1.

(a) (i) $[k-4, k-3, k-2, k-1]$ (iii) $[k-2, k-1, k, k+1]$ (v) $[k, k+1, k+2, k+3]$

(ii) $[k-3, k-2, k-1, k]$ (iv) $[k-1, k, k+1, k+2]$

(b)

(i) $[k-4, k-3, k-2, k-1]$ (iii) $[k-2, k-1]$ (v) ϕ

(ii) $[k-3, k-2, k-1]$ (iv) $[k-1]$

$\therefore$ All possible value of ACK $= [k-4, k-3, k-2, k-1]$

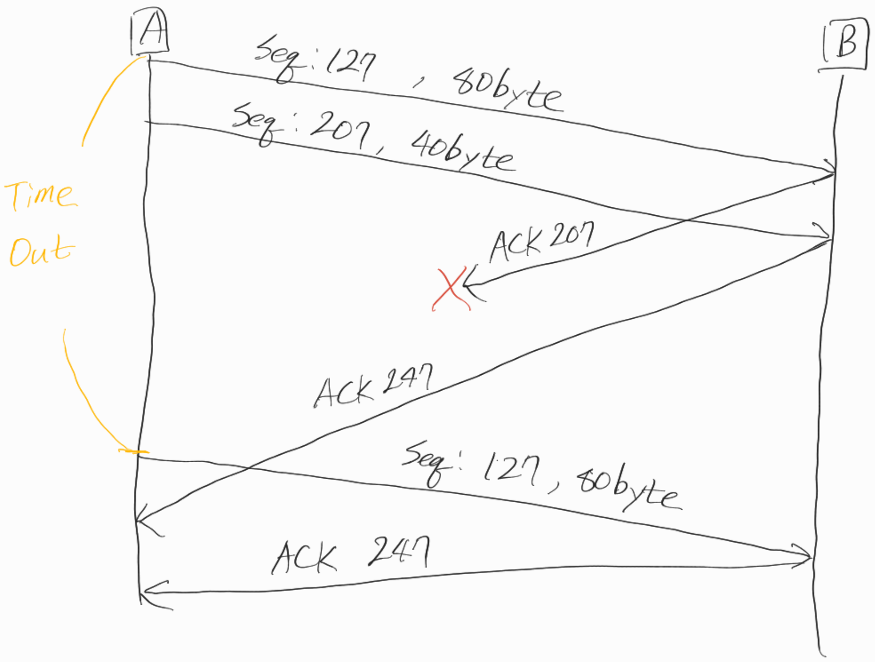
2.

(a) Sequence Number: 207, Source Port: 302, Destination Port: 80

(b) ACK Number: 207, Source Port: 80, Destination Port: 302

(c) ACK Number: 127

(d)



3.

(a) Assume there is initial Estimated RTT, Estimated RTT_5.

$$\text{Estimated } RTT_4 = (1-\alpha)\,\text{Estimated } RTT_5 + \alpha\,\text{Sample}RTT_4$$

$$\text{Estimated } RTT_3 = (1-\alpha)\,\text{Estimated } RTT_4 + \alpha\,\text{Sample}RTT_3$$
$$= (1-\alpha)^2\,\text{Estimated } RTT_5 + \alpha(1-\alpha)\,\text{Sample}RTT_4 + \alpha\,\text{Sample}RTT_3$$

$$\text{Estimated } RTT_2 = (1-\alpha)\,\text{Estimated } RTT_3 + \alpha\,\text{Sample } RTT_2$$
$$= (1-\alpha)^3\,\text{Estimated}RTT_5 + \alpha(1-\alpha)^2\,\text{Sample}RTT_4 + \alpha(1-\alpha)\,\text{Sample}RTT_3 + \alpha\,\text{Sample}RTT_2$$

$\text{EstimatedRTT}_1 = (1-\alpha)\,\text{EstimatedRTT}_2 + \alpha\,\text{SampleRTT}_1$

$= (1-\alpha)^4\,\text{EstimatedRTT}_5 + \alpha(1-\alpha)^3\,\text{SampleRTT}_4 + \alpha(1-\alpha)^2\,\text{SampleRTT}_3 + \alpha(1-\alpha)\,\text{SampleRTT}_2 + \alpha\,\text{SampleRTT}_1$

$\therefore \text{Estimated RTT}_1 = 0.9^4\,\text{EstimatedRTT}_5 + 0.1\cdot 0.9^3\,\text{SampleRTT}_4 + 0.1\cdot 0.9^2\,\text{SampleRTT}_3$
$+ 0.1\cdot 0.9\,\text{SampleRTT}_2 + 0.1\,\text{Sample RTT}_1$

(Estimated RTT_5 is a constant)

(b)

$$\text{Estimated RTT}_1 = 0.9^n\,\text{EstimatedRTT}_{n+1} + 0.1\sum_{k=1}^{n}(0.9)^{k-1}\,\text{SampleRTT}_k$$

(c)

$$\lim_{n\to\infty}\text{EstimatedRTT}_1 = 0\cdot\text{EstimatedRTT}_{n+1} + 0.1\sum_{k=1}^{\infty}(0.9)^{k-1}\,\text{SampleRTT}_k$$

In each movement, 0.9 is multiplyed to the old sample RTT so that this movement is exponential moving average.

4.

(a) [0, 6], [23, 26]

(b) [6, 23] (AIMD Used)

(c) Triple Duplicate ACK

(d) Time out

(e) 32

(f) 21

(g) 13

(h) 7th round

(i) Window size = 4, ssthresh = 4

(j) ssthresh = 21
Window size = 4

(k)

Round	17	18	19	20	21	22
W	1	2	4	8	16	21

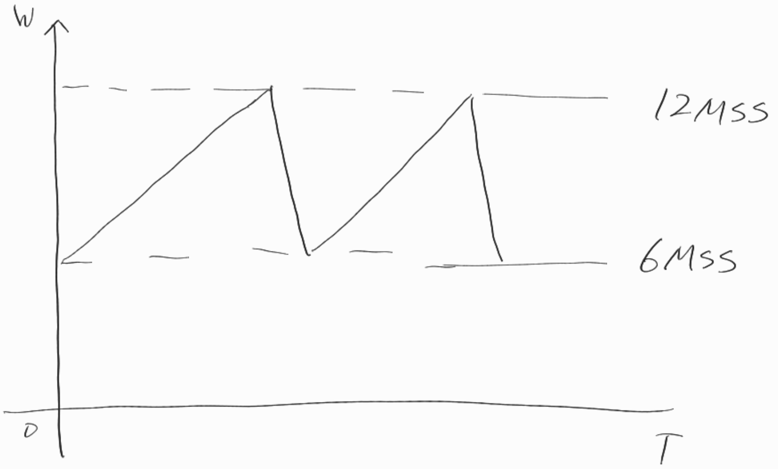
$\therefore$ 52 packets

5.

(a) 1MSS increse /RTT

6MSS ~ 12MSS => 6RTT $\quad \therefore$ 6RTT

(b)

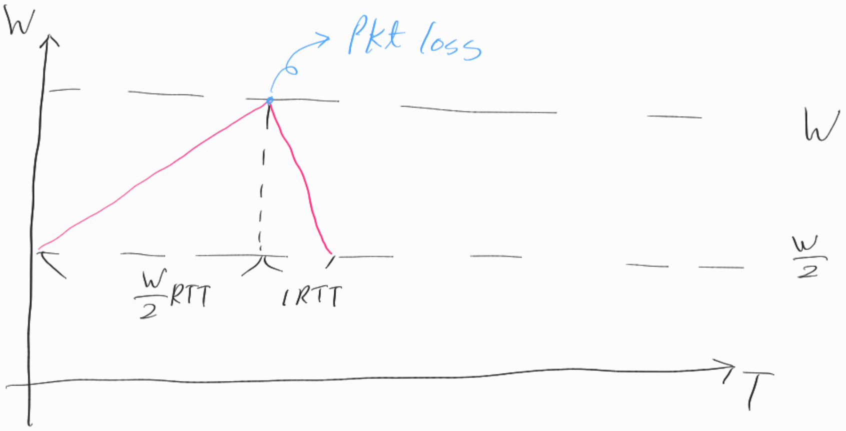


$$\left(\frac{3}{4} \cdot \frac{12MSS}{RTT} = \frac{9MSS}{RTT}\right)$$

$$\therefore \frac{9MSS}{RTT}$$

6.

(a)



Avg Throughput

$$= \frac{3}{4} \frac{W\,MSS}{RTT}$$

$$\frac{3}{4}W\left(\frac{W}{2}+1\right) = \frac{3}{8}W^2 + \frac{3}{4}W \Rightarrow \text{\# of pkt.}$$

There was only one loss.

$$\therefore L = \frac{1}{\frac{3}{8}W^2 + \frac{3}{4}W}$$

(b) $\frac{3}{8}W^2 >> \frac{3}{4}W \longrightarrow L \simeq \frac{1}{\frac{3}{8}W^2} = \frac{8}{3W^2}$

$$\sqrt{L} = \frac{1}{W}\sqrt{\frac{8}{3}} \Rightarrow W = \sqrt{\frac{8}{3L}}$$

$$\text{Avg throughput} = \frac{3W \cdot MSS}{4RTT} = \frac{3 \cdot \sqrt{8} \cdot MSS}{4\sqrt{3L} \cdot RTT} = \frac{1\ MSS}{RTT\sqrt{L}} \times \frac{3\sqrt{8}}{4\sqrt{3}}$$

$$\left(\because \frac{3\sqrt{8}}{4\sqrt{3}} \simeq 1.22\right) \qquad \approx \frac{1.22 \cdot MSS}{RTT\sqrt{L}}$$

7.

$$2\text{-way } d_{prop} = RTT = 150ms = 0.15s$$

$$1MSS = 1500byte$$

$$Throughput_{max} = 10Mbps$$

(a)

$$\frac{W_{max} \cdot 1MSS}{RTT} = 10^7 bps \Rightarrow W_{max} = 10^7 bps \times \frac{0.15s}{1500 \cdot 8bit} = 125$$

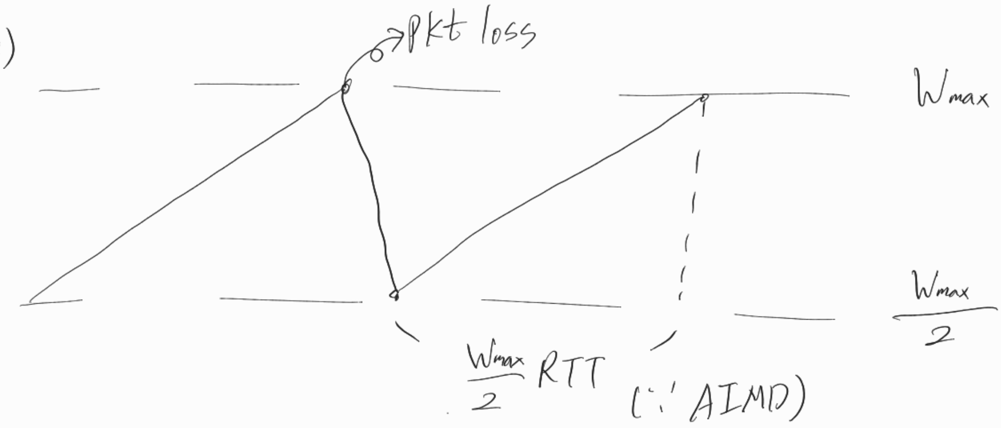
$\therefore$ 125 segments

(b)

$$Avg\ Throughput = \frac{3}{4}\frac{W_{max} \cdot 1MSS}{RTT} = \frac{3}{4} \times 10Mbps = 7.5Mbps$$

$$Avg\ Window size = \frac{3}{4} \times W_{max} = \frac{3}{4} \times 125 = 93.75 \text{ segments}$$

(c)



$$\frac{125}{2} \times 0.15s = 9.375s \qquad \therefore 9.375s$$