Advanced Operating Systems: Lab 3 - TCP

Lecturelet 3

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Lab 3 objectives

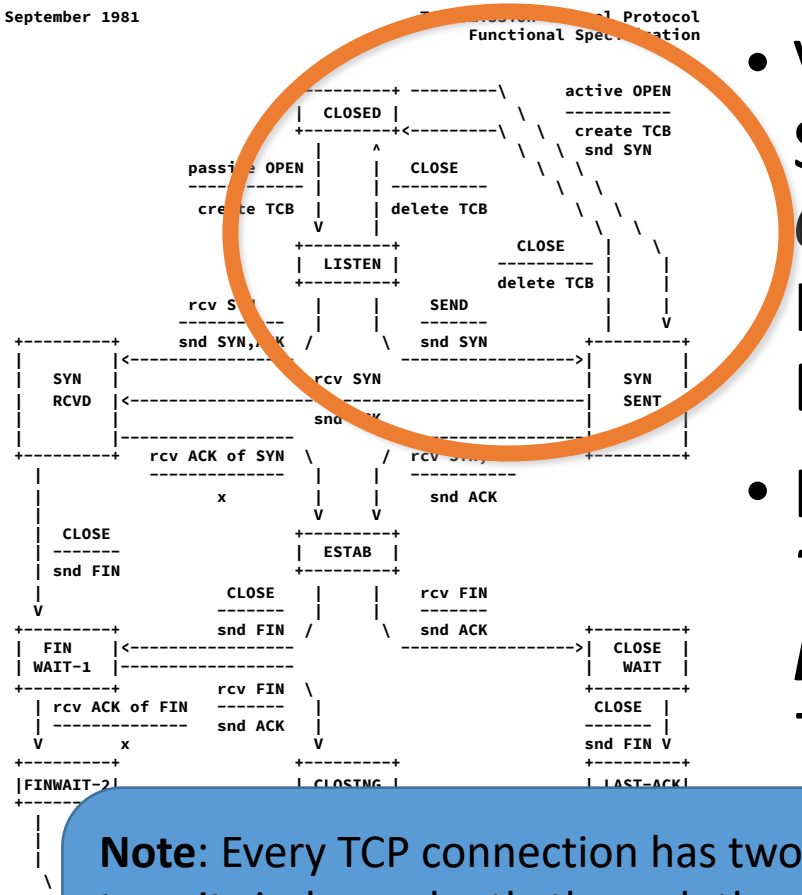
- Further develop tracing, analysis, presentation skills around network-stack protocols and implementation
- Explore the TCP protocol **and** implementation, tracing and analysing wire-level behaviours and internal state
  - Quite different from purely packet-centric analysis
- Experiment with the interactions between TCP and variable network latency; explore:
  - **No Part II assignment**
  - TCP congestion-control behaviour (**L41 assignment**)
- Gather and analyse data for the third L41 lab report

New documents

- Advanced Operating Systems: Lab 3 – TCP – General Information (**read this first**)
- Advanced Operating Systems: Lab 3 – TCP – L41 Assignment

- There is no new JupyterLab notebook for Lab 3
  - If desired, you can start with the Lab 2 – IPC notebook

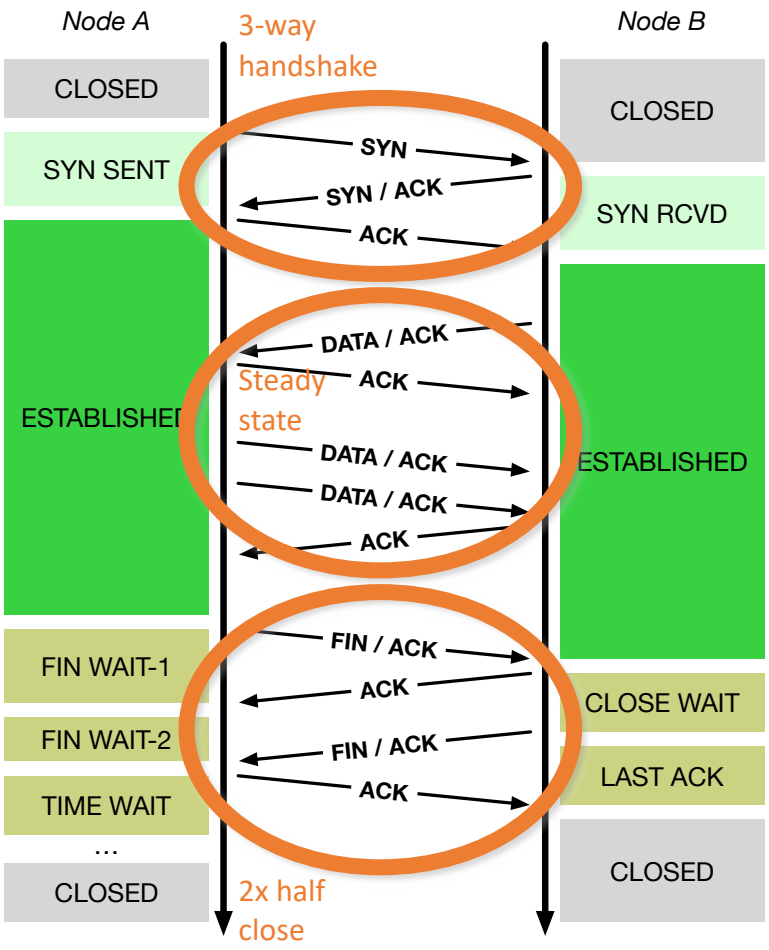
Lecture 6: The Transmission Control Protocol (TCP)



- V. Cerf, K. Dalal, and C. Sunshine, ***Transmission Control Protocol (version 1)***, INWG General Note #72, December 1974.
- In practice: J. Postel, Ed., ***Transmission Control Protocol: Protocol Specification***, RFC 793, September, 1981.

Note: Every TCP connection has two TCBs, one at each endpoint – each of which transits independently through the state machine. When we use loopback connections in our lab assignment, there will be two open sockets, one for each endpoint, and hence two TCP control blocks (tcpcbs). The two endpoints have inverted 4-tuples, so can be identified (with suitable care).

Lecture 6: TCP principles and properties



- Assumptions: Network may delay, (reorder), drop, corrupt IP packets
- TCP implements reliable, ordered, stream transport protocol over IP
- Three-way handshake: SYN / SYN-ACK / ACK (mostly!)
- Steady state
  - Sequence numbers ACK'd
  - Round-Trip Time (RTT) measured to time out loss
  - Data retransmitted on loss
  - Flow control via advertised window size in ACKs
  - Congestion control ('fairness') detects congestion via loss (and, recently, via delay: BBR)
- NB: "Half close" allows communications in one direction to end while the other continues

TCP in the IPC benchmark

```
ipc-benchmark [-Bgjqsv] [-b buffersize] [-i pipe|local|tcp] [-n iterations]
    [-p tcp_port] [-P arch|dcache|instr|tlbmem] [-t totalsize] mode

Modes (pick one - default 1thread):
    1thread     IPC within a single thread
    2thread     IPC between two threads in one process
    2proc       IPC between two threads in two different processes
    describe    Describe the hardware, OS, and benchmark configurations

Optional flags:
    -B                      Run in bare mode: no preparatory activities
    -g                      Enable getrusage(2) collection
    -i pipe|local|tcp       Select pipe, local sockets, or TCP (default: pipe)
    -j                      Output as JSON
    -p tcp_port             Set TCP port number (default: 10141)
    -P arch|dcache|instr|tlbmem  Enable hardware performance counters
    -q                      Just run the benchmark, don't print stuff out
    -s                      Set send/receive socket-buffer sizes to buffersize
    -v                      Provide a verbose benchmark description
    -b buffersize           Specify the buffer size (default: 131072)
    -n iterations           Specify the number of times to run (default: 1)
    -t totalsize            Specify the total I/O size (default: 16777216)
```

- `-i tcp` Set IPC type to TCP
- `-p 10141` Set TCP port number

Loopback networking, IPFW, DUMMYNET

- Loopback network interface
  - Synthetic local network interface: packets “loop back” when sent
  - Interface name lo0
  - Assigned IPv4 address 127.0.0.1
  - **Set the MTU to 1500 bytes**

- IPFW – IP firewall by Rizzo, et al.
  - Numbered rules classify packets and perform actions
  - Actions include accept, reject, and inject into DUMMYNET
  - **Set up IPFW to match port 10141 and inject into DUMMYNET**

- DUMMYNET – Link simulation tool by Rizzo, et al.
  - Impose simulated network conditions (e.g., latency) on “pipes”
  - **Configure DUMMYNET pipes as required for the assignment**

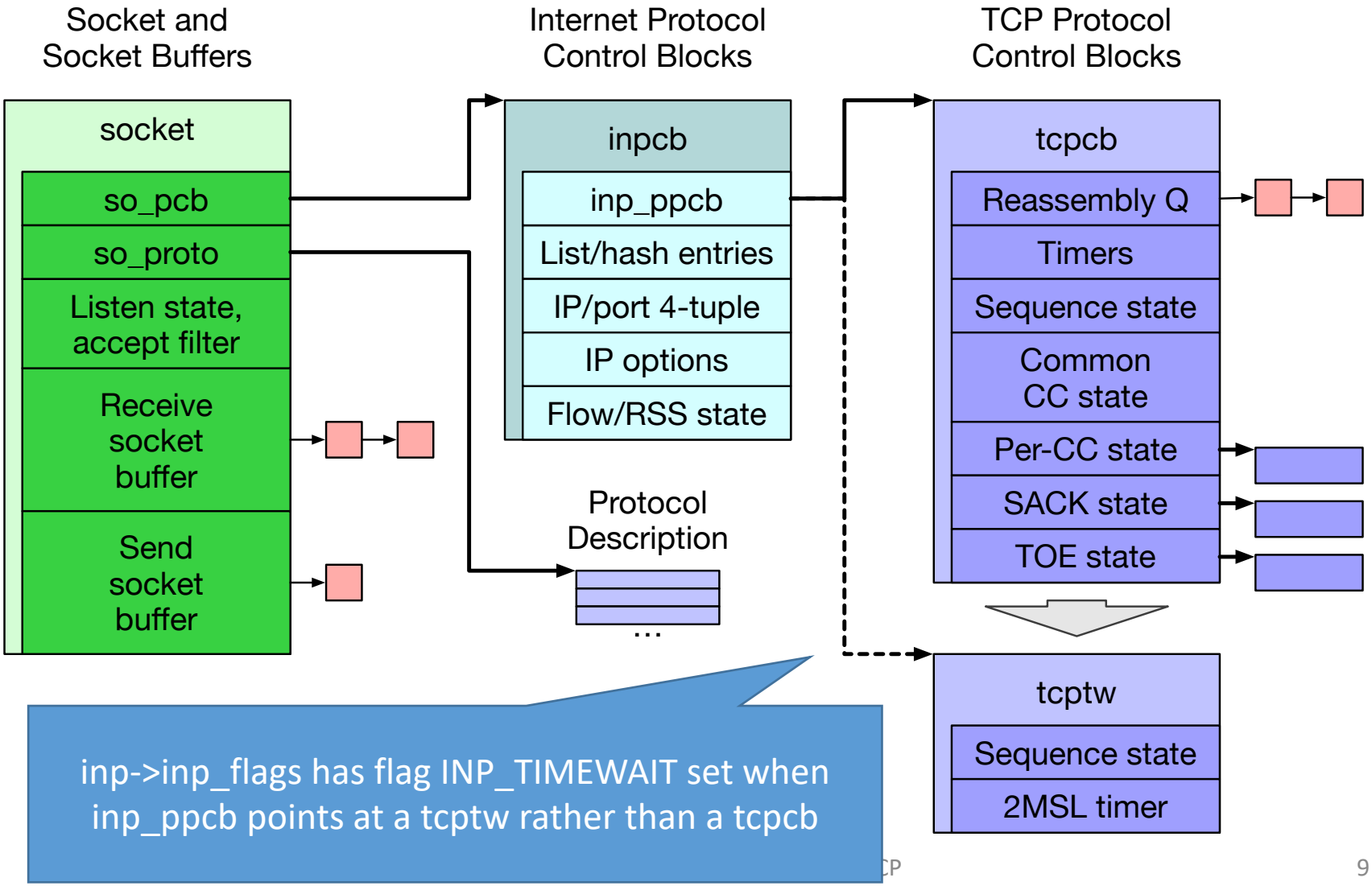
Some TCP-relevant DTrace probes

- Described in more detail in the lab assignment:

`fbt::syncache_add:entry`	TCP segment installs new SYN-cache entry
`fbt::syncache_expand:entry`	TCP segment converts SYN-cache entry to full connection
`fbt::tcp_do_segment:entry`	TCP segment received post-SYN cache
`fbt::tcp_state_change:entry`	TCP state transition

- We are using implementation-specific probes (FBT) rather than portable TCP provider probes in order to:
  - avoid the 5-argument limit to FreeBSD/arm64 DTrace; and
  - provide easier access to internal data structures
- Do not limit yourself to only these probes!

Lecture 6: Data structures – sockets, control blocks



L41: Latency and TCP congestion control

- This lab explores how latency and TCP congestion control interact to affected achieved bandwidth:
  - How do slow start and congestion control interact?
  - How do socket-buffer auto-resizing and congestion control interact?
- As we are working over the loopback interface, we can instrument both ends of the TCP connection
  - Track packet-level headers on transmit and receive
  - Also track TCP-internal parameters such as:
    - Whether TCP is in “slow start” or the steady state
    - What the achieved socket-buffer sizes are with auto-resizing

L41: `tcpcb` sender-side data-structure fields

- In this lab, there are two parties with **`tcpcb`**s as we run:
  - The 'client' is receiving data
  - The 'server' is sending data ← **Instrument CC send state here**
- For the purposes of classical TCP congestion control, only the sender retains congestion-control state
- Described in more detail in the lab assignment:

  `snd_wnd` Last received advertised flow-control window.
  `snd_cwnd` Current calculated congestion-control window.
  `snd_ssthresh` Current slow-start threshold:

  if (`snd_cwnd` <= `snd_ssthresh`), then TCP is in slowstart; otherwise, it is in congestion avoidance
- Instrument **`tcp_do_segment`** using DTrace to inspect TCP header fields and **`tcpcb`** state for **only the server**
  - Inspect port number to decide which way the packet is going

L41: Lab 3 hypotheses

1. Longer round-trip times extend the period over which TCP slow start takes place, but bandwidths achieved at different latencies rapidly converge once slow start has completed.
2. Socket buffer auto-resizing uniformly improves performance by allowing the TCP window to open more quickly during slow start.

L41: Experimental questions for the lab report

1. How do latency, congestion control, and the two socket-buffer resizing strategies impact bandwidth?
   - Vary latency, socket-buffer resizing strategy.
   - Plot a **latency-bandwidth graph** over many connections:
     - X axis: DUMMYNET-imposed latency.
     - Y axis: Distribution of achieved bandwidths over connections.
2. Explore how latency and congestion control interact through detailed TCP connection case studies
   - Vary latency, socket-buffer resizing strategy.
   - Plot a **time-bandwidth graph** comparing the effects of these variables for specific TCP connections:
     - X axis: Time since the connection opened
     - Y axis: Achieved bandwidth for the specific connection.
   - Stack graphs showing the sender's last received advertised window and congestion window on the same X axis.

Get in touch if you need a hand

- Attend the in-person Lab 3 session
  - If you can’t, contact me to book a 1:1 supervision session
- After that:
  - You can reach us on Slack – we try to reply quickly
  - We are happy to arrange 1:1 supervision sessions during the assignment period as you work through the lab
  - Or drop me email directly