

COMP3331 Assignment 1

Name : Lean Lynn Oh

zID: z5144464

STP protocol implementation details

- STP Protocol is implemented in python 3.6.5 and consist 3 modules; sender.py, receiver.py and stp_packet.py. There are 4 classes in total in my program: Sender, Receiver, Timeout and STPPacket.
- STP protocol is implemented with single thread. Hence, the output is slightly different from the sample log but it behaves the same.

Structure of the program

- sender.py includes the following:
 - Sender class: in charge of connection establishment, connection termination, read file, calculate file size, create payload with size of mss, write to log file, send packet and receive packet. The pld module (in sender class) is used to emulate events that may occur such as packet loss, delays, reorder packet, corrupt packet and send duplicate packet.
 - Timeout class: to calculate timeout interval and store current timeout interval
- receiver.py includes receiver class: in charge of connection establishment, connection termination, write to log file, write received data to file, receive packet and send packet.
- stp_packet.py includes the followings:
 - STPPacket class: the packet structure. My STP packet includes payload, sequence number, ack number, checksum and booleans such as ack, syn and fin.
 - Additional functions for manipulating the packet
 - checksum: calculate the checksum of payload in a packet at the sender
 - corrupt: corrupt the payload in a packet by flipping 1 bit
 - receiver_checksum function: calculate the checksum of payload in a packet at the receiver.

Sender's features and its implementations

1. **3 way handshake** for connection establishment is implemented in handshake in sender.py. Sender sends SYN, receive SYNACK and send ACK. During the 3 way handshake, sender updates its states (closed, syn sent and established) accordingly. In the syn sent state, the sequence number and acknowledgment number is incremented by 1.
2. **4 segment connection** termination is implemented in close_connection in sender.py. Sender sends FIN when it has received the ack for the last packet. At this point, it would not send any delayed packets. Sender receive ACK and FIN from receiver and send ACK to acknowledge the fin packet. The sender updates its states (end, fin wait 1, fin wait 2, time wait and closed) accordingly. In the end state, the sequence number is incremented by 1. In the fin wait 2 state, the ack number is the sequence number of received fin incremented by 1.
3. Sender implements the event loop in Figure 3.33 (pg. 273) in the textbook and uses the concepts of sequence number, acknowledge number and flags(ACK, FIN, SYN) in its STP header.

4. In process_data, sender open the file with given filename and read its contents in bytes. Then, it **splits the data into MSS size** and stores them in a list. Sender also calculate the total file size in calc_total_payload for logging purposes.
5. To send a packet, sender **checks for any space in the current window** (last byte sent – last byte acked <= mws) and **check for any unsend bytes** (last byte sent < file size). If there is any unsend bytes, the sender will **create a packet** with the correct payload from the list (self.contents) and **add it to the packet buffer**. The sender will send as many packets as possible without exceeding MWS bytes. The sequence number of the next packet is incremented with the current payload length. This packet is then **send to the pld** module. In the pld module, the sender will add the send time to self.rtt_time and self.send_time. self.rtt_time is a buffer to keep track of the send time of all the packet for RTT calculation. self.send_time keep track of the send time for each packet including for retransmission and it is use in timeout retransmission. If the timer isn't start yet, the sender will **start the timer**.
6. Sender maintain **a single timer** for timeout operation. I implement my timer by setting self.timer to True to indicate there is a timer. The RTO timer is always place at the **send base** (smallest unacknowledged packet in the window). For the **initial timeout** (when send base = 1), the **estRTT** and **DevRTT** are initiated to **500ms** and **250ms** respectively and calculated with the timeout interval formula. Upon receiving an ack for not retransmitted packet, the sender will calculate the sampleRTT by taking the difference between the send time and the receive time. Then, this is pass to calc_timeout in the Timeout class to calculate the timeout with the following fomulas:

$$\text{estRTT} = (1 - \alpha) * \text{estRTT} + \alpha * \text{sampleRTT}$$

$$\text{devRTT} = (1 - \beta) * \text{devRTT} + \beta * \text{abs}(\text{sampleRTT} - \text{estRTT})$$

$$\text{timeout} = (\text{estRTT} + \gamma * \text{devRTT}) / 1000$$

***alpha = 0.125 , beta = 0.25, gamma = user input**

Once a packet in the window is retransmitted, I disregard the whole window including the retransmitted packet for timeout interval calculation by removing everything in self.rtt_time. I have set my minimum RTO to be 0.2 second and maximum RTO to be 1 minute based on Linux TCP implementation and suggestion from Nadeem.
7. The STP sender implements **cumulative acknowledgements** as it acknowledges all previously send packet with sequence number smaller than currently received ack number. Current acknowledge number will be the new send base. The sender will remove all acknowledged packets from the packet buffer. If there are packets remaining in the buffer, the sender will start the timer.
8. Upon receiving a duplicate ack, the sender will increment the dup_num counter. The dup_num counter keeps track of the number of ack received with the same ack number. Once the sender had received 3 duplicate acks, the sender will carried out **fast retransmission** by retransmitting the smallest unacknowledged packet.
9. **Timeout transmission** is implemented in sender. It is manually calculated by comparing the send time of the smallest unacknowledged packet and the current time during socket timeout. Socket timeout is set to 0.1. If the time difference is larger or equal to the timeout, the sender will retransmit this smallest unacknowledged packet.
10. The **pld module** is implemented with pseudorandom number generator to determine the condition a packet has to go through. I have initialise the random number generator with a seed value and used random.random() to generate a random number. The probability of an occurrence for a condition is supplied with user input probability. The condition are as the following:
 - a. Drop packet: drop a packet if the random number is less than pDrop

- b. Duplicate packet: send 2 back to back packets if the random number is less than pDuplicate and the packet isn't dropped.
 - c. Corrupt packet: corrupt a packet by flipping a bit if the random number is less than pCorrupt and the packet isn't dropped and duplicated
 - d. Order packet: order a packet if the random number is less than pOrder and the packet isn't dropped, duplicated or corrupted. Also, there isn't any packet waiting for reordering.
 - e. Delay packet: delay a packet if the random number is less than pDelay and the packet isn't dropped, duplicated, corrupted or reordered.
 - f. Send a packet without error: send the packet if all the conditions in a-e are not fulfilled.
11. The sender **update Sender_log.txt** with the information about each packet it sends and receives. At the end of execution, the sender updates the required statistics in the assignment specification to the log file.

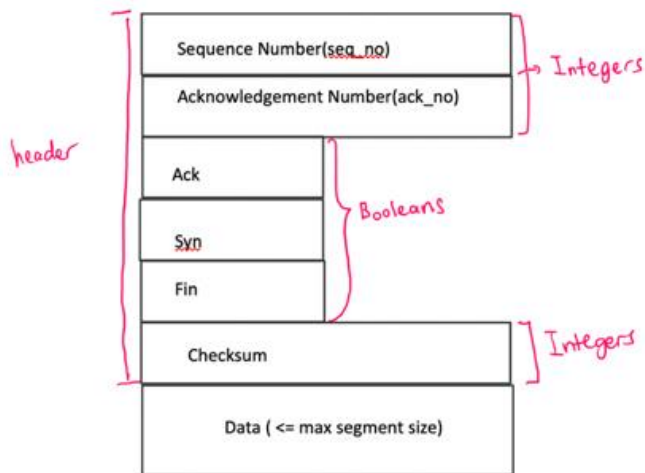
Receiver's features and its implementation

1. **3 ways handshake** for connection establishment is implemented in handshake in receiver.py. Receiver receives SYN, send SYNACK and receive ACK. Receivers updates its states(listen, SYN receive, established) accordingly. Receiver's ack number and seq number are incremented by 1 upon receiving a SYN.
2. **4 segment connection termination** is implemented in close in receiver.py. Receiver receives FIN, sends FIN, sends ACK and receives ACK. Receiver updates its states (closed wait, last ack, closed) accordingly. The seq number and ack number is incremented by 1.
3. Receiver uses the concepts of **sequence number**, **acknowledge number** and flags(ACK, FIN, SYN) in its STP header. The acknowledge number will be incremented by the length of the payload in the STP segment.
4. Receiver sends ack upon receiving a packet. If the packet is out of order, receiver stores it in a **buffer** and sends a duplicate ack. If the packet is in order, the receiver will fill the gap, remove the correct packet out of the buffer and sends an ack. Receiver uses cumulative ack. If the receiver receives a corrupted packet, the receiver will drop it without sending a duplicate ack.
5. After the receiver has received the complete file, it will write the bytes into a file.
6. The receiver updates Receiver_log.txt with the information about each packet it sends and receives. At the end of execution, the receiver updates the required statistics in the assignment specification to the log file.

STP header

Structure of STP header

The following is the structure of my STP header:



Explanation of all fields

- Sequence number (seq_no): the sequence number of a packet. It is used to identify the first byte of the payload in a packet. Both sender and receiver use this number to track the packet they are up to sending and acknowledging respectively.
- Acknowledge number (ack_no): the acknowledge number of a packet. It is used to identify the next expected byte. Receiver use this number to check if a packet is out of order and to inform sender the next byte it is supposed to send.
- ack: a boolean to indicate an ack packet, used for acknowledging a received packet
- fin: a boolean to indicate a fin packet, used for connection termination.
- syn: a boolean to indicate a syn packet, used for connection establishment.
- Checksum: used for error detection. Receiver calculates the checksum of the payload value and compare it with this number. If it matches, the payload is not corrupted.

Design trade-offs and possible improvement

I tried to implement STP protocol using multithreading but my lack of knowledge in python's multithreading has caused my program fail to execute properly. Currently, the STP sender and receiver is single threaded. Both sender and receiver implements a blocking single threaded event loop that rotates between sending a packet and receiving a packet. The event loops follows an order of execution. To improve my program, I would use multithreading as it would allow sender to receive and send a packet asynchronously.

Besides, I am calculating the timeout manually every time socket timeout by using the difference between `time.time()` and the send time of the send base to determine should I retransmit the packet. To improve, I would use python's Timer object as it would call the retransmission function on timeout automatically.

Experiment result

- The sequence of STP packets observed at the Receiver when $pDrop = 0.1$, $MWS = 500$ bytes, $MSS = 100$ bytes, $seed = 100$, $gamma = 4$ is as follows:
0 1 1 101 301 401 501 601 201 701 801 901 1001 1101 1201 1301 1401 1501 1601
1701 1801 1901 2101 2201 2301 2401 2001 2501 2601 2901 3001 2701 2801 3029
3030

The sequence of STP packets observed at the Receiver when pDrop = 0.3, MWS = 500 bytes, MSS = 100 bytes, seed = 100, gamma = 4 is as follows:

0 1 101 201 301 1 501 801 401 1001 601 1101 701 1201 901 1601 1701 1301 1801 1401 1501 2001 2101 2201 2301 1901 2701 2801 2401 2501 3001 2601 2901 3029 3030

From the example above, packet used for connection establishment(ie. 0,1) and termination(ie. 3029, 3030) won't get dropped. When pDrop is 0.3, packet loss occurs earlier as we can see packet 1 is dropped. This is because with higher value of pDrop, we increase the likelihood of a drop. 24 packets are dropped when pDrop = 0.3 as compared to 4 packets are drop when pDrop = 0.1.

In the second sequence, there are more missing sequence numbers in between which indicates those packets with the missing sequence number are dropped. These dropped packets are retransmitted on timeout or fast retransmission (result in appendix).Also, the window will not slide if the sender hasn't received an ack for the send base.

b.

Gamma value	Overall transfer time	Number of Packets transmitted
2	48 minutes 31s	12669
4	77 minutes 34s	12459
6	105 minutes 15s	12457

The higher the gamma value, the longer the overall transfer time as the time needed for timeout retransmission increases. For low gamma value(ie. 2), the number of retransmission is higher as there might be pre mature retransmission. For large gamma value (ie. 4 and 6), the number of packets transmitted is the same but the overall transfer time is much higher when gamma value is 6 as the timeout interval is larger. A packet waits longer before retransmission.

- c. The file has been transferred successfully. The STP took 9 minutes and 27 seconds to transmit the file. pDrop is the most critical factor contributing most in the overall time as the number of packets dropped is higher than corrupted packets, duplicate packets and reordered packets. The second most critical factor contributing in the overall time is pCorrupt. Duplicate packets has no effect on the overall time as it will be transmitted immediately to receiver. Reordered packet has little effect on the overall time as the maxOrder is less than the number of packets allowed in the window size, making it being transmitted quite quickly.

Most of the overall time is spend on timeout retransmission and fast retransmission caused by both pDrop and pCorrupt. If sender receive 3 dup acks, it can carry out retransmission which means the time needed to retransmit is much lesser. If the sender isn't receiving any 3 dup acks, it can only retransmit on timeout which takes much longer.

Appendix

Part a

- i. Receiver log for pDrop = 0.1, MWS = 500 bytes, MSS = 100 bytes, seed = 100, gamma = 4

```

rcv      1.3574438095092773      S      0      0      0
snd      1.357792854309082      SA     0      0      1
rcv      1.3638548851013184      A      1      0      1
rcv      1.364677906036377      D      1      100     1
snd      1.3648898601531982      A      1      0      101
rcv      1.365332841873169      D     101      100     1
snd      1.3656036853790283      A      1      0      201
rcv      1.3661108016967773      D     301      100     1
snd/DA   1.3663060665130615      A      1      0      201
rcv      1.3665897846221924      D     401      100     1
snd/DA   1.3667409420013428      A      1      0      201
rcv      1.36741304397583      D     501      100     1
snd/DA   1.3675997257232666      A      1      0      201
rcv      1.3682377338409424      D     601      100     1
snd/DA   1.3684580326080322      A      1      0      201
rcv      1.3697237968444824      D     201      100     1
snd      1.3699889183044434      A      1      0      701
rcv      1.370934009552002      D     701      100     1
snd      1.3711817264556885      A      1      0      801
rcv      1.3715319633483887      D     801      100     1
snd      1.3717570304870605      A      1      0      901
rcv      1.37217378616333      D     901      100     1
snd      1.3723740577697754      A      1      0     1001
rcv      1.3729207515716553      D    1001      100     1
snd      1.3731927871704102      A      1      0     1101
rcv      1.3734426498413086      D    1101      100     1
snd      1.3736577033996582      A      1      0     1201
rcv      1.374236822128296      D    1201      100     1
snd      1.3744828701019287      A      1      0     1301
rcv      1.3750519752502441      D    1301      100     1
snd      1.3753318786621094      A      1      0     1401
rcv      1.3758728504180908      D    1401      100     1
snd      1.376086950302124      A      1      0     1501
rcv      1.376847743988037      D    1501      100     1
snd      1.3771028518676758      A      1      0     1601
rcv      1.3776538372039795      D    1601      100     1
snd      1.3778958320617676      A      1      0     1701
rcv      1.3784518241882324      D    1701      100     1
snd      1.3787007331848145      A      1      0     1801
rcv      1.3793599605560303      D    1801      100     1
snd      1.3795437812805176      A      1      0     1901
rcv      1.3802478313446045      D    1901      100     1
snd      1.380445957183838      A      1      0     2001
rcv      1.381678819656372      D    2101      100     1
snd/DA   1.3818519115447998      A      1      0     2001
rcv      1.3825318813323975      D    2201      100     1
snd/DA   1.38270902633667      A      1      0     2001
rcv      1.3832788467407227      D    2301      100     1
snd/DA   1.3835289478302002      A      1      0     2001
rcv      1.3841488361358643      D    2401      100     1
snd/DA   1.3843467235565186      A      1      0     2001
rcv      1.3851346969604492      D    2001      100     1
snd      1.3854057788848877      A      1      0     2501
rcv      1.3861417770385742      D    2501      100     1
snd      1.3864009380340576      A      1      0     2601
rcv      1.386657953262329      D    2601      100     1
snd      1.386915683746338      A      1      0     2701
rcv      1.3877570629119873      D    2901      100     1
snd/DA   1.3879287242889404      A      1      0     2701
rcv      1.388873815536499      D    3001      28      1
snd/DA   1.389096975326538      A      1      0     2701
rcv      1.7992548942565918      D    2701      100     1
snd      1.7996418476104736      A      1      0     2801
rcv      2.222522735595703      D    2801      100     1
snd      2.2228879928588867      A      1      0     3029
rcv      2.2296230792999268      F    3029      0      1
snd      2.230048894882202      A      1      0     3030
snd      2.2303178310394287      F      1      0     3030
rcv      2.2312707901000977      A    3030      0      2
=====
Amount of data received (bytes) 3028
Total Segments Received 35
Data segments received 31
Data segments with Bit Errors 0
Duplicate data segments received 0
Duplicate ACKs sent 10
=====

```


- ii. Receiver log for pDrop = 0.3, MWS = 500 bytes, MSS = 100 bytes, seed = 100, gamma = 4

```

rcv      1.7958438396453857      S      0      0      0
snd      1.796189785003662      SA     0      0      1
rcv      1.802778720855713      A      1      0      1
rcv      1.8050198554992676      D     101    100    1
snd/DA   1.8052940368652344      A      1      0      1
rcv      1.8058948516845703      D     201    100    1
snd/DA   1.806175947189331      A      1      0      1
rcv      1.8067529201507568      D     301    100    1
snd/DA   1.8069849014282227      A      1      0      1
rcv      4.876204967498779      D      1     100    1
snd      4.876881837844849      A      1      0    401
rcv      4.883692979812622      D     501    100    1
snd/DA   4.884018898010254      A      1      0    401
rcv      4.88575005531311      D     801    100    1
snd/DA   4.88599705696106      A      1      0    401
rcv      4.991438865661621      D     401    100    1
snd      4.991797924041748      A      1      0    601
rcv      4.999392986297607      D    1001    100    1
snd/DA   4.999751806259155      A      1      0    601
rcv      6.437016010284424      D     601    100    1
snd      6.437298774719238      A      1      0    701
rcv      6.443940877914429      D    1101    100    1
snd/DA   6.444252967834473      A      1      0    701
rcv      6.549964904785156      D     701    100    1
snd      6.550179719924927      A      1      0    901
rcv      6.551091909408569      D    1201    100    1
snd/DA   6.55132794380188      A      1      0    901
rcv      6.653841733932495      D     901    100    1
snd      6.654197931289673      A      1      0   1301
rcv      6.661164045333862      D    1601    100    1
snd/DA   6.661386966705322      A      1      0   1301
rcv      6.661648750305176      D    1701    100    1
snd/DA   6.66179895401001      A      1      0   1301
rcv      9.639891862869263      D    1301    100    1
snd      9.640259027481079      A      1      0   1401
rcv      9.646968841552734      D    1801    100    1
snd/DA   9.647271871566772      A      1      0   1401
rcv      9.749449968338013      D    1401    100    1
snd      9.749693870544434      A      1      0   1501
rcv      16.062294006347656      D    1501    100    1
snd      16.06280279159546      A      1      0   1901
rcv      16.069315671920776      D    2001    100    1
snd/DA   16.06963872909546      A      1      0   1901
rcv      16.07028293609619      D    2101    100    1
snd/DA   16.07054090499878      A      1      0   1901
rcv      16.070990800857544      D    2201    100    1
snd/DA   16.071224689483643      A      1      0   1901
rcv      16.071810960769653      D    2301    100    1
snd/DA   16.072048902511597      A      1      0   1901
rcv      17.636900901794434      D    1901    100    1
snd      17.63728094100952      A      1      0   2401
rcv      17.645330905914307      D    2701    100    1
snd/DA   17.64566707611084      A      1      0   2401
rcv      17.64608097076416      D    2801    100    1
snd/DA   17.646366834640503      A      1      0   2401
rcv      20.772132873535156      D    2401    100    1
snd      20.77249002456665      A      1      0   2501
rcv      20.8796968460083      D    2501    100    1
snd      20.880084991455078      A      1      0   2601
rcv      20.88254189491272      D    3001    28     1
snd/DA   20.882706880569458      A      1      0   2601
rcv      22.5326509475708      D    2601    100    1
snd      22.53327202796936      A      1      0   2901
rcv      24.181724786758423      D    2901    100    1
snd      24.182101011276245      A      1      0   3029
rcv      24.18884301185608      F    3029     0     1
snd      24.189197063446045      A      1      0   3030
snd      24.18949604034424      F      1      0   3030
rcv      24.190464973449707      A    3030     0     2
=====
Amount of data received (bytes) 3028
Total Segments Received 35
Data segments received 31
Data segments with Bit Errors 0
Duplicate data segments received 0
Duplicate ACKs sent 18
=====

```

Part b

- i. Receiver log when gamma value = 2

First 23 entries

rcv	2.0264811515808105	S	0	0	0
snd	2.0268139839172363	SA	0	0	1
rcv	2.0336880683898926	A	1	0	1
rcv	2.037454128265381	D	1	50	1
snd	2.0378191471099854	A	1	0	51
rcv	2.039260149002075	D	201	50	1
snd/DA	2.0395872592926025	A	1	0	51
rcv	2.040304183959961	D	301	50	1
snd/DA	2.040508270263672	A	1	0	51
rcv	2.041027069091797	D	401	50	1
snd/DA	2.0412511825561523	A	1	0	51
rcv	2.041616201400757	D	451	50	1
snd/DA	2.041806221008301	A	1	0	51
rcv	2.043701171875	D	51	50	1
snd	2.04390025138855	A	1	0	101
rcv	2.288067102432251	D	101	50	1
snd	2.2883331775665283	A	1	0	151
rcv	2.2934672832489014	D	601	50	1
snd/DA	2.2936840057373047	A	1	0	151
rcv	2.9366049766540527	D	501	50	1
snd/DA	2.937073230743408	A	1	0	151
rcv	4.271443128585815	D	151	50	1
snd	4.271868944168091	A	1	0	251

Last 24 entries

rcv	2900.702337026596	D	308051	50	1
snd/DA	2900.7026660442352	A	1	0	307601
rcv	2900.8087890148163	D	307601	50	1
snd	2900.809233188629	A	1	0	307651
rcv	2905.2471990585327	D	307651	50	1
snd	2905.2476370334625	A	1	0	307701
rcv	2905.359565258026	D	307701	50	1
snd	2905.3599841594696	A	1	0	307751
rcv	2907.7511932849884	D	307751	50	1
snd	2907.751615047455	A	1	0	307801
rcv	2910.3264672756195	D	307801	50	1
snd	2910.3267850875854	A	1	0	307851
rcv	2910.4312691688538	D	307851	50	1
snd	2910.431797027588	A	1	0	308101
rcv	2911.777492046356	D	308101	50	1
snd	2911.7778601646423	A	1	0	308151
rcv	2912.4607322216034	D	308151	50	1
snd	2912.4613740444183	A	1	0	308201
rcv	2912.9841871261597	D	308201	3	1
snd	2912.9846341609955	A	1	0	308204
rcv	2912.9907331466675	F	308204	0	1
snd	2912.9916191101074	A	1	0	308205
snd	2912.991903066635	F	1	0	308205
rcv	2912.99286031723	A	308205	0	2

```

=====
Amount of data received (bytes) 313653
Total Segments Received 6278
Data segments received 6274
Data segments with Bit Errors 0
Duplicate data segments received 109
Duplicate ACKs sent 3159
=====

```


Sender log when gamma value = 2

First 23 entries

snd	0.0025300979614257812	S	0	0	0
rcv	0.0030798912048339844	SA	0	0	1
snd	0.009759902954101562	A	1	0	1
snd	0.013469934463500977	D	1	50	1
drop	0.013819217681884766	D	51	50	1
drop	0.014601945877075195	D	151	50	1
snd	0.015311002731323242	D	201	50	1
drop	0.01559591293334961	D	251	50	1
snd	0.016353130340576172	D	301	50	1
drop	0.01659703254699707	D	351	50	1
snd	0.017108917236328125	D	401	50	1
snd	0.01770186424255371	D	451	50	1
rcv	0.017956018447875977	A	1	0	51
rcv/DA	0.018619060516357422	A	1	0	51
rcv/DA	0.018823862075805664	A	1	0	51
rcv/DA	0.019121885299682617	A	1	0	51
snd/RXT	0.019781112670898438	D	51	50	1
rcv/DA	0.019982099533081055	A	1	0	51
rcv	0.020256996154785156	A	1	0	101
drop	0.02051401138305664	D	551	50	1
snd/deliv	0.26324987411499023	D	101	50	1
rcv	0.2646009922027588	A	1	0	151
snd	0.2695350646972656	D	601	50	1

Last 24 entries

drop	2903.9658110141754	D	307751	50	1
drop	2904.583813905716	D	307751	50	1
drop	2905.10618019104	D	307751	50	1
snd/RXT	2905.7271690368652	D	307751	50	1
rcv	2905.7279419898987	A	1	0	307801
drop	2905.834856033325	D	307801	50	1
drop	2906.454868078232	D	307801	50	1
drop	2907.074684858322	D	307801	50	1
drop	2907.6890330314636	D	307801	50	1
snd/RXT	2908.3025019168854	D	307801	50	1
rcv	2908.303048849106	A	1	0	307851
snd/RXT	2908.4072439670563	D	307851	50	1
rcv	2908.408129930496	A	1	0	308101
drop	2908.51327586174	D	308101	50	1
drop	2909.131549835205	D	308101	50	1
snd/RXT	2909.7534458637238	D	308101	50	1
rcv	2909.7541649341583	A	1	0	308151
snd/deliv	2910.435119152069	D	308151	50	1
rcv	2910.437670946121	A	1	0	308201
snd/deliv	2910.958750963211	D	308201	3	1
rcv	2910.9609348773956	A	1	0	308204
snd	2910.966089963913	F	308204	0	1
rcv	2910.967871904373	A	1	0	308205
rcv	2910.9682240486145	F	1	0	308205
snd	2910.968961954117	A	308205	0	2

```

=====
Size of the file (in Bytes)      308203
Segments transmitted (including drop & RXT)      12669
Number of Segments handled by PLD      12665
Number of Segments dropped      6391
Number of Segments Corrupted      0
Number of Segments Re-ordered      0
Number of Segments Duplicated      0
Number of Segments Delayed      1254
Number of Retransmissions due to TIMEOUT      6238
Number of FAST RETRANSMISSION      262
Number of DUP ACKS received      3159
=====

```

ii. Receiver log when gamma value = 4

First 23 entries

rcv	1.2431871891021729	S	0	0	0
snd	1.2435472011566162	SA	0	0	1
rcv	1.2444782257080078	A	1	0	1
rcv	1.2473080158233643	D	1	50	1
snd	1.2475221157073975	A	1	0	51
rcv	1.2495951652526855	D	201	50	1
snd/DA	1.2498669624328613	A	1	0	51
rcv	1.2506911754608154	D	301	50	1
snd/DA	1.2509691715240479	A	1	0	51
rcv	1.251622200012207	D	401	50	1
snd/DA	1.251805067062378	A	1	0	51
rcv	1.2521851062774658	D	451	50	1
snd/DA	1.25246000289917	A	1	0	51
rcv	1.2544610500335693	D	51	50	1
snd	1.254762887954712	A	1	0	101
rcv	1.500340223312378	D	101	50	1
snd	1.5006201267242432	A	1	0	151
rcv	1.5017693042755127	D	601	50	1
snd/DA	1.502007007598877	A	1	0	151
rcv	2.1504812240600586	D	501	50	1
snd/DA	2.1506900787353516	A	1	0	151
rcv	4.525280952453613	D	151	50	1
snd	4.525639057159424	A	1	0	251

Last 24 entries

snd/DA	4647.164834976196	A	1	0	307501
rcv	4647.165166139603	D	307901	50	1
snd/DA	4647.165423154831	A	1	0	307501
rcv	4647.165897130966	D	307951	50	1
snd/DA	4647.1661648750305	A	1	0	307501
rcv	4647.23890209198	D	307751	50	1
snd/DA	4647.239260196686	A	1	0	307501
rcv	4649.220139026642	D	307501	50	1
snd	4649.220728158951	A	1	0	307801
rcv	4649.228480100632	D	308101	50	1
snd/DA	4649.2289361953735	A	1	0	307801
rcv	4649.229246139526	D	308151	50	1
snd/DA	4649.229453086853	A	1	0	307801
rcv	4649.229907274246	D	308201	3	1
snd/DA	4649.230161190033	A	1	0	307801
rcv	4650.364925146103	D	307801	50	1
snd	4650.365438222885	A	1	0	308001
rcv	4653.916039228439	D	308001	50	1
snd	4653.916529178619	A	1	0	308051
rcv	4655.327594995499	D	308051	50	1
snd	4655.32820224762	A	1	0	308204
rcv	4655.3330092430115	F	308204	0	1
snd	4655.33341217041	A	1	0	308205
snd	4655.333706140518	F	1	0	308205
rcv	4655.33447432518	A	308205	0	2

```

=====
Amount of data received (bytes) 308503
Total Segments Received 6175
Data segments received 6171
Data segments with Bit Errors 0
Duplicate data segments received 6
Duplicate ACKs sent 3111
=====

```

Sender log when gamma value = 4

First 23 entries

snd	0.004385948181152344	S	0	0	0
rcv	0.0049610137939453125	SA	0	0	1
snd	0.005753040313720703	A	1	0	1
snd	0.0084991455078125	D	1	50	1
drop	0.008851289749145508	D	51	50	1
drop	0.00972890853881836	D	151	50	1
snd	0.010766983032226562	D	201	50	1
drop	0.011220932006835938	D	251	50	1
snd	0.011890172958374023	D	301	50	1
drop	0.012140035629272461	D	351	50	1
snd	0.012830257415771484	D	401	50	1
snd	0.01341104507446289	D	451	50	1
rcv	0.013786077499389648	A	1	0	51
rcv/DA	0.014406204223632812	A	1	0	51
rcv/DA	0.014668941497802734	A	1	0	51
rcv/DA	0.01491403579711914	A	1	0	51
snd/RXT	0.015664100646972656	D	51	50	1
rcv/DA	0.015903949737548828	A	1	0	51
rcv	0.016149044036865234	A	1	0	101
drop	0.01654219627380371	D	551	50	1
snd/dely	0.2603781223297119	D	101	50	1
rcv	0.262066125869751	A	1	0	151
snd	0.26299118995666504	D	601	50	1

Last 24 entries

rcv	4647.982227087021	A	1	0	307801
drop	4647.988079071045	D	308001	50	1
drop	4647.988562107086	D	308051	50	1
snd	4647.98960518837	D	308101	50	1
snd	4647.990442991257	D	308151	50	1
snd	4647.991117954254	D	308201	3	1
rcv/DA	4647.991426944733	A	1	0	307801
rcv/DA	4647.991724014282	A	1	0	307801
rcv/DA	4647.991974115372	A	1	0	307801
drop	4647.992289066315	D	307801	50	1
snd/dely	4649.124757051468	D	307801	50	1
rcv	4649.126892089844	A	1	0	308001
drop	4649.236585140228	D	308001	50	1
drop	4650.255452156067	D	308001	50	1
drop	4651.294048070908	D	308001	50	1
snd/dely	4652.675668954849	D	308001	50	1
rcv	4652.67803311348	A	1	0	308051
drop	4652.7873430252075	D	308051	50	1
snd/dely	4654.087316274643	D	308051	50	1
rcv	4654.089672088623	A	1	0	308204
snd	4654.094222068787	F	308204	0	1
rcv	4654.09485411644	A	1	0	308205
rcv	4654.095170974731	F	1	0	308205
snd	4654.095738172531	A	308205	0	2

```

=====
Size of the file (in Bytes)      308203
Segments transmitted (including drop & RXT) 12459
Number of Segments handled by PLD      12455
Number of Segments dropped      6284
Number of Segments Corrupted    0
Number of Segments Re-ordered   0
Number of Segments Duplicated   0
Number of Segments Delayed      1237
Number of Retransmissions due to TIMEOUT      6039
Number of FAST RETRANSMISSION    251
Number of DUP ACKS received      3111
=====

```


iii. Receiver log when gamma value = 6

First 23 entries

rcv	1.9483890533447266	S	0	0	0
snd	1.9487760066986084	SA	0	0	1
rcv	1.9506731033325195	A	1	0	1
rcv	1.9523861408233643	D	1	50	1
snd	1.9525930881500244	A	1	0	51
rcv	1.953296184539795	D	201	50	1
snd/DA	1.953477144241333	A	1	0	51
rcv	1.953841209411621	D	301	50	1
snd/DA	1.9539620876312256	A	1	0	51
rcv	1.9544520378112793	D	401	50	1
snd/DA	1.9546160697937012	A	1	0	51
rcv	1.9548850059509277	D	451	50	1
snd/DA	1.955029010772705	A	1	0	51
rcv	1.9559438228607178	D	51	50	1
snd	1.956115961074829	A	1	0	101
rcv	2.203666925430298	D	101	50	1
snd	2.2038519382476807	A	1	0	151
rcv	2.2056219577789307	D	601	50	1
snd/DA	2.205811023712158	A	1	0	151
rcv	2.853760004043579	D	501	50	1
snd/DA	2.8539390563964844	A	1	0	151
rcv	6.477586984634399	D	151	50	1
---	---	-	-	-	---

Last 24 entries

snd	6306.822555065155	A	1	0	307551
rcv	6306.825296163559	D	307901	50	1
snd/DA	6306.825552225113	A	1	0	307551
rcv	6306.825779914856	D	307951	50	1
snd/DA	6306.825980901718	A	1	0	307551
rcv	6306.826216936111	D	308001	50	1
snd/DA	6306.826399087906	A	1	0	307551
rcv	6306.905774116516	D	307801	50	1
snd/DA	6306.905961036682	A	1	0	307551
rcv	6309.78910112381	D	307551	50	1
snd	6309.789425134659	A	1	0	307851
rcv	6309.792222976685	D	308151	50	1
snd/DA	6309.792416095734	A	1	0	307851
rcv	6309.792552947998	D	308201	3	1
snd/DA	6309.792689085007	A	1	0	307851
rcv	6309.898061990738	D	307851	50	1
snd	6309.898353099823	A	1	0	308051
rcv	6312.8585431575775	D	308051	50	1
snd	6312.858776092529	A	1	0	308101
rcv	6317.786384105682	D	308101	50	1
snd	6317.786662101746	A	1	0	308204
rcv	6317.788233041763	F	308204	0	1
snd	6317.7884311676025	A	1	0	308205
snd	6317.788671016693	F	1	0	308205
rcv	6317.789224863052	A	308205	0	2

Amount of data received (bytes) 308453

Total Segments Received 6174

Data segments received 6170

Data segments with Bit Errors 0

Duplicate data segments received 5

Duplicate ACKs sent 3109

Sender log when gamma value = 6

First 23 entries

```
rcv/DA 6304.959438085556 A 1 0 307551
drop 6306.3386759758 D 307551 50 1
snd/RXT 6307.842406272888 D 307551 50 1
rcv 6307.842880010605 A 1 0 307851
drop 6307.844774246216 D 308051 50 1
drop 6307.844947338104 D 308101 50 1
snd 6307.84552025795 D 308151 50 1
snd 6307.845925092697 D 308201 3 1
rcv/DA 6307.846093177795 A 1 0 307851
rcv/DA 6307.846248149872 A 1 0 307851
snd/RXT 6307.951377153397 D 307851 50 1
rcv 6307.951807975769 A 1 0 308051
drop 6309.334675312042 D 308051 50 1
snd/dely6310.9111070632935 D 308051 50 1
rcv 6310.912251234055 A 1 0 308101
drop 6311.013741016388 D 308101 50 1
drop 6312.502346992493 D 308101 50 1
drop 6314.000136137009 D 308101 50 1
snd/dely6315.838685274124 D 308101 50 1
rcv 6315.840134143829 A 1 0 308204
snd 6315.841559171677 F 308204 0 1
rcv 6315.841876983643 A 1 0 308205
rcv 6315.842129230499 F 1 0 308205
snd 6315.842586040497 A 308205 0 2
```

```
=====
Size of the file (in Bytes) 308203
Segments transmitted (including drop & RXT) 12457
Number of Segments handled by PLD 12453
Number of Segments dropped 6283
Number of Segments Corrupted 0
Number of Segments Re-ordered 0
Number of Segments Duplicated 0
Number of Segments Delayed 1236
Number of Retransmissions due to TIMEOUT 6038
Number of FAST RETRANSMISSION 250
Number of DUP ACKS received 3109
=====
```

Las 24 entries

```
snd 0.0016751289367675781 S 0 0 0
rcv 0.0022499561309814453 SA 0 0 1
snd 0.004022121429443359 A 1 0 1
snd 0.005726337432861328 D 1 50 1
drop 0.005872249603271484 D 51 50 1
drop 0.0062520503997802734 D 151 50 1
snd 0.006639242172241211 D 201 50 1
drop 0.006773948669433594 D 251 50 1
snd 0.007182121276855469 D 301 50 1
drop 0.007318973541259766 D 351 50 1
snd 0.00778508186340332 D 401 50 1
snd 0.008240222930908203 D 451 50 1
rcv 0.008432149887084961 A 1 0 51
rcv/DA 0.008747100830078125 A 1 0 51
rcv/DA 0.008870124816894531 A 1 0 51
rcv/DA 0.008985042572021484 A 1 0 51
snd/RXT 0.009293079376220703 D 51 50 1
rcv/DA 0.009437322616577148 A 1 0 51
rcv 0.009611129760742188 A 1 0 101
drop 0.00974726676940918 D 551 50 1
snd/dely0.256256103515625 D 101 50 1
rcv 0.25733304023742676 A 1 0 151
snd 0.2589230537414551 D 601 50 1
-- -- -- -- --
```


Part c

Receiver log for MWS=500bytes MSS=50 gamma=4 pDrop=0.1 pDuplicate=0.1
pCorrupt=0.1 pOrder=0.1 maxOrder=4 pDelay=0 maxDelay=0 seed=300

First 23 entries

rcv	4.085698127746582	S	0	0	0
snd	4.086038112640381	SA	0	0	1
rcv	4.087976932525635	A	1	0	1
rcv/corr	4.095623970031738	D	1	50	1
rcv	4.096120119094849	D	51	50	1
snd/DA	4.09632420539856	A	1	0	1
rcv	4.09660792350769	D	101	50	1
snd/DA	4.096798896789551	A	1	0	1
rcv	4.097042083740234	D	151	50	1
snd/DA	4.097177028656006	A	1	0	1
rcv	4.0974650382995605	D	201	50	1
snd/DA	4.097643136978149	A	1	0	1
rcv	4.09796404838562	D	251	50	1
snd/DA	4.098161220550537	A	1	0	1
rcv	4.098300218582153	D	251	50	1
snd/DA	4.098429203033447	A	1	0	1
rcv	4.0987701416015625	D	301	50	1
snd/DA	4.098936080932617	A	1	0	1
rcv/corr	4.099234104156494	D	351	50	1
rcv	4.099591970443726	D	401	50	1
snd/DA	4.099778175354004	A	1	0	1
rcv	4.099992990493774	D	451	50	1
snd/DA	4.100162982940674	A	1	0	1

Last 24 entries

snd/DA	571.1745569705963	A	1	0	1604901
rcv	571.1748311519623	D	1605201	50	1
snd/DA	571.1750199794769	A	1	0	1604901
rcv	571.1753120422363	D	1605251	50	1
snd/DA	571.1755230426788	A	1	0	1604901
rcv	571.1758131980896	D	1605301	50	1
snd/DA	571.1759889125824	A	1	0	1604901
rcv	571.1762120723724	D	1605351	50	1
snd/DA	571.1763591766357	A	1	0	1604901
rcv	571.3881211280823	D	1604901	50	1
snd	571.3886210918427	A	1	0	1605051
rcv	571.391144990921	D	1605451	50	1
snd/DA	571.3913340568542	A	1	0	1605051
rcv	571.3916029930115	D	1605501	50	1
snd/DA	571.3917570114136	A	1	0	1605051
rcv	571.4978301525116	D	1605051	50	1
snd	571.4985949993134	A	1	0	1605401
rcv	571.5006470680237	D	1605551	35	1
snd/DA	571.500892162323	A	1	0	1605401
rcv	571.6054241657257	D	1605401	50	1
snd	571.6059801578522	A	1	0	1605586
rcv	571.6082911491394	F	1605586	0	1
snd	571.6085350513458	A	1	0	1605587
snd	571.6086890697479	F	1	0	1605587
rcv	571.609365940094	A	1605587	0	2

```

=====
Amount of data received (bytes) 2110085
Total Segments Received 42206
Data segments received 42202
Data segments with Bit Errors 3467
Duplicate data segments received 6623
Duplicate ACKs sent 29532
=====

```

Sender log for MWS=500bytes MSS=50 gamma=4 pDrop=0.1 pDuplicate=0.1 pCorrupt=0.1
pOrder=0.1 maxOrder=4 pDelay=0 maxDelay=0 seed=300

First 23 entries

snd	0.0015139579772949219	S	0	0	0
rcv	0.002038717269897461	SA	0	0	1
snd	0.0038628578186035156	A	1	0	1
snd/corr	0.0114288330078125	D	1	50	1
snd	0.011977910995483398	D	51	50	1
snd	0.012468099594116211	D	101	50	1
snd	0.012916088104248047	D	151	50	1
snd	0.013341903686523438	D	201	50	1
snd	0.014095783233642578	D	251	50	1
snd/dup	0.01421809196472168	D	251	50	1
snd	0.014639854431152344	D	301	50	1
snd/corr	0.015111923217773438	D	351	50	1
snd	0.015452861785888672	D	401	50	1
snd	0.015877962112426758	D	451	50	1
rcv/DA	0.0160369873046875	A	1	0	1
rcv/DA	0.01619577407836914	A	1	0	1
rcv/DA	0.016337871551513672	A	1	0	1
snd/RXT	0.016675949096679688	D	1	50	1
rcv/DA	0.01681685447692871	A	1	0	1
rcv/DA	0.016937971115112305	A	1	0	1
rcv/DA	0.017065048217773438	A	1	0	1
snd/RXT	0.017398834228515625	D	1	50	1
rcv/DA	0.01755976676940918	A	1	0	1

Last 24 entries

snd	567.0920889377594	D	1605351	50	1
rcv/DA	567.0922698974609	A	1	0	1604901
rcv/DA	567.0924277305603	A	1	0	1604901
rcv/DA	567.0925719738007	A	1	0	1604901
drop	567.0926830768585	D	1604901	50	1
rcv/DA	567.0928299427032	A	1	0	1604901
rcv/DA	567.0929658412933	A	1	0	1604901
snd/RXT	567.3039560317993	D	1604901	50	1
rcv	567.3046228885651	A	1	0	1605051
drop	567.3062720298767	D	1605401	50	1
snd	567.3069567680359	D	1605451	50	1
snd	567.3074650764465	D	1605501	50	1
rcv/DA	567.3076858520508	A	1	0	1605051
rcv/DA	567.307865858078	A	1	0	1605051
snd/RXT	567.4136641025543	D	1605051	50	1
rcv	567.4145958423615	A	1	0	1605401
snd	567.4164917469025	D	1605551	35	1
rcv/DA	567.4169070720673	A	1	0	1605401
snd/RXT	567.5212638378143	D	1605401	50	1
rcv	567.5219819545746	A	1	0	1605586
snd	567.5241539478302	F	1605586	0	1
rcv	567.5245289802551	A	1	0	1605587
rcv	567.5247719287872	F	1	0	1605587
snd	567.5252528190613	A	1605587	0	2

```

=====
Size of the file (in Bytes)      1605585
Segments transmitted (including drop & RXT)  46546
Number of Segments handled by PLD      46542
Number of Segments dropped          4340
Number of Segments Corrupted        3467
Number of Segments Re-ordered        2139
Number of Segments Duplicated        3860
Number of Segments Delayed           0
Number of Retransmissions due to TIMEOUT      3054
Number of FAST RETRANSMISSION      7516
Number of DUP ACKS received        29532
=====

```