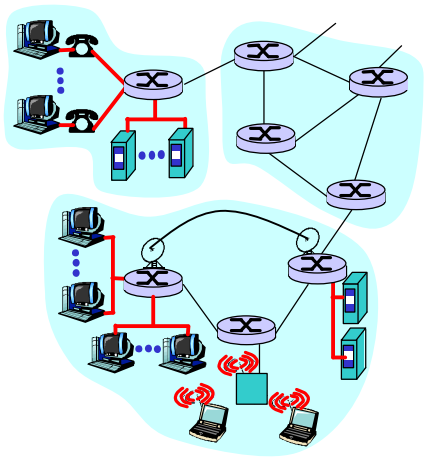
Access networks and physical media

Q: How to connection end systems to edge router?

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

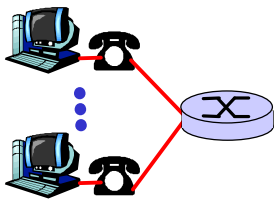
Keep in mind:

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



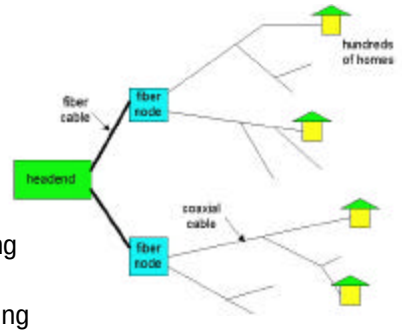
Residential access: point to point access

- Dialup via modem
  - up to 56Kbps direct access to router (conceptually)
- ISDN: intergrated services digital network: 128Kbps all-digital connect to router
- ADSL: asymmetric digital subscriber line
  - up to 1 Mbps home-to-router
  - up to 8 Mbps router-to-home
  - DSL/ADSL deployment: SBC, Covad



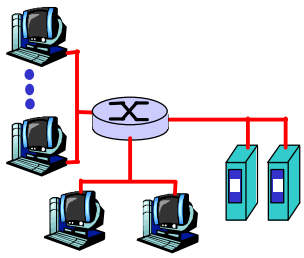
Residential access: cable modems

- HFC: hybrid fiber coax
  - asymmetric: up to 27Mbps (1~3Mbps realistically) downstream, and 1 Mbps (256kbps typical) upstream
- network of cable and fiber attaches homes to ISP router
  - shared access to router among home
  - issues: congestion, dimensioning
- deployment: available via cable companies, e.g., Road Runner, @Home, MediaOne



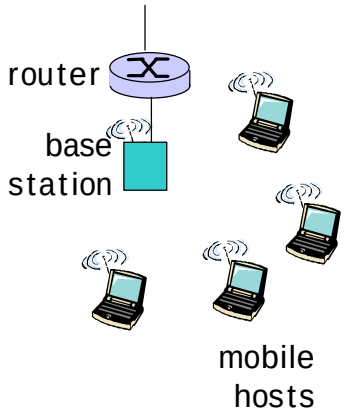
Institutional access: local area networks

- company/univ local area network (LAN) connects end system to edge router
- Ethernet:
  - shared or dedicated cable connects end system and router
  - 10 Mbs, 100Mbps, Gigabit Ethernet
- deployment: institutions, home LANs soon
- LANs: chapter 5



Wireless access networks

- shared *wireless* access network connects end system to router
- wireless LANs:
  - radio spectrum replaces wire
  - e.g., Lucent Orinoco 11 Mbps (and will be 54 Mbps soon)
- wider-area wireless access
  - CDPD: wireless access to ISP router via cellular network



Physical Media

- physical link: transmitted data bit propagates across link
- guided media:
  - signals propagate in solid media: copper, fiber, laser
- unguided media:
  - signals propagate freely e.g., radio, fluorescent light, pigeons(RFC1149)

Twisted Pair (TP)

- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps ethernet
  - Category 5 TP: 100Mbps ethernet
  - Category 5E/6 TP: 1000Mbps ethernet

Physical Media: coax, fiber

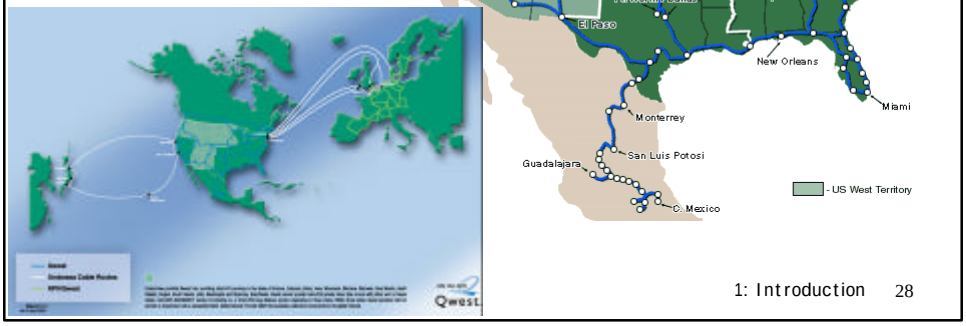
Coaxial cable:

- wire (signal carrier) within a wire (shield)
  - baseband: single channel on cable
  - broadband: multiple channel on cable
- bidirectional
- common use in 10Mbs Ethernet

Fiber optic cable:

- glass fiber carrying light pulses
- high-speed operation:
  - 100Mbps/1Gbps Ethernet
  - high-speed point-to-point transmission (e.g., 5 Gps)
- low error rate

Qwest Fiber Networks



Physical media: radio

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

Radio link types:

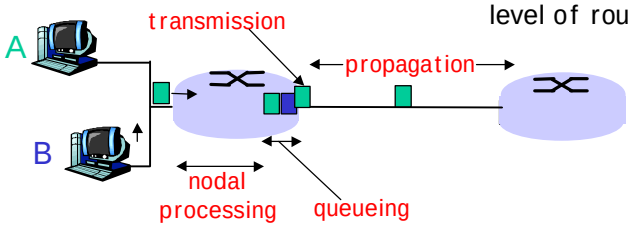
- microwave
  - e.g. 155 Mbps per channel (622 Mbps total) - DMC Altium
- LAN (e.g., waveLAN)
  - 2Mbps, 11Mbps, 54Mbps
- wide-area (e.g., cellular)
  - e.g. CDPD, 10's Kbps, Sprint PCS - 2.4 Mbps
- satellite
  - up to 155Mbps channel (or multiple smaller channels)
  - 260 Msec end-end delay
  - geosynchronous versus LEOS

Delay in packet-switched networks

packets experience delay on end-to-end path

- four sources of delay at each hop

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



Delay in packet-switched networks

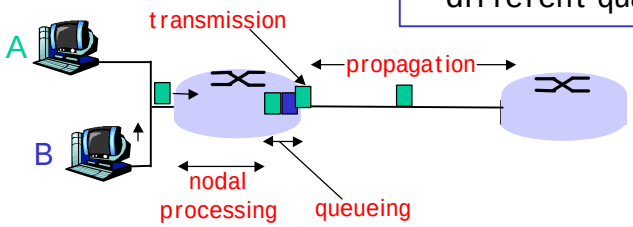
Transmission delay:

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

Propagation delay:

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

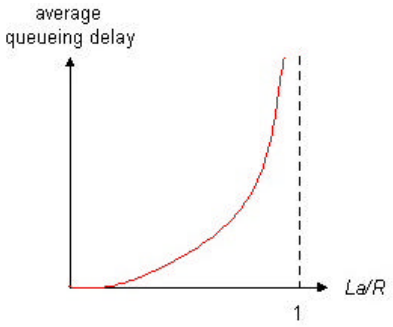
Note: s and R are *very* different quantitites!



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!