Chair of Distributed Systems and Security
School of Computation, Information and Technology
Technical University of Munich

Computer Networking and IT Security (INHN0012)

Tutorial 11

Problem 1 Flow and congestion control with TCP

The most widely used transport protocol on the Internet is TCP. It implements mechanisms for flow and congestion control.

a)* Discuss the differences between flow and congestion control. What are the objectives of each mechanism?

b) Assign each of the following terms to TCP flow or congestion control:

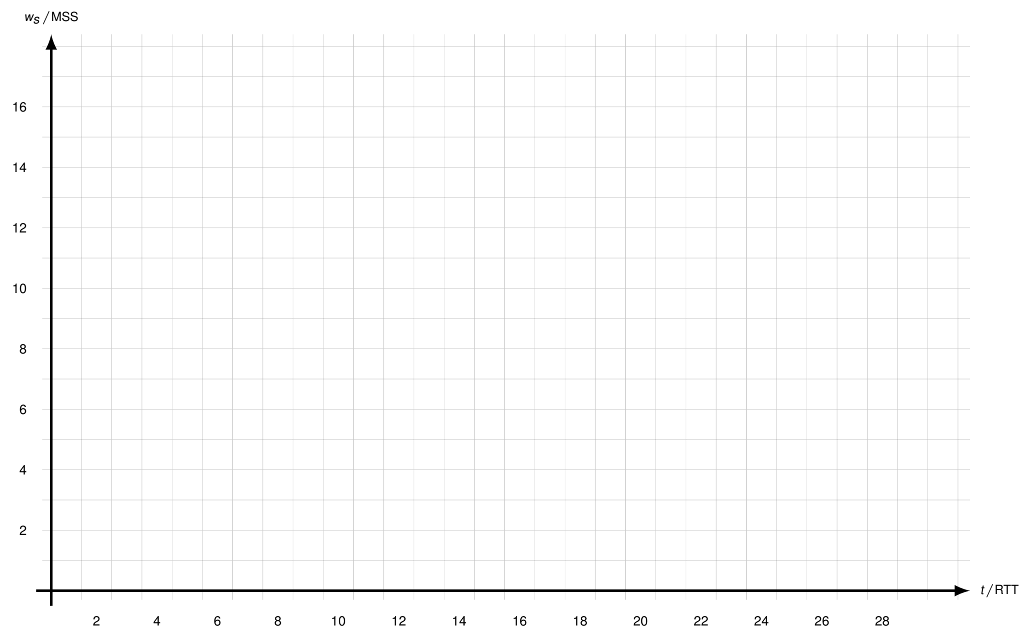
- Slow-Start
- Receive window
- Congestion-Avoidance
- Multiplicative-Decrease

To analyze the data rate that can be achieved with TCP, we consider the course of a contiguous data transmission in which the slow-start phase has already been completed. TCP is therefore operating in the congestion-avoidance phase. We define the individual windows as follows:

- Send window W_s, $|W_s| = w_s$
- Receive window W_r, $|W_r| = w_r$
- Congestion-control window W_c, $|W_c| = w_c$

We assume that the receive window is arbitrarily large, so that the send window is determined solely by the congestion-control window, i. e., $W_s = W_c$. No losses occur as long as the send window is smaller than a maximum value x, i. e., $w_s < x$.
If a full send window is acknowledged, the currently used window increases by exactly 1 MSS. If the send window reaches the value x, exactly one of the sent TCP segments is lost. The sender detects the loss by receiving the same ACK number multiple times. The sender then halves the congestion-control window, but still remains in the congestion-avoidance phase, i. e., no new slow-start takes place. This approach corresponds to a simplified variant of TCP-Reno (cf. lecture).
As concrete numerical values, we assume that the maximum TCP segment size (MSS) is 1460 B and that the RTT is 200 ms. Let the serialization time of segments be negligible compared to the propagation delay. Segment loss occurs as soon as the send window reaches a size of $w_s \geq x = 16\,\text{MSS}$.

c)* Create a graph plotting the current size of the send window w_s, measured in MSS, over the time axis t, measured in RTT. In your diagram, at time $t_0 = 0\,\mathrm{s}$, the send window size has just been halved, so that $w_s = x/2$ holds. Draw the diagram for the time interval $t = \{0, \dots, 27\}$.



d)* How much time elapses before the congestion control window is reduced again after a segment loss as a result of another segment loss?

e)* Determine the average loss rate L.
Note: Since the behavior of TCP is periodic in this idealized model, it is sufficient to consider only a single period. Set the total number of transmitted segments in relation to the number of lost segments (specification as a truncated fraction is sufficient).

f) Using the results from subtasks d) and e), determine the average achievable transmission rate in kB/s during the TCP transmission phase under consideration.
Note: Use the exact value (fraction) from subtask e).

g)* What is the maximum transmission rate that could be achieved over the channel using UDP without causing congestion? Take into account that the UDP header is 12 B shorter than the TCP header without options.

Problem 2 Compression: Huffman Coding

Given the alphabet $\mathcal{A} = \{a, b, c, d\}$ and the message

$$m = \text{aabcbdacababbbbcbddbbbaababdbdbb} \in \mathcal{A}^{32}.$$

a)* Determine the occurrence probabilities p_i of each character $i \in \mathcal{A}$ in the message m.

b) Determine the information content $I(i)$ of each character from $\mathcal{A}$.

c) The message m originates from a message source X. Based on the previous results, determine the source entropy $H(X)$.

d) Now determine a binary Huffman code C for this message source.

e) Determine the average codeword length of C.

f) Compare the average codeword length of C with the codeword length of a uniform[1] binary code.

g) **Homework:** Create a binary Huffman-Code C' for another message source Q', which emits characters of the alphabet $\chi = \{a, b, c, d, e\}$.
The relative probabilities of the characters are $p_a = \frac{2}{22}, p_b = \frac{3}{22}, p_c = \frac{4}{22}, p_d = \frac{5}{22}, p_e = \frac{8}{22}$.

[1] A code is called *uniform* if all codewords have the same length