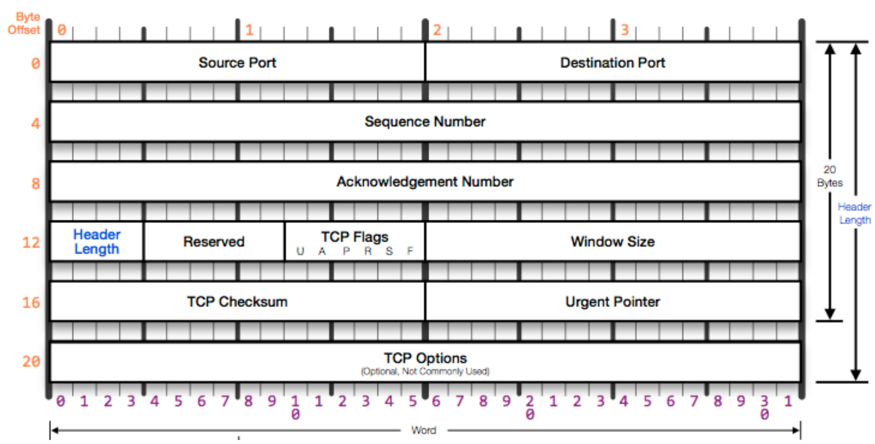
Satellite Transport Layer

March 20, 2013

1 Transmission control protocol (TCP)

- TCP is the protocol for end-to-end (implemented within the client host or server)
- TCP is a byte stream, full-duplex connections and point to point protocol (no multicasting or broadcasting.)
- TCP entities exchange data in the form of segments. A segment consists of a fixed 20-byte header (plus an optional part) followed by zero or more data bytes. Maximum segment size is mandated by IP packet length or the link MTU.



- TCP relies on mechanisms between the client and server hosts including
  - flow control: ensuring that data is transmitted at a rate consistent with the capacities of both the receiver and sender.
  - error control: ensuring that the segments are correctly received.
  - congestion control: ensuring that data is transmitted at a rate consistent with the capacities of the intermediate links in the network path.

1.1 TCP Congesion control

- TCP senders use two state variables to accomplish congestion control.
  - The first variable is the congestion window (cwnd)
    - * an upper bound on the amount of data the sender can inject into the network before receiving an acknowledgement (ACK).
    - * less than receiver window
  - The second variable is the slow start threshold (ssthresh).
    - * determines which algorithm is used to increase the value of cwnd.
- TCP employs four congestion control algorithms

- slow start
- congestion avoidance
- fast retransmit before RTO expiresf
- ast recovery to avoid slow start.

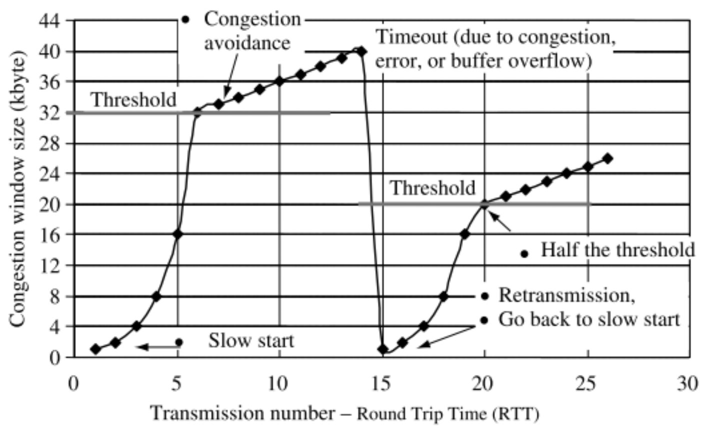


Figure 1: TCP congestion control behavior with Timeout occuring at RTT#14

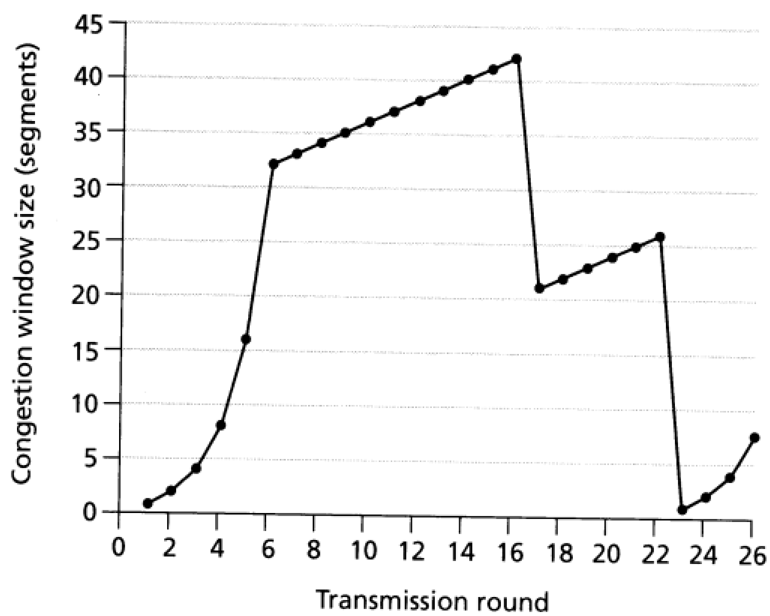
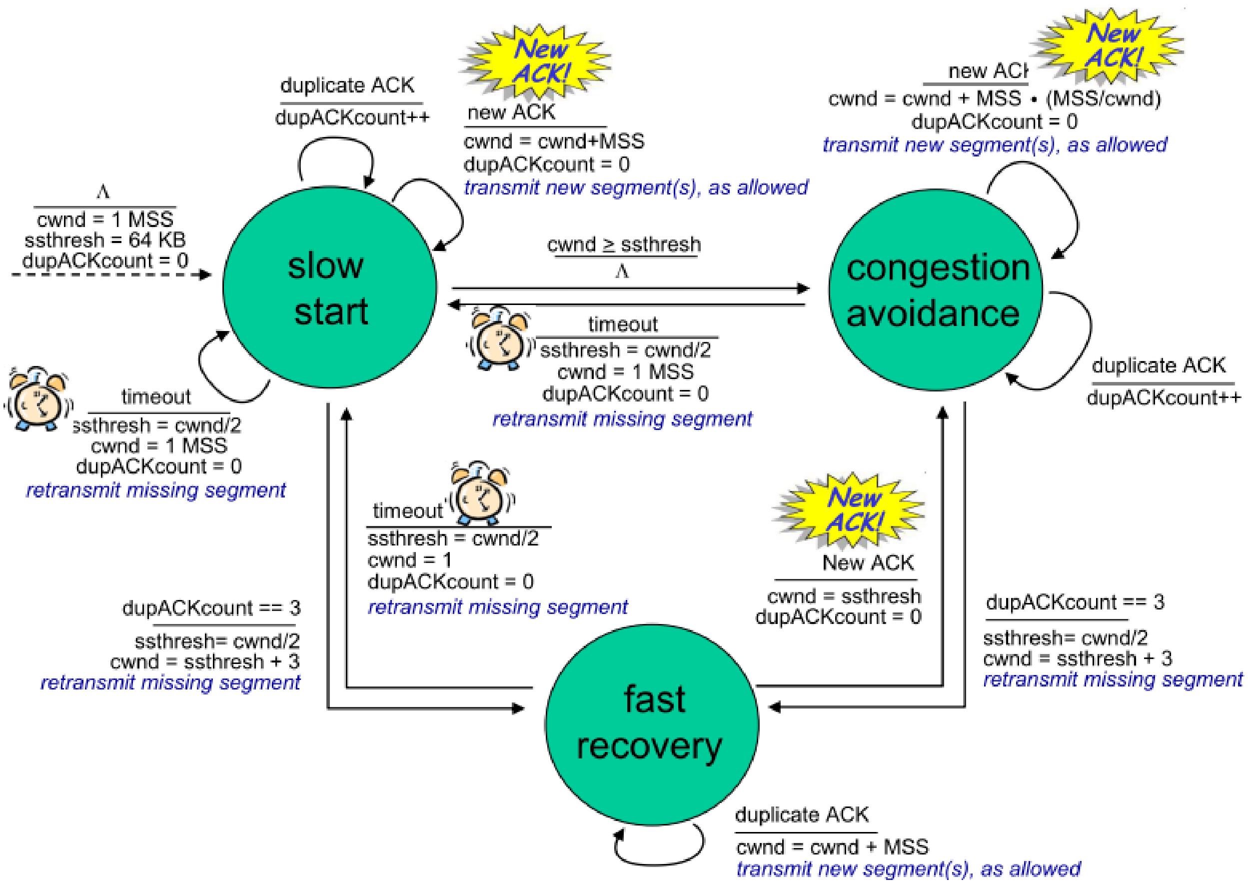


Figure 2: TCP Reno with three duplicate ACKs received in window # 16



- The retransmission timeout (RTO) alcluation is performed as follows

$$RTO = RTT_{n-1} + 4D_n$$

$$RTT_n = \alpha RTT_{n-1} + (1-\alpha)M_n$$

$$D_n = \alpha D_{n-1} + (1-\alpha)\left|M_n - RTT_{n-1}\right|$$

  where

  - RTT_n represents the average retranmission timeout for the first n packets
  - D_n represents the deviation of the RTT from the average value
  - M_n the RTT delay for the packet n

- The above congestion management algorithms have a negative impact on the performance of individual TCP connections' performance because the algorithms slowly probe the network for additional capacity, which in turn wastes bandwidth. This is especially true over long-delay satellite channels because of the large amount of time required for the sender to obtain feedback from the receiver.

1.2 TCP Performance Analysis

- The key parameter considered here is satellite ***link utilisation*** (U) as satellite networks are very expensive
- The TCP transmission may complete before full bandwidth speed has been reached due to the slow-start algorithm, congestion control mechanism, and network congestion or network errors.
- The first TCP segment Bandwidth utilization (U_1) can be calculated as

$$U_1 = \frac{T}{T+2D} = \frac{M/B}{M/B+2D} = 1/(1+2\frac{DB}{M})$$

  where

- T is the time to transmit the data
- M is the data size (MSS)
- D is the one-way propagation delay
- B is the system bandwidth

- Note that this expression ignores the TCP three-way handshake connection set-up delay and connection close-down delay.
- It can be seen that the delay $*$ bandwidth product is a key parameter affecting TCP performance.

1.2.1 Slow-start Phase analysis

- the number of traffic blocks (L) increases exponentially as $2^i L$, $i = 1, 2, ..., n-1$
- During n RTT, transmitted data can be estimated as

$$L_n = \left(\sum_{i=0}^{n-1} 2^i\right) M = (2^n - 1)M$$

and the system utilization can be expressed as

$$U_n = 1/\left(1 + \frac{2n}{(2^n-1)M} DB\right)$$

- A more general expression for data completely transmitted during the slow-start can be expressed as

$$\begin{aligned} L &= \left(\sum_{i=0}^{n-1} 2^i + \alpha 2^n\right) M \\ &= (2^n(1+\alpha) - 1)M \end{aligned}$$

- For this transmission, the total consumed time is $\frac{(2^n(1+\alpha)-1)M}{B} + 2D(n+1)$

1.2.2 Congestion Avoidance Analysis

- The congestion avoidance phase starts on reaching the ssthresh after p RTTs
- The total transmitted data

$$\begin{aligned} L_m &= \left(\sum_{i=0}^{p-1} 2^i + \sum_{i=1}^{m} \left(2^{p-1}+1\right) + \beta(2^{p-1} + m + 1)\right) M \\ &= \left((m+\beta+2)2^{p-1} + \frac{m^2 + (2\beta+1)m}{2} + \beta - 1\right) M \end{aligned}$$

- Hence, the utilization can estimated as

$$U_{p+m} = 1/\left(1 + DB \frac{2(p+m)}{(m+\beta+2)2^{p-1} + \frac{m^2+(2\beta+1)m}{2} + \beta - 1}\right), \ \forall 0 \le \beta < 1 \& 2^m M \le W$$

where W is the receiver window size.

References

[1] Zhili Sun, "Satellite Networking: Principles and Protocols," John Wiley & Sons Ltd, 2005