Advanced Operating Systems: Lab 3 - TCP

Lecturelet 3

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Lab 3 objectives

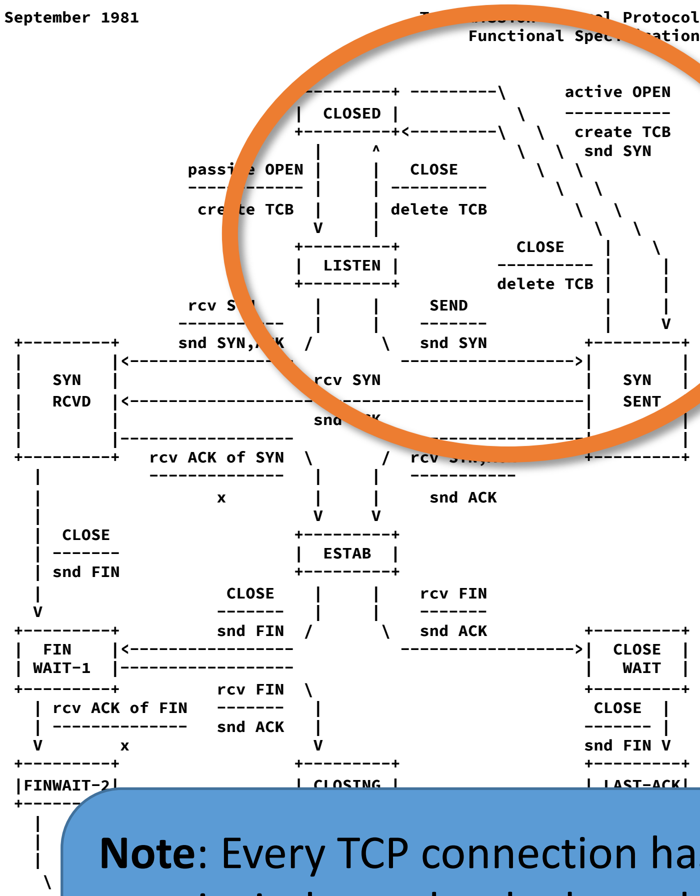
- Further develop tracing, analysis, presentation skills by exploring network-stack protocols and implementation
- Explore the TCP protocol **and** implementation, tracing and analysing wire-level behaviours and internal state
  - Quite different from purely packet-centric analysis
- Experiment with the interactions between TCP and variable network latency:
  - TCP congestion control **(Part II/ACS/Part III assignment)**
  - DTrace probe effect (**ACS/Part III assignment**)
- Gather, analyse, and present data for the third lab submission.

New documents

- Advanced Operating Systems: Lab 3 – TCP – General Information (**read this first**)
- Advanced Operating Systems: Lab 3 – TCP – Part II Assignment
- Advanced Operating Systems: Lab 3 – TCP – ACS/Part III Assignment

- There is no new lab notebook – you can just reuse the Lab 2 notebook as your starting point.
- But please do read the lab assignment notes on DTrace limitations, plotting, etc., carefully.

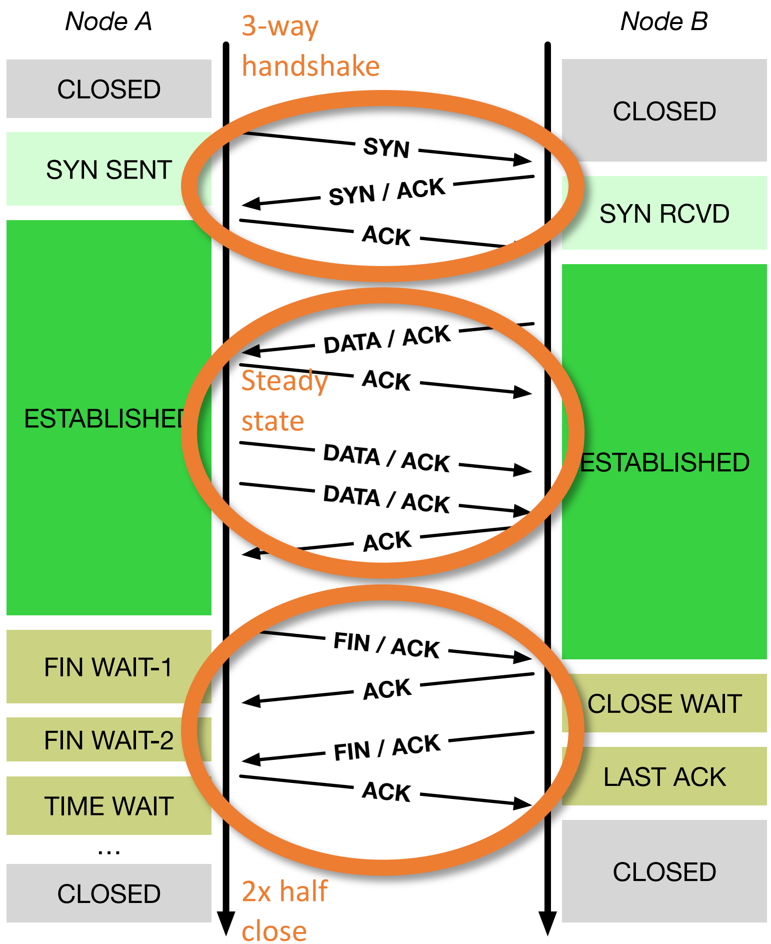
Lecture 6: The Transmission Control Protocol (TCP)



- 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|shmem]
    [-n iterations] [-p tcp_port] [-P arch|dcache|instr|tlbmem]
    [-t totalsize] mode

Modes (pick one - default 2thread):
    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|shmem   Select pipe, local sockets, TCP, or shared memory
                              (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**

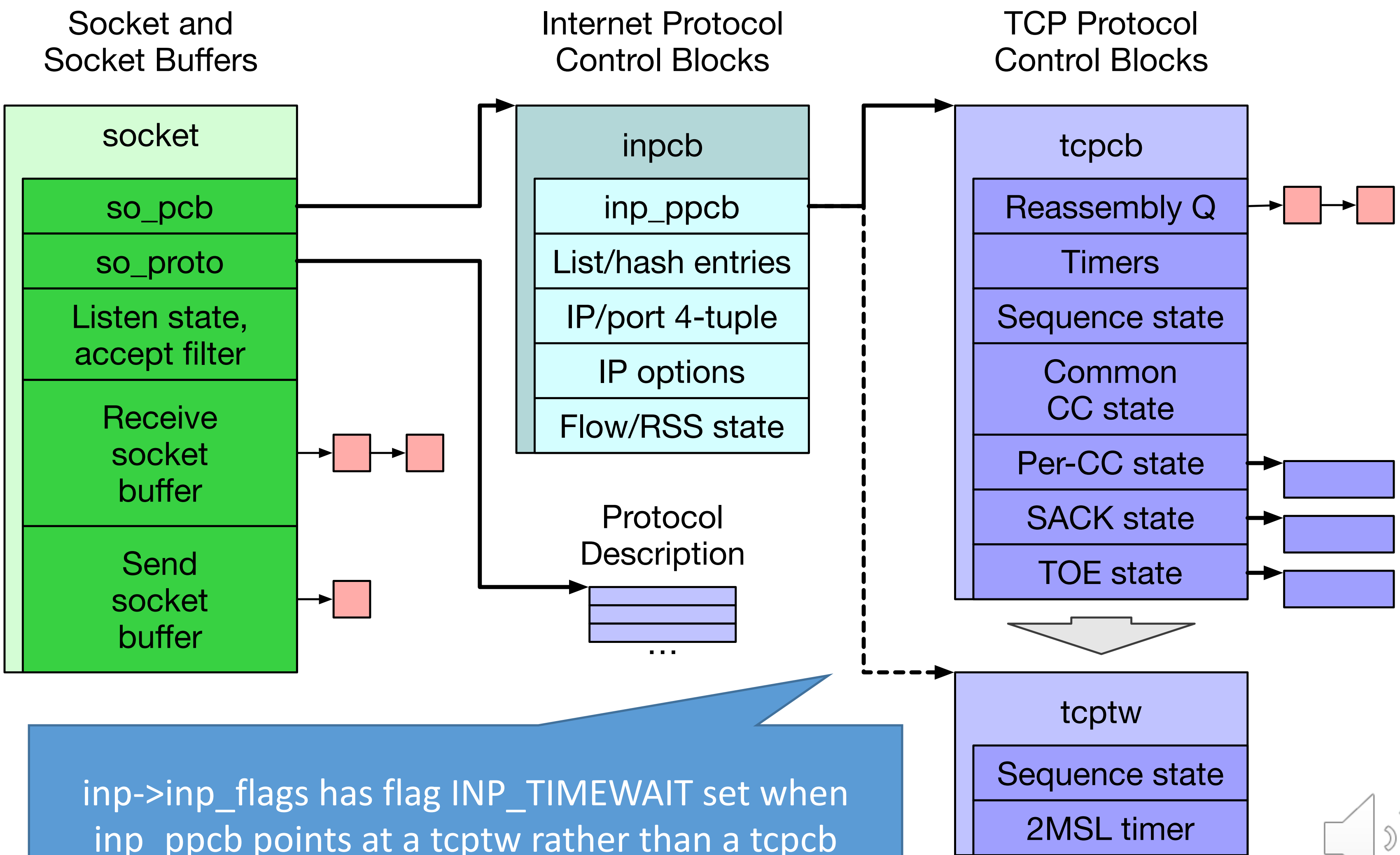
Some TCP-relevant DTrace probes

- 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



inp->inp_flags has flag INP_TIMEWAIT set when inp_ppcb points at a tcptw rather than a tcpcb

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?
- 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 most recent advertised window was
    - What the current congestion-control window is

`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 maintains 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
- Check for INP_TIMEWAIT before using **inp_ppcb** cast to **tcpcb** – typically if instrumenting socket code rather than TCP itself

Lab 3 hypotheses

1. Longer round-trip times extend the period over which TCP slow start takes place, but TCP is able to achieve equivalent performance through rapid identification of, and adaptation to, available bandwidth.
2. Despite TCP's sensitivity to execution timing, the probe effect arising from using DTrace leaves your analysis valid. (**Part III/ACS only**)

Approach

1. Take performance measurements varying latency
   - Vary latency (0ms, 10ms, 20ms), measure bandwidth.
   - Plot distributions and describe the resulting behaviour.
2. Analyse specific runs at each simulated latency, plotting results with an X axis of time, and a series of Y axes (as well as other DTrace exploration):
   - Achieved bandwidth
   - Packet-loss detection
   - Entry into and exit from slow start
   - Advertised and congestion-control windows
3. Measure the probe effect using one or more DTrace scripts, and explore the impact (**Part III /ACS only**).
4. Confirm or reject the hypotheses – and explain why.

Get in touch if you need a hand

- Attend the in-person Lab 3 session
  - If you can't, contact us 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
- If desired, we can offer a "drop-in" lab session during the normal teaching window next Thursday from 15:00-17:00
  - Let us know if you are interested and we can make arrangements