Last time

- Course mechanics
- What is the Internet?
    - hosts, routers, communication links
    - communications services, protocols
- Network Edge
    - client-server, peer-to-peer
    - TCP, UDP
- Network Core
    - Circuit-switched networks
        - FDM
        - TDM
    - Packet-switched networks

This time

- Finish introduction and overview:
  - Network access and physical media
  - Internet structure and ISPs
  - Delay & loss in packet-switched networks
  - Protocol layers, service models

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

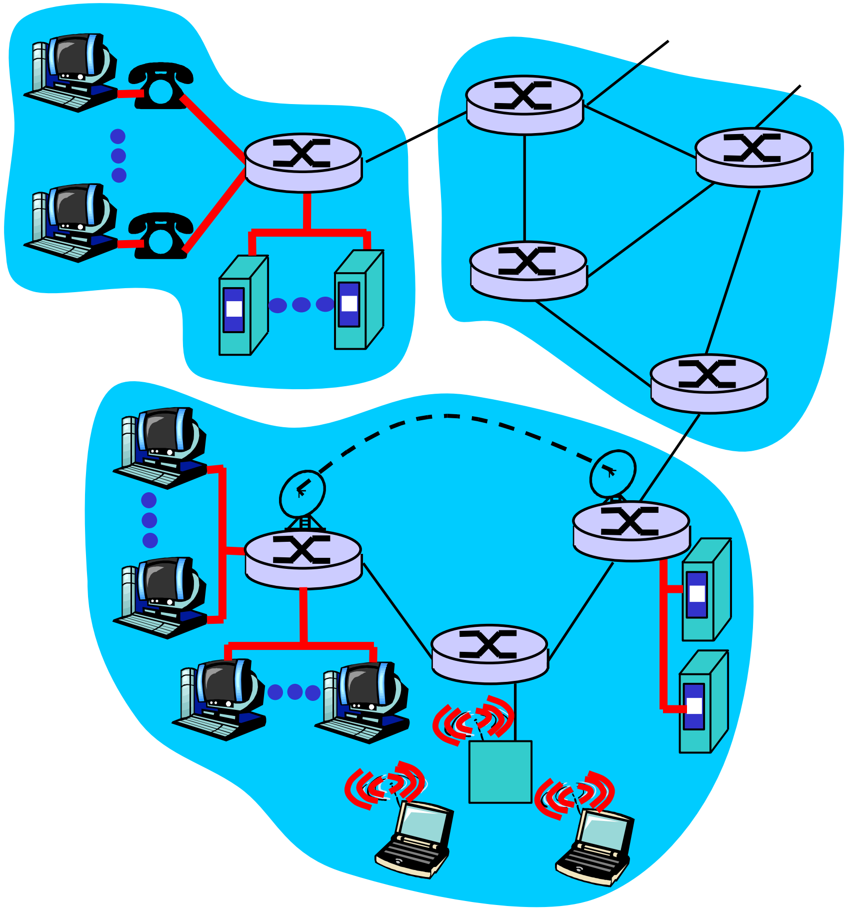
Access networks and physical media

Q: How to connect end systems to edge router?

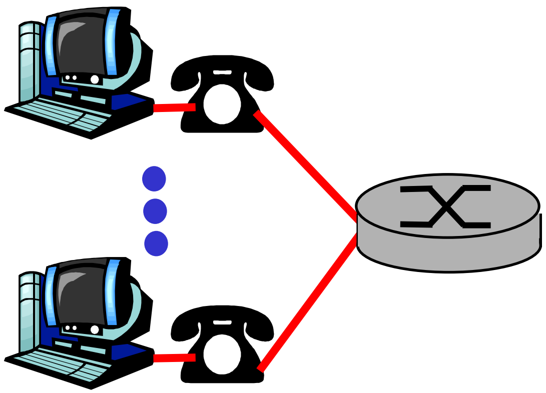
- ❑ residential access nets
- ❑ institutional access networks (school, company)
- ❑ mobile access networks

Keep in mind:

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



Residential access: point to point access



- Dialup via modem
  - up to 56 kbps direct access to router (often less)
  - Can’t surf and phone at same time: not “always on”
- ADSL: asymmetric digital subscriber line
  - up to 1 Mbps upstream
  - up to 8 Mbps downstream

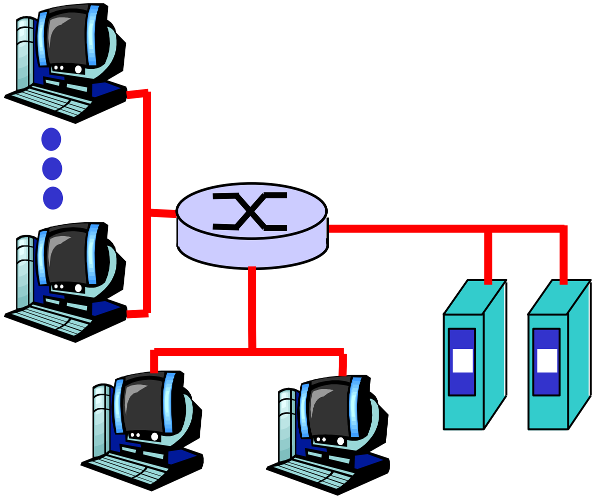
FDM: 200 kHz – 1 MHz for downstream
25 kHz – 160 kHz for upstream
0 kHz – 4 kHz for ordinary telephone

Residential access: cable modems

- HFC: hybrid fiber coax
  - asymmetric: up to 30 Mbps 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

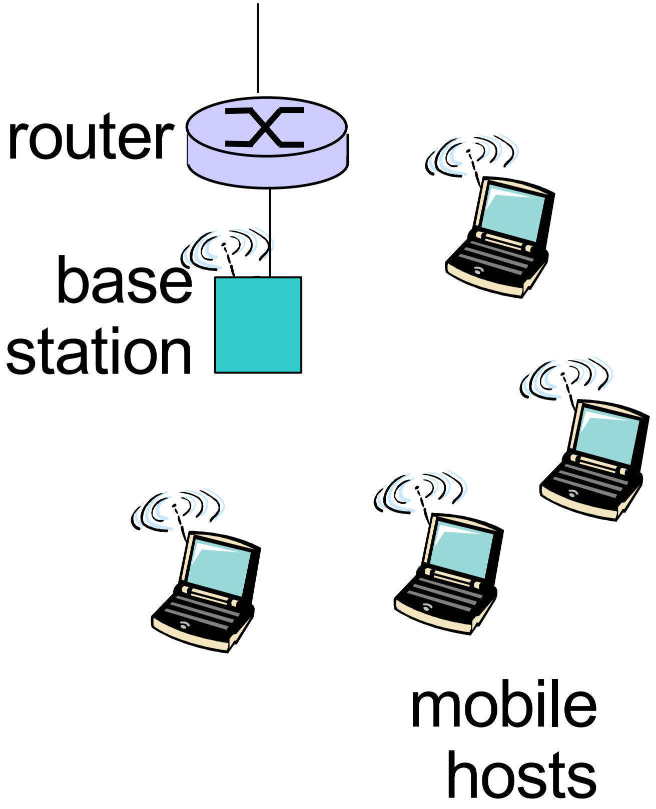
Company access: local area networks

- Company/univ local area network (LAN) connects end system to edge router
- Ethernet:
  - shared or dedicated link connects end system and router
  - 10 Mbps, 100Mbps, Gigabit Ethernet
- LANs: chapter 5



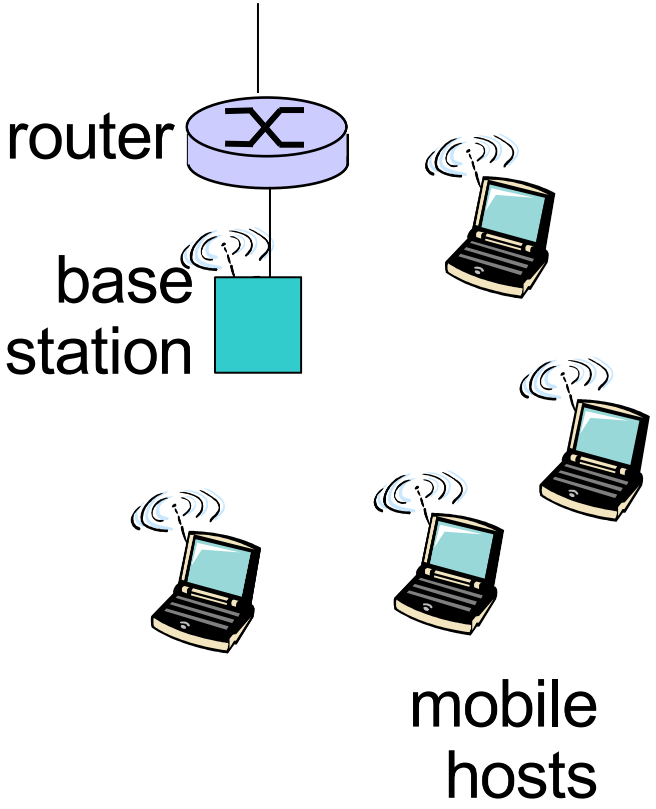
Wireless access networks

- Shared *wireless* access network connects end system to router
    - via base station aka "access point"
- Wireless LANs:
    - 802.11b/g (WiFi): 11 or 54 Mbps
    - This is what most laptops use to connect wirelessly.
    - Easy to set up your own base station.



Wireless access networks

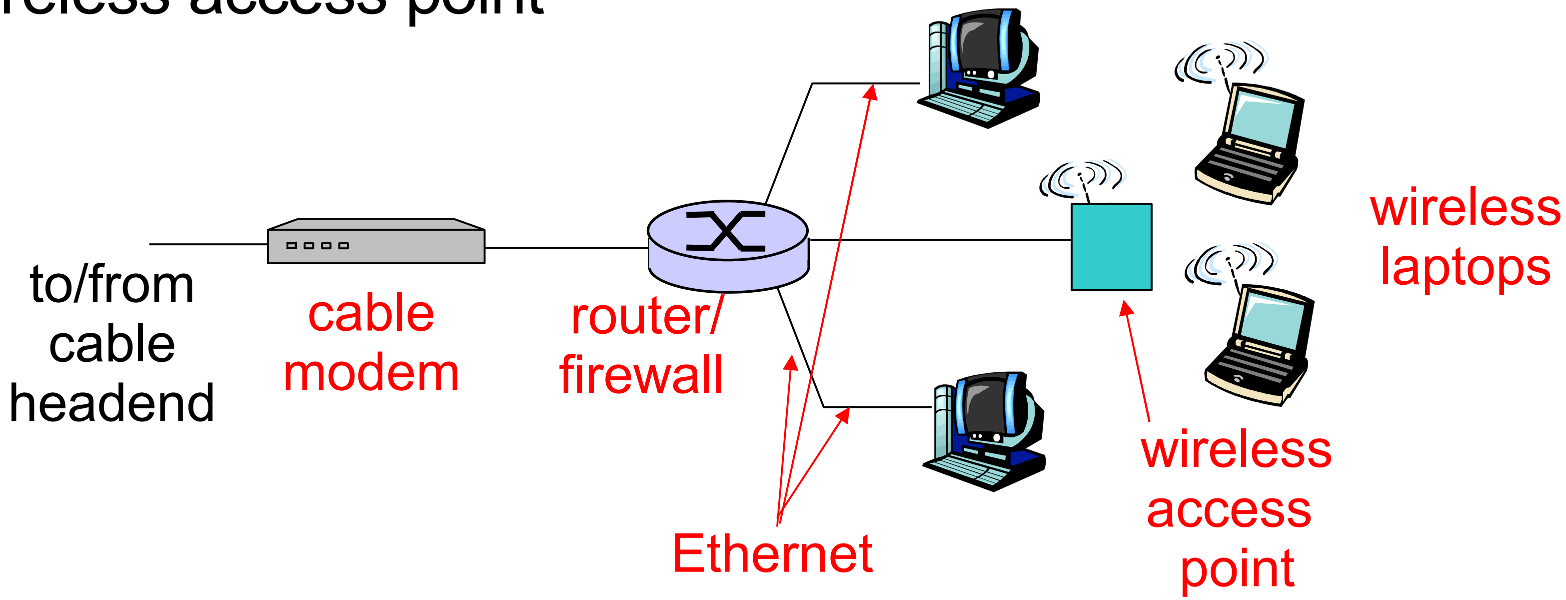
- Wider-area wireless access
  - Provided by telco operator
    - You can't set this up yourself
  - This is what cellphones use to connect wirelessly.
  - 2.5G: EDGE, GPRS, 1xRTT
    - 30 – 384 kbps
  - 3G: UMTS, 1xEV-DO
    - 144 kpbs – 2 Mbps
  - 3.5G: HSDPA
    - 10 Mbps
    - Rogers has been testing this in Toronto, and should be rolling it out commercially this Fall.



Home networks

Typical home network components:

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



Physical Media

- 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

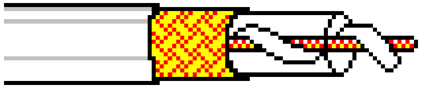
Twisted Pair (TP)

- Two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5:
    100 Mbps Ethernet
    1000 Mbps Ethernet

Physical Media: coax, fiber

Coaxial cable:

- Two concentric copper conductors
- 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 Gbps)
- Low error rate: repeaters spaced far apart; immune to electromagnetic noise

Physical media: radio

- Signal carried in electromagnetic spectrum
- No physical “wire”
- 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)
  - e.g. 3G: hundreds of kbps
- Satellite
  - 240–270 msec end-to-end delay for geosynchronous
  - low altitude satellites?

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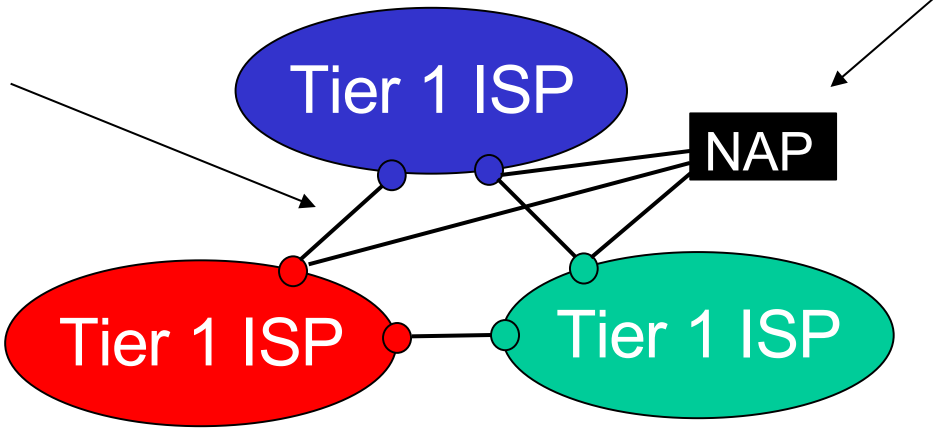
Internet structure: network of networks

- Roughly hierarchical
- At center: “tier-1” ISPs (e.g., MCI, Sprint, AT&T, Cable and Wireless), national/international coverage
  - treat each other as equals

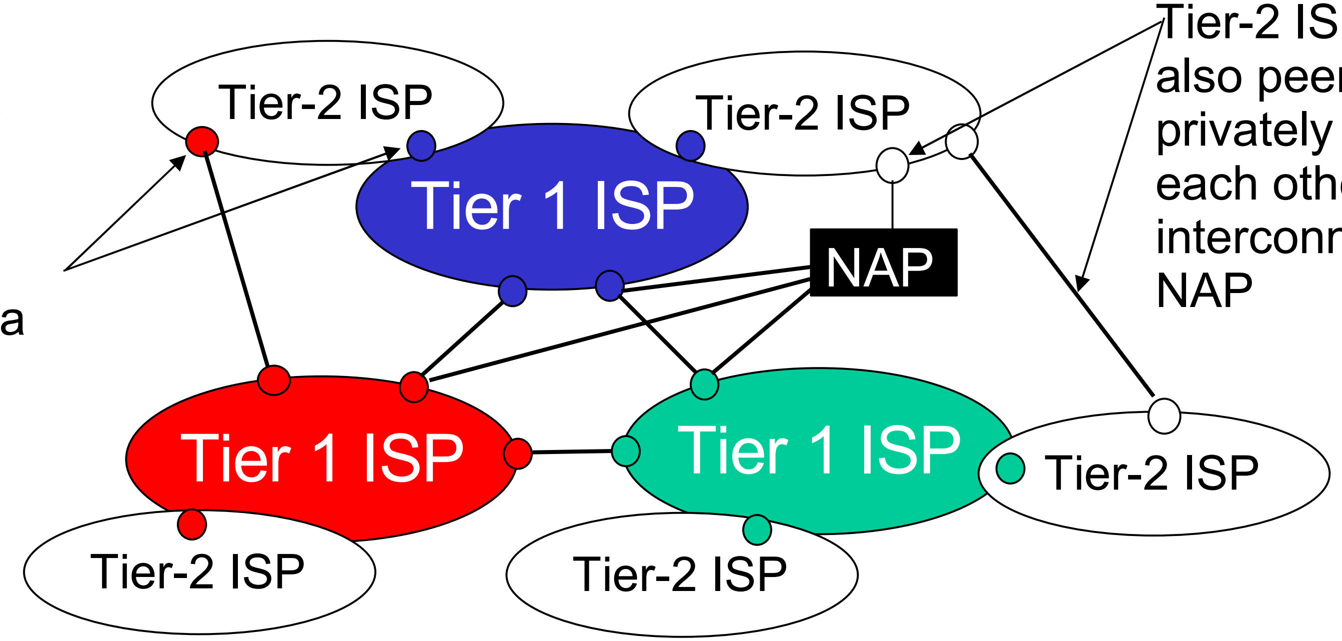


Tier-1 providers interconnect (peer) privately

Tier-1 providers also interconnect at public network access points (NAPs)

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



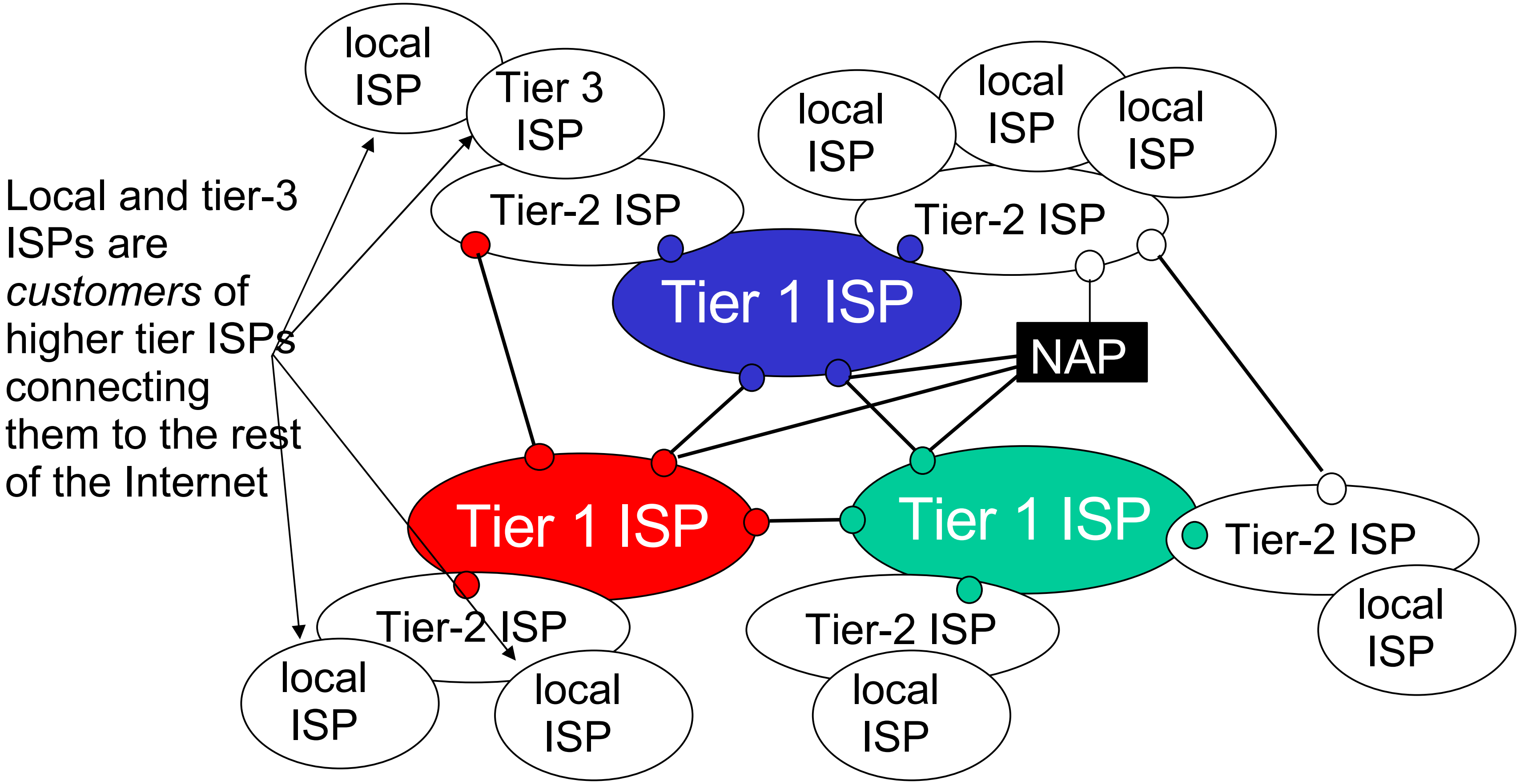
Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet

- Tier-2 ISP is a *customer* of tier-1 provider

Tier-2 ISPs also peer privately with each other, interconnect at NAP

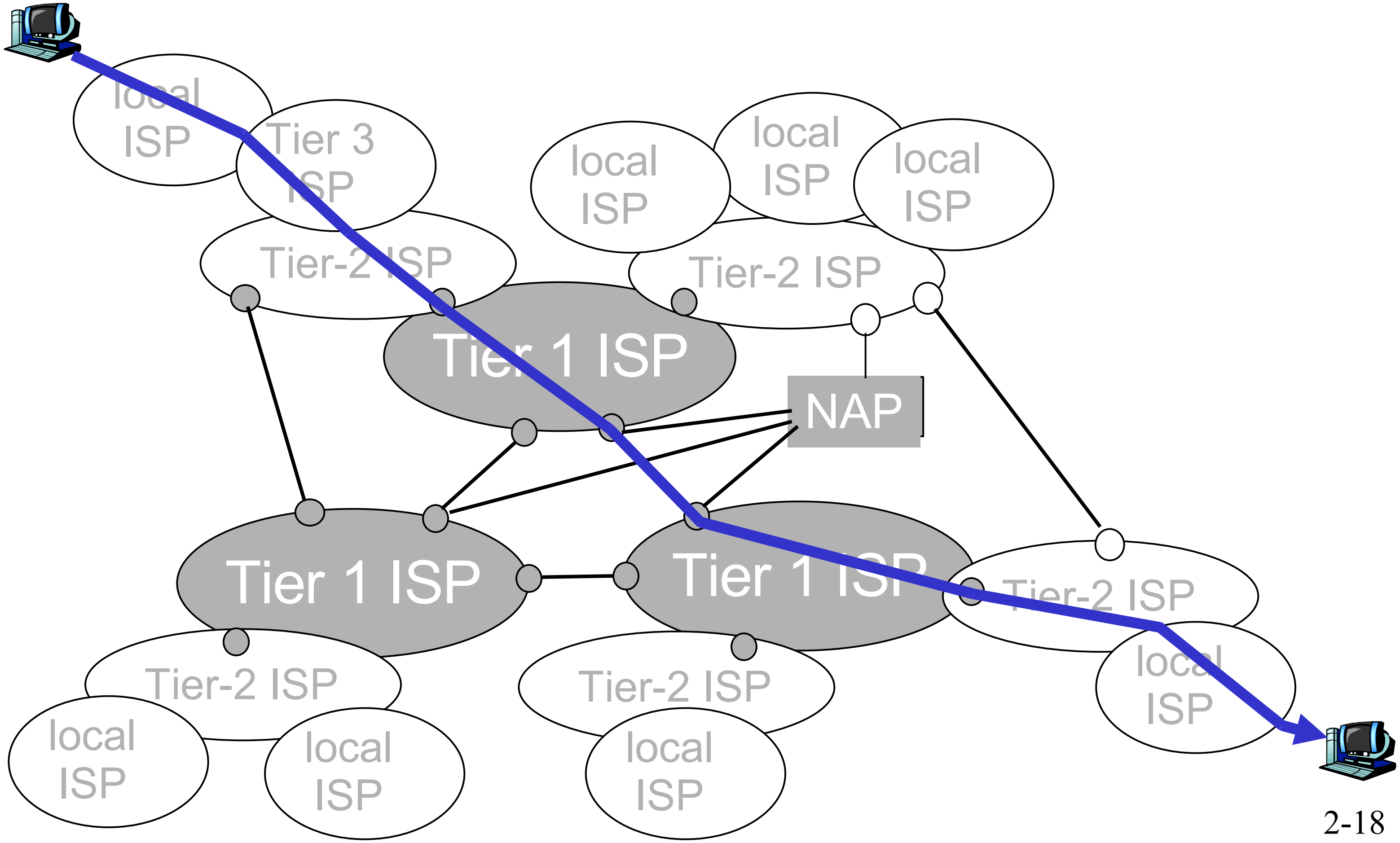
Internet structure: network of networks

- “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!



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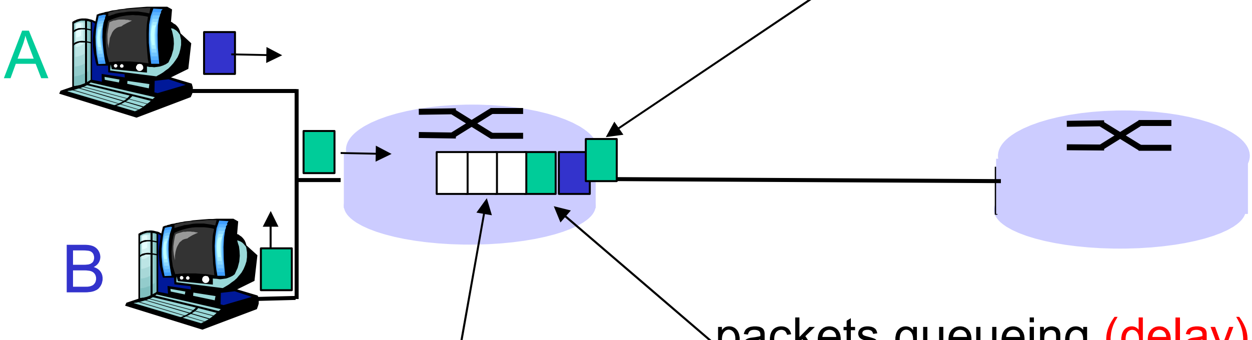
How do loss and delay occur?

Packets *queue* in router buffers

- Packet arrival rate to link exceeds output link capacity
- Packets queue, wait for their turn



packet being transmitted (delay)

packets queueing (delay)

free (available) buffers: arriving packets dropped (loss) if no free buffers

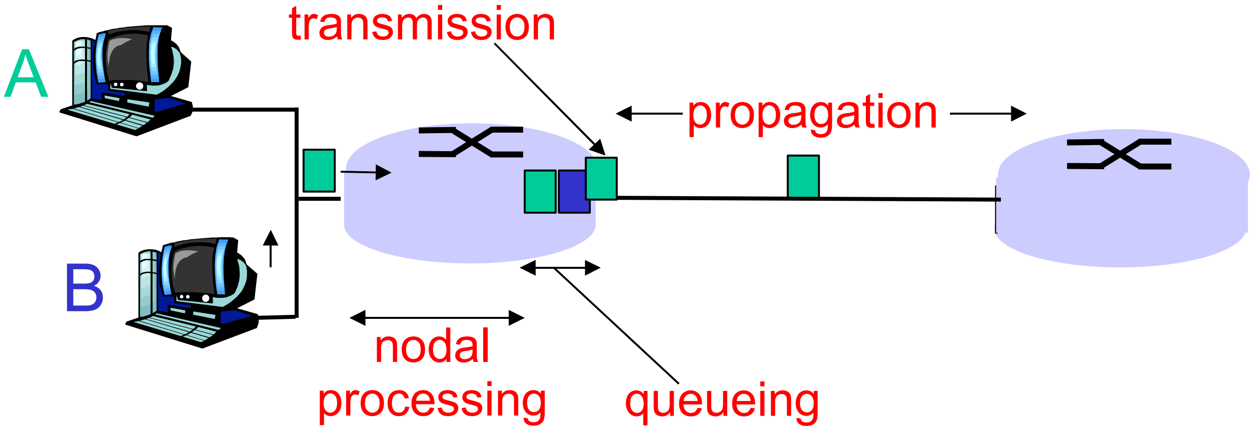
Four sources of packet delay

1. Processing delay:

- ☐ check bit errors
- ☐ determine output link
- ☐ depends on processing power of router

2. Queueing delay:

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



Four sources of packet delay

3. Transmission delay:

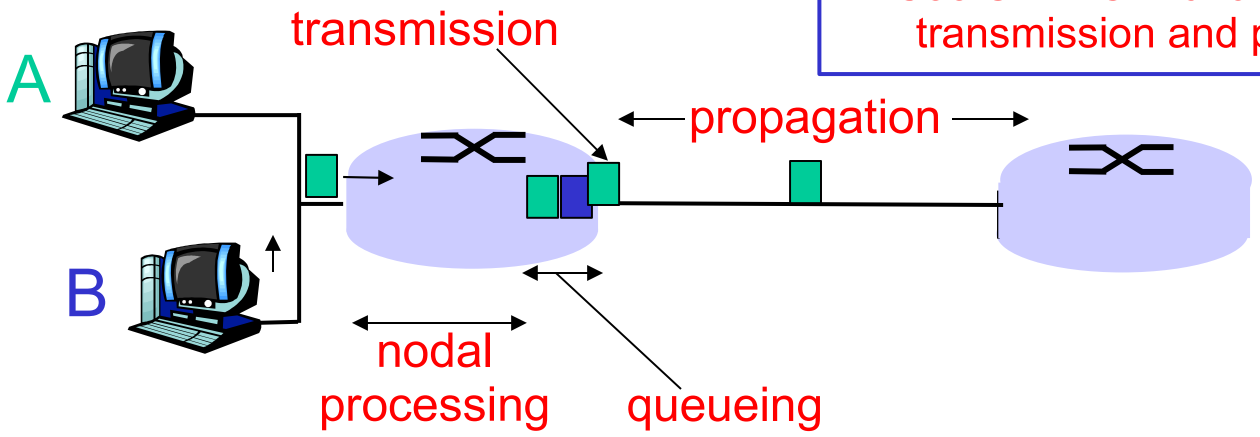
- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

4. Propagation delay:

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

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

➙ See UW-ACE for an applet comparing transmission and propagation delay.



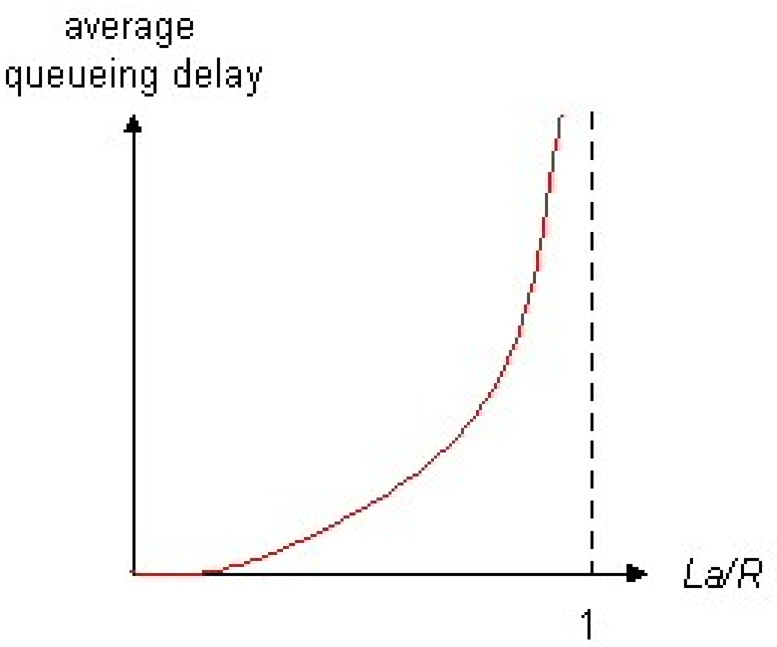
Nodal delay

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

- 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

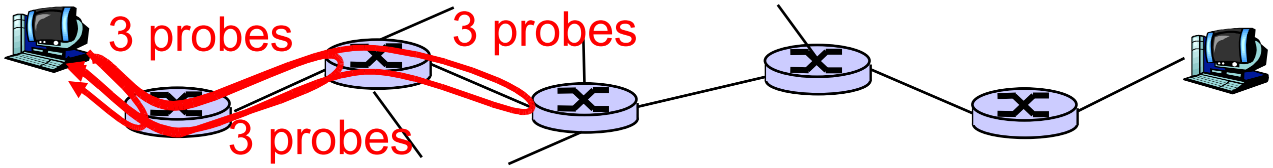


traffic intensity = La/R

- 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?
- `traceroute` program: provides delay measurement from source to router along end-to-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
- When a packet arrives to a full queue, the packet is dropped (aka lost)
- The lost packet may be retransmitted by previous node, by source end system, or not retransmitted at all

- Other sources of loss?

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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* the structure of networks?

Or at least our discussion of networks?

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”

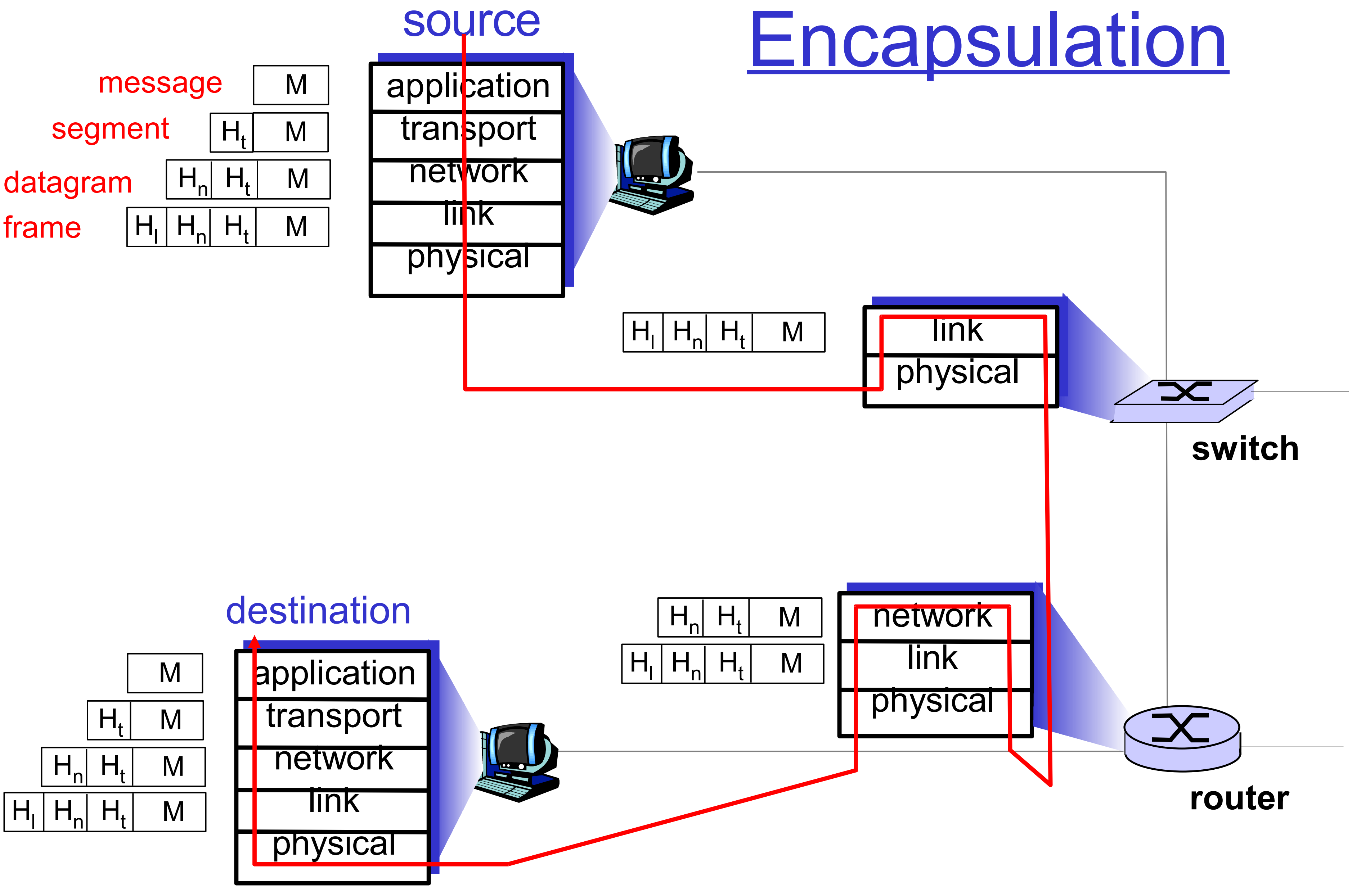
application
transport
network
link
physical

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
  - you probably saw similar things before (e.g. CS 350)

Encapsulation



source

message M

segment H_t M

datagram H_n H_t M

frame H_l H_n H_t M

application

transport

network

link

physical

H_l H_n H_t M

link

physical

switch

H_n H_t M

H_l H_n H_t M

network

link

physical

router

destination

M

H_t M

H_n H_t M

H_l H_n H_t M

application

transport

network

link

physical

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Recap

- Finished introduction and overview:
  - Network access and physical media
  - Internet structure and ISPs
  - Delay & loss in packet-switched networks
  - Protocol layers, service models

Next time

- Start looking at the layers in turn
  - From physical layer up to application layer
- Physical layer: already done
- Next up: link layer
  - overview
  - error detection and correction
  - PPP