1. At time t, a TCP connection has a congestion window of 4000 bytes. The maximum segment size used by the connection is 1000 bytes. What is the congestion window after it sends out 4 packets and receives acks for all of them? Suppose there is one ack per packet.
(a) If the connection is in slow-start?
Solution: 8000 bytes. In slow start, the sender increases its window for each byte successfully received.
(b) If the connection is in congestion avoidance (linear mode)?
Solution: 5000 bytes. The sender increases its window by one segment each window.

2. Suppose we have a ten-gigabit/second network with a roundtrip time of 100 milliseconds. The maximum segment size (MSS) is 1500 bytes.

a. How long will it take for a TCP connection to reach maximum speed after starting in slow-start mode?

Solution: The transmission rate starts at one MSS-size segment per roundtrip time, or 15,000 bytes/second. The maximum speed is 1.25 gigabytes/second. Thus it must increase its speed by a factor of 83,333.33. Assuming no packet loss, after each roundtrip time (100 milliseconds), the speed doubles. So, after log2(83,333.33) (= ≈16.347) roundtrips, the speed will reach the maximum. Thus maximum speed is reached in 1.7 seconds.

A common mistake was to try to reach a 10 gigabit window size, but you only need a tenth of that because of the 100 ms (1/10 second) RTT.

b. Assume there is some probability that a packet is lost in transmission, even though there is no congestion. Give a scenario in which the congestion window becomes 1 MSS (i.e., 1500 bytes) and TCP begins growing the window linearly rather than exponentially (i.e., it's not in slow-start mode).

Solution: Suppose the first segment sent is received and ack'd, but the second segment sent is lost. Thus after timing out on the ack for the second segment, the sending TCP sets its congestion window to one MSS and begins the linear increase of its congestion window.

c. How long will it take the TCP connection to achieve maximum speed after the scenario of part 2, assuming no further packet loss?

Solution: 83,333 roundtrips, or 8,333 seconds (two hours, eighteen minutes, and 53 seconds).

3. Suppose the TCP congestion window is set to 18KB and a timeout occurs. How big will the window be if the next four transmission bursts are all successful? Assume that the maximum segment size is 1KB.

Solution: When a timeout occurs, three things happend. First, slow start will be initiated. Second, the congestion window would start at 1. Third, the threshold will be reset to 18KB/2=9KB. If the next four transmission are all successful, then

- 1st transmission: 1 segment, 1KB
- 2nd transmission: 2 segments, 2KB
- 3rd transmission: 4 segments, 4KB
- 4th transmission: 8 segments, 8KB

After these four successful transmissions, the window size is supposed to be 16. However, since the threshold is 9KB, the window size can only be 9KB.

4. If the TCP round-trip time, RTT, is currently 30 msec and the following acknowledgements come in after 26, 32, and 24 msec, respectively, what is the new RTT estimate using the Jacobson algorithm? Use $\alpha = 0.9$.

RTT = 30 msec

RTT1 = 0.9 * 30 + (1 – 0.9) * 26 = 29.6

RTT2 = 0.9 * 29.6 + (1 – 0.9) * 32 = 29.84

RTT3 = 0.9 * 29.84 + (1- 0.9) * 24 = 29.256

The new round trip time is <u>29.256 msec</u>