L41: Lab 4
The TCP State Machine

Lecturelet 4

Dr Robert N. M. Watson and Dr Graeme Jenkinson

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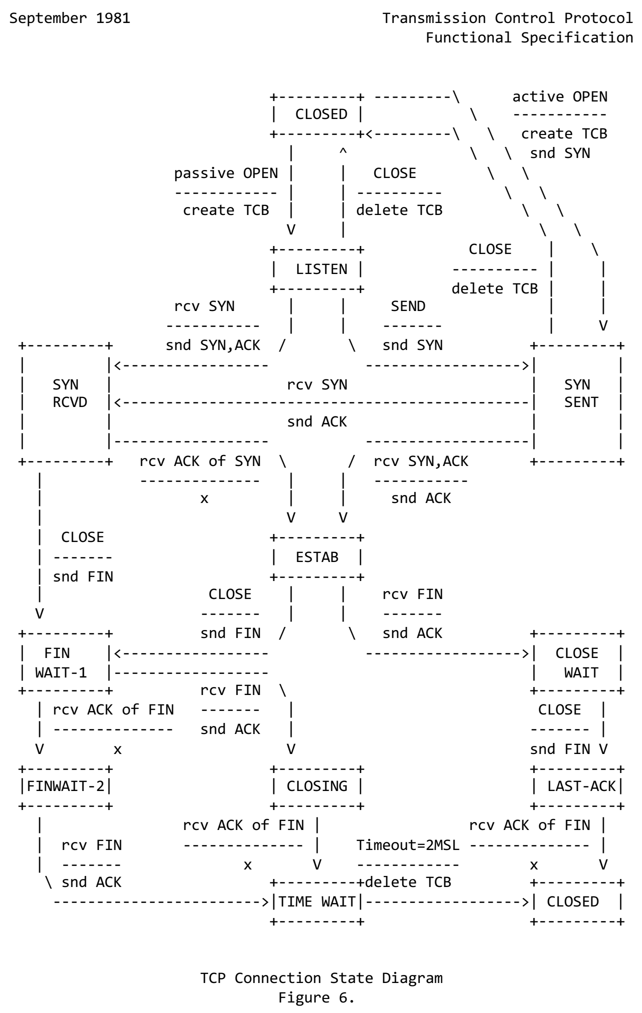
L41: Lab 4 – The TCP State Machine

- The TCP state machine.
- Setting the MTU, IPFW, and DUMMYNET.
- TCP mode for the IPC benchmark.
- DTrace probes of interest.
- Plotting the state machine with Graphviz.
- Experimental questions.

Lecture 6: The Transmission Control Protocol (TCP)



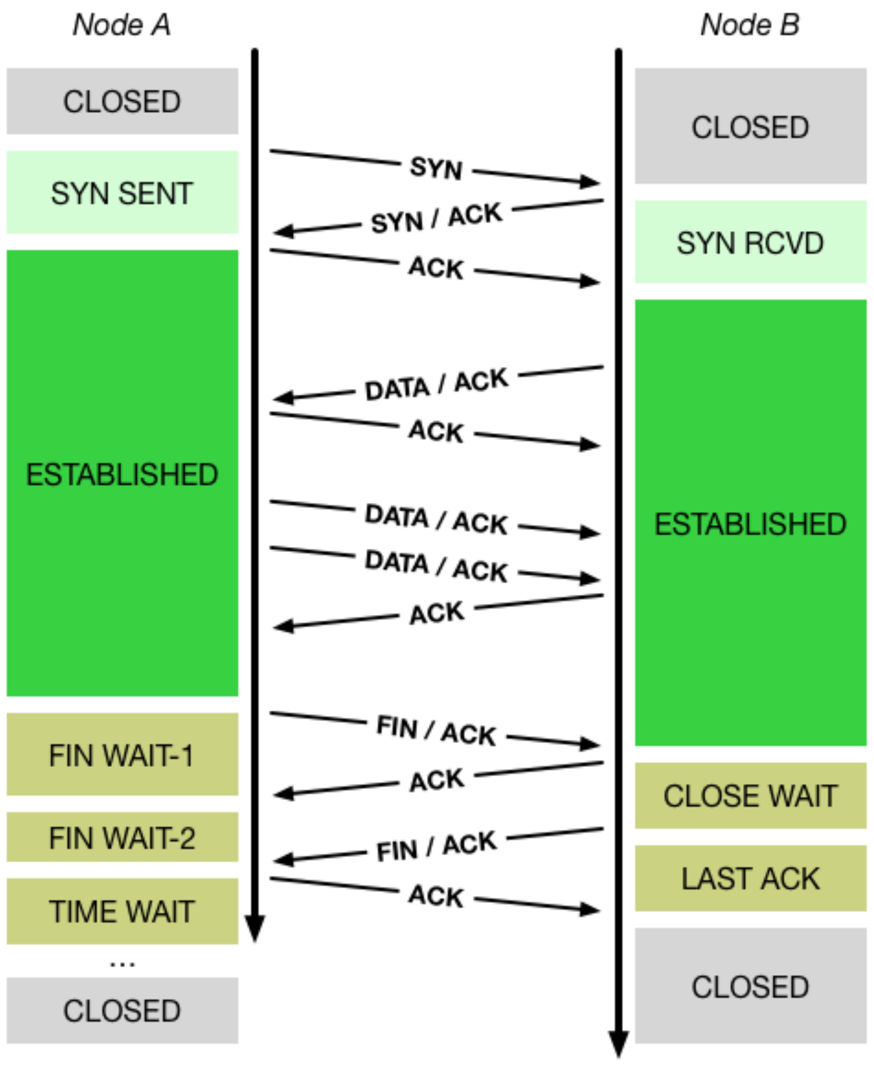
```
September 1981                                 Transmission Control Protocol
                                                    Functional Specification


                              +---------+ ---------\      active OPEN
                              |  CLOSED |            \    -----------
                              +---------+<---------\   \   create TCB
                                |     ^              \   \  snd SYN
                   passive OPEN |     |   CLOSE        \   \
                   ------------ |     | ----------       \   \
                    create TCB  |     | delete TCB         \   \
                                V     |                      \   \
                              +---------+            CLOSE    |    \
                              |  LISTEN |          ---------- |     |
                              +---------+          delete TCB |     |
                   rcv SYN      |     |     SEND              |     |
                  -----------   |     |    -------            |     V
 +---------+      snd SYN,ACK  /       \   snd SYN          +---------+
 |         |<-----------------           ------------------>|         |
 |   SYN   |                    rcv SYN                     |   SYN   |
 |   RCVD  |<-----------------------------------------------|   SENT  |
 |         |                    snd ACK                     |         |
 |         |------------------           -------------------|         |
 +---------+   rcv ACK of SYN  \       /  rcv SYN,ACK       +---------+
   |           --------------   |     |   -----------
   |                  x         |     |     snd ACK
   |                            V     V
   |  CLOSE                   +---------+
   | -------                  |  ESTAB  |
   | snd FIN                  +---------+
   |                   CLOSE    |     |    rcv FIN
   V                  -------   |     |    -------
 +---------+          snd FIN  /       \   snd ACK          +---------+
 |  FIN    |<-----------------           ------------------>|  CLOSE  |
 | WAIT-1  |------------------                              |   WAIT  |
 +---------+          rcv FIN  \                            +---------+
   | rcv ACK of FIN   -------   |                            CLOSE  |
   | --------------   snd ACK   |                           ------- |
   V        x                   V                           snd FIN V
 +---------+                  +---------+                   +---------+
 |FINWAIT-2|                  | CLOSING |                   | LAST-ACK|
 +---------+                  +---------+                   +---------+
   |                rcv ACK of FIN |                 rcv ACK of FIN |
   |  rcv FIN       -------------- |    Timeout=2MSL -------------- |
   |  -------              x       V    ------------        x       V
    \ snd ACK                 +---------+delete TCB         +---------+
     ------------------------>|TIME WAIT|------------------>| CLOSED  |
                              +---------+                   +---------+

                      TCP Connection State Diagram
                               Figure 6.
```

- V. Cerf, K. Dalal, and C. Sunshine, *Transmission Control Protocol (version1)*, INWG General Note#72, December 1974.
- In practice: Jon Postel, Ed, *Transmission Control Protocol: Protocol Specification*, RFC 793, September, 1981.

Lecture 6: TCP goals and properties



- Network may delay, (reorder), drop, corrupt packets
- TCP: Reliable, ordered, stream transport protocol over IP
- Three-way handshake: SYN / SYN-ACK / ACK (mostly!)
- Sequence numbers ACK'd; data retransmitted on loss
- Round-Trip Time (RTT) measured to time out loss
- Flow control via advertised window size in ACKs
- Congestion control ('fairness') via packet loss and ECN

Loopback interface, IPFW, and DUMMYNET

- Network-stack features to configure **once per-boot**
- Loopback interface
  - Simulated local network interface: packets “loop back”
  - Interface name `lo0`
  - Assigned IPv4 address `127.0.0.1`
- IPFW - IP firewall by Rizzo, et al.
  - Numbered rules classify packets and perform actions
  - Actions include accept, reject, inject into DUMMYNET ...
  - We will match lab flows using the TCP port number `10141`
- Configure (and reconfigure) **for each experiment**
- DUMMYNET – link simulation tool by Rizzo, et al.
  - Widely used in network research
  - Impose simulated network conditions – delay, bandwidth, loss, ...

TCP in the IPC benchmark

```
root@beaglebone:/data/ipc # ./ipc-static ipc-static [-Bqsv] [-b buffersize] [-i pipe|local|tcp]
            [-p tcp_port] [-P l1d|l1i|l2|mem|tlb|axi] [-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

Optional flags:

            -B                      Run in bare mode: no preparatory activities

            -i pipe|local|tcp       Select pipe, local sockets, or TCP (default: pipe)

            -p tcp_port             Set TCP port number (default: 10141)

            -P l1d|l1i|l2|mem|tlb|axi  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 a buffer size (default: 131072)

            -t totalsize            Specify total I/O size (default: 16777216)
```

- `tcp` IPC type
- `-p` argument to set the port number

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 probes due to abug in the FreeBSD/armv7 implementation of DTrace – the last (and most critical!) argumentgoes missing: the TCP header! We will fix this .. but not today.

pygraphviz

Graphviz is open source graph visualization software for drawing graphs specified in DOT language scripts. This language describes three kinds of objects: graphs, nodes, and edges.

Graph	`graph` or `digraph` undirected or directed graph
Node	`syn-sent;`
Edge	`"closed"` ->`"syn-sent"`;

Nodes and Edges can be assigned attributes changing, for example, their colour or shape:

Node	syn-sent [color=blue];
Edge	"closed" ->"syn-sent" [label="Active open", color=green];

pygraphviz

Programmatic interface for creating visualizations with Graphviz.

```
>>> import pygraphviz as pgv
>>> G = pgv.AGraph(strict=False, directed=True)
>>> G.add_node(’a’)
>>> G.add_edge(’b’,’c’)
>>> print(G)
digraph {
   a;
   b ->c;}
```

pygraphviz graphs can be viewed directly in a Juyter Notebook (see laboratory template).

Experimental questions for the lab report

- Plot a TCP state-transition diagram for both directions of a flow
- Label the state-transition diagram with causes
- Compare the diagram with RFC 793
- What observations can we make about state-machine transitions as latency increases?

In the next lab, we will start a causal analysis of why latency affects bandwidth in the way that it does

This lab session

- Setup IPFW, DUMMYNET, and loopback MTU (see notes).
- Start with the analysis of the TCP state machine.
- Do ask us if you have any questions or need help.
- Remember to use data from both Lab 4 and Lab 5 to write the second assessed lab report.