COMP3331 Assignment 1

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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 classess 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.
4. Sender uses the concepts of sequence number, acknowledge number and flags(ACK, FIN, SYN) in its STP header.

5. 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.
6. 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. If the timer isn't start yet, the sender will **start the timer**.
7. Sender maintain **a single timer** for timeout operation. The 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:
   estRTT = (1 – alpha) * estRTT + alpha*sampleRTT
   devRTT = (1- beta)*devRTT + beta*abs(sampleRTT – estRTT)
   timeout = (estRTT + gamma * devRTT) / 1000
   *alpha = 0.125 , beta = 0.25, gamma = user input
   Retransmitted packet will not take into account for timeout interval calculation.
8. 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.
9. 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.
10. **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 packet.
11. 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 corruped. 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.

12. 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.

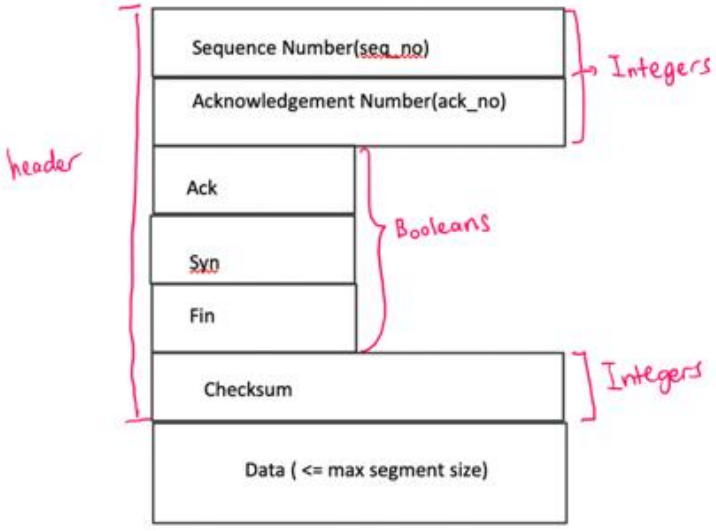
Receiver's features and its implementation

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 receivers. 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

a.

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, both sequence number traces start with 0, 1 and ends with 3029, 3030 as these sequence number are used in connection establishment and connection termination. These packets 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). Therefore, the higher the pDrop, the higher the retransmission rate.

b.

Gamma value	Overall transfer time	Number of Packets transmitted
2	75 minutes 36s	12652
4	140 minutes 9s	12450
6	188 minutes 49s	12450

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 5 minutes and 32 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     3.283729314804077       S       0       0       0
snd     3.2840771675109863      SA      0       0       1
rcv     3.290163993835449       A       1       0       1
rcv     3.291300058364868       D       101     100     1
snd/DA  3.291499137878418       A       1       0       1
rcv     3.2919769287109375      D       201     100     1
snd/DA  3.2922210693359375      A       1       0       1
rcv     3.292546033859253       D       301     100     1
snd/DA  3.2926909923553467      A       1       0       1
rcv     6.384371995925903       D       1       100     1
snd     6.384742259979248       A       1       0       401
rcv     6.391824245452881       D       501     100     1
snd/DA  6.392182111740112       A       1       0       401
rcv     6.39349102973938        D       801     100     1
snd/DA  6.393737077713013       A       1       0       401
rcv     7.930902004241943       D       401     100     1
snd     7.931342124938965       A       1       0       601
rcv     7.938889980316162       D       1001    100     1
snd/DA  7.939219951629639       A       1       0       601
rcv     9.482835054397583       D       601     100     1
snd     9.483155965805054       A       1       0       701
rcv     9.489699125289917       D       1101    100     1
snd/DA  9.489936113357544       A       1       0       701
rcv     11.024418115615845      D       701     100     1
snd     11.024780035018921      A       1       0       901
rcv     11.031934022903442      D       1201    100     1
snd/DA  11.032336235046387      A       1       0       901
rcv     12.558386325836182      D       901     100     1
snd     12.558895111083984      A       1       0       1301
rcv     12.566914081573486      D       1601    100     1
snd/DA  12.567275047302246      A       1       0       1301
rcv     12.568042993545532      D       1701    100     1
snd/DA  12.56829309463501       A       1       0       1301
rcv     15.665170907974243      D       1301    100     1
snd     15.665527105331421      A       1       0       1401
rcv     15.672463178634644      D       1801    100     1
snd/DA  15.672794103622437      A       1       0       1401
rcv     17.21840000152588       D       1401    100     1
snd     17.218761920928955      A       1       0       1501
rcv     24.9931058883667        D       1501    100     1
snd     24.993479251861572      A       1       0       1901
rcv     25.000044107437134      D       2001    100     1
snd/DA  25.00038194656372       A       1       0       1901
rcv     25.00084090232849       D       2101    100     1
snd/DA  25.001092195510864      A       1       0       1901
rcv     25.00153398513794       D       2201    100     1
snd/DA  25.00174903869629       A       1       0       1901
rcv     25.00220799446106       D       2301    100     1
snd/DA  25.002482175827026      A       1       0       1901
rcv     26.555557250976562      D       1901    100     1
snd     26.55592703819275       A       1       0       2401
rcv     26.564129114151         D       2701    100     1
snd/DA  26.564507246017456      A       1       0       2401
rcv     26.56491708755493       D       2801    100     1
snd/DA  26.56514310836792       A       1       0       2401
rcv     29.66197395324707       D       2401    100     1
snd     29.662256240844727      A       1       0       2501
rcv     31.200538158416748      D       2501    100     1
snd     31.201029062271118      A       1       0       2601
rcv     31.20797896385193       D       3001    28      1
snd/DA  31.208325147628784      A       1       0       2601
rcv     34.28462100028992       D       2601    100     1
snd     34.285151958465576      A       1       0       2901
rcv     37.39996123313904       D       2901    100     1
snd     37.4003701210022        A       1       0       3029
rcv     37.40730810165405       F       3029    0       1
snd     37.40773916244507       A       1       0       3030
snd     37.40816617012024       F       1       0       3030
rcv     37.40907597541809       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	4.03152060508728	S	0	0	0
snd	4.031834840774536	SA	0	0	1
rcv	4.0382399559021 A	1	0	1	
rcv	4.041621685028076	D	1	50	1
snd	4.041963815689087	A	1	0	51
rcv	4.043031692504883	D	201	50	1
snd/DA	4.043261766433716	A	1	0	51
rcv	4.043877840042114	D	301	50	1
snd/DA	4.044104814529419	A	1	0	51
rcv	4.044569730758667	D	401	50	1
snd/DA	4.044761896133423	A	1	0	51
rcv	4.045240640640259	D	451	50	1
snd/DA	4.045496702194214	A	1	0	51
rcv	4.047060966491699	D	51	50	1
snd	4.047363758087158	A	1	0	101
rcv	4.294320821762085	D	101	50	1
snd	4.294761896133423	A	1	0	151
rcv	4.300058841705322	D	601	50	1
snd/DA	4.30033278465271	A	1	0	151
rcv	4.9452807903289795	D	501	50	1
snd/DA	4.945640802383423	A	1	0	151
rcv	6.279058933258057	D	151	50	1
snd	6.279336929321289	A	1	0	251

Last 24 entries

rcv	4532.25474691391	D	307601	50	1
snd	4532.255168676376	A	1	0	307651
rcv	4533.499159812927	D	307651	50	1
snd	4533.499695777893	A	1	0	307801
rcv	4533.506839752197	D	308201	3	1
snd/DA	4533.507169723511	A	1	0	307801
rcv	4533.928792715073	D	307801	50	1
snd	4533.929243803024	A	1	0	307901
rcv	4534.349561691284	D	307901	50	1
snd	4534.350119829178	A	1	0	307951
rcv	4535.185138940811	D	307951	50	1
snd	4535.185569763184	A	1	0	308001
rcv	4535.607903003693	D	308001	50	1
snd	4535.6083216667175	A	1	0	308051
rcv	4536.032282829285	D	308051	50	1
snd	4536.032830953598	A	1	0	308101
rcv	4539.764276981354	D	308101	50	1
snd	4539.764701843262	A	1	0	308151
rcv	4540.601687669754	D	308151	50	1
snd	4540.602274656296	A	1	0	308204
rcv	4540.608935832977	F	308204	0	1
snd	4540.6095979213715	A	1	0	308205
snd	4540.609952688217	F	1	0	308205
rcv	4540.610842704773	A	308205	0	2

```
============================================================================
Amount of data received (bytes) 313353
Total Segments Received 6272
Data segments received  6268
Data segments with Bit Errors   0
Duplicate data segments received        103
Duplicate ACKs sent     3182
============================================================================
```

Sender log when gamma value = 2

First 23 entries

```
snd      0.0026051998138427734    S       0       0       0
rcv      0.0031092166900634766    SA      0       0       1
snd      0.009346246719360352     A       1       0       1
snd      0.012675285339355469     D       1       50      1
drop     0.012942075729370117     D       51      50      1
drop     0.013529300689697266     D       151     50      1
snd      0.01413416862487793      D       201     50      1
drop     0.014454126358032227     D       251     50      1
snd      0.014939308166503906     D       301     50      1
drop     0.015153169631958008     D       351     50      1
snd      0.01567816734313965      D       401     50      1
snd      0.01633620262145996      D       451     50      1
rcv      0.01668715476989746      A       1       0       51
rcv/DA   0.017208099365234375     A       1       0       51
rcv/DA   0.017454147338867188     A       1       0       51
rcv/DA   0.017724275588989258     A       1       0       51
snd/RXT  0.018180131912231445     D       51      50      1
rcv/DA   0.018360137939453125     A       1       0       51
rcv      0.01862025260925293      A       1       0       101
drop     0.018880128860473633     D       551     50      1
snd/dely0.2638981342315674        D       101     50      1
rcv      0.2661292552947998       A       1       0       151
snd      0.27108216285705566      D       601     50      1
rcv/DA   0.27159714698791504      A       1       0       151
```

Last 24 entries

```
drop     4530.743220090866        D       307951  50      1
snd/RXT  4531.15616106987         D       307951  50      1
rcv      4531.156925201416        A       1       0       308001
snd/RXT  4531.578909397125        D       308001  50      1
rcv      4531.57966709137         A       1       0       308051
snd/RXT  4532.003293275833        D       308051  50      1
rcv      4532.004145145416        A       1       0       308101
drop     4532.428192138672        D       308101  50      1
drop     4532.847578287125        D       308101  50      1
drop     4533.2548842430115       D       308101  50      1
drop     4533.665438175201        D       308101  50      1
drop     4534.076267004013        D       308101  50      1
drop     4534.488182067871        D       308101  50      1
drop     4534.9000923633575       D       308101  50      1
drop     4535.317720174789        D       308101  50      1
snd/RXT  4535.7353003025055       D       308101  50      1
rcv      4535.736042022705        A       1       0       308151
drop     4536.153655052185        D       308151  50      1
snd/RXT  4536.57270026207         D       308151  50      1
rcv      4536.573627233505        A       1       0       308204
snd      4536.580655097961        F       308204  0       1
rcv      4536.581030368805        A       1       0       308205
rcv      4536.581344127655        F       1       0       308205
snd      4536.581993103027        A       308205  0       2
=====================================================================
Size of the file (in Bytes)     308203
Segments transmitted (including drop & RXT)     12652
Number of Segments handled by PLD       12648
Number of Segments dropped      6380
Number of Segments Corrupted    0
Number of Segments Re-ordered   0
Number of Segments Duplicated   0
Number of Segments Delayed      1252
Number of Retransmissions due to TIMEOUT        6232
Number of FAST RETRANSMISSION   251
Number of DUP ACKS received     3182
=====================================================================
```

ii. Receiver log when gamma value = 4

First 23 entries

```
rcv     1.8539960384368896      S       0       0       0
snd     1.8543269634246826      SA      0       0       1
rcv     1.860102891921997       A       1       0       1
rcv     1.8627219200134277      D       1       50      1
snd     1.8629717826843262      A       1       0       51
rcv     1.8641548156738281      D       201     50      1
snd/DA  1.8643858432769775      A       1       0       51
rcv     1.8649320602416992      D       301     50      1
snd/DA  1.8651628494262695      A       1       0       51
rcv     1.8657479286193848      D       401     50      1
snd/DA  1.8659148216247559      A       1       0       51
rcv     1.8662419319152832      D       451     50      1
snd/DA  1.8664288520812988      A       1       0       51
rcv     1.868135929107666       D       51      50      1
snd     1.868393898010254       A       1       0       101
rcv     2.1122570037841797      D       101     50      1
snd     2.1125118732452393      A       1       0       151
rcv     2.1178488731384277      D       601     50      1
snd/DA  2.118109941482544       A       1       0       151
rcv     2.76173996925354        D       501     50      1
snd/DA  2.762089967727661       A       1       0       151
rcv     5.241450786590576       D       151     50      1
snd     5.24181604385376        A       1       0       251
```

Last 24 entries

```
rcv     8403.725098848343       D       307851  50      1
snd/DA  8403.725496053696       A       1       0       307451
rcv     8403.725980758667       D       307901  50      1
snd/DA  8403.726239919662       A       1       0       307451
rcv     8404.983958005905       D       307451  50      1
snd     8404.984484672546       A       1       0       307701
rcv     8404.992028713226       D       308051  50      1
snd/DA  8404.992460012436       A       1       0       307701
rcv     8404.99298787117        D       308101  50      1
snd/DA  8404.993242740631       A       1       0       307701
rcv     8404.9935836792 D       308151  50      1
snd/DA  8404.993861675262       A       1       0       307701
rcv     8405.06700372696        D       307951  50      1
snd/DA  8405.06735086441        A       1       0       307701
rcv     8407.479194879532       D       307701  50      1
snd     8407.479766845703       A       1       0       308001
rcv     8409.994572877884       D       308001  50      1
snd     8409.995088815689       A       1       0       308201
rcv     8411.249433755875       D       308201  3       1
snd     8411.249866962433       A       1       0       308204
rcv     8411.256516695023       F       308204  0       1
snd     8411.256903886795       A       1       0       308205
snd     8411.257178783417       F       1       0       308205
rcv     8411.258103847504       A       308205  0       2
=================================================================
Amount of data received (bytes) 308303
Total Segments Received 6171
Data segments received  6167
Data segments with Bit Errors   0
Duplicate data segments received        2
Duplicate ACKs sent     3102
=================================================================
```

Sender log when gamma value = 4

First 23 entries

```
snd      0.0026030540466308594    S        0        0        0
rcv      0.003142118453979492     SA       0        0        1
snd      0.008759021759033203     A        1        0        1
snd      0.011349916458129883     D        1        50       1
drop     0.011766910552978516     D        51       50       1
drop     0.012273073196411133     D        151      50       1
snd      0.012799978256225586     D        201      50       1
drop     0.012989997863769531     D        251      50       1
snd      0.013554811477661133     D        301      50       1
drop     0.013783931732177734     D        351      50       1
snd      0.01437687873840332      D        401      50       1
snd      0.014890909194946289     D        451      50       1
rcv      0.015091896057128906     A        1        0        51
rcv/DA   0.015670061111450195     A        1        0        51
rcv/DA   0.015851974487304688     A        1        0        51
rcv/DA   0.01608896255493164      A        1        0        51
snd/RXT  0.01676011085510254      D        51       50       1
rcv/DA   0.016957998275756836     A        1        0        51
rcv      0.017191171646118164     A        1        0        101
drop     0.017462968826293945     D        551      50       1
snd/dely         0.2600429058074951       D        101      50       1
rcv      0.26135897636413574      A        1        0        151
snd      0.26645898818969727      D        601      50       1
```

Last 24 entries

```
rcv      8403.133339166641        A        1        0        307701
drop     8403.139544963837        D        308001   50       1
snd      8403.140565872192        D        308051   50       1
snd      8403.141525030136        D        308101   50       1
snd      8403.142195940018        D        308151   50       1
rcv/DA   8403.142460823059        A        1        0        307701
rcv/DA   8403.142710924149        A        1        0        307701
rcv/DA   8403.142951965332        A        1        0        307701
drop     8403.14320898056         D        307701   50       1
snd/dely         8403.214241981506        D        307951   50       1
rcv/DA   8403.21623301506         A        1        0        307701
drop     8404.366578817368        D        307701   50       1
snd/RXT  8405.627744913101        D        307701   50       1
rcv      8405.628670930862        A        1        0        308001
drop     8405.634231090546        D        308201   3        1
drop     8406.887465000153        D        308001   50       1
snd/RXT  8408.143084049225        D        308001   50       1
rcv      8408.14394903183         A        1        0        308201
snd/RXT  8409.397996902466        D        308201   3        1
rcv      8409.398738861084        A        1        0        308204
snd      8409.405104160309        F        308204   0        1
rcv      8409.405777931213        A        1        0        308205
rcv      8409.406100988388        F        1        0        308205
snd      8409.406769990921        A        308205   0        2
=====================================================================
Size of the file (in Bytes)     308203
Segments transmitted (including drop & RXT)     12450
Number of Segments handled by PLD       12446
Number of Segments dropped      6279
Number of Segments Corrupted    0
Number of Segments Re-ordered   0
Number of Segments Duplicated   0
Number of Segments Delayed      1234
Number of Retransmissions due to TIMEOUT        6030
Number of FAST RETRANSMISSION   251
Number of DUP ACKS received     3102
=====================================================================
```

iii. Receiver log when gamma value = 6

First 23 entries

rcv	2.3742520809173584	S	0	0	0
snd	2.3745720386505127	SA	0	0	1
rcv	2.375174045562744	A	1	0	1
rcv	2.3777780532836914	D	1	50	1
snd	2.3780229091644287	A	1	0	51
rcv	2.3790159225463867	D	201	50	1
snd/DA	2.3792221546173096	A	1	0	51
rcv	2.379669189453125	D	301	50	1
snd/DA	2.379909038543701	A	1	0	51
rcv	2.380350112915039	D	401	50	1
snd/DA	2.3804931640625 A	1	0	51	
rcv	2.3808441162109375	D	451	50	1
snd/DA	2.3809821605682373	A	1	0	51
rcv	2.3825650215148926	D	51	50	1
snd	2.3827409744262695	A	1	0	101
rcv	2.6285321712493896	D	101	50	1
snd	2.628824234008789	A	1	0	151
rcv	2.634472131729126	D	601	50	1
snd/DA	2.6347579956054688	A	1	0	151
rcv	3.280783176422119	D	501	50	1
snd/DA	3.2811291217803955	A	1	0	151
rcv	6.703956127166748	D	151	50	1
snd	6.704317092895508	A	1	0	251

Last 24 entries

rcv	11321.146994113922	D	307851	50	1
snd/DA	11321.147247076035	A	1	0	307451
rcv	11321.14770412445	D	307901	50	1
snd/DA	11321.147922992706	A	1	0	307451
rcv	11322.878204107285	D	307451	50	1
snd	11322.878586292267	A	1	0	307701
rcv	11322.886312007904	D	308051	50	1
snd/DA	11322.886628866196	A	1	0	307701
rcv	11322.88753914833	D	308101	50	1
snd/DA	11322.887810230255	A	1	0	307701
rcv	11322.888648033142	D	308151	50	1
snd/DA	11322.888954162598	A	1	0	307701
rcv	11322.962260007858	D	307951	50	1
snd/DA	11322.962585926056	A	1	0	307701
rcv	11326.228837966919	D	307701	50	1
snd	11326.229451179504	A	1	0	308001
rcv	11329.606193065643	D	308001	50	1
snd	11329.606590032578	A	1	0	308201
rcv	11331.343907117844	D	308201	3	1
snd	11331.344216108322	A	1	0	308204
rcv	11331.351260900497	F	308204	0	1
snd	11331.351619243622	A	1	0	308205
snd	11331.351881980896	F	1	0	308205
rcv	11331.352880954742	A	308205	0	2

```
================================================================================
Amount of data received (bytes) 308303
Total Segments Received 6171
Data segments received  6167
Data segments with Bit Errors   0
Duplicate data segments received        2
Duplicate ACKs sent     3102
================================================================================
```

Sender log when gamma value = 6

First 23 entries

```
snd      0.008333921432495117    S       0       0       0
rcv      0.008837699890136719    SA      0       0       1
snd      0.009340763092041016    A       1       0       1
snd      0.011845827102661133    D       1       50      1
drop     0.012188911437988281    D       51      50      1
drop     0.012645721435546875    D       151     50      1
snd      0.013138771057128906    D       201     50      1
drop     0.013314962387084961    D       251     50      1
snd      0.013774871826171875    D       301     50      1
drop     0.014052867889404297    D       351     50      1
snd      0.014480829238891602    D       401     50      1
snd      0.01497793197631836     D       451     50      1
rcv      0.015186786651611328    A       1       0       51
rcv/DA   0.01576685905456543     A       1       0       51
rcv/DA   0.016057729721069336    A       1       0       51
rcv/DA   0.016223907470703125    A       1       0       51
snd/RXT  0.016679763793945312    D       51      50      1
rcv/DA   0.016941070556640625    A       1       0       51
rcv      0.017133712768554688    A       1       0       101
drop     0.017334938049316406    D       551     50      1
snd/dely0.26164674758911133      D       101     50      1
rcv      0.2631528377532959      A       1       0       151
snd      0.2685129642486572      D       601     50      1
```

Las 24 entries

```
snd/RXT 11320.512235879898      D       307451  50      1
rcv     11320.512902736664      A       1       0       307701
drop    11320.519154787064      D       308001  50      1
snd     11320.520322084427      D       308051  50      1
snd     11320.521580934525      D       308101  50      1
snd     11320.522665977478      D       308151  50      1
rcv/DA  11320.52304983139       A       1       0       307701
rcv/DA  11320.523360967636      A       1       0       307701
rcv/DA  11320.523694753647      A       1       0       307701
drop    11320.523907661438      D       307701  50      1
snd/dely        11320.595154762268      D       307951  50      1
rcv/DA  11320.59691786766       A       1       0       307701
drop    11322.229460954666      D       307701  50      1
snd/RXT 11323.862783908844      D       307701  50      1
rcv     11323.863773822784      A       1       0       308001
drop    11323.868996858597      D       308201  3       1
drop    11325.506870985031      D       308001  50      1
snd/RXT 11327.240120649338      D       308001  50      1
rcv     11327.24090385437       A       1       0       308201
snd/RXT 11328.977965831757      D       308201  3       1
rcv     11328.978491783142      A       1       0       308204
snd     11328.98532295227       F       308204  0       1
rcv     11328.98592877388       A       1       0       308205
rcv     11328.986275672913      F       1       0       308205
snd     11328.986988067627      A       308205  0       2
=====================================================================
Size of the file (in Bytes)     308203
Segments transmitted (including drop & RXT)     12450
Number of Segments handled by PLD       12446
Number of Segments dropped      6279
Number of Segments Corrupted    0
Number of Segments Re-ordered   0
Number of Segments Duplicated   0
Number of Segments Delayed      1234
Number of Retransmissions due to TIMEOUT        6030
Number of FAST RETRANSMISSION   251
Number of DUP ACKS received     3102
=====================================================================
```

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      1.598672866821289       S       0       0       0
snd      1.5990209579467773      SA      0       0       1
rcv      1.601470947265625       A       1       0       1
rcv/corr1.6180129051208496       D       1       50      1
rcv      1.61869478225708        D       51      50      1
snd/DA   1.6188929080963135      A       1       0       1
rcv      1.6191658973693848      D       101     50      1
snd/DA   1.61940598487854        A       1       0       1
rcv      1.6196799278259277      D       151     50      1
snd/DA   1.6199848651885986      A       1       0       1
rcv      1.6201648712158203      D       201     50      1
snd/DA   1.620356798171997       A       1       0       1
rcv      1.6205408573150635      D       251     50      1
snd/DA   1.6207668781280518      A       1       0       1
rcv      1.6209619045257568      D       251     50      1
snd/DA   1.6212239265441895      A       1       0       1
rcv      1.6214168071746826      D       301     50      1
snd/DA   1.6216790676116943      A       1       0       1
rcv/corr1.6219429969787598       D       351     50      1
rcv      1.622565746307373       D       401     50      1
snd/DA   1.6228218078613281      A       1       0       1
rcv      1.6231279373168945      D       451     50      1
snd/DA   1.6233158111572266      A       1       0       1
```

Last 24 entries

```
rcv      340.70622992515564      D       1605151 50      1
snd/DA   340.7064039707184       A       1       0       1605201
rcv      340.7068657875061       D       1605201 50      1
snd      340.7072207927704       A       1       0       1605251
rcv      340.708438873291        D       1605301 50      1
snd/DA   340.7086100578308       A       1       0       1605251
rcv      340.70916771888733      D       1605351 50      1
snd/DA   340.7093207836151       A       1       0       1605251
rcv      340.7098569869995       D       1605401 50      1
snd/DA   340.71002292633057      A       1       0       1605251
rcv      340.71072578430176      D       1605451 50      1
snd/DA   340.71096992492676      A       1       0       1605251
rcv      340.7116758823395       D       1605501 50      1
snd/DA   340.71186685562134      A       1       0       1605251
rcv      340.7124779224396       D       1605551 35      1
snd/DA   340.71264576911926      A       1       0       1605251
rcv      340.7142860889435       D       1605251 50      1
snd      340.71508598327637      A       1       0       1605586
rcv      340.7153117656708       D       1605251 50      1
snd/DA   340.71548199653625      A       1       0       1605586
rcv      340.71613788604736      F       1605586 0       1
snd      340.716383934021        A       1       0       1605587
snd      340.71653175354004      F       1       0       1605587
rcv      340.7170059680939       A       1605587 0       2
================================================================================
Amount of data received (bytes) 2066285
Total Segments Received 41330
Data segments received  41326
Data segments with Bit Errors   3403
Duplicate data segments received        5811
Duplicate ACKs sent     27821
================================================================================
```

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      0.0024297237396240234   S       0       0       0
rcv      0.002998828887939453    SA      0       0       1
snd      0.005252838134765625    A       1       0       1
snd/corr0.02174687385559082      D       1       50      1
snd      0.022472858428955078    D       51      50      1
snd      0.022961854934692383    D       101     50      1
snd      0.023447036743164062    D       151     50      1
snd      0.023878812789916992    D       201     50      1
snd      0.024579763412475586    D       251     50      1
snd/dup  0.024722814559936523    D       251     50      1
snd      0.025160789489746094    D       301     50      1
snd/corr0.025746822357177734     D       351     50      1
snd      0.02633190155029297     D       401     50      1
snd      0.02687692642211914     D       451     50      1
rcv/DA   0.02707076072692871     A       1       0       1
rcv/DA   0.027233600616455078    A       1       0       1
rcv/DA   0.027396678924560547    A       1       0       1
snd/RXT  0.027788639068603516    D       1       50      1
rcv/DA   0.027966976165771484    A       1       0       1
rcv/DA   0.028168916702270508    A       1       0       1
rcv/DA   0.028339862823486328    A       1       0       1
snd/RXT  0.028709888458251953    D       1       50      1
rcv/DA   0.028868675231933594    A       1       0       1
```

Last 24 entries

```
snd      332.98664808273315      D       1605401 50      1
rcv      332.98694014549255      A       1       0       1605001
snd      332.9875581264496       D       1605451 50      1
rcv      332.9878580570221       A       1       0       1605051
snd      332.98829412460327      D       1605501 50      1
rcv      332.98846316337585      A       1       0       1605101
snd      332.98897910118103      D       1605551 35      1
rcv      332.98918294906616      A       1       0       1605151
rcv      332.98937916755676      A       1       0       1605201
rcv/DA   332.9895601272583       A       1       0       1605201
rcv      332.98983001708984      A       1       0       1605251
rcv/DA   332.989981174469        A       1       0       1605251
rcv/DA   332.9901430606842       A       1       0       1605251
rcv/DA   332.99028396606445      A       1       0       1605251
snd/RXT  332.9907991886139       D       1605251 50      1
rcv/DA   332.99097418785095      A       1       0       1605251
rcv/DA   332.99117517471313      A       1       0       1605251
rcv/DA   332.9913399219513       A       1       0       1605251
snd/RXT  332.99181723594666      D       1605251 50      1
rcv      332.9920060634613       A       1       0       1605586
snd      332.9924190044403       F       1605586 0       1
rcv      332.9926791191101       A       1       0       1605587
rcv      332.9928560256958       F       1       0       1605587
snd      332.9933741092682       A       1605587 0       2
=====================================================================
Size of the file (in Bytes)     1605585
Segments transmitted (including drop & RXT)     45570
Number of Segments handled by PLD       45567
Number of Segments dropped      4240
Number of Segments Corrupted    3403
Number of Segments Re-ordered   2
Number of Segments Duplicated   3775
Number of Segments Delayed      0
Number of Retransmissions due to TIMEOUT        2723
Number of FAST RETRANSMISSION   6957
Number of DUP ACKS received     27820
=====================================================================
```