Computer Networks.

Nuts-and-Bolts view

computers + packet switches + Comm^{tn} links

- computers
  - servers
  - clients
- packet switches
  - Routers
  - switches
- Comm^{tn} links
  - wired
  - wireless

- No longer simply computer Networks
  - washing machines / Refrigerators
  - speakers
  - thermostats
  - Garage Doors

$\underbrace{\hphantom{washing machines / Refrigerators}}_{\text{Collectively Internet of things}}$

Collectively **Internet of things**

- A better term for modern networks is

Computers ⟶ end systems / Hosts.

How to interconnect end systems?

- ~5 billion (2015) end systems
- 1 billion DNS advertised
  ftp.isc.org/www/survey/reports/current/

Not practical at all to connect each device through commu^{n} links.

- → Alternative := Packet switches

multiplex incoming and outgoing links to forward packets

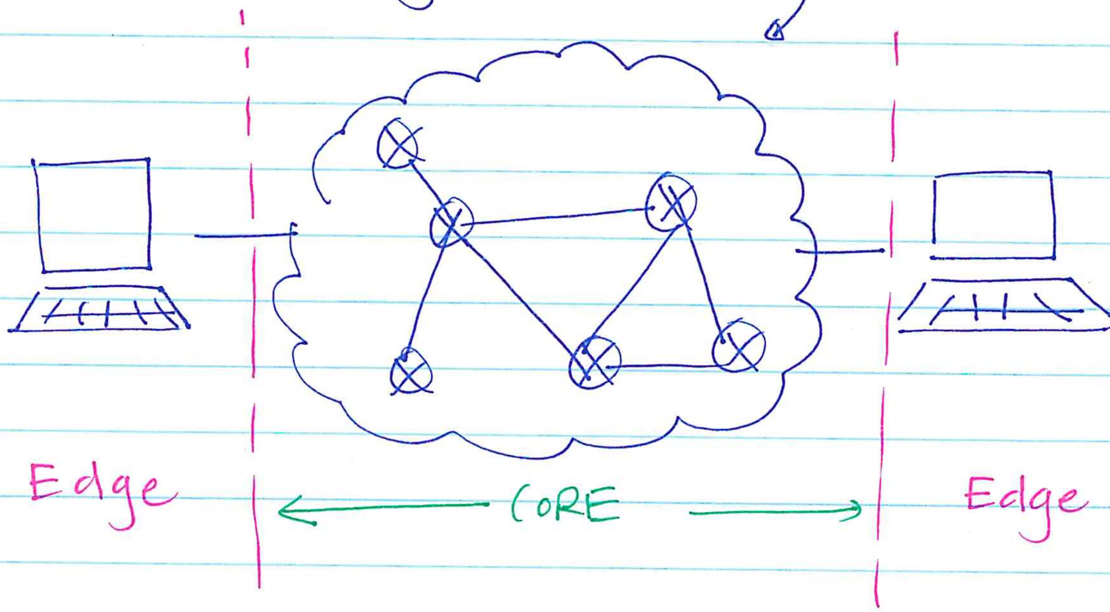
→ what is a 'packet'?

- Segmented data + Info about data.

$\boxed{\text{payload + Header.}}$

→ A packet switch operates per packet basis to forward incoming packets to the appropriate outgoing link.

Hollistically it seems we are dealing with something like this



How long does it take to send "packits" from one end system to another?

- Transmission : Putting bits on the "wire"
- propagation : Amount of time spent on "wire" moving towards destination
- Queuing : waiting to get transmitted typically @ packet switches
- Processing : Figuring out where to go.

Network performance measures

- Transmission Rate : Amount of bits that can be put on a wire / channel / medium per second.

  bits / second.

- Propagation Rate : The speed @ which bits / signals "move" through the comm^{tn} medium towards destination.

  ~~bits/second~~. meters / sec.

  →
  - speed of light ~ 3×10^8 m/s
  - speed of light over fibers 31% slower ~ 2×10^8 m/s

$$d_{transmission} = \frac{\text{Packet size } (L)}{R_{transmission} (R)}$$

$$d_{propagation} = \frac{\text{Distance } (d)}{R_{propagation} (S)}$$

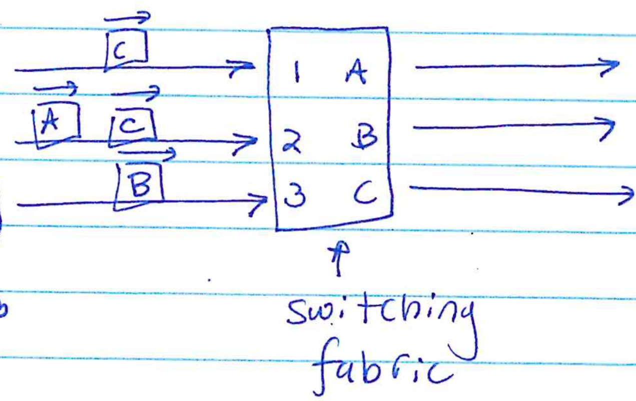
Transmission Delay **does NOT** depend on distance between nodes.

Propagation Delay **does NOT** depend on packet size

Queuing and packet loss

Queuing occurs @ packet swiches

Analogy: traffic intersection



- Packets must wait to use the switching fabric
  - might have to wait longer on a queue.
    - If/when queue is **full** will be **dropped**
      - Packet loss

Queuing theory is a science itself.
NOT covered here

Mbps vs. MBps

Processing Delay packet header must be examined for destination, correctness, assembly/disassembly

- Typically in intermediate points in CORE and @ destination.

Jitter : → variance in overall delay due to (mainly) queuing delays

End-to-End delay / Latency

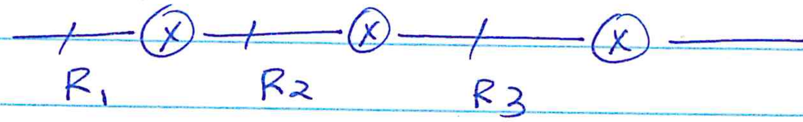
$$d_{end\text{-}to\text{-}end} = d_{proc} + d_{prop} + d_{trans} + d_{queue}.$$

Throughput →

Amount of work done (data transferred) per unit amount of time.

$$\frac{\text{file size } (F)}{\text{Time } (T)}$$

througput dominated by the slowest link



if $R_1, R_2 \gg R_3$

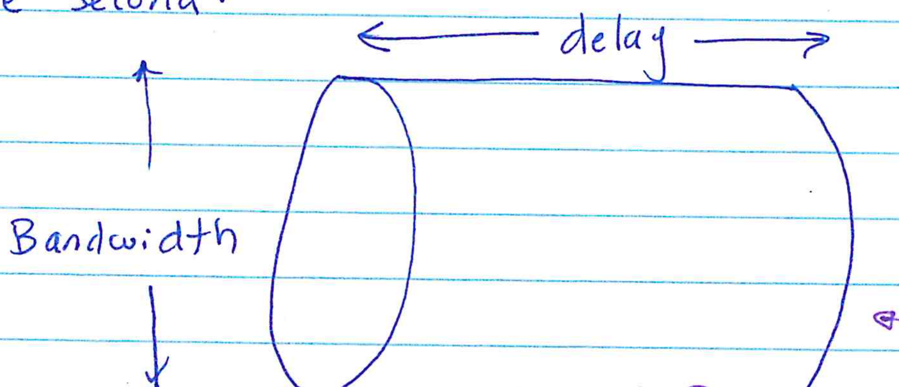
(slowest transmi$^{\underline{n}}$ rate)

→ throughput $= R_3$

→ slowest link is a.k.a. <u>Bottleneck link</u>

Bandwidth - Delay product

- Number of bits transmitted and retained in the distance propagated by the signal in one second.



defines a volume of data

e.g. 9600 km link, Fiber optic with a 10 Gbps bandwidth.

How many bits?

$$\cancel{10}^{5} \times 10^{9} \times \frac{9600 \times 10^3}{\cancel{2} \times 10^8} = 48000 \times 10^3$$

$$= \underline{\underline{480 \text{ M } b\cancel{ps}}}$$

Note: For full-duplex links double this amount.

An important measure in calculating the maximum number of packets to be transmitted before receiving first ACK. (later in $\boxed{TL}$)

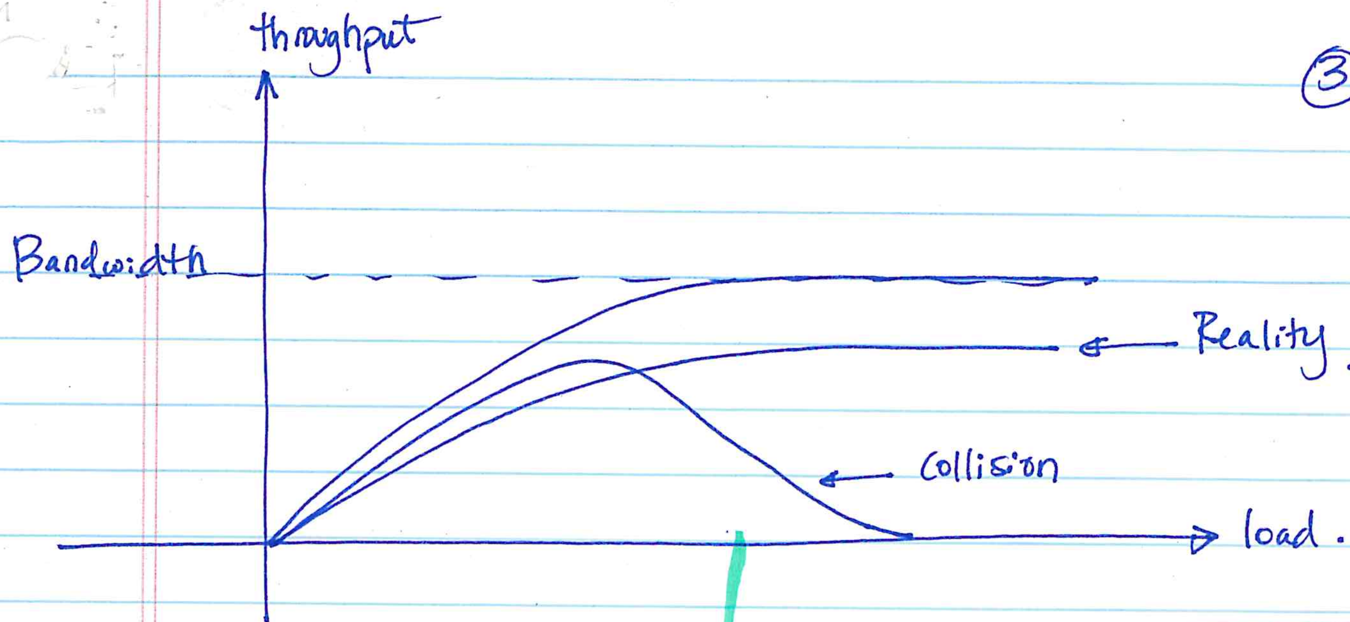
$$\text{width of a bit} = \frac{\text{length of link}}{\text{Bandwidth} \times \text{Delay}}$$

Round Trip time (RTT)

- Amount of time to send and receive (feedback) a small message across the CORE

small enough to ignore d_{trans}

$$RTT = \left(d_{prop} + d_{proc} + d_{queue}\right) \times 2$$



Latency = transmit + Propagation + Queue + Process

Propagation = Distance / Speed of light

Transmission = Size / Bandwidth

Throughput = Transfer size / Transfer time

$$\text{Transfer time} = \text{RTT} + \frac{\text{Transfer Size}}{\text{Bandwidth}}$$

Round trip time (RTT) : Amount of time it takes to send a small message from one end of a network to the other and back.

e.g. A network of bandwidth 10 Mbps can pass on average 12,000 frames/min, each frame with an average 10,000 bits. what is the throughput?

$$\frac{12{,}000 \times 10{,}00\cancel{0}}{6\cancel{0}} \qquad \frac{\cancel{12}^{2} \times 10^{6}}{\cancel{6}} \text{ bps}$$

$= 2$ Mbps.

e.g. File 2.5 KB
bandwidth 1 Gbps
distance 12,000 km
Propagation speed 2.4×10^{8} m/s

Transmission delay $= \dfrac{2.5 \times 10^{3} \times 8}{1 \times 10^{9}} = 20 \times 10^{-6}$
$= 0.02$ ms.

Propagation delay $= \dfrac{12{,}000 \times 1000}{2.4 \times 10^{8}} = \dfrac{\cancel{12} \times \cancel{10^{6}}}{2\,\cancel{24} \times 10^{\cancel{7}}}$

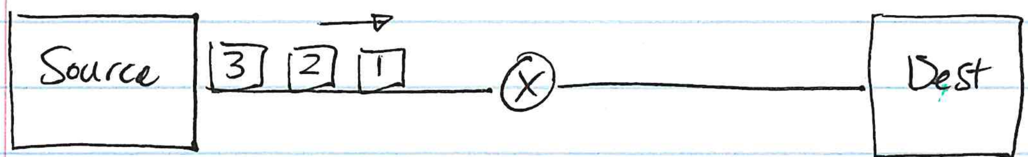
$= \dfrac{1}{2} \times 10^{-1}$

$0.5 \times 10^{-1} = 50$ ms.

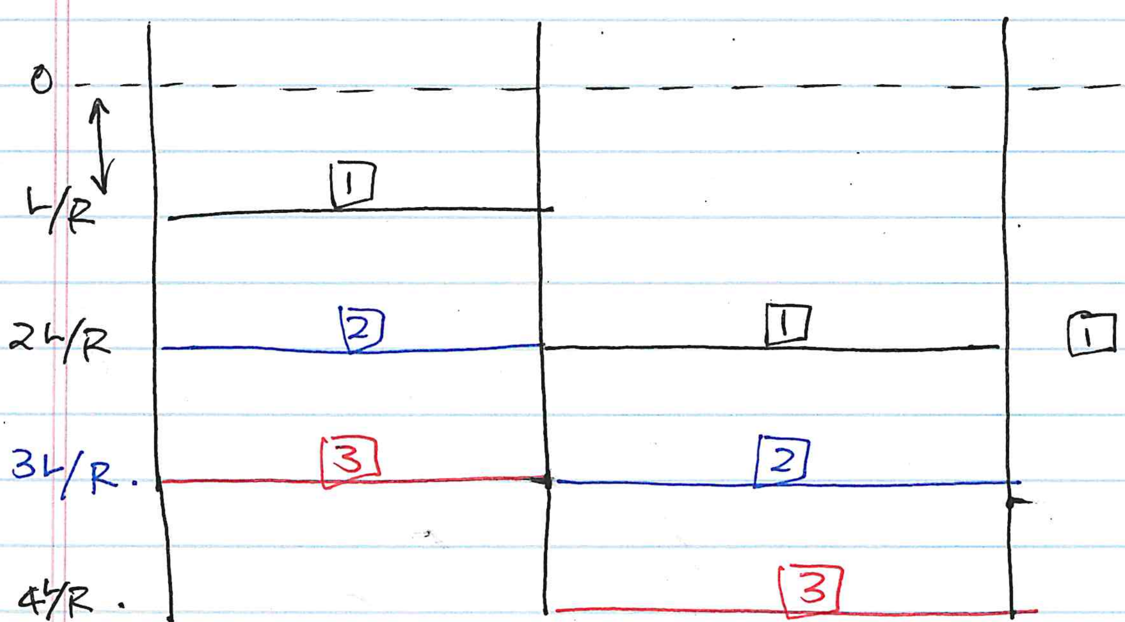
$$\frac{\cancel{12}^{2}{,}000 \times 10{,}00\cancel{0}}{\cancel{6}\cancel{0}} \qquad \underline{\underline{2 \times 10^{6}}}.$$

Store-and-Forward Transmission.

↳ The whole pkt must be received before transmitting on outbound link.



Assuming No propagation Delay.



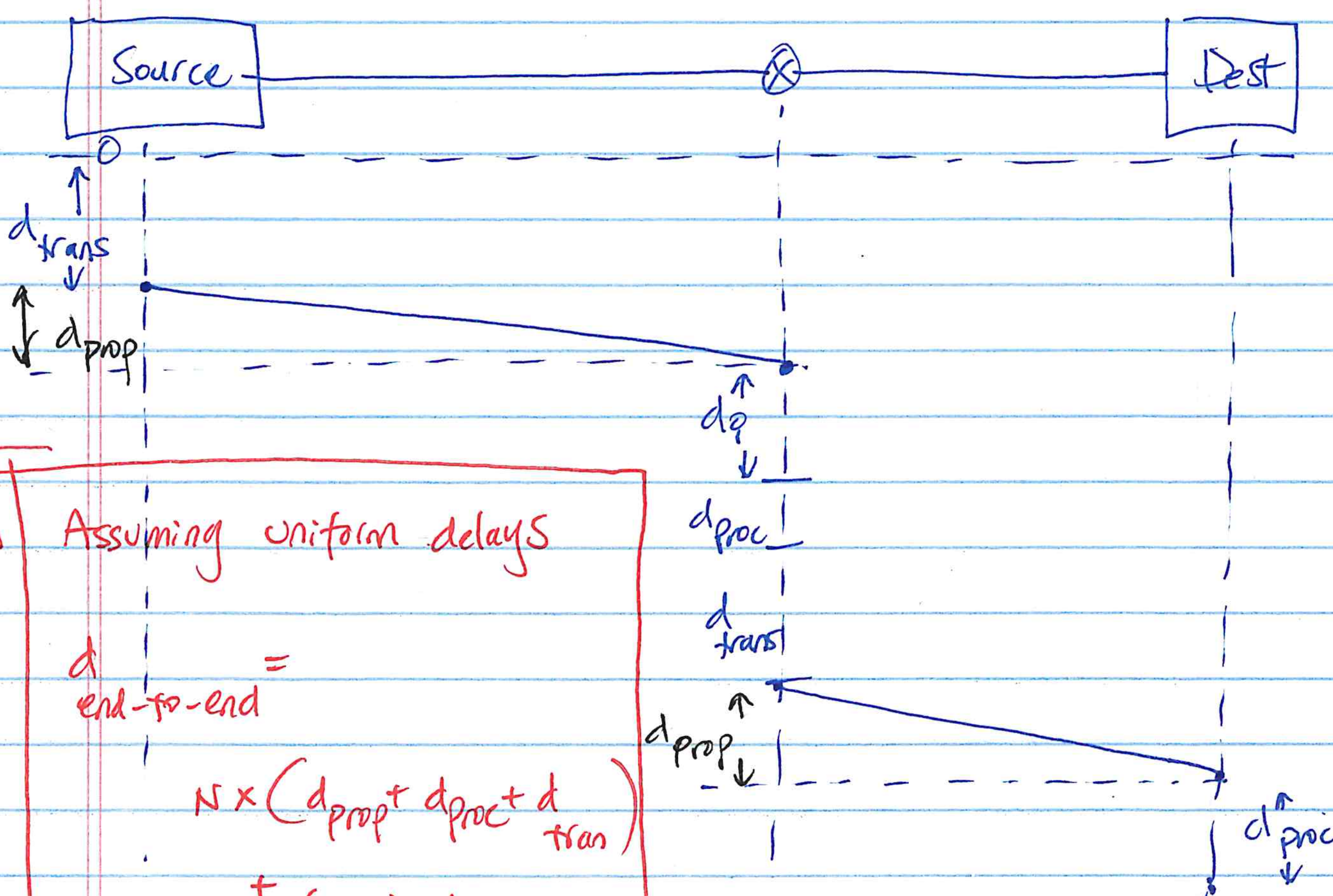
who-is who? host (hostname ↔ IP)
LAN: who is who? Arp (IP ↔ mac)
who am I? ifconfig
are you there? Ping
How do I get to you? traceroute/tracepath.

General Rule:

N links of rate R bps (N−1 routers), one packet,

$$d_{end\text{-}to\text{-}end} = \left(N \times \frac{L}{R} \right)$$

Assuming propagation delay + processing delay + queing delay.



Assuming uniform delays

$$d_{end\text{-}to\text{-}end} = N \times (d_{prop} + d_{proc} + d_{tran}) + (N-1)\, d_{queue}.$$

Service View of Networks

- Five layers (in TCP/IP stack) arranged based on a service-level agreement

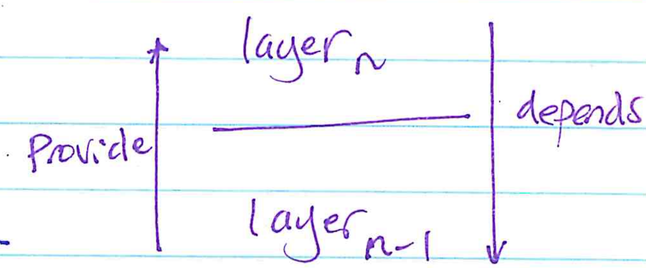
Application

Transport

Network

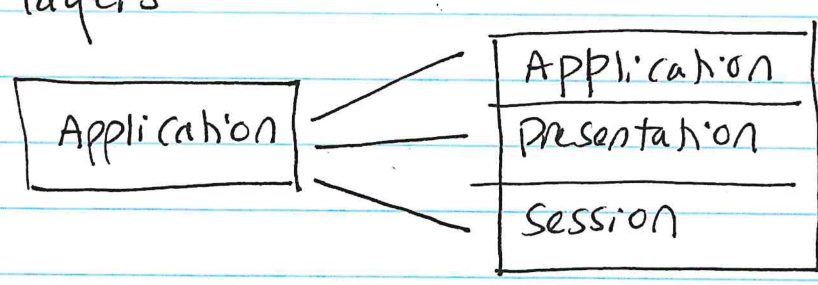
Data link

Physical.



- layer$_n$ depends on services provided by layer$_{n-1}$.

- Alternative (more standardized) model is the OSI / ISO model
  - 7 layers



Service-level Agreement

- Networks are heterogenous
  - ↳ different vendors, hardware, software, specifications etc.
- Everyone must agree upon common conventions for communication
  - → Protocols : Defines the format and ordering of message exchanges between two (or more) communicating entities.

→ what actions to take on which event
→ A whole bunch of if/else statements.

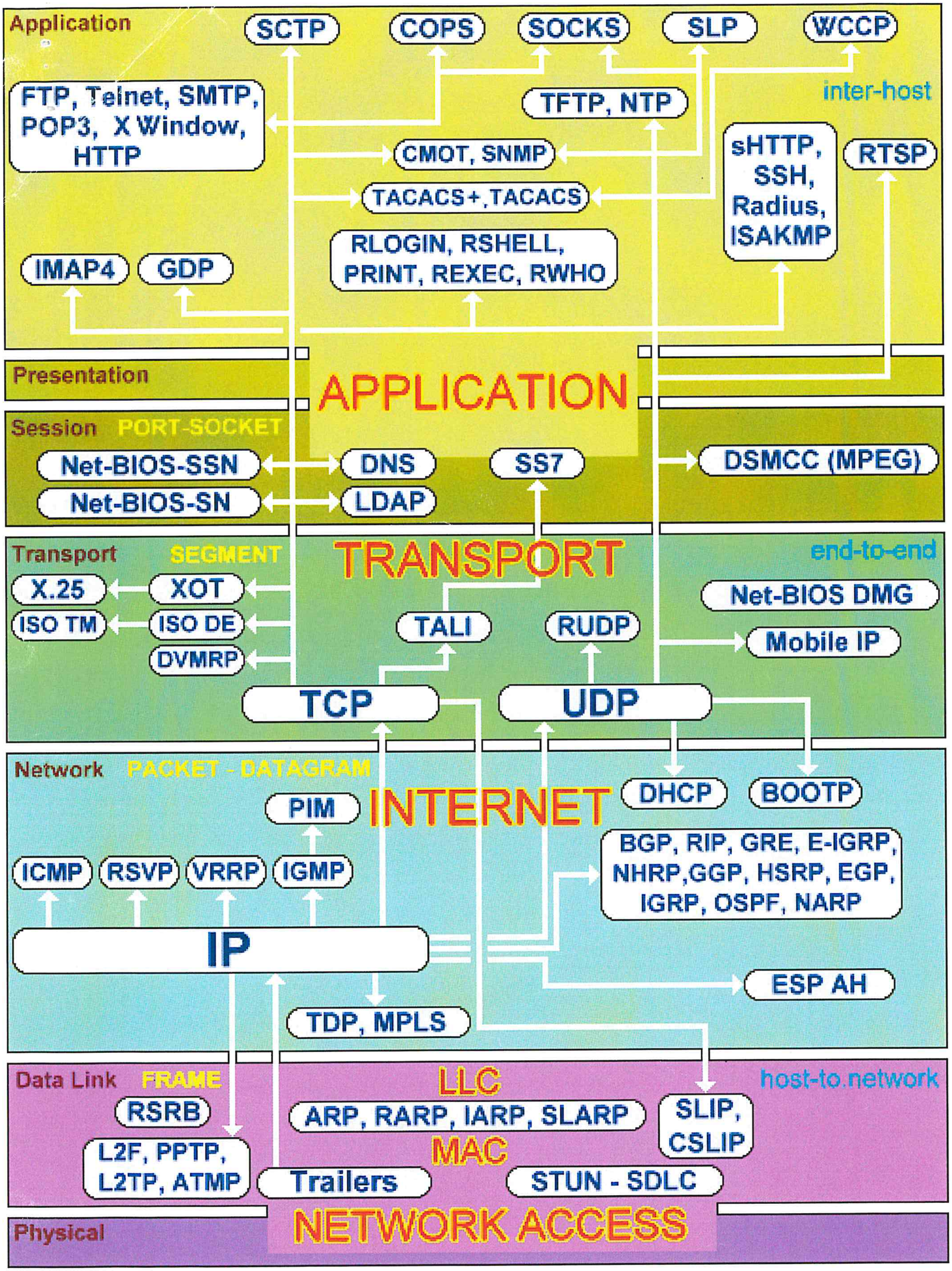
Examples.

Application Layer : HTTP, FTP, SMTP, . .

Transport Layer : TCP, UDP, SCTP

Network Layer : IP

Data Link Layer : ATM, PPP, Ethernet, I^2C, PPP, Token Ring



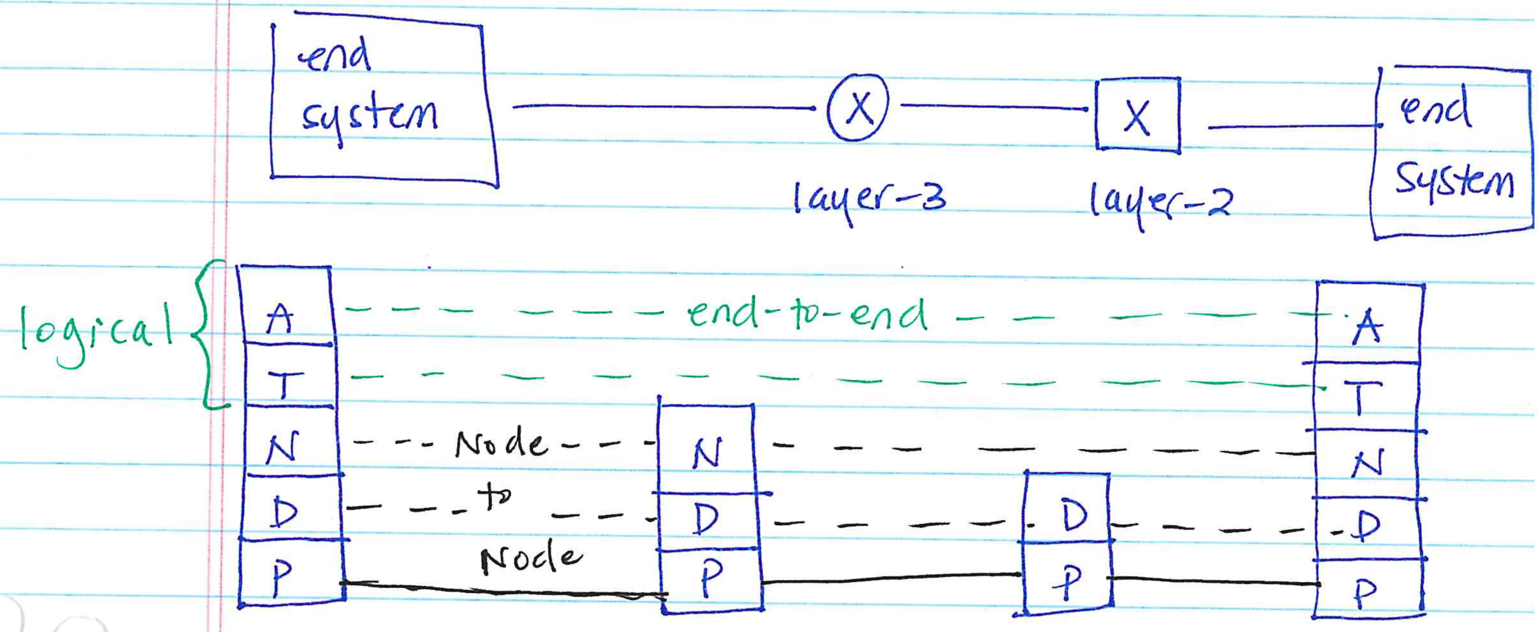
Application
SCTP
COPS
SOCKS
SLP
WCCP
inter-host
FTP, Telnet, SMTP, POP3, X Window, HTTP
TFTP, NTP
CMOT, SNMP
TACACS+,TACACS
sHTTP, SSH, Radius, ISAKMP
RTSP
RLOGIN, RSHELL, PRINT, REXEC, RWHO
IMAP4
GDP
Presentation
APPLICATION
Session
PORT-SOCKET
Net-BIOS-SSN
DNS
SS7
DSMCC (MPEG)
Net-BIOS-SN
LDAP
Transport
SEGMENT
TRANSPORT
end-to-end
X.25
XOT
ISO TM
ISO DE
DVMRP
TALI
RUDP
Net-BIOS DMG
Mobile IP
TCP
UDP
Network
PACKET - DATAGRAM
DHCP
BOOTP
PIM
INTERNET
BGP, RIP, GRE, E-IGRP, NHRP,GGP, HSRP, EGP, IGRP, OSPF, NARP
ICMP
RSVP
VRRP
IGMP
IP
ESP AH
TDP, MPLS
Data Link
FRAME
LLC
host-to.network
RSRB
ARP, RARP, IARP, SLARP
SLIP, CSLIP
MAC
L2F, PPTP, L2TP, ATMP
Trailers
STUN - SDLC
Physical
NETWORK ACCESS

who decides protocol rules ?

- Community → submit RFCs to IETF (Internet Eng. Task Force) for public to comment.
  - Adopted if widely accepted.

Further discuss the concept behind protocols using "asking for time" example.

protocol communication



protocol exchange can be between

end-system ⟷ end system

end system ⟷ Packet switch

Packet switch ⟷ Packet switch.

→ what do they exchange?

- Packets.

Application layer → messages

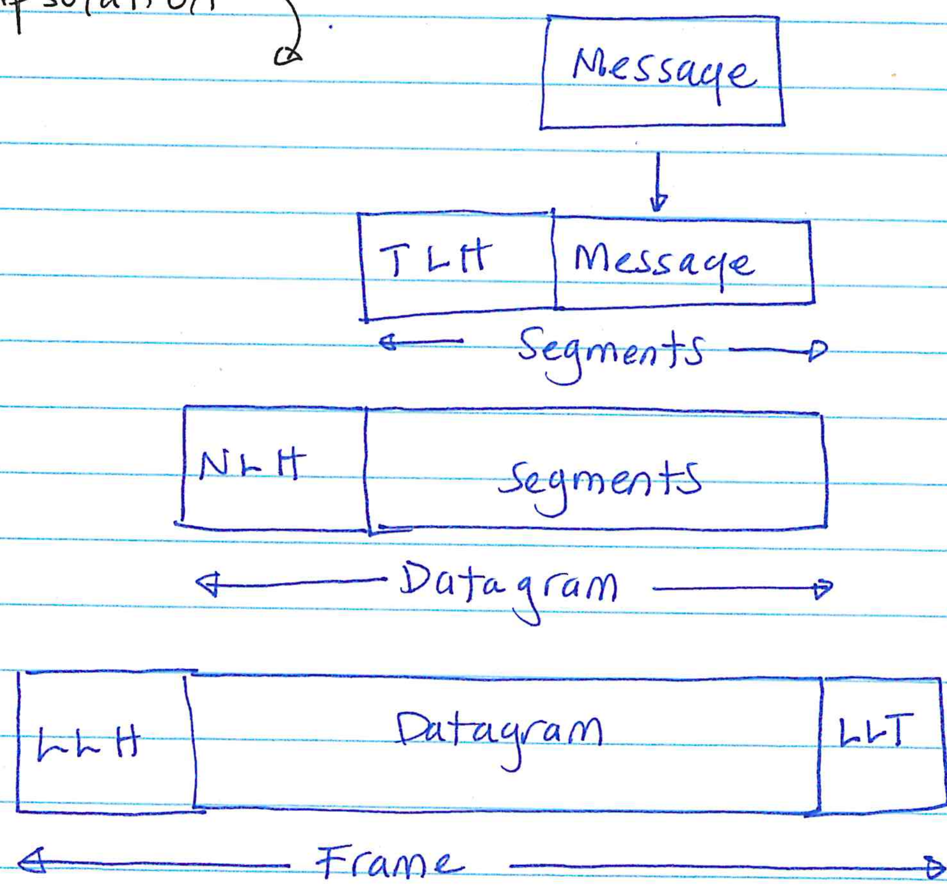
Transport layer → segments

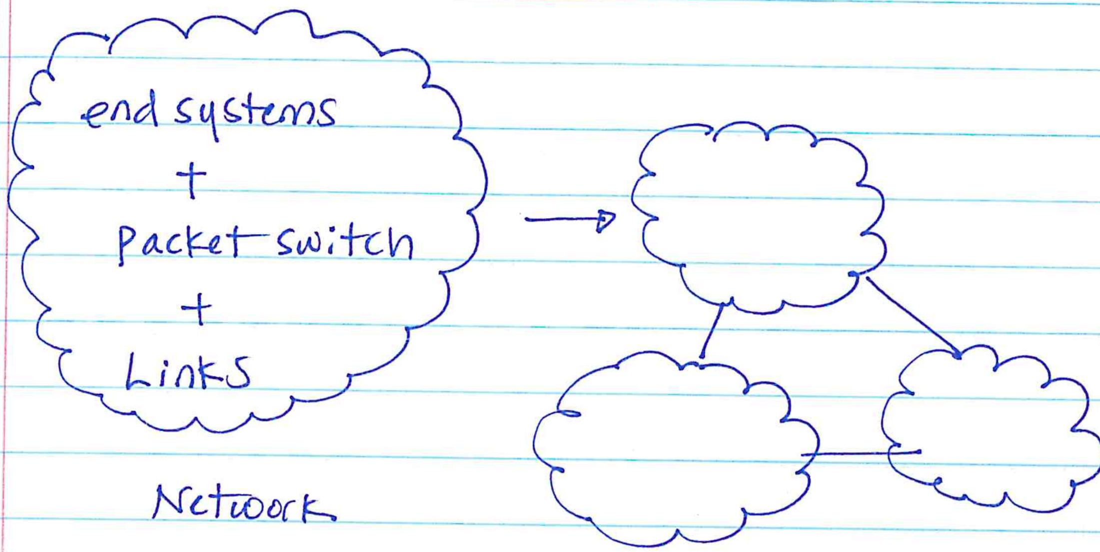
Network layer → Datagrams

Data-link layer → Frames

Physical layer → bits (signals).

Encapsulation





Network

Network of Networks
A Internet

Most popular (arguenbly the biggest) network of Networks

is The Internet

→ who owns this massive infrastructure?

→ No single entity

Ascess ISP → Regional ISPS → Tier-1 ISPS (Backbone)

A Network of packet switches and comm^n links.

Switching

- Occurs in several layers, even @ $\boxed{\text{AL}}$ (logically)

- One-to-one connectivity between end-systems is **NOT** practical. and wasteful.
  - Solution: A switched network
    - Packet-based switching (Packet switched)
      - Virtual circuit
      - ** Datagram Approach.
    - Message switching (Message switch) ... Phased out
    - Circuit-based switching (Circuit switch)

packet switching : - No dedicated paths between communicating parties.

(Visiting New york)

- Connection is based on ~~m~~ packet exchanges that may or may not follow the same path thrugh the CORE.

(President visiting New york)

Circuit switching : A connth between two end systems established over a dedicated path.

- Connetn uses only a dedicated channel on each link.

  - link divided
    - Based on Frequency, time, wavelength, code.

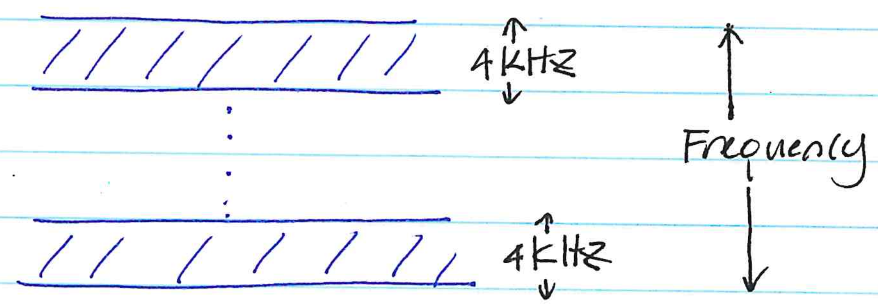
(based on color in Fiber optics)

- Resources required along the path (Buffers, rates, etc..) pre-arranged / allocated.

Frequency Division Multiplexing (FDM)

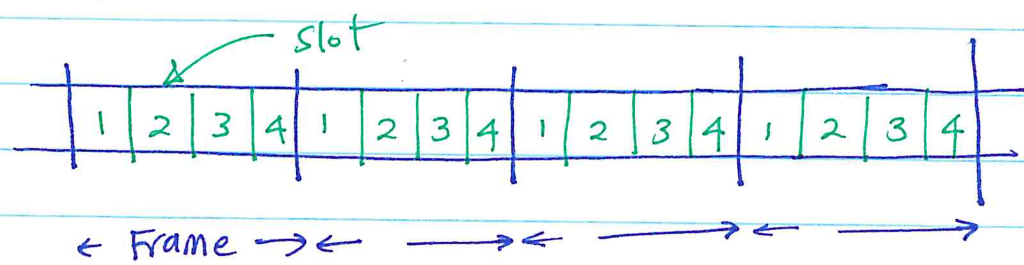
- The frequency spectrum (of the link) is divided among Conne^{hs}.

e.g.



Time Division Multiplexing (TDM)

- Time divided into frames of fixed duration
- Each connection gets a slot in the frame
  - One slot is dedicated per Conn^{tn}.



E.g. 8000 frames / sec with 8-bit slots

Each circuit has $\frac{8000 \times 8 \text{ bits}}{\text{sec}}$

capacity / transmission Rate.

64 kbps.

E.g. ~~Cha~~ channel capacity 1.536 Mbps
24 slot TDM

↳ Effective transmission Rate

$$= \frac{1.536 \times 10^6}{24} = \underline{\underline{64 \text{ kbps}}}$$

→ Compare and Contrast TDM vs FDM and Circuit Switching vs. packet switching with students.

Data links ↴

Simplex : $\square \longrightarrow \square$

Half-Duplex : $\square \underset{\xleftarrow{time_{i+1}}}{\xrightarrow{time_i}} \square$

Full-duplex : $\square \underset{\xleftarrow{time_i}}{\xrightarrow{time_i}} \square$