Exam in
SSY305 Kommunikationssystem

Department of Signals and Systems

Exam date: April 8, 2016, 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 April 12, 2016. The grading review is on April 13 and April 20, 2016, 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.

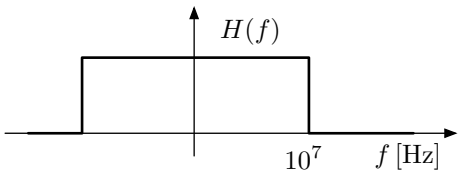
Total Score	0–39	40–59	60–79	≥ 80
Grade	Fail	3	4	5

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 over an AWGN channel with frequency response $H(f)$ and noise power spectral density $N_0/2$, where $N_0 = 1.10 \times 10^{-20}\,\mathrm{W/Hz}$.



   (a) Propose a modulation format for ISI-free transmission of $R_b = 18\,\mathrm{Mbit/s}$. Specify the constellation and pulse shape. (3p)

   (b) What average received power is required to achieve a frame error probability of 10^{-3} when transmitting 1200 byte long frames? (4p)

   (c) Suppose we transmit frames with a Stop-and-Wait link layer protocol. Assume that the propagation delay and processing delay is together 0.5 ms, the ACK frames are 25 byte long, and the protocol overhead (header, trailer) in the data frame is 50 byte. The time-out is set to maximize the effective data rate. Assume that ACKs are always transmitted error-free. If the physical layer specified in (b) is used, what is the effective data rate for the layer above the link layer? (3p)

   (d) Suppose we want to improve the effective data rate by replacing the ARQ protocol. Which ARQ protocol would be a good choice? Motivate. (2p)

2. (a) Explain what the hidden terminal problem is. Explain the mechanism that can be used in 802.11 to mitigate the hidden terminal problem. (4p)

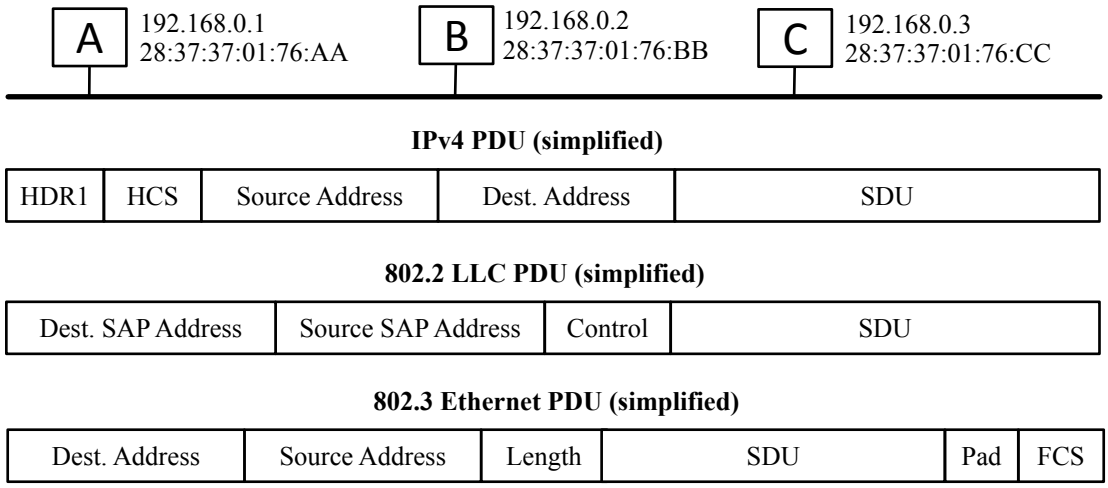
   (b) What is the purpose of the physical layer in the OSI reference model? (2p)

   (c) Give an example of an application layer protocol in the TCP/IP reference model. (2p)

   (d) What is the purpose of the modulator block in Shannon's model for digital communications? (2p)

   (e) Consider a $(n = 7, k = 4)$ code $\mathcal{C} = \{\mathbf{c}_0, \mathbf{c}_1, \ldots\}$ with minimum distance $d_{\min} = 3$ that is used for error-detection. Suppose the received word is $\mathbf{y} = \mathbf{c} \oplus \mathbf{e}$. How many bit error are guaranteed to be detected by the receiver? Motivate. (2p)

3. Consider three hosts, A, B, and C, that are connected to the same Ethernet LAN. The hosts exchange IP packets over an 802 stack consisting of an 802.2 LLC layer and an 802.3 Ethernet layer. The PDU structures are depicted below.



The IPv4 header consists of the 12-byte HDR1 field, the 2-byte HCS (header check sum) field, and addresses. The header check sum is the Internet checksum computed over the bits that made up by the HDR1 and address fields.

The LLC header consists of destination and source SAP addresses and a control field. An incomplete list SAP addresses is found in the table below.

SAP Address	Meaning
02	Individual LLC Sublayer Mgt
03	Group LLC Sublayer Mgt
04	SNA Path Control (individual)
05	SNA Path Control (group)
06	Internet Protocol
0E	ProWay-LAN

The Ethernet header consist of address fields and a length field. The trailer consist of a Pad fields and the frame check sum (i.e., the check bits from a CRC-32 computed over the entire PDU). The Pad field consist of a number of null bytes (0x00) such that the SDU plus Pad fields is at least 46 bytes long. The Pad field is empty if no padding is necessary.

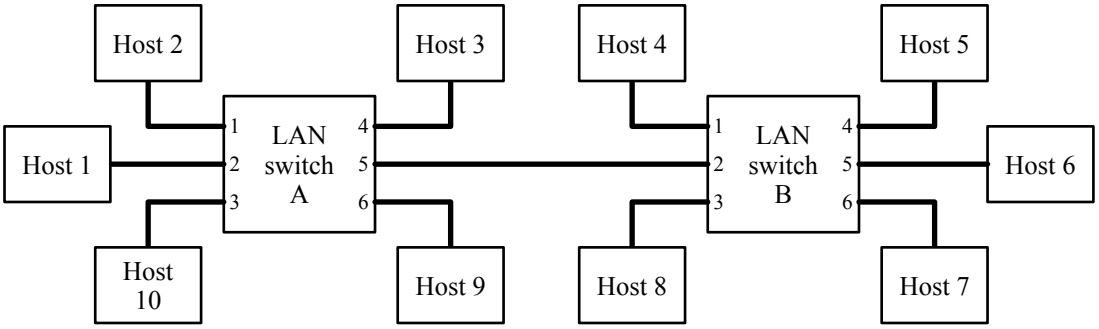
(a) Why is there a Pad field in the Ethernet frame? That is, why must short SDUs be padded? (2p)

(b) Suppose Host A wants to transmit an IP packet to Host B. What is the content of the address fields in the IP, LLC, and Ethernet PDUs? (3p)

(c) Suppose that during transmission, a single bit is flipped in the Ethernet PDU. Depending on the position of the bit error, explain the possible actions that can be taken by the Ethernet layer at Host B. (3p)

(d) Describe a possible scenario in which the Host B IP layer will receive an erroneous packet. In this situation, explain the possible actions that would be taken by the IP layer at Host B. (4p)

4. Consider the following network in which 10 hosts are connected together via two LAN-switches (transparant bridges). The transmission cables (marked with bold lines) support 100 Mbit/s full duplex transmission and are each 100 m long. The propagation speed in the cables is $c = 2c_0/3$, where $c_0 = 3 \times 10^8$ m/s. The switches operate in store-and-forward mode. That is, an incoming frame is completely received before it is forwarded to the corresponding output port. Assume that the processing times in the switches and hosts are negligible. The number next to the transmission cable attachement is the LAN switch port number.



(a) Suppose the only data traffic is from Host 1 and Host 6. We define the transmission time as the time it takes from when the first bit of the transmitted packet leaves Host 1 until the final bit of the transmitted packet has reached Host 6. What is the transmission time for a 1500 byte long packet? (4p)

(b) Suppose we want to implement a link-layer ARQ protocol. If the ACK packets are 25 byte long, what is a suitable timeout duration for the traffic situation in part (a)? Motivate. (4p)

(c) The routing tables in the LAN switches is the form

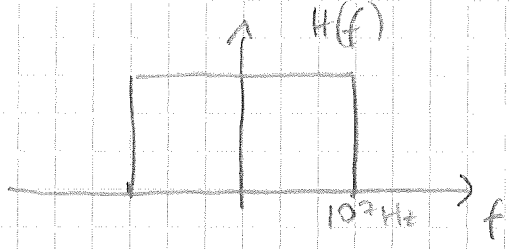
Destination Address	**Output Port**
a	x
b	y
$\vdots$	$\vdots$

That is, when the LAN switch receives a frame with destination address a it forwards the frame to port x, etc. Suppose the LAN switches are powered up at time $t = 0$, which implies that the routing tables are empty. Explain how the tables in LAN switch A and B change for each of the following transmissions.

Time t [s]	**Source Host**	**Destination Host**
1	1	6
2	1	2
3	5	6
4	5	1
5	2	5

Assume that backwards learning is used. (4p)

(P1)



→ bandlimited channel (f(0))

$B = 10^7$ Hz = 10 MHz

B: bandwidth of channel

a) for a bandlimited channel we use a bandlimited pulse shape

→ choose RC-pulse as overall pulse shape!

$R_s = \frac{2W}{1+\alpha}$ $\quad \max W = B \quad 0 \leq \alpha \leq 1$

→ choose M-PAM: $R_b = R_s \cdot \log_2(M) = 18 \cdot 10^6$ bit/s

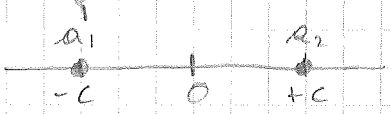
$$\frac{18 \cdot 10^6}{\log_2(M)} \leq \frac{20 \cdot 10^6}{(1+\alpha)}$$

$$\frac{9}{10} \leq \frac{\log_2(M)}{(1+\alpha)}$$

→ for M=2: $\frac{9}{10} \leq \frac{1}{1+\alpha} \Rightarrow \alpha \leq \frac{1}{9}$

⇒ RC-pulse with $\alpha = \frac{1}{9}$ and 2-PAM

constellation:



b) $n_f = 1200$ byte $= 9600$ bit

$P_f = 10^{-3}$

$P_f = 1-(1-P_e)^{\frac{n_f}{\log_2(M)}} = 1-(1-P_e)^{n_f}$ (for 2-PAM)

$\rightarrow P_e = 1 - \sqrt[n_f]{1-P_f} = 1.0422 \cdot 10^{-7}$

$$P_e = \frac{2(M-1)}{M} Q\left(\sqrt{\frac{6}{M^2-1}\frac{E_s}{N_0}}\right) = Q\left(\sqrt{\frac{2E_s}{N_0}}\right) = 1.0422 \cdot 10^{-7}$$

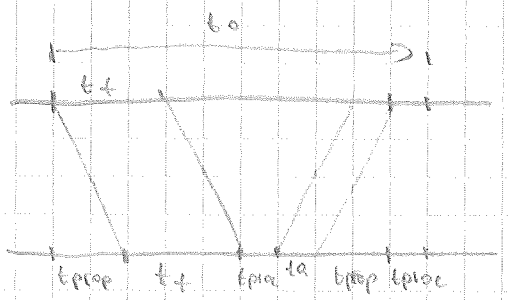
$\Rightarrow \sqrt{\frac{2E_s}{N_0}} = 5.1917 \rightarrow E_s = (5.1917)^2 \cdot \frac{N_0}{2} = 1.4824 \cdot 10^{-19}$ Ws

$P = \frac{E_s}{T} = E_s \cdot R_s = E_s \cdot \frac{20 \cdot 10^6}{(1+\frac{1}{9})} = 2.6684 \cdot 10^{-12}$ W

c) $n_a = 25\,\text{byte} = 200\,\text{bit}$

$n_f = 9600\,\text{bit}$

$n_o = 80\,\text{byte} = 400\,\text{bit}$



$t_{prop} + t_{proc} = 0.5\,\text{ms} = 0.5 \cdot 10^{-3}\,\text{s}$

$t_0 = t_f + t_a + 2(t_{prop} + t_{proc})$

$= \frac{n_f}{R_b} + \frac{n_a}{R_b} + 10^{-3} = 0.0015\,\text{s}$

$\text{Reff}_{NW} = \frac{n_f - n_o}{t_{SW}}$

$= \frac{n_f - n_o}{t_0}(1 - P_f)$

$= 5.9509\,\text{Mbit/s}$

$t_{SW} = t_0 + \frac{t_{out} P_f}{(1-P_f)}$

$\Rightarrow t_{out} = t_0$ for maximize Reff

$= \frac{t_0}{(1-P_f)}$

d) Reff for go-back-N:

$\text{Reff}_{GBN} = \frac{n_f - n_o}{t_{GBN}}$

$= 17.198\,\text{Mbit/s}$

$t_{GBN} = t_f \left(1 + \frac{P_f W_s}{1-P_f}\right)$

W_s > delay-bandwidth product / n_f

$W_s > 2(t_{prop} + t_{proc}) \cdot \frac{R}{n_f}$

$\Rightarrow W_s = 2$

Reff for selective repeat:

$\text{Reff}_{SR} = \frac{n_f - n_o}{t_{SR}}$

$= 17.2328\,\text{Mbit/s}$

$t_{SR} = \frac{t_f}{1-P_f}$

→ The best Reff for this system can be achieved with selective-repeat ARQ. However, the difference between go-back-N and selective-repeat ARQ is very small. Considering that the complexity for go-back-N is smaller, both ARQ protocols could be considered as good choices.

Problem 2

a) The hidden terminal problem in wireless networks is when one (or more) terminals within the range of an access point are out-of-range of one or more other terminals. Problems occur when terminals that are hidden from each other want to transmit to the access point at the same time. Terminals that are out of range of each other cannot sense each other's transmissions. This means that the medium can appear to be idle to hidden stations even though it is not and that these stations cannot detect collisions. IEEE 802.11 (optionally) uses RTS/CTS messages to mitigate the hidden terminal problem. If a terminal A wants to transmit data, it first send a short message (RTS, request to send) to request permission to transmit. The access point then sends a broadcast message (CTS, clear to send) that informs all stations that terminal A has the permission to transmit. All stations will remain silent for the period that terminal A is transmitting, whether they can sense the transmission or not.

b) The physical layer in the OSI reference model is responsible for the transfer of bits over a physical channel. This includes for example modulation, channel coding, forward error correction, …

c) Examples for application layer protocols are DNS, HTTP, IMAP, SMTP, FTP, SSH, BitTorrent, …

d) The modulator block translates bits (the output of the channel encoder) into an analog waveform that can be transmitted over the physical channel.

e) A minimum distance of 3 means that each valid codeword differs in at least 3 bit positions from all other valid codewords. Error patterns that change only 1 or 2 bits cannot change a valid codeword into another valid codeword. Therefore, for $d_{\min} = 3$, the detection of all 1-bit and all 2-bit error patterns can be guaranteed.

(P3) a) Ethernet uses CSMA/CD, where collision detection is essential. To avoid undetectable collisions, Ethernet frames must have a minimum length of 64 byte. If a frame is to short, zero-bits are added in the PAD field.

b) → IP: ◦ source address: 192.168.0.1 (IP address of A)
◦ destination address: 192.168.0.2 (IP address of B)
→ LLC: ◦ source SAP addr: 06 (for IP protocol)
◦ dest. SAP addr: 06
→ Ethernet: ◦ source addr: 28:37:37:01:76:AA
◦ dest. addr.: 28:37:37:01:76:BB

c) bit flip in ...
... dest. address: B will never even process the frame as it thinks the frame is for someone else
... any other field: Ethernet layer of B receives frame and performs error detection. Since every 1-bit error can be detected with CRC-32, the PDU will be discarded

d) for the IP layer of Host B to receive an erroneous packet, the following things must have happened:
◦ Ethernet layer: the destination address of the Ethernet PDU is error-free and Host B realizes that they are the recipient. The CRC-32 error check does not detect any errors (the error is undetectable). There can be errors in any of the fields (except for the dest. address). There definitely has to be error(s) in the Ethernet SDU. Otherwise no erroneous packet would arrive at the IP layer. The SDU is handed to the LLC layer.

- LLC layer: There is no error check at the LLC layer. However, if an invalid SAP address is found, the LLC layer will discard the PDU. This means that the address fields are error-free. There has to be errors in the SDU
- IP layer: The IP layer has error check only for the header. If an error is detected, the PDU is discarded. If no error is detected in the header, the SDU is delivered to the layer that it is destined for.

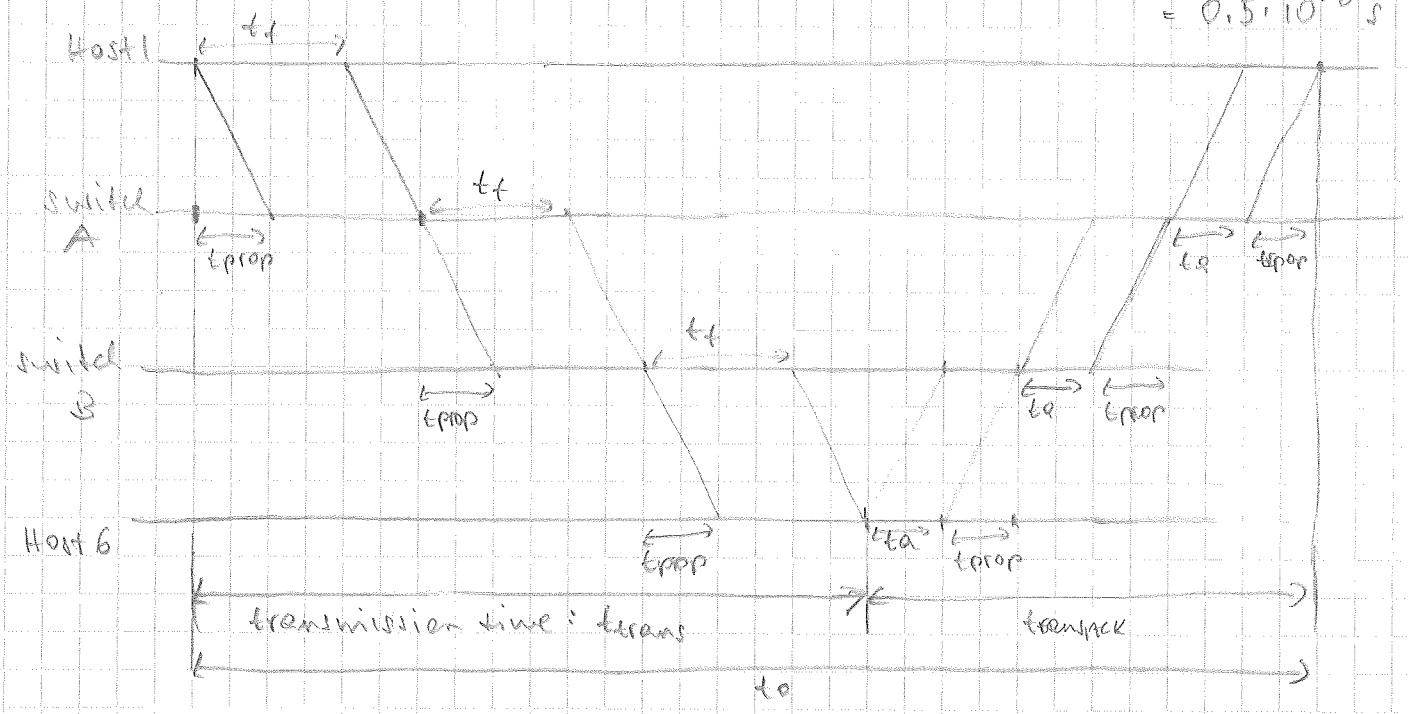
P4) $n_f = 1500 \text{ byte} = 12000 \text{ bit} \rightarrow t_f = \frac{n_f}{R} = 120 \cdot 10^{-6}$

a) $R = 100 \cdot 10^6 \text{ bit/s}$

length of one cable: at 100 m $\rightarrow t_{prop} = \frac{d}{c} = \frac{100 \cdot 3}{2 \cdot 3 \cdot 10^8}$

$= 0.5 \cdot 10^{-6} \text{ s}$

Host 1 to Host 6:



$\Rightarrow t_{trans} = 3 t_{prop} + 3 t_f = 1.5 \cdot 10^{-6} + 360 \cdot 10^{-6} = 361.5 \cdot 10^{-6} \text{ s}$

b) t_{out}: has to be at least as long as it takes from the when the first bit of the frame is transmitted until the acknowledgement can be received by Host 1

$t_{out} = t_o = t_{trans} + t_{transack}$

$t_a = \frac{25 \cdot 8}{100 \cdot 10^6} = 2 \cdot 10^{-6} \text{ s}$

$= 361.5 \cdot 10^{-6} + 3 t_{prop} + 3 t_a$

$= 361.5 \cdot 10^{-6} + 1.5 \cdot 10^{-6} + 6 \cdot 10^{-6} = 369 \cdot 10^{-6} \text{ s}$

c)

	SWITCH A		SWITCH B	
$t=0$:	tables of both switches are empty			
$t=1$:	Address	Port	Address	Port
	1	2	1	2
$t=2$:	again Host 1 is transmitting → no new information is added to either table			

t=2

(A)

A	P
1	2
5	5

(B)

A	P
1	2
5	4

t=4 no change in either table

t=5

A	P
1	2
5	5
2	1

A	P
1	2
5	4
2	2