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]

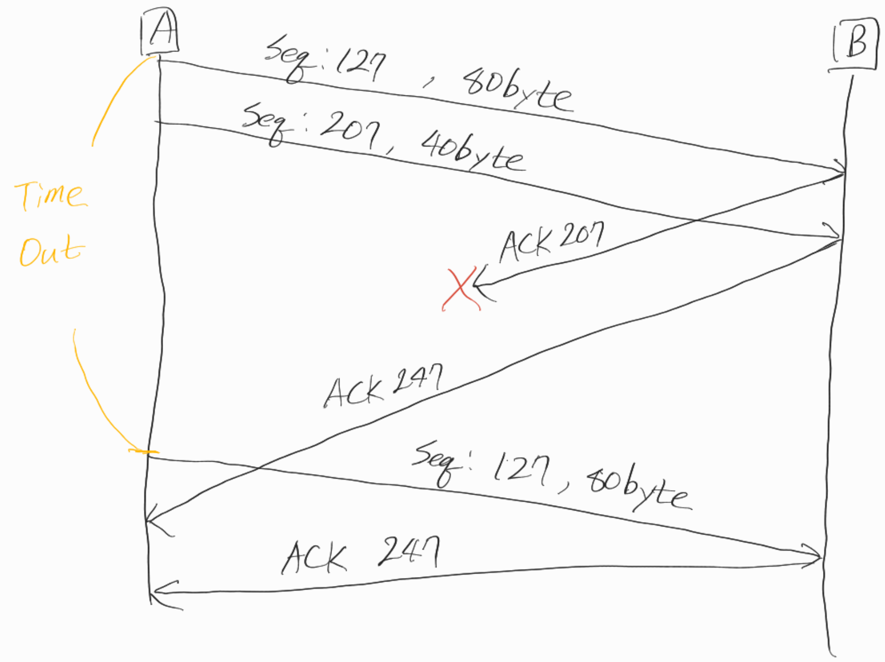
2.

(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, $EstimatedRTT_5$.

$EstimatedRTT_4 = (1-\alpha) EstimatedRTT_5 + \alpha\, SampleRTT_4$

$EstimatedRTT_3 = (1-\alpha)\, EstimatedRTT_4 + \alpha\, SampleRTT_3$

$= (1-\alpha)^2 EstimatedRTT_5 + \alpha(1-\alpha)\, SampleRTT_4 + \alpha\, SampleRTT_3$

$EstimatedRTT_2 = (1-\alpha)\, EstimatedRTT_3 + \alpha\, SampleRTT_2$

$= (1-\alpha)^3 EstimatedRTT_5 + \alpha(1-\alpha)^2 SampleRTT_4 + \alpha(1-\alpha)\, SampleRTT_3 + \alpha\, SampleRTT_2$

$EstimatedRTT_1 = (1-\alpha) EstimatedRTT_2 + \alpha SampleRTT_1$

$= (1-\alpha)^4 EstimatedRTT_5 + \alpha (1-\alpha)^3 SampleRTT_4 + \alpha(1-\alpha)^2 SampleRTT_3 + \alpha(1-\alpha) SampleRTT_2 + \alpha SampleRTT_1$

$\therefore EstimatedRTT_1 = 0.9^4 EstimatedRTT_5 + 0.1 \cdot 0.9^3 SampleRTT_4 + 0.1 \cdot 0.9^2 SampleRTT_3$
$+ 0.1 \cdot 0.9 SampleRTT_2 + 0.1 SampleRTT_1$

($EstimatedRTT_5$ is a constant)

(b)

$$EstimatedRTT_1 = 0.9^n EstimatedRTT_{n+1} + 0.1 \sum_{k=1}^{n} (0.9)^{k-1} SampleRTT_k$$

(c)

$$\lim_{n \to \infty} EstimatedRTT_1 = 0 \cdot EstimatedRTT_{n+1} + 0.1 \sum_{k=1}^{\infty} (0.9)^{k-1} SampleRTT_k$$

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, 22] (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

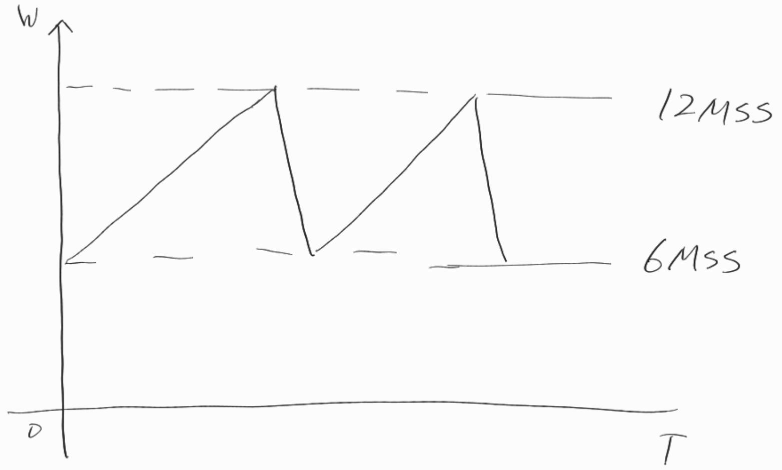
$\therefore$ 52 packets

5.

(a) 1MSS incrase /RTT

6MSS ~ 12MSS ⇒ 6RTT $\qquad \therefore$ 6RTT

(b)

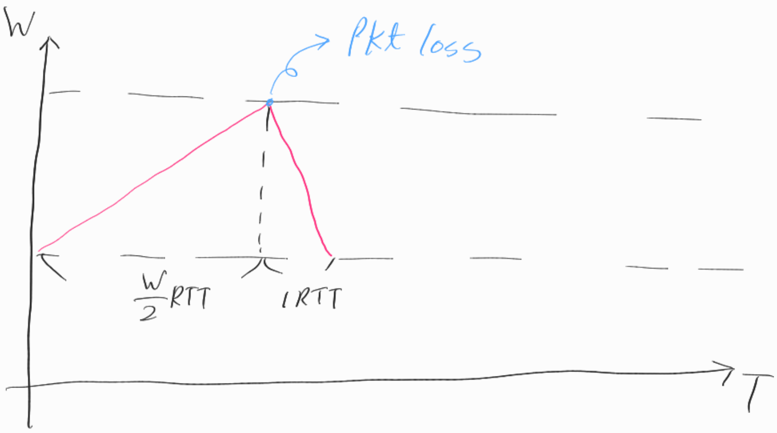


$$\left(\frac{3}{4}\cdot\frac{12MSS}{RTT} = \frac{9MSS}{RTT}\right)$$

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

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

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

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

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

7.

2-way dprop $= RTT = 150ms = 0.15s$

$1MSS = 1500byte$

$Throughput_{max} = 10Mbps$

(a)

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

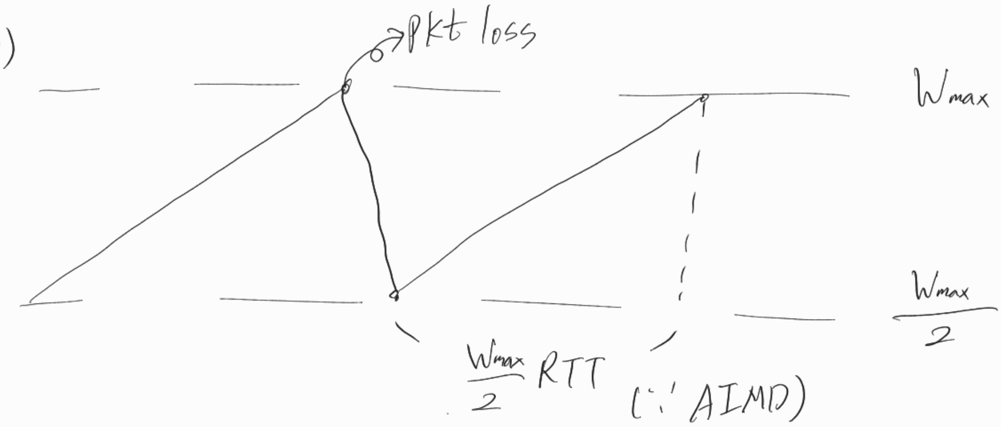
$\therefore$ 125 segments

(b)

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

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

(c)



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