Exam in
SSY305 Kommunikationssystem

Department of Electrical Engineering

Exam date: June 9, 2017, 14:00–18:00
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Material Allowed material is

- Chalmers-approved calculator
- L. Råde, B. Westergren. Beta, Mathematics Handbook, any edition.
- One A4 page with your own handwritten notes. Both sides of the page can be used. Photo copies, printouts, other students' notes, or any other material is not allowed.
- A paper-based dictionary, without added notes (electronic dictionaries are not allowed).

Grading A correct, clear and well-motivated solution gives a maximum of 12 points per problem.

An erroneous answer, unclear, incomplete or badly motivated solutions give point reductions down to a minimum of 0 points. No fractional points are awarded.

Answers in any other language than Swedish or English are ignored.

Solutions Are made available at the earliest at 19:00 on the course web page.

Results Exam results are posted on Ping-Pong no later than June 13, 2017. The grading review is on June 15 and June 21, 2017, 12:00–13:00 in room 6414 in the ED-building.

Grades The final grade on the course will be decided by the projects (maximum score 46), quizzes (maximum score 6), and final exam (maximum score 48). Project and exam must be passed (see course-PM for rules). The sum of all scores will decide the grade according to the following table.

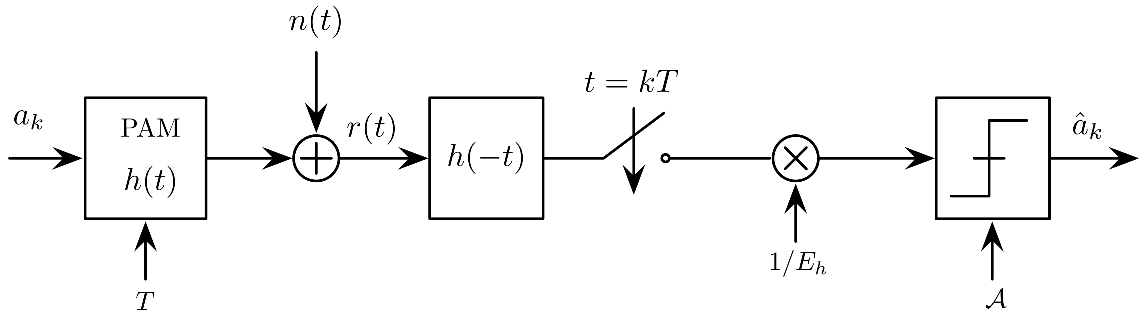
Total Score	0–39	40–59	60–79	≥ 80
Grade	Fail	3	4	5

PLEASE NOTE THAT THE PROBLEMS ARE NOT NECESSARILY ORDERED IN DIFFICULTY.
Good luck!

Table over the Q-function

x	Q(x)	x	Q(x)	x	Q(x)	x	Q(x)	x	Q(x)	x	Q(x)	x	Q(x)	x	Q(x)
0.00	5.0000E-01	0.76	2.2360E-01	1.52	6.4260E-02	2.28	1.1300E-02	3.04	1.1830E-03	3.80	7.2350E-05	4.56	2.5580E-06	5.32	5.1880E-08
0.01	4.9600E-01	0.77	2.2060E-01	1.53	6.3010E-02	2.29	1.1010E-02	3.05	1.1440E-03	3.81	6.9480E-05	4.57	2.4390E-06	5.33	4.9110E-08
0.02	4.9200E-01	0.78	2.1770E-01	1.54	6.1780E-02	2.30	1.0720E-02	3.06	1.1070E-03	3.82	6.6730E-05	4.58	2.3250E-06	5.34	4.6470E-08
0.03	4.8800E-01	0.79	2.1480E-01	1.55	6.0570E-02	2.31	1.0440E-02	3.07	1.0700E-03	3.83	6.4070E-05	4.59	2.2160E-06	5.35	4.3980E-08
0.04	4.8400E-01	0.80	2.1190E-01	1.56	5.9380E-02	2.32	1.0170E-02	3.08	1.0350E-03	3.84	6.1520E-05	4.60	2.1120E-06	5.36	4.1610E-08
0.05	4.8010E-01	0.81	2.0900E-01	1.57	5.8210E-02	2.33	9.9030E-03	3.09	1.0010E-03	3.85	5.9060E-05	4.61	2.0130E-06	5.37	3.9370E-08
0.06	4.7610E-01	0.82	2.0610E-01	1.58	5.7050E-02	2.34	9.6420E-03	3.10	9.6760E-04	3.86	5.6690E-05	4.62	1.9190E-06	5.38	3.7240E-08
0.07	4.7210E-01	0.83	2.0330E-01	1.59	5.5920E-02	2.35	9.3870E-03	3.11	9.3540E-04	3.87	5.4420E-05	4.63	1.8280E-06	5.39	3.5230E-08
0.08	4.6810E-01	0.84	2.0050E-01	1.60	5.4800E-02	2.36	9.1370E-03	3.12	9.0430E-04	3.88	5.2230E-05	4.64	1.7420E-06	5.40	3.3320E-08
0.09	4.6410E-01	0.85	1.9770E-01	1.61	5.3700E-02	2.37	8.8940E-03	3.13	8.7400E-04	3.89	5.0120E-05	4.65	1.6600E-06	5.41	3.1510E-08
0.10	4.6020E-01	0.86	1.9490E-01	1.62	5.2620E-02	2.38	8.6560E-03	3.14	8.4470E-04	3.90	4.8100E-05	4.66	1.5810E-06	5.42	2.9800E-08
0.11	4.5620E-01	0.87	1.9220E-01	1.63	5.1550E-02	2.39	8.4240E-03	3.15	8.1640E-04	3.91	4.6150E-05	4.67	1.5060E-06	5.43	2.8180E-08
0.12	4.5220E-01	0.88	1.8940E-01	1.64	5.0500E-02	2.40	8.1980E-03	3.16	7.8880E-04	3.92	4.4270E-05	4.68	1.4340E-06	5.44	2.6640E-08
0.13	4.4830E-01	0.89	1.8670E-01	1.65	4.9470E-02	2.41	7.9760E-03	3.17	7.6220E-04	3.93	4.2470E-05	4.69	1.3660E-06	5.45	2.5180E-08
0.14	4.4430E-01	0.90	1.8410E-01	1.66	4.8460E-02	2.42	7.7600E-03	3.18	7.3640E-04	3.94	4.0740E-05	4.70	1.3010E-06	5.46	2.3810E-08
0.15	4.4040E-01	0.91	1.8140E-01	1.67	4.7460E-02	2.43	7.5490E-03	3.19	7.1140E-04	3.95	3.9080E-05	4.71	1.2390E-06	5.47	2.2500E-08
0.16	4.3640E-01	0.92	1.7880E-01	1.68	4.6480E-02	2.44	7.3440E-03	3.20	6.8710E-04	3.96	3.7470E-05	4.72	1.1790E-06	5.48	2.1270E-08
0.17	4.3250E-01	0.93	1.7620E-01	1.69	4.5510E-02	2.45	7.1430E-03	3.21	6.6370E-04	3.97	3.5940E-05	4.73	1.1230E-06	5.49	2.0100E-08
0.18	4.2860E-01	0.94	1.7360E-01	1.70	4.4570E-02	2.46	6.9470E-03	3.22	6.4100E-04	3.98	3.4460E-05	4.74	1.0690E-06	5.50	1.8990E-08
0.19	4.2470E-01	0.95	1.7110E-01	1.71	4.3630E-02	2.47	6.7560E-03	3.23	6.1900E-04	3.99	3.3040E-05	4.75	1.0170E-06	5.51	1.7940E-08
0.20	4.2070E-01	0.96	1.6850E-01	1.72	4.2720E-02	2.48	6.5690E-03	3.24	5.9760E-04	4.00	3.1670E-05	4.76	9.6800E-07	5.52	1.6950E-08
0.21	4.1680E-01	0.97	1.6600E-01	1.73	4.1820E-02	2.49	6.3870E-03	3.25	5.7700E-04	4.01	3.0360E-05	4.77	9.2110E-07	5.53	1.6010E-08
0.22	4.1290E-01	0.98	1.6350E-01	1.74	4.0930E-02	2.50	6.2100E-03	3.26	5.5710E-04	4.02	2.9100E-05	4.78	8.7650E-07	5.54	1.5120E-08
0.23	4.0900E-01	0.99	1.6110E-01	1.75	4.0060E-02	2.51	6.0370E-03	3.27	5.3770E-04	4.03	2.7890E-05	4.79	8.3390E-07	5.55	1.4280E-08
0.24	4.0520E-01	1.00	1.5870E-01	1.76	3.9200E-02	2.52	5.8680E-03	3.28	5.1900E-04	4.04	2.6730E-05	4.80	7.9330E-07	5.56	1.3490E-08
0.25	4.0130E-01	1.01	1.5620E-01	1.77	3.8360E-02	2.53	5.7030E-03	3.29	5.0090E-04	4.05	2.5610E-05	4.81	7.5470E-07	5.57	1.2740E-08
0.26	3.9740E-01	1.02	1.5390E-01	1.78	3.7540E-02	2.54	5.5430E-03	3.30	4.8340E-04	4.06	2.4540E-05	4.82	7.1780E-07	5.58	1.2030E-08
0.27	3.9360E-01	1.03	1.5150E-01	1.79	3.6730E-02	2.55	5.3860E-03	3.31	4.6650E-04	4.07	2.3510E-05	4.83	6.8270E-07	5.59	1.1350E-08
0.28	3.8970E-01	1.04	1.4920E-01	1.80	3.5930E-02	2.56	5.2340E-03	3.32	4.5010E-04	4.08	2.2520E-05	4.84	6.4920E-07	5.60	1.0720E-08
0.29	3.8590E-01	1.05	1.4690E-01	1.81	3.5150E-02	2.57	5.0850E-03	3.33	4.3420E-04	4.09	2.1570E-05	4.85	6.1730E-07	5.61	1.0120E-08
0.30	3.8210E-01	1.06	1.4460E-01	1.82	3.4380E-02	2.58	4.9400E-03	3.34	4.1890E-04	4.10	2.0660E-05	4.86	5.8690E-07	5.62	9.5480E-09
0.31	3.7830E-01	1.07	1.4230E-01	1.83	3.3620E-02	2.59	4.7990E-03	3.35	4.0410E-04	4.11	1.9780E-05	4.87	5.5800E-07	5.63	9.0100E-09
0.32	3.7450E-01	1.08	1.4010E-01	1.84	3.2880E-02	2.60	4.6610E-03	3.36	3.8970E-04	4.12	1.8940E-05	4.88	5.3040E-07	5.64	8.5030E-09
0.33	3.7070E-01	1.09	1.3790E-01	1.85	3.2160E-02	2.61	4.5270E-03	3.37	3.7580E-04	4.13	1.8140E-05	4.89	5.0420E-07	5.65	8.0220E-09
0.34	3.6690E-01	1.10	1.3570E-01	1.86	3.1440E-02	2.62	4.3960E-03	3.38	3.6240E-04	4.14	1.7370E-05	4.90	4.7920E-07	5.66	7.5690E-09
0.35	3.6320E-01	1.11	1.3350E-01	1.87	3.0740E-02	2.63	4.2690E-03	3.39	3.4950E-04	4.15	1.6620E-05	4.91	4.5540E-07	5.67	7.1400E-09
0.36	3.5940E-01	1.12	1.3140E-01	1.88	3.0050E-02	2.64	4.1450E-03	3.40	3.3690E-04	4.16	1.5910E-05	4.92	4.3270E-07	5.68	6.7350E-09
0.37	3.5570E-01	1.13	1.2920E-01	1.89	2.9380E-02	2.65	4.0250E-03	3.41	3.2480E-04	4.17	1.5230E-05	4.93	4.1110E-07	5.69	6.3520E-09
0.38	3.5200E-01	1.14	1.2710E-01	1.90	2.8720E-02	2.66	3.9070E-03	3.42	3.1310E-04	4.18	1.4580E-05	4.94	3.9060E-07	5.70	5.9900E-09
0.39	3.4830E-01	1.15	1.2510E-01	1.91	2.8070E-02	2.67	3.7930E-03	3.43	3.0180E-04	4.19	1.3950E-05	4.95	3.7110E-07	5.71	5.6490E-09
0.40	3.4460E-01	1.16	1.2300E-01	1.92	2.7430E-02	2.68	3.6810E-03	3.44	2.9090E-04	4.20	1.3350E-05	4.96	3.5250E-07	5.72	5.3260E-09
0.41	3.4090E-01	1.17	1.2100E-01	1.93	2.6800E-02	2.69	3.5730E-03	3.45	2.8030E-04	4.21	1.2770E-05	4.97	3.3480E-07	5.73	5.0220E-09
0.42	3.3720E-01	1.18	1.1900E-01	1.94	2.6190E-02	2.70	3.4670E-03	3.46	2.7010E-04	4.22	1.2220E-05	4.98	3.1790E-07	5.74	4.7340E-09
0.43	3.3360E-01	1.19	1.1700E-01	1.95	2.5590E-02	2.71	3.3640E-03	3.47	2.6020E-04	4.23	1.1680E-05	4.99	3.0190E-07	5.75	4.4620E-09
0.44	3.3000E-01	1.20	1.1510E-01	1.96	2.5000E-02	2.72	3.2640E-03	3.48	2.5070E-04	4.24	1.1180E-05	5.00	2.8670E-07	5.76	4.2060E-09
0.45	3.2640E-01	1.21	1.1310E-01	1.97	2.4420E-02	2.73	3.1670E-03	3.49	2.4150E-04	4.25	1.0690E-05	5.01	2.7220E-07	5.77	3.9640E-09
0.46	3.2280E-01	1.22	1.1120E-01	1.98	2.3850E-02	2.74	3.0720E-03	3.50	2.3260E-04	4.26	1.0220E-05	5.02	2.5840E-07	5.78	3.7350E-09
0.47	3.1920E-01	1.23	1.0930E-01	1.99	2.3300E-02	2.75	2.9800E-03	3.51	2.2410E-04	4.27	9.7740E-06	5.03	2.4520E-07	5.79	3.5190E-09
0.48	3.1560E-01	1.24	1.0750E-01	2.00	2.2750E-02	2.76	2.8900E-03	3.52	2.1580E-04	4.28	9.3450E-06	5.04	2.3280E-07	5.80	3.3160E-09
0.49	3.1210E-01	1.25	1.0560E-01	2.01	2.2220E-02	2.77	2.8030E-03	3.53	2.0780E-04	4.29	8.9340E-06	5.05	2.2090E-07	5.81	3.1240E-09
0.50	3.0850E-01	1.26	1.0380E-01	2.02	2.1690E-02	2.78	2.7180E-03	3.54	2.0010E-04	4.30	8.5400E-06	5.06	2.0960E-07	5.82	2.9420E-09
0.51	3.0500E-01	1.27	1.0200E-01	2.03	2.1180E-02	2.79	2.6350E-03	3.55	1.9260E-04	4.31	8.1630E-06	5.07	1.9890E-07	5.83	2.7710E-09
0.52	3.0150E-01	1.28	1.0030E-01	2.04	2.0680E-02	2.80	2.5550E-03	3.56	1.8540E-04	4.32	7.8010E-06	5.08	1.8870E-07	5.84	2.6100E-09
0.53	2.9810E-01	1.29	9.8530E-02	2.05	2.0180E-02	2.81	2.4770E-03	3.57	1.7850E-04	4.33	7.4550E-06	5.09	1.7900E-07	5.85	2.4580E-09
0.54	2.9460E-01	1.30	9.6800E-02	2.06	1.9700E-02	2.82	2.4010E-03	3.58	1.7180E-04	4.34	7.1240E-06	5.10	1.6980E-07	5.86	2.3140E-09
0.55	2.9120E-01	1.31	9.5100E-02	2.07	1.9230E-02	2.83	2.3270E-03	3.59	1.6530E-04	4.35	6.8070E-06	5.11	1.6110E-07	5.87	2.1790E-09
0.56	2.8770E-01	1.32	9.3420E-02	2.08	1.8760E-02	2.84	2.2560E-03	3.60	1.5910E-04	4.36	6.5030E-06	5.12	1.5280E-07	5.88	2.0510E-09
0.57	2.8430E-01	1.33	9.1760E-02	2.09	1.8310E-02	2.85	2.1860E-03	3.61	1.5310E-04	4.37	6.2120E-06	5.13	1.4490E-07	5.89	1.9310E-09
0.58	2.8100E-01	1.34	9.0120E-02	2.10	1.7860E-02	2.86	2.1180E-03	3.62	1.4730E-04	4.38	5.9340E-06	5.14	1.3740E-07	5.90	1.8180E-09
0.59	2.7760E-01	1.35	8.8510E-02	2.11	1.7430E-02	2.87	2.0520E-03	3.63	1.4170E-04	4.39	5.6680E-06	5.15	1.3020E-07	5.91	1.7110E-09
0.60	2.7430E-01	1.36	8.6910E-02	2.12	1.7000E-02	2.88	1.9880E-03	3.64	1.3630E-04	4.40	5.4130E-06	5.16	1.2350E-07	5.92	1.6100E-09
0.61	2.7090E-01	1.37	8.5340E-02	2.13	1.6590E-02	2.89	1.9260E-03	3.65	1.3110E-04	4.41	5.1690E-06	5.17	1.1700E-07	5.93	1.5150E-09
0.62	2.6760E-01	1.38	8.3790E-02	2.14	1.6180E-02	2.90	1.8660E-03	3.66	1.2610E-04	4.42	4.9350E-06	5.18	1.1090E-07	5.94	1.4250E-09
0.63	2.6430E-01	1.39	8.2260E-02	2.15	1.5780E-02	2.91	1.8070E-03	3.67	1.2130E-04	4.43	4.7120E-06	5.19	1.0510E-07	5.95	1.3410E-09
0.64	2.6110E-01	1.40	8.0760E-02	2.16	1.5390E-02	2.92	1.7500E-03	3.68	1.1660E-04	4.44	4.4980E-06	5.20	9.9640E-08	5.96	1.2610E-09
0.65	2.5780E-01	1.41	7.9270E-02	2.17	1.5000E-02	2.93	1.6950E-03	3.69	1.1210E-04	4.45	4.2940E-06	5.21	9.4420E-08	5.97	1.1860E-09
0.66	2.5460E-01	1.42	7.7800E-02	2.18	1.4630E-02	2.94	1.6410E-03	3.70	1.0780E-04	4.46	4.0980E-06	5.22	8.9460E-08	5.98	1.1160E-09
0.67	2.5140E-01	1.43	7.6360E-02	2.19	1.4260E-02	2.95	1.5890E-03	3.71	1.0360E-04	4.47	3.9110E-06	5.23	8.4760E-08	5.99	1.0490E-09
0.68	2.4830E-01	1.44	7.4930E-02	2.20	1.3900E-02	2.96	1.5380E-03	3.72	9.9610E-05	4.48	3.7320E-06	5.24	8.0290E-08	6.00	9.8660E-10
0.69	2.4510E-01	1.45	7.3530E-02	2.21	1.3550E-02	2.97	1.4890E-03	3.73	9.5740E-05	4.49	3.5610E-06	5.25	7.6050E-08	6.01	9.2760E-10
0.70	2.4200E-01	1.46	7.2150E-02	2.22	1.3210E-02	2.98	1.4410E-03	3.74	9.2010E-05	4.50	3.3980E-06	5.26	7.2030E-08	6.02	8.7210E-10
0.71	2.3890E-01	1.47	7.0780E-02	2.23	1.2870E-02	2.99	1.3950E-03	3.75	8.8420E-05	4.51	3.2410E-06	5.27	6.8210E-08	6.03	8.1980E-10
0.72	2.3580E-01	1.48	6.9440E-02	2.24	1.2550E-02	3.00	1.3500E-03	3.76	8.4960E-05	4.52	3.0920E-06	5.28	6.4590E-08	6.04	7.7060E-10
0.73	2.3270E-01	1.49	6.8110E-02	2.25	1.2220E-02	3.01	1.3060E-03	3.77	8.1620E-05	4.53	2.9490E-06	5.29	6.1160E-08	6.05	7.2420E-10
0.74	2.2960E-01	1.50	6.6810E-02	2.26	1.1910E-02	3.02	1.2640E-03	3.78	7.8410E-05	4.54	2.8130E-06	5.30	5.7900E-08	6.06	6.8060E-10
0.75	2.2660E-01	1.51	6.5520E-02	2.27	1.1600E-02	3.03	1.2230E-03	3.79	7.5320E-05	4.55	2.6820E-06	5.31	5.4810E-08	6.07	6.3960E-10

1. Consider transmission of equally likely independent bits using PAM over an AWGN channel with noise power spectral density $N_0/2$, with a matched filter receiver:



We require that transmission is ISI-free and that the pulse shape $h(t)$ is bandlimited to W Hz. As usual, the energy of $h(t)$ is denoted by E_h. The modulation alphabet is $\mathcal{A} = \{A_1, A_2, \ldots, A_M\}$, where $A_k = (k-1)2c$.

(a) Give a combination of $h(t)$, T, and M such that the data rate is equal to 1 Mbit/s for $W = 1$ MHz. (1p)

(b) Repeat Part (a) for $W = 0.5$ MHz. (1p)

(c) Repeat Part (a) for $W = 0.25$ MHz. (1p)

(d) Repeat Part (a) for $W = 2$ MHz. (1p)

(e) Give an expression for the constellation energy in c and M. Hint: the expression for the standard PAM constellation $\{\pm c, \pm 3c, \ldots, \pm(M-1)c\}$ is $c^2(M^2-1)/3$. (4p)

(f) Suppose the data rate is 1 Mbit/s, transmit power is $P = 1.65 \times 10^{-13}$ W and $N_0 = 1.10 \times 10^{-20}$ W/Hz. Compute the symbol error probability for $M = 4$. (4p)

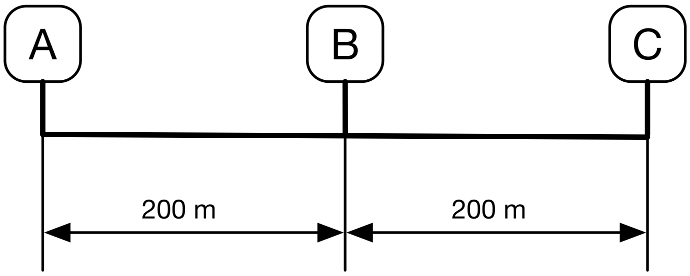
2. (a) Compare symmetric and asymmetric cryptography. What are the advantages and disadvantages with them? (3p)

(b) What is characteristic of an end-to-end protocol? Give an example of a TCP/IP protocols that is an end-to-end protocol. Give an example of a TCP/IP protocols that is not an end-to-end protocol. (3p)

(c) Explain why systematic codes are easy to use for error detection. (3p)

(d) Give at least three examples of challenges (i.e., problems) that eHealth can provide solutions to. (3p)

3. Consider a LAN with three stations: A, B, and C.



The propagation speed is $(2/3)c_0$, where $c_0 = 3 \times 10^8$ m/s and the LAN data rate is 1 Gbit/s. Suppose the stations transmit 750 byte frames.

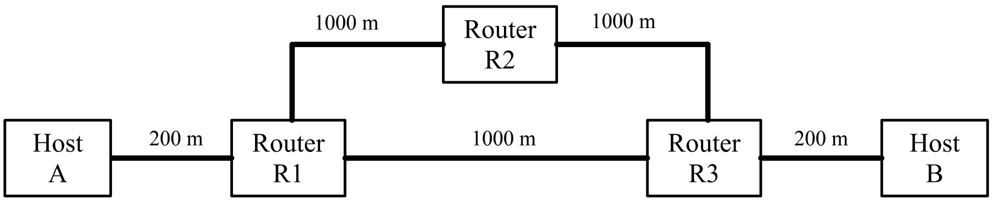
Suppose that the MAC layer in station A receives a frame for transmission by its upper layer at time $t = t_A = 0$. The MAC layers in stations B and C similarly receive frames from their respective higher layers at times $t_B = t_C = 1.5\,\mu$s. If used by the MAC protocol, assume that carrier sensing and collision detection takes negligible time and that the timeout is 4 frame durations.

(a) Suppose the MAC layer use Aloha for medium access. Draw a timing diagram for each station and indicate when all relevant events (start and stop of transmitted and received frames, carrier sensing, start of backoffs, etc.) occur. Make sure to label the time axis such that the time when events occur is clear. (4p)

(b) Repeat Part (a) for persistent CSMA. (4p)

(c) Repeat Part (a) for persistent CSMA/CD. (4p)

4. Consider transmission of data from end-nodes A and B over network depicted below.



Suppose we want to design an application layer protocol that use an ARQ protocol to provide a reliable, in-sequence transmission service of 1000 byte SDUs. The transmission is done over UDP, IP, and Ethernet.

The application layer protocol header is 25 byte and the ACK PDU is also 25 byte. Furthermore, we assume that the IP header is 20 byte, the UDP header is 8 byte, and that the Ethernet header and trailer is 22 byte and 4 byte, respectively.

The routers are store-and-forward routers. The links are full-duplex links with a line data rate of 100 Mbit/s. The length of each link segment is indicated in the figure and we assume that the link propagation speed is $(2/3)c_0$, where $c_0 = 3 \times 10^8$ m/s. The processing time in the hosts and routers is assumed to be negligible.

(a) Sketch the layout of the Ethernet frames carrying the application layer data SDUs. That is, indicate the order and length the different protocol elements (headers, trailers, payloads, etc.) that make up the frame. (1p)

(b) Repeat Part (a) for the application layer ACK PDUs. (1p)

(c) Suppose we use Stop-and-Wait ARQ (for the application layer protocol). What would be a good value for the time-out if Route 1 = (A—R1—R3—B) is used? Motivate. Repeat for Route 2 = (A—R1—R2—R3—B). (4p)

(d) Suppose the application layer does not know which route is used. What would be a good value for the time-out? Motivate. (2p)

(e) Suppose that, on the average, 50% of the packets are transmitted over Route 1 and 50% of the packets over Route 2. What is the effective data rate of the application layer service? Use the timeout value from Part (d) and assume that transmission is error-free. (4p)

Exam in
SSY305 Kommunikationssystem

Department of Electrical Engineering

Exam date: June 9, 2017, 14:00–18:00

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Teaching Staff

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Material Allowed material is

- Chalmers-approved calculator
- L. Råde, B. Westergren. Beta, Mathematics Handbook, any edition.
- One A4 page with your own handwritten notes. Both sides of the page can be used. Photo copies, printouts, other students' notes, or any other material is not allowed.
- A paper-based dictionary, without added notes (electronic dictionaries are not allowed).

Grading A correct, clear and well-motivated solution gives a maximum of 12 points per problem.

An erroneous answer, unclear, incomplete or badly motivated solutions give point reductions down to a minimum of 0 points. No fractional points are awarded.

Answers in any other language than Swedish or English are ignored.

Solutions Are made available at the earliest at 19:00 on the course web page.

Results Exam results are posted on Ping-Pong no later than [*todo: March 29, 2017.*] The grading review is on [*todo: March 29 and April 5, 2017, 12:00–13:00 in room 6414 in the ED-building.*]

Grades The final grade on the course will be decided by the projects (maximum score 46), quizzes (maximum score 6), and final exam (maximum score 48). Project and exam must be passed (see course-PM for rules). The sum of all scores will decide the grade according to the following table.

Total Score	0–39	40–59	60–79	≥ 80
Grade	Fail	3	4	5

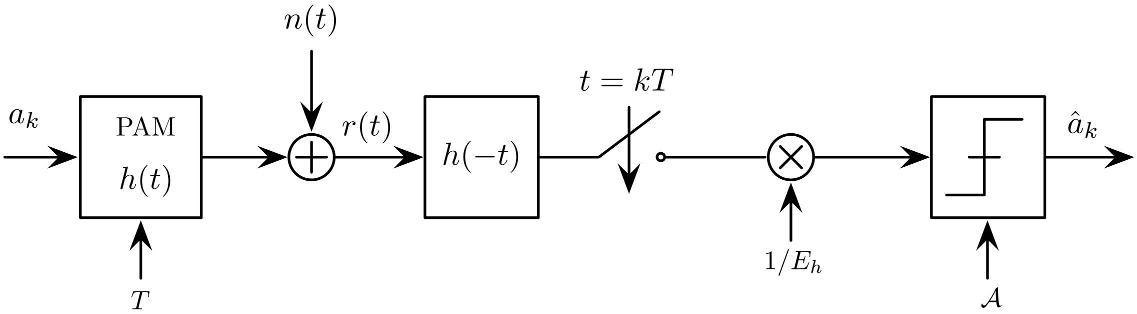
PLEASE NOTE THAT THE PROBLEMS ARE NOT NECESSARILY ORDERED IN DIFFICULTY.

Good luck!

Table over the Q-function

x	Q(x)	x	Q(x)	x	Q(x)	x	Q(x)	x	Q(x)	x	Q(x)	x	Q(x)	x	Q(x)
0.00	5.0000E-01	0.76	2.2360E-01	1.52	6.4260E-02	2.28	1.1300E-02	3.04	1.1830E-03	3.80	7.2350E-05	4.56	2.5580E-06	5.32	5.1880E-08
0.01	4.9600E-01	0.77	2.2060E-01	1.53	6.3010E-02	2.29	1.1010E-02	3.05	1.1440E-03	3.81	6.9480E-05	4.57	2.4390E-06	5.33	4.9110E-08
0.02	4.9200E-01	0.78	2.1770E-01	1.54	6.1780E-02	2.30	1.0720E-02	3.06	1.1070E-03	3.82	6.6730E-05	4.58	2.3250E-06	5.34	4.6470E-08
0.03	4.8800E-01	0.79	2.1480E-01	1.55	6.0570E-02	2.31	1.0440E-02	3.07	1.0700E-03	3.83	6.4070E-05	4.59	2.2160E-06	5.35	4.3980E-08
0.04	4.8400E-01	0.80	2.1190E-01	1.56	5.9380E-02	2.32	1.0170E-02	3.08	1.0350E-03	3.84	6.1520E-05	4.60	2.1120E-06	5.36	4.1610E-08
0.05	4.8010E-01	0.81	2.0900E-01	1.57	5.8210E-02	2.33	9.9030E-03	3.09	1.0010E-03	3.85	5.9060E-05	4.61	2.0130E-06	5.37	3.9370E-08
0.06	4.7610E-01	0.82	2.0610E-01	1.58	5.7050E-02	2.34	9.6420E-03	3.10	9.6760E-04	3.86	5.6690E-05	4.62	1.9190E-06	5.38	3.7240E-08
0.07	4.7210E-01	0.83	2.0330E-01	1.59	5.5920E-02	2.35	9.3870E-03	3.11	9.3540E-04	3.87	5.4420E-05	4.63	1.8280E-06	5.39	3.5230E-08
0.08	4.6810E-01	0.84	2.0050E-01	1.60	5.4800E-02	2.36	9.1370E-03	3.12	9.0430E-04	3.88	5.2230E-05	4.64	1.7420E-06	5.40	3.3320E-08
0.09	4.6410E-01	0.85	1.9770E-01	1.61	5.3700E-02	2.37	8.8940E-03	3.13	8.7400E-04	3.89	5.0120E-05	4.65	1.6600E-06	5.41	3.1510E-08
0.10	4.6020E-01	0.86	1.9490E-01	1.62	5.2620E-02	2.38	8.6560E-03	3.14	8.4470E-04	3.90	4.8100E-05	4.66	1.5810E-06	5.42	2.9800E-08
0.11	4.5620E-01	0.87	1.9220E-01	1.63	5.1550E-02	2.39	8.4240E-03	3.15	8.1640E-04	3.91	4.6150E-05	4.67	1.5060E-06	5.43	2.8180E-08
0.12	4.5220E-01	0.88	1.8940E-01	1.64	5.0500E-02	2.40	8.1980E-03	3.16	7.8880E-04	3.92	4.4270E-05	4.68	1.4340E-06	5.44	2.6640E-08
0.13	4.4830E-01	0.89	1.8670E-01	1.65	4.9470E-02	2.41	7.9760E-03	3.17	7.6220E-04	3.93	4.2470E-05	4.69	1.3660E-06	5.45	2.5180E-08
0.14	4.4430E-01	0.90	1.8410E-01	1.66	4.8460E-02	2.42	7.7600E-03	3.18	7.3640E-04	3.94	4.0740E-05	4.70	1.3010E-06	5.46	2.3810E-08
0.15	4.4040E-01	0.91	1.8140E-01	1.67	4.7460E-02	2.43	7.5490E-03	3.19	7.1140E-04	3.95	3.9080E-05	4.71	1.2390E-06	5.47	2.2500E-08
0.16	4.3640E-01	0.92	1.7880E-01	1.68	4.6480E-02	2.44	7.3440E-03	3.20	6.8710E-04	3.96	3.7470E-05	4.72	1.1790E-06	5.48	2.1270E-08
0.17	4.3250E-01	0.93	1.7620E-01	1.69	4.5510E-02	2.45	7.1430E-03	3.21	6.6370E-04	3.97	3.5940E-05	4.73	1.1230E-06	5.49	2.0100E-08
0.18	4.2860E-01	0.94	1.7360E-01	1.70	4.4570E-02	2.46	6.9470E-03	3.22	6.4100E-04	3.98	3.4460E-05	4.74	1.0690E-06	5.50	1.8990E-08
0.19	4.2470E-01	0.95	1.7110E-01	1.71	4.3630E-02	2.47	6.7560E-03	3.23	6.1900E-04	3.99	3.3040E-05	4.75	1.0170E-06	5.51	1.7940E-08
0.20	4.2070E-01	0.96	1.6850E-01	1.72	4.2720E-02	2.48	6.5690E-03	3.24	5.9760E-04	4.00	3.1670E-05	4.76	9.6800E-07	5.52	1.6950E-08
0.21	4.1680E-01	0.97	1.6600E-01	1.73	4.1820E-02	2.49	6.3870E-03	3.25	5.7700E-04	4.01	3.0360E-05	4.77	9.2110E-07	5.53	1.6010E-08
0.22	4.1290E-01	0.98	1.6350E-01	1.74	4.0930E-02	2.50	6.2100E-03	3.26	5.5710E-04	4.02	2.9100E-05	4.78	8.7650E-07	5.54	1.5120E-08
0.23	4.0900E-01	0.99	1.6110E-01	1.75	4.0060E-02	2.51	6.0370E-03	3.27	5.3770E-04	4.03	2.7890E-05	4.79	8.3390E-07	5.55	1.4280E-08
0.24	4.0520E-01	1.00	1.5870E-01	1.76	3.9200E-02	2.52	5.8680E-03	3.28	5.1900E-04	4.04	2.6730E-05	4.80	7.9330E-07	5.56	1.3490E-08
0.25	4.0130E-01	1.01	1.5620E-01	1.77	3.8360E-02	2.53	5.7030E-03	3.29	5.0090E-04	4.05	2.5610E-05	4.81	7.5470E-07	5.57	1.2740E-08
0.26	3.9740E-01	1.02	1.5390E-01	1.78	3.7540E-02	2.54	5.5430E-03	3.30	4.8340E-04	4.06	2.4540E-05	4.82	7.1780E-07	5.58	1.2030E-08
0.27	3.9360E-01	1.03	1.5150E-01	1.79	3.6730E-02	2.55	5.3860E-03	3.31	4.6650E-04	4.07	2.3510E-05	4.83	6.8270E-07	5.59	1.1350E-08
0.28	3.8970E-01	1.04	1.4920E-01	1.80	3.5930E-02	2.56	5.2340E-03	3.32	4.5010E-04	4.08	2.2520E-05	4.84	6.4920E-07	5.60	1.0720E-08
0.29	3.8590E-01	1.05	1.4690E-01	1.81	3.5150E-02	2.57	5.0850E-03	3.33	4.3420E-04	4.09	2.1570E-05	4.85	6.1730E-07	5.61	1.0120E-08
0.30	3.8210E-01	1.06	1.4460E-01	1.82	3.4380E-02	2.58	4.9400E-03	3.34	4.1890E-04	4.10	2.0660E-05	4.86	5.8690E-07	5.62	9.5480E-09
0.31	3.7830E-01	1.07	1.4230E-01	1.83	3.3620E-02	2.59	4.7990E-03	3.35	4.0410E-04	4.11	1.9780E-05	4.87	5.5800E-07	5.63	9.0100E-09
0.32	3.7450E-01	1.08	1.4010E-01	1.84	3.2880E-02	2.60	4.6610E-03	3.36	3.8970E-04	4.12	1.8940E-05	4.88	5.3040E-07	5.64	8.5030E-09
0.33	3.7070E-01	1.09	1.3790E-01	1.85	3.2160E-02	2.61	4.5270E-03	3.37	3.7580E-04	4.13	1.8140E-05	4.89	5.0420E-07	5.65	8.0220E-09
0.34	3.6690E-01	1.10	1.3570E-01	1.86	3.1440E-02	2.62	4.3960E-03	3.38	3.6240E-04	4.14	1.7370E-05	4.90	4.7920E-07	5.66	7.5690E-09
0.35	3.6320E-01	1.11	1.3350E-01	1.87	3.0740E-02	2.63	4.2690E-03	3.39	3.4950E-04	4.15	1.6620E-05	4.91	4.5540E-07	5.67	7.1400E-09
0.36	3.5940E-01	1.12	1.3140E-01	1.88	3.0050E-02	2.64	4.1450E-03	3.40	3.3690E-04	4.16	1.5910E-05	4.92	4.3270E-07	5.68	6.7350E-09
0.37	3.5570E-01	1.13	1.2920E-01	1.89	2.9380E-02	2.65	4.0250E-03	3.41	3.2480E-04	4.17	1.5230E-05	4.93	4.1110E-07	5.69	6.3520E-09
0.38	3.5200E-01	1.14	1.2710E-01	1.90	2.8720E-02	2.66	3.9070E-03	3.42	3.1310E-04	4.18	1.4580E-05	4.94	3.9060E-07	5.70	5.9900E-09
0.39	3.4830E-01	1.15	1.2510E-01	1.91	2.8070E-02	2.67	3.7930E-03	3.43	3.0180E-04	4.19	1.3950E-05	4.95	3.7110E-07	5.71	5.6490E-09
0.40	3.4460E-01	1.16	1.2300E-01	1.92	2.7430E-02	2.68	3.6810E-03	3.44	2.9090E-04	4.20	1.3350E-05	4.96	3.5250E-07	5.72	5.3260E-09
0.41	3.4090E-01	1.17	1.2100E-01	1.93	2.6800E-02	2.69	3.5730E-03	3.45	2.8030E-04	4.21	1.2770E-05	4.97	3.3480E-07	5.73	5.0220E-09
0.42	3.3720E-01	1.18	1.1900E-01	1.94	2.6190E-02	2.70	3.4670E-03	3.46	2.7010E-04	4.22	1.2220E-05	4.98	3.1790E-07	5.74	4.7340E-09
0.43	3.3360E-01	1.19	1.1700E-01	1.95	2.5590E-02	2.71	3.3640E-03	3.47	2.6020E-04	4.23	1.1680E-05	4.99	3.0190E-07	5.75	4.4620E-09
0.44	3.3000E-01	1.20	1.1510E-01	1.96	2.5000E-02	2.72	3.2640E-03	3.48	2.5070E-04	4.24	1.1180E-05	5.00	2.8670E-07	5.76	4.2060E-09
0.45	3.2640E-01	1.21	1.1310E-01	1.97	2.4420E-02	2.73	3.1670E-03	3.49	2.4150E-04	4.25	1.0690E-05	5.01	2.7220E-07	5.77	3.9640E-09
0.46	3.2280E-01	1.22	1.1120E-01	1.98	2.3850E-02	2.74	3.0720E-03	3.50	2.3260E-04	4.26	1.0220E-05	5.02	2.5840E-07	5.78	3.7350E-09
0.47	3.1920E-01	1.23	1.0930E-01	1.99	2.3300E-02	2.75	2.9800E-03	3.51	2.2410E-04	4.27	9.7740E-06	5.03	2.4520E-07	5.79	3.5190E-09
0.48	3.1560E-01	1.24	1.0750E-01	2.00	2.2750E-02	2.76	2.8900E-03	3.52	2.1580E-04	4.28	9.3450E-06	5.04	2.3280E-07	5.80	3.3160E-09
0.49	3.1210E-01	1.25	1.0560E-01	2.01	2.2220E-02	2.77	2.8030E-03	3.53	2.0780E-04	4.29	8.9340E-06	5.05	2.2090E-07	5.81	3.1240E-09
0.50	3.0850E-01	1.26	1.0380E-01	2.02	2.1690E-02	2.78	2.7180E-03	3.54	2.0010E-04	4.30	8.5400E-06	5.06	2.0960E-07	5.82	2.9420E-09
0.51	3.0500E-01	1.27	1.0200E-01	2.03	2.1180E-02	2.79	2.6350E-03	3.55	1.9260E-04	4.31	8.1630E-06	5.07	1.9890E-07	5.83	2.7710E-09
0.52	3.0150E-01	1.28	1.0030E-01	2.04	2.0680E-02	2.80	2.5550E-03	3.56	1.8540E-04	4.32	7.8010E-06	5.08	1.8870E-07	5.84	2.6100E-09
0.53	2.9810E-01	1.29	9.8530E-02	2.05	2.0180E-02	2.81	2.4770E-03	3.57	1.7850E-04	4.33	7.4550E-06	5.09	1.7900E-07	5.85	2.4580E-09
0.54	2.9460E-01	1.30	9.6800E-02	2.06	1.9700E-02	2.82	2.4010E-03	3.58	1.7180E-04	4.34	7.1240E-06	5.10	1.6980E-07	5.86	2.3140E-09
0.55	2.9120E-01	1.31	9.5100E-02	2.07	1.9230E-02	2.83	2.3270E-03	3.59	1.6530E-04	4.35	6.8070E-06	5.11	1.6110E-07	5.87	2.1790E-09
0.56	2.8770E-01	1.32	9.3420E-02	2.08	1.8760E-02	2.84	2.2560E-03	3.60	1.5910E-04	4.36	6.5030E-06	5.12	1.5280E-07	5.88	2.0510E-09
0.57	2.8430E-01	1.33	9.1760E-02	2.09	1.8310E-02	2.85	2.1860E-03	3.61	1.5310E-04	4.37	6.2120E-06	5.13	1.4490E-07	5.89	1.9310E-09
0.58	2.8100E-01	1.34	9.0120E-02	2.10	1.7860E-02	2.86	2.1180E-03	3.62	1.4730E-04	4.38	5.9340E-06	5.14	1.3740E-07	5.90	1.8180E-09
0.59	2.7760E-01	1.35	8.8510E-02	2.11	1.7430E-02	2.87	2.0520E-03	3.63	1.4170E-04	4.39	5.6680E-06	5.15	1.3020E-07	5.91	1.7110E-09
0.60	2.7430E-01	1.36	8.6910E-02	2.12	1.7000E-02	2.88	1.9880E-03	3.64	1.3630E-04	4.40	5.4130E-06	5.16	1.2350E-07	5.92	1.6100E-09
0.61	2.7090E-01	1.37	8.5340E-02	2.13	1.6590E-02	2.89	1.9260E-03	3.65	1.3110E-04	4.41	5.1690E-06	5.17	1.1700E-07	5.93	1.5150E-09
0.62	2.6760E-01	1.38	8.3790E-02	2.14	1.6180E-02	2.90	1.8660E-03	3.66	1.2610E-04	4.42	4.9350E-06	5.18	1.1090E-07	5.94	1.4250E-09
0.63	2.6430E-01	1.39	8.2260E-02	2.15	1.5780E-02	2.91	1.8070E-03	3.67	1.2130E-04	4.43	4.7120E-06	5.19	1.0510E-07	5.95	1.3410E-09
0.64	2.6110E-01	1.40	8.0760E-02	2.16	1.5390E-02	2.92	1.7500E-03	3.68	1.1660E-04	4.44	4.4980E-06	5.20	9.9640E-08	5.96	1.2610E-09
0.65	2.5780E-01	1.41	7.9270E-02	2.17	1.5000E-02	2.93	1.6950E-03	3.69	1.1210E-04	4.45	4.2940E-06	5.21	9.4420E-08	5.97	1.1860E-09
0.66	2.5460E-01	1.42	7.7800E-02	2.18	1.4630E-02	2.94	1.6410E-03	3.70	1.0780E-04	4.46	4.0980E-06	5.22	8.9460E-08	5.98	1.1160E-09
0.67	2.5140E-01	1.43	7.6360E-02	2.19	1.4260E-02	2.95	1.5890E-03	3.71	1.0360E-04	4.47	3.9110E-06	5.23	8.4760E-08	5.99	1.0490E-09
0.68	2.4830E-01	1.44	7.4930E-02	2.20	1.3900E-02	2.96	1.5380E-03	3.72	9.9610E-05	4.48	3.7320E-06	5.24	8.0290E-08	6.00	9.8660E-10
0.69	2.4510E-01	1.45	7.3530E-02	2.21	1.3550E-02	2.97	1.4890E-03	3.73	9.5740E-05	4.49	3.5610E-06	5.25	7.6050E-08	6.01	9.2760E-10
0.70	2.4200E-01	1.46	7.2150E-02	2.22	1.3210E-02	2.98	1.4410E-03	3.74	9.2010E-05	4.50	3.3980E-06	5.26	7.2030E-08	6.02	8.7210E-10
0.71	2.3890E-01	1.47	7.0780E-02	2.23	1.2870E-02	2.99	1.3950E-03	3.75	8.8420E-05	4.51	3.2410E-06	5.27	6.8210E-08	6.03	8.1980E-10
0.72	2.3580E-01	1.48	6.9440E-02	2.24	1.2550E-02	3.00	1.3500E-03	3.76	8.4960E-05	4.52	3.0920E-06	5.28	6.4590E-08	6.04	7.7060E-10
0.73	2.3270E-01	1.49	6.8110E-02	2.25	1.2220E-02	3.01	1.3060E-03	3.77	8.1620E-05	4.53	2.9490E-06	5.29	6.1160E-08	6.05	7.2420E-10
0.74	2.2960E-01	1.50	6.6810E-02	2.26	1.1910E-02	3.02	1.2640E-03	3.78	7.8410E-05	4.54	2.8130E-06	5.30	5.7900E-08	6.06	6.8060E-10
0.75	2.2660E-01	1.51	6.5520E-02	2.27	1.1600E-02	3.03	1.2230E-03	3.79	7.5320E-05	4.55	2.6820E-06	5.31	5.4810E-08	6.07	6.3960E-10

1. Consider transmission of equally likely independent bits using PAM over an AWGN channel with noise power spectral density $N_0/2$, with a matched filter receiver:



We require that transmission is ISI-free and that the pulse shape $h(t)$ is bandlimited to W Hz. As usual, the energy of $h(t)$ is denoted by E_h. The modulation alphabet is $\mathcal{A} = \{A_1, A_2, \ldots, A_M\}$, where $A_k = (k-1)2c$.

(a) Give a combination of $h(t)$, T, and M such that the data rate is equal to 1 Mbit/s for $W = 1$ MHz. (1p)

(b) Repeat Part (a) for $W = 0.5$ MHz. (1p)

(c) Repeat Part (a) for $W = 0.25$ MHz. (1p)

(d) Repeat Part (a) for $W = 2$ MHz. (1p)

(e) Give an expression for the constellation energy in c and M. Hint: the expression for the standard PAM constellation $\{\pm c, \pm 3c, \ldots, \pm(M-1)c\}$ is $c^2(M^2-1)/3$. (4p)

(f) Suppose the data rate is 1 Mbit/s, transmit power is $P = 1.65 \times 10^{-13}$ W and $N_0 = 1.10 \times 10^{-20}$ W/Hz. Compute the symbol error probability for $M = 4$. (4p)

solution:

(a)

$$
\begin{aligned}
R_b &= \frac{2W}{1+\alpha} \times \log_2(M) \\
\log_2(M) &= \frac{(1+\alpha)R_b}{2W}
\end{aligned}
$$

By substituting $W = 1$ MHz, and $R_b = 1$ Mbit/s, we have

$$0.5 \leq \log_2(M) = \frac{1+\alpha}{2} \leq 1$$

Therefore, we can choose $M = 2$, $\alpha = 1$, $T = \frac{1+\alpha}{2W} = 10^{-6}s$, and $h(t)$ is root raised cosine pulse.

(b) By substituting $W = 0.5$ MHz, and $R_b = 1$ Mbit/s, we have

$$1 \leq \log_2(M) = 1 + \alpha \leq 2$$

Therefore, we can choose $M = 2$, $\alpha = 0$, $T = \frac{1+\alpha}{2W} = 10^{-6}s$ or $M = 4$, $\alpha = 1$, $T = \frac{1+\alpha}{2W} = 2 \times 10^{-6}s$, and $h(t)$ is root raised cosine pulse.

(c) By substituting $W = 0.25\,\text{MHz}$, and $R_b = 1\,\text{Mbit/s}$, we have

$$2 \leq \log_2(M) = 2(1+\alpha) \leq 4$$

Therefore, we can choose $M = 4$, $\alpha = 0$, $T = \frac{1+\alpha}{2W} = 2 \times 10^{-6}s$ or $M = 8$, $\alpha = 0.5$, $T = \frac{1+\alpha}{2W} = 3 \times 10^{-6}s$, or $M = 16$, $\alpha = 1$, $T = \frac{1+\alpha}{2W} = 4 \times 10^{-6}s$, and $h(t)$ is root raised cosine pulse.

(d) By substituting $W = 2\,\text{MHz}$, and $R_b = 1\,\text{Mbit/s}$, we have

$$0.25 \leq \log_2(M) = \frac{1+\alpha}{4} \leq 0.5$$

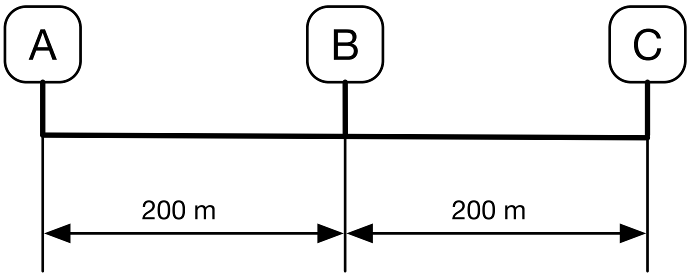
Therefore, there is no possible value for M.

(e) We assume that the symbols are equiprobable.

$$\begin{aligned}
E_a &= \mathbb{E}[A^2] \\
&= \sum_{a \in \mathcal{A}} a^2 p_A(a) \\
&= \frac{1}{M} \sum_{a \in \mathcal{A}} a^2 \\
&= \frac{1}{M} \sum_{k=1}^{M} A_k^2 \\
&= \frac{1}{M} \sum_{k=1}^{M} \left(2c\,(k-1)\right)^2 \\
&= \frac{4c^2}{M} \sum_{k=1}^{M} (k-1)^2 \\
&= \frac{4c^2}{M} \sum_{k=1}^{M-1} k^2 \\
&= \frac{4c^2}{M} \times \frac{M(M-1)(2M-1)}{6} \\
&= \frac{2c^2(M-1)(2M-1)}{3}.
\end{aligned}$$

(f) The probability of symbol error for M-PAM is $\frac{2(M-1)}{M} Q(\frac{c}{\sigma})$. For $M = 4$, the average energy of symbols is $E_a = 14c^2$. Moreover, we know that, $E_a E_h = P \times T = 3.3 \times 10^{-19}$. As a result, $c = \sqrt{\frac{3.3 \times 10^{-19}}{14 E_h}} = \frac{1.535 \times 10^{-10}}{\sqrt{E_h}}$, and $\sigma = \sqrt{\frac{N_0}{2E_h}} = \sqrt{\frac{1.1 \times 10^{-20}}{2E_h}} = \frac{7.4162 \times 10^{-11}}{E_h}$. Thus $P_e = \frac{3}{2} Q(\frac{1.535 \times 10^{-10}}{7.4162 \times 10^{-11}}) = 1.5 \times Q(2.07) = 1.5 \times 1.923 \times 10^{-2} = 2.885 \times 10^{-2}$.

2. Consider a LAN with three stations: A, B, and C.



The propagation speed is $(2/3)c_0$, where $c_0 = 3 \times 10^8$ m/s and the LAN data rate is 1 Gbit/s. Suppose the stations transmit 750 byte frames.

Suppose that the MAC layer in station A receives a frame for transmission by its upper layer at time $t = t_A = 0$. The MAC layers in stations B and C similarly receive frames from their respective higher layers at times $t_B = t_C = 1.5\,\mu$s. If used by the MAC protocol, assume that carrier sensing and collision detection takes negligible time and that the timeout is 4 frame durations.

(a) Suppose the MAC layer use Aloha for medium access. Draw a timing diagram for each station and indicate when all relevant events (start and stop of transmitted and received frames, carrier sensing, start of backoffs, etc.) occur. Make sure to label the time axis such that the time when events occur is clear. (4p)

(b) Repeat Part (a) for persistent CSMA. (4p)

(c) Repeat Part (a) for persistent CSMA/CD. (4p)

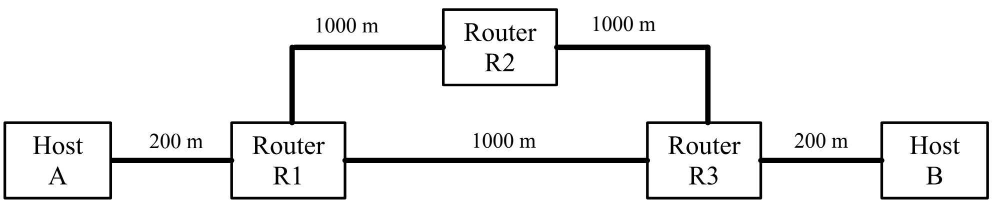
3. (a) Compare symmetric and asymmetric cryptography. What are the advantages and disadvantages with them? (3p)

   (b) What is characteristic of an end-to-end protocol? Give an example of a TCP/IP protocols that is an end-to-end protocol. Give an example of a TCP/IP protocols that is not an end-to-end protocol. (3p)

   (c) Explain why systematic codes are easy to use for error detection. (3p)

   (d) Give at least three examples of challenges (i.e., problems) that eHealth can provide solutions to. (3p)

4. Consider transmission of data from end-nodes A and B over network depicted below.



Suppose we want to design an application layer protocol that use an ARQ protocol to provide a reliable, in-sequence transmission service of 1000 byte SDUs. The transmission is done over UDP, IP, and Ethernet.

The application layer protocol header is 25 byte and the ACK PDU is also 25 byte. Furthermore, we assume that the IP header is 20 byte, the UDP header is 8 byte, and that the Ethernet header and trailer is 22 byte and 4 byte, respectively.

The routers are store-and-forward routers. The links are full-duplex links with a line data rate of 100 Mbit/s. The length of each link segment is indicated in the figure and we assume that the link propagation speed is $(2/3)c_0$, where $c_0 = 3 \times 10^8$ m/s. The processing time in the hosts and routers is assumed to be negligible.

(a) Sketch the layout of the Ethernet frames carrying the application layer data SDUs. That is, indicate the order and length the different protocol elements (headers, trailers, payloads, etc.) that make up the frame. (1p)

(b) Repeat Part (a) for the application layer ACK PDUs. (1p)

(c) Suppose we use Stop-and-Wait ARQ (for the application layer protocol). What would be a good value for the time-out if Route 1 = (A—R1—R3—B) is used? Motivate. Repeat for Route 2 = (A—R1—R2—R3—B). (4p)

(d) Suppose the application layer does not know which route is used. What would be a good value for the time-out? Motivate. (2p)

(e) Suppose that, on the average, 50% of the packets are transmitted over Route 1 and 50% of the packets over Route 2. What is the effective data rate of the application layer service? Use the timeout value from Part (d) and assume that transmission is error-free. (4p)

$\boxed{P2}$

$V = \frac{2}{3} c_0 = 2 \times 10^8 \, m/s$

$R = 10^9 \, bit/s$

$n_f = 750 \times 8 \, bit$

t_f - frame duration

$t_f = \frac{n_f}{R} = 6 \, \mu s$

$t_{ad} = 4 \, t_f = 24 \, \mu s$

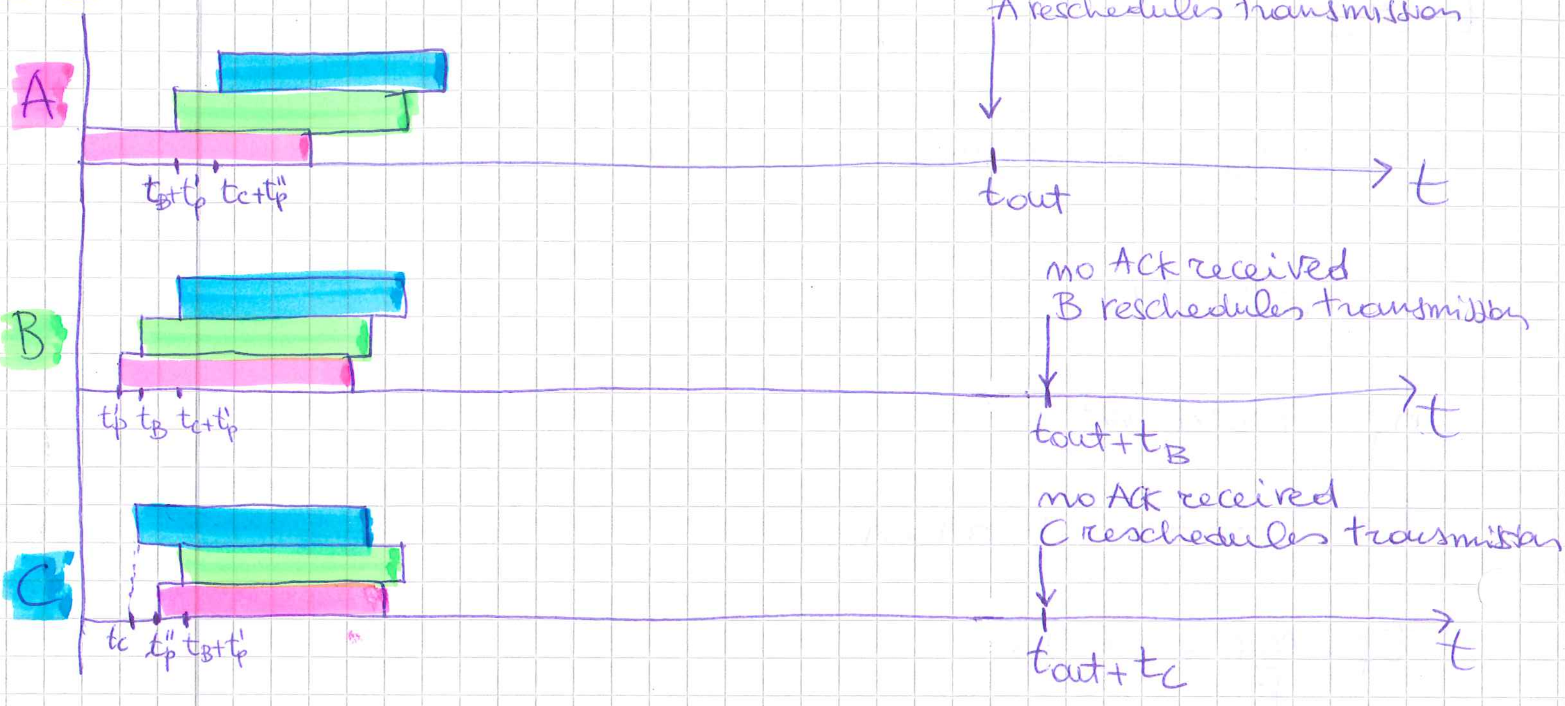
t_p' = propogation time betwem A and B and B and C

t_p'' = propogation time between A and C

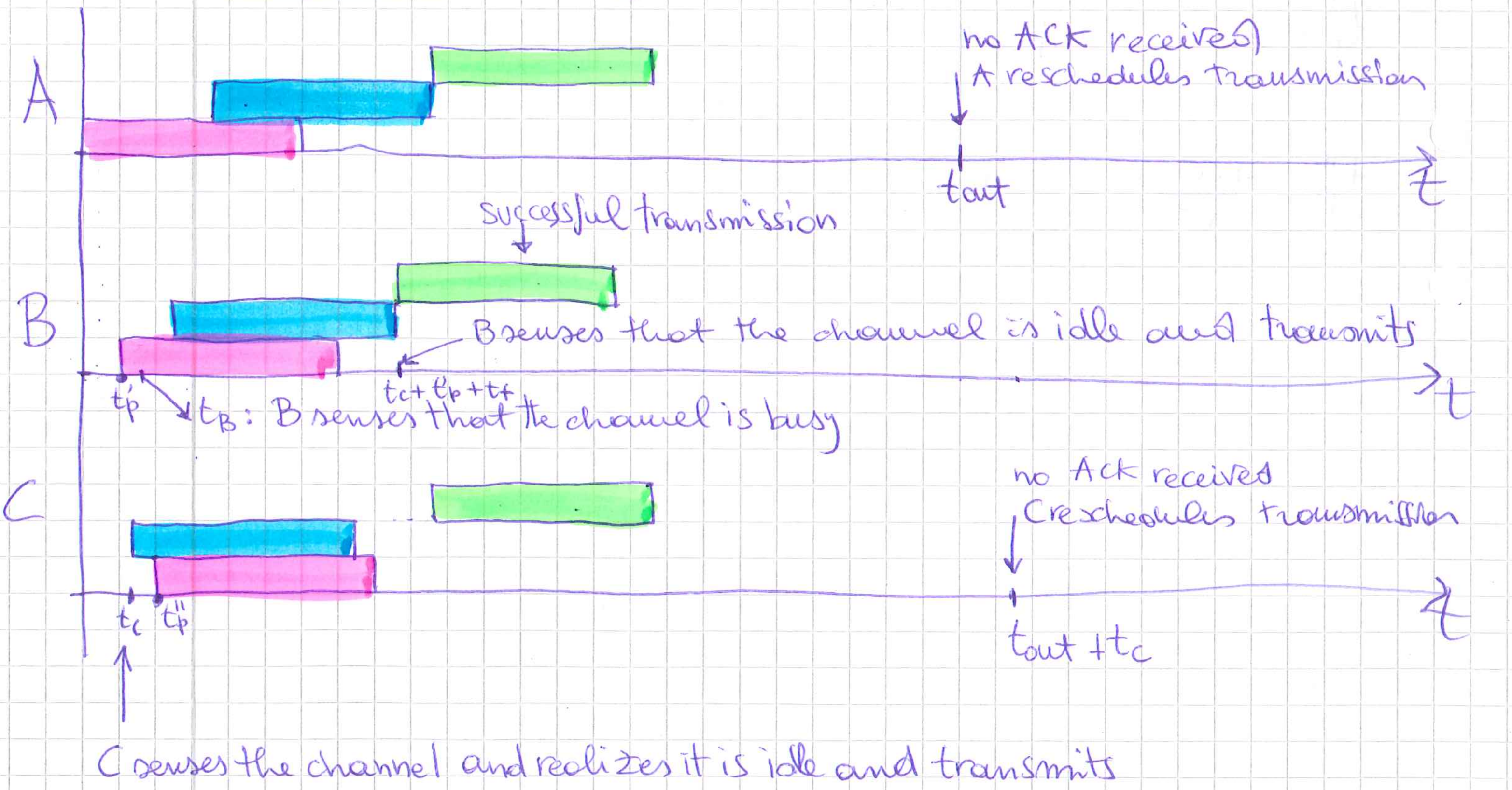
$t_p' = \frac{200 m}{v} = 1 \, \mu s$

$t_p'' = \frac{400 m}{v} = 2 \, \mu s$

(a) ALOHA

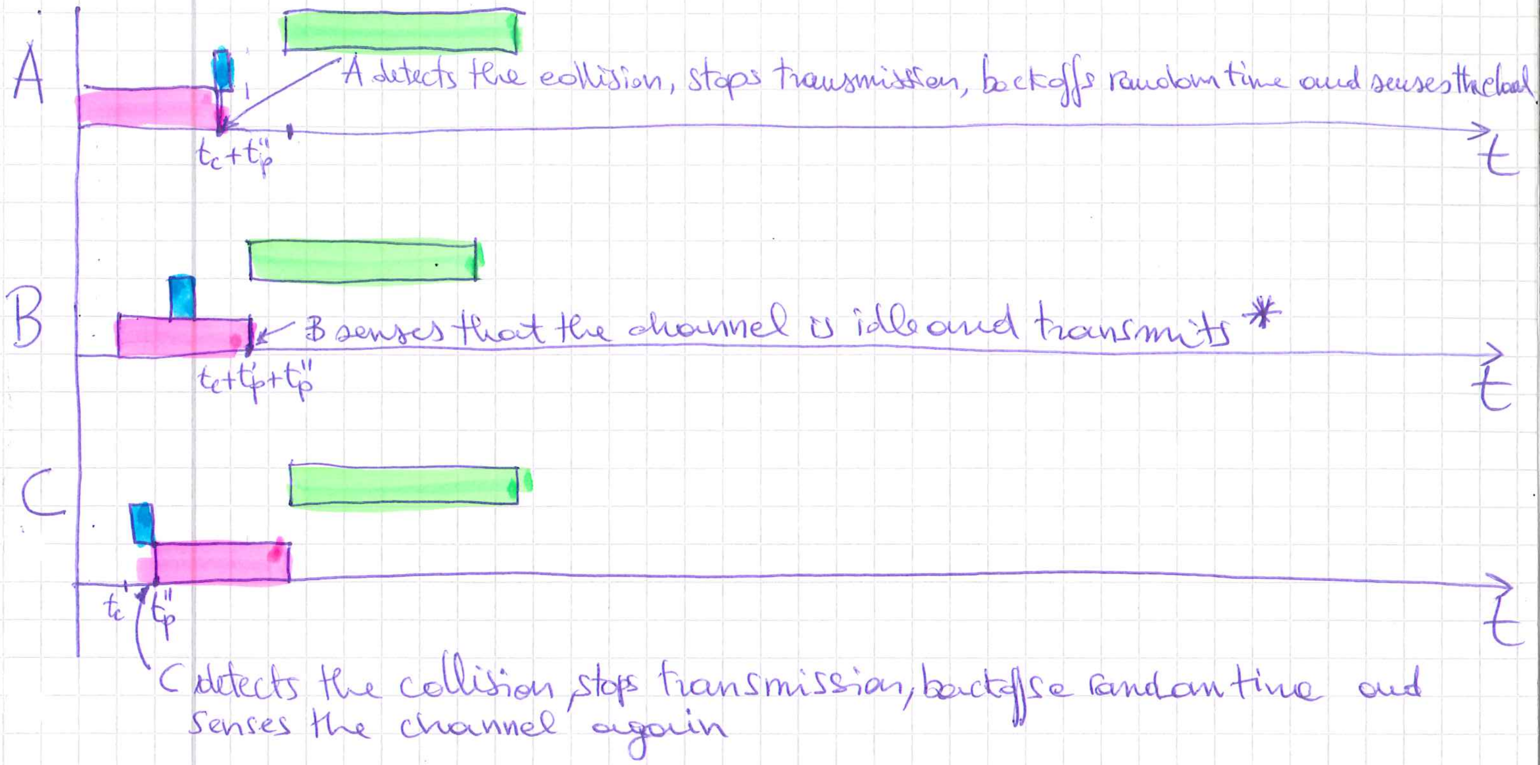


(b) PERSISTENT CSMA



P2, 2

(c) PERSISTENT CSMA/CD



* We assume that A senses again the channel after $t_c+t_p''+t_p'+0.5\,\mu s$

(4)

$m_f = 1000$ byte   ACK PDU = 25 byte

AH = 25 byte

IH = 20 byte

UH = 8 byte

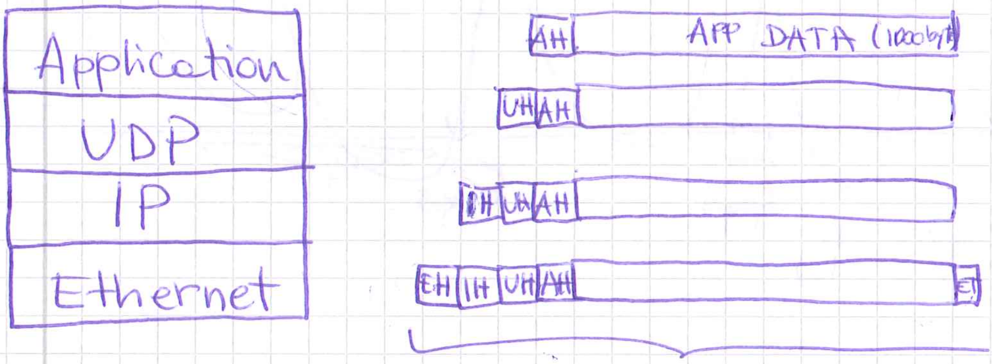
EH = 22 byte

ET = 4 byte

$R = 10^8$ bit/s

$v = 2/3\, c_0 = 2 \times 10^8$ m/s

(a)



1079 byte

(b)

Since the ACK PDU is 25 byte and the AH is 25 byte, the ACK payload is composed only by the AH for the application layer. Then we add the UDP header, the IP header, the Ethernet header and trailer

(c) $t_f = \frac{M_f + M_o}{R} = \frac{1079 \times 8}{10^8} = 8,632 \times 10^{-5}$ s

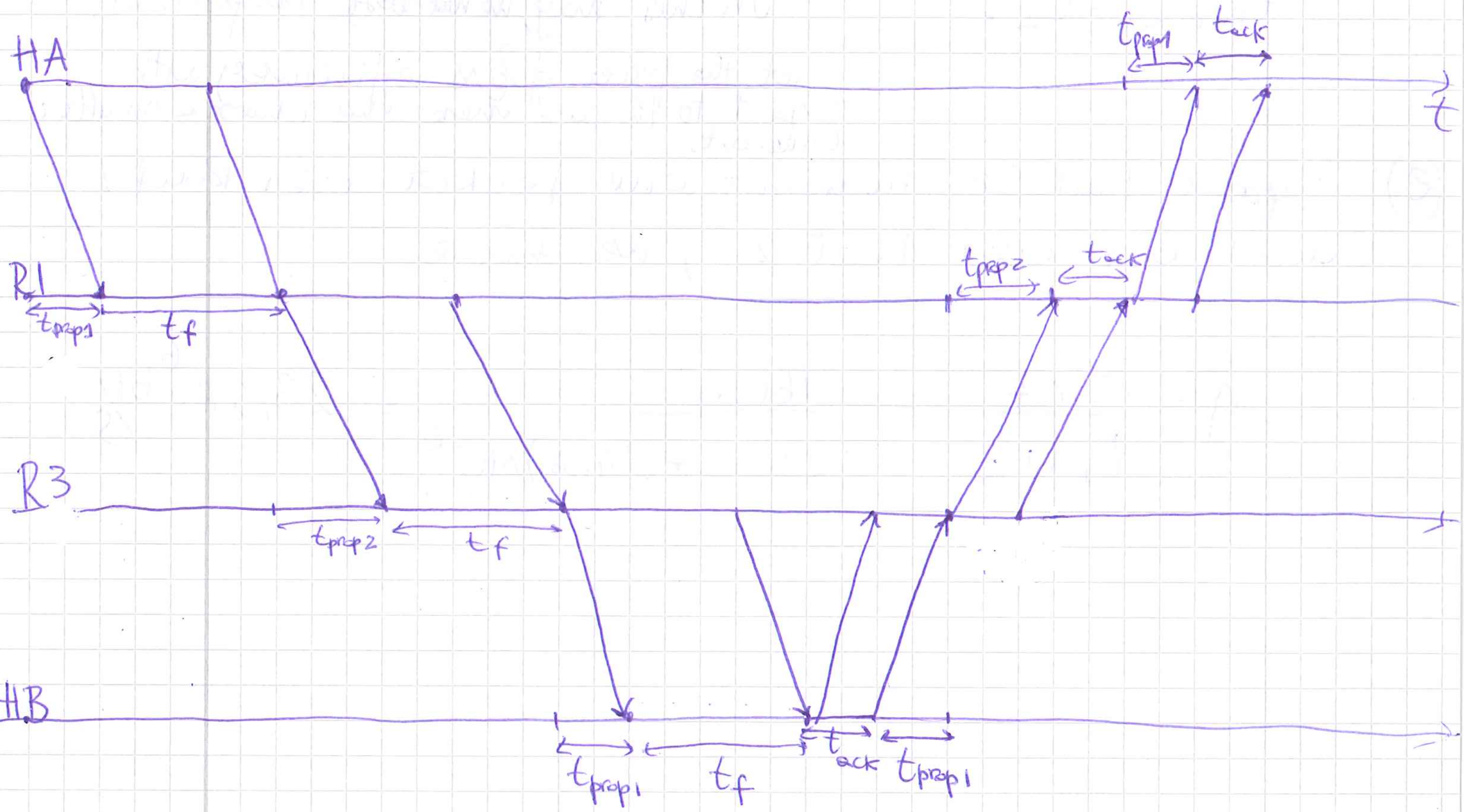
$t_{ack} = \frac{79 \cdot 8}{R} = 6,32 \times 10^{-6}$ s

$d_1 = 200$ m , $d_2 = 1000$ m

$t_{prop1} = \frac{d_1}{c} = 10^{-6}$ s , $t_{prop2} = 5 \times 10^{-6}$ s

We compute the time between the transmission of the first bit and the reception of the ACK.

ROUTE 1 : A - R1 - R3 - B



$t_{trans} = 3t_f + 2t_{prop1} + t_{prop2} = (3 \cdot 86,32 + 2 + 5) \times 10^{-6}$ s $= 265,96 \times 10^{-6}$

$t_{transack} = 3t_{ack} + 2t_{prop_1} + t_{prop_2} = (3 \cdot 6,32 + 2 + 5) \times 10^{-6}$ s $= 25,96 \times 10^{-6}$ s

$t_1 = t_{trans} + t_{transack} = 291,92 \times 10^{-6}$ s

$t_{time\text{-}out} = t_1$

ROUTE 2 : A - R1 - R2 - R3 - B

$t_{trans} = 4 t_f + 2 t_{prop_1} + 2 t_{prop_2} = (4 \cdot 86{,}32 + 2 + 10) \times 10^{-6} s = 357{,}28 \times 10^{-6} s$

$t_{transack} = 4 t_{ack} + 2 t_{prop_1} + 2 t_{prop_2} = (4 \cdot 6{,}32 + 2 + 10) \times 10^{-6} s = 37{,}28 \times 10^{-6} s$

$t_2 = t_{trans} + t_{transack} = 394{,}56 \times 10^{-6} s$

$t_{time\text{-}out} = t_2$

(d) ~~We~~ can choose the maximum between the time-out for route 1 and that for route 2

$t_{time\text{-}out} = t_2$.

In this way, we have less congestion, at the price of less efficiency with respect to the case where we chose a smaller time-out.

(e) Suppose that we transmit one packet over Route 1 and one over Route 2, we have

$$\eta = \frac{2 n_f}{t_1 + t_2} = \frac{16000}{(281{,}92 + 394{,}56) \times 10^{-6}} = 23{,}3 \times 10^{6} \text{ bit/s}$$