TCP

- Transport protocol:
  - Communication between applications
  - API: sockets
  - Uses IP as network protocol
  - De-/Multiplexing via port numbers

- Point-to-point:
  - One sender, one receiver

- Full duplex data:
  - MSS: maximum segment size
    - IP is packet switching
  - Bi-directional data flow in same connection
    - Bi-directional byte stream

TCP (cont.)

- Pipelined:
  - Multiple packet in flight
  - Controlled via sliding window of size $n$:
    - Can send up to $n$ bytes without ack
    - When data acked window slides forward

- Flow controlled:
  - Sender will not overwhelm receiver
  - Use receiver side window
  - Receiver explicitly informs sender of (dynamically changing) amount of free buffer space
  - Depends on consuming application
  - Persist timer
    - If $rwnd = 0$
    - Exponentially backed off (up to 60 s)
TCP (cont.)

- Reliable, in-order byte stream:
  - No “message boundaries”
  - Sequence numbers (per byte)
  - Acknowledgements (per byte)
    - Cumulative
    - Selective
    - Delayed
      - Max 2 packets or 200 ms
      - Always ACK out of order data
  - Retransmissions:
    - Timeout based on RTT estimation
    - Three duplicated ACKs

TCP (cont.)

- Reliable, in-order byte stream (cont.):
  - RTT (round trip time) estimation:
    - Smoothed RTT estimation
      - $RTT = a \times RTT + (1-a) \times \text{measured RTT}$
    - Single timer for all connections
      - Typically every 500 ms
    - Traditional:
      - Single packet per window
      - Invalid by retransmitted packets
    - New:
      - Timestamp option for every window
  - RTO (recovery time objective):
    - Static: $RTO = b \times RTT$ ($b=2$)
    - Dynamic: $RTO = RTT + 4 \times D$
      - $D = \text{smoothed RTT deviation}$
TCP (cont.)

- **Reliable, in-order byte stream (cont.):**
  - Small packets == silly window syndrome:
    - Sender side (Nagle)
      - Only one partial packet outstanding
    - Receiver side (Clark)
      - Only advertise reasonable window changes
      - Min(MSS, ½ of receiver buffer space)

TCP (cont.)

- **Connection-oriented:**
  - Handshaking (exchange of control msgs) init’s sender, receiver state before data exchange
  - Control flags:
    - SYN: connection establishment
    - FIN: connection close
    - RST: connection reset
    - SYN, FIN use one byte of segment space enables reuse of existing mechanisms
  - Connection establishment:
    - 3-way handshake
  - Connection teardown
    - 4-way handshake
  - Initial sequence number: best unpredictable
  - Receiver state: for flow control
  - Time wait state: avoid reuse of sockets
TCP (cont.)

- TCP congestion control:
  - Sender will not overwhelm network
  - End-to-end control
  - Congestion detection
    - Lost packets
    - Marked packets
  - Use sender side window: cwnd
  - AIMD for window size control:
    - Additive increase
    - Multiplicative decrease

TCP (cont.)

- TCP congestion control (cont.):
  - Selfclocking
    - ACK clocking
  - Two stages
    - Reaching equilibrium
      - Slow start
    - Adapting to resource availability
      - Congestion avoidance
TCP (cont.)

- TCP congestion control (cont.):
  - Slow start
    - Init:
      - cwnd = MSS
      - ssthresh = 64K
    - ACK:
      - cwnd += MSS
      - If (cwnd > ssthresh)
        - congestion avoidance
    - Timeout:
      - cwnd = MSS
      - RTO = min(2*RTO, 64 s)
      - restart

TCP (cont.)

- TCP congestion control (cont.):
  - Congestion avoidance
    - ACK:
      - cwnd += MSS/cwnd
  - Lost packet indication:
    - ssthresh = max(min(rwnd, cwnd)/2, 2*MSS)
    - RTO = min(2*RTO, 64 s)
    - Cont or switch to slow start
TCP (cont.)

- TCP congestion control (cont.):
  - Retransmissions
    - Fast retransmit
      - Receiver acks out-of-order segments immediately
      - $\geq 3$ duplicate ACKs $\Rightarrow$ lost packet
      - Retransmit packet
      - Switch to slow start
    - Fast recovery
      - Fast retransmit
      - Congesting avoidance
      - (Allowed to transmit packet for every dup ACK)
  - Partial ACK
    - Not all outstanding data is Acked after retransmission
    - Retransmit next packet