1. Problem 1.13

- If the musicians were actually 10 m apart the delay they would experience in hearing the dulcet tones of their partner would be

$$t_{10} = \frac{\text{separation distance}}{\text{velocity of sound}} = \frac{10\,m}{330\,m/s} = 30.3 \text{ milliseconds}$$

$$= 30.3\ ms$$

- how long does a cable capable of supporting electrical signal propagation at the speed of light have to be to experience the same delay?

distance of cable = velocity of signal through cable × delay through cable

$$d = 2.3\times10^{8}\ \frac{m}{s} \times 30.3\times10^{-3}\ s$$

$$= 6.969\times10^{6}\ m$$

$$\boxed{d = 6969\ km}$$

← that's about the distance from Toronto to Warsaw about a 7 hr. flight

2. Problem 1.14. For both parts (a) and (b) just show your calculation for the circuit board and the continent.

a) to find the propagation delay divide distance of medium by the speed of light through the medium

circuit board $t_{prop} = \frac{10 \times 10^{-2}\ m}{2.3 \times 10^{8}\ m/s} = 4.347 \times 10^{-10}\ s = 0.4347\ ns$ (nanoseconds)

continent $t_{prop} = \frac{5000 \times 10^{3}\ m}{2.3 \times 10^{8}\ m/s} = 0.02174\ s = 21.74\ ms$ (milliseconds)

b)

bit rate	circuit board	continent
10 kbps	4.347×10^{-6}	217.4
1 Mbps	4.347×10^{-4}	21740
100 Mbps	0.04347	2.174×10^{6}
10 Gbps	4.3478	2.174×10^{8}

calculate with $t_{prop} \times$ bit rate

- as we'll see in Ch. 5 these terms specify the so-called DELAY-BANDWIDTH product, this is a measure of the size of your communication pipe, how many bits can be in transit at a time

we get a sense of this in the next problem
- this is important for the data link layer, the smaller your ACK frames are the less effectively are you utilizing your medium

3. Problem 1.15. Just show your calculation for the circuit board and continent operating at 10~Gbps for 1000-byte messages.

- say ~~you~~ your transmitter is launching bits into your medium at a rate of R bits/s (bps)
- if your message consists of $L_{message}$ bits it takes your transmitter

$$\frac{L_{message}}{R}$$ seconds to load the entire message into your medium ("pipe")

- that's just getting the message INTO the pipe, don't forget it takes time for all these bits to propagate to the other side, that's the propagation delay t_{prop}
- thus the total time it takes to get your <u>whole</u> message to the destination is

$$\frac{L_{message}}{R} + t_{prop}$$

- similarly to send an acknowledgment message consisting of L_{ack} bit requires

$$\frac{L_{ack}}{R} + t_{prop}$$

thus the <u>total</u> time to send a message & get a complete acknowledgment of that message is

$$t_{total} = \frac{L_{message}}{R} + \frac{L_{ack}}{R} + 2 \cdot t_{prop}$$

recall that t_{prop} is just distance for the signal to travel over the speed of light in the communication medium so we can re-write the above as

$$t_{total} = \frac{L_{message}}{R} + \frac{L_{ack}}{R} + 2 \cdot \frac{d}{c}$$

at 10-Gbps $\frac{L_{message}}{R} = 0.8008\ s$ (1000-byte message)

$\frac{L_{ack}}{R} = 0.0016\ s$ (1-byte ACK)

for the 10-cm circuit board $\frac{2d}{c} = 0.00087\ s$

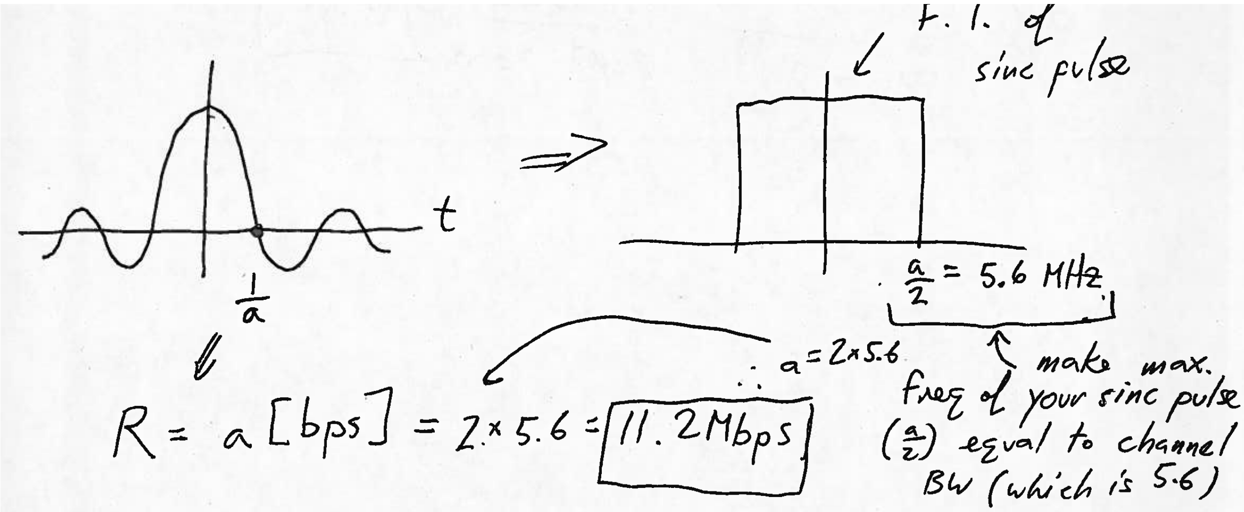
for the 5-km continent $\frac{2d}{c} = 43478.26\ s$

$$t_{total}\big|_{10cm} = 0.80167$$

$$t_{total}\big|_{5km} = 43479.06$$

note the huge propagation time in a continental connection, waiting for a 1-byte ACK in such a link can be extremely wasteful of resources

4. A signalling process represents 1's and 0's with sinc pulses.



$$R = a\,[\text{bps}] = 2 \times 5.6 = \boxed{11.2\text{Mbps}}$$

5. A message consisting of 1024 Bytes is transmitted over a network with links operating at a rate of 2.048 Mbps.

$$\text{Delay of message} = \frac{8}{R}\left(\frac{M}{K} + H\right)(N + K)$$

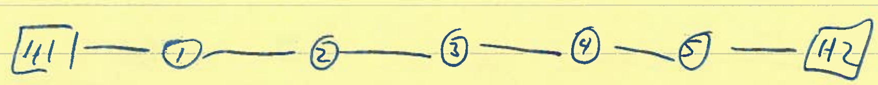
(R: data rate in bps)

$M = 1024$ message size [bytes]

$K = 4$ message split into 4 packets

$H = 10$ bytes (header size per packet)

$N = 5$ hopping over 5 routers



$R = 2.048$ Mbps

$$\boxed{\text{Delay} = 9.35\text{ms}}$$

6. A router processes packets at a rate of 2345 packets per second.

$$\mu = 2345$$

$$\lambda = 2000$$

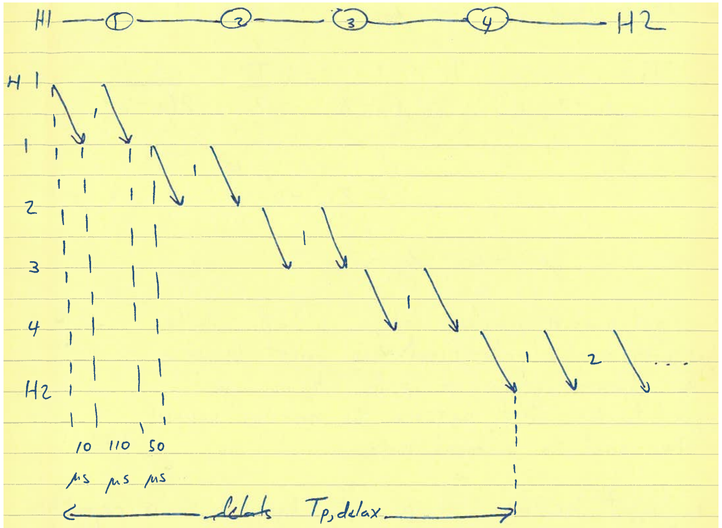
$$T = \frac{1}{\mu - \lambda}$$

$$L = \frac{\lambda}{\mu - \lambda} = \frac{2000}{2345 - 2000} = \boxed{5.8}$$

7. A 15-KB file is to be sent through a network consisting of 5 links and 4 routers.

$$t_t = \frac{L_p}{R} = \frac{1.2 \times 8 \times 10^3}{10 \times 10^6} = 960 \mu s = \boxed{960 \times 10^{-6} s}$$

8. **For the system outlined in the question above assume that the packet transmission time is**



$T_{p,delay} = 5 \times t_{prop} + 4 \times t_{tx} + 4 \times t_{proc}$

$= 5 \times 10 + 4 \times 110 + 4 \times 50 = 690\,\mu s$

$K = \left\lceil \frac{15}{1.2} \right\rceil = 13$

$\therefore$ total time to send file $= 690 + 13 \times 110 = 2120\,\mu s$

$\therefore S = \frac{15 \times 8 \times 10^3}{2120 \times 10^{-6}} = 56.6$ Mbps

9. For a system with a queue having an arrival rate

At μ_1 At μ_2

$T_1 = \frac{1}{\mu_1 - \lambda}$ $T_2 = \frac{1}{\mu_2 - \lambda} = \frac{T_1}{2} = \frac{1}{2(\mu_1 - \lambda)}$

$\mu_2 = 2\mu_1 - \lambda$

$\therefore \mu_2 - \mu_1 = \mu_1 - \lambda$

to cut mean packet delay in half while keeping arrival rate fixed we must increase the processing/service rate by an amt. equal to the diff between the original service rate and the arrival rate

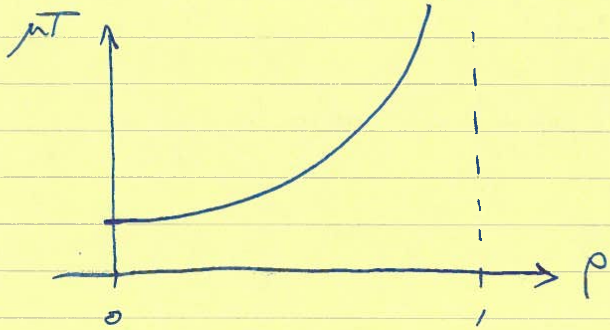
i.e. must increase service rate by the spare capacity in the original system

$\boxed{\% \text{ increase} = \frac{\mu_2 - \mu_1}{\mu_1}}$

10. Plot (just a sketch conveying the characteristics) the normalized delay

$$T = \frac{1}{\mu-\lambda}$$

$$\mu T = \frac{\mu}{\mu-\lambda} = \frac{1}{1-\frac{\lambda}{\mu}} = \frac{1}{1-\rho}$$



11. Problem 5.3.

a) 10 kB message $L_{max} = N_f = 1$ kB

∴ 10 packets/frames constitute a message

p : probability of packet error over 1 hop

1-p : probability of no error in packet over 1 hop

$P_{packet} = (1-p)^3$: no error in packet over 3 hops

$P_{message} = [(1-p)^3]^{10} = (1-p)^{30} \approx e^{-30p}$ } prob. message arrives error free

b) avg. # of required retransmits

$$\frac{1}{P_{message}} = e^{30p}$$

c) avg. # of retransmits per packet

$$\frac{1}{P_{packet}} = \frac{1}{(1-p)^3} \approx \frac{1}{e^{-3p}} = e^{3p}$$

total number of packet re-transmits

$$\frac{10}{P_{packet}} = 10e^{3p}$$

12. Problem 5.15 just (a) and (b). For (b) calculate your answer for N = 80.

a) 1 MB = 8×2^{20} bits must be sent

with bit error rate of $p = 10^{-6}$, probability of not a single bit error in the file is

$$(1-p)^n = (1-10^{-6})^{8 \times 2^{20}} = 2.27 \times 10^{-4}$$

b) $(1-p)^{\frac{8\times 2^{20}}{80}} = 0.9005$ chance of frame being error free

∴ 10% chance of frame being in error

13. Problem 2.4.

Yes, data link layer still needed

data link layer takes care of data framing & for flow control, in a multiple access medium like WiFi & simpler Ethernet the data link layer is required to coordinate access to shared medium among multiple users (i.e. implement the MAC: medium access control)

14. Problem 2.6.

a) The network layer is concerned with selection of path across the network

b) The transport layer is concerned with providing reliable service on an end-to-end basis across the network

c) The data link layer provides for the reliable transfer of information between adjacent nodes in a network

15. Problem 2.10.

Features in Common

- both layers can provide recovery from transmission errors
- both layers can provide flow control
- both layers can support multiplex
  - → TCP over multiple ports
  - → data link through MAC

Differences

- transport layer is end-to-end over indirect links, data link is on direct links, thus is less likely to run into out-of-sequence PDUs
- data link concerned with framing, transport not
- data link concerned with shared medium networks like wireless LAN, transport not

16. In which layer of the OSI model is the Ethernet layer best placed?

- as noted in 2.14 Ethernet is considered a protocol in the data link layer

17. Problem 2.19.

• the message overhead is

20 B ← from TCP
+20 B ← from IP
+18 B ← from Ethernet
58 bytes

for $L = 100B$ efficiency $= \frac{100}{158} = 63\%$

$L = 500B$ efficiency $= \frac{500}{558} = 90\%$

$L = 1000B$ efficiency $= \frac{1000}{1058} = 95\%$ ← headers ~~has~~ have marginal effect for a 1000B payload

max Ethernet frame size is 1500 so we can make efficiency even better

18. Problem 2.20.

→ the problem allows maximum packet sizes of 1500 B

→ if you ~~check~~ check the book you'll note that the minimum IP header size is 20B so in this case our IP packet can carry a minimum payload of 1480 B

→ however this payload must also account for the TCP segment header size whose minimum size is also 20 B

→ thus the maximum data payload that can be sent under the constraints imposed by this problem is 1460 B

$\therefore \frac{1.5\ MB}{1460\ B} = 1027.4$ thus 1028 packets are needed to transfer this file

$\therefore$ overhead is $\left(\frac{1028 \times 1500 - 1.5M}{1.5M}\right) \times 100 = 2.8\%$

19. Problem 2.25.

server-to-PC

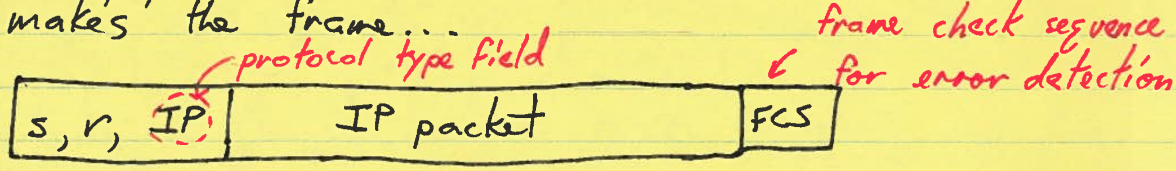
- server prepares a packet with its IP address as well as that of its destination in the header

IP ~~paste~~ packet

- the ~~routing~~ form of the ~~IP add~~ destination IP address indicates to the server that the destination is on another network. In these cases the sending host knows that its packet must be sent to the router (also known as the "default gateway") which is its connection to any networks exterior to the LAN

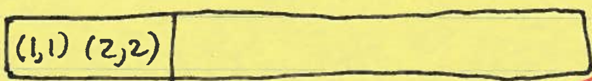
- of course the server does not directly send the IP packet, it needs to encapsulate it in an Ethernet frame which is, so-to-speak, the "native language" of the LAN in Fig. 2.15

- the Ethernet frame of course localizes components in the LAN in terms of their physical addresses. There is actually a special protocol called Address Resolution Protocol (ARP) that machines use to find the physical addresses of other machines on a LAN. We will not detail this here, but instead assume that the server has somehow discovered that the physical address of the router is r and hence makes the frame...



- this Ethernet frame is broadcast over the LAN and obviously accepted only by the router because the router's physical address, r_i, is listed as the frame's destination physical address

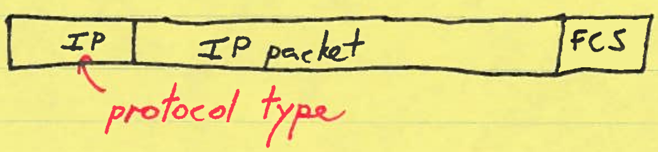
- the router then strips off the Ethernet header and is left to inspect the remaining IP header contents



it "knows" this because earlier it presumably ran a routing protocol like OSPF

- the router knows that the IP destinations (2,2) is connected to it via a point-to-point link running the PPP protocol

- so it packages the IP packet in a PPP frame and sends it off



- no physical address is needed in a point-to-point link as there is no ambiguity about what machines are connected to the wire (i.e. unlike most LANs the medium is not shared between more than 2 elements)

PC - to - server

- PC makes an IP packet with appropriate source & destination address

(2,2) (1,1)		IP packet

- it then sends it to its data link layer running PPP which makes the PPP frame

IP	IP packet	FCS

- the PPP frame is sent to the router which strips off the header and sends it to its IP entity

(2,2) (1,1)	

- the router learns the physical address of the destination (again by referencing the destination IP and running ARP ~~which~~ a protocol which we have not detailed in any way, so you don't have to know how ARP works) and creates the Ethernet frame

r, s, IP	IP packet	FCS

- which it broadcasts into the LAN

20. Problem 2.28.

- physical address: unique hardware address that identifies an interface of a machine on a physical network such as a LAN. Physical addresses are used in the data link layer
- network address: logical address (i.e. it is assigned by software) on a network. Used in network layer. Internet's network address is the IP address.
- domain names: Used as an aid to identify hosts & networks in the Internet since names are easier to remember than numbers DNS system is used to translate between domain names & IP addresses.

21. Problem 2.33.

- Physical address does not change. It is globally unique to the computer's NIC card
- IP address may need to be changed to reflect a new subnetwork ID & host ID
- Situation same for laptops

22. Problem 2.34.

- $\log_2(6\times10^9 \times 10^3) = 42.44$

  ⇒ 43 bits are required to assign a unique host address to each communicating device

- $\log_2(6\times10^9\times10^3/1000) = 29.2$

  ⇒ 30 bits are required to provide unique network IDs to each network

23. Problem 2.39.

H1

Destination	Next Hop
(1,0)	(1,2)
(2,0)	(1,1)
(3,0)	(1,4)

H2

Destination	Next Hop
(1,0)	(1,3)
(2,0)	(1,1)
(3,0)	(1,4)

R2

Destination	Next Hop
(1,0)	(2,1) ← maintaining the route from part (a)
(2,0)	(2,4)
(3,0)	(3,1)

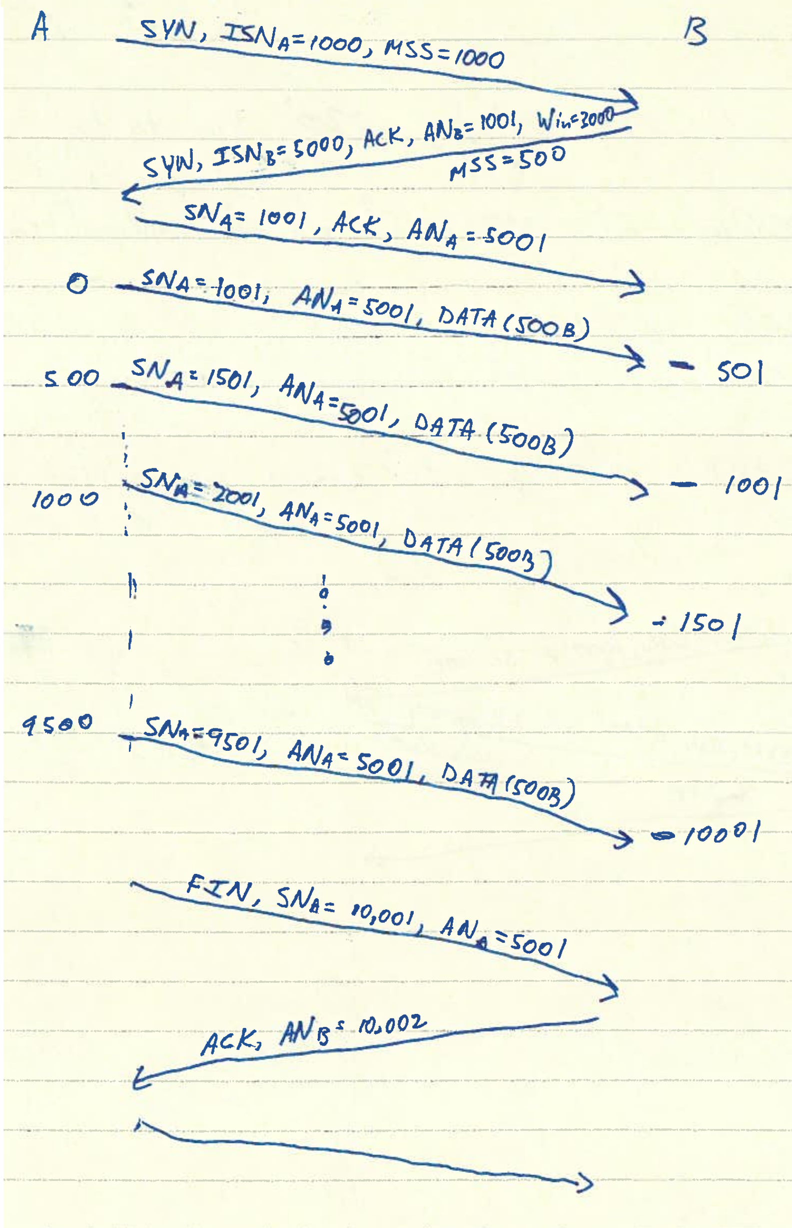
24. Problem 8.29(a).

$R = 8\,\text{Mbps}$ ∴ 1 byte takes ~~8/10~~ $1\,\mu s$ to tx

for $d = 200\,m$ at $v = 2\times10^8\,m/s$ in optical cable

$$t_{prop} = \frac{200}{2\times10^8} = 1\,\mu s$$

∴ 500 B takes $501\,\mu s$ to arrive completely at destination



during A's transmission B will provide inter-mittant ACKs e.g.