

## Internet and Stuff: The Basics

- o What is the Internet?
- o What does it consist of?
- o Main terminology and lingo
- o Fundamental Concepts

Re-using some slides from Kurose and Ross book

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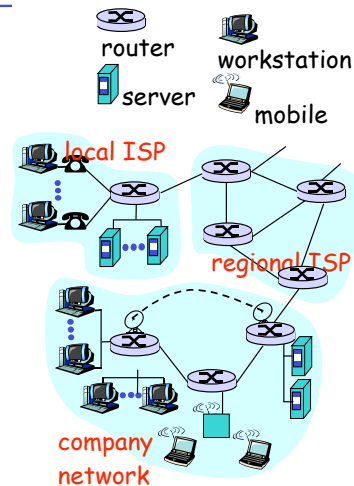
## The Internet

- o A network of networks
- o Hierarchical structure
  - Multiple possible levels
  - Two official levels
    - Intra-domain: within an Autonomous System (AS)
    - Inter-domain: between Autonomous Systems
    - AS: autonomously administered part of the Internet
    - ASes are identified by their AS number

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## Visualizing the Internet

- o millions of connected computing devices: *hosts, end-systems*
  - pc's workstations, servers
  - PDA's phones, toastersrunning *network apps*
- o *communication links*
  - fiber, copper, radio, satellite
- o *routers*: forward packets (chunks) of data thru network

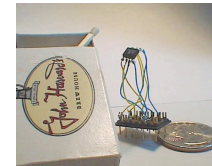


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## "Cool" Internet Appliances



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



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



Web-enabled toaster+weather forecaster  
<http://dancing-man.com/robin/toasty/>

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## Some Internet Lingo

- o A packet switched best effort network
- o TCP or Transmission Control Protocol:
  - Communication between end-points
- o IP or Internet Protocol:
  - How things are routed
- o Packets are similar to postal letters
  - From, to, content
  - Postman handles all packets similarly
  - Addressing is hierarchical
- o IETF: Internet Engineering Task Force: the body
- o RFC: Request For Comments: (pseudo)-standards

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## Faloutsos Golden Rules of Networking

1. Nothing is absolute in networks research
2. This applies for first rule
3. There are no complicated concepts, just obscure jargon

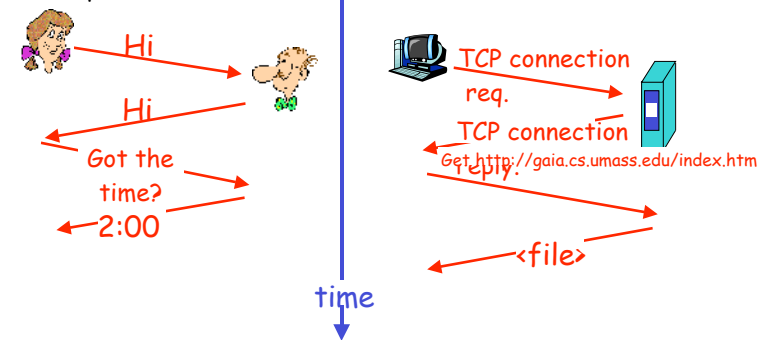
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## What's a protocol?

The definition of a behavior

Here: the format of a communication exchange:

Sequence of actions, format of information, predefined interpretation



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## Centralised versus Distributed Protocols

- o Centralised: all information is collected in one place and then processed
- o Distributed: decisions are taken locally with partial or summary of the information

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## The Principles of the Internet

- o Goal: Interconnect existing net technologies
  - ARPA packet radio, and ARPANET
  - Packet switching? Flexibility
  - Trade-off: poorer non-guaranteed performance
- o "The Design Philosophy of The DARPA Internet Protocols", David Clark, MIT.

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## Internet Architecture Characteristics

- o Scalability to millions of users
  - Stateless routing: Routers cannot keep detailed info per connection
- o Best-effort service: no guarantees
- o Decentralized control
- o Self-configuration

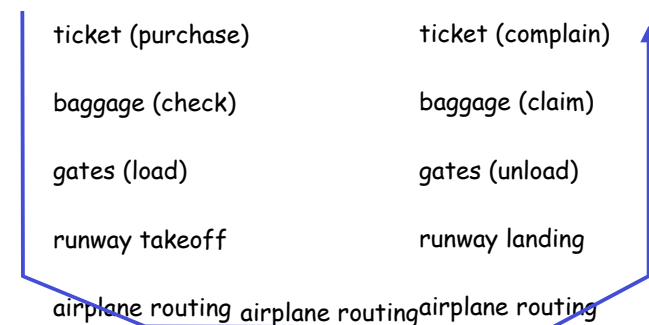
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## Secondary Internet Principles

1. Fault-tolerance to component failures
2. Support multiple types of services
3. Interoperate with different technologies
4. Allow distributed management
5. Be cost effective (ie sharing)
6. Be easily extendible
7. Resources and entities must be accountable (for security purpose)

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## Organization of air travel



- o a series of steps

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## Organization of air travel: a different view

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

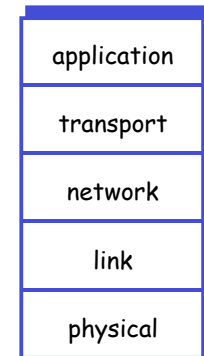
**Layers:** each layer implements a service

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

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## Internet protocol stack

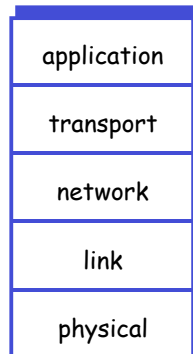
- **application:** supporting network applications
  - ftp, smtp, http
- **transport:** host-host data transfer
  - tcp, udp
- **network:** routing of datagrams from source to destination
  - ip, routing protocols
- **link:** data transfer between neighboring network elements
  - ppp, ethernet
- **physical:** bits "on the wire"



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## Roles of Layers

- **application:** support application
  - HTTP, ftp,
- **transport:** end-to-end issues
  - TCP, UDP
- **network:** pick the route (delays, QoS)
  - OSPF, BGP, PIM
- **link:** given a link transfer a packet
  - Ethernet, PPP
- **physical:** bits "on the wire", ie. Voltage modulation



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## Types of Communications

- **Circuit Switching** (reserve a slice of resources)
  - Frequency division multiplexing
  - Time division multiplexing
- **Packet switching**
  - Virtual Circuits: routers keep per connection info
  - Datagrams: no per conn. Information
    - Connection oriented (state at end points, handshake - TCP)
    - Connectionless (no state at end points - UDP)

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## Types of Communications

- o Advantage of packet switching:
  - Resource sharing
  - No need for reservations
  - Easier to implement distributedly
- o Advantage of circuit switching:
  - Can guarantee performance (Quality of Service)

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## Basic Routing Concepts

- o Packet = postal letter
- o Router receives packet
- o Needs to decide which link to send it to
- o Scalability: decide on local information
- o Routers keep "summary" of information
- o Exploit the hierarchy in the IP address

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## IP Addresses

- o IPv4 addresses have 32 bits: 4 octets of bits
  - 128.32.101.5 is an IP address (32 bits)
- o An IP prefix is a group of IP addresses
  - 128.32.0.0/16 is a prefix of the first 16 bits
  - = 128.32.0.0 - 128.32.255.255 ( $2^{16}$  addresses)
  - 128.32.4.0/24 is a longer prefix 24 bits
- o Routing: find the longest match:
  - IP prefix in table that matches most bits of the address

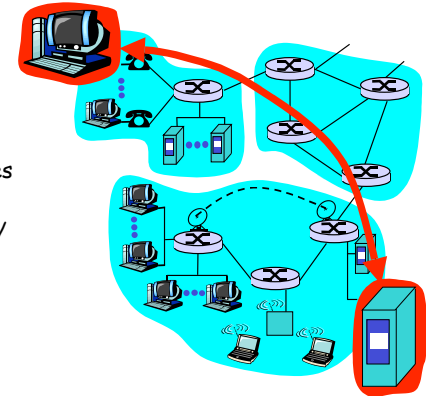
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## A Closer Look at a Router

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## The network edge:

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



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## Network edge: connection-oriented service

Goal: data transfer between end sys.

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

TCP service [RFC 793]

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

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## Network edge: connectionless service

Goal: data transfer between end systems

- same as before!
- o **UDP** - User Datagram Protocol [RFC 768]: Internet's connectionless service
  - unreliable data transfer
  - no flow control
  - no congestion control

App's using TCP:

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

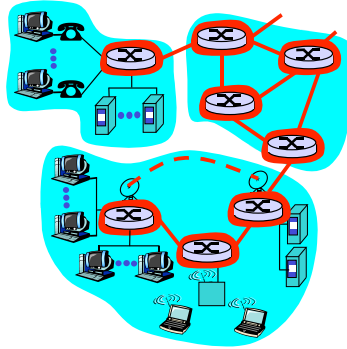
App's using UDP:

- o streaming media, teleconferencing, Internet telephony

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## The Network Core

- o mesh of interconnected routers
- o 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"

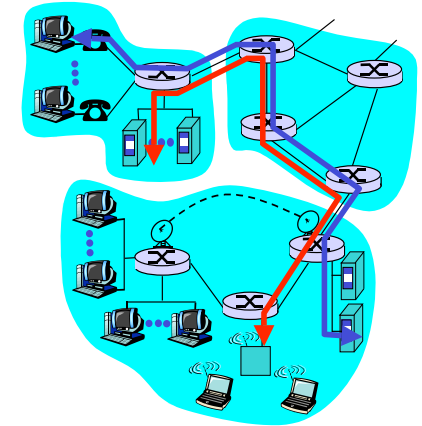


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## Network Core: Circuit Switching

### End-end resources reserved for "call"

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



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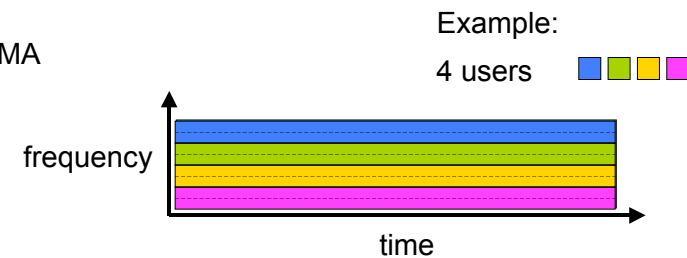
## Network Core: Circuit Switching

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

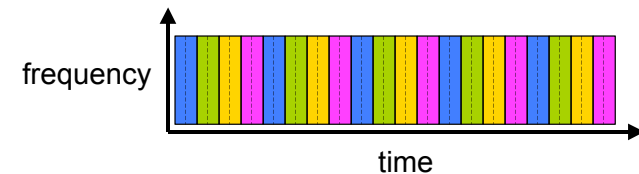
- o pieces allocated to calls
- o resource piece **idle** if not used by owning call (*no sharing*)
- o dividing link bandwidth into "pieces"
  - frequency division
  - time division

## Circuit Switching: TDMA and TDMA

FDMA



TDMA



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## 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*,

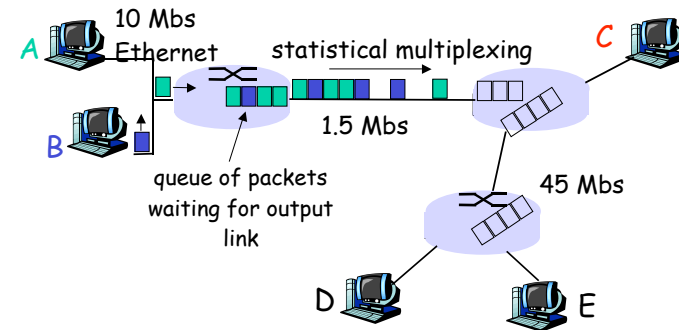
resource contention:

- 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

Bandwidth division into "pieces"  
 Dedicated allocation  
 Resource reservation

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## Network Core: Packet Switching



Packet-switching versus circuit switching: human restaurant analogy

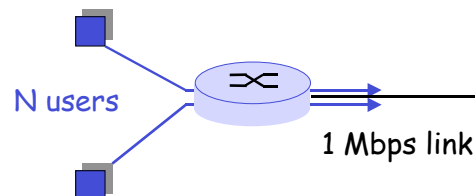
- other human analogies?

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## 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 than .0004



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## Packet switching versus circuit switching

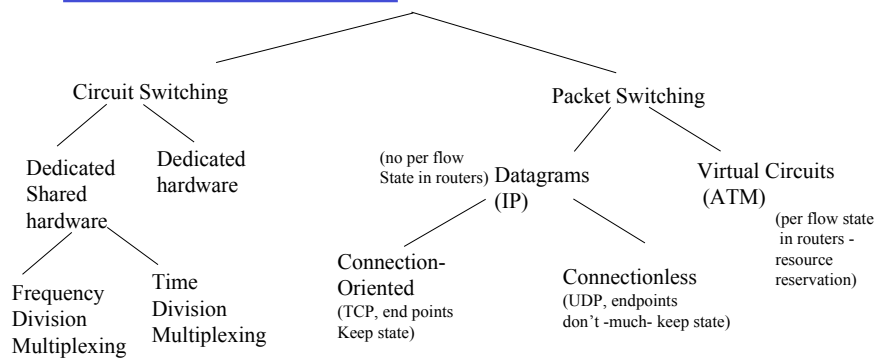
Is packet switching a "slam dunk winner?"

- 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 (see QoS, multimedia)

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# Classification of the Types of Communication



- Things are more fuzzy in practice

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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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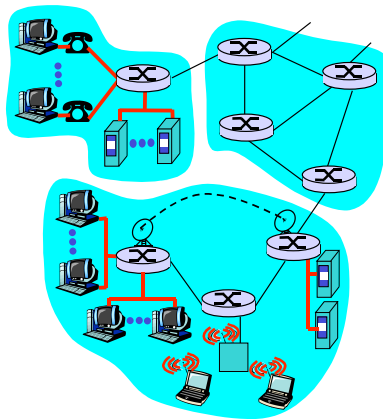
## Access networks and physical media

*Q: How to connect end systems to edge router?*

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

*Keep in mind:*

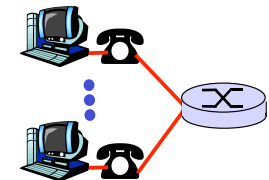
- bandwidth (bits per second) of access network?
- shared or dedicated?



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## Residential access: point to point access

- Dialup via modem**
  - up to 56Kbps direct access to router (conceptually)
- ISDN:** integrated 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
  - ADSL deployment: *happening*



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## Residential access: cable modems

- o **HFC: hybrid fiber coax**
  - asymmetric: up to 10Mbps upstream, 1 Mbps downstream
- o **network** of cable and fiber attaches homes to ISP router
  - shared access to router among home
  - issues: congestion, dimensioning
- o deployment: available via cable companies, e.g., MediaOne

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## Residential access: cable modems

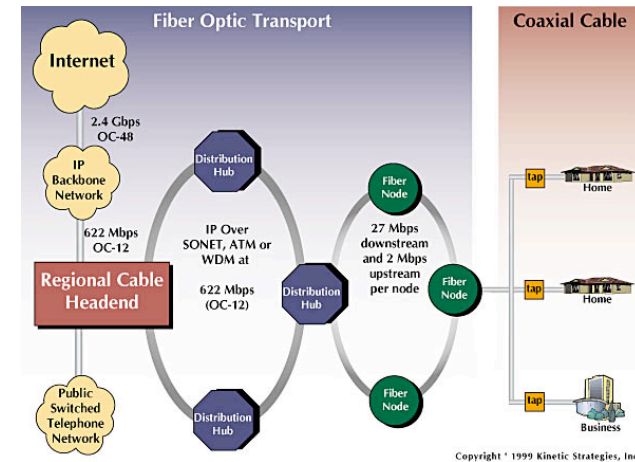
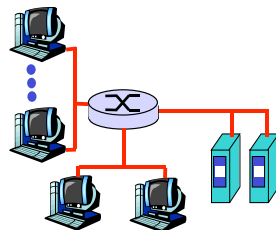


Diagram: <http://www.cabledatcomnews.com/cm/c/diagram.html>

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## Institutional access: local area networks

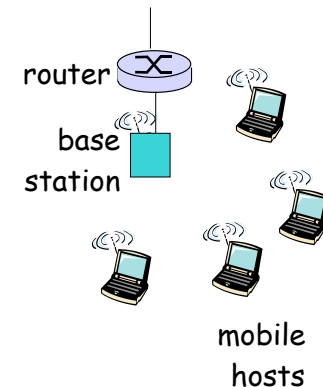
- o company/univ **local area network** (LAN) connects end system to edge router
- o **Ethernet:**
  - shared or dedicated cable connects end system and router
  - 10 Mbs, 100Mbps, Gigabit Ethernet
- o **deployment:** institutions, home LANs happening now



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## Wireless access networks

- o shared **wireless access** network connects end system to router
- o **wireless LANs:**
  - radio spectrum replaces wire
  - e.g., Lucent Wavelan 11 Mbps
- o **wider-area wireless access**
  - CDPD: wireless access to ISP router via cellular network

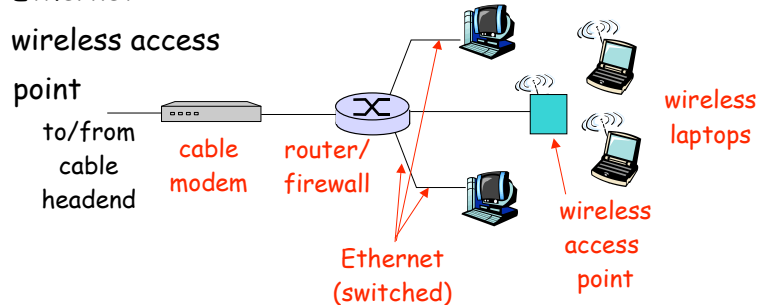


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## Home networks

### Typical home network components:

- o ADSL or cable modem
- o router/firewall
- o Ethernet
- o wireless access point



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## Physical Media

- o **physical link:**  
transmitted data bit propagates across link
- o **guided media:**
  - signals propagate in solid media: copper, fiber
- o **unguided media:**
  - signals propagate freely, e.g., radio

### Twisted Pair (TP)

- o two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5 TP: 100Mbps Ethernet



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## Physical Media: coax, fiber

### Coaxial cable:

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



### Fiber optic cable:

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



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## Physical media: radio

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

### Radio link types:

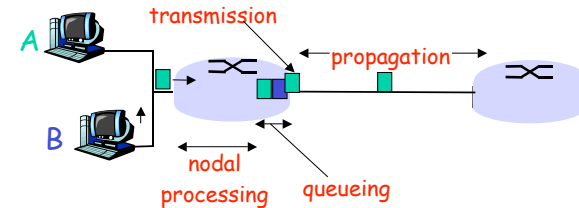
- o **microwave**
  - e.g. up to 45 Mbps channels
- o **LAN** (e.g., WaveLAN)
  - 2Mbps, 11Mbps
- o **wide-area** (e.g., cellular)
  - e.g. CDPD, 10's Kbps
- o **satellite**
  - up to 50Mbps channel (or multiple smaller channels)
  - 270 Msec end-end delay
  - geosynchronous versus LEOS

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## Performance Issues

## 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



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## Delay in packet-switched networks

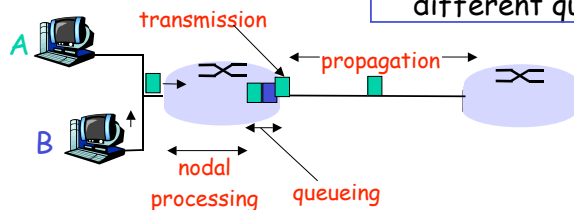
### Transmission delay:

- $R$  = 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 ( $\sim 2 \times 10^8$  m/sec)
- propagation delay =  $d/s$

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

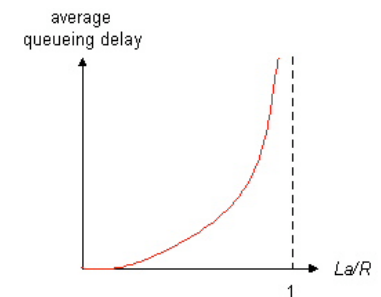


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## Queueing delay (revisited)

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

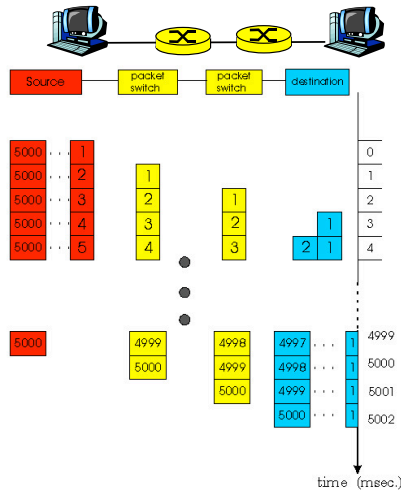
**traffic intensity** =  $\frac{La}{R}$



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

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## Network Core: Packet Switching



Packet-switching:  
store and forward behavior

- break message into smaller chunks: "packets"
- Store-and-forward: switch waits until chunk has completely arrived, then forwards/routes
- Q: what if message was sent as single unit?

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## Why layering?

Dealing with complex systems:

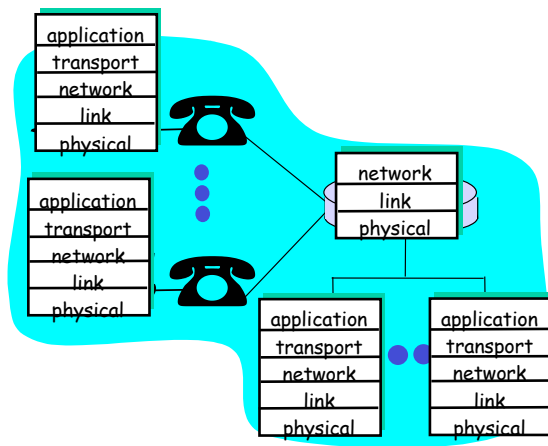
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system
- Isolating "functions" and interactions components
  - layered **reference model** for discussion
- layering considered harmful?

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## Layering: logical communication

Each layer:

- distributed
- "entities" implement layer functions at each node
- entities perform actions, exchange messages with peers

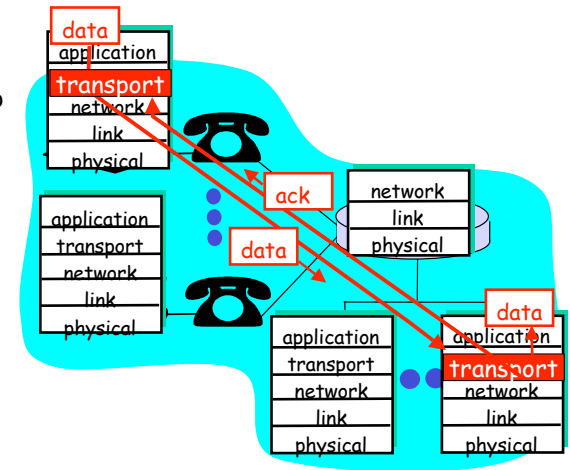


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## Layering: logical communication

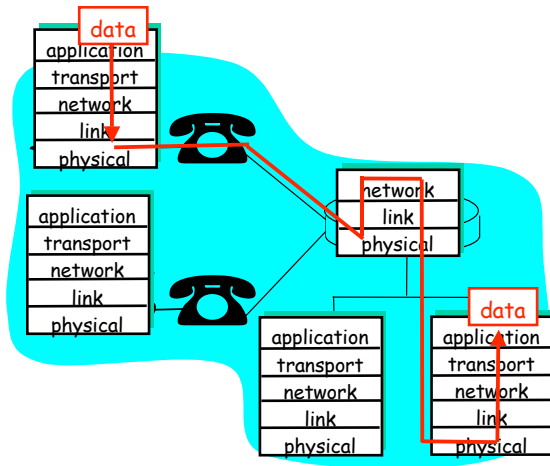
E.g.: transport

- take data from app
- add addressing, reliability check info to form "datagram"
- send datagram to peer
- wait for peer to ack receipt
- analogy: post office



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## Layering: physical communication

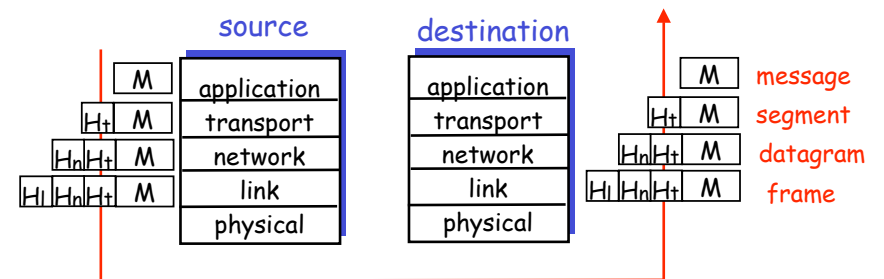


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## Protocol layering and data

Each layer takes data from above

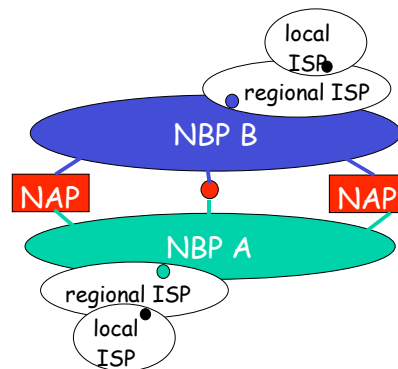
- o adds header information to create new data unit
- o passes new data unit to layer below



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## Internet structure: network of networks

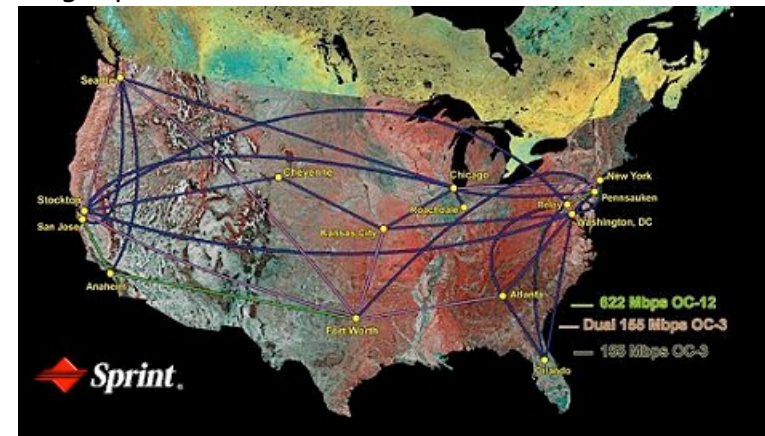
- o roughly hierarchical
- o national/international backbone providers (NBP)
  - e.g. BBN/GTE, Sprint, AT&T, IBM, UUNet
  - interconnect (peer) with each other privately, or at public Network Access Point (NAPs)
- o regional ISPs
  - connect into NBPs
- o local ISP, company
  - connect into regional ISPs



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## National Backbone Provider

e.g. Sprint US backbone network



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## Internet History

### 1961-1972: Early packet-switching principles

- o 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- o 1964: Baran - packet-switching in military nets
- o 1967: ARPAnet conceived by Advanced Research Projects Agency
- o 1969: first ARPAnet node operational
- o 1972:
  - ARPAnet demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

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## Internet History

### 1972-1980: Internetworking, new and proprietary nets

- o 1970: ALOHAnet satellite network in Hawaii  
Faloutsos is born 26 May '70
- o 1973: Metcalfe's PhD thesis proposes Ethernet
- o 1974: Cerf and Kahn - architecture for interconnecting networks
- o late 70's: proprietary architectures: DECnet, SNA, XNA
- o late 70's: switching fixed length packets (ATM precursor)
- o 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

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## Internet History

### 1980-1990: new protocols, a proliferation of networks

- o 1983: deployment of TCP/IP
- o 1982: smtp e-mail protocol defined
- o 1983: DNS defined for name-to-IP-address translation
- o 1985: ftp protocol defined
- o 1988: TCP congestion control
- o new national networks: Cset, BITnet, NSFnet, Minitel
- o 100,000 hosts connected to confederation of networks

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## Internet History

### 1990's: commercialization, the WWW

- o Early 1990's: ARPAnet decommissioned
- o 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- o early 1990s: WWW
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, http: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the WWW

#### Late 1990's:

- o est. 50 million computers on Internet
- o est. 100 million+ users
- o backbone links running at 1 Gbps

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# Introduction: Summary

## Covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
- performance: loss, delay
- layering and service models
- backbones, NAPs, ISPs
- history

## You now have:

- context, overview, "feel" of networking
- more depth, detail *later* in course