Exam in
SSY305 Kommunikationssystem

Department of Electrical Engineering

Exam date: June 10, 2020, 14:00–18:00

Document updated: June 8, 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 your solutions to a pdf file. Ensure proper light conditions and and use a document scanning app, e.g., CamScanner or Genius Scan.
- Name the file `SSY305-FirstnameLastname.pdf`, where `FirstnameLastname` is your name. For example, a student Erik Ström shall use the filename `SSY305-ErikStrom.pdf`. Please do not use Swedish characters åäö, accents, etc.
- The exam ends at 18:00. The solutions should be uploaded via Canvas before 18:30

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 Wednesday June 17, 2020. Graded exam sheets will be available online via Canvas. Requests to review the grading can be sent via e-mail to `chouaib@chalmers.se` within one week after the results are available.

Grades The final grade on the course will be decided by the projects (max score 46), quizzes (max score 6), the written exam (max score 36), and the oral exam (max score 12). The project must be passed (see course-PM for rules). The exam is passed if the total score from the written and oral parts is at least 20p. If the project and exam is passed, 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

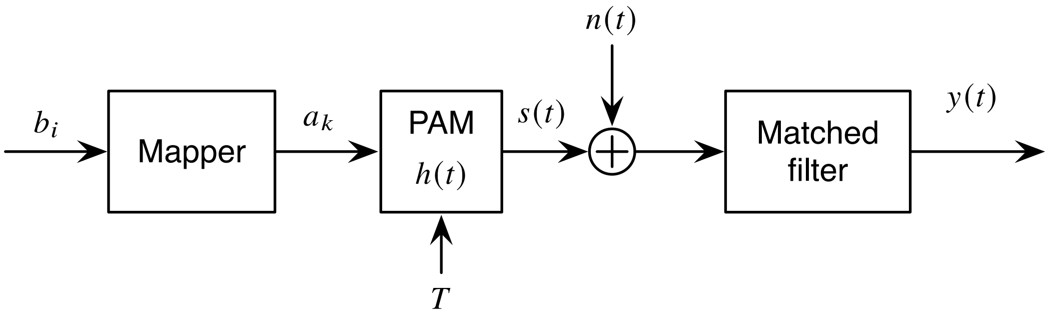
PLEASE NOTE THAT THE PROBLEMS ARE NOT NECESSARILY ORDERED IN DIFFICULTY.

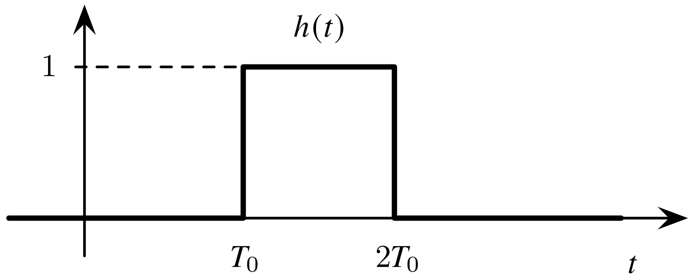
Good luck!

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 transmission of bits stream $b_i \in \{0,1\}$, where $i = 0, 1, \ldots, 15$ is the time index, using PAM with symbol rate $1/T$ and pulseshape $h(t)$ over an additive noise channel as illustrated in the figure below.





The mapper implements a Gray code according to the following table.

b_{2k}	b_{2k+1}	a_k
0	0	-3
0	1	-1
1	1	1
1	0	3

Suppose that the bit stream is

i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
b_i	1	0	0	1	0	0	0	0	0	0	1	1	0	1	1	0

(a) Plot $s(t)$ when $T = 3T_0$. Label both axes carefully. (3p)

(b) Suppose we choose the matched filter impulse response to be causal. Plot $y(t)$ when $T = 3T_0$ and indicate the optimal sampling points for decoding the transmitted data. Ignore the noise, i.e., set $n(t) = 0$. Label both axes carefully. (4p)

(c) Choose T such that (i) the data rate is maximized and (ii) the transmission is ISI-free. Give expressions for T and the maximum data rate in terms of T_0. (3p)

(d) Repeat Part (a) and (b) for the symbol rate chosen in Part (c). (2p)

2. Consider a wireless LAN in which a number of stations STA1, STA2, ..., are transmitting IP packets to a central access point (AP). The involved protocols are IP, 802.11, and LLC. The IP packet are 1500 byte long.

   Suppose the 802.11 header and trailer is 30 byte and 4 byte long, respectively, the LLC header is 5 byte long, and the IP header is 40 byte long. The 802.11 ACK frame (including header and trailer) is 14 byte. We use DCF without RTS/CTS handshake as medium access and assume that the SIFS is 16 μs and the DIFS is 34 μs. The contention window is $[0, 15]$ slots, where the slot duration is 9 μs.

   We will use a simplified model of the PHY layer in which we ignore any overhead (preambles, training symbols, etc.). In fact, we consider the PHY layer as a bit pipe with data rate 54 Mbit/s. In the absence of a collision, the PHY layer is error-free.

   We ignore propagation delays and consider carrier sensing to be perfect and instantaneous.

   (a) Sketch the layout of the transmitted data frames. That is, indicate in which order the various headers, trailers, and the IP packet are placed in the MAC layer PDU. (3p)

   (b) Suppose STA1 has a long sequence of IP packets to transmit, while all other stations are idle. What is the highest and lowest data rate the transport layer in STA1 can experience? (3p)

   (c) Suppose that there has been no data traffic for a while. Hence, no station is in backoff. Suppose that STA1 becomes ready to transmit a frame at time $t_1 = 0$ and that STA2 and STA3 becomes ready to transmit frames at time $t_2 > 0$ and $t_3 > 0$, respectively, while all other stations remain inactive. Explain under what conditions the frames from STA2 and STA3 will collide. Assume that all stations can sense each others transmissions. (3p)

   (d) Assume the same starting point as in Part (c): no station is in backoff and STA1 becomes ready to transmit at time $t_1 = 0$. Suppose STA1 is a hidden terminal to STA2 and that STA2 becomes ready at time $t_2 > 0$, while all other stations are inactive. For which values of t_2 will STA1 be forced to retransmit its data frame? Assume that collisions destroys all frames involved in the collision, regardless of which station is transmitting or receiving. (3p)

3. Consider bidirectional communication between STA A and STA B over a wireless medium using Stop-and-Wait ARQ. The distance between the communication stations is 180 km and we assume that the propagation speed is $c = 3 \times 10^8$ m/s. Processing delays are assumed to be negligible.

   The SDU size is 1500 byte and the header size 40 byte. An ACK frame consists of a header plus 1 byte of control information. We assume that the Stop-and-Wait timeout is set large enough to avoid unnecessary retransmissions.

   We can use the total available wireless bandwidth W in full-duplex or half-duplex mode. In full-duplex, transmissions from STA A and from STA B are separated in frequency, i.e., each transmission has bandwidth $W/2$. For half-duplex, transmissions from STA A and from STA B are separated in time. Hence, each transmission can use the full bandwidth W, but only half the time. As a consequence, the underlying PHY layer has data rate 10 Mbit/s when full-duplex is used and 20 Mbit/s when half-duplex is used. Moreover, we assume that no bit errors occur during transmission.

   We assume that STA A and STA B always have data to transmit. In the half-duplex case, the stations take turns in transmitting information frames. That is, suppose STA A starts by transmitting an information frame. The next information frame from STA A is then not allowed to be transmitted before STA A has received an information frame from STA B.

   (a) Compute the effective data rate for STA A provided by the Stop-and-Wait protocol when full-duplex is used. (2p)

   (b) Compute the effective data rate for STA A provided by the Stop-and-Wait protocol when half-duplex is used. (3p)

   (c) Now suppose we use piggybacking for the acknowledgements. That is, the payload in the information frames consist of an SDU plus the ACK control information (1 byte). No explicit ACK frames are transmitted. Compute the effective data rate for full-duplex communication. (3p)

   (d) Repeat Part (c) for half-duplex communication. (4p)

Exam in
SSY305 Kommunikationssystem

Department of Electrical Engineering

Exam date: June 10, 2020, 14:00–18:00

Document updated: June 16, 2020

Teaching Staff

Erik Ström (examiner), 031-772 5182
Chouaib Bencheikh Lehocine (teaching assistant), 073-742 6431

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 your solutions to a pdf file. Ensure proper light conditions and and use a document scanning app, e.g., CamScanner or Genius Scan.
- Name the file `SSY305-FirstnameLastname.pdf`, where `FirstnameLastname` is your name. For example, a student Erik Ström shall use the filename `SSY305-ErikStrom.pdf`. Please do not use Swedish characters åäö, accents, etc.
- The exam ends at 18:00. The solutions should be uploaded via Canvas before 18:30

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

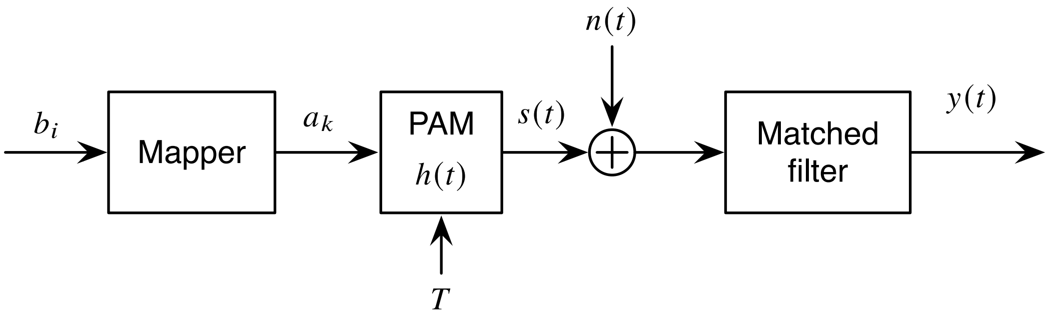
Results Exam results are posted on Canvas no later than Wednesday June 17, 2020. Graded exam sheets will be available online via Canvas. Requests to review the grading can be sent via e-mail to `chouaib@chalmers.se` within one week after the results are available.

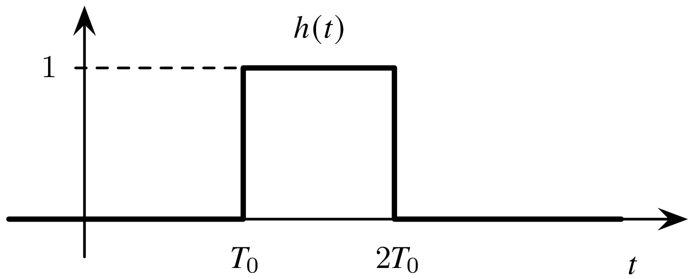
Grades The final grade on the course will be decided by the projects (max score 46), quizzes (max score 6), the written exam (max score 36), and the oral exam (max score 12). The project must be passed (see course-PM for rules). The exam is passed if the total score from the written and oral parts is at least 20p. If the project and exam is passed, 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!

1. Consider transmission of bits stream $b_i \in \{0, 1\}$, where $i = 0, 1, \ldots, 15$ is the time index, using PAM with symbol rate $1/T$ and pulseshape $h(t)$ over an additive noise channel as illustrated in the figure below.





The mapper implements a Gray code according to the following table.

b_{2k}	b_{2k+1}	a_k
0	0	-3
0	1	-1
1	1	1
1	0	3

Suppose that the bit stream is

i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
b_i	1	0	0	1	0	0	0	0	0	0	1	1	0	1	1	0

(a) Plot $s(t)$ when $T = 3T_0$. Label both axes carefully. (3p)

(b) Suppose we choose the matched filter impulse response to be causal. Plot $y(t)$ when $T = 3T_0$ and indicate the optimal sampling points for decoding the transmitted data. Ignore the noise, i.e., set $n(t) = 0$. Label both axes carefully. (4p)

(c) Choose T such that (i) the data rate is maximized and (ii) the transmission is ISI-free. Give expressions for T and the maximum data rate in terms of T_0. (3p)

(d) Repeat Part (a) and (b) for the symbol rate chosen in Part (c). (2p)

(a) The output from the mapper (i.e., the symbol sequence) is

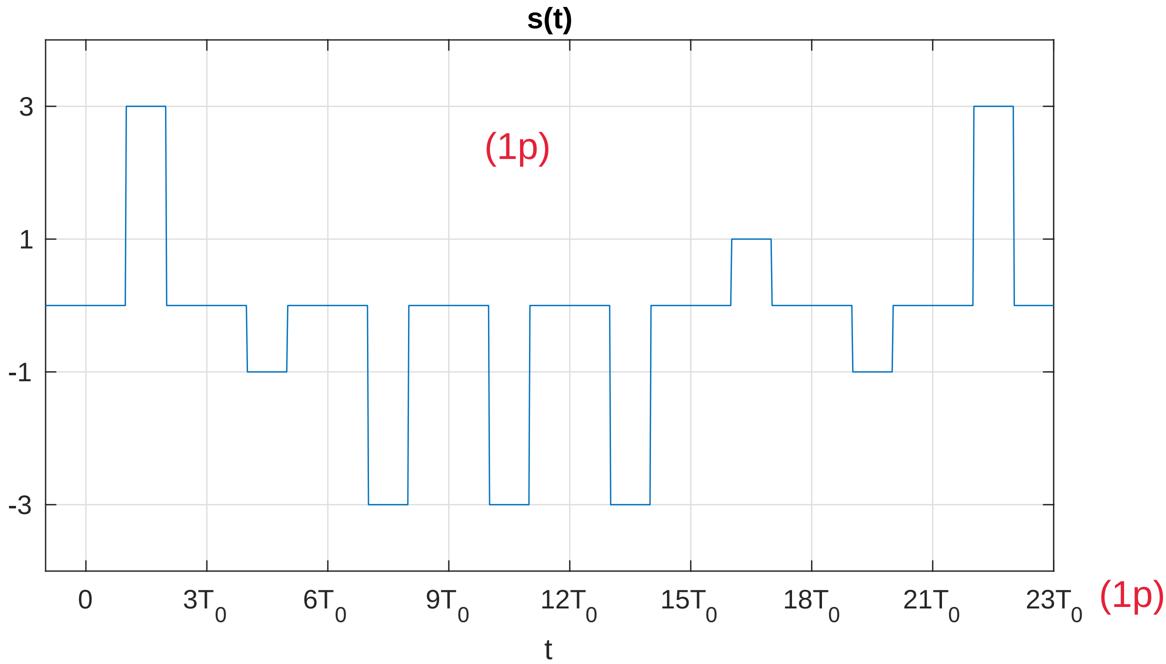
k	0	1	2	3	4	5	6	7
a_k	3	-1	-3	-3	-3	1	-1	3

(1p)

Hence, there are $K = 8$ symbols and the transmitted signal is

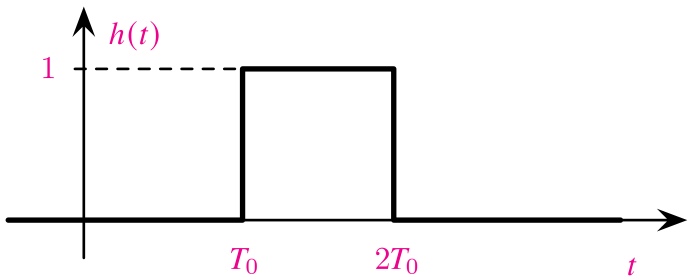
$$s(t) = \sum_{k=0}^{K-1} a_k h(t - kT) = \sum_{k=0}^{7} a_k h(t - k3T_0),$$

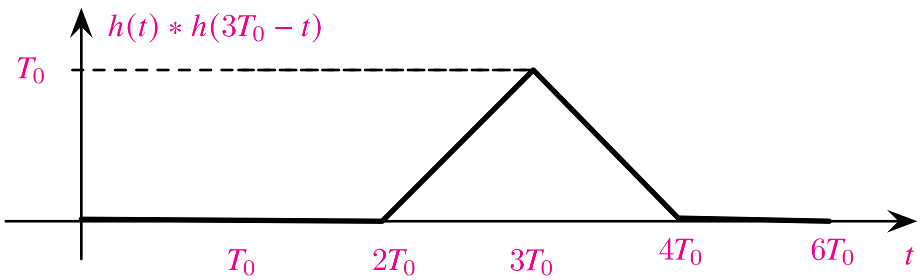
which is depicted below.



(1p)

(b) Let us choose the matched filter impulse response as $h(3T_0 - t)$ (other choices are possible: the impulse response $h(T' - t)$ is matched and causal if $T' \geq 2T_0$). The output from the matched filter is then $x(t) = h(t) * h(3T_0 - t)$, as depicted below.

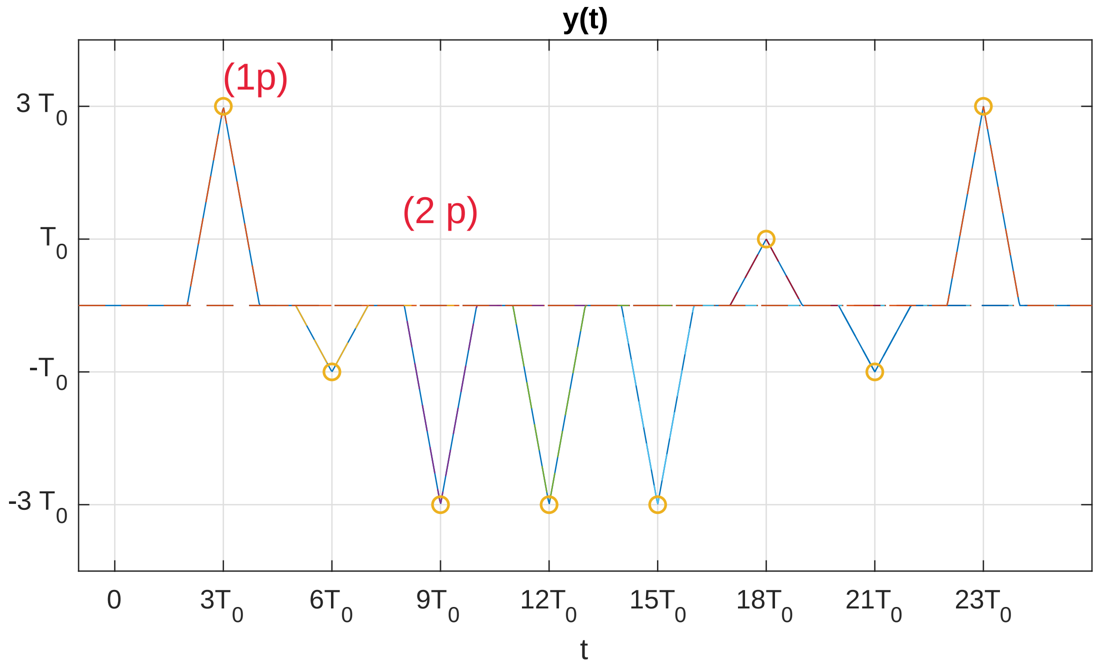




The matched filter output (ignoring the noise) will be

$$y(t) = s(t) * h(3T_0 - t) = \sum_{k=0}^{7} a_k x(t - kT) = \sum_{k=0}^{7} a_k x(t - k3T_0),$$

and the optimal sampling points are $t = 3T_0 + kT = (k+1)3T_0$, $k = 0, 1, \ldots, 7$.



(c) We note that the support (duration of nonzero part) of $h(t)$ is T_0. Hence, we can transmit ISI-free with a matched filter receiver if $T \geq T_0$. The data rate is $R = \log_2(M)/T = 2/T$ and is maximized when $T = T_0$. That is, we choose $T = T_0$ and the data rate is $R = 2/T_0$. (1.5p)

(1.5p)

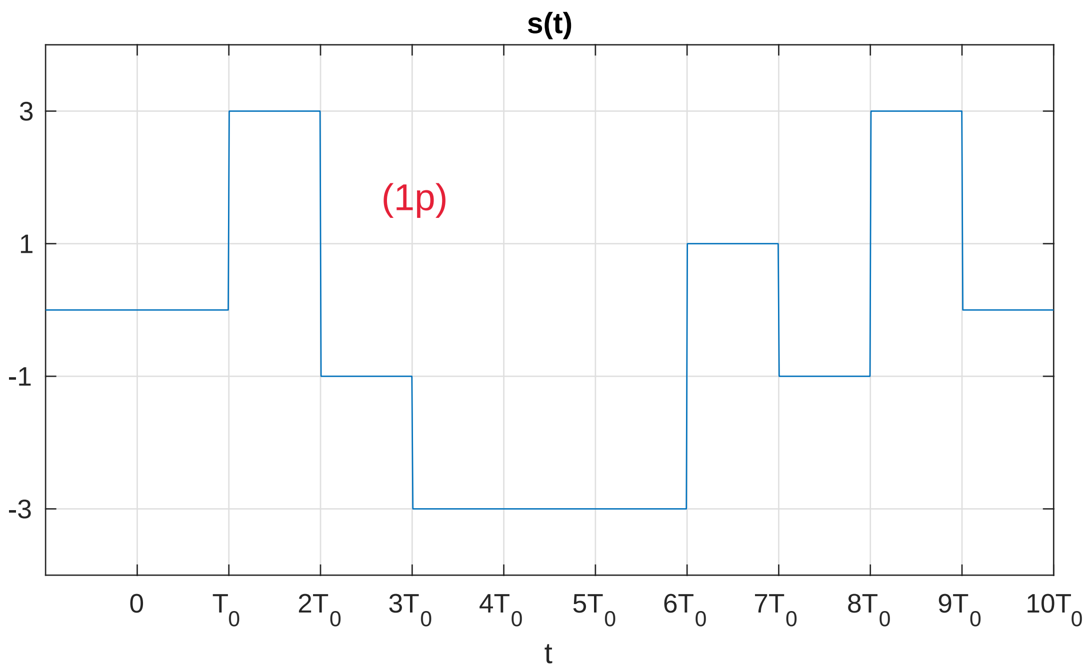
(d) The transmitted signal is

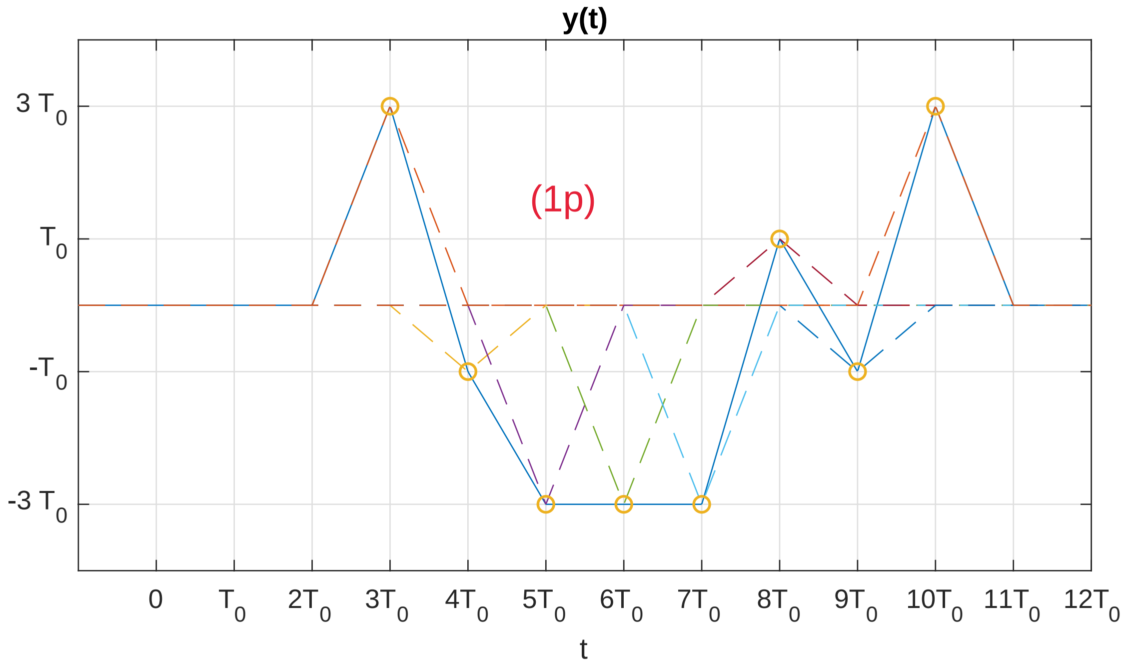
$$s(t) = \sum_{k=0}^{7} a_k h(t - kT) = \sum_{k=0}^{7} a_k h(t - kT_0),$$

and the noiseless output of the matched filter is

$$y(t) = \sum_{k=0}^{7} a_k x(t - kT) = \sum_{k=0}^{7} a_k x(t - kT_0).$$

and the optimal sampling points are $t = 3T_0 + kT = (k+3)T_0$, $k = 0, 1, \ldots, 7$.





The dashed lines in the figure above indicate the pulses $a_k x(t - kT)$, $k = 0, 1, \ldots, 7$ that make up $y(t)$.

2. Consider a wireless LAN in which a number of stations STA1, STA2, ..., are transmitting IP packets to a central access point (AP). The involved protocols are IP, 802.11, and LLC. The IP packet are 1500 byte long.

   Suppose the 802.11 header and trailer is 30 byte and 4 byte long, respectively, the LLC header is 5 byte long, and the IP header is 40 byte long. The 802.11 ACK frame (including header and trailer) is 14 byte. We use DCF without RTS/CTS handshake as medium access and assume that the SIFS is 16 μs and the DIFS is 34 μs. The contention window is $[0, 15]$ slots, where the slot duration is 9 μs.

   We will use a simplified model of the PHY layer in which we ignore any overhead (preambles, training symbols, etc.). In fact, we consider the PHY layer as a bit pipe with data rate 54 Mbit/s. In the absence of a collision, the PHY layer is error-free.

   We ignore propagation delays and consider carrier sensing to be perfect and instantaneous.

   (a) Sketch the layout of the transmitted data frames. That is, indicate in which order the various headers, trailers, and the IP packet are placed in the MAC layer PDU. (3p)

   (b) Suppose STA1 has a long sequence of IP packets to transmit, while all other stations are idle. What is the highest and lowest data rate the transport layer in STA1 can experience? (3p)

   (c) Suppose that there has been no data traffic for a while. Hence, no station is in backoff. Suppose that STA1 becomes ready to transmit a frame at time $t_1 = 0$ and that STA2 and STA3 becomes ready to transmit frames at time $t_2 > 0$ and $t_3 > 0$, respectively, while all other stations remain inactive. Explain under what conditions the frames from STA2 and STA3 will collide. Assume that all stations can sense each others transmissions. (3p)

   (d) Assume the same starting point as in Part (c): no station is in backoff and STA1 becomes ready to transmit at time $t_1 = 0$. Suppose STA1 is a hidden terminal to STA2 and that STA2 becomes ready at time $t_2 > 0$, while all other stations are inactive. For which values of t_2 will STA1 be forced to retransmit its data frame? Assume that collisions destroys all frames involved in the collision, regardless of which station is transmitting or receiving. (3p)

   (a) Let 'H' denote header and 'T' trailer. The data frames will have the following structure: |802.11H|LLCH|IP Packet|802.11T|. (3p)

   (b) Using the DCF, a STA that has transmitted a frame successfully apply a back-off before it transmits again. Following that, the maximum data rate experienced is for the first frame transmitted or for a frame transmitted when the backoff counter was 0 slots. the minimum data rate that can be experienced corresponds to a back-off of 15 slots. The round-trip time for a transmission can be expressed, ignoring the processing and propagation delays, as $T = \text{DIFS} + K_{\text{BO}} t_{\text{s}} + t_{\text{f}} + \text{SIFS} + t_{\text{a}}$, where $K_{\text{BO}} \in [0, 15]$ is the number of backoff slots, t_{s} is the slot duration, t_{f} and t_{a} are the frame and ACK transmission times respectively.

$$t_{\text{f}} = \frac{(1500 + 30 + 4 + 5) \times 8}{54} = 228\ \mu\text{s}$$

$$t_{\text{a}} = \frac{14 \times 8}{54} \approx 2.1\ \mu\text{s}$$

$$T_{\text{max}} = 415.1\ \mu\text{s}$$

$$T_{\text{min}} = 280.1\ \mu\text{s}$$

Then, the transport layer SDU is given by $1500 - 40 = 1460$ byte, and the corresponding data rate experienced by the transport layer is

$$\text{(2p)} \quad R_{\max} = 41.70 \text{ Mbit/s}, \qquad R_{\min} = 28.14 \text{ Mbit/s} \quad \text{(1p)}$$

(c) If $t_2 < t_1'$ and $t_3 < t_1'$, where $t_1' = \text{DIFS} + t_\text{f} + \text{SIFS} + t_\text{a}$ is the time instant the ACK from the AP is received at STA1, then both STA2 and STA3 will sense the channel as busy and apply backoff. If the backoff counter drawn for both stations is the same then, the stations will collide. This will happen with probability (3p)

$$1/(\text{number of possible backoff counter values}) = 1/15.$$

The other event that leads to a collision is if $t_2 = t_3 > t_1'$, then both stations will transmit after sensing the channel for DIFS and the transmission will collide. The probability for this event is zero.

(d) STA1 starts its transmission (to the AP) at time $t_1 = 0$ and the transmission is completed when the ACK from the AP is received. Since STA1 is hidden to STA2, the transmission from STA1 will not be detectable by STA2. Hence, STA2 will sense the channel as idle, regardless if STA1 is transmitting or not. However, the ACK from the AP can be detected by STA2. Therefore, if STA2 becomes ready at time $t_2 \leq (\text{DIFS} + t_\text{f} + \text{SIFS}) - \text{DIFS}$, then the transmission from STA2 will start sometime during the time is takes to complete the transmission of the frame from STA1. Hence, STA1 will have to retransmit. (3p)

3. Consider bidirectional communication between STA A and STA B over a wireless medium using Stop-and-Wait ARQ. The distance between the communication stations is 180 km and we assume that the propagation speed is $c = 3 \times 10^8$ m/s. Processing delays are assumed to be negligible.

   The SDU size is 1500 byte and the header size 40 byte. An ACK frame consists of a header plus 1 byte of control information. We assume that the Stop-and-Wait timeout is set large enough to avoid unnecessary retransmissions.

   We can use the total available wireless bandwidth W in full-duplex or half-duplex mode. In full-duplex, transmissions from STA A and from STA B are separated in frequency, i.e., each transmission has bandwidth $W/2$. For half-duplex, transmissions from STA A and from STA B are separated in time. Hence, each transmission can use the full bandwidth W, but only half the time. As a consequence, the underlying PHY layer has data rate 10 Mbit/s when full-duplex is used and 20 Mbit/s when half-duplex is used. Moreover, we assume that no bit errors occur during transmission.

   We assume that STA A and STA B always have data to transmit. In the half-duplex case, the stations take turns in transmitting information frames. That is, suppose STA A starts by transmitting an information frame. The next information frame from STA A is then not allowed to be transmitted before STA A has received an information frame from STA B.

   (a) Compute the effective data rate for STA A provided by the Stop-and-Wait protocol when full-duplex is used. (2p)

   (b) Compute the effective data rate for STA A provided by the Stop-and-Wait protocol when half-duplex is used. (3p)

   (c) Now suppose we use piggybacking for the acknowledgements. That is, the payload in the information frames consist of an SDU plus the ACK control information (1 byte). No explicit ACK frames are transmitted. Compute the effective data rate for full-duplex communication. (3p)

   (d) Repeat Part (c) for half-duplex communication. (4p)

(a) Let t_f be the duration to transmit a PDU, t_a the duration to transmit an ACK and τ the propagation time. The round-trip time for the full duplex case is given by $T_\text{FD} = t_\text{f} + 2\tau + t_\text{a}$.

$$t_\text{f} = \frac{(1500 + 40) \times 8}{10^7} = 1.232 \text{ ms}$$
$$t_\text{a} = \frac{(40 + 1) \times 8}{10^7} = 0.0328 \text{ ms}$$
$$\tau = \frac{180 \times 10^3}{3 \times 10^8} = 0.6 \text{ ms}$$
$$T_\text{FD} = 2.467\text{ms} \qquad \text{(1p)}$$

Following that the effective data rate is

$$R_\text{FD} = \frac{1500 \times 8}{T_\text{FD}} = 4.86 \text{ Mbit/s} \qquad \text{(1p)}$$

(b) In absence of errors, the communication will take place as indicated in Figure 1. Following that, we can compute the total period separating two consecutive transmitted

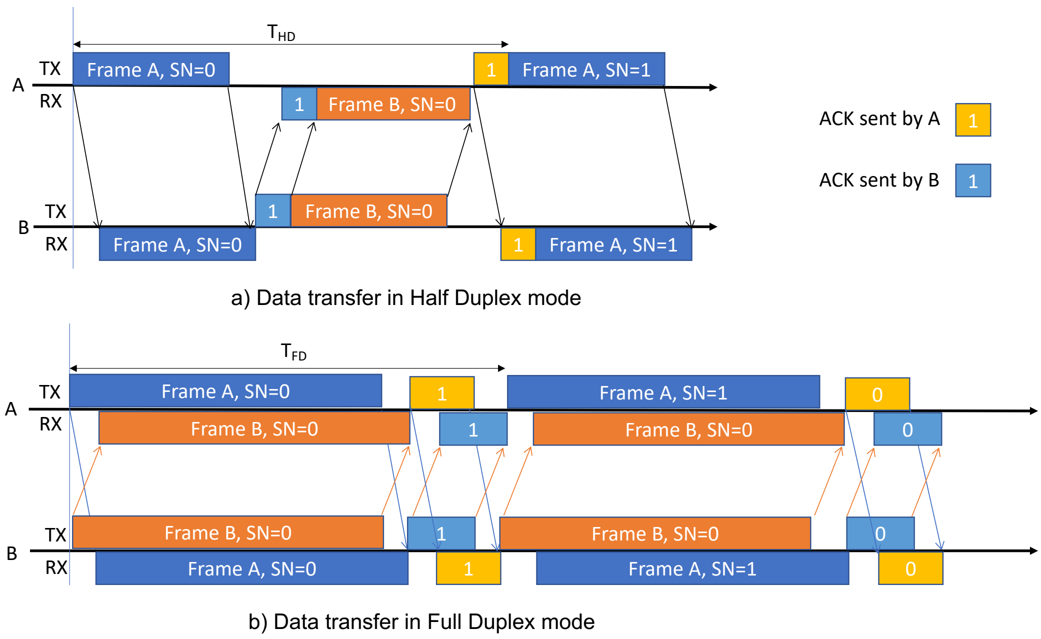


Figure 1: Data transfer for HD and FD modes

(1p)

PDU by the STA A as $T_{\mathrm{HD}} = 2t'_{\mathrm{f}} + 2\tau + 2t'_{\mathrm{a}}$ where t'_{f} and t'_{a} are the transmission time of a PDU and an ACK, respectively, in half duplex mode.

$$t'_{\mathrm{f}} = \frac{(1500+40)\times 8}{2\times 10^7} = 0.616 \text{ ms}$$

$$t'_{\mathrm{a}} = \frac{(40+1)\times 8}{2\times 10^7} = 0.0164 \text{ ms}$$

$$T_{\mathrm{HD}} = T_{\mathrm{FD}} = 2.467\text{ms}$$ (1p)

Then, the effective data rate is $R_{\mathrm{HD}} = R_{\mathrm{FD}}$. (1p)

(c) In case piggybacking is used—Figure 2, the round-trip time for the FD mode (assuming that STA A starts transmitting first) is given by $T_{\mathrm{FD}} = 2t_{\mathrm{f}} + 2\tau$. (1p)

$$t_{\mathrm{f}} = \frac{(1500+1+40)\times 8}{10^7} = 1.238 \text{ ms}$$ (1p)

$$T_{\mathrm{FD}} = 3.676 \text{ ms}$$

$$R_{\mathrm{FD}} = 3.264 \text{ Mbit/s}$$ (1p)

(d) The total period separating two consecutive transmitted PDUs by STA A is $T_{\mathrm{HD}} = 2t'_{\mathrm{f}} + 2\tau$. (2p)

$$t_{\mathrm{f}} = \frac{(1500+1+40)\times 8}{2\times 10^7} = 0.619 \text{ ms}$$

$$T_{\mathrm{HD}} = 2.438 \text{ ms}$$ (1p)

$$R_{\mathrm{HD}} = 4.922 \text{ Mbit/s}$$ (1p)

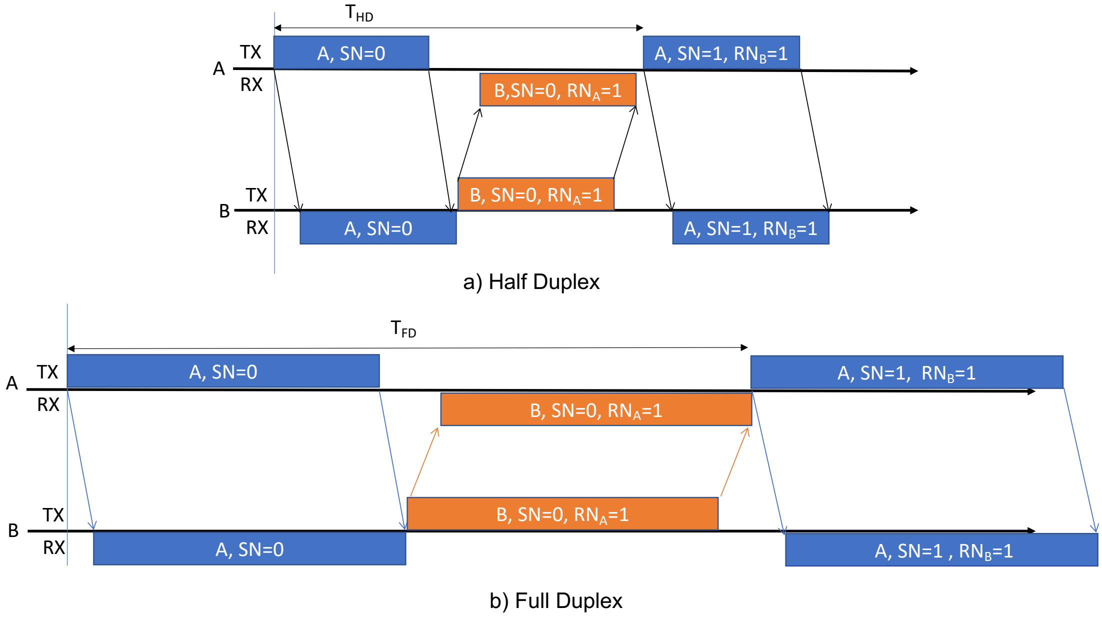


Figure 2: Data transfer for HD and FD modes when piggybacking of ACKs is used