Lab 4 Writeup
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This lab took me about 12 hours to do. I did attend the lab session.

1. Program Structure and Design:

核心函数 -- 思路 & 代码:

（1）发起连接
- 将 `sender` 中的 `segment` push 到 `connection` 中
- 尽量设置 `ackno` 和 `window_size`

Code:

<u>void TCPConnection::_send_data()</u>

```
    while(!_sender.segments_out().empty())
    {
        TCPSegment seg = _sender.segments_out().front();
        _sender.segments_out().pop();

        if(_receiver.ackno().has_value())
        {
            seg.header().ack = true;
            seg.header().ackno = _receiver.ackno().value();
            seg.header().win = _receiver.window_size();
        }
        _segments_out.push(seg);
    }
```

（1.1）发起连接
- 调用 `TCPSender::fill_window` ，发送 `SYN`

Code:

```
    void TCPConnection::connect()
    {
        _sender.fill_window();
        _send_data();
    }
```

（2）关闭连接
- 发送完毕：
    - `sender` 的 `stream_in` 已经 `eof`
    - `receiver` 的 `stream_out` 已经 `input_ended`

Code:

<u>void TCPConnection::_send_data()</u>

```
    if(_receiver.stream_out().input_ended())
    {
        if(!_sender.stream_in().eof())
            _linger_after_streams_finish = false;

        else if(_sender.bytes_in_flight() == 0)
        {
            if (!_linger_after_streams_finish ||
time_since_last_segment_received() >= 10 * _cfg.rt_timeout)
                active_ = false;
        }
    }
```

（3）写入数据 & 发送数据包
- 将数据写入 `TCPSender` 的 `ByteStream` 中
- 填充窗口，发送

Code:

```
    size_t TCPConnection::write(const string &data) {
        //DUMMY_CODE(data);

        if(data.empty())
            return 0;

        // 在 sender 中写入数据并发送
        size_t size = _sender.stream_in().write(data);
        _sender.fill_window();
        _send_data();
        return size;
    }
```

（4）接收数据包

TCP 连接状态

image.png

TCP 三次握手

image.png

<u>CLOSED / LISTEN</u>
- CLOSED：初始状态，表示 TCP 连接是“关闭着”或“未打开”的
- LISTEN：表示服务器端的某个 SOCKET 处于监听状态，可以接受客户端的连接
- 等待来自远程 TCP 应用程序的请求

- 收到 `SYN` ：说明 TCP 连接由对方启动，进入 Syn-Revd 状态
- 因为还没有 ACK，所以 `sender` 不需要 `ack_received`
- 主动发送一个 `SYN`

Code:

```
    else if(_sender.next_seqno_absolute() == 0)
    {
        // 收到 SYN：TCP 连接由对方启动，进入 SYN-REVD 状态
        if(seg.header().syn)
        {
            // 还没有 ACK，sender 不需要 ack_received
            _receiver.segment_received(seg);
            // 主动发送一个 SYN
            connect();
        }
    }
```

<u>SYN-SENT</u>
- 发送连接请求后等待来自远程端点的确认
- TCP 第一次握手后客户端所处的状态

- 收到 `SYN` 和 `ACK`：说明由对方主动开启连接，进入 ESTABLISHED 状态
    - 通过一个空包来发送 `ACK`
- 只收到了 `SYN`：说明由双方同时开启连接，进入 SYN-REVD 状态
    - 没有接收到对方的 `ACK`，主动发一个

Code:

```
    else if(_sender.next_seqno_absolute() == _sender.bytes_in_flight()
&& !_receiver.ackno().has_value())
    {
        // 收到 SYN 和 ACK：由对方主动开启连接，进入 ESTABLISHED 状态
```

```
        if(seg.header().syn && seg.header().ack)
        {
            _sender.ack_received(seg.header().ackno, seg.header().win);
            _receiver.segment_received(seg);
            // 通过空包发送一个 ACK
            _sender.send_empty_segment();
            _send_data();
        }
        // 只收到 SYN：由双方同时开启连接，进入 SYN-REVD 状态
        else if(seg.header().syn && !seg.header().ack)
        {
            // 没有接收到对方的 ACK
            _receiver.segment_received(seg);
            // 主动发送一个 ACK
            _sender.send_empty_segment();
            _send_data();
        }
    }
```

<u>SYN-REVD</u>
- 该端点已经接收到连接请求并发送确认
- 该端点正在等待最终确认
- TCP 第二次握手后服务端所处的状态

- 输入没有结束
- 接收 `ACK`，进入 ESTABLISHED 状态

Code:

```
    else if(_sender.next_seqno_absolute() == _sender.bytes_in_flight() &&
_receiver.ackno().has_value() && !_receiver.stream_out().input_ended())
    {
        // 接收 ACK，进入 ESTABLISHED 状态
        _sender.ack_received(seg.header().ackno, seg.header().win);
        _receiver.segment_received(seg);
    }
```

<u>ESTABLISHED</u>
- 代表连接已经建立起来
- 连接数据传输阶段的正常状态

- 发送数据
- 如果接到数据，则更新 `ACK`

Code:

```
    else if(_sender.next_seqno_absolute() > _sender.bytes_in_flight()
&& !_sender.stream_in().eof())
    {
        // 发送数据：如果接到数据，则更新 ACK
        _sender.ack_received(seg.header().ackno, seg.header().win);
        _receiver.segment_received(seg);

        if(seg.length_in_sequence_space() > 0)
            _sender.send_empty_segment();
        _sender.fill_window();
        _send_data();
    }
```

TCP 四次挥手

image.png

<u>FIN-WAIT-1</u>
- 等待来自远程 TCP 的终止连接请求或终止请求的确认

- 收到 `FIN`：发送新 `ACK`，进入 CLOSING/TIME-WAIT
- 收到 `ACK`：进入 FIN-WAIT-2

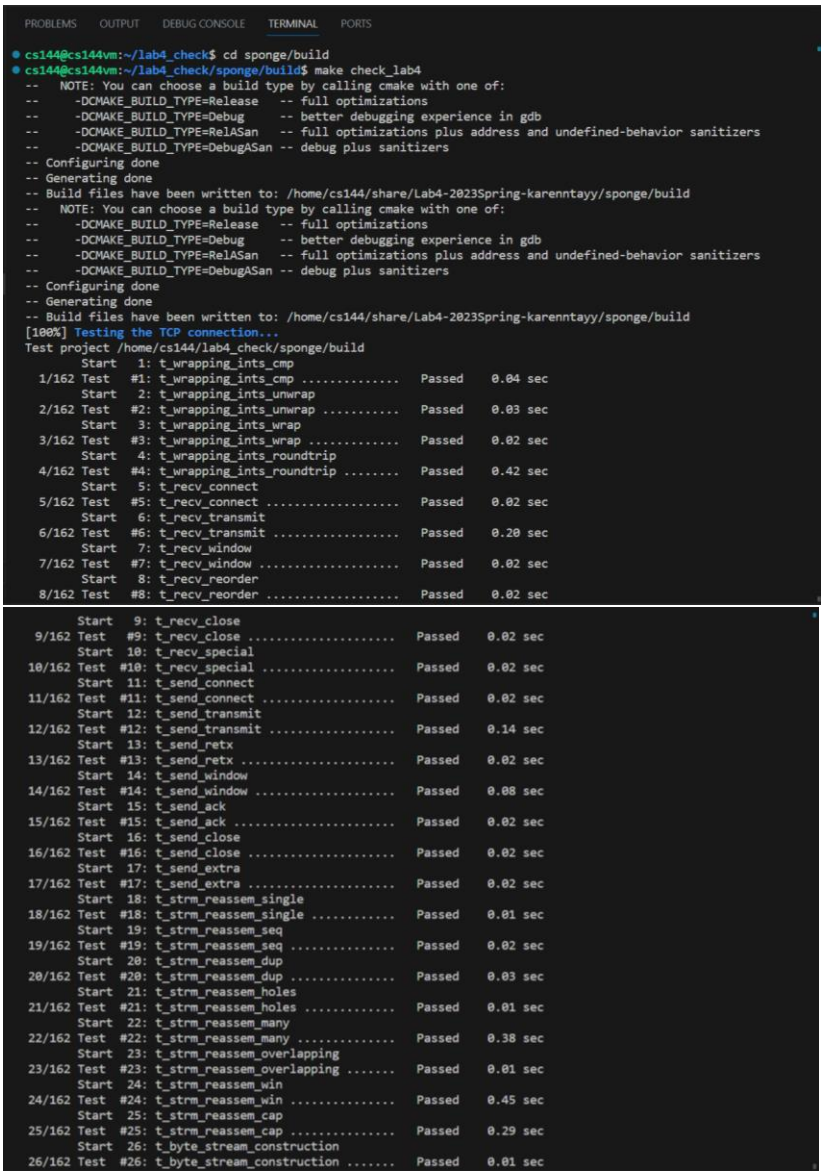
Code:

```
    else if(_sender.next_seqno_absolute() == _sender.stream_in().bytes_written()
+ 2 && _sender.bytes_in_flight() > 0
    && _sender.stream_in().eof() && !_receiver.stream_out().input_ended())
    {
        if(seg.header().fin)
        {
            // 收到 FIN：发送新 ACK，进入 CLOSING/TIME-WAIT
            _sender.ack_received(seg.header().ackno, seg.header().win);
            _receiver.segment_received(seg);
            _sender.send_empty_segment();
            _send_data();
        }
        else if(seg.header().ack)
        {
            // 收到 ACK：进入 FIN-WAIT-2
            _sender.ack_received(seg.header().ackno, seg.header().win);
            _receiver.segment_received(seg);
            _send_data();
        }
```

```
    }

<u>FIN-WAIT-2</u>
- 在此端点发送终止连接请求
- 等待来自远程 TCP 的连接终止请求

Code:

    else if(_sender.next_seqno_absolute() == _sender.stream_in().bytes_written()
+ 2 && _sender.bytes_in_flight() == 0
    && _sender.stream_in().eof() && !_receiver.stream_out().input_ended())
    {
        _sender.ack_received(seg.header().ackno, seg.header().win);
        _receiver.segment_received(seg);
        _sender.send_empty_segment();
        _send_data();
    }

<u>TIME-WAIT</u>
- 等待足够的时间来确保远程 TCP 接收到其连接终止请求的确认

- 收到 FIN：保持 TIME-WAIT 状态
    - 可靠地实现 TCP 的全双工连接终止
    - 允许旧的重复数据段在网络中过期

Code:

    else if(_sender.next_seqno_absolute() == _sender.stream_in().bytes_written()
+ 2 && _sender.bytes_in_flight() == 0
    && _sender.stream_in().eof() && _receiver.stream_out().input_ended())
    {
        if(seg.header().fin)
        {
           // 收到 FIN：保持 TIME-WAIT 状态
            _sender.ack_received(seg.header().ackno, seg.header().win);
            _receiver.segment_received(seg);
            _sender.send_empty_segment();
            _send_data();
        }
    }

<u>其他</u>

Code:
```

```
    else
    {
        _sender.ack_received(seg.header().ackno, seg.header().win);
        _receiver.segment_received(seg);
        _sender.fill_window();
        _send_data();
    }

#### 2. Implementation Challenges:

...

...

#### 3. Remaining Bugs:

...

...

*More details and requirements of sections above can be found in
`lab5_tutorials.pdf/10.submit`*
```

SNAPSHOT of TEST RESULT of make check_lab4:


PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL PORTS
cs144@cs144vm:~/lab4_check$ cd sponge/build
cs144@cs144vm:~/lab4_check/sponge/build$ make check_lab4
-- NOTE: You can choose a build type by calling cmake with one of:
-- -DCMAKE_BUILD_TYPE=Release -- full optimizations
-- -DCMAKE_BUILD_TYPE=Debug -- better debugging experience in gdb
-- -DCMAKE_BUILD_TYPE=RelASan -- full optimizations plus address and undefined-behavior sanitizers
-- -DCMAKE_BUILD_TYPE=DebugASan -- debug plus sanitizers
-- Configuring done
-- Generating done
-- Build files have been written to: /home/cs144/share/Lab4-2023Spring-karenntayy/sponge/build
-- NOTE: You can choose a build type by calling cmake with one of:
-- -DCMAKE_BUILD_TYPE=Release -- full optimizations
-- -DCMAKE_BUILD_TYPE=Debug -- better debugging experience in gdb
-- -DCMAKE_BUILD_TYPE=RelASan -- full optimizations plus address and undefined-behavior sanitizers
-- -DCMAKE_BUILD_TYPE=DebugASan -- debug plus sanitizers
-- Configuring done
-- Generating done
-- Build files have been written to: /home/cs144/share/Lab4-2023Spring-karenntayy/sponge/build
[100%] Testing the TCP connection...
Test project /home/cs144/lab4_check/sponge/build
Start 1: t_wrapping_ints_cmp
1/162 Test #1: t_wrapping_ints_cmp ..... Passed 0.04 sec
Start 2: t_wrapping_ints_unwrap
2/162 Test #2: t_wrapping_ints_unwrap ..... Passed 0.03 sec
Start 3: t_wrapping_ints_wrap
3/162 Test #3: t_wrapping_ints_wrap ..... Passed 0.02 sec
Start 4: t_wrapping_ints_roundtrip
4/162 Test #4: t_wrapping_ints_roundtrip ..... Passed 0.42 sec
Start 5: t_recv_connect
5/162 Test #5: t_recv_connect ..... Passed 0.02 sec
Start 6: t_recv_transmit
6/162 Test #6: t_recv_transmit ..... Passed 0.20 sec
Start 7: t_recv_window
7/162 Test #7: t_recv_window ..... Passed 0.02 sec
Start 8: t_recv_reorder
8/162 Test #8: t_recv_reorder ..... Passed 0.02 sec

Start 9: t_recv_close
9/162 Test #9: t_recv_close ..... Passed 0.02 sec
Start 10: t_recv_special
10/162 Test #10: t_recv_special ..... Passed 0.02 sec
Start 11: t_send_connect
11/162 Test #11: t_send_connect ..... Passed 0.02 sec
Start 12: t_send_transmit
12/162 Test #12: t_send_transmit ..... Passed 0.14 sec
Start 13: t_send_retx
13/162 Test #13: t_send_retx ..... Passed 0.02 sec
Start 14: t_send_window
14/162 Test #14: t_send_window ..... Passed 0.08 sec
Start 15: t_send_ack
15/162 Test #15: t_send_ack ..... Passed 0.02 sec
Start 16: t_send_close
16/162 Test #16: t_send_close ..... Passed 0.02 sec
Start 17: t_send_extra
17/162 Test #17: t_send_extra ..... Passed 0.02 sec
Start 18: t_strm_reassem_single
18/162 Test #18: t_strm_reassem_single ..... Passed 0.01 sec
Start 19: t_strm_reassem_seq
19/162 Test #19: t_strm_reassem_seq ..... Passed 0.02 sec
Start 20: t_strm_reassem_dup
20/162 Test #20: t_strm_reassem_dup ..... Passed 0.03 sec
Start 21: t_strm_reassem_holes
21/162 Test #21: t_strm_reassem_holes ..... Passed 0.01 sec
Start 22: t_strm_reassem_many
22/162 Test #22: t_strm_reassem_many ..... Passed 0.38 sec
Start 23: t_strm_reassem_overlapping
23/162 Test #23: t_strm_reassem_overlapping ..... Passed 0.01 sec
Start 24: t_strm_reassem_win
24/162 Test #24: t_strm_reassem_win ..... Passed 0.45 sec
Start 25: t_strm_reassem_cap
25/162 Test #25: t_strm_reassem_cap ..... Passed 0.29 sec
Start 26: t_byte_stream_construction
26/162 Test #26: t_byte_stream_construction ..... Passed 0.01 sec

```
 27/162 Test  #27: t_byte_stream_one_write .....   Passed    0.02 sec
        Start  28: t_byte_stream_two_writes
 28/162 Test  #28: t_byte_stream_two_writes .....   Passed    0.02 sec
        Start  29: t_byte_stream_capacity
 29/162 Test  #29: t_byte_stream_capacity .......   Passed    2.20 sec
        Start  30: t_byte_stream_many_writes
 30/162 Test  #30: t_byte_stream_many_writes .....   Passed    0.09 sec
        Start  31: t_webget
 31/162 Test  #31: t_webget .....................   Passed    1.70 sec
        Start  34: t_tcp_parser
 32/162 Test  #34: t_tcp_parser .................   Passed    0.02 sec
        Start  35: t_ipv4_parser
 33/162 Test  #35: t_ipv4_parser ................   Passed    0.02 sec
        Start  36: t_active_close
 34/162 Test  #36: t_active_close ...............   Passed    0.03 sec
        Start  37: t_passive_close
 35/162 Test  #37: t_passive_close ..............   Passed    0.02 sec
        Start  38: t_ack_rst
 36/162 Test  #38: t_ack_rst ....................   Passed    0.02 sec
        Start  39: t_ack_rst_win
 37/162 Test  #39: t_ack_rst_win ................   Passed    0.01 sec
        Start  40: t_connect
 38/162 Test  #40: t_connect ....................   Passed    0.10 sec
        Start  41: t_listen
 39/162 Test  #41: t_listen .....................   Passed    0.01 sec
        Start  42: t_winsize
 40/162 Test  #42: t_winsize ....................   Passed    0.36 sec
        Start  43: t_retx
 41/162 Test  #43: t_retx .......................   Passed    0.01 sec
        Start  44: t_retx_win
 42/162 Test  #44: t_retx_win ...................   Passed    0.03 sec
        Start  45: t_loopback
 43/162 Test  #45: t_loopback ...................   Passed    0.69 sec
        Start  46: t_loopback_win
 44/162 Test  #46: t_loopback_win ...............   Passed    0.44 sec
        Start  47: t_reorder
```

```
 45/162 Test  #47: t_reorder ....................   Passed    0.64 sec
        Start  48: t_address_dt
 46/162 Test  #48: t_address_dt .................   Passed    0.06 sec
        Start  49: t_parser_dt
 47/162 Test  #49: t_parser_dt ..................   Passed    0.01 sec
        Start  50: t_socket_dt
 48/162 Test  #50: t_socket_dt ..................   Passed    0.03 sec
        Start  51: t_udp_client_send
 49/162 Test  #51: t_udp_client_send ............   Passed    0.47 sec
        Start  52: t_udp_server_send
 50/162 Test  #52: t_udp_server_send ............   Passed    0.33 sec
        Start  53: t_udp_client_recv
 51/162 Test  #53: t_udp_client_recv ............   Passed    0.34 sec
        Start  54: t_udp_server_recv
 52/162 Test  #54: t_udp_server_recv ............   Passed    0.36 sec
        Start  55: t_udp_client_dupl
 53/162 Test  #55: t_udp_client_dupl ............   Passed    0.33 sec
        Start  56: t_udp_server_dupl
 54/162 Test  #56: t_udp_server_dupl ............   Passed    0.33 sec
        Start  57: t_ucS_1M_32k
 55/162 Test  #57: t_ucS_1M_32k .................   Passed    0.65 sec
        Start  58: t_ucS_128K_8K
 56/162 Test  #58: t_ucS_128K_8K ................   Passed    0.35 sec
        Start  59: t_ucS_16_1
 57/162 Test  #59: t_ucS_16_1 ...................   Passed    0.32 sec
        Start  60: t_ucS_32K_d
 58/162 Test  #60: t_ucS_32K_d ..................   Passed    0.37 sec
        Start  61: t_ucR_1M_32k
 59/162 Test  #61: t_ucR_1M_32k .................   Passed    0.63 sec
        Start  62: t_ucR_128K_8K
 60/162 Test  #62: t_ucR_128K_8K ................   Passed    0.41 sec
        Start  63: t_ucR_16_1
 61/162 Test  #63: t_ucR_16_1 ...................   Passed    0.35 sec
        Start  64: t_ucR_32K_d
 62/162 Test  #64: t_ucR_32K_d ..................   Passed    0.36 sec
        Start  65: t_ucD_1M_32k
```

```
 63/162 Test  #65: t_ucD_1M_32k .....................   Passed    0.89 sec
        Start  66: t_ucD_128K_8K
 64/162 Test  #66: t_ucD_128K_8K .....................   Passed    0.41 sec
        Start  67: t_ucD_16_1
 65/162 Test  #67: t_ucD_16_1 .......................   Passed    0.36 sec
        Start  68: t_ucD_32K_d
 66/162 Test  #68: t_ucD_32K_d .......................   Passed    0.41 sec
        Start  69: t_usS_1M_32k
 67/162 Test  #69: t_usS_1M_32k .....................   Passed    0.66 sec
        Start  70: t_usS_128K_8K
 68/162 Test  #70: t_usS_128K_8K .....................   Passed    0.35 sec
        Start  71: t_usS_16_1
 69/162 Test  #71: t_usS_16_1 .......................   Passed    0.32 sec
        Start  72: t_usS_32K_d
 70/162 Test  #72: t_usS_32K_d .......................   Passed    0.33 sec
        Start  73: t_usR_1M_32k
 71/162 Test  #73: t_usR_1M_32k .....................   Passed    0.62 sec
        Start  74: t_usR_128K_8K
 72/162 Test  #74: t_usR_128K_8K .....................   Passed    0.36 sec
        Start  75: t_usR_16_1
 73/162 Test  #75: t_usR_16_1 .......................   Passed    0.32 sec
        Start  76: t_usR_32K_d
 74/162 Test  #76: t_usR_32K_d .......................   Passed    0.37 sec
        Start  77: t_usD_1M_32k
 75/162 Test  #77: t_usD_1M_32k .....................   Passed    0.89 sec
        Start  78: t_usD_128K_8K
 76/162 Test  #78: t_usD_128K_8K .....................   Passed    0.46 sec
        Start  79: t_usD_16_1
 77/162 Test  #79: t_usD_16_1 .......................   Passed    0.46 sec
        Start  80: t_usD_32K_d
 78/162 Test  #80: t_usD_32K_d .......................   Passed    0.40 sec
        Start  81: t_ucS_128K_8K_l
 79/162 Test  #81: t_ucS_128K_8K_l ...................   Passed    0.39 sec
        Start  82: t_ucS_128K_8K_L
 80/162 Test  #82: t_ucS_128K_8K_L ...................   Passed    0.51 sec
        Start  83: t_ucS_128K_8K_lL
```

```
 81/162 Test  #83: t_ucS_128K_8K_lL ..................   Passed    0.48 sec
        Start  84: t_ucR_128K_8K_l
 82/162 Test  #84: t_ucR_128K_8K_l ...................   Passed    0.57 sec
        Start  85: t_ucR_128K_8K_L
 83/162 Test  #85: t_ucR_128K_8K_L ...................   Passed    0.38 sec
        Start  86: t_ucR_128K_8K_lL
 84/162 Test  #86: t_ucR_128K_8K_lL ..................   Passed    0.59 sec
        Start  87: t_ucD_128K_8K_l
 85/162 Test  #87: t_ucD_128K_8K_l ...................   Passed    0.50 sec
        Start  88: t_ucD_128K_8K_L
 86/162 Test  #88: t_ucD_128K_8K_L ...................   Passed    0.66 sec
        Start  89: t_ucD_128K_8K_lL
 87/162 Test  #89: t_ucD_128K_8K_lL ..................   Passed    0.65 sec
        Start  90: t_usS_128K_8K_l
 88/162 Test  #90: t_usS_128K_8K_l ...................   Passed    0.38 sec
        Start  91: t_usS_128K_8K_L
 89/162 Test  #91: t_usS_128K_8K_L ...................   Passed    0.62 sec
        Start  92: t_usS_128K_8K_lL
 90/162 Test  #92: t_usS_128K_8K_lL ..................   Passed    0.55 sec
        Start  93: t_usR_128K_8K_l
 91/162 Test  #93: t_usR_128K_8K_l ...................   Passed    0.51 sec
        Start  94: t_usR_128K_8K_L
 92/162 Test  #94: t_usR_128K_8K_L ...................   Passed    0.36 sec
        Start  95: t_usR_128K_8K_lL
 93/162 Test  #95: t_usR_128K_8K_lL ..................   Passed    0.52 sec
        Start  96: t_usD_128K_8K_l
 94/162 Test  #96: t_usD_128K_8K_l ...................   Passed    0.50 sec
        Start  97: t_usD_128K_8K_L
 95/162 Test  #97: t_usD_128K_8K_L ...................   Passed    0.55 sec
        Start  98: t_usD_128K_8K_lL
 96/162 Test  #98: t_usD_128K_8K_lL ..................   Passed    0.66 sec
        Start  99: t_ipv4_client_send
 97/162 Test  #99: t_ipv4_client_send ................   Passed    0.37 sec
        Start 100: t_ipv4_server_send
 98/162 Test #100: t_ipv4_server_send ................   Passed    0.33 sec
        Start 101: t_ipv4_client_recv
```

```
 99/162 Test #101: t_ipv4_client_recv ..............   Passed    0.35 sec
        Start 102: t_ipv4_server_recv
100/162 Test #102: t_ipv4_server_recv ..............   Passed    0.36 sec
        Start 103: t_ipv4_client_dupl
101/162 Test #103: t_ipv4_client_dupl ..............   Passed    0.38 sec
        Start 104: t_ipv4_server_dupl
102/162 Test #104: t_ipv4_server_dupl ..............   Passed    0.33 sec
        Start 105: t_icS_1M_32k
103/162 Test #105: t_icS_1M_32k .....................   Passed    0.90 sec
        Start 106: t_icS_128K_8K
104/162 Test #106: t_icS_128K_8K ....................   Passed    0.43 sec
        Start 107: t_icS_16_1
105/162 Test #107: t_icS_16_1 .......................   Passed    0.34 sec
        Start 108: t_icS_32K_d
106/162 Test #108: t_icS_32K_d ......................   Passed    0.38 sec
        Start 109: t_icR_1M_32k
107/162 Test #109: t_icR_1M_32k .....................   Passed    0.92 sec
        Start 110: t_icR_128K_8K
108/162 Test #110: t_icR_128K_8K ....................   Passed    0.41 sec
        Start 111: t_icR_16_1
109/162 Test #111: t_icR_16_1 .......................   Passed    0.32 sec
        Start 112: t_icR_32K_d
110/162 Test #112: t_icR_32K_d ......................   Passed    0.37 sec
        Start 113: t_icD_1M_32k
111/162 Test #113: t_icD_1M_32k .....................   Passed    1.34 sec
        Start 114: t_icD_128K_8K
112/162 Test #114: t_icD_128K_8K ....................   Passed    0.48 sec
        Start 115: t_icD_16_1
113/162 Test #115: t_icD_16_1 .......................   Passed    0.40 sec
        Start 116: t_icD_32K_d
114/162 Test #116: t_icD_32K_d ......................   Passed    0.39 sec
        Start 117: t_isS_1M_32k
115/162 Test #117: t_isS_1M_32k .....................   Passed    0.79 sec
        Start 118: t_isS_128K_8K
116/162 Test #118: t_isS_128K_8K ....................   Passed    0.42 sec
        Start 119: t_isS_16_1
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117/162 Test #119: t_isS_16_1 .......................   Passed    0.33 sec
        Start 120: t_isS_32K_d
118/162 Test #120: t_isS_32K_d ......................   Passed    0.38 sec
        Start 121: t_isR_1M_32k
119/162 Test #121: t_isR_1M_32k .....................   Passed    0.90 sec
        Start 122: t_isR_128K_8K
120/162 Test #122: t_isR_128K_8K ....................   Passed    0.42 sec
        Start 123: t_isR_16_1
121/162 Test #123: t_isR_16_1 .......................   Passed    0.35 sec
        Start 124: t_isR_32K_d
122/162 Test #124: t_isR_32K_d ......................   Passed    0.35 sec
        Start 125: t_isD_1M_32k
123/162 Test #125: t_isD_1M_32k .....................   Passed    1.33 sec
        Start 126: t_isD_128K_8K
124/162 Test #126: t_isD_128K_8K ....................   Passed    0.61 sec
        Start 127: t_isD_16_1
125/162 Test #127: t_isD_16_1 .......................   Passed    0.37 sec
        Start 128: t_isD_32K_d
126/162 Test #128: t_isD_32K_d ......................   Passed    0.41 sec
        Start 129: t_icS_128K_8K_l
127/162 Test #129: t_icS_128K_8K_l ..................   Passed    0.44 sec
        Start 130: t_icS_128K_8K_L
128/162 Test #130: t_icS_128K_8K_L ..................   Passed    0.53 sec
        Start 131: t_icS_128K_8K_lL
129/162 Test #131: t_icS_128K_8K_lL .................   Passed    0.59 sec
        Start 132: t_icR_128K_8K_l
130/162 Test #132: t_icR_128K_8K_l ..................   Passed    0.57 sec
        Start 133: t_icR_128K_8K_L
131/162 Test #133: t_icR_128K_8K_L ..................   Passed    0.44 sec
        Start 134: t_icR_128K_8K_lL
132/162 Test #134: t_icR_128K_8K_lL .................   Passed    0.68 sec
        Start 135: t_icD_128K_8K_l
133/162 Test #135: t_icD_128K_8K_l ..................   Passed    0.51 sec
        Start 136: t_icD_128K_8K_L
134/162 Test #136: t_icD_128K_8K_L ..................   Passed    0.65 sec
        Start 137: t_icD_128K_8K_lL
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135/162 Test #137: t_icD_128K_8K_lL .................   Passed    0.61 sec
        Start 138: t_isS_128K_8K_l
136/162 Test #138: t_isS_128K_8K_l ..................   Passed    0.43 sec
        Start 139: t_isS_128K_8K_L
137/162 Test #139: t_isS_128K_8K_L ..................   Passed    0.54 sec
        Start 140: t_isS_128K_8K_lL
138/162 Test #140: t_isS_128K_8K_lL .................   Passed    0.57 sec
        Start 141: t_isR_128K_8K_l
139/162 Test #141: t_isR_128K_8K_l ..................   Passed    0.52 sec
        Start 142: t_isR_128K_8K_L
140/162 Test #142: t_isR_128K_8K_L ..................   Passed    0.42 sec
        Start 143: t_isR_128K_8K_lL
141/162 Test #143: t_isR_128K_8K_lL .................   Passed    0.56 sec
        Start 144: t_isD_128K_8K_l
142/162 Test #144: t_isD_128K_8K_l ..................   Passed    0.52 sec
        Start 145: t_isD_128K_8K_L
143/162 Test #145: t_isD_128K_8K_L ..................   Passed    0.52 sec
        Start 146: t_isD_128K_8K_lL
144/162 Test #146: t_isD_128K_8K_lL .................   Passed    0.67 sec
        Start 147: t_icnS_128K_8K_l
145/162 Test #147: t_icnS_128K_8K_l ..................   Passed    0.24 sec
        Start 148: t_icnS_128K_8K_L
146/162 Test #148: t_icnS_128K_8K_L ..................   Passed    0.38 sec
        Start 149: t_icnS_128K_8K_lL
147/162 Test #149: t_icnS_128K_8K_lL .................   Passed    0.44 sec
        Start 150: t_icnR_128K_8K_l
148/162 Test #150: t_icnR_128K_8K_l ..................   Passed    1.68 sec
        Start 151: t_icnR_128K_8K_L
149/162 Test #151: t_icnR_128K_8K_L ..................   Passed    0.30 sec
        Start 152: t_icnR_128K_8K_lL
150/162 Test #152: t_icnR_128K_8K_lL .................   Passed    0.54 sec
        Start 153: t_icnD_128K_8K_l
151/162 Test #153: t_icnD_128K_8K_l ..................   Passed    0.75 sec
        Start 154: t_icnD_128K_8K_L
152/162 Test #154: t_icnD_128K_8K_L ..................   Passed    0.43 sec
        Start 155: t_icnD_128K_8K_lL
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153/162 Test #155: t_icnD_128K_8K_lL .................   Passed    0.60 sec
        Start 156: t_isnS_128K_8K_l
154/162 Test #156: t_isnS_128K_8K_l ..................   Passed    1.28 sec
        Start 157: t_isnS_128K_8K_L
155/162 Test #157: t_isnS_128K_8K_L ..................   Passed    0.29 sec
        Start 158: t_isnS_128K_8K_lL
156/162 Test #158: t_isnS_128K_8K_lL .................   Passed    1.47 sec
        Start 159: t_isnR_128K_8K_l
157/162 Test #159: t_isnR_128K_8K_l ..................   Passed    0.71 sec
        Start 160: t_isnR_128K_8K_L
158/162 Test #160: t_isnR_128K_8K_L ..................   Passed    0.47 sec
        Start 161: t_isnR_128K_8K_lL
159/162 Test #161: t_isnR_128K_8K_lL .................   Passed    1.42 sec
        Start 162: t_isnD_128K_8K_l
160/162 Test #162: t_isnD_128K_8K_l ..................   Passed    0.85 sec
        Start 163: t_isnD_128K_8K_L
161/162 Test #163: t_isnD_128K_8K_L ..................   Passed    0.42 sec
        Start 164: t_isnD_128K_8K_lL
162/162 Test #164: t_isnD_128K_8K_lL .................   Passed    0.47 sec

100% tests passed, 0 tests failed out of 162

Total Test time (real) =  70.63 sec
[100%] Built target check_lab4
```