

Computer Networking and Traffic Control

DSC-DO-02 Graduate School: Homework 5

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This document contains the exercises for Homework 5 (Routing and TCP).

1 Congestion control for best effort: TCP/IP

Exercise 1.1. *The following trace was captured with TCPDump. It was generated by a Web session. The S, P, and F letters indicate the corresponding TCP flags (SYN, PSH, FIN). Starting with the second packets in each direction, Sequence and Acknowledgement numbers are given by their offset from the values in the first packets. The notation 1:449(448) means that the packet sequence number is 1, it carries 448 bytes of data, and the last byte has sequence number 449 -1.*

1. Explain the use of the flags.
2. Some packets have been mis-ordered. At which lines is that visible ?
3. Which lines are retransmissions ?
4. Show the states (from the slide "TCP Finite State Machine") for each of the two ends of the connection, for the first and last 10 lines of the trace, after the packet has been received.

```
15:07:24.544104 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: S
3695173790:3695173790(0) win 512 <mss 448>
15:07:24.584105 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: S
1043264000:1043264000(0) ack 3695173791 win 4096
15:07:24.584105 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 1 win 14247
15:07:24.594105 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . 1:449(448) ack 1
win 14335
15:07:24.704107 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . ack 449 win 3648
15:07:24.704107 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: P 449:500(51) ack 1
win 14335
15:07:24.764108 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: P 1:182(181) ack 500
win 4096
15:07:24.764108 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 182 win 14159
15:07:24.804109 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 182:630(448) ack
500 win 4096
```

15:07:24.804109 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 630 win 14023
15:07:24.814109 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 630:1078(448) ack
500 win 4096
15:07:24.814109 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 1078 win 14023
15:07:24.814109 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 1078:1526(448) ack
500 win 4096
15:07:24.814109 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 1526 win 14023
15:07:24.834109 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 1526:1974(448) ack
500 win 4096
15:07:24.834109 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 1974 win 14023
15:07:24.834109 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 1974:2422(448) ack
500 win 4096
15:07:24.834109 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 2422 win 14023
15:07:24.844109 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 2422:2870(448) ack
500 win 4096
15:07:24.844109 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 2870 win 14023
15:07:24.844109 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 2870:3318(448) ack
500 win 4096
15:07:24.844109 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 3318 win 13711
15:07:24.844109 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 3318 win 14335
15:07:24.844109 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 3318:3766(448) ack
500 win 4096
15:07:24.844109 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 3766 win 14023
15:07:24.844109 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 3766:4214(448) ack
500 win 4096
15:07:24.844109 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 4214 win 14023
15:07:24.864110 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 4214:4662(448) ack
500 win 4096
15:07:24.864110 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 4662 win 14023
15:07:24.874110 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 4662:5110(448) ack
500 win 4096
15:07:24.874110 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 5110 win 14023
15:07:24.914111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 5110:5558(448) ack
500 win 4096
15:07:24.914111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 5558 win 14023
15:07:24.914111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 5558:6006(448) ack
500 win 4096
15:07:24.914111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 6006 win 14023
15:07:24.914111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 6006:6454(448) ack
500 win 4096
15:07:24.914111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 6454 win 14023
15:07:24.914111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 6454:6902(448) ack
500 win 4096
15:07:24.914111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 6902 win 14023
15:07:24.924111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 6902:7350(448) ack
500 win 4096
15:07:24.924111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 7350 win 14023
15:07:24.924111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 7350:7798(448) ack

500 win 4096
15:07:24.924111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 7798 win 14023
15:07:24.924111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 7798:8246(448) ack
500 win 4096
15:07:24.924111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 8246 win 14023
15:07:24.934111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 8694:9142(448) ack
500 win 4096
15:07:24.934111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 8246 win 14023
15:07:24.944111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 9142:9590(448) ack
500 win 4096
15:07:24.944111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 8246 win 14023
15:07:24.954111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 9590:10038(448)
ack 500 win 4096
15:07:24.954111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 8246 win 14023
15:07:24.954111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 10038:10486(448)
ack 500 win 4096
15:07:24.954111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 8246 win 14023
15:07:24.964111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 10934:11382(448)
ack 500 win 4096
15:07:24.964111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 8246 win 14023
15:07:24.964111 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 11830:12278(448)
ack 500 win 4096
15:07:24.964111 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 8246 win 14023
15:07:24.974112 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 11382:11830(448)
ack 500 win 4096
15:07:24.974112 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 8246 win 14023
15:07:24.984112 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 8246:8694(448) ack
500 win 4096
15:07:24.984112 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 10486 win 11839
15:07:24.984112 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 10486 win 13399
15:07:26.014129 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 10486:10934(448)
ack 500 win 4096
15:07:26.014129 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 12278 win 13087
15:07:26.014129 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 12278 win 14335
15:07:26.034129 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 12278:12726(448)
ack 500 win 4096
15:07:26.034129 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 12726 win 14023
15:07:26.034129 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 12726:13174(448)
ack 500 win 4096
15:07:26.034129 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 13174 win 14023
15:07:26.074130 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 13174:13622(448)
ack 500 win 4096
15:07:26.074130 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 13622 win 14023
15:07:26.074130 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 13622:14070(448)
ack 500 win 4096
15:07:26.074130 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 14070 win 14023
15:07:26.084130 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 14070:14518(448)
ack 500 win 4096

15:07:26.084130 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 14518 win 14023
15:07:26.114131 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 14518:14966(448)
ack 500 win 4096
15:07:26.114131 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 14966 win 14023
15:07:26.134131 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 14966:15414(448)
ack 500 win 4096
15:07:26.134131 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 15414 win 14023
15:07:26.144131 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 15414:15862(448)
ack 500 win 4096
15:07:26.144131 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 15862 win 14023
15:07:26.144131 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 15862:16310(448)
ack 500 win 4096
15:07:26.144131 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 16310 win 14023
15:07:26.144131 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 16310:16758(448)
ack 500 win 4096
15:07:26.144131 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 16758 win 14023
15:07:26.154131 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 16758:17206(448)
ack 500 win 4096
15:07:26.154131 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 17206 win 14023
15:07:26.164132 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 17206:17654(448)
ack 500 win 4096
15:07:26.164132 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 17654 win 14023
15:07:26.164132 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 17654:18102(448)
ack 500 win 4096
15:07:26.164132 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 18102 win 14023
15:07:26.164132 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 18102:18550(448)
ack 500 win 4096
15:07:26.164132 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 18550 win 14023
15:07:26.164132 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 18550:18998(448)
ack 500 win 4096
15:07:26.164132 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 18998 win 14023
15:07:26.174132 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 18998:19446(448)
ack 500 win 4096
15:07:26.174132 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 19446 win 14023
15:07:26.184132 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 19446:19894(448)
ack 500 win 4096
15:07:26.184132 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 19894 win 14023
15:07:26.194132 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 19894:20342(448)
ack 500 win 4096
15:07:26.194132 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 20342 win 14023
15:07:26.194132 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 20342:20790(448)
ack 500 win 4096
15:07:26.194132 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 20790 win 14023
15:07:26.204132 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 20790:21238(448)
ack 500 win 4096
15:07:26.204132 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 21238 win 14023
15:07:26.234133 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 21238:21686(448)
ack 500 win 4096

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15:07:26.234133 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 21686 win 14023
15:07:26.234133 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 21686:22134(448)
ack 500 win 4096
15:07:26.234133 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 22134 win 14023
15:07:26.234133 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 22134:22582(448)
ack 500 win 4096
15:07:26.234133 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 22582 win 14023
15:07:26.234133 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 22582:23030(448)
ack 500 win 4096
15:07:26.234133 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 23030 win 14023
15:07:26.234133 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 23030:23478(448)
ack 500 win 4096
15:07:26.234133 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 23478 win 14023
15:07:26.244133 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 23478:23926(448)
ack 500 win 4096
15:07:26.244133 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 23926 win 14023
15:07:26.284134 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 24374:24822(448)
ack 500 win 4096
15:07:26.284134 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 23926 win 14023
15:07:26.284134 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 24822:25270(448)
ack 500 win 4096
15:07:26.284134 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 23926 win 14023
15:07:26.284134 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: FP 25270:25653(383)
ack 500 win 4096
15:07:26.284134 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 23926 win 14023
15:07:27.044146 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . 23926:24374(448)
ack 500 win 4096
15:07:27.044146 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 25654 win 13119
15:07:27.044146 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: . ack 25654 win 14335
15:07:27.064147 lrcpc8.epfl.ch.1071 > ezinfo.ethz.ch.www: F 500:500(0) ack
25654 win 14335
15:07:27.104147 ezinfo.ethz.ch.www > lrcpc8.epfl.ch.1071: . ack 501 win 409

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Exercise 1.2. *What is the time taken by slow start to fully utilize a link of capacity C b/s ? Call τ the round trip time, including packet transmission, propagation, and ack processing time. Assume that every packet is acknowledged. Also assume that all packets have a fixed size L .*

Exercise 1.3. *Consider the first model used for analyzing the fairness of additive increase, multiplicative decrease (with one update per RTT)*

$$\frac{dx_i}{dt} = \frac{r}{\tau} - x_i(r + \eta x_i) \sum_{l=1}^L g_l(f_l(t)) A_{l,i}$$

All notations are the same as in the course notes. Congestion is indicated by packet losses.

Call $q_i(t)$ the packet loss ratio experienced during timeslot t on the path of flow i . Define the limiting rate $x_i^ = \lim_{t \rightarrow +\infty} x_i(t)$ and the limiting loss probability $q_i^* = \lim_{t \rightarrow +\infty} q_i(t)$.*

1. *Compute x_i^* as a function of q_i^* .*

2. For very small values of q_i^* , compare with the TCP loss-throughput formula and discuss.

Exercise 1.4. Assume two hosts have a very large file to transfer, and decide to open n parallel TCP connections for the transfer.

1. Find one advantage and one drawback, for the user of the two hosts, of having $n > 1$. Justify your answer.

2. Find one advantage or one drawback, for the rest of the network, of having $n > 1$. Justify your answer.

2 Routing

Exercise 2.1. Consider the network with point to point links and costs as given in Table 1.

	A	B	C	D
A		1	X	8
B	1		1	1
C	X	1		1
D	8	1	1	

Table 1: Costs $c(i, j)$ for Exercise 2.1

1. Give the routing tables built at A using the distance vector method.

2. Assume the link between nodes A and B fails. B sees the failure and computes new distances. Just after that, B receives from C an old distance vector, sent by C before C could notice the failure. Explain what will happen and comment.

Exercise 2.2. Same question as exercise 2.1, assuming the nodes use the link state method. Show the detailed steps of the Dijkstra shortest path algorithm at node B (before and after the failure).

Exercise 2.3. Consider the slide “Example” just following the slide “Principles of OSPF Hierarchical Routing”.

1. What is the next-hop for packets with destination $n1$ or $n2$ at A1 ? at A2 ?

2. Assume that the link X4–X6 breaks. What happens to the topology databases ?

3. Assume that the link B1–B2 also breaks. Same question.

Exercise 2.4. Consider a routing algorithm based on the link state principle, but that uses the following modification of Dijkstra’s algorithm.

```

m(0) = + INF; M = {0};
for k=1 to N {
  find
  (i0, j0) that maximizes min (m(i), c(i,j)),

with i in M, j not in M;
  m(j0) = min(m(i0), c(i0, j0));
  pred(j0) = i0;
  M = M + {j0};
}

```

1. What are the differences with standard Dijkstra's algorithm ?
2. Consider a network with four nodes, numbered A to D, with the link costs given by the matrix in Table 2 (an X indicates that there is no link).

	A	B	C	D
A		10	X	14
B	30		20	X
C	X	12		3
D	4	X	15	

Table 2: Costs $c(i, j)$ for Exercise 2.4

- Find the best paths determined by this algorithm for a flow from A to B and from B to A. What are the costs of these paths ?*
3. Find an interpretation and a possible use of such a routing method. Comment on advantages and drawbacks.
 4. Comment on the routing tables built with such an algorithm.