Exam in
SSY305 Kommunikationssystem

Department of Signals and Systems

Exam date: March 19, 2015, 08:30–12:30

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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 Results are posted no later than April 1, 2015. The grading review is on April 1, 2015, 12:00–13:00 in room 7430 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 with pulse-amplitude modulation over an AWGN channel with noise power spectral density $N_0/2$, where $N_0 = 1.10 \times 10^{-20}$ W/Hz. Let the transmit pulse be

$$h(t) = \begin{cases} A, & 0 \leq t < 1\,\mu\text{s} \\ 0, & \text{otherwise} \end{cases}.$$

The receiver is a matched-filter minimum distance receiver, and the symbol rate is chosen to be the maximum possible for ISI-free transmission.

(a) Consider the symbol alphabet $\mathcal{A}_1 = \{-1, 1\}$. What is the data rate? (2p)

(b) Suppose the bit error probability is 10^{-4}, what is the frame error rate if the frame length is 20 byte? What is the frame error rate for a 2000 byte frame? (2p)

(c) What is the required signal power to reach bit error probability 10^{-4} if we use the symbol alphabet $\mathcal{A}_1$? (4p)

(d) What is required transmit power to reach bit error probability 10^{-4} if we use the symbol alphabet $\mathcal{A}_2 = \{0, 2\}$? (4p)

2. (a) Explain the difference between CSMA with collision detection (CD) and CSMA with collision avoidance (CA). Which method gives the best performance on a wired medium? Which method would you recommend to be used in wireless systems? Motivate. (4p)

(b) What is the purpose of the transport layer in the OSI reference model? Give an example of a TCP/IP transport layer protocol. (2p)

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

(d) Explain the purpose of the domain name system (DNS). (2p)

(e) Why is a hierarchical addressing scheme preferable to a flat addressing scheme for routing? (2p)

3. Consider a single-parity check code with 7 information bits $d_0, d_1, \ldots, d_6$ and one parity bit $p = d_0 \oplus d_1 \oplus \cdots \oplus d_6$.

The codeword $\mathbf{c} = [d_0 d_1 \cdots d_6 p]$ is transmitted over a channel with error pattern $\mathbf{e} = [e_0 e_1 \cdots e_7]$. That is, the received word is $\mathbf{y} = \mathbf{c} \oplus \mathbf{e}$. Assume that the information bits are equally likely and independent.

(a) Suppose bit errors occur independent of each other with probability 10^{-4}. Compute the frame error probability $P_f = \Pr\{\mathbf{y} \neq \mathbf{c}\}$. (4p)

(b) Suppose the parity check code is used for error detection. What is the probability of undetected error? (4p)

(c) Now suppose the channel is such that all nonzero error patterns are equally likely, i.e., $\Pr\{\mathbf{e} = \mathbf{u}\} = p$, where p is a constant, for all $\mathbf{u} \neq [0000000]$. For the same frame error probability as in part (a), what is the probability of undetected error? (4p)

4. Consider transmission of IP-packets (i.e., IP PDUs) over an 802.11 WLAN with DCF (distributed coordinating function). Hence, the protocol stack below IP is 802.2 logical link control (LLC), 802.11 medium access control (MAC) using DCF, 802.11 physical (PHY) layer convergence procedure (PLCP), and a 802.11 PHY layer.

   The LLC PDU consist of a 3-byte header followed by the LLC SDU.

   A 802.11 MAC PDU that carries higher layer data consists of a 30-byte header followed by the MAC SDU and a 4-byte CRC check sum field. The MAC SDU can have length from 0 to 2312 byte. The 802.11 MAC control PDUs have the following lengths: RTS frame is 20 byte long; CTS and ACK frames are 14 byte long. A DCF interframe space (DIFS) is 25 μs and a short interframe space (SIFS) is 16 μs.

   The PLCP PDU consist of a PLCP preamble and header that combined have duration 20 μs followed by the PLCP SDU.

   The PHY layer data rate is 54 Mbit/s.

   We assume that there is only one transmitter (i.e., there is no channel contention or packet collisions) and that there are no frame errors on the wireless medium. The propagation delay is assumed to be negligible.

   (a) What is the maximum length of an IP packet that can be transmitted in a single 802.11 MAC PDU? (2p)

   (b) What is the highest data rate that the IP layer can experience if RTS/CTS is not used? (6p)

   (c) What is the highest data rate that the IP layer can experience if RTS/CTS is used? (4p)

① noise: AWGN with spectral density $\frac{N_0}{2}$ $\qquad N_0 = 1.1 \cdot 10^{-22}\,W/Hz$

$$R_s = \frac{1}{T} = \frac{1}{1 \cdot 10^{-6}} = 10^6 \text{ symbol/s}$$

a) 2-PAM (2 symbols) $\Rightarrow$ $M = 2$

$$R_b = R_s \cdot \log_2(M) = D_s = 10^6 \text{ bit/s} = 1 \text{ Mbit/s}$$

b) bit error probability: $p = 10^{-4}$

frame length: n_f

frame error rate: $P_f = 1 - Pr\{\text{error-free frame}\}$

$$= 1 - (1-p)^{n_f}$$

$\Rightarrow$ for $n_f = 20$ byte $= 8 \cdot 20$ bit $= 160$ bit

$$P_f = 1 - (1-10^{-4})^{160} = 0.0159$$

$\Rightarrow$ for $n_f = 2000$ byte

$$P_f = 1 - (1-10^{-4})^{16000} = 0.7981$$

c) 2-PAM $\rightarrow$ bit error probability P_b = symbol error prob. P_e

noise: normal distribution with mean μ equal to zero and variance σ^2 equal to $\frac{N_0}{2E_h}$

$$n_k \sim \mathcal{N}\left(0, \frac{N_0}{2E_h}\right)$$

$$E_h = \int_{-\infty}^{\infty} |h(t)|^2\, dt = \int_0^{10^{-6}} A^2\, dt = 10^{-6} A^2$$

for $A_i = \{-1, 1\}$: $\quad \underset{-c}{a_1} \quad 0 \quad \underset{+c}{a_2} \qquad c = 1$

$$P_b = Q\left(\frac{c}{\sigma}\right) = Q\left(\sqrt{\frac{2E_h}{N_0}}\right) = Q\left(\sqrt{\frac{2A^2\, 10^{-6}}{N_0}}\right) = Q\left(A\sqrt{\frac{2 \cdot 10^{-6}}{N_0}}\right)$$

$$Q(3.71901) = 10^{-4}$$

$$\Rightarrow A\sqrt{\frac{2\cdot 10^{-6}}{N_0}} = 3.71901$$

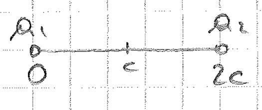
$$A = 3.71901\sqrt{\frac{N_0}{2\cdot 10^{-6}}} = 2.7581\cdot 10^{-8}$$

average power $P_{avg} = \frac{E_s}{T} = \frac{E_h \cdot E_a}{T}$

$$E_a = \frac{1}{2}\left(|-1|^2 + |1|^2\right) = 1$$

$$P_{avg} = \frac{A^2\cdot 10^{-6}}{10^{-6}} = A^2 = 7.6071\cdot 10^{-16}$$

peak power $P_{peak} = \max\limits_{t,k}\left\{|a_k \cdot h(t)|^2\right\} = A^2$

d) 

$c = 1$

distance between symbols is the same as in c) $\Rightarrow$ for the same pulse shape, the same P_b is reached

$$E_a = \frac{1}{2}\left(|0|^2 + |2|^2\right) = 2$$

$$P_{avg} = 2\frac{E_s}{T} = 2A^2 = 1.5214\cdot 10^{-15}$$

$$P_{peak} = 4A^2 = 3.0428\cdot 10^{-15}$$

2]

a) In CSMA/CD the channel is sensed at the same time as a packet is transmitted. In this way the amount of wasted bandwidth can be reduced by aborting a transmission when a collision is detected. In CSMA/CA on the other hand nodes attempt to avoid collisions by using RTS and CTS messages to coordinate the transmission.

On a wired medium CSMA/CD gives the best performance. However the collision detection scheme is very difficult in a wireless system (due to the power differences between the transmitted and received signals, which easily can be 100 dB). Hence CSMA/CA is often used in the wireless case to avoid packet collisions due to hidden nodes.

Note that the answer to this question is not onesided, but depends on which performance metric is the most important. For exampel consider vehicular communication where latency is extremely important. Even though this communication is wireless RTS/CTS messages are not used as they would imply extra latency, and also would be very difficult to handle due to the fact that most of this comm. is done in broadcast mode.

b) The transport layer is responsible for end-to-end services. It is independent of the underlaying network and provides end-to-end transfer of application layer messages, using either reliable stream transfer (e.g. TCP) or unreliable datagram transfer (e.g. UDP). Depending on the type of service it implements:

- segmentation and reassembly
- multiplexing
- sequence control
- error control
- flow control
- connection setup, maintenance, and releas

c) The modulator takes symbols (or bits) and maps them to wave forms

d) The DNS system translates between domain names (e.g. www.chalmers.se) and IP addresses (e.g. 129.16.71.10). The purpose with the DNS system is to facilitate for the user as a domain name is much easier to remember than an IP-address. (Also the IP address can change while the domain name is kept the same)

e) With a flat addressing scheme, a router need to maintain a table with as many rows as there are addresses. This table becomes very large as the network grows. With a hierarchical addressing scheme, all addresses with a certain prefix can shape an entry in the table. For instance, suppose that all packets with prefix 192, i.e., addresses of the form 192.xxx.xxx.xxx, should be forwarded to port 2, then this requires only one entry in the routing table. For a flat scheme, we would need 2^{32} entries for a 32-bit address.

(3)

a) $p = 10^{-4}$

$P_f = 1 - Pr\{\text{no error in frame}\} = 1 - (1-p)^8 = 7.9972 \cdot 10^{-4}$

b) errors that can be detected:

- 1-bit-errors: 8 possible error patterns:

  $Pr\{\text{1-bit-error}\} = p \cdot (1-p)^7 \cdot 8$

- 3-bit-errors: $\binom{8}{3} = 56$ possible error patterns

  $Pr\{\text{3-bit-error}\} = p^3 (1-p)^5 \cdot 56$

- 5-bit-errors: $\binom{8}{5} = 56$ possible error patterns

  $Pr\{\text{5-bit-error}\} = p^5 (1-p)^3 \cdot 56$

- 7-bit-errors: $\binom{8}{7} = 8$ possible error patterns

  $Pr\{\text{7-bit-error}\} = p^7 (1-p) \cdot 8$

$Pr\{\text{undetected error}\} = 1 - Pr\{\text{detected error}\} - Pr\{\text{no error}\}$

$= 1 - (1-p)^8 - 8p(1-p)^7 - 56p^3(1-p)^5 - 56p^5(1-p)^3 - 8p^7(1-p)$

$= 2.7983 \cdot 10^{-7}$

c) number of error patterns: $2^8 = 256$ (incl. [00000000])

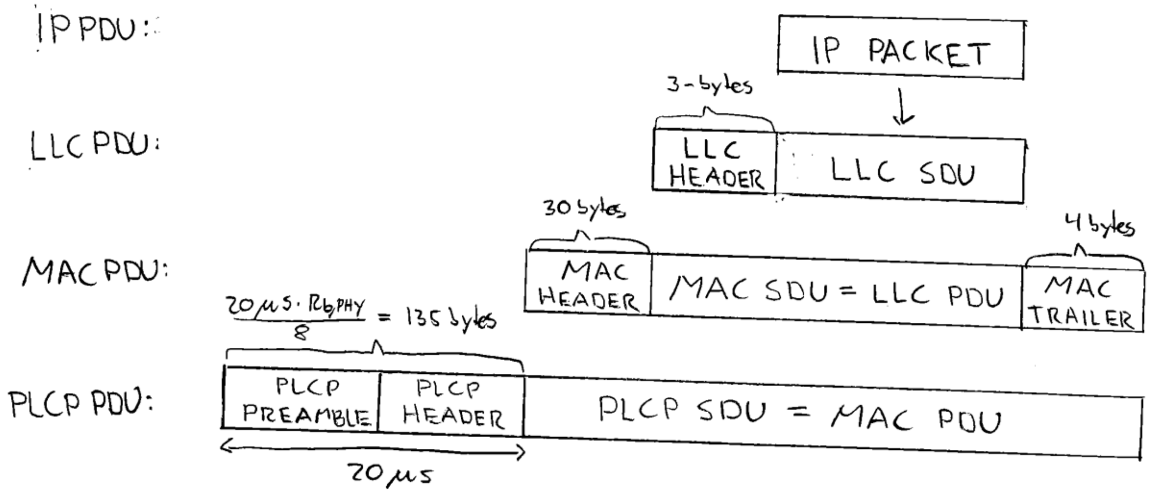
total number of undetectable error patterns =

$\binom{8}{2} + \binom{8}{4} + \binom{8}{6} + \binom{8}{8} = 28 + 70 + 28 + 1 = 127$

$p = \frac{P_f}{255} = 3.1362 \cdot 10^{-6}$

$Pr\{\text{undetectable error pattern}\} = 127p = 3.9829 \cdot 10^{-04}$

4]

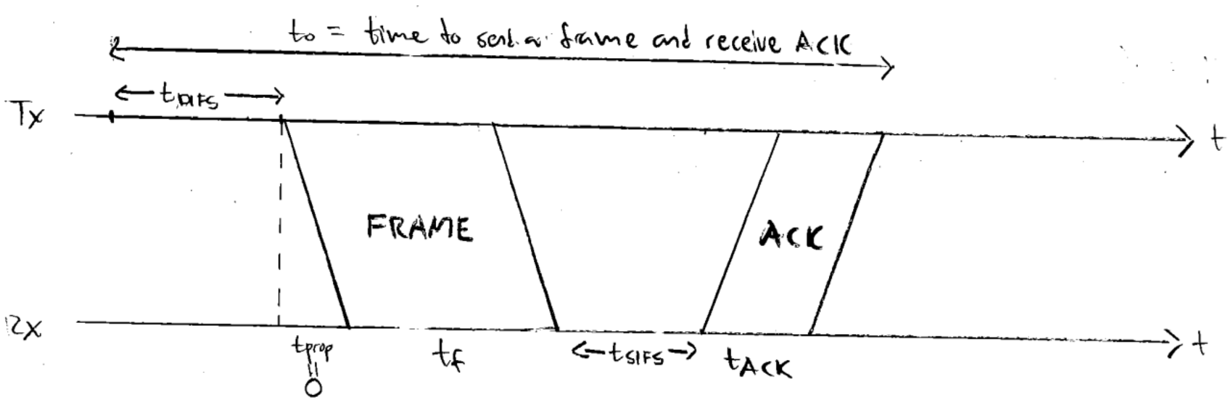


a) Maximum length MAC SDU: 2312 bytes

LLC header: 3 bytes

Hence the maximum length of an IP packet that can be transmitted in a single MAC PDU is 2309 bytes ($n_{f,IP\,PDU} = 18472$ bits)

b) $R_{b,PHY} = 54$ Mbit/s , $n_{f,IP} = 18472$ bits (from a)



To maximize the data rate we want to send as long frame as possible, i.e. $t_f = t_{f,max}$

Maximum frame time:

Maximum length of PLCP PDU: $n_{PLCP\ PDU} = \frac{135+30+2312+4}{8} = 19848$ bits

$$\Rightarrow t_{f,max} = \frac{n_{PLCP\ PDU}}{R_{s,PHY}} = \frac{19848}{54 \cdot 10^6} \approx 3{,}676 \cdot 10^{-4}\ s$$

ACK time:

$$t_{ACK} = \frac{(14+135) \cdot 8}{54 \cdot 10^6} \approx 2{,}207 \cdot 10^{-5}$$

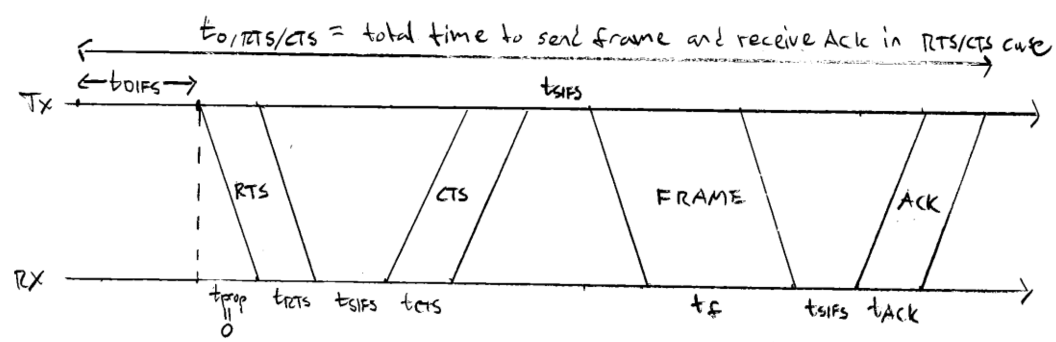
The total time to send a frame and receive an ACK is now:

$$t_0 = t_{DIFS} + t_{f,max} + t_{SIFS} + t_{ACK} \approx 4{,}306 \cdot 10^{-4}\ s$$

and the maximum data rate the IP layer can experience is given by

$$R_{b,IP} = \frac{n_{f,IP}}{t_0} \approx 42{,}9\ \text{Mbit/s}$$

c) Here we also have to consider the time it takes to exchange the extra time it takes to exchange the RTS/CTS messages.



With negligible propagation delay (i.e. $t_{prop} \approx 0$) the total time to send a frame and receiv an ACK is:

$$t_0 = t_{DIFS} + t_{RTS} + t_{SIFS} + t_{CTS} + t_{SIFS} + t_f + t_{SIFS} + t_{ACK}$$

$$t_{0,RTS/CTS} = t_{DIFS} + t_{RTS} + t_{SIFS} + t_{CTS} + t_{SIFS} + t_f + t_{SIFS} + t_{ACK} = 5{,}077 \cdot 10^{-4}$$

Finally the bit rate experienced by the IP layer in the RTS/CTS case is given by

$$R_{b,IP} = \frac{n_{f,IP}}{t_{0,RTS/CTS}} \approx 36{,}4 \text{ Mbit/s}$$