Exam in
SSY305 Kommunikationssystem

Department of Electrical Engineering

Exam date: March 19, 2020, 14:00–18:00

Document updated: March 18, 2020

Teaching Staff
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Material All material is allowed on this exam. Students are required to solve the exam problems individually. Cooperation, in any form or with anyone, is strictly forbidden.

Grading A correct, clear and well-motivated solution gives at most 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.

Submission Exam problem solutions should be solved on paper as in a normal exam.

- Make sure that each paper is clearly marked with your name, exam problem number and page number.
- Scan or photograph your solutions.
- Name your image files `Problem_YY_Page_XX`. Example: `Problem_01_Page_02.jpg`.
- If you want, you can combine images for the same problem into a single document (e.g., Word or PDF) named `Problem_YY`.
- Submit your solutions by uploading the image files or documents via Canvas before **March 19, 18:10**

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

Results Exam results are posted on Canvas no later than on March 25, 2020. The grading reviews will have to be done remotely according to a process that has not yet been decided.

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	40–69	70–79	≥ 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 a CRC with generator polynomial $g(x) = x^4 + 1$. The received polynomial is denoted $y(x) = c(x) + e(x)$, where $c(x)$ is the transmitted codeword and $e(x)$ is the error pattern.

   (a) How many parity bits will the codewords have? (1p)

   (b) Compute the codewords for all possible 2-bit information patterns. (3p)

   (c) Using the answer from Part (b), show that the code is linear. (2p)

   (d) Suppose bit errors occur independently with probability $p = 0.1$. What is the probability that an undetected error occurs? (3p)

   (e) Suppose that all error patterns $e(x)$ are equally likely. That is, if $u(x)$ is a deterministic polynomial that could be an error pattern (i.e., the degree of $u(x)$ is less or equal to the largest degree among the code polynomials), then $\Pr\{e(x) = u(x)\} = K$, for some constant K. Compute K and the probability that an undetected error occurs. (3p)

2. Suppose transmission over a shared medium is coordinated using a reservation scheme. There are N stations attached to the medium. A cycle consists of a reservation interval followed by a data transmission interval. The reservation interval consists of N reservation slots during which each station can reserve up to $k_{\max}$ data slots in the upcoming data transmission interval. Suppose the slot length in the reservation and data transmission intervals is the same and is denoted by T_{slot}.

   Assume that at the start of the first cycle, the nth station has a frame that requires k_n slots to transmit. Furthermore, assume that $0 < k_1 \leq k_2 \leq \cdots \leq k_M \leq k_{\max}$ and $k_n = 0$ for $n = M+1, M+2, \ldots, N$. That is, only the first M users have data to transmit. (Obviously, $1 \leq M \leq N$.)

   (a) Give an expression for the cycle duration, i.e., the reservation interval duration plus the data transmission interval duration. (3p)

   (b) Suppose we use TDMA instead. A TDMA cycle consists on N consecutive timeslots, and each station receives a single time slot for data transmission during each TDMA cycle. Give an expression for the time it takes until all stations have transmitted their frames. (3p)

   (c) Suppose $k_n = k$ for $n = 1, 2, \ldots, M$. We say that a scheme that can complete the transmission of all station data frames in the shortest time is the best. Specify for which combinations of M and k the reservation scheme, is better than or equally good as the TDMA scheme. Consider $1 \leq M \leq N$ and $k_{\max} = \infty$. (4p)

   (d) Suppose $\sum_{n=1}^{N} k_n = \sum_{n=1}^{M} k_n = 2N$. Find a sequence k_n for which the TDMA scheme is better than the reservation scheme and another sequence k_n for which the reservation scheme is better than the TDMA scheme. What conclusion can be drawn about the suitability for a fixed MAC (e.g., TMDA) versus a dynamic MAC (such as reservation schemes) when traffic is bursty? (2p)

3. Consider communication between two ground stations over a satellite link. The satellite is in a geo-stationary orbit at $h = 3.6 \times 10^7$ m over the Earth's surface. We model the satellite as a bent-pipe, which means that the received signal from one ground station is amplified and then transmitted down to the other ground station. We assume that the ground stations operate in half-duplex mode.

   We approximate the distance from each ground station to the satellite as h. The processing times at the satellite and ground stations are assumed to be negligible in comparison with the propagation delay. The propagation speed is assumed to be 3×10^8 m/s.

   Suppose that the datalink layer in the ground station should provide a reliable service that delivers packets error-free, in order, and without duplication. Suppose the packets are 1500 byte long and that the datalink protocol overhead is 10 byte. Assume that the ACK frame is 40 byte long. The data rate on the satellite link is 10 Mbit/s.

   (a) Suppose we use a Stop-and-Wait protocol. Determine a suitable time-out value and compute the data rate the network layer in the ground station experiences. Assume error-free transmission. (4p)

   (b) Suppose we use a variant of Go-Back-N where the transmitter send N consecutive frames and the receiver responds with an ACK frame if all N frames have been received correctly. (Hence, the acknowledgment is cumulative, as usual for Go-Back-N. The difference from standard Go-Back-N is that not every received frame is ACKed.) Determine a suitable time-out value and compute the data rate the network layer in the ground station experiences as a function of N. Assume error-free transmission. (4p)

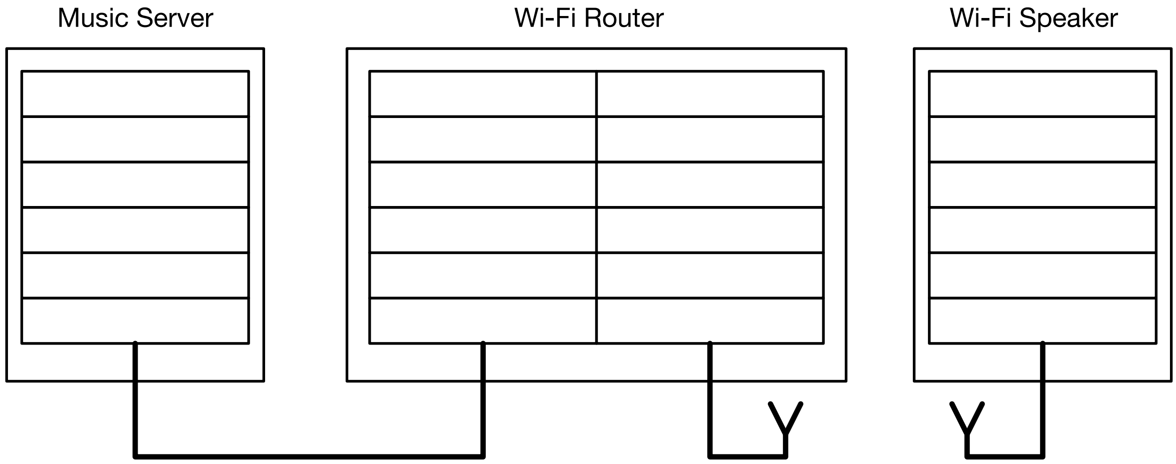
   (c) Suppose the probability of frame error is 10^{-3}. Compute the N that maximizes the data rate the network layer experiences. Assume that ACK frames are transmitted error-free and the frame errors occur independently of each other. (4p)

   Hint: suppose p is the probability of success of an experiment. Let i be the total number of consecutive, independent experiments we need to carry out until the first successful experiment. Then then i is a random variable with PMF

$$\begin{aligned}\Pr\{i = k\} &= \Pr\{(k-1) \text{ failed experiments followed by one successful experiment}\} \\ &= (1-p)^{k-1}p, \qquad k = 1, 2, \ldots\end{aligned}$$

   and $\mathrm{E}[i] = 1/p$.

4. Consider a network consisting of a music server, a Wi-Fi router, and a Wi-Fi speaker. The music server is connected to the Wi-Fi router with a twisted pair cable. Obviously, the Wi-Fi router and Wi-Fi speaker are connected wirelessly.



The protocols used for streaming music to the speaker are (in alphabetic order) 802.11 MAC, 802.11 PHY, 802.3 MAC, 802.3 PHY, IP, LLC, RTP, and UDP.

(a) Copy the figure above and put in the protocols in their correct places in the protocols stacks. Note that some boxes in the protocol stacks might be empty. (2p)

(b) Let the IP addresses in the network be of the form 192.168.1.xxx, where xxx is a member of the set $\{0, 1, ..., 255\}$. Assign IP addresses to the appropriate places in the figure. Use IP addresses in order, i.e., start with assigning 192.168.1.0, then 192.168.1.1 and so on. (2p)

(c) Let the physical addresses in the network be of the form 30:23:03:00:00:yy, where yy is a member of the set $\{00, 01, ..., FF\}$ (all two-digit hex numbers). Assign physical addresses to the appropriate places in the figure. Use physical addresses in order, i.e., start with assigning 30:23:03:00:00:00, then 30:23:03:00:00:01 and so on. (2p)

(d) Let PH denote the header and PT denote the trailer (if it exists) for protocol P. For example, the IP header is denoted IPH and 802.3 trailer is denoted 802.3T. Moreover, let the payload (music bits) be denoted MUSIC. Indicate the order of the headers, trailer, and payload on a frame going from the music server to the Wi-Fi router. Do the same for the frame from the Wi-Fi router to the Wi-Fi speaker. (2p)

(e) What destination and source IP addresses are used in the frame from the music server to the Wi-Fi router and the frame from the Wi-Fi router to the Wi-Fi speaker? (2p)

(f) What destination and source physical addresses are used in the frame from the music server to the Wi-Fi router and the frame from the Wi-Fi router to the Wi-Fi speaker? (2p)

Exam in
SSY305 Kommunikationssystem

Department of Electrical Engineering

Exam date: March 19, 2020, 14:00–18:00

Document updated: March 27, 2020

Teaching Staff

Erik Strm (examiner), 031-772 5182

Material All material is allowed on this exam. Students are required to solve the exam problems individually. Cooperation, in any form or with anyone, is strictly forbidden.

Grading A correct, clear and well-motivated solution gives at most 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.

Submission Exam problem solutions should be solved on paper as in a normal exam.

- Make sure that each paper is clearly marked with your name, exam problem number and page number.
- Scan or photograph your solutions.
- Name your image files `Problem_YY_Page_XX`. Example: `Problem_01_Page_02.jpg`.
- If you want, you can combine images for the same problem into a single document (e.g., Word or PDF) named `Problem_YY`.
- Submit your solutions by uploading the image files or documents via Canvas before **March 19, 18:10**

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

Results Exam results are posted on Canvas no later than on March 25, 2020. The grading review is on March 26 and April 2, 2020, 12:00–13:00 in Heisenberg, room 6435 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	40–69	70–79	≥ 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 a CRC with generator polynomial $g(x) = x^4 + 1$. The received polynomial is denoted $y(x) = c(x) + e(x)$, where $c(x)$ is the transmitted codeword and $e(x)$ is the error pattern.

   (a) How many parity bits will the codewords have? (1p)

   (b) Compute the codewords for all possible 2-bit information patterns. (3p)

   (c) Using the answer from Part (b), show that the code is linear. (2p)

   (d) Suppose bit errors occur independently with probability $p = 0.1$. What is the probability that an undetected error occurs? (3p)

   (e) Suppose that all error patterns $e(x)$ are equally likely. That is, if $u(x)$ is a deterministic polynomial that could be an error pattern (i.e., the degree of $u(x)$ is less or equal to the largest degree among the code polynomials), then $\Pr\{e(x) = u(x)\} = K$, for some constant K. Compute K and the probability that an undetected error occurs. (3p)

Solution

(a) The number of parity bits are equal to the degree of the generator polynomial. Hence, codewords will have 4 parity bits.

1p (b) We have 4 information patterns [00], [01], [10] and [11]. We can represent these with the binary polynomials $i_0(x) = 0$, $i_1(x) = 1$, $i_2(x) = x$ and $i_3(x) = x + 1$, respectively. Note that addition of these polynomial is done modulo-2. The code words are given by $c(x) = i(x)x^4 + r(x)$ where $r(x)$ is the remainder of the division $i(x)x^4/g(x)$, that is, $i(x)x^4 = g(x)q(x) + r(x)$. Down below you can find the division performed in binary system, using $\mathbf{g} = [10001]$.

1p The code words are given by $\mathbf{c}_0 = [000000]$, $\mathbf{c}_1 = [010001]$, $\mathbf{c}_2 = [100010]$, $\mathbf{c}_3 = [110011]$.

1p

0	1	0	0	0	0
	1	0	0	0	1
0	0	0	0	0	1

1	0	0	0	0	0
1	0	0	0	1	
0	0	0	0	1	0

1	1	0	0	0	0
1	0	0	0	1	
0	1	0	0	1	0
	1	0	0	0	1
0	0	0	0	1	1

0.5p (c) A code is linear if $\forall \mathbf{c}_i, \mathbf{c}_j \in \mathcal{C}$, $(\mathbf{c}_i \oplus \mathbf{c}_j) \in \mathcal{C}$.

Then, for the codebook $\mathcal{C} = \{\mathbf{c}_0, \mathbf{c}_1, \mathbf{c}_2, \mathbf{c}_3\}$ we have, $\mathbf{c}_0 \oplus \mathbf{c}_i = \mathbf{c}_i \in \mathcal{C}, i = 0, 1, 2, 3$

1.5p and $\mathbf{c}_i \oplus \mathbf{c}_i = \mathbf{c}_0$, $\forall i$. Moreover, $\mathbf{c}_1 \oplus \mathbf{c}_2 = \mathbf{c}_3$, $\mathbf{c}_1 \oplus \mathbf{c}_3 = \mathbf{c}_2$, $\mathbf{c}_2 \oplus \mathbf{c}_3 = \mathbf{c}_1$. Hence, the code is linear.

Computation of all the combinations needs to be done (Giving only and example gives 0.5p

0.5p (d) Given an error pattern $\mathbf{e}$, if $\mathbf{c}_i \oplus \mathbf{e} \in \mathcal{C}$ then the error is undetectable. If the code is

0.5p linear than that implies that all undetectable error patterns satisfies $\mathbf{e} \in \mathcal{C}$. Following that, we have

$$\begin{aligned}
\Pr\{\text{error}\} &= \Pr\{\mathbf{e} \text{ is undetectable }\} \\
&= \Pr\{\mathbf{e} \in \mathcal{C}\} \\
&= \Pr\big\{\{\mathbf{e} = \mathbf{c}_1\} \text{ or } \{\mathbf{e} = \mathbf{c}_2\} \text{ or } \{\mathbf{e} = \mathbf{c}_3\}\big\} \\
&= (1-p)^4p^2 + (1-p)^4p^2 + (1-p)^2p^4 && \text{1.5p} \\
&= 0.0132. && \text{0.5p}
\end{aligned}$$

(e) Since $\mathbf{e}$ is composed of 6 bits and excluding the all-zeros pattern, we have a total

1.5p of $2^6 - 1$ error patterns. Hence, $K = 1/63$. Only 3 errors patterns, of the total 63 patterns, results in error. Therefore,

1.5p $$\Pr\{\text{error}\} = 3/63 = 0.0476.$$

2. Suppose transmission over a shared medium is coordinated using a reservation scheme. There are N stations attached to the medium. A cycle consists of a reservation interval followed by a data transmission interval. The reservation interval consists of N reservation slots during which each station can reserve up to $k_{\max}$ data slots in the upcoming data transmission interval. Suppose the slot length in the reservation and data transmission intervals is the same and is denoted by T_{slot}.

   Assume that at the start of the first cycle, the nth station has a frame that requires k_n slots to transmit. Furthermore, assume that $0 < k_1 \leq k_2 \leq \cdots \leq k_M \leq k_{\max}$ and $k_n = 0$ for $n = M+1, M+2, \ldots, N$. That is, only the first M users have data to transmit. (Obviously, $1 \leq M \leq N$.)

   (a) Give an expression for the cycle duration, i.e., the reservation interval duration plus the data transmission interval duration. (3p)

   (b) Suppose we use TDMA instead. A TDMA cycle consists on N consecutive timeslots, and each station receives a single time slot for data transmission during each TDMA cycle. Give an expression for the time it takes until all stations have transmitted their frames. (3p)

   (c) Suppose $k_n = k$ for $n = 1, 2, \ldots, M$. We say that a scheme that can complete the transmission of all station data frames in the shortest time is the best. Specify for which combinations of M and k the reservation scheme, is better than or equally good as the TDMA scheme. Consider $1 \leq M \leq N$ and $k_{\max} = \infty$. (4p)

   (d) Suppose $\sum_{n=1}^{N} k_n = \sum_{n=1}^{M} k_n = 2N$. Find a sequence k_n for which the TDMA scheme is better than the reservation scheme and another sequence k_n for which the reservation scheme is better than the TDMA scheme. What conclusion can be drawn about the suitability for a fixed MAC (e.g., TMDA) versus a dynamic MAC (such as reservation schemes) when traffic is bursty? (2p)

   Solution

   (a) The cycle duration of the reservation scheme can be expressed straightforwardly as

   1.5p 1.5p
   $$\tau_{\text{res}} = NT_{\text{slot}} + T_{\text{slot}} \sum_{n=1}^{M} k_n.$$

   (b) Since $0 < k_1 \leq k_2 \leq \cdots \leq k_M \leq k_{\max}$, the Mth station will be the one to finish its transmission last. Hence, the time taken until all stations have transmitted their frames in TDMA system, is

   1.5p 1.5p
   $$\tau_{\text{TDMA}} = (k_M - 1)NT_{\text{slot}} + MT_{\text{slot}}.$$

   (c) Given that $k_n = k$, $n = 1, 2, \ldots, M$, then

   0.5p 0.5p
   $$\tau_{\text{res}} = (N + Mk)T_{\text{slot}}, \quad \tau_{\text{TDMA}} = ((k-1)N + M)T_{\text{slot}}.$$

   Clearly, for $k = 1$, $\tau_{\text{TDMA}} = MT_{\text{slot}}$ which is less than $\tau_{\text{res}} = (N + M)T_{\text{slot}}$ for all M.

For $k > 1$, let us assume that $\tau_{\text{res}} \leq \tau_{\text{TDMA}}$, this implies that

1.5p
$$\begin{aligned} (N + Mk)T_{\text{slot}} &\leq ((k-1)N + M)T_{\text{slot}} \\ N + Mk &\leq (k-1)N + M \\ M(k-1) &\leq (k-2)N. \end{aligned}$$

Since $M > 0$, we can deduce that for $\tau_{\text{res}} \leq \tau_{\text{TDMA}}$ holds for all pairs (k, M) where $k = 2, 3, \ldots, k_{\max}$ and

1.5p
$$M \leq \frac{k-2}{k-1}N. \tag{1}$$

(d) Let $\sum_{n=1}^{M} = 2N$, then

$$\tau_{\text{res}} = 3NT_{\text{slot}}.$$

0.5p Steady state traffic sequence

Let $M = N$, $k_n = k = 2$, $n = 1, 2, \ldots, N$, then

$$\tau_{\text{TDMA}} = 2NT_{\text{slot}} < \tau_{\text{res}}. \tag{2}$$

1p Bursty traffic sequence

Let $M = 1$, $k_1 = 2N$, $k_n = 0$ for $n = 2, 3, \ldots N$ we have

$$\begin{aligned} \tau_{\text{res}} &= 3NT_{\text{slot}} \\ \tau_{\text{TDMA}} &= ((2N-1)N + 1)T_{\text{slot}}. \end{aligned}$$

We note that

$$\tau_{\text{TDMA}} - \tau_{\text{res}} = ([(2N-1)N + 1] - 3N)T_{\text{slot}} = (2N^2 - 4N + 1)T_{\text{slot}}$$

is increasing with positive N. Also, we have that for $N = 2$,

$$\tau_{\text{TDMA}} - \tau_{\text{res}} = (2N^2 - 4N + 1)T_{\text{slot}} = T_{\text{slot}} > 0,$$

and therefore we can conclude that

$$\tau_{\text{TDMA}} > \tau_{\text{res}}, \qquad N \geq 2. \tag{3}$$

0.5p From (2) and (3) we can observe that, a dynamic MAC has lower delivery time (delay) when the traffic is bursty compared to a fixed MAC. Hence, dynamic MAC schemes are more suitable for bursty traffic. On the other hand, fixed MAC schemes are more suitable for steady-state traffic.

3. Consider communication between two ground stations over a satellite link. The satellite is in a geo-stationary orbit at $h = 3.6 \times 10^7$ m over the Earth's surface. We model the satellite as a bent-pipe, which means that the received signal from one ground station is amplified and then transmitted down to the other ground station. We assume that the ground stations operate in half-duplex mode.

   We approximate the distance from each ground station to the satellite as h. The processing times at the satellite and ground stations are assumed to be negligible in comparison with the propagation delay. The propagation speed is assumed to be 3×10^8 m/s.

   Suppose that the datalink layer in the ground station should provide a reliable service that delivers packets error-free, in order, and without duplication. Suppose the packets are 1500 byte long and that the datalink protocol overhead is 10 byte. Assume that the ACK frame is 40 byte long. The data rate on the satellite link is 10 Mbit/s.

   (a) Suppose we use a Stop-and-Wait protocol. Determine a suitable time-out value and compute the data rate the network layer in the ground station experiences. Assume error-free transmission. (4p)

   (b) Suppose we use a variant of Go-Back-N where the transmitter send N consecutive frames and the receiver responds with an ACK frame if all N frames have been received correctly. (Hence, the acknowledgment is cumulative, as usual for Go-Back-N. The difference from standard Go-Back-N is that not every received frame is ACKed.) Determine a suitable time-out value and compute the data rate the network layer in the ground station experiences as a function of N. Assume error-free transmission. (4p)

   (c) Suppose the probability of frame error is 10^{-3}. Compute the N that maximizes the data rate the network layer experiences. Assume that ACK frames are transmitted error-free and the frame errors occur independently of each other. (4p)

   Hint: suppose p is the probability of success of an experiment. Let i be the total number of consecutive, independent experiments we need to carry out until the first successful experiment. Then then i is a random variable with PMF

$$\begin{aligned}\Pr\{i = k\} &= \Pr\{(k-1) \text{ failed experiments followed by one successful experiment}\}\\ &= (1-p)^{k-1}p, \qquad k = 1, 2, \ldots\end{aligned}$$

   and $\mathrm{E}[i] = 1/p$.

   Solution

   (a) The turn-around time is $t_0 = t_f + 2t_{\text{prop}} + t_a$, where $t_f = n_f/R = 8 \times (1500 + 10)/10^7$, $t_{\text{prop}} = 2h/v_{\text{prop}} = 7.2 \times 10^7/3 \times 10^8$, and $t_a = n_a/R = 8 \times 40/10^7$ is the frame duration, propagation delay, and ACK frame duration, respectively. We select the timeout as $t_{\text{out}} = t_0$. The number of payload bits in the information frame is $n_p = 8 \times 1500$. The effective data rate is $R^0_{\text{eff, SW}} = n_p/t_0 \approx 25$ kbit/s.

   1p 0.5p 0.5p 0.5p 1.5p

   (b) The turn-around time is $t_0 = Nt_f + 2t_{\text{prop}} + t_a$. As before, we select the timeout as $t_{\text{out}} = t_0$, and the effective data rate for error-free transmission is 2p

$$R^0_{\text{eff, GBN}} = \frac{Nn_p}{t_0} = \frac{Nn_p}{Nt_f + 2t_{\text{prop}} + t_a}$$

   2p

   We note as $N \to \infty$, the effective data rate approaches $n_p/t_f = (n_f - n_o)/t_f = R(1 - n_o/n_f)$, which is the best we can hope for.

0.5p

(c) The probability that N consecutive frames are error-free is $p = (1 - P_f)^N$. If at least one frames is in error, then this triggers retransmission of all N frames, which adds t_0 seconds to the delivery time. Let i be the number of times the N frames are transmitted, including the final successful transmission, then the average time it takes to deliver N frames is $\mathrm{E}[it_0] = t_0\,\mathrm{E}[i] = t_0/p$. Hence, the effective data rate is

$$R_{\text{eff, GBN}}(N) = \frac{Nn_p}{t_0/p} = \frac{Nn_p(1-P_f)^N}{Nt_f + 2t_{\text{prop}} + t_a}$$ 0.5p

We note that as $\lim_{N\to\infty} R_{\text{eff, GBN}}(N) = 0$ for any $P_f > 0$. To find the best N, we momentary forget that N is an integer and instead treat it as real number. We can then differentiate $R_{\text{eff, GBN}}(N)$ with respect to N and find an extreme point as the solution to $\frac{d}{dN} R_{\text{eff, GBN}}(N) = 0$. Hence, the equation we need to solve is

$$\frac{d}{dN} R_{\text{eff, GBN}}(N) = \frac{n_p}{t_f} \frac{d}{dN} \frac{NP_s^N}{N+a} = 0$$ 1p

where $P_s = 1 - P_f$ and $a = (2t_{\text{prop}} + t_a)/t_f$. We recall that $\frac{d}{dx} b^x = b^x \ln(b)$ when $b > 0$, and

Procedure need to be mentioned

1p

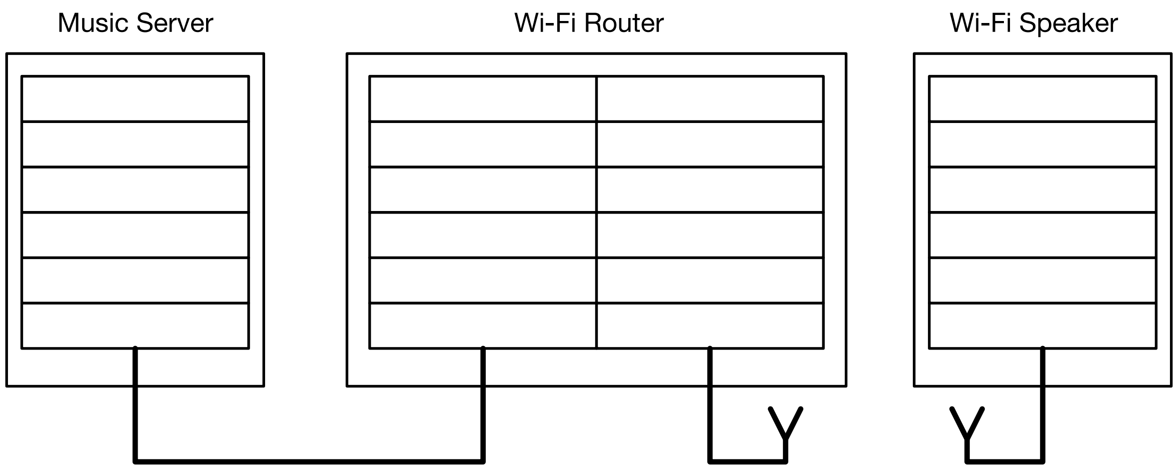
$$\begin{aligned}
\frac{d}{dN} \frac{NP_s^N}{N+a} &= -\frac{NP_s^N}{(N+a)^2} + \frac{P_s^N}{N+a} + \frac{NP_s^N \ln P_s}{N+a} \\
&= \frac{P_s^N}{(N+a)^2}(-N + (N+a) + N(N+a)\ln P_s) \\
&= \frac{P_s^N}{(N+a)^2}(a + N(N+a)\ln P_s) \\
&= \frac{P_s^N \ln P_s}{(N+a)^2}\left(N^2 + Na + \frac{a}{\ln P_s}\right) = 0
\end{aligned}$$

which yields the solutions

$$N = -\frac{a}{2} \pm \sqrt{\frac{a^2}{4} - \frac{a}{\ln P_s}}$$

1p Discarding the negative solution, we arrive at $N \approx 462.11$. Testing $N = 462$ and $N = 463$ proves that $N = 462$ gives the best effective rate $R_{\text{eff, GBN}}(462) \approx 3.36\,\text{Mbit/s}$.

4. Consider a network consisting of a music server, a Wi-Fi router, and a Wi-Fi speaker. The music server is connected to the Wi-Fi router with a twisted pair cable. Obviously, the Wi-Fi router and Wi-Fi speaker are connected wirelessly.



The protocols used for streaming music to the speaker are (in alphabetic order) 802.11 MAC, 802.11 PHY, 802.3 MAC, 802.3 PHY, IP, LLC, RTP, and UDP.

(a) Copy the figure above and put in the protocols in their correct places in the protocols stacks. Note that some boxes in the protocol stacks might be empty. (2p)

(b) Let the IP addresses in the network be of the form 192.168.1.xxx, where xxx is a member of the set $\{0, 1, ..., 255\}$. Assign IP addresses to the appropriate places in the figure. Use IP addresses in order, i.e., start with assigning 192.168.1.0, then 192.168.1.1 and so on. (2p)

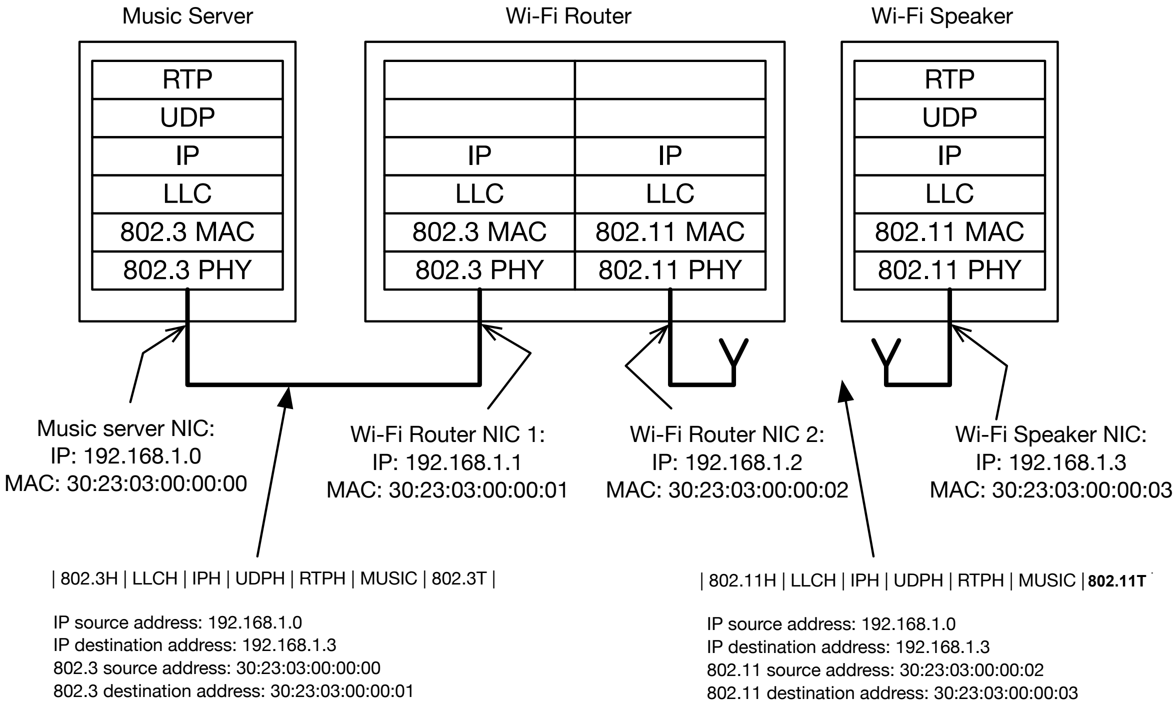
(c) Let the physical addresses in the network be of the form 30:23:03:00:00:yy, where yy is a member of the set $\{00, 01, ..., FF\}$ (all two-digit hex numbers). Assign physical addresses to the appropriate places in the figure. Use physical addresses in order, i.e., start with assigning 30:23:03:00:00:00, then 30:23:03:00:00:01 and so on. (2p)

(d) Let PH denote the header and PT denote the trailer (if it exists) for protocol P. For example, the IP header is denoted IPH and 802.3 trailer is denoted 802.3T. Moreover, let the payload (music bits) be denoted MUSIC. Indicate the order of the headers, trailer, and payload on a frame going from the music server to the Wi-Fi router. Do the same for the frame from the Wi-Fi router to the Wi-Fi speaker. (2p)

(e) What destination and source IP addresses are used in the frame from the music server to the Wi-Fi router and the frame from the Wi-Fi router to the Wi-Fi speaker? (2p)

(f) What destination and source physical addresses are used in the frame from the music server to the Wi-Fi router and the frame from the Wi-Fi router to the Wi-Fi speaker? (2p)

Solution



b),c) If only one address is assigned to the router, the answer is attributed 1/2p