L41: Lab 5 - TCP Latency and Bandwidth

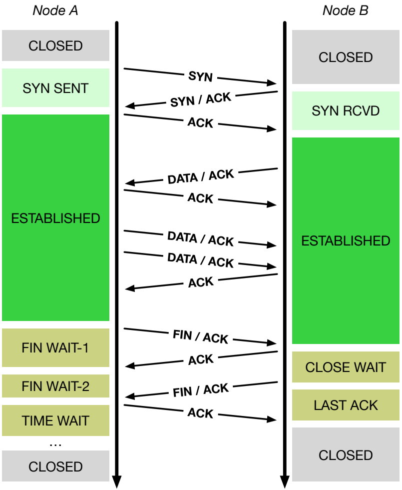
Dr Robert N. M. Watson

10 February 2016

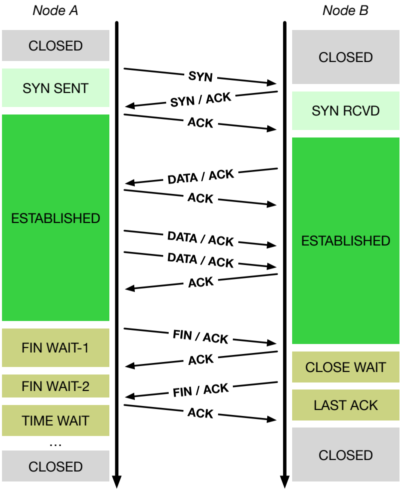
L41: Lab 5 - TCP latency and bandwidth

- TCP congestion control
- TCP Protocol Control Block (TCPCB)
- Exploratory and experimental questions

Lect 6: TCP goals and properties

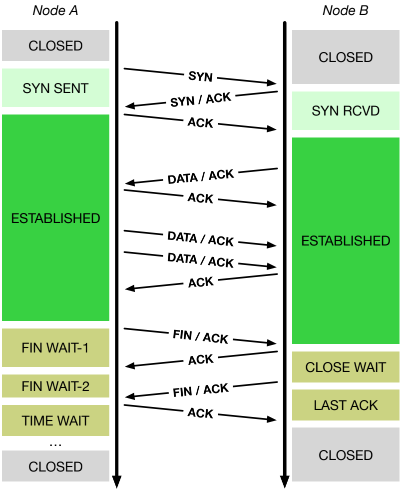


Lect 6: TCP goals and properties



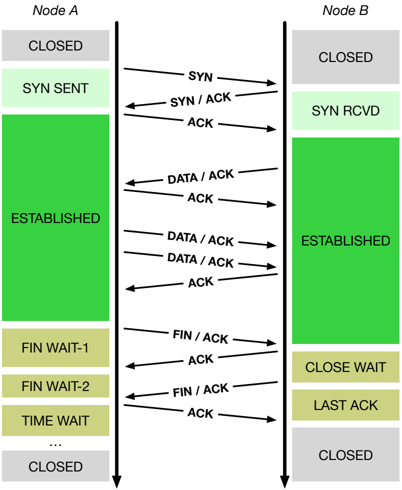
- Network may delay, (reorder), drop, corrupt packets

Lect 6: TCP goals and properties



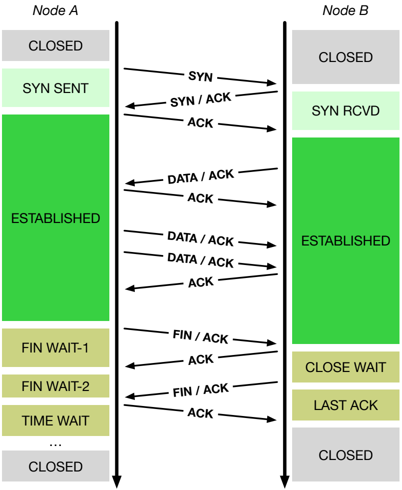
- Network may delay, (reorder), drop, corrupt packets
- TCP: Reliable, ordered, stream transport protocol over IP

Lect 6: TCP goals and properties



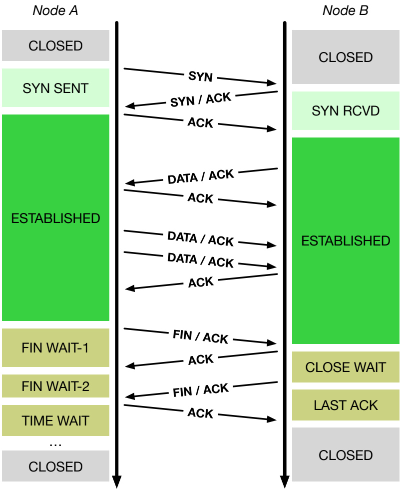
- Network may delay, (reorder), drop, corrupt packets
- TCP: Reliable, ordered, stream transport protocol over IP
- Three-way handshake: SYN / SYN-ACK / ACK (mostly!)

Lect 6: TCP goals and properties



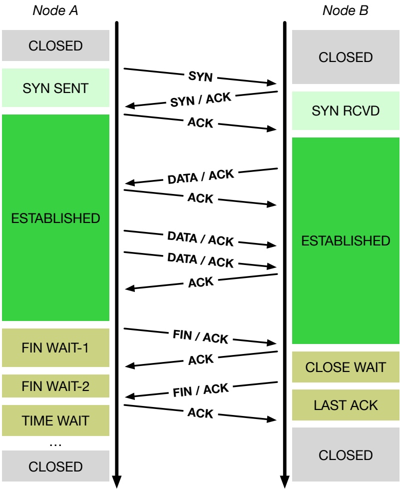
- Network may delay, (reorder), drop, corrupt packets
- TCP: Reliable, ordered, stream transport protocol over IP
- Three-way handshake: SYN / SYN-ACK / ACK (mostly!)
- Sequence numbers ACK'd; data retransmitted on loss

Lect 6: TCP goals and properties



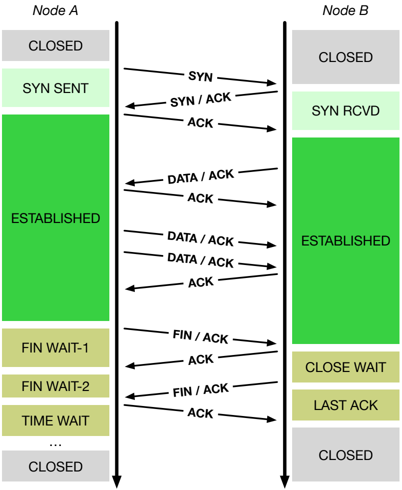
- Network may delay, (reorder), drop, corrupt packets
- TCP: Reliable, ordered, stream transport protocol over IP
- Three-way handshake: SYN / SYN-ACK / ACK (mostly!)
- Sequence numbers ACK'd; data retransmitted on loss
- Round-Trip Time (RTT) measured to time out loss

Lect 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

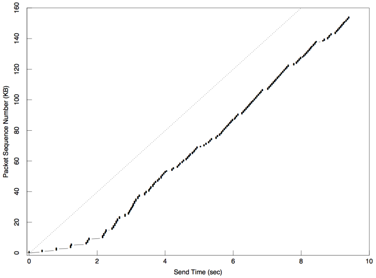
Lect 6: TCP goals and properties



- 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

Lect 6: TCP congestion control and avoidance

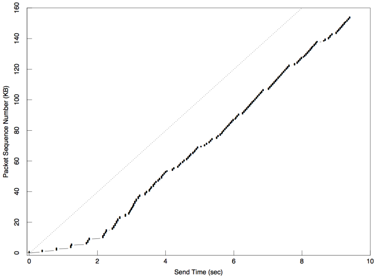
Figure 4: Startup behavior of TCP with Slow-start



Same conditions as the previous figure (same time of day, same Suns, same network path, same buffer and window sizes), except the machines were running the 4.3^{+}TCP with slow-start. No bandwidth is wasted on retransmits but two seconds is spent on the slow-start so the effective bandwidth of this part of the trace is 16 KBps — two times better than figure 3. (This is slightly misleading: Unlike the previous figure, the slope of the trace is 20 KBps and the effect of the 2 second offset decreases as the trace lengthens. E.g., if this trace had run a minute, the effective bandwidth would have been 19 KBps. The effective bandwidth without slow-start stays at 7 KBps no matter how long the trace.)

Lect 6: TCP congestion control and avoidance

Figure 4: Startup behavior of TCP with Slow-start

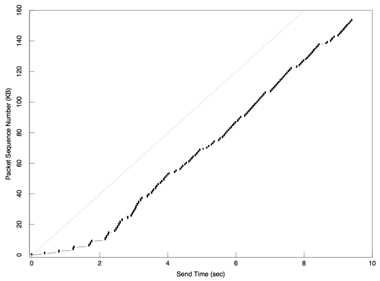


Same conditions as the previous figure (same time of day, same Suns, same network path, same buffer and window sizes), except the machines were running the 4.3^{+}TCP with slow-start. No bandwidth is wasted on retransmits but two seconds is spent on the slow-start so the effective bandwidth of this part of the trace is 16 KBps — two times better than figure 3. (This is slightly misleading: Unlike the previous figure, the slope of the trace is 20 KBps and the effect of the 2 second offset decreases as the trace lengthens. E.g., if this trace had run a minute, the effective bandwidth would have been 19 KBps. The effective bandwidth without slow-start stays at 7 KBps no matter how long the trace.)

- 1986 Internet CC collapse
  - 32Kbps -> **40bps**

Lect 6: TCP congestion control and avoidance

Figure 4: Startup behavior of TCP with Slow-start

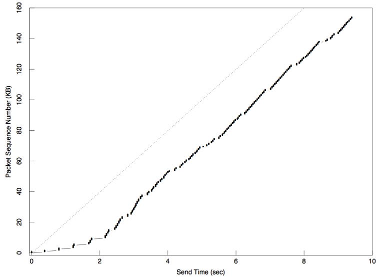


Same conditions as the previous figure (same time of day, same Suns, same network path, same buffer and window sizes), except the machines were running the 4.3+TCP with slow-start. No bandwidth is wasted on retransmits but two seconds is spent on the slow-start so the effective bandwidth of this part of the trace is 16 KBps — two times better than figure 3. (This is slightly misleading: Unlike the previous figure, the slope of the trace is 20 KBps and the effect of the 2 second offset decreases as the trace lengthens. E.g., if this trace had run a minute, the effective bandwidth would have been 19 KBps. The effective bandwidth without slow-start stays at 7 KBps no matter how long the trace.)

- 1986 Internet CC collapse
  - 32Kbps -> **40bps**
- Van Jacobson, SIGCOMM 1988
  - Don't send more data than the network can handle!

Lect 6: TCP congestion control and avoidance

Figure 4: Startup behavior of TCP with Slow-start

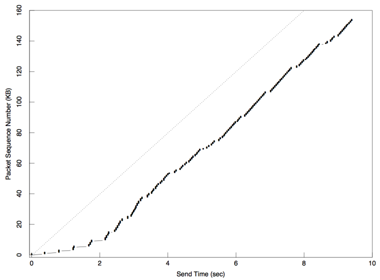


Same conditions as the previous figure (same time of day, same Suns, same network path, same buffer and window sizes), except the machines were running the 4.3+TCP with slow-start. No bandwidth is wasted on retransmits but two seconds is spent on the slow-start so the effective bandwidth of this part of the trace is 16 KBps — two times better than figure 3. (This is slightly misleading: Unlike the previous figure, the slope of the trace is 20 KBps and the effect of the 2 second offset decreases as the trace lengthens. E.g., if this trace had run a minute, the effective bandwidth would have been 19 KBps. The effective bandwidth without slow-start stays at 7 KBps no matter how long the trace.)

- 1986 Internet CC collapse
  - 32Kbps -> **40bps**
- Van Jacobson, SIGCOMM 1988
  - Don't send more data than the network can handle!
  - **Conservation of packets** via ACK clocking

Lect 6: TCP congestion control and avoidance

Figure 4: Startup behavior of TCP with Slow-start

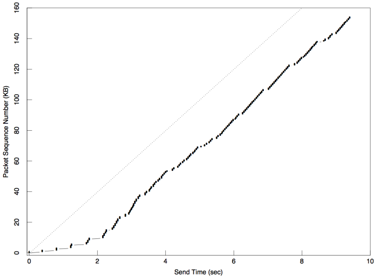


Same conditions as the previous figure (same time of day, same Suns, same network path, same buffer and window sizes), except the machines were running the 4.3^{+}TCP with slow-start. No bandwidth is wasted on retransmits but two seconds is spent on the slow-start so the effective bandwidth of this part of the trace is 16 KBps — two times better than figure 3. (This is slightly misleading: Unlike the previous figure, the slope of the trace is 20 KBps and the effect of the 2 second offset decreases as the trace lengthens. E.g., if this trace had run a minute, the effective bandwidth would have been 19 KBps. The effective bandwidth without slow-start stays at 7 KBps no matter how long the trace.)

- 1986 Internet CC collapse
  - 32Kbps -> **40bps**
- Van Jacobson, SIGCOMM 1988
  - Don't send more data than the network can handle!
  - **Conservation of packets** via ACK clocking
  - Exponential retransmit timer, slow start, aggressive receiver ACK, and dynamic window sizing on congestion

Lect 6: TCP congestion control and avoidance

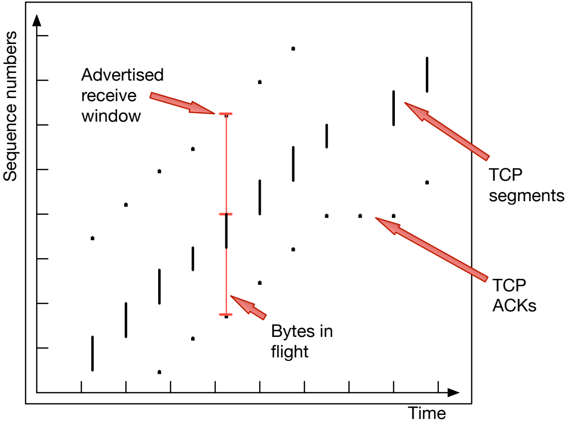
Figure 4: Startup behavior of TCP with Slow-start



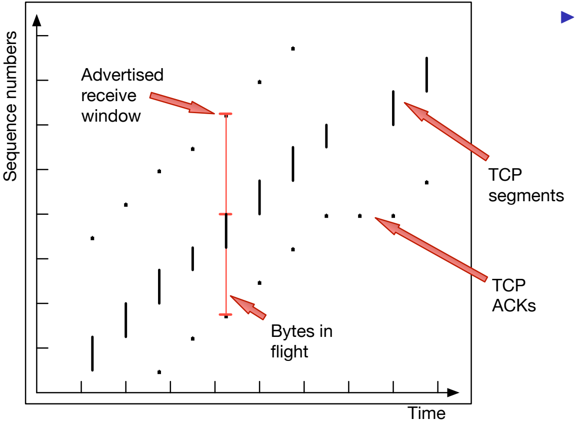
Same conditions as the previous figure (same time of day, same Suns, same network path, same buffer and window sizes), except the machines were running the 4.3+TCP with slow-start. No bandwidth is wasted on retransmits but two seconds is spent on the slow-start so the effective bandwidth of this part of the trace is 16 KBps — two times better than figure 3. (This is slightly misleading: Unlike the previous figure, the slope of the trace is 20 KBps and the effect of the 2 second offset decreases as the trace lengthens. E.g., if this trace had run a minute, the effective bandwidth would have been 19 KBps. The effective bandwidth without slow-start stays at 7 KBps no matter how long the trace.)

- 1986 Internet CC collapse
  - 32Kbps -> **40bps**
- Van Jacobson, SIGCOMM 1988
  - Don't send more data than the network can handle!
  - **Conservation of packets** via ACK clocking
  - Exponential retransmit timer, slow start, aggressive receiver ACK, and dynamic window sizing on congestion
- ECN (RFC 3168), ABC (RFC 3465), Compound (Tan, et al, INFOCOM 2006), Cubic (Rhee and Xu, ACM OSR 2008)

Lect 6: TCP time/sequence graphs

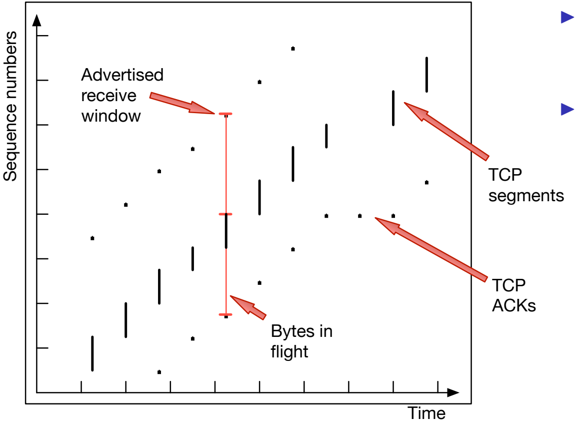


Lect 6: TCP time/sequence graphs



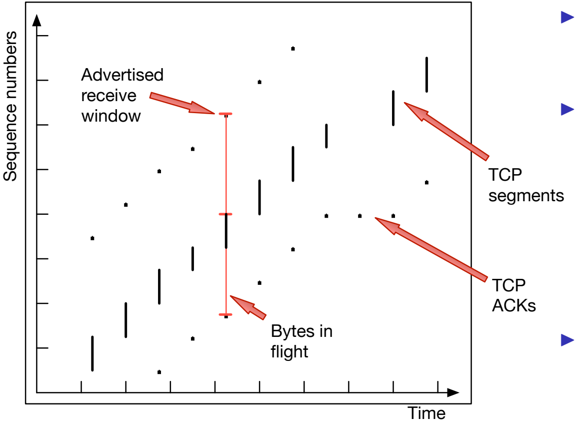
- Extracted from TCP packet traces

Lect 6: TCP time/sequence graphs



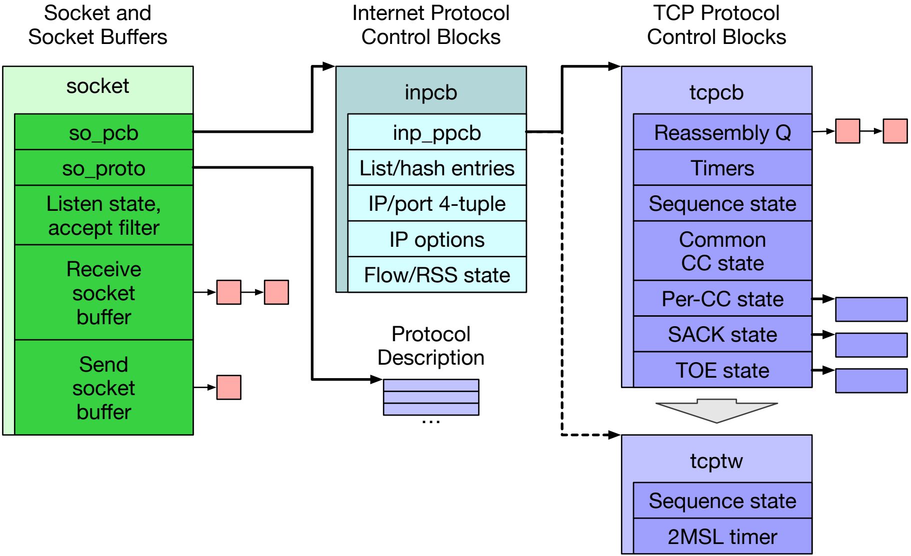
- Extracted from TCP packet traces
- Visualise windows, congestion response, RTT, etc.
  - X: Time
  - Y: Sequence number

Lect 6: TCP time/sequence graphs



- Extracted from TCP packet traces
- Visualise windows, congestion response, RTT, etc.
  - X: Time
  - Y: Sequence number
- We can also extract this data from the stack using DTrace

Lect 6: Data structures - sockets, control blocks



tcpcb sender-side data-structure fields

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 show-start threshold: if snd_cwnd is less than or equal to snd_ssthresh, then TCP is in slow start; otherwise, it is in congestion avoidance.

- Instrument tcp_do_segment using DTrace to inspect TCP header fields and tcpcb state
- Packets on ‘client’ and ‘server’; tcpcb only on ‘server’.
- Use as input to time–sequence-number or time–bandwidth plots.
- Make sure to flush the TCP host cache between benchmark runs.

Exploratory questions

- As latency varies, how does overall bandwidth change?
- How does using a fixed rather than auto-resized socket buffer affect advertised receive window? Use a fixed buffer size (1MB).
- How quickly does TCP enter steady state (i.e., shift out of slow start) at a 10ms RTT? Is this a product of the congestion or the socket-buffer limit?

Experimental questions for the lab report

- Plot network latency vs. TCP bandwidth. Does linear increase in latency mean linear decrease in bandwidth? How does socket-buffer auto-resizing help/hurt/not change performance?
- Explore the effects of socket-buffer limits and stack graph information on the flow-control versus congestion-control limits. How does socket-buffer auto-resizing help/hurt/not change performance?
- Explore how latency affects the time taken to leave slow start.

This lab session

- Ensure that you are able to properly extract both TCP header and `tcpcb` fields from the `tcp_do_segment` FBT probe
- Generate the data for a time–bandwidth graph
- Generate the data for a time–sequence-number graph
- Ask us if you have any questions or need help