

## STP Protocol Report

1.

### Implementation

The STP protocol was implemented in java similar to the pseudocode provided in 'Computer Networks Top Down Approach chapter 3.5.4'. List of features that were implemented:

- Three-way handshake (SYN, SYNACK, ACK)
- Four-segment Termination (FIN,ACK,FIN,ACK)
- Checksum CRC32
- Cumulative acknowledgements
- Multithreading (Sender only)
- RTO calculation using packet timestamps (Sender only)
- Timeout Retransmission (Sender only)
- Fast Retransmit (Sender only)
- PLD (Sender only)
- Buffering out-of-order packets (Receiver only)
- Duplicated acknowledgements (Receiver only)

### Multithreading implementation (for the Sender only):

One thread is created to receive acknowledgements and another to send data packets so that packets to-be-sent do not need to wait for *socket.receive(packet)* to finish before sending.

A semaphore is used to ensure that when shared variables such as *send\_base* and *nextSeqNum* are modified or used in either thread, that section of code needs to acquire the lock and release it when it finishes to ensure the program is thread safe.

### Three-way handshake implementation:

This follows the finite-state-machine in 3.5.6 of the textbook, where the actions of the sender is determined by the current state of the sender. Initially the state is set to *NONE*. In Sender loop:

- 1) If state is *NONE*: (in sending thread)
  - a. Create a packet with *SYN* flag set to *true*
  - b. Send packet and set *STATE = SYN\_SENT*
- 2) If state is *SYN\_SENT* (in receiving thread):
  - a. If received packet is a SYN ACK send an acknowledgment
  - b. Set *STATE = ESTABLISHED*

In Receiver loop (initial *STATE = LISTENING*):

- 1) If *STATE = LISTENING*
  - a. If packet is a SYN, extract sender IP and port from received packet and initialize buffer

- b. Send *SYNACK* and set *STATE = SYN\_RCVD*
- 2) If *STATE = SYN\_RCVD*
  - a. If packet is an ACK and not a SYN and has expected sequence and acknowledgement number set *STATE = ESTABLISHED*

Teardown is also implemented in similar manner according to the textbook

#### RTO calculation implementation:

At the Sender:

- 1) Set timestamp on every packet just before it is sent (but before PLD). Set the 'use timestamp' flag to 'true' in the packet header. If it is a retransmission set it to 'false'.
- 2) When a correct acknowledgment arrives (ack number > send base) that has its 'use timestamp' flag set to 'true', use the timestamp to calculate a Sample RTT
- 3) Update the Timeout interval using the formulas:

$$EstimatedRTT = (1 - \alpha) \times EstimatedRTT + \alpha \times SampleRTT$$

$$DevRTT = (1 - \beta) \times DevRTT + \beta \times |SampleRTT - EstimatedRTT|$$

$$TimeoutInterval = EstimatedRTT + \gamma \times DevRTT$$

$\alpha$  is set to recommended value of 0.125,  $\beta$  is set to the recommended value of 0.25

At the Receiver:

- 1) When a packet carrying data arrives, create an ack packet and copy over the value of the 'use timestamp' flag and the timestamp value of the arriving packet to this ack and send it back to the sender.

#### Timeout timer implementation:

A single timer was used to implement timeout. Whenever the timer is set a new thread is started using java's *Timer.schedule(< timeout function >, TimeoutInterval)*. In Sender:

- 1) If *STATE = ESTABLISHED* (in sending thread)
  - a. If MWS is not violated after send:
    - i. If timer is not started start it
    - ii. Send next data packet (all data packets are stored in a *HashMap < SeqNum, Packet >*) called *packetMap*
- 2) If *STATE = ESTABLISHED* (in receiving thread)
  - a. If received ack has *ackNum > send\_base*:
    - i. *send\_base = ackNum* (cumulative acknowledgement)
    - ii. If no un-acknowledged packets turn timer off
    - iii. Else cancel and restart timer
    - iv. Add ack to a duplicate ack map that maps the ack number to the number times the duplicate of the ack was received i.e., *ackMap < ackNum, 0 >*
- 3) If *TIMEOUT* event (in timeout function):
  - a. Cancel and restart timer

- b. Retransmit unacknowledged packet with lowest sequence number by doing *send(packetMap.get(send\_base))*

#### Fast Retransmit Implementation

In Sender:

- 1) If *STATE = ESTABLISHED* (in receiving thread)
  - a. if *ackNum ≤ send\_base* (this is a duplicate ack)
  - b. Increment the number of times this ack was received in the *ackMap*
  - c. If the number of times this ack was received is equal to three
    - i. Fast retransmit by sending the packet mapped to *ackNum* in *packetMap*
    - ii. Reset the number of times this ack was received to zero

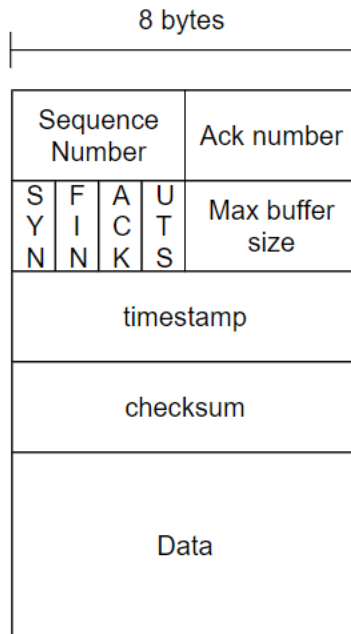
#### Buffering out-of-order packet implementation

Whenever packet arrive out of order, i.e., packets with sequence numbers greater than the sequence number of the next in-order packet, it is buffered so that when the gap is filled, the ack for the latest consecutive buffered packet is sent. In Receiver:

- 1) If *STATE = ESTABLISHED*
  - a. If the received packet does not have expected sequence number:
    - i. Send duplicate ack
    - ii. If packet is not already buffered:
      1. Add the sequence number to a priority queue (smallest to largest)
      2. Store packet in a *HashMap < seqNum, Packet >* called *packetMap*
  - b. If the received packet has expected sequence number:
    - i. Add packet to *ArrayList < Packet >* of in order packets
    - ii. Increment next expected sequence number by packet data size
    - iii. While next sequence number is at the head of priority queue and not empty
      1. add the packet mapped to this sequence number to in-order packet list
      2. increment expected sequence number by this packet data size
    - iv. Send ack packet with ack number set to this new expected sequence number

#### PLD Implementation

Implemented packet drop, duplication, bit errors and out-of-order packets as specified in assignment specification. Every time a packet is randomly delayed with probability *pDelay* a new thread is created using java's *Timer.schedule(< delay send function >, TimeoutInterval)* so that other processes can continue.



Note: Assume that java boolean objects take up one byte

- 4 byte sequence number is the byte offset into the payload relative to the sequence number of the first byte of payload data
- 4 byte acknowledgment number indicates the next expected sequence number of the packet the ack-sender expects to receive
- SYN, FIN are flags used for connection establishment and teardown
- ACK flag indicates whether this packet is acknowledging a received packet or not
- UTS is 'Use Timestamp' flag which is set when the timestamp is to be used for RTT calculation
- The 'Max buffer Size' is set in the SYN, so the receiver can initialize its datagram buffer.
- 8 byte 'long' Timestamp is the time when this packet is sent
- 8 byte checksum is the calculated using java's CRC32 module which should be compared to the same checksum calculation at the receiver to see if there any bit errors
- The header ends here and the payload 'Data' is appended at the end of the header

3.

Design tradeoffs considered and made:

- Multithreading was implemented and was a tradeoff between difficulty of implementation and the performance of the sender process, in the end it helped modularize the different tasks of sending and receiving and well as independent assertions of timeouts and delayed sending of packets.
- As an extension for slight improvement of performance, timestamps were implemented so that when the correct acknowledgments are rare due to high probability of network errors, updates to the timeout interval were more frequent to better reflect the state of the network.
- A possible improvement/extension would be to have a dynamic window size at both sender and receiver that changes based on the detected congestion of the network, i.e., congestion control.

This would help promote fair use of shared bandwidth if multiple people are simultaneously using this program to transfer data. This would be implemented by slowly increasing the congestion window to probe the state of the network. When a loss event occurs the congestion window size is cut down appropriately and the process restarts.

4.

The pseudocode from the 'Computer Networks Top Down approach' chapter 3.5.4 was used and is screenshot in the appendix

5.

a)

In the appendix for both pDrop 0.1, 0.3 in the sender log, the dropping occurred at the highlighted lines. For pDrop=0.3, duplicate acks are more rare than with pDrop=0.1 as the receiver can only send acks per packet it receives resulting in less fast retransmits and more timeouts.

b)

Gamma	No. packets sent	Total time (s)	No. of Retransmits	No. Fast Retransmit
2	12168	6627.71	5778	221
4	12167	10242.59	5780	218
6	12167	13884.70	5780	218

When the drop out is high, it makes it very rare for a correct ack to be received that does not come from a retransmission of a packet, so the timeout value is very rarely updated. The gamma value linearly affects the calculation of the timeout interval which can be seen in the formula:

$$TimeoutInterval = EstimatedRTT + gamma \times DevRTT$$

This is reflected in the results, where when the gamma value is increased by two, the total time to send the file takes approximately one hour more. Since high dropout probability lowers the number of duplicate acknowledgements that the receiver can send, the number of fast retransmissions is quite low for all cases. The number of retransmissions due to timeout are all approximately equal, meaning that increasing the value of gamma more than two i.e., effectively increasing the timeout interval, would be unnecessary as gamma=2 effectively accounts for all fluctuations in RTT i.e., there is enough time to allow all acknowledgements to arrive at the sender despite some outliers to prevent premature timeout.

c)

For test2.pdf, the file was successfully transferred with the specified parameters. The overall transfer took 848.19 seconds. If duplicate acks are not sent for corrupt packets, pCorrupt is the most critical factor that contributes the most overall transfer time with pDrop coming in on a close second. This was determined by setting all probabilities to zero except the target factor and checking the amount of time it takes to complete the file transfer. The log summaries and last entry is shown for all experiments in the appendix. The reason is because dropped and corrupt packets are not acknowledged by the receiver, so they cause more timeouts than the other factors and timeouts contribute the most time. Furthermore, corrupt packets must be received and processed at the receiver which is not the case for dropped packets. Hence it made sense that the corrupt experiment took the most time to complete.

## Appendix

### 4. Pseudo code used from 'Computer Network Top Down Approach' chapter 3.5.4

```
NextSeqNum=InitialSeqNumber
SendBase=InitialSeqNumber

loop (forever) {
    switch(event)

        event: data received from application above
            create TCP segment with sequence number NextSeqNum
            if (timer currently not running)
                start timer
            pass segment to IP
            NextSeqNum=NextSeqNum+length(data)
            break;

        event: timer timeout
            retransmit not-yet-acknowledged segment with
                smallest sequence number
            start timer
            break;

        event: ACK received, with ACK field value of y
            if (y > SendBase) {
                SendBase=y
                if (there are currently any not yet
                    acknowledged segments)
                    start timer
            }
            else { /* a duplicate ACK for already ACKed
                segment */
                increment number of duplicate ACKs
                received for y
                if (number of duplicate ACKS received
                    for y==3)
                    /* TCP fast retransmit */
                    resend segment with sequence number y
            }
            break;
```

5a. test0.pdf

pDrop = 0.1

Sender\_log.txt:

snd	0.00	S	0	0	0
rcv	0.14	SA	0	0	1
snd	0.14	A	1	0	1
snd	0.14	D	1	100	1
drop	0.14	D	101	100	1
snd	0.14	D	201	100	1
snd	0.15	D	301	100	1
rcv	0.15	A	1	0	101
snd	0.16	D	401	100	1
snd	0.16	D	501	100	1
rcv/DA	0.16	A	1	0	101
rcv/DA	0.16	A	1	0	101
rcv/DA	0.16	A	1	0	101
snd/RXT	0.16	D	101	100	1
rcv/DA	0.16	A	1	0	101
rcv	0.16	A	1	0	601
snd	0.16	D	601	100	1
snd	0.16	D	701	100	1
snd	0.16	D	801	100	1
snd	0.16	D	901	100	1
snd	0.16	D	1001	100	1
rcv	0.16	A	1	0	701
snd	0.17	D	1101	100	1
rcv	0.17	A	1	0	801
snd	0.17	D	1201	100	1
rcv	0.17	A	1	0	901
snd	0.17	D	1301	100	1
rcv	0.17	A	1	0	1001
snd	0.17	D	1401	100	1
rcv	0.17	A	1	0	1101
snd	0.17	D	1501	100	1
rcv	0.17	A	1	0	1201
snd	0.17	D	1601	100	1
rcv	0.17	A	1	0	1301
snd	0.17	D	1701	100	1
rcv	0.17	A	1	0	1401
snd	0.17	D	1801	100	1
rcv	0.17	A	1	0	1501
drop	0.17	D	1901	100	1
rcv	0.17	A	1	0	1601
snd	0.17	D	2001	100	1
rcv	0.17	A	1	0	1701
snd	0.17	D	2101	100	1
rcv	0.17	A	1	0	1801
snd	0.17	D	2201	100	1
rcv	0.18	A	1	0	1901
snd	0.18	D	2301	100	1

rcv/DA	0.18	A	1	0	1901
rcv/DA	0.18	A	1	0	1901
rcv/DA	0.18	A	1	0	1901
snd/RXT	0.18	D	1901	100	1
rcv/DA	0.18	A	1	0	1901
rcv	0.18	A	1	0	2401
snd	0.18	D	2401	100	1
snd	0.18	D	2501	100	1
snd	0.18	D	2601	100	1
snd	0.18	D	2701	100	1
snd	0.18	D	2801	100	1
rcv	0.18	A	1	0	2501
snd	0.18	D	2901	100	1
rcv	0.18	A	1	0	2601
snd	0.18	D	3001	28	1
rcv	0.18	A	1	0	2701
rcv	0.18	A	1	0	2801
rcv	0.18	A	1	0	2901
rcv	0.18	A	1	0	3001
rcv	0.19	A	1	0	3029
snd	0.19	F	3029	0	1
rcv	0.19	A	1	0	3030
rcv	0.19	F	1	0	3030
snd	0.19	A	3030	0	2

```

=====
Size of the file (in Bytes)                                3028
Segments transmitted (including drop & RXT)                37
Number of Segments handled by PLD                          33
Number of Segments dropped                                  2
Number of Segments Corrupted                               0
Number of Segments Re-ordered                              0
Number of Segments Duplicated                              0
Number of Segments Delayed                                  0
Number of Retransmissions due to TIMEOUT                   0
Number of FAST RETRANSMISSION                              2
Number of DUP ACKS received                                8
=====

```

#### Receiver\_log.txt

rcv	0.00	S	0	0	0
snd	0.02	SA	0	0	1
rcv	0.07	A	1	0	1
rcv	0.08	D	1	100	1
snd	0.08	A	1	0	101
rcv	0.08	D	201	100	1
snd/DA	0.08	A	1	0	101
rcv	0.08	D	301	100	1
snd/DA	0.08	A	1	0	101
rcv	0.08	D	401	100	1
snd/DA	0.08	A	1	0	101



rcv	0.08	D	501	100	1
snd/DA	0.08	A	1	0	101
rcv	0.09	D	101	100	1
snd	0.09	A	1	0	601
rcv	0.09	D	601	100	1
snd	0.09	A	1	0	701
rcv	0.09	D	701	100	1
snd	0.09	A	1	0	801
rcv	0.09	D	801	100	1
snd	0.09	A	1	0	901
rcv	0.09	D	901	100	1
snd	0.09	A	1	0	1001
rcv	0.09	D	1001	100	1
snd	0.09	A	1	0	1101
rcv	0.09	D	1101	100	1
snd	0.09	A	1	0	1201
rcv	0.09	D	1201	100	1
snd	0.09	A	1	0	1301
rcv	0.09	D	1301	100	1
snd	0.09	A	1	0	1401
rcv	0.09	D	1401	100	1
snd	0.09	A	1	0	1501
rcv	0.10	D	1501	100	1
snd	0.10	A	1	0	1601
rcv	0.10	D	1601	100	1
snd	0.10	A	1	0	1701
rcv	0.10	D	1701	100	1
snd	0.10	A	1	0	1801
rcv	0.10	D	1801	100	1
snd	0.10	A	1	0	1901
rcv	0.10	D	2001	100	1
snd/DA	0.10	A	1	0	1901
rcv	0.10	D	2101	100	1
snd/DA	0.10	A	1	0	1901
rcv	0.10	D	2201	100	1
snd/DA	0.10	A	1	0	1901
rcv	0.10	D	2301	100	1
snd/DA	0.10	A	1	0	1901
rcv	0.10	D	1901	100	1
snd	0.10	A	1	0	2401
rcv	0.11	D	2401	100	1
snd	0.11	A	1	0	2501
rcv	0.11	D	2501	100	1
snd	0.11	A	1	0	2601
rcv	0.11	D	2601	100	1
snd	0.11	A	1	0	2701
rcv	0.11	D	2701	100	1
snd	0.11	A	1	0	2801
rcv	0.11	D	2801	100	1
snd	0.11	A	1	0	2901
rcv	0.11	D	2901	100	1
snd	0.11	A	1	0	3001

rcv	0.11	D	3001	28	1
snd	0.11	A	1	0	3029
rcv	0.11	F	3029	0	1
snd	0.11	A	1	0	3030
snd	0.11	F	1	0	3030
rcv	0.11	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                     8
=====

```

### pDrop = 0.3

Sender\_log.txt:

snd	0.00	S	0	0	0
rcv	0.17	SA	0	0	1
snd	0.17	A	1	0	1
snd	0.17	D	1	100	1
drop	0.17	D	101	100	1
snd	0.17	D	201	100	1
drop	0.18	D	301	100	1
rcv	0.18	A	1	0	101
drop	0.18	D	401	100	1
drop	0.18	D	501	100	1
rcv/DA	0.18	A	1	0	101
snd/RXT	1.80	D	101	100	1
rcv	1.80	A	1	0	301
drop	1.81	D	601	100	1
snd	1.81	D	701	100	1
rcv/DA	1.81	A	1	0	301
drop	3.45	D	301	100	1
snd/RXT	5.07	D	301	100	1
rcv	5.07	A	1	0	401
snd	5.07	D	801	100	1
rcv/DA	5.07	A	1	0	401
drop	6.70	D	401	100	1
snd/RXT	8.34	D	401	100	1
rcv	8.34	A	1	0	501
drop	8.34	D	901	100	1
snd/RXT	9.96	D	501	100	1
rcv	9.96	A	1	0	601
snd	9.96	D	1001	100	1
rcv/DA	9.97	A	1	0	601
snd/RXT	11.59	D	601	100	1
rcv	11.59	A	1	0	901
drop	11.59	D	1101	100	1

snd	11.59	D	1201	100	1
drop	11.59	D	1301	100	1
rcv/DA	11.59	A	1	0	901
snd/RXT	13.23	D	901	100	1
rcv	13.23	A	1	0	1101
snd	13.23	D	1401	100	1
snd	13.23	D	1501	100	1
rcv/DA	13.23	A	1	0	1101
rcv/DA	13.23	A	1	0	1101
drop	14.85	D	1101	100	1
drop	16.49	D	1101	100	1
snd/RXT	18.12	D	1101	100	1
rcv	18.12	A	1	0	1301
snd	18.12	D	1601	100	1
drop	18.12	D	1701	100	1
rcv/DA	18.12	A	1	0	1301
drop	19.75	D	1301	100	1
snd/RXT	21.38	D	1301	100	1
rcv	21.38	A	1	0	1701
drop	21.38	D	1801	100	1
snd	21.38	D	1901	100	1
drop	21.38	D	2001	100	1
snd	21.38	D	2101	100	1
rcv/DA	21.38	A	1	0	1701
rcv/DA	21.39	A	1	0	1701
drop	23.02	D	1701	100	1
drop	24.64	D	1701	100	1
snd/RXT	26.27	D	1701	100	1
rcv	26.27	A	1	0	1801
drop	26.27	D	2201	100	1
snd/RXT	27.90	D	1801	100	1
rcv	27.90	A	1	0	2001
snd	27.90	D	2301	100	1
drop	27.90	D	2401	100	1
rcv/DA	27.90	A	1	0	2001
snd/RXT	29.52	D	2001	100	1
rcv	29.52	A	1	0	2201
snd	29.52	D	2501	100	1
snd	29.52	D	2601	100	1
rcv/DA	29.52	A	1	0	2201
rcv/DA	29.52	A	1	0	2201
snd/RXT	31.15	D	2201	100	1
rcv	31.15	A	1	0	2401
drop	31.15	D	2701	100	1
drop	31.15	D	2801	100	1
snd/RXT	32.77	D	2401	100	1
rcv	32.77	A	1	0	2701
snd	32.77	D	2901	100	1
drop	32.77	D	3001	28	1
rcv/DA	32.77	A	1	0	2701
snd/RXT	34.38	D	2701	100	1
rcv	34.39	A	1	0	2801

snd/RXT	36.01	D	2801	100	1
rcv	36.01	A	1	0	3001
snd/RXT	37.64	D	3001	28	1
rcv	37.64	A	1	0	3029
snd	37.64	F	3029	0	1
rcv	37.64	A	1	0	3030
rcv	37.64	F	1	0	3030
snd	37.64	A	3030	0	2

```

=====
Size of the file (in Bytes)                                3028
Segments transmitted (including drop & RXT)                58
Number of Segments handled by PLD                          54
Number of Segments dropped                                  23
Number of Segments Corrupted                                0
Number of Segments Re-ordered                              0
Number of Segments Duplicated                              0
Number of Segments Delayed                                  0
Number of Retransmissions due to TIMEOUT                   23
Number of FAST RETRANSMISSION                              0
Number of DUP ACKS received                                14
=====

```

#### Receiver\_log.txt

rcv	0.00	S	0	0	0
snd	0.02	SA	0	0	1
rcv	0.10	A	1	0	1
rcv	0.11	D	1	100	1
snd	0.11	A	1	0	101
rcv	0.11	D	201	100	1
snd/DA	0.11	A	1	0	101
rcv	1.74	D	101	100	1
snd	1.74	A	1	0	301
rcv	1.74	D	701	100	1
snd/DA	1.74	A	1	0	301
rcv	5.00	D	301	100	1
snd	5.00	A	1	0	401
rcv	5.00	D	801	100	1
snd/DA	5.00	A	1	0	401
rcv	8.27	D	401	100	1
snd	8.27	A	1	0	501
rcv	9.90	D	501	100	1
snd	9.90	A	1	0	601
rcv	9.90	D	1001	100	1
snd/DA	9.90	A	1	0	601
rcv	11.52	D	601	100	1
snd	11.52	A	1	0	901
rcv	11.52	D	1201	100	1
snd/DA	11.52	A	1	0	901
rcv	13.16	D	901	100	1
snd	13.16	A	1	0	1101

rcv	13.16	D	1401	100	1
snd/DA	13.16	A	1	0	1101
rcv	13.16	D	1501	100	1
snd/DA	13.16	A	1	0	1101
rcv	18.05	D	1101	100	1
snd	18.05	A	1	0	1301
rcv	18.05	D	1601	100	1
snd/DA	18.05	A	1	0	1301
rcv	21.32	D	1301	100	1
snd	21.32	A	1	0	1701
rcv	21.32	D	1901	100	1
snd/DA	21.32	A	1	0	1701
rcv	21.32	D	2101	100	1
snd/DA	21.32	A	1	0	1701
rcv	26.20	D	1701	100	1
snd	26.20	A	1	0	1801
rcv	27.83	D	1801	100	1
snd	27.83	A	1	0	2001
rcv	27.83	D	2301	100	1
snd/DA	27.83	A	1	0	2001
rcv	29.45	D	2001	100	1
snd	29.45	A	1	0	2201
rcv	29.45	D	2501	100	1
snd/DA	29.45	A	1	0	2201
rcv	29.45	D	2601	100	1
snd/DA	29.45	A	1	0	2201
rcv	31.08	D	2201	100	1
snd	31.08	A	1	0	2401
rcv	32.70	D	2401	100	1
snd	32.70	A	1	0	2701
rcv	32.70	D	2901	100	1
snd/DA	32.70	A	1	0	2701
rcv	34.32	D	2701	100	1
snd	34.32	A	1	0	2801
rcv	35.94	D	2801	100	1
snd	35.94	A	1	0	3001
rcv	37.57	D	3001	28	1
snd	37.57	A	1	0	3029
rcv	37.57	F	3029	0	1
snd	37.57	A	1	0	3030
snd	37.57	F	1	0	3030
rcv	37.57	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	14

## Appendix

5b i

Sender\_log.txt, test1.pdf

First 23 entries:

snd	0.00	S	0	0	0
rcv	0.17	SA	0	0	1
snd	0.17	A	1	0	1
snd	0.17	D	1	50	1
drop	0.17	D	51	50	1
snd	0.17	D	101	50	1
drop	0.17	D	151	50	1
snd	0.17	D	201	50	1
snd	0.17	D	251	50	1
snd	0.17	D	301	50	1
drop	0.17	D	351	50	1
snd	0.17	D	401	50	1
rcv	0.17	A	1	0	51
snd	0.17	D	451	50	1
rcv/DA	0.17	A	1	0	51
rcv/DA	0.17	A	1	0	51
rcv/DA	0.17	A	1	0	51
snd/RXT	0.17	D	51	50	1
rcv/DA	0.17	A	1	0	51
rcv/DA	0.17	A	1	0	51
rcv/DA	0.19	A	1	0	51
drop	0.19	D	51	50	1
rcv	0.19	A	1	0	151

## Appendix

5b i

Sender\_log.txt, test1.pdf

Last 20 entries + summary stats

snd	6623.05	D	308051	50	1
rcv/DA	6623.05	A	1	0	307601
snd/RXT	6624.19	D	307601	50	1
rcv	6624.19	A	1	0	307851
snd	6624.19	D	308101	50	1
snd	6624.19	D	308151	50	1
snd	6624.19	D	308201	3	1
rcv/DA	6624.19	A	1	0	307851
rcv/DA	6624.20	A	1	0	307851
rcv/DA	6624.20	A	1	0	307851
drop	6624.20	D	307851	50	1
snd/RXT	6625.33	D	307851	50	1
rcv	6625.33	A	1	0	307901
snd/RXT	6626.46	D	307901	50	1
rcv	6626.46	A	1	0	308001
rcv	6627.70	A	1	0	308204
snd	6627.71	F	308204	0	1
rcv	6627.71	A	1	0	308205
rcv	6627.71	F	1	0	308205
snd	6627.71	A	308205	0	2

```
=====
Size of the file (in Bytes)                308203
Segments transmitted (including drop & RXT) 12168
Number of Segments handled by PLD          12164
Number of Segments dropped                 5996
Number of Segments Corrupted               0
Number of Segments Re-ordered              0
Number of Segments Duplicated              0
Number of Segments Delayed                 1187
Number of Retransmissions due to TIMEOUT   5778
Number of FAST RETRANSMISSION              221
Number of DUP ACKS received                3108
=====
```

## Appendix

5b i

Receiver\_log.txt, test1.pdf

First 23 entries:

rcv	0.00	S	0	0	0
snd	0.02	SA	0	0	1
rcv	0.09	A	1	0	1
rcv	0.09	D	1	50	1
snd	0.09	A	1	0	51
rcv	0.09	D	101	50	1
snd/DA	0.09	A	1	0	51
rcv	0.09	D	201	50	1
snd/DA	0.09	A	1	0	51
rcv	0.09	D	251	50	1
snd/DA	0.09	A	1	0	51
rcv	0.09	D	301	50	1
snd/DA	0.09	A	1	0	51
rcv	0.09	D	401	50	1
snd/DA	0.09	A	1	0	51
rcv	0.11	D	451	50	1
snd/DA	0.11	A	1	0	51
rcv	0.11	D	51	50	1
snd	0.11	A	1	0	151
rcv	0.41	D	551	50	1
snd/DA	0.41	A	1	0	151
rcv	0.89	D	501	50	1
snd/DA	0.89	A	1	0	151



## Appendix

5b i

Reciever\_log.txt, test1.pdf

Last 20 entries + summary stats

rcv	6622.98	D	308051	50	1
snd/DA	6622.98	A	1	0	307601
rcv	6624.11	D	307601	50	1
snd	6624.12	A	1	0	307851
rcv	6624.12	D	308101	50	1
snd/DA	6624.12	A	1	0	307851
rcv	6624.12	D	308151	50	1
snd/DA	6624.12	A	1	0	307851
rcv	6624.12	D	308201	3	1
snd/DA	6624.12	A	1	0	307851
rcv	6625.25	D	307851	50	1
snd	6625.25	A	1	0	307901
rcv	6626.38	D	307901	50	1
snd	6626.38	A	1	0	308001
rcv	6627.63	D	308001	50	1
snd	6627.63	A	1	0	308204
rcv	6627.63	F	308204	0	1
snd	6627.63	A	1	0	308205
snd	6627.63	F	1	0	308205
rcv	6627.63	A	308205	0	2

```
=====
Amount of data received (bytes)          308353
Total segments Received                   6172
Data segments received                    6168
Data segments with Bit Errors              0
Duplicate data segments received           0
Duplicate ACKs sent                       3108
=====
```

## Appendix

5b ii

Sender\_log.txt, test1.pdf

First 23 entries:

snd	0.00	S	0	0	0
rcv	0.14	SA	0	0	1
snd	0.14	A	1	0	1
snd	0.14	D	1	50	1
drop	0.14	D	51	50	1
snd	0.14	D	101	50	1
drop	0.14	D	151	50	1
snd	0.14	D	201	50	1
snd	0.14	D	251	50	1
snd	0.14	D	301	50	1
drop	0.14	D	351	50	1
snd	0.14	D	401	50	1
rcv	0.16	A	1	0	51
snd	0.16	D	451	50	1
rcv/DA	0.16	A	1	0	51
rcv/DA	0.16	A	1	0	51
rcv/DA	0.16	A	1	0	51
snd/RXT	0.16	D	51	50	1
rcv/DA	0.16	A	1	0	51
rcv/DA	0.16	A	1	0	51
rcv/DA	0.16	A	1	0	51
drop	0.16	D	51	50	1
rcv	0.16	A	1	0	151

## Appendix

5b ii

Sender\_log.txt, test1.pdf

Last 20 entries + summary stats

drop	10234.07	D	308051	50	1
snd	10234.07	D	308101	50	1
rcv/DA	10234.08	A	1	0	307651
snd/RXT	10235.77	D	307651	50	1
rcv	10235.77	A	1	0	307901
snd	10235.78	D	308151	50	1
snd	10235.78	D	308201	3	1
rcv/DA	10235.78	A	1	0	307901
rcv/DA	10235.78	A	1	0	307901
snd/RXT	10237.48	D	307901	50	1
rcv	10237.48	A	1	0	307951
drop	10239.18	D	307951	50	1
snd/RXT	10240.88	D	307951	50	1
rcv	10240.88	A	1	0	308051
snd/RXT	10242.58	D	308051	50	1
rcv	10242.58	A	1	0	308204
snd	10242.59	F	308204	0	1
rcv	10242.59	A	1	0	308205
rcv	10242.59	F	1	0	308205
snd	10242.59	A	308205	0	2

```
=====
Size of the file (in Bytes)                308203
Segments transmitted (including drop & RXT) 12167
Number of Segments handled by PLD          12163
Number of Segments dropped                  5996
Number of Segments Corrupted                0
Number of Segments Re-ordered               0
Number of Segments Duplicated               0
Number of Segments Delayed                  1186
Number of Retransmissions due to TIMEOUT    5780
Number of FAST RETRANSMISSION              218
Number of DUP ACKS received                 3110
=====
```

## Appendix

5b ii

Receiver\_log.txt, test1.pdf

First 23 entries:

rcv	0.00	S	0	0	0
snd	0.02	SA	0	0	1
rcv	0.06	A	1	0	1
rcv	0.08	D	1	50	1
snd	0.08	A	1	0	51
rcv	0.08	D	101	50	1
snd/DA	0.08	A	1	0	51
rcv	0.08	D	201	50	1
snd/DA	0.08	A	1	0	51
rcv	0.08	D	251	50	1
snd/DA	0.08	A	1	0	51
rcv	0.08	D	301	50	1
snd/DA	0.08	A	1	0	51
rcv	0.08	D	401	50	1
snd/DA	0.08	A	1	0	51
rcv	0.08	D	451	50	1
snd/DA	0.08	A	1	0	51
rcv	0.08	D	51	50	1
snd	0.08	A	1	0	151
rcv	0.38	D	551	50	1
snd/DA	0.38	A	1	0	151
rcv	0.87	D	501	50	1
snd/DA	0.87	A	1	0	151

## Appendix

5b ii

Reciever\_log.txt, test1.pdf

Last 20 entries + summary stats

rcv	10233.99	D	307551	50	1
snd	10233.99	A	1	0	307651
rcv	10234.00	D	308101	50	1
snd/DA	10234.00	A	1	0	307651
rcv	10235.70	D	307651	50	1
snd	10235.70	A	1	0	307901
rcv	10235.70	D	308151	50	1
snd/DA	10235.70	A	1	0	307901
rcv	10235.70	D	308201	3	1
snd/DA	10235.70	A	1	0	307901
rcv	10237.40	D	307901	50	1
snd	10237.40	A	1	0	307951
rcv	10240.80	D	307951	50	1
snd	10240.80	A	1	0	308051
rcv	10242.51	D	308051	50	1
snd	10242.51	A	1	0	308204
rcv	10242.51	F	308204	0	1
snd	10242.51	A	1	0	308205
snd	10242.51	F	1	0	308205
rcv	10242.52	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           0
Duplicate ACKs sent                       3110
=====
```

## Appendix

5b iii

Sender\_log.txt, test1.pdf

First 23 entries:

snd	0.00	S	0	0	0
rcv	0.15	SA	0	0	1
snd	0.15	A	1	0	1
snd	0.15	D	1	50	1
drop	0.16	D	51	50	1
snd	0.16	D	101	50	1
drop	0.16	D	151	50	1
snd	0.16	D	201	50	1
snd	0.16	D	251	50	1
snd	0.16	D	301	50	1
drop	0.16	D	351	50	1
snd	0.16	D	401	50	1
rcv	0.17	A	1	0	51
snd	0.17	D	451	50	1
rcv/DA	0.17	A	1	0	51
rcv/DA	0.17	A	1	0	51
rcv/DA	0.18	A	1	0	51
snd/RXT	0.18	D	51	50	1
rcv/DA	0.18	A	1	0	51
rcv/DA	0.18	A	1	0	51
rcv/DA	0.18	A	1	0	51
drop	0.18	D	51	50	1
rcv	0.18	A	1	0	151

## Appendix

5b iii

Sender\_log.txt, test1.pdf

Last 20 entries + summary stats

drop	13873.29	D	308051	50	1
snd	13873.29	D	308101	50	1
rcv/DA	13873.29	A	1	0	307651
snd/RXT	13875.57	D	307651	50	1
rcv	13875.57	A	1	0	307901
snd	13875.57	D	308151	50	1
snd	13875.57	D	308201	3	1
rcv/DA	13875.57	A	1	0	307901
rcv/DA	13875.57	A	1	0	307901
snd/RXT	13877.86	D	307901	50	1
rcv	13877.86	A	1	0	307951
drop	13880.14	D	307951	50	1
snd/RXT	13882.42	D	307951	50	1
rcv	13882.42	A	1	0	308051
snd/RXT	13884.70	D	308051	50	1
rcv	13884.70	A	1	0	308204
snd	13884.70	F	308204	0	1
rcv	13884.70	A	1	0	308205
rcv	13884.70	F	1	0	308205
snd	13884.70	A	308205	0	2

```
=====
Size of the file (in Bytes)                308203
Segments transmitted (including drop & RXT) 12167
Number of Segments handled by PLD          12163
Number of Segments dropped                  5996
Number of Segments Corrupted                0
Number of Segments Re-ordered               0
Number of Segments Duplicated               0
Number of Segments Delayed                  1186
Number of Retransmissions due to TIMEOUT    5780
Number of FAST RETRANSMISSION              218
Number of DUP ACKS received                 3110
=====
```

## Appendix

5b iii

Receiver\_log.txt, test1.pdf

First 23 entries:

rcv	0.00	S	0	0	0
snd	0.02	SA	0	0	1
rcv	0.08	A	1	0	1
rcv	0.10	D	1	50	1
snd	0.10	A	1	0	51
rcv	0.10	D	101	50	1
snd/DA	0.10	A	1	0	51
rcv	0.10	D	201	50	1
snd/DA	0.10	A	1	0	51
rcv	0.10	D	251	50	1
snd/DA	0.10	A	1	0	51
rcv	0.11	D	301	50	1
snd/DA	0.11	A	1	0	51
rcv	0.11	D	401	50	1
snd/DA	0.11	A	1	0	51
rcv	0.11	D	451	50	1
snd/DA	0.11	A	1	0	51
rcv	0.11	D	51	50	1
snd	0.11	A	1	0	151
rcv	0.41	D	551	50	1
snd/DA	0.41	A	1	0	151
rcv	0.89	D	501	50	1
snd/DA	0.89	A	1	0	151



## Appendix

5b iii

Reciever\_log.txt, test1.pdf

Last 20 entries + summary stats

rcv	13873.22	D	307551	50	1
snd	13873.22	A	1	0	307651
rcv	13873.22	D	308101	50	1
snd/DA	13873.22	A	1	0	307651
rcv	13875.50	D	307651	50	1
snd	13875.50	A	1	0	307901
rcv	13875.50	D	308151	50	1
snd/DA	13875.50	A	1	0	307901
rcv	13875.50	D	308201	3	1
snd/DA	13875.50	A	1	0	307901
rcv	13877.79	D	307901	50	1
snd	13877.79	A	1	0	307951
rcv	13882.35	D	307951	50	1
snd	13882.35	A	1	0	308051
rcv	13884.63	D	308051	50	1
snd	13884.63	A	1	0	308204
rcv	13884.63	F	308204	0	1
snd	13884.63	A	1	0	308205
snd	13884.63	F	1	0	308205
rcv	13884.63	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	0
Duplicate ACKs sent	3110

=====

## Appendix

5c.

Sender\_log.txt

Connection establishment + first 30 of entries

snd	0.00	S	0	0	0
rcv	0.15	SA	0	0	1
snd	0.15	A	1	0	1
snd	0.15	D	1	50	1
snd	0.15	D	51	50	1
snd	0.15	D	101	50	1
snd	0.15	D	151	50	1
snd	0.15	D	201	50	1
snd/corr	0.15	D	251	50	1
snd/corr	0.15	D	301	50	1
snd	0.15	D	351	50	1
snd	0.15	D	401	50	1
rcv	0.16	A	1	0	51
snd	0.16	D	451	50	1
snd/dup	0.16	D	451	50	1
snd	0.16	D	501	50	1
rcv	0.16	A	1	0	101
snd	0.16	D	551	50	1
rcv	0.16	A	1	0	151
snd	0.16	D	601	50	1
rcv	0.16	A	1	0	201
rcv	0.16	A	1	0	251
snd/corr	0.16	D	701	50	1
rcv/DA	0.16	A	1	0	251
rcv/DA	0.17	A	1	0	251
rcv/DA	0.17	A	1	0	251
snd/RXT	0.17	D	251	50	1
rcv/DA	0.17	A	1	0	251
rcv/DA	0.17	A	1	0	251
rcv/DA	0.17	A	1	0	251
rcv/DA	0.17	A	1	0	251
snd/RXT	0.17	D	251	50	1
rcv/DA	0.17	A	1	0	251
rcv	0.17	A	1	0	301

Last 20 entries + tear down + summary statistics

rcv/DA	846.43	A	1	0	1604851
drop	846.94	D	1604851	50	1
snd/RXT/rord	847.47	D	1604801	50	1
snd/RXT	847.47	D	1604851	50	1
rcv	847.49	A	1	0	1604951
snd/corr	847.51	D	1605351	50	1
snd	847.52	D	1605401	50	1
rcv/DA	847.53	A	1	0	1604951
rcv/DA	847.54	A	1	0	1604951
snd/RXT	848.03	D	1604951	50	1
rcv	848.04	A	1	0	1605351
snd	848.05	D	1605451	50	1
snd	848.06	D	1605501	50	1
snd	848.07	D	1605551	35	1
rcv/DA	848.08	A	1	0	1605351
rcv/DA	848.09	A	1	0	1605351
rcv/DA	848.10	A	1	0	1605351
snd/RXT	848.11	D	1605351	50	1
snd/RXT/dup	848.11	D	1605351	50	1
rcv	848.13	A	1	0	1605586
snd	848.14	F	1605586	0	1
rcv	848.17	A	1	0	1605587
rcv	848.18	F	1	0	1605587
snd	848.19	A	1605587	0	2
=====					
Size of the file (in Bytes)	1605585				
Segments transmitted (including drop & RXT)	45977				
Number of Segments handled by PLD	45973				
Number of Segments dropped	4210				
Number of Segments Corrupted	3316				
Number of Segments Re-ordered	2419				
Number of Segments Duplicated	3767				
Number of Segments Delayed	0				
Number of Retransmissions due to TIMEOUT	2894				
Number of FAST RETRANSMISSION	7200				
Number of DUP ACKS received	28700				
=====					

Receiver\_log.txt

Connection establishment + first 30 entries

rcv	0.00	S	0	0	0
snd	0.02	SA	0	0	1
rcv	0.07	A	1	0	1
rcv	0.07	D	1	50	1
snd	0.08	A	1	0	51
rcv	0.08	D	51	50	1
snd	0.08	A	1	0	101
rcv	0.08	D	101	50	1
snd	0.08	A	1	0	151
rcv	0.08	D	151	50	1
snd	0.08	A	1	0	201
rcv	0.08	D	201	50	1
snd	0.08	A	1	0	251
rcv/corr	0.08	D	251	50	1
rcv/corr	0.08	D	301	50	1
rcv	0.08	D	351	50	1
snd/DA	0.08	A	1	0	251
rcv	0.08	D	401	50	1
snd/DA	0.08	A	1	0	251
rcv	0.08	D	451	50	1
snd/DA	0.08	A	1	0	251
rcv	0.08	D	451	50	1
snd/DA	0.08	A	1	0	251

---

Last 20 entries + teardown + summary statistics

snd/DA	846.35	A	1	0	1604851
rcv	847.39	D	1604851	50	1
snd	847.40	A	1	0	1604951
rcv	847.41	D	1604801	50	1
snd/DA	847.42	A	1	0	1604951
rcv/corr	847.43	D	1605351	50	1
rcv	847.44	D	1605401	50	1
snd/DA	847.45	A	1	0	1604951
rcv	847.95	D	1604951	50	1
snd	847.96	A	1	0	1605351
rcv	847.97	D	1605451	50	1
snd/DA	847.98	A	1	0	1605351
rcv	847.99	D	1605501	50	1
snd/DA	848.00	A	1	0	1605351
rcv	848.01	D	1605551	35	1
snd/DA	848.02	A	1	0	1605351
rcv	848.04	D	1605351	50	1
snd	848.05	A	1	0	1605586
rcv	848.06	D	1605351	50	1
snd/DA	848.07	A	1	0	1605586
rcv	848.08	F	1605586	0	1
snd	848.09	A	1	0	1605587
snd	848.09	F	1	0	1605587
rcv	848.10	A	1605587	0	2

```
=====
Amount of data received (bytes)          2088135
Total segments Received                   41767
Data segments received                   41763
Data segments with Bit Errors             3316
Duplicate data segments received          2486
Duplicate ACKs sent                       28701
=====
```

## 5c experiments

### Dropout only

```
snd                348.18          A 1605587          0          2
=====
Size of the file (in Bytes)                1605585
Segments transmitted (including drop & RXT)    38128
Number of Segments handled by PLD            38124
Number of Segments dropped                    3822
Number of Segments Corrupted                  0
Number of Segments Re-ordered                 0
Number of Segments Duplicated                 0
Number of Segments Delayed                   0
Number of Retransmissions due to TIMEOUT      795
Number of FAST RETRANSMISSION                5217
Number of DUP ACKS received                  20020
=====
```

### Corrupt only

```
snd                356.79          A 1605587          0          2
=====
Size of the file (in Bytes)                1605585
Segments transmitted (including drop & RXT)    38019
Number of Segments handled by PLD            38015
Number of Segments dropped                    0
Number of Segments Corrupted                 3804
Number of Segments Re-ordered                 0
Number of Segments Duplicated                 0
Number of Segments Delayed                   0
Number of Retransmissions due to TIMEOUT      725
Number of FAST RETRANSMISSION                5178
Number of DUP ACKS received                  19835
=====
```

### Duplicate only

```
snd                287.57          A 1605587          0          2
=====
Size of the file (in Bytes)                1605585
Segments transmitted (including drop & RXT)    35400
Number of Segments handled by PLD            35396
Number of Segments dropped                    0
Number of Segments Corrupted                  0
Number of Segments Re-ordered                 0
Number of Segments Duplicated                 3283
Number of Segments Delayed                   0
Number of Retransmissions due to TIMEOUT      1
Number of FAST RETRANSMISSION                0
Number of DUP ACKS received                  3284
=====
```

Reordering only

snd	265.32	A 1605587	0	2
=====				
Size of the file (in Bytes)			1605585	
Segments transmitted (including drop & RXT)			34434	
Number of Segments handled by PLD			34430	
Number of Segments dropped			0	
Number of Segments Corrupted			0	
Number of Segments Re-ordered			2470	
Number of Segments Duplicated			0	
Number of Segments Delayed			0	
Number of Retransmissions due to TIMEOUT			2	
Number of FAST RETRANSMISSION			2316	
Number of DUP ACKS received			10880	
=====				