SSY125
Digital Communications
Fall 2023
Course Memo

October 24, 2023

Contents

1 Course Information

This document describes the course SSY125 Digital Communications, 7.5 credit units. Any changes to the information in this document will be posted on Canvas.

1.1 Prerequisites

A passing grade in SSY121 Introduction to Communication Engineering, or a similar course is required for MPCOM students and recommended for non-MPCOM students. Working knowledge of probability theory and signals and systems and experience of MATLAB is required. Knowledge of random processes is very useful, but not essential.

1.2 Aim

This course introduces the basics of information and coding theory. We will be concerned with the fundamental communication problem of sending information from a transmitter (source) to a receiver over a physical channel efficiently and reliably.

Several questions immediately come to mind when reading the above paragraph. What is meant by information? How can we represent efficiently (i.e., compress) a source? How is the transmission cost calculated? How is reliability defined and measured? How much information can be transmitted reliably over the channel? What design tradeoffs can be made? The aim of this course is to answer these questions.

1.3 Learning Outcomes

After completion of this course, the student should be able to

- Define entropy and mutual information and explain their operational meaning.
- Describe Shannon's source coding and channel coding theorems.
- Apply Huffmann codes to compress discrete memoryless sources losslessly.
- Compute the capacity of discrete memoryless point-to-point channels.
- Describe Shannon's capacity formula on the additive white Gaussian noise (AWGN) channel and elaborate on the fundamental tradeoff between power and bandwidth.
- Compute and estimate the symbol and bit error probability of simple modulations (PAM, PSK, QAM) for transmission over the AWGN channel.
- Estimate the performance of communication links (i.e., modulation formats, channel codes and decoders) over the AWGN channel by computer simulation. This includes determining simulation parameters to reach the desired accuracy as well as programming the simulation in MATLAB.
- Understand the basic principles and concepts of coding.
- Explain the advantages and disadvantages of block and convolutional channel coding, define and compare some major decoding methods (syndrome, Viterbi), and estimate the error performance of coded systems.
- Design communication links (modulation, channel coding, and receiver algorithms) for the AWGN channel such that specified requirements on power and spectral efficiency are satisfied.

1.4 Content

- Entropy, data compression, prefix-free codes, Kraft inequality, Huffman codes, the source coding theorem.
- Mutual information, channel capacity, the channel coding theorem.
- Detection theory: maximum likelihood (ML) and maximum a posteriori detection.

- Methods for computing and bounding the symbol and bit error probabilities: decision regions, Q-function, union bound techniques.
- Analysis of linear modulation formats (PAM, PSK, QAM), power and spectral efficiency.
- Channel coding, Hamming distance, hard- and soft-decision decoding.
- Linear binary block codes: generator and parity-check matrices, syndrome decoding, error correction and error detection capability.
- Binary convolutional codes: trellis diagram, ML decoding, Viterbi algorithm, union bound on the error probability for ML soft- and hard-decision decoding.
- Modern codes: turbo codes and low-density parity-check codes, iterative message-passing decoding.

1.5 Course Staff

- Examiner: Alexandre Graell i Amat (alexandre.graell@chalmers.se, office: 6409)
- Lecturers: Alexandre Graell i Amat (alexandre.graell@chalmers.se, office: 6409) and Christian Häger (christian.haeger@chalmers.se, office: 6439)
- Teaching assistants: Mohammad Farsi (farsim@chalmers.se, office: 6340)

1.6 Course literature (not mandatory)

The course is based on a complete set of lecture notes that will be made available in Canvas and therefore it does not follow a particular textbook.

For those students who wish to delve deeper the following books may be interesting:

- Stefan M. Moser and Po-Ning Chen, *A Student's Guide to Coding and Information Theory*, Cambridge University Press, 2012.
- W. E. Ryan and S. Lin, *Channel codes. Classical and modern*, Cambridge: Cambridge University Press, 2009.
- Sergio Benedetto, Ezio Biglieri, *Principles of Digital Transmission: With Wireless Applications*, Kluwer Academic Publishers, 1999;

1.7 Additional course material

Slides for the lectures, exercises for the tutorial sessions, and additional material will be made available on the course web page.

1.8 Exam dates

- SSY125 Exam : January 13, 2023, 14:00-18:00. Duration: 4 hours

As a general Chalmers' rule, it is allowed to bring a dictionary to the exam. Furthermore, another general Chalmers' rule states that answers to exam problems should be in English. Answers in any other language will be ignored when grading the exam.

1.9 Projects

There is one mandatory project in the course, details can be found in Section 5.

1.10 Quizzes

There are three quizzes in the course, details can be found in Section 6.

1.11 Student Administration Office

The office is in room 3342 ED-building, phone 772 3720, studadm.e2@chalmers.se. For updated information, see https://www.chalmers.se/en/departments/e2/education/Pages/Exam-Office-.aspx

2 Schedule

Updates in the schedule will be announced in Canvas. Room allocations can be found on TimeEdit.

2.1 Lectures

Lectures are typically on Mondays 10:00–11:45, Wednesdays 10:00–11:45, and Wednesdays 13:15–15:00. However, there will be a few exceptions. Please check Section 3.2 for the schedule and check Canvas during the course for any updates.

2.2 Tutorials

Tutorials are typically on Mondays 08:00–09:45, and Wednesdays 13:15–15. Check Canvas for exceptions.

2.3 Projects

Project deadlines: December 8 and January 8, 23:59
Project oral exam: January 12

3 Lectures

3.1 Objective

The objective of the lectures is to highlight the most important parts of the course. However, it is not motivated (and there is not enough time) to cover all relevant parts in all details. Most of the learning takes place outside the lecture hall, and the number of lectures has therefore been reduced to free up more time for group and individual work.

3.2 Lectures schedule

The lectures are organized as follows (please note that adjustments may be performed during the course).

Lecture 1: Oct 30 10:00

- Course info.
- Introduction: the big picture.

Lecture 2: Nov 1 10:00 (Chapters 2 and 3 of the lecture notes)

- A measure of information: Entropy.
- Data compression.

Lecture 3: Nov 1 13:15 (Chapter 3 of the lecture notes)

- Data compression.

Lecture 4: Nov 6 10:00 (Chapter 3 of the lecture notes)

- Data Compression.

Lecture 5: Nov 8 10:00 (Chapter 4 of the lecture notes)

- *Quiz 1.*
- Communication over a noisy channel.

Lecture 6: Nov 8 13:15 (Chapters 4 and 5 of the lecture notes)

- Communication over a noisy channel.
- Communication over the AWGN channel.

Lecture 7: Nov 13 10:00 (Chapter 6 of the lecture notes)

- Analysis of linear modulations.

Lecture 8: Nov 20 10:00 (Chapter 7 of the lecture notes)

- *Quiz 2.*
- Basics of error correcting coding.

Lecture 9: Nov 22 10:00 (Chapter 8 of the lecture notes)

- Linear block codes.

Lecture 10: Nov 22 13:15 (Chapter 9 of the lecture notes)

- Convolutional codes.

Lecture 11: Nov 27 10:00 (Chapter 9 of the lecture notes)

- Convolutional codes.

Lecture 12: Nov 29 10:00 (Chapter 10 of the lecture notes)

- Modern codes: Turbo-like codes.

Lecture 13: Nov 29 13:15 (Chapter 11 of the lecture notes)

- Modern codes: LDPC codes.

Lecture 14: Dec 11 10:00

- *Quiz 3.*
- Coding beyond communications and storage.

4 Tutorials

The purpose of the exercise sessions is not to solve a lot of standard problems at high speed. It is to facilitate learning and understanding of the course material. The ability to solve standard problems does not imply understanding; however, understanding gives problem solving skills. It is important that you come prepared to the exercise sessions, i.e., that you have read the relevant lecture notes (and eventually sections of the course book), and also solved the suggested homework problems. It is also important that you are active during the exercise sessions. Always try to understand what aspects of digital communications the problems are treating. If you cannot see the point with a certain problem, ask the assistant! There is a meaning behind every problem in this course.

Each tutorial session will start with a recap (around 10-15 minutes) of the concepts introduced in the lectures. The recap will also be based on the feedback provided by the students at the end of each lecture, if any.

Each tutorial session will comprise two problems, which will be given around one week before the tutorial session. Students will be requested to solve the problems in pairs, and one of them (selected by the teaching assistant (TA)) will be collected by the TA at the beginning of the tutorial session and graded. The problems will be solved by the TA on the blackboard and the solutions will be uploaded after the session.

5 Project

The course has one mandatory project. The project is carried out in groups of three students (the groups will be decided by the TAs) and is demonstrated and examined at an oral exam. Cooperation between the groups is considered cheating and is subject to disciplinary actions. A TA will be available for consultation, and the TA will also approve and grade the project.

5.1 General instructions

The project work should be done according to the principles used in SSY121 Introduction to Communications Engineering. The principles are described in the document "Working in Projects," rev. B, by Pär Mattisson. The document is available for download at the course web and can be used free of charge in SSY125 Digital Communications. However, it is not allowed to share the document with anyone that is not a student in SSY125.

5.2 Report guidelines

The project should be documented in a short report which is due a few days before the oral exam. Reports handed in after the deadline will not be considered. The report should confirm to standard practices for technical reports, see Chapter 2 in "Student Writing Manual," Dept. Language and Communication, Chalmers University of Technology, 2007 (available at Cremona). It should fully document the project, i.e., explain what was done, why it was done, who did what, and what the results were. Furthermore, the results should be commented and checked that they are reasonable and consistent with each other and the relevant theory. Plots must be clearly labeled. Any program code should be carefully commented and be attached to the report. It is important not to blindly use formulas from the book without checking that the formula is applicable for the situation at hand. Moreover, some of the formulas in the book are surely in error (as the case is for most books). The report should not be longer than necessary. A too long or verbose report will not give full points. Do not spend a lot of space on background material. The purpose of the report is to document your work, not someone else's. The report should be submitted in pdf-format. Please do not submit your report in any other format, as this complicates the processing of your report.

5.3 Report deadlines

The reports should in be submitted in pdf-format before the deadlines specified in Section 2.3 above. Note that late reports will not be graded, and no points will be awarded the group. The date for the oral exam is given in Section 2.3 (if the date was to be changed, the new date will be published in Canvas).

5.4 Grading

The reports for project are graded according to the following guidelines.

- The report should be concise, written in good English, easy to follow, and comply with Chapter 2 in "Student Writing Manual," Dept. Language and Communication, Chalmers University of Technology, 2007 (available at Cremona). The results should be commented and checked that they are reasonable and consistent with theory. The maximum score is 15 points.

- All members of the group should be able to explain and defend all details about the project at the oral exam. The maximum score is 15.

The report score is common to all group members, while the oral exam score is assigned individually. That is, the total project score can be different for the members in a group. A total score (i.e., the total score from the report and the oral exam) less than 15 points will cause the project to be graded as failed. Students that fail a project will have to make up the project the next academic year. Since the project is mandatory, this will also imply that the course cannot be completed until the project has been approved. Furthermore, the points of the project are valid over a window of two successive academic years.

6 Quizzes

Students can get points from the three quizzes that will be given at the lectures as detailed in the week plan. Each quiz will have four multiple choice questions that are to be answered in 10 minutes. Questions at the quiz can be from both lectures and exercises that have been covered until the date of the quiz. A correct answer will give 1/4 point (there is no penalty for a wrong answer).

7 Final (written) exam

The course will be concluded with a written exam with four problems. Each problem can yield a maximum of 15 points. A minimum score of 15 points is required to pass the course. An erroneous answer, incomplete or badly motivated solutions give point reductions down to a minimum of 0 points. As a general rule, bad motivation or errors that relate to fundamental principles of the course will lead to large point reductions. Computational errors that do not lead to unreasonable answers generally give smaller reductions. The purpose of all exam problems is to test to what degree the students have reached the aims and objectives of the course. It will therefore not be possible to solve the exam problem by just finding the correct formula on the note sheet or by remembering and imitating the solution of one of the exercise problems. The course is about understanding not remembering digital communications.

7.1 Re-exam

The re-exam is typically an **oral exam**. If you intend to do a re-exam, besides signing for it, **it is very important to send an email to Àlex and the TAs**. If you do not contact us directly, we will not be able to organize the exam.

8 Final grades

The final grade on the course will be decided by the project (maximum score 30), quizzes (maximum score 3, rounded to the nearest integer), tutorials (maximum score 7), and final exam (maximum score 60). The sum of all scores will decide the grade according to the following table. A minimum score of 15 points in the exam is required to pass the course. Furthermore, the project must be approved to receive a passing grade (see Section 5).

- Total Score: 0–39 $\Longrightarrow$ Grade: Fail
- Total Score: 40–59 $\Longrightarrow$ Grade: 3
- Total Score: 60–79 $\Longrightarrow$ Grade: 4
- Total Score: $\geq$80 $\Longrightarrow$ Grade: 5