P4. Consider the circuit-switched network in Figure 1.13. Recall that there are four circuits on each link. Label the four switches A, B, C, and D, going in the clockwise direction.

a. What is the maximum number of simultaneous connections that can be in progress at any one time in this network?

b. Suppose that all connections are between switches A and C. What is the maximum number of simultaneous connections that can be in progress?

c. Suppose we want to make four connections between switches A and C, and another four connections between switches B and D. Can we route these calls through the four links to accommodate all eight connections?

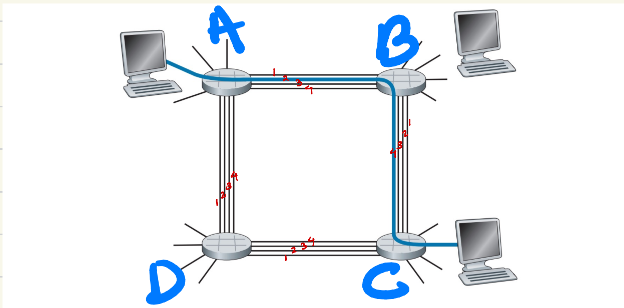


Figure 1.13 ♦ A simple circuit-switched network consisting of four switches and four links

a) 16 → 4 connections/@ each Router /link

→ 4 Router

4 connctions on each link fully utilized

A – B
B – C
C – D
D – A

* to get max ⇒ use less lengthy connecti- — link → free for other connect'- setups

b) 8 4 on A-B-C
4 on A-D-C

c) yes - see below

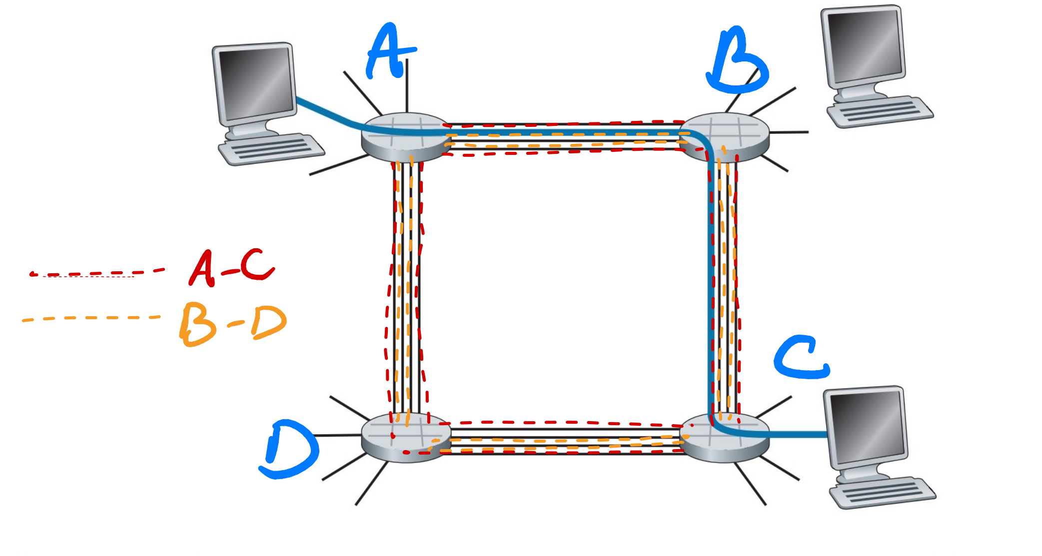


Figure 1.13 ♦ A simple circuit-switched network consisting of four sw
and four links

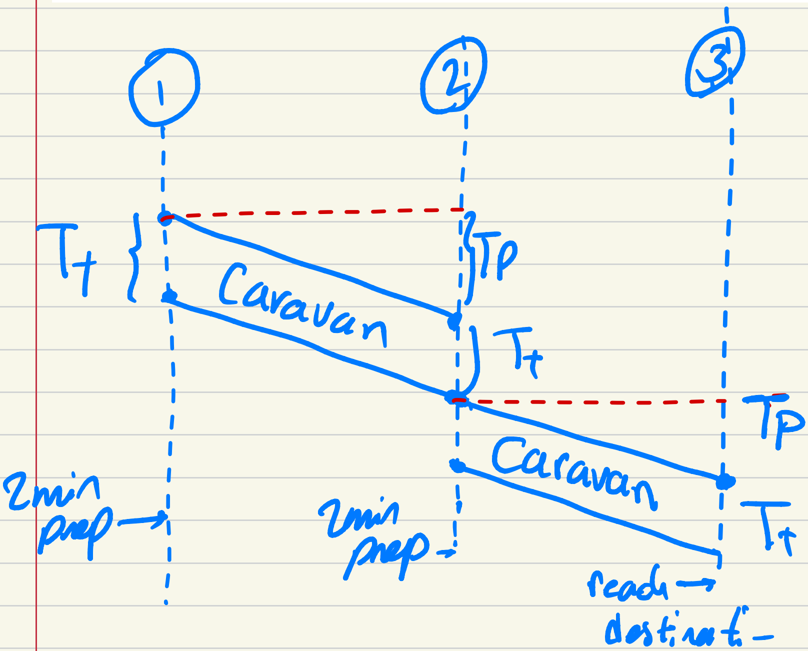
a connection = end 2 end circuit
link = single circuit

2. each connection consumes up to multiple circuits

P5. Review the car-caravan analogy in Section 1.4. Assume a propagation speed of 100 km/hour.

a. Suppose the caravan travels 175 km, beginning in front of one tollbooth, passing through a second tollbooth, and finishing just after a third tollbooth. What is the end-to-end delay?

b. Repeat (a), now assuming that there are eight cars in the caravan instead of ten.



a) $T_t = 2\,\text{min}$

Speed of cars = 100 km/h $\Rightarrow T_p = \frac{175}{100} \times 60 = 105$ (Combined)

end to end delay time =

$\underbrace{T_p + T_t + T_p}_{\text{combined}} + T_t \Rightarrow 105 + 4 = \boxed{109\ \text{min}}$

b) 5 car in 60 Sec
8 in ?

$\Rightarrow T_t = 96$ Sec

$$\Rightarrow T_{P_{comb}} + 2T_t = 105 \text{ min} + 2\left(\frac{96}{60}\right)_{\text{min}}$$

$$= \boxed{108.2 \text{ min}}$$

Prop velocity ≠ link bit rate

P6. This elementary problem begins to explore propagation delay and transmission delay, two central concepts in data networking. Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by m meters, and suppose the propagation speed along the link is s meters/sec. Host A is to send a packet of size L bits to Host B.

a. Express the propagation delay, d_{prop}, in terms of m and s.

b. Determine the transmission time of the packet, d_{trans}, in terms of L and R.

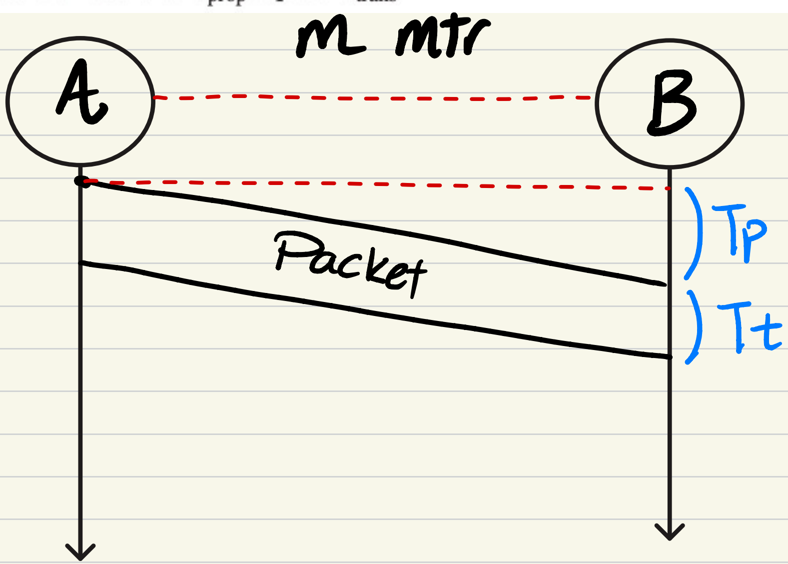
c. Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.

d. Suppose Host A begins to transmit the packet at time $t = 0$. At time $t = d_{trans}$, where is the last bit of the packet?

e. Suppose d_{prop} is greater than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?

f. Suppose d_{prop} is less than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?

g. Suppose $s = 2.5 \cdot 10^8$, $L = 1500$ bytes, and $R = 10$ Mbps. Find the distance m so that d_{prop} equals d_{trans}.



a) $d_{prop} = \dfrac{\text{distance}}{\text{Prop. Speed}} = \boxed{m/s}$

Prop velocity ≠ link bit rate

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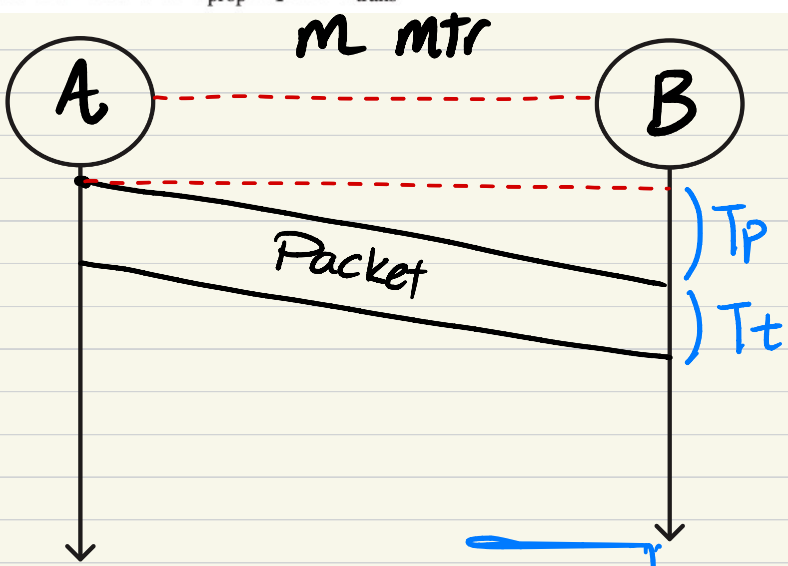

b) $d_{trans} = \dfrac{\text{Packet Size}}{\text{Transmission Rate}} = \boxed{\dfrac{L}{R}}$

Prop velocity ≠ link bit rate

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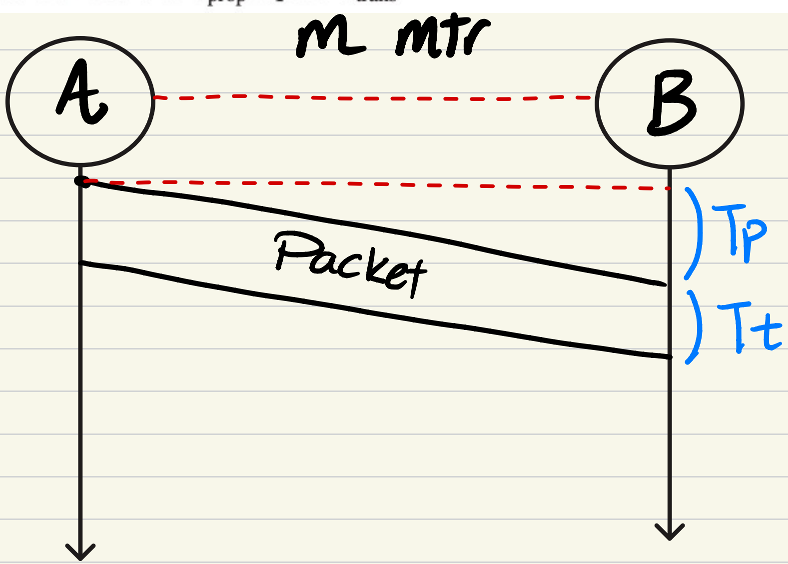

c) end_to_end delay $= d_{prop} + d_{trans}$

Prop velocity ≠ link bit rate

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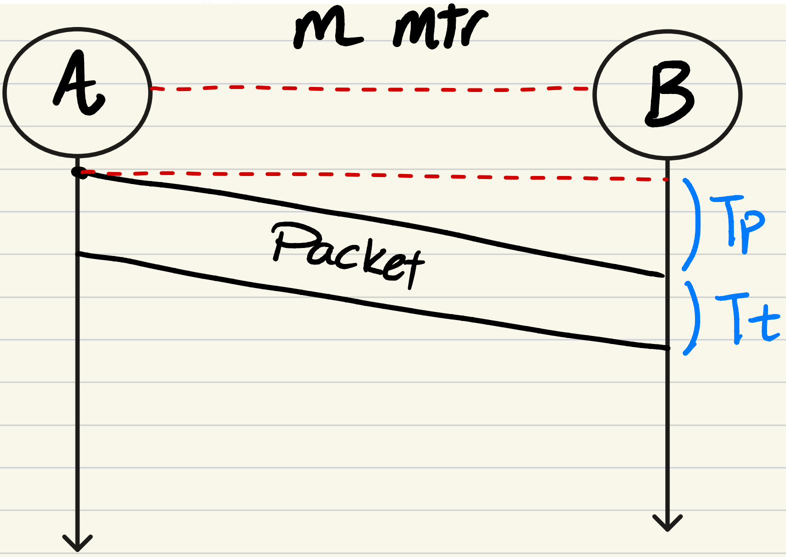

d) just left host A & pushed to link or medium or cable

Prop velocity ≠ link bit rate

P6. This elementary problem begins to explore propagation delay and transmission delay, two central concepts in data networking. Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by m meters, and suppose the propagation speed along the link is s meters/sec. Host A is to send a packet of size L bits to Host B.

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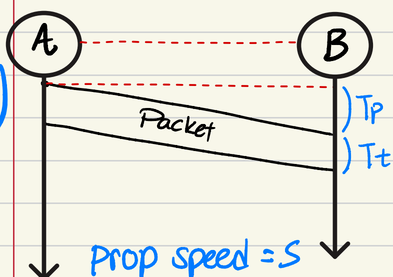
e)



Finding out location of A

Speed = S
time elapsed = d trans

=> location A → S × d trans

distance to reach Host B = S × d prop

d trans < d prop

→ location A < location of host B

→ First bit is somewhere in the link not reached to host B yet!

P6. This elementary problem begins to explore propagation delay and transmission delay, two central concepts in data networking. Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by m meters, and suppose the propagation speed along the link is s meters/sec. Host A is to send a packet of size L bits to Host B.

a. Express the propagation delay, d_{prop}, in terms of m and s.

b. Determine the transmission time of the packet, d_{trans}, in terms of L and R.

c. Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.

d. Suppose Host A begins to transmit the packet at time $t = 0$. At time $t = d_{trans}$, where is the last bit of the packet?

e. Suppose d_{prop} is greater than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?

f. Suppose d_{prop} is less than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?

g. Suppose $s = 2.5 \cdot 10^8$, $L = 1500$ bytes, and $R = 10$ Mbps. Find the distance m so that d_{prop} equals d_{trans}.

f) Location_A = S (speed) * d trans

Location_host$_B$ = S * d prop

$d_{prop} < d_{trans}$

→ Location_A > locati_host$_B$

→ First bit of packet has reached to host B

P6. This elementary problem begins to explore propagation delay and transmission delay, two central concepts in data networking. Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by m meters, and suppose the propagation speed along the link is s meters/sec. Host A is to send a packet of size L bits to Host B.

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f. Suppose d_{prop} is less than d_{trans}. At time $t = d_{trans}$, where is the first bit of the packet?

g. Suppose $s = 2.5 \cdot 10^8$, $L = 1500$ bytes, and $R = 10$ Mbps. Find the distance m so that d_{prop} equals d_{trans}.

g) $S = 2.5 * 10^8$

$L = 1500 * 8$ bites

$R = 10$ Mbps

$$\left(d\,prop = \frac{m}{S}\right) = \left(d\,trans = \frac{L}{R}\right)$$

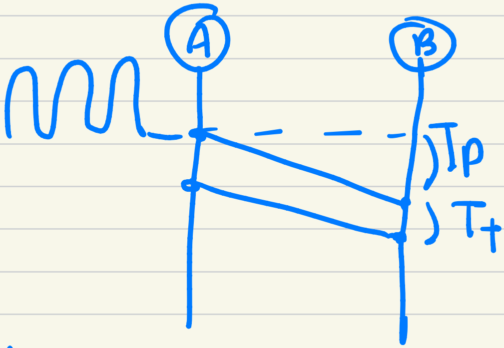
$$\frac{m}{2.5*10^8} = \frac{1500 \times 8}{10 \times 10^6} = \boxed{3 \times 10^5 \text{ meter} = 300\text{ km}}$$

P7. In this problem, we consider sending real-time voice from Host A to Host B over a packet-switched network (VoIP). Host A converts analog voice to a digital 64 kbps bit stream on the fly. Host A then groups the bits into 56-byte packets. There is one link between Hosts A and B; its transmission rate is 10 Mbps and its propagation delay is 10 msec. As soon as Host A gathers a packet, it sends it to Host B. As soon as Host B receives an entire packet, it converts the packet's bits to an analog signal. How much time elapses from the time a bit is created (from the original analog signal at Host A) until the bit is decoded (as part of the analog signal at Host B)?

link $R_{trans} = 10 \times 10^6$ bps

$d_{prop} = 10 \times 10^{-3}$ sec $= 1000 \times 10^{-5}$ sec

packet size $= 56 * 8$ bite



- $d_{prop} = T_p$

$+$

- Time to create a packet $=$

$+ \; \dfrac{56 \times 8}{64 \times 10^3} = \boxed{4.48 \times 10^{-5}\,s}$

Transmit delay $=$

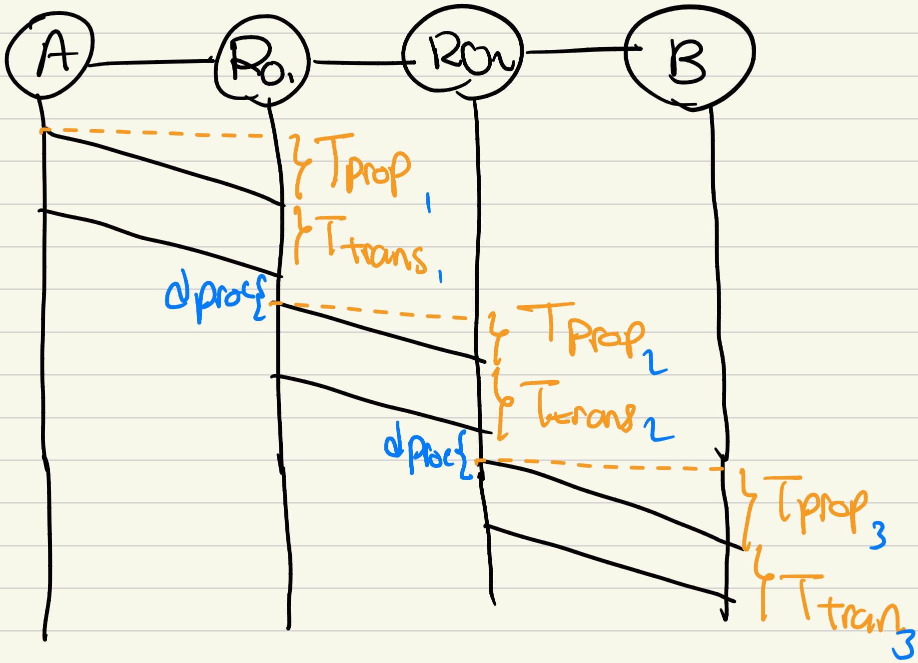
- $d_{trans} = \dfrac{56 * 8}{10^7} = \boxed{700 \times 10^{-5}\,s}$

$\boxed{\text{Total Elapsed Time } 1704.48 \times 10^{-5} \text{ sec}}$

$\simeq 17$ ms

P10. Consider a packet of length L that begins at end system A and travels over three links to a destination end system. These three links are connected by two packet switches. Let d_i, s_i, and R_i denote the length, propagation speed, and the transmission rate of link i, for $i = 1, 2, 3$. The packet switch delays each packet by d_{proc}. Assuming no queuing delays, in terms of d_i, s_i, R_i, ($i = 1, 2, 3$), and L, what is the total end-to-end delay for the packet? Suppose now the packet is 1,500 bytes, the propagation speed on all three links is $2.5 \cdot 10^8$m/s, the transmission rates of all three links are 2.5 Mbps, the packet switch processing delay is 3 msec, the length of the first link is 5,000 km, the length of the second link is 4,000 km, and the length of the last link is 1,000 km. For these values, what is the end-to-end delay?

a)



a) $\Rightarrow T_{prop_1} + T_{trans_1} + d_{proc} + T_{prop_2} + T_{trans_2} + d_{proc} + T_{prop_3} + T_{trans_3}$

end-to-end delay =

$$\left[\frac{d_1}{s_1} + \frac{L}{R_1} + \frac{d_2}{s_2} + \frac{L}{R_2} + \frac{d_3}{s_3} + \frac{L}{R_3} + 2 * d_{proc}\right]$$

P10. Consider a packet of length L that begins at end system A and travels over three links to a destination end system. These three links are connected by two packet switches. Let d_i, s_i, and R_i denote the length, propagation speed, and the transmission rate of link i, for $i = 1, 2, 3$. The packet switch delays each packet by d_{proc}. Assuming no queuing delays, in terms of d_i, s_i, R_i, ($i = 1, 2, 3$), and L, what is the total end-to-end delay for the packet? Suppose now the packet is 1,500 bytes, the propagation speed on all three links is $2.5 \cdot 10^8$m/s, the transmission rates of all three links are 2.5 Mbps, the packet switch processing delay is 3 msec, the length of the first link is 5,000 km, the

b) length of the second link is 4,000 km, and the length of the last link is 1,000 km. For these values, what is the end-to-end delay?

b) $L = 1500 * 8$ bites

$S = 2.5 \times 10^8$ m/s

$R = 2.5 \times 10^6$ b/s

$d_{proc} = 3 \times 10^{-3}$ s

$d_1 = 5 \times 10^6$ m $d_2 = 4 \times 10^6$ m $d_3 = 10^6$ m

$$\frac{d_1}{S_1} + \frac{L}{R_1} + \frac{d_2}{S_2} + \frac{L}{R_2} + \frac{d_3}{S_3} + \frac{L}{R_3} + 2 * d_{proc}$$

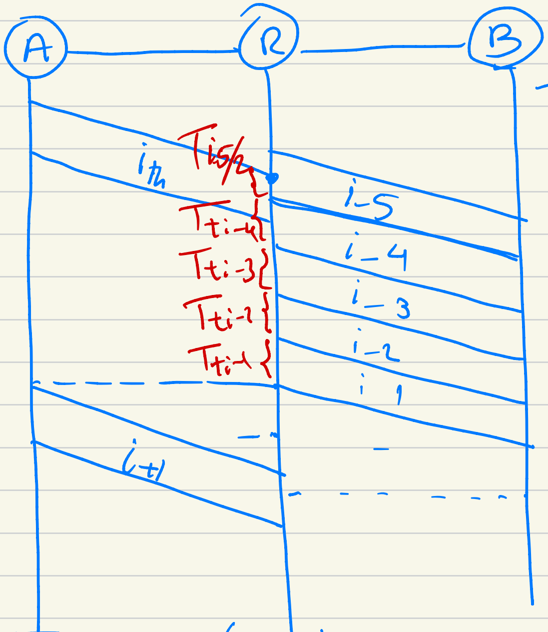
$$\frac{5 \times 10^6}{2.5 \times 10^8} + \frac{1500 * 8}{2.5 \times 10^6} + \frac{4 \times 10^6}{2.5 \times 10^8} + \frac{1500 * 8}{2.5 \times 10^6} +$$

$$\frac{10^6}{2.5 \times 10^8} + \frac{1500 * 8}{2.5 \times 10^6} + (2 * 3 \times 10^{-3}) =$$

end_to_end delay $\boxed{60.4 \text{ ms}}$

Queing delay → Time elapsed from first bit recvd till we can send sec packe first bit

P12. A packet switch receives a packet and determines the outbound link to which the packet should be forwarded. When the packet arrives, one other packet is halfway done being transmitted on this outbound link and four other packets are waiting to be transmitted. Packets are transmitted in order of arrival. Suppose
a) all packets are 1,500 bytes and the link rate is 2.5 Mbps. What is the queuing delay for the packet? More generally, what is the queuing delay when all packets
b) have length L, the transmission rate is R, x bits of the currently-being-transmitted packet have been transmitted, and n packets are already in the queue?



$T_{ti} = \frac{12000}{2.5 \times 10^6} =$

4.8 ms

a) $T_{ti}/2 + 4(T_{ti}) = 4.5 \times 4.8\ ms =$

$d_Q \Longrightarrow \boxed{21.6\ ms}$

$$\boxed{b) \Rightarrow \left(\frac{L-X}{R}\right) + n(L/R)}$$

P20. Consider the throughput example corresponding to Figure 1.20(b). Now suppose that there are M client-server pairs rather than 10. Denote R_s, R_c, and R for the rates of the server links, client links, and network link. Assume all other links have abundant capacity and that there is no other traffic in the network besides the traffic generated by the M client-server pairs. Derive a general expression for throughput in terms of R_s, R_c, R, and M.

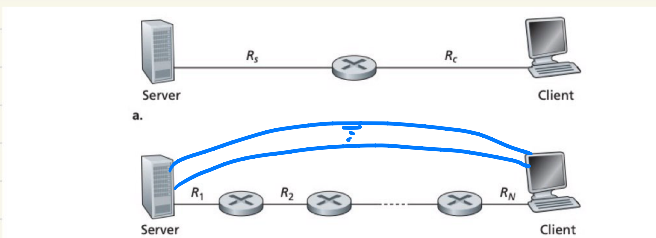
Rc
Rs
M clients

$$\Rightarrow \boxed{\min\left(R_s, R_c, R/M\right)}$$

P21. Consider Figure 1.19(b). Now suppose that there are M paths between the server and the client. No two paths share any link. Path k ($k = 1, \ldots, M$) consists of N links with transmission rates $R_1^k, R_2^k, \ldots, R_N^k$. If the server can only use one path to send data to the client, what is the maximum throughput that the server can achieve? If the server can use all M paths to send data, what is the maximum throughput that the server can achieve?

a)

b)



a) $\max\left(\min\left(R_1^1, R_2^1, \ldots, R_N^1\right), \min\left(R_1^2, R_2^2, \ldots, R_N^2\right), \ldots, \min\left(R_1^M, R_2^M, \ldots, R_N^M\right)\right)$

$$= \max_{k=1,\ldots,M}\left(\min_{i=1,\ldots,N} R_i^k\right)$$

b) Through put → rate @ which bits leave server successfully & reach client

\# of bits per second can server deliver to client

⇒ parallel network ⇒ max throughput = sum of bits leave server @ a second

$$\Rightarrow \sum_{k=1}^{M} \left(\min_{i=1,\dots,N} R_i^k \right)$$

P25. Suppose two hosts, A and B, are separated by 20,000 kilometers and are connected by a direct link of $R = 5$ Mbps. Suppose the propagation speed over the link is $2.5 \cdot 10^8$ meters/sec.

a. Calculate the bandwidth-delay product, $R \cdot d_{prop}$.

b. Consider sending a file of 800,000 bits from Host A to Host B. Suppose the file is sent continuously as one large message. What is the maximum number of bits that will be in the link at any given time?

c. Provide an interpretation of the bandwidth-delay product.

d. What is the width (in meters) of a bit in the link? Is it longer than a football field?

e. Derive a general expression for the width of a bit in terms of the propagation speed s, the transmission rate R, and the length of the link m.

Sender kept link Busy & has data always

A —— 20K km —— B

$R = 5 \times 10^6$ bps

Prop Speed = 2.5×10^8 m/s

a) $d_{prop} = \dfrac{20 \times 10^3 \times 10^3}{2.5 \times 10^8} = 0.08\,s = 80\,ms$

$(BW)(delay) = (5 \times 10^6)(8 \times 10^{-2}) =$

a) $\boxed{400\ Kb}$

b) (bandwidth)(delay) = 400 Kb

800 Kb > 400 Kb

↳ So $\boxed{\text{max \# of bit on link } 400\text{Kb}}$

c) it describes fullness of link —
it's number of bits that can
fill the link

it has 2 Definiti—
Def 1 ⇒ max number of bits
that fill up pipe @ anytime till the
packet fully propagates
↳ (BW)(delay | prop)

Def 2 ⇒ max number of bits
that fill up pip till sender
receives acknowledgment
from receiver ⇒
max number of bits transmitd
from packet $t = 0$ till
sender receives ack is
Bandwidth-delay product
= (BW)(RTT)

d) $\dfrac{\text{occupied length}}{\text{\# of bits on occupied length}} = \dfrac{20\times10^{6}}{4\times10^{5}} = \boxed{\dfrac{50m}{mpb}}$

[almost half of a football field]

e) $\dfrac{m}{(BW)(\text{delay}_{\text{prop}})} = \dfrac{m}{(R)(m/s)} = \dfrac{S}{R}$

$\boxed{\text{width of a bit is propagati-speed divided by link rate } \left(\frac{S}{R}\right)}$

it's in meter

P28. Refer again to problem P24.

a. How long does it take to send the file, assuming it is sent continuously?

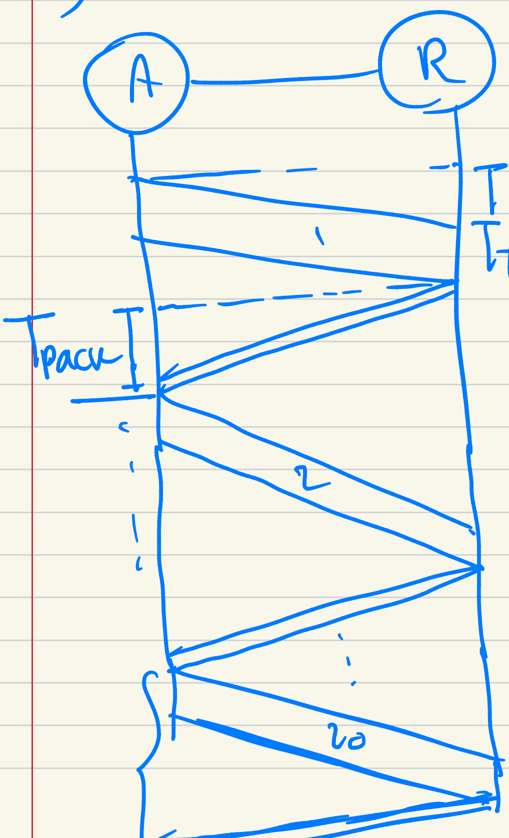
b. Suppose now the file is broken up into 20 packets with each packet containing 40,000 bits. Suppose that each packet is acknowledged by the receiver and the transmission time of an acknowledgment packet is negligible. Finally, assume that the sender cannot send a packet until the preceding one is acknowledged. How long does it take to send the file?

c. Compare the results from (a) and (b).

a) $T_t = \frac{\text{Length}}{\text{bitRate}} = \frac{8\times10^5\,b}{5\times10^6} = 1.6\times10^{-1}\,s$

$+ \underline{T_{prop}} = 80ms \Rightarrow \boxed{240\,ms}$

b)



$\Rightarrow$ Senders can only confirm the transmission is complete after reciving ack for last package

$20(T_p + T_t + T_{pack})$

$20\left(80ms + \frac{4\times10^4}{5\times10^6}s + 80ms\right)$

$\boxed{20(160\,ms + 8) = 3360\,ms}$

c) breaking a packet into smaller ones & sending them one by one after each acknowledgment is very time consuming