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 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_tine 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:
   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
   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 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.

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.

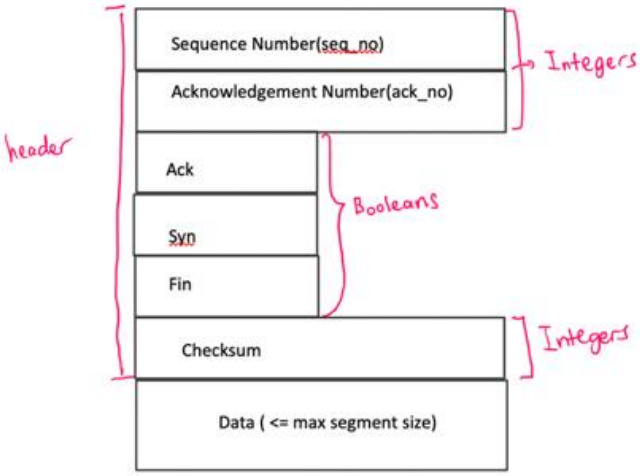
Receiver's features and its implementation

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 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, 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/dely0.26324987411499023       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/dely         2910.435119152069        D       308151  50      1
rcv      2910.437670946121        A       1       0       308201
snd/dely         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

```
snd      0.002540111541748047    S       0       0       0
rcv      0.0032711029052734375   SA      0       0       1
snd      0.00896310806274414     A       1       0       1
snd      0.011135101318359375    D       1       50      1
drop     0.011376142501831055    D       51      50      1
drop     0.011972188949584961    D       151     50      1
snd      0.012658119201660156    D       201     50      1
drop     0.012882232666015625    D       251     50      1
snd      0.013438224792480469    D       301     50      1
drop     0.013721227645874023    D       351     50      1
snd      0.014321088790893555    D       401     50      1
snd      0.01513218879699707     D       451     50      1
rcv      0.015421152114868164    A       1       0       51
rcv/DA   0.01612710952758789     A       1       0       51
rcv/DA   0.0163271427154541      A       1       0       51
rcv/DA   0.016509294509887695    A       1       0       51
snd/RXT  0.017072200775146484    D       51      50      1
rcv/DA   0.017284154891967773    A       1       0       51
rcv      0.017529010772705078    A       1       0       101
drop     0.017786026000976562    D       551     50      1
snd/dely0.2605302333831787       D       101     50      1
rcv      0.26271629333496094     A       1       0       151
snd      0.26391124725341797     D       601     50      1
```

Las 24 entries

```
rcv/DA   6315.877982139587       A       1       0       307551
drop     6317.249156236649       D       307551  50      1
snd/RXT  6318.715593338013       D       307551  50      1
rcv      6318.716485261917       A       1       0       307851
drop     6318.722184181213       D       308051  50      1
drop     6318.722700119019       D       308101  50      1
snd      6318.723853111267       D       308151  50      1
snd      6318.724888086319       D       308201  3       1
rcv/DA   6318.725359201431       A       1       0       307851
rcv/DA   6318.725604057312       A       1       0       307851
snd/RXT  6318.831942081451       D       307851  50      1
rcv      6318.83262014389        A       1       0       308051
drop     6320.2315311431885      D       308051  50      1
snd/dely6321.791805267334        D       308051  50      1
rcv      6321.793674945831       A       1       0       308101
drop     6321.90599322319        D       308101  50      1
drop     6323.389278888702       D       308101  50      1
drop     6324.871083021164       D       308101  50      1
snd/dely6326.699568271637        D       308101  50      1
rcv      6326.702065229416       A       1       0       308204
snd      6326.706885099411       F       308204  0       1
rcv      6326.70735001564        A       1       0       308205
rcv      6326.707645177841       F       1       0       308205
snd      6326.708296298981       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        6040
Number of FAST RETRANSMISSION   248
Number of DUP ACKS received     3109
================================================================================
```

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/corr4.095623970031738        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/corr4.099234104156494        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/corr0.0114288330078125       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/corr0.015111923217773438    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   0.016195774078369140    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
================================================================================
```