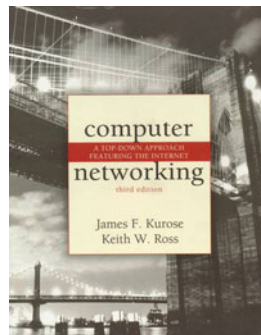


Chapter 1

Introduction



*Computer Networking:
A Top Down Approach
Featuring the Internet,
3rd edition.
Jim Kurose, Keith Ross
Addison-Wesley, July
2004.*

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Introduction 1-1

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
- network core
- access net, physical media
- Internet/ISP structure
- performance: loss, delay
- protocol layers, service models
- network modeling

Introduction 1-2

Chapter 1: roadmap

1.1 What *is* the Internet?

1.2 Network edge

1.3 Network core

1.4 Network access and physical media

1.5 Internet structure and ISPs

1.6 Delay & loss in packet-switched networks

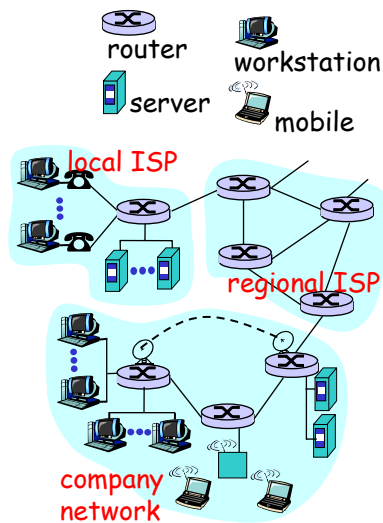
1.7 Protocol layers, service models

1.8 History

Introduction 1-3

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

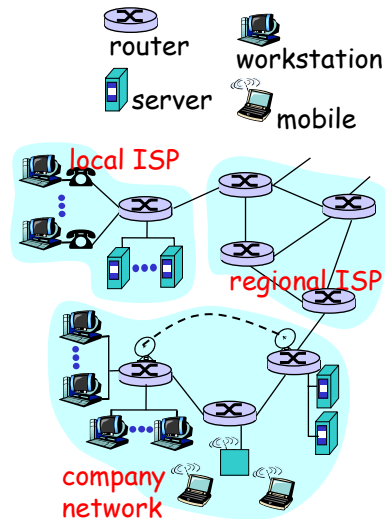
- ❑ millions of connected computing devices: *hosts = end systems*
- ❑ running *network apps*
- ❑ *communication links*
 - fiber, copper, radio, satellite
 - transmission rate = *bandwidth*
- ❑ *routers*: forward packets (chunks of data)



Introduction 1-4

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

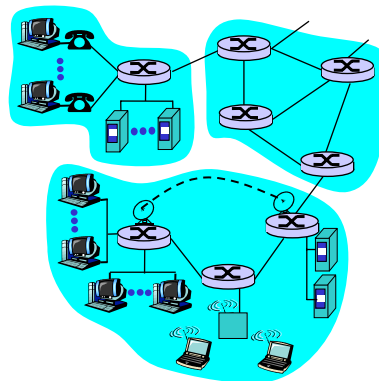
- *protocols* control sending, receiving of msgs
 - e.g., TCP, IP, HTTP, FTP, PPP
- *Internet: "network of networks"*
 - loosely hierarchical
 - public Internet versus private intranet
- Internet standards
 - RFC: Request for comments
 - IETF: Internet Engineering Task Force



Introduction 1-5

What's the Internet: a service view

- *communication infrastructure* enables distributed applications:
 - Web, email, games, e-commerce, file sharing
- *communication services provided to apps:*
 - Connectionless unreliable
 - connection-oriented reliable



Introduction 1-6

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

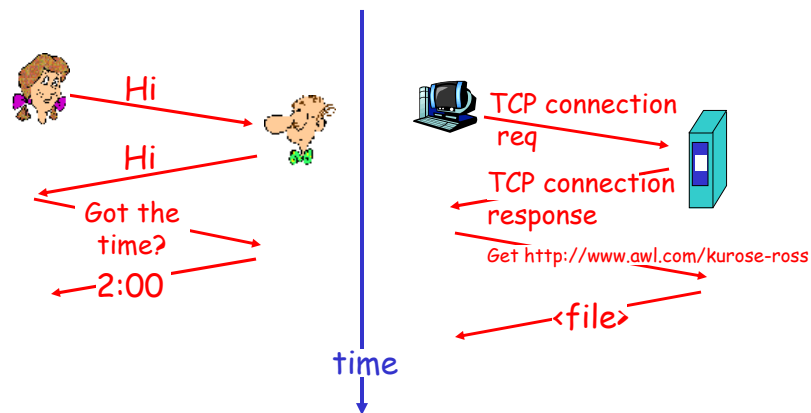
network protocols:

- ❑ 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?

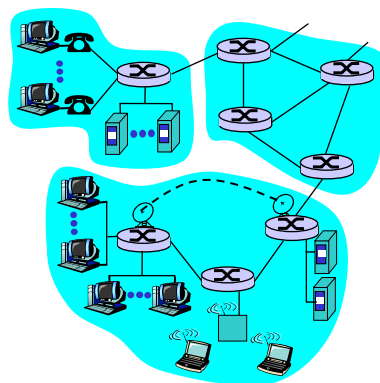
Chapter 1: roadmap

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- 1.2 Network edge
- 1.3 Network core
- 1.4 Network access and physical media
- 1.5 Internet structure and ISPs
- 1.6 Delay & loss in packet-switched networks
- 1.7 Protocol layers, service models
- 1.8 History

Introduction 1-9

A closer look at network structure:

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



Introduction 1-10

The network edge:

□ end systems (hosts):

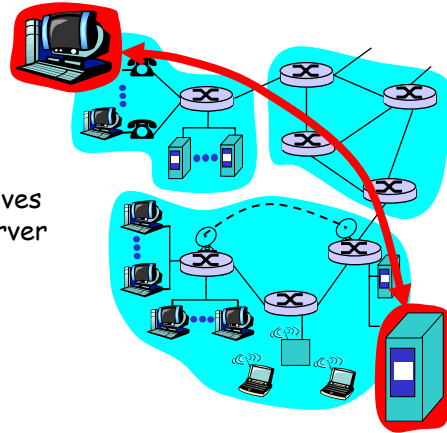
- run application programs
- e.g. Web, email
- at "edge of network"

□ 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. Gnutella, KaZaA



Introduction 1-11

Network edge: connection-oriented 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 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

Introduction 1-12

Network edge: connectionless 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

Introduction 1-13

Chapter 1: roadmap

1.1 What *is* the Internet?

1.2 Network edge

1.3 **Network core**

1.4 Network access and physical media

1.5 Internet structure and ISPs

1.6 Delay & loss in packet-switched networks

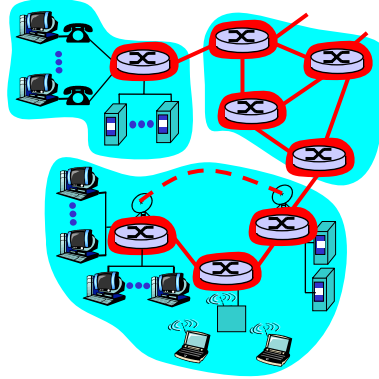
1.7 Protocol layers, service models

1.8 History

Introduction 1-14

The Network Core

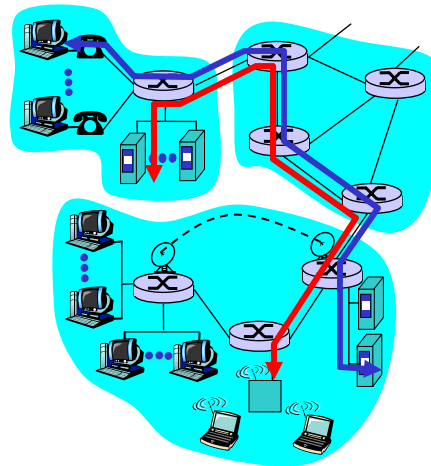
- mesh of interconnected routers
- **the fundamental question:** how is data transferred through net?
 - **circuit switching:** dedicated circuit per call: telephone net
 - **packet-switching:** data sent thru net in discrete "chunks"



Introduction 1-15

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



Introduction 1-16

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*)

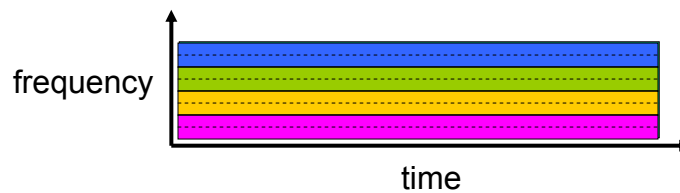
□ dividing link bandwidth into "pieces"

- frequency division
- time division

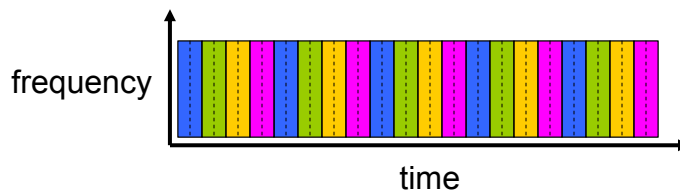
Introduction 1-17

Circuit Switching: FDM and TDM

FDM



TDM



Introduction 1-18

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
 - 500 msec to establish end-to-end circuit

Work it out!

Introduction 1-19

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*

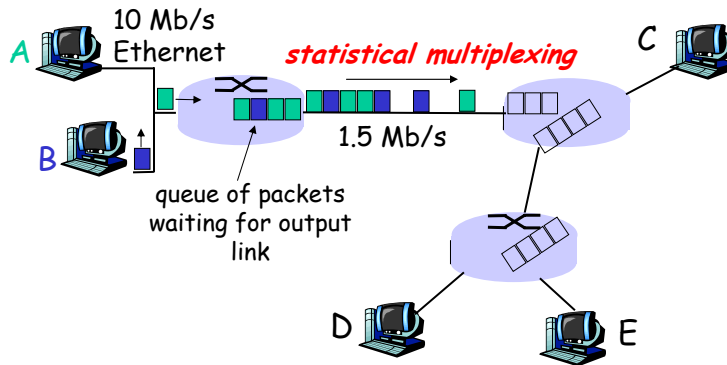
Bandwidth division into "pieces"
Dedicated allocation
Resource reservation

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

Introduction 1-20

Packet Switching: Statistical Multiplexing



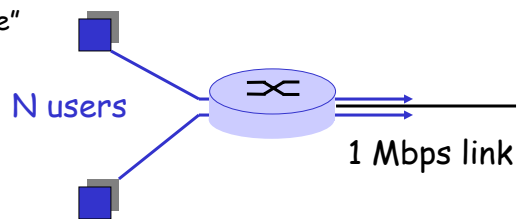
Sequence of A & B packets does not have fixed pattern → **statistical multiplexing**.
 In TDM each host gets same slot in revolving TDM frame.

Introduction 1-21

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 less than .0004



Introduction 1-22

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 6)

Introduction 1-23

Packet-switching: store-and-forward



- ❑ Takes L/R seconds to transmit (push out) packet of L bits on to link of R bps
 - ❑ Entire packet must arrive at router before it can be transmitted on next link: *store and forward*
 - ❑ delay = $3L/R$
- Example:**
- ❑ $L = 7.5$ Mbits
 - ❑ $R = 1.5$ Mbps
 - ❑ delay = 15 sec

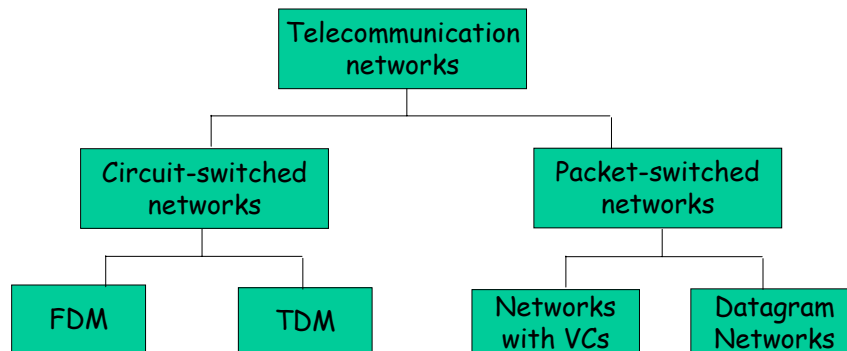
Introduction 1-24

Packet-switched networks: forwarding

- **Goal:** move packets through routers from source to destination
 - we'll study several path selection (i.e. routing) algorithms (chapter 4)
- **datagram network:**
 - *destination address* in packet 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*

Introduction 1-25

Network Taxonomy



- Datagram network is *not* either connection-oriented or connectionless.
- Internet provides both connection-oriented (TCP) and connectionless services (UDP) to apps.

Introduction 1-26

Chapter 1: roadmap

- 1.1 What *is* the Internet?
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- 1.6 Delay & loss in packet-switched networks
- 1.7 Protocol layers, service models
- 1.8 History

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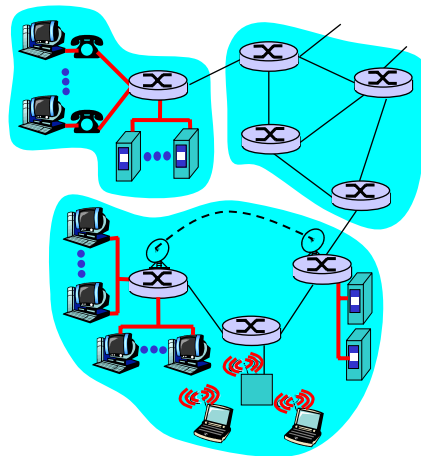
Access networks and physical media

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?

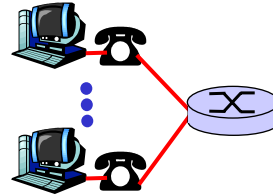


Introduction 1-28

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"



□ ADSL: asymmetric digital subscriber line

- up to 1 Mbps upstream (today typically < 256 kbps)
- up to 8 Mbps downstream (today typically < 1 Mbps)
- FDM: 50 kHz - 1 MHz for downstream
4 kHz - 50 kHz for upstream
0 kHz - 4 kHz for ordinary telephone

Introduction 1-29

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

Introduction 1-30

Residential access: cable modems

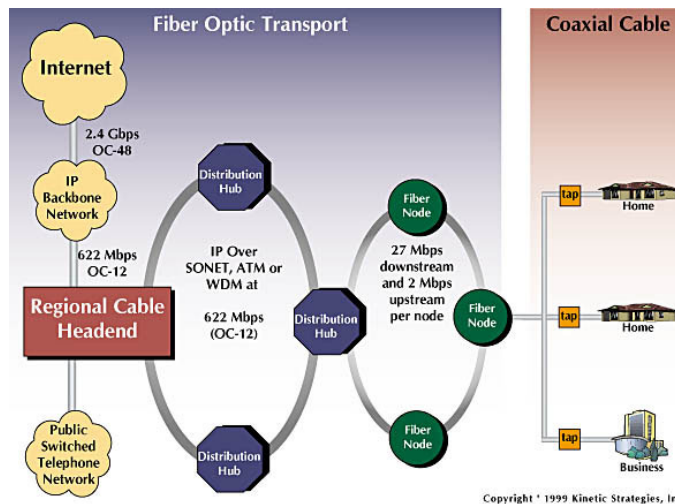
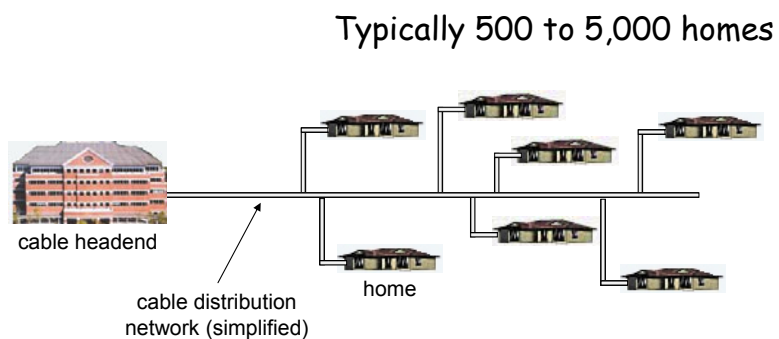


Diagram: <http://www.cabledatcomnews.com/cm/c/diagram.html>

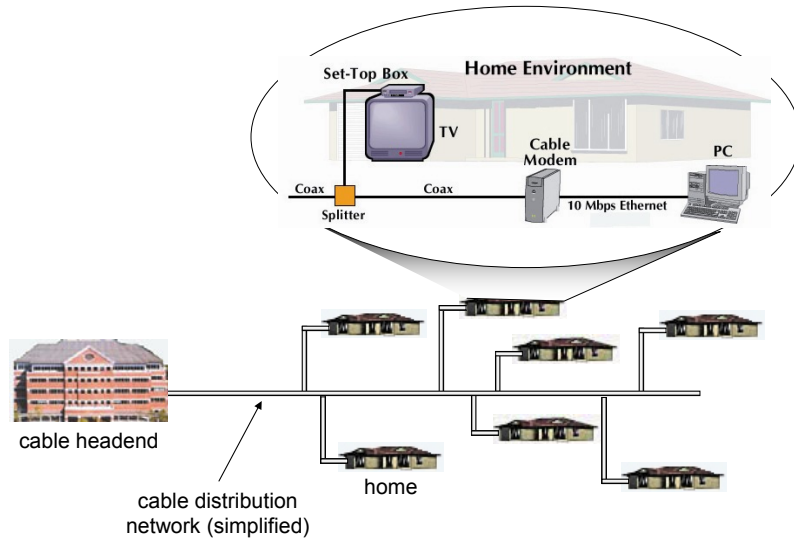
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Cable Network Architecture: Overview



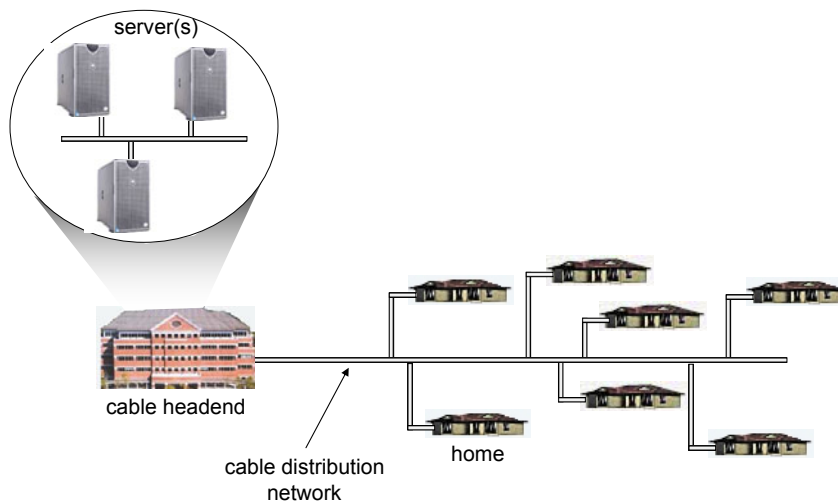
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Cable Network Architecture: Overview



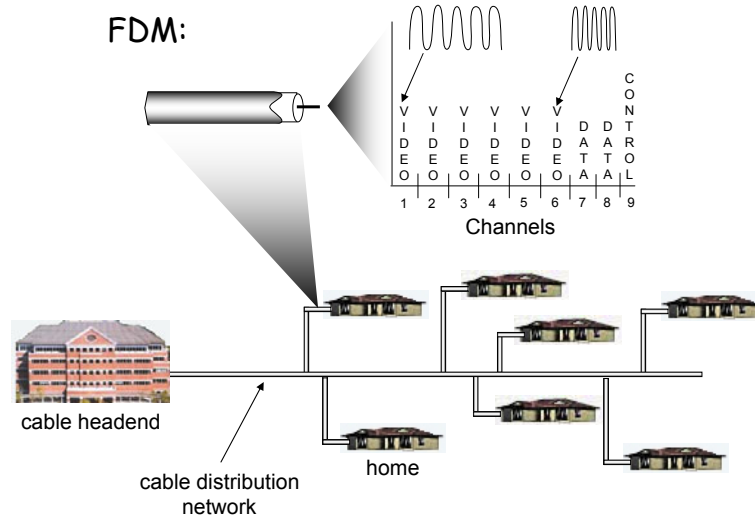
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Cable Network Architecture: Overview



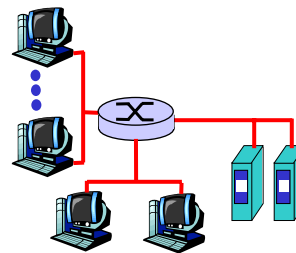
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Cable Network Architecture: Overview



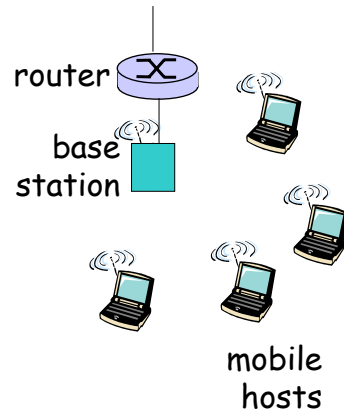
Company access: local area networks

- company/univ **local area network** (LAN) connects end system to edge router
- **Ethernet:**
 - shared or dedicated link connects end system and router
 - 10 Mbs, 100Mbps, Gigabit Ethernet
- 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 (WiFi): 11 Mbps
- ❑ **wider-area wireless access**
 - provided by telco operator
 - 3G ~ 384 kbps
 - Will it happen??
 - WAP/GPRS in Europe

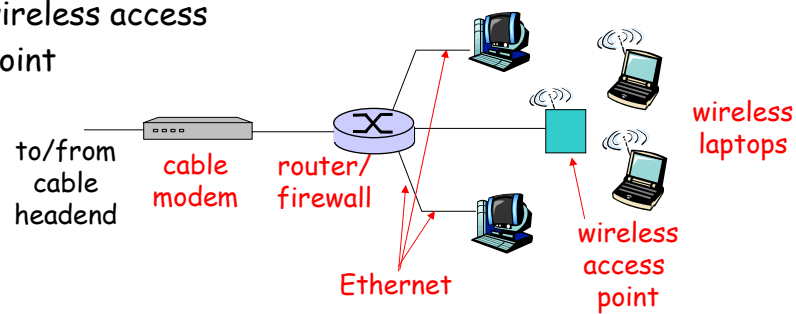


Introduction 1-37

Home networks

Typical home network components:

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



Introduction 1-38

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



Introduction 1-39

Physical Media: coax, fiber

Coaxial cable:

- ❑ two concentric copper conductors
- ❑ bidirectional
- ❑ baseband:
 - single channel on cable
 - legacy Ethernet
- ❑ broadband:
 - multiple channel 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., 5 Gps)
- ❑ low error rate: repeaters spaced far apart ; immune to electromagnetic noise



Introduction 1-40

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)**
 - 2Mbps, 11Mbps
 - ❑ **wide-area (e.g., cellular)**
 - e.g. 3G: hundreds of kbps
 - ❑ **satellite**
 - up to 50Mbps channel (or multiple smaller channels)
 - 270 msec end-end delay
 - geosynchronous versus low altitude

Introduction 1-41

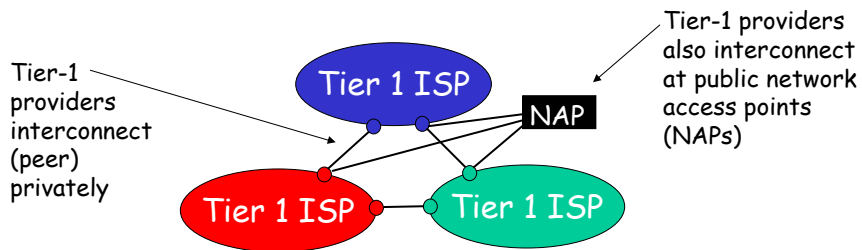
Chapter 1: roadmap

- 1.1 What *is* the Internet?
- 1.2 Network edge
- 1.3 Network core
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- 1.5 **Internet structure and ISPs**
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- 1.7 Protocol layers, service models
- 1.8 History

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Internet structure: network of networks

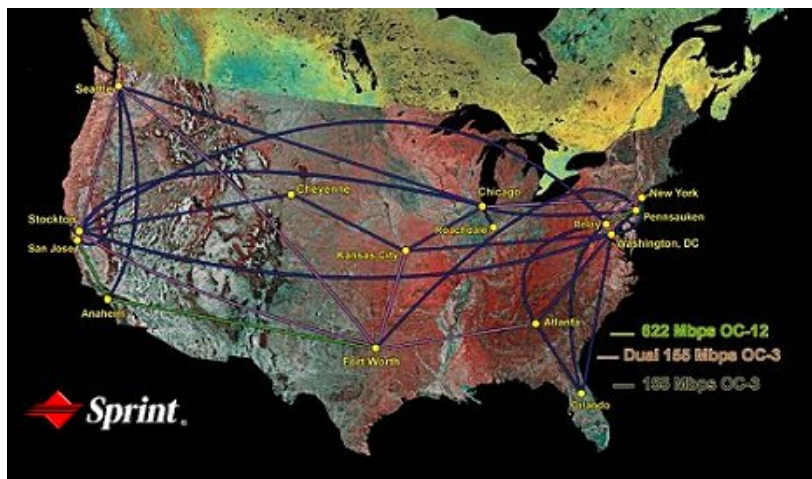
- roughly hierarchical
- **at center: "tier-1" ISPs** (e.g., UUNet, BBN/Genuity, Sprint, AT&T), national/international coverage
 - treat each other as equals



Introduction 1-43

Tier-1 ISP: e.g., Sprint

Sprint US backbone network

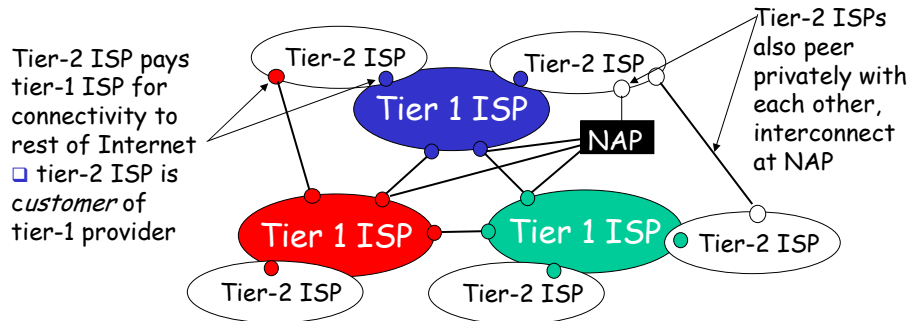


Introduction 1-44

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

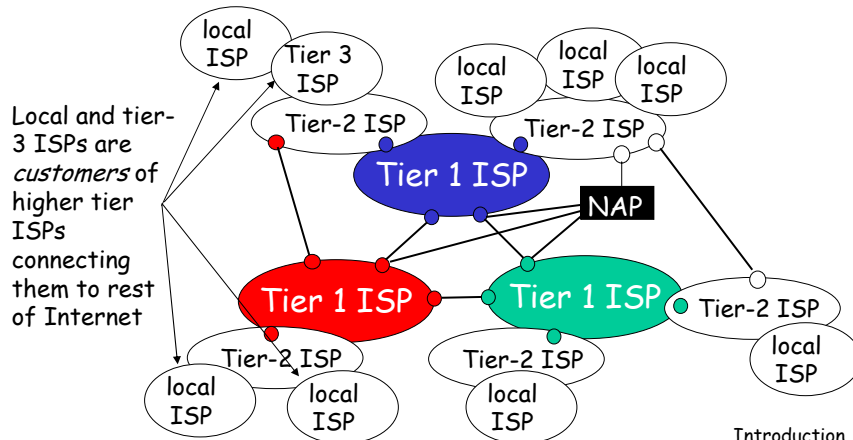


Introduction 1-45

Internet structure: network of networks

□ "Tier-3" ISPs and local ISPs

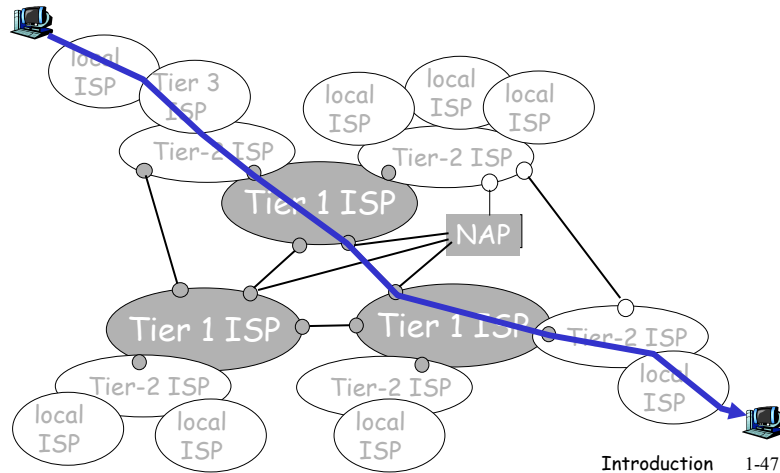
- last hop ("access") network (closest to end systems)



Introduction 1-46

Internet structure: network of networks

- a packet passes through many networks!



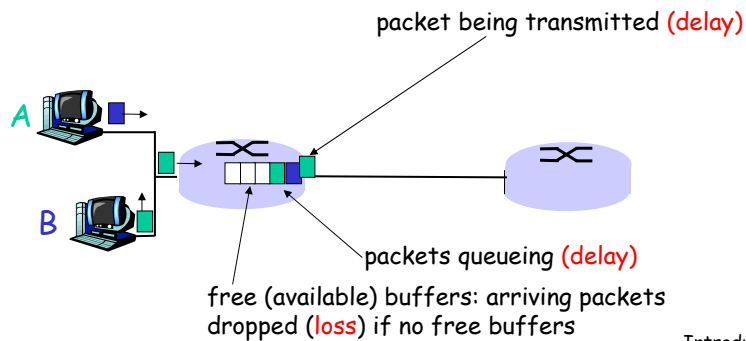
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How do loss and delay occur?

packets *queue* in router buffers

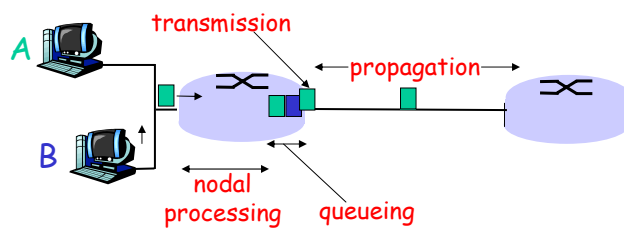
- ❑ packet arrival rate to link exceeds output link capacity
- ❑ packets queue, wait for turn



Introduction 1-49

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



Introduction 1-50

Delay in packet-switched networks

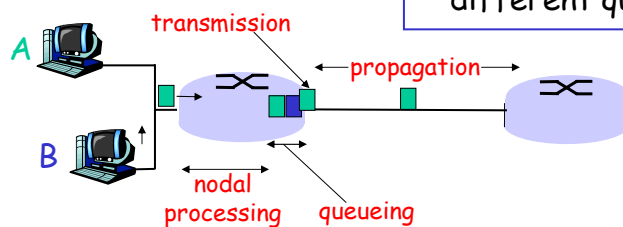
3. Transmission delay:

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

4. Propagation delay:

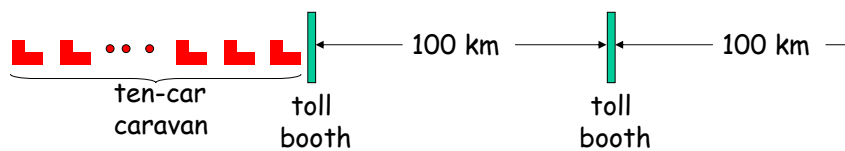
- d = length of physical link
- s = propagation speed in medium ($\sim 2 \times 10^8$ m/sec)
- propagation delay = d/s

Note: s and R are very different quantities!



Introduction 1-51

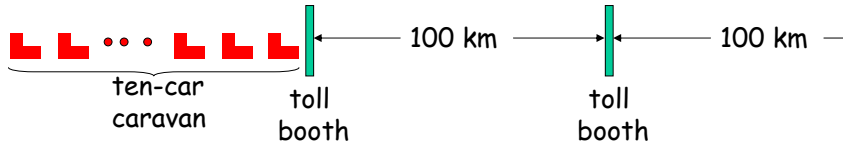
Caravan analogy



- Cars "propagate" at 100 km/hr
- Toll booth takes 12 sec to service a 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 = $12 \times 10 = 120$ 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

Introduction 1-52

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

Introduction 1-53

Nodal delay

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

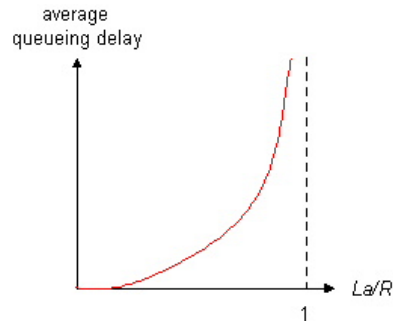
- d_{proc} = processing delay
 - typically a few microseconds or less
- d_{queue} = queuing delay
 - depends on congestion
- d_{trans} = transmission delay
 - = L/R , significant for low-speed links
- d_{prop} = propagation delay
 - a few microseconds to hundreds of msecs

Introduction 1-54

Queueing delay (revisited)

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

traffic intensity = La/R

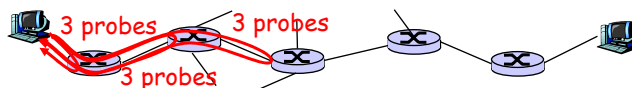


- $La/R \sim 0$: average queueing delay small
- $La/R \rightarrow 1$: delays become large
- $La/R > 1$: more "work" arriving than can be serviced, average delay infinite!

Introduction 1-55

"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.



Introduction 1-56

"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 ← trans-oceanic link
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 *** ← * means no response (probe lost, router not replying)
18 ***
19 fantasia.eurecom.fr (193.55.113.142) 132 ms 128 ms 136 ms
```

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Packet loss

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

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Chapter 1: roadmap

- 1.1 What *is* the Internet?
- 1.2 Network edge
- 1.3 Network core
- 1.4 Network access and physical media
- 1.5 Internet structure and ISPs
- 1.6 Delay & loss in packet-switched networks
- 1.7 Protocol layers, service models
- 1.8 History

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Protocol "Layers"

Networks are complex!

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

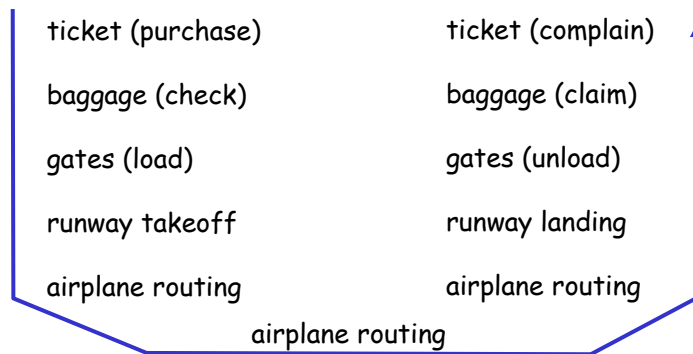
Question:

Is there any hope of
organizing structure of
network?

Or at least our discussion
of networks?

Introduction 1-60

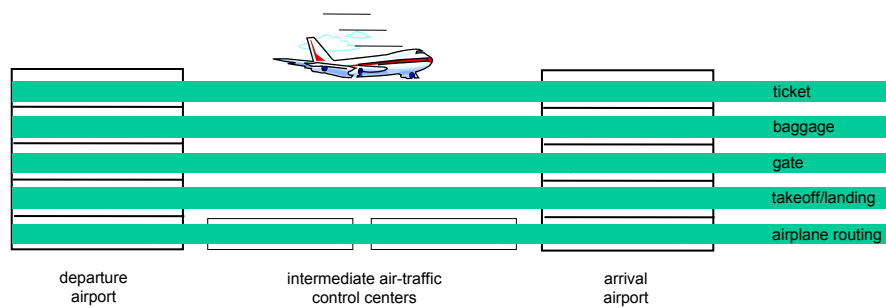
Organization of air travel



□ a series of steps

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Layering of airline functionality



Layers: each layer implements a service

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

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Why layering?

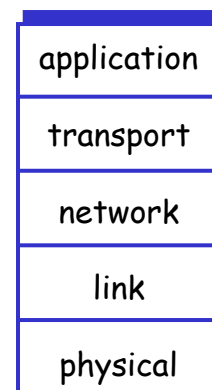
Dealing with complex systems:

- ❑ 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?

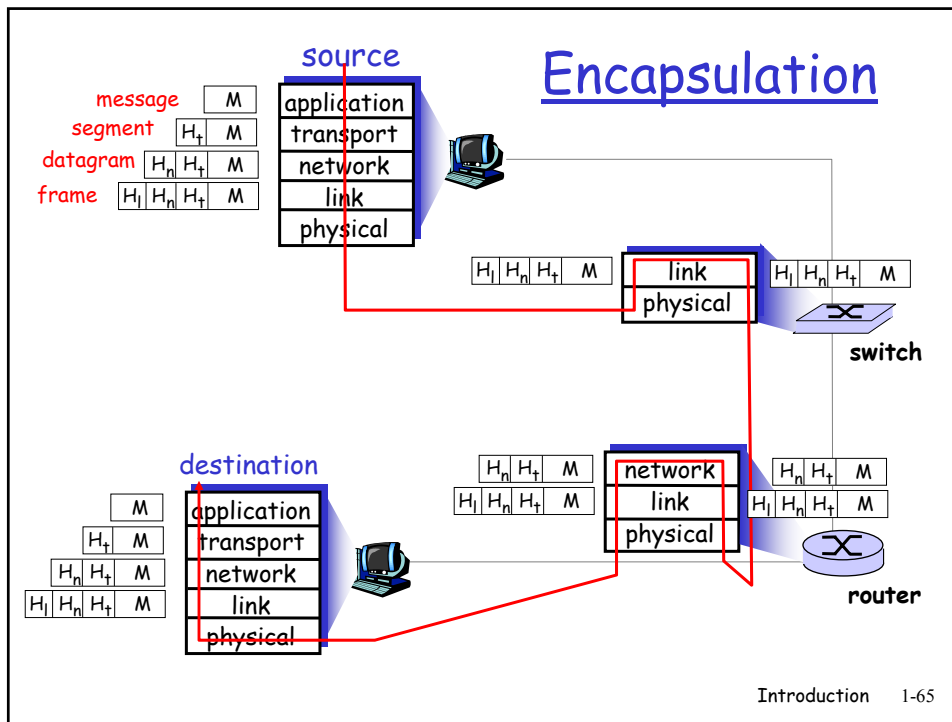
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Internet protocol stack

- ❑ **application**: supporting network applications
 - FTP, SMTP, STTP
- ❑ **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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Chapter 1: roadmap

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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 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

- ❑ 1970: ALOHAnet satellite network in Hawaii
- ❑ 1973: Metcalfe's PhD thesis proposes Ethernet
- ❑ 1974: Cerf and Kahn - architecture for interconnecting networks
- ❑ late70'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

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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

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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
- ❑ Internet/ISP structure
- ❑ performance: loss, delay
- ❑ layering and service models
- ❑ history

You now have:

- ❑ context, overview, "feel" of networking
- ❑ more depth, detail *to follow!*

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