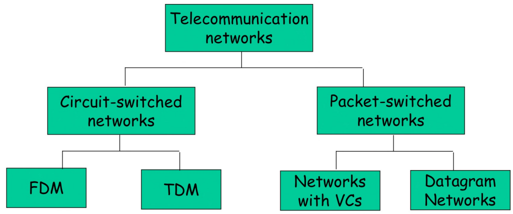
Lecture 5

- Network core
  - → circuit switching (Deterministic)
    - ↓ Resource allocation / Call admission control — *lot of coordinat^n, dependencies*
      - FDM
      - TDM — *Problem to show equivalence*
  - → Packet Switching (stochastic) — *Airline sell more tickets*
    - ↓ Statistical multiplexing (Store & forward) — *no guarantees*
      - Datagram networks — *numerical problem*
      - Network with VCs — *(Differential queueing)*

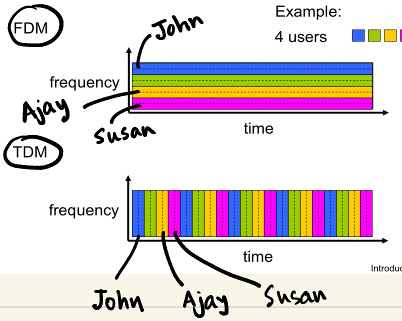
Discuss tradeoffs

show taxonomy picture

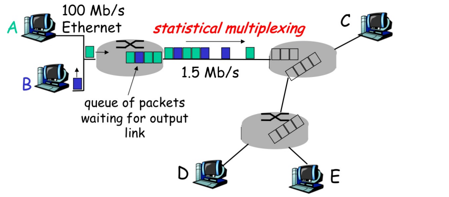
Network Taxonomy



Circuit Switching: FDM and TDM



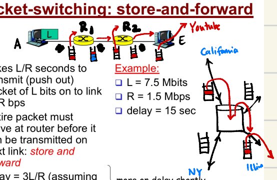
Packet Switching: Statistical Multiplexing



Sequence of A & B packets does not have fixed pattern, 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 or R bps
- Entire packet must arrive at router before it can be transmitted on next link: *store and forward*
- delay = 3L/R (assuming zero propagation delay)

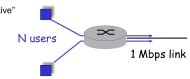
} more on delay shortly …

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

Packet switching versus circuit switching → Stat. Mux

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



Q: how did we get value 0.0004?

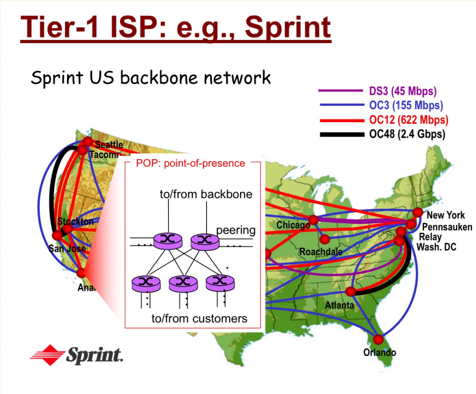
Packet switching versus circuit switching

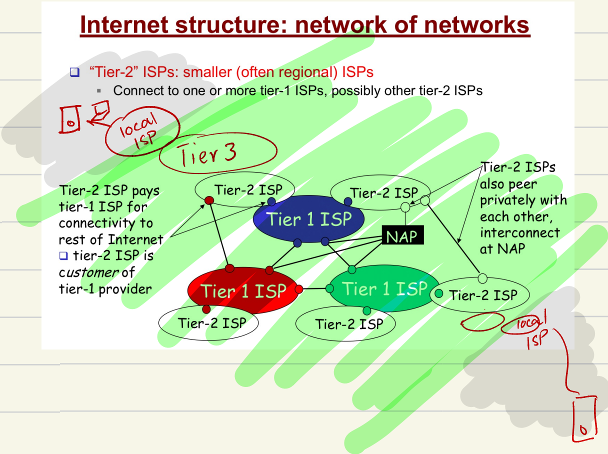
Is packet switching a "slam dunk winner?"

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

Why?

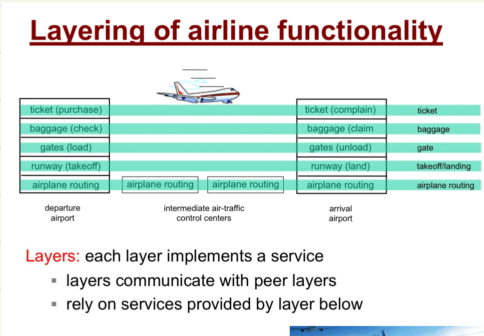
- Internet service Providers (ISPs)
    - Tier 1, 2, 3 ... hierarchical
    - Partnerships, peering
    - Geo-political, socio-economic factors

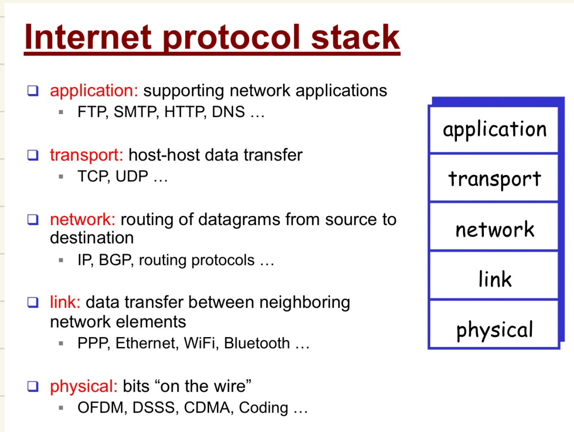


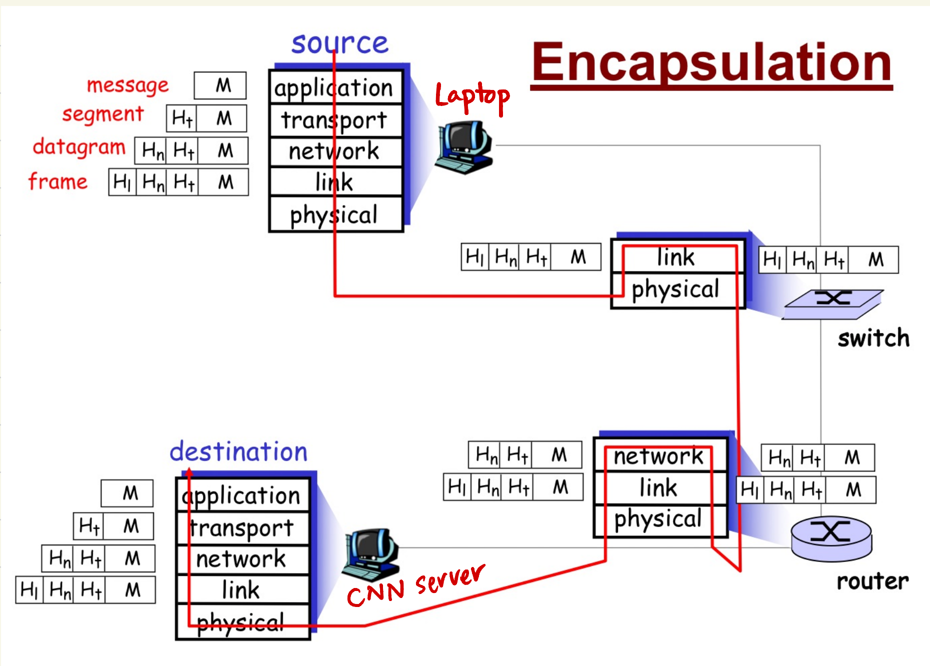


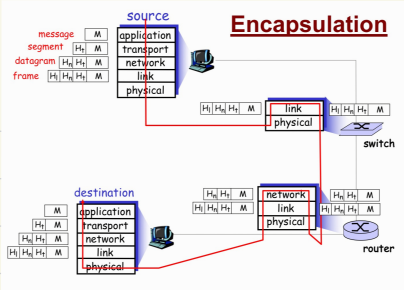
- Internet protocol stack
  - 5 Layers (app, transport, network, link, physical)
  - Encapsulation
  - Layering philosophy → horizontal
  - End to end principle

- show headers
- highlight e2e layers, and local layers (net, link)





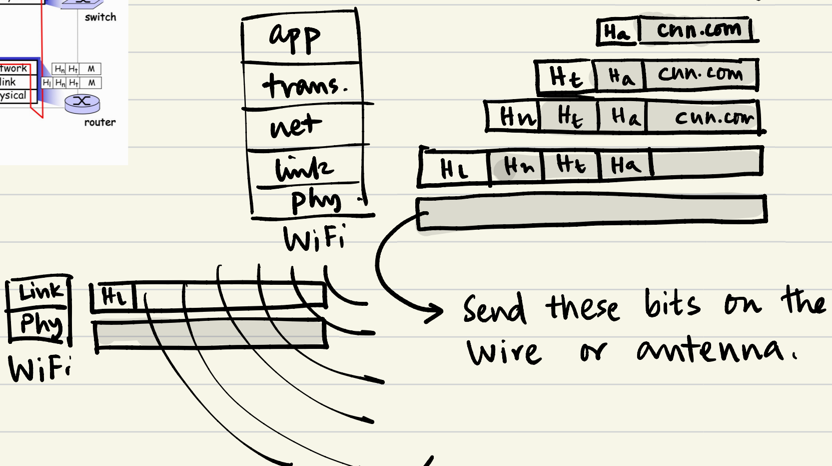


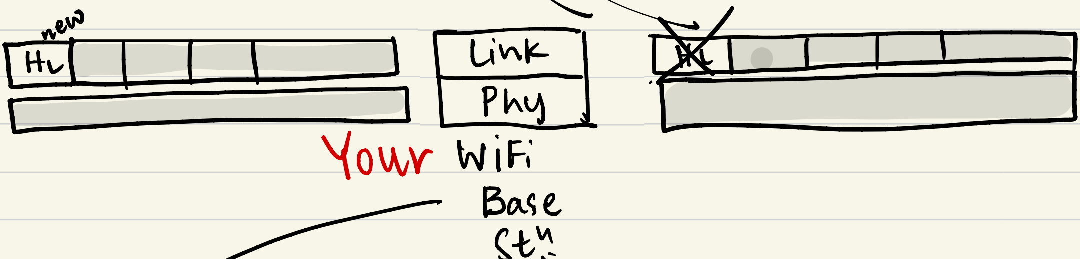


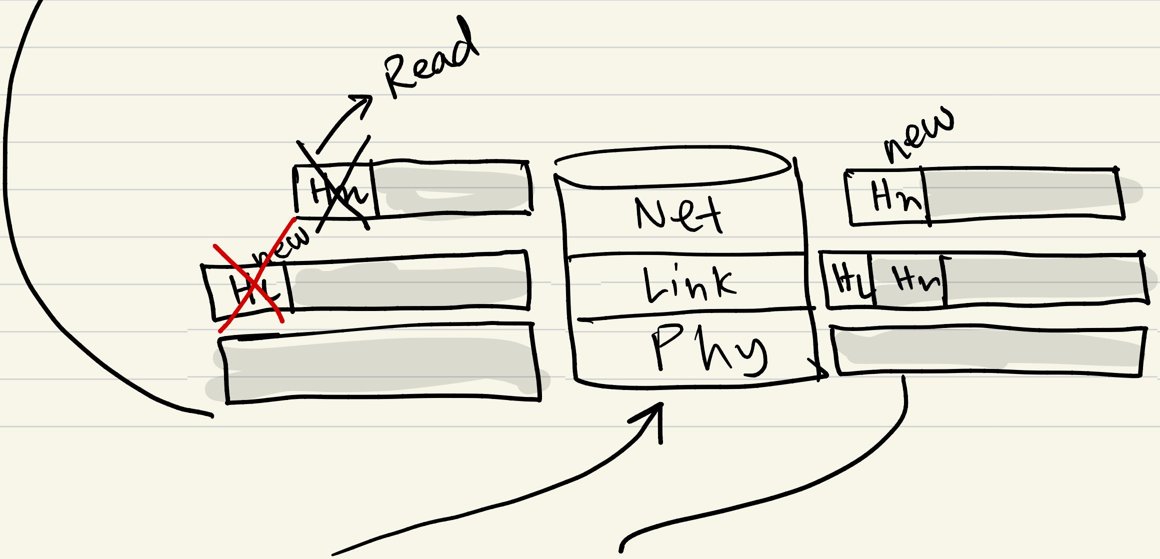
Ha | cnn.com

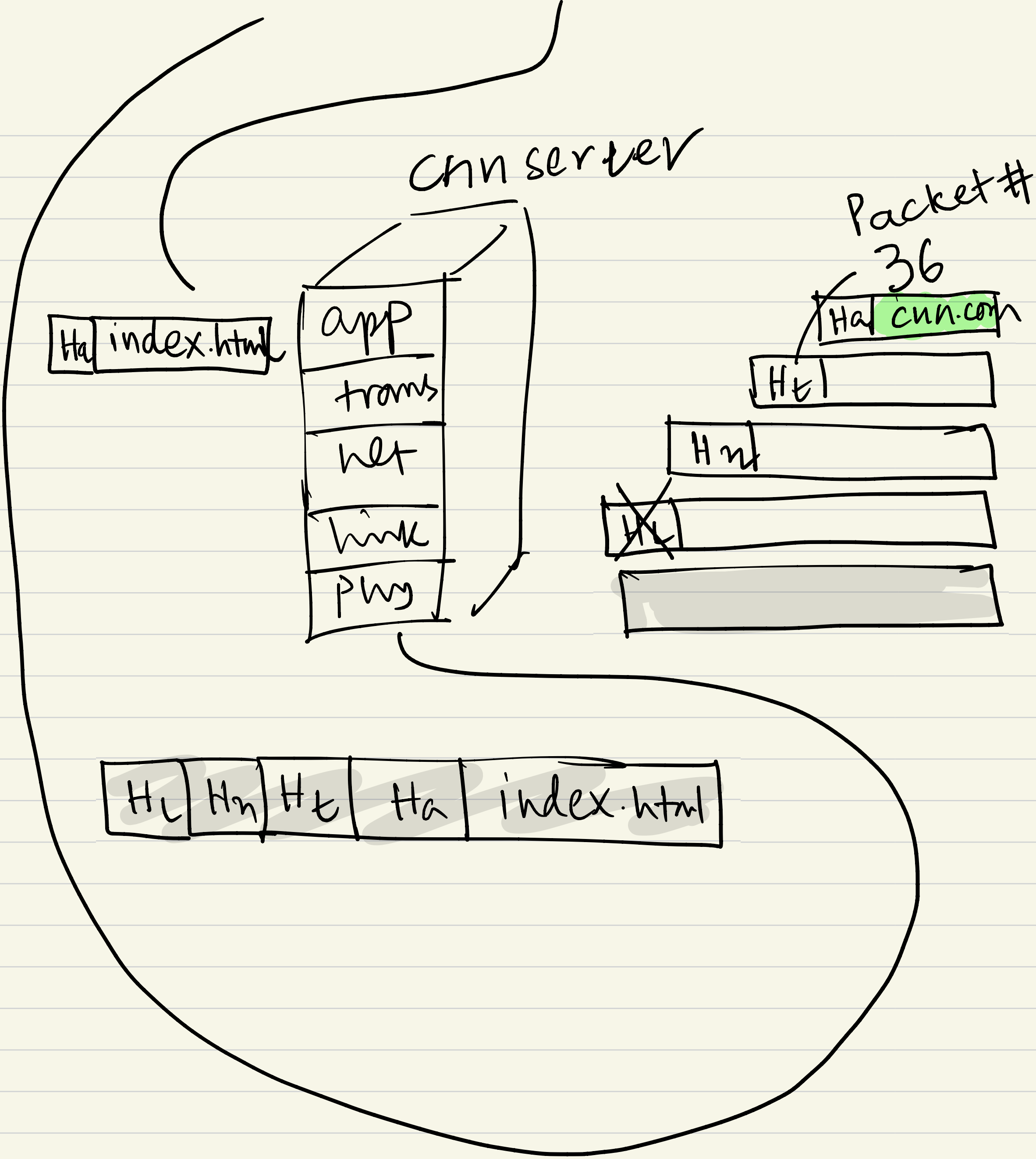
Ha ≡ App. layer header.

Ht ≡ Transport layer header









cnn server
app
trans
net
link
phy
Ha
index.html
Packet #
36
Ha
cnn.com
Ht
Hn
Hl
Hl
Hn
Ht
Ha
index.html

Is high tput ⇔ low latency ?

Vacation analogy

- Throughput, goodput
- Latency, delay
  - → Processing, Queueing delay
  - → Propagation delay, transmit time
- Avg. queueing delay vs. traffic intensity

why

Throughput ≡ No. of bits received per unit time.

goodput ≡ No. of useful bits received per unit time.

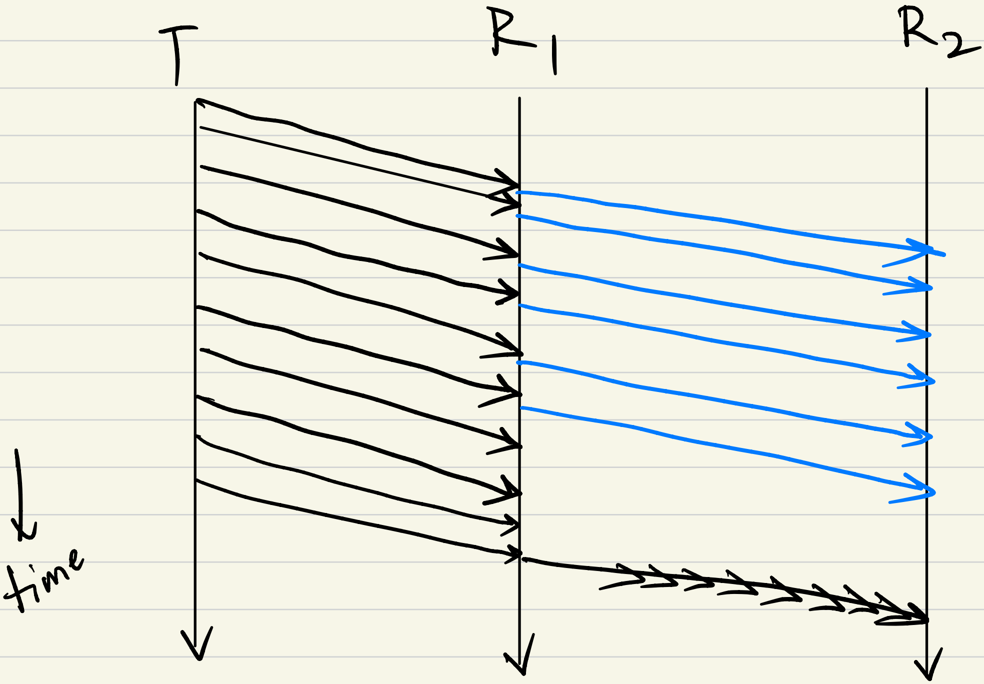
Tput = 10,000 bps

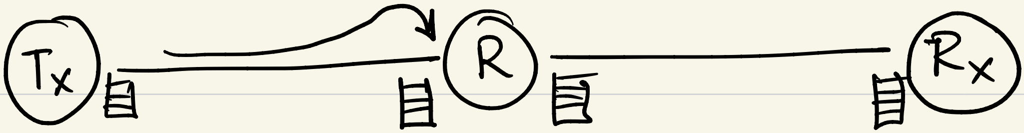
Goodput = 6,000 bps.

Latency = time taken for a packet to reach the dest^n starting from when it was transmitted at the source.

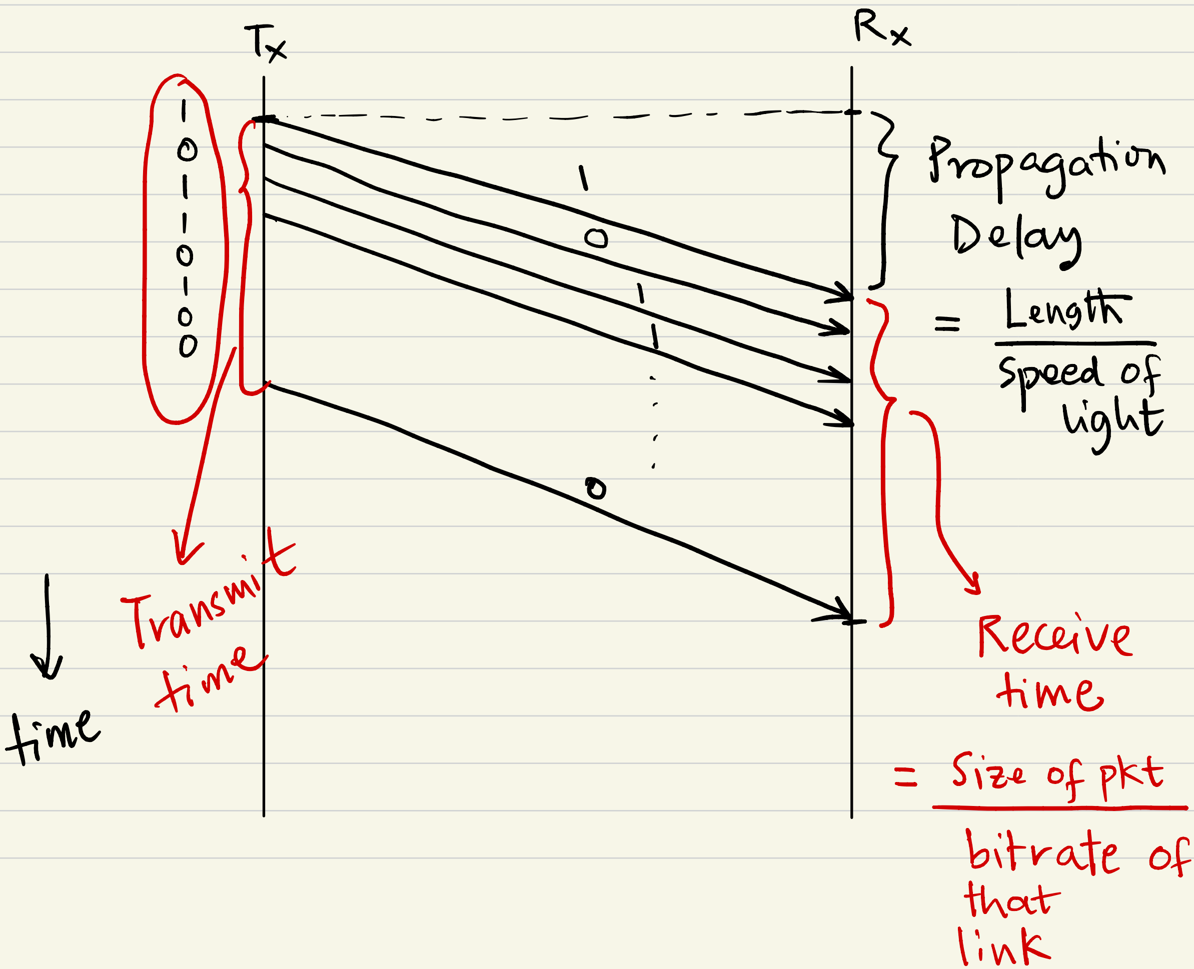
⑤ Avg. Throughput = 10 pkts/s } A

Avg. Latency = 0.1 s } B





1. Processing delay → CPU cycles.
2. Queuing " → total time waiting in diff. queues.
3. Prop. delay & transmit time.



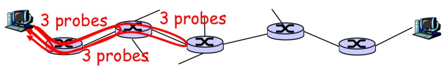
- Real Internet delays
  ↳ Traceroute

show on laptop

"Real" Internet delays and routes

Traceroute google.com

- 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.



"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

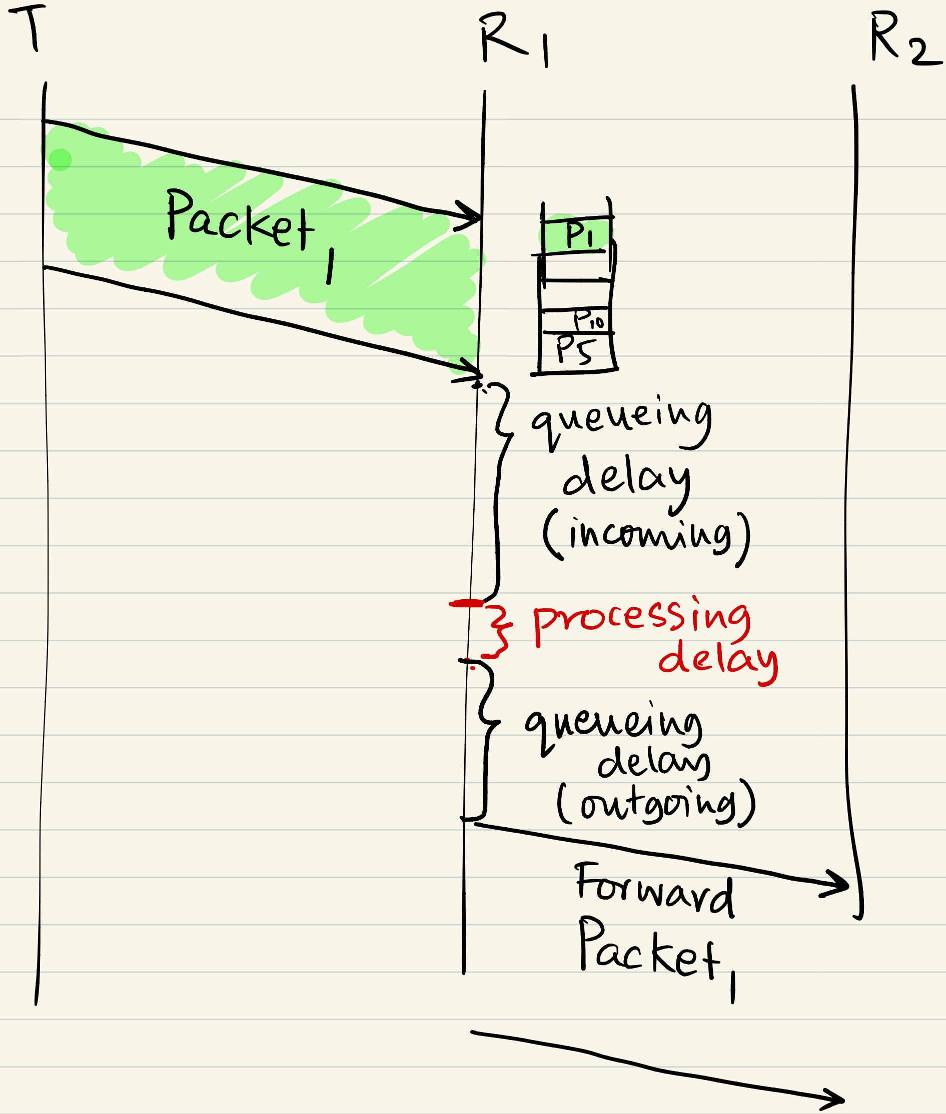
```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 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 (between hops 7 and 8)

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

Q delay >> processing delay > transmit time > Prop. Delay.

Total Delay from Chicago to India ≈ 150 ms.
w/o Q delay ⟶ ≈ 5 ms.



Throughput → used by networking people to measure end to end performance

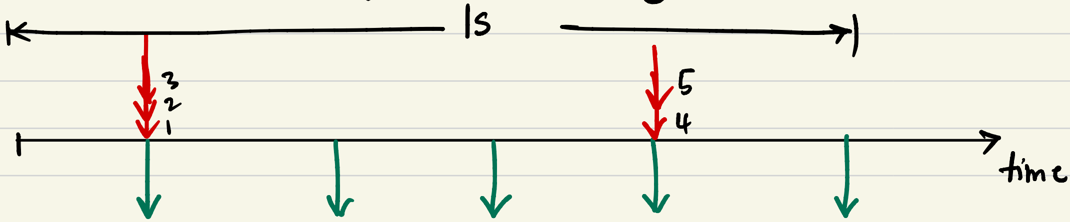
Bitrate → Used by Phy layer people

to measure a specific link's performance

Both units are bits/s.

A router forwards 5 pkts/s on average.
Incoming traffic is ~~5~~ 3 pkts/s on average.

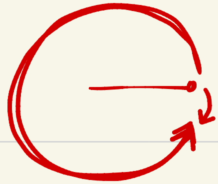
What is avg. queuing delay?



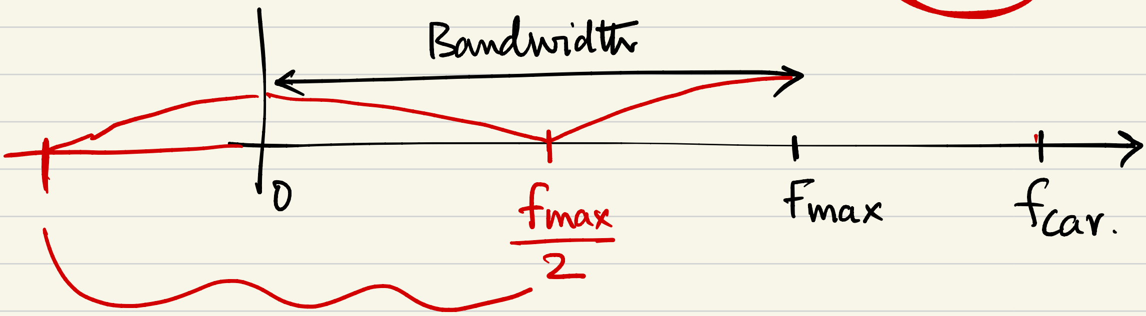
queuing delay = 0 ✗

$$\text{avg queuing delay} = \frac{0 + 0.2 + 0.4 + 0 + 0.2}{5}$$

DFT

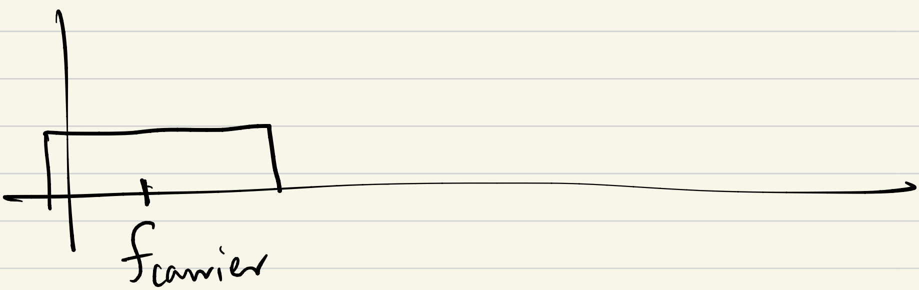


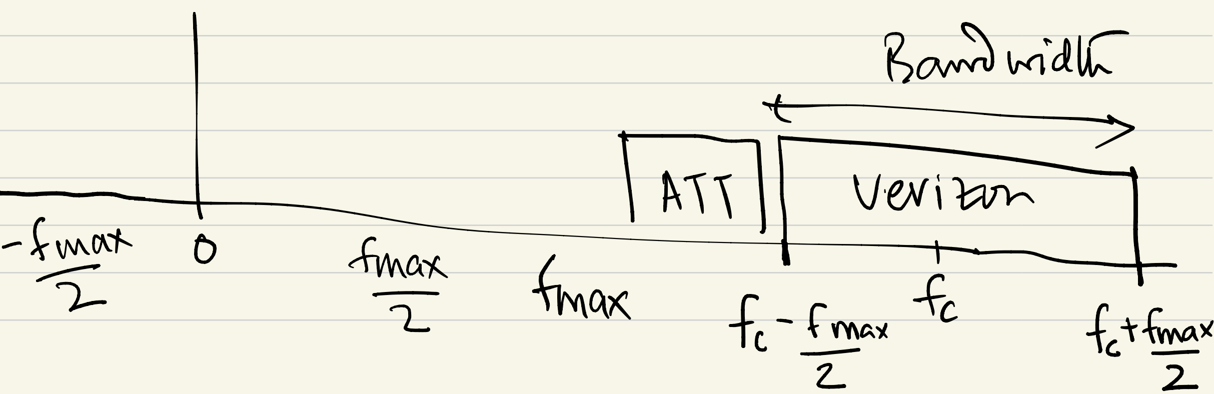
Bandwidth

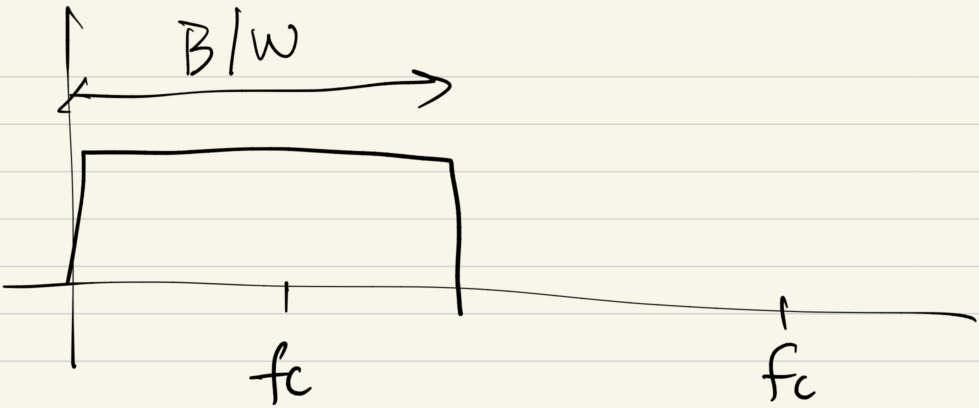


Bandwidth

Carrier Freq.







$$f_c < \frac{B/W}{2}$$